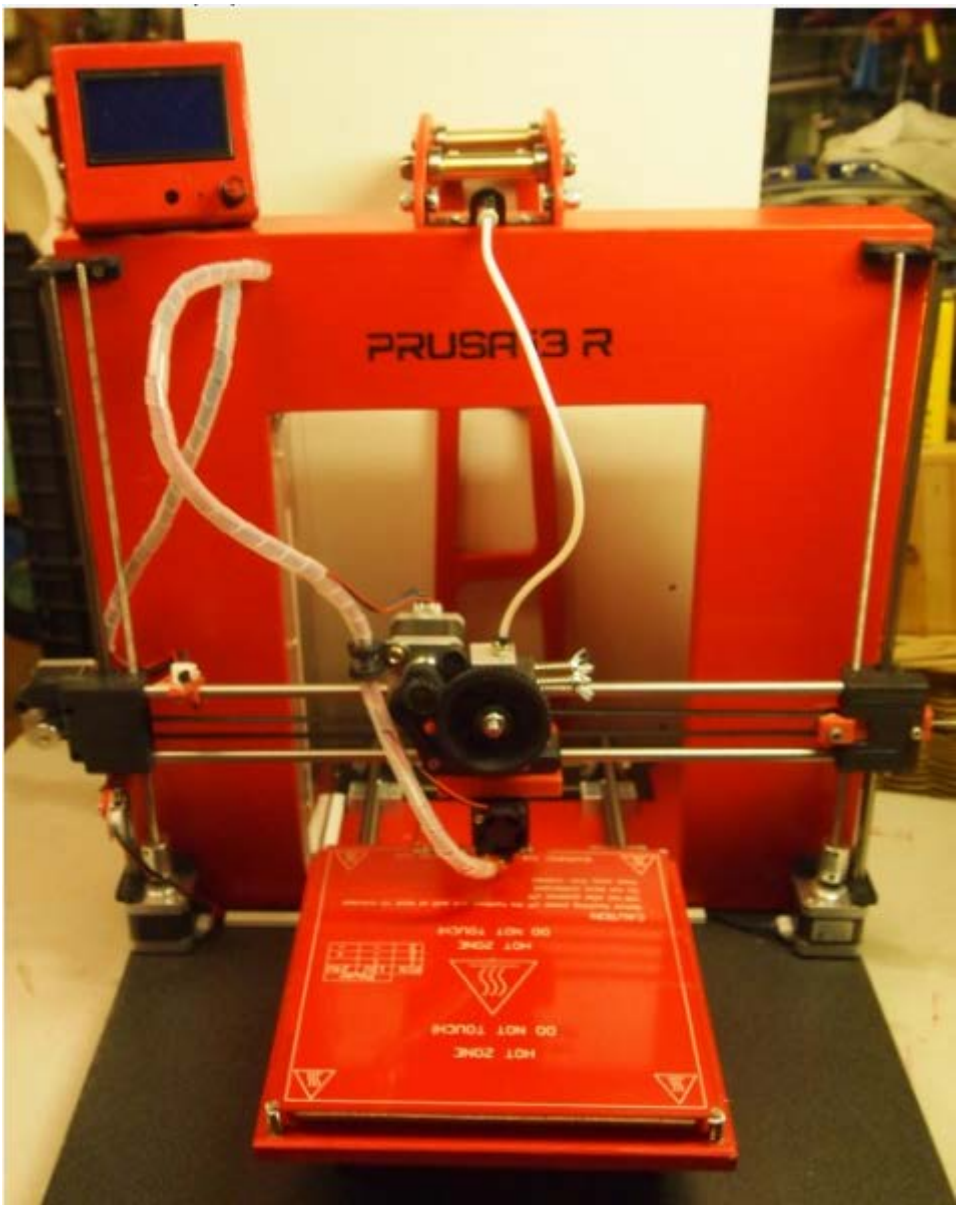
Building a 3D Printer



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The Beginning

It all started after reading about the possibilities for an ordinary hobbyist to be able to build a 3D printer and then make own object for the hobby. In my case the hobby is model railroading in H0 scale. This is a hobby that gives a lot to be desired in terms of commercially available model kits, and if you want models of specific items in your neighborhood, the market will be very small if any. This is where the 3D printer comes into play.

So some surfing on the internet revealed that there are quite a lot of both information and available kits from Do-It-Yourself (DIY) RepRap versions, via complete kits to ready-made machines of several different types. The most common one seemed at the time to be the Cartesian type with the Prusa i3 Rework as the most common and up to date. There are other types, but this one seems to be the easiest to build for my purposes, so a Prusa i3 Rework is my choice.

For those who wants to dive into this the RepRap OpenSource community provide a lot of good info that has been my support all through my build. The online pages are easy to use and you learn a lot while building. The link to RepRap is: http://reprap.org/

A reprap 3D printer can be made without any special tools, but in my case I do have access to a quite extensive workshop making my build easier in some cases. If you buy a kit the need for tools comes down to a good set of hand tools.

I did find a couple of good build threads on the web and would like to share these two as I found them very good for me:

http://www.dragonflydiy.com/p/building-3d-printer.html

http://morgandemers.com/making-a-box-frame-prusa-i3-3d-printer/

Both these build logs will complement my writings and fill in where I missed. As I used these for my build, I did not take as many pictures. Both logs also points to where the orginal files to print the necessary parts are found.

Now let’s start the build!

1 The Frame

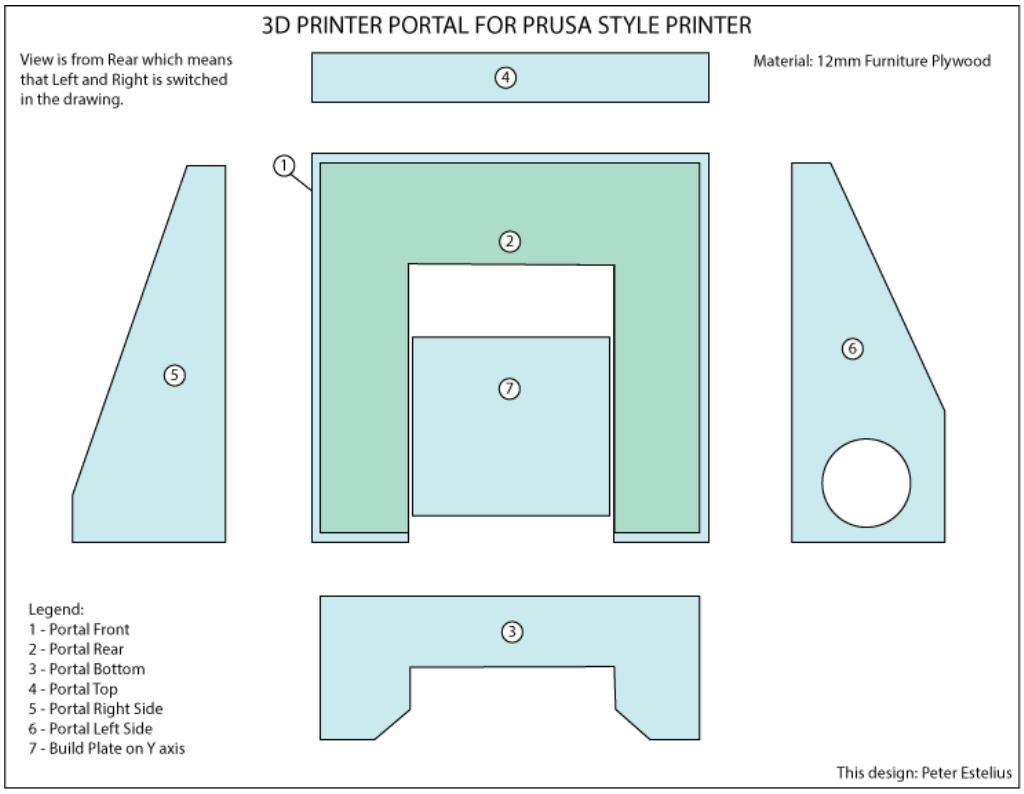
My machine frame was built from wooden parts all through. A thick baseboard and a sturdy plywood portal will be stiff enough to provide the accuracy needed for handling movements of 10th of a mm or less. Using good quality material will further insure a stable and lasting build.

I used the following description as base for my build (which I tweaked a little): http://www.dragonflydiy.com/2010/10/building-prusa-i3-printer-wood-box-frame.html

Frame material list:

- A piece of 40mm thick countertop for baseboard
- 1/3rd of a 12mm, 7 layer plywood board, furniture quality.
- One box of Nx20mm countersunk wood screws
- One box of Nx30mm countersunk wood screws.
- A good wood glue.

With this material at hand we can start with the portal. The first thing to do is to cut the pieces according to the drawing below (a larger drawing with measurements is found in the Drawings section at the end of the document).



Drawing 1: Frame Portal

Start by carefully measure and cut as the precision during this work will be vital to get a printer portal that is square and perpendicular in X, Y and Z axis.

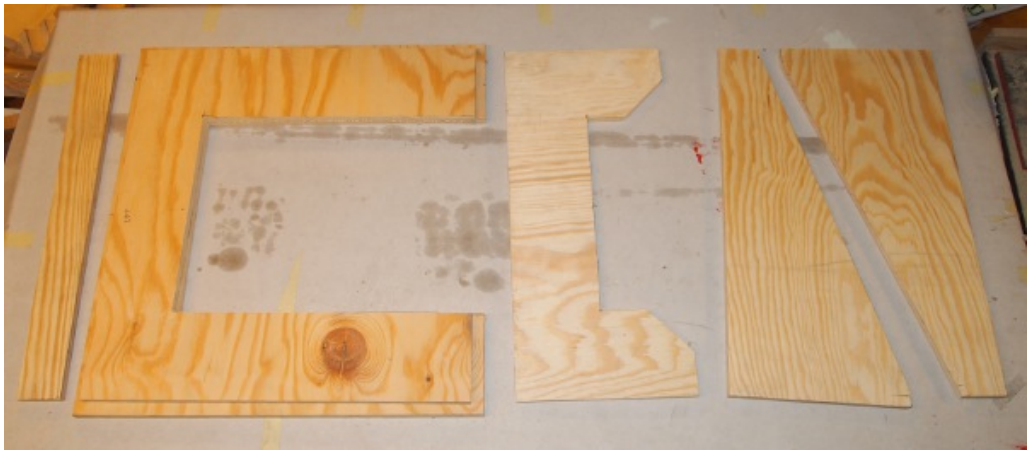


Figure 1 Portal Parts Cut Out

Note: *The image above is taken during the build and some changes or add-ons were added along the way making the actual parts look a little different from the above, the drawing however, shows the design as it should be. The parts are (from left to right): Top (4), Outer Upright (1) and Inner Upright (2), Bottom (3), and Sides (5 & 6).*

When all pieces are cut a test assembly will tell if there are things to adjust or even if a piece needs to be re-cut for a good result. Use a minor amount of screws to hold the bits together; clamps tend to get in the way. The parts are assembled in the following order:

1. Portal Upright, parts 1+2
2. Portal bottom
3. Left side
4. Right side
5. Portal top

The last part, the Build Plate will be used when assembling the Y axis.

1.1 Building the Portal

1.1.1 Portal Upright

The first parts to assemble are the two pieces for the portal upright. This is also the side onto which later the Z and X axis will be mounted so a sturdy plate is what we are after.

The portal upright is therefore made up from two pieces of plywood, one slightly smaller than the other. The reason for this is that the bottom piece, side pieces and the top piece will be fit into an inside corner giving more meat for the assembly screws and hence a greater rigidity.

Check that the portal upright pieces are truly square on all corners. This is really important as it will affect the Z-movement precision of the printer if out of square.

The inner (back) part (2) is placed so that it leaves 12 mm of the front part (1) outer edge free at all sides. Clamp the Pieces together and fit four screws – one in each corner to secure the position. The sides of the portal opening should be flush and equal for the two pieces.

1.1.2 Portal Bottom

The portal bottom is used to secure the portal to the baseboard. It is also to this the Y axis movement is fitted so the measures and squareness of the portal bottom is also vital.

Place the bottom part (3) so that the long straight edge is turned towards the portal upright. Fit a couple of screws to keep the parts together but do not tighten them fully for now.

Make sure that the bottom part is flush with the inner sheet of the portal on both sides, and that the portal does not stick out below the bottoms underside.

1.1.3 Portal Top

Then fit the relatively narrow portal top (4) to the portal upright. Make sure it is flush with the upper edge of the portal and is flush against the inner sheet of the portal upright.

Secure the top with a screw in each end but do not finally tighten yet.

1.1.4 Right Side Stretcher

The fitting of the right side stretcher (5) is stabilizing the portal upright so that it cannot tilt backwards or forwards. Make sure that the bottom edge and the edge towards the portal are precisely square. Otherwise the portal will not be completely upright and perpendicular to the baseboard, which in turn will affect the print precision.

Fit the stretcher to the portal upright, top and bottom with a screw in each corner. Please note that the screw in the upper corner must be placed to avoid fouling any other screw in that area. Do not tighten the screws fully yet.

Now make sure that all parts are fully square and perpendicular to each other so far. At this point the portal as such is ready and can be taken apart for final assembly. Before taking apart, make some light marks to maintain outer and inner sides and correct edges towards each other. Left Side Stretcher

The Left Side Stretcher (6) is the final part in the portal assembly. This side has been decided for the power supply which is why there is a big hole in the sheet and a different shape than the left side. This will also be the side where the electronics will be placed

Fit the left side stretcher to the portal upright and bottom with a screw in each corner. Please note that the position of the screw at the top of the portal upright must be placed so that it will not foul any other screw in that corner. Do not tighten the screws completely yet.

Make sure that the parts are now square and perpendicular to each other so far. That will simplify the final assembly.

1.1.5 Portal Final Assembly

Start final assembly by spreading an even layer of wood glue on the inner portal upright plywood piece. Use the screws to re-position the sheets together and make sure all is still square and aligned. Tighten the screws so that glue is squeezed out between the mating surfaces. Add more screws to make sure that good contact over the whole surface is achieved between the two sheets.

With the two sheets done, fit the portal bottom. Put a good string of glue in the bottom corner of the portal and secure the portal bottom using the test fit screws that now is fully tightened.

Then follow on with the portal top. Put a good string of glues in the top recess and fit the portal top with the screws. Tighten fully.

Next up is the left side stretcher. Put a good string of glue in the portal side recess and on the top and bottom pieces. Fit the side and tighten the screws. Add some more screws along the edge to make sure the pieces are in complete contact with each other.

Finally, the right side stretcher is fitted in the same way as the left side stretcher. Screws of course tightened fully.

At this point we have the portal completely assembled with glue and screws, and now we have a rigid portal for the printer. Make a final measurement for squareness and perpendicularity before leaving the glue to set completely.

1.1.6 Portal Finishing

To even further ensure that the printer is unaffected by temperature and moisture differences, it is a very good idea to give the portal a nice paint finish.

Begin this by filling pores and screws and then sand over the surfaces to get a smooth surface suitable for painting.

Use a colour of your choice and give the portal two nice coats with a light sanding in between. As you can see, my colour of choice is red, which is also my tool and shop colour.

1.2 Fitting Portal to Baseboard

When the portal paint is dry and the finish is completed, the portal shall be fitted to the baseboard. In my case I had a piece of baseboard left over from an interior remake and just had to cut it to the same width as the portal.

Figure 2 Printer Baseboard

Place the portal so that it is square to the baseboard both horizontally and vertically, and 200mm from the back end of the base. That will leave room for the printer bed and provide good access for the user. The center of the portal must align with the center of the baseboard.

A tip here is to use masking tape to make alignment marks easy and readable during fitting, and then simple to remove once all marks and screw holes has been made. (Sorry for the odd angle.)

Figure 3: Portal fitted to Baseboard

Once all markings and measures are correct, the portal can finally be glued and secured to the baseplate. The printer frame is now done but the last glue needs to set properly before work proceeds further.

Note: The image shows a version where no ventilation hole is done to the rear left side as the hole was an addition found at power supply fitting time. If you follow the drawing for the different parts, this ventilation hole will already be in place.

1.3 Preparing for the power supply

Needed to finish this section is:

- An ordinary PC power Supply (PSU) of at least 500W power.
- Two off Assembly Aid 1 – screws with pointed heads
- One 12-pole Electrical Connection Strip for 2.5 mm^2 cable

My printer is designed to have the power supply at the rear left of the portal. That way an ordinary PC PSU with its built-in fan blowing through a hole in the right side stretcher can be used. Depending on make we need to mark out its position and make a suitable hole.

Make up two special marking screws with pointed heads [*assembly aid 1*]. The pointed heads will act as marking pegs. Replace two of the four screws holding the fan shroud with the pointed ones. Use diagonal positions across the fan shroud. Now temporarily fit an electrical screw strip with tape to the rear of the power supply.

Place the power supply on its side with the main inlet towards the back on the right side of the portal. Push it so that the pointed screws can make a mark on the inside of the right side stretcher and remove it again after checking that the marks are visible and readable. This marks the exact future position of the PSU and will be spot on.

Drill a smallish hole in the marked-out positions to transfer them to the outside. Mark out the center between the two holes and draw a circle. Fill in with a good pen or pencil if necessary.

Cut out the hole, either by chain drilling, or by sawing.

Figure 4: The Fan Hole Cut Out

Clean up the holes edges and give it a bit of paint and leave to dry. The picture above shows the fan hole right after cleaning up and putting on some necessary filler prior to sanding and painting. (I had to add a strip of plywood to the edge of the side to increase material thickness. This has been changed on the drawing in the beginning of this document to allow for such a big hole from the beginning.)

When dry, drill through the two guide holes with a size slightly larger than the screws to use to secure the PSU to the frame. As of now the PSU can be fitted to the portal but before doing that the PSU needs to be re-built to become a 3D-printer PSU with less cables than normal. The rebuild description is found in Section 6 - Modify a Power Supply to 3D Printer Use.

2 The Mechanics

With the portal and baseboard finished, it is time to assemble the mechanics of the printer. The following parts are needed for the complete assembly

Y axis

- Two M12x350mm stainless threaded rods
- Four M8x280mm stainless threaded rods
- Two 8x350mm smooth stainless rods
- Three LM8UU 8mm linear bearings
- Four 12mm securing blocks (see drawing xxx)
- 10 M12 Stainless Nuts
- 10 12mm Stainless washers
- 20 M8 Stainless Nuts
- 20 8mm stainless washers
- Four printed ABS corner blocks
- One printed ABS Motor mount
- One printed ABS Toothed belt tensioner
- One M4 Tensioning screw
- One M4 Nut for tensioning screw
- Three printed ABS linear bearing holders for bed
- One printed Toothed belt anchor for Y axis.
- Eight Nx12mm wood screws
- One NEMA17 Stepper Motor
- One Toothed belt pulley for motor
- One toothed belt pulley with ball bearing as idler
- Two M3x12 Cap head screws for motor
- One M3x6 set screw for motor pulley
- One M5x20 Stainless cap head screw for idler pulley
- One M5 nut and washer for idler pulley
- Eight 4.7x50 wood screws for securing the Y axis to the baseboard

Z+X axis

- Two M5x400mm stainless threaded rods
- Two 8x400mm stainless smooth rods
- Two printed ABS lower motor brackets (left and right side)
- Two printed ABS smooth rod brackets (left and right side)
- Eight nx20mm stainless wood screws
- Two printed ABS X axis ends
- One printed ABS extruder carrier
- Two 8x450mm stainless smooth rods
- Two M5 stainless nuts
- Seven LM8UU 8mm linear bearings
- Three NEMA17 Stepper Motors (two for Z axis and one for X axis)
- One printed ABS X axis toothed belt tensioner
- Nine M3x12 cap head screws for motors
- One M4x25 stainless screw for belt tensioner
- One M5x20 stainless cap head screw for X axis idler pulley

- One M3x6 setscrew for X axis motor toothed belt drive pulley
- Two 5x5mm flexible shaft joiners
- Four M3x8 set screws for shaft joiners

Extruder

- One printed Wades extruder body
- One printed Wades extruder feed roller bracket
- One printed wades extruder carrier distance piece
- One printed Wades extruder hot-end bracket
- One filament guide bracket – see drawing xxx
- Two M4xNNmm stainless threaded rod
- Two stainless springs for filament feed tensioning
- Two stainless M4 wing nuts for filament tensioner
- One M6 PTFE tube fitting
- One M8 filament feed screw
- Two M8 stainless nuts
- Two M8 stainless washers
- Two M3x6 set screws
- Two printed Wades extruder fishbone gears
- Two M4x70 stainless screws – Alt. see drawing xxx.
- Two M4 stainless nyloc nuts
- Two M4x20 stainless cheese head screws
- Two M4 stainless nyloc nuts

Filament spool carrier and filament guides

- Four M8x100 stainless threaded rod
- Two 10x65mm stainless tube
- Four M8 stainless nyloc nuts
- 12 M8 stainless washers
- One filament guide bracket – see drawing xxx
- Two 4x12mm wood screws
- One M6 PTFE Tube fitting
- One special M6 nut – see drawing xxx
- One rear post for filament roll support – see drawing xxx
- One bracket for rear post – see drawing xxx
- Two 4x30mm wood screws

2.1 The Y Axis

The mechanical assembly starts off with the Y axis, the one carrying the build plate and heat-bed. It moves towards or away from the operator – standing in front of the machine.

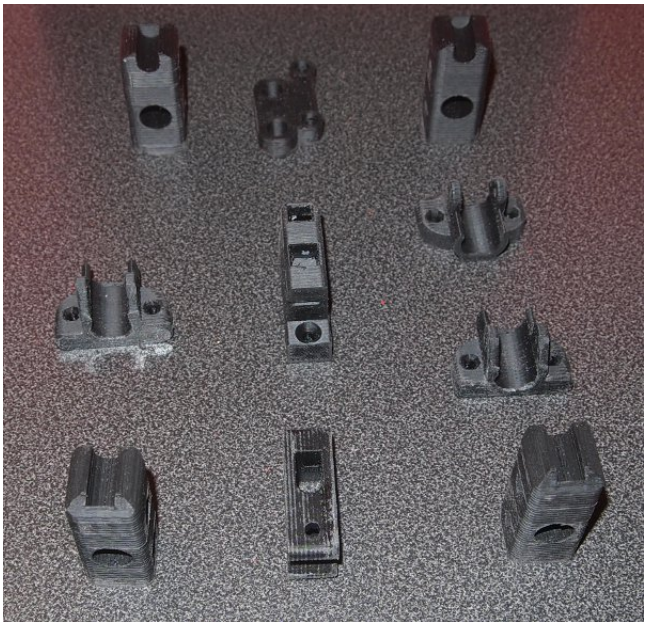


Figure 5: The ABS Plastic Printed Parts

The Y axis use the following printed parts:

- Four corner posts
- Three linear bearing brackets
- One toothed belt anchor
- One motor bracket
- One toothed belt tensioner

Together with some threaded and smooth rods, nuts and washers we will get a complete and rigid movement. The two threaded rods in the figure above are 8mm stainless rods. It turned out that the precision and quality of the stainless rods was much better than ordinary galvanized ones. Hence I used stainless stuff for all bare metal parts throughout the machine.

As basic instruction for this section I used this description:
http://www.dragonflydiy.com/2013/10/building-prusa-i3-printer-y-axis.html

Begin by cutting four pieces of 8mm threaded rod (two for front and two for back) to 205mm length and file the ends clean. Add two nuts to one of the rods and wind them onto the rod about 50mm. Take the second rod and wind on one nut close to the middle and then fit the tensioner followed by a second nut. Wind the nuts so that the tensioner is at the center of the rod. Now fit two more nuts and wind them on about 50mm. Add washers to the rods and fit them into two of the corner posts. Make sure that the notches on the top of corner posts face the same direction.

Add a washer on the outside as well followed by a nyloc nut. Do not tighten the assembly yet as that will be done in one go once all the bits for the Y axis are assembled. The back end is done.

Repeat the procedure once again with two 205mm long 8mm threaded rods. Add nuts, the motor bracket, and washers in the same manner as already described to make the front end ready.

The two ends are held together with two 440mm long, 12mm stainless threaded rod. This rod is so stiff it will make the base part very rigid. Wind on six nuts. Two nut are wound on about 50mm onto the thread, two ar4e wound about 200 mm, and the final two are wound on about 50mm.Add washers and fit them into the large hole of the corner posts. Make sure the notches at the top of the posts are turned towards each other. Add further washers and nyloc nuts to hold everything together. You will now have an assembly looking like this.

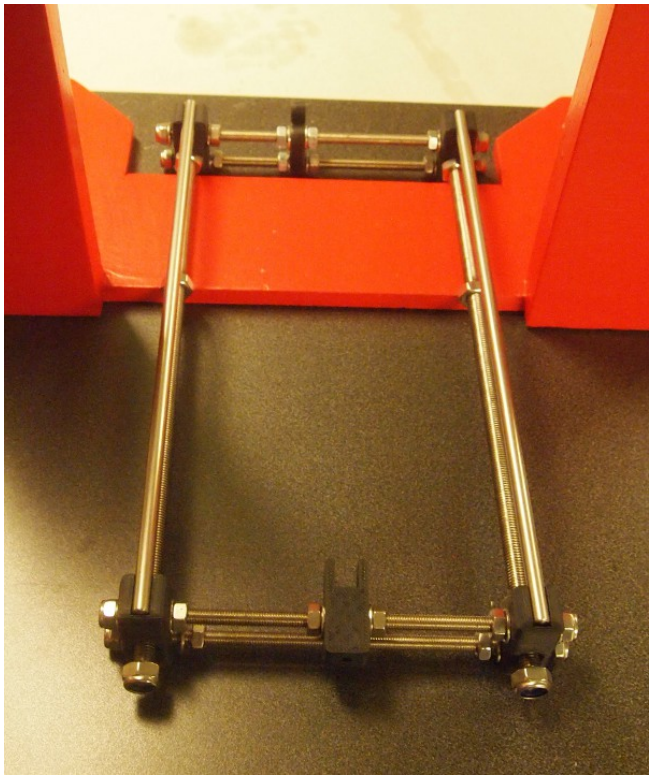


Figure 6: The assembled Y-axis Base

It is quite easy and obvious to understand that the rod assembly must be secured to both the base plate and the portal so that nothing can move and to keep the squareness both length-wise and cross-wise. To do this I decided to make four securing blocks from a piece of aluminium I had lying around – for drawing, see Y Movement Fittings in the Drawings Section.

The four securing blocks turned out very nice and are about the same size as the printable ones for the same purpose. By adding the M12x1.75mm thread I do not need any other length-wise fixing of the Y movement. I think it will make it all more stable this way.

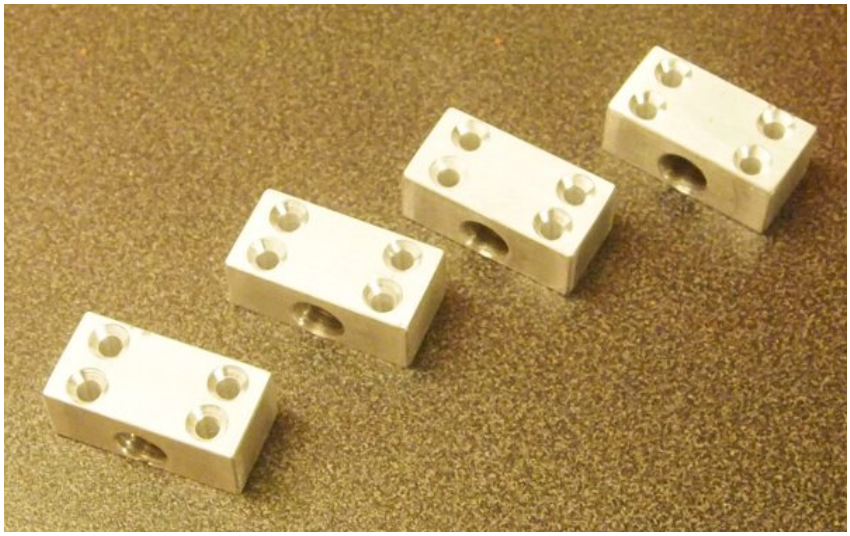


Figure 7: Four Y-axis Securing Blocks

As I began fitting the blocks I noticed tha tht e all-thread passes along the surface of the bottom sheet of the portal assembly. This is why the securing blocks are milled down to show the tops of the thread on the under side. This will also place the threaded rods correctly in héight.

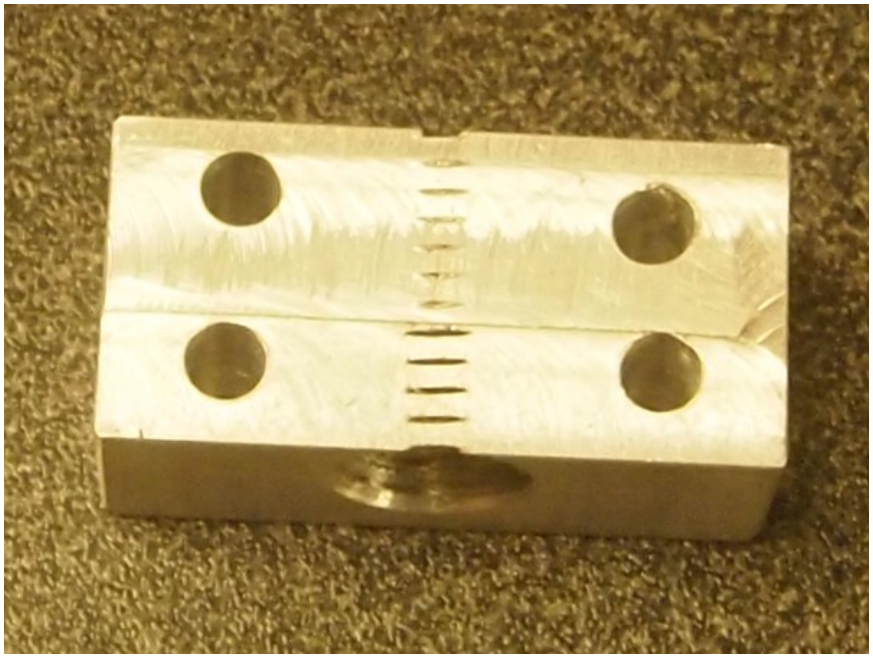


Figure 8: Securing Block Under-side.

The 12mm hole is threaded and placed so that the rod comes as close as possible to the portal bottom. To add those it is necessary to un-wind the nuts and washers at the tensioiner end to wind on these four blocks, two on each 12mm rod. Re-fit the washers and nuts and make a first test assembly to make sure there is a good fit backwards and forwards.

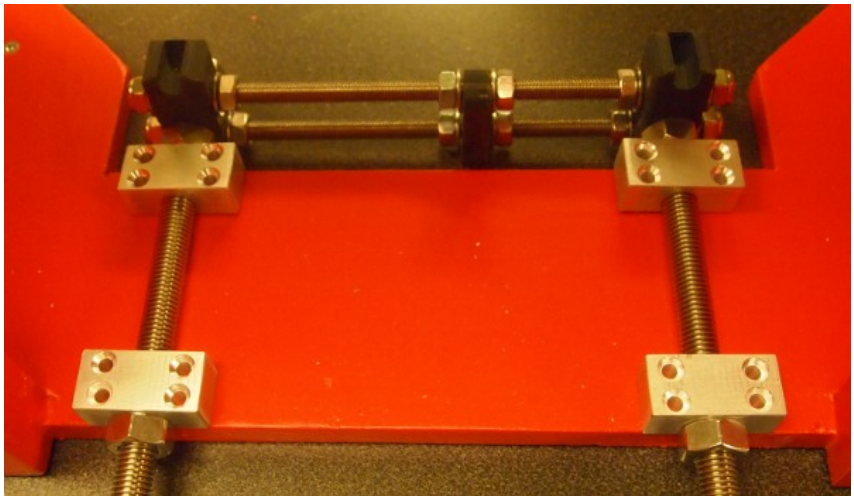


Figure 9: Securing Blocks Added

The picture shows the intended assembly position for these blocks.

As soon as the blocks are fitted we cut two pieces of 440mm long 8mm smooth rod for the bearings. Add two bearing brackets to one rod and one bracket to the other.

Tighten all the nuts after making sure that the whole assembly is straight and square. The last bit is to secure the smooth rods to the corner posts using a tie-strap.

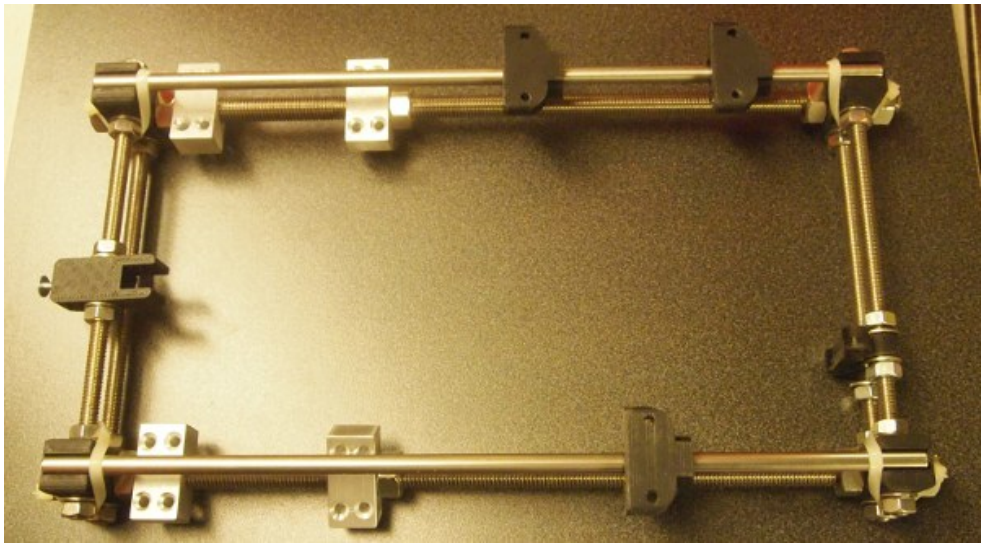


Figure 10: The Assembled Y Axis Movement

At this point it is just the carrier plate of the build board the needs to be fitted to the movement before fitting the whole thing to the portal.

Put the whole assembly upside-down on top of the square piece of board that will carry the build plate. Mark the positions for the brackets and a centerline at the back of the build board. Fit brackets with bearings and rods in place using 12mm long wood screws. Also fit the toothed belt anchor part to the center of the build plate. When fitting the toothed belt anchor, make sure that it does not collide with the motor or tensioner brackets when in outside conditions.

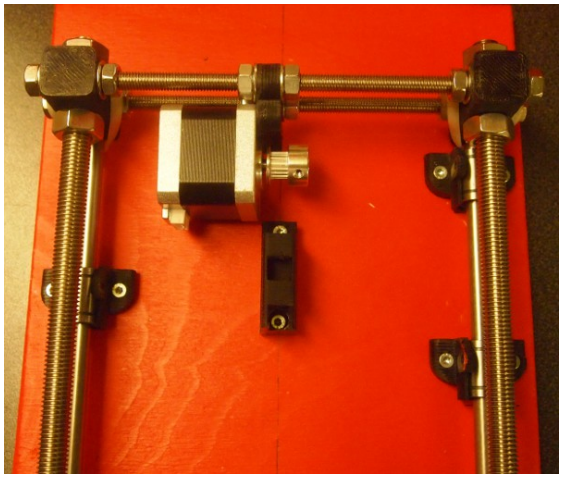


Figure 11: Fitting the Belt Anchor

In the other end at the tensioning unit, the toothed belt anchor shall not collide with the tensioning unit to avoid un-necessary breaking forces.

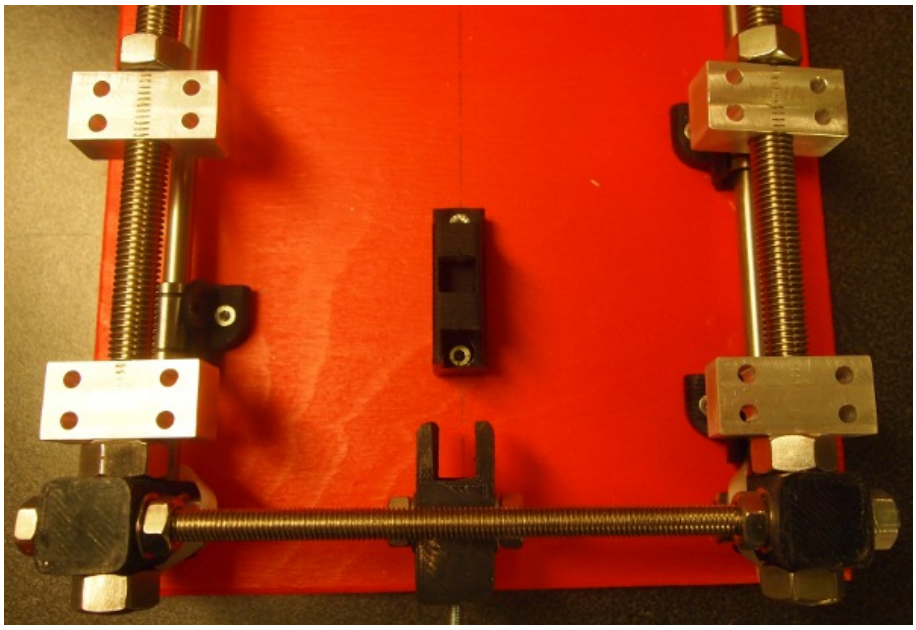


Figure 12: Nothing Collides

With the centerline and the mounted belt anchor it is also possible to adjust the motor and the tensioner so that the belt runs along the centerline as well. The belt pinion on the motor is fitted “outside-in” as this will remove most of the bending forces on the motor axle.

With all this done it is now time to trial fit the Y-axis assembly to the portal. Start in one corner for final squareness measuring and tightening. The outside Nyloc nuts for the 8mm rods shall be flush with the rod end on both sides. Tighten the inside nuts to nip the corner post firmly in sideways position.

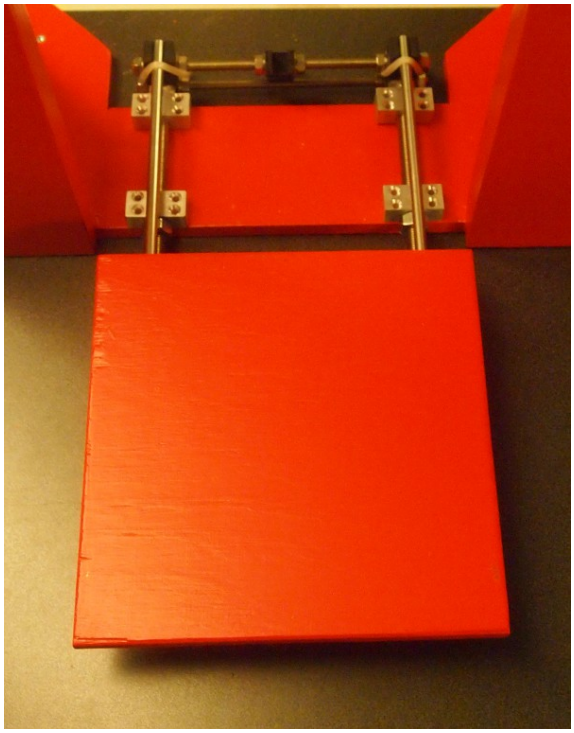


Figure 13: Y Movement Trial Fitting – Fully Front

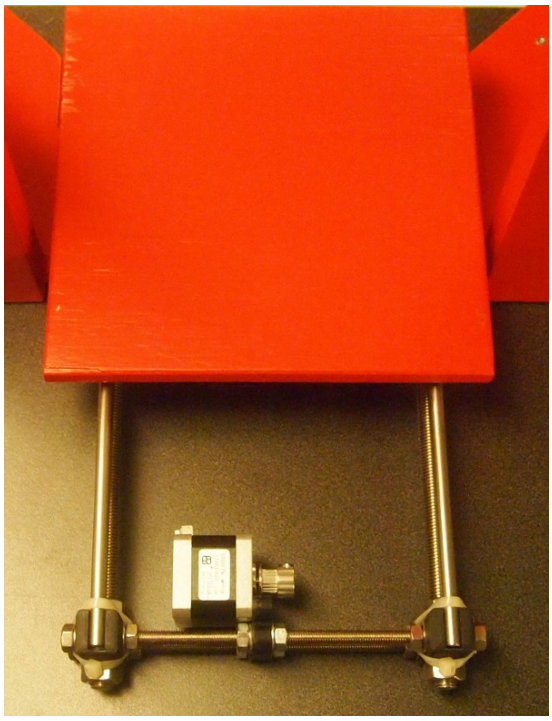


Figure 14: Y Movement Trial Fitting - Fully Back

For smooth operation and minimal ware, I decided to use idlers with bearings for the GT2 toothed belt drives.

Figure 15: Toothed Belt Idlers with Bearings

I can now finish the Y movement by fitting the toothed belt and adjust everything to run in line and without any interferences. Fitting the belt was a little fiddly, but once discovered the technique, it went quick and easy.

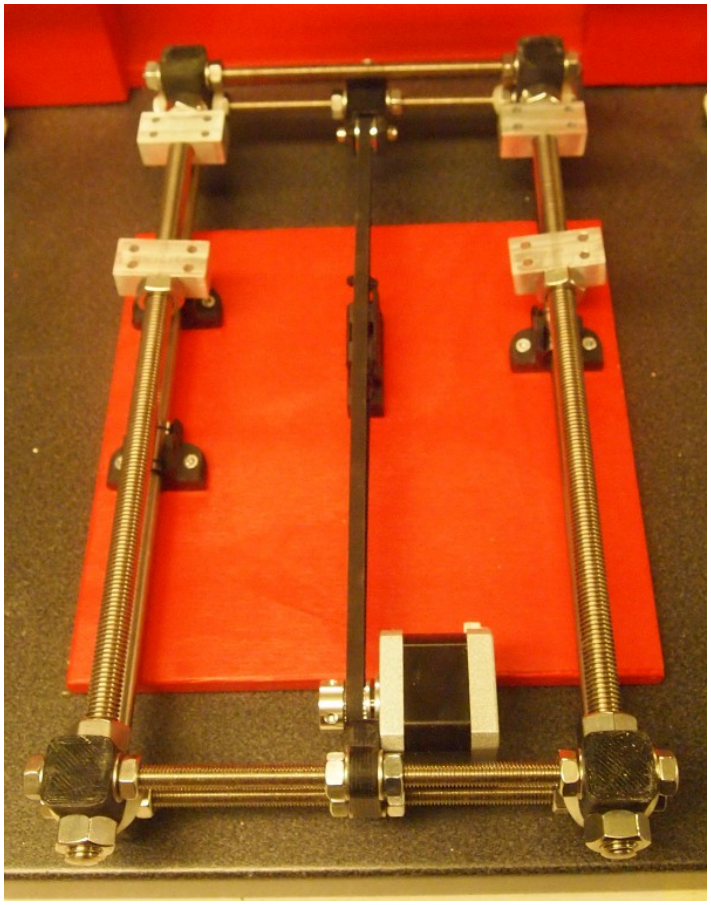


Figure 16: Drive Belt Fitted.

With that done, I could also mount the complete Y movement to the baseboard and portal. After carefully measuring and aligning the assemblies, I could secure the whole thing using with screws into both the portal base and down into the thick base board. 16 screws will make sure that it stays put.

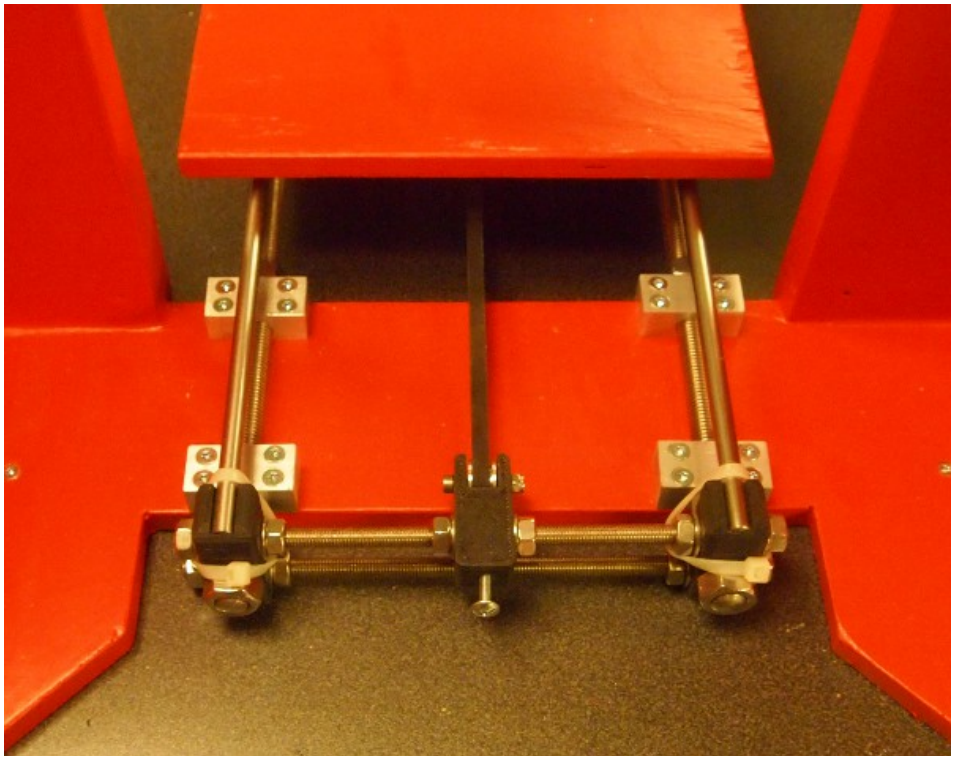


Figure 17: Y Movement Fitted.

With this the base of the 3D printer is done and the technical work to continue with the other two axis.

2.2 The X & Z Axis

The Z axis of the printer is fitted to the portal and secured by a corner bracket in each of the four corners. The lower ones carry the lift motors for the Z movement and the upper corners hold the smooth rod in place and parallel. The following overview picture shows the general assembly. I used the following description to build: http://www.dragonflydiy.com/2010/10/building-prusa-i3-printer-x-and-z-axis.html

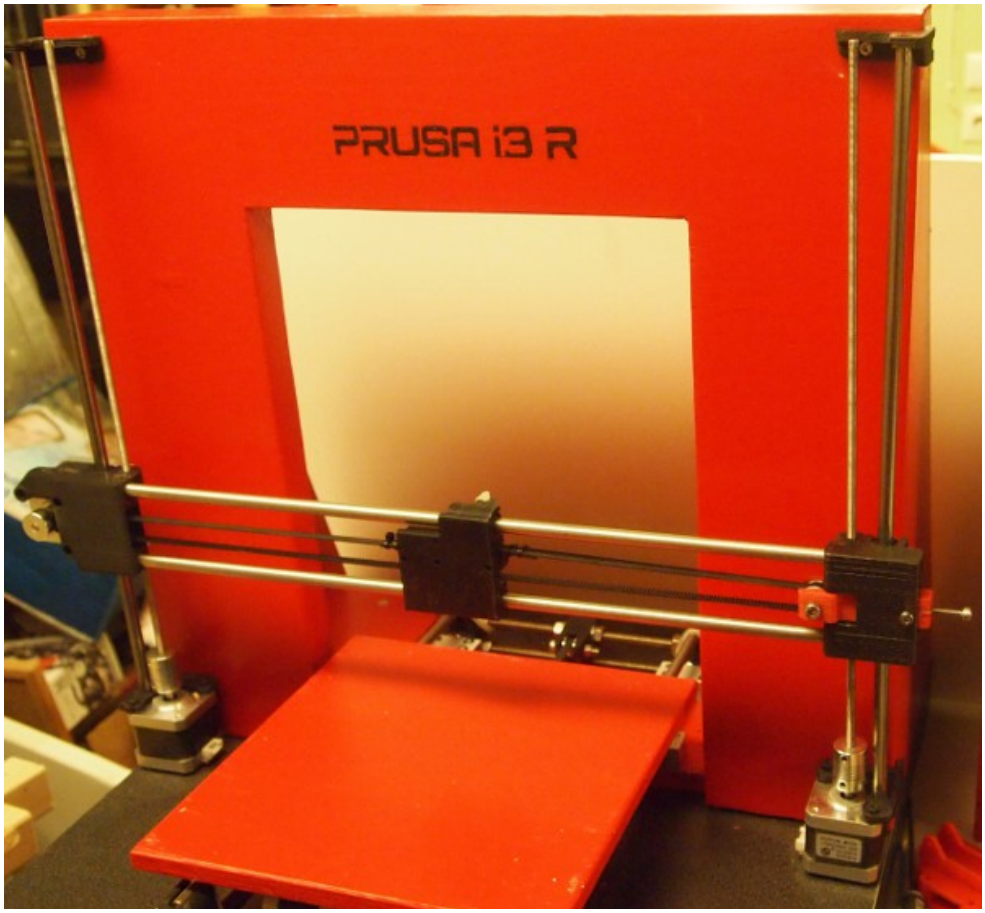


Figure 18: X and Z axis General Assembly

I started the assembly with the two lower corner brackets on each side of the Y movement. Make sure the brackets are cleaned up from print waste and that the smooth rod hole is exactly 8mm. No more no less. The smooth rods must have a tight fit in the holes for the whole assembly to work well.

To get the perfect distance from the base plate I used a 3mm sheet of cork or what have you for positioning and support during fitting. Mark out the positions and fit the corner brackets with 3.5x20mm wood screws. The Z axis motors are fitted to the lower brackets with three M3x12mm screws each. Make sure that the cable connection is turned towards the centerline of the baseboard. This ensures an easy electrical connection later on.

Note: *At this point it is wise to measure the length of the upright Z-smooth rods, as well as the horizontal X smooth rods. The instructions I used said that the length should be 350 and 370 mm respectively, but when measuring on my printer frame the measures were to be 430 and 470 mm instead!*

Do the assembly in the following order:

1. Place a smooth rod in its hole in the motor bracket and push it home firmly. Do the same thing on both sides. Leave the upper end free for now.

2. Now take the one of the printed X axis ends, clean it up and fit two LM8UU bearings and secure them with a zip-tie. Also fit the M5 nut into its place in the bracket. This nut is to be used for the Z axis movement.

3. Fit the two X axis smooth rods in place. The rods are pushed into the printed part till it stops firmly.

4. Add linear bearings to the Extruder carrier and slide it onto the X axis rods. Then add and an M5 nut and LM8UU linear bearings to the other X axis end and secure the bearings with a zip-tie. Take the whole package and slip onto the Z axis rods and let the sub-assembly rest on the build plate for now.

5. Clean up the top corner brackets for the Z axis and push them onto the smooth rods and secure them with 3.5x20 wood screws. The X axis assembly should now move freely and without any binding all the way along the two Z axis rods, and the extruder carrier (the X axis movement) shall also move freely without binding all along the X axis.

Now the assembly shall look as follows.

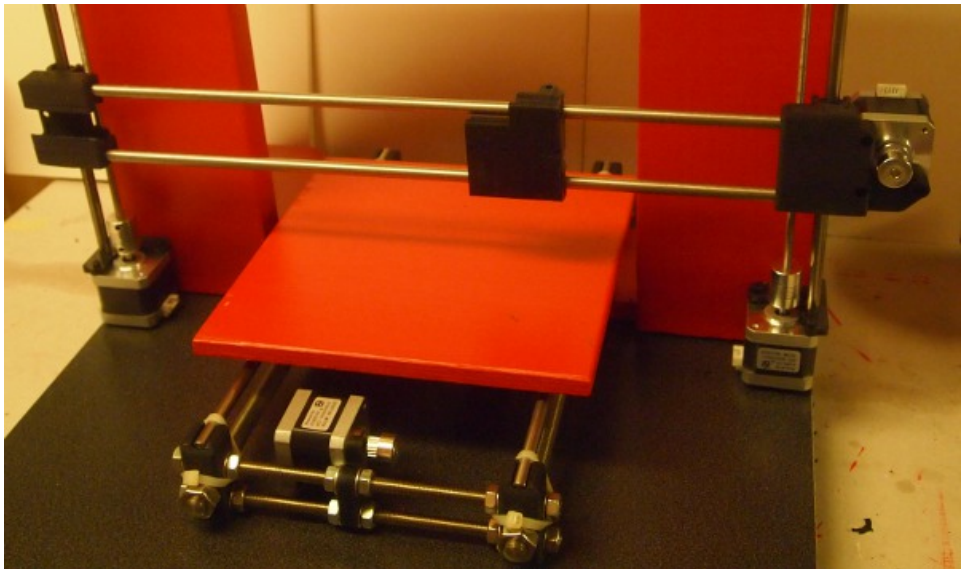


Figure 19: X and Z Axis together with Y Axis and Extruder.

Sometimes it turns out that trial assemblies and test fittings are quite useful and prevents time consuming errors. The picture above shows the motor bracket to the right, but it shall be placed to the left as in the general assembly picture above! So please put the X axis motor bracket to the left.

6. Continue the assembly by fitting the toothed belt tensioner to the right X axis bracket (the red item in the general picture). Fit the idler with bearings to the tensioner.

7. Fit a stepper motor to the left X axis bracket and fit a toothed GT2 belt gear to the motor axis. The gear should be turned so that the belt runs as close to the motor housing as possible to avoid un-necessary bending forces.

8. Fit one end of the GT2 belt to the extruder carrier and run it from the carrier to the tensioner and back via the motor gear to the carrier again. Secure the belt in the same way as done for the Y axis belt.

9. Add a little tension to the belt without stressing the assembly and check that the carrier runs freely without binding over the whole distance.

10. Cut two lengths of M5 stainless all-thread to length. Fit a flex coupling to each of the Z axis stepper motors and fit the M5 rods. The rods must be threaded all the way from above down to the flex couplings. Secure with the set screws.

11. Turn the Z axis screws so that the X axis assembly rises from the build table about 10 cm. Measure carefully so that both sides are absolutely equal, if not it will affect the printing results. Measure from the base board beside the motors on both sides and make sure the readings are the same.

At this point all the mechanics for the movements are assembled and it is time to focus on the extruder itself.

2.3 Extruder Assembly

I choose to use the Wades extruder with fishbone gears as it seems to be the variety with the least backlash, and should provide a good and steady flow of filament when in use. I used the following description for my build: http://www.dragonflydiy.com/2013/10/building-prusa-i3-printer-extruder.html

The printed parts used looks as follows.

Figure 20: Wades Extruder Parts

The parts are a main body to which the feed stepper motor is attached, a small fishbone gear to be fitted to the motor, a large fishbone gear to be fitted to the filament feed axle, and a push-plate that pushes the filament to the feed axle. The filament feed axle is made from an ordinary M8 bolt onto which have been added a gear-like section to grip the filament.

Assembling it all will result in a very compact unit to be fitted to the X axis carrier later on. The assembly is done as follows:

1. Fit the small fishbone gear to the motor. An M4 nut is pressed into the side of the gear and an M4 set screw is used to secure the gear to the motor shaft.

2. Fit the motor to the extruder main body and secure using three M3x12 socket cap screws. The cable connection should point upwards.

3. Fit a 20 mm long piece of 8mm rod as shaft for the bearing on the filament push-block and fit the assembly to the extruder main body. The push-block shall move easily but without slop.

4. Snap a ball bearing in place in the extruder main body and after checking the length of the filament feed geared axle, put a washer under the bolt head and secure the large fishbone gear using a Nyloc nut.

   The assembly should run freely but without slop. The filament feed geared section must be placed exactly in line with the filament feed holes in the extruder.

The fishbone gears makes for a surprisingly stable and backlash-free assembly. It feels really good so far. What I did not like was that I had to use far too many washers to get the gear-like feeder section in line with the holes in the extruder. I obviously got hold of a feed axle bolt see picture below.

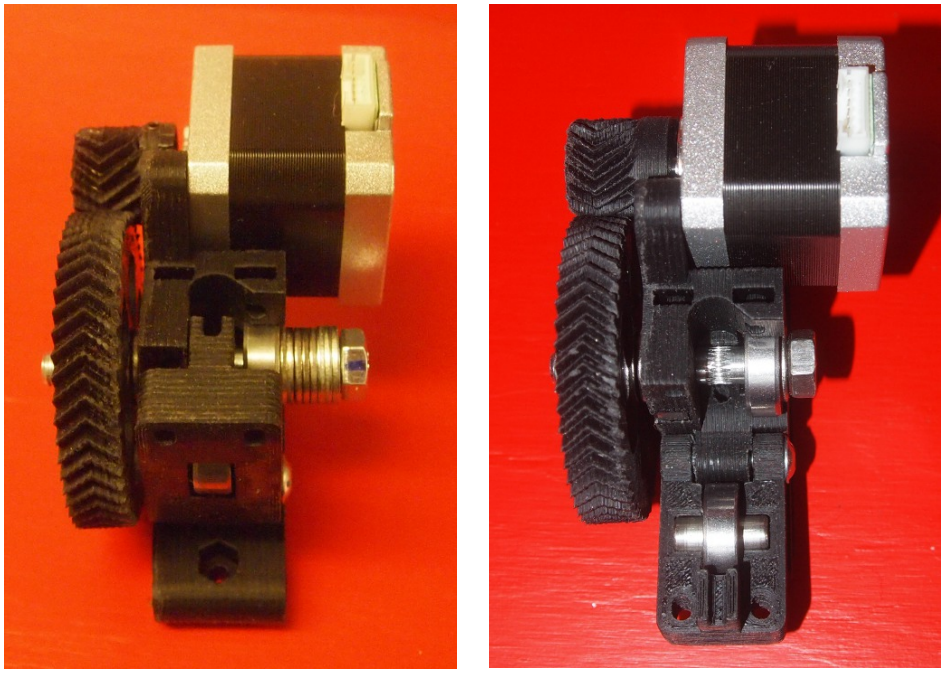


Figure 21: The Too Long Filament Feed Axle Before & After Adjustment

To solve this I will cut off the bolt head (to the right) and Loctite a nut to re-create a shorter bolt. This way I can make sure I get the filament feed “gear” section in the proper position using only one washer. The Picture to the right shows the result of the bolt adjustment. Much tidier!

What is left to do on the extruder is to fit the hot-end and add the mounting distance block to the carrier, but we will leave this to the point where the electrics come into play.

Instead it is time to find and fix a suitable power supply for this printer. There are several varieties to choose from, but I choose to use an ordinary PC PSU of around 500 W. That is the next job in line.

To mount the Extruder to the X axis I need two M4x60mm cap head screws. Easy to find, naaah, think not. Time to do my own it is. I used two short pieces of the left-overs from the way bars, drilled a sufficiently deep hole and added an M4 thread. Then cut off a piece of M4 all-thread which was screwed and secured with a drop of Loctite, and voilá, we have a screw of correct dimensions. There is a drawing in the Drawings section for those who want to do the same.

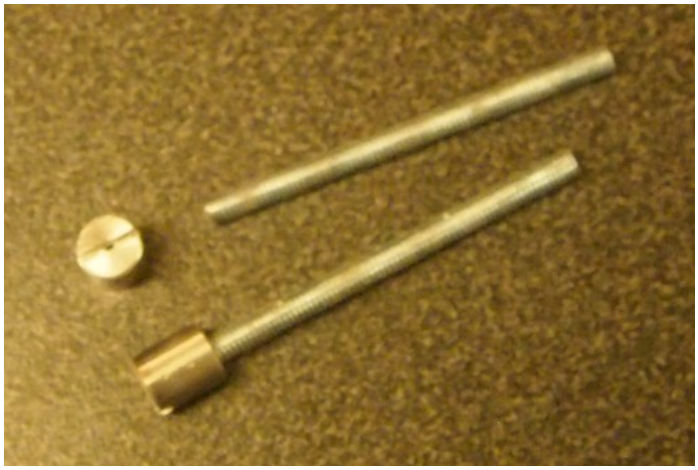


Figure 22: Home-made Extruder Mounting Screws

With the new screws it was easy to mount the extruder to the X axis and it sits very well indeed.

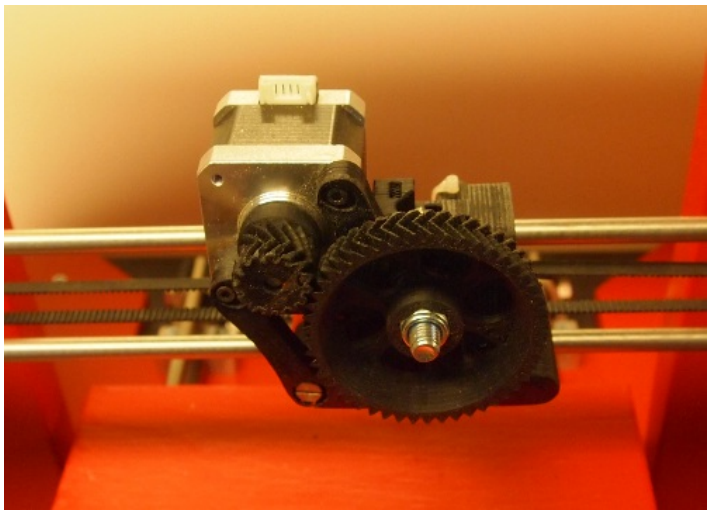


Figure 23: Extruder Fitted

Main mechanics OK then time to fit the hot-end. I got the following hot-end through eBay. It was equipped with both a fan and a PTFE tube connector. The tube connector will be very much in the way at assembly, so have to go for now. Time for some modification again.

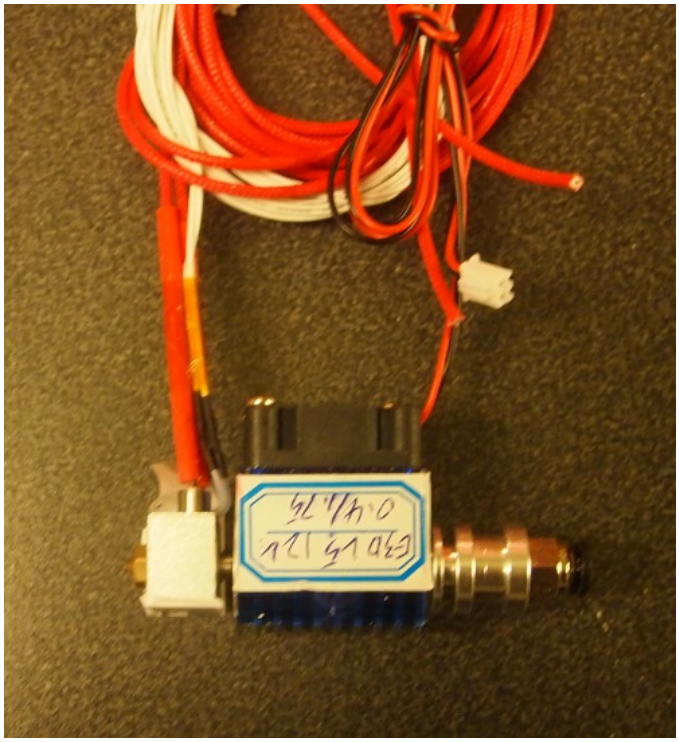


Figure 24: Extruder Head with Nozzle and Fan

Un-screwed the tube connector to see more. It turned out that the connector used a 1/8”-NPT thread instead of the now more common M6x1.

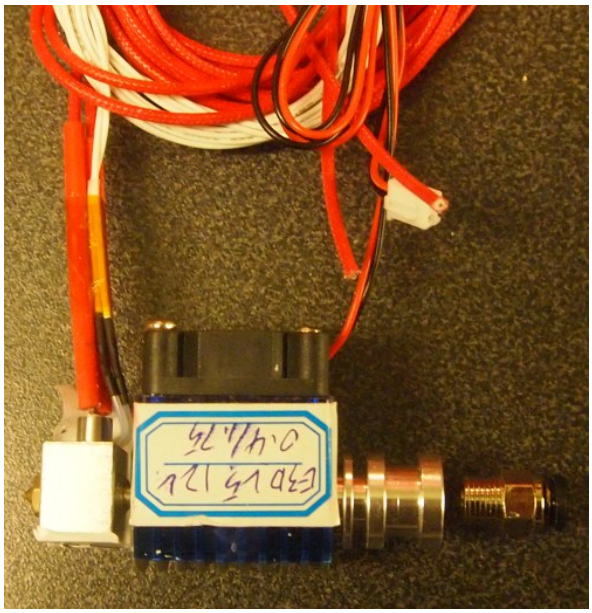


Figure 25: PTFE Tube Connector Un-screwed

The hole in the hot-end for the connector is quite large and deep and if I don't make a replacement I guess I can get problems with the filament.

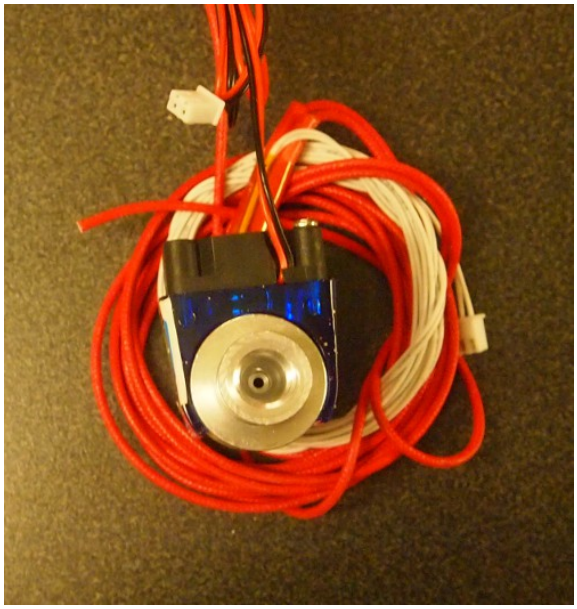


Figure 26: Large hole in the Hot-end

Without the connector I could also check the fit of the hot-end in the extruder body. It turned out to be slightly oversize, but nothing that couldn't be fixed with a few stokes with a file.

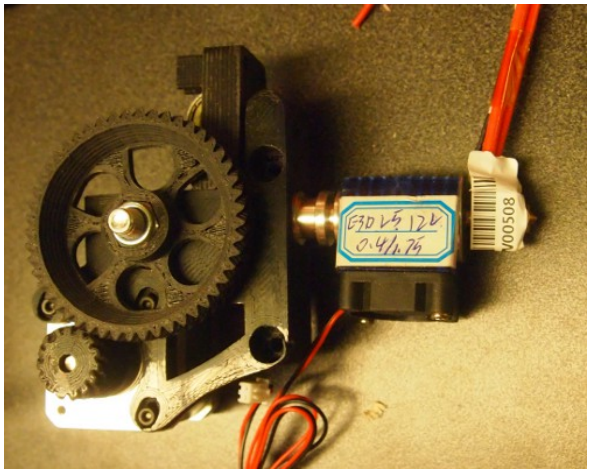


Figure 27: Hot-end Fitting Test

Further careful checks also showed that the hot-end wnet in a bit too deep into the extruder body. This would mean that it will not be held securely enough so have to be fixed by the adapter as well.

The narrow part goes into the hole in the extruder body and leads the filament from the feeder therough the head into the hot-end. Now there should be no problems I think. The adapter is secured with fiunger force only and then the whole package is clamped to the extruder body by the large clamp.

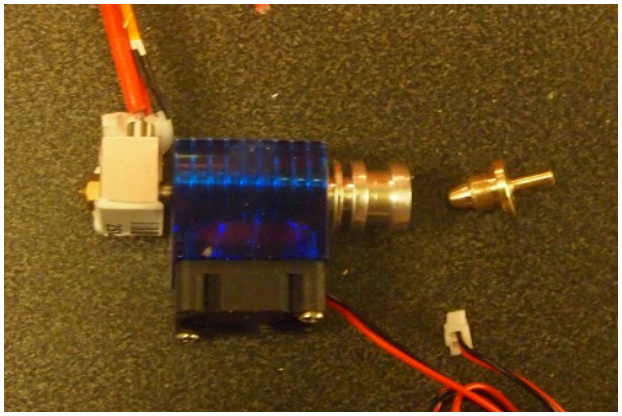


Figure 28: Adapter Made and Test Fitted

Next picture shows clearly how it is assembled before re-mounting to the X carrtier. The hot-end is nicely clamped to the extruder body without any chance of sloppiness.

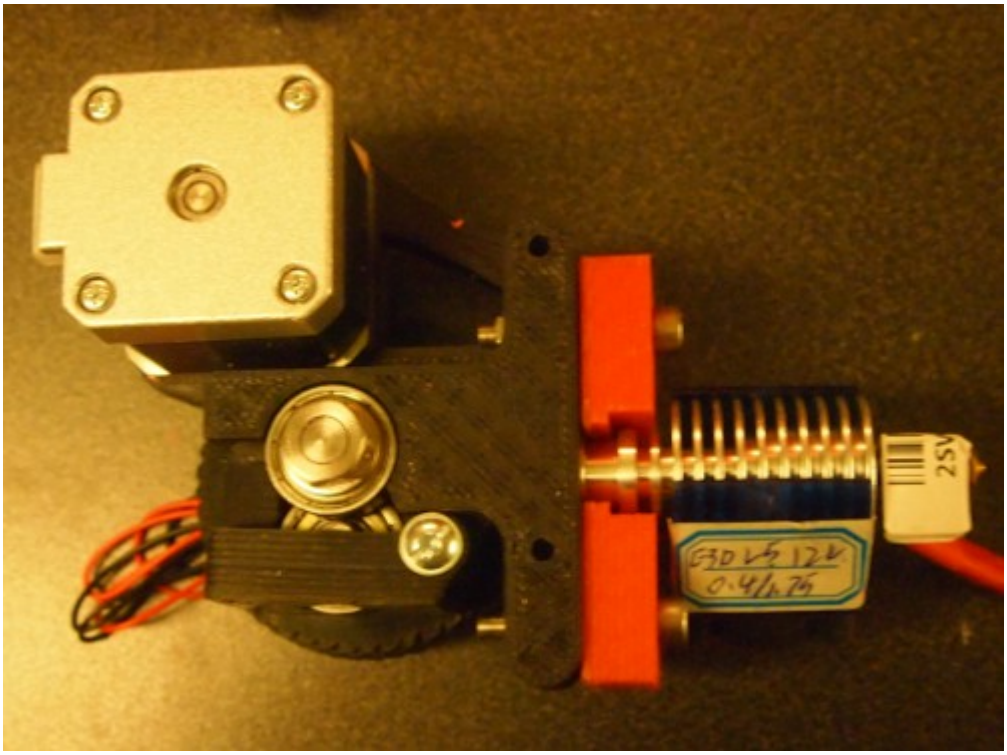


Figure 29: Hot-end Fitted to Extruder

With that the most of the parts for the extruder is done, except from the electrical connection.

The last mechanical fix here is to make something that the conenctor we removed can be attached to. It must be placed before and above the feed screw, but there is nothing to use at the moment.

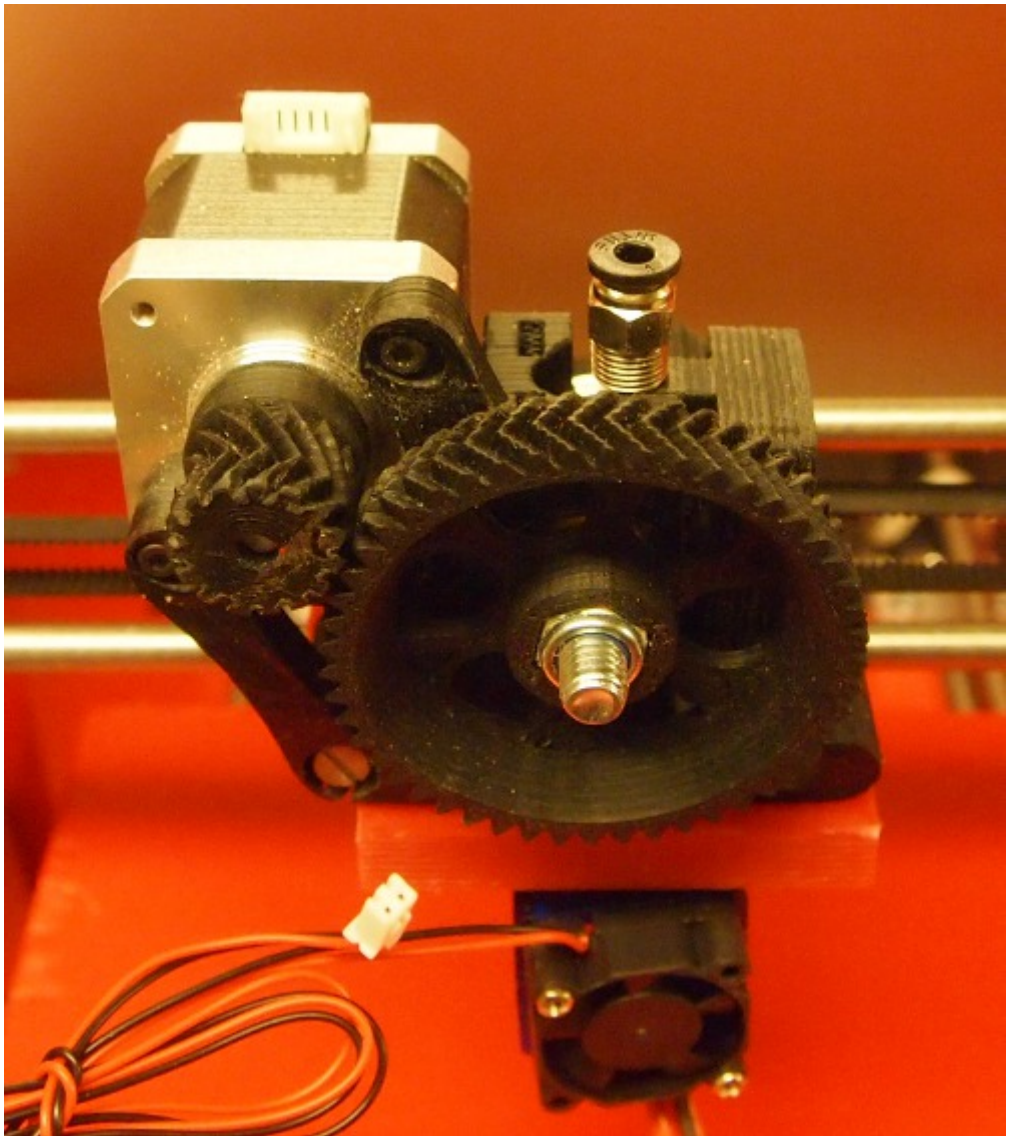


Figure 30: New Place for the PTFE Tube Connector

The new part for the PTFE-connector looks like this when laid on its “back”.

Figure 31: New PTFE Tube Connector Bracket

The two tabs with M4 threaded holes will hold the bracket to the extruder body and the larger hole is of course for the PTFE Tube connector. The two tabs goes into the holes for the nuts to the long screws holding the pressure springs pressing the filament to the feed axle.

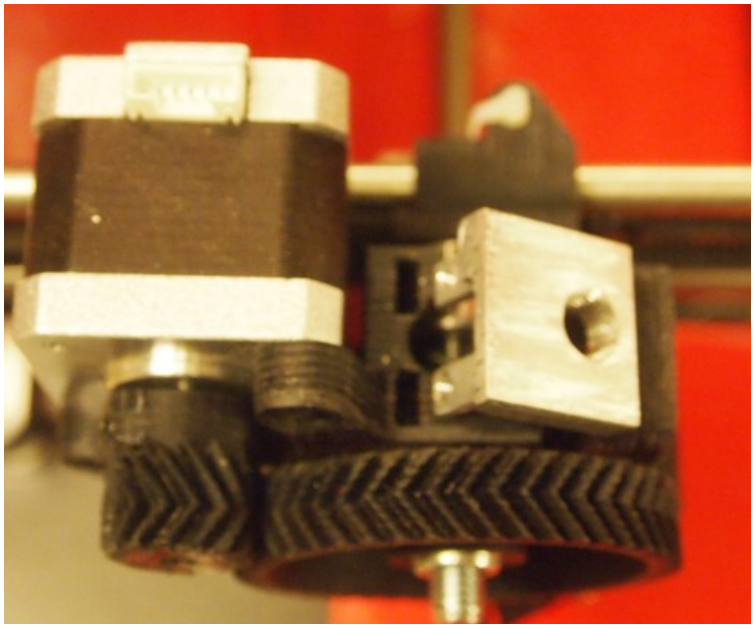


Figure 32: PTFE Connector Bracket

The tabs are inserted in the holes which make the bracket sit flat on top of the body. The connector is then just screwed into the hole and sits as it should.

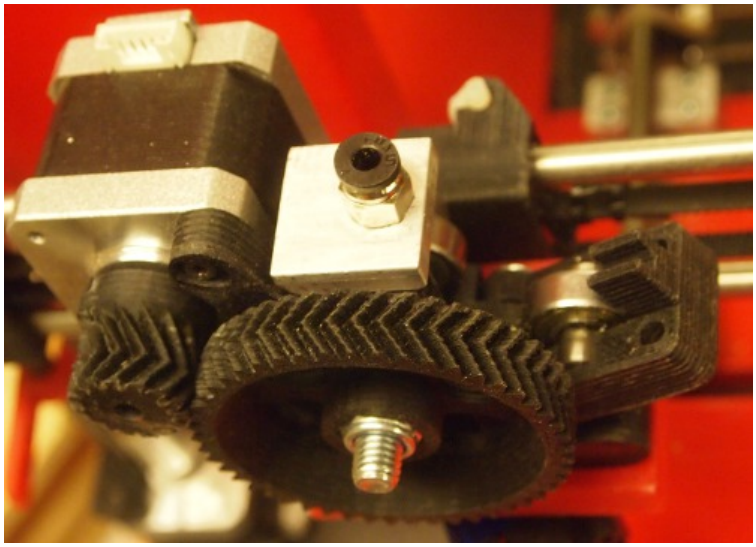


Figure 33: Connector Fitted

3 Modify a Power Supply to 3D Printer Use

Needed to finish this section is:

- An ordinary PC power Supply (PSU) of at least 500W power.
- One 4.7 Ohm 10W load resistor (ceramic)
- One 47 Ohm 1/4W load resistor (for PS_ON)
- One 12-pole Electrical Connection Strip for 2.5 mm^2 cable

The 3D printer uses 12 or 24 VDC so an ordinary PC power supply (PSU) will do very well. The small downside is that either one have to modify the cabling of the PSU or need to hide a quite large tail of un-used wires somewhere on the printer.

After finding a suitable PSU at my local electronics shop, I used the following web pages to modify it to get as little un-used wires as possible. Thought that would look best.

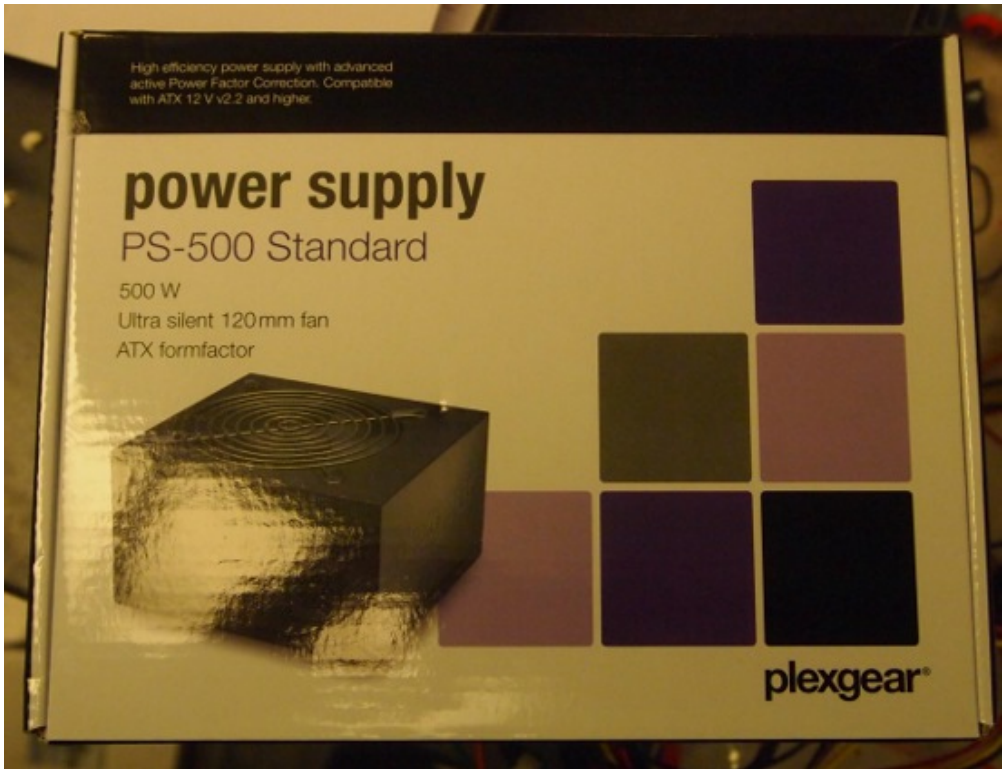


Figure 34: A Standard 500W ATX PSU

After un-boxing I followed these instructions to do what was needed to make it fit a 3D printer:
http://reprap.org/wiki/Choosing_a_Power_Supply_for_your_RepRap

Note: *When opening a PSU like this you will automatically revoke any guarantees! If you still want it, look at the end of the web pages for instructions on how to do it without changing anything instead.*

It was easy to follow, but take it slow and read twice to avoid cutting the wrong cables. It would be bad to foul up a completely new PSU. Here we can see how it looks internally after removing the unwanted cables.

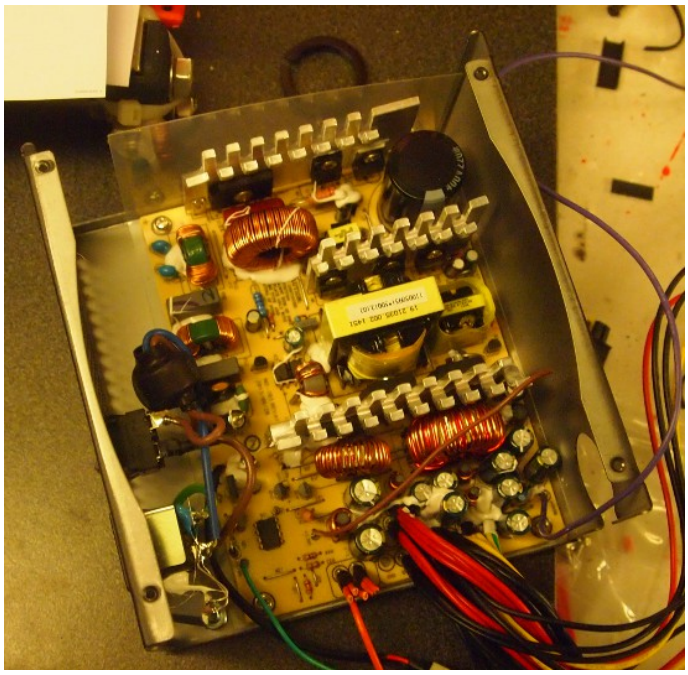


Figure 35: The Inside of the PSU After Modifcation

Since the PSU will not be hooked up to a load in the same way as in a PC, it needs to have a load resistor to make the voltage and current adjustment function work properly. The load is a common 4.7 Ohm 10W ceramic resistor. I put some shrink tubing over the solder to avoid any mishaps later on.

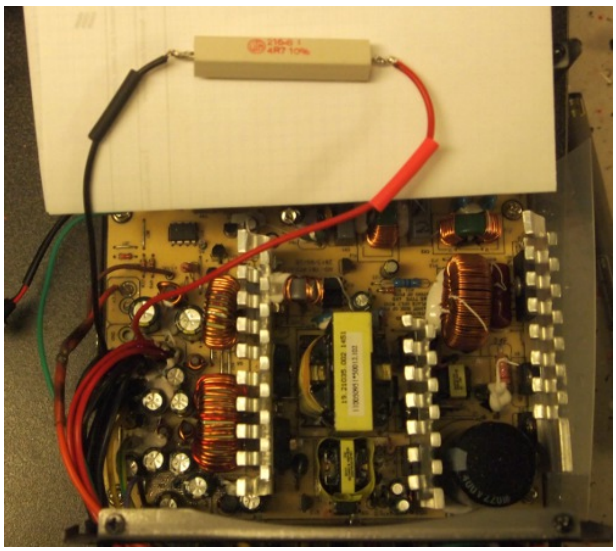


Figure 36: Load Resistor in Place

To avoid having a part bouncing around inside a box with power electronics I secured the load resistor to the ventilation grid with two tie-straps. That also provides some cooling for the load resistor which is good.

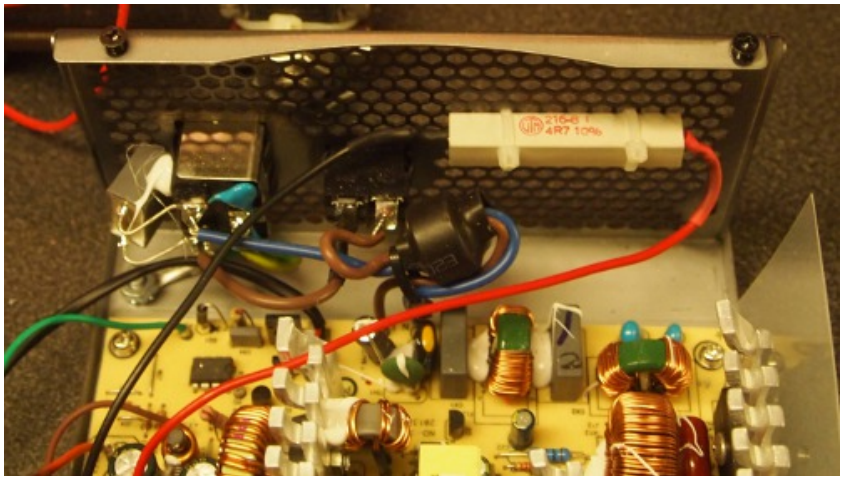


Figure 37: Securing the Load Resistor

This was the last of the internal modifications, now time to sort out the outside.

Personally I do not like a tail of cables flopping around so I choose to fit an ordinary 12-pole screw connection strip to the rear of the PSU. I also made a label in addition to the cable color coding to remember which connections are which at service later on if needed.

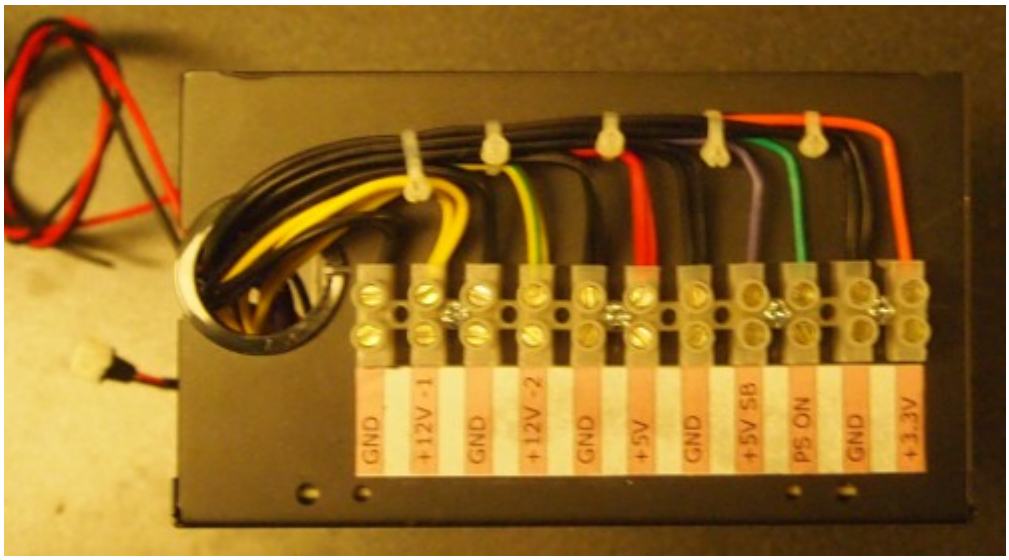


Figure 38: The Cable Connection Strip

The PSU cables are AWG16 (about 1.3 mm^2) which is very much OK for the power required. Try to use about the same size for the external connections (I re-used some of the cut-off ones). As can be seen, I used two cables for each 12V line just to be sure that the output current could be sufficiently handled.

As can be seen, I decided to make it possible to connect the PSU ON connection in the strip as well, this way preparing for the control electronics to also control the PSU power on. But right now II just added a small 47 Ohm 1/4W resistor to connect the PS_ON to ground. It will be very easy to change this later on.

Figure 39 The PS_ON Resistor in the Connection Strip

3.1 Mount the PSU to the Printer

With the PSU done it is time to make place for it on the printer. To think of at the same time is where to put the rest of the electronic parts so that it looks appropriate and don't require a massive cabling.

Start with attaching cables to the "outlet side" of the connections strip for the different connections. Use the same colors and as you go, attach a small "flag" on each connection wire to show its use. It is a great help during assembly.

Then fit the PSU to the frame using the holes in the left stretcher made earlier with a couple of longer screws for the fan shroud. This way the PSU cooing airstream will be taken in from behind the printer and let out through the hole in the side away from the build surface. That should prevent un-necessary cooling or heating of the build object.

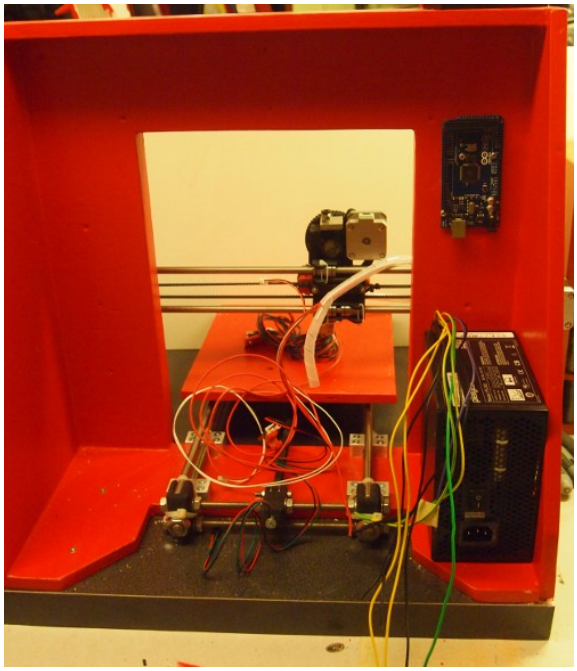


Figure 40: The PSU In Place with Cabling

The picture shows the mounted PSU and also where I decided to mount the Arduino board. Quite close to the PSU and I will place the controller board on top of the frame right above the board, all to limit the cabling.

This placement will also make the PSU power cord to enter below the power switch and make the whole arrangement look good.

4 Setting up the Electronics

The control electronics are based on an Arduino Mega 2560. It can be bought together with the rest that is necessary like a kit on eBay. I got this lot for a very fair bit of money.

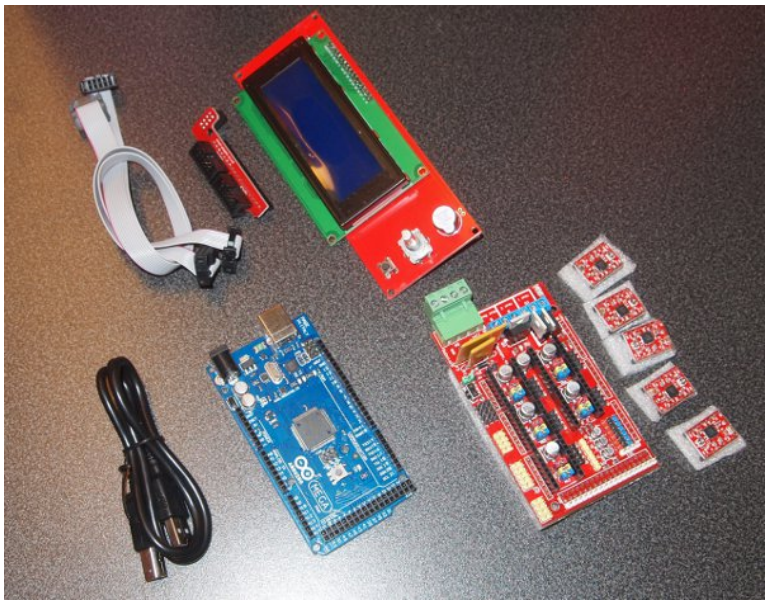


Figure 41: Main Electronics

The blue board is the Arduino, The red board beside it is the RAMPS 1.4 controller board and the five small ones are the stepper drivers. I choose to use the standard 4988 to begin with. The display board above is the small one and it has been exchanged for the newer and larger graphical one as shown later on.

In addition I need three end switches to tell the end of the ways.

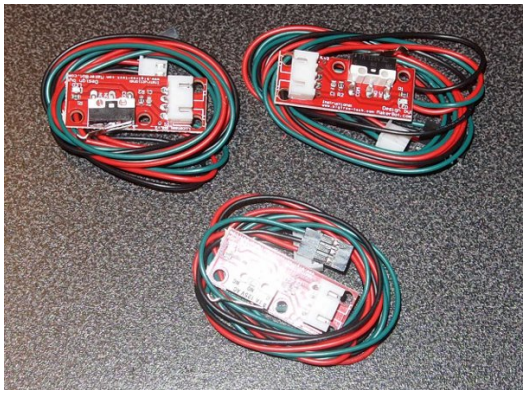


Figure 42: End Switches

It all starts with loading the Arduino board with the applicable software and settings. I used this link to fetch, compile and setup the software: http://www.dragonflydiy.com/2013/10/building-prusa-i3-printer-configuring.html

It is all done when connecting the Arduino to the PC using the included cable (coming in from the left in the picture).

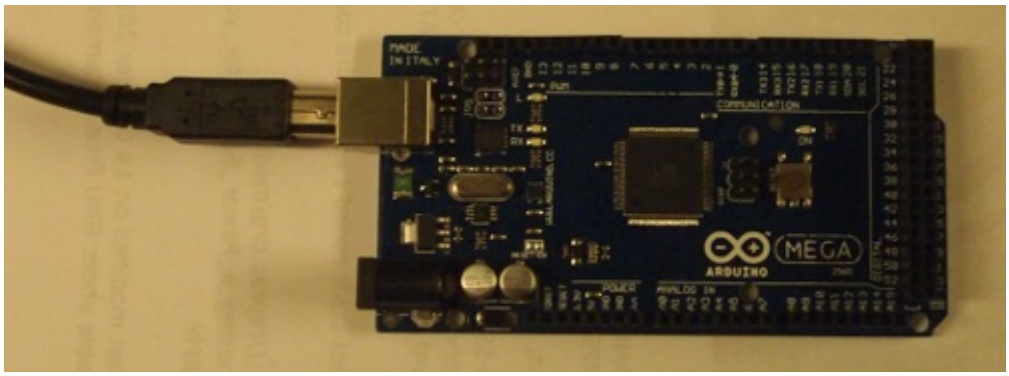


Figure 43: The Arduino Main Processor Board

After loading the Arduino board is mounted above the PSU at the rear left of the printer frame above the PSU. Then the other boards are assembled in the following order.

On top of the Arduino board we put the RQMPS 1.4 stepper controller board.

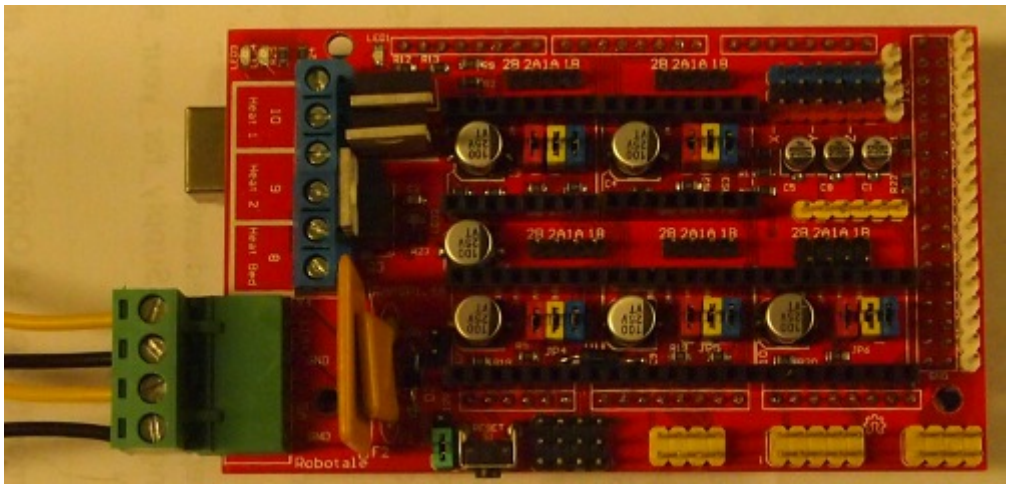


Figure 44: he RAMPS 1.4 Stepper Controller Board

The power to the whole setup is connected to the large green connectors at the lower left. The power will in turn be fed down to the Arduino board when power is switched on. The power connections comes from the two power rails on the PSU.

Then time for the adapter board for the graphical controller board to the far right.

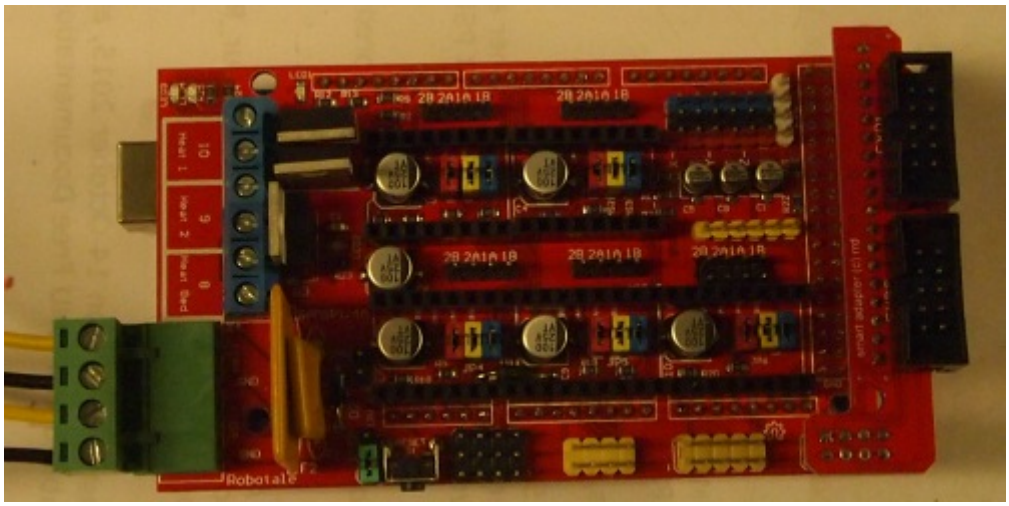


Figure 45: The Graphical Display Board Adapter

The graphical controller and its box will be described separately later on, but the connection cables are fitted now and will in principal look like the below.

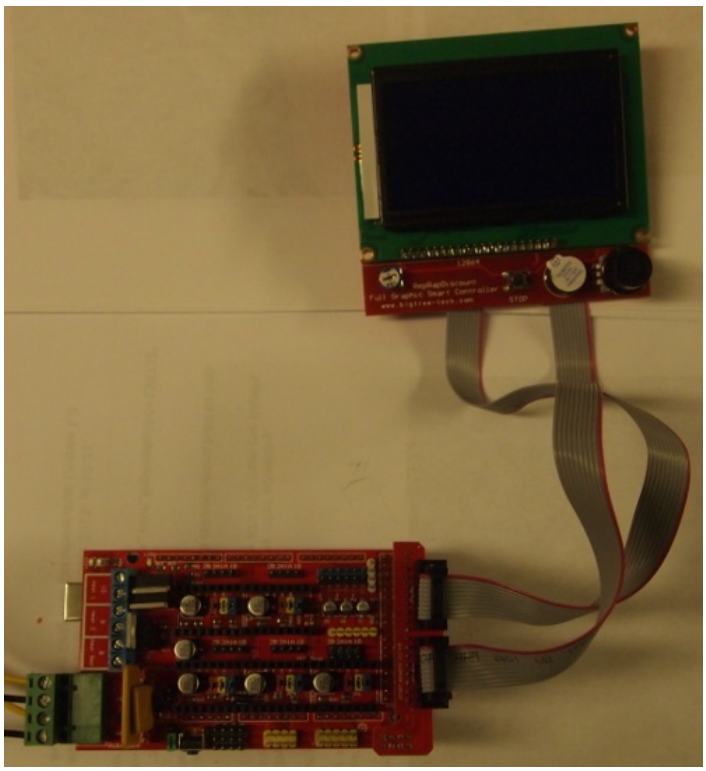


Figure 46: The Graphical Display Connected

Last but not least we add the five stepper motor control boards to the RAMPS board.

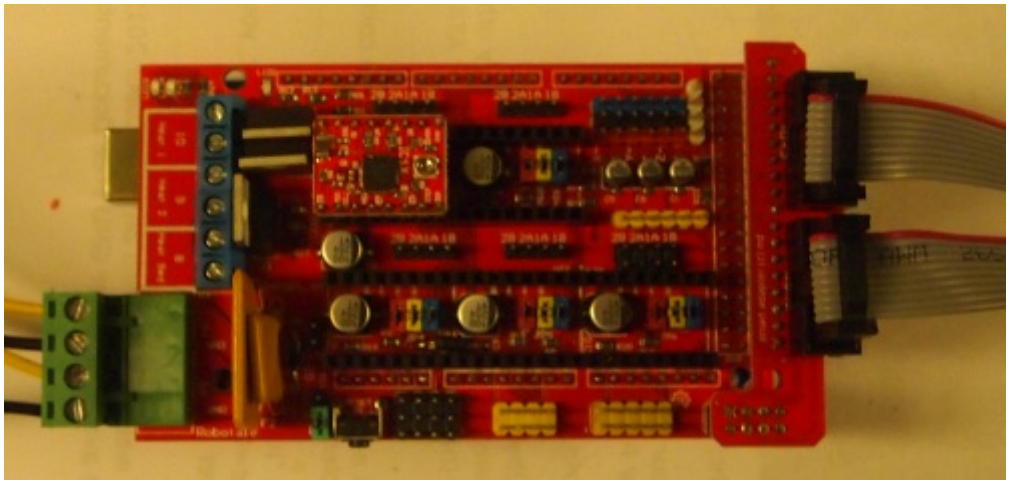


Figure 47: Stepper Controllers added

I just added one of the five to show where and in which direction they should be fitted. If turned wrong they and the whole electronics setup will blow at power-up. Be careful!

At this point we are basically ready to start connecting everything together. One thing to do first though is to fix a box or housing to the graphical controller to avoid harming the board during use.

4.1 Make a Housing for the Graphical Controller

There are several variants of boxes and housings for the graphical controller on the web, a few examples are:

http://www.thingiverse.com/thing:652552

http://www.thingiverse.com/thing:1116163

and

http://www.thingiverse.com/thing:87250

But since I do not yet have the possibility to print a case, I made one from ordinary Styrene sheets instead. That also gave me a chance to see how I really want the display controller to look and be secured to the printer.

The mock-up used today looks as follows.

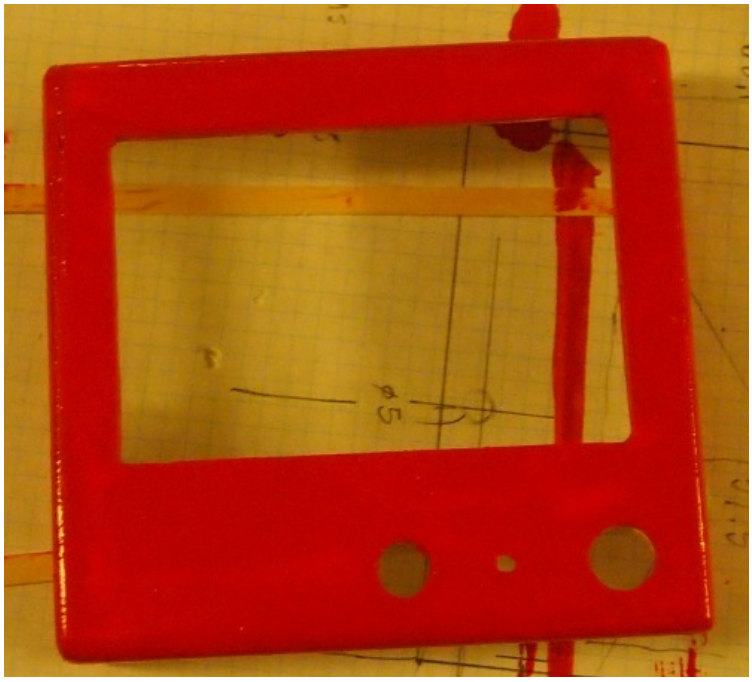


Figure 48: Graphical Display Front Panel

And …

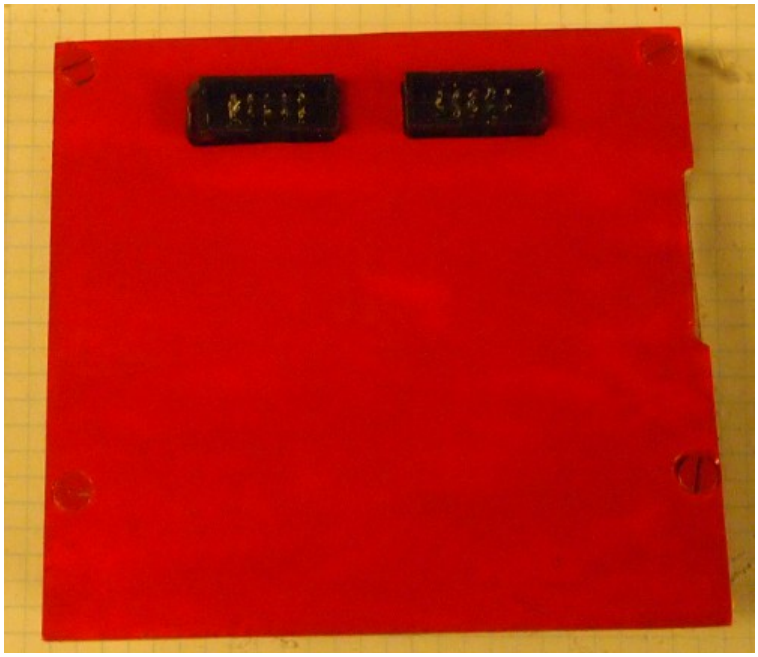


Figure 49: Graphical Display Rear Panel

The box will probably be used for some time but that also allows finding the proper placing and if something should be added like room for extra SD-cards for example.

I also made an angled base so it is directed better towards the user.

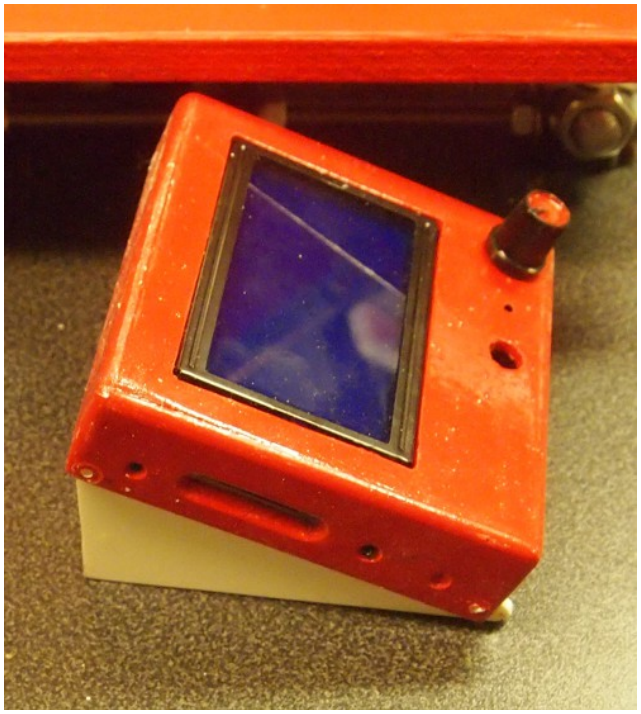


Figure 50: Angled Display Case Base

The base is made to possible to use either in a near-horizontal position like shown, or in a near-vertical position if required.

In the end it turned out to wind up at the top left of the portal as that position was the best from a cabling perspective.

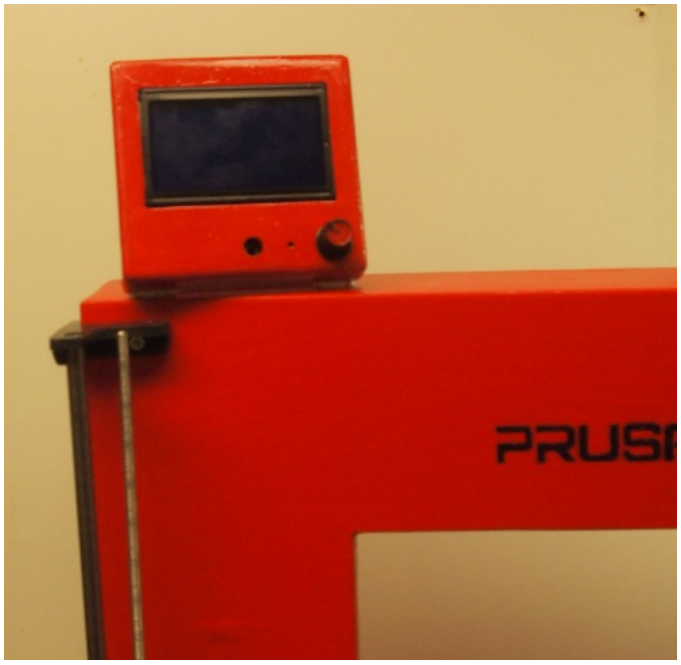


Figure 51: Final Position of the Graphic Display

4.2 Assembling the Electronics

The Arduino being the central unit for the printer is placed above the PSU. A few more cables have been added and now we have this.

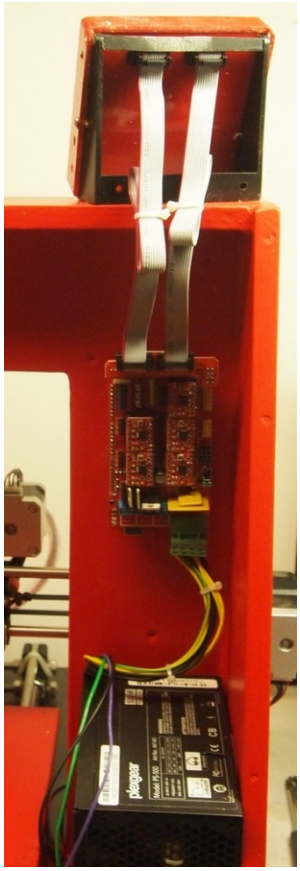


Figure 52: Main Electronics Assembled

The boards are fitted as described earlier, stacked on top of each other. It makes for a very compact solution. From bottom up we have:

- Main Arduino board screwed to the portal back
- RAMPS 1.4 board with main power inlet and driver connections
- Graphic display adapter connection
- Stepper motor driver boards.

Remaining is to connect the stepper motors and other parts to the electronics. This will make a very compact installation and still be quite easy to service.

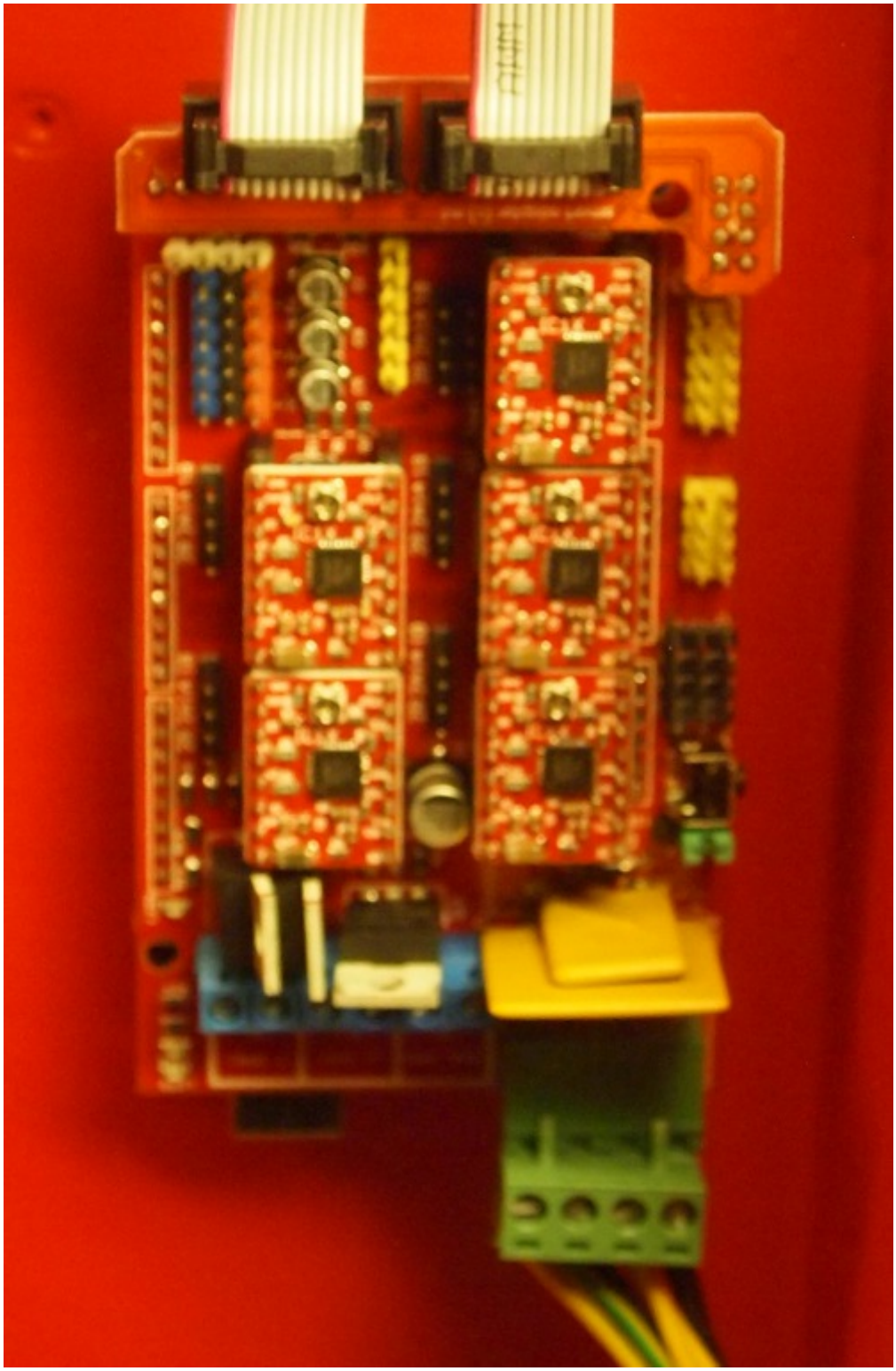


Figure 53: Stepper Driver Board Direction

The stepper driver boards shall be fitted so that the little trimmer is directed towards the graphic display adapter connection. If turned wrong they burn instantly together with the rest of the electronics. Be careful.

Before starting to connect all the cables, the last electrical part to assemble and mount is the heat-bed.

4.3 Assembling the Heat-bed

The heat-bed will rest on a sheet of cork (old IKEA cork place mat) cut to size. I cut the corners off and a suitable chunk for the electrical connection to avoid disturbing the height setting screws.

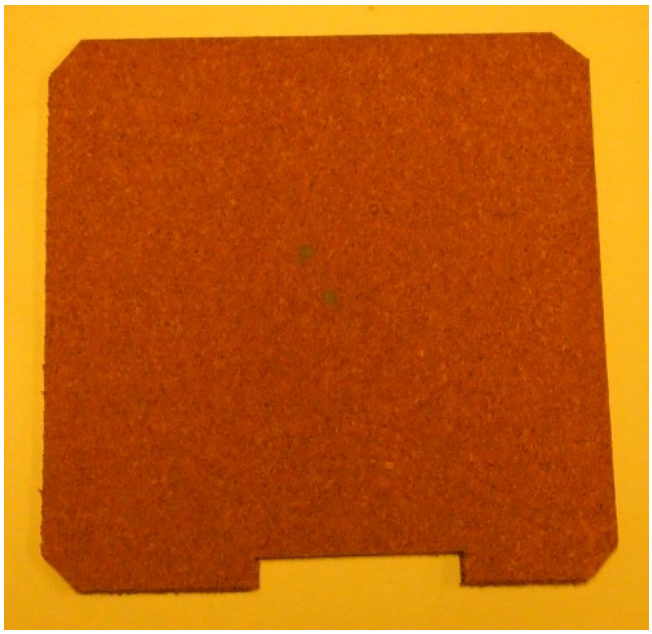


Figure 54: Heat-bed Cork Sheet

Connection cables and indicator LEDs are now soldered to the heat-bed. I use a MK2a bed that can be used for both 12VDC and 24VDC. I will use 12VDC so connect +12 VDC to terminal 1 and -12 VDC to terminals 2 and 3. A 1kOhm ¼ W resistor will supply the LEDS with power. There are two LEDS, one set for each current direction to be completely sure that they light up regardless of current direction. If one was sure it would be enough with just one. I follow the instruction so use two here.

Figure 55: Heat-bed Electrical Connections

LEDS and the resistor are soldered to the under-side of the heat-bed so that the glass sheet will lie flat on top. Therefore the LEDS need to have long enough legs to show outside the edge of the heat-bed.

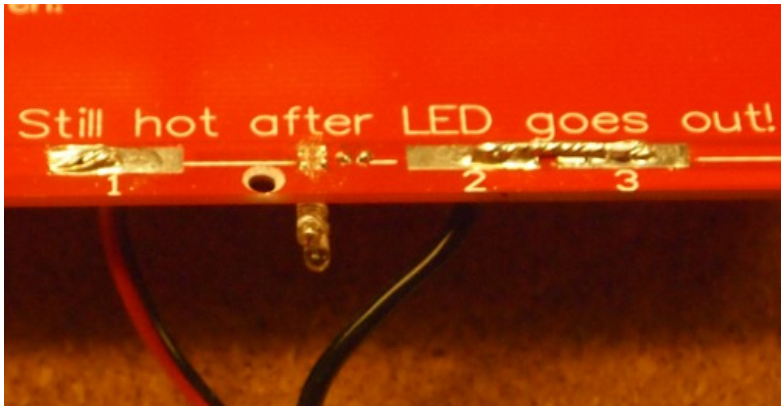


Figure 56: LEDS Sticking Out Over the Edge

The last part to fit to the heat-bed is the temperature sensor resistor. To make sure it works right I use a little drop of heat sink compound. To avoid loose wires I also put a piece of Aluminium tape over the temp sensor and its cable.

Figure 57: Heat-bed Temp Sensor Fitted

As all electrical connections are done it is time to put it all on the build plate on the Y axis.

4.4 Fitting Heat-bed to Y-axis Carrier

The heat-bed is fitted to the carrier board with screws and springs will make it possible to level the surface. Since I use a plywood sheet for carrier, I wanted to make a set of metal “plugs” for the levelling screws. I think that will make it last longer. I started from a piece of the 8mm smooth rods.

Figure 58: Stainless Rod to Become Levelling Adaptors

Out of that I made three hat-like bushings with M3 through-holes to be glued to the plywood carrier in the proper places.

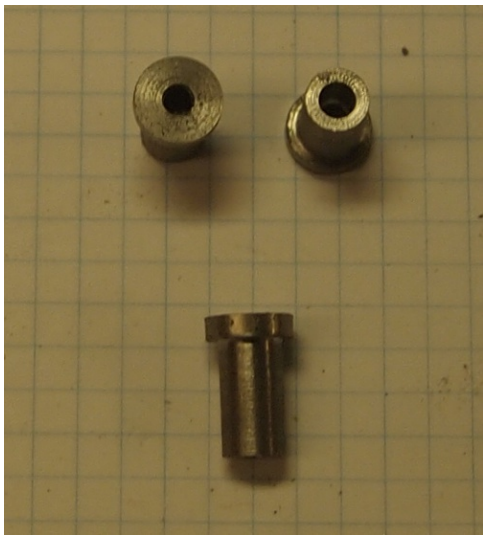


Figure 59: The three Adapters

To avoid having to thread all the way through the 13mm long bushing, I drilled a larger hole for about half way through. The remaining length should be more than enough for good function.

Then the bushings were glued in place.

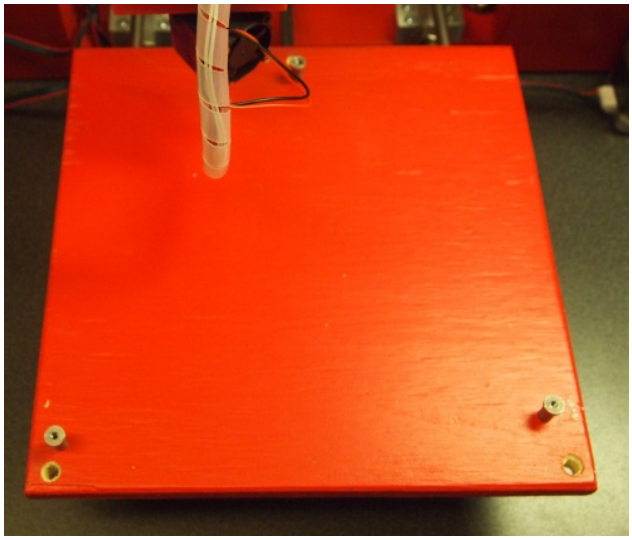


Figure 60: Adapter Plugs Before Gluing in Place

With the adapter plugs in place, the heatbed is fitted and levelled for a future proper print. The heatbed needs to be level compared with the extruder so checking the level is done by measuring from the heatbed to the nozzleat the following eigth points:

- *Front Left Corner*
- *Front Right Corner*
- *Rear Left Corner*
- *Rear Right Corner*
- *Center Front*
- *Center Rear*
- *Center Left and*
- *Center Right*

The reading must be the same in all places, and this result in the heat-bed to be level in a proper way.

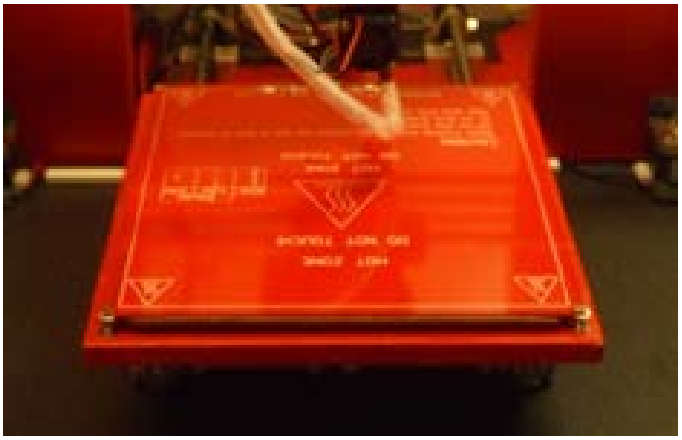


Figure 61: Fitting the Heat-bed

To make leveling simple, there is a coil spring between the carrier board and the heat-bed and the screws used are long enough to provide ample adjustment range. The three-point mount allows for easy leveling

With this all mechanical assembly is done and now time to look further into the electrical side of the printer.

4.5 Fixing the Wiring

The electrical wiring requires a bit of thought. No cables should get entangled in the machine mechanics at work, so I choose to use some small cable channels and a 10mm cable spiral to collect and guide the cables.

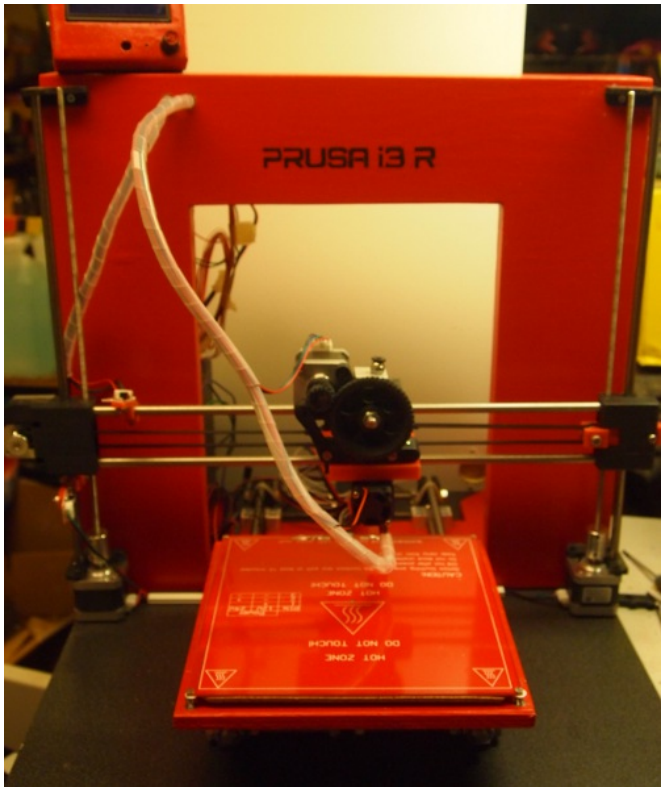


Figure 62: Beginning the Wiring

The cable channels on the base board helps get the cables out of the way and protect from damage as well. The cables from the X-axis motor and end-stop got its own spiral tube with the cables held together with a small zip-tie. The cables are led through the portal upright through a 10 mm hole to the rear for connection to the electronics boards.

I did the same for the cables from the extruder, the hot-end, temp sensor, fan, and extruder motor. They all got their own 10mm spiral tube and a 10mm hole in the portal right beside the other one.

It all looks tidier and no cables go over the portal. That in turn will give more room for the filament tube movements.

The end-stops are placed as follows:

- X axis – On the left side and is triggered by the extruder stepper motor housing
- Y axis – On the left side and is triggered by the left bearing housing beneath the build plate carrier
- Z axis – On the left side under the X axis stepper motor and is triggered by the underside of the stepper motor mount.

I have just used three end stops so far as it seems to be a minimum, but have been thinking of adding more to define all ends of the movements.

A view from the rear shows the cable channels and spiral a bit more clearly.

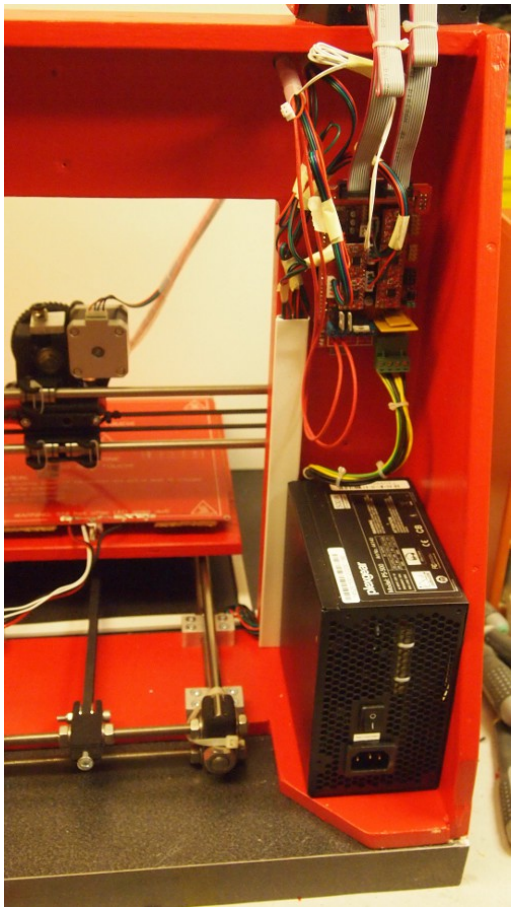


Figure 63: Cable Channels and the Spirals

A couple of small channels guide the cables from the Y axis movement and the Z axis motors. All cables apart from the ones in the two spirals are then laid in a slightly larger channel on the rear of the portal beside the PSU. This is to avoid any cables to be caught by the heat-beds movement.

The cables are connected to the RAMPS 1.4 board according to the following drawing: http://reprap.org/wiki/File:Rampswire14.svg

At this point I found a discussion around heat spreading from the electronics and thereby altering the environment around the build board. To avoid that and prepare for future electronics cooling, I added a screen in the form of a piece of clear acrylic sheet as shown below.

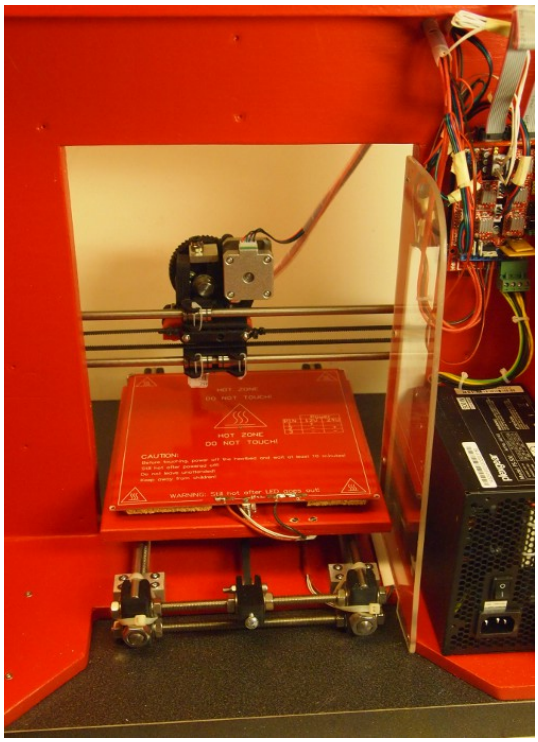


Figure 64: The Clear Acrylic Screen

The acrylic screen drawing is found in Acrylic Screen for the Electronics. Seen from front with the glass sheet on the build board, the printer now looks quite nice.

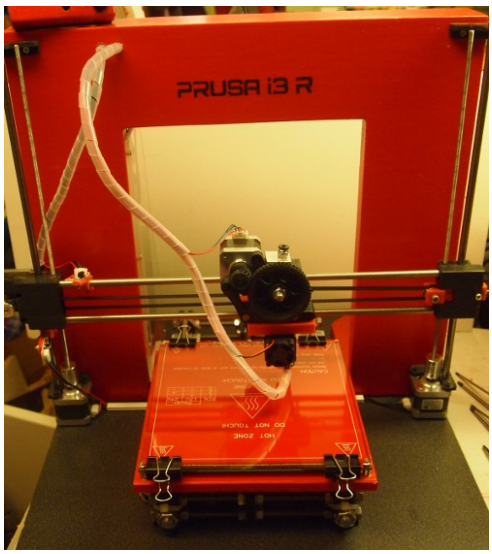


Figure 65: Front View

5 Final Touches before Programming

Just as one thinks everything is done, they turn up, the small things necessary for the functionality. The Filament Roll Carrier is one of those more important extras described in the following.

5.1 Filament Roll Carrier

The filament roll carrier is not a very complicated thing, just needs to be fixed. It took a little longer than I anticipated, but that was one of those “design as you go” jobs and I had to make some calculations to make sure everything wound up correctly. Then some time for paint and finish. Here it is.

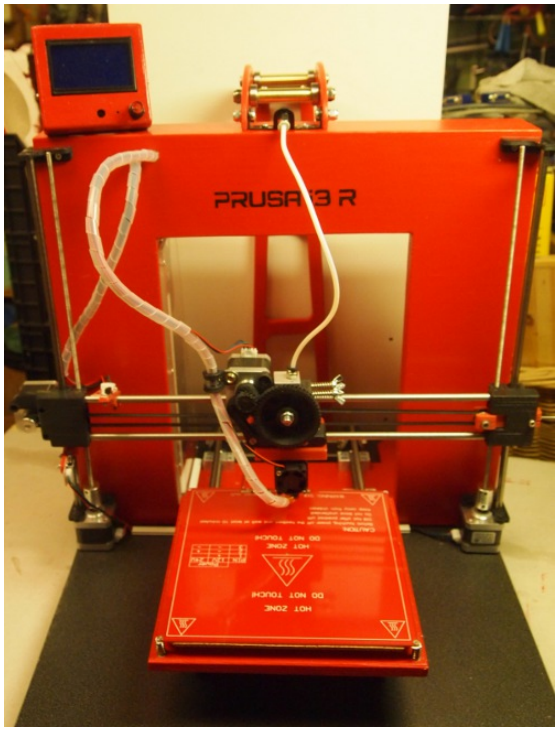


Figure 66: Filament Carrier and Feed

I decided to place it on top of the portal with the filament roll on the machine centerline. The bracket holding the filament roll carrier is also the fixed point for the PTFE filament tube mount. I could not refrain myself from giving the roll carrier some sort of “design”.

Figure 67: Filament Roll Carrier, Side view

The arc is used to provide some extra side support for the filament roll as it otherwise just rests on a set of old skate board ball bearings, and I wanted to be sure it stayed in place.

The smaller nuts at both end secures the bracket to the portal while the larger nuts holds the axles with bearings in place.

The following three pictures show the arrangement from different angles which I hope will be informative. The sides of the thingy are made from some MDF I had and the brackets are cut out of a piece of aluminium from the metal storage (the scrap box).

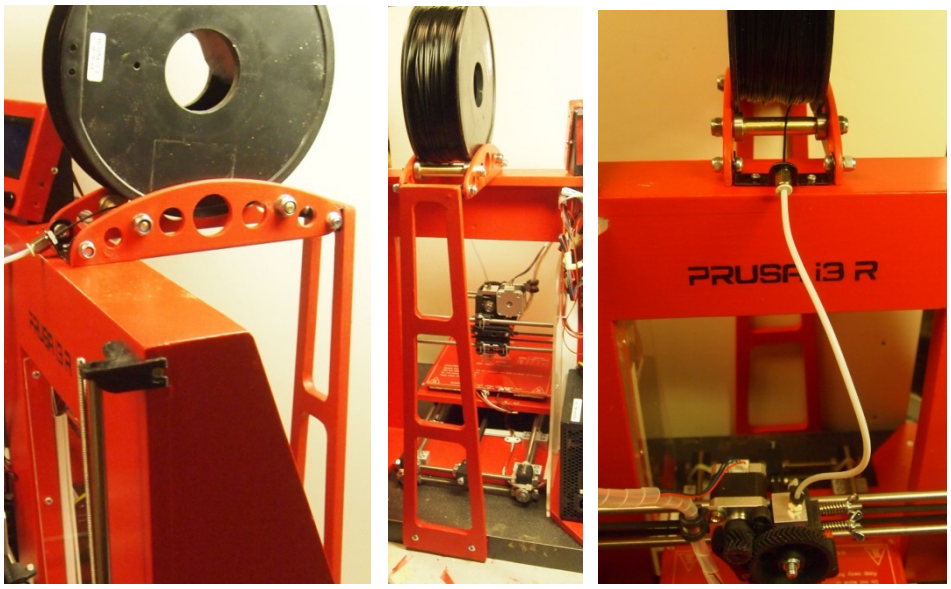


Figure 68: Filament Roll Bracket Design

This way I think I have got an easily workable setup which will provide useful for the print jobs.

6 Software Setup

The software setup can be divided into two main parts, Compiling the software and calibrating the printer using the software. As I made everything from scratch in this build I also set the software up from scratch. The compiling and setup instructions I used was published by “Dragonfly DIY” on the following address: http://www.dragonflydiy.com/2013/10/building-prusa-i3-printer-configuring.html

If you have purchased a build kit over the internet, you probably don’t have to compile the software as it will probably be pre-loaded onto the Arduino as delivered. If you, like me, build from scratch you need to do what I did.

6.1 Fetch and Compile the Software

As said, I used the fetch and compile instructions on this link: http://www.dragonflydiy.com/2013/10/building-prusa-i3-printer-configuring.html and followed it carefully.

Take your time and read carefully as there are quite a few steps to pass. A notebook on the side is most useful.

6.2 Testing and Calibration

Next step is to test the machine and calibrate its movements. The instructions I used are also found on Dragonfly’s pages: http://www.dragonflydiy.com/2010/10/building-prusa-i3-printer-testing-and.html and these should also be read carefully. This step is to set up all stepper motors properly and to make sure the temp control of the heat-bed works as intended. Also the end stops function is set so that any major happenings will not occur later on.

Since the PSU has its own power switch, it will be easy to cut the power during calibration if so needed.

Comment: The stepper driver boards/modules I bought did not have the test point described in the instruction. Instead I set the little trimmer half way betwee3n the ends to start with. That setting later proved to be quite OK seem from a power and speed point of view.

6.3 Final Calibration

The final calibration step is to fine-tune all the movements and set the heat ranges absolutely correct. This is required to be able to make the first print tests as good as possible.

The instruction for final calibration I used is found here: http://www.dragonflydiy.com/2013/10/building-prusa-i3-printer-final.html

6.4 First Print(s)

Now that all setup and calibration is done it is time for the first test prints to verify the printer and all the settings. There are a couple of standard objects that is of great use for this, and these items are:

- Test Cube – a simple hollow cube with 10mm sides, http://www.thingiverse.com/thing:271736
- Test Coin – A simple coin to match the size needed to release shopping carts.
- A small Frog – To ensure that 3D items are well reproduced. http://www.thingiverse.com/thing:18479
- A case for the graphical display. http://www.thingiverse.com/thing:617468

When all these items are done the printer should be ready for “production” of the items it was built to make in the first place. We are finally done and can enjoy the result of the efforts.

ENJOY!

7 Drawings

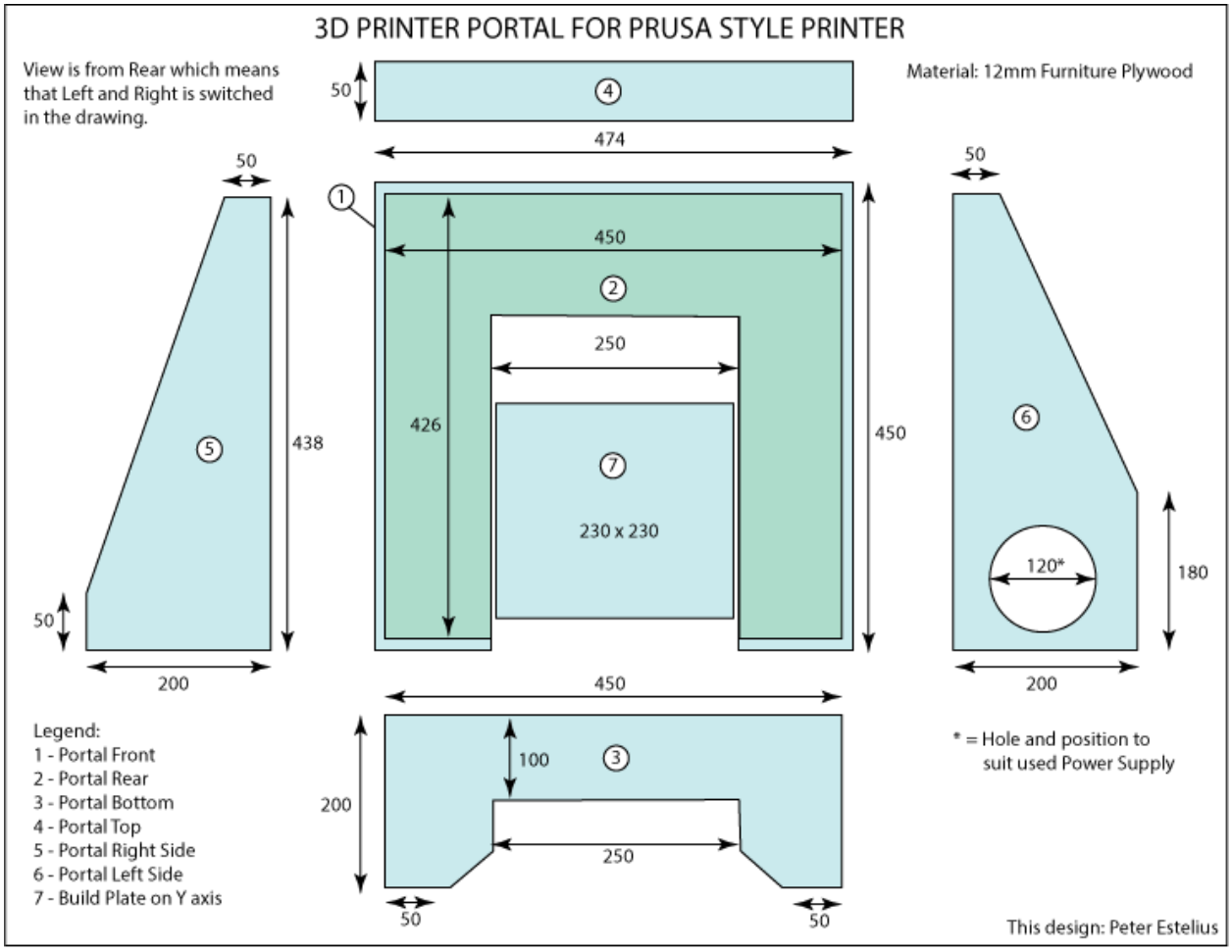
This section contains all the different drawings used to build my 3D printer.

The drawings are:

- Frame and Baseboard
- Y Movement Fixings
- Graphic Display Box and Stand
- Filament Reel Support
- PTFE Tube Fittings
- Acrylic Screen for Electronics

7.1 Frame & Baseboard

The box frame for my printer was made from 12mm thick furniture (multi-layer) plywood:



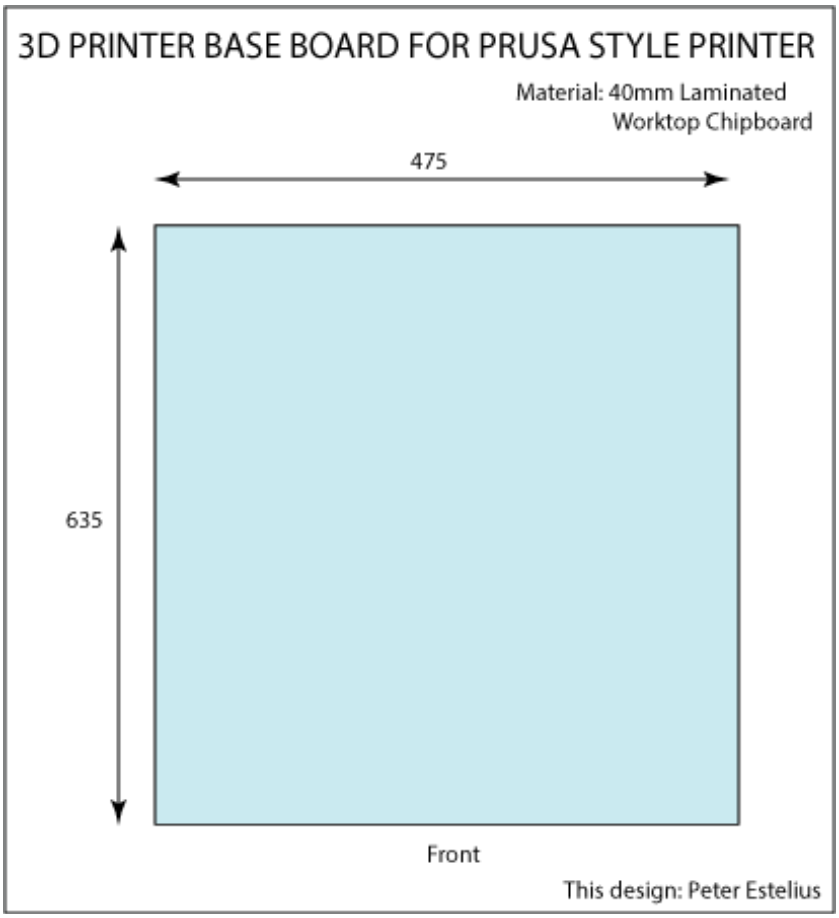
Drawing 2: Box Frame

The cut-out pieces were glued and screwed together to form a very rigid vertical portal for the printer. The screws used were 3.5x20 for securing the two portal upright sheets together and 3.5x25 for all other fitting.

The portal was then sanded smooth, painted left to dry well before continuing.

The Base Board

The base board was a left-over piece of 40mm thick laminated kitchen bench-top according to the dimensions below.



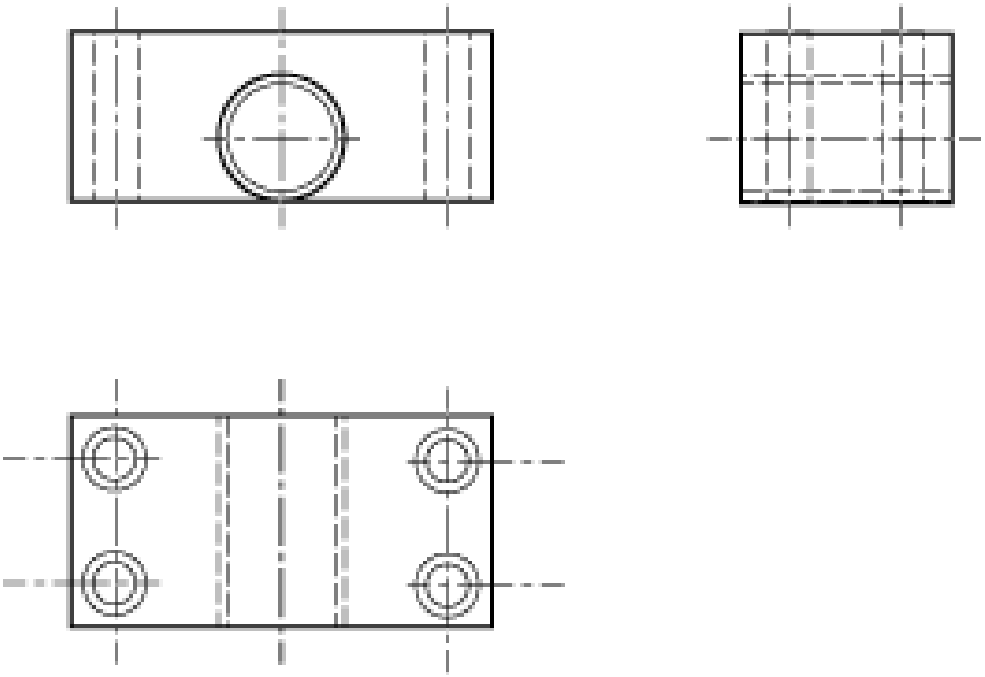
Drawing 3: Base Board

Even though the piece of board is nicely laminated on top and probably bottom, it is always nice to put some laminate on the sides as well to hide the cut sides.

The portal is placed 200mm from the back end of the base board, leaving about 410mm open towards the front.

7.2 Y Movement Fittings

The four Y movement securing blocks are made from a piece of 20x40mm aluminium (aluminum) bar according to the drawing below.



Drawing 4: Y Movement Securing Blocks

There are 3D-printable securing blocks available on Thingiverse to use to securing the Y axis movement, but The printed ones does not make use of the thread at all.

I therefore decided to make my own securing blocks from alu as I wanted to use the thread as axial fixing. This is quite OK as the stainless all-thread has a very good precision in the screw cut, and consequently fits quite closely into the thread.

7.3 Graphic Display Box & Stand

7.4 Filament Reel Support

7.5 PTFE Tube Fittings

7.6 Acrylic Screen for the Electronics

8 Assembly Aids

I also made a few assembly aids that will make the assembly and maintenance of the printer easier. These assembly aids are:

1. Marking screws for fitting the PSU
2.

8.1 Marking Screws

On my PSU the fan shroud was fitted using four screws for sheet metal or plastics. I used two of those to secure the PSU to the 3D printer frame and had to make marks in the exact spots for new longer screws.

What I did was to find a pair of similar screws and do the following:

- Cut off the head
- Use a thin hack saw and make a new screw driver slot in place of the head.
- Hold the screw slot outwards in a drill chuck and with a file make a point.
- Do this for two screws.

The result should look something like this:

Figure 69: Marking Screws

The marking screws can now temporarily replace two of the fan shroud screws for marking holes in the right side portal frame.

9 Links

9.1 Prusa i3 Printed Parts

There are several sources for the Prusa i3 Printed Parts. I used the list on this link link: http://www.dragonflydiy.com/2010/11/building-prusa-i3-printer-printed-parts.html

… but could just as well have bought a set off eBay for example. See this exemplary link: http://www.ebay.com/sch/i.html?_from=R40&_trksid=p2047675.m570.l1313.TR0.TRC0.H0.XReworked+Prusa+i3+printed+parts+.TRS0&_nkw=Reworked+Prusa+i3+printed+parts+&_sacat=0

The third (and cheapest) alternative is if you can find someone nearby to help you print the parts as the files are available on the web at RepRap: https://github.com/josefprusa/Prusa3

9.2 RepRap.org

The 3D printer I decided to make is an Open Source vesion from the RepRap.org group. As it is an open source thing it is freely available for anyone interested. The RepRap.org web pages are found here: http://reprap.org/wiki/RepRap

Very informative pages around a very interesting concept.

10 Acronyms and Abbreviations

This document uses the following descriptions, acronyms, and abbreviations:

ABS	**A**crylonitrile **B**utadiene **S**tyrene
PTFE	**P**oly**T**etra**F**luoro**E**thylene (e g Teflon)
RepRap	**Rep**licating **Rap**id-prototyper