# Background Research Report

## Annotated Bibliography

X. C. Wang and H. Y. Zheng, “High quality laser cutting of electronic printed circuit board substrates,” *Circuit World*, vol. 35, no. 4, pp. 46–55, Nov. 2009, doi: <https://doi.org/10.1108/03056120911002415>.

This research paper from Wang and Zheng, from the Singapore Institute of Manufacturing Technology, explores fabrication of PCBs using different laser cutting settings on a diode laser. The paper aimed to explore fabrication that minimized charring, delamination, and the heat affected zone that are often found on laser cut PCBs.

This paper was useful to compare PCB milling to laser cutting methods. Laser cutting appears to be very viable as a process, however it can be difficult to get the settings correct and the required equipment is expensive.

D. Wise, "PCB Fabrication," \*Technology Interface International Journal\*, Fall 2007. [Online]. Available: https://tiij.org/issues/issues/fall2007/01\_Wise/Wise-PCB%20Fabrication.pdf. [Accessed: 30-Sep-2024].

This is a paper from a Departmental Engineer at the University of New Mexico (UNM). It discusses the use of a mill to cut printed circuit boards(PCBs). The paper is written somewhat informally, and the references listed are not the most reliable. However, most of the information within the paper describes the hands-on process at UNM.

The paper walks the reader through the process of manufacturing a PCB on a desktop mill, all the way from design to settings up the machine and cutting. It discusses common issues and how to effectively set up a FR4 board.

A. Nae and B. Toma, "Study on Equipment for Manufacturing PCB," \*Journal of Petroleum-Gas University of Ploiesti\*, vol. 1, pp. 9-15, 2010. [Online]. Available: <http://jpgt.upg-ploiesti.ro/wp-content/uploads/2024/02/9_T_1_2010_Nae-Andrei-BT.pdf>. [Accessed: 30-Sep-2024].

This is a paper from two researchers at Petroleum and Gas University of Ploiești. It discusses the use of stepper motors for creating CNC routers. It highlights design principles and details, and different ways in which routers are frequently designed. There is also some discussion on electrical design and software controls.

This is useful as a guide for designing a rigid motion system that can carry a spindle. There is good discussion on different design choices such as moving gantry vs bed, as well as different components and how they affect the motion system.

Y. Crama, O. E. Flippo, J. van de Klundert, and F. C. R. Spieksma, "The assembly of printed circuit boards: A case with multiple machines and multiple board types," \*European Journal of Operational Research\*, vol. 98, no. 2, pp. 457-472, 1997. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0377221796002287. [Accessed: 30-Sep-2024].

This paper by Crama et al. Optimizes the process of placing components onto a PCB in a production line.

This paper was not very useful to this project; while it provided some insight into PCB assembly, it was highly focused on a factory setting rather than a custom production/hobbyist environment.

‌ "Principles of Mechanical Design," MIT Center for Bits and Atoms, 2021. [Online]. Available: <https://fab.cba.mit.edu/classes/865.21/topics/mechanical_design/index.html>. [Accessed: 01-Oct-2024].

A guide from MIT on mechanical design principles for building rigid and precise systems. It discusses important concepts such as stiffness, backlash, pretension, and more.

This is a useful reference for any potential designs in the future. It outlines many important fundamental concepts, both theoretically as well as physical design choices.

K. K. Tan, T. H. Lee, and S. Huang, \*Precision Motion Control: Design and Implementation\*, 2nd ed. London, UK: Springer-Verlag, 2008. Available: DOI: 10.1007/978-1-84800-021-6

This is a textbook on motion control systems. It covers everything from actuators to gantry designs, to control systems, and more.

It is very useful as an in depth guide to designing a motion system. While it is a bit old, many of the fundamental concepts are still applicable.

## Product History Report

## User Research

Discussion with the owner of a desktop PCB mill (Ottermill):

* The Ottermill takes some setup to be able to run effectively
* PCB mills are very useful for quick prototyping and short turnaround times
* 2 side setup is difficult and time consuming to set up accurately

Industry professional advice

See full email in appendix.

## Related Designs

[PrintNC V4 | PrintNC Wiki](https://wiki.printnc.info/en/home)

Super nice design, 1.5-3k price range but super rigid frame

[Introduction to The MPCNC - V1 Engineering Documentation](https://docs.v1e.com/mpcnc/intro/)

Sub 500$ CNC router

[Prusa MK3s Pick and Place Extension [3D printed] 👌 (youtube.com)](https://www.youtube.com/watch?v=Mx4swtSQmE0)

Little head that goes onto any motion system, 25$ for a PNP head and can be controlled using any slicer

## Case Studies

## Regulations and Code

## Appendix

**Email from industry professional:**

This is a pretty cool idea.  I’ve designed many PCBAs both for work and personal use over the years.  None of my personal PCBAs have needed smaller etch/spacing than 0.010” (~250um).  I have even used PCB routing tools before.  Most of recommendations are of the mechanical type.  The electronics is pretty well supported in the maker community.  Stuff like this for HW: [E3 Free-runs Silent Motherboard Shenzhen Creality 3D Technology Co., Ltd | Prototyping, Fabrication Products | DigiKey](https://www.digikey.com/en/products/detail/shenzhen-creality-3d-technology-co.,-ltd/E3%2520FREE-RUNS%2520SILENT%2520MOTHERBOARD/21840110)

Comments on Option 1:

There are lots of sources for mechanical backlash in 3D printers.  This mostly munges out in the end due to the nature of the process.  Belt drives are largely to blame.  But vibrations in the frame can also cause interesting artifacts in the finished print.  This amounts to over-shoot in the XY movements.  If making a PCB with right angle etch features you would probably be able to see the vibration in one axis under the microscope as a wavy edge immediately following the direction change.

I recommend building an XY table based on a solid aluminum frame with guide rails as opposed to cylindrical rods.  The rods are much less stiff and will make vibrations more difficult to deal with.  I have seen articles written about clever software for open source printers to introduce active damping into the motor drive algorithms.  So the software exists somewhere.  But it will still be better if you can prevent the vibrations to begin with.  If the mechanical engineers on your team have their heart set on rod-guides, then you probably will want to do some research into active damping algorithms in software.

[linear shafts | McMaster-Carr](https://www.mcmaster.com/products/linear-shafts/guide-rail-carriages~/ball-bearing-carriages-and-guide-rails-9/)

[New Software Reduces FDM 3D Printer Vibration Without Losing Speed - 3Dnatives](https://www.3dnatives.com/en/new-software-reduces-fdm-3d-printer-vibration-without-losing-speed/)

The head will still need to be able to pick up to move to different places.  So the drilling head should also be placed on a Z-axis rail to prevent angular lash facing the PCB.  I recommend against relying on the motor bearings to support the chuck.  Small high-speed motors will have several vibration modes that will transmit to the shaft and cause the router tip to wobble around.  Instead, run the shaft through a high-speed coupler to a double overhung bearing using ceramic bearings.  The coupler will isolate the vibrations from the motor from the drive shaft that holds the chuck.  Make sure you get a high-quality chuck that has be ground for zero runout.

[couplers | McMaster-Carr](https://www.mcmaster.com/products/shaft-couplings/shaft-couplings-2~/high-speed-vibration-damping-flexible-shaft-couplings-9/)

Or screw it and just use this: [CNC Spindle, 500W CNC Spindle Motor,52mm Clamp with ER11 Collet and 10pcs Router Bit，High Precision for DIY CNC Router Milling and CNC Router Machine - Amazon.com](https://www.amazon.com/Spindle-500W-Bit%EF%BC%8CHigh-Precision-Milling/dp/B0CP95VWPY/)

For the XY movement I recommend ball-screw drive mechanisms to minimize lash errors and vibration modes related to the length/tension of a belt.

[ball-screws | McMaster-Carr](https://www.mcmaster.com/products/linear-shafts/ball-screws-and-nuts~/ball-screws-and-nuts-5/)

In general I am sure you could take the guts of a Prussia clone and move it over to a more rigid mechanical structure.  Something with a Z-axis calibration would also be useful for leveling.  This will be even easier to implement with a clad piece of FR4.  A feeler probe touching the copper surface will be grounded as soon as the router bit makes contact in the z-axis.

Option 2:

Probably a lot easier than re-making a 3d printer on a more rigid frame.  But also a lot more expensive.  A small desktop CNC probably will come with a PCB cutting example project.  As long as the drive head can supply the needed RPMs.  But that is much more likely in a small desktop model.  So arguably there will be so much less work here as to not really be a “design” project.

As far as your goal to make 2-sided PCBs, I recommend designing the bed with two calibrated straight edges positioned at a right angle to each other and parallel to the movement axes.  You can implement these with straight-edge metal rulers, but will need a micrometer to align them to the axes and router head.  Then the board just flips at the origin so that the 0-0 remains in the same corner.  This will keep the sides aligned with known datums so routing the other side will have decent accuracy.  Your spec of 0.8mm via size should be plenty to allow for small errors.

Other suggestions:

Make a design with a head that is stationary in X-Y so that a vacuum hood can be positioned around the routing bit.  The PCB workpiece and table would move in the X-Y.  This way the weight of the vacuum hood and hose will not affect the movement.  Downside is that the structure holding the head will need a larger reach to allow for the table to move around.  This increases the machine’s footprint.

[Amazon.com: 52MM Diameter Dust Shoe for Mastuer Pro, Masuter 4040 3018 CNC Router Machine with 52MM Spindle Motor, Hose Diameter 38mm (52MM) : Tools & Home Improvement](https://www.amazon.com/Diameter-Dust-Shoe-Mastuer-Masuter/dp/B0D4CM3RKT/)

If you select a small milling machine as your starting platform, or if you make the frame from scratch using guide rails; Make sure you shield the rails from milling debris.  The glass particles from the FR4 will very quickly grind away surface coatings on the rails and cause friction to increase dramatically in a fairly small amount of time.  This could confound your development process as things will move less freely as you make other improvements.

[Protective Three-Sided Industrial Equipment Way Covers Repairing (nabell.com)](https://nabell.com/products/way-protective-covers/)

If you really want to impress ASML people, use precision linear encoders on each X-Y axis for high accuracy and precision.  Feed back into positioning algorithms to decouple vibrations and other mechanical errors.

[539-808R | Linear Scale ABS AT715 - Slim Spar Type, Series 539 | MITUTOYO | MISUMI (misumi-ec.com)](https://us.misumi-ec.com/vona2/detail/223300519544/?HissuCode=539-808R&gad_source=1&gclid=EAIaIQobChMIk46-sdPZiAMVoEf_AR0zdjdmEAQYASABEgK2NfD_BwE)

If you try to integrate a software vibration damping algorithm that would be very cool.  Having read an article about it over a year ago and still not being able to find any documented implementations this might be a good novel thing to try to develop.  The rest of the electronics are pretty much settled art.  So while there will be some crafting to integrate all the wiring and sensors, it isn’t much more than an integration exercise in my opinion.