Texas Tech University
Electrical Engineering Department

IEEE Student Branch Milling Tutorial

"An EE's Guide to Using the Milling Machine"

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Introduction

So you've probably heard people in project lab asking about milling, and maybe have seen a board or two before, but never knew exactly what it was. Well, this guide is just for you! It's written by an EE student, for EE students! If you have doubts about how something is done after reading this guide, ask *upperclassmen*. It will help everyone to have a positive milling experience (and also keep you from being the guy who broke the machine!)

What is milling?

Milling is "the process by which a circuit design is etched into a copper substrate by means of a 2-axis CNC machine", or for us EE's, it's basically a way to design and build circuits quickly and easily. Once you understand how the procedure works, and with a bit of practice, you can have a full circuit board in about 20 minutes! This method may also become your preferred method of prototyping instead of using proto-board or breadboards with break-out boards.

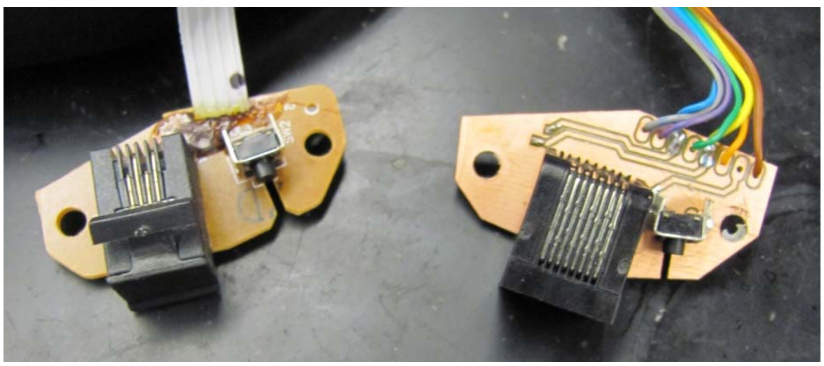


Figure 1 - Original Circuit Board vs. Milled Replacement Board

Why learn how to mill?

While milling is not strictly necessary for the early project labs (1 & 2), it is a good idea to get your feet wet and learn how it's done before it becomes necessary in future labs. Milling also makes it possible to make much more complicated and cleaner circuit designs.

Milling opens the door to surface mount parts which are nearly impossible to use on proto-board and much less, breadboards. More and more manufacturers are moving from DIP (through-hole) packages to much smaller and cheaper SMT (surface mount) parts. While soldering these parts may require some more practice, as stated earlier, the sooner you begin working with these parts and tools, the easier future projects will be.

What will you need in order to mill?

While Texas Tech and the EE department provide the machine and software necessary to mill, you must provide some tools yourself.

Copper Substrate

This one is pretty essential; if you don't have copper to mill your circuit onto, you can't mill! The substrate is basically two thin pieces of copper glued onto a fiberglass substrate. This substrate is called a dielectric and can vary in width, as can the width of the copper. If you're doing some sort of VHF/UHF project where impedance must be precisely controlled, you must take these measurements into account, but for most projects, any copper available in the stock room should suffice.

It should also be noted that since the substrate is two conductors separated by a dielectric, it is basically a capacitor. Because of this, you can expect slightly more capacitance between traces.

Milling Bits

As mentioned earlier, this process uses a special bit called an *endmill* to separate traces from the rest of the plane. There are many types of endmills available, but typical sizes are anything from 10 to 100 mills (1 mill = 1/1000 inch). You may find some endmills are sold in 45, 60, and 90 degree increments as well. These measurements specify the angle which the endmill's point makes. 90 degree endmills can cut traces of about 16 mills, 45 degrees can cut traces of about 12 mills and 45 degrees can cut about 6 mill traces if you're careful. Most of these bits can be found online. The retailer which is typically used is http://www.precisebits.com

Figure 2 - 30 Degree (Left) vs. 60 Degree (Right) Endmill

There is also another set of bits that is required to mill. These bits are called *drill bits* and are used to drill holes for IC legs, header mounts, VIAs, etc. You must use different sizes of bits in order to drill different sized holes. If your circuit requires a certain size of bit, it is imperative that the proper size be used. If this rule is not followed, the holes drilled may either be too large or too small for your part. Too small, and the part will not fit into the board. Too large, and there will not be enough of a pad left on the board to solder to. Typical sizes will range from 28 to 45 mills. These bits may be purchased from the previously mentioned website, or from Harbor Freight Tools (34^{th} and I-27).

Figure 3 - Drill Bit (Left) and Routing Bit (Right)

The final set of bits are optional, but will make cutting out the completed board much easier. This bit is called a *routing bit* (also known as a cut-out bit) because it will cleanly cut out the completed circuit from the rest of the copper. Some prefer to use a copper press or a Dremel, but I have found these bits to produce the best results.

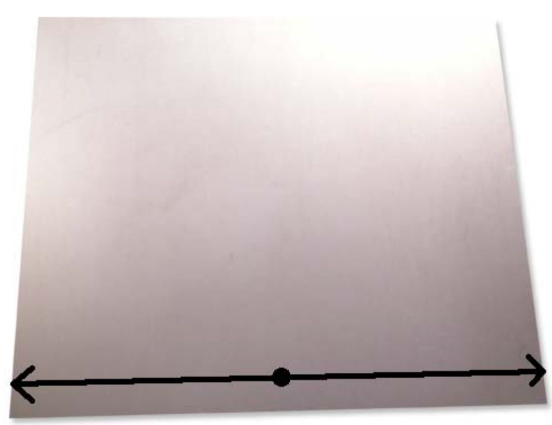
Tape

Tape will be required in order to temporarily hold your copper board to the machine and sacrificial layer placed on the machine. Silver duct tape is typically used, but most other types of tape will also work.

How to Mill

Drilling an Alignment Hole

First thing you have to do is drill an alignment hole for your copper board. Be sure to measure exactly the middle of the board and drill as shown in the figure. If the hole you drill is off by even a tiny bit, the board will be slightly offset later on in the process and will not line up properly.



Turning on and Initializing the Machine

To turn on the machine, first flip the power switches on the three machines next to the milling PC. Also turn on the milling PC if it is off. Once finished, open the program named "IsoPro" on the desktop. This is the program we will be using to control the milling machine.

The first thing to do is *initialize* the machine. This process resets the machine and lets the computer know where the machine's boundaries are. Go to Mill>Initialize to initialize the machine. It should begin moving and once it's finished, it should stop at the front center of the table, just above the alignment pin. Initialization must be done every time IsoPro is started.

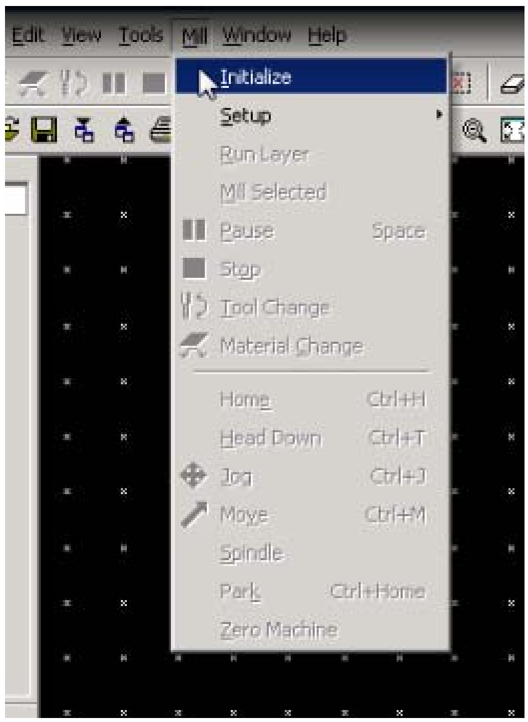


Figure 4 - Initializing Selection

Once the machine is finished, a new button labeled "Material Change" should become active. Clicking this will cause the machine to move the machine head, or *spindle*, out of the way, allowing you to replace material on the machine table.

Figure 5 - Material Change Button

Placing Copper on the Table

With the spindle out of the way, make sure the table is clean and place your copper board on it. Once aligned with the face of the machine as shown, tape down the board. 2 or 3 pieces of tape should suffice.

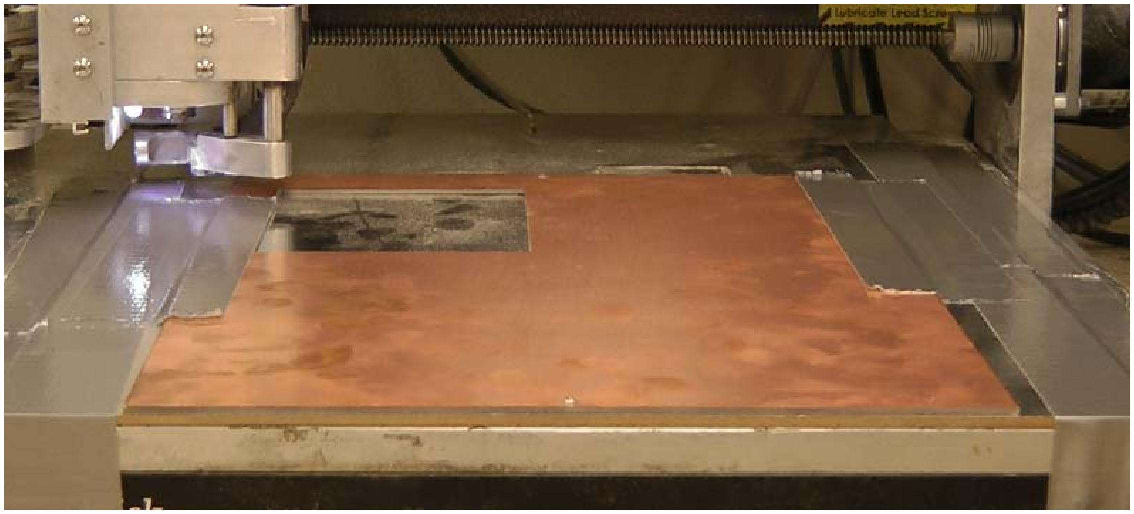


Figure 6 - Copper Placed on the Machine Table

Loading Files, Mirroring, and Isolating

The next step is to load your files into the program and begin preparing them. In order to do that, click on File>Import>Auto Detect Files

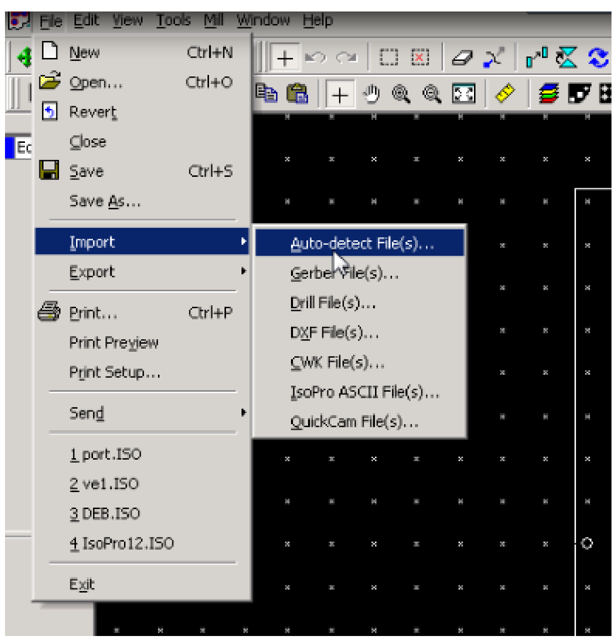


Figure 7 - Selecting to Auto-Detect Files

If you are using the TTUMilling.cam file from EagleCAD or importing from OrCAD you must select the options shown in the following figure. This setting tells the machine how many decimal places it should take into account when interpreting your gerber files. The correct setting is four integer digits and four decimal digits.

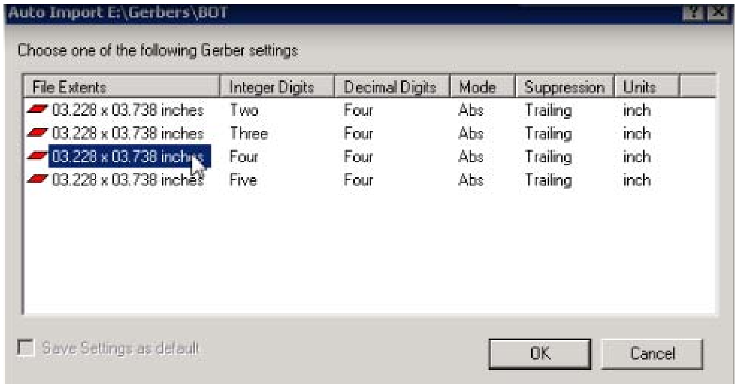


Figure 8 - Decimal Selection

Once the machine is finished importing your files, the next step is to isolate your traces. *Isolation* is the process of isolating your traces from the rest of the copper board. To do this, click on the "Isolate" button, select your top and bottom layers, and type in the space which you wish to isolate.

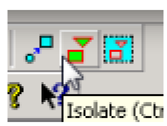


Figure 9 - Isolate Button

For most applications 15 mills is usually more than enough, but if you are working with surface mount components as little as 6 mills might be required.

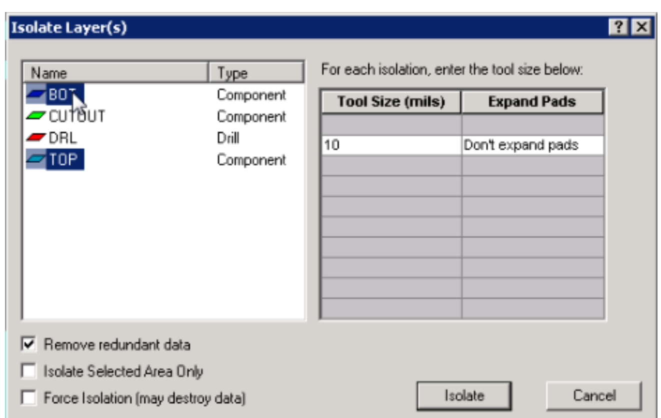


Figure 10 - Isolation Window

Once the computer finishes isolating, you will see that the program has drawn lines around your traces. These lines are the paths that the spindle will take when cutting out your traces. Be sure to check for errors or parts where isolation did not work correctly and adjust as needed.

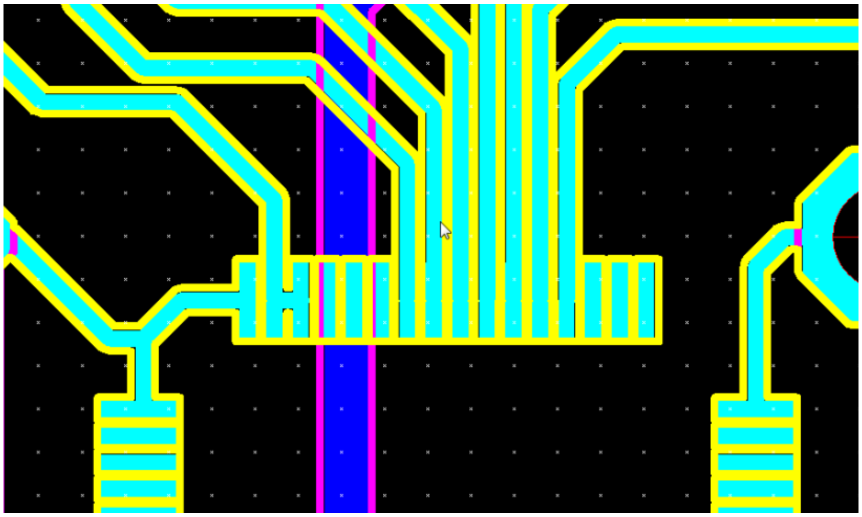


Figure 11 - Isolated Circuit

Once you are happy with the results, click on the “Layers” button and select “Mirror” next to your bottom and cutout layers (if one exists). *Mirroring* these layers will make the machine interpret everything properly when the board is flipped later on in the process. Also note that if you are using a cutout layer, you must also change its type from “Component” to “Isolation” in addition to mirroring it.

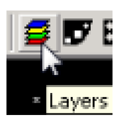
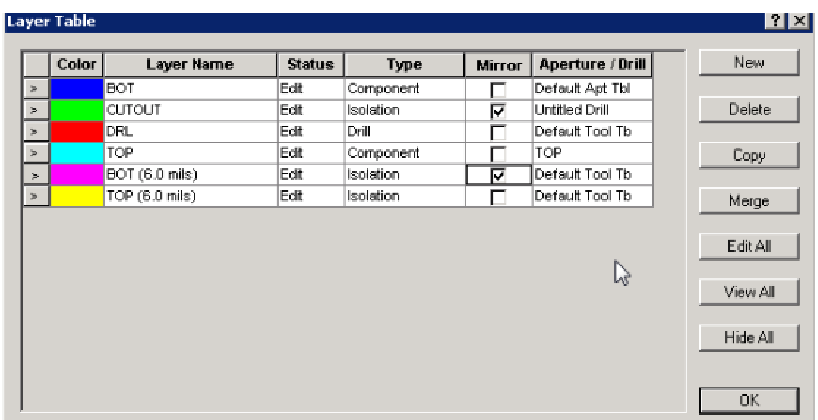


Figure 12 - Layers Button



Color	Layer Name	Status	Type	Mirror	Aperture / Drill
	BOT	Edit	Component	☐	Default Apt Tbl
	CUTOUT	Edit	Isolation	☑	Untitled Drill
	DRL	Edit	Drill	☐	Default Tool Tb
	TOP	Edit	Component	☐	TOP
	BOT (6.0 mils)	Edit	Isolation	☑	Default Tool Tb
	TOP (6.0 mils)	Edit	Isolation	☐	Default Tool Tb

Figure 13 - Isolation Window with Mirroring Enabled

Placing the Circuit

The final thing to do before milling is to make sure that your circuit will properly fit on the copper substrate you have placed on the machine. To do this, right click on any of the layers to the left and select “Edit All”. After doing so, draw a box around all your traces and cutout layer. Be sure to select every layer. You can zoom out if needed.

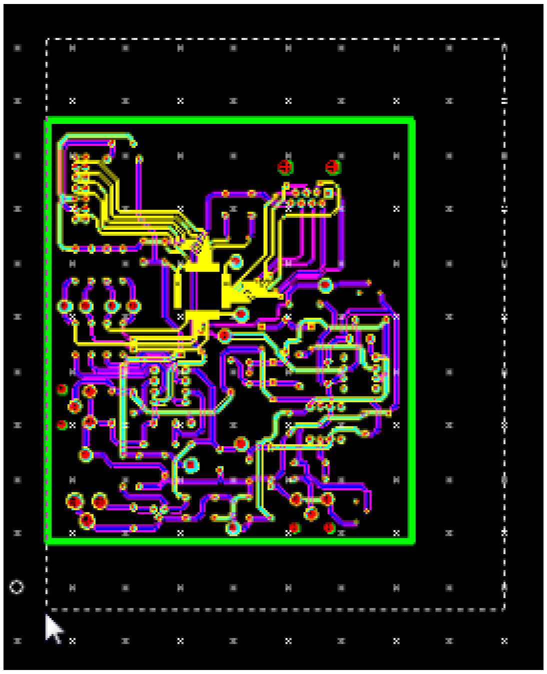


Figure 14 - Selecting Layout for Moving

A bit of guesswork is required to get the board to fit properly sometimes, but it is important to make sure that the board is properly positioned for a good circuit to be milled. Once placed, right click on one of the corners of your layout and select “Jump to Cursor”. The machine will move to the location specified. Do this for the opposite corner and make sure you have enough space. Keep repeating this process until you’re sure you have enough.

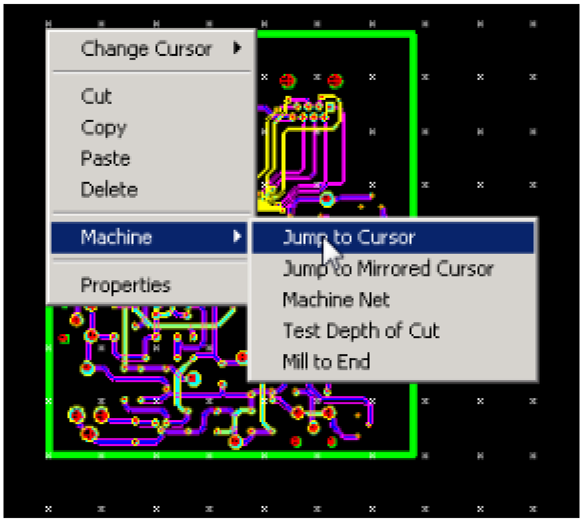


Figure 15 - Jump to Cursor

Running Layers

Now that everything has been prepared, layers must be run. I recommend running your drill layer first in order to ensure that pads do not get damaged and also to give you reference points when milling the rest of the circuit.

Drill Layer

In order to run the drill layer, right click on the layer to the left of the screen and select "Run Layer".

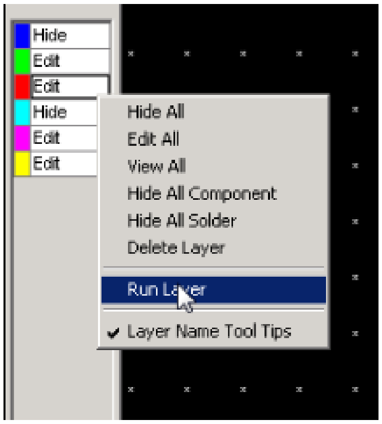


Figure 16 - Running a Layer

You will notice that the machine will move off of the table and is asking for a bit. This dialog window will ask for a specific bit and it will also show you what the diameter of the bit should be. Be sure to give the machine a bit close to the size it requests! If you don't do this, you may not have enough of your pads left to solder to! You can safely round up or down 1 or 2 mills if you don't have the exact measurement.

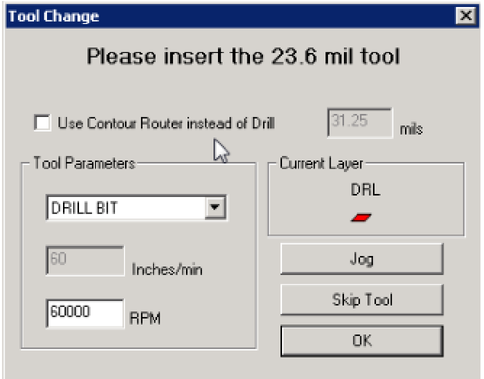


Figure 17 - Tool Change Window

The tool should be snug, but not overly tight. Be sure to not drop the tools when inserting or removing them! If one is dropped, it will shatter!!

Once you've inserted your tool into the machine, you must ensure that the speed is correct. The *spindle speed* (how fast the tool spins) should read 60,000 RPM. A *feed rate* (how fast the tool cuts traces) of 60 in/min is okay for *drilling* **only**. Slower speeds should be used for every other process.

The last step before starting is checking depth. In order to do this, press the head of the machine down manually and compare it to the edge of the board. The tool should just penetrate the lower edge of your copper board. To adjust the height of the bit, turn the knob on the machine head marked with a + and -. Do not adjust the four nuts to the left of the spindle!! Also, don't go too deep into the sacrificial layer as you might hit the aluminum table and shatter a bit!

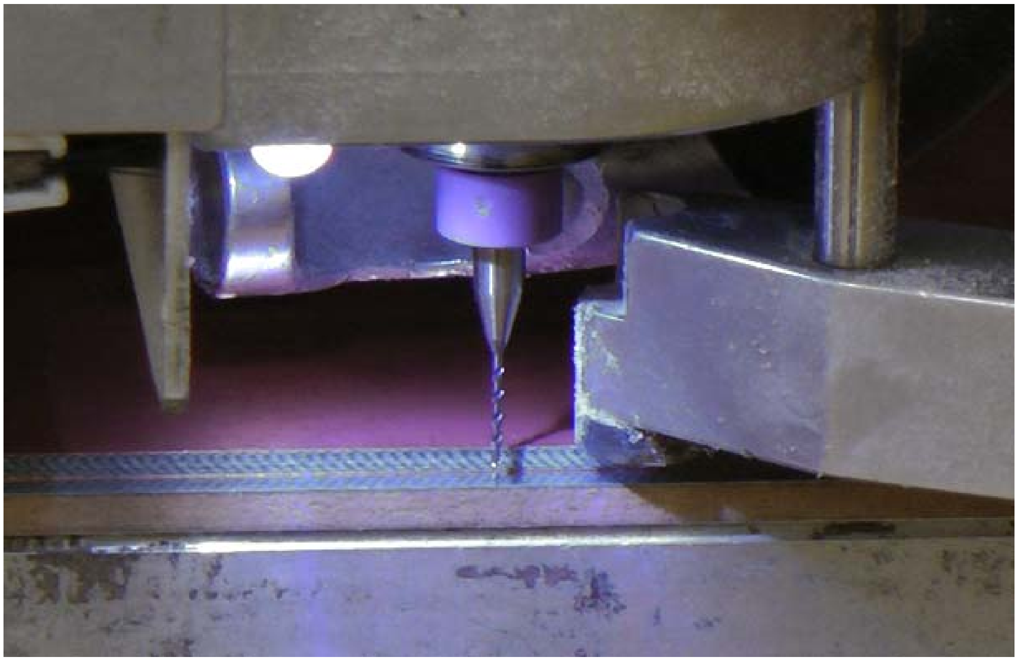


Figure 18 - Checking Depth of a Drill Bit

Once all these preparations are completed, click “Run Layer” to begin the drilling process. The machine will stop and ask for different size bits if you used them in your design.

Top Isolation Layer

The next thing we have to run is the isolation layer. In order to do this, we must once again check for depth. The process is nearly identical to the previous one, the only difference being that we have to slow the feed rate to about 14 in/min while keeping the spindle speed at 60,000 RPM. The slower the feed rate the slower the wear on your tools and the more precise you can be, but the longer it will take to mill.

The tool should just barely cut the copper surface; just enough for it to completely cut through the copper, but not dive into the fiberglass substrate. Once you insert your tool into the machine, click on the “Jog” button. This button will allow you to control the machine head manually in order adjust the bit depth. You can move the spindle with the arrow keys on the keyboard. Clicking the “Spindle On” button will turn on the spindle and “Head Down” will lower the head using air, just as if you were running the layer. I recommend turning on the spindle before lowering the head because it will cause less stress on the tool and keep you from breaking it.

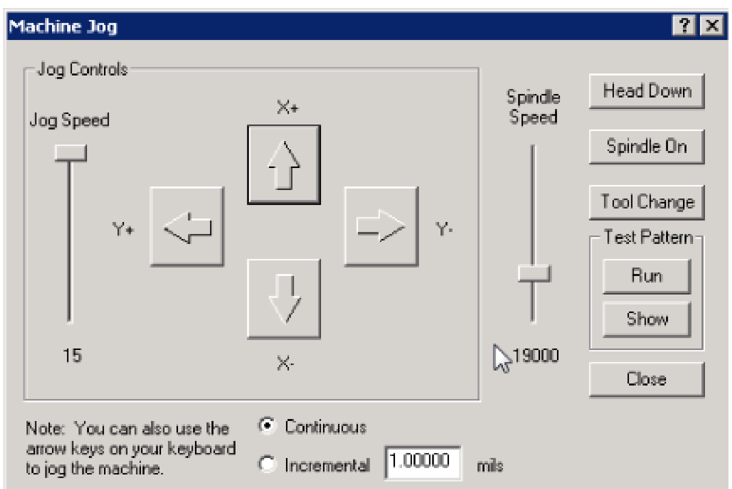


Figure 19 - Machine Jog Window

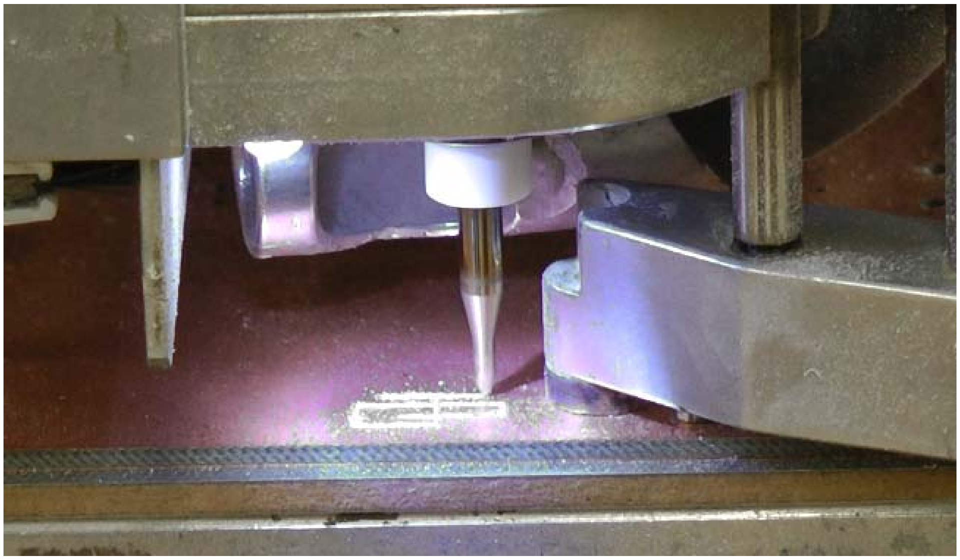


Figure 20 - Isolation Depth Testing

Once those adjustments are made, click "Run Layer" and sit back while your board is made. You should watch the process a bit to make sure that the tool is cutting enough copper.

Flipping the Board

Once the isolation layer is finished running, click the "Material Change" button and flip the board 180 degrees as shown. You should flip it so that the alignment hole is still over the peg at the front of the machine. Tape the board down just as you did before.

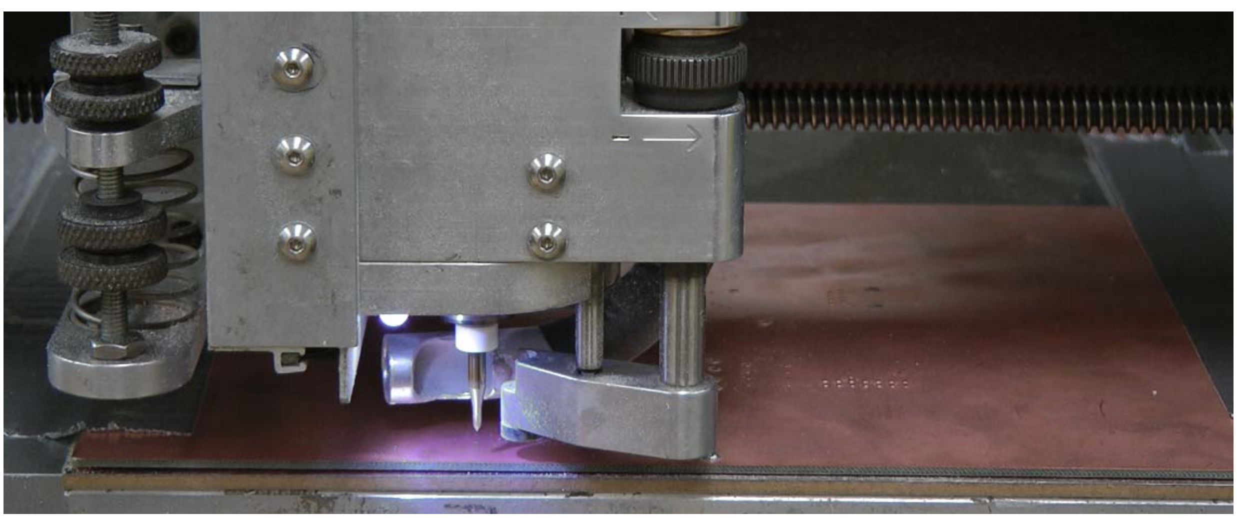


Figure 21 - Copper Board Flipped 180 Degrees

The process for running the bottom isolation layer should be identical to the top, with the exception of one step. We must first make sure that the holes line up properly so that the isolation doesn't cut traces incorrectly. To do that, right click on the center of any hole on your schematic and select "Jump to Mirrored Cursor". This will force the machine to move the spindle to that specific hole. Do this with a couple holes on opposite ends of your circuit and check to make sure they line up. Make adjustments to the tape and copper board as needed.

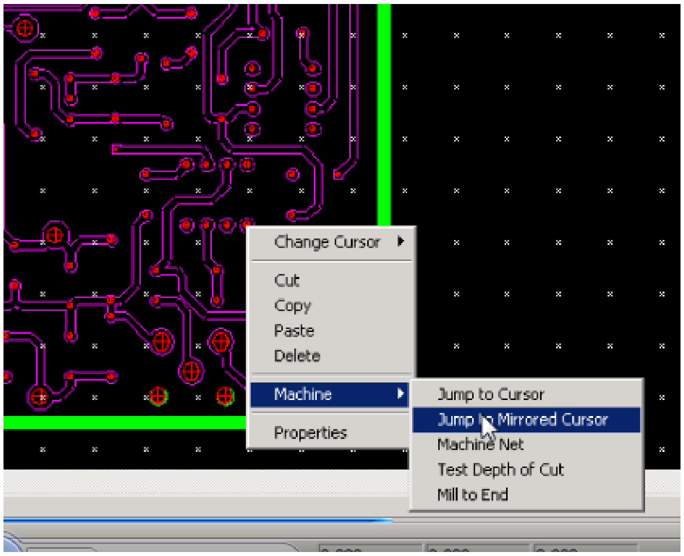


Figure 22 - Jumping to Mirror Cursor

Remember that depth must be checked once again in order to ensure that you don't break a bit! The process is the same as before. Be sure to check the settings and once you are ready to proceed, click "Run Layer".

Cutting Out Your Design

If the TTUMilling.cam file was used in EagleCAD, it will have a cutout layer ready made for you. This layer will be generated using the “Dimensions” layer in EagleCAD. If you would like to cut out your design using this layer, some minor changes will need to be made for it to work. If you have followed this tutorial, you should have already changed the layer type from “Component” to “Isolation” and mirrored it. If you are not sure, go back into the “Layers” window and double check.

Once you are finished, right click on the cutout layer, select "Run Layer", insert your cutout tool, and adjust the depth. It should be about the same used for drilling. Be sure that the spindle speed is 60,000 RPM and the feed rate is about 12 in/min.

Cleanup

Once finished, remove your tool, click the “Change Material” button to give you enough space to remove your copper board and your circuit, sweep off any excess dust, close the program, and turn off all devices.

Congratulations! You've just finished milling a board!