The M-Guide
Version 3: Linear Servo Motor Microarrayer

Revision 1
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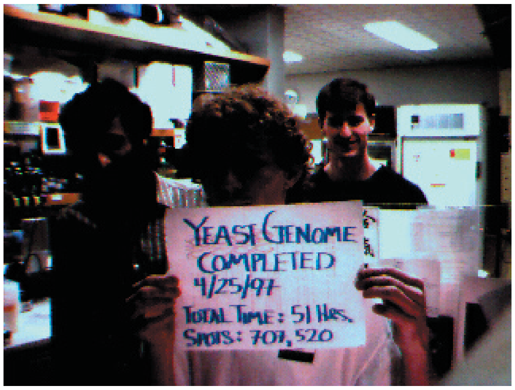
Table of Contents

Appendices



Vishy Iyer, Joe DeRisi, and Tim Heuer after the first whole yeast genome print, Stanford University, 1997.

History of this Guide
(J. DeRisi 2004)

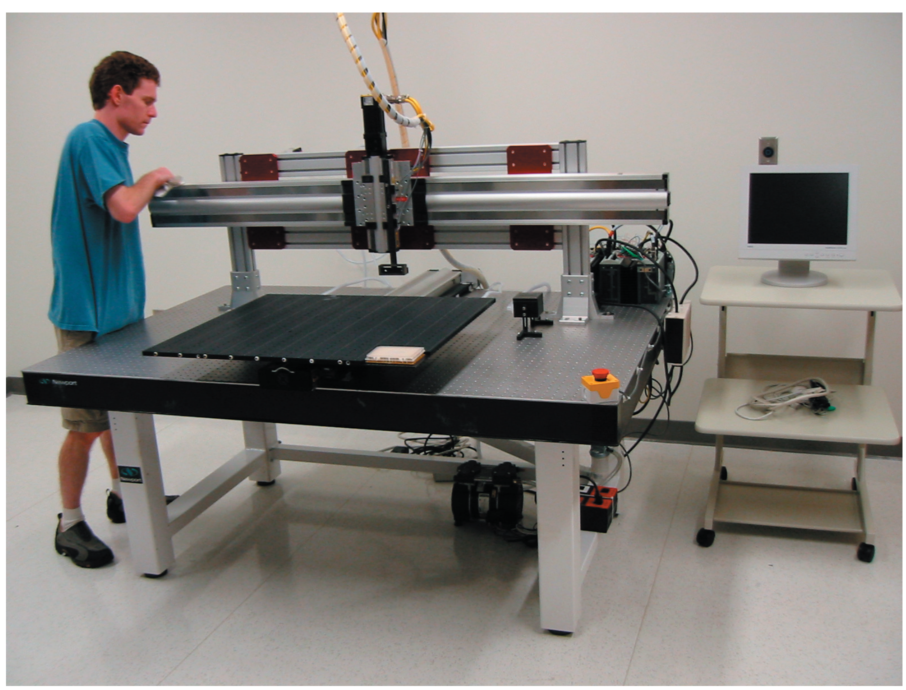
The genesis of the "build it yourself" microarrayer guide was the 1997 Cold Spring Harbor Genome Meeting. After a five-minute talk on the Brown Lab effort to put the entire yeast genome on a single microarray, an audience member asked whether directions would be available for replicating the technology. It seemed obvious to me that the construction plans and software should be posted on the Internet and so I replied that I would do just that. Of course, it took me about a year to actually make it happen. Vishy Iyer and several other members of the Brown Lab assisted me in this process.

The original "MGuide" was written in April 1998 and finally posted to the web on May 13th, 1997. The second half of the MGuide was published on the Brown lab website on August 10th, 1998. The first version of the ArrayMaker software package was posted a week later. Many improvements followed, and the second version of the MGuide was posted in November 1999 along with updated versions of the software.

The last MGuide described in detail the fabrication of a microarray robot that used screw-driven motors and could make 137 microarrays of nearly 20,000 spots in 20 hours.

This guide describes the assembly of a Linear Servo Microarraying Robot capable of printing more than 30,000 spots on 261 slides in 20 hours. Many aspects of the assembly are the same or similar to the previous design, but the product is much improved.

One thing that has not changed is that the arrayer described in this guide is faster, more flexible, bigger, and better than virtually any product commercially available. Also, at a cost of about $40,000 in parts, it is also a fraction of the cost of most commercial systems.



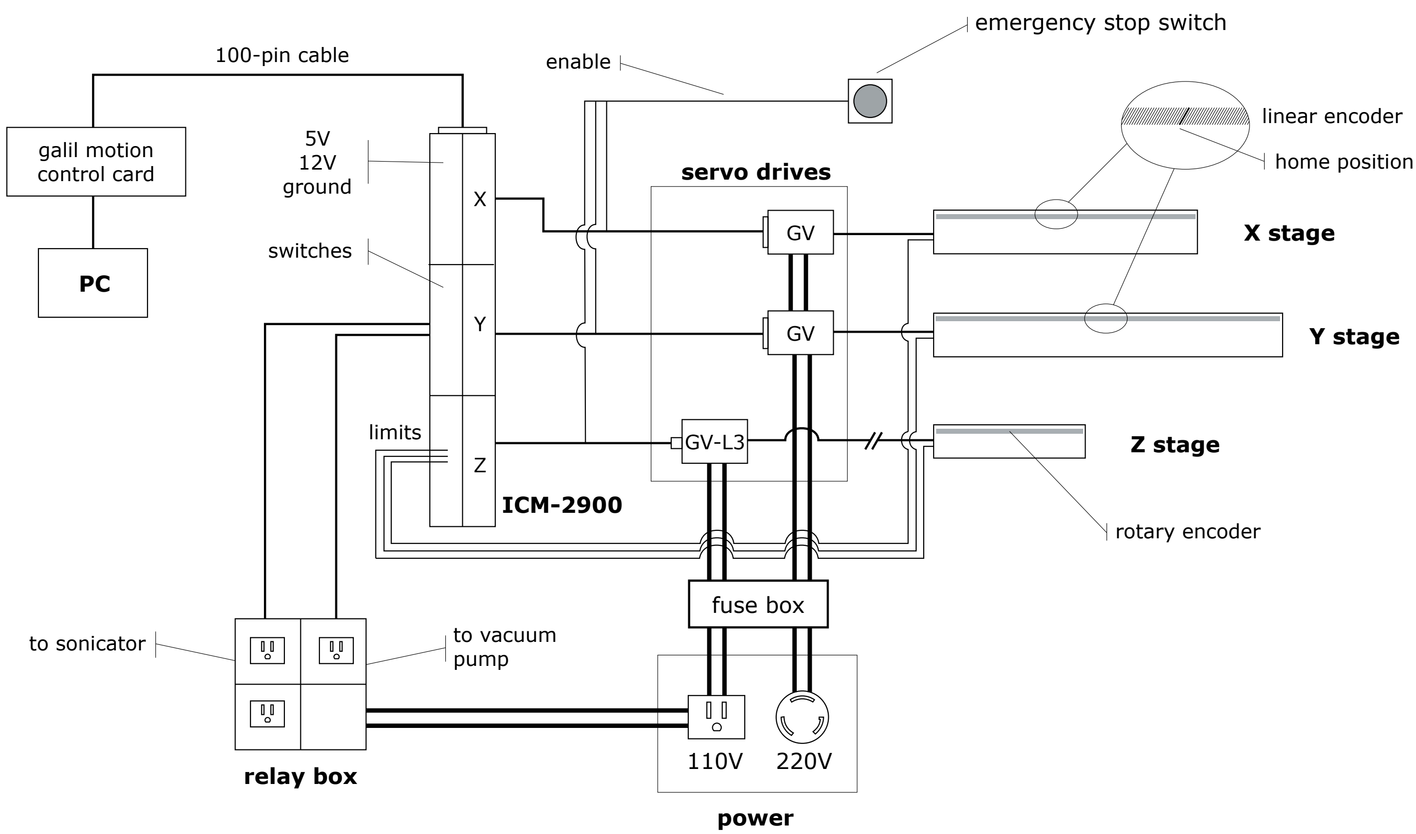
Joe DeRisi putting the finishing touches on the linear servo motor arrayer at the Stowers Institute in Kansas City, MO, 2002.

Overview & Schematic

This is not a standard electrical schematic, but it may prove useful to you in understanding the layout and function of the arrayer.

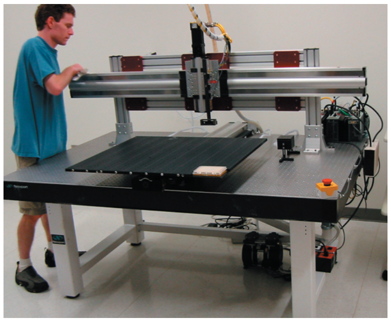
The brain of the computer is a motion control card installed in an ordinary PC. This controller card sends low voltage electrical signals to a set of servo drives, which take this signal, amplify it, and send it to the motors. The motors report back about their progress, which they monitor with a simple system of distance indicators called encoders, so the controller card can decide what signal to send next. The controller card also controls the peripheral devices on the arrayer, using solid-state relays that you will build into a box. Of course, all of this motion requires power, for which you will construct a fuse box. Finally, you will give yourself the capability to stop the arrayer in its tracks with an emergency stop switch that will disable the servo drives.

If, during the construction of the arrayer, you become confused about what a particular piece of the arrayer does, see if you can find it in this diagram.



Advice

back

left  right

front

Orientation and Direction

Throughout this guide, spatial directions should conform to a standard reference. Right, left, back, and front refer to the directions you see as you stand in front of the arrayer. The front is the side with the open face of the table support and is the side of the table to which the platter will be at rest. Up and down should be pretty clear.

Metric vs U.S. Customary Units

Almost every bolt and fitting on this arrayer is a metric one, with the exceptions of the threaded aspects of the dry station, vacuum pump, and the plugs on the platter. Therefore, you will need metric hex wrenches and ball drivers in sizes from 1.5 mm to 5 mm. You will need a 3/16" hex wrench for the U.S.-style bolts. With that in mind, all the distances and measurements in this guide are given in metric units. The exception is the measurements for the dustcover, for which both are given so that the plexiglass shop in your area doesn't have to use their calculator.

Making Changes

In writing this guide, we have included many refinements that have been added over the evolution of this design. If you see something that you think could be substantially improved, do not hesitate to let us know, or even better, try it yourself and share your improvements with us and with others.

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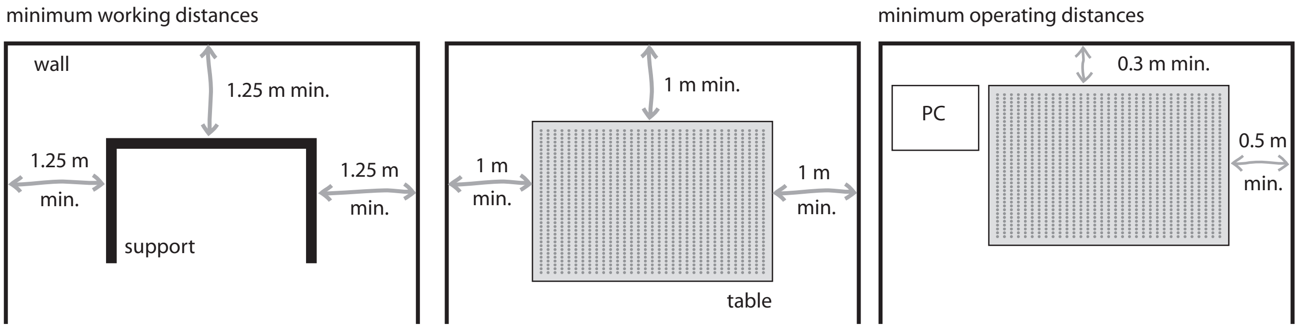
Disclaimer

The instructions in this guide are intended to assist you, a knowledgable and careful person, in the assembly of a microarrayer. Because you are working with electricity and heavy objects moving fast, there is a very real potential for bodily injury if you are inattentive or careless. Care has been taken to point out aspects of the asssembly that carry the highest risk, but this alone will not protect you if you do not show the instrument you are constructing the proper respect. A rigorous self-assessment of mechanical and electrical acumen should be undertaken before proceeding. Please be careful.

Preparing a Room

You will need a room at least 3 m x 3 m to assemble this robot. Preferably, you will have a meter on each side of the table, which is 1.3 m x 2 m.



The room should be as dust-free as is reasonably achievable. No HEPA filtering or other similarly aggressive dust removal measures are expressly required.

The room should be around 22°C and at about 50-60% RH. Humidity levels below 20% (or below 40% with certain tips) or above 85% can be problematic for a print. If you expect levels such as this at a reasonable frequency, you can take measures to control the heat and humidity in the room.

The power receptacles in this design require one L6-20 R and at least one 110 V 15 A circuit with standard North American receptacles.

Your arrayer will be much easier to use if you have house vacuum in the room (-63 cm Hg). Otherwise, you will need to run a small pump whenever the arrayer is in operation.

The cabling for the arrayer is most easily managed by suspending it from the ceiling. Make sure that it is permissible to modify the ceiling of your room.

Other items that you should have in the proximity of your arrayer include a refrigerator for storing plates, a centrifuge for spinning plates, and a sink for discarding wash solution.

You will not need an ethernet connection for the computer, as such additional demands on the computer will only produce problems.

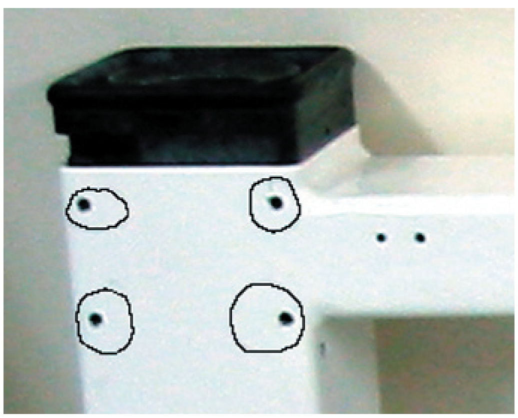
Table Assembly


Assembled table, 1.3 m x 2 m (4 ft x 6 ft)

An arrayer that sits on the floor is a pain to use. The very first step of assembling the arrayer is build the table to put it on. The table top is a 1.3 m x 2 m (4 ft. x 6 ft.) breadboard with M6 bolt holes drilled in it every 2.5 cm. It rests on top of a support structure with four feet. Three pieces, two uprights and an N-shaped crosspiece, are assembled to make a C-shaped support with an open front.

The table is HEAVY. To lift or move the table-top, you should have 6 strong individuals who all speak the same language. Trying to move the table-top with fewer people or poor communication is a BAD IDEA. The table-top is secured to the support structure by its weight ONLY; *in any attempt to move the table by sliding it across the floor, the force should be applied to the legs, not the table top*.

To begin, remove the top from the crate containing the table (use a crowbar, watch out for rusty nails) and open the cardboard box containing the legs. The box with the legs should also contain bolts and washers for the legs, as well as two flat wrenches that you will use to make the table level.


Top of table support upright, with bolt holes marked for assembly

The support uprights are painted after the holes are tapped, so it is very helpful to drive a bolt into the holes you intend to use to remove the residual paint from the threads. This will be much easier to do now than when you have the crosspiece in place. Mark the holes you intend to use on each of the supports, so that when the crosspiece is attached, the support will be C-shaped when viewed from above. Use a ratcheting socket wrench to drive the bolts, then remove them.


Attaching crosspiece to first upright

Attach the crosspiece to the first support by placing the support on the ground, bolt holes facing up. Align the crosspiece with the bolt holes on top of the support. The crosspiece is symmetrical, so the orientation does not matter. Attach the crosspiece to the support using the supplied bolts and washers. Again, a socket wrench is the best tool for the job, but a crescent wrench or a flat-head screwdriver will also work.


Driving the first set of bolts with a wrench

After the crosspiece is attached, stand the support up so that the adjustable feet are on the floor. Place the second upright at the other end of the crosspiece.

Prop up the crosspiece so that the holes are level with the bolt holes in the second upright. You can also just hold it in place while a partner places the bolts. This is where having the threads cleared of paint is most helpful, as driving the bolts can be more difficult. After the crosspiece is completely attached to the uprights (8 bolts per upright), you are ready to place the table on the support.

Driving the second set of bolts with a screw driver (a socket wrench is also a good choice)

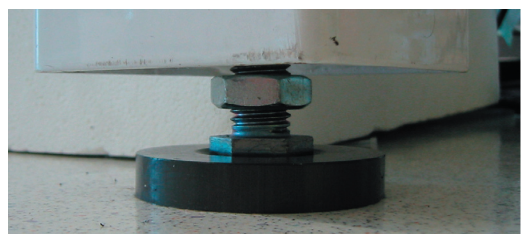
Assemble the support in an appropriate location in the lab: at least 1.25 m from the wall on each side of the table. This will translate into about 1 m of space on each side when the table top is in place. This is the minimum space you will require to facilitate work on the arrayer, so if you have more space, use it. When you are finished with the construction, you can push the table into position closer to the walls that will be satisfactory for print runs.

Again, the table is HEAVY. Lift with your legs, not your back. Have at least one person per corner and one more on each of the long edges. Be careful of nails in the wood crate when removing the table top and when stepping over the empty crate.

Set the table top on the support and center it. Use a bubble level to determine what adjustments you will have to make to the feet to level the table. The bubble level that comes with the table is a little weak; a serious level is more effective. That said, the table does not have to be perfectly level to accommodate a high-quality arrayer, but it will facilitate the assembly of other components on the arrayer. At the very least, all four feet should be squarely on the floor so that the table does not rock.

Check that the table is centered over the support structure!

Adjust the feet using the provided wrenches. The feet are mounted on a screw that drives into the support. A nut is placed on the screw, so there are two ways to move the foot relative to the support. To extend the feet, you tighten the nut by turning it clockwise; to retract the feet, the foot itself must be tightened while the nut is loosened. Using two wrenches, one to hold the foot and one to hold the nut, will help make the adjustments easy. When you are finished, the table should be mostly level and should certainly not wobble.



Foot of the support structure, showing both the adjustable foot and the nut

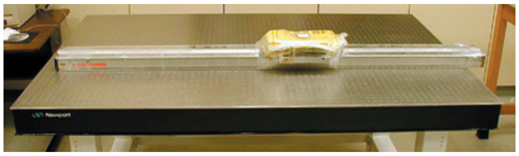
If you move the arrayer by sliding the table, then you should recheck the levelness and wobble of the table. Sliding the support across the floor can also introduce tension into the support structure; since the support has an open side, this can potentially introduce a wobble. This tension can be relieved by lifting the table off the support briefly, adjusting the support, and setting the table back down. You may need to adjust the feet again, depending on the levelness of the floor of the lab.

You now have an excellent work surface for the next steps of the assembly.

Y-Stage & Adapter Plates

The Y-stage is the longest of the motor axes and is the motor that is mounted onto the gantry above the surface of the table. The assembly of this gantry and mounting of the Y-stage take up a lot of workspace, which the assembled table handily provides.

Additional details and specifications for working with the motor can be found in the guides provided with the motor, or online at: http://www.daedalpositioning.com/Support/Product_Manuals/406LXR.pdf

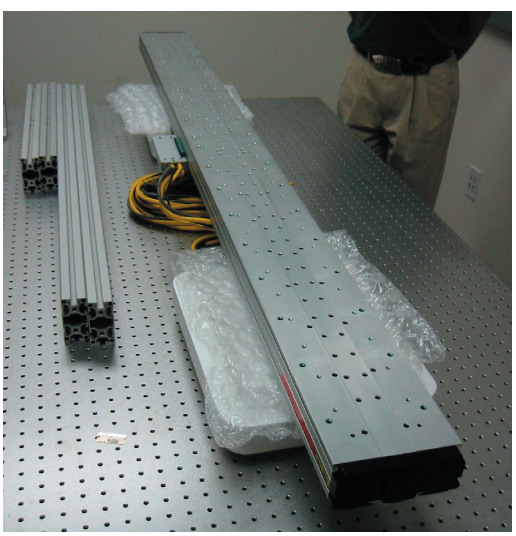


Y-stage motor, still in its shrink wrap packaging, resting on the assembled table

Unpack the Y-stage from its crate. The Y-stage is heavy and fragile; to lift it is a two-person job. You want to support it from the flat underside, taking care not to put pressure on the top of the motor. The top is comprised of two thin metal strips and a domed metal cover that is only a few millimeters thick. It is not a surface that will withstand a lot of finger pressure.

Set the Y-stage on the table, flat side down. Remove the shrink wrap packaging; the easiest method is to make a cut in the wrap with a razor blade along the side of the long axis opposite the cable travel module, where the bundle of yellow and black cables exit the motor. Take care to avoid damaging the cable travel module or the cables coming out of it.

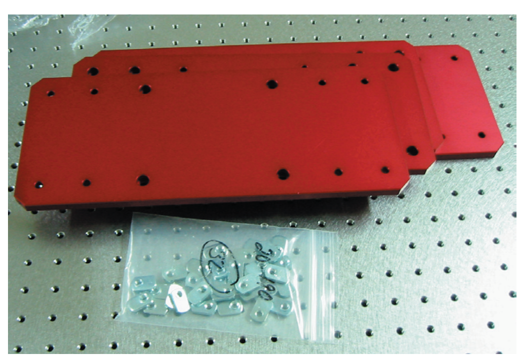
Test the travel of the motor by sliding it gently from one end of the travel length to the other. *Make sure that it moves smoothly and is free from obstructions*. If an obstruction is detected, you will need to remove the cover; read the instructions below for the X-stage mounting for accessing the inside of the motor or see the instructions in the pdf link above.



Y-stage motor, inverted and resting on styrofoam blocks

Remove three of the Styrofoam cushions from the packing crate and set them on the table, spaced along the length of the motor. Invert the motor so that the domed side rests on the cushions.

Unpack the red adapter plates for connecting the ParFrame to the Y-stage. Each adapter plate has drilled holes: 4 on one end, 4 in the center, and 4 on the other end. The group of 4 in the center will be used to mount the adapter plate to the Y-stage. These holes are countersunk so that the head of the bolt will be below the surface of the plate; make sure the countersunk side is facing away from the Y-stage.



Adapter plates for ParFrame, with butterfly nuts in the plastic bag

Place two adapter plates side-by-side so that they are in the center of the travel length. Bolt the other two adapter plates at either end of the length, leaving 3 tapped holes to the outside of each plate; that is, mount the plate using the 4th and 5th holes from the end. You can double-check your spacing by holding a ParFrame crosspiece up to the Y-stage; the plates should be no further apart than the crosspiece is long.

Mount the plates onto the Y-stage with M6x16 bolts. Make sure the bolts are good and tight. As with all mounting systems like this, tighten the bolts gradually and use a criss-cross pattern for the tightening, just like changing a tire on your car.

Mounting adapter plates onto the Y-stage motor, remember to tighten bolts gradually and in a criss-cross pattern

The adapter plates come with a set of 32 butterfly nuts. These are attached to the adapter plates using the remaining holes. The nuts have one side that is flat and one side that sticks up a little around the hole. Place the nut on the adapter plate with the flat side down. Reach under the plate and thread an M6x12 bolt into the nut. Do not insert the bolt very far into the nut; just insert it enough so that the end of the bolt is not protruding above the nut. The nut needs to be loose to slide properly into the ParFrame.

Mounted adapter plate with butterfly nuts attached and oriented correctly

Once all of the butterfly nuts are loosely attached to the adapter plates, turn them all the same direction so that the long ends of the nuts are pointing towards the end of the motor that is closest to where the cables come out of the cable travel module. Eventually, this will be the right side of the arrayer. The ParFrame will slide on to these nuts; if the long end of a butterfly nut is facing the direction the ParFrame is coming from, it will almost certainly turn and get wedged inside the ParFrame. This is a royal pain, as you will have to remove the bolt to remove the ParFrame. Try to avoid it.

ParFrame Assembly

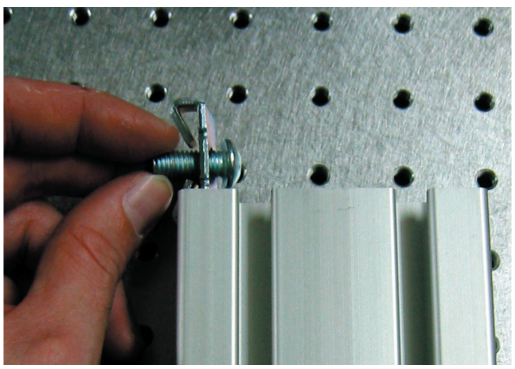
The ParFrame will comprise the gantry that holds the Y-stage above the table. The ParFrame has two uprights and two crosspieces. Each upright has four feet, two wide and two narrow. The ParFrame must be partially assembled so that it can be attached to the Y-stage using the adapter plates.

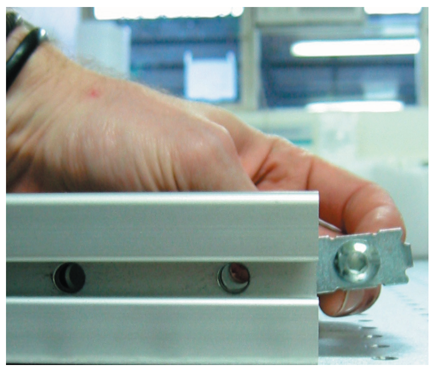

ParFrame laid out on the table in the required "squat backwards F shape"

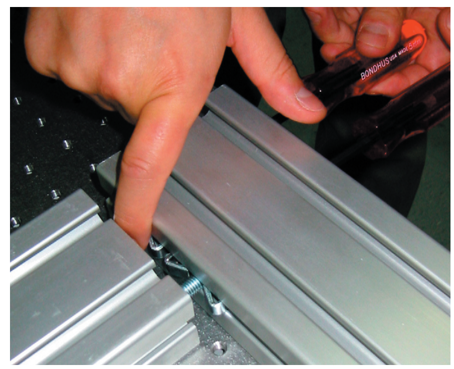
Select the two crosspieces and one of the uprights. The uprights are identical to one another. The assembly you will make as a first step will look like a squat backwards "F". Set the two crosspieces on the table so that they line up with the bolt holes drilled through the upright.

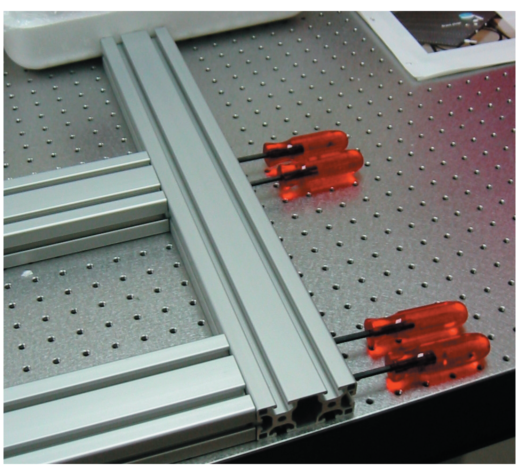
To attach the crosspieces, insert the provided mounting bolts into the "washers" and slide this assembly into the channel in the ParFrame upright that faces the crosspieces. You will need four bolts for each upright.


ParFrame bolt and "washer"


Insertion of bolt into ParFrame upright, top view


Insertion of bolt into ParFrame upright, side view, showing holes

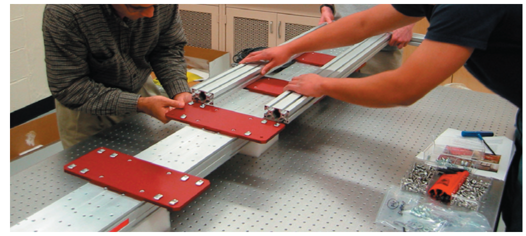

Engaging ball driver in bolt and the bolt threads in ParFrame crosspiece


Four ball drivers inserted into the four bolts securing the ParFrame crosspieces

A helpful trick that will keep the bolts aligned with the holes during assembly: leave the bolt drivers in the holes while you work. You will need to have four bolt drivers for this trick, but it keeps the bolts from sliding around in the ParFrame.

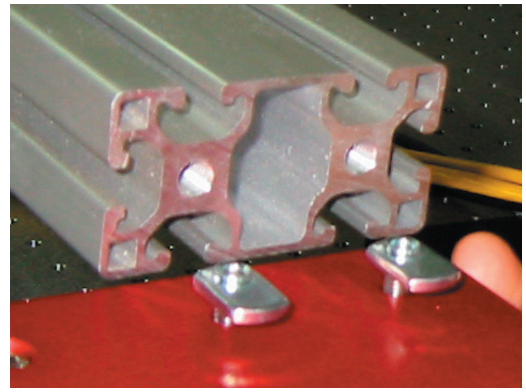
Once you have the four bolts aligned, loosely attach them to the ParFrame crosspieces. The ends of the crosspieces are threaded to accept the bolts. Do not over tighten the bolts; you will need a little play in the assembly to slide it onto the Y-stage adapter plates.

Mounting Y-Stage onto ParFrame



Mounting the ParFrame is a team effort.

If you followed the instructions in the preceding sections, the butterfly nuts should all be oriented so that the ParFrame can slide onto them. Before sliding the ParFrame on to the butterfly nuts, make sure that you have the correct upright attached. The leg portion of the upright should extend to the side OPPOSITE the cable travel module on the Y-stage. This will seem obvious once the Y-stage setup is complete, but you want the Y-stage cables coming out of the top of the motor and the feet underneath the motor.

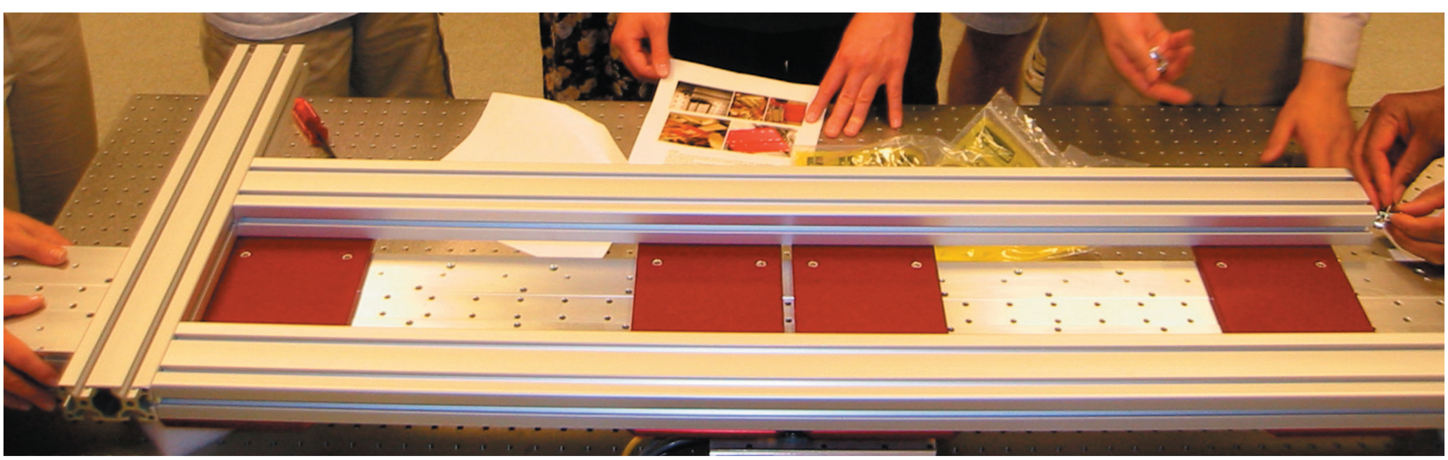


Lifting the butterfly nuts to slide the ParFrame crosspieces onto the adapter plates

This next part is a good time to have several people. The loosely assembled, open-ended ParFrame should be lifted off the table with its crosspieces well supported. The open end of the ParFrame is then placed on the adapter plate closest to the end of the Y-stage. Two people can then push the bolts holding the butterfly nuts up from underneath so that the nut rises to the level of the opening in the ParFrame crosspiece. *If the butterfly nut is too tight on the bolt, you will not be able to lift it high enough to slide the nut into the crosspiece*.

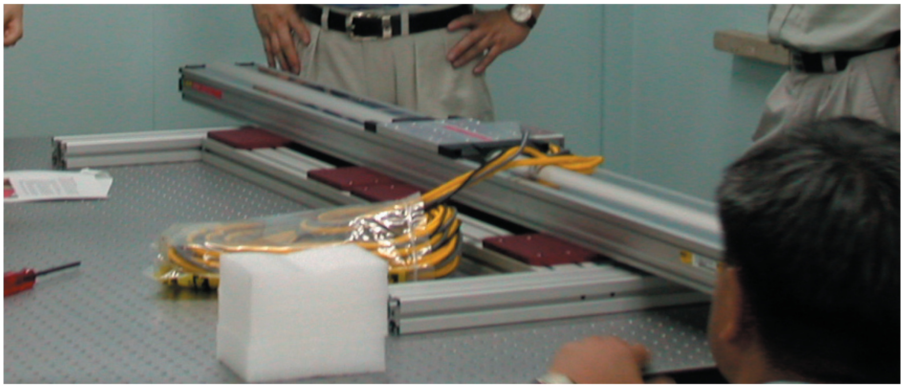
The ParFrame is slowly pushed from row to row of butterfly bolts, with two people guiding the open end and raising the nuts, while two others support the closed end of the ParFrame. This process is a definite test of *communication and teamwork*. Try to avoid backing up by communicating effectively; the more you back up, the more likely it is that one of the butterfly bolts will turn the wrong way and sieze. If this happens, you may have to remove the bolts from all of the butterfly nuts and start over.

Once all the butterfly nuts are inside the ParFrame crosspieces, center the ParFrame relative to the adapter plates. Using the same procedure as before, attach the other upright to the open end of the ParFrame. Again, be certain that the long ends of the uprights are pointing in the same direction. Otherwise it will be difficult to mount on a table designed by anyone other than M.C. Escher.

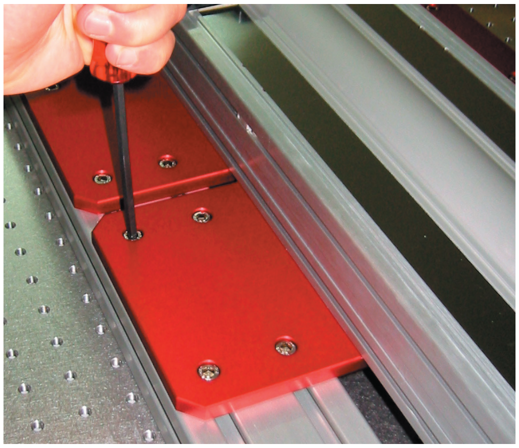


ParFrame fully inserted onto adapter plates and butterfly nuts

With both uprights attached to the ParFrame, go back and tighten each of the bolts so that the uprights are solidly attached. Again, do this gradually; don't tighten one of the four bolts all the way and then start on the others. Also, do not over-tighten these bolts.


ParFrame and Y-stage after lifting off the foam blocks and turning the assembly over to rest flat on the table

Now that the ParFrame is completed, gather a few people to flip the whole assembly over so that the ParFrame is resting on the table. Both the motor and the ParFrame should be supported during this maneuver, as they are not yet firmly attached to one another. This is a job for at least three people. One of those people should tend to the cables coming out of the Y-stage motor during turning, making sure they are not crushed, stressed, or yanked.

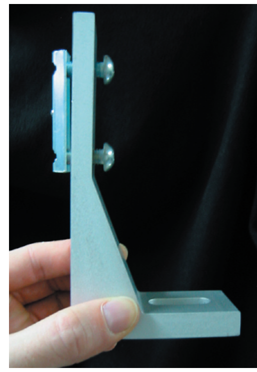

Tightening the butterfly nut bolts on the adapter plates

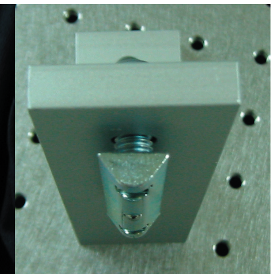
The Y-stage can then be centered (although it should be pretty close already) on the ParFrame and then the bolts to the butterfly nuts tightened. Make sure that you are tightening a bolt, not loosening it; if the bolt is over-loosened, the butterfly nut can drop into the body of the ParFrame. These are difficult to retrieve, without flipping the assembly back over and removing the ParFrame. Again, tighten the bolts gradually and in an alternating pattern, ensuring that they are completely tight.

Mounting ParFrame onto Table

Now the ParFrame is ready for some feet. The feet come packaged with the ParFrame, along with bolts and connectors. There are two wide feet and two narrow feet for each leg. The feet are attached with a method similar to that used in attaching the adapter plates. Connectors are loosely attached to the feet, and the feet then slide onto the ParFrame.

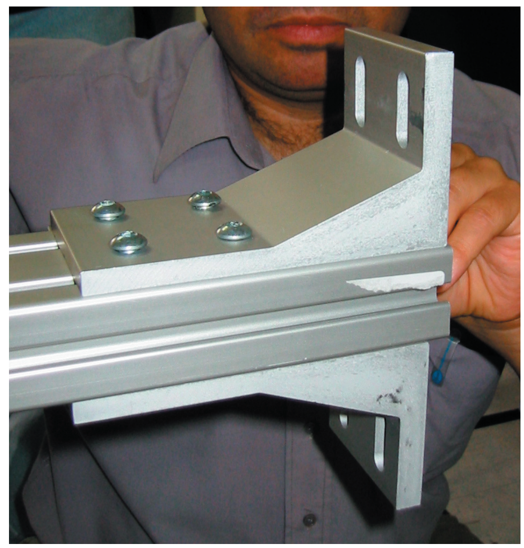
First, loosely attach the connectors to the feet. The feet are L-shaped; the slotted side sits on the table and the drilled side faces the ParFrame. The flat side of the connector should face the back side of the foot (that is, the left side of an L). Use the provided bolts to loosely attach the connector to the back-side of the feet.





ParFrame feet, with bolts and connector, top view (above) and side view (right).

Slide the ParFrame-Y-stage assembly to the edge of the table so that the legs overhang the edge by about 20 cm. Having the leg sticking off the end of the table will allow you to put on the back-most feet as well. Slide the feet on to the legs. Position the bottom of the feet about 1 cm above the bottom of the leg and gently tighten the bolts. Just tighten the bolts enough to keep the foot from sliding; this is just to hold it in place when the ParFrame is moved into a vertical position.



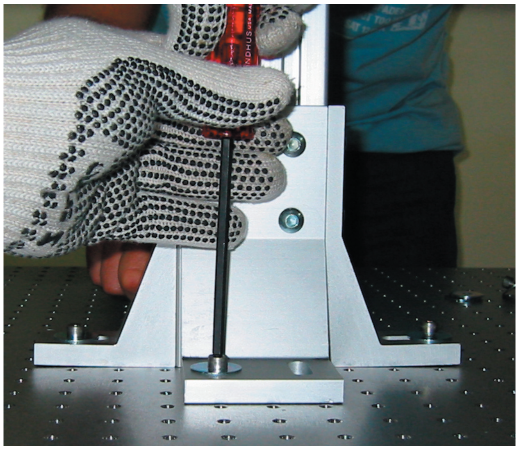
ParFrame upright extending off table edge, two of four feet attached slightly above the bottom

Once again, you need at least 3 people for this next step, as well as fender washers and M6x25 bolts. With one person at each end of the Y-stage motor, lift the assembly up and rotate it 90°, so that the legs are on the table and the Y-stage cables are on top. The assembly is VERY TOP-HEAVY, so use a lot of care in supporting it so that it will not tip forward.

Now that the assembly is resting on its legs, loosen the bolts that hold the feet on to the Par Frame just enough so that the foot will slide. The feet should drop down until they are flush against the table. Do not over-loosen the bolts or they will detach from the connector, and the foot will need to be removed completely.

You will be able to feel a balance point when the ParFrame assembly is resting flat on the bottom of the legs. When you achieve this balance, tighten all the bolts that attach the feet to the legs; as always, use an alternating pattern and tighten the bolts gradually. Finally, make sure that all of these bolts are very tight. The assembly is still very top-heavy and NOT attached to the table, so be alert so that it will not tip over as you position it on the table.

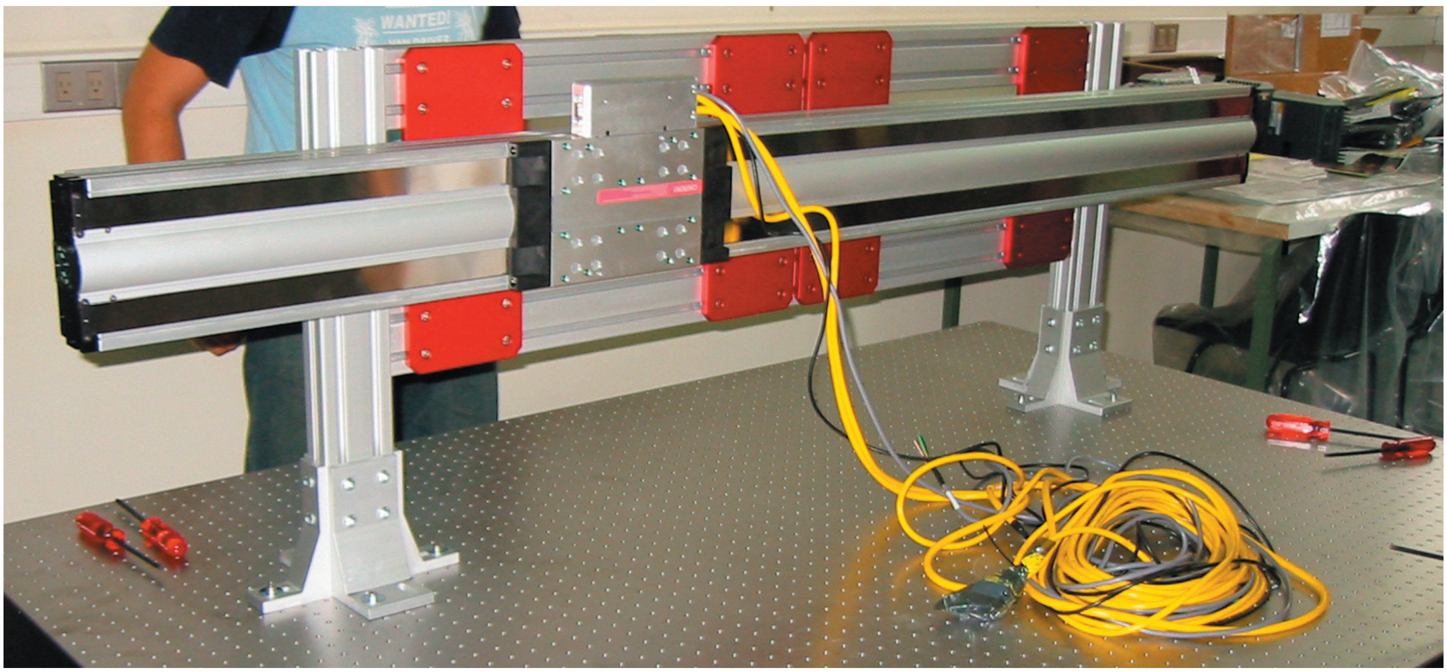
The carriage side of the motor should face the front of the table, so you may need to turn it around. To place the Y-stage gantry correctly on the table, you will identify a reference hole into which you will bolt the right-most foot of the right ParFrame leg. Start counting from zero at the back-most, right-most corner and count 17 holes towards the front and 8 holes in from the right edge. Mark this hole with a pen. Remember that “right” refers to the



attaching the feet of the ParFrame, using four bolts per leg and fender washers

right side of the table as you look at it from the front; make sure that the person counting your holes is starting from the correct corner.

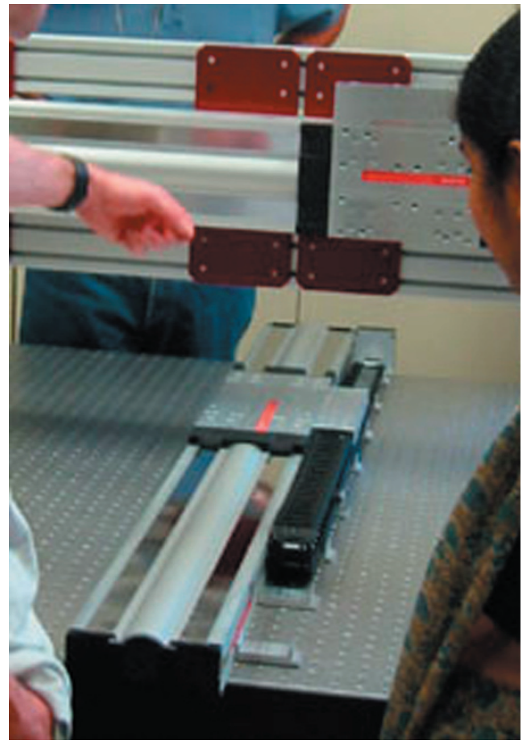
Once the hole is identified and marked, move the gantry into position so that the hole is visible through the foot. Align the gantry so that it is parallel to the edge of the table so that the other feet allow access to the same rows of holes. Now, you will need to make a few adjustments to the position of the gantry so that you can put one bolt into each of the wider feet as well. Even though the wider feet have two slots, they will not line up with the holes to allow two bolts to attach to the table. These feet will perform just fine with one bolt per foot. Attach the feet using M6x25 bolts and fender washers. Before tightening all the bolts, push the gantry firmly towards the front or the back of the table, so that the feet sit flush against the bolts in the table. This is the simplest way of making sure the Y-stage runs perpendicular to the X-stage. Make certain that the mounting bolts for the feet are all well tightened.



The assembled ParFrame and Y-stage, bolted to the table at the appropriate location and in the correct orientation, parallel to the table's long axis and with the cables exiting the Y-stage on the top side of the axis.

X-Stage Mounting

The mounting of the X-stage motor is much easier than assembling and mounting the Y-stage gantry. The X-stage can simply be bolted directly to the table. The main considerations are making sure that it is centered and facing the proper direction.



X-stage motor in the approximately correct position for mounting, centered under the Y-stage and overhanging the front and back of the table equally, with the connection ports facing the back of the table.

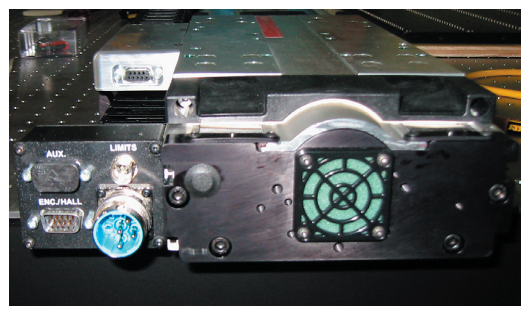
Additional details and specifications for working with the motor can be found in the guides provided with the motor, or online at: http://www.daedalpositioning.com/Support/Product_Manuals/406LXR.pdf

Unpack the X-stage from its crate. The motor is heavy and fragile; to lift it is a two-person job. You want to support it from the flat side underneath, taking care not to put pressure on the top of the motor. The top is comprised of two thin metal strips and a domed metal cover that is only a few millimeters thick. It is not a surface that will withstand a lot of finger pressure.

Set the motor on the table, flat side down, carriage side up. Remove the shrink-wrap packaging; the easiest method is to make a cut in the wrap with a razor blade along the side of the long axis opposite the plastic cable travel module. Take care to avoid damaging the cable travel module or the cables coming out of it.

Test the travel of the motor by sliding it gently from one end of the travel length to another. Make sure that it moves smoothly and is free from obstructions. If an obstruction is detected, proceed with removing the cover and inspect the inside of the motor visually, as described below.

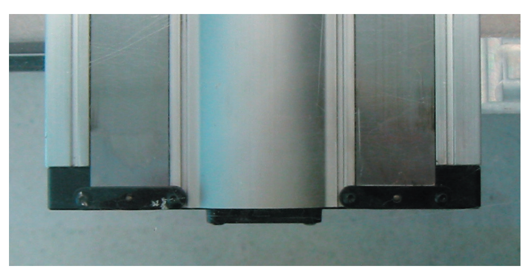
At one end of the motor, there are several outlet ports for connecting cables. This end of the X-stage should face the back of the table. The black articulated cable travel module should be on the right side of the X-stage.



X-stage (-) end, with connections for wiring, which faces the back of the table

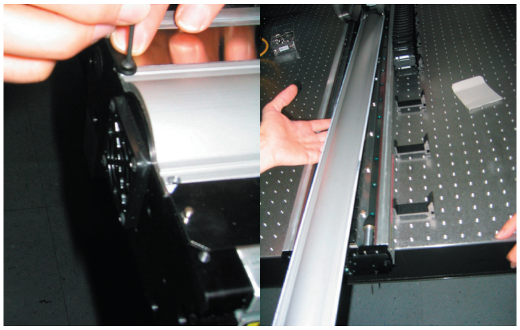
To mount the X-stage, you will need to remove its cover. The inside of the motor contains *very strong rare-earth magnets*. Any watches and jewelry should be removed before working with the motor with its cover off. Please read and heed all warning that comes in the documentation accompanying the motor.

Also, exposing the inside of the arrayer exposes the *encoder strip*, the gold foil attached to the inside of one side of the housing. This is what the motor uses to determine where it is and how fast it is moving. Be very careful not to get grease or dirt onto the encoder, as this can produce *dangerous behavior in the arrayer*. If there is grease or dirt on the encoder, it can be removed with a kimwipe moistened with ethanol.



Front-most end of the X-stage, showing the domed cover (center), foil strips (either side), and the clamps that secure the strips. The observant reader will note that the left-most bolt has a slot ground into it, necessitated by its being stripped by an abusive user.

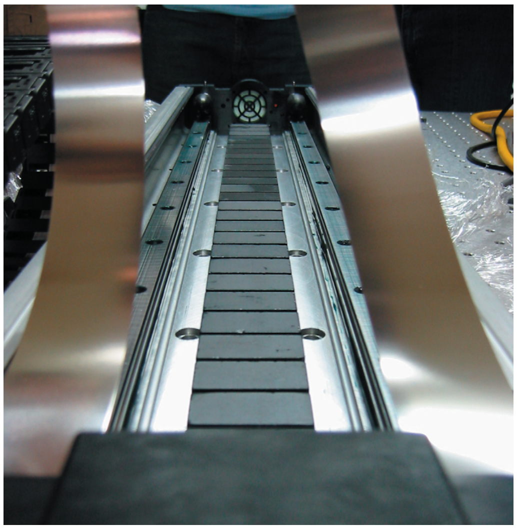
Remove the protective covers from the top of the motor by unscrewing the small black bolts at each end of the motor. Use a 2 mm hex wrench and EXTREME CARE in loosening these small bolts. If you strip one, you may find yourself in a wee bit of trouble and improving your Dremel skills.



Removing the domed cover. Left, removing the small bolts that secure the clamp. Right, removing the cover itself.

Remove all four bolts, along with the two rounded rectangular clamps that they secure, from each end of the motor. The bolts are small enough to fall into the holes in the table, so be sure to place them carefully in a tip box lid or a drawer from your organizer. If you do drop a bolt into the table, you can magnetize a hex wrench on the magnets in the motor and try to extract the bolt with that.

Once the bolts and clamps are off, the domed top cover can be slid off the motor. Do this slowly, applying gentle downward pressure on the end that is being pulled; this pressure will keep the far end from dropping onto the magnets or the bearings inside the motor. When the far end emerges from the carriage, cease the downward pressure and pull the cover straight out.

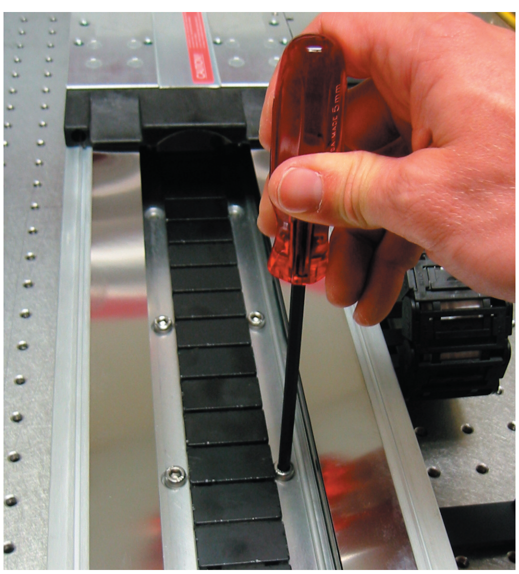


Inside the X-stage. The magnets are the series of black rectangles in the center. The mounting holes are immediately to either side of the magnets. The square rail bearings, which should be relubricated yearly, are immeidately adjacent to the mounting holes. The foil strips are the blurry reflective pieces in the foreground.

Without the domed cover, the magnets that drive the motor should be visible. Again, these are very strong and should be regarded with the sense of awe, fascination, and caution befitting physical manifestations of powerful fundamental forces.

You will be able to see the mounting holes that are drilled into the bottom surface of the motor. These are spaced at the same interval as the holes in the table, so you should be able to line them up. Position the X-stage motor so that it is perpendicular to the Y-stage and centered under the gantry, with an equal amount of travel length extending beyond each edge of the table. An easy method for centering is to count the number of holes between the nearest foot and the motor on each side. Remember that the cable transport module (the black plastic cable bundle on the right side of the motor) is covering several of the holes.

In order to access the holes easily, you will want to pull back the foil strips and have a colleague hold them out of your way while you tighten the bolts. Lift the strips over the pins at the end that secure them in place, using a screwdriver or a razor blade to get underneath them. The edges of these strips are SHARP and the strips themselves are ferromagnetic, meaning the magnets can yank them out of your grasp if you don't handle them carefully. Be VERY careful when handling them. You also want to avoid bending or creasing them, as this will create noise and friction as the carriage passes over the bent or creased section during arraying.



Mounting the X-stage to the table. The magnets will try to pull the ball driver off target.

If you have no colleague willing to hold the foil while you drive the bolts, the foil strips can be completely removed. Remove the black plastic end caps from the sides of the carriage using a 3 mm hex wrench. Lift both ends of the foil off of the pins that hold their ends in place. Pull the foil completely out from the carriage, taking care not to let the magnets grab the trailing end of the foil. Be very careful not to crease the foil or cut yourself.

After the motor is centered on the table, aligned with the holes, and the foil strips are out of your way, bolt the motor to the table. Use M6x20 bolts, placing 3 on each side of the magnets, for a total of 6 at each end of the travel length. The magnets will try to grab your tool away from the bolt. Try using two hands or a small piece of cardboard inserted in between the bolt and the magnets.

Don't tighten the bolts at one end until you're sure that the bolts will go into the holes at the other end. There's a little play in the mounting holes, so you'll want to check that the motor is straight before tightening everything down. The easiest way to see this is to look at how much the holes in the table are exposed at the outside edge of the motor at each end of the travel length. Once it's all straight, tighten the bolts down. Do not overtighten.

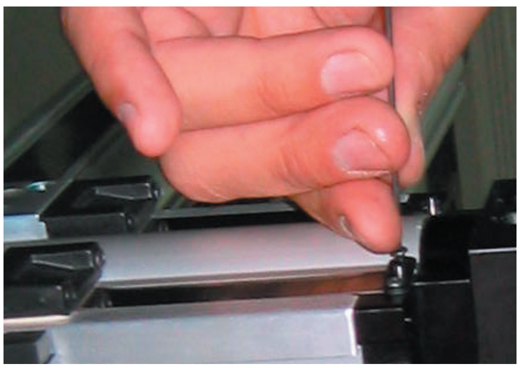
Replace the foil strips over the pegs (and through the carriage, if you removed them). Then slide the domed cover back into place. It is very helpful to have two people for this job, so that one can lift the far end into place as you push. Replace the clamps and bolt them into place, being VERY careful not to strip the bolts. These bolts do not need to be ferociously tight and are easily stripped, so take care in tightening them.

Z-Stage Mounting

The Z-stage motor is a little different from the other motors in that it's a screw-driven servomotor and not a linear servomotor. You will need to open it up to mount it similar to the X-stage motor, but the insides look a lot different. This is definitely a two person job, as the Z-stage must be supported in place on the Y-stage carriage while it is bolted on.

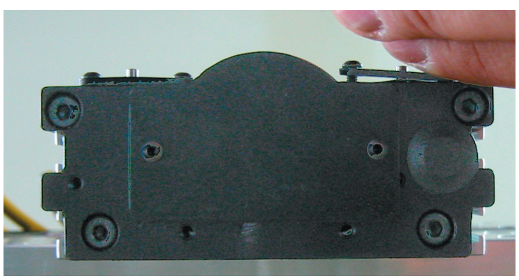
Remove the Z-stage from its box and set it on the table. The servomotor should already be attached to the travel length; this is the black portion that extends above the travel length. If it is not, follow the instructions provided for attaching the motor to the coupler. This is a challenging connection to make and really should be done by Parker before it is shipped.

The motor has two capped ports on the back for attaching cabling. These will keep the Z-stage from lying perfectly flat on the table. Placing the Z-stage so that the ports hang just over the edge of the table will make the motor easier to work on.



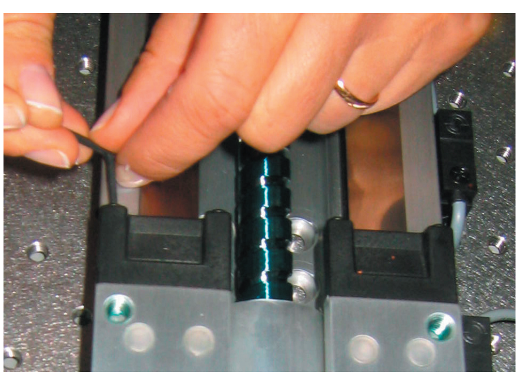
Removing the clamps, domed cover and metal strips from the Z-stage motor.

The motor will be mounted onto the Y-stage carriage in the same manner as the X-stage was mounted on to the table, using bolt holes drilled in the back of the motor housing. To expose these holes, remove the domed cover and foil strips just as we did with the X-stage.



Non-motor end of Z-stage, showing the plate that must be removed to extract the cover.

Additionally, remove the plate from the non-motor end of the travel length; the domed cover will not slide out until this is removed. Note that this is the small plate held with two small bolts, not the entire end cap, secured with four larger bolts. Because the foil strips on this axis are much shorter and not powerfully drawn towards the inside of the motor housing by magnets, it is easier to remove them completely.



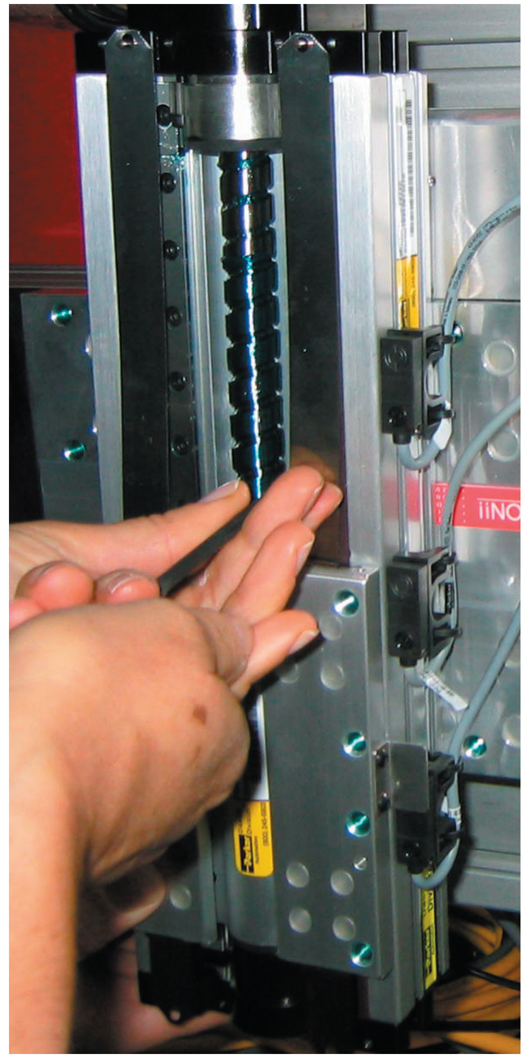
Removing the carriage end caps from the Z-stage motor.

Finally, you will also want to remove the end caps from the Z-stage carriage. These black plastic caps keep the foil strips feeding cleanly into the carriage during motion. They obscure the mounting holes just enough to warrant removal. Remove them by loosening the four 2 mm bolts inside each cap. Remove the bolts and the springs that they hold in place and set them aside. It is easiest to access the bolts with your tool when the carriage is at the end of the travel length.

When the inside of the motor is completely exposed, push the carriage to each end of the travel length. This takes some force, as there is more friction in this screw-driven motor than the linear servomotors. When the carriage is at either end of the travel length, one pair of the 4 holes used for mounting will be visible in the back of the housing.

Have a colleague hold the Z-stage motor in place in front of the Y-stage carriage. The motor of the Z-stage should extend from the top. Rotate the motor slightly around its long axis so that the holes on the back of the housing and the tapped holes in the carriage are visible and can be roughly aligned. The holes in th e motor housing you will use are the 4 closest to the center of the travel length.

Attach the first bolts. You MUST use M6x12 LOW HEAD bolts and a 4 mm hex wrench. There is a bag of these supplied with the motor and included in the items you ordered. These bolts must be driven almost entirely in to the carriage to be low enough to allow clearance for the carriage to slide over them. Non-low head bolts will never work. There is some play between the bolts and the hole, so try to roughly level the Z-stage before tightening completely. A bubble level placed on top of the motor is useful for this purpose.

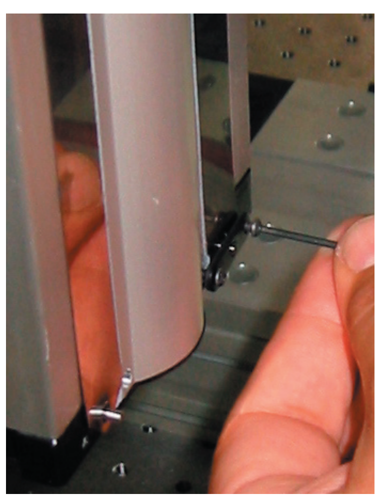


Z-stage being mounted. Make sure a colleague supports the Z-stage during mounting. Note that the carriage is pushed to the bottom of the travel length.

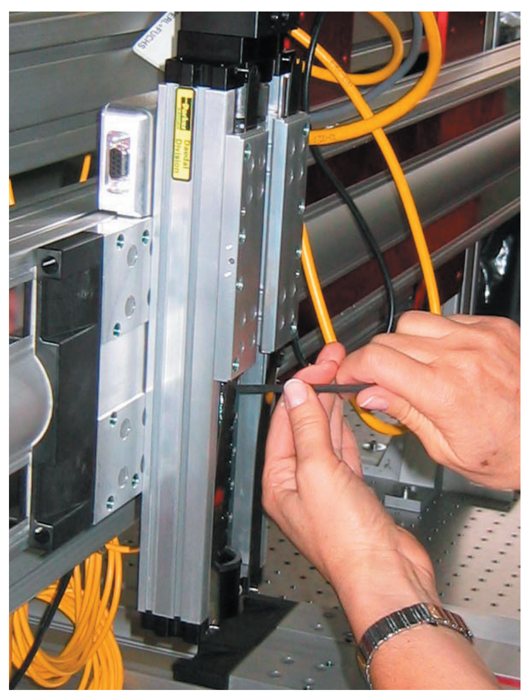
Now that the Z-stage is attached with two bolts, push the carriage to the other end of the Z-stage to expose the other pair of holes. They should line up with the holes in the carriage. Use another two M6x12 LOW HEAD bolts here. Make sure all 4 bolts are nice and tight, but take care and DO NOT STRIP any of these bolts. It will make removing a misplaced Z-stage extremely difficult or impossible.

Make sure the motor travels the length cleanly, with no rubbing whatsoever on the mounting bolts. It takes some force to push the carriage, but definitely test it.

Replace the domed cover first, sliding it back into the carriage. Hold the domed cover in place, and secure it by replacing the plate on the bottom with its two bolts. Then, replace the foil strips over their posts and reattach the plastic caps on the carriage. Finally, reattach the clamps at the ends of the travel length and bolt them on.

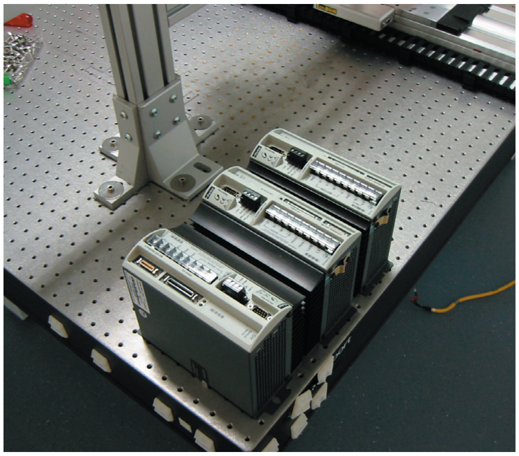


Replacing the domed cover and clamps on the Z-stage.

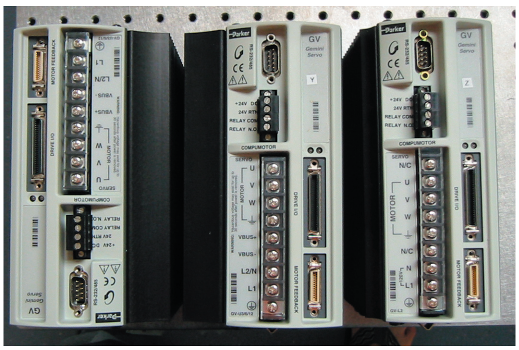


Z-stage mounting, part 2. The carriage is now at the top of the travel length.

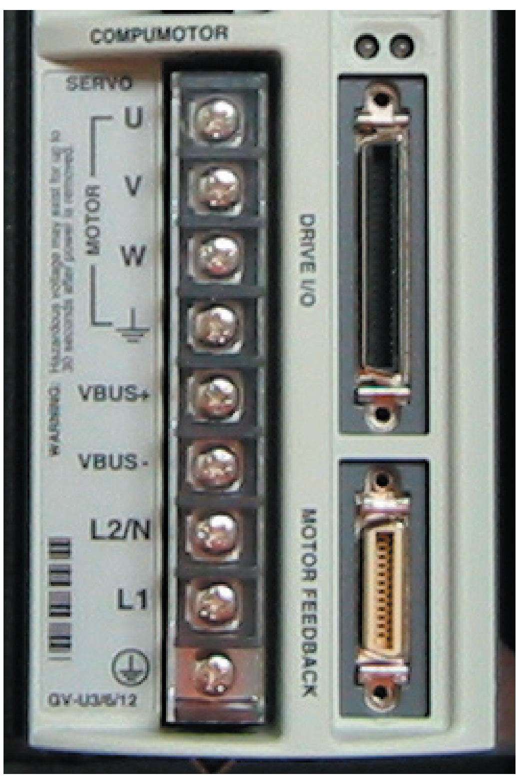
Position the Servo Drives



Servo drives placed in the correct location and orientation on the table.



Gemini Servo drives for (left-to-right): the X-, Y-, and Z-stages. The X-stage drive is turned around to facilitate power sharing with the Y-stage drive.



Close up of the connections on the top of one of the servo drives. This aspect of the drive is referred to as the bezel in the drive manuals.

The servo drives receive the signals from the controller card and send the appropriate power to the arrayer motors. They also receive feedback from the motors about the motion and return that information to the controller card. Obviously, they are a very important piece of the arrayer and are second only to the motors themselves in expense.

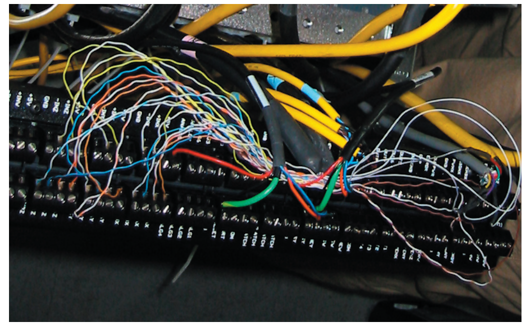
The drives for the kit should be preconfigured for the type of motor they will operate. The Z-stage drive is easiest to identify: it has smaller heat fins and is a different model number, GV-L3. The X- and Y-stage drives (GV-U3/6/12) should be distinguishable by the labels Parker puts on the side of them. If it does not specify X- or Y-stage, the information can be gleaned from the serial number. The X- and Y-stage motors, while similar in appearance, are *actually quite different* in the number of electromagnetic poles inside the motor. The X-stage drive should have “D15” on its label, and the Y-stage should have “D13”. When you have correctly identified the drives, make your life easier by marking each drive X, Y, or Z with a sharpie on the bezel where it can be clearly seen.

The servo drives are placed at the back of the table adjacent to where you will place the ICM-2900 in the next section. When placing the drives on the table, the X- and Y-stage drives should be placed with their heat fins facing one another. This will facilitate the sharing of power between these two drives. The long axis of the drives should run parallel to the ICM-2900. This will provide optimal cooling by the fan you will install later.

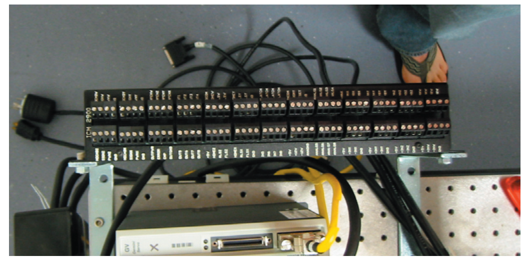
When you are finished with the wiring and confident that the location of the drives is correct, you will bolt them to the table. Hold off doing this until the wiring is finished.

Install the ICM-2900

The ICM-2900 is a "breakout box." Basically, it gives you access to all the tiny individual contacts in a specialized connector (in this case, the one on our 100-pin cable) at a scale that you can actually manipulate. The 100-pin cable will attach to the bottom of the unit, and wires will be attached to it through the many ports on the top of the unit. The ICM-2900 is specifically designed for our controller card and cable. Each position on the ICM-2900 is specific to one pin of the 100-pin cable. The positions are named on the surface of the ICM-2900 on either side of the ports with descriptive names like "IN5", "MOCMDX", and "HOMEY."


The ICM-2900. While it appears like a total rat's nest right now, it is a highly organized component of the wiring of your arrayer.

The ICM-2900 should be mounted on the back edge of the table. It is not crucial whether the ICM-2900 is mounted on the left side or the right side of the table. The optimal location will be determined largely by the layout of your room, especially the location of the power outlets and where there will be space for a PC. If you have the choice, select the back left corner, as this places all of the electronics on the other side of the table from the sonicator. There are a pair of L-shaped brackets for this purpose that allow the ICM-2900 to hang about 5 cm off the edge of the table. This enables the 100-pin cable to be connected to the bottom of the ICM-2900 and the cables that will connect to the top to be fed through the gap between the ICM-2900 and the table.


The ICM-2900, properly mounted to the side of the table, adjacent to the servo drives.

Bolt the L-shaped brackets to the table, so that they are as far apart as the ICM-2900 is long. The vertical part of the bracket should be about 5 cm beyond the edge of the table. This space is important for making the wiring neat and tidy. Hold the ICM-2900 up to one of the brackets, using an M6x16 bolt and a nut to attach the bracket to one drilled flange of the ICM-2900. Then attach the second bracket to the flange on the far end. You may have to turn the bracket a little to get it to reach properly, as the spacing of table holes to the length of the ICM-2900 is not exact.

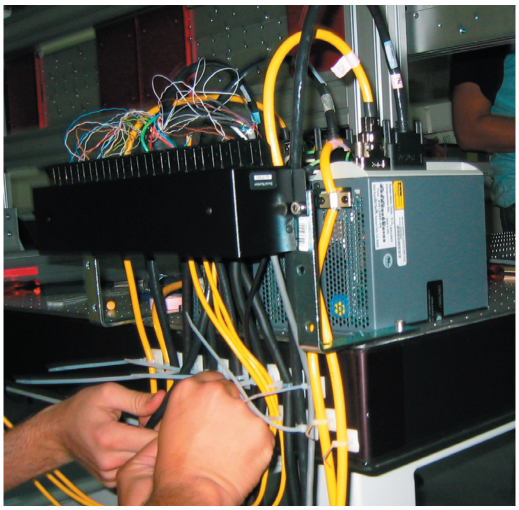

The ICM-2900, properly mounted to the side of the table, adjacent to the servo drives. In this photograph, some wiring of the drives has already been performed.

Instructions for and tips on the wiring of the ICM-2900 are included in the next section.

General Wiring Instructions

All of the cables on this arrayer carry information vital to the performance of the machine. Some carry information that if interrupted will cause dangerous behavior in the motor. Some carry dangerous amounts of electric current, too.

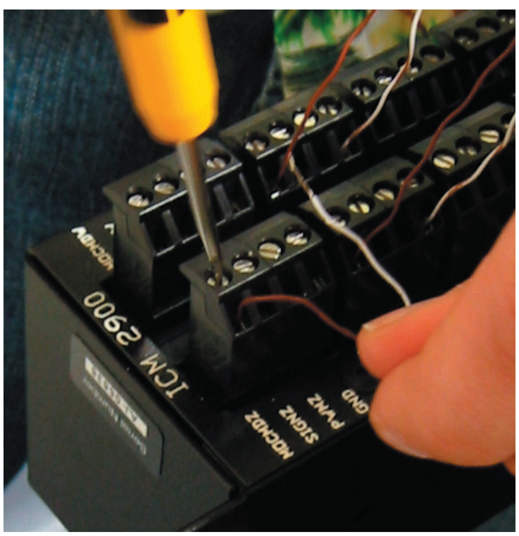
Make sure that any wire that you are working with has no power! For wires coming out of the ICM-2900, this means the computer must be off or the 100-pin cable must be unplugged. For wires coming from the servo drives, that means the power cords must be unplugged from the wall. Certainly, do NOT try to make any adjustments to any aspect of the wiring while the arrayer is running. You will not be at risk of damaging yourself or the arrayer if you are doing ALL of your wiring without power flowing to the arrayer.



The Cable Management System, using zip ties to protect the connections from strain.

To avoid degradation in the performance of the arrayer, install the wiring so that there is *minimal stress at the connectors for every wire.* For the cables that run to the ICM-2900, the best way to accomplish this is to zip-tie the cables to the back of the table so they feed up to the ports on the top of the ICM-2900 through the 5 cm gap between the ICM-2900 and the table. Cinch the zip-tie loosely at first, so the reach of the cable can be properly adjusted later.

If you don't know much about electronics, you will still be able to assemble the arrayer -- it's troubleshooting that's the hardest. One important piece of information for the uninitiated: *you can share ground connections in the wiring of the ICM-2900* -- that is, you can have more than one wire per port. These are labeled "GND" on the ICM-2900. There aren't enough of them for every wire to have its own, so they have to share. The "GND" ports are NOT interchangeable with the "ANA GND" ports.



A close up view of connecting the wires to the ICM-2900.

To make a connection to the ICM-2900, strip the wire so there are about 5 or 6 mm of wire exposed. Most of the wires are 24 gauge -- your wire strippers should be marked which hole is appropriate for that gauge. Make sure your technique is good, so that you only remove shielding and not wire. If you do damage the wire, just cut off the damaged portion and strip it again. You can practice with wire scraps or with a length of cable from the spool of 10-conductor cable.

Insert the stripped portion of wire into the appropriate port on the ICM-2900. The ports should be shipped mostly open, so the wire should insert easily. Tighten the clamp with a small flathead screwdriver. When the screw will turn no further and the clamp is closed, apply *the tug test*. A gentle tug on the wire should reveal it to be firmly held in place by the clamp. If it pulls free, you will need to loosen the clamp, reinsert the wire, and retighten the clamp. *Do not over-insert the wire so the clamp bites on the shielding. Do not under-insert the wire so that unshielded wire is visible above the port.* Having the wire properly stripped, fully inserted, and exposing just a few mm of wire are the keys to a successful and stable connection.

Don't be afraid to practice with one of the ports and a scrap of wire. Honed skills will benefit you greatly if it means you don't have to go back and troubleshoot all of your connections later.

The ports themselves can also detach from the ICM-2900 in groups of four. If you are having a difficult time making a connection, removing the port from the ICM-2900 may make it easier to complete. Be careful doing so, as the labels for the ports are on the body of the ICM-2900, not the port itself. As a final inspection of the ICM-2900 when all the wiring is complete, all of the ports should be pushed down to make sure they are securely seated in the ICM-2900.

What are all these connections? One is power, which the motor needs to move. Another is feedback: information about where the motor is, how fast it's moving, how hard it's working to get there, etc. Another are the limit switches, little induction switches that the arrayer uses to know if it has moved beyond its safe range or is in the proximity of the center of the travel length. Finally, there are the commands from the computer: low voltage signals that are converted by the servo drives into the higher power sent to the motors.

Wiring X-Stage

This is the easiest one to do, as each of the different cables has a different connector and the attached cables do not need to run through an overhead bracket.

The back end of the X-stage, showing the ports that will be connected.

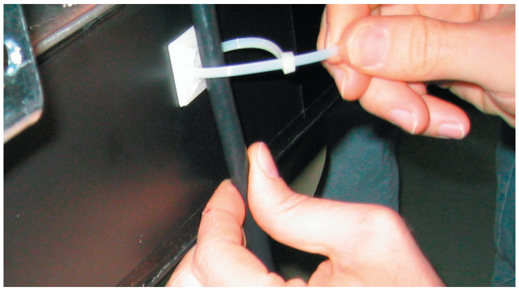
Start with the limit swiches. This is a small black cable with a round connector at one end and 6 wires at the other. The small connector attaches to the back of the X-stage where it says "LIMITS." Feed the cable through the gap between the ICM-2900 and the table and attach the six wires to the ports of the ICM-2900.

ICM-2900	Cable Color
GND	Green/Yellow
GND	Black
HOMEX	Dark Green
RLSX	Blue
FLSX	Orange
+5V	Red

Limit switch connections to the ICM-2900 for the X-stage.

You should have a sufficient length of each individual wire exposed as the cable is shipped to reach these connections, but if you don't, you can trim back the cable shielding a little to expose more of the individual wires. A razor blade is a fine tool for the job. Be very careful not to damage the shielding on the individual wires.

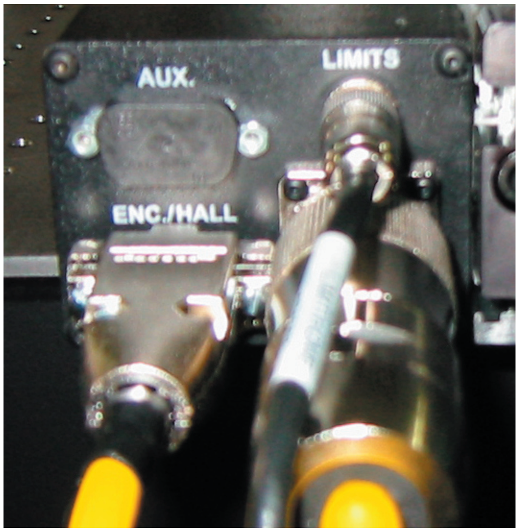
Make sure your connections pass the tug test, then secure the cable to the back of the table with a zip tie and adhesive connector from the cable tie kit.



Cable Management. Secure the cables loosely at first so they can be adjusted later, if required.

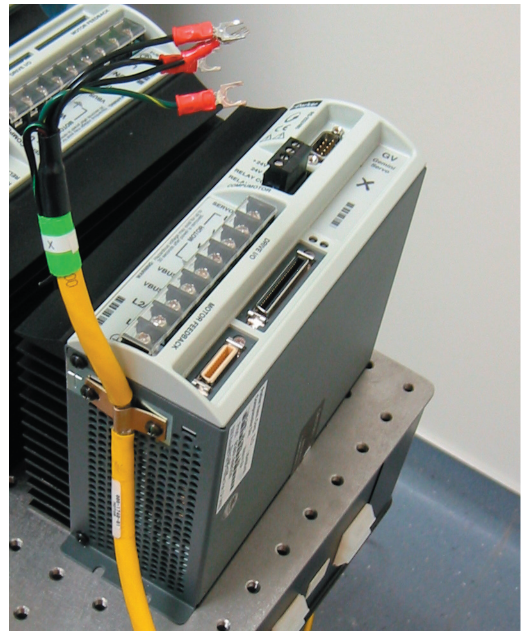
Next, connect the Encoder cable. This is the yellow cable with the trapezoidal connector on one end and a thumbscrew connector on the other end. The trapezoidal connector attaches to the "ENC./HALL" port on the back of the X-stage. Feed the cable through the gap behind the ICM-2900 and attach the connector with the thumbscrews to the "MOTOR FEEDBACK" port on the top of the X-stage drive. How easy was that? Secure the cable with a zip tie and adhesive connector.

Finally, connect the largest of the cables. This is the fat yellow cable with the circular connector at one end and the wires with the spade terminals (little U-shaped metal attachments) at the other. The connector has ridges on the rim that permit only one orientation for attachment. Screw the connector down firmly by hand with the collar. Feed the cable behind the ICM-2900.



Completed connections on the back side of the X-stage motor. Note that the AUX port is not used.

Before you attach the spade terminals to the drive, you will connect the cable to the housing of the drive. Identify the small bracket secured to the outside of the housing by two screws. Loosen these screws and feed the spade terminal end of the cable through the bracket, going up away from the table. The cable has a cut-out in its insulation where the metal shielding of the cable is visible; it is this part that you want to secure in the bracket. *This is an important safety feature and must not be omitted.*

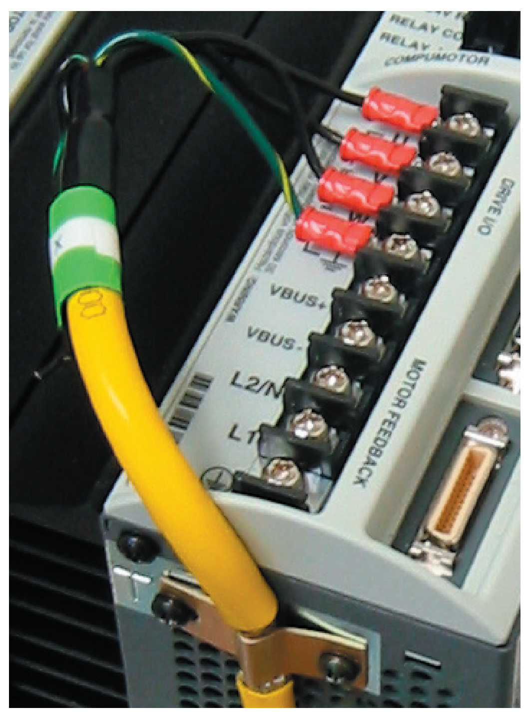


Proper attachment of the motor power cable shielding to the housing of its servo drive.

Remove the plastic cover from the terminals and set it in a safe place. Loosen each Phillips head screw on the drive connections, insert the appropriate spade terminal from the table below, and tighten the screw. The black cables have numbers printed on their shielding. The connection should pass the tug test. Use the ground (⏚) connection in the 'MOTOR' section of the connections, not the protective ground (⏚), which will be used for power coming in from the wall outlet.

DRIVE	**CABLE**
U	Black #1
V	Black #2
W	Black #3
⏚	Green/Yellow

Servo drive connections for the X-stage.



The motor power cable properly secured, grounded, labeled, and connected.

Wiring the Y-Stage

Y-stage cable travel module.

The wiring for the Y-stage is very similar to the X-stage. You don't have to worry about the connections to the motor, as the cables are already directly attached to the carriage. But now you have give a little thought to how to get the cables to travel without snagging as the arrayer moves back and forth. In the end, you will secure the cables to the ceiling, but while wiring and testing, you don't want this additional hindrance.

Begin by extending the cables coming out of the Y-stage to their full length. If there are any kinks or twists, unwind them so that there is no tension in the cables, then make a neat coil of each. If your room is small, this is a pain in the butt, but still worth doing. There should be four cables: two yellow, one black, and one gray.

The black cable is the limit switch cable. This connects to the ICM-2900 in the same fashion as the X-stage limit switch cable, but to the ports for the Y-stage. Make sure you get the right ports for the right stage, or the limit swtiches, one of the most important safety features of the arrayer, will not function as required. Don't forget to feed the cable through behind the ICM-2900.

ICM-2900	Cable Color
GND	Green/Yellow
GND	Black
HOMEY	Dark Green
RLSY	Blue
FLSY	Orange
+5V	Red

ICM-2900 connections for the Y-stage limit switches.

The gray cable is an Auxiliary cable. It doesn't do anything for the arrayer. Just set it aside for now. It will still need to be bundled with the other Y-stage cables so it doesn't cause trouble when the arrayer moves.

The fatter of the two yellow cables is the power cable and should have spade terminals at its end. This connects to the Y-stage drive in the same way the X-stage did. Before you make the connections to the drive, secure the cable with the bracket on the outside of the drive housing.

DRIVE	CABLE
U	Black #1
V	Black #2
W	Black #3
⏚	Green/Yellow

Limit switch wiring for the Y-stage. Remember to bundle the Brown and Blue wires.

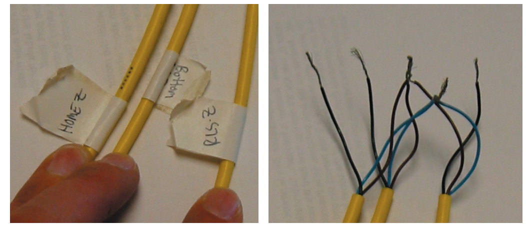
The thinner of the two yellow cables is the Motor Feedback cable, readily identifiable by its connector end. Attach this to the top of the Y-stage drive, after feeding it behind the ICM-2900.

Make sure all of your cables are properly secured to the back of the table with a zip tie.

Wiring the Z-stage

The Z-stage can be a bit more troublesome to connect than the other stages. The primary causes of this troublesomeness are the limit switch cables, which are not combined into a single cable as they are for the other motors and are visually indistinguishable. These are the yellow cables that arrive already attached to switches mounted to the outside of the Z-stage.

Begin by extending the limit switch cables to their full length, removing any kinks or twists, and neatly recoiling them. Now, while they are clearly separated from one another, LABEL THEM at their distal ends on the cable shielding. The most permanent way to do this is with a label maker, but a piece of lab tape will also suffice. The bottom switch is the "forward" one: label this FLSZ. The upper one is the "reverse" switch: RLSZ. The one in the center of the travel length is the home switch: HOMEZ. Make sure the label is permanently attached.



Limit switch cables for the Z-stage. Clearly labeled cables will prevent miswiring; the blue and brown wires must be bundled to share ICM-2900 ports.

Now that the cables are clearly labeled, you can connect them to the ICM-2900. The switches will share a common power source (+5V DC) and ground on the ICM-2900. To make the wires' reach longer, strip the cable shielding a few cm farther back from the end of each cable. Strip the brown and the blue wires so that a full cm of wire is exposed. Twist all of the blue wires together into a single bundle. Twist all of the brown wires together into a single bundle. Trim the resulting bundles so that the length of the bundled wire is about the 5 - 6 mm desired for connecting to the ICM-2900 ports. Connect the wires to the ICM-2900, after feeding the cable behind the ICM-2900.

ICM-2900	Cable Color
+5V	Brown (bundled)
GND	Blue (bundled)
FLSZ	Black FLSZ
HOMEZ	Black HOMEZ
RLSZ	Black RLSZ

Limit switch wiring for the Z-stage. Remember to bundle the Brown and Blue wires.

Now connect the power and Motor Feedback cables to the Z-stage. Both of these cables have round connectors, but the pin patterns clearly show that it is impossible to connect these to the incorrect port on the Z-stage motor. Remove the protective yellow plastic caps from the ports on the top of the Z-stage motor. Attach the connectors for each cable. Feed the cables up behind the ICM-2900. Attach the thinner of the two to the Motor Feedback port. Attach the thicker of the two to the Power terminals, after securing the cable to the bracket on the drive housing.

DRIVE	CABLE
U	Black #1
V	Black #2
W	Black #3
⏚	Green/Yellow

Motor power wiring for the Z-stage servo drive.

Make sure all of your cables are properly secured to the back of the table with a zip tie.

Wiring the 50-pin cables

A 50-pin DRIVE I/O cable, unfinished end on the left, connector end on the right.

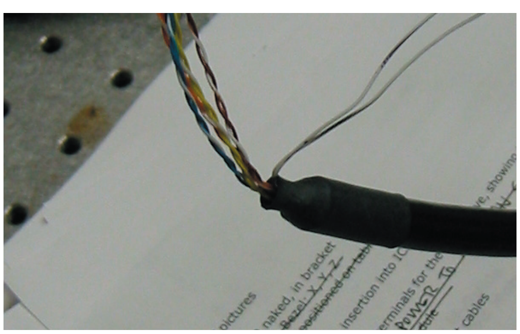
Now the motors are properly attached to the drives and the ICM-2900, but one important piece of the wiring is missing: the connections between the ICM-2900 and the drives. This is where the vital information about the motors and their motion is transmitted between the computer and the drive. There are 3 identical 50-pin cables, one for each axis, that serve this purpose.

Begin by stripping the unfinished end of each 50-pin cable. Make a shallow incision in the rubber shielding with a razor blade around the circumference of the cable about 25 or 30 cm from the end of the cable. Make a longitudinal incision from the first cut down to the end of the cable. These two cuts should enable you to remove the outermost rubber shielding from this 25 cm section. This will reveal a metal mesh protective covering; it is difficult, but not impossible to damage this mesh when you are removing the rubber shielding, so you should inspect the metal for damage where you may have nicked the wires underneath the metal mesh. If you do detect damage, you can simply remove more of the shielding so you will still have 25 cm of loose wire at the end.

Now, remove the metal mesh. Push the mesh down the length of the cable away from the end of the cable, so that it bunches up. Now you should be able to carefully cut the mesh with a razor blade or wire cutters. Finally, remove the protective foil shielding so that the individual wires are exposed. Again, inspect the wires carefully to ensure that they are not damaged.

50-pin Cable Wire Colors to Retain	
Orange	White/Orange
Brown	White/Brown
Light Blue	White/Light Blue
Yellow	White/Yellow
White/Violet	White/Gray

You will use 10 wires for each 50-pin cable, indicated in the table at left. The colored pairs (color X and white/color X) should be twisted together in the bundle; you do not need to untwist them except for a few cm at the ends. The remaining unused wires can be cut off at the end of the shielding. Make sure you have the correct wires before you cut any off. The White/Gray and White/Violet are the hardest to identify, as they are not a twisted pair. If you do happen to cut one off that you need, you'll have to go through the shielding removal again to get wires that are long enough to reach all the connections in the ICM-2900.



Finished end of 50-pin cable, with heat-shrink covering.

A nice aesthetic touch that will make your arrayer look a little more professional is to cover the end of the shielding with a piece of heat-shrink tubing. Select a piece that just barely fits over the shielding of the cable and cut a 4 cm length. Slide this over the wires and onto the shielding. Apply heat to the tubing with the shaft (not the point) of a soldering iron. DO NOT OVERHEAT. The shielding of the wires in the bundle is not heat resistant. Too much heat will fuse the wires together. That is not good. If you want to get an idea of how much heat the shielding can withstand, test it out with some of the unused wires you cut from the cable.

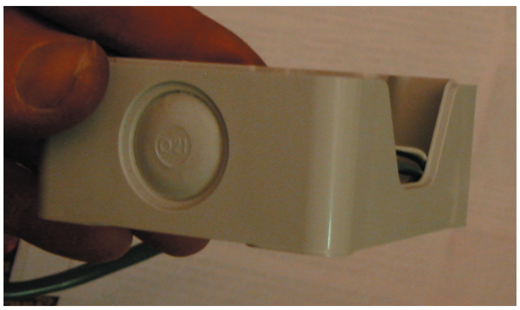
Strip 5 - 6 mm of shielding from the end of each individual wire. Then, label each 50-pin cable as belonging to one of the axes at the wire end (it doesn't matter which cable is used for which axis as all the cables are the same), and connect each to the ICM-2900 following the chart at the top of the facing page. Make sure you are clear on which cable is for which axis.

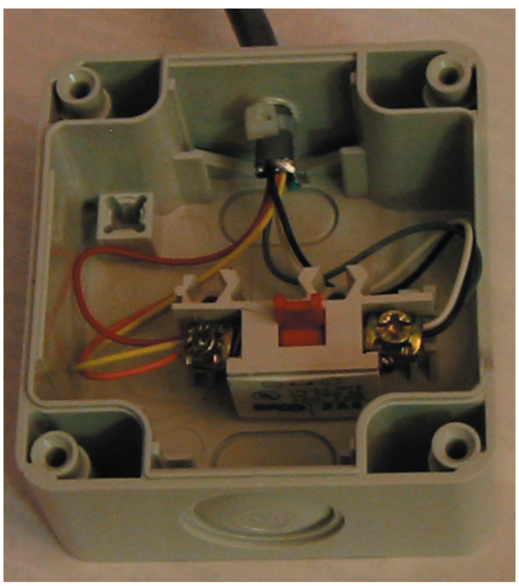
Cable Color	X-Stage	Y-Stage	Z-Stage
Orange	+MAX	+MAY	+MAZ
White/Orange	−MAX	−MAY	−MAZ
Light Blue	+MBX	+MBY	+MBZ
White/Light Blue	−MBX	−MBY	−MBZ
Yellow	+INX	+INY	+INZ
White/Yellow	-INX	-INY	-INZ
Brown	MOCMDX	MOCMDY	MOCMDZ
White/Brown	GND	GND	GND
White/Violet	These will be connected to the Emergency Stop Switch in the next section.		
White/Gray			

When all of the connections to the ICM-2900 are complete, you can connect the 50-pin connector to the top of the drive in the "DRIVE I/O" port. Make CERTAIN that you attach the 50-pin cable to the correct servo drive: X to X, Y to Y, Z to Z. Feed the loop of cable down between the table and the ICM-2900 and secure BOTH ends of the cable to the back of the table with zip ties and adhesive connectors so that no tension is applied to the connection to the drive or the ICM-2900.

Now that everything is connected, go back and double-check it. The only truly frightening experience that I have had with one of these arrayers was due to a wiring mistake in the 50-pin cable. Give every wire a tug test and make sure there is no tension in the wires or on the cable. Also make sure that the ports are firmly inserted in to the ICM-2900.

Completed Emergency Stop Switch.


Bottom of Emergency Stop Switch housing before cutting a small hole for the wires.


Inside the Emergency Stop Switch, showing zip tie securing the cable and bundled wires at the terminals.

Axis	Enable (White/Violet)	Digital Ground (White/Gray)
X	Yellow	Black
Y	Orange	Gray
Z	Red	White

Wiring Emergency Stop Switch

The emergency stop switch is certainly one of the most important features of the arrayer. It has prevented many a confusing or objectionable situation from becoming a disastrous one.

The switch works at a very fundamental level: the Enable function of the drive. If there is no current flowing from the enable wire to the digital ground, no power will be applied to the motors. The big red candy-like Emergency Stop Switch is nothing more than a way to disrupt this circuit. For maximum safety, all three axes are disabled by a single switch.

Unscrew the bolts in the yellow lid of the stop switch to reveal the terminals inside. Cut a 5 cm length of multistrand cable. Using the Dremel and a drill bit, cut a hole in one side of the lower, gray portion of the switch housing that is just big enough to feed the short cable through. The thinnest walls of the housing are in the center of the domed circles on either side of the base. Remove the short length of cable and discard.

Cut a 4 m length of multistrand cable. Strip 6 or 7 cm of shielding from one end to expose the wires. Isolate the black, gray, white, yellow, orange, and red wires; cut the other wires off. Strip 2 cm of shielding from each wire. Twist the black, gray, and white wires together. Twist the yellow, orange, and red wires together. Feed the bundles through the hole into the base of the switch until there is 1 cm of shielding inside the switch. Cinch a zip tie around the shielding inside the switch and tighten securely so that the cable cannot pull out of the switch. Connect each bundle of wires to one of the terminals inside the switch and secure the connection tightly with the screw. Replace the cover of the switch and reattach the screws.

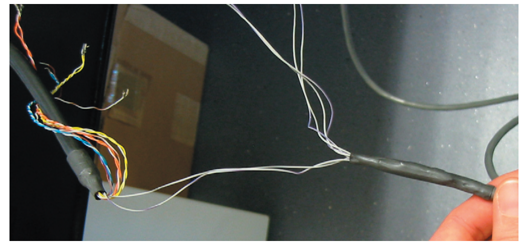
At the other end of the cable, strip 20 - 30 cm of shielding away from the end of the cable. Remove the protective foil. Cut the unused wires away at end of the shielding -- cut all the wires that are NOT black, gray, white, yellow, orange, or red. Strip each individual wire so that 1 cm of wire is exposed.

Cut 6 3 cm lengths of small heat-shrink shielding that will fit easily over the small wires. If desired, you can also place a larger piece of shielding over the pairs of wires or all 6 wires. Place the heat shrink tubing on the wires before you start making connections to the enable wires. You must be careful with the heat shrink tubing while soldering, because if you get it too close to the iron, it will shrink in place, and you will not be able to place it over the junction to serve the insulating function required.

One axis and one wire at a time, solder the wires together. This can be a challenge if you’re not very handy with a soldering iron; having an extra pair of hands is almost required to manage the two loose wires, the solder, and the soldering iron. Follow the table at left.

After each connection is complete, blow on it gently so that it cools off. When it is cool enough not to constrict the heat shrink, slide the heat shrink that is already in place on the wire over the soldered joint. Shrink it in place with a little heat from the shaft of the soldering iron.

The switch should now be operational, but will require power to the drives to test.



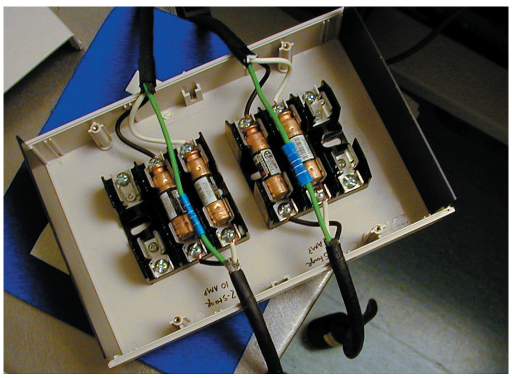
Heat shrink in place over wires for Emergency Stop Switch after soldering. One of the attached 50-pin cables is visible.

Fuse Box Assembly & Installation

Your arrayer is comprised of some really expensive hardware, so in the interest of protecting it from unpleasant surges in electrical current, you will construct a fuse box. A fuse is just a way to limit how much current can flow into the motors. We will use the white plastic box from the parts list to construct the fuse box. The black plastic box is used for constructing the relay box, as you will see below.

The cords from one end of the fuse box will go to the wall. Under no circumstances should you open the fuse box while one of the power cords is plugged into the wall.

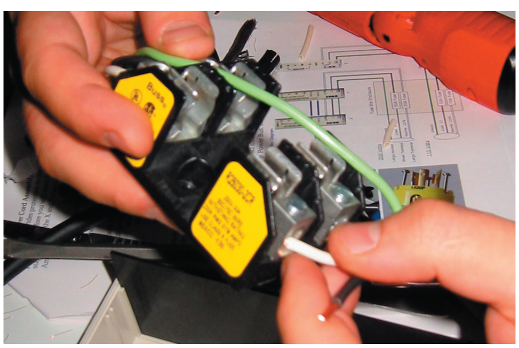
The other end will go to the power connections of the drives. The X- and Y-stages will share power from a single outlet with a specialized plug and receptacle: a 220 V, 20 A, NEMA L6-20 receptacle. The Z-stage will be powered by a standard 110 V grounded wall outlet (see next section for other countries).



Inside the fuse box, with fuse blocks glued in place, fuses installed, cable holes in the sides of the box, and the wires connected to the terminals. The green ground wire is joined with a blue butt splice.

Open the box and glue two fuse blocks to the base of the box using epxoy; the long axis of the fuse should be perpendicular to the long axis of the box. Into the first block, snap two 10 A fuses; which spot in the block does not matter. This can take a little bit of force to get them to snap in. Make sure the fin at the end of the fuse fits into the notch in the block. Into the other block, insert two 20 A fuses. Make sure you know which is which.

Using the Dremel, cut two opposing semi-circles in each half of the box on both sides of the box, even with the fuse blocks. The box halves are not symmetrical; there are notches where they meet that allow only one orientation, so make sure you have the correct orientation. These holes should be just big enough to hold the power cords. Test them as you make the cuts to ensure the holes are not overly large.



Attaching the white cable to one connector of the fuse block (can be done before placing fuse block in fuse box).

The Z-stage power is easier to assemble so start with that. Take the power cord with a NEMA 5-15 (standard US 3 prong plug, McMaster 70355K35) plug on one end, remove about 15 cm of shielding from the distal end, and strip each individual conductor to reveal 2 cm of wire. DO NOT PLUG INTO WALL OUTLET. Using the screwed connections in the fuse block, connect the black wire to one 10 A fuse and the white wire to the other 10 A fuse.

Now, take a 3 m length (or less, if you can place your fuse box close to the outlets) of the 14 AWG power cord from the 50 ft. you ordered (McMaster part 7082K23). Remove 15 cm of shielding from one end of the cord and strip the wires as before. Connect the black wire to the connection opposite the first black wire, as shown in the diagram. Do the same for the white wire. For the green (ground) wires, insert each wire into opposite ends of a butt splice and crimp the butt splice with a pair of pliers. Make sure that the connection in each end of the butt splice passes the tug test. The Ground wire SHOULD NOT BE CONNECTED TO A FUSE.

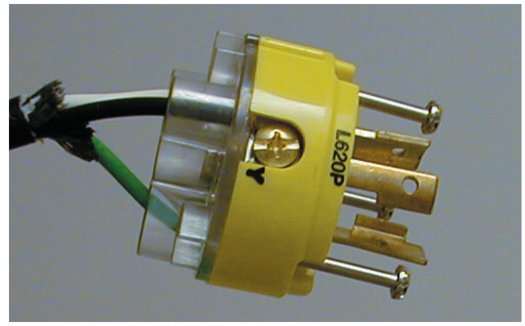
Wire	Connection	
Black	L1	Load
White	N	Neutral
Green	⏚	Ground

Power connections from the fuse box to the Z-stage servo drive power bus.

At the other end of this power cord, strip about 10 cm of shielding and about 1 cm of insulation from each wire. Connect the wires to the drive as shown in the table at left using a phillips head screwdriver. It is extremely important to get these right; damage will result if the cables are not connected correctly. You don’t want an excess of wire poking out beyond the connection, as it could make contact with one of the other connections. That would be "bad."

DO NOT PLUG THE POWER CORDS INTO THE WALL YET. YOU ARE NOT READY TO APPLY POWER TO THE MOTORS.

For the X- and Y-stage power, start with two 3 m lengths of the 14 AWG cord. Strip and connect the black and white wires at one end of each length to the 20 A fuses and splice the green wires together just as you did for the Z-stage. For the plug end of the cord (make sure this extends from the same side of the fuse box as the 110 V plug, or you will have a topologically undesirable situation), attach the NEMA L6-20 Plug. Strip about 5 cm of insulation and 1 cm from the end of each wire. Slide the cover and housing over the cord before you make connections to the plug. Insert each wire into the connection and crimp securely with a screwdriver. Apply the tug test.



The L6 Turn-Loc plug, with the power cables attached to the terminals.

Wire	Connection	
Black	Y	small terminal
White	X	large terminal
Green	G	hooked terminal

Connections in the L6-30 Turn-Loc plug.

When all three wires are secured in the plug, screw the plug into the housing. Crimp the cord in the clamp in the housing. Place the cover over the housing.

To connect the power to the drives, you will need to have a few jumpers (short wires, not sweaters) cut from your 14 AWG cord to share the power between the X-stage drive and the Y-stage drive. It is easiest if these are about 15 - 20 cm long and of the same color as the corresponding wire: green for ground, etc. Cut the black shielding entirely off the individual wires. Strip 1 cm from each end of each wire. To being, attach one end of each to the appropriate connection on the Y-stage drive.

Strip the drive end of the power cord coming from the fuse box as you did for the Z-stage: 10 cm of shielding, 1 cm of wire. Place the wire from the fuse box on the appropriate connection of the X-stage drive to one side of the screw; then, insert the jumper to the Y-stage drive on the other side of the screw for the same connection, as seen at right. Tighten the screw so that both wires are securely held in the connector and pass the tug test. You don't want an excess of wire in this situation either, as it could make contact with a wire from one of the other connections.

Power bus connections on the X-stage servo drive. One wire of each color is coming in from the fuse box, the other goes to the corresponding terminal on the Y-stage.

Wire	Connection	
Black	L1	Load 1
White	L2/N	Load 2/Neutral
Green	⏚	Ground

Power connections from the fuse box to the X-stage servo drive power bus, which will be shared with the Y-stage.

Finally, cut two additional jumpers (color doesn't matter) as you did for the power sharing. Connect the VBUS+ connection of the X-stage drive to the VBUS+ connection of the Y-stage drive. Do the same for the VBUS- connections on the two drives. This allows the drives to conserve power, allowing one to use the power generated by deceleration of the other drive to power its own acceleration.

Replace the plastic covers over the power connections on the bezels of the servo drives. These are an important safety feature and reduce the risk of accidental electrocution significantly.

Replace the cover of the fuse box and screw securely into place.

DO NOT PLUG THE POWER CORDS INTO THE WALL YET. YOU ARE STILL NOT READY TO APPLY POWER TO THE MOTORS.

Some Words About Power In Foreign Countries

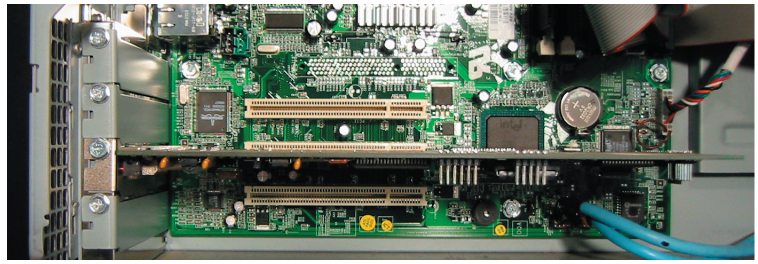
Easiest option, changing the least about the design: step-down transformer to provide 110 V power to the Z-stage and relays for accessories. Successful in Korea and Chile.

Harder option, not explicitly described in this guide: replace the GV-L3 servo drive with GV-U3/6/12 (same model as X- and Y-stages) and order outlets, power cords, and accessories that use 220 V power. Ask Dynamic Solutions to have Parker preconfigure the drive for the Z-stage motor. You will also have to redesign the relay box with new outlets for location-appropriate devices, including vacuum pump and sonicator. As of yet untried.... Please let us know if you make such a modification to the design!

Controller Card Installation

If you've ever put memory into your computer, this will seem like a walk in the park for you. If you've never opened the case of a computer before, it will feel a little intimidating at first. Just remember to keep yourself grounded so you don't generate lots of static electricity; touching the metal frame of the inside of the case is usually a good option. Don't do this on a carpeted floor and don't shuffle around in your socks or roll around in your chair while you're doing it. Finally, if there's anything you don't recognize inside the computer, don't touch it.

The Galil DMC-1832 controller card is a PCI card that fits into a PCI slot. Most PCs have several of these, unless they happen to be a very low "form-factor" computer. You don't want to bend, flex, or shove the card into position. The card is worth more than most of the PCs in which you'd consider installing it, so don't think twice about replacing the PC if the card isn't going to fit easily.



The DMC-1832 Controller Card installed in the middle of 3 PCI slots in a typical PC and secured to the chassis with a screw.

PC requirements are very lax. A Windows machine running 95, 98, NT, 2000, or XP is required. Very little is required in terms of processing power, disk space, or memory. Our installation uses a Win2000 machine, with a 500 MHz processor, 128 MB of RAM, and a 12 GB hard drive. Nowadays, this will be much less computer than you can get at the very bottom of the line from most manufacturers, so go cheap and don't splurge.

The 100-pin cable connector should be readily accessible from the outside of the computer when the card is properly installed.

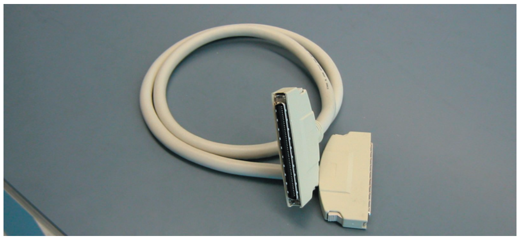
Start with the computer on, by inserting the Galil drivers disk. You need the version of the drivers circa 1999. These can be downloaded from our web site. Subsequent revisions broke the connection with our ArrayMaker software and will not run properly. If you install the newest drivers, you will be faced with a cryptic error stating "Component not registered" or something to that effect.

Install the DMC Set-Up Utility for Win32. Then, shut down the computer and unplug it from the wall.

Open the computer case and identify an empty PCI slot. Remove the metal cover that blocks the external opening, usually held in place by a single screw. Make sure you are static electricity free! Remove the controller card from its protective packaging, handling it by the edges only. It should be easy to identify the copper contacts on the edge of the card (don't touch them, please) and how they align with the PCI slot. Push the card into place. It should be firmly and evenly inserted. Screw the card into the frame using the screw from the cover you just removed. Close the case and reboot the computer.

The computer should recognize the new controller card automatically and identify the drivers on the CD.

You can test the installation by attempting to start the ArrayMaker software; see below. If the Galil Controller Card is not properly installed, ArrayMaker will throw a Class not Configured error.

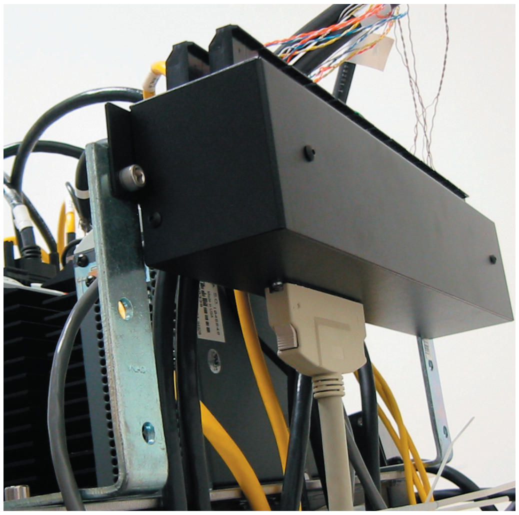


100-pin cable from Galil.

100-Pin Cable

This cable carries all of the communication between the motors and computer. One of the most common and trivial causes of erratic arrayer behavior is a loose connection in the 100-pin cable. The design of the cable connection is not especially robust, and thus, the cable can become partially disconnected on occasion.

The cable is symmetrical, with the same connector at each end. One end connects to the back of the computer, where the port on the card is exposed. Make sure your card is securely attached to the computer housing by a screw, or you will have a difficult time getting your cable attached securely. The other end connects to the underside of the ICM-2900. Make sure it is hanging straight down and is not under tension. In both cases, the connector should snap into place with the clamps on either side securely engaged. To reduce stress on the computer-side of the cable, the cable can be supported by a small riser so that the weight of the cable is not torquing the connection to the controller card.



100-pin cable attached to ICM-2900.

100-pin cable attached to the installed Controller Card.

Software Installation

You will run your arrayer with ArrayMaker, a fast and flexible program that has been frequently and extensively refined over the past seven years. ArrayMaker was written with Borland C++ and is free to academic and not-for-profit institutions. The current version at time of writing is 2.61.

You can download the license information for ArrayMaker here:
http://derisilab.ucsf.edu/arraymaker.shtml
You will then be directed to the appropriate location to download the software. You should definitely sign up to get ArrayMaker through the appropriate channels, as that will add you to the mailing list that announces updates, changes, troubleshooting information, etc.

Create an ArrayMaker Folder in the Program Files Folder of your hard drive. Extract the zipped archive into this folder. There should be several files. The first is the ArrayMaker executable: ArrayMaker.exe. Create a shortcut to this file and place it on your desktop.

There are several other files required for ArrayMaker to run: BORLNDMM.DLL, CP3245MT.DLL, DMCPackage.bpl, and vcl40.bpl. These are not text files and are not readable by anything other than ArrayMaker. Don't mess around with them.

There are also two ".cfg" files that are text and can be read in a text editor: motor.cfg and newplatter.cfg. Although you can edit these by hand in unusual circumstances, you will make most of your adjustments to them through the ArrayMaker program. Motor.cfg contains the parameters for how fast the arrayer will move and where the "station" positions are; newplatter.cfg tells the arrayer the precise location of each slide on the platter in XYZ coordinates.

In the future, to make upgrades to ArrayMaker, you will simply replace the old .exe with a new one and, in some cases, change the motor.cfg file.

Start ArrayMaker by double-clicking your shortcut. If the Galil Controller Card is not properly installed, ArrayMaker will throw a Class not Configured error. If this occurs, ensure that your controller card is properly identified as a plug-n-play device by your computer. If not, reinstall and re-run the setup utility and make certain that the installation has properly identified the device drivers for the card. Again, remember that the current Galil drivers are not compatible with ArrayMaker. You can download the proper 1999 drivers from our website.

If ArrayMaker does launch, you will be greeted by a Welcome screen. At the top of the window, there are two tabs: Welcome and Connect. Click on the Connect tab. There is only one button clickable on this page: Connect to Controller. If everything is working as it should, a lot of information will be posted in the text box and the "Home All Axes" button will become clickable -- do not click this button yet. Also, the Configure, Terminal, and Version Notes tabs will become visible.

If Arraymaker has not been properly shut down (i.e. it crashes), upon connecting to the controller subsequently, you will be greeted with an error that says “there is another copy of ArrayMaker running.” Double check the taskbar to make sure there is NOT another copy running. If not, go to Program Files\ArrayMaker\ and delete the lockfile.run file that you find there.

Limit Switch Testing

If you have the software running and are connected to the controller, you will be able to test the limit switches. It is very important to know if these are working both for safety and for the homing routine to complete, and should be done before the motors are powered up!

For the first time, some power is flowing to the arrayer. The +5V DC power that the controller card produces is used to run the limit switches. You should be able to detect this by the illumination of pale yellow lights on the switches on the side of the Z-stage housing.

Because the power to the motors is off, you can move the motor stages by hand. Start with the Z-stage. Push the Z-stage all the way down to the bottom of its travel length (the end closest to the table). The small metal protrusion from the carriage should be positioned over the forward limit switch. This should cause the light on the switch to go out. This confirms that the physical aspect of the switch is functioning; now you must check if the software is receiving the information.

Go to the Terminal tab of the ArrayMaker software. Engage the Caps Lock key. Click once in the text box at the top of the window. Type “TS” and hit return. The software should echo your command in the box below and print out a series of 3 numbers, one for each axis: like 13, 13, 5. The first number is the value for the X axis, the second for the Y axis, and the third for the Z axis.

TS send the command “Tell Switches” and returns the decimal form of 3 8-bit binary numbers. The guide for which bit corresponds to what information is on page 149 of the DMC-18x2 Command Reference manual. The most common values are listed at right.

Value	Interpretation
5	at Forward Limit
9	at Reverse Limit
13	not at either Limit or Home
15	at Home

Common return values of the TS (Tell Switch-es) command.

It’s a bit of a pain to translate more complex values, but at this stage you really should see only one of these 4 values. The interpretation of more complex values demands a little bit of understanding of binary numbers (see appendix).

With the Z-stage all the way down, you should expect to get a 5 for the Z. Push it all the way up to the top, and you should get a 9. Bring it down to the center, so that the Home switch light goes on, and you should get a 15.

For the X- and Y-stages, it’s a little hard to see the lights. If you look on the cable-bearing side of either of these axes, you will see a small black plastic trapezoid with three lights in it attached to the carriage. These lights are the detectors for the axis. The targets for these switches are attached to the outside of the motor housing. These are small pieces of metal with a set screw to hold them in place. The limits are red and the home switch is plain sliver.

The home/limit switch detector apparatus for the Y-stage, located behind the cable travel module.


Targets for the limit/home system. Left, home target. Right, limit target.

Push the X-stage so that it is over the front-most target and the front-most light goes on (this is the side opposite where the cables come in to the motor). It’s a little harder to see, because the switch housing obscures the target itself, but the light should be pretty obvious. Check the switches with the TS command.

You should get a value of 9 for the X-stage. With the carriage pushed all the way back, you should get a value of 5. In the center, it should be 15.

Repeat this for the Y-stage as well, taking care not to snag the bundle of cables coming out of the Y- and Z-stages.

You should be able to detect each of the switches, or the arrayer will be impossible to home and may run unsafely. If you cannot get the arrayer to detect one of the switches, the most likely cause is a poor connection to the ICM-2900. Check the wires for the switch that is giving you trouble, recalling that the +5V and GND connections are also important for the function of the switch.

Another possibility is a loose connection in the 100-pin cable. Make sure the 100-pin cable is attached securely to both the computer and the ICM-2900.

If you are confident that you have a broken switch, contact your Parker motor distributor to arrange for a replacement.

Plug In the Arrayer

This is the moment of truth. You held off on giving power to the arrayer until you knew that the computer was working, that the computer had control of the brains of the arrayer (the controller card), and that safety features like the limit switches were in place.

Take a moment to double-check all of your connections. Check the connections for each axis and each drive.   Check all of the connections on the ICM-2900. Are the connections secure and are the blocks of the ICM-2900 securely seated. Is the 100-pin cable properly installed?

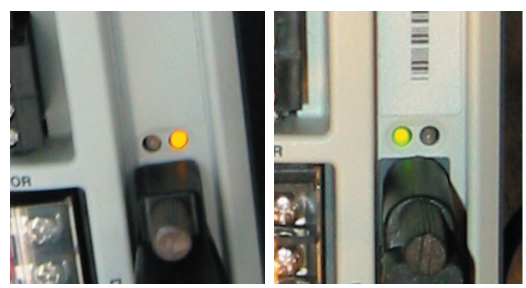
Push the carriages to their "ready" positions: X towards the front of the table, Y to the right side of the table, and Z approximately centered. This is the position required for successful homing.

Place the cables for the Y- and Z-stages behind the ParFrame gantry, so that they will not snag if there is unexpected movement.

Place the emergency stop switch on the surface of the table and have a colleague ready to strike it should the arrayer move unexpectedly. While this is not yet properly tested (that's the next step), you need power to know if it's working.

Start the software (or restart it if it is running) and connect to the controller. Powering the arrayer without the software running and connected to the controller is unsafe.

Here's what to expect. You should see lights go on on the top of each servo drive when it is powered up. The right light should go yellow when power is applied to indicate the drive is initializing. After a few seconds, you should hear a click, and the right light will go out and the left light will come on green to indicate that the drive is ready and enabled. The arrayer SHOULD NOT MOVE. It will begin to hum quietly with the effort of keeping itself in place, but it should not move.



Indicator lights on top of one of the servo drives. Left, initializing. Right, ready!

To turn the arrayer off, you will simply unplug the motors. After unplugging the power, the lights on top of the drives, will stay lit for a few seconds. Wait for these to go completely out before handling the drives. The drives store electrical charge. If you handle a drive with the lights on, you are risking a dangerous shock.

Plug in the motors to the wall outlets. The order of which plug goes in first does not matter. Check the lights on the drives. If you've got three greens, you're good to go. Now, the carriages cannot be moved by hand, as the arrayer will hold itself in place. Proceed to the next section and test the stop switch.

A red indicator light on top of one of the servo drives indicates a fault, left. At right, you must wait for all lights to go out before touching the servo drives to check connections. Failure to do so presents a servere risk of electric shock.

If the left light becomes red, not green, then you have a fault somewhere. First, check the emergency stop switch: is the button depressed? **If it is, do not release it**. *First*, unplug the motors and **wait for both lights to go out**. *Then* release the switch. Restart the software and reconnect to the controller. Then plug the motors in again.

If the lights are still red, you may have a bad connection in your soldered connections for the emergency stop switch or in the clamped connections on the ICM-2900.

If the lights are still red after checking the above possibilities, you may have a mis-configured drive. Please see the appendix on drive configurations for how to check and update your drive configurations.

Emergency Stop Switch Testing

Emergency Stop Switch test: before, the light is green (left); after it is red (right).

Now, with power to the motors, you can properly test the emergency stop switch. To do so, simply push the switch down. The arrayer should stop humming and the lights on top of the drives should all turn red. Now, you should be able to adjust the position of the carriages by hand.

After you have pressed the emergency stop switch, YOU MUST UNPLUG THE ARRAYER. The stop switch is reset by twisting it so the button pops back up, but you DO NOT WANT TO DO THIS with the arrayer powered on. As soon as the switch is released, the arrayer will try to return to its assigned position and may move with undesirable rapidity to do so. Power off the arrayer first, make sure the lights on the drives go out, then twist the button to release it.

If the lights do not turn red, you may have mis-wired your stop switch. The most common mistake is to mix up the colors of the wires so that you do not have all the white/violet wires going to one terminal and all the white/gray wires going to the other terminal. In this situation, there is no circuit for the switch to break, as it is already closed at each terminal.

You can test the stop switch one axis at a time by unplugging the power and the 50-pin MOTOR I/O cables from the other axes, but this is not necessary, except for troubleshooting.

Motion Testing

This is the really exciting part. You will use the Terminal interface to send very simple commands to the arrayer to make sure it is moving properly. If there is a problem with the feedback from the motor, the arrayer may move erratically. The homing procedure built in to ArrayMaker homes all three axes at once. Moving them individually at first to isolate any problems is preferable.

Start ArrayMaker, connect to the controller, and power up the motors. When you have green lights on top of the drives, go ahead and open the Terminal tab.

The commands are the same for each axis and come in three flavors: how far to move, how fast to move, and when to start moving. Which axis is to respond to the command is specified by the numerical arguments following the command.

Command		**Examples**	**Results**
PR	Position Relative	PR 3000	move X-stage 3000 μm forward
		PR 3000,0,0	move X-stage 3000 μm forward
		PR 0,-3000,0	move Y-stage 3000 μm backward (right)
		PR ,-3000	move Y-stage 3000 μm backward (right)
		PR ,,300	move Z-stage 300 μm forward (down)
		PR 3000,3000,300	move X-stage 3000 μm forward, Y-stage 3000 μm forward (left), Z-stage 300 μm forward (down)
SP	Speed	SP 5000	move X-stage at 5000 counts/sec (μm/sec)
		SP 5000,0,0	move X-stage at 5000 counts/sec (μm/sec)
		SP 0,5000,0	move Y-stage at 5000 counts/sec (μm/sec)
		SP ,5000	move Y-stage at 5000 counts/sec (μm/sec)
		SP ,,5000	move Z-stage at 5000 counts/sec (~μm/sec)
		SP 5000,5000,500	move X-stage at 5000 counts/sec, Y-stage at 5000 counts/sec, Z-stage at 500 counts/sec
BG	Begin	BG	Begin motion on all stages
		BGX	Begin motion on X-stage
		BGXYZ	Begin motion in X-, Y-, and Z-stages

So, to make a 5000 count move (5 mm) forward at a speed of 1000 counts/sec (1 mm/sec) in the X axis, you would issue the following commands, one at a time, each followed by the Enter key:

```
PR 5000
SP 1000
BGX
```

The arrayer will actually move when you issue the BG command and not before. In case of erratic motion, have someone stationed with their hand over the emergency stop switch when you are making these moves for the first time. Start with very small moves like this one both forward and backward for each axis. Make the moves a little smaller for the Z-stage, because of its much short travel length. This will help you get the feel of the commands. You can execute the same move repeatedly by calling BG again. If you accidentally trip a limit switch, you will have to unplug the motors and restart the software to get going again.

Homing the Arrayer

If each axis moves as it should, both forward and backward, you should be in pretty good shape for the homing routine. This is a simple routine that finds and sets the zero point for each axis coordinate system. For the X- and Y-stages, this is a unique tick mark on the linear encoder inside the housing. To identify this mark, known as the index, the arrayer must be moving very slowly. Since the Z-stage is a rotary motor, it has a rotary encoder that's a little different (and almost never presents a problem).

Before moving the axes, have someone gather the Y- and Z-stage cables in hand so that they do not catch on the ParFrame gantry or the table when the arrayer moves.

Simply click the "Home All Axes" button in the Connect tab. The Z-stage should move all the way up to its reverse limit switch. This is a safety feature for when you have the platter and the print head attached to the arrayer. Then, all three axes will move at once towards the center of their travel length and appear to stop when they reach the home switch. The carriages have not actually stopped. They are moving very slowly looking for their indexed home position. You will know when they stop from the colored indicators on the computer screen.

If everything works properly, you should get a window popping up saying that all axes are home. Make sure there is nothing in the travel length of the stages. Click OK; the arrayer will rush to its ready position, with the X-stage to the front of the arrayer, the Y-stage to the right, and the Z-stage near its home switch. You should now be able to access the other features of the software that control the calibration and print runs. To become familiar with these aspects, it is best to inspect the print protocol, available from our web site.

If the homing routine fails and times out, see the instructions below.

Troubleshooting the Homing Process

If the motors are set up properly by Parker, the home switch target will be very close to the index on the encoder. The homing routine moves the arrayer until the switch trips, then it backs up to find the edge of the switch again, then it moves forward very slowly looking for the index. If the switch is past the index or too far in front of the index, the motor will never find the index. Fortunately, you can move the targets for the home switch easily with a small hex wrench.

When describing adjustments here, forward is used to indicate motion in the direction of the homing routine for that axis and backwards is the other direction, not towards the front or back of the table, as is the custom usually. For both the X- and Y-stages, this "forward" direction is the positive direction on the encoder.

The first question is, did the carriage slow down at the home switch target? If the arrayer failed to stop and proceeded to the end of the travel length without slowing down to look for its home position, it is not detecting the home switch. Check the wiring for this switch. The arrayer should detect the target before proceeding.

If the problem is that the arrayer "times out" trying to home, the positions of the target and the home position are not aligned. It's helpful to have a pencil for this step. Unplug the motors and restart the software. Before you plug the motors in again, push the carriage of the offending stage(s) to the center of their travel length so the light for the home switch goes on. Now back it up 5 or 10 cm. Then power up the motors.

Command		**Examples**	**Results**
JG	Jog	JG 500	sets the X-stage jog speed to 500 counts/sec
		JG 0,500	sets the Y-stage jog speed to 500 counts/sec
FI	Find Index	FIX	puts the X-stage in Find Index mode
		FIY	puts the Y-stage in Find Index mode
BG	Begin	BG	Begin motion on all stages
		BGY	Begin motion on Y-stage

Issue the following commands in the Terminal. Using the Y-stage as the example; just do one stage at a time.

```
JG 0,500
FIY
BGY
```

It's hard to see that it's doing anything, but it is moving very slowly. You can observe this by comparing the carriage position to a small pencil mark on the motor housing. Let it run as long as it needs to find the index. If you see the target emerge from underneath the carriage, stop the motion, back up the stage using the PR command, and try it again from a starting position farther back than the one used for your previous attempt. If this also fails to find the index, it is most likely that your problem is a wiring problem, as it would be well beyond the center of the travel length. Power down the motors and the computer, check the wiring for that stage (especially the ICM-2900 connections to

+IN and -IN for that axis), and try again. We have experienced issues with bent pins in connectors, so it is worth a quick visual inspection of those, too.

To know when it has stopped moving, you can sometimes hear the arrayer stop, but a more reliable way is to use the Tell Position command: TP. TP will return 3 numbers, one position for each axis in encoder counts. While the arrayer is looking for its index, these numbers will slowly increment (send the command multiple times and look at the differences). When it finds the index, it will set the position to zero and stop. You can tell that the FI move is finished when the TP command returns a zero for that axis.
Once the arrayer has found its index, make a mark with the pencil on travel length at the advancing edge of the carriage. Unplug the motors, restart the software, pull the carriage back to its starting position, and power up the motors. Send the arrayer into the homing routine. When the arrayer makes the transition from moving quickly to moving slowly, mark the travel length again with a pencil.

You haven't changed anything, so the homing process will time out again. You can now unplug the motors and restart the software. Pull the carriage back out of the way, so you can see the two marks. Now you can see where the problem lies.

If the second mark is farther forward than the first, then the target is too far forward on the axis. Mark the forward edge of the target with the pencil, loosen the set screw, slide the switch back at least the distance between the pencil marks, and tighten the screw. Now, power up the motors and try the homing again.

If the second mark is before the first, you need to move the target forwards. Mark its leading edge with a pencil, loosen the set screw, slide it forward to within a few mm of the first mark, and tighten the set screw. Now, power up the motors and try the homing again.

By repeating the homing procedure, you should get the arrayer to home within the time limit. If it fails again, you may have moved the target too far. Simply repeat the instructions above, making a new mark with the pencil.

If you tend to be slightly obsessive, you can trim the homing time significantly by optimizing the location of the targets. If your arrayer takes longer than about 30 seconds to home, go ahead and try to adjust the targets so they are closer to the homed position. You won't be able to make much difference in the Z-stage, but the other axes should be easy to adjust. This will make future trouble-shooting easier by decreasing the time to restart the arrayer.

Suspending the Y- and Z-stage Cables from the Ceiling

As you are no doubt aware after your (possibly repeated) homing of the arrayer, the cables from the Y- and Z-stages must be secured so that they will not snag on the edge of the ParFrame. The easiest way to do this is to suspend them from the ceiling. We hold off on doing this until now in case substantial rewiring needs to occur. Once you have completed this step, you should be able to move the arrayer anywhere it needs to go without stress to the cables.

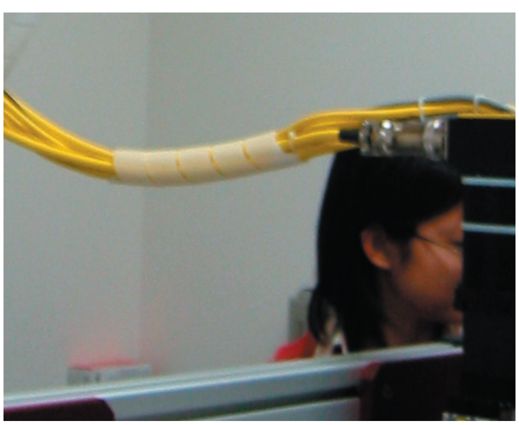
The Y- and Z-stage cables secured to the Z-stage motor and protected from abrasion.

To keep the appearance of the cable bundle neat, now is a good time to prepare to install your height detection switch. Cut a length of 10-conductor cable long enough to hang 15 cm below the end of the Z-stage motor, that will to the ceiling and back down to the ICM-2900. There is no way to make it too long, so err on the side of caution and make it plenty long. Include this cable in the bundle that you attach to the ceiling.

To begin, arrange the cables coming from the Y- and Z-stages so that they are not under tension. Using a small 10 cm piece of helical bundling wrap, wrap the cables from the Y-stage and the Z-stage limit switches together. Then, use another piece of bundling wrap to wrap the same cables plus the power cables to the Z-stage motor. This should hold the cables in place until you apply more bundling wrap.

Zip tie the Z-stage limit switch cables to the the motor housing. Do not tighten these cable ties too aggressively, as the hard plastic can cut in to the cable insulation, although the bundling wrap will help protect the insulation. Starting a few cm from the connections to the Z-stage, hold all of the cables together.

Now is a good time to push the table into its working position. You do not need more than about 30 cm of clearance behind the table now that most of the wiring is complete. When sliding the table, make certain that no cables are being stressed or tensioned. Remember to move the table by pushing on the legs and support, not the table top!



A small piece of bundling wrap can help hold the cables together as you determine the correct height for suspending the bundle.

Select a location in the ceiling that is slightly behind the ParFrame and centered left to right. If you are not supposed to muck around in the ceiling of your buidling, do not do so. Have one of your building engineers install an appropriate support for you at the location you designate.

If you do this work yourself, you need a solid structure to support the weight of the hanging cables. If you have a paneled drop ceiling like the majority of modern buildings, you will want to remove one of the panels. Identify a structural element that you can use (i.e. NOT a water or gas pipe). Secure a support to this and feed it below the panel and replace the panel. Many things will work here, including a daisy chain of zip ties, a coat hanger, etc.

Place the cables in the support and secure them loosely so they will not fall out. Adjust the length of cable between the support and the arrayer so that the Y-stage can travel the full length of its range. Test this by pushing the Y-stage carriage from one end to the other with the power to the arrayer off. There should be enough cable to reach both ends, but not so much that a loose bight of cable can catch the ParFrame gantry. Make sure all of the cables have the same amount of slack and that none are tighter or looser than the others.

When the correct length is identified, tighten the connection to the ceiling support, but do not damage the cable insulation. Wrap the cables in helical bundling wrap, using one or more pieces between the arrayer and the support and one or more pieces between the support and the ICM-2900. You do not need to wrap the cables all the way to their distal connections. Wrapping the cables as far as the height table on this side is fine, as it's more for aesthetics than anything.

When the cables are secured to the ceiling support, wrap the remaining cable in the helical bundling wrap.

General Arrayer Hardware Addition Advice

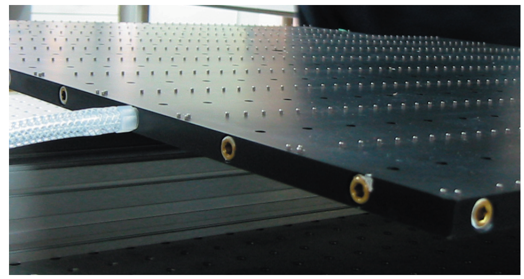
Now that the arrayer is correctly wired and will home, you can begin to add the pieces that make the arrayer an arrayer. These include a platter to hold the slides, a plate holder to hold the microtiter plate with the material to print, a bracket to hold the tips, a rinse station for cleaning the tips, a dry station for drying the tips, and a relay box for powering the rinse and dry stations.

This is also where you begin to make the arrayer more dangerous. With the addition of the platter, the reach and weight of the X-stage become much greater, as does the severity of making a miscalculation and moving it somewhere it shouldn't go. Furthermore, the risk of financial damage increases as you attach the bracket, print head, and print tips to the Z-stage. It's a fine idea to get comfortable with the movement of the arrayer using the joystick in the Align tab before you begin bolting the hardware on to the arrayer.

Platter Assembly

The platter is a vital component of the arrayer and is more delicate than it appears. Its important qualities are its light weight, flatness, and smoothness. The light weight allows the X-stage motor to move rapidly. The flatness and smoothness permit the slides to be held in place with no more than vacuum and the friction of the slides against the surface. In handling the platter, be careful not to scratch the black anodized surface or to bend the corners by dropping it. Lifting and moving the platter is a TWO person job. Take particular care with the thinnest part of the platter, where the plate holder will be attached.

The small holes in the platter hold dowels that define the rows of slides and hold them in a precise alignment. These need to be filled with the dowels provided. Be careful not to drop the dowels into the large holes in the platter. If you do this, simply hold the platter up and tilt it so the dowel falls out one of the holes. The dowels should extend no more than a mm or so above the surface of the platter. Push any that are not fully inserted down as far as they will go. Do NOT hammer them into place, as you will risk damaging the surface of the platter.



The platter, showing the dowels on top, the plugs in the back and side, and one of the nozzles for the vacuum line.

The large holes on the surface of the platter are for the vacuum. These link up with long channels in the platter that are drilled with a bit used for gun barrels. There are two independent channel systems in the platter: one for the first column of slides (right-most, closest to the plate holder cutout) and another for the rest of the platter. These two systems will be connected to the house vacuum by nozzles. The remaining holes in the sides of the platter must be sealed so that the vacuum pulls through the holes in the surface only.

Insert one nozzle into the right most channel. Simply tighten this PFTE nozzle by hand. Do not over tighten. Insert a second nozzle into the 3rd channel from the left side of the platter. Use of this channel will prevent the vacuum hose you will eventually attach to the nozzle from dragging on the X-stage.

The brass plugs for the remaining holes are provided with the platter. These plugs are NOT METRIC. You will need a 3/16” hex wrench to install them. Cut a 3 cm length of Teflon tape for each plug. Hold the plug with the hex side facing you and wrap a piece of Teflon tape around the threads in a counter-clockwise direction. Insert the plug and tighten with a 3/16 ball driver. DO NOT OVERTIGHTEN. The plug does not need to be flush with or inserted beyond the side of the platter. Over insertion of the plug can cause the surface of the platter to buckle, which would render that section of the platter useless. You will be able to identify any leaks easily by sound when you apply vacuum to the platter.

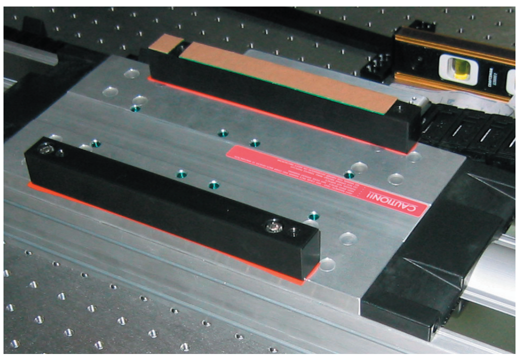
There are also four counter-sink holes in the surface that accommodate the mounting bolts. We will use these in the next section.

Platter Mounting

The X-stage will carry the platter. To keep vibration to a minimum, the platter is mounted on a pair of riser blocks with a little bit of shock absorption. It is best to have the power to the arrayer off when installing the platter.

The two delrin riser blocks should be included with the other parts from Die-Tech. These each have four holes: two threaded and two not threaded and countersunk. The side with the countersinks is the up side. The countersink holes are used to secure the blocks to the carriage of the X-stage. The threaded holes are then used to attach the platter to the blocks.

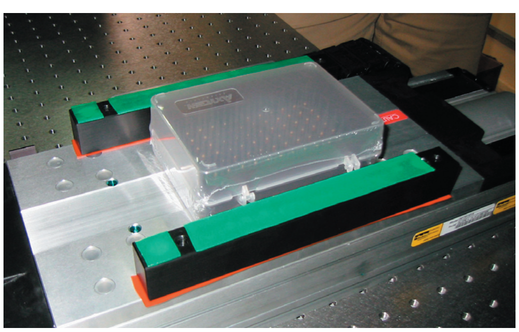
Cut two pieces of silicone rubber that are the same size as the bottom side of one of the riser blocks. Place this strip of silicone underneath the block on a flat surface. Insert a pen through the countersink holes on top of the block so that you mark the location of the hole on the silicone; try to mark the center of the hole. Using a hole punch, make a hole in the silicone centered on your marks. These will allow the bolts to pass through the silicone.



The platter risers secured to the X-stage carriage, with GSS (under its protective tape) applied to one of them.

Put the pieces of silicone on the X-stage carriage and align the holes in the silicone with the outer-most threaded holes in the carriage. Orient the silicone so that the end with the excess faces the front of the arrayer. Place the riser blocks on top of the silicone (make sure they are right-side-up) so the holes in the block can access the holes in the carriage. Bolt the blocks to the carriage using M6x25 bolts. Do NOT OVERTIGHTEN these bolts. The connection should be secure, but not overly tight. If the bolts are too tight, undesirable vibrations will be transferred to the platter. Don't worry about seeing this problem, you will HEAR it.

The shock-abosorbing system for the upper side of the blocks is a little bit different. We use a very useful substance known formally as "Green Sticky Stuff". While a little expensive, GSS has excellent properties useful in the assembly of your arrayer. To cut GSS, the best trick is to stick it to a piece of parafilm and then cut it with scissors. If a piece of GSS gets stretched out, deformed, or stuck to itself, you can either trim the damaged portion away or discard it entirely.

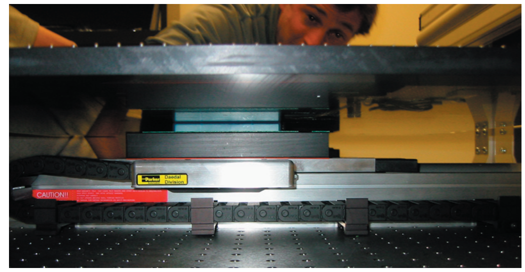


The X-stage carriage ready to mount the platter. The risers are covered with GSS and a box is in place to support the platter during alignment.

Cut a length of GSS as long as the riser blocks. Cut this piece in half lengthwise; this should be exactly as wide as the riser blocks. Trim the ends so that the threaded screw holes will not be obscured by the GSS. Reserve the trimmed pieces so that the top of the countersink hole can also be covered. Remove the parafilm carefully from each piece, pulling parallel to the surface of the GSS so as not to stretch it. Stick this to the top surface of the block, taking care not to impede access to the threaded holes. Remove the protective tan paper covering.

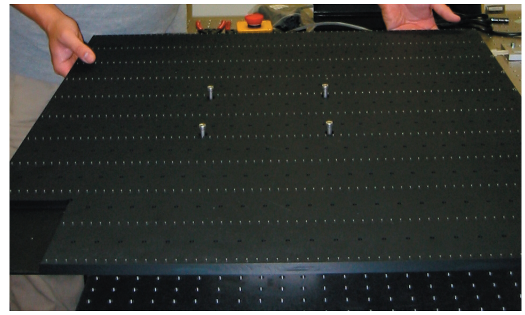
Now, the riser blocks are ready for the platter. Since the GSS is not very good at letting go of something once it has touched it, precise placement of the platter is a priority. Find a tip box or something similarly sized and sturdy and place it on the center of the carriage in between the riser blocks. This tip box must be TALLER than the riser blocks for this to work. Ideally, it should only be 1 or 2 cm taller.

Lift up the platter (two people, please) and set it on the tip box. Support the platter so that it does not tilt or touch the GSS on the riser blocks. Insert four long M6x40 bolts through the holes in the platter and use these to find the threaded holes in the riser block. Try to avoid sticking the bolts into the GSS on top of the blocks. Thread the bolts into the holes just enough so that they are stably inserted.



The platter resting on the box ABOVE the GSS on the risers, ready for insertion of guide bolts.

When you have all four of the bolts threaded, lift the platter up off the supporting tip box. You will be limited in how high you can lift it by the bolts. Remove the supporting tip box and SLOWLY lower the platter onto the GSS on the risers. When the platter is down, you can remove the M6x40 bolts. Bolt the platter to the risers with LOW HEAD M6x12 bolts. You will know if you have used the wrong bolts if the head sticks up above the countersink. Do NOT OVERTIGHTEN these bolts. In fact, these bolts will barely be tightened at all. Again, you will hear it if these are too tight the next time you power up the arrayer.



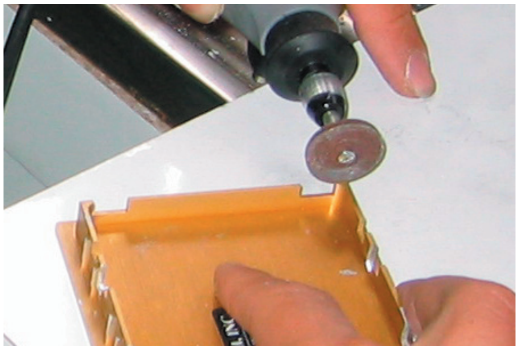
The platter being lowered onto the GSS. The M6x40 guide bolts are visible sticking up above the surface of the platter.

A word of warning. Now, the arrayer is no longer safely confined to the limits of the table. At both the front and back side, the platter now reaches well beyond the travel length of the motor and the table. Push the platter all the way to both ends of its travel and mark the floor in front and behind the arrayer with a piece of lab tape to indicate where it is safe to stand. The arrayer can move VERY fast and the platter is heavy. Be careful.

Launch the software and power up the arrayer. When you begin the home routine, do not be surprised if the room is filled with the noise of the vibrating platter. Allow the arrayer to finish homing. When it is in its home position, it will probably hum less than when it is in motion. Loosen the mounting bolts slightly and retighten just enough. Try moving the platter around, either with the Terminal or some of the buttons in the Align tab, to check the noise level. Ideally, you should not really hear any of the vibration noise. Your cause can also be aided by fashioning a small o-ring out of silicon rubber, removing the platter mounting bolts completely, and reinserting them with the o-ring around the threads and against the head.

Connect the nozzles to the house vacuum using the smaller of the two sizes of vacuum hose you ordered. Split the vacuum coming from the wall with a Y-junction. If you have stopcocks, insert these into the line after the Y-junction. Connect the each hose to one of the nozzles. Make sure that when the platter is all the way to the front of the arrayer, the hoses are long enough so that the vacuum fittings do not bind on the cables or catch on anything.

Plate Holder Modification and Installation

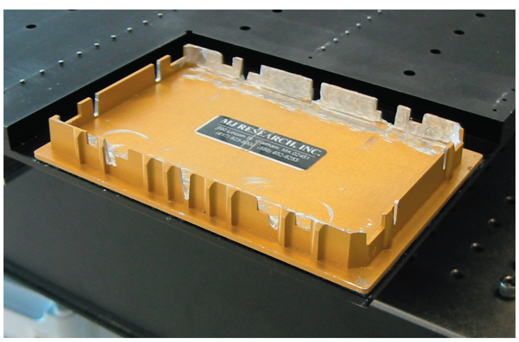


Modifying the plate holder with the Dremel. Watch your fingers!

For our arrayer, we use a modified MJ Research plate holder to secure the plate. This plate holder has the advantage of only accommodating the plates in one orientation, which vastly reduces the misorientation of plates by researchers during late-night print runs. It also has the disadvantage of not being designed specifically for our plates, which are usually Genetix 384-well polypropylene. So the holder must be modified to accommodate the plates.

The right tool for this job is a Dremel hand tool. Install the disk cutting tool according to the directions for the Dremel. Place a plate over the plate holder and inspect the area around the skirt. There are several pieces of plastic that connect the skirt to the wells of the plate, which then collide with the rim of the plate holder. Mark the areas where this occurs on the outside of the plate holder with a Sharpie. Allow about 1 mm on either side of the plastic. Make the mark a filled in rectangle that extends from the top of the rim down to the level of the inside surface of the plate holder.

Using the Dremel, completely excise the marked area. Be REALLY CAREFUL doing this. Since the cutting tool spins, if it bites a little to deeply, it can spin away from where you are trying to hold it. Don’t cut yourself. Use a vise to secure the plate holder to a work surface and a hold the Dremel with both hands.



The plate holder attahced to the platter with GSS,

You will also need to take a fraction of a mm off of the outside ridges of the plate holder. The cutting wheel can also be used for this. Just do this lightly, enough to remove the golden anodizing and expose the silver metal underneath, but no more.

You will know when you are finished when the plate slides easily yet snugly into the plate holder. If it is too tight, it will be difficult to remove, but do not make it too loose, as you can’t make it tighter again. When you are finished, clean all of the metal dust off of the plate holder.

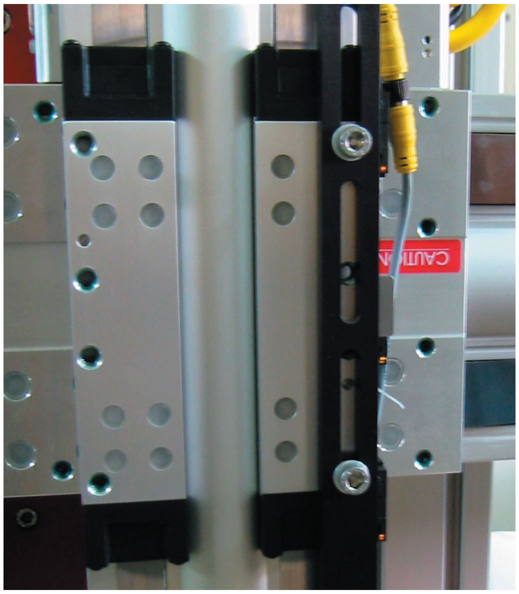
To attach the plate holder to the platter, we will use a little GSS. Remember to use the parafilm trick to cut it. Cut a piece of GSS that is just a mm or two shorter than the long axis of the plate holder. Cut this in half lengthwise. Remove the parafilm and apply to the underside of the plate holder along both of the long sides. Now cut a 3 cm long piece of GSS. Cut this in half lengthwise (to get two pieces 1.5 cm wide). Apply these to the short sides on the underside of the plate holder. Leave a gap between both the longer pieces of GSS; these gaps will facilitate removal of the plate holder, should this ever be necessary.

Before you attach the plate holder, figure out which orientation is right for your plates. The notches in the plate holder should face either right or left, so that well A1 of your plates is in the back left corner. That is, the well labels on the plate should not be upside down when you are reading them.

Remove the protective tan paper from the GSS. Hold the plate holder securely a few cm above the platter. Using your fingers, align the edges of the plate holder with the edges of the platter. Slowly lower the plate holder, maintaining this alignment with your fingers. If the edges remain flush, you should have the plate holder installed without any rotation. Squeeze the plate holder firmly in place, pushing on the plate holder from above, while pushing up from the underside of the platter.

You won't know for certain that your alignment is a good one until you have the tips installed. If you have made a mistake, you can get the GSS to release by squirting a little ethanol underneath the plate holder through the gaps in the GSS. Let it sit for a few minutes, then pry it up using a weighing spatula to encourage the GSS to let go. Try not to gouge or bend the platter in the process. You will probably need new GSS, as the old stuff will be stretched out during the removal.

Z-Stage Bracket & Print Head Mounting

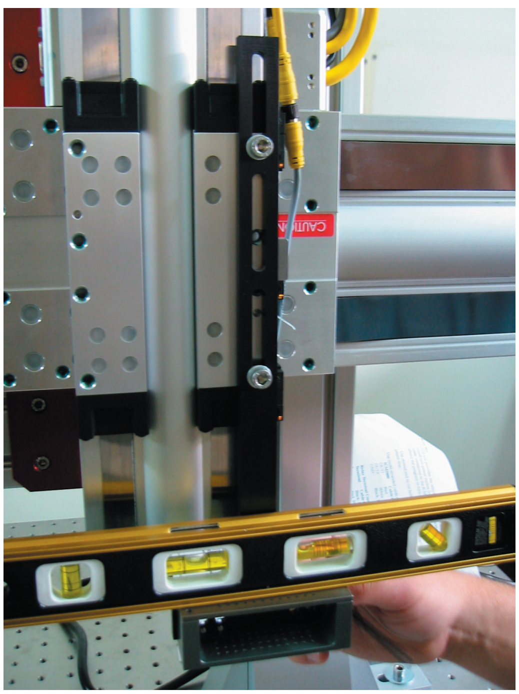

The attachment of the Z-print bracket to the Z-stage carriage.

The Z-stage bracket connects the Z stage carriage to the printing tips. It is important that this be set to a height that does not place the tips at risk. It is also important that the print head be level so that the tips all strike the slides evenly.

To begin, the arrayer should be powered up and homed. When it finishes homing, it returns to what is called its Ready position. The height of the Ready position is very important as this is used as the "safe" height. That is, when the arrayer is at that height, the tips should be unable to contact anything on the surface of the arrayer. Generally, the object that stands the highest is the sonicator used for the Rinse station. Place this on the table for a reference point.

Attach the tip holder to the bracket. There are two small bolts that hold the tip holder in place. The back of the bracket has the countersinks for these bolts. Try to make the connection a level one, with the long axis of the tip holder perpendicular to the arm of the bracket.

Bolt the bracket onto the Z-stage carriage. It doesn't really matter which side of the carriage you use, but using the right-most set of threaded holes is preferred. This will keep the arrayer farther from the end of its travel length. Notice that the upper-most and lower-most holes are perfectly aligned with each other, but are a little out of line from the middle pair. Use the upper- and lower-most holes; do not use the middle holes. Use M6x16 bolts and washers for mounting.


Leveling the print head.

Mount the bracket loosely at first, then tighten it in to place at the correct height and with the print head level. Having a bubble level is essential for leveling the print head this way, but it can also be done with the tips inserted later. Remember that the tips extend below the printhead several centimeters. Insert a tip to check the height. How to do this depends on the style of print head. See the Printing Manual for complete instructions.

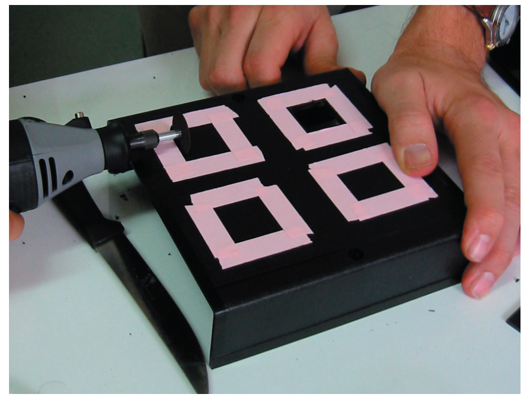
If you cannot get the print head level by adjusting the bracket, you can adjust it further using the bolts that secure the print head. There is some play in the countersink for the bolts, so you can adjust the level there, too.

Relay Box Assembly

Time to dust off your wiring and soldering skills. The relay box turns the rinse and dry stations on and off as they are required. The controller card sends a small signal into the solid state relays in the box which power the outlets coming out of the box. The outlets all share power from one inlet; you will wire the connections that make this possible.

Remove the lid from the black plastic enclosure by undoing the screws in the bottom. Remove the side panels also so that the interior can be accessed easily. Glue 3 solid state relays to the bottom of the relay box. Make sure they are all facing the same direction.

Using the Dremel and a drill bit or cutting disc, cut four squares in the lid of the plastic enclosure to accommodate the power inlets and outlets. Mark the area to cut out with a pen or tape, as shown at right, so that you do not make the hole unnecessarily large. Distribute the holes so that they are not too close to one another or the sides of the box. Glue three power outlets and one power inlet into the holes so that they face the outside of the box. The inlet snaps into place. If it is not inserted far enough into the hole, the piece that snaps in will protrude into the inlet and prevent you from inserting a power cord. You can remove this piece carefully with the Dremel.

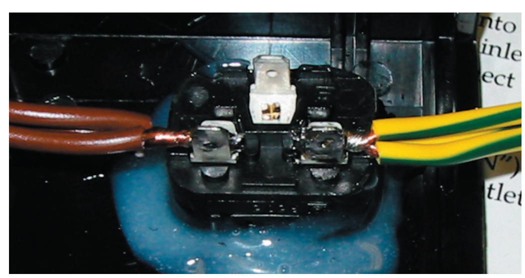


Cutting outlet and inlet holes in the top of the relay box.

Replace the lid on the enclosure, and make certain that you have the ridges on the top and bottom aligned so that it closes completely. Now open the lid, invert it, and set it down immediately next to the bottom. This will ensure that you can easily close the box when you are finished wiring it.

Cut and strip the wires you will need. Ideally, these will be long enough to make assembly easy, but not so long as to impede the closing of the box: about 25 cm. You will need 4 different groups, 3 wires each; here we use black, brown, blue, and green, but you will not have a separate color for each, so take care when wiring. Use the wires from the 10 ft. length of 3-conductor cord (McMaster 7422K21). Remove the shielding and strip 3 cm of insulation from one end of each wire and about 6 mm from the other.

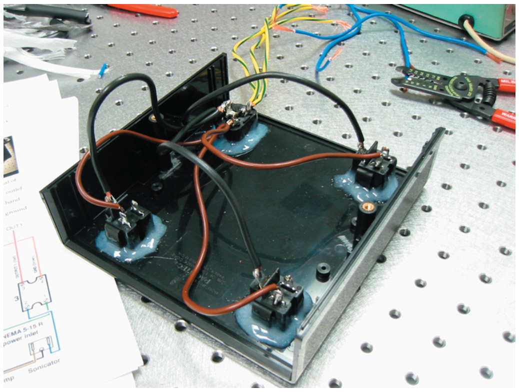
For three of the colors of wire (black, brown, and green), twist the longer exposed end together with the other wires of that color and trim the combined wire to about 1 cm.



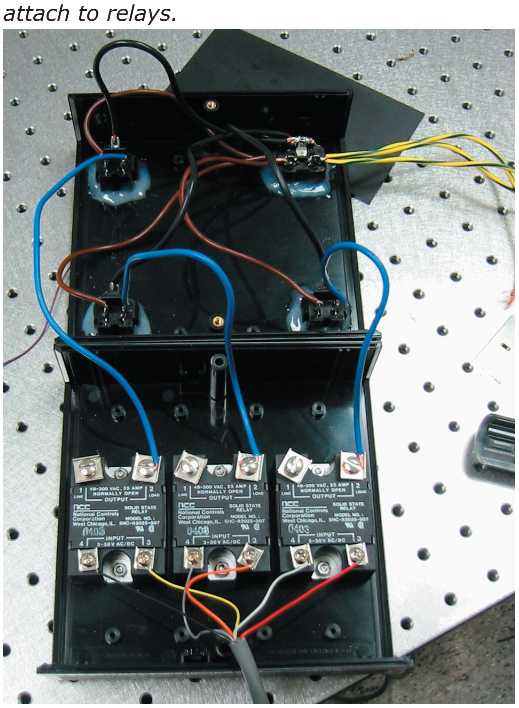
Load and Neutral wires soldered to the back of the relay box power inlet.

Connect the brown wires to the neutral terminals. Solder the bundled end to the terminal of the power inlet labeled "N". With the ground terminal on top when viewed from the side you will solder, this is the left terminal. Again, the hole is too small for the wire, so you must solder it to the side of the terminal. Connect each of the other ends of the wires to a neutral terminal of one of the power outlets. This is the terminal for the larger of the two holes in the outlet. When looking at the outlet from the inside of the box, with the ground terminal on top, this is the left terminal. Feed the wire through the hole in the terminal on the outlet and solder it in place.

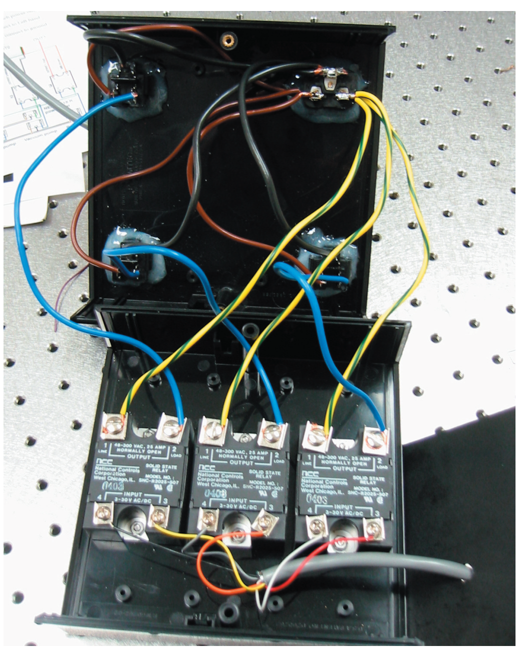
Connect the green wires to the load on the inlet and terminal 1



Lid of relay box, with ground and neutral connections complete, and load wires ready to attach to relays.



Inside of relay box, with load connections to relays complete and control wire attached.



Inside of relay box, with all connections complete and control wire fed through side panel.

on the relays. Solder the bundled end to the last terminal on the power inlet, labeled "L". With the ground terminal on top when viewed from the side you will solder, this is the right terminal. Again, the hole is too small for the wire, so you must solder it to the side of the terminal. Connect each of the other ends of the wires to terminal 1 "LINE" of one of the relays. Place the metal fitting over the hole, insert the screw provided with the relay, loop the stripped wire around the screw, and tighten. It does not matter which wire goes to which relay.

Connect the black wires to the ground terminals. Solder the bundled end to the central terminal on the back of the inlet, marked with the ground symbol. The hole in the inlet terminal is too small to feed the wire through, so solder it to the side of the terminal facing away from the other terminals. It is helpful to put a little solder on the terminal before trying to connect the bundled wire. Connect each of the other ends of the wires to one of the ground terminals (the one in the center, perpendicular to the others) on the power outlets. Feed the wire through the hole in the terminal on the outlet and solder it in place.

Connect the blue wires to the load on each outlet and terminal 2 on the relays. Insert a blue wire into the hole on the load terminal on each outlet and solder into place. With the ground terminal on top when viewed from the side you will solder, this is the right terminal. It is the terminal for the smaller hole of the power outlet. Connect the other end of the each wire to terminal 2 "LOAD" of one of the relays. Place the metal fitting over the hole, insert the screw provided with the relay, loop the stripped wire around the screw, and tighten. It does not matter which wire goes to which relay. They are all equivalent at this point.

Using the Dremel, cut a small hole in the center of one side panel. The hole should be just large enough to insert a piece of 10-conductor cable. Place the side panel in the notches in the bottom of the box. Cut a 3 m piece of 10-conductor cable. Strip about 10 cm of insulation from one end of the cable and strip 1 cm of insulation from the black, gray, white, red, orange, and yellow wires. Cut off the other wires. Feed this end through the hole in the side panel.

Number the relays, left to right, one, two, and three. Connect the wires from the 10 conductor cable.

Relay	Terminal 3	Terminal 4
One	Yellow	Black
Two	Orange	Gray
Three	Red	White

Secure the cable coming into the side panel with a cable tie so it can not pull out. Mark the number corresponding to each relay on the outside of the box next to the outlet it controls. Simply follow the blue wire to the outlet to determine which outlet is controlled by which relay. Replace the sides and lid and screw the box closed.

Strip 10 cm of insulation from the other end of the 10-conductor cable. Strip 5 or 6 mm from the red, orange, and yellow wires. Strip about 1 cm from the black, gray, and white wires. Twist the black, gray, and white wires together and trim the wire to about 5 or 6 mm. Remove the unused wires. Cover the end of the cable insulation with a little heat shrink. Connect to the ICM-2900 as shown at right. Remember to feed this cable, like all the others, through the gap behind the ICM-2900 so that it can be included in the cable management system.

ICM-2900	Cable Color
GND	Black, Gray, White
OUT1	Yellow
OUT2	Orange
OUT3	Red

Relay box control connections to the ICM-2900

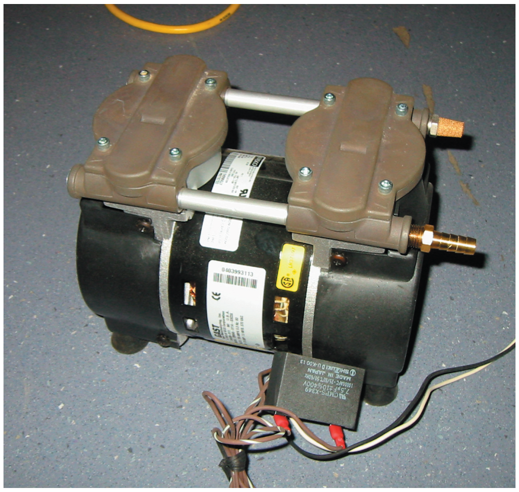
Test the relay box. Plug the box into a 110 V wall outlet. The most convenient and small electrical device in the room is usually the Dremel, but almost anything will do. Start the software and connect to the controller; the arrayer does not need to be plugged in. Go to the Terminal tab. Plug the Dremel into each of the outlets in turn and test it.

Command		Examples	Results
OP	Output	OP 0	All outlets OFF
		OP 1	Outlet 1 ON
		OP 2	Outlet 2 ON
		OP 4	Outlet 3 ON
		OP 7	Outlets 1, 2, and 3 ON

If one of the outlets does not appear to work, try turning them all on. If it goes on, you might just have it misnumbered. Turn them all off and then turn them on one by one. If it still won't work, check the colors of the wires for the 10-conductor cable and that they are properly connected to the relays and the ICM-2900. ALWAYS UNPLUG THE RELAY BOX FROM THE WALL BEFORE OPENING! If none of the outlets work, check the power connections inside the box.

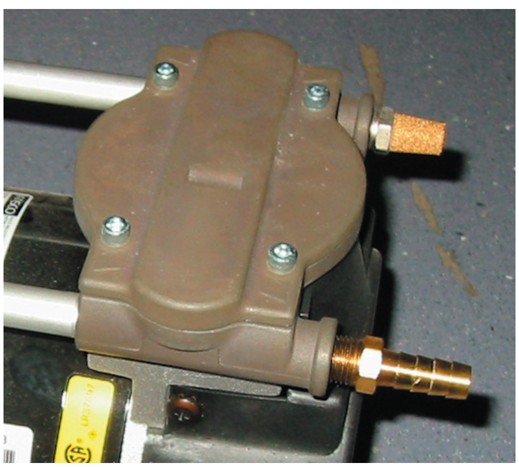
If all works as it should, place the relay box on the floor underneath the arrayer table.

Vacuum Pump Assembly



The vacuum pump for the dry station.

Vacuum pump capacitor connected to pump wires.



Air ports on the vaccum pump, near intake port with barbed fitting, and exhaust port with muffler, far port.

Vacuum trap secured to table support and attached to the vacuum pump by hosing. The free barbed fitting will be attached to hosing to the dry station.

The vacuum pump is fairly easy to assemble. It is shipped, somewhat inconveniently, without a power plug installed.

The cable coming out of the pump has four wires: two brown, one black, and one white. The black and white wires are for the power cord. Take one of the smaller capacity 110 V power cords with a plug on the end and connect it to the wires to the pump. Which wire connects to the load or neutral wire for the power cord does not matter. Use a length of wire to extend the ground wire from the plug to the screw on the outside of the pump chassis. Butt splices are probably the easiest method to connect the wires, although the junctions could also be soldered and covered with heat shrink. In either case, a larger piece of heat shrink should be used to cover the connections for all three of the wires. Don't forget to put this over the wire before you begin connecting.

The two brown wires are attached to the terminals of the capacitor, the small black box that comes with the vacuum pump. They have attached connectors that slide directly over the terminals of the capacitor. It doesn't matter which wire goes to which terminal.

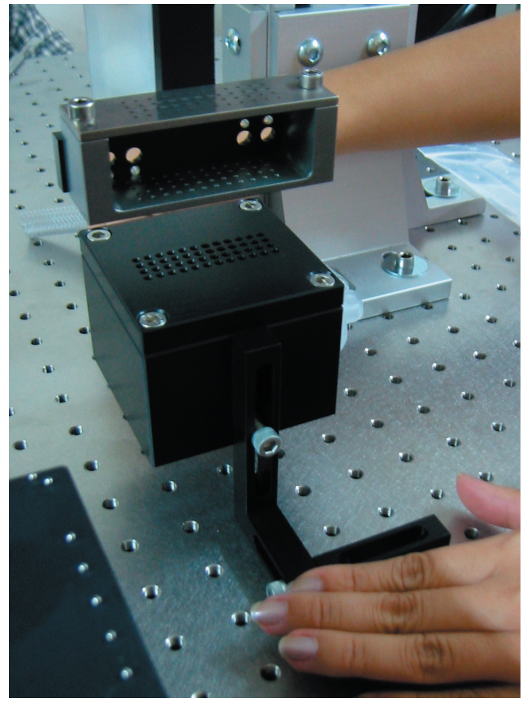
Air is drawn in to the pump at the top. There are arrows on the top to indicate the direction of flow. Two of these, one for each direction, should be closed with small organge plastic caps; the others will be sealed with bolts. Pull the orange plastic caps out. Replace the intake (arrow into pump) with the brass fittings with the barbed connectors. Attach the provided muffler to the exhaust port. Put a little teflon tape around the threads of each before insertion.

Cut a 0.5 m length of the thicker vacuum hose. Attach this to the pump intake. Attach barbed fittings to either side of the lid of the trap. Remove the packing materials from the trap bottle so the ball rattles around inside. Screw the lid on to the bottle. Attach the other end of the vacuum hose to the exhaust from the trap. Cut a 2 m length from the remaining hose and attach this to the intake of the trap. You will connect this to the dry station in the next section.

Plug the power cord into the relay box, using outlet 3 (should be connected to OUT3) on the ICM-2900. You can test the pump wiring by using the "OP 4" command as you did above, with the software on, but no power to the motors. The pump is really loud, so that's normal.

Dry Station Assembly & Mounting

The dry station is not a complicated device, but it can be a challenge to install correctly. You want it to be level and square with respect to the tips so that they go straight into it, make a good seal, and don't get bent or damaged. It is not trivial to adjust, so take your time and don't drink too much coffee beforehand.

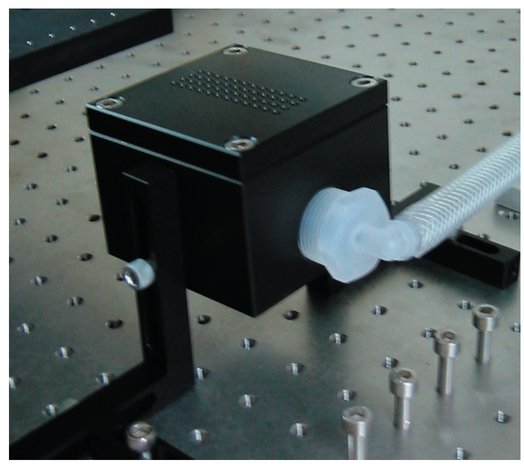


Roughly align the dry station with the print head without tips.

All the threads on the dry station and its pieces are Standard sizes, not Metric. The only metric bolts you will use are to attach the dry station to the table. The others should all be 1/4-20 3/4" bolts. Only gently tighten these bolts at first, as they will need to be adjusted after assembly.

Attach the L-shaped brackets to the dry station so that the attached side extends down away from the top side (the one with the small holes for the tips). The other arm of the L should point directly away from the side of the station. Use only the upper of the two holes in the dry station to attach the L-shaped bracket. Having two bolts will make it a little too unmovable an object, should the arrayer be induced to collide with it.

Hold the dry station so that the large hole is on the left hand side. Attach the straight brackets to the legs of the L-shaped bracket so that the straight bracket extends to the right, away from the side with the hole. Slide these straight brackets so they attach to the middle slot in the L-shaped bracket. The end of these straight brackets is threaded so you can attach a bolt. Make sure the straight bracket is turned so that the slot in it faces the table.



Attached barbed elbow fitting and vacuum hose to the vacuum trap.

Take one of the large barbed elbow fittings and screw it in to the dry station. Holding this with the hole on the left-hand side of the station, tighten it so that the barbed end points away from you.

Place the station on the table to the right of the platter. The edge of the station itself should be about 6 or 7 cm away from the platter to allow room for the dustcover (the holes in the table are 2.5 cm apart). The barbed end of the elbow should face the back of the table. The straight brackets should extend to the right. Roughly align the station by eye so that it is in line with the print head. Attach the dry station to the table with M6x20 bolts through the straight brackets. Try to pick a hole in the table that will allow a little adjustment and not one that is at the end of the slot.

Before you begin fine tuning the alignment, attach the barbed fitting to the end of the vacuum hose. Simply push the hose onto the nozzle. It should fit very snugly.

Now, loosen the bolts that secure the station to the L-brackets. Place the station in the brackets so that the top of the station is about 1 cm higher than the top of the platter. Tighten the bolts. Check the levelness of the dry station, both left-to-right and front-to-back. Adjust it so that it is both level and at the correct height.

Put four printing tips in the print head, with one in each corner. Push the arrayer into position so that the tips are just above the surface of the dry station. Align the dry station front-to-back and rotationally, so that the tips align with the holes in the dry station. To do this, you will be loosening both the 3/16 bolts on the straight brackets and the M6 bolts to the table. The bolts to the table will help the rotational alignment, while the ones on the straight brackets will do the front to back.

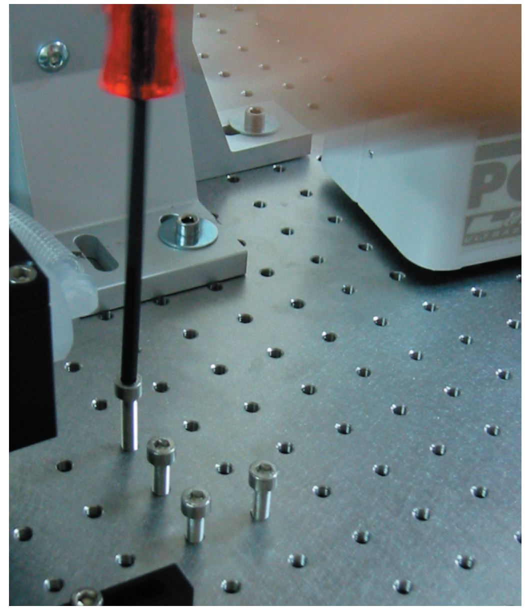
As you tighten a bolt, the friction of the bolt head against the bracket will sometimes pull the station out of alignment. Tighten the bolts carefully and avoid sudden movements. Be patient. You won't have to move this very often, if ever, so get it right the first time.

Test your vacuum connection to the dry station by turning the pump on ("OP 4"). You should hear the air rushing through the holes in the dry station. Cover these holes with your hand or a piece of lab tape, and you should hear the pitch of the pump change as it makes a good seal. You will expect the same change in pitch when you insert the tips for drying. Make sure that your fittings on the pump and the trap are secure and not leaking vacuum.

When you are confident that the pump and dry station are properly connected, secure the trap to the table so that it is in an upright orientation. The trap will not function correctly if it is not upright. If water gets into your pump, it will break.

Wash Station Positioning

This is a lot easier than anything else in this guide. Take the sonicator out of the box. Remove the cover and the cage. Place the sonicator on the table next to the dry station, further from the platter. Align the long axis of the sonicator with the long axis of the print head. Position the sonicator so that there is at least one column of bolt holes exposed in the table between the dry station and the sonicator. Fill these bolt holes with M6 bolts. Also fill the holes in front and in back of the sonicator with bolts. Leave the right side open so the sonicator can be slid across the table.



Constraining the placement of the sonicator may seem trivial, but it's very crucial.

CHECK YOUR READY POSITION! Are the tips positioned high enough when the arrayer is in its Ready position to clear the edge of the sonicator? If not, adjust either the position of the bracket on the Z-stage carriage, or change the Z setting for the Ready position in the Configure tab of the software.

DO NOT FORGET: If you adjust the Z-stage bracket, you will need to realign the dry station and plate position.

Plug the sonicator into outlet 1 of the relay box. Test the relay box and the sonicator with the OP 1 command.

Rinse the inside of the sonicator thoroughly before use, but do not use soap. Just use lots of distilled water. When rinsing, be careful not to get water inside the housing of the sonicator, through the vents on the back.

Dust Cover Measurements

Have a local plexiglass shop cut these pieces for you.

Metric

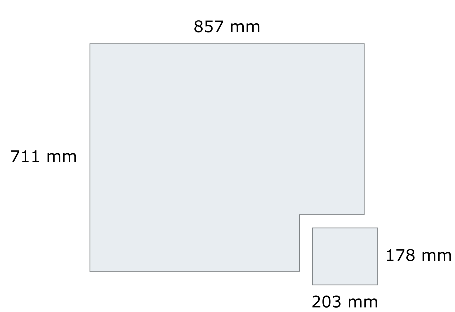
Cover	Piece	Thick	Width	Length	Quantity
Front	Side	12 mm	127 mm	711 mm	2
	Front	6 mm	133 mm	857 mm	1
	Bottom	6 mm	127 mm	857 mm	1
	Top	6 mm	711 mm	857 mm	1
		includes a cutout 178 mm W x 203 mm L -- see diagram			
Back	Side	12 mm	127 mm	737 mm	2
	Top	6 mm	737 mm	857 mm	1
Amps	Side	12 mm	406 mm	279 mm	1
	Top	6 mm	406 mm	457 mm	1
	Side	6 mm	445 mm	279 mm	2
		includes a cutout 127 mm W x 114 mm L -- see diagram			

U.S. Customary

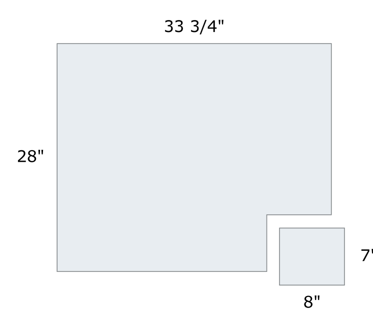
Cover	Piece	Thick	Width	Length	Quantity
Front	Side	1/2”	5”	28”	2
	Front	1/4”	5 1/4”	33 3/4”	1
	Bottom	1/4”	5”	33 3/4”	1
	Top	1/4”	28”	33 3/4”	1
		includes a cutout 7” W x 8” L -- see diagram			
Back	Side	1/2”	5”	29”	2
	Top	1/4”	29”	33 3/4”	1
Amps	Side	1/2”	16”	11”	1
	Top	1/4”	16”	18”	1
	Side	1/4”	17 1/2”	11”	2
		includes a cutout 5” W x 4 1/2” L -- see diagram			

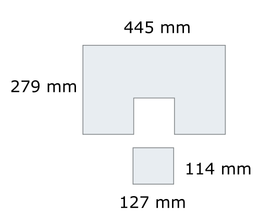
Diagrams

Front Dustcover, Top

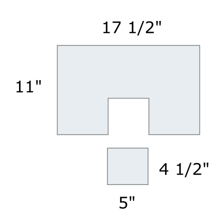


Front Dustcover, Top





Servos Dustcover, Sides



Servos Dustcover, Sides

Diagrams for cutting the plexiglass for the dustcovers.

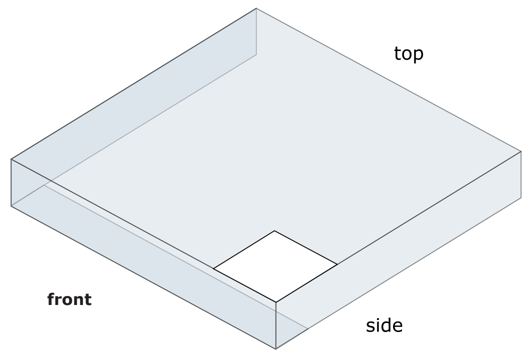
Dust Cover Assembly

The dust cover is a very important feature of the arrayer. Not only does it prevent particulates from gathering on your slides, it also prevents the arrayer itself from doing harm to its users. The dustcover will prevent users from standing in the region adjacent to the table that the X-stage can reach.

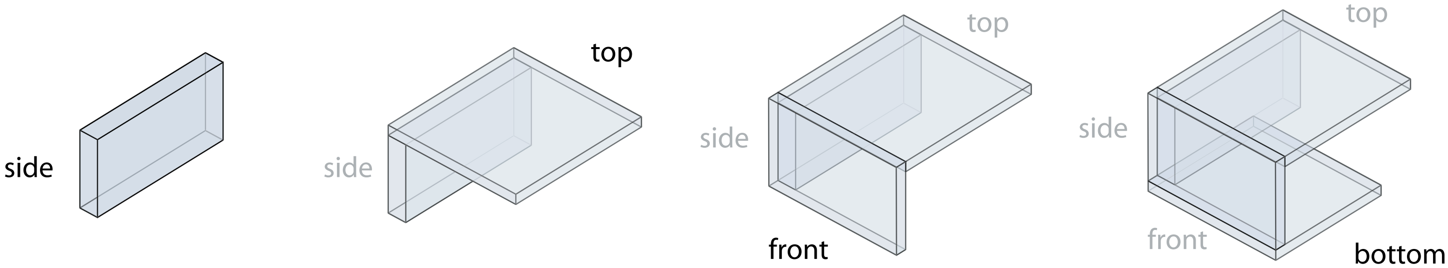
You will join the pieces of acrylic with methylene chloride, which melts the plastic and seals it together. If straight methylene chloride is a little too difficult to handle (read: drippy), you can buy commerical plexiglass cement. This product is just methylene chloride with a little plexiglass dissolved in it, so you can make it yourself from a few spare scraps of plexiglass. Methylene chloride is toxic and flammable, so please be careful when handling.

One thing to remember about the front dustcover is that you will look through this to check the quality of your arrays during printing. Try to be careful when assembling this part of the dustcover not to drip methylene chloride on the top piece of the cover; it will be difficult to see clearly through the parts that get splashed.

Assemble the pieces, following the diagrams. Remember that the hole for the plate holder should be where the plate holder is: in the front-most, right-most corner of the platter. You will be holding the cover upside down to assemble it, so make sure you have it in the correct orientation to be used when it is right-side up.



Diagrams for assembling the front dustcovers: above, showing the assembled front dustcover; below, the assembly of the left front corner, showing how the pieces align.

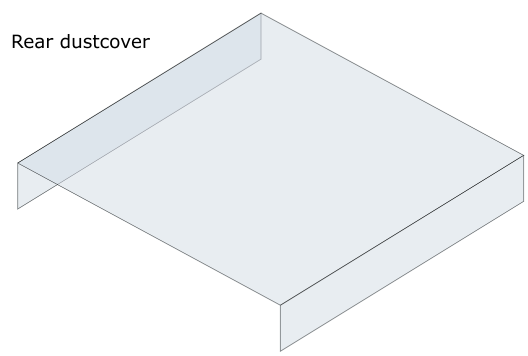


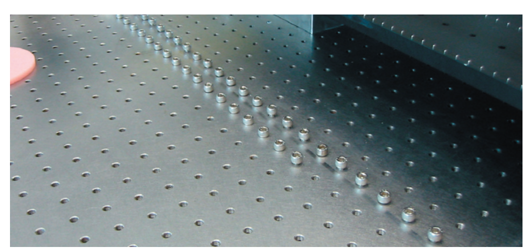
For the front dustcover, the top rests on top of the side pieces so that the sides pieces are flush with the all edges of the top. The front goes on flush with the top, so that it only reaches as far down as the bottom of the side pieces. The bottom piece then goes flush with the edges of the sides and front.

For the back dustcover, the top rests on the sides as for the front, so that the edges are all flush.

For the servo drive dustcover, the thick piece is the front most, the sides with the cutouts go on the left and right sides. The top sits on all 3. The open end should face the back and accomodate the ICM-2900.

For the front and rear dustcovers, make guides on the table using bolts on either side of each side piece of the dustcover. Constraining the placement of the dustcover in this manner is essential to the safety that the dustcover provides. The bottom of the front dustcover should constrain how far the dustcover can be pushed in, but if it comes too close to the print head, then limit it with a pair of bolts and a zip tie, as shown at left.





Rows of bolts in the platter will help align the dustcovers and offer industrial chic.

Fan Installation

Finally, now that you are ready to begin putting your arrayer through its paces more seriously, install the fan to keep the servo drives nice and cool.

The 12V fan is very easy to install. Attach the black wire to one of the GND connections on the ICM-2900. Attach the red wire to one of the +12V connections on the ICM-2900. As soon as you make this second connection, the fan should go on, so watch your fingers. The fan will run whenever the computer is powered on. Place the fan so it blows air along the heat fins of the X- and Y-stage servo drives.

The fan will run as long as the computer is on, so it is best to power down the computer when the arrayer is not running.

Platter Height Mapping Switch

This switch will be used with the automatic script to generate a relative platter height map, that is, a measure of how different a given slide is from the set Print Position height.

Wiring the Switch

If you have not already done so during the bundling of the Y- and Z-stage cables, cut a length of Belden 10-conductor cable so that it will reach from the print head to the ICM-2900, following the cable bundle to the overhead support. Attaching the wire to the cable bundle will make it easy to move the switch between its working position and an out-of-the-way position for print runs. If you have already included the wire for the switch in the bundle, even better.

Strip the shielding from both ends of the cable to expose 5 cm of wire. Choose two colors of wire to use; for our example here, we will use red and black. Cut away the remaining 8 wires from both ends. Strip 5 mm of each wire at both ends.

If you are interested in the appearance of your switch, cut a length of heat shrink to cover both the end of the shielding and the end of each wire for the switch end of the wire. Place these over the wire before soldering.

There are three terminals on the top of each switch. You will use two of them. Solder the wires to the switch terminals, being careful to make a solid contact. Because the switch will be moving around a lot, having these solder points be strong is essential to a functional, durable switch. Be careful not to damage other components of the arrayer if you are working on a cable that is already bundled into those supported from the ceiling.

Wire	Switch Terminal	`ICM-2900`
Red	C	`IN5`
Black	NO	`GND`

Testing the Switch

The ArrayMaker software has error-checking capabilities with the switch, but using the Terminal tab is a simple method of testing switch functionality without the need to restart the arrayer.

All of the digital inputs of that the Arrayer is capable of identifying are reported as a single 8-bit number. You can query the status of these inputs using the **`TI`** ("tell inputs") command. In the normal state, all of these inputs are off and each bit is high -- **`TI`** should return "255". Depress the switch with your finger and call **`TI`** again -- it should now return "239", which is 255 minus 16, the value of the 5th bit (for IN5). If the switch is not properly connected, it will still read 255. Releasing the switch should return the value to 255.

Consult the printing manual for the proper attachment of the assembled switch to the printing bracket.

Printing Protocol

Building an arrayer is a great first step in the production of a large volume of high quality arrays. However, the fabrication of the arrays themselves is a skill in itself. We have written a printing protocol specific to this arrayer that should cover all of the facets of printing in some detial. Please take the time to become familiar with the necessary subleties so that your arrays are of the highest possible quality.

The latest version of the printing protocol can be obtained from our web site.

http://derisilab.ucsf.edu/core/resources/

Appendix A -- Binary Numbers

Several of the commands to the Controller Card receive or return binary numbers as arguments. They express these numbers to you as a decimal number, like 255. Understanding how they work can help you troubleshoot several potential problems with the arrayer.

A binary number is just a collection of 1's and 0's that can represent any number you can think of. It's very easy for a computer to represent 1's and 0's, so binary is its preferred notation. A binary number looks like this: 11010001.

Each place in a binary number corresponds to a multiple of 2, instead of a multiple of 10 as in a decimal number. For example a simple binary number like 10 has a decimal equivalent of 2 -- that is, one 2 and no 1's. So a binary 11 is decimal 3. A decimal value of 255 corresponds to an 8 digit binary number: 11111111 (128 + 64 +32 + 16 + 8 + 4 + 2 + 1 = 255).

So, the way these numbers convey information is that each digit in the number corresponds to something physical about the arrayer. Like, the height detection switch is tripped -- this is Input 5 for the Controller Card, so the 5th bit (the one worth 16) drops to zero: 11101111 = 239. When the switch is untripped, none of the Inputs are on, so the value is 11111111 = 255.

The information in the TS command works the same way. Each binary digit corresponds to an event, like the limit switch being tripped, the motor moving, the motor being in error, etc. It's all represented as a digit in a binary number.

Appendix B --
Drive Configuration

The servo drives should arrive preconfigured for the appropriate motor. If, after powering up the drives, you see the left LED on one of the servo drives red and not green and you are confident that your emergency stop switch is properly connected, the problem may reside in the servo drive configuration.

You can obtain the correct configuration files (X_drive.prg, etc.) by contacting us.

The CDs included with the motors and manuals should include the Parker Compumotor Motion Planner software. This will allow you to communicate with the drives through the RS232 port on your computer. You will need a Null Modem cable, available at most Radio Shack or other computer stores.

You want to do this one servo drive at a time, so if you are concerned about the X- or Y-stages, unplug the L6-20 power cord and disconnect the jumpers between the drives. To test one of the drives, simply wire the power from the L6-20 cord directly to the servo drive in question.

Make sure the power cord for the drive is not plugged into the wall before you work with it. Detach the 50-pin cable from the DRIVE I/O port on the servo drive. It is not necessary to disconnect the Motor Feedback and motor power connections. Connect the RS232 port on the drive to the RS232 port on your computer. Plug in the power cord for the drive.

Open the Parker Compumotor Motion Planner software.

Upload brings data from Drive to Computer. Do this first to see how the drive is configured. Make sure you do Upload first. If you don't, you will send the empty settings in the software to the drive. You can always replace this information with the correct values later, but it will prevent you from knowing if you were getting an error due to a misconfigured drive without having to plug it in and test it again.

The correct settings for each servo drive can be downloaded from our web site. Compare what you recover from the drive to the correct files.

If the configuration must be replaced, load the appropriate configuration into the software and Download it. Download sends data from Computer to Servo Drive.

Appendix C --
A Few Previously Documented Problems

100-pin cable fails to make good contacts with controller card or ICM-2900, either due to bent pins in the connector or the connectors not attaching securely.

Bad limit switch constantly tripped. This should be replaced completely. Contact your Parker representative for details. The switches can be by-passed with some creative wiring, but this is not recommended. Consult the manuals accompanying the motors for details.

Limit switch too close to range of motion. This is a common problem on the Z-axis if the reach of the motion brings it very close to its forward limit switch. The position of the switch can be adjusted a little lower with a hex wrench.

Home switches not aligned to index. This will produce a failure to home during the routine and is addressed in detail above.

Screw from inside of carriage stuck on magnets inside motor. This actually happened once. We discovered it by sliding the carriage from one end of the travel length to the other by hand. The carriage would not move past a certain point. This would've been a disaster during powered motion, had it not been removed.

Packing foam in motor during shipping. If you have to move your arrayer, hopefully, you have retained the original shipping packaging. If you use a liquid foam to make custom pacakaging, be certain that this foam does not contact the motors.

Rubbing of domed cover, Y-stage. This is the result of a helicoil in the Y-stage carriage rubbing on the cover. Parker has fixed this problem in their assembly process. If you experience this problem, they will replace your domed cover, which can be shimmed at the mounting screws to provide a little extra space between cover and carriage.

Bent pins in cable, causing failure to detect home switch. This is a rare one, but if one of the cable connectors with your arrayer is damaged, you may experience something like this. Be careful with the cables!

Appendix D --
Common Controller Card Commands

TP Tell Position No Arguments
Returns 3 digits, the encoder coordinates for the X-, Y-, and Z-stages, respectively.
Use for Homing, Encoder Wiring, Motion Testing.

TI Tell Inputs No Arguments
Returns a single decimal number encoding the binary information about digital inputs (e.g. IN5). If no Inputs are active, the number will be 255. If one of the Inputs is active (e.g. the Height Detector Switch at IN5), the number will change (to 239 in this example), as that binary digit (16) is removed from the number.
Use for Height Detector Switch Testing.

TS Tell Switches No Arguments
Returns the limit and home switch status for the X-, Y-, and Z-stages, respectively, as a series of three decimal numbers. The interpretation of these numbers requires the following table, also found in the Galil Command Reference:

Binary Digit	Decimal Value	Status Information (inclusion of value indicates presence of condition listed)
7	128	Axis in Motion
6	64	Axis Error beyond Error Limit
5	32	Motor Off
4	16	Undefined
3	8	Forward Limit Switch inactive (not tripped)
2	4	Reverse Limit Switch inactive (not tripped)
1	2	Home Switch active (tripped)
0	1	Latched (encoder is armed)

Example, an arrayer with X- and Y-axes at their home positions and the Z-axis at neither limit would return 15, 15, 13.
Use for Wiring, Switch, and Motion Troubleshooting.

PR Position Relative Three Arguments, comma-delimited
Set the distance in encoder counts for a move for the X-, Y-, and Z-stages, respectively. The most common error with this command is to forget which axis is being specified; include commas to specify the correct axis. Remember that 1000 encoder counts is equivalent to 1 mm for the X- and Y-axes, and 1.1 mm for the Z-axis.
Use for Motion Testing.

SP Speed Three Arguments, comma-delimited
Set the speed for motion in encoder counts per second for the X-, Y-, and Z-stages, respectively. The most common error with this command is to forget which axis is being specified; include commas to specify the correct axis. The maximum value for these speed parameters is
Use for Motion Testing.

BG Begin Axis Arguments (X, Y, Z)
Begin Motion, using the previously established position and speed parameters. Specify one or more axes by appending the letter to the command: e.g. BGX. Failing to specify an axis will begin motion in ALL axes. The same motion can be repeated by calling

BG again. If you do not input a relative position and a speed before calling BG, no motion will occur; of course, the controller will always remember the last input you gave it until it is reset, so make sure you specify each move.
Use for Motion Testing.

FI	Find Index	Axis Arguments (X, Y, Z)
Puts the motor into a mode to look for the index on the encoder strip, the uniqe mark that indicates the origin of the coordinate system the arrayer will use. Choose a speed with the JG command that is no faster than 500. Begin the Find Index routine with the BG command.
Use for Homing Routine Troubleshooting.

FE	Find Edge	Axis Arguments (X, Y, Z)
Similar to the FI command, but instead of looking for the encoder origin, the motor will search for the edge of the home switch. Faster jog speeds will work in this case.
Use for Homing Routine Troubleshooting.

OP	Outputs	Binary Argument
Turns the output signals on and off. These are used to run the solid state relays in the relay box.
Use for Relay Box testing.

Command	Result
OP 0	All outlets OFF
OP 1	Outlet 1 ON
OP 2	Outlet 2 ON
OP 3	Outlet 3 ON
OP 7	Outlets 1,2, and 3 ON

MO	Motors Off	Axis Arguments (X, Y, Z)
Shuts off the motors. The easiest way to restart is to unplug the motors and restart the software.
Use to position the motors manually with the software on and the motors powered.

JG	Jog	Three Arguments, comma-delimited
Sets the arrayer to move at the jog speed (in encoder counts per second) until commanded to stop. Begin a jog motion with BG. Stop with ST.
Use for Homing Routine Troubleshooting.

ST	Stop	Axis Arguments (X, Y, Z)
Stops the current motion. Useful to abort a FI or FE mode motion that has not found its target.
Use for Homing Routine Troubleshooting, stopping any motion.

Appendix E --
Order of Assembly

Dependent Installation

Table
Y-Stage & Gantry
X-Stage
Z-Stage
ICM-2900 & Servo Drives
Wiring
Stop Switch
Power
Motion Testing
Homing

Remaining components can be assembled in any order, but the safest and easiest is usually:

Platter
Plate Holder
Print Head
Dry Station
Vacuum Pump
Rinse Station

Independent Preparative Steps can be undertaken by others during Dependent Steps:

50-pin cables, stripped
Emergency Stop Switch construction
Fuse Box construction & wiring
Relay Box construction & wiring
Vacuum pump assembly
Dustcover assembly
Platter dowels and plugs
Plate holder modification

Appendix F --
Parts Lists

Parts (require advance preparation)	Vendor	Phone	Cat #	unit	cost	qty	total cost
DeRisi Three Axis Arrayer Subsystem	Dynamic Solutions	949-585-9009	802-2933C		$25,058.00	1	$25,058.00
Y-Axis support	Dynamic Solutions	949-585-9009	DK100001A-1		$378.00	1	$378.00
Vacuum Platter	Die-Tech	408-279-3363	UCSF Style		$4,700.00	1	$4,700.00
Riser blocks for platter	Die-Tech	408-279-3363	UCSF Style		$95.00	2	$190.00
Dry Station	Die-Tech	408-279-3363			$760.00	1	$760.00
Dry Station Table Bracket	Die-Tech	408-279-3363			$95.00	2	$190.00
Dry Station Upright Bracket	Die-Tech	408-279-3363			$160.00	2	$320.00
Stage-ParFrame Mounting Plates	Die-Tech	408-279-3363			$120.00	4	$480.00
Breadboard, Scientific Gr 4, 4ft x 6ft, 4 inch thick, metric mounting holes	Newport	800-222-6440	M-SG-46-4		$3,113.70	1	$3,113.70
SLT-Workstation 36” x 72” (No Table, Non-isolated, No Castors)	Newport	800-222-6440	SLT-3672-OPT-NN-01-NN		$1,173.70	1	$1,173.70
DMC 1832 3-axis motion controller	Galil	916-626-0102	DMC-1832		$1,045.00	1	$1,045.00
DMC 2900 inter-connect module	Galil	916-626-0102	ICM-2900-FL		$295.00	1	$295.00
100 pin cable	Galil	916-626-0102	CABLE-100-4M		$150.00	1	$150.00
Vacuum Pump	Gast Manufacturing	616-926-6171	72R645-V114-D303X	each	$404.00	1	$404.00
Vacuum Trap Assembly	Gast Manufacturing	616-926-6171	AA672K	each	$38.00	1	$38.00
Exhaust Muffler	Gast Manufacturing	616-926-6171	EM2	each	$4.30	1	$4.30
				SECTION SUBTOTAL			$38,299.70

Tools (order if you don’t already have an equivalent tool on hand)	Vendor	Phone	Cat #	unit	cost	qty	total cost
10” straight jaw vice grip	McMaster-Carr Supply Co.	562-692-2323	5369A2	each	$3.00	1	$3.00
16-8 AWG wire stripper	McMaster-Carr Supply Co.	562-692-2323	7294K56	each	$9.00	1	$9.00
26-16 AWG wire stripper	McMaster-Carr Supply Co.	562-692-2323	7294K58	each	$9.00	1	$9.00
Dremel Light Duty Grinder, Standard Variable Speed	McMaster-Carr Supply Co.	562-692-2323	4344A56	each	$72.00	1	$72.00
Long nose pliers 5.5”	McMaster-Carr Supply Co.	562-692-2323	5614A5	each	$11.00	1	$11.00
Standard Ball Point Hex Driver, 5mm	McMaster-Carr Supply Co.	562-692-2323	5497A58	each	$3.00	5	$15.00
Ball Point T-Handle Hex Key, 4mm, standard length	McMaster-Carr Supply Co.	562-692-2323	37165A63	each	$3.01	1	$3.01
Ball Point Metric Hex set, 9 pcs.	McMaster-Carr Supply Co.	562-692-2323	57185A33	each	$14.15	1	$14.15
Comfort Grip Ball Driver, 3/16” Hex	McMaster-Carr Supply Co.	562-692-2323	5497A31	each	$3.22	1	$3.22
Crescent Wrench	McMaster-Carr Supply Co.	562-692-2323	5385A13	each	$12.24	1	$12.24
Standard Screwdriver phillips #1	McMaster-Carr Supply Co.	562-692-2323	5682A27	each	$3.20	1	$3.20
Slotted Screwdriver, pocket style 1/8” wide	McMaster-Carr Supply Co.	562-692-2323	5682A12	each	$1.73	1	$1.73
Soldering Iron, pencil grip	McMaster-Carr Supply Co.	562-692-2323	7722A8	each	$52.90	1	$52.90
				SECTION SUBTOTAL			$209.45

Parts (should be in stock and arrive quickly)	Vendor	Phone	Cat #	unit	cost	qty	total cost
22mm Push-Button Control Station. N.C. Maintained	McMaster-Carr Supply Co.	562-692-2323	7546-K79	each	$28.00	1	$28.00
6 Outlet strip with remote switch	McMaster-Carr Supply Co.	562-692-2323	69565K76	each	$32.00	1	$32.00
Brace	McMaster-Carr Supply Co.	562-692-2323	1556A18	each	$2.00	2	$4.00
Brass Double Barbed Tube Fitting for 1/4” pipe size, 3/8” tube ID	McMaster-Carr Supply Co.	562-692-2323	44555K133	each	$1.05	5	$5.25
Cable Tie kit	McMaster-Carr Supply Co.	562-692-2323	7338K33	each	$59.00	1	$59.00
Coated Alloy Steel Socket Head Cap Screw 1/4”-20 Thread, 3/4” Length	McMaster-Carr Supply Co.	562-692-2323	91274A164	pack of 50	$5.45	1	$5.45
Compact Ultrasonic Cleaner	McMaster-Carr Supply Co.	562-692-2323	32695K21	each	$237.00	1	$237.00
Fuse Block, class R, 250 VAC, 2 pole, up to 30 amps	McMaster-Carr Supply Co.	562-692-2323	7688K42	each	$10.26	3	$30.78
Grease, Mobilgrease XHP 222, 14oz. Cartridge, color Gray/ Black	McMaster-Carr Supply Co.	562-692-2323	1416K14	each	$2.14	1	$2.14
Helical Bundling Wrap, 25 ft. spool, 1” size	McMaster-Carr Supply Co.	562-692-2323	7432K75	each	$4.00	1	$4.00
M5 Low Head Socket Head Cap Screw, 10mm length	McMaster-Carr Supply Co.	562-692-2323	93070A121	pack of 100	$17.00	1	$17.00
M6 Low Head Socket Head Cap Screw, 12mm length	McMaster-Carr Supply Co.	562-692-2323	93070A143	pack of 100	$17.00	1	$17.00
M6 hex nuts, standard	McMaster-Carr Supply Co.	562-692-2323	90592A016	box of 100	$1.21	1	$1.21
M6 Metric Steel Flat Washers	McMaster-Carr Supply Co.	562-692-2323	91455A120	pack of 100	$2.00	1	$2.00
M6 Metric Zinc-Plated Fender Washers	McMaster-Carr Supply Co.	562-692-2323	91100A150	pack of 100	$3.37	1	$3.37
M6 Socket Head Cap Screws, 8mm length	McMaster-Carr Supply Co.	562-692-2323	91292A201	pack of 100	$16.00	1	$16.00
M6 Socket Head Cap Screws, 12mm length	McMaster-Carr Supply Co.	562-692-2323	91292A134	pack of 100	$15.00	1	$15.00
M6 Socket Head Cap Screws, 16mm length	McMaster-Carr Supply Co.	562-692-2323	91292A135	pack of 100	$14.00	1	$14.00
M6 Socket Head Cap Screws, 20mm length	McMaster-Carr Supply Co.	562-692-2323	91292A137	pack of 100	$15.00	1	$15.00
M6 Socket Head Cap Screws, 25mm length	McMaster-Carr Supply Co.	562-692-2323	91292A138	pack of 100	$13.03	1	$13.03
M6 Socket Head Cap Screws, 30mm length	McMaster-Carr Supply Co.	562-692-2323	91292A139	pack of 100	$14.18	1	$14.18
M6 Socket Head Cap Screws, 35mm length	McMaster-Carr Supply Co.	562-692-2323	91292A141	pack of 100	$29.00	1	$29.00
M6 Socket Head Cap Screws, 40mm length	McMaster-Carr Supply Co.	562-692-2323	91292A142	pack of 100	$26.00	1	$26.00
NEMA L6 20P TurnLock Plug	McMaster-Carr Supply Co.	562-692-2323	7162K5	each	$11.54	1	$11.54
Plastic Cabinet	McMaster-Carr Supply Co.	562-692-2323	9619T37	each	$22.84	1	$22.84
Polyethylene single-Barbed Tube 1/8” pipe, 1/4” ID	McMaster-Carr Supply Co.	562-692-2323	53415K201	pack of 10	$3.81	1	$3.81
Polyethylene single-Barbed Tube Elbow 3/4” pipe, 3/8” ID	McMaster-Carr Supply Co.	562-692-2323	53415K181	pack of 10	$8.10	1	$8.10
Polyolefin Heat Shrink Tubing kit	McMaster-Carr Supply Co.	562-692-2323	7496K21	each	$16.00	1	$16.00
Polypropylene Single-Barbed Tube Fitting Wye For 1/4” Tube ID	McMaster-Carr Supply Co.	562-692-2323	53415K139	pack of 10	$13.10	1	$13.10
Polypropylene Stop Cock For 1/4” To 5/16” Tubing Inside Diameter, Barb	McMaster-Carr Supply Co.	562-692-2323	48285K24	each	$27.57	1	$27.57

Parts (continued)	Vendor	Phone	Cat #	unit	cost	qty	total cost
Power Cord, 14 AWG, 15 A, SJEOW, 6 ft., NEMA 5-15 Plug	McMaster-Carr Supply Co.	562-692-2323	70355K35	each	$5.40	1	$5.40
Thermoplastic 3 conductor cord, 14 AWG, 18 A, SJEOOW, 50 ft.	McMaster-Carr Supply Co.	562-692-2323	7082K23	50 ft.	$24.50	1	$24.50
Thermoplastic 3 conductor cord, 18 AWG, 10 A, SJOOW, 10 ft.	McMaster-Carr Supply Co.	562-692-2323	7422K21	10 ft.	$3.00	1	$3.00
PVC tubing, 20ft @ $0.31/ft	McMaster-Carr Supply Co.	562-692-2323	52375K12	20 ft.	$6.50	1	$6.50
PVC tubing, 3/8" ID, 20ft @ $0.43/ft	McMaster-Carr Supply Co.	562-692-2323	52375K13	20 ft.	$8.60	1	$8.60
Silicone Rubber, 24" x 24" , Durometer Hardness: 40	McMaster-Carr Supply Co.	562-692-2323	8632K51	each	$29.00	1	$29.00
Solid State Power Relay cat. 7456K14	McMaster-Carr Supply Co.	562-692-2323	7456K14	each	$27.00	3	$81.00
12 Volt DC Fan	Newark	800-463-9275	44F8978	each	$20.00	1	$20.00
Power Supply Cord, 18 AWG, 10 A, 3 conductor, SJT, inlet connector end	Newark	800-463-9275	37F3333	each	$8.00	2	$16.00
5 Minute Epoxy Cement	Newark	800-463-9275	00Z416	each	$6.00	2	$12.00
Belden 10-conductor Cable, 24 AWG, 300 V, 80 degC	Newark	800-463-9275	03F1648	each	$30.87	1	$30.87
Butt Splices Type 8-55825-2	Newark	800-463-9275	92F1054	each	$38.00	1	$38.00
CM Series Enclosure	Newark	800-463-9275	89F3993	each	$19.00	1	$19.00
FRN-R10 series 10-Amp fuse	Newark	800-463-9275	28F260	each	$5.25	2	$10.50
FRN-R20 series 20-Amp fuse	Newark	800-463-9275	28F264	each	$5.43	4	$21.72
HONEYWELL MICROSWITCH SM Series	Newark	800-463-9275	23F4178	each	$3.45	2	$6.90
NEMA 5-15R AC Appliance Snap-In Inlets	Newark	800-463-9275	50F2843	each	$1.00	4	$4.00
PacTec Black Plastic Enclosure	Newark	800-463-9275	89F4006	each	$17.00	2	$34.00
SR Series AC Connector, Snap-in Mount	Newark	800-463-9275	87F1825	each	$2.00	2	$4.00
Power supply cord, 18 AWG, 10 A, 3 conductor, SJT, unshielded	Newark	800-463-9275	37F3297	each	$3.50	2	$7.00
Microseal 384 Plate Positioner	MJ Research	888-729-2165	ADR-3841	each	$100.00	1	$100.00
Hoffman Clamp, Swivel Jaw; Opening: 3/4 to 1 in. (19 to 25mm)	Fisher	800-766-7000	05-871B	pack of 10	$33.53	1	$33.53
Green sticky stuff	ATR	800-827-5931	ATH-001	roll	$218.00	1	$218.00
				SECTION SUBTOTAL			$1,426.89

Tips	Vendor	Phone	Cat #	unit	cost	quantity	total cost
Z-Bracket for print head	Majer Precision	480-777-8222		each	$275.00	1	$275.00
either (recommended)							
48 tip print head	Parallel Synthesis	408-749-8318	SMT-H192	each	$1,000.00	1	$1,000.00
Silicon Microcontact Spotting Pins	Parallel Synthesis	408-749-8318	SMT-S50	each	$100.00	16	$1,600.00
						SUBTOTAL	$2,875.00
or (alternative)							
48 tip print head	Majer Precision	480-777-8222		each	$1,200.00	1	$1,200.00
MicroQuill 2000, new style	Majer Precision	480-777-8222		each	$139.00	16	$2,224.00
						SUBTOTAL	$3,699.00

Please note: This arrayer design is compatible with print heads and tips from almost any manufacturer; all that is required is the appropirate bracket for mounting the print head. Many brands have been used with this design with great success.

Currently, we are recommending the Silicon tips from Parallel Synthesis Technologies, but the automated platter height mapping switch described in this guide and our print protocol requires one MicroQuill tip and the print head from Majer Precision. We are developing less expensive parts to perform this function, for those without legacy equipment to do so, but do not have the designs prepared at the time of writing.

Summary of Categories	**cost**	**lead time**
Parts (advance)	$38,299.70	2 months
Tools	$209.45	2 weeks
Parts	$1,426.89	2 weeks
Tips	$2,875.00	4 weeks
GRAND TOTAL	$42,811.04	