



CNC for the desktop machinist and hobbyist.

Without Detail Drawings DIY CNC Router Plans

Rev 03

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Forward

These plans are based on the second DIY CNC Router that I made. I made every effort to ensure the measurements are accurate, however, I **strongly recommend** you verify everything before you start cutting! These plans are provided “as is”, with no warranty or guarantee.

Building your own 3-Axis CNC router is both fun and educational. These plans document all the steps I followed to make my DIY CNC Router. This is the second DIY CNC Router I made, after learning a lot from building the first version.

This is a very good router that can be built at a reasonable price using readily available materials. This design uses DIY linear bearings, threaded rod and plywood (or MDF) construction. No fancy materials, no expensive drive screws. This is a **hobby** router project. It is a router designed to route wood, plastic and some aluminum. It is a low-cost, decent quality system that will teach you all you need to know about 3-axis routing.

If you take care during cutting and assembly, you can achieve very good accuracy. I also use mine to do printed circuit board isolation routing, and I can do surface-mount ICs with 50mil (.050”) pitch. Not bad at all!

I’m proud to report that over 1,000 copies of these plans have been downloaded.

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Discussion Forum

If you have questions or suggestions regarding these plans, please post to the [HobbyCNC DIY CNC Router Plans forum](http://hobbycnc.com/forums/forum/diy-cnc-router-plans/) (hobbycnc.com/forums/forum/diy-cnc-router-plans/). By using the forum you can enhance the community by sharing your questions, answers and your build progress.

I'd love to post photos of your build on my [HobbyCNC Customer Builds](http://hobbycnc.com/customer-builds/) page (hobbycnc.com/customer-builds/) – send photos to brian@hobbycnc.com or post your photos to the forum.

My Machine in Action

If you want to see my build actually doing something, I made a short video (1 min, 34 sec) of it machining some HobbyCNC PRO heat sinks. [Vimeo Heatsink Video](https://vimeo.com/166901487) (vimeo.com/166901487).

Material Selection

Preferred: High quality, furniture-grade plywood. Both good looking and strong.

OK: MDF (Medium Density Fiberboard)

Not good: Particle Board, 'regular old plywood'



This DIY CNC Router is made out of wood. I would strongly recommend high quality, furniture-grade plywood. It is both good looking and strong.

The other option is MDF (Medium Density Fiberboard). Not recommended is Particle Board or "regular old plywood".

- **Furniture Grade Plywood** is constructed with many fine layers of alternating grain. It is typically free of voids and is surfaced with a clean veneer that looks great when finished. It is also damn strong and resists bending well.
- **MDF** is made of very fine, evenly distributed material. It is heavy and dimensionally stable. It is easy to cut (but can dull blades quickly). It's mortal enemy is water. My first build was with MDF & scrap plywood. It worked well and was perfect for experimenting. Build number 2 was with a high-quality furniture grade plywood.
- **Regular old plywood.** I found local home-store type plywood to be too full of voids and imperfections to be worthwhile.

- **Particle board** can easily be identified by the very coarse and uneven density. It is cheap and not strong. Do not go there.

My first build (with MDF and scrap plywood) worked OK (it just wasn't square) and was perfect for experimenting. Build number 2 was with a high-quality furniture grade plywood.

I've also been told that there is a "High Density Fiberboard", but I have no experience with it. Sounds like it should work well too.

Hardboard, also called high-density fiberboard (HDF), is a type of fiberboard, which is an engineered wood product.

It is similar to particle board and medium-density fiberboard, but is denser and much stronger and harder because it is made out of exploded wood fibers that have been highly compressed. Consequently, the density of hardboard is 31 lbs or more per cubic foot (500 kg/m³)[2] and is usually about 50-65 lbs per cubic foot (800–1040 kg/m³). It differs from particle board in that the bonding of the wood fibers requires no additional materials, although resin is often added.

Retrieved from <https://en.wikipedia.org/wiki/Hardboard>, Dec 2018

Size

My build is 24 x 36 inches. I'm not confident to go any larger as wood does flex under load.

Attention to detail

It is critical that all cuts are as perfectly square as you can make them. I was in a hurry for my first build and the problem became evident when I milled "mirror opposite" parts that did not line up to each other after milling! D'oh!

Straight, true, accurate cuts during assembly are very important to ensure a great quality outcome!

Holding it all together - Barrel (or Cross Dowel) Nuts

Using a jig is highly recommended. Instructions for creating the jig are on page 15



Figure 1 - Barrel or Cross Dowel nut

Other things to consider

CNC Router storage – think about this when you are sizing your machine. Bigger is cool, and you can fit more and larger ‘stuff’ into it, but you have to store the thing when you are not using it. And when you are using it, you need space to get around it (mine is on wheels, and on a dedicated cabinet).

Tooling Storage - You will also likely end up with associated tools, tooling, spindles, clamps, wrenches, dial gauges, and on and on. Plan on a lot more ‘stuff’ than you initially think. Plan to have some dedicated space near (or in my case, under) the machine for ready access during setup and for tool changes.

Noise – they are pretty quiet – until you start the spindle, and louder yet when the tool hits the work piece. Have a good set of ear and eye protection handy AND USE IT.

Dust / Mess – if you are routing wood, these things generate a LOT of sawdust. And it gets EVERYWHERE (this is the primary reason I don’t recommend laptops in the shop!). Consider a dust removal system (not discussed in this document). Machining MDF sends A LOT of fine dust into the air. I can’t imagine any of it is good for your lungs. If you are going to mill in a small space or with poor ventilation and without any type of dust extraction, **wear a dust mask.**

Smell – If you are engraving metals and use a coolant or lubricant – some of them really smell. Multiply that by 100 if you use a mist-type system.

Clamping – nothing is more frustrating than the work piece moving in the middle of a run. I have come to learn that **clamping is an art form.** This is why I suggest “T tracks” in the bed of the router table. This allows use of inexpensive woodworking clamps – or make-your-own clamps. One can never have too many clamps.

Leveling the work piece – I did not realize how critical it is to use a dial gauge and level your work piece or base before you start. Especially engraving or milling PC boards – a few thousandths makes a big difference. Figure 2 shows a Harbor Freight part – under \$20. It is mandatory in my opinion.

For milling PC Boards, (which have a naturally wavy surface, I have used leveling software with very good success.



Figure 2 - 1 inch Travel Machinist's Dial Indicator (Harbor Freight)

Two of my most interesting learning experiences were:

- the importance (and difficulty) of **leveling** your work piece
- **clamping** the work piece – clamps must be firm, plentiful and out of the way of the tool and any moving parts.

Learning the software – you have at least two (and possibly three) bits of software to get competent with:

CAD – somehow, somewhere, you need to design what you are going to machine. You can use Google Sketchup for some tasks. It is free and probably the easiest to learn. There is ProE and Autocad and other high-end, parametric CAD software, that is super-powerful (and quite expensive). And there is a huge array in-between.

I have started using Autodesk Fusion 360. It is a full-function, parametric-driven CAD software and it is free to makers, students and small business with annual revenue under \$100k. It is an amazing product that supports g-code creation and 3D printing.

The free **Start-Up/ Enthusiast** licenses allow you to access Fusion 360 Ultimate with a yearly subscription after the trial period has ended. You can use this license if you are a small business making less than \$100,000 per year (or equivalent), or if you're a hobbyist using Fusion 360 for non-commercial purposes.

Retrieved from: <https://knowledge.autodesk.com/support/fusion-360/learn-explore/caas/sfdcarticles/sfdcarticles/How-to-activate-start-up-or-educational-licensing-for-Fusion-360.html>, Dec 2018

CAM: G-Code Creation – this can be built-in to the CAD software (like Fusion 360), or it can be a separate software (I use CamBam). This is where you decide which tools to cut with (shape, length, diameter), how fast, how deep each pass is, whether the tool cuts “inside” or “outside” the line, create holding tabs, define the order of operations, types of operations (e.g. drill, pocket, engrave).

CAM: Machine Control– this is the software that actually drives the stepper motors. It takes the G-Code from the previous step and converts it into the proper movement of the three axis. Some common CAM software is LinuxCNC (free), BobCAD, Mach3.

Cost – The HobbyCNC board, stepper motors can be as little as \$150 USD (HobbyCNC EZ + 3 130oz-in stepper motors) or the HobbyCNC PRO 3-axis & 3 305oz-in for \$220 USD (Check the HobbyCNC website for current pricing). A 32V 10A DC power supply will be around \$75 to \$100 USD (a regulated switching supply works fine too). Other materials (and this is a guess) would be around \$300 USD. This would be for the CNC Router only, no dust control, no noise control, no cabinet, no spindle, no tools/bits. I'd budget \$6-800 USD – again I did not cost-out the BOM, this is just a SWAG¹.

Cheap Import Electronics – My daddy use to say “the lowest price is not always the best value”. Caveat Emptor.

Time – it takes time to build the machine. And time to learn all the associated software.

Fun – it is super-rewarding to see the sawdust fly and your design come into reality. You will be called a Geek by all your friends. Wear it with pride.

Safety – these tools have a lot of power, and, although generally well-behaved, they can do some unexpected things. Be safe, wear hearing and eye protection, as well as a mask if there is dust, and keep your hands away from pinch points (there are many of them).

¹ Scientific Wild-Assed Guess

Cutting Diagram

Drawing 1001

All the parts for this machine can be cut from a single sheet of $\frac{3}{4}$ " stock. I've prepared a cutting guide. I've laid-out the parts such that the sheet can be cut into six sections for easier handling.

Important notes when cutting components

- Take your time and ensure everything is P E R F E C T Y square. If not, you will route parallelograms instead of squares!
- When cutting identical parts, make sure to set-up your saw one time and make all the cuts. It is most important that related parts are the same size

A $\frac{1}{8}$ " Kerf is assumed for this drawing. Adjust for your blade width. Cut parts a *little* oversize and finish-trim to the precise dimensions.

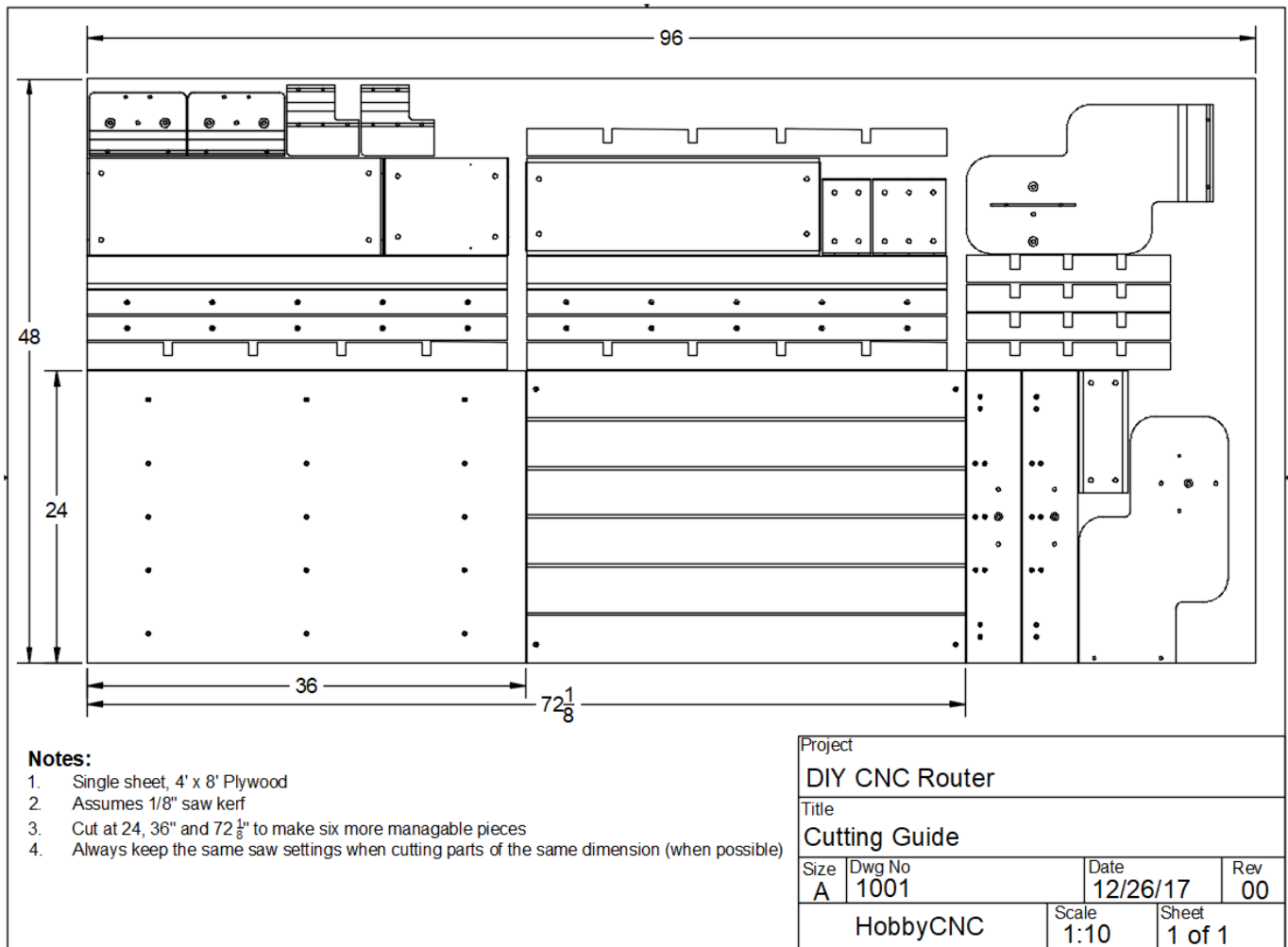


Figure 3 - Drawing 1001 Cutting Guide



Parts List

Item #	Qty	Description	Part No	Base	X-axis	Y-axis	Z-axis	Bearings	Stepper Motors	Anti Backlash
1	26	1/4-20 x 2" Hex Head Bolts			8	8	10			
2	6	1/4-20 x 1 1/2" Hex Head Bolts							6	
3	9	1/4-20 Hex Nuts		3	3	3				
4	2	1/4-20 Acorn Nut		1	1					
5	1	1/4-20 Jam Nut				1				
6	32	1/4" USS Flat Washers		2	8	8	8		6	
7	78	1/4-20 threaded rod (inches)		38	28	12				
8	24	5/16-18 x 3/4" hex bolt						24		
9	24	5/16-18 hex nut						24		
10	12	10-32 x 3" Cap Head machine screws	Length depends						12	
11	10	#8 x 2" flat head wood screw		10						
12	37	#8 x 1 1/2" flat head wood screw		37						
13	6	#8 x 3/4 flat head wood screw								6
14	6	#6 x 3/4 round head wood screw								6
15	12	#4 x 3/4" pan head wood screws			4	8				
16	12	T-Nuts 10-32							12	
17	6	T-Nuts 1/4-20	Rockler # 26054	2	2	2				
18	26	Barrel Nuts / Threaded cross dowels	Rockler # 31823		8	8	10			
19	178	3/4 x 3/4 x 1/8 Al Angle 6061 or 63 (inches)		70	48	20		40		
20	6	Bearing, R4ZZ, 1/4" x 5/8" x 0.196"	VXB Bearing R4ZZ-1	2	2	2				
21	24	Bearing, 608ZZ, 8x22x7mm	VXB Bearing 608ZZ					24		
22	6	Limit Switches	Jameco 2117333		2	4				
23	3	Stepper Motors	HobbyCNC 23-305, 23-205 or 23-130						3	
24	3	Flexible Shaft Coupling	VXB Bearing 6-35X10_COUPLING						3	
25	3	Mending Brace	Granger 4PB67							3
26	3	Steel Compression Spring	Mc-Master Carr 9657K156							3
27	3	Coupling Nut	Mc-Master Carr 90264A435							3
28	3	1/4-20 Square Nut								3
29	3	Small angle bracket	Keystone 617							3
30	1	Plywood Sheet, 4' x 8'								

The Base

Drawings 1002 through 1008

A strong, sturdy base is requisite for quality results. For this, I recommend a torsion box design. A torsion box will provide a strong, stable yet light weight base for your project.

In addition to strength and flatness for milling provided by a torsion box, remember that ANY FLAT SURFACE in your garage or shop has a high likelihood of collecting ‘stuff’ and becoming a storage space. Without a strong base, a pile-o-crap sitting on your mill bed for a long time can warp it.

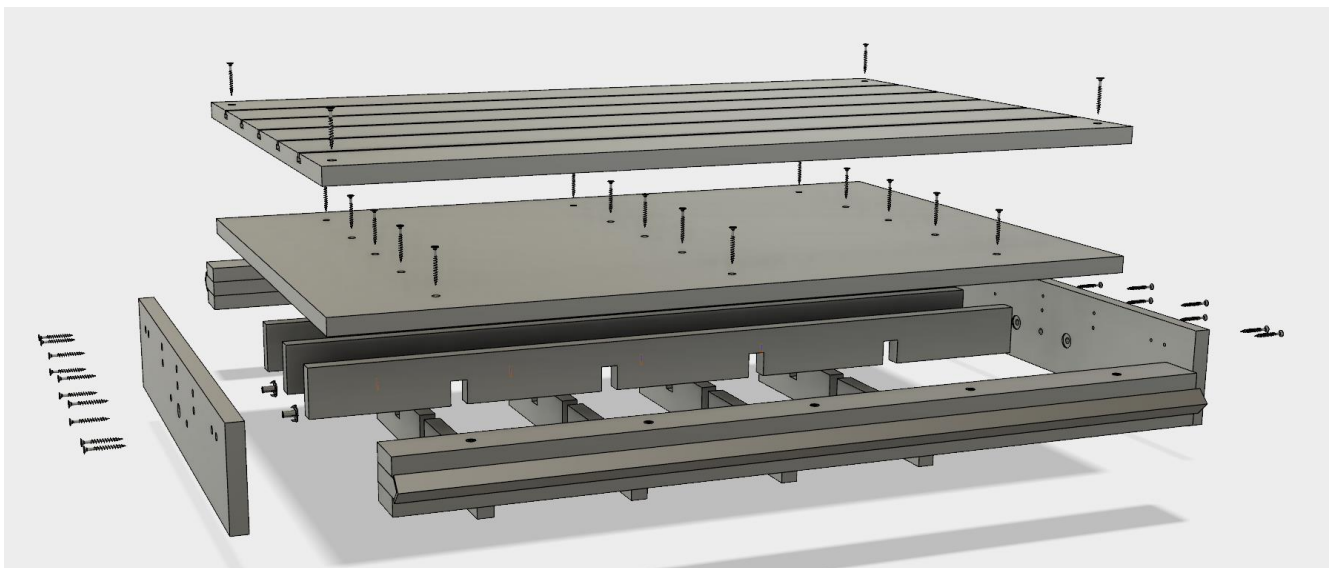


Figure 4 - Exploded View of the Base (Drawing 1008)

The base is the most complex of all the components. Extra care must be taken to ensure the entire Base assembly is square and flat.

I designed the Base Linear Bearing Rail Supports (Figure 9) to be particularly robust as this supports the Y and Z gantries as well as the cutting tool.

The design recesses the Base Linear Bearing Rail Supports underneath the Base Top (Drawing 1007) in an effort to minimize contamination by sawdust and to somewhat protect another pinch-point. This made assembly a bit more complex, but the results are worth the effort.

Sacrificial Top

In Figure 4, you will notice there are two “tops” to the Base assembly.

- The lower of the two tops is part of the **Torsion Base**, and is screwed to the underlying framework, becoming the final part of the torsion box.
- The upper of the two tops is a “sacrificial” top board which is a replaceable 24 x 36” piece of MDF with “T” slots cut into it. This can be easily replaced if it becomes damaged.

Assemble the Torsion Base

NOTE: The thickness of your stock will vary based on the type of material you use. MDF is typically 3/4 of an inch thick, whereas 3/4" plywood is 23/32" (0.71875"). So cut the slots in the **Torsion Base** frame to fit your stock. The tighter the tolerance the better.

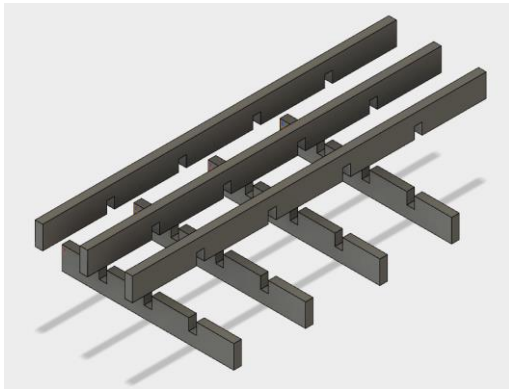


Figure 5 – Illustration of core

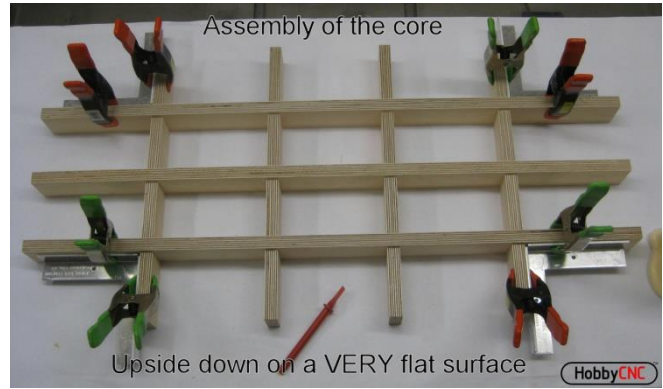


Figure 6 – Actual core

IMPORTANT: Assemble the **Torsion Base** frame upside down on a **VERY FLAT SURFACE**. Make sure the frame is sitting flat and flush against the flat work surface.

Torsion Box Internal Frame

When cutting the notches, use double-sided tape, or otherwise bind all the similar parts together, so you make only one set of cuts for all like pieces.

If you don't have some 90° woodworking clamps (see Figure 6). I would suggest making some before you begin glue-up (Figure 7). Adjust the dimensions to match your project.

IMPORTANT:

- Assemble the **Torsion Base** frame upside down on a **VERY FLAT SURFACE**. Make sure the frame is sitting flat and flush against the flat work surface. Add weights if necessary.
- Put down paper to prevent glue from ruining the table.
- Allow the **Torsion Base** core to dry thoroughly before the next step.

This step benefits from two people working together.

After test-fitting all parts, apply glue liberally on both mating pieces of wood.

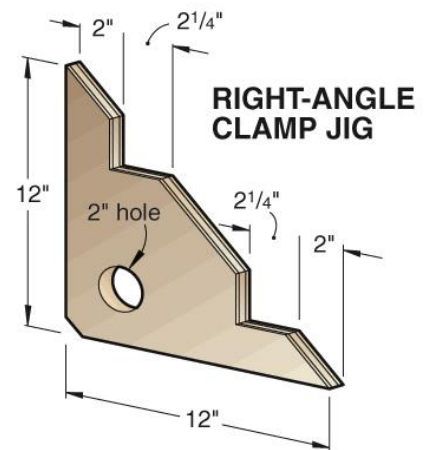


Figure 7 - Right Angle Clamp jig
 Source: <http://my.woodmagazine.com/woodworking-plans/clamping/right-angle-jig-gives-you-a-corner-on-clamping-tasks/>

Base End Panels

Attach the **Base End Panels** with wood screws (Figure 8). Keep the **Torsion Base** core face-down on the flat surface while attaching the front and back. The **Torsion Base** core is centered on the Base Front and Rear panels. Attach with glue and screws.

Two end-panels are added (Figure 8) to hold the **Torsion Base** up off the work surface providing space for the axis drive screw the X-Axis assembly to slide under.

Put the end panels on with the base upside-down – the top against the flat surface.

The stepper motors are added later and are the same for all axis. See page 30

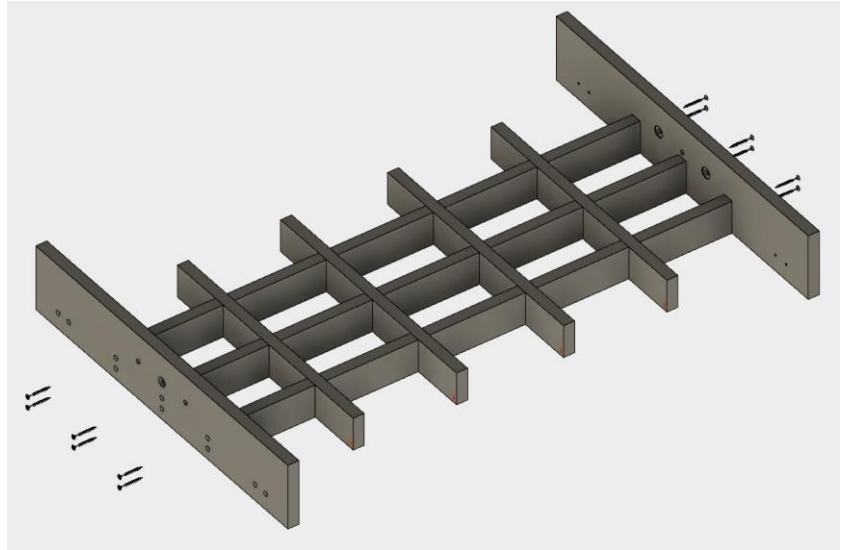


Figure 8 - Attach Base End panels. Assemble upside-down (as shown) on flat surface

Base Linear Bearing Rail Supports

For the **Base Linear Bearing Rail Supports** (Figure 9), it is critical that these are very carefully assembled so everything remains square and true. Dry-clamp the parts, ensure that all three pieces have their back end (facing away from us in Figure 9) flush and straight.

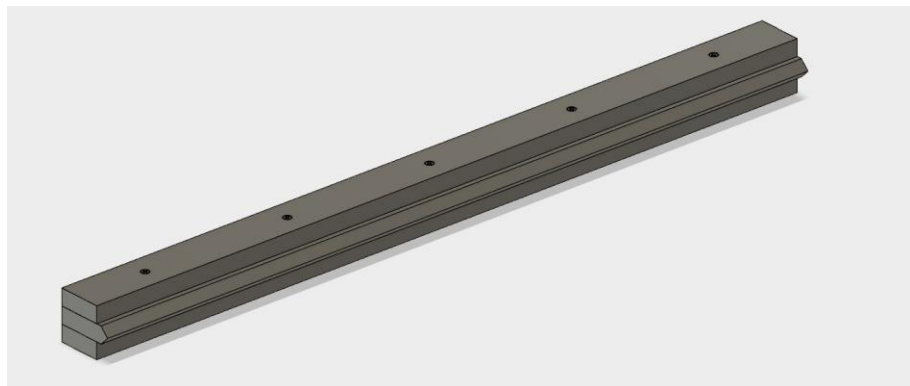


Figure 9 - Base Linear Bearing Rail Supports (Drawing 1004)

Drill pilot holes for the screws. Remove the clamps, glue, re-clamp and screw together. Keep clamped until glue sets-up.

Attach Base Linear Bearing Rail Supports

Glue-and screw the **Base Linear Bearing Rail Supports** (Figure 9) to the Torsion Base (Figure 10). Assemble upside-down on a flat surface, all parts must be flush at the top.

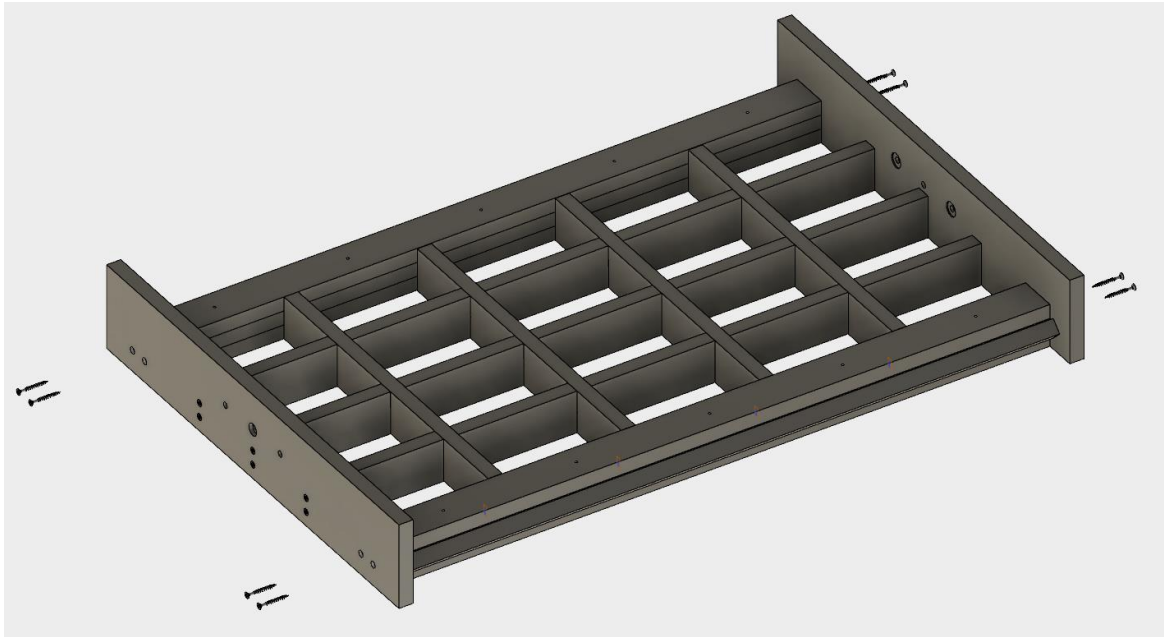


Figure 10 - Install Base Linear Bearing Rail Supports (shown upside-down)



Figure 11 - Underside of my Torsion Base (as built)

Test the fit of the X-Axis Gantry on the Torsion base (Figure 12) before attaching the top of the **Base Top**.

Screw the **Base Top** in place.

Sacrificial Top

Using only 4 small wood screws, one in each corner, attach the **Base Sacrificial Board** to the **Base Top** (no glue).

To aid in clamping work during milling, I recommend cutting T-slots into the sacrificial top (Figure 13).

This will come in VERY HANDY when you start milling. One thing that I really learned to appreciate was just how important (and difficult) properly securing your work-piece is before milling.



Figure 12 - Torsion Base (without top) test X-Axis gantry

Summary

Yes, the torsion box method requires a lot of parts-pieces. I believe you need a super-sturdy base to support all the work that will be going on above it!



Figure 13 - T-Slot router bit and T-slot Rockler.com

The Cross-Dowel Jig

I went the extra mile and used a tongue-and-groove approach on all joints to be double-damn-sure everything went together square (the “belt-and-suspenders” approach).

The drilling jig using brass bushings the size of the bolt (1/4” in my case) and the barrel nut (3/8”) that would allow me to drill perfectly aligned holes without having to measure (a HUGE time saver).

In addition to drawing a center line, I also added ruler markings to the underside to speed the alignment process, for example, drilling 1 1/2” in from the edges (Figure 16).

In Figure 17 I have inserted two drill bits (1/4” and 3/8”) backwards to give you a visual of how the holes will line up.



Figure 14 – Cross Dowel Jig, top view

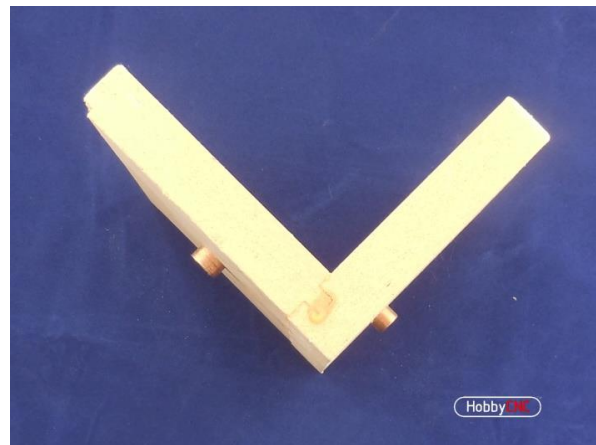


Figure 15 – Cross Dowel Jig, side view



Figure 16 – Cross Dowel Jig, bottom view, note inch markings

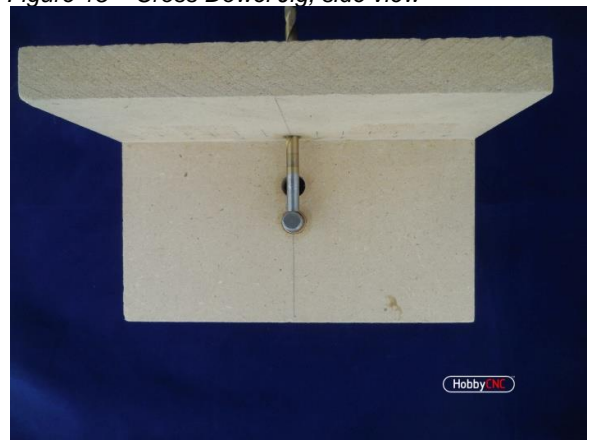


Figure 17 – Cross Dowel Jig with drill bits inserted to see alignment

To use the jig, carefully line up the parts to be drilled and mark where the holes are to go. Clamp the jig over the parts and drill both target parts at one time, without removing the clamps (Figure 18). Having two drill motors (one with a 1/4” drill and one with a 3/8” drill is super handy).

The 3/8" drill goes completely through the stock. For the 1/4" drill, mark the drill bit with tape to indicate how deep to drill. The 1/4" hole will need to go past the 3/8" hole to allow space for the bolt to pass through.

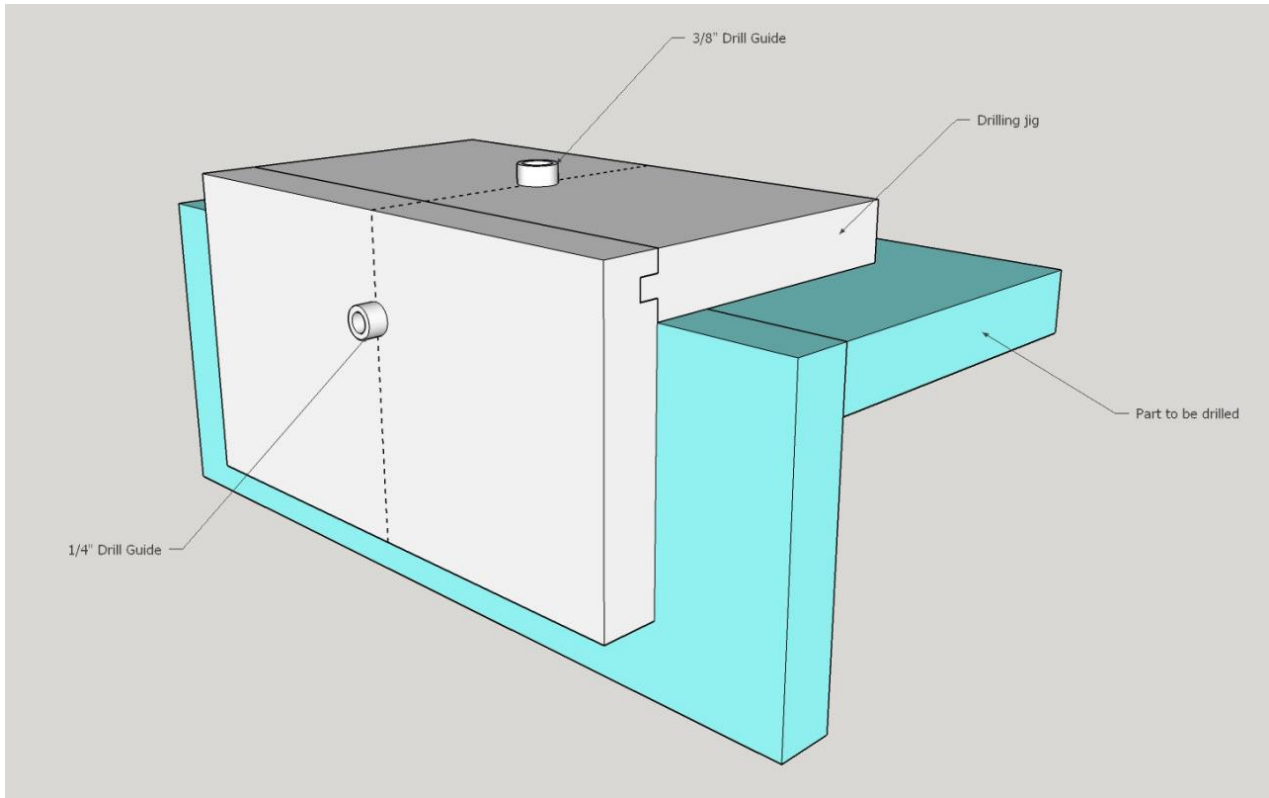


Figure 18 - Drill jig in place over parts to be drilled (light blue)

The threaded hole in the Cross Dowel Nut may be in the center, or it may be offset. Adjust the position of the 1/4" bushing as necessary for your Cross

Dowel Nuts. The 1 1/8" dimension in Figure 22 will drill the 1/4" hole in the center of the part. Move up-or-down as necessary for your Cross Dowel Nuts. Try on some scrap pieces first!

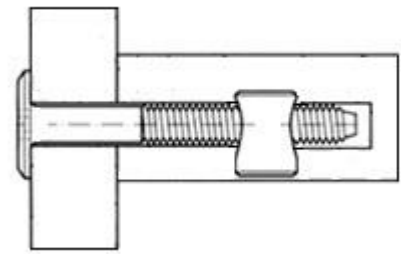


Figure 19 - Cross Dowel cut-away view

Figure 21 includes a 1/4-20 x 2" bolt to show the position of the Cross Dowel nut.

Ensure the part is square during assembly.

You can also purchase pre-made jigs (Figure 20) for example: <http://www.woodpeck.com/crossdoweljig.html>



Figure 20 - Woodpeckers Cross Dowel Drill Jig

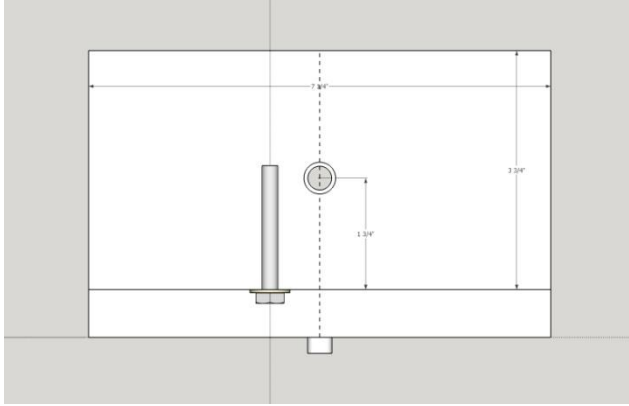


Figure 21 - Drill jig top view with 2" bolt for reference

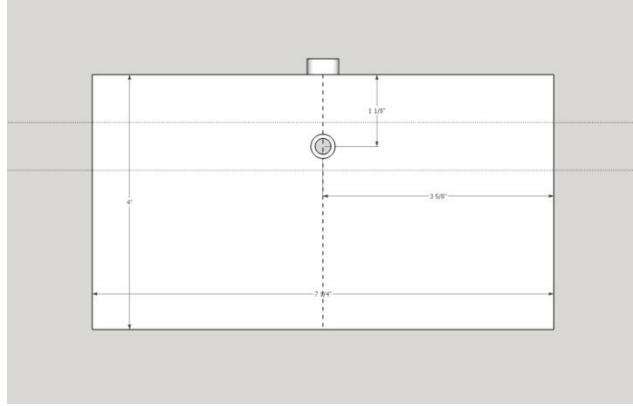


Figure 22 - Drilling jig front view

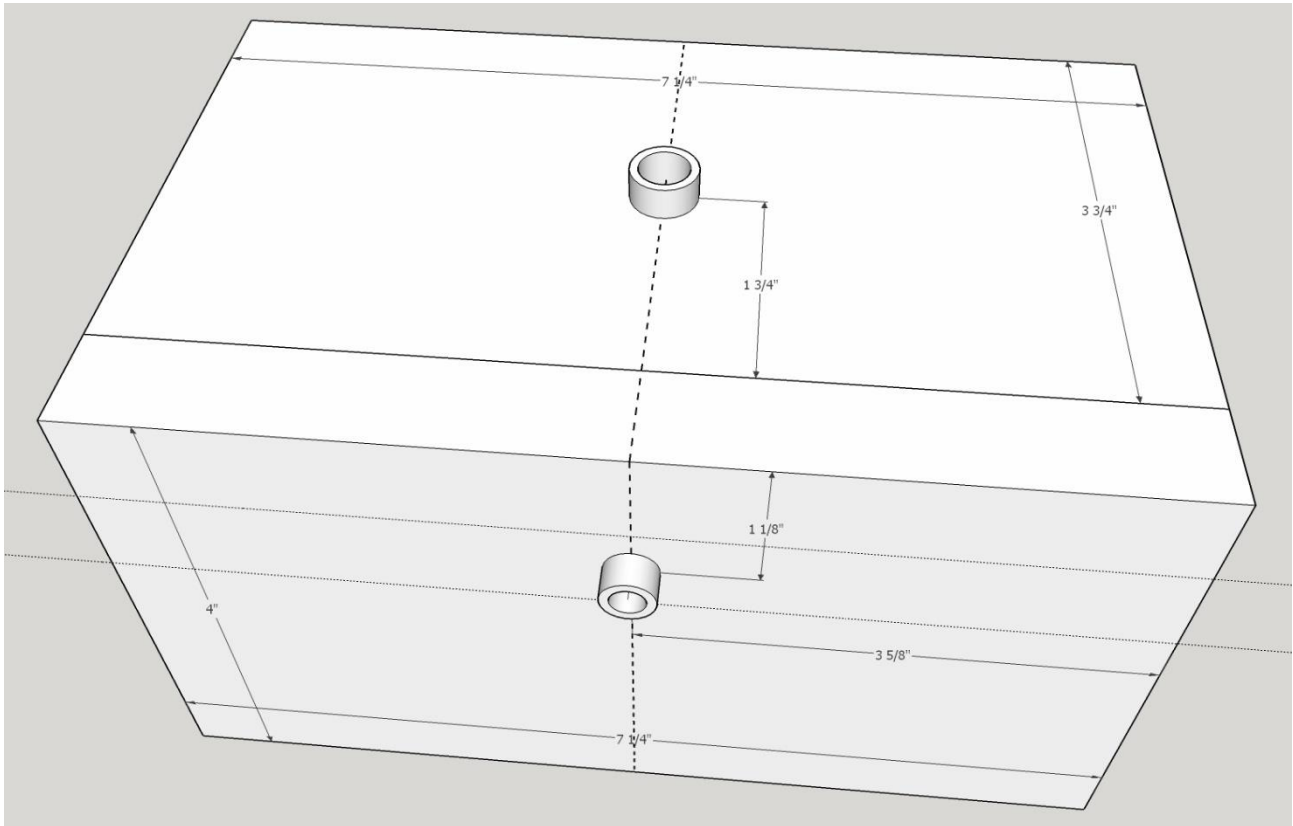


Figure 23 - Drilling jig, assembled

The drive nut and anti-backlash assembly

Drawing 1026, 2 pages. You will need three of these assemblies.

I have employed this solution and I find it works quite well. Once I added the anti-backlash component, the quality and accuracy during PCB milling was improved considerably.

Drive nut

It is made of a standard Hex Coupling Nut and a Stanley 118 Mending Brace. These need to be carefully aligned and welded **to form a strong, single piece.**

It is secured to the axis by two #8 x 3/4 flat head wood screws.

Caution: Use extra care when mounting this part to avoid any binding or bending of the drive screw. The fit should be as passive as possible.

Anti Backlash

To improve repeatability for fine work like PCB isolation routing, I needed to eliminate backlash which was causing wavy, uneven traces during etching. I came up with a simple and effective solution that used a square nut, a spring and two small L brackets. The idea is to 'loosely retain' the spring between the square nut and the lead screw nut, thereby always 'pushing' the lead screw away from the square nut (which remains fixed to the lead screw). Change the spring to impact the amount of backlash control.

Adjust the distance between the coupling nut (#27) and the square nut (#25) to provide the proper tension (e.g. "whatever feels about right") on the spring, then 'loosely capture' the nut between the two L brackets (with #6 x 3/4 wood screws). This will ensure the square nut remains the exact distance from the lead screw nut.

The square nut should not be "pinched" tightly between the L brackets, but just close enough to prevent the square nut from turning.

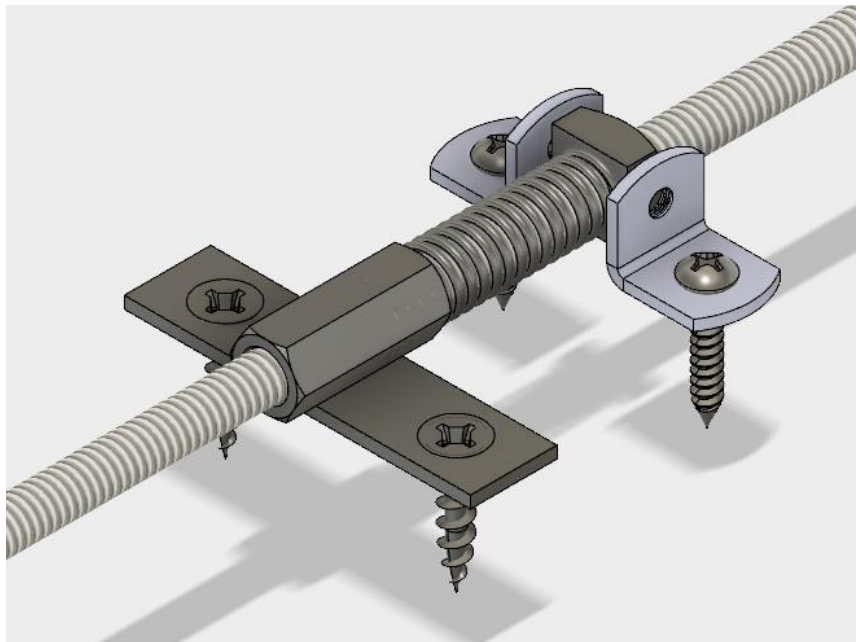
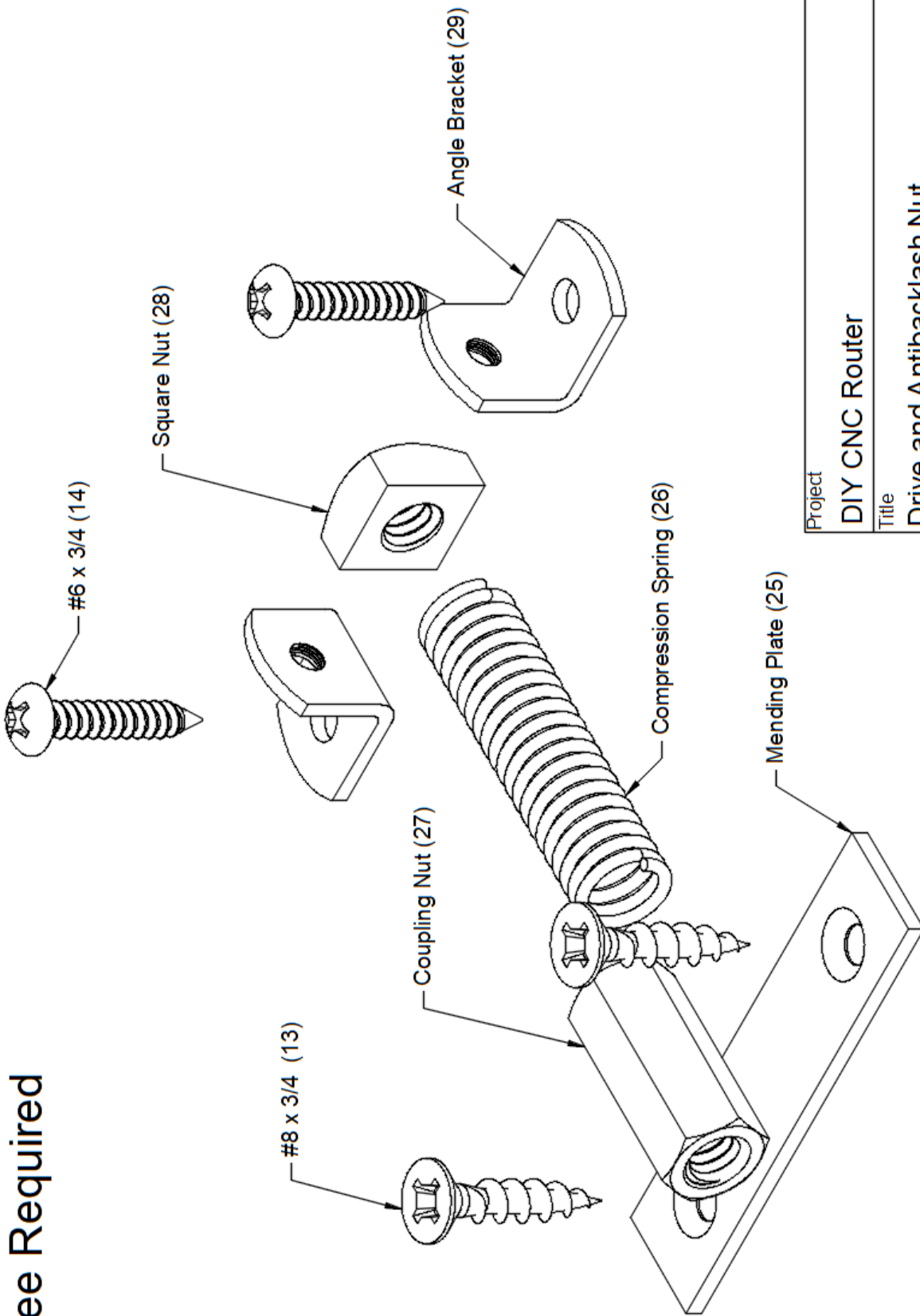


Figure 24 - Drive nut and anti-backlash assembly

Three Required



Project		DIY CNC Router	
Title			
Drive and Antibacklash Nut		Date	10/21/17
Size	A	Rev	00
HobbyCNC		Scale	2:1
		Sheet	2 of 2

Figure 25 - Drive nut and anti-backlash assembly, exploded

Example with and without anti-backlash

Figure 26 is a microscope image (20x) of an early PC board etch. The pads (going diagonal from bottom left to top right) are .050" on center. Notice the wavy traces coming off the pads

The trace in Figure 27 (same magnification) is clean and crisp. The trace is a narrow because I had my depth-of-cut a bit too deep. Still worked, though.

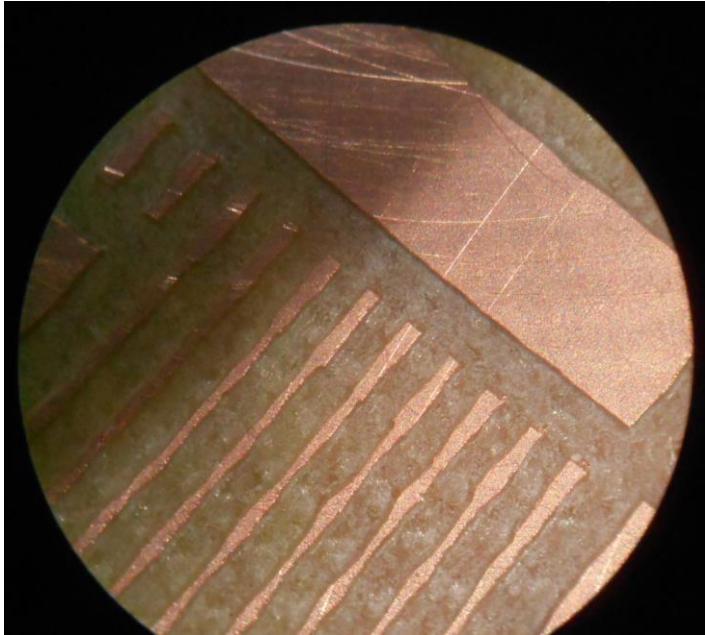


Figure 26 - Without anti-backlash

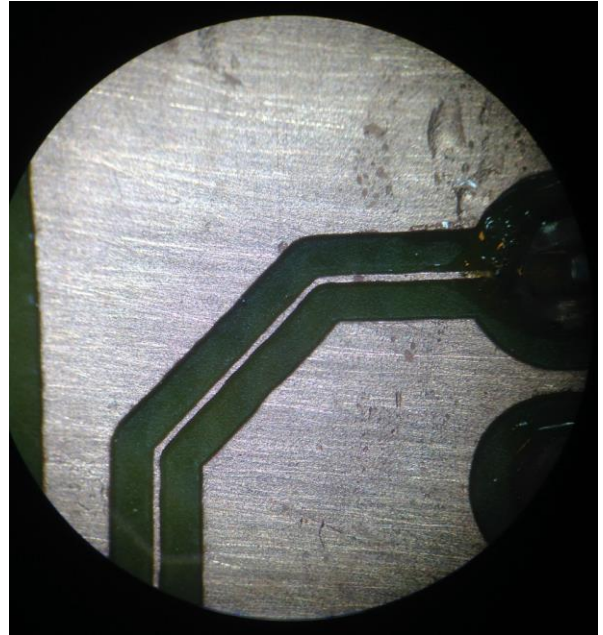


Figure 27 - With anti-backlash

Linear Bearings

Drawings 1021, 1022, 1027

This is another big area where our simple plywood CNC Router design is different than "real" mills - the approach used here is a very inexpensive implementation that will still yield acceptable results for a Hobby CNC Router. This system uses a very simple and inexpensive linear bearings using $\frac{3}{4}$ " aluminum angle (6061 or 6063) and skateboard bearings. If made right, it is quite rigid and durable. I would imagine you could substitute steel angle for the aluminum. Don't know for sure, didn't try it.

Care must be taken to drill the mounting holes E X A C T L Y the same distance from the corner of the aluminum angle stock. This will determine how well all four bearings ride against the opposing angle and distribute the forces.

Put the bolt through the bearing and follow this with a nut. Tighten to secure the bearing. No washer. Then place the bolt/bearing/nut assembly into the threaded hole in the angle bracket.

If your $\frac{5}{16}$ " bolts are too long, you can offset the holes for the bearings, as long as you respect the identical distance from the apex of the angle. There are four 8 inches long and two 4 inches long. Other than the length, the construction is identical. Drill-and-tap all holes $\frac{5}{16}$ -18. Assemble as shown.

Build one and test for proper clearance (Figure 30) before drilling all the parts.

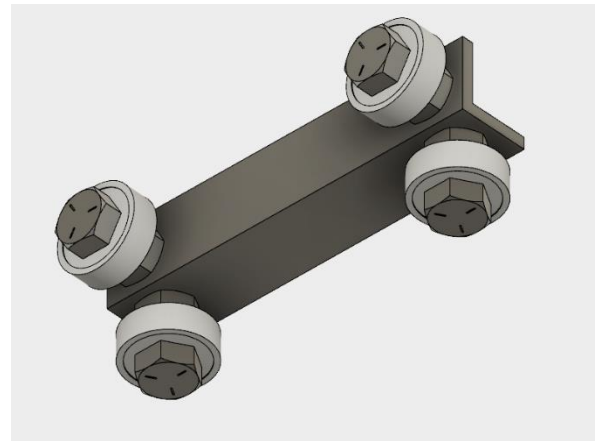


Figure 28 - 4" Linear Bearing Assembly

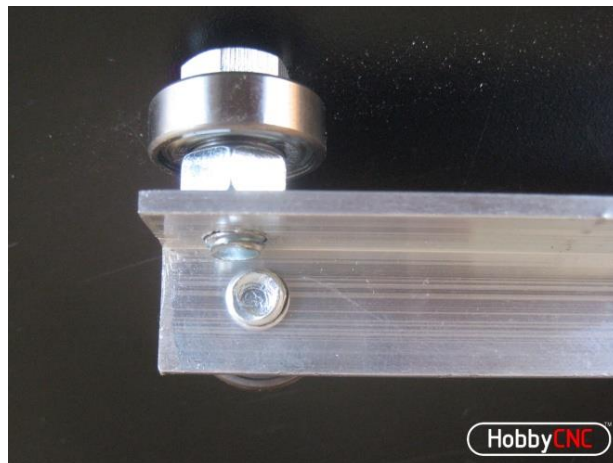


Figure 29

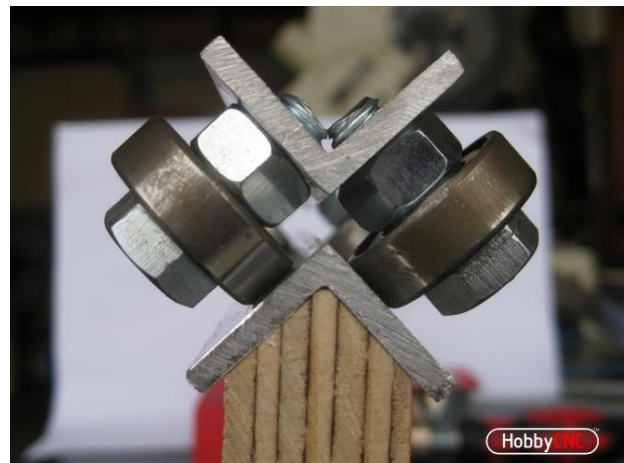


Figure 30 – Test for clearance

Linear Bearing Support

The Linear Bearing Support is a small “house shaped” strip of material that sits between the Linear Bearing and the associated gantry, colored orange in Figure 32. These are cut intentionally long. You will need to make a few “trial and error” attempts at getting the bearing support the right length.

You will also need to remove some material from the bearing support where the 5/16” bolts stick through the aluminum angle (Figure 31).

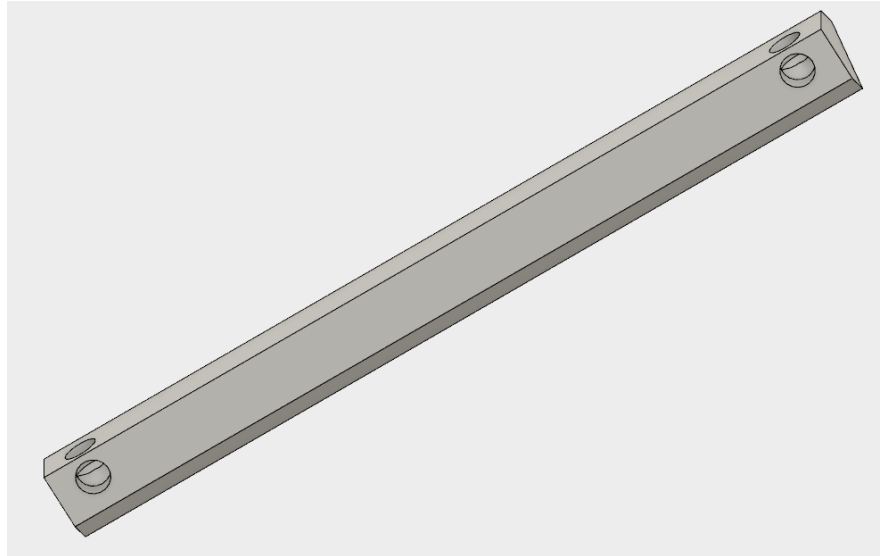


Figure 31 - Linear Bearing Support (8 in) showing recesses for bolts

Shimming the linear bearings

This part of the assembly is test-modify-test-modify until you get the linear bearings riding firmly against the opposing rails.

If you need to shim it, you can put shim stock between the **Linear Bearing** and the **Linear Bearing Support** or between the **Linear Bearing Support** and the **gantry**. You can use cut-up soda cans, or you can use the ‘fingers’ from an inexpensive feeler gauge.

For my build, I used business cards. Probably not recommended, but it did work for me.

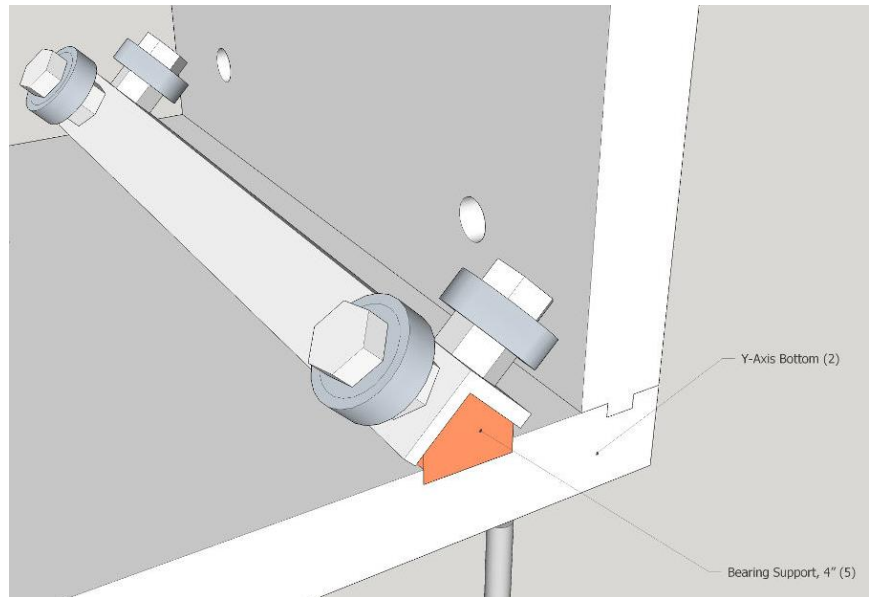


Figure 32 - Linear Bearing Mount (orange)

I also counter-sunk a hole in the dead-center of the **Linear Bearing** to accommodate a small, flat head screw (not shown) to hold the **linear bearing** in place during assembly and disassembly.

The X-Axis

Drawings 1009 through 1012.

The X-Axis slides along the Base, front-to-back. As with all the parts, care in cutting and layout are important to ensure a quality output from your router.

Carefully align the X-Axis **Linear Bearing Nut and anti-backlash** parts perpendicular and on the center line of the **X-Axis-Bottom**.

Now bolt the X-axis together around the **Base** (Figure 12). Test the bearings for a snug - but free moving - fit. Shim or trim as necessary to get a perfect fit.

Slide the axis forward and backward to ensure smooth movement with no binding. At each end of movement, verify and mark the **Base-End-Panels** where you will drill the holes for the drive screw.

After you have adjusted for a perfect fit, glue (or screw) the **Linear Bearing Supports** onto the X-Axis sides. Optionally attach the 8" **Linear Bearing Assemblies** (I put a small, flathead screw dead-center to hold it in place - not shown).

Slide the X-Axis drive screw through one side of a **Base-End-Panel**, add the small square nut (part of the anti backlash assembly), then the spring, then thread into the X-Axis **Drive Nut and Anti-backlash Assembly**, making sure the spring is well compressed. An electric drill carefully clamped on one end of the threaded rod will speed up this process.

Add bearings to both ends of the X-Axis drive screw and double-nut (See Drawing 1102) making sure there is some tension on the threaded rod to keeping it from "flopping around" at higher speeds.

Mount the limit switches with one screw only. Wait until assembly is completed to add the final screw.

You will need to remove the threaded rod when it is time to install the Y-Axis gantry.

The stepper motors are added later and are the same for all axis. See page 30.

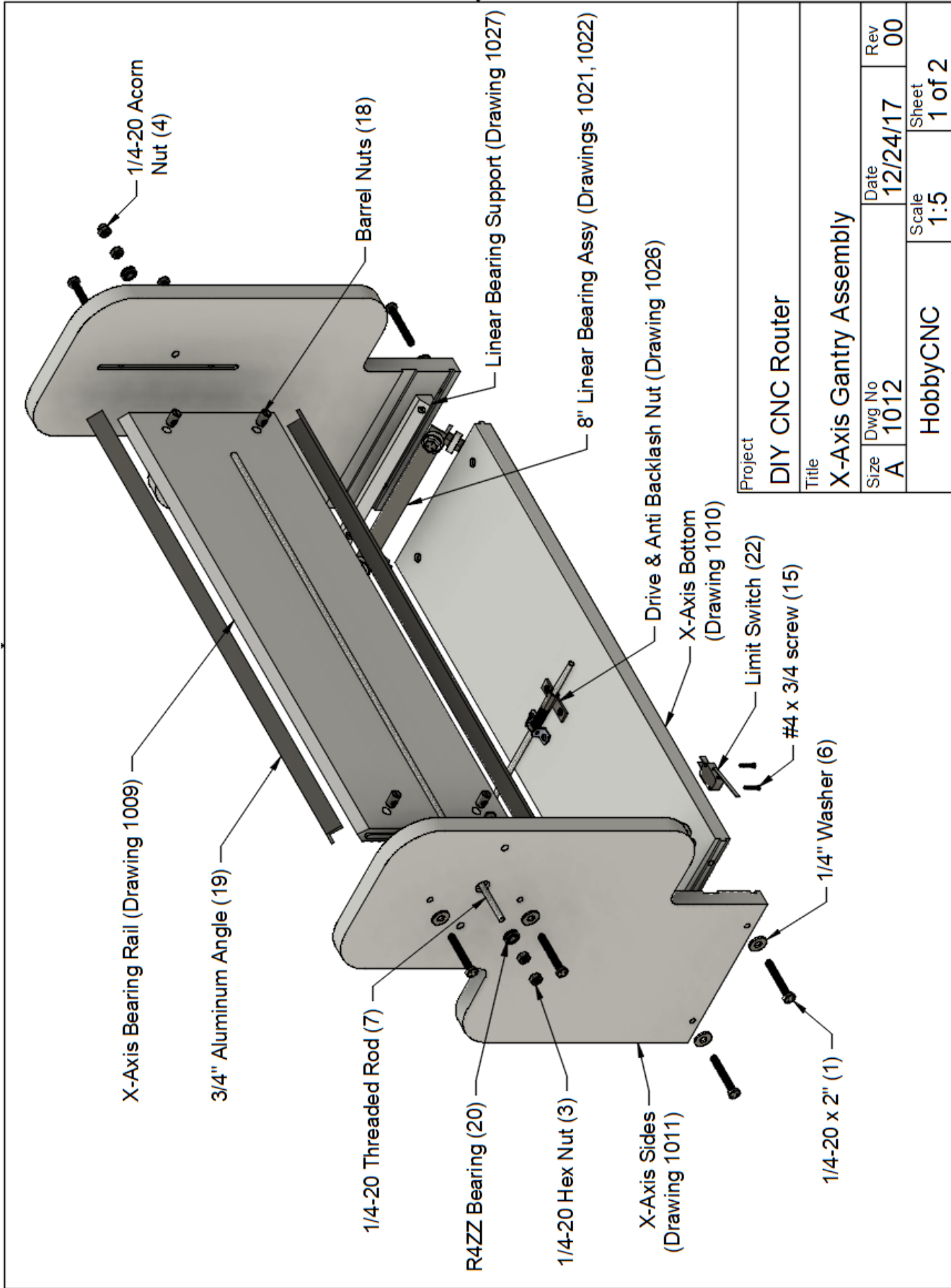


Figure 33 - X-Axis Gantry Assembly, Exploded

The Y-Axis

Drawings 1013 through 1016

Assembly of the Y-Axis is identical to the X-Axis. The Y-Axis slides along the X-Axis, left-to-right. As with all the parts, care in cutting and layout are important to ensure a quality output from your router.

Carefully align the Y-Axis **Linear Bearing Nut and anti-backlash Assembly** perpendicular and on the center line of the **Y-Axis back**.

Now bolt the axis together around the **X-Axis Bearing Rail**. Test the bearings for a snug but free moving fit. Shim or trim as necessary to get a perfect fit. Slide the axis left and right to ensure smooth movement with no binding.

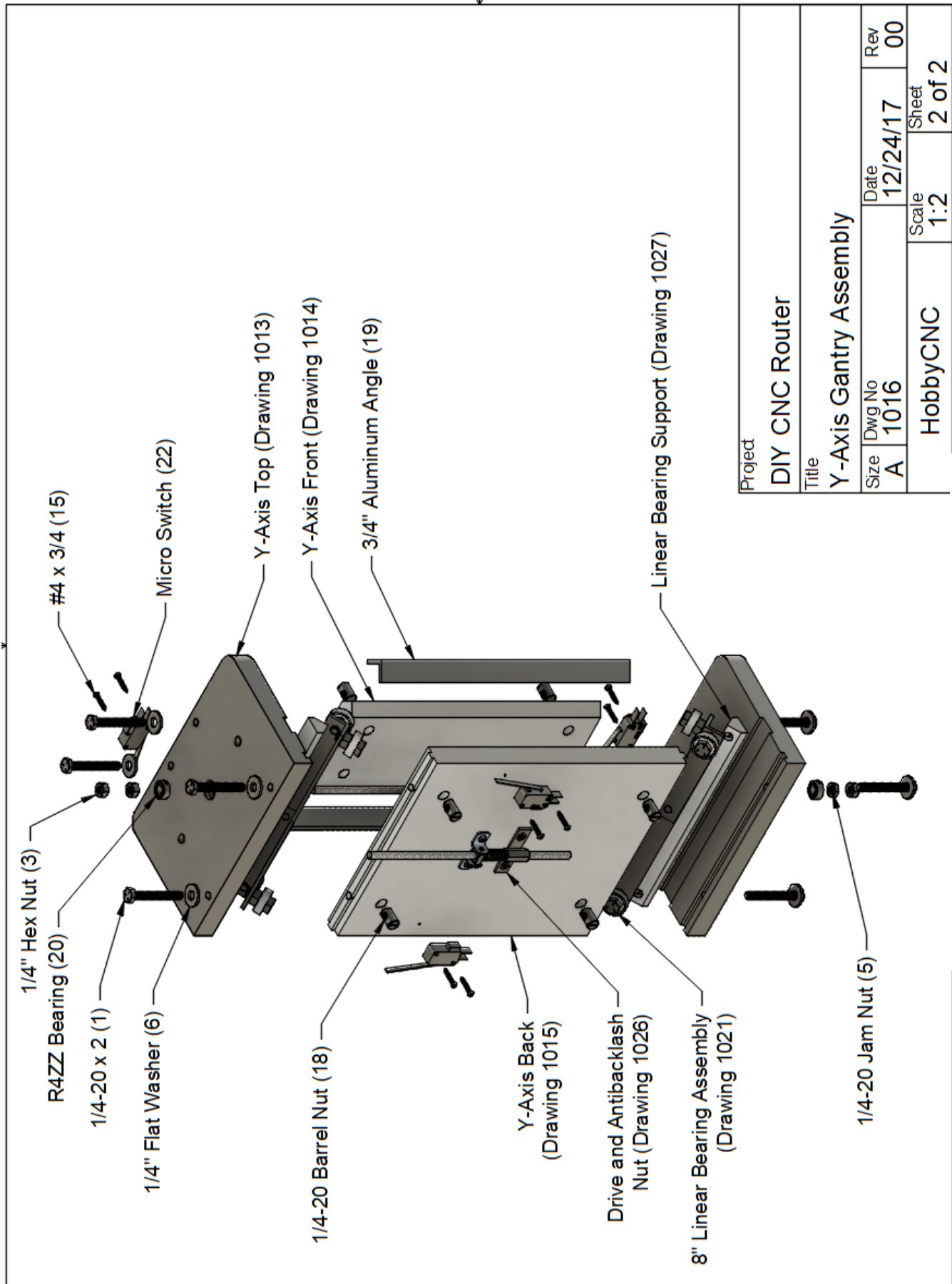
Screw or glue the Y-Axis **Linear Bearing Mounts** onto the **Y-Axis top and bottom**. Optionally attach the **Linear Bearings** (I put a small, flathead screw dead-center to hold it in place - not shown).

Mount the limit switches with one screw only. Wait until assembly is completed to add the final screw.

At each end of movement, mark the **X-Axis sides** where you will drill the holes for the drive screw. Thread the Y-Axis drive screw through one side of the **X-Axis Side**, add the small square nut (part of the anti-backlash assembly), then the spring, then thread into the Linear Bearing Nut, making sure the spring is well compressed. An electric drill carefully clamped on one end of the threaded rod will speed up this process.

Add bearings to both ends of the Y-Axis drive screw and double-nut making sure there is some tension on the screw.

The stepper motors are added later and are the same for all axis. See page 30.



Project		DIY CNC Router	
Title			
Y-Axis Gantry Assembly		Date	12/24/17
Size	Dwg No	Rev	00
A	1016	Scale	1:2
HobbyCNC		Sheet	2 of 2

Figure 34 - Y-Axis Assembly Exploded

The Z-Axis

The Z-Axis provides the up-and-down component of movement. As with all the parts, care in cutting and layout are important to ensure a quality output from your router. It is assembled-around and slides on the Y-Axis. The Z-Axis will hold your router or Dremel² or pen or whatever you wish to move.

Carefully align the Z-Axis Linear Bearing Nut and anti-backlash parts perpendicular and on the center line of the Z-Axis back.

Now bolt the axis together around the base. Test the bearings for a snug but free moving fit. Shim or trim as necessary to get a perfect fit.

Slide the axis up and down to ensure smooth movement with no binding. At each end of movement, mark the Y-Axis top and bottom where you will drill the holes for the drive screw.

Screw or glue the Z-Axis Linear Bearing Mounts onto the Z-Axis sides. Optionally attach the Linear Bearings (I put a small, flathead screw dead-center to hold it in place - not shown).

Thread the Z-Axis drive screw through the top of the Y-Axis, add the small square nut (part of the anti-backlash assembly), then the spring, then thread into the Linear Bearing Nut, making sure the spring is well compressed. An electric drill carefully clamped on one end of the threaded rod will speed up this process.

Add bearings to both ends of the Z-Axis drive screw and double-nut making sure there is some tension on the screw.

The stepper motor mount will be added later.

² I know the Dremel is famous for excessive runout – but it is fine for beginning.

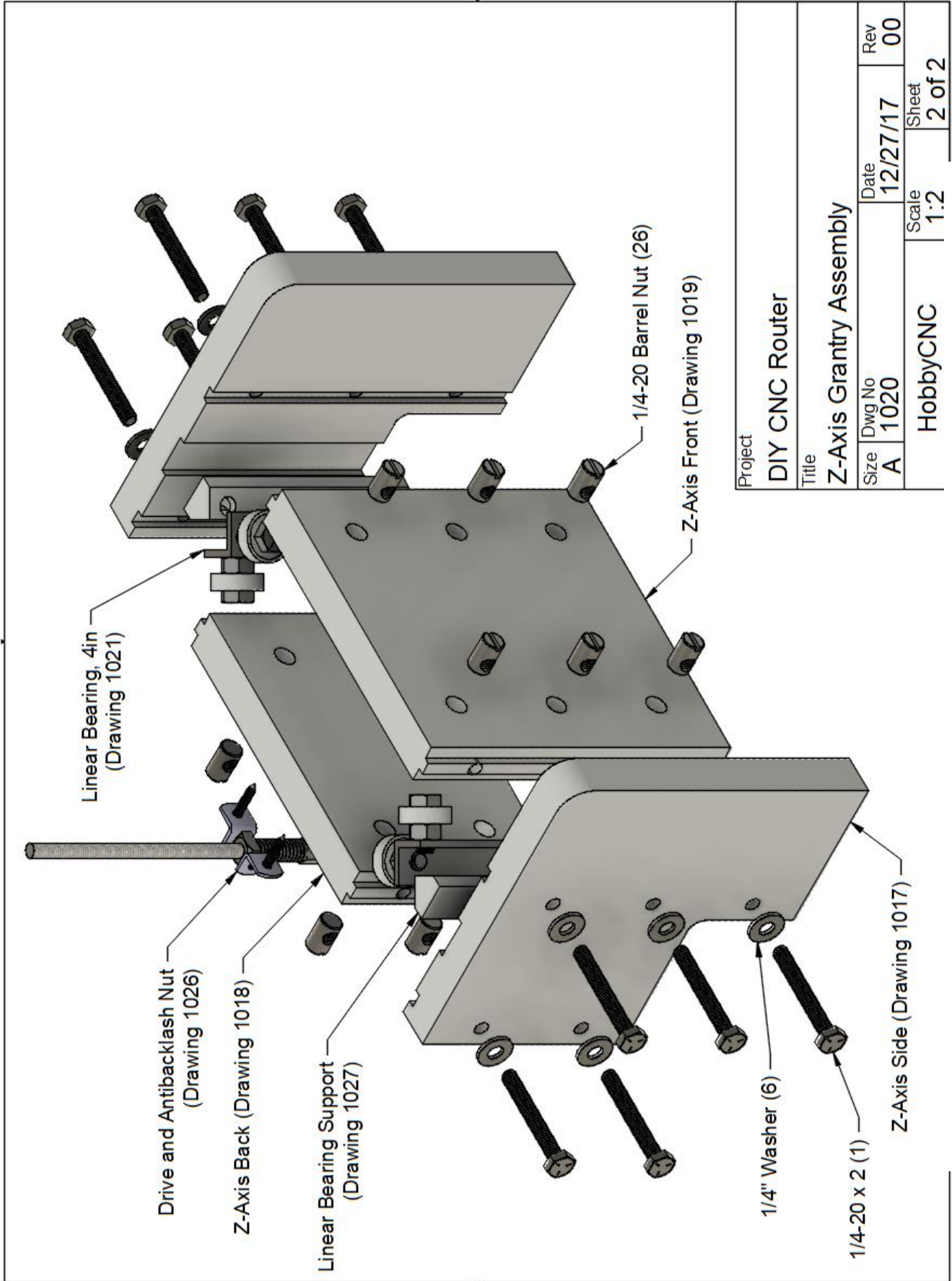


Figure 35 - Z-Axis Assembly, Exploded

Spindle Mounting

The actual mounting of your spindle to the Z-Axis is up to you and will, of course, vary based upon the spindle you use. Figure 36 is a photo of one of my spindles mounted.

The small metal plate (Figure 36) to the lower right of my Z-axis carriage contains a $\frac{1}{4}$ -20 threaded hole where I can quickly attach a dial indicator or a plotting pen.

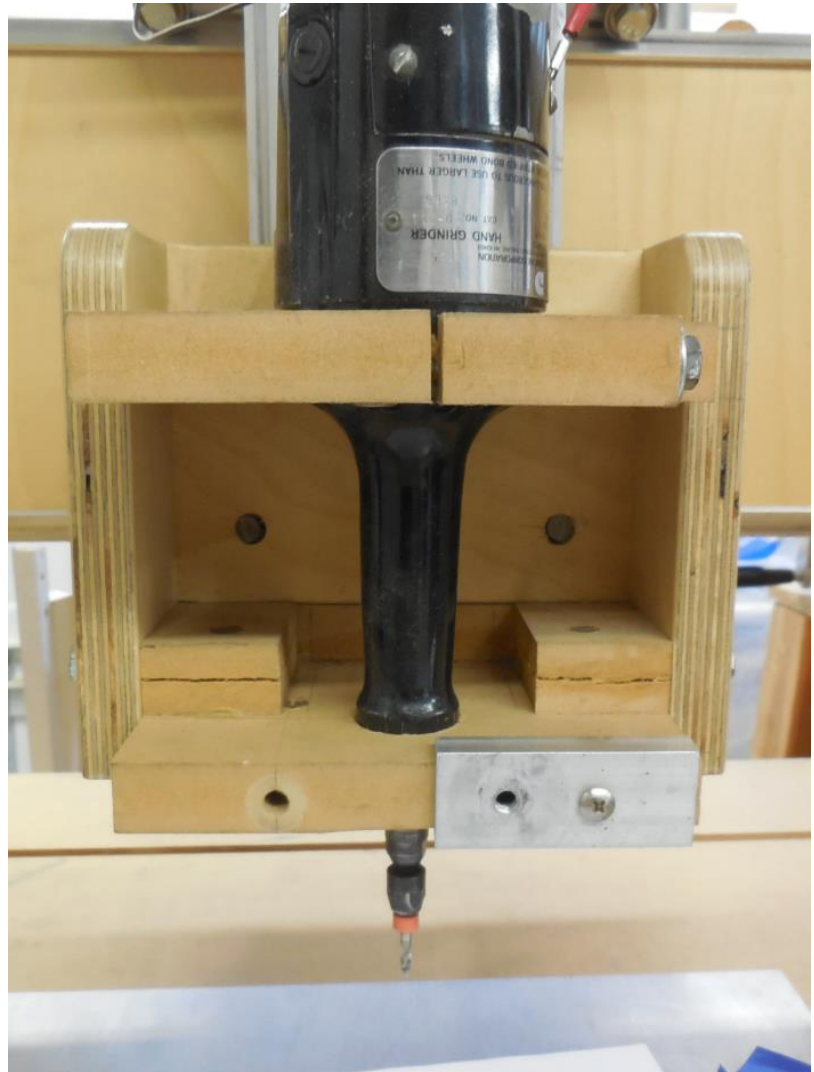


Figure 36 - Example of motor mounting to the Z-Axis carriage

Stepper Motor Mounting

Three of these assemblies are required.

Stepper motors need to mount straight-and-true to the drive screws. To minimize the potential for misalignment I recommend a flexible coupling (Figure 37). I currently use a spider assembly (Figure 38). The spiders I use had too much "slop" in them that I had to shim out. I am planning to move to a flexible shaft coupling to further eliminate any backlash issues in the spider. There are several different variations of flexible couplers. You could even go with a non-flexible coupler.

The motors mount via "T Nuts" to their associated panels.

The dimensions and design will need to be adapted to your specific motor and coupling mechanism.

I recommend using a connector on the motor wiring. This just makes assembly and disassembly (and troubleshooting) so much easier.

Make all the screw holes in the **Stepper Motor Spacer Block** as tight to the screws as possible. It wouldn't hurt if you had to use a drill motor to put the screws into the **Stepper Motor Spacer Block**. This assembly is subject to constant back-and-forth torque, so keeping everything tight and close tolerance will help keep everything from coming loose.

I went with this design to simplify installing and removing the stepper motors during construction. Also, if I had any stepper motor problems (I didn't), I could more easily swap motors.



Figure 37 - Flexible Shaft Coupling



Figure 38 - Spider Coupling

Alternative mounting technique

Another option I see often is to use standoffs (Figure 39). If you go this route, remember that these standoffs have to deal with all the back-and-forth torque the motors generate, so if you go this way, make them **STURDY**. Looks like this guy has some decent stock (aluminum, I'm guessing). This would be one place to err on the side of "too big" rather than risk any movement.

I also like the "shroud" effect my design has, in that it does keep *some* of the crap out of the Flexible Shaft Coupling mechanism.

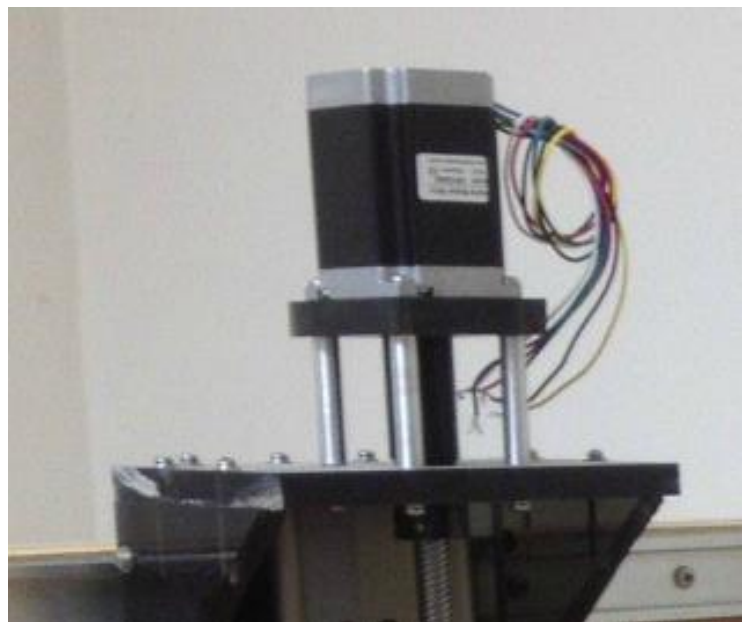
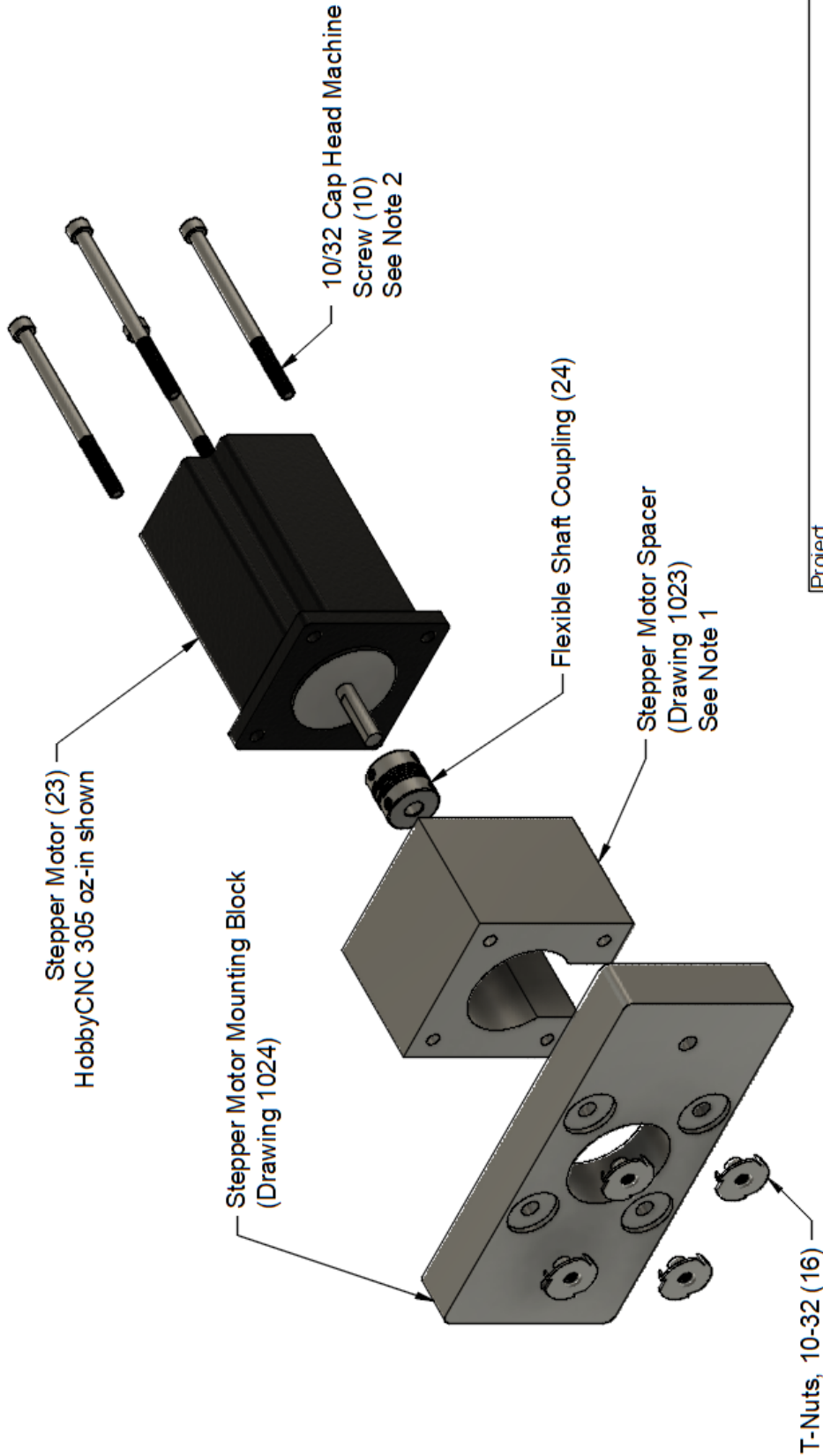


Figure 39 – Alternate mounting approach - motor on standoffs

Three Required



Notes:

1. The thickness of the **Stepper Motor Spacer** needs to be adjusted to match your particular system dimensions
2. The length of these 4 machine screws is dependent upon the thickness of your motor spacer block + 1 in (24.5mm).

Project

DIY CNC Router

Title

Stepper Motor Assembly

Size

Dwg No

A 1025

Date

12/15/17

Rev

00

Scale

1:2

Sheet

1 of 2

Figure 40 - Stepper Motor Mounting, exploded

Electronics

You will need four main components:

- Computer (ideally with a parallel port)
- Stepper motor driver
- Stepper motors
- Power supply (to drive steppers)

Computer

Ideally with a parallel port

Suggestion: Get a small desk-side computer from a friend, yard sale or an electronics recycler and throw a parallel port card in it. The motherboard may even already have the connector installed, you just need a back plate with ribbon cable. Don't bring your laptop into the shop. It is dirty and generally not safe for delicate electronics. With a cheap-o desktide machine, you can open it up and blow it clean whenever you need to. CAM software is not terribly demanding on your PC, since the machine can only move so fast, which is not a challenge for any fairly current computer.

Stepper motor driver

I recommend to "keep it simple". I use and recommend the **HobbyCNC board kit** (Figure 41). One board, up to 4 axis. No break-out board and much simplified wiring and a much smaller footprint.

This product is provided as a kit and you need to solder it together yourself, but the functionality and price are great.

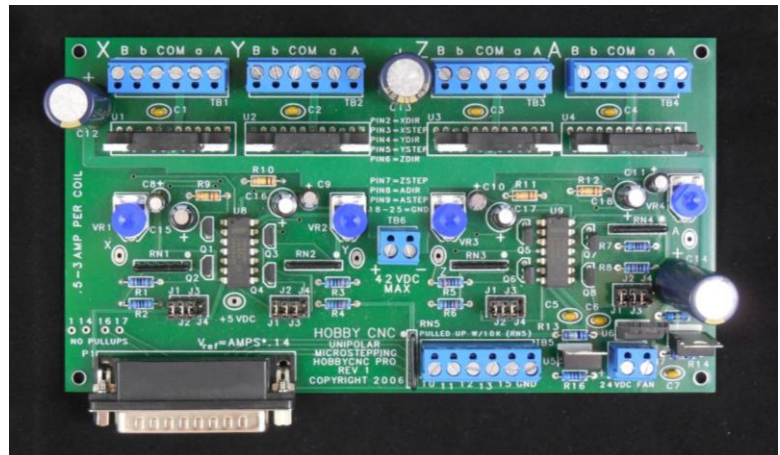


Figure 41 - HobbyCNC PRO 4-Axis board (assembled)

For visual assembly instructions, see [Instructables](http://www.instructables.com/id/HobbyCNC-4-Axis-Stepper-Motor-Driver-Board/) (instructables.com/id/HobbyCNC-4-Axis-Stepper-Motor-Driver-Board/).

CAUTION: Whatever you do, avoid cheap eBay foreign-made driver boards. Confusing instructions and no tech support await you. You want to be a CAD CAM expert, not a "fix the cheap import" expert.

You need a parallel cable with all pins wired straight through.

If you must use USB or Ethernet there are solutions (price goes up quite a bit, though).

Stepper motors

NEMA 23 motors are plenty big enough. Make sure you get the right type for your driver board. There are two main families: Unipolar and Bipolar. The HobbyCNC boards are unipolar - which means you need a 5, 6 or 8 wire stepper motor (4 wire is bipolar only). I don't know how to 'size' the motors. I

went with a fairly 'beefy' motor. The tradeoff: More torque, more power (bigger power supply) slower speeds.

Power supply (to drive steppers)

For the HobbyCNC solution, a burly, unregulated linear supply is fine. Around 32 Volts DC and figure 2.5 Amps per stepper motor. You can use a regulated 'switching' supply too, no problem. I see lots of cheap ones on eBay. Caveat Emptor. I built my own.

Optional (but recommended) Emergency OFF switch

I purchased this (Figure 42 - Emergency power-kill switch Figure 42) at my local woodworking store (Rockler). When things go bad, they tend to go bad very fast, I want a large target. This will kill my motors and my spindle.

Optional - UPS

I have had a few jobs ruined by kicking a plug or my compressor turning on. The UPS stops all that stuff. No more interrupted jobs. This UPS only powers the PC. The power supply for the motors has enough storage to deal with transients.

Cabinet

I built a rolling cabinet for my CNC router so I have a place for all the tooling, wrenches, spindles, stock, keyboard drawer and a large drawer for the electronics.

Yellow box is the HobbyCNC Stepper Motor Driver board.

Red box is the linear power supply to drive the steppers.

Blue box is an opto isolator board for my limit and home switches.

Green box is my power distribution.

Purple box is my small PC. Drawer is cooled by two fans.



Figure 42 - Emergency power-kill switch

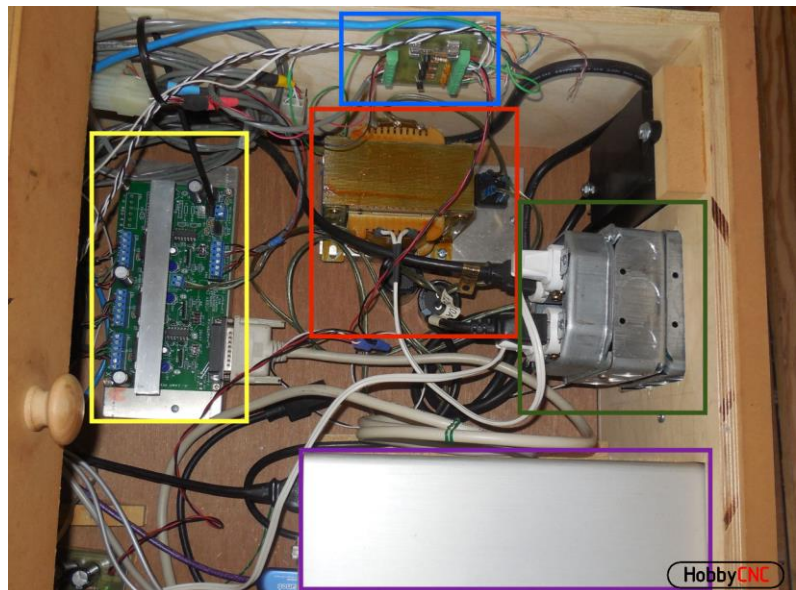


Figure 43 - Electronics Drawer

Limit Switches

Limit Switches should be included in your build. These switches are located at both ends of each axis-of-movement such that an “over extension” of any axis will trigger the software to stop moving the motors and halt the program.

This can prevent serious damage to your CNC machine, and potentially to your body.

Figure 44 shows a very typical limit switch. You will need 6 for your build. They are super-easy to install and wire-up. Notice the long lever on the switch. This can be bent and adjusted as necessary so as to ‘trip’ at the right time.

All 6 limit switches are wired in series – if any limit switch is tripped, regardless of which one, the circuit is ‘broken’, no current flows and the input on the HobbyCNC board is pull high (10k internal pullup). The wiring ‘daisy chains’ from the NC of switch 1 to the COM of switch 2, from the NC of switch 2 to the COM of switch 3, from the NC of switch 3 to the COM of switch 4, etc.

You will need to configure your CAM software to accept the proper level (e.g. ‘active high’ or ‘active low’) and pin.

Figure 45 attempts a combination schematic and diagram to show how the wire leaves one switch and goes to the next (red and green wires).

The blue wires go to the HobbyCNC PRO board, pins 11 and GND.

You could add one more switch as an E-Stop switch also.

This type of wiring where current flows until there is a limit situation is a more “fail safe” approach than using the N.O. pins and wiring the switches in parallel (very not recommended).



Figure 44 - Typical Limit Switch

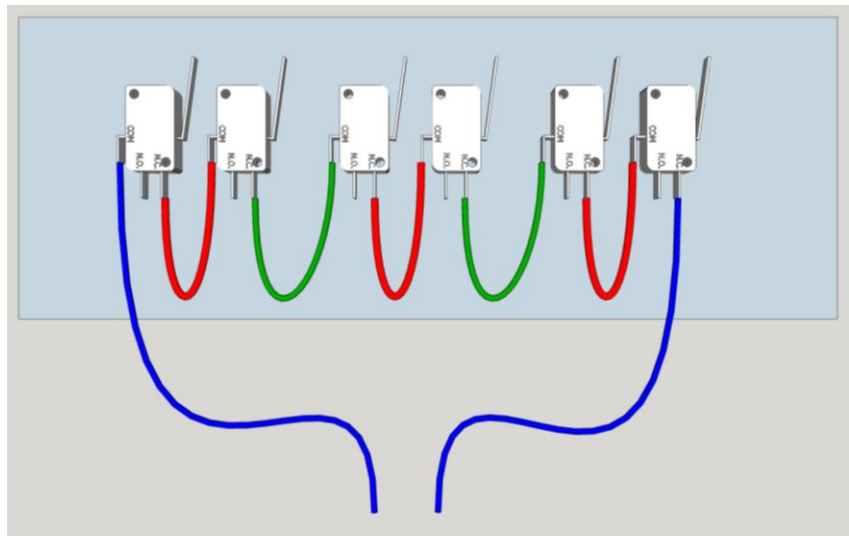


Figure 45 - Limit Switch Wiring Explained

Figure 46 shows how my HobbyCNC PRO board is wired. You need to focus only on the connector highlighted in red. Each of the inputs on this terminal block have a 10k pull-up resistor. Take care when routing the wires from this connector to the limit switches so that the limit switch wiring is not in close proximity to the stepper motor wiring (potential for induced noise to trigger a shut-down)

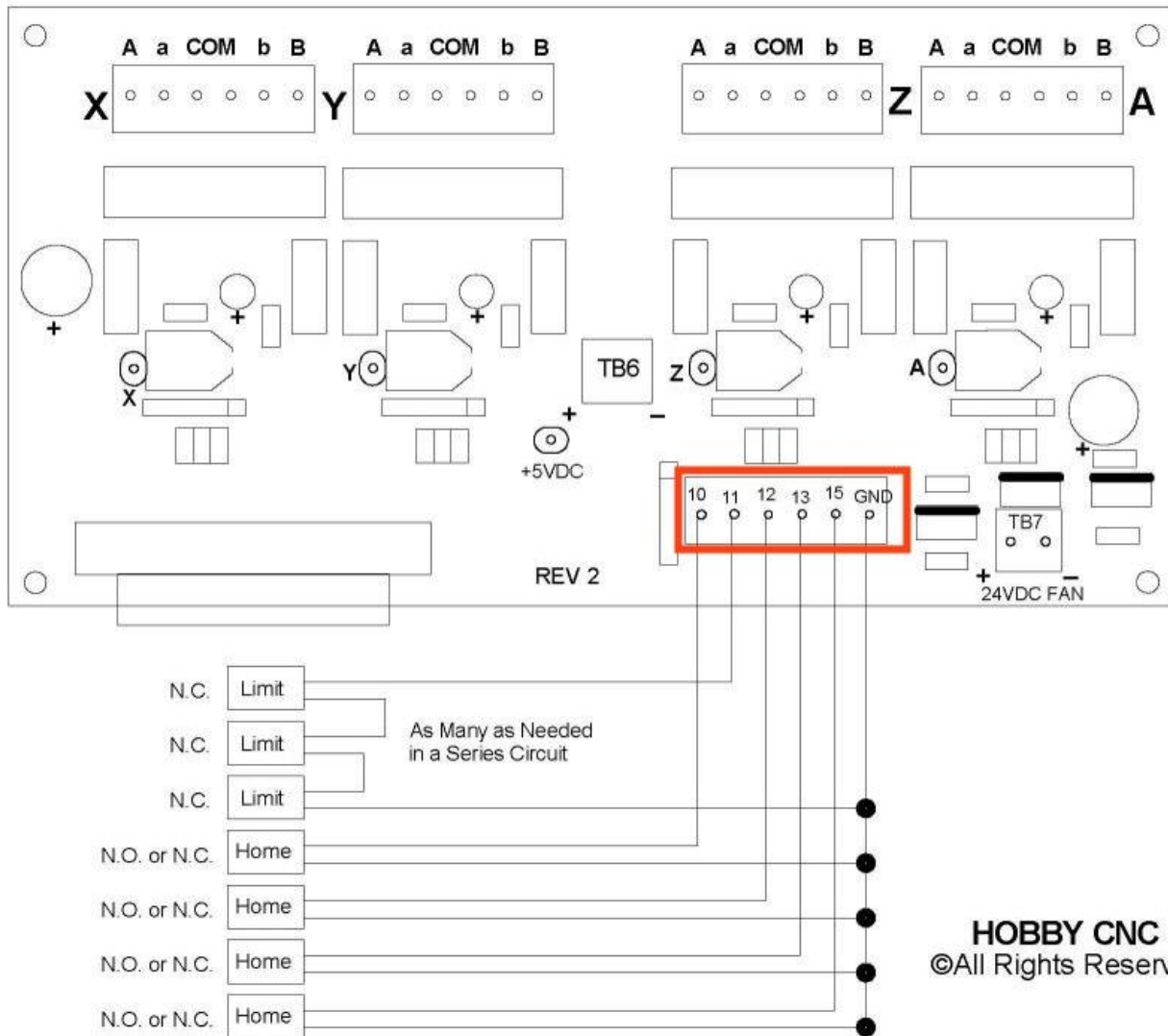


Figure 46 - Limit Switch Wiring Schematic

Stepper Motor Wiring

The details for this section are based upon using the HobbyCNC Combo Kit which includes the HobbyCNC driver board, 6 conductor cable (unshielded) and stepper motors. All wire colors are very likely to change if you source other hardware.

General rules

- Keep all stepper motor wiring as short as reasonable. Eliminate all excess cabling.
- Do not run limit switch wiring in the same cable as the stepper motors
- Do double-check wire colors at both ends. The instructions below are designed to minimize this as being an issue
- NO wire nuts. Ever. Period.
- Optional but a good idea: use a quality connector at the stepper-motor end. **If not**, then twist, solder and cover with shrink tubing.

Attach cable to the PC Board

1. Strip back 2" of the outer jacket of the 6 conductor wire. Go gently and use caution to not nick the conductors within. Nicks lead to fatigue/failure points

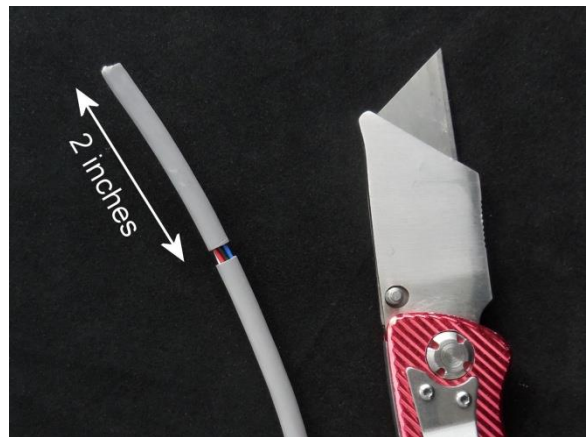


Figure 47

2. Remove the outer cover and cut out the fiber strengthening cord (on the left)

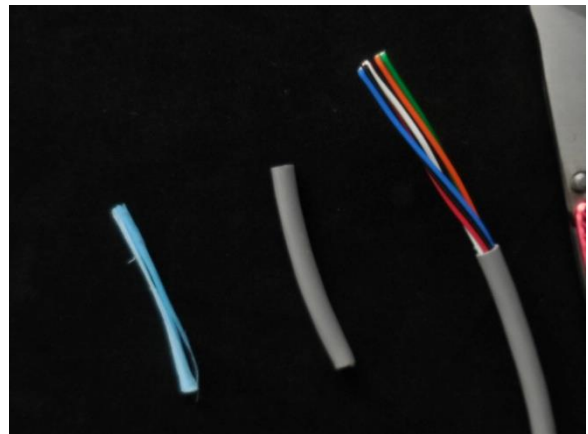


Figure 48

- Strip 1/4" from each wire, Go gently and use caution to not nick the conductors within. Nicks lead to fatigue/failure points.

Fan the wires in this order (left-to-right)
red, black, blue, orange, white, green

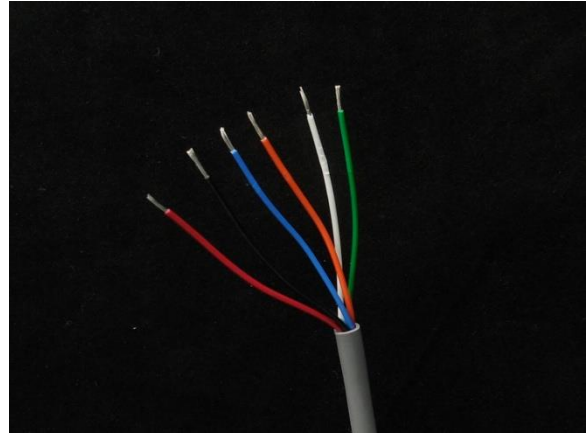


Figure 49

- Carefully insert each wire into the terminal block and tighten the screw. Make sure that insulation is NOT inside the connector.

Gently tug on each wire to confirm it is indeed captured in the clamping mechanism.

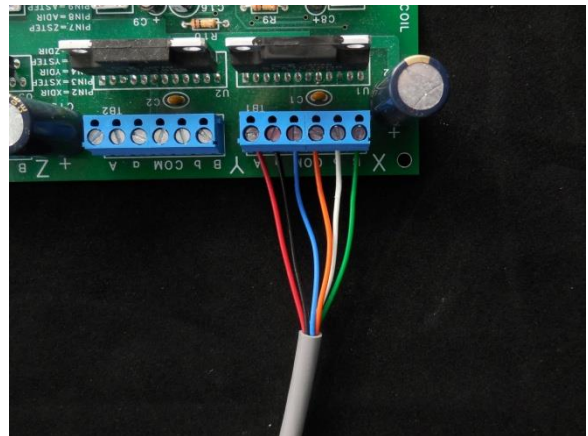


Figure 50

- Give one final, visual inspection and confirm:
 - Wires are in the proper order
red, black, blue, orange, white, green
 - no insulation is captured inside the connector
 - each wire is firmly captured (gentle tug test)
- Repeat for each remaining axis

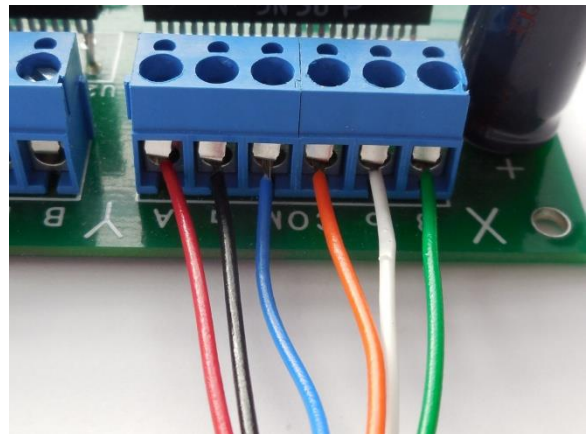
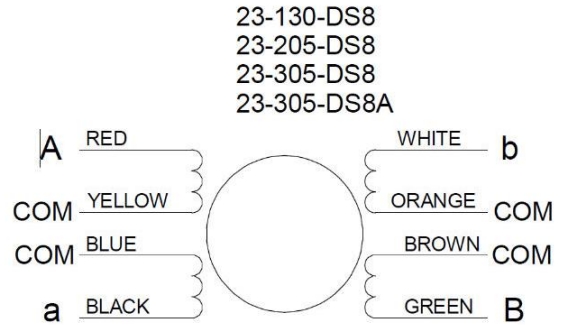


Figure 51

Stepper motor wiring

1. Follow the same first three steps from above
 - a) trim 2" from the cable outer jacket
 - b) remove strengthening cord
 - c) strip wire ends **3/8"**

Note: wire colors are for HobbyCNC motors only. Other motors will likely have different colors.



www.HobbyCNC.com

Figure 52

2. Match stepper motor wire color to cable wire color.

Cable	Stepper
Red	Red
Black	Black
White	White
Green	Green

Notice the heat shrink tubing is slid over the wiring before soldering. Solder and cover joint with heat-shrink tubing.



Figure 53

3. This step requires connecting **two** stepper motor wires to **one** wire in the cable.

Cable	Stepper
Blue	Blue and Yellow
Orange	Orange and Brown

Notice the heat shrink tubing is slid over the wiring before soldering. Solder and cover joint with heat-shrink tubing.

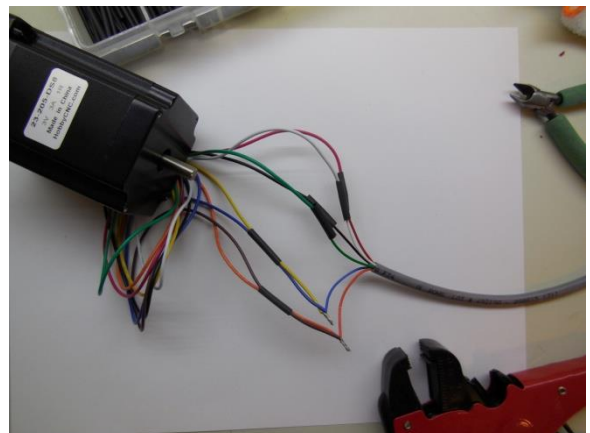


Figure 54

4. Solder the last two joints and cover with heat-shrink tubing.

Option: instead of soldering the wires together, consider using a 6-position Molex connector or similar high-current connector. This is particularly handy when you are in the design/build/modify phase

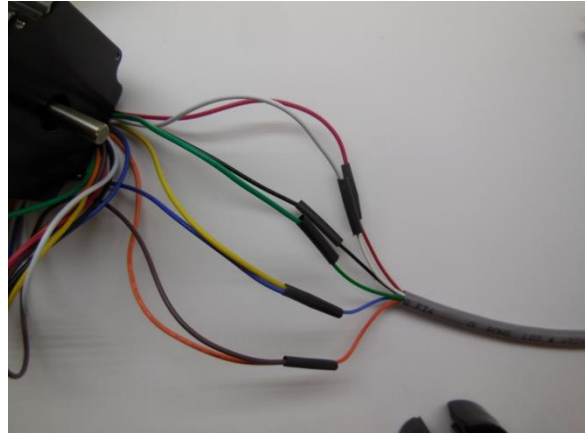


Figure 55

Cable Management

Although optional, all the wiring and cables will get in the way. It is very bad if your wiring gets jammed in the moving parts (for a whole bunch of reasons). There are a lot of ways to keep them out of the way, but I wanted something cool-looking that I could make from stock I had available.

This design is simple, inexpensive, fully functional.

X-Axis Wire Management

You can 'futz' with these dimensions. Make the angle sharper for a tighter turn, make the tray wider or narrower, whatever suits your design. I started by ripping two lengths of 1/2" plywood to a width of 1 1/2 inches. I ripped two equal length strips of 3/16" hardboard (1/4" would work fine too) to a width of 1 1/4 inches. I glued-and-clamped the hardboard strips onto the 1/2" plywood, forming a U-shaped 'trough'. In the drawing you can already see how the tray will fold.

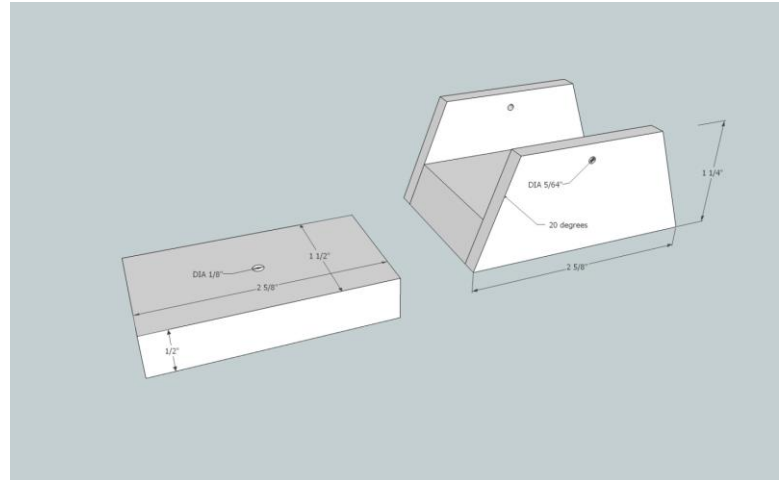


Figure 56

Cut the other 1 1/2" strip onto segments exactly as long as each of the tray segments (2 5/8" in my case). These small segments are screwed to the "bottom" of the tray – this will prevent unwanted bending in the "wrong" direction when the tray is suspended upside down.

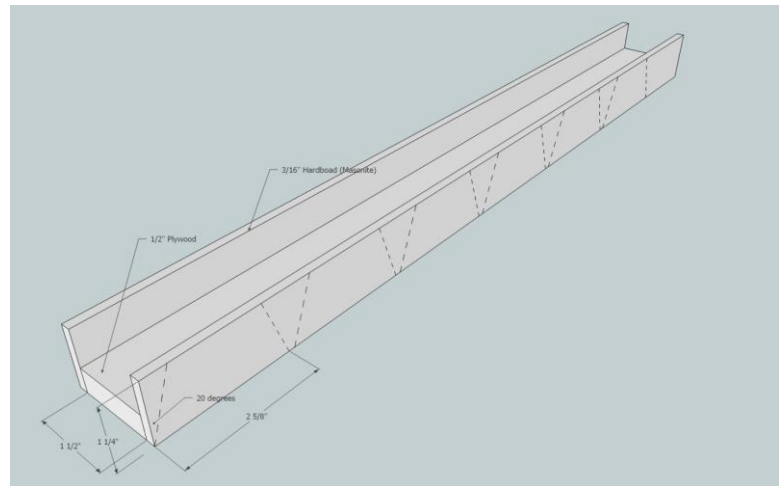


Figure 57

The idea is to end up with a 'sandwich' of parts, as demonstrated below. This is only one segment for example only, the orange "duck cloth" (bright orange, canvas like material) needs to be a continuous strip the length of the cable tray.

Cut a long strip of duck cloth 1 1/2" wide, a bit longer than the total length of the cable tray. I lined-up all the cable tray segments and secured them between two boards so the wouldn't move during the gluing step. I coated the underside of the tray and one side of the duck cloth with contact cement. Once dry per the instructions, gently stretch the duck cloth and glue it to the tray. Two people works best here.

The bottom piece is carefully lined up and held in place with a #6 x 3/4" wood screw (no contact cement). A small bit of bent coat-hanger completes the assembly.

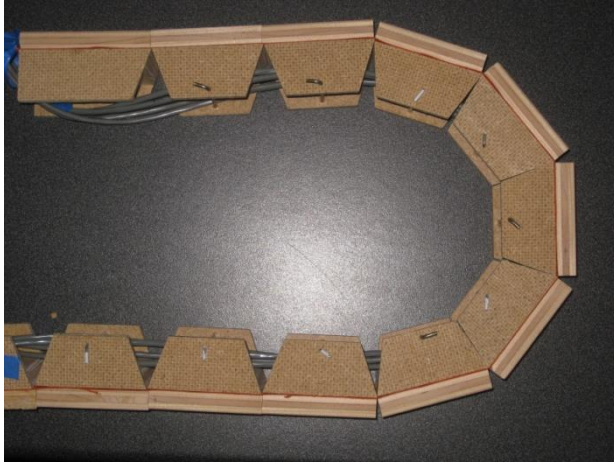


Figure 58

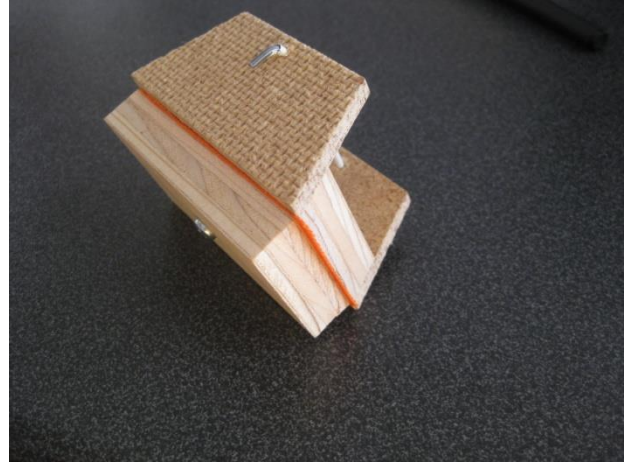


Figure 59

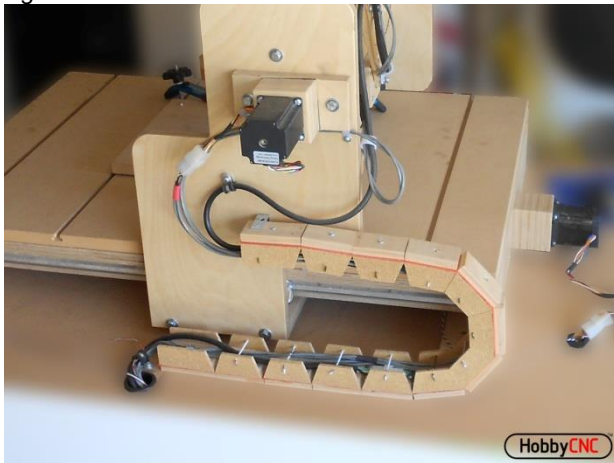


Figure 60

Well documented cable tray build

John Nicol posted a well documented page on his implementation of the cable carrier. He took more photos as he built his than I did. Check it out: [DIY CNC Cable Carrier by John Nicol](http://makerplane.org/?p=1753) (makerplane.org/?p=1753).

Y-Axis Wire Management

For the Y-Axis I just made a simple articulated arm. It needs to remain slightly bent when the Y-Axis is at its most distant point.

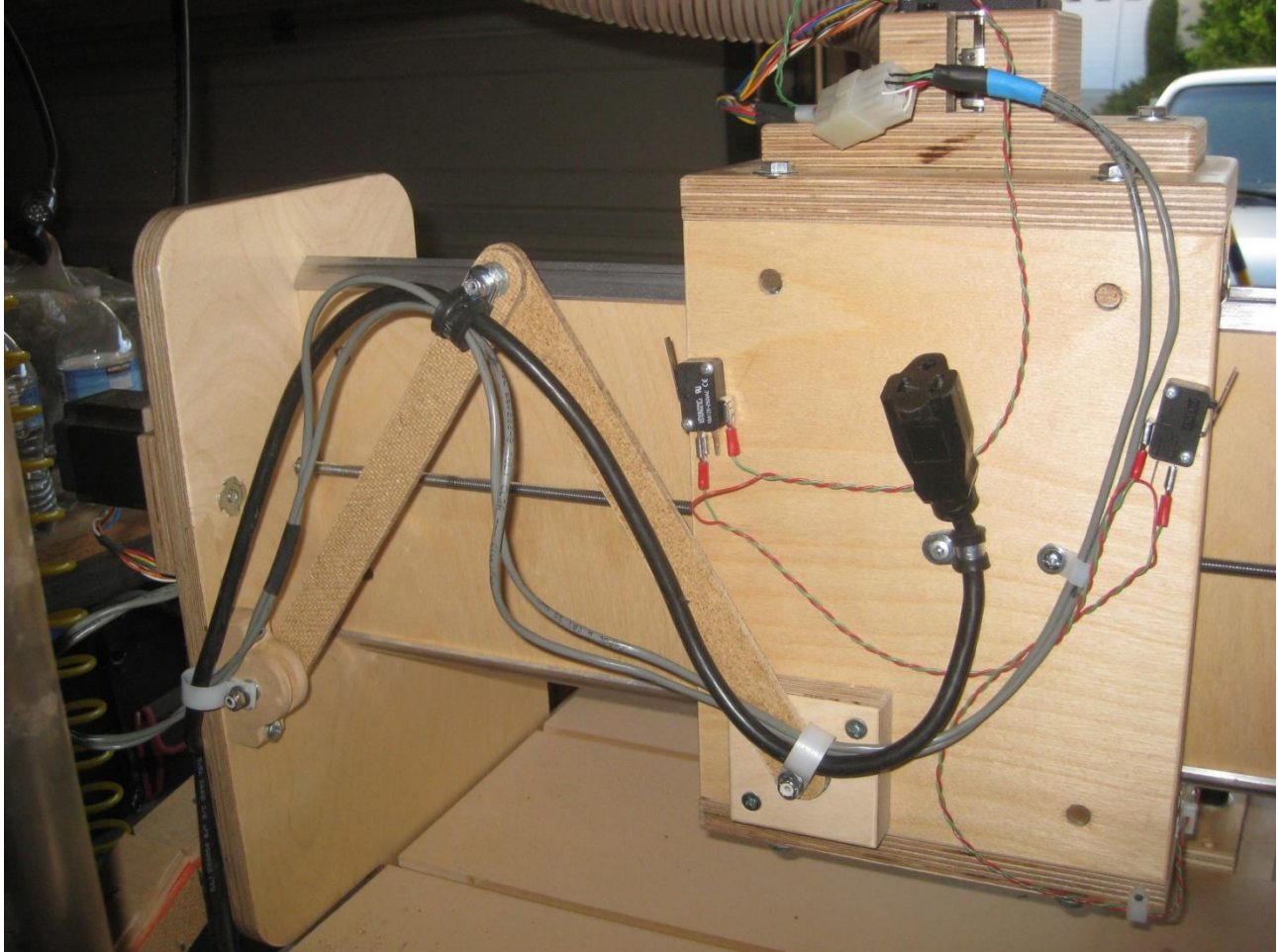


Figure 61 – Y-Axis cable management

Wiring the electronics

Here I can only discuss the set-up I installed – the HobbyCNC controller kit. I run LinuxCNC on Ubuntu. The LinuxCNC folks make it easy, and the price is great (Free).

Instructions for wiring the stepper motors to the HobbyCNC board, goto [Stepper Motor Wiring](#) on page 36.

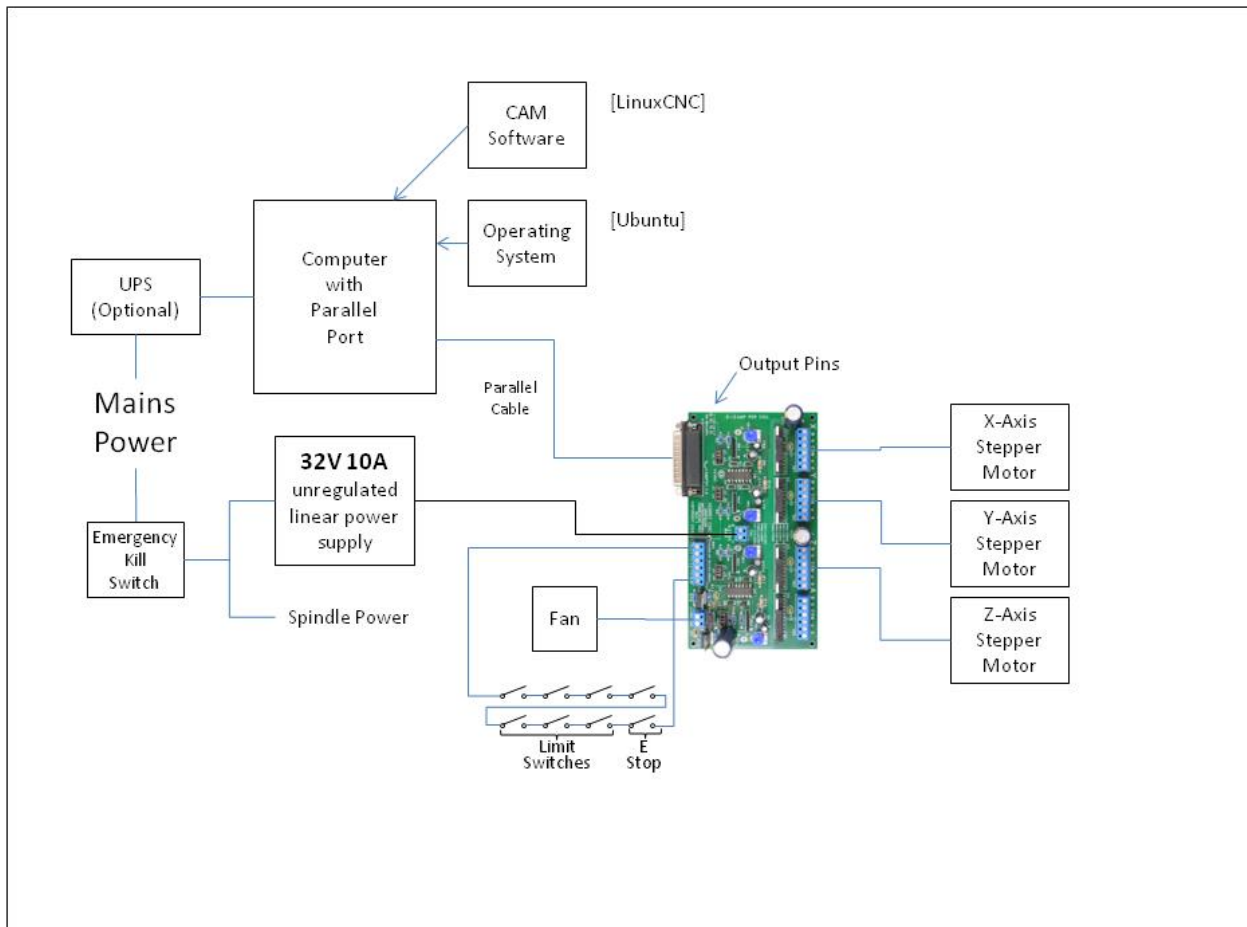


Figure 62 - Electronics Block Diagram

Glossary

Axis	A single direction of movement. Identified by letters X = Forward and backward Y = Left and Right Z = Up and Down
Backlash	<i>“Backlash is any non-movement that occurs during axis reversals. Say, for instance, the X axis is commanded to move 1 inch in the positive direction. Immediately after this X movement, the X axis is commanded to move 1 inch in the negative direction. If any backlash exists in the X axis, then it will not immediately start moving in the negative direction, and the motion departure will not be precisely 1 inch.”</i> Source: machinetoolhelp.com/Repairing/What_is_backlash.html
Bed	The large, flat part of your mill to which you fasten your workpiece
Bipolar	Relates to the design of the stepper motor and the associated drive electronics. Bipolar (e.g. Two Poles) uses an H-Driver for the electronics to reverse polarity on the stepper motor windings. See also <i>Unipolar</i> .
BOB	See <i>Break out Board</i>
Break out Board	A small board that ‘breaks out’ (distributes) the step and direction signals from a cable (like a parallel port cable) into screw terminals for wiring to the individual stepper motor driver boards (not required with a HobbyCNC solution).
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CAM Software	Software that drives the stepper motors on your mill
Collet	A device that holds the tool in the “business end” of the spindle
DIY	Do it yourself
e-stop	Emergency Stop. A large, hard-to-miss button that can be pressed by the operator in case of emergency (like machining through one of your clamps)
Gcode	The “language” that is run by the milling machine. It specifies all relevant tool motion, direction, speed, tools, etc.
GRBL	<i>“Grbl is a free, open source, high performance software for controlling the motion of machines that move, that make things, or that make things move, and will run on a straight Arduino.”</i> Source: github.com/grbl/grbl/wiki
Home	The point in space (also referred-to as 0,0,0) which is the ‘starting point’ for all machining operations.
Home Switch	A device that is tripped by the tool to determine a “zero” or ‘home’ for that axis
Limit Switch	A device that will “turn off” the stepper motors in the case any axis moves near the end of its physical travel

Motor Driver	The electronics that can deliver controlled high current to the motors
NEMA	National Electrical Manufacturers Association. http://www.nema.org . Though you won't find anything useful on stepper motors here.
Operating System	Typically Microsoft Windows or Linux
SMPS	Switch Mode Power Supply. See <i>Switching Power Supply</i> .
Spindle	A motor that holds and spins the cutting tool
Stepper Motor	A motor that rotates in discrete, predictable increments
Switching Power Supply	<p><i>"A switched-mode power supply (SMPS) is an electronic circuit that converts power using switching devices that are turned on and off at high frequencies, and storage components such as inductors or capacitors to supply power when the switching device is in its non-conduction state."</i></p> <p>Source: https://www.techopedia.com/definition/12378/switched-mode-power-supply-smps, Dec 2017</p>
Unipolar	Relates to the design of the stepper motor and the associated drive electronics. Unipolar (e.g. One Pole) uses simpler switching circuits for the electronics to power different stepper motor windings. See also <i>Bipolar</i> .



Change Log

- Rev03
- Consolidated, single parts list for parts to purchase
 - Added example sources to parts list
 - Improved organization of drawings, added drawing list (all consolidated at the end of the instructions)
 - All drawings converted to Autodesk Fusion 360
 - Added metric dimensions to all drawings
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- Rev02
- Updates to Stepper Motor Mounting section:
 - a. Added parts list
 - b. Enlarged Figure 38 - Stepper Motor Mounting, exploded
 - Parts List
 - LOTS of updated drawings
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- Rev 01
- Improve quality of Figure 40 - Y-Axis Cutting Guide. Add more dimensions.
 - Add Y-Axis bill-of-materials.
 - Fixed odd location of Figure 45 - Example of motor mounting to the Z-Axis carriage.
 - Improve Figure 23 - Drive nut and anti-backlash assembly
 - Added sections:
 - My Machine in Action
 - Discussion Forum
 - Limit Switches
 - Shimming the linear bearings
 - Stepper Motor Wiring
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- Rev 00 Initial Release

Drawings

The drawing list is divided into two sections, the top is drawings and dimensions for all components. The lower list **Detail Drawings** covers specific details that are typically duplicated for each axis.

1001	Cutting Guide	
1002	Base Torsion Rail, Long	
1003	Base Torsion Rail, Short	
1004	Base Linear Bearing Rail Support	4 drawings
1005	Base Front and Rear	
1006	Base Top	
1007	Base Sacrificial Top	
1008	Base Assembly	7 drawings
1009	X Axis Bearing Rail	
1010	X-Axis Bottom	
1011	X-Axis Sides	3 drawings
1012	X-Axis Gantry Assembly	2 drawings
1013	Y-Axis Top and Bottom	
1014	Y-Axis Front / Bearing Rail Mount	
1015	Y-Axis Back	
1016	Y-Axis Gantry Assembly	2 drawings
1017	Z-Axis Sides	2 drawings
1018	Z-Axis Back	
1019	Z-Axis Front	
1020	Z-Axis Grantry Assembly	2 drawings
1021	Linear Bearing Assembly (4 & 8")	2 drawings
1022	Shimming the Linear Bearing	2 drawings
1027	Linear Bearing Support	
1023	Stepper Motor Spacer Block	
1024	Stepper Motor Mounting Block	
1025	Stepper Motor Assembly	2 drawings
1026	Drive and Antbacklash Nut	2 drawings
Detail Drawings		
1101	Axis Bearing and Motor Mount T-Nuts	
1102	Double-Nut Detail	
1103	Barrel-Nut Detail	