Hot Bed Leveling: It's NOT your Hot Bed!

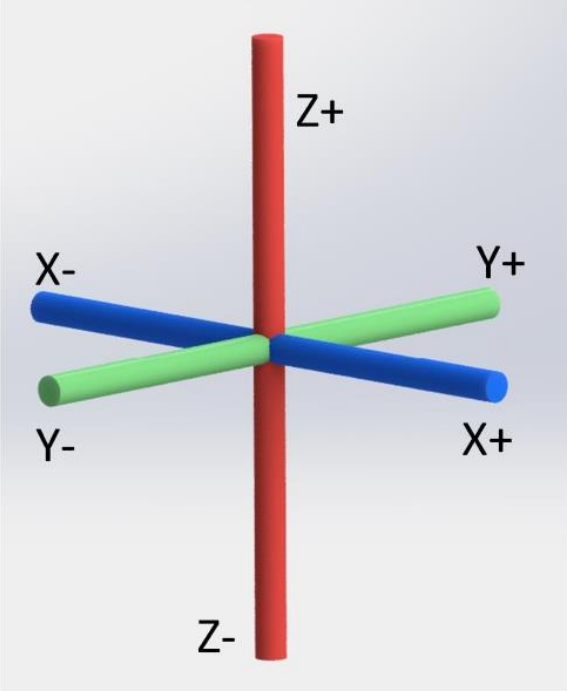
This information applies primarily to Prusa i3 style printers.

Alignment Alignment Alignment

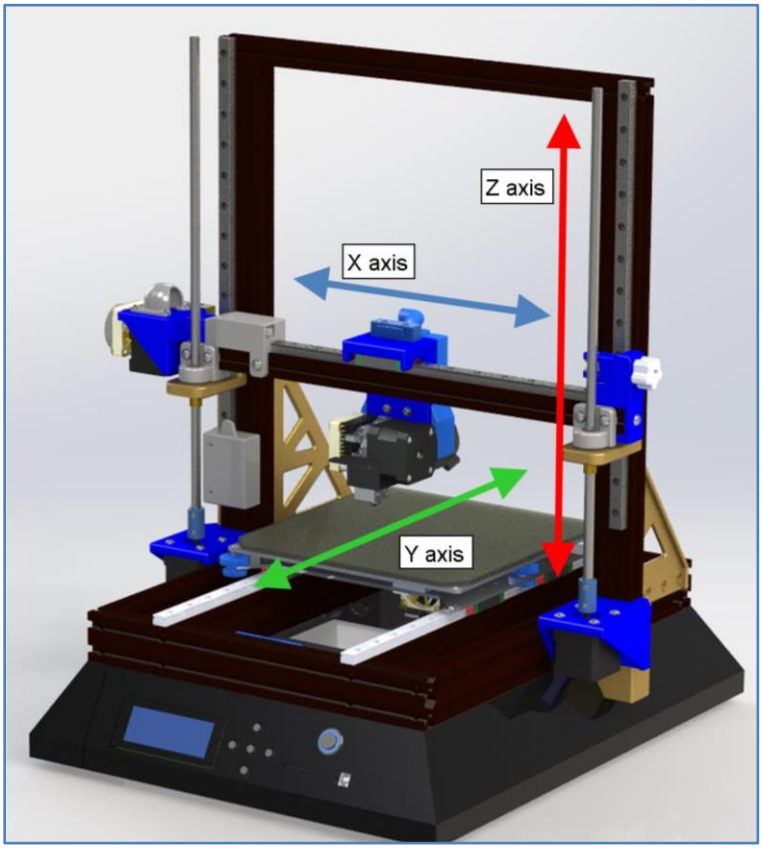
Your 3D printer is a machine. Machines NEED proper ALIGNMENT and calibration for accurate and repeatable results.

When your 3D printer frame is properly aligned, all 3 axes are perpendicular to each other, or 90 degrees.

This is known as "The Right Hand Rule" and describes the 3 axes present in a Cartesian coordinate system, which is the numerical framework that 3D printers/3-axis CNC/laser cutters/etc.… operate within.



X is Left/Right, Y is Forward/Back, Z is Up/Down.



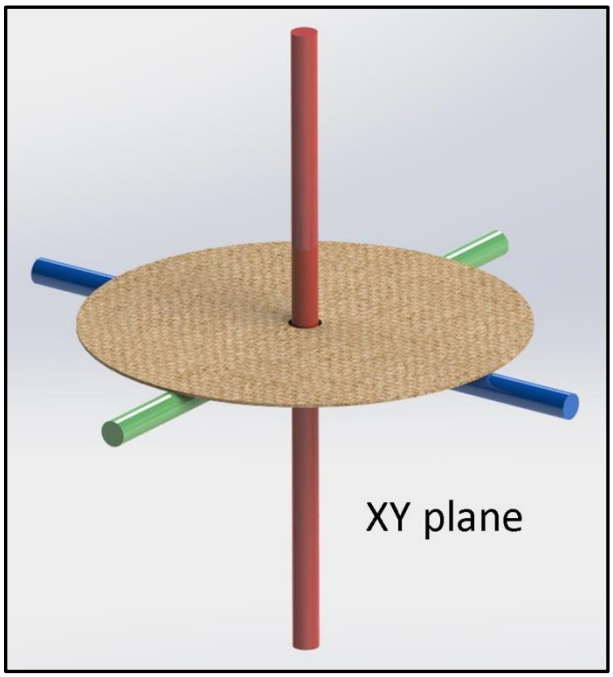
You can see how this coordinate system is applied and utilized when viewing it in the context of a 3D printer.

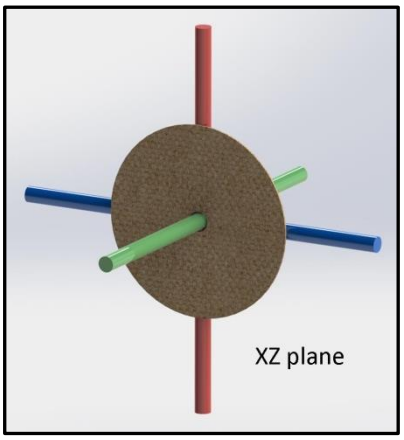
The Gcode in your slicer-created files can only move the printers' components in specified directions and distances. It cannot compensate for any misalignment of your hardware without additional input, such as an auto level sensor, and even then, it cannot correct any actual misalignment problem.

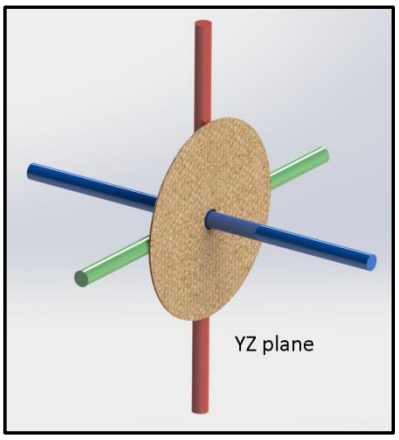
All of your extruder and bed movements are dependent on ACCURATE alignment of all 3 axes in order to produce consistent printing results.

Planes Planes Planes

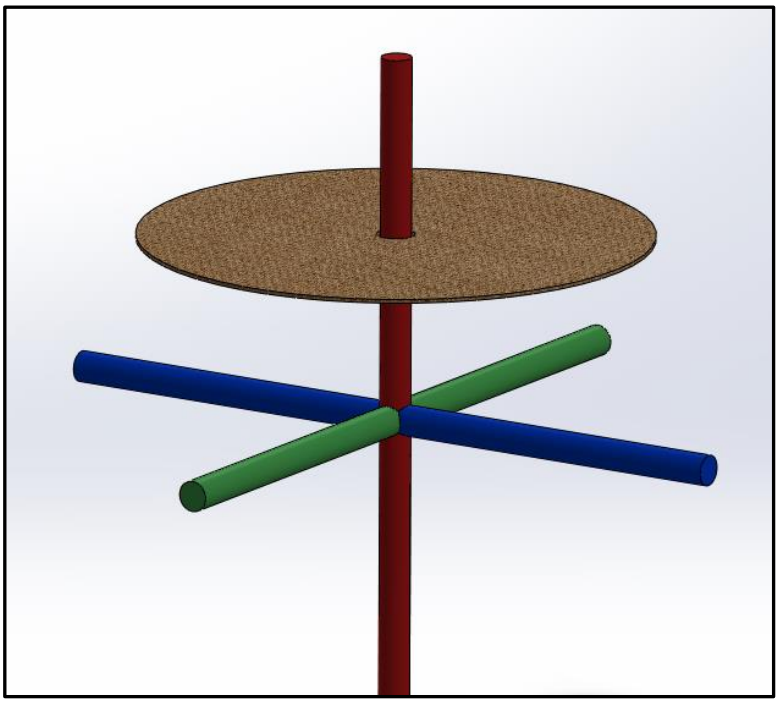
If we slide a sheet of cardboard with a hole in the center down over the top of the Z axis and let it rest on the Y and X axes, we would see a visualization of the XY plane, at that location along the Z axis.







If we slide it over the Y or X axes, we would see the XZ and YZ planes illustrated.



If we slide the XY plane cardboard UP the Z axis 12 inches, we would see the representation of the XY plane along the Z axis at that 12 inch height.

Note that these illustrations represent flat, planar surface alignment characteristics: in each instance, the circle is aligned with two axes while being perpendicular to the axis it was slid over.

These conditions and alignments, i.e., perpendicularity in all 3 axes, at EVERY point along ALL 3 axes, are NECESSARY if you wish to obtain consistent printing results.

Therefore, the MOST IMPORTANT component that contributes to accurate and reliable bed leveling is…

NOT the Hot Bed.

Yes, you read that right: IGNORE the Hot Bed.

For now…

The MOST IMPORTANT Component

The MOST IMPORTANT component of your printer is the XY PLANE, as **IT** is the FOUNDATION upon which the Y carriage travels.

The Y-carriage, when properly aligned, rides perfectly with its large flat surfaces in the XY plane, traveling forward and back along the Y axis.

Each new layer of plastic being laid down by your printer represents another instance of the XY plane, just a little higher up along the Z axis.

Obtaining this perfect alignment REQUIRES that the printer table surface be level from Front-to-Back, Left-to-Right, and Diagonally across the corners.

The table surface is then the “reference” XY plane, as it establishes a base XY plane for the XYZ coordinate system.

The printer sits on the table surface, with its XY plane parallel to the table surface, and all axes 90° to each other.

The Hot Bed itself has NO effect, impact or influence on the underlying foundation/XY plane.

NONE.

The Hot Bed is just SITTING there, going back and forth for a ride, like a passenger in a car.

If there’s a sagging spring in the car, then the passenger sags along with it.

It doesn’t matter how many pillows the passenger sits on: they will **NEVER** fix the sagging spring in that manner.

So PLEASE comprehend this: **NO** amount of fiddling with the 4 corner wingnuts, and **NO** amount of use of an auto-leveling sensor, will **EVER** get your **foundation/XY plane** properly aligned to the table surface/printer frame.

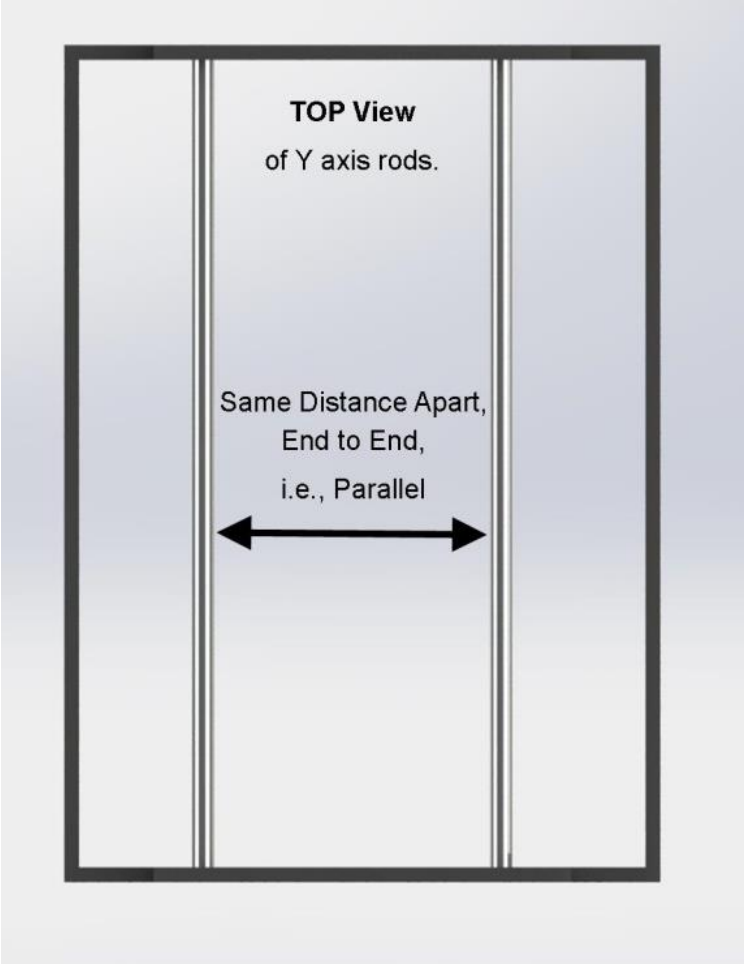
To use the car analogy, all you’d be doing is adding or subtracting pillows to try to get to a better view out of the car.

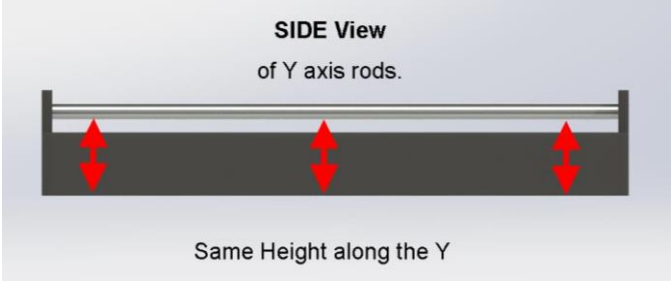
It **DOESN’T FIX** the sagging spring!

If your Y carriage/XY plane is out of alignment and you DON’T KNOW it, then ANYTHING you do is nothing more than a Band-Aid, as you’re NOT correcting the actual PROBLEM.

Accurate and repeatable Hot Bed leveling will CONTINUE to be an UNATTAINABLE MOVING TARGET until you do.

Looking at the Y axis rods in your printer frame: they MUST be aligned so that they are parallel/the same distance apart, aligned in the Y axis, and parallel to the table surface/printer frame (in the XY plane).





With this alignment, when the Y carriage rides the rods, EVERY spot on the Y carriage plate will be perfectly in the XY plane, that is, the SAME distance above the table, with NO high low spots ANYWHERE on its surface.

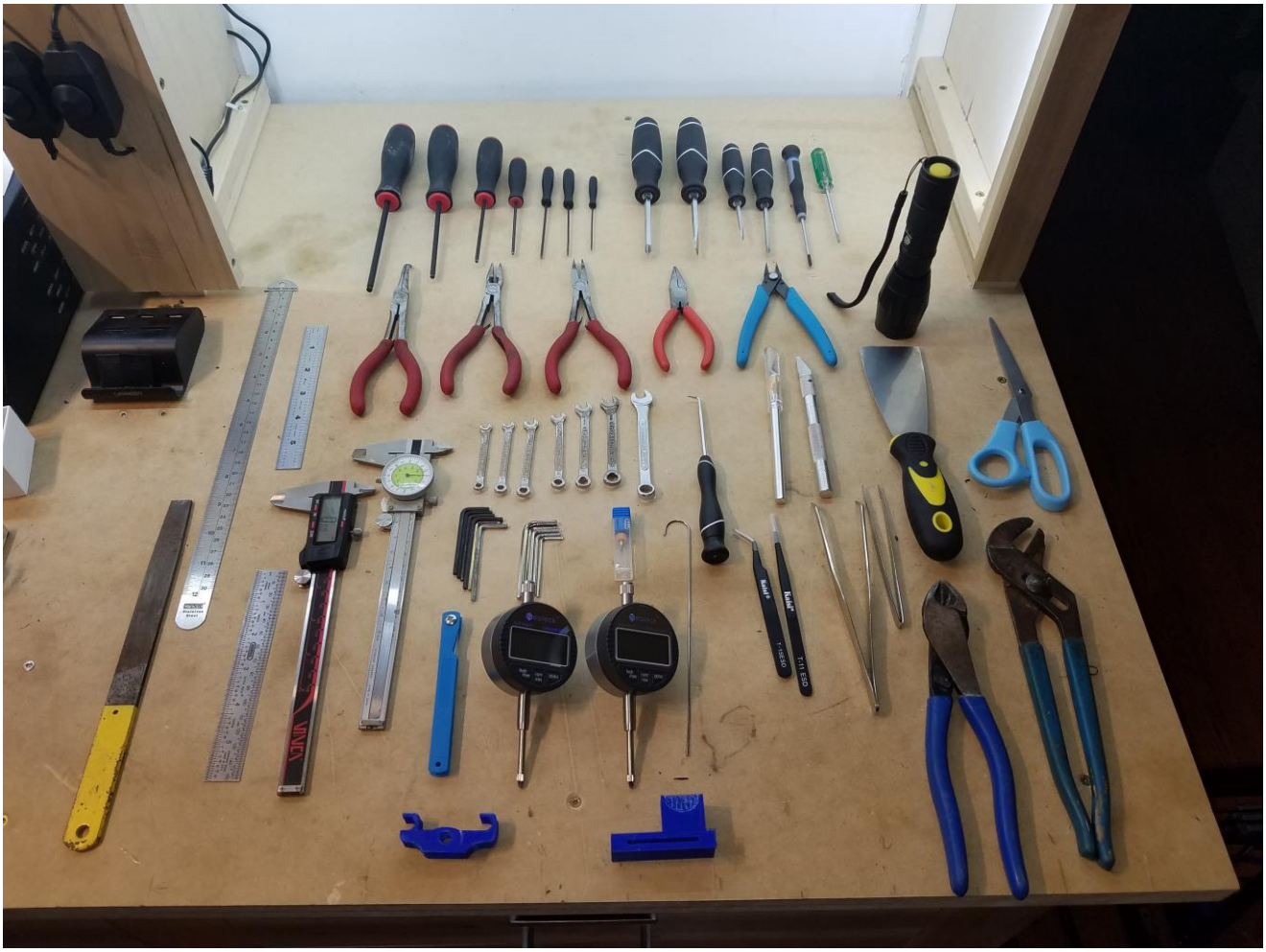
In other words, a perfect XY plane to set the Hot Bed on.

Getting The Perfect XY Plane

Getting that perfect XY plane alignment simply takes some time, patience, attention to detail, wrenches/tools, accurate measuring equipment such as dial gauges, calipers, rulers, jigs, levels, “things,” etc., and the desire to make your printer yield accurate and precise results EVERY time.

Remember, it’s a machine: machines NEED maintenance, and maintenance REQUIRES tools.

In my honest opinion, it’s a good idea to invest in some quality tools that make your job easy.



Of all the tools displayed above, in my honest opinion, the ball-end Allen’s with the molded handles (upper left) are the best investment I made. (by Bondhuis, available on Amazon)

You don’t NEED every single tool pictured, but it sure does help. ☺

Let’s not forget that if you are an industrious and creative individual, you may also want to invest in drill bits, taps and dies. And electrical components. And wire. And crimpers. And replacement parts. And etc., etc., etc.

Again, not necessary, but if your machine ever breaks, and you have the replacement part on hand and the tools to fix it, well, your 3D printing life just got a whole lot nicer. ☺

So, let's get that perfect XY plane.

Start by removing the Hot Bed. Yes, get it out of the way.

Remember, it's JUST a passenger that goes for the ride. WE want to get into the SUSPENSION.

Remove the Y carriage plate if necessary to gain access/clearance. The Y plate and upper half of each bearing block should measure to the same value, within tolerances, so we can work directly to the smooth rods, knowing that once reassembled, the Y plate will be, effectively, perfectly in the XY plane.

Now, align the Y carriage rods: loosen, measure, snug, measure again, tighten, measure again, loosen if necessary, re-adjust, etc.

Be **ridiculously** picky.

The XY plane of your table surface is your "reference" plane. Your Y carriage rods should be aligned parallel to the table surface along their entire length.

Triple check it all and tighten everything securely.

You want that Y carriage to be as PERFECTLY in the XY plane as possible and to STAY that way.

This will be time VERY WELL SPENT. It's an investment in guaranteed future perfect 1st layers/prints.

Leveling the X Axis (a.k.a. Calibrating the Z)

So now you're done with your alignment. You've got your machine's XY plane perfectly dialed in.

Let's also presume that your Z axis is also perfectly aligned. If it's not, MAKE it so.

Now, at this point, if there were no screw heads or holes in the Y plate, (*after leveling the X axis*) you could PRINT on it, and if it stuck, you'd get a PERFECT 1st layer and continuing print.

And **WHY NOT?**

It's what you should **EXPECT** with a properly aligned and calibrated machine!

The Y carriage/print surface is riding in a perfect XY plane, the X is parallel to the XY plane, and the Z is perpendicular to it.

ALL 3 axes are 90° to each other in all respects: Perfect planar and axis alignment.

WAIT. What's this about (*after leveling the X axis)*?

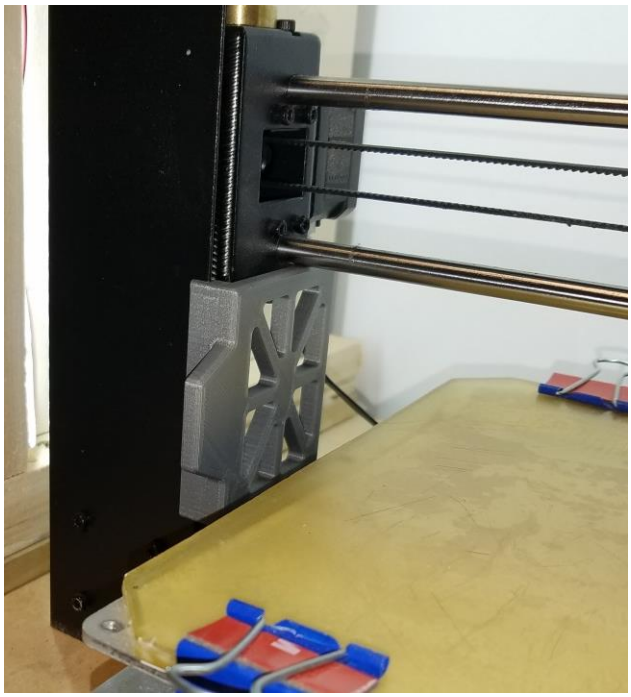
Well, a VERY bothersome quirk/design flaw of dual Z- motored printers is that the Z motors go out of sync QUITE often, even when turning your machine on.

The Z motors drive the X axis up and down. When they go out of sync, the X axis “tilts” out of alignment with the XY plane.

It’s VERY IMPORTANT and NECESSARY to level X axis at the start of EVERY print. This puts the X axis back into parallel alignment with the XY plane. EVERY print.

Takes maybe a half a minute to level it, and it’s SO worth it.

There are numerous “Things” that folks have designed for X axis leveling to make this an effortless and easily repeatable task. I designed my own and printed 2 of them: one for each side. No more pill bottles.



I turn my printer on, slide in my spacers, adjust the Z screws till they’re the same “no-tension” feel, pull out the spacers, and select Print. (Notice, I DIDN’T level the Hot Bed. Read on and you’ll learn WHY.)

Now, to all those enterprising folks who have eliminated that problem by synching your Z motors physically, as with a belt, or converted to a single motor with a belt, I say, **BRAVO!**

One Z motor does the job just fine, and NO more out of sync issues.

I would say that the rest of us (myself included) have some catching up to do. ☺

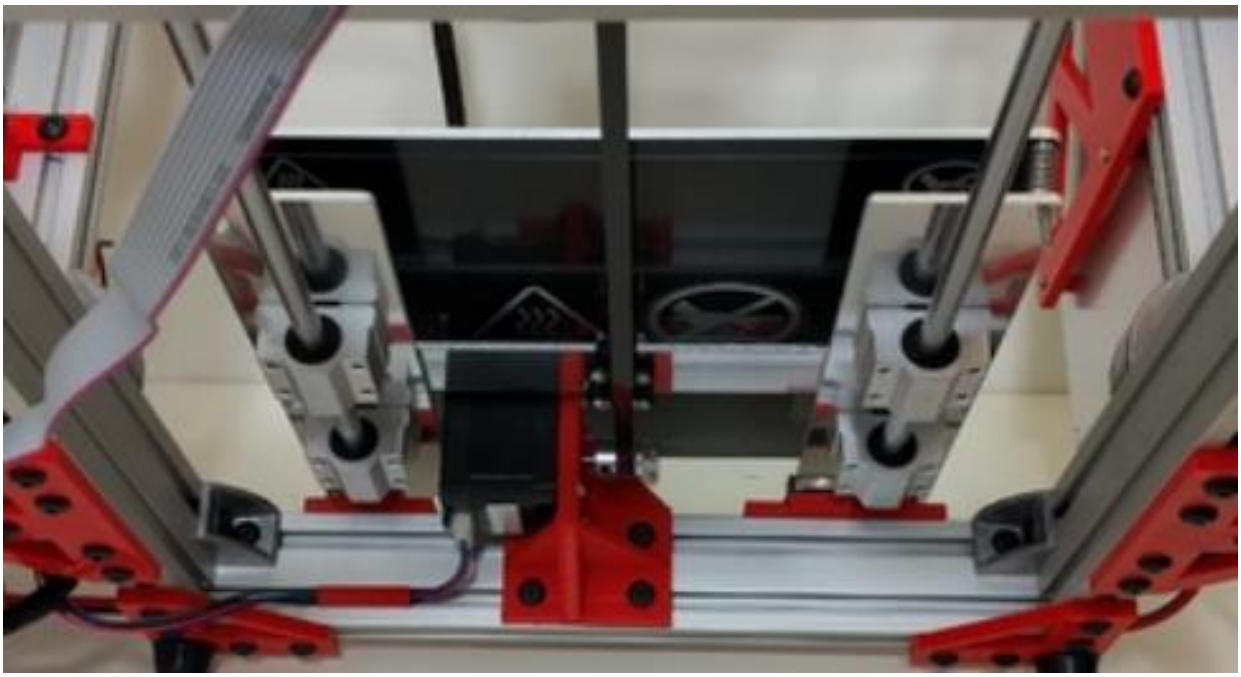
And of course, let’s NOT forget about all of the other pieces that have to sing along with this band: belts, pulleys, bearings, motors, extruders, electronics, settings, firmware, etc., as it’s only when all are working in perfect harmony can you expect to get consistent results.

Regular maintenance and calibration goes a long way in keeping your machine running smoothly and consistently.

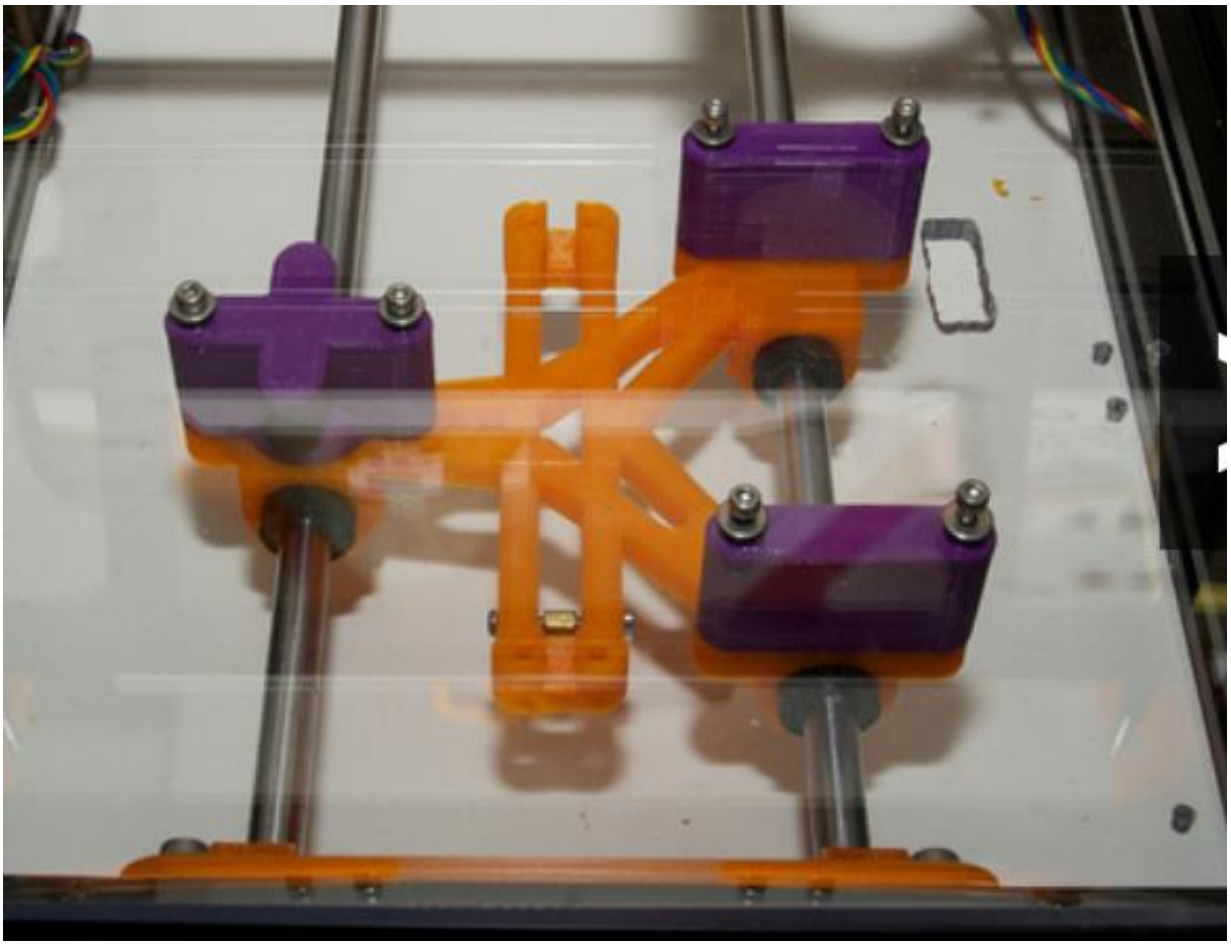
Mounting the Y carriage

Now, let's briefly discuss HOW the Y plate is mounted to the smooth rods.

Some printers use 4 bearings. (printer design/photo credit to pheneeny)



Others use 3. (bearing mount design/photo credit to tommyc)



Three or four, four or three. What gives?

Well, we know that a plane is defined geometrically by three (3) points. NOT four (4).

And, as you know, your Y carriage plate is a PLANE. and a PLANE is defined by, Anyone?, Anyone?

Yup, 3 points.

Yet, we've seen a mix between 3 and 4 bearing mounts.

I will not argue the pros/cons of either method.

That's a whole 'nother topic for discussion: just not in this document. ☺

EITHER WAY, the Y axis rods STILL require the SAME alignment process.

Mounting the Hot Bed

Now, here is where I see the FALLACY of using 4 corner screws to mount your hot bed to the Y plate:

Trying to level a Hot Bed with 4 corner screws is more like "bending" than leveling.

Tighten one screw and you impact ALL of the remaining screws AND the Y plate AND the Hot bed.

That really can't be good for any of the components.

AND you're chasing a bed level that you'll NEVER find or accurately repeat.

Remember, your Hot Bed is a PLANE.

Support it on three (3) points and it will sit there comfortably and stably.

You could say "Perfectly" in balance.

Do you really want to add a 4th point and DISRUPT the perfect balance of the initial three?

NO, YOU DON'T NEED IT.

As I said before, all the Hot Bed is doing is going along for the ride.

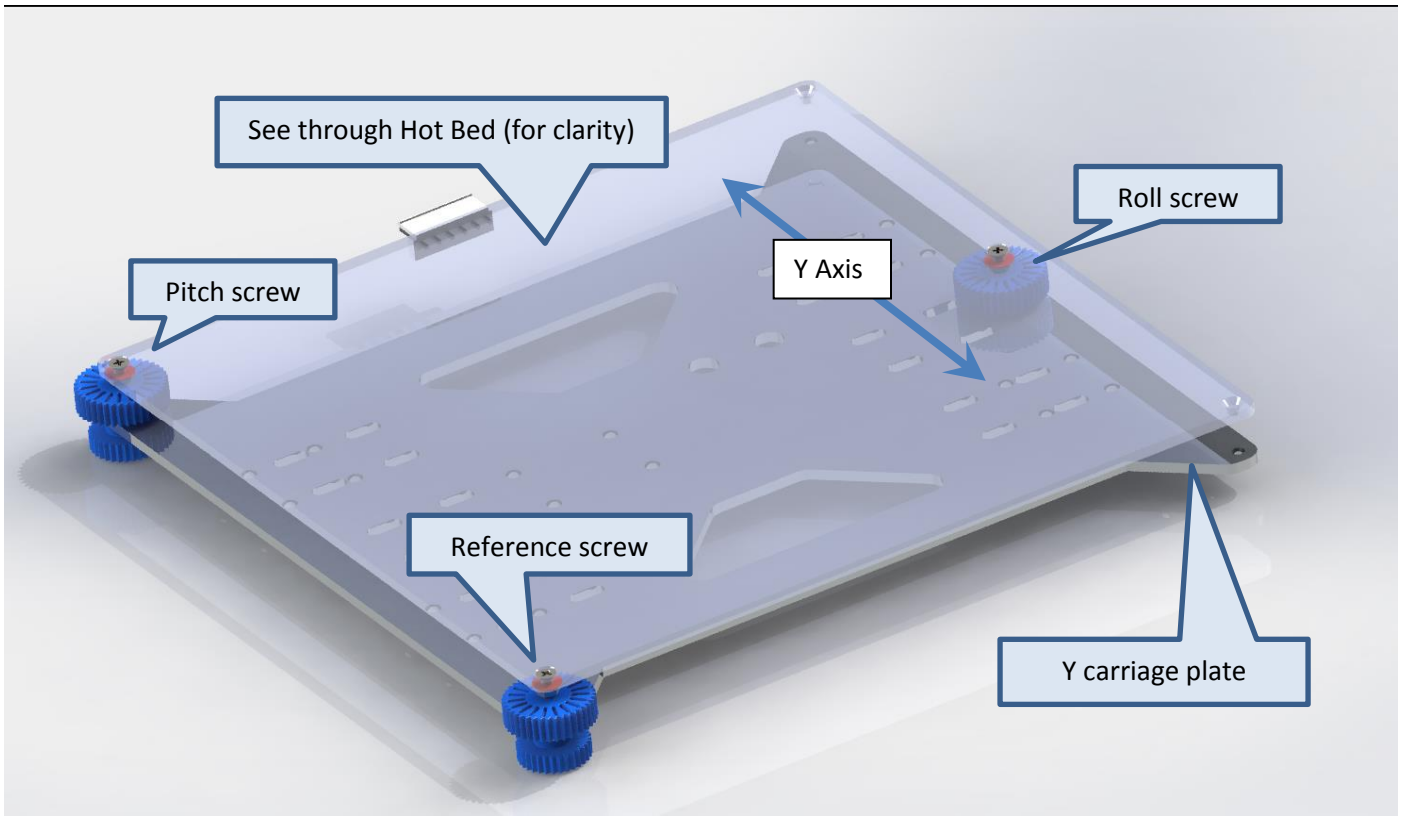
So let's just install it, level it, and print. Let's not **COMPLICATE** it.

By supporting the Hot Bed on 2 corners on one side, and in the middle of the opposite side, raising one support would simply allow the Hot Bed to **PIVOT** on the remaining two.

There would **NO FIGHTING** of the remaining 3 that exist in a 4-point mount.

Your entire Y-carriage/Hot Bed is **NEVER** stressed in ANY manner, in that there is **ZERO** tension between the perfect balance of the three (3) mounting screws.

And here's the GREAT part: 3-point mounting your Hot Bed makes LEVELING the Hot Bed as EASY as 1-2-3, that is, Reference, Pitch, and Roll.



The **1st** mounting point is preferably one of the front corners of your Hot Bed, let's say Front Left. That is the Reference screw. The Reference screw establishes the actual overall Z height or "Reference" height for the rest of the bed to follow. That's the 1st point on the XY plane.

The **2nd** mounting point is on the Back Left corner: this is the Pitch screw. Reference and Pitch are in the same Y axis. The Pitch screw brings that corner on that edge of the Hot Bed up to Reference height. That's the 2nd point on the XY plane.

The **3rd** mounting point is on the Right side of the Hot Bed, as close to halfway front-to-back as possible (based on mounting possibilities): this is the Roll screw. The Roll screw brings that side of the bed up to Reference height. That's the 3rd point on the XY plane.

Now you have a Hot Bed that is resting on 3 points, comfortably, stably, and securely, with your Y carriage perfectly aligned in the XY plane.

So let's just adjust the Hot Bed to make it parallel to the Y carriage XY plane, at your desired nozzle height.

In other words, let's LEVEL it.

This is again, as ALWAYS, contingent on proper ALIGNMENT.

A simple IF – THEN is all it takes to get a perfectly leveled Hot Bed.

IF:

the XYZ axes are in perpendicular alignment with each other, AND

the X axis is parallel to the XY plane, AND

your Z Home nozzle height is set

THEN….

1. Adjust the Reference screw to your desired paper tension.
2. Adjust the Pitch screw to your desired paper tension.
3. Adjust the Roll screw to your desired paper tension.

That’s it, the bed is LEVEL.

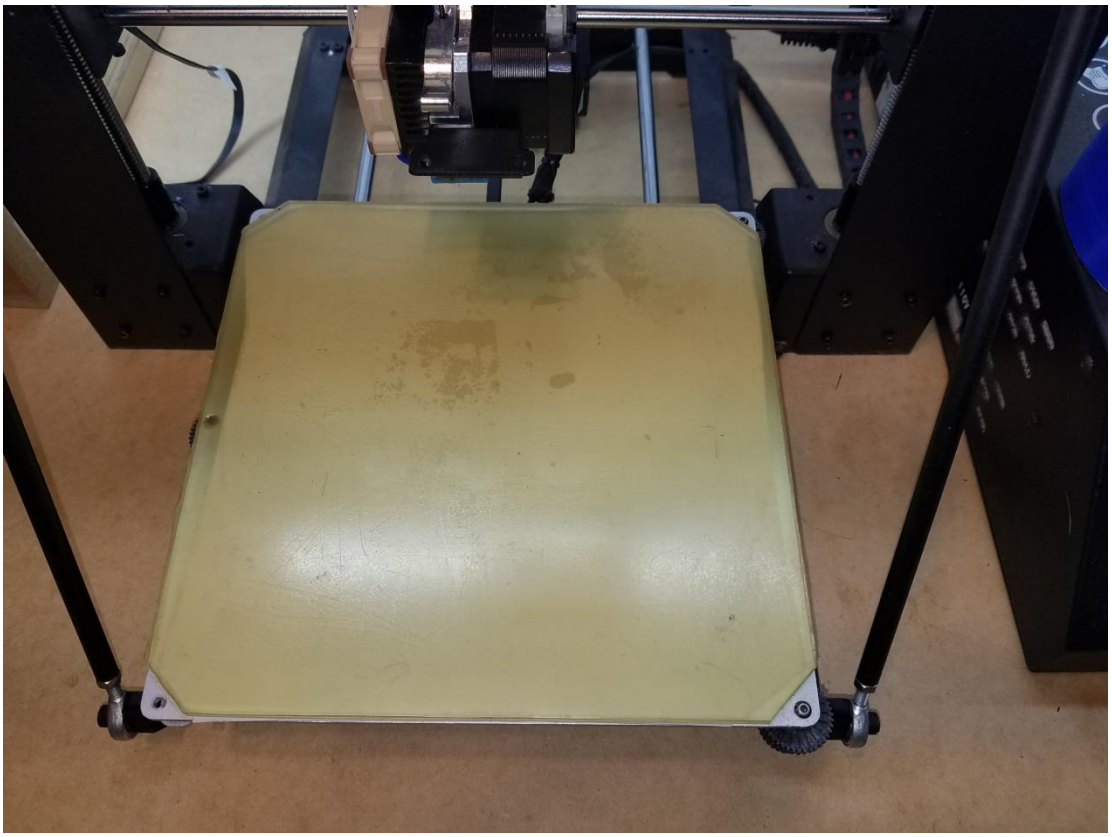
Chasing, guessing, going around the 4 corners 3 or 4 times and hoping, witchcraft, or auto leveling: it’s just NOT needed.

As long as you keep your machine in perfect alignment, leveling the bed is EFFORTLESS, EASILY repeatable, and ACCURATE.

It’s just simple, proven, geometry. And it ALWAYS works.

3-Point Hot Bed Mount

My Hot Bed is 3-point SOLID mounted. Once it's leveled it, STAYS where it's put.



I saw this mod a long time ago on the 'verse. Whoever posted it, please take the credit. It's not my idea, but it works flawlessly!

It uses 2 locking thumbwheels per mounting screw. Each thumbwheel has a Nyloc nut in it. There are NO springs, washers or cups.

I spent some careful time with dial gauges, calipers, rulers and such, and ensured that my Y axis rods and Y carriage were as dead perfect in all respects as I could get them.

Then I 3 point mounted the Hot Bed: 2 corner screws on the Left side were removed.

I drilled and chamfered a hole in the center of that side of the Hot Bed so as to fit a flat head style screw for the Roll screw, in that I use a sheet of borosilicate glass with PEI on top of it. The new hole is in a blank spot on the bed.

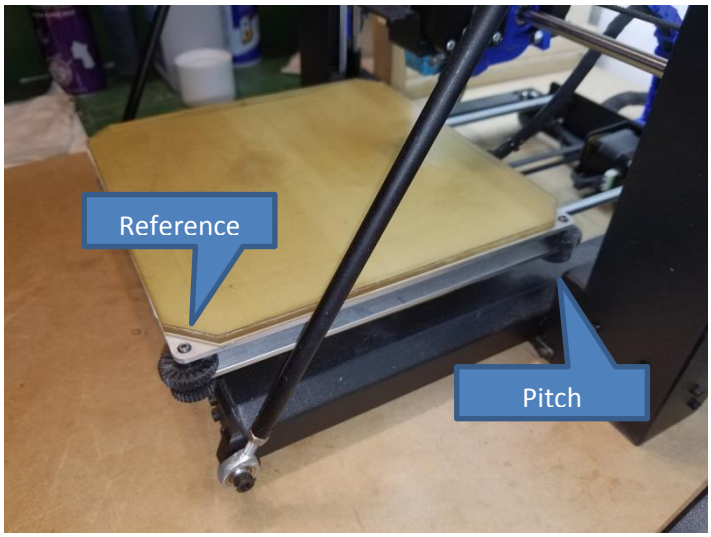
It also required a drilled hole in the Y carriage plate at the corresponding location.

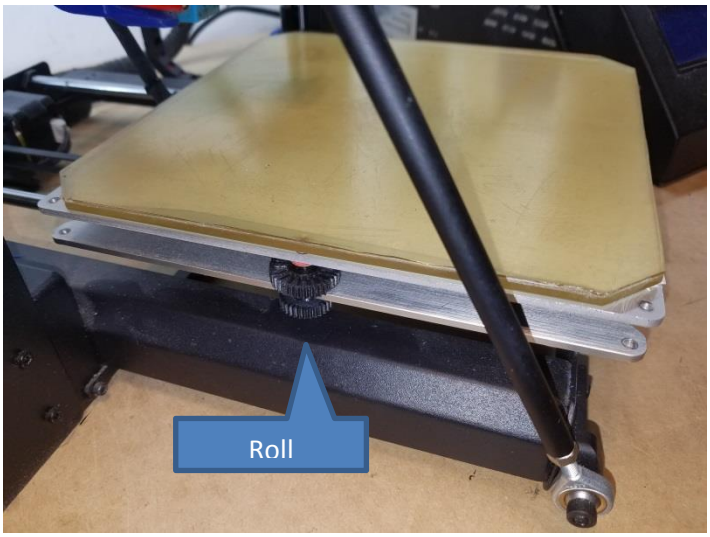
The dual locking thumbscrews KEEP the Hot Bed exactly where I put it.

My Z end stop is firmly installed: no slip or unwanted movement. I have NO fears of a nozzle crash ever occurring.

I have Z braces for maintaining Z axis perpendicularity. A crooked/misaligned Z means crooked/misaligned parts.

Here’s what my three (3) Hot Bed mounting screw placements looks like:





With all my axes properly aligned, once I’ve made the needed leveling adjustment to an Upper leveling thumbwheel, I tighten the Bottom thumbwheel against the Y-plate/Upper thumbwheel. This LOCKS the bed in that position.

As I mentioned before, a dual Z-motor printer will have its Z motors go out of sync far more often than any human should have to suffer through.

But that’s NOT a reason to have to RE-level the bed: just level the X axis.

My Y carriage XY plane is perfectly LEVEL, and my Hot Bed is LOCKED parallel to it.

I **RELY** on that.

Set It and Forget It

Not to be cheeky, but for lack of a better phrase, I did the “Ronco” thing: I Set it and Forget it.

That was over 2 months ago when I changed to 3-point.

BECAUSE I started with a perfectly aligned machine, once I leveled my bed and locked it, it STAYS leveled and locked. (things will ultimately loosen over time, hence regular maintenance)

I KNOW that my Hot Bed is riding in that perfect XY plane, which is parallel to my perfect Y carriage XY plane, which is parallel to the perfect base XY plane of the table surface.

Everything is locked in perfect planar and perpendicular alignment.

Now, we know dual Z-motors go out of sync.

So, at print time, here’s what I do: I level the X axis, and I Print. **THAT’S** it.

NO bed leveling required.

I SPENT the quality time aligning everything, 3-point mounting the bed, and using locking thumbwheels, so I WOULDN’T HAVE to keep re-leveling.

I’ve spoken with other folks who have gone 3-point mount and they have experienced the same results: CONSISTENT 1st layers and successful prints with NO releveling. Who doesn’t want that?

Folks, it’s JUST a machine. Keep it ALIGNED, calibrated and maintained, and it will keep producing quality prints. It’s that geometry thing again…..

I’ve printed well over 200 parts since I changed over, with multiple 15+hr and 30+hr prints, and they’ve ALL had perfect 1st layers, they’ve ALL printed wonderfully and accurately, and I haven’t touched a bed leveling thumbwheel since I leveled it at installation.

Printing is a joy now, as I don’t think AT ALL about Hot Bed leveling, because I don’t HAVE to.

It already IS level, and it STAYS that way. ☺

This material is based solely the author’s experiences and opinions and is for informational purposes only.