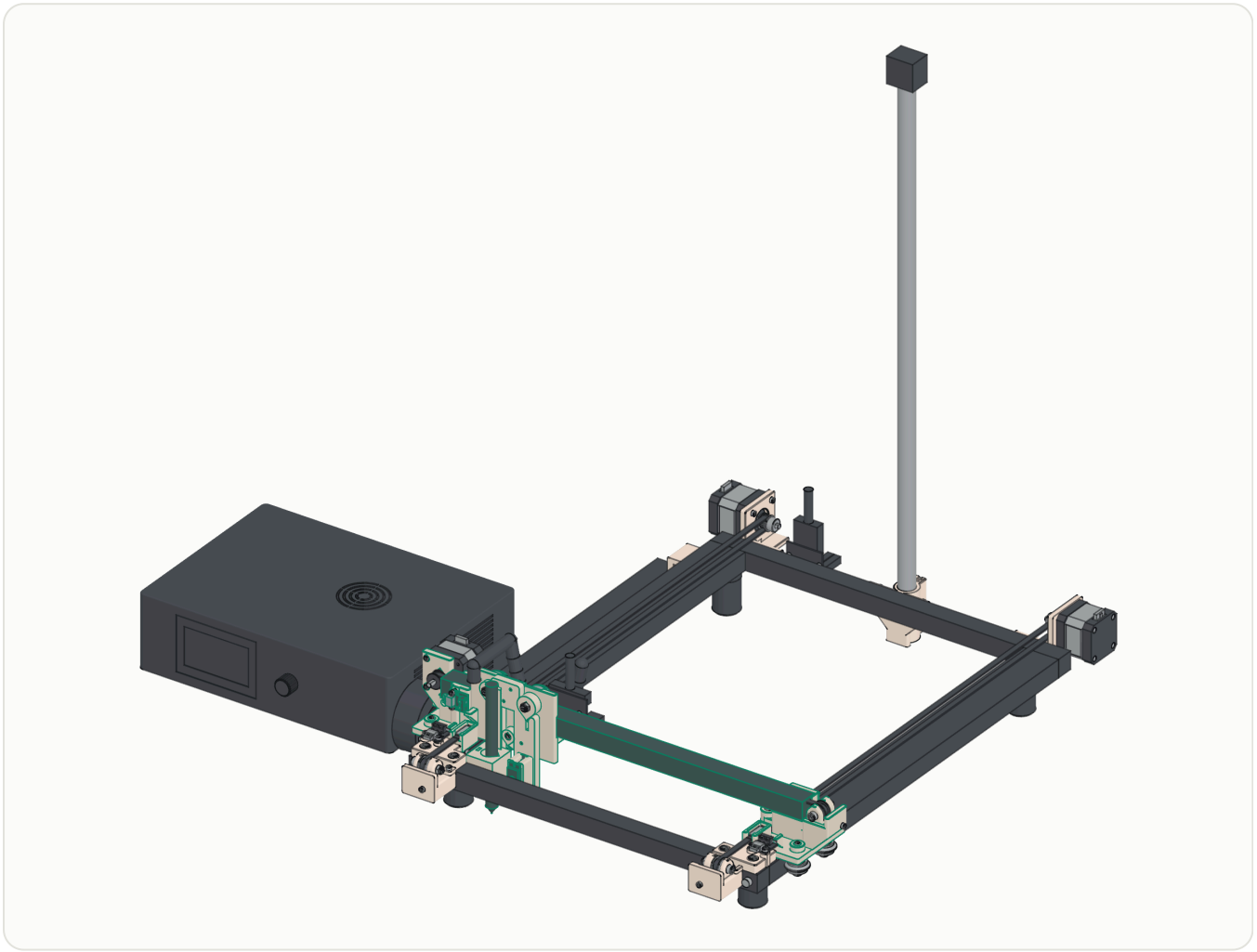
BUILD GUIDE

PEN PLOTTER

A table plotter from a Creality CR-10 V3



Travel	245 × 390 mm	**Controller**	Stock CR-10 V3 box (ATmega2560)
Axes	Stock V-wheels, two Y motors	**Firmware**	Go, built with TinyGo
Printed parts	16 parts, 21 h 45 min, 383 g PLA	**Software**	plotstudio over USB
Pens	T0 to T15 by hand, 8 to 15 mm	**Parts cost**	about $199 + $8 of PLA

10 November 2026

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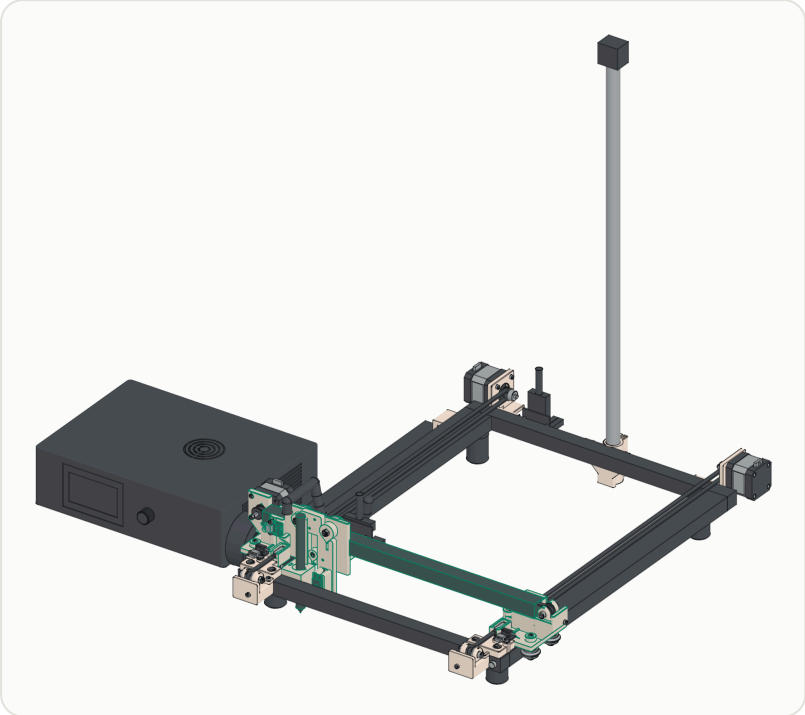
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CHAPTER 1

1 Overview



The pen plotter is the base frame of a dismantled Creality CR-10 V3 on a table. The table is the bed: the paper lies on the table, and the gantry moves over it. Stock V-wheels carry both axes: three on each printed Y carriage, and three on the printed X plate. The motors do not move. Two Y motors stand behind the back bar, and the X motor stands at the left end of the beam. The X belt runs in the slots of the beam, as on the stock CR-10. A servo lifts the pen. The stock CR-10 V3 control box stands beside the frame and drives the plotter. The stock harness stays. The two small Creality boards of the harness stand bare on nylon standoffs, held by cable ties.

The printed parts copy the stock CR-10 layouts. They keep only the features that the plotter uses. Each Y carriage is a flat 6 mm plate, in the form of the stock Z carriage plate.

The firmware is written in Go and built with TinyGo. It runs on the ATmega2560 of the stock mainboard. A simulator runs the same firmware code on a computer. Plotstudio is the computer program for the plotter: it scans the bed with a camera, places SVG drawings and signatures on the paper, and plots them in up to 16 pen colours over USB. You change the pens by hand.

Specifications

	Value
Pen travel	245 × 390 mm in the firmware (the model allows 245.9 × 395.1 mm)
Paper	A4 and Letter fit. Larger sheets fit under the frame, and the plotter draws on the travel area.
Home	The front left corner. Homing squares the gantry on two Y switches.
Resolution	80 steps/mm on X, Y1 and Y2 (1/16 microsteps, 20T GT2 pulleys)

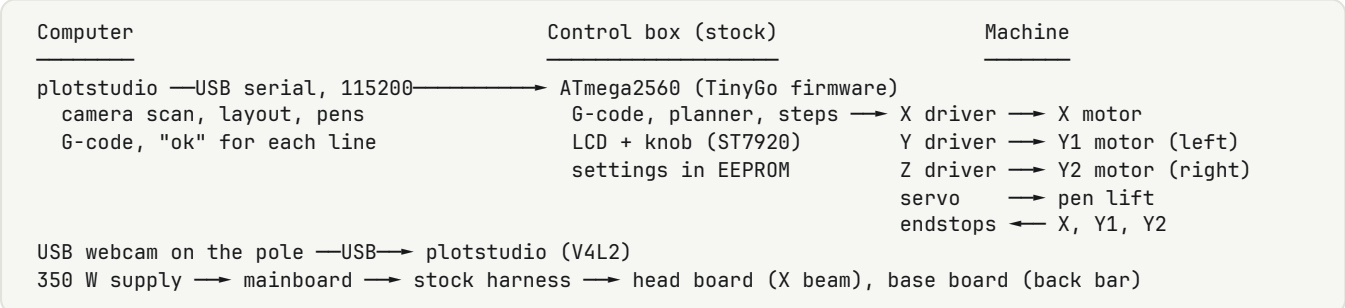
Value	
Speeds	Draw 50 mm/s (plotstudio default), limit 120 mm/s, acceleration 1500 mm/s²
Pen lift	7.0 mm, by a hobby servo
Pen force	The weight of the pen slider and the pen
Pens	One pen in the V bore of the pen slider: round barrels 8 to 15 mm. `T0` to `T15` in the G-code. You change the pen by hand at each `M6`.
Motors	X: a 42-34 (213.4 g). Y1 and Y2: 42-40 (286.7 g).
Controller	The stock CR-10 V3 control box: Creality v2.5.2 mainboard, ATmega2560, 16 MHz, 8 KB RAM
Drivers	The onboard drivers of the mainboard: X, Y (Y1) and Z (Y2). E is free.
Power	The stock 350 W supply in the control box
LCD	The stock ST7920 LCD: 4 text lines, an 11-item knob menu
Connection	USB serial at 115200 baud
Camera	A USB webcam on your 590 mm pole, in an optional printed pole foot, for plotstudio

Cost and print time

Item	Value
Purchased parts	about $199 before tax
Printed parts	16 parts (15 print jobs) in 21 h 45 min, 383 g of PLA, $7.66. This includes the camera pole foot.
Total cost	about $207 before tax
Fit tests	3 parts, 49 min, 14 g
Heat-set inserts	9: 3 M5 (long) and 6 M3

The print values come from CuraEngine slices: PLA, 0.3 mm layers, a LulzBot TAZ Workhorse with the 0.5 mm SE tool head, and PLA at $19.99/kg (`hardware/stats.py`). `05-parts-and-cost` has the details.

How the pieces connect



The `HEAT` output of the head board (the heater MOSFET, D10, PB4) is not used. The firmware holds it off.

The chapters

- **Parts and cost** (`05-parts-and-cost`): what to buy and what to print.

- **Hardware** (`10-hardware`, `15-assembly`): the frame, the V-wheels, the fixed motors, the belts, the printed parts, the breakout boards, the moving cables.
- **Electronics and wiring** (`20-electronics-and-wiring`): the control box, the stock harness, the servo, the switches.
- **Firmware** (`25-firmware`): the ATmega2560 build, the LCD and the knob, the G-code, the pen change.
- **Software** (`30-software`): plotstudio, the simulator, multi-pen jobs.
- **Calibration and first plots** (`40-calibration-and-first-plots`).
- **Review history, troubleshooting and reference** (`75-review-history`, `80-troubleshooting`, `90-reference`).

The repository

Folder	Content
`hardware/`	The printed parts in build123d, the checks, the slices, the build guide PDF
`firmware/`	The TinyGo firmware: portable core packages, the small controller and the board code for the ATmega2560. The folder also has code for a Pico W board. This build does not use it.
`sim/`	The simulator: the same firmware code, a 3D window, an LCD window and a camera
`studio/`	Plotstudio: camera, calibration, SVG, layout, pens, G-code, serial and network links
`integrations/printdeck/`	The Printdeck package and the patch. Printdeck needs a Pico W board, so this build does not use it.
`samples/`	Test drawings, a blueprint generator, and the six-pen mandala (`samples/mandala`)
`tools/`	The progress site and the guide generator
`docs/`	This guide and the reference documents

Status

The design is complete and checked in software. It is not built yet. These parts have no test on real hardware: the step and LCD timing on the ATmega2560, the `BL_T` pin order, the fit of the printed parts, the sag of the servo loom, and the camera capture. Values marked ESTIMATE come from data sheets or photos. `hardware/MEASURE.md` lists the measurements to take before you print.

One question is open. The cable ties of the head board go round the beam, in the path of the X plate and its wheels. `hardware/REVIEW.md` lists the options. Check this before you tie the head board on (`15-assembly`).

CHAPTER 2

2 Parts and cost

This chapter lists what to buy, what to print, and what it costs. Prices are approximate and are from 2026-11-07. "est." marks an estimate.

The build keeps the stock CR-10 V3 control box and its harness. The plotter reuses the 9 stock V-wheels with their spacers and eccentric spacers, the motors, the pulleys and the 4 stock rubber feet. A printed X plate replaces the stock X carriage plate. The two Y carriages are printed flat plates. You buy the belts, the toothed idlers, the screws, the T-nuts, the heat-set inserts, the belt crimp clips, a drag chain, nylon standoffs, a servo and a few cables. The 1/2 inch split wire loom for the servo lead is on hand.

Printed parts

All parts print in PLA with 0.3 mm layers on a LulzBot TAZ Workhorse (SE tool head, 0.5 mm nozzle, 2.85 mm filament). No part needs supports. The values come from CuraEngine slices with the profiles in `hardware/cura/` (PLA at $19.99/kg). `hardware/stats.py` prints them.

Part	Count	Print time	Filament	Cost
`y_carriage_left`	1	3 h 50 min	67 g	$1.34
`y_carriage_right`	1	3 h 30 min	63 g	$1.26
`x_carriage_plate`	1	2 h 32 min	47 g	$0.94
`pen_carriage`	1	2 h 07 min	37 g	$0.74
`pen_slider`	1	54 min	16 g	$0.32
`y_motor_mount_left`	1	1 h 08 min	19 g	$0.38
`y_motor_mount_right`	1	1 h 08 min	19 g	$0.38
`y_front_left`	1	42 min	12 g	$0.24
`y_front_right`	1	42 min	12 g	$0.24
`y_idler_bracket_left`	1	52 min	16 g	$0.32
`y_idler_bracket_right`	1	52 min	16 g	$0.32
`y_idler_fork`	2	51 min	14 g	$0.28
`x_idler_fork`	1	25 min	7 g	$0.14
`y_chain_anchor`	1	40 min	12 g	$0.24
`mast_foot` (optional, the camera pole foot)	1	1 h 32 min	26 g	$0.52
Total, 16 parts in 15 print jobs		**21 h 45 min**	**383 g**	**$7.66**
`fit_rail`	1	10 min	3 g	$0.06
`fit_slider`	1	22 min	6 g	$0.12
`fit_wheel`	1	17 min	5 g	$0.10
Fit tests, 3 parts (print first)		**49 min**	**14 g**	**$0.28**

The values for `y_idler_fork` are for both copies. The camera is a USB webcam on your own 590 mm pole. The printed `mast_foot` holds the pole behind the back bar.

Before the simplification of 2026-11-10, the main build printed 27 parts in 30 h 28 min with 544 g of PLA ($10.88). `75-review-history` lists the changes.

Fasteners

The hardware model has each screw, nut, washer, spacer, T-nut, insert and belt clip of the build (`hardware/fasteners.py`). The fit check moves them with the parts over the whole travel. `hardware/model.py` checks the length of each screw. The M2 and M3 screws in plastic without an insert cut their own thread. The list below is the model total. `docs/bom.md` has the kits.

Fastener	Count	Where	BOM line
M5 drop-in T-nut	13 (buy 15)	Front bases 4, Y motor brackets 4, beam 2, Y chain anchor 1, pole foot 2	M22
M5 × 12 socket head	13	Front bases 4, Y motor brackets 4, beam 2, Y chain anchor 1, pole foot 2	M24
M5 × 30 socket head	5	Front outer Y wheels 2 (into the inserts), idler fork axles 3	M24
M5 × 35 socket head	4	Back outer Y wheels on the eccentric spacers 2, inner Y wheels 2	M24
M5 × 25, M5 × 30, M5 × 35 button head (ISO 7380)	1 each	X wheels: bottom (into the insert), top left, top right (eccentric)	M24
M5 nyloc nut	9	Y wheels 4, top X wheels 2, idler forks 3	M27
M5 washer, small (7.5 mm across)	6	Idler forks, one each side of each idler	M27
M5 heat-set insert, long (9.5 mm)	3	Front outer Y wheel axles 2, bottom X wheel axle 1	M34
M3 heat-set insert (5.7 mm)	6	Y endstop boards 4 (front bases), X endstop board 2 (left Y carriage)	M28
M3 × 8 socket head	6	The three endstop boards (all into inserts)	M23
M3 × 10 socket head	15	X motor 3, Y motors 8, Y chain end links 4	M23
M3 × 12 socket head	6	Pen carriage 4 (T1, T2, H1, H2), front base lip into each Y idler bracket 2	M23
M3 × 16 socket head	1	Pole foot collar	M23
M3 × 20 socket head	4	Tension screws 3 (X fork 1, Y forks 2), pen slider clamp 1	M23
M3 nut	5	Idler forks 3, pole foot collar 1, pen slider 1	M23
M6 × 16 socket head	1	The pole end in the pole foot	M26
GT2 6 mm belt crimp clip	6 (buy 8)	2 on each Y belt, 2 on the X belt	M30
Nylon M3 standoff, 4 mm	4	Two under each breakout board	M38

The model also uses these stock parts: 8 M5 × 30 frame screws, 6 plain 6 mm wheel spacers, 3 eccentric spacers, and the 2 M2 × 8 servo screws from the servo bag. Count your plain spacers first (`hardware/MEASURE.md`, item 62). The build needs 6: 4 on the Y carriages and 2 on the X plate.

The idlers are 3 toothed GT2 20T idlers with a 5 mm bore (M20): one in each Y fork and one in the X fork. The moving cables need the openable drag chain (M32) and the 1/2 inch split wire loom (M33).

Notes on the screws:

- An M5 × 12 screw through a 6 mm wall puts 4 mm of thread in the T-nut. Its tip goes 6 mm into the 6.3 mm slot. The slot depth is an ESTIMATE.
- The M3 heads of the right Y motor bracket bear on PLA. At full torque the pressure is too high. Put an M3 washer under each head, or tighten by feel. The left bracket has the same joint.

Cost summary

Item	Value
Purchased parts	about $199
Printed parts	$7.66 (16 parts)
Total before tax	about $207

The purchases are the servo about $7, the electronics about $46 and the mechanics about $146. The pens, the tie mounts (M37), the standoffs (M38) and the camera are not in these totals. The servo loom (M33) is on hand.

Bill of materials

The sections below come from `docs/bom.md`.

How to read the prices

- The prices are approximate. Check the price and the stock before you buy.
- The links are product searches. Any shop that sells the same part is good.
- "est." means an estimate. The search result did not show a live price.
- The totals use the middle of each price range.

Part 1: What to buy (stock controller build)

Electronics

The control box, the mainboard, the drivers, the LCD and the harness come from the CR-10 V3. Buy only these parts:

#	Item	Qty	Where to find (approx. price)	Notes
S1	Small servo, 180° (SG90 type)	1	Search: SG90 servo, about **$7**. An MG90S also fits (search: MG90S servo, est. $9–11 for a 2-pack).	The pen lift. It plugs into `BL_T` on the head board. Not the 360° type. Do not use a large servo: the mainboard 5 V supply feeds it.

#	Item	Qty	Where to find (approx. price)	Notes
S2	Servo extension cable, 70 cm (or make one)	1	Search: servo extension 70cm, est. $6 (pack)	The servo lead runs from `BL_T` of the head board through the servo loom (M33) to the servo on the pen carriage: about 45 cm (ESTIMATE from the model). A 50 or 70 cm extension fits. You can also make it with S3 and S6.
S3	JST-XH (2.50 mm) and Dupont (2.54 mm) crimp kit with a ratcheting crimper	1	Search: JST-XH Dupont crimp kit with ratcheting crimper, about **$30**	Makes S4 and S5. It has XH housings with 2 to 5 pins, 2R to 5R inline male housings, Dupont housings, terminals, and a 0.08–1.0 mm² (AWG 28–17) crimper. Use the S6 wire: the 1 m of ribbon cable in the kit is thin.
S6	Hook-up wire, 24 AWG silicone, 6 colours × 10 ft	1	Search: 24 AWG silicone wire 6 colors 10 ft, about **$10**	For S4 and S5. Black for GND, red for 5 V, one more colour for the signal. 24 AWG silicone fits the XH and Dupont terminals of S3.
S4	JST XH 5-pin pigtail	1	Make it with S3.	From `BL_T` to the servo extension. The servo end is a 3-pin Dupont plug from S3. Three wires: GND, 5 V, signal (`docs/wiring.md`).
S5	JST XH 2-pin extension, 50 cm	0 to 2	Make it with S3.	A 2P housing on one end and a 2R inline male housing on the other end. Only if a stock endstop cable does not reach the front base of its belt.

Mechanics

#	Item	Qty	Where to find (approx. price)	Notes
M18	GT2 open timing belt: 2 mm pitch, 6 mm wide, glass fibre core, 5 m roll	1	Search: GT2 belt 6mm 5m, est. $8–10	2 Y belts and 1 X belt. Cut each Y belt about 1200 mm long and the X belt about 950 mm long, then crimp them to length (1135 mm and 898 mm between the folds). Each belt is a loop round a motor pulley and an idler, cut at the carriage. Not GT2-3M, not 9 or 10 mm wide, not a closed loop. The stock belts are too short now.
M19	GT2 20 tooth pulley, 5 mm bore	1	Search: GT2 20 tooth pulley 5 mm bore, est. $7 (pack)	The second Y motor. The 2 stock pulleys are reused (X and Y1). 80 steps/mm stays.
M20	GT2 20 tooth idler, **toothed**, 5 mm bore (ball bearings), 6 mm belt	2 (3 if the stock X idler is not a 20T toothed idler)	Search: GT2 20 tooth toothed idler 5 mm bore, est. $8 (pack)	One for each Y belt, in the fork in front of the front bar. The belt teeth run on it, so it is toothed (the runs stay parallel). The model uses 18 mm flanges and 8.5 mm width (ESTIMATE; `MEASURE.md` item 43).
M22	M5 drop-in T-nuts for 2020/2040	15	Amazon search: M5 drop in T nut, est. $7	Y front bases (4), Y motor brackets (4), the beam (2, one at each end in the back slot), Y chain anchor (1), camera pole foot (2), spare (2). The model has the 13 in use. Packs of 20 are common.

#	Item	Qty	Where to find (approx. price)	Notes
M23	M3 socket head kit (6–30 mm), with nuts	1	Search: M3 socket head screw kit, est. $14–16	15 × M3 × 10 (X motor 3, Y motors 8, Y chain end links 4), 6 × M3 × 12 (pen carriage T1, T2, H1 and H2, 1 through the inner lip of each Y front base into its idler bracket), 6 × M3 × 8 (the endstop boards, into M3 inserts), 4 × M3 × 20 (the X and the two Y tension screws with nuts, the pen clamp screw with a nut), 1 × M3 × 16 with a nut (pole collar).
M24	M5 socket head kit, with nuts	1	Amazon search: M5 socket head screw kit, est. $12	13 × M5 × 12 (front bases 4, Y motor brackets 4, beam 2, Y chain anchor 1, pole foot 2), 5 × M5 × 30 (front outer Y wheels 2, the 3 idler fork axles), 4 × M5 × 35 (back outer Y wheels on the eccentric spacers 2, inner Y wheels 2), 3 × button head ISO 7380 for the X wheels: M5 × 30 (top left), M5 × 35 (top right, eccentric), M5 × 25 (bottom). Most kits stop at 30 mm: buy the 35 mm screws separately if needed.
M25	Cable ties, 2.5 mm	1 pack	Any brand, est. $4	2 for each breakout board (4: through the board holes and round the extrusion), 1 at each end of the servo loom (2), the head cable on the beam (about 4), 8 at the M37 tie mounts, 2 at the chain end combs, 2 spare.
M26	M6 × 16 socket head screw	1	Any source. Price not checked.	Camera pole into the pole foot (optional).
M27	M5 nyloc nuts, M5 flat washers (small, 7.5 mm across)	9 nuts, 6 small washers	Amazon search: M5 nylon lock nut washer, est. $6	The nuts: 4 Y wheels (the 2 front outer wheels go into inserts), the 2 top X wheels, the 3 idler forks. The washers are SMALL M5 washers (5.3 × 7.5 × 1): 6 in the idler forks (one each side of each idler). The fixed X wheels use stock 6 mm spacers now.
M28	M3 heat-set inserts, brass, M3 × 5.7 mm (about 4.6 mm across)	6 (buy a pack)	Search: M3 heat set insert 5.7mm, est. $8 (pack)	The 3 endstop boards (2 Y boards in the front bases, the X board on the X endstop wall of the left Y carriage). Hole 4.0 mm, 7 mm deep.
M29	8 mm open-end wrench	1	Search: 8mm wrench, est. $5	Turns the eccentric spacers. Skip it if your CR-10 tool kit has one.
M30	GT2 6 mm belt crimp clips, metal (OpenBuilds style "belt clamp, crimp style")	8	Amazon search: GT2 belt crimp clamp, est. $8–10 (pack of 10)	2 on each Y belt and 2 on the X belt, and 2 spare. Each folded belt end gets one clip. The clip sits in a pocket and takes the pull. Listed as 18 × 7 × 8 mm, stamped steel; the size is an ESTIMATE (hardware/MEASURE.md).
M31	Stepper motor cable, 1.5 m: JST XH 4-pin to PH2.0 6-pin	0 to 2	Amazon search: stepper motor cable 1.5m XH2.54 4pin PH2.0 6pin, est. $10 (pack)	Only if a stock cable is too short. The Y motors stand behind the back bar now: Y1 is about 0.4 m from the base board, Y2 about 0.8 m along the table behind the frame. They do not move.
M32	Drag chain (cable carrier), **openable**, inner 10 × 20 mm (10 × 15 is enough now), bend radius R28, with end brackets	1 m (use about 0.51 m)	Search: openable drag chain 10x20 R28, est. $12–15	The head harness only (the Y motor cables are static now). Openable, because the big harness plug does not pass a closed link. The model reads the size and the radius from `YCH_*` in hardware/shape.py.

#	Item	Qty	Where to find (approx. price)	Notes
M33	Split wire loom, 1/2 inch (12.7 mm)	295 mm	**On hand**: no purchase.	The servo lead runs in it from the head board to the X plate. Cut it to 295 mm. The loop between the two ties is 189 mm long. One cable tie (M25) goes through the slot at the top left of the X plate. The other tie holds the loom to the head harness cable, above the big plug of the head board.
M34	M5 heat-set inserts, brass, **long**: 9.5 mm long, about 7 mm across (CNC Kitchen or Ruthex style)	3 (buy a pack)	Search: M5 heat set insert 9.5mm, est. $8–10 (pack)	One in each Y carriage (the front outer wheel axle) and one in the bottom wheel boss of the X plate. Hole 6.4 mm, 10.5 mm deep.
M35	Soldering iron tips for M5 and M3 heat-set inserts	1	Amazon search: heat set insert tip M5, est. $8–12	Fits most 900M-style and pen-style irons. Check the thread of your iron first. 220 °C for PLA. Skip it if you have an insert tip; a plain conical tip also works with care.
M36	Slot cover strip for 2020 V-slot, 6 mm, flexible PVC, black or grey	2 m pack (uses 1.21 m)	Search: 2020 slot cover strip 6mm, est. $8–12	Holds the Y endstop wires in the slots. Cut lengths: left rail bottom outer slot 428 mm (y 36–464), right rail bottom outer slot 452 mm (y 36–488), back bar bottom slot 29 mm (x 29–58) and 302 mm (x 76–378). Leave the gaps at the cable entries and exits (`hardware/context_detail_HOOKUP.md`).
M38	Nylon M3 standoffs, 4 mm long	4	Search: nylon M3 standoff 4mm. Price not checked.	Two under each breakout board (the head board on the beam, the base board on the back bar). A cable tie goes through each board hole and standoff, round the extrusion.
M37	Adhesive cable tie mounts, 19 × 19 × 3 mm	8 (pack of 50)	Search: adhesive cable tie mounts 19mm. Price not checked.	Hold the static cables on the table under the trunk, one cable tie at each mount. The positions are in `hardware/context_detail_HOOKUP.md`. M25 has the 12 extra cable ties.

Three M5 heat-set inserts (M34) and six M3 inserts (M28). You need a soldering iron for them.

Reused from the CR-10 V3

- The base frame (2 2020 bars, 2 2040 frame rails, the 4 rubber feet) and the 2020 X beam.
- The 3 V-wheels, the eccentric spacer and the two 6 mm spacers of the Creality X carriage plate. The stock X plate itself and its wheel bolts are not used now: a printed X plate replaces it.
- 6 free V-wheels with 4 × 6 mm spacers and 2 eccentric spacers (from the Z carriages and the bed carriage), for the Y carriages.
- The X idler wheel if it is a 20T toothed idler (otherwise use an M20 idler). The stock X belt is too short now (898 mm between the folds): cut the X belt from the roll (M18).
- The five NEMA 17 motors (on hand: two 42-34 and three 42-40). X: a 42-34 (213.4 g, measured): it rides on the gantry, so the shorter, lighter motor cuts the moving mass (73.3 g less than a 42-40). Y1 and Y2: 42-40 (286.7 g, measured); they stand still. Spares: one 42-40 and one 42-34.
- 3 endstop boards, 2 GT2 pulleys and 1 GT2 idler (the X idler).
- The control box: the Creality v2.5.2 mainboard, the 350 W supply, and the 12864 LCD with the knob.
- The stock harness with the head board and the base board, and the motor and endstop cables.

Spare parts after the build: the Z lead screw, the two uprights, the top bar, the bed, the stock Y belt, and the extruder and hot end.

Plotting supplies

Item	Source	Notes
Pens	Search: Sakura Pigma Micron 05 6-pack, about $16	The pen slider holds one pen in its V bore. Round barrels 8 to 15 mm fit.
Blue painter's tape or a cutting mat	Any source	Holds the paper on the table.

Totals, stock controller build (estimates)

Group	Lines	Subtotal
Servo	S1	about **$7**
Electronics	S2, S3, S6	about **$46**
Mechanics	M18–M25, M27–M32, M34–M36	about **$146** ($138–156)
Printed parts (PLA)	16 parts, see the build guide	**$7.66**
Total		**about $207 before tax** ($199–217)

The pens, the M37 tie mounts and the M38 standoffs (price not checked) are not in the total. The servo loom (M33) is on hand. The camera (a USB webcam on a 590 mm camera pole) and its printed pole foot are optional and not in the total.

Mainboard

- **Confirmed:** The CR-10 V3 (2020) mainboard is a Creality v2.5.2 with an ATmega2560. Source: the Klipper config `printer-creality-cr10-v3-2020.cfg` (GitHub).
- **Likely:** The stepper drivers on that board are TMC2208 in standalone mode. Some later units may have a different board revision. Read the silkscreen on your board.
- **Unknown:** Board size and hole spacing. No public drawing exists. Creality did not publish the V2 / V3 board files (GitHub issue). The board stays in the stock control box, so the build does not need them.

Stepper motors

- **Likely:** Creality 42-40 type (42 × 42 × 40 mm, 1.8°, about 0.4 N·m). Sellers list it for the CR-10 V3 Y axis.
- **Confirmed (measured):** a 42-34 is 213.4 g, a 42-40 is 286.7 g.
- **Uncertain:** Rated current. Most listings say 1.0 A per phase. Some say 1.5 A. **Read the label on each motor.** The onboard drivers keep the current setting of the printer.
- **Likely:** Connector at the motor is a 6-pin JST-PH (2.0 mm) with 4 wires. Connector at the board end is a 4-pin JST-XH (2.50 mm). Check your cables.
- **Confirmed:** X and Y use GT2 belts on 20-tooth pulleys. Klipper uses `rotation_distance: 40` with 16 microsteps. That gives 200 × 16 / 40 = **80 steps/mm** for X and Y at 1/16.
- **Confirmed:** Travel: `position_max: 300` for X and Y. Endstops at 0.

Control box power supply

- **Confirmed:** 24 V, 350 W, Mean Well brand per the CR-10 V3 manual (manuals.plus).
- **Unknown:** Exact model number. Read the PSU label.
- Set the input switch to 115 V for the US. Check this before first power-on.
- In the stock controller build, the supply stays in the control box and feeds the mainboard.

CHAPTER 3

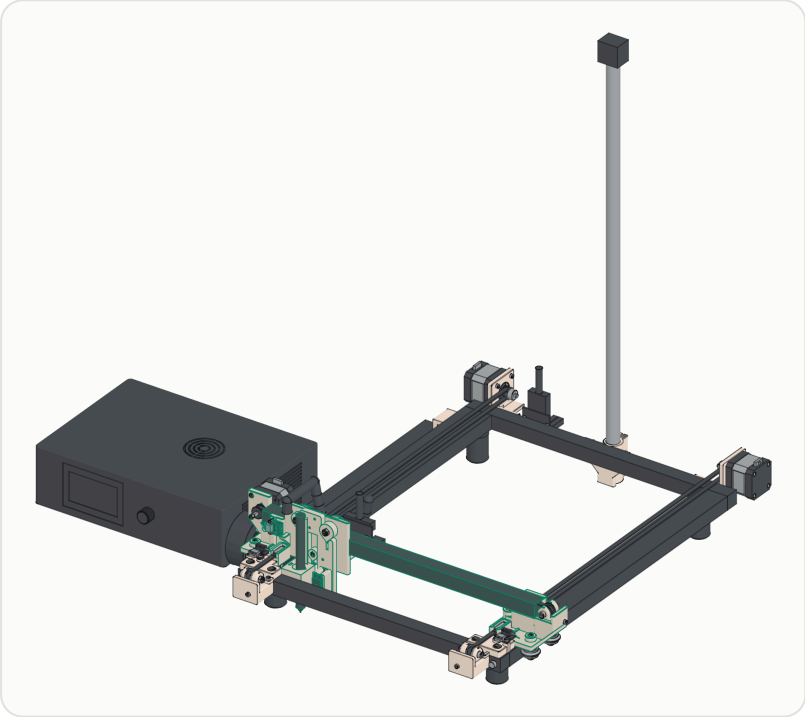
3 Hardware

The plotter is the base frame of a Creality CR-10 V3 on a table. The table is the bed. Stock V-wheels carry both axes. The motors do not move. Printed parts join the CR-10 parts. No metal part is cut or drilled.

The printed parts copy the stock CR-10 layouts, but they keep only the features that the plotter uses. No stock carriage plate stays on the machine.

The design files are in `hardware/`. `hardware/make.sh` builds the parts, checks them, slices them, and writes `hardware/penplotter-build-guide.pdf`. `hardware/REVIEW.md` records the review rounds.

The machine



- **Frame.** The CR-10 base frame. The front and back cross bars are 2020 and run the full width of the frame. The two long 2040 frame rails lie flat between them. Outside 400 × 520 mm, inside 320 × 480 mm. The frame rail tops are 57 mm over the table.
- **Feet.** Your own 4 round rubber feet stay under the long rails, 37.5 mm from each end of the frame. The model uses 28 mm across and 37 mm high (ESTIMATE). Nothing of a carriage goes under the rail, so the feet do not limit the travel.
- **Y carriages.** Each Y carriage is one flat 6 mm printed plate, in the form of the stock CR-10 Z carriage plate. It prints flat. It runs on 3 stock V-wheels on vertical axles in the side slots of the rail. Two wheels run in the outer slot, 44 mm apart. The back outer wheel turns on an eccentric spacer, which sets the preload. The front outer wheel axle goes into a long M5 heat-set insert. One wheel runs in the inner slot, 18 mm behind the beam centre, under a 12 mm boss. The plate also has two clamp blocks for the Y belt and a striker fin for the Y endstop. It carries no motor.

- **Y drive.** The two Y motors (42-40) are fixed. Each one stands behind the back bar on a printed bracket (`y_motor_mount_*`), about 20 mm outside the frame line, as on the stock CR-10. Two M5 × 12 screws in T-nuts hold each bracket in the back face slot of the bar. A toothed 20T idler turns in a fork (`y_idler_fork`) in front of the front bar. The fork sits in a bracket (`y_idler_bracket_*`) under the two lips of the front base. An M3 tension screw from the front pulls the fork forward.
- **Y belt.** Each Y belt is a loop round the motor pulley and the idler. It lies flat over the inner top slot of the 2040 rail, 31.5 mm from the outer face of the side. The belt does not go into the slot: the 2020 bars close the slot ends. The carriage clamps the upper run in two clamp blocks, with a crimp clip in each pocket. The Y motor cables do not move.
- **X axis.** The CR-10 2020 X beam lies on a saddle at each Y carriage. One M5 × 12 screw goes through the short back wall of the saddle into a T-nut in the back slot of the beam, 14 mm from the beam end. A stop at the outer end of each saddle holds the beam along X. The inner face of the saddle is the hard stop of the X plate.
- **X drive.** The X belt follows the stock CR-10 belt path. The pulley axis lies along Y, on the beam centre line, past the left beam end. The X motor (a 42-34) stands behind it, on the motor wall of the left carriage. The belt lies flat: one run in the channel of the top slot, one in the channel of the bottom slot, under the V-wheel tips. A toothed 20T idler turns in a fork (`x_idler_fork`) past the right beam end. An M3 × 20 screw with a nut pulls the fork outward from outside the right carriage. No belt stands in front of the beam.
- **X carriage.** Two printed parts: the X plate (`x_carriage_plate`) and the pen carriage. Four M3 × 12 screws join them. The X plate replaces the stock Creality plate. It takes the 3 stock V-wheels. The eccentric spacer is on the top right wheel: its hex is reachable from above. The other two wheels use stock 6 mm spacers. The bottom wheel axle goes into a long M5 heat-set insert. At each end of the plate, the bottom belt run leaves the slot at 45 degrees into a crimp clip pocket under the beam. The plate also has the X endstop trigger lug at the bottom left and the tie slot of the servo loom at the top left.
- **Pen carriage.** One part on the front of the X plate, held by the 4 M3 × 12 tool head screws from the back of the plate (T1, T2, H1, H2). A servo lifts the pen slider on a dovetail rail. The slider holds the pen in a V bore with an M3 clamp screw. The weight of the slider and the pen is the pen force.
- **Moving cables.** One openable drag chain (inner 10 × 20 mm, R28, about 506 mm) lies beside the left rail, outside the frame. It carries only the head harness. A 10 × 15 chain is enough. Its lower run lies on the table. Its fixed end sits in `y_chain_anchor` at the back left corner. Its moving end bolts to a tab of the left carriage plate. The servo lead runs in a 1/2 inch split wire loom, in a free loop behind the beam. A cable tie at each end holds the loom: through the slot at the top left of the X plate, and round the head harness cable above the big plug. The X motor plugs into the head board on the beam, so its cable does not move.
- **Static wires.** The Y endstop wires run in the bottom outer slots of the rails and in the bottom slot of the back bar, under flexible 6 mm slot cover strips. The Y motor cables run on the table behind the frame to the base board. These wires do not move (`hardware/context_detail_HOOKUP.md`).
- **Endstops.** The stock Creality endstop boards (20 × 20 mm, KW12 switch, XH plug). Each Y board lies on the two standoffs of a front base. A striker fin on the front edge of the carriage plate meets the lever tip. The X board sits on the front of the X endstop wall of the left Y carriage, in front of the beam end. The trigger lug at the bottom left of the X plate meets its lever. At each hard stop the trigger is 1.5 mm past the click. There are no switches at the far ends: the firmware uses soft limits there.
- **Controller.** The stock CR-10 V3 control box stands on the table beside the frame. The stock harness stays. The head board stands bare on the back face of the X beam, at x = 96 mm. The base board stands bare on the back face of the back bar, at x = 71 mm. Each board stands on two 4 mm nylon standoffs, held by two cable ties. The big plug points up.

- **Camera pole (optional).** The camera is a USB webcam on the top end of your 590 mm pole (17.85 mm diameter). The printed pole foot (`mast_foot`) holds the pole behind the centre of the back bar. An M6 × 16 screw goes up through its floor into the pole end. A split collar with one M3 screw takes up the play. Two M5 × 12 screws in T-nuts hold the foot on the back bar.

Value	
Pen travel	245.9 × 395.1 mm in the model. The firmware uses 245 × 390 mm.
Travel stops	Y min: the carriage plate at the front base. Y max: the inner Y wheel at the back bar.
Home	The front left corner. Homing squares the gantry on the two Y switches.
Belts	GT2 6 mm. Y: 1135.0 mm between the folds. X: 898.3 mm.
Pulleys and idlers	GT2 20T pulleys and GT2 20T toothed idlers: 80 steps/mm on X and Y
Motors	X: 42-34 (213.4 g, measured). Y1 and Y2: 42-40 (286.7 g, measured). One 42-40 and one 42-34 stay as spares.
Pen lift	7.0 mm
Pens	Round barrels 8 to 15 mm in the V bore of the pen slider

The gantry is about 630 g lighter than with the motors on the carriages. The 42-34 X motor is 73.3 g lighter than a 42-40.

Printed parts

All parts print in PLA, 0.3 mm layers, on a LulzBot TAZ Workhorse with the SE tool head (0.5 mm nozzle). No part needs supports.

Part	Count	Notes
`y_carriage_left`, `y_carriage_right`	1 each	Flat, the plate on the bed. A 6 mm plate on 3 side wheels with the Y belt clamps, the beam saddle and the Y endstop striker. The left one has the chain tab, the X motor wall and the X endstop wall. The right one has the seat of the X idler fork.
`x_carriage_plate`	1	Upright, the bottom edge on the bed. 3 wheel bosses, the 2 X belt clamps under the beam, the X endstop trigger lug, the tie slot of the servo loom.
`y_motor_mount_left`, `y_motor_mount_right`	1 each	On the motor face. Holds a Y motor behind the back bar.
`y_front_left`, `y_front_right`	1 each	Bottom on the bed. The Y endstop board, and the lips over the front of the bar.
`y_idler_bracket_left`, `y_idler_bracket_right`	1 each	On the end wall. The seat and the end wall of a Y idler fork, in front of the front bar.
`y_idler_fork`	2	Floor on the bed. Holds a Y idler between two cheeks.
`x_idler_fork`	1	Floor on the bed. Holds the X idler past the right beam end.
`y_chain_anchor`	1	On its front face. The fixed end of the drag chain at the back left corner.

Part	Count	Notes
`pen_carriage`	1	Back face on the bed. The pen lift. It bolts to the front of the X plate.
`pen_slider`	1	Upright. Holds the pen in its V bore with an M3 clamp screw. It slides on the dovetail rail of the pen carriage.
`mast_foot`	1	Optional. The camera pole foot. Floor on the bed.
`fit_rail`, `fit_slider`, `fit_wheel`	1 each	Print first. The first two test the dovetail fit. `fit_wheel` tests the eccentric hole of an outer Y wheel and the hole of the inner wheel.

The build prints 16 parts in 15 print jobs: 21 h 45 min, 383 g, $7.66. `05-parts-and-cost` has the values for each part and the fastener list.

Heat-set inserts

The build uses 9 heat-set inserts. You need a soldering iron with insert tips (BOM M35).

Insert	Count	Where
M5, long (9.5 mm)	3	The front outer wheel axle of each Y carriage, and the bottom wheel boss of the X plate
M3 (5.7 mm)	6	The two Y endstop boards (two in each front base) and the X endstop board (two on the X endstop wall of the left Y carriage)

The review

The design went through many review rounds. `75-review-history` lists them, and `hardware/REVIEW.md` has the details. The last change (2026-11-10) simplifies the build:

1. **Fewer parts, manual pen changes.** The build drops 11 printed parts that the plotter does not need (`75-review-history` lists them). You change the pens by hand.
2. **Flat Y plates.** Each Y carriage is a flat 6 mm plate on the stock wheel layout. A saddle holds the beam at its old height. The home and the travel do not change.
3. **The X endstop in front of the beam end.** The board faces the front. A lug at the bottom left of the X plate presses its lever.
4. **Bare boards.** The two breakout boards stand on nylon standoffs, held by cable ties.
5. **The servo loom.** The servo lead runs in a 1/2 inch split wire loom, with a cable tie at each end.
6. **A 42-34 X motor.** The X motor rides on the gantry, so the shorter motor keeps the moving mass low.

	Before	Now
Printed parts (main build, no fit tests)	27 parts, 30 h 28 min, 544 g	16 parts, 21 h 45 min, 383 g
Heat-set inserts	13	9
Pen travel (model)	245.9 × 395.1 mm	245.9 × 395.1 mm
Pen changes	Automatic (6 bins) or by hand	By hand

The joint audit passes with `--gate`. Six notes stay outside the gate, all on the Y motor brackets. They are tool and torque notes, not strength faults:

- Fit the motor screw that the bar hides before each Y bracket goes on the bar.
- The M3 heads of the right Y motor bracket bear on PLA. Put an M3 washer under each head, or tighten by feel. The left bracket has the same joint.

One question is open. The two cable ties of the head board go round the beam, through the top and the bottom slots and over the front face. The X plate and its wheels pass that place. `hardware/REVIEW.md` lists the options. Check this before you tie the head board on.

Measure before you print

`hardware/MEASURE.md` lists all measurements. These are the most important ones:

- The feet (items 1 to 3): their height (37 mm in the design) and their place. The height moves all the other parts.
- **Item 59: the V-wheel tip in its slot.** The X belt runs under the wheel tips. The fit check needs 0.3 mm or more between the tip and the belt. If the gap is less than 0.3 mm, use a GT2 16T pulley and a 16T toothed idler. The runs then lie 1.3 mm deeper, and the firmware needs 100 steps/mm.
- **Item 60: the slot channel of the beam.** The opening, the channel width, the lip depth and the depth to the core (6.2, 11.0, 1.8 and 6.3 mm in the model, ESTIMATE).
- **Item 61: the X belt on the stock machine.** Before you take the CR-10 apart: does the X belt touch the wheel tips or the slot lips? Is the stock X idler a 20T toothed idler?
- **Item 62: the plain wheel spacers.** Count the plain 6 mm spacers on the stock X plate, the Z carriages and the bed carriage. The build needs 6.
- Item 43: a GT2 20T toothed idler: the flange diameter and the width (18 and 8.5 mm in the design).
- Items 46 and 47: the head harness and the drag chain. The harness must pass through the openable chain.
- Items 24 to 33: the head board and the base board: their size and the hole spacing. The model uses estimates from photos.
- Items 63 to 65: the X endstop overtravel, the head harness cable at the loom tie, and the body length of the 42-34 motor.

CHAPTER 4

4 Assembly

This chapter takes you from the bare CR-10 base frame to the first plot. The steps follow `hardware/penplotter-build-guide.pdf`, which has a full page and a large image for each step.

Before you start:

- Print the parts (`05-parts-and-cost`). Print the three fit tests first.
- Take the measurements in `hardware/MEASURE.md`. Measure the feet first: their height moves all the other parts.
- Before you take the CR-10 apart, check the X belt on the stock machine (`hardware/MEASURE.md`, item 61). Count the plain wheel spacers (item 62).
- Measure the head harness and the drag chain before you print the chain anchor (`hardware/MEASURE.md`, items 46 and 47).
- Keep the control box off until the wiring checks (`20-electronics-and-wiring`).

You need hex keys (2.5, 3, 4 and 5 mm), the 8 mm wrench for the eccentric spacers, pliers for the belt crimp clips, calipers, a tape measure, a meter, and a soldering iron with M5 and M3 heat-set insert tips. `05-parts-and-cost` lists the fasteners.

No step cuts or drills the metal of the frame.

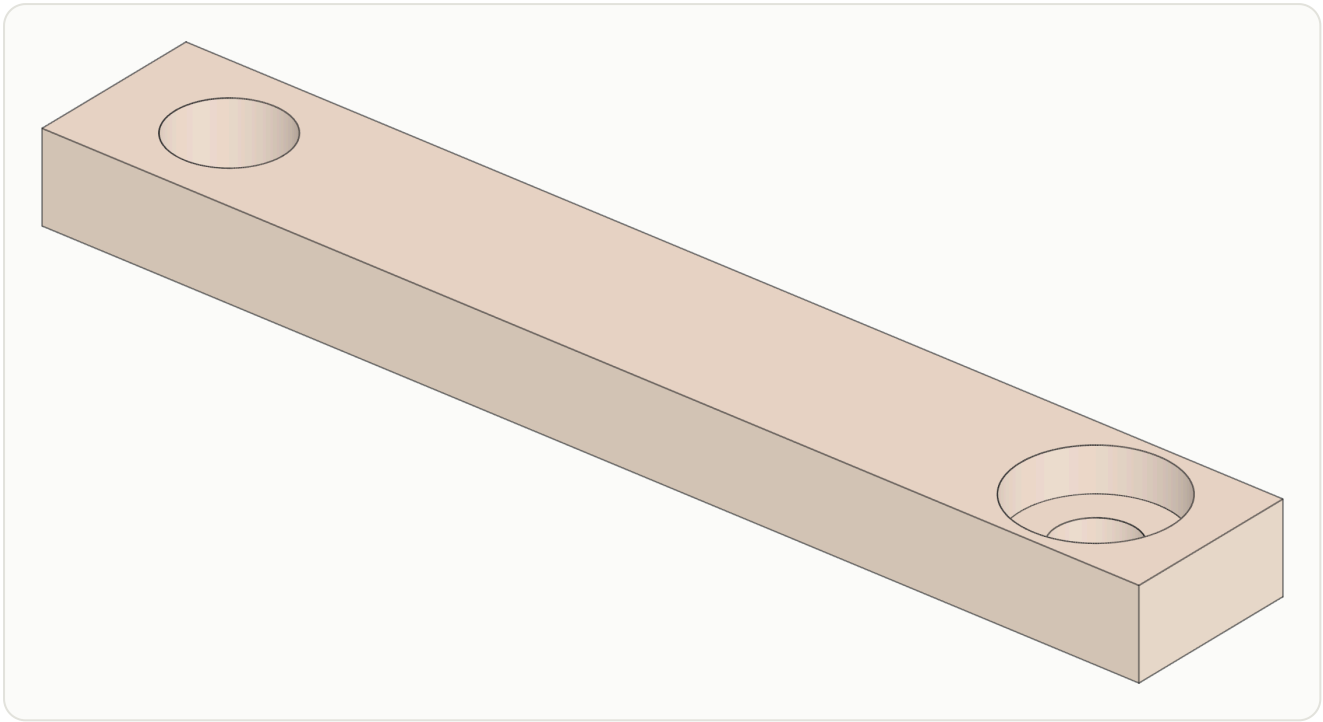
The wheel adjustment

The Y carriages and the X plate run on stock V-wheels. One wheel of each carriage turns on an eccentric spacer. Turn the eccentric with the 8 mm wrench to set the preload:

1. Turn the eccentric until the wheels touch both flanks of their slots.
2. Rock the carriage by hand. Turn the eccentric a little more until the play is gone.
3. Push the carriage along its frame rail or beam. It must roll freely over the full length.
4. Hold the eccentric with the wrench and tighten its nut.

Stop when the play is gone. Too much preload makes flat spots on the wheels.

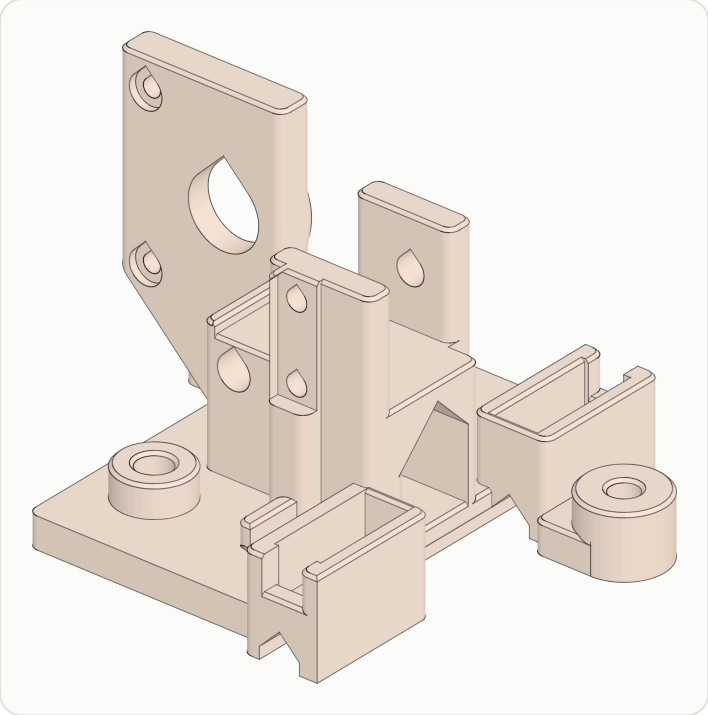
1. Fit tests



1. Slide the fit slider onto the fit rail. It must slide by its weight, with no side play.
2. Push an M3 nut into the slot in the top of the fit slider. Put a pen in the bore. Turn an M3 × 20 screw in until it holds the pen.
3. Put a wheel under the eccentric hole of the fit wheel strip: an M5 × 30 screw from below, the wheel, an eccentric spacer, the strip, a nyloc nut.
4. Put a wheel under the counterbored hole: an M5 × 30 button head screw from the top, the strip, a 6 mm spacer, the wheel, a nyloc nut.
5. Lay the strip across the end of a frame rail, the wheels in the two side slots.
6. Turn the eccentric spacer. Both wheels must grip the slots before the eccentric reaches its end.

If the slider is tight or loose, change `DT_CLR` in `hardware/shape.py` by 0.05 mm. If the eccentric cannot reach, change `WHEEL_OFF` by 0.2 mm. If the eccentric spacer is loose or tight in its hole, change `ECC_HOLE`. Run `hardware/make.sh` and print the fit tests again.

2. Heat-set inserts

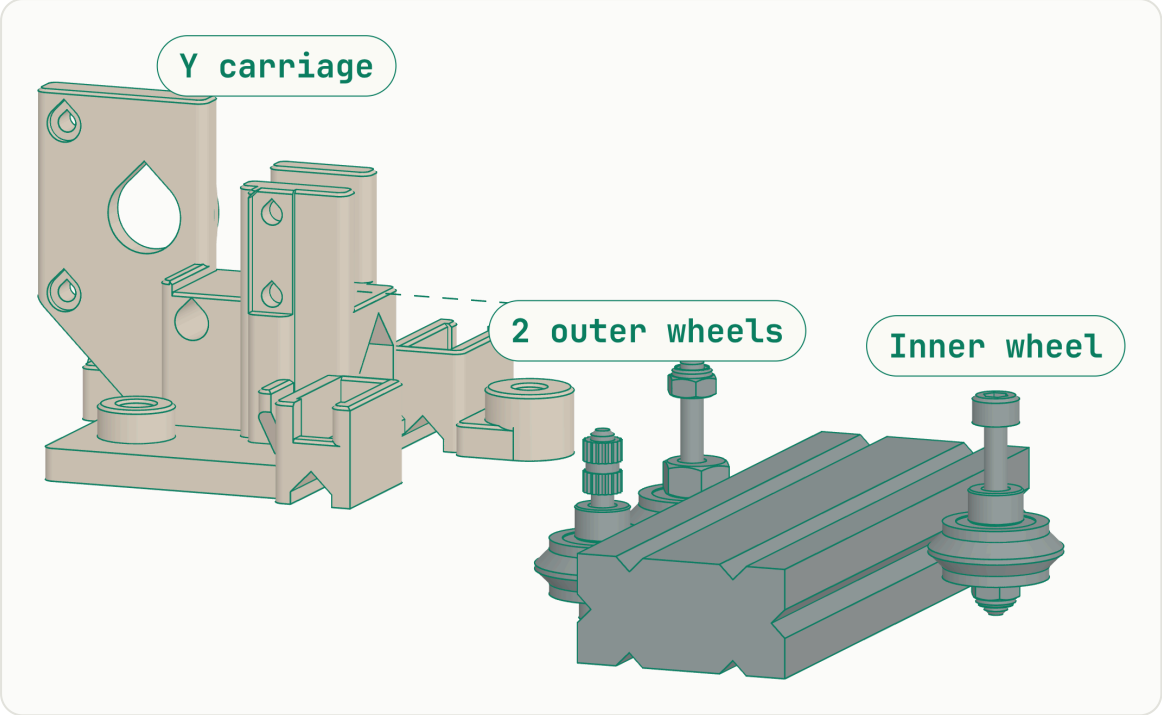


You need the 2 Y carriages, the X plate, the 2 front bases, 3 long M5 inserts and 6 M3 inserts.

1. Set the iron to 220 °C. Let the tip get hot.
2. Lay each Y carriage on its plate. Find the round boss on the plate top, at the front outer wheel.
3. Put an insert on the hole, the small end down. Push it straight down with the tip, with light force, until its top is flush with the boss.
4. Take the tip out straight up. Let the part cool for one minute. Turn an M5 × 30 screw in and out once from below.
5. Put an M5 insert in the bottom wheel boss of the X plate in the same way.
6. Put an M3 insert in each standoff of the two front bases.
7. Put an M3 insert in each of the two standoffs on the front of the X endstop wall of the left Y carriage.

The M5 inserts hold the front outer Y wheel axles and the bottom X wheel axle. The M3 inserts hold the three endstop boards.

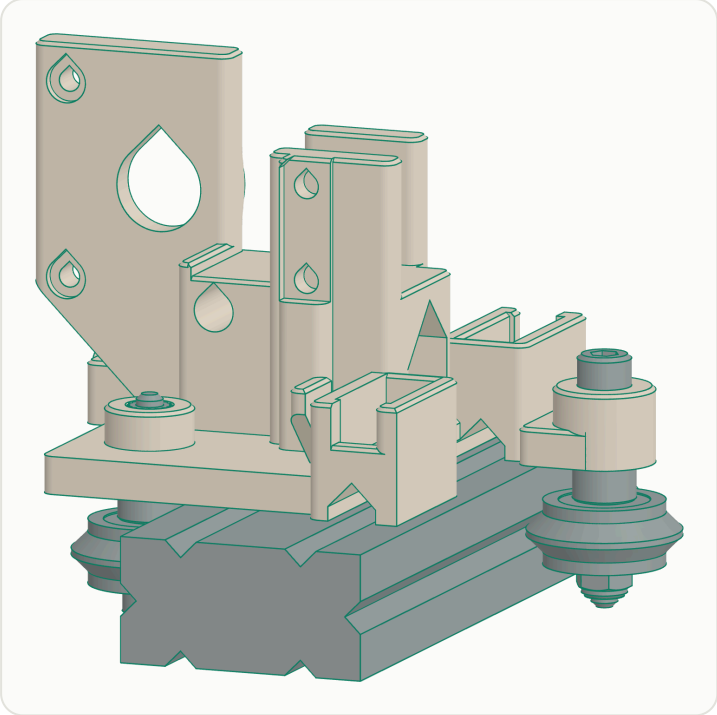
3. Wheels on the Y carriages



1. Front outer wheel: put an M5 × 30 screw up through a wheel and a 6 mm spacer, into the insert in the front boss. There is no nut.
2. Back outer wheel: put an M5 × 35 screw up through a wheel and an eccentric spacer into the back hole. The hex is between the wheel and the plate. Put a nyloc nut on top.
3. Inner wheel: put an M5 × 35 screw down through the 12 mm boss behind the beam. Do not put the spacer, the wheel and the nut on yet.
4. Tighten the front screw and the back nut until the wheels turn freely with no wobble.

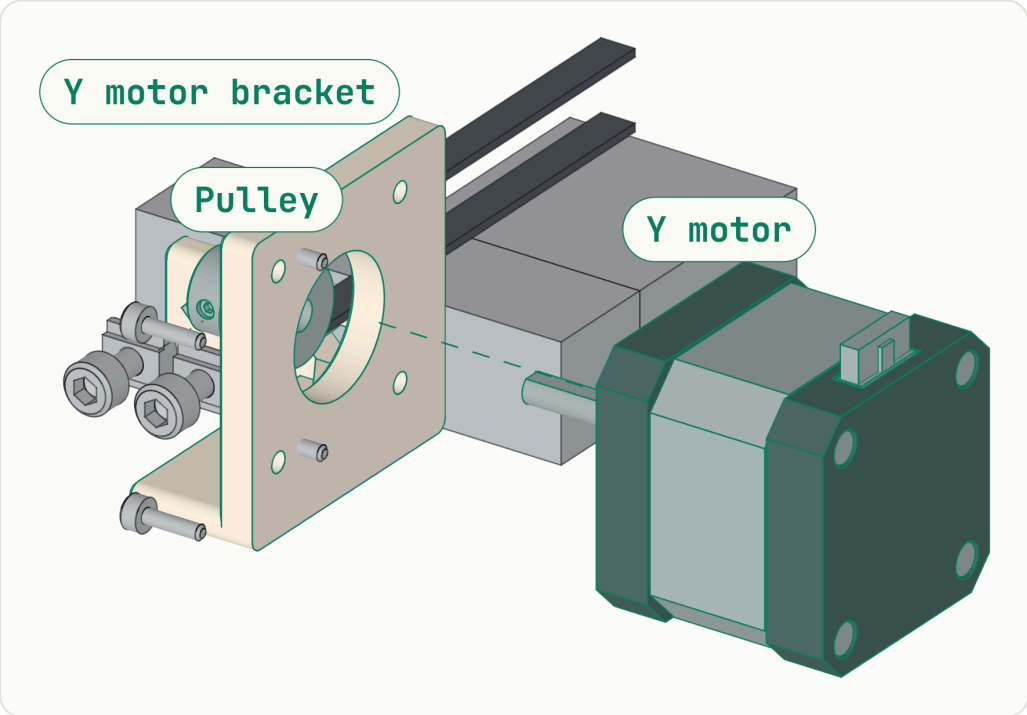
Each carriage is a flat plate, in the form of the stock CR-10 Z carriage plate. The left carriage has the X motor wall behind the beam end. The right carriage has the seat of the X idler fork. The inner wheel goes on when the carriage is on the rail.

4. Y carriages on the frame rails



1. Stand the frame on the table, feet down.
2. Set each carriage on its rail from above: the plate on the rail top, the two outer wheels in the outer side slot.
3. Under the inner boss, put a 6 mm spacer, the inner wheel and a nyloc nut on the inner screw. The wheel runs in the inner side slot.
4. Do the wheel adjustment on each carriage. Turn the eccentric hex from outside the frame.
5. Measure the two diagonals of the frame. Make them equal, then tighten the bar screws.

5. Y motors behind the back bar

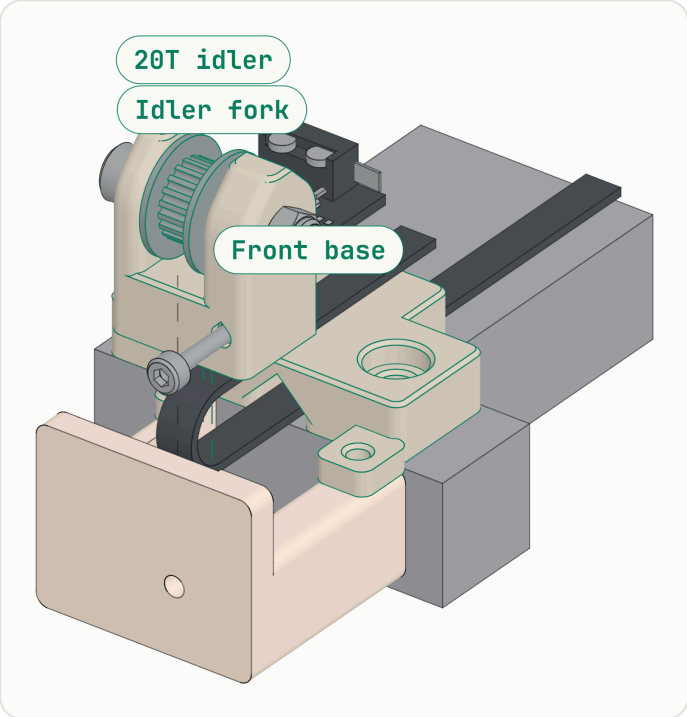


You need the 2 Y motor brackets, the 2 Y motors (42-40), 2 GT2 pulleys, 8 M3 × 10 screws, 4 M5 × 12 screws and 4 T-nuts.

1. Hold a motor on the outer face of each bracket plate, the shaft to the inside, the socket up. Put four M3 × 10 screws from the inside into the motor. Put an M3 washer under each head, or tighten by feel: the heads bear on PLA.
2. Put a GT2 pulley on each shaft, the hub to the inside. Line up its teeth with the inner top slot of the rail (31.5 mm from the outer face of the side). Tighten the set screws on the flat of the shaft.
3. Turn two M5 drop-in T-nuts into the slot in the back face of the back bar, near each end.
4. Hold each bracket on the back face of the back bar, the recess over the head of the bar end screw. Screw it on with two M5 × 12 screws.
5. Plug in each motor cable. It runs on the table behind the frame to the base board. It does not move.

Fit the motor screw that the bar hides before the bracket goes on the bar.

6. Front bases, Y idlers and endstops



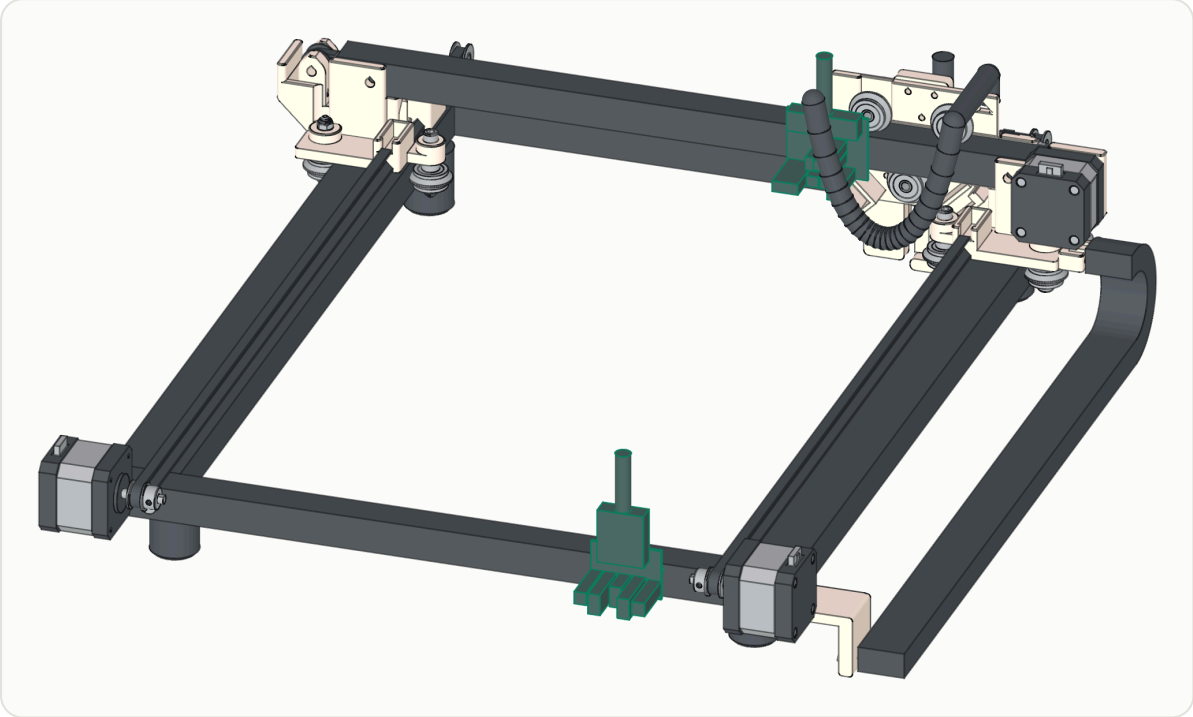
You need the 2 front bases, the 2 idler brackets, the 2 Y idler forks, 2 GT2 20T toothed idlers, 2 M5 × 30 screws with 4 small washers and 2 nyloc nuts, 2 M3 × 20 screws with 2 M3 nuts, 2 M3 × 12 screws, 4 M5 × 12 screws with T-nuts, 2 endstop boards and 4 M3 × 8 screws.

1. Push an M3 nut into the slot in the thick cheek of each Y idler fork, from below.
2. Hold an idler between the two cheeks, a washer on each side. Put the M5 × 30 screw through. Tighten the nyloc nut until the idler turns freely with no play.
3. Turn two M5 drop-in T-nuts into the top slot of the front bar, near each end. Screw a front base on each end with two M5 × 12 screws. Its two lips reach over the front of the bar.
4. Hold an idler bracket on the front face of the front bar, under the two lips. Put an M3 × 12 screw down through the inner lip into the bracket.
5. Set each fork on the seat of the bracket, between the two guides. Put an M3 × 20 screw through the end wall from the front into the nut. Turn it two turns only.

6. Lay a Y endstop board on the two standoffs of each front base: the parts up, the plug to the front, the switch to the back. Screw it down with two M3 × 8 screws.
7. Plug in the endstop cable from the front. Leave 20 mm for the plug and the bend of the wires.

Home is the front left corner. A striker fin on the front edge of each carriage plate meets the lever tip. At the front stop it is 1.5 mm past the click.

7. Base board

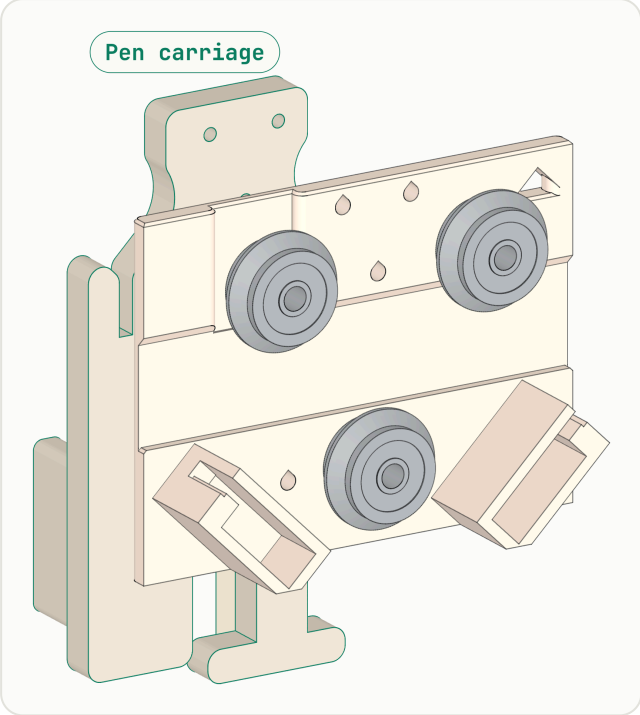


You need the base board, 2 nylon M3 standoffs (4 mm) and 2 cable ties.

1. Hold the base board on the back face of the back bar, 71 mm from the left end. Put a standoff under each of its two holes. The standoffs stand on the face of the bar, beside the slot.
2. Put a cable tie through each board hole and its standoff, round the bar. Pull the ties tight.
3. Plug in `Y` (Y1 motor, left), `Z1` (Y2 motor, right), `Y-` (Y1 endstop) and `Z-` (Y2 endstop). Leave `Z2` empty.
4. Push the big 2 × 8 plug into the header. The big plug points up.

The firmware maps `Z1` to the Y2 motor and `Z-` to the Y2 endstop. Lay the endstop wires in the bottom slots of the rails and the back bar. Press the slot cover strips over them. The board sizes are estimates. Measure the board first (`hardware/MEASURE.md`, items 30 to 33).

8. X plate and pen carriage

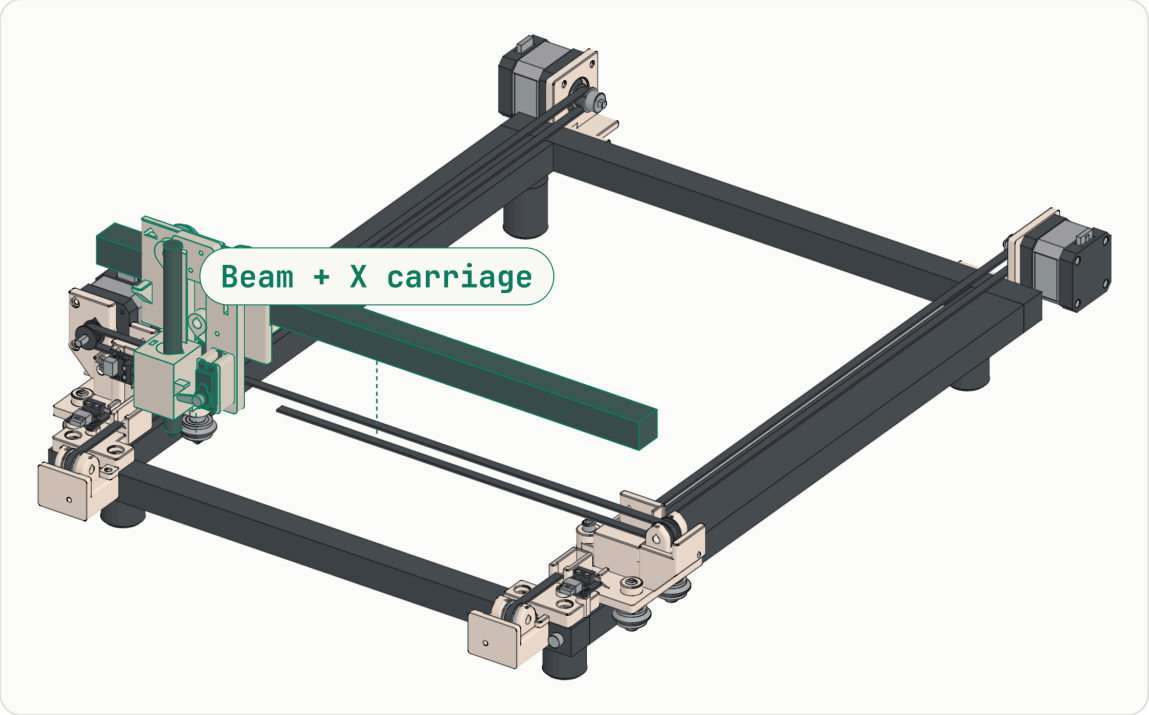


You need the X plate, the pen carriage, the 3 V-wheels, 1 eccentric spacer, 2 stock 6 mm spacers, M5 × 30, M5 × 35 and M5 × 25 button head screws, 2 nyloc nuts and 4 M3 × 12 screws.

1. Hold the pen carriage on the front face of the X plate. The three wheel bosses come through the round holes of the pen carriage.
2. Put four M3 × 12 screws from the back through the plate into the pen carriage (T1, T2, H1, H2). They cut their own thread. Do not overtighten them.
3. Top left wheel: from the back, an M5 × 30 screw through the wheel and a 6 mm spacer into the boss. Put a nyloc nut on the front.
4. Top right wheel: from the back, an M5 × 35 screw through the wheel and the eccentric spacer (the hex toward the plate) into the boss. Put a nyloc nut on the front. Leave it loose.
5. Bottom wheel: from the back, an M5 × 25 screw through the wheel and a 6 mm spacer into the insert in the bottom boss.

The eccentric is on the top right wheel. You turn its hex from above.

9. Beam and X plate

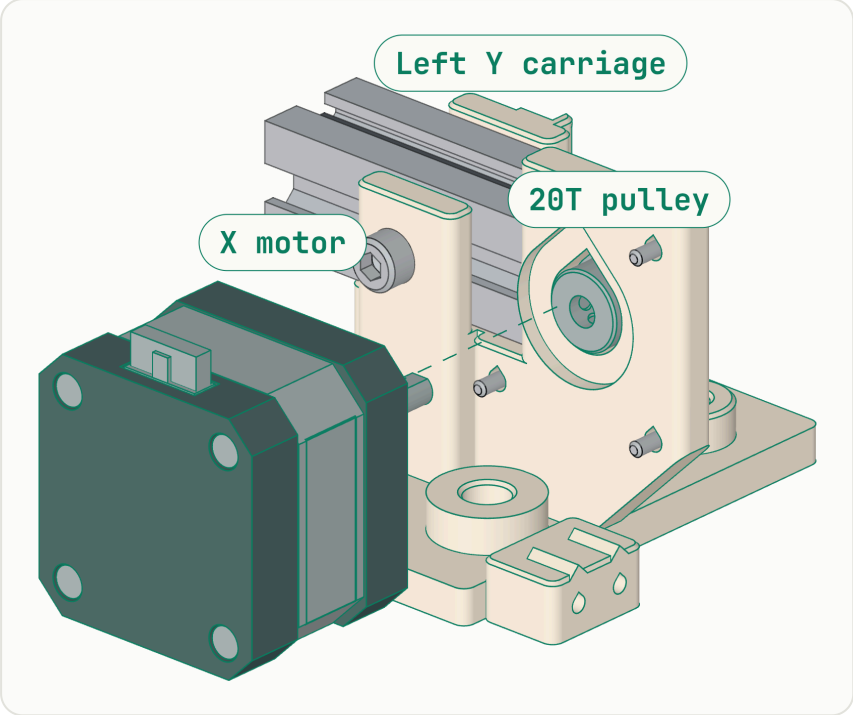


You need the 2020 beam, the X plate with the pen carriage, 2 M5 × 12 screws with T-nuts, the X endstop board and 2 M3 × 8 screws.

1. Slide the X plate onto the beam from one end. The top wheels go in the top slot, the bottom wheel in the bottom slot.
2. Turn the eccentric hex of the top right wheel from above until the plate has no play. It must still roll freely. Tighten its nut.
3. Turn an M5 drop-in T-nut into the back slot of the beam, 14 mm from each end.
4. Lay the beam on the two saddles, the pen carriage to the front. The beam ends touch the stops at the outer ends of the saddles.
5. Screw the beam to each carriage with one M5 × 12 screw, through the back wall of the saddle into the T-nut.
6. Hold the X endstop board on the two standoffs on the front of the X endstop wall of the left carriage. The parts face the front, the switch is on the right, and the plug is on the left.
7. Screw the board on with two M3 × 8 screws into the inserts.

The trigger lug at the bottom left of the X plate meets the lever tip. The inner face of the left saddle is the hard stop of the X plate. Keep the top and the bottom slots of the beam free: the X belt runs in them.

10. X motor

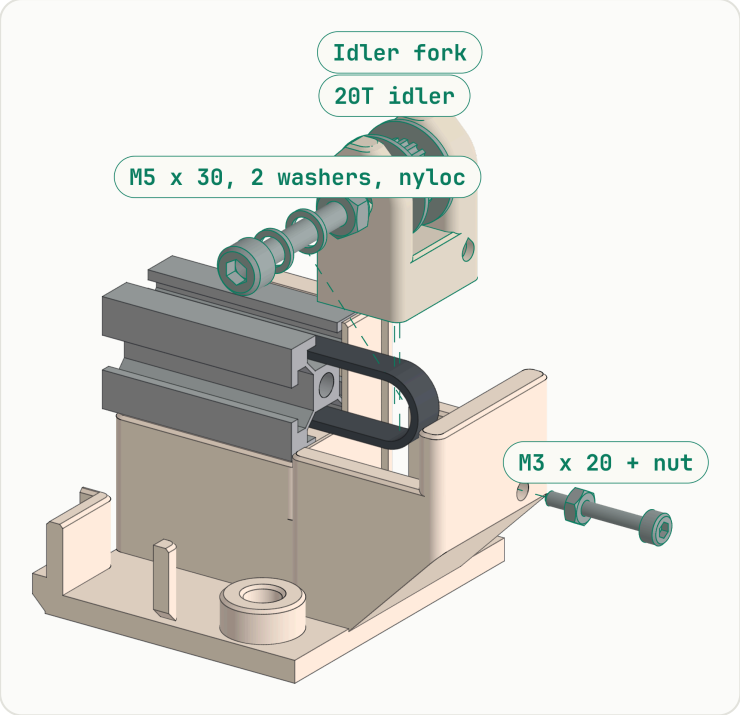


You need the X motor (a 42-34), a GT2 pulley and 3 M3 × 10 screws.

1. Put the GT2 pulley on the X motor shaft, the hub toward the motor. Do not tighten it yet.
2. Hold the motor behind the left beam end, the shaft to the front through the motor wall of the left carriage, the socket up.
3. Put three M3 × 10 screws from the front through the wall into the motor. The heads sit in counterbores. The hole over the beam end stays empty.
4. Slide the pulley along the shaft until its teeth are on the beam centre line, in line with the top and the bottom slots. Tighten the set screws.

The X motor rides on the gantry, so the shorter 42-34 keeps the moving mass low.

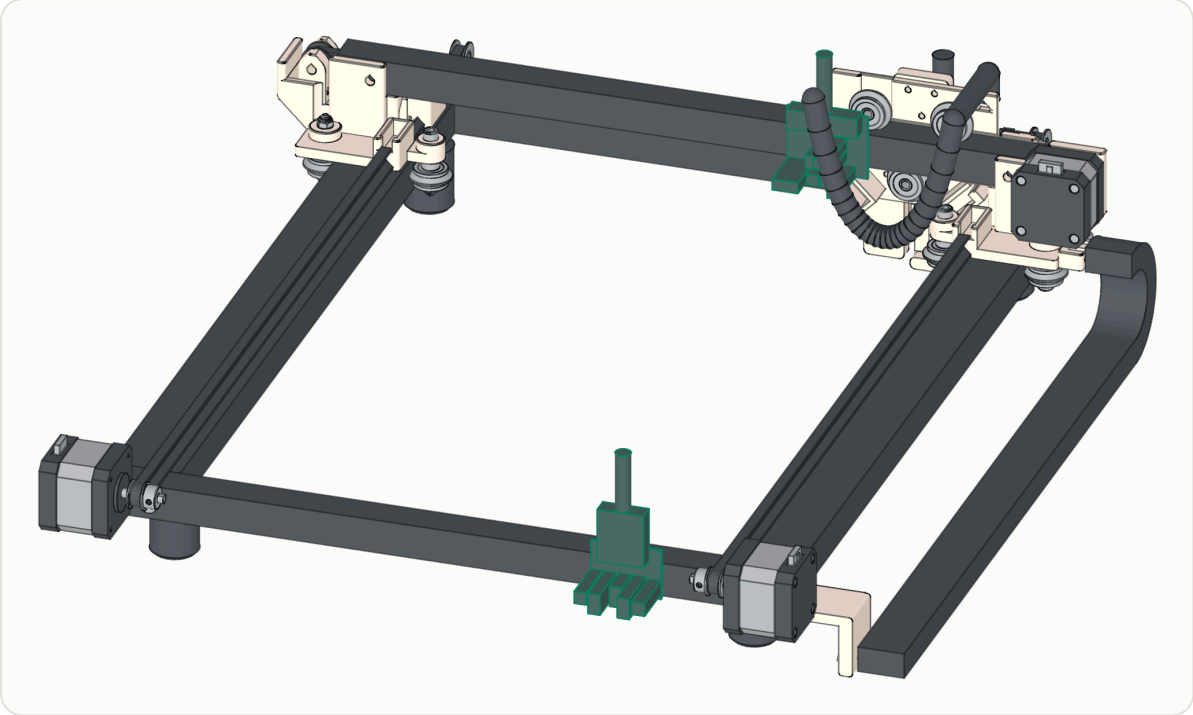
11. X idler fork



1. Push an M3 nut into the slot in the thick (back) cheek of the fork, from below.
2. Hold the 20T toothed idler between the two cheeks, a small washer on each side.
3. Put the M5 × 30 screw through the front cheek, the washer, the idler, the washer and the back cheek. Put the nyloc nut on the back. Hold the head and turn the nut until the idler turns freely with no play.
4. Set the fork in the seat past the right beam end, the floor on the seat.
5. Put the M3 × 20 screw through the end wall from the right side of the machine, into the nut in the fork. Turn it two turns only.

The fork slides 4 mm out and 2.5 mm in. You reach the tension screw from outside the right carriage.

12. Head board



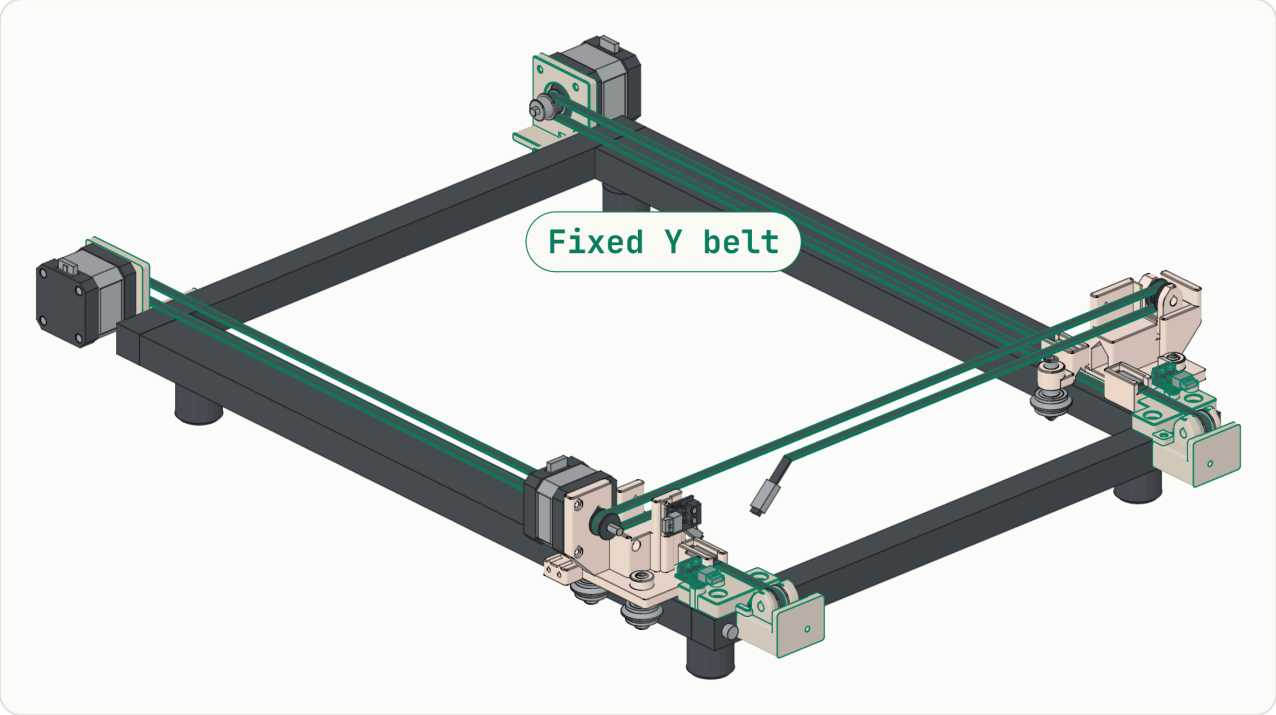
You need the head board, 2 nylon M3 standoffs (4 mm) and 2 cable ties.

> **Caution:** The two cable ties go round the beam, through the top and the bottom slots and over the front face. The X plate and its wheels pass that place. This question is open: `hardware/REVIEW.md` lists the options. Check that the X plate passes the ties before you power the motors.

1. Hold the head board on the back face of the X beam, 96 mm from the left side of the frame, the big header up. Put a standoff under each of its two holes.
2. Put a cable tie through each board hole and its standoff, round the beam. Pull the ties tight.
3. Plug in `X` (X motor), `X-` (X endstop) and the servo pigtail on `BL_T`.
4. Push the big 2 × 15 plug into the header from the top. Keep the cable straight for 35 mm, then bend it back toward the control box.

The board sizes are estimates. Measure the board first (`hardware/MEASURE.md`, items 24 to 29). The `HEAT` socket of the head board is not used.

13. Y belts and crimp clips

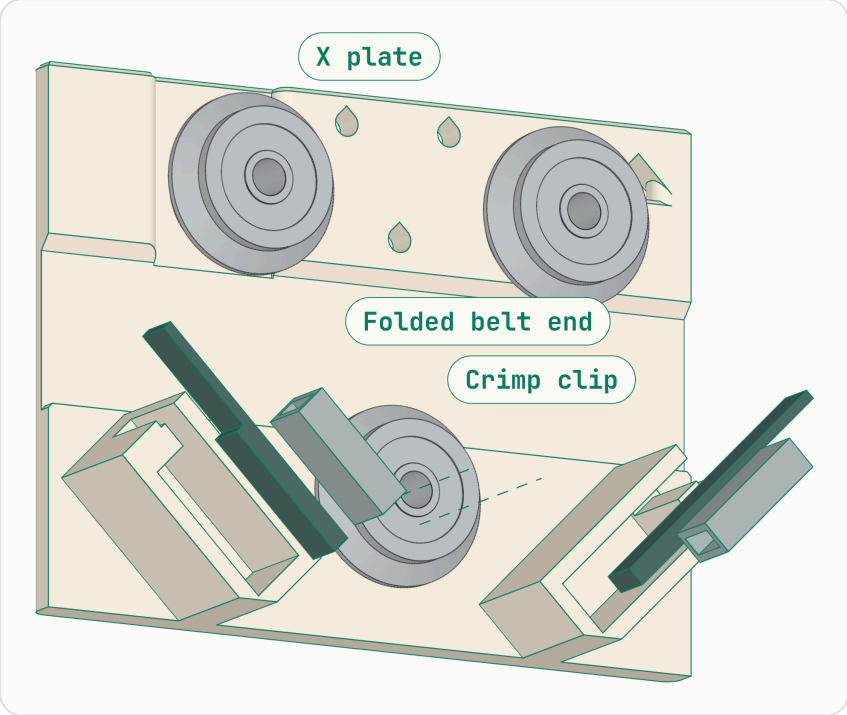


You need the 2 Y belts, 4 crimp clips, pliers and a tape measure.

1. Cut each Y belt about 1200 mm long.
2. Fold one end back on itself for 20 mm, teeth to teeth. Put a crimp clip over the two layers, 1.5 mm from the fold. Squeeze the clip flat.
3. Measure 1135 mm along the belt from the fold. Mark it. Fold the belt at the mark and crimp the second clip. Cut off the rest of the tail.
4. Turn the Y tension screw out until the fork is at the back end of its travel.
5. Lay the belt round the motor pulley at the back and the idler at the front, teeth inside. The lower run lies flat over the rail, under the two clamp blocks of the carriage.
6. Drop the two clips into the pockets of the two clamp blocks from the top, the belt in the slits of the end walls.
7. Turn the tension screw in until the belt is tight. Do the same on the other side.

The length is between the middles of the two folds: 1135.0 mm in the model, with the fork at the middle of its travel. The fork moves 4 mm forward and 3 mm back. If the belt is too long, crimp a new clip closer to the other clip.

14. X belt and crimp clips

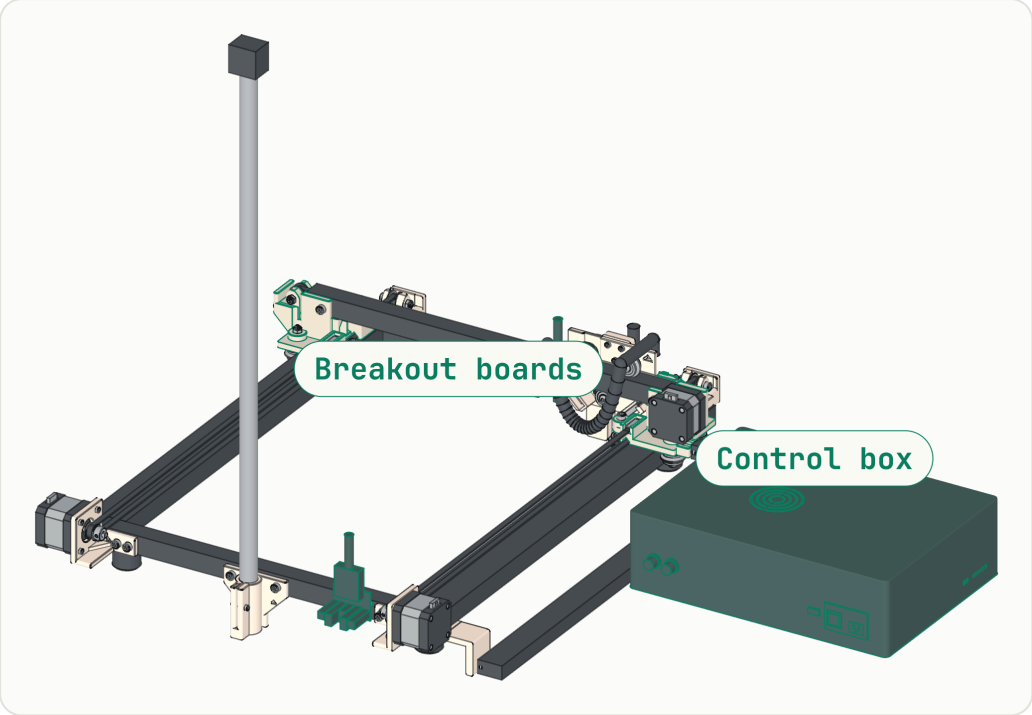


You need the X belt, 2 crimp clips, pliers, and a ruler or tape.

1. Cut the X belt about 950 mm long.
2. Crimp the first clip as on the Y belts. Measure 898 mm from the fold, and crimp the second clip at the mark.
3. Turn the M3 tension screw out until the X idler fork is at the inner end of its travel.
4. Feed the belt flat, teeth down, through the top slot of the beam from the idler end to the motor end, under the top wheels. Lay it round the pulley and back through the bottom slot.
5. At each end of the X plate, lead the belt out of the bottom slot into the 45 degree slit of the clamp. Push the clip into its pocket from the back.
6. Turn the M3 tension screw in. It pulls the fork outward. Stop when the belt is tight.

This is the stock CR-10 belt path: both runs lie in the slot channels of the beam. The length is 898.3 mm in the model, with the fork at the middle of its travel. Keep the belt centred where it passes the 6.2 mm slot opening at the clamps.

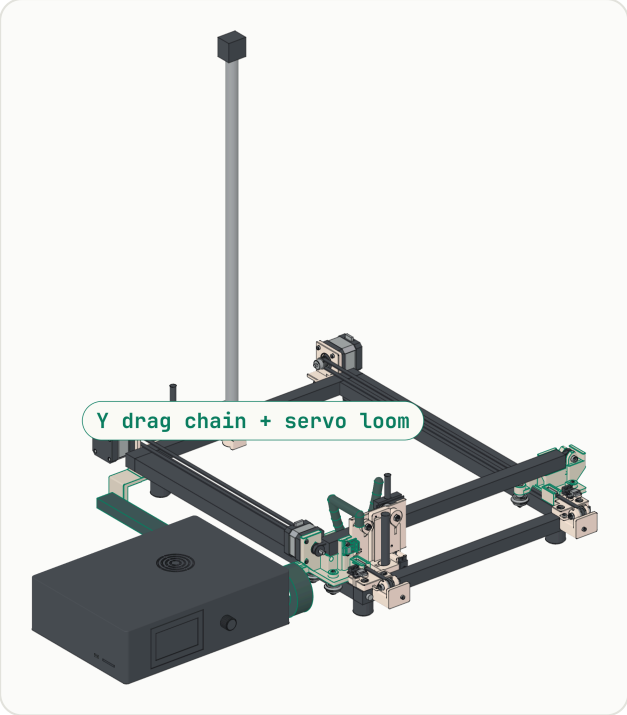
15. Control box and harness



1. Stand the control box on the table, left of the frame. The LCD faces the front.
2. Run the head cable from the head board along the back of the beam to the left carriage. It goes into the drag chain in the next step.
3. Tie the head cable to the back of the beam. Tie the base cable along the back bar.
4. Plug the two cables into the box. Check the mains voltage setting of the supply.
5. Connect the USB port of the box to the computer. Flash the plotter firmware (`25-firmware`).

The size of the control box is an estimate. Put the box where the stock cables reach.

16. Moving cables

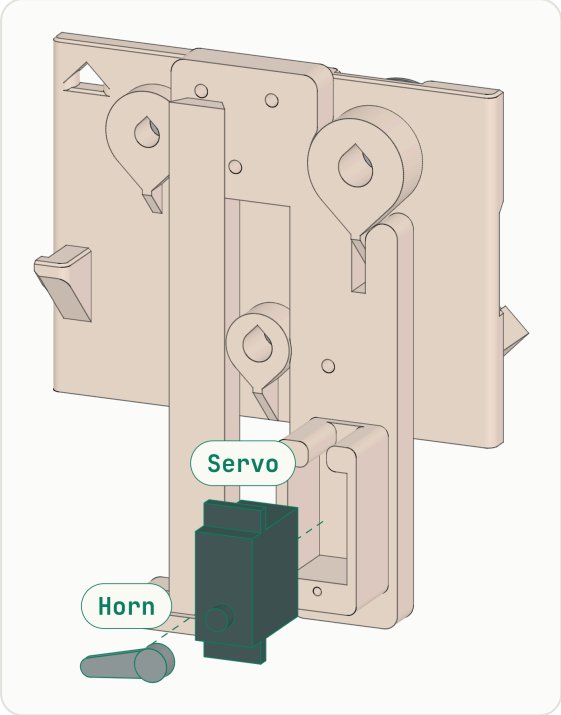


You need the drag chain, the chain anchor, 1 M5 × 12 screw with a T-nut, 4 M3 × 10 screws, the 1/2 inch split wire loom and 2 cable ties.

1. Put the chain anchor at the back left corner, beside the left rail. Its arm goes under the rail: one M5 × 12 screw up into a T-nut in the bottom outer slot of the rail.
2. Open the links of the chain. Lay in the head harness. Close the links. The Y motor cables do not go in the chain.
3. Bolt each end link with two M3 × 10 screws: the fixed end to the anchor wall, the moving end to the tab of the left carriage plate. The lower run lies on the table, and the bend points to the front.
4. Cut the split loom to 295 mm. Push the servo lead into it.
5. Moving end: lay the loom on the front of the X plate at the top left. Put a cable tie through the slot in the plate and round the loom.
6. Lead the loom up over the plate top and back over the beam.
7. Fixed end: tie the loom to the head harness cable, just above the big plug of the head board.

Cut the chain to 506 mm. The loop of the loom between the two ties is 189 mm long. It hangs free behind the beam and needs no printed holder. In the model its lowest point stays 41 mm or more above the paper. A real loom is stiffer and sags less (`hardware/MEASURE.md`, item 48).

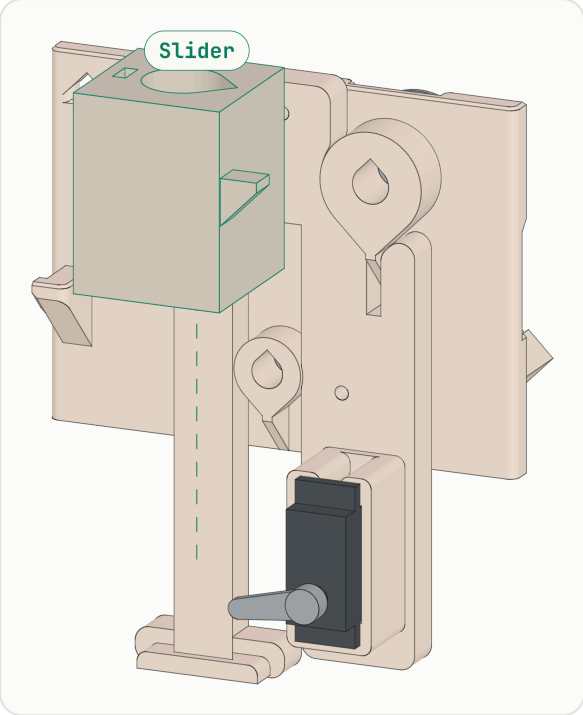
17. Servo



1. Push the servo into the pocket, the shaft at the bottom. The wire goes out through the slot.
2. Put the two servo screws through the tabs into the tower. Plug the servo into the servo lead.
3. Do the power-up checklist (`20-electronics-and-wiring`).
4. Send `M5` (pen up), then `M3` (pen down). Leave it at pen down.
5. Put the horn on the spline. The arm points at the tab of the slider, 10° below level.

At pen up the horn lifts the slider 7.0 mm. Fine-tune the angles with the knob menu (Pen up +1 and -1, Pen down +1 and -1).

18. Pen slider and pen

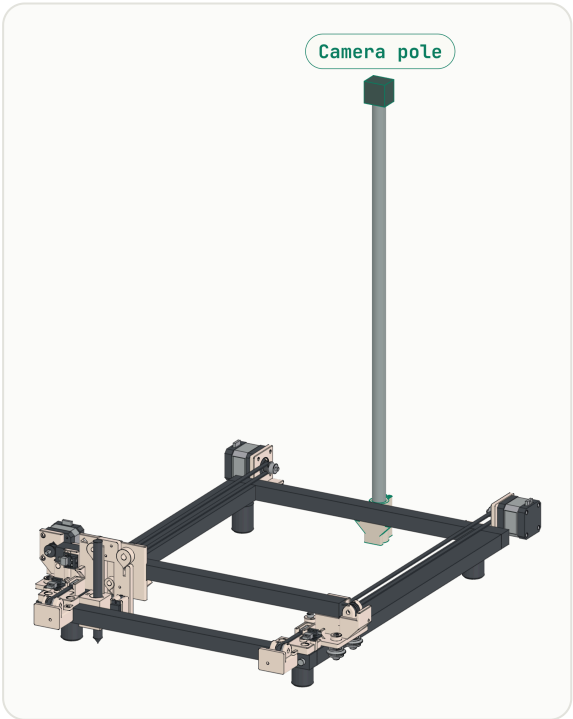


You need the pen slider, a pen, an M3 × 20 screw and an M3 nut.

1. Push the M3 nut into the slot in the top of the slider. Turn the M3 × 20 clamp screw into it a few turns.
2. Slide the slider onto the dovetail rail of the pen carriage from the top.
3. Send `M3` (pen down). Put the pen in the V bore until its tip touches the paper. Tighten the clamp screw.

The weight of the slider and the pen is the pen force. Pens of 8 to 15 mm fit the V bore.

19. Camera pole (optional)

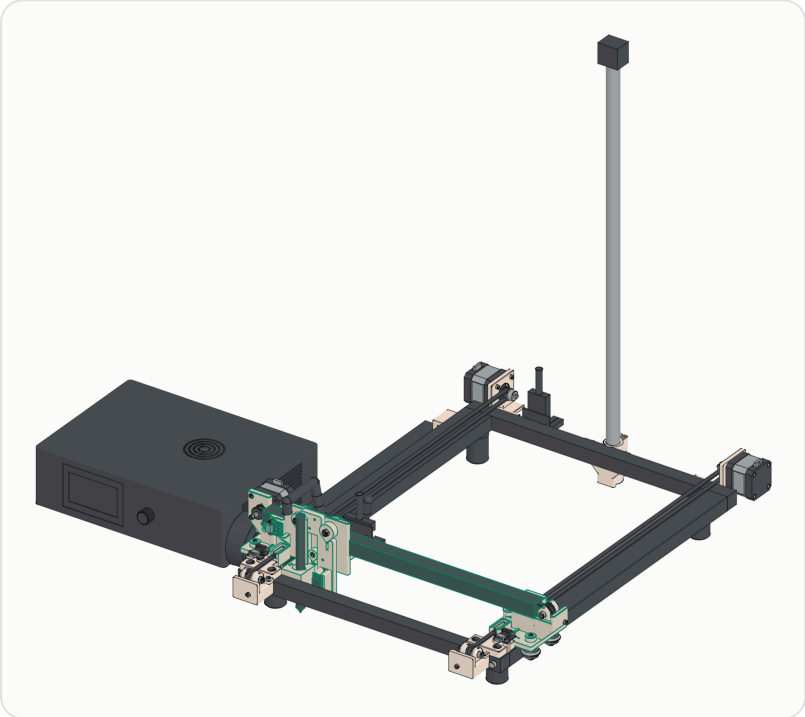


You need your camera pole with the USB webcam, the pole foot, 2 M5 × 12 screws with T-nuts, an M6 × 16 screw, an M3 × 16 screw with an M3 nut, and cable ties.

1. Turn two M5 drop-in T-nuts into the slot in the back face of the back bar, at the centre.
2. Drop the M3 nut into the slot in the top of the right collar ear. Put the M3 × 16 screw through the two ears. Leave it loose.
3. Put the pole in the socket. Hold the foot on its side. Put the M6 × 16 screw up through the floor into the pole end. Tighten it.
4. Stand the foot and the pole on the table behind the back bar. Screw the foot to the bar with two M5 × 12 screws.
5. Tighten the M3 collar screw.
6. Tie the USB cable to the foot through the two slots, and to the pole.

The pole is 590 mm long. The camera lens is about 15 mm above the top of the pole. Plotstudio calibrates the view (`30-software`).

20. First run



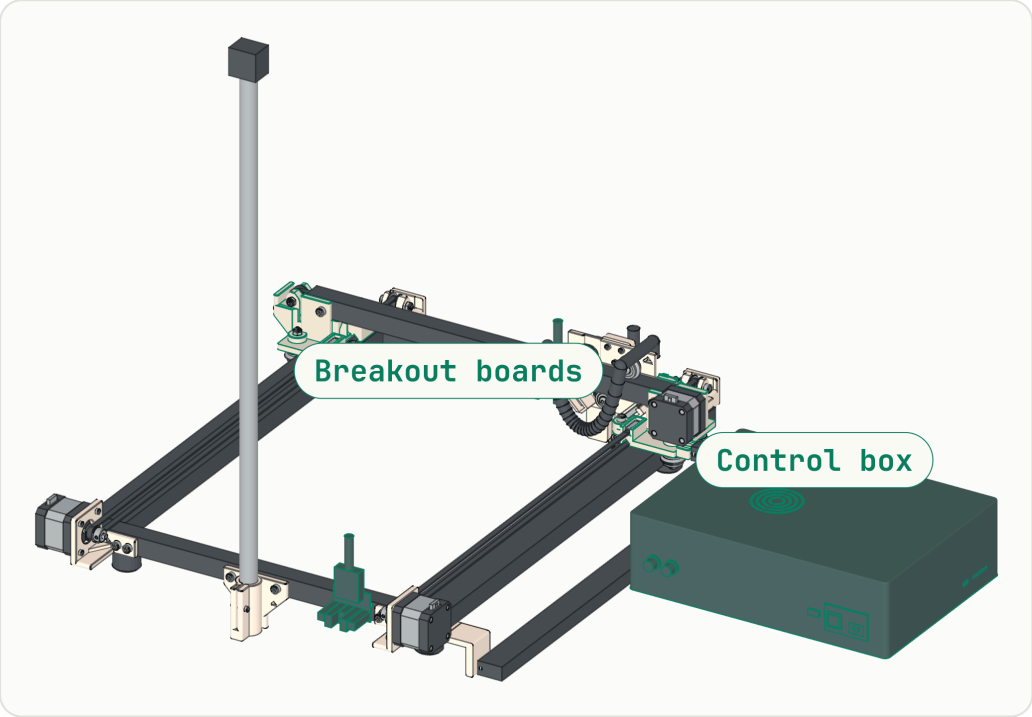
1. Do the power-up checklist in `20-electronics-and-wiring`.
2. Turn on the control box. Connect its USB port to the computer.
3. Send `M119`. Push each endstop by hand and check that it changes.
4. Send `G28`. Both Y sides go to the front switches. This squares the gantry.
5. Plot `samples/square.gcode`. Measure the square: it must be 40 × 40 mm.
6. Continue with `40-calibration-and-first-plots`.

The travel is 245.9 × 395.1 mm in the model. At the back, the inner Y wheel stops at the back bar. The firmware uses 245 × 390 mm. A4 and Letter fit.

CHAPTER 5

5 Electronics and wiring

The plotter uses the CR-10 V3 control box as it is: the Creality v2.5.2 mainboard (ATmega2560), the onboard stepper drivers, the 350 W supply, and the LCD with the knob. The box stands on the table beside the frame. The stock harness stays. The two small Creality boards at the ends of the harness stand bare on nylon standoffs. You make no changes inside the box.



The parts

Part	Job
Control box	Holds the mainboard and the 350 W supply. Connects to the computer with USB.
Creality v2.5.2 mainboard	ATmega2560 at 16 MHz with 8 KB of RAM. Runs the firmware. Drives the motors with its onboard drivers.
LCD with the knob	ST7920 display on the stock ribbon. Shows 4 text lines and a short menu.
Head board	Rides on the back face of the X beam. Connects the X motor, the X endstop and the pen servo.
Base board	Sits on the back face of the back bar. Connects the two Y motors and the two Y endstops.
Pen servo	SG90 or MG90S. Plugs into `BL_T` on the head board, through a pigtail and a 70 cm extension (or a lead that you make with S3 and S6).

The mainboard has four drivers: X, Y, Z and E. The plotter uses X for the X motor, Y for the Y1 motor (left), and Z for the Y2 motor (right). The E driver is free. The hotend heater output (`HEAT`, the MOSFET on D10, PB4) is not used. The firmware holds it off.

The breakout boards

Each board stands bare on two 4 mm nylon M3 standoffs (BOM M38). A cable tie goes through each board hole and its standoff, round the extrusion. The standoffs give room for the pins under the board. The big plug points up.

Board	Place	Notes
Head board	Back face of the X beam, from x = 96 mm	Rides with the gantry. The big header is at the top.
Base board	Back face of the back bar, from x = 71 mm	The standoffs stand on the face of the bar, beside the slot.

> **Caution:** The two ties of the head board go round the beam. The X plate and its wheels pass that place. This question is open: `hardware/REVIEW.md` lists the options. Push the X plate by hand over the full travel before you power the motors.

The cables

The motors do not move, so few cables move. No part stands tall over the frame.

- **Drag chain.** An openable drag chain (inner 10 × 20 mm, bend radius R28, about 506 mm long) lies beside the left rail, outside the frame. It carries only the head harness. A 10 × 15 mm chain is enough. Its lower run lies on the table. Its fixed end sits in `y_chain_anchor` at the back left corner. Its moving end bolts to a tab of the left carriage.
- **Y motor cables.** The Y motors stand behind the back bar. Their cables run on the table behind the frame to the base board. They do not move. If a stock cable is too short, use a 1.5 m stepper cable (BOM line M31).
- **Endstop wires.** The Y endstop wires run in the bottom outer slots of the rails and in the bottom slot of the back bar, under 6 mm slot cover strips. They do not move.
- **X motor.** The X motor plugs into the head board on the beam. Its cable does not move.
- **Servo loom.** The servo lead runs in a 1/2 inch split wire loom, 295 mm long. The loom hangs in a free loop behind the beam, 189 mm between the two ties. One tie goes through the slot at the top left of the X plate. The other tie holds the loom to the head harness cable, above the big plug of the head board.
- The control box stands left of the frame, clear of the chain.

> **Caution:** The board sizes come from photos. Measure the two boards before you place the standoffs (`hardware/MEASURE.md`, items 24 to 33). Start with the hole spacing.

Make the servo pigtail and the extensions

The crimp kit (S3) has the housings, the terminals and the crimper. Use the 24 AWG silicone wire (S6).

Cable	End 1	End 2
Servo pigtail (S4)	XH 5P housing, into `BL_T`	Dupont 3P housing with male pins, into the servo extension
Endstop extension (S5), 50 cm	XH 2P housing	XH 2R inline male housing

To crimp a terminal:

1. Strip 2 mm of insulation.
2. Put the terminal in the die with the open side up. Use the 0.25 die for 24 to 26 AWG and the 0.5 die for 22 AWG.
3. Put the wire in the terminal. The bare wire goes under the front tabs. The insulation goes under the rear tabs.
4. Close the crimper until the ratchet releases.
5. Pull on the wire. A good crimp does not move.
6. Push the terminal into the housing until it clicks. The latch tab of the terminal faces the window of the housing.

> **Caution:** Check the pin order of `BL_T` before you make the servo pigtail (`docs/wiring.md`). A wrong 5 V pin can damage the servo.

Power-up checklist

Do these steps in this order. Each step protects the parts of the next one.

1. Check the voltage switch of the supply: 115 V for the US.
2. Check the plugs against the socket table below with the box off.
3. Push the X plate by hand over the full X travel. It must pass the head board ties.
4. Leave the servo disconnected. Turn on the box.
5. Measure the `BL_T` pins with a meter: 5 V from pin 2 to pin 1.
6. Turn off the box. Connect the servo.
7. Connect USB. Flash the firmware (`25-firmware`).
8. Send `M115`, then `M119`. Test each endstop by hand.
9. Test the motor directions with a short relative move (see "Motor directions" below).
10. Send `G28`.

Never connect or disconnect a motor while the box is on. A disconnected coil can destroy the driver.

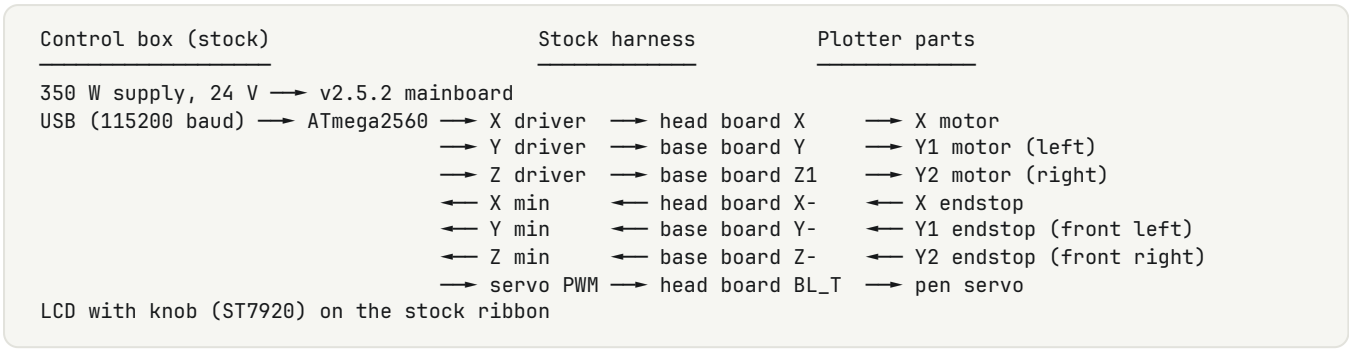
Wiring reference

The sections below come from `docs/wiring.md`. The pin map is also in `firmware/board/mega/pins.go`. The cable routes are in "The cables" above.

Safety rules

- Turn off the control box before you connect or disconnect a motor. A motor that you disconnect from a powered driver can destroy the driver.
- Turn off the control box before you connect the servo.
- Make no changes inside the control box. All plotter parts connect to the head board and the base board.
- Check the voltage switch of the supply before the first power on. Set 115 V for the US.

Block diagram



Board sockets

Board socket	Plotter part	Mainboard driver or pin
Head board `X`	X motor	X driver
Head board `X-`	X endstop	X min (PE5)
Head board `BL_T`	Pen servo (through a pigtail)	Servo signal PB5 (D11), 5 V, GND
Base board `Y`	Y1 motor (left)	Y driver
Base board `Z1`	Y2 motor (right)	Z driver
Base board `Y-`	Y1 endstop (front left)	Y min (PJ1)
Base board `Z-`	Y2 endstop (front right)	Z min (PD3)
Base board `Z2`	Not used	Z driver (parallel to `Z1`)
Head board `HEAT`	Not used	Heater MOSFET PB4 (D10). The firmware holds it off.
Head board `E`, `TH`, `FAN`, `K_FAN`	Not used	Leave them empty

Pen servo on `BL_T`

The `BL_T` socket has five pins: GND, 5 V, signal, GND, and a sensor pin that the plotter does not use. A JST XH 5-pin pigtail connects the socket to a 70 cm servo extension (BOM line S2). You can also make the lead with S3 and S6.

Servo wire	`BL_T` pin
Brown (GND)	GND (pin 1)
Red (5 V)	5 V (pin 2)
Orange (signal)	Signal (pin 3)

> **Caution:** Measure the `BL_T` pins with a meter before you connect the servo. With the box on, pin 2 must show 5 V to pin 1. The pin order comes from the board silkscreen and from earlier work on this tool head. It is not checked on your board.

The mainboard 5 V supply also feeds the LCD and the processor. An SG90 servo takes about 0.25 A when it moves. Use an SG90 or an MG90S. Do not use a large servo.

The default angles are 130° for pen up and 80° for pen down. At 90° the horn is level. Tune the angles with the knob menu (Pen up +1 and -1, Pen down +1 and -1), or send `M281 U<up> D<down>`.

Mainboard pin map

The firmware uses these ATmega2560 pins. Nothing in this table needs a wire from you. The stock harness and the stock LCD ribbon connect them.

Signal	ATmega2560 pin	Note
X STEP, DIR, EN	PF0, PF1, PD7	X driver
Y1 STEP, DIR, EN	PF6, PF7, PF2	Y driver
Y2 STEP, DIR, EN	PL3, PL1, PK0	Z driver
X endstop	PE5	Head board `X-`
Y1 endstop	PJ1	Base board `Y-`
Y2 endstop	PD3	Base board `Z-`
Servo	PB5 (D11, OC1A)	Head board `BL_T`, signal pin
LCD CS (RS)	PH1	ST7920
LCD SCK (E)	PA1	ST7920
LCD data (R/W)	PH0	ST7920
Encoder A, B	PC4, PC6	The knob
Encoder button	PC2	Low when pressed
Beeper	PC0 (D37)	Check it on your board
E STEP, DIR, EN	PA4, PA6, PA2	Free. Kept for a later Z axis.

The EN pins are active low. The firmware sets them high at power on, so the motors are off until a move. The onboard drivers run at 1/16 microsteps. The firmware uses 80 steps/mm, which needs 1/16.

Motor current

The onboard drivers keep the current setting of the printer. Do not change it. A pen plotter needs less force than a printer. If a motor gets hot, read `docs/bom.md`, "Mainboard", before you touch the drivers.

Endstops

There are three switches: X min (left), Y1 min (front left) and Y2 min (front right). The stock switches are probably normally closed to GND. The firmware treats a HIGH pin as triggered, the same as the stock firmware. The mainboard pins use their internal pull-ups.

Test the switches before the first `G28`:

1. Send `M119`.
2. The reply shows `x_min: open`, `y1_min: open` and `y2_min: open` when the carriages are away from the switches.

3. Push each switch by hand and send `M119` again. The reply must show `TRIGGERED` for that switch only.
4. If the result is the opposite, set `EndstopTriggeredHigh = false` in `firmware/config/config.go`. Then build and flash the firmware again.

Motor directions

The Y2 motor is a mirror of the Y1 motor, so `InvertDirY2 = true` is the default. In normal moves Y2 steps with Y1. Test the Y direction before the first `G28`. Two sides that move in opposite directions twist the beam.

1. Move both Y carriages by hand to the middle of the travel.
2. Send `G91`, then `G1 Y5 F600`, then `G90`.
3. Both Y carriages must move 5 mm to the back.
4. If one side moves to the front, turn off the box at once. Set `InvertDirY` or `InvertDirY2` in `firmware/config/config.go`, then build and flash the firmware again.
5. Do the same test for X with `G1 X5 F600`. The carriage must move to the right. If not, set `InvertDirX`.

Homing and squaring

`G28` homes X, then Y. `G28 Y` homes Y only.

1. Both Y motors move to the front at the same time.
2. Each side stops when its own switch triggers. This makes the beam square to the frame rails.
3. Both sides back off 3 mm and move to the switches again slowly.
4. If the beam is still not square, measure the error. Set `Y2HomeOffsetMM` in `firmware/config/config.go`. After homing, Y2 moves this distance alone. A positive value moves Y2 away from its switch.

`M114` shows the step counters of X, Y1 and Y2. After homing, the Y1 and Y2 counters are 0.

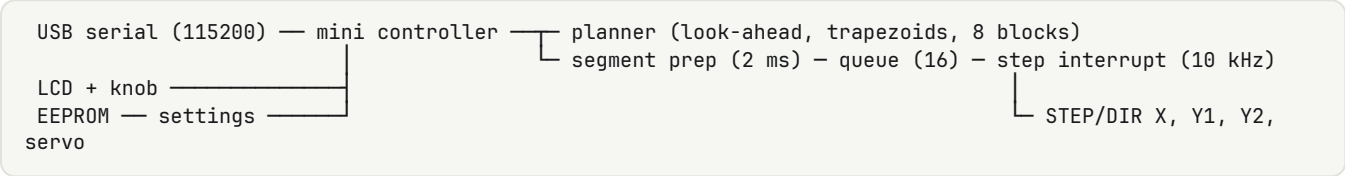
CHAPTER 6

6 Firmware

The firmware is written in Go and built with TinyGo. On the stock controller build it runs on the ATmega2560 of the Creality v2.5.2 mainboard. The computer talks to it over USB serial at 115200 baud. The simulator runs the same code on a computer.

The ATmega2560 has 8 KB of RAM. The full controller (`firmware/controller`, for a Pico W board) does not fit. The stock board runs the small controller (`firmware/mini`). It uses the same G-code parser, the same planner and the same step code. It gives the same replies to the host, so plotstudio drives it in the same way.

Architecture



Package	Job
`firmware/config`	All machine numbers: steps/mm, travel, speeds, homing, servo, switches. `rate_avr.go` has the values for the ATmega2560.
`firmware/gcode`	Parses a line into words. No allocations. Arcs (G2/G3) as short lines.
`firmware/planner`	The look-ahead planner and the segment preparation.
`firmware/stepgen`	The step executor. The step interrupt runs it 10 000 times per second.
`firmware/mini`	The small controller: the serial input, the G-code commands, homing, the pen change, the knob menu, and the settings.
`firmware/board/mega`	The mainboard code: pins, the step timer, the servo PWM, the LCD, the knob, the EEPROM. It holds the heater MOSFET (`HEAT`) off.
`firmware/cmd/mega`	The firmware program.

The main loop (`Controller.Poll`) runs without a pause. Each pass reads the serial port, runs the next line, fills the segment queue, reads the knob, and writes one LCD line. The step interrupt takes segments from the queue. It uses integer math only and does not allocate memory.

Value	ATmega2560
Step timer	10 kHz. One step per axis per tick at most.
Top speed	120 mm/s. The planner limits all moves to this speed.
Planner	8 blocks
Step queue	16 segments of 2 ms (32 ms of motion)
Flash	92 KB of 248 KB

Value	ATmega2560
RAM (static)	4.2 KB of 8 KB

Build and flash

> **Caution:** Make a copy of the stock firmware first if you want it back exactly. Run `avrdude -c wiring -p atmega2560 -P /dev/ttyUSB0 -b 115200 -U flash:r:cr10v3-stock.hex:i`.

Install Go 1.26 and TinyGo 0.44. Then:

1. Connect the USB port of the control box to your computer.
2. Flash the firmware:

   ```
   tinygo flash -target=arduino-mega2560 -port /dev/ttyUSB0 ./firmware/cmd/mega
   ```

3. To build a HEX file only, run `tinygo build -target=arduino-mega2560 -o build/plotter-mega.hex ./firmware/cmd/mega`.

The Creality bootloader stays on the board. `tinygo flash` writes the program over USB with avrdude. You can put Marlin back with the same USB cable.

First boot

1. Open a terminal at 115200 baud, for example `screen /dev/ttyUSB0 115200`.
2. The firmware sends `start` and `PenPlotter 0.1.0 (TinyGo, ATmega2560)`.
3. Send `M115`. The reply names the ATmega2560 build.
4. Send `M119`. Push each switch by hand and send `M119` again. Each switch must change.
5. Check the motor directions before the first homing (`20-electronics-and-wiring`).
6. Send `G28`. X homes, then both Y sides. Each Y side stops at its own switch. This squares the gantry.
7. Tune the pen angles with the knob menu, or with `M281 U<up> D<down>`.
8. Send `M500` to save.

The LCD and the knob

The LCD shows four lines of 16 characters.

Line	Content
1	The state (`Idle`, `Run 45%`, `Homing`, `Paused`, `Pen T2`, `ALARM`) and the pen (`Pen up` or `Pen dn`)
2	The X and Y position in mm
3	A message: `Ready`, `Homing`, `Paused`, `Saved`, `Home failed`, `STOP` and the cause, or `Press the knob` at a pen change
4	The menu item, with `>` in front. The pen and speed items show the value.

- Turn the knob to choose a menu item. Press it to run the item.

- Press and hold the knob for 0.8 s to stop the machine. The long press works while the machine moves, homes, or waits for a pen. When the machine is idle, the long press does nothing.
- Send `M999` over USB to clear the stop. Then send `G28`. The knob cannot clear the stop.

Menu item	Job
Home	Runs `G28`. Only when the machine is idle.
Pen up/down	Lifts or lowers the pen. Only when the machine is idle.
Pause/resume	Stops the next lines. The moves in the buffer finish first. Press again to continue.
Motors off	Turns off the drivers. Only when the machine is idle. The machine is then not homed.
Pen up +1, Pen up -1	Changes the pen-up angle by 1°. The servo moves at once.
Pen down +1, Pen down -1	Changes the pen-down angle by 1°. The servo moves at once.
Speed +10%, Speed -10%	Changes the feed override, from 10 % to 200 %.
Save settings	Writes the settings to the EEPROM at once (also `M500`).

The firmware also saves the pen angles and the speed 3 s after the last change, when the machine is idle.

Pen changes

The stock build has no pen table in the firmware. Plotstudio keeps it. You change the pens by hand. Plotstudio puts `T<n>` and `M6` before the lines of each pen.

1. `T<n>` selects pen n (0 to 15).
2. `M6` lifts the pen and waits. The carriage stays where it is.
3. The beeper sounds once. LCD line 1 shows `Pen T2`. Line 3 shows `Press the knob`.
4. Loosen the clamp screw of the pen slider. Take out the old pen.
5. Put the new pen in the V bore. Set its tip height and tighten the clamp screw (`40-calibration-and-first-plots`).
6. Press the knob. A host can also send `M108`. The job continues.

G-code reference

The firmware sends `ok` when it has queued a line. A sender sends the next line after each `ok`. Text after `;` is a comment. The G-code part of a line can have up to 96 characters.

Code	Action
`G0 X Y`	Travel move at the rapid speed (limited to 120 mm/s).
`G1 X Y F`	Draw move at F (mm/min).
`G2`, `G3`	Clockwise and counter-clockwise arcs with I/J or R.
`G4 P<ms>`, `G4 S<s>`	Wait.
`G20`, `G21`	Inches, millimetres.
`G28`, `G28 X`, `G28 Y`	Home. Y homes both sides and squares the gantry.
`G90`, `G91`	Absolute, relative.

Code	Action
`G92 X Y`	Set the current position.
`M3`, `M4` / `M5`	Pen down / pen up.
`T<n>`, `M6`	Select pen n (0 to 15); wait for a pen change by hand.
`M108`	Continue after the pen change prompt.
`M17`	Motors on.
`M18`, `M84`	Motors off, after the queued moves. The machine is then not homed.
`M73 P<percent>`	Progress on the LCD.
`M105`	A dummy temperature reply for print hosts.
`M112`, Ctrl-X	Emergency stop. Then `M999` and `G28`.
`M114`	Position, with the step counts of X, Y1 and Y2.
`M115`	Firmware name.
`M119`	Switches: `x_min`, `y1_min`, `y2_min`.
`M280 P0 S<deg>`	Move the servo.
`M281 U<deg> D<deg>`	Set the pen up and down angles.
`M400`	Wait for the moves to end.
`M500`, `M501`, `M502`	Save the settings to the EEPROM, load them, set the defaults (not saved).
`M503`	Report the pen angles and the speed override.
`M999`	Clear the alarm.
`?`	Status line: `<Idle

Notes:

- A Z word does not move the pen. Use `M3` and `M5`.
- Printer codes (`M82`, `M83`, `M104`, `M106`, `M107`, `M109`, `M140`, `M190`) get `ok` with no action. Other M codes, for example `M117`, get `echo:ignored` and `ok`.
- An unknown G code gets `error:unsupported`.

Safety:

- **Soft limits:** after homing, the firmware keeps all moves inside the travel (245 × 390 mm).
- **Hard limits:** a switch that closes during a move toward it stops all motion and sets the alarm (`!! hard limit`). After homing, a switch that closes within 1 mm of home is the home position, so a move to 0,0 works.
- **Failed homing:** if a switch does not trigger, the reply is `error:homing failed` and the alarm is set. The LCD shows `Home failed`.
- **Alarm:** after an alarm, the firmware answers only `M999`, `M112`, `M108` and the queries (`M105`, `M114`, `M115`, `M119`, `M503`, `?`). Other lines get `error:alarm, send M999`. Send `M999`, then `G28`.

Settings

The settings record is in the EEPROM. It holds the pen-up angle, the pen-down angle, the speed override and the Y2 trim. A new board uses the values of `firmware/config/config.go`.

Command	Action
`M281 U<deg> D<deg>`	Set the pen angles. The firmware saves them 3 s later.
`M500`	Save now.
`M501`	Load the saved record.
`M502`	Set the values of `config.go`. Send `M500` to keep them.
`M503`	Report: `M281 U130 D80` and `echo:speed 100%`.

The Y2 trim comes from `Y2HomeOffsetMM` in `config.go`. No G-code changes it. After you change it and flash the firmware, send `M502` and `M500`. `M502` also resets the pen angles, so set them again.

Simulator

The simulator runs the same controller code with a model of the machine. With no `-board` flag, it simulates the stock board.

```
go run ./sim/cmd/plotsim -gcode samples/test-drawing.gcode
```

Two windows show the LCD with the knob, and the machine in 3D. The pen change prompt shows on the simulated LCD, and a press of the simulated knob answers it.

Flag	Default	Content
`-board`	`mega`	`mega`: the stock board. `pico`: the Pico W firmware. This build does not use it.
`-addr`	`127.0.0.1:8765`	The windows and the simulated camera
`-tcp`	`127.0.0.1:2323`	G-code over TCP. With `-board mega`, it stands in for the USB serial port.
`-settings`	a file for each board in the user config folder	The settings file (`M500`). `-settings -` keeps them in RAM only.
`-speed`	1	Simulation speed factor
`-gcode`	none	A file to plot at the start

The simulator also prints a serial device, for example `/dev/pts/3`. Plotstudio can use it, or `tcp://127.0.0.1:2323` (`30-software`).

Limits of this build

- No Wi-Fi, no HTTP API, no Printdeck. Connect a computer or a Raspberry Pi with USB.
- No pen table with names and colours. Plotstudio keeps the pen table on the computer.
- No graphic menus and no jog menu. Use G-code for jog moves.

- 120 mm/s top speed. A pen plotter seldom goes faster than 60 mm/s with ink on paper.
- 8 planner blocks and 16 step segments (32 ms of motion). Short lines at high speed can slow down at the corners.
- Pen changes are by hand, at each `M6`.
- The step timing and the LCD timing are not tested on a real board. If the motors stutter, lower `TickHz` in `firmware/config/rate_avr.go` to 8000 and lower `MaxFeed` to 100.

The repository also has a full controller for a Pico W board (`firmware/cmd/pico`), with Wi-Fi and the network API. This build does not use it. `firmware/README.md` describes it.

CHAPTER 7

7 Software

This chapter sets up the software that you use each day: plotstudio on a computer, the USB link to the plotter, the camera, the pens, and the simulator. `25-firmware` has the flash of the control box and the G-code list. The plotter connects over USB only.

The parts

Part	Where it runs	What it does
Firmware	The ATmega2560 in the control box	Plans the moves, drives the motors and the servo, shows the LCD. Written in Go, built with TinyGo.
plotstudio	A computer with the camera (Linux)	Scans the bed, places drawings, plots them over USB.
plotsim	A computer	Runs the same firmware code with a 3D window and a simulated camera. No hardware needed.

Plotstudio, plotsim and the firmware are pure Go. They need no Python, no OpenCV and no cgo.

Install plotstudio

1. Install Go 1.26 or later.
2. Get the repository, and build plotstudio:

```
cd penplotter
go build -o plotstudio ./studio/cmd/plotstudio
```

3. Start it. Give the plotter and the camera:

```
./plotstudio -port /dev/ttyUSB0 -camera /dev/video0
```

4. Open http://127.0.0.1:8780 in a browser. A phone works too: start plotstudio with `-addr 0.0.0.0:8780` and open the address of the computer.

Plotstudio keeps its files in `~/.config/plotstudio/`: the calibration of each camera, the pen table, and the signature library.

Connect the plotter

USB

1. Connect the USB port of the control box to the computer.
2. Type `/dev/ttyUSB0` in the **Plotter** card, or push **Find**. Push **Connect**.

The control box shows up as `/dev/ttyUSB0`. With no `-port`, plotstudio uses the first `/dev/ttyUSB*` device, then the first `/dev/ttyACM*` device. Plotstudio opens the port at 115200 baud.

A lost link does not stop plotstudio. It connects to the same plotter again every 3 s. A job that ran on a lost link stops; plot it again.

Set up the camera

1. Put the USB webcam on the top of the camera pole, behind the centre of the back bar (`15-assembly`). The lens is about 616 mm above the table. Point it down and a little forward.
2. Run `./plotstudio -list-cameras`, and start plotstudio with the camera: `-camera /dev/video0`.
3. Open the **Camera** tab and push **Live view**. The picture must show the whole frame opening.
4. Push **Focus → Lock** when the picture is sharp. A change of focus after the calibration moves the picture.

Calibrate the camera

Do this once for each camera position.

1. Tape a sheet of paper over the whole travel.
2. In **Calibrate**, select **3 × 3 points** (or 4 × 4 for the best result).
3. Push **1. Draw marks**. The plotter homes and draws 9 small dots.
4. Push **2. Click marks**. Click each dot in the order of the hint. The click snaps to the centre of the dot.
5. Push **Solve**. An error below 0.3 mm is good. The chip shows **Calibrated ±0.xx mm**.

Each camera has its own calibration file. A move of the camera or the pole needs a new calibration.

Scan and place

1. Put the paper (or the form) on the table.
2. Push **Scan the bed**. The gantry moves to the back and to the front, and plotstudio joins the two pictures into a flat top view in millimetres.
3. Push **SVG file**, or drop an SVG file on the bed view. Push **Signature** to sign with the mouse or a finger.
4. Drag the item to its place. Drag a corner to scale it, and the round handle to turn it. The fields give exact values in mm.
5. Check **Show path** to see the pen-up moves.
6. Push **Plot**.

An item outside the travel has a red frame. Plotstudio does not plot it.

Pens and multi-colour drawings

The plotter has 16 pen numbers: T0 to T15. The pen slider holds one pen at a time. You change the pen by hand at each `M6`.

Set up the pen table

1. Open **Pens → Pen table**.

2. Give each pen in your set a name and its colour. Leave a row empty for no pen.
3. Push **Save the table**. The table stays in plotstudio.

Plot a drawing with colours

1. Make the drawing with one colour for each pen, or one Inkscape layer for each pen.
2. Add the drawing. The **Pens** card lists each colour with its pen: the pen with the nearest colour. Change a pen in the list if you want.
3. To pick pens by layer, name the layers `T0`, `T1`, … (or `Pen 3`, `3 - red`). Keep **layer names pick pens** checked.
4. Push **Plot**. The light pens go first and the dark pens last. Each pen changes once.
5. At each pen change, the plotter stops with the pen up. The carriage stays where it is. The LCD shows `Pen Tn` and `Press the knob`. Plotstudio shows the pen to load.
6. Change the pen in the pen slider (`25-firmware`, "Pen changes"). Press the knob.

Tips for good colour plots:

- Use pens of one type and one tip size in a job. The line width then stays the same.
- Plot a light colour under a dark colour, not the other way round.
- Let a wet gel or paint pen dry before a pen crosses its lines.

More jobs in a row

While a job runs, **Plot** reads **Add to queue**. The queue is under the progress bar. A queued job waits for a press of **Start**, so that you can change the paper first.

When the plotter stops with an alarm

The firmware stops after a failed homing, a pressed switch during a move, a long press of the knob, or `M112`. Then it refuses moves. The LCD shows `ALARM` and the cause.

1. Find the cause: a pen or paper that blocks the gantry, a loose cable, a switch.
2. Push **Clear alarm** in the **Plotter** card. Plotstudio sends `M999` and homes the plotter.

Try it all in the simulator

The simulator runs the firmware code on the computer, with a 3D window, the LCD with the knob, and a camera that sees the table.

1. Start the simulator. With no `-board` flag, it simulates the stock board:

   ```
   go run ./sim/cmd/plotsim -cam-k1 -0.08
   ```

   It opens the LCD and 3D windows. It takes G-code on `127.0.0.1:2323`, in place of the USB serial port. It also prints a serial device, for example `/dev/pts/3`.

2. Start plotstudio with the simulator:

```
go run ./studio/cmd/plotstudio -port tcp://127.0.0.1:2323 -camera http://127.0.0.1:8765/camera.jpg
```

`-port /dev/pts/3` also works.

3. Calibrate, scan, place and plot as on the real plotter. The 3D window shows the ink on the paper. At a pen change, press the knob in the LCD window.

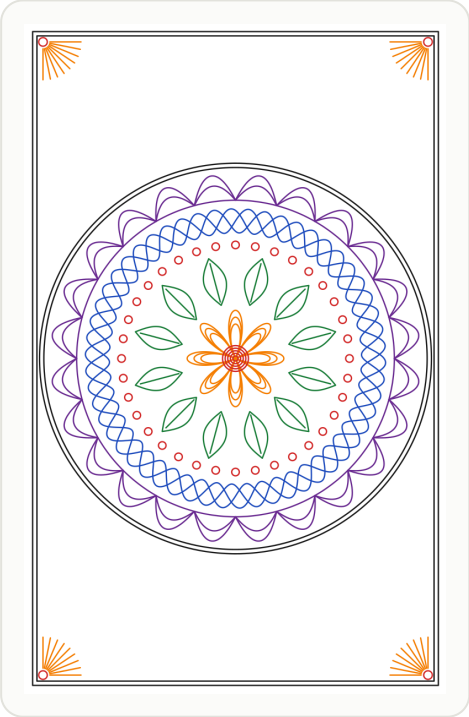
The simulator camera sees a form with a signature line on the paper. Place a signature on the line and plot it, then scan again to see the ink in the bed view.

The six-pen test

`samples/mandala.gcode` is a six-colour mandala on the full 245 × 390 mm travel. It tests the manual pen change.

1. Have six pens ready: T0 Black, T1 Red, T2 Orange, T3 Green, T4 Blue, T5 Purple (all Sharpie Fine Point).
2. Tape a sheet of paper over the travel.
3. Send the file to the plotter with a G-code sender. The job homes first.
4. At each `M6`, put in the pen that the LCD shows, then press the knob. The job has 6 pen changes.
5. The light colours draw first: T2, T3, T1, T4, T5, and T0 last.

Try the file in the simulator first: `go run ./sim/cmd/plotsim -gcode samples/mandala.gcode`. Press the knob in the LCD window at each pen change. `go run ./samples/mandala` writes the file again, with `samples/mandala.svg` as a preview.



CHAPTER 8

8 Calibration and first plots

Do these steps after the assembly and the power-up checklist. Each step needs the one before it. Send the G-code from a terminal on the USB port, for example `screen /dev/ttyUSB0 115200`. Close the terminal before you connect plotstudio. Only one program can use the port.

1. Wheels and eccentrics

Check the wheels before you square the gantry. A loose carriage gives a false squaring result.

1. Turn the motors off. Rock each Y carriage and the X carriage plate by hand.
2. If a carriage has play, turn its eccentric spacer a little with the 8 mm wrench. Then tighten its nut.
3. Push the gantry from the front to the back, and the X carriage from the left to the right. Each must roll freely, with no tight spot.
4. Turn each wheel with a finger. A wheel that does not turn has too little preload. A wheel that is hard to push along has too much.

2. Homing and squaring

1. Send `M119` with the carriages away from the switches. All three switches read `open`.
2. Send `G28`. X homes first. Then both Y sides move to the front.
3. Each Y side stops at its own switch. This makes the beam square to the frame rails.
4. Measure the beam position at the left and at the right end, from the front bar.
5. If the two values differ, set `Y2HomeOffsetMM` in `firmware/config/config.go` to the difference. A positive value moves Y2 away from its switch after homing.
6. Build and flash the firmware (`25-firmware`).
7. Send `M502`, then `M500`. The saved settings now hold the new trim. `M502` also resets the pen angles, so set them again in section 5.
8. Home again.

`M114` shows the step counts of X, Y1 and Y2. After homing, the Y1 and Y2 counts are 0.

3. Steps per millimetre

The firmware uses 80 steps/mm on all axes: 200 steps per turn, 1/16 microsteps, and a 20-tooth GT2 pulley (40 mm per turn).

1. Tape a sheet of paper to the table.
2. Set the pen height (section 4), then plot `samples/square.gcode`.
3. Measure the square with calipers. It must be 40.0 × 40.0 mm.
4. A value of 20 mm or 80 mm means a different microstep setting on the drivers or a different pulley. The stock board runs at 1/16. Fix the hardware first.
5. For a small error on a correct setup, set `StepsPerMMX` or `StepsPerMMY` in `firmware/config/config.go`: new value = 80 × 40 / measured.

4. Pen height

The gantry height is fixed. The clamp screw of the pen slider sets the pen height.

1. Send `M3` (pen down).
2. Loosen the clamp screw. Put the pen in the V bore until its tip touches the paper.
3. Tighten the clamp screw. Do not overtighten it: the slider is PLA.
4. Send `M5` (pen up). The tip must lift clear of the paper.

The weight of the slider and the pen is the pen force. A heavier pen gives more force. Pens of 8 to 15 mm fit the V bore. Set the height again after each pen change.

5. Servo angles

The horn must clear the tab at pen down and lift the slider 7 mm at pen up.

1. Send `M5`. The pen must lift clear of the paper.
2. Send `M3`. The pen must rest on the paper. The horn must not touch the tab.
3. Change the angles with the knob. Turn it to `Pen up +1`, `Pen up -1`, `Pen down +1` or `Pen down -1`, and press it. Each press changes the angle by 1°, and the servo moves at once. The menu line shows the angle.
4. Or send `M281 U<up degrees> D<down degrees>`. `M503` reports the angles.
5. Start from the defaults: up 130°, down 80° (90° is the horn level).
6. Turn the knob to `Save settings` and press it, or send `M500`. The firmware also saves 3 s after the last change.

6. Camera calibration

Do this once for each camera position. `30-software` has the full steps.

1. Start plotstudio with the camera.
2. Lock the focus when the picture is sharp.
3. Push **Calibrate → Draw marks**. The plotter draws a grid of dots.
4. Push **Click marks** and click each dot.
5. Push **Solve**. An error below 0.3 mm is good. The simulator gives about 0.05 mm.

7. First SVG

1. Put the paper on the table, inside the travel.
2. Push **Scan the bed** in plotstudio.
3. Drop an SVG file on the bed view. Drag, scale and turn it onto the paper.
4. Check **Show path**, then push **Plot**.

Start with a line drawing. Plotstudio plots the lines (strokes) of the SVG. It does not fill areas.

8. A multi-pen job

1. Open the pen table in plotstudio. Give each pen a name and a colour. The table stays in plotstudio.

2. Load an SVG with coloured lines, or with Inkscape layers named after pens (for example "T2 red").
3. Plotstudio maps each colour to the nearest pen. Change a mapping in the list if needed.
4. Push **Plot**. The job plots the pens from light to dark.
5. At each pen change, the pen lifts and the carriage stops where it is. The beeper sounds once. The LCD shows `Pen Tn` on line 1 and `Press the knob` on line 3.
6. Change the pen in the pen slider and set its height (section 4). Press the knob to go on. A host can also send `M108`.
7. Run `samples/mandala.gcode` as the first six-pen test (`30-software`).

To stop a job at once, press and hold the knob for 0.8 s. Send `M999` and `G28` before the next job.

CHAPTER 9

9 Review history

The design went through several rounds of review. Each round checked the design, changed it, and ran the checks again. The tables below are a record. Many of the parts that they name are no longer in the build: the pod, the housings, the X band and the pen changer went away on 2026-11-10 (step 19). The detailed logs are:

- `hardware/REVIEW.md`: the printed parts, five rounds, the change back to V-wheels, the vertical Y wheels, the feet, the belt clips, the Y brackets, the omega Y drive, the side wheels, the moving cables, the printed X plate, the fixed Y motors, and the simplification of 2026-11-10.
- `firmware/REVIEW.md`: the firmware and Wi-Fi, five rounds.
- `studio/REVIEW.md`: plotstudio and Printdeck, five rounds.
- `docs/REVIEW-integration.md`: the cross-track review, two rounds.

The design changes

Step	Change	Reason
1	A pen lift on the CR-10 X carriage, the CR-10 moving bed	The first layout used the CR-10 as it was.
2	The frame on the table; the table is the bed	No moving bed. Any surface under the frame is the bed.
3	Two Y motors, each with its own belt and switch	A gantry on two frame rails needs a drive on each side. Homing squares it.
4	X on two 10 mm rods with LM10UU bearings	This replaced the CR-10 X carriage and its V-wheels.
5	MGN12 linear rails on X and Y	More accurate, and the travel grew from 216 × 384 mm to 253 × 400 mm.
6	A small control pod and a 24 V brick	The CR-10 box held a 350 W supply. The plotter needs 30 to 40 W.
7	PLA only	All parts print in PLA.
8	Print time review	15 % gyroid infill, 3 top and bottom layers, faster outer walls, thinner pod walls. About a third less print time.
9	The stock controller build is the main build	The stock control box, its drivers and its harness work for a pen plotter. Two small housings replace the pod. The Pico W build becomes an optional upgrade.
10	Back to V-wheels	The plotter reuses the 9 stock V-wheels and the stock X carriage plate. The MGN12 rails cost money, and the stock wheels are free. The travel is 245.9 × 397.0 mm (245 × 395 mm in the firmware).
11	Vertical Y wheels, 2020 cross bars, camera pole	All axes use vertical wheels. The Y carriage became a C shape: 2 wheels on top of the rail, 1 under it. A printed foot holds a camera pole. The camera mount went away.
12	Printed feet, tried and removed	Printed feet under the cross bar ends gave 397 mm of Y travel. The machine already has feet, so they stay under the rails. The back feet stop the bottom Y wheels: 381 mm in the model, 380 mm in the firmware.

Step	Change	Reason
13	Belt crimp clips	A metal clip closes each folded belt end. You crimp each belt to length on the bench and drop it into pockets. The idler slots set the tension.
14	Y brackets on two faces	4 screws in two slots of the bar end. The most loaded screw drops from 92 N to 56 N (motor bracket) and from 147 N to 52 N (idler bracket).
15	Y belts fixed on the rails, Y motors on the carriages (omega drive)	The goal is a simpler design with compact parts. The 4 corner brackets and the belt loops outside the frame go away. The cost is Y travel: 381 → 365 mm in the model (364 mm in the firmware).
16	Side wheels again, belt ends on the bar faces, a drag chain and a band for the moving cables	The side-mounted wheels come back. The stock feet stay under the rails, and the omega Y drive stays. Nothing goes under the rail, so the feet do not limit the travel. The back belt end moves to the back face of the back bar. The travel grows from 365 to 392 mm in the model (390 mm in the firmware). All moving wires are carried low.
17	Pen changer at the front	A rack with 6 bins hooks over the front bar. A magnetic dock replaces the pen slider. The old 16-pen rack at the back is gone: the beam passes over the back of the travel and hits standing pens. The drawing area with the changer starts at Y 95.
18	Printed X plate, the stock X belt path, fixed Y motors	A printed X carriage replaces the stock plate, and the X belt runs in the beam slots. The old belt loop in front of the beam hit the parked tall tools at Y 0. The Y motors moved behind the back bar: the gantry is about 630 g lighter, and the Y motor cables do not move. The travel is 395.1 mm in the model (390 mm in the firmware).
19	Simplification: no pen changer, flat Y plates, bare boards, servo loom	The pen changer is dropped and the build is simpler. The pen changer, the Pico W pod, the board housings, the servo cover, the bar end caps, the pen gauge and the X band went away. The printed plates copy the stock CR-10 layouts with only the features in use. Pen changes are by hand. 16 parts, 21 h 45 min, 383 g.

Hardware rounds

Round	Change	Parts	Print time	Filament	Cost
0	Start	16	25 h 12 min	453 g	$9.06
1	The pen lift and the X carriage are one part. The paper clips and the X carriage fit test go away.	11	24 h 23 min	440 g	$8.80
2	No heat-set inserts. Rail screws in every second hole (52 instead of 100). Cable tie slots.	11	24 h 33 min	441 g	$8.82
3	A 4th driver slot in the pod. The 16-pen rack area is reserved.	11	24 h 37 min	442 g	$8.84
4	A camera mast foot and a camera mount (optional)	13	26 h 45 min	478 g	$9.56
5	A lower pod front, thinner Y carriage plates, print orientation checks	13	26 h 02 min	464 g	$9.28

Without the 2 optional camera parts, the result is 11 parts, 23 h 54 min, 428 g and $8.56. The fit tests went from 78 min to 32 min. The heat-set inserts went from 8 to 0. The loose fasteners went from about 183 to 127.

The stock controller build drops the pod and adds 4 small housing parts. With the MGN12 rails, it was 13 parts, 19 h 53 min, 354 g and $7.08.

Back to V-wheels

The review rounds used MGN12 rails on both axes. After the rounds, the design went back to the stock V-wheels. The reasons:

- The plotter reuses the 9 stock V-wheels: 3 on the stock X carriage plate and 6 free wheels from the Z carriages and the bed carriage.
- The stock X carriage plate stays. The pen carriage bolts to its 4 tool head holes.
- No rails to buy. The 3 MGN12 rails with their blocks and 38 rail and block screws go away. The purchased parts drop from about $165 to about $103.

	MGN12 build	V-wheel build
Printed parts, main build	13	13
Print time	19 h 53 min	18 h 07 min
Filament	354 g	323 g
Cost	$7.08	$6.46
With the camera mast (15 parts)	22 h 01 min, 390 g, $7.80	20 h 15 min, 359 g, $7.18
Fit tests	2 parts, 32 min, 9 g	3 parts, 51 min, 14 g
Pen travel (model)	253 × 400 mm	245.9 × 397.0 mm
Pen travel (firmware)	250 × 395 mm	245 × 395 mm

The open measurements are in `hardware/MEASURE.md`, items 16 to 23: the wheel size, the axle-to-face distance, the spacer height, the eccentric shank, the plate-to-beam distance, the wheel bolt length behind the beam, the wheel bolt positions, and the switch size and holes.

Feet, fasteners, belt clips and brackets

Feet. The stock rubber feet stand under the 2040 rails, 37.5 mm from each end. The bottom wheel of each Y carriage runs under the rail, so the back feet stop the gantry. A design with four printed feet under the cross bar ends gave 397.0 mm of Y travel. The machine already has feet, so the printed feet went away again. The Y travel is 381.0 mm in the model and 380 mm in the firmware.

Fasteners. The fasteners are now in the model. The fit check moves them with the parts. The length check found four errors:

Screw	Before	Now
M5 into a T-nut through a 6 mm wall (brackets, beam, pole foot)	M5 × 10: 2.2 mm of thread in the T-nut	M5 × 12: 4 mm of thread, the tip 6 mm into a 6.3 mm slot
Housing screws through a 3 mm floor	M5 × 10 button head: the tip hit the core	M5 × 8 button head: 3.2 mm of thread
Beam tower T-nut screw	M5 × 12: the tip reached the core	M5 × 12 with a washer under the head
Endstop screws through a 6.4 mm switch body	M2 × 8: 1.6 mm of thread	M2 × 10

Belt clips. Each belt end folds back on itself, and a metal crimp clip closes it. Each clip sits in a pocket behind an end wall. The belt lies in a slit in the wall. The Y idlers and the X idler move 5 mm each way in their slots. This takes up a crimp error and the stretch of the belt.

Y brackets. Each bracket held on 2 screws in one slot. Now it has 2 screws in the outer face slot (at x = 41 and 64 mm) and 2 in the top slot of the bar end.

Bracket	Most loaded screw before	Now
Y motor bracket	92 N	56 N
Y idler bracket	147 N	52 N

	Before (vertical Y wheels)	After these changes
Main build	13 parts, 18 h 22 min, 322 g, $6.44	13 parts, 19 h 59 min, 348 g, $6.96
With the camera part	14 parts, 19 h 53 min, 347 g, $6.94	14 parts, 21 h 30 min, 373 g, $7.46
Pen travel (model)	245.9 × 381.0 mm	245.9 × 381.0 mm

Omega Y drive

The design becomes simpler and more compact. Each Y belt now lies fixed along its rail, teeth down. A front base with a tensioner sled and a back anchor hold its two clips. Each Y motor rides on its carriage, on a drive mount behind the beam. The belt goes under a smooth idler, over the motor pulley (180° of wrap), and under a second smooth idler. The 4 corner brackets and the belt loops outside the frame are gone.

- The back idler of each omega stops at the back anchor. The Y travel is 365.1 mm in the model (381.0 mm before). The firmware uses 364 mm.
- The two Y motors ride on the gantry: about 668 g more moving mass.
- The Y motor cables move with the carriages. BOM line M31 adds two 1 m stepper cables in case a stock cable is short.
- The head housing moved right to x = 92 mm, beside the left Y motor.

	Before	Now
Main build	13 parts, 19 h 59 min, 348 g, $6.96	17 parts, 17 h 40 min, 304 g, $6.08
With the camera part	14 parts, 21 h 30 min, 373 g, $7.46	18 parts, 19 h 11 min, 329 g, $6.58
Pen travel (model)	245.9 × 381.0 mm	245.9 × 365.1 mm

Side wheels, belt ends on the bar faces, moving cables

The design goes back to the side-mounted wheels. The stock feet stay under the rails. The omega Y drive stays.

- **Y carriage.** A 6 mm plate over the rail top runs on 3 V-wheels on vertical axles in the side slots. Two wheels run outside, 22 mm in front of and behind the beam centre. The back one turns on the eccentric spacer. One wheel runs inside at the beam centre, on a tongue that crosses over the belt. Nothing goes under the rail.

- **Belt ends.** The front base stays on the top of the front bar. The sled moves 3.5 mm each way. A back block on the back face of the back bar holds the back end, with two M5 screws in the face slot. A recess clears the bar end screw head, so one part fits both sides. The Y belt is 598.2 mm between the folds.
- **Travel.** 245.9 × 391.8 mm in the model (245.9 × 365.1 mm before). At the front the carriage plate stops at the front base. At the back the drive mount stops at the back block. The firmware uses 245 × 390 mm.
- **Control box.** Its right side is now at x = −70 mm.

All moving wires must be carried low, with no tall part. These were the options for the Y axis (the head harness and the two Y motor cables):

Option	Cost	Print	Stops travel	Wear and snag	Build
Openable drag chain 10 × 20 R28 beside the left rail, lower run on the table (chosen)	about $13	anchor 39 min, 11 g	no	low: the chain takes the bending	easy: open the links, lay in the cables
Bridge (closed) drag chain 10 × 20 R28	about $10	the same	no	low	hard: the big harness plug does not pass, so you must unpin it
Band on edge (steel or PET) beside the rail	about $7	the same	no	medium: the 7 mm harness twists the band	medium: ties every 30 mm
Spiral wrap loop on the table with clip points	about $5	clips, 20 min	no	high: it drags on the table and catches the control box	easy

These were the options for the X axis (the servo lead only):

Option	Cost	Print	Stops travel	Wear and snag	Build
Band on edge behind the beam, rolling U loop, as in an inkjet printer (chosen)	about $7	bracket and clip 47 min, 13 g	no	low: nothing rubs, and the band is light	easy: ties, two small parts
Small drag chain (7 × 7 or 10 × 10, R18)	about $10	a 300 mm support shelf, 2 h or more	no, but the shelf is a tall part over the gantry	low	hard: no low space (the X plate wheels sweep the beam top, and the X belt loop the front)
Braided sleeve service loop, low	about $5	none	no	medium: the loop sags onto the head housing and the Y motors	easy
Spiral wrap with clip points	about $3	clips, 15 min	no	medium to high	easy

The fit check moves the chain over the Y travel and the band over the X travel. They touch nothing but their mounts. The chain and band sizes are values in `hardware/shape.py`, so another chain or band is a change of numbers.

	Before	Now
Main build	17 parts, 17 h 40 min, 304 g, $6.08	20 parts, 19 h 34 min, 336 g, $6.72

	Before	Now
With the camera part	18 parts, 19 h 11 min, 329 g, $6.58	21 parts, 21 h 05 min, 361 g, $7.22
Fit tests	1 h 13 min, 18 g	48 min, 13 g
Pen travel (model)	245.9 × 365.1 mm	245.9 × 391.8 mm

Simplification (2026-11-10)

The pen changer is dropped and the whole build is simpler. The build uses no stock plates, because they have many mounting points that the plotter does not use.

- **Removed.** The pen changer, the Pico W control pod, both board housings, the servo cover, the four bar end caps, the pen gauge, and the X band with its two holders.
- **Y carriages.** Each one is a flat 6 mm plate, in the form of the stock CR-10 Z carriage plate. The outer wheels are 44 mm apart. The inner wheel is 18 mm behind the beam, on a 12 mm boss. A saddle holds the beam at its old height. The Y travel stays 390 mm.
- **X endstop.** The board moved to the front of a wall in front of the beam end. A lug at the bottom left of the X plate presses its lever. The wall is 22 mm lower than before.
- **Boards.** The two breakout boards stand bare on nylon standoffs, held by cable ties.
- **Servo lead.** It runs in a 1/2 inch split wire loom, with a cable tie at each end. The model hangs the loop as a catenary. Its lowest point stays 41 mm or more above the paper.
- **Motors.** The X motor is a 42-34 (213.4 g). The Y motors are 42-40 (286.7 g).

	Before	Now
Main build	27 parts, 30 h 28 min, 544 g, $10.88	16 parts, 21 h 45 min, 383 g, $7.66
Heat-set inserts	13 (and 1 M4 for the changer dock)	9
Pen travel (model)	245.9 × 395.1 mm	245.9 × 395.1 mm
Fit tests	49 min, 14 g	49 min, 14 g

One question is open. The cable ties of the head board go round the beam, in the path of the X plate. The options are M3 drop-in T-nuts in the back slot of the beam with M3 screws through the board and the standoffs, or a board place outside the X travel. This decision is open.

Firmware rounds

Round	Topic	Main changes
1	Core and settings	Long comment lines no longer fail a job. Hard limits stop all motion. A 1 mm floor after homing allows a move to 0,0. Settings in flash with a CRC: pen angles, pen table, Wi-Fi, park position (`M500` to `M503`).
2	Several hosts	Up to 6 connections, one owner at a time. Queries and safety lines from any connection. The `firmware/netapi` package. The network API in the simulator.
3	Wi-Fi	The Pico W driver and network stack in pure Go. DHCP or a fixed address, mDNS, HTTP on port 80, G-code on port 23. Credentials from the LCD or USB.
4	Pens	The 16-pen table, `T<n>`, `M6`, `M108`. The manual change with an LCD prompt. The `Changer` interface. Pins reserved for a changer.

Round	Topic	Main changes
5	Robustness	Lower-case API states. Fewer allocations on the Pico H. Tests for vpype and Inkscape G-code and for the pen change prompt.

Build	Flash	Static RAM
Pico H	75 772 B	7 444 B
Pico W	550 896 B	9 584 B (about 40 KB at run time)

Software rounds

Round	Topic	Main changes
1	Wi-Fi	TCP link, mDNS discovery, HTTP client, reconnect every 3 s.
2	Multi-pen	SVG stroke colours and Inkscape layers. Nearest pen by colour (CIE Lab). Pens from light to dark with `T<n>` and `M6`. The pen table editor.
3	Printdeck	Plotstudio as a library at `/plotter/`, with the deck camera. A patch for Printdeck.
4	Robustness	A job queue, a calibration file for each camera, scan parks 5 mm clear of the switches, a clear-alarm button.
5	Quality	A status decoding bug fixed. Clean `gofmt` and `go vet`. The documents.

Cross-track rounds

`docs/REVIEW-integration.md` has the findings. The main ones:

- The simulator camera reads its position from the mast in `frame.json`.
- The parts list gives the exact belt and idler type.
- Old code of earlier designs is gone from `hardware/`.

CHAPTER 10

10 Troubleshooting

Find the symptom in the left column. Do the checks in order.

Control box and electronics

Symptom	Checks
The box does not start	Check the mains cable and the switch of the box. Check the voltage switch of the supply (115 V for the US).
A motor hums but does not turn	Check the plug at the head board or the base board. Check the coil pairs with a meter (about 2 Ω in a pair).
A motor is hot	The onboard drivers keep the printer current. Read "Mainboard" in `docs/bom.md` before you change it.
A driver is dead	Never plug a motor in or out with the box on. The E driver is free, but the firmware does not use it. A move to E needs a change in `firmware/board/mega/pins.go`.
The motors move half the distance or twice the distance	The firmware needs 1/16 microsteps and 20-tooth pulleys. Check the pulleys. Check the board revision.
The servo does not move	Measure 5 V from pin 2 to pin 1 of `BL_T`. Check the signal wire on pin 3. Send `M280 P0 S90`.
The box resets when the servo moves	The servo takes too much current from the 5 V supply of the mainboard. Use an SG90, not a larger servo.
The motors stutter	Lower `TickHz` in `firmware/config/rate_avr.go` to 8000 and `MaxFeed` to 100. Build and flash again.

LCD and knob

Symptom	Checks
The LCD is blank or shows garbage	Check the stock LCD ribbon at both ends. Turn the box off and on.
A knob item does nothing	Home, Pen up/down and Motors off work only when the machine is idle.
A long press does nothing	The long press stops a moving or waiting machine only. At idle it does nothing.
The LCD shows `ALARM`	Send `M999` over USB, then `G28`. The knob cannot clear the alarm.
The LCD shows `Pen T2` and `Press the knob`	This is a manual pen change. Change the pen and press the knob, or send `M108`.
The beeper is silent	The beeper pin (PC0) is not checked on a real board. The firmware works without it.

Motion and homing

Symptom	Checks
`M119` shows a switch as triggered when it is not	Set `EndstopTriggeredHigh = false` for normally open switches.
One Y side moves the wrong way	Stop at once: the beam twists. Set `InvertDirY2` (or `InvertDirY`), or turn the motor plug with the power off.
`G28` stops with `error:homing failed`	A switch did not trigger. Send `M119` and push each switch. Check the Y2 switch at base board `Z-` and the Y1 switch at `Y-`.
The beam is not square after homing	Measure the error at both ends. Set `Y2HomeOffsetMM`. Flash, then send `M502` and `M500`.
An alarm after a move to X 0 or Y 0	The firmware keeps a 1 mm floor after homing. Send `M999` to clear the alarm, then `G28`.
The square is not 40 × 40 mm	See "Steps per millimetre" in `40-calibration-and-first-plots`.
Lines are wavy	Tighten the belts. Rock each carriage by hand. If it has play, turn its eccentric spacer (`40-calibration-and-first-plots`).
A carriage has play, or the lines shift after a direction change	An eccentric spacer is loose. Turn it until the play is gone, and tighten its nut. Check that the wheel nuts are tight.
A carriage is hard to push, or it bumps along the travel	The preload is too high, or a wheel has a flat spot. Turn the eccentric back a little. Replace a wheel with a flat spot.
Rows of small waves (wobble) in long lines	A wheel wobbles on its axle, or a spacer is missing. Check the 6 mm spacers and tighten the axle nuts. Turn each wheel by hand: it must run true.
The beam is not square after homing, and the error changes	A Y carriage has play. Do the wheel check in `40-calibration-and-first-plots` before you set `Y2HomeOffsetMM`.
The X plate hits the head board ties	The ties go round the beam in the path of the X plate. This question is open: `hardware/REVIEW.md` lists the options.
Corners are rounded or overshoot	Lower `Accel` or `JunctionDev` in `firmware/config/config.go`.
Short lines draw slowly	The stock board plans 8 blocks ahead. Lower the draw speed.

Pen

Symptom	Checks
The pen does not touch the paper	Set the pen height again in the pen slider (`40-calibration-and-first-plots`). Check the pen-down angle: the horn must clear the tab.
The pen drags at pen up	Raise the pen-up angle with `Pen up +1` on the knob, or with `M281`. Save with `M500`.
Lines are too thin or skip	The pen force is too low. The force is the weight of the slider and the pen. Try a heavier pen.
The slider sticks	Clean the dovetail. Rub PTFE dry lube on the rail. Print the fit tests with a larger `DT_CLR`.
The pen turns or slips in the slider	Tighten the M3 clamp screw a little.
The servo loom drags on the paper or a part	Check the two ties of the loom. The loop between the ties must be 189 mm. In the model the loop stays 41 mm or more above the paper (`hardware/MEASURE.md`, item 48).
A Z word in the G-code does not move the pen	The stock firmware uses `M3` and `M5` only. Plotstudio sends `M3` and `M5`.

Connections

Symptom	Checks
No `/dev/ttyUSB0`	Use a data USB cable, not a charge cable. Turn on the box. Run `ls /dev/ttyUSB* /dev/ttyACM*`.
`tinygo flash` fails	Close all programs that use the port: plotstudio, `screen`. Check the `-port` value.
Plotstudio does not find the plotter	Start it with `-port /dev/ttyUSB0`.
The terminal shows garbage	Set 115200 baud.
`echo:ignored M117`	The stock firmware ignores some codes of other hosts. The job continues.

Camera and plotstudio

Symptom	Checks
The calibration error is above 0.3 mm	Lock the focus before the calibration. Use 4 × 4 points. Click the centre of each dot.
The plot is offset from the scan	The camera moved after the calibration. Calibrate again.
The gantry hides part of the bed	Plotstudio scans twice, with the gantry at the back and at the front. Check `-scan-twice`.
A drawing has a red frame and does not plot	It is outside the travel. Move it or scale it.
A colour plots with the wrong pen	Change the colour mapping in the pen list. Or name an Inkscape layer after the pen, for example "T2 red".

CHAPTER 11

11 Reference

G-code reference

The firmware sends `ok` when it has queued a line. A sender sends the next line after each `ok`. Text after `;` is a comment. The G-code part of a line can have up to 96 characters.

Code	Action
`G0 X Y`	Travel move at the rapid speed (limited to 120 mm/s).
`G1 X Y F`	Draw move at F (mm/min).
`G2`, `G3`	Clockwise and counter-clockwise arcs with I/J or R.
`G4 P<ms>`, `G4 S<s>`	Wait.
`G20`, `G21`	Inches, millimetres.
`G28`, `G28 X`, `G28 Y`	Home. Y homes both sides and squares the gantry.
`G90`, `G91`	Absolute, relative.
`G92 X Y`	Set the current position.
`M3`, `M4` / `M5`	Pen down / pen up.
`T<n>`, `M6`	Select pen n (0 to 15); wait for a pen change by hand.
`M108`	Continue after the pen change prompt.
`M17`	Motors on.
`M18`, `M84`	Motors off, after the queued moves. The machine is then not homed.
`M73 P<percent>`	Progress on the LCD.
`M105`	A dummy temperature reply for print hosts.
`M112`, Ctrl-X	Emergency stop. Then `M999` and `G28`.
`M114`	Position, with the step counts of X, Y1 and Y2.
`M115`	Firmware name.
`M119`	Switches: `x_min`, `y1_min`, `y2_min`.
`M280 P0 S<deg>`	Move the servo.
`M281 U<deg> D<deg>`	Set the pen up and down angles.
`M400`	Wait for the moves to end.
`M500`, `M501`, `M502`	Save the settings to the EEPROM, load them, set the defaults (not saved).
`M503`	Report the pen angles and the speed override.
`M999`	Clear the alarm.
`?`	Status line: `<Idle

Notes:

- A Z word does not move the pen. Use `M3` and `M5`.
- Printer codes (`M82`, `M83`, `M104`, `M106`, `M107`, `M109`, `M140`, `M190`) get `ok` with no action. Other M codes, for example `M117`, get `echo:ignored` and `ok`.
- An unknown G code gets `error:unsupported`.

Safety:

- **Soft limits:** after homing, the firmware keeps all moves inside the travel (245 × 390 mm).
- **Hard limits:** a switch that closes during a move toward it stops all motion and sets the alarm (`!! hard limit`). After homing, a switch that closes within 1 mm of home is the home position, so a move to 0,0 works.
- **Failed homing:** if a switch does not trigger, the reply is `error:homing failed` and the alarm is set. The LCD shows `Home failed`.
- **Alarm:** after an alarm, the firmware answers only `M999`, `M112`, `M108` and the queries (`M105`, `M114`, `M115`, `M119`, `M503`, `?`). Other lines get `error:alarm, send M999`. Send `M999`, then `G28`.

Configuration values

The values are in `firmware/config/config.go`. Change a value, then rebuild and flash the firmware. The values in the settings record change at run time: `M503` reports them, and `M500` saves them. On the stock board the record holds the pen angles, the speed override and the Y2 trim.

The ATmega2560 build uses five values of `firmware/config/rate_avr.go` in place of the values below: `TickHz` 10 000, `SegmentTick` 20, `MaxFeed` 120 mm/s, `PlannerSize` 8, `SegQueue` 16.

Value	Default	Meaning
`StepsPerMMX`, `StepsPerMMY`	80	Steps per mm (1/16 microsteps, 20T GT2 pulley). Use 100 with a 16T pulley and idler (`hardware/MEASURE.md`, item 59).
`TravelX`, `TravelY`	245, 390	Travel in mm from the home switches (the model allows 245.9 × 395.1)
`InvertDirX`, `InvertDirY`, `InvertDirY2`	false, false, true	Motor directions
`Y2HomeOffsetMM`	0	Y2 moves this far after homing, to square the beam
`EndstopTriggeredHigh`	true	true for normally closed switches
`HomeFastFeed`, `HomeSlowFeed`	30, 4 mm/s	Homing speeds
`HomeBackoff`	3 mm	Back-off before the slow homing pass
`MaxFeed`, `RapidFeed`, `DefaultFeed`	250, 150, 50 mm/s	Speed limit, G0 speed, G1 speed before the first F word
`Accel`	1500 mm/s²	Acceleration of all moves
`JunctionDev`	0.02 mm	Corner tolerance of the look-ahead
`PlannerSize`	32	Blocks in the look-ahead buffer
`TickHz`, `SegmentTick`	40 000 Hz, 80	Step timer rate; ticks per 2 ms segment
`PenUpDeg`, `PenDownDeg`	130, 80	Servo angles (90° is the horn level). Tune them in the menu.

Value	Default	Meaning
`PenSettleMs`	150 ms	Wait after each pen move
`EncoderPulsesPerDetent`	4	Encoder pulses for one knob click

Plotstudio options

Option	Meaning
`-port`	The plotter: `/dev/ttyUSB0` (the control box), or `tcp://host:port` (a serial line over TCP, for example the simulated stock board)
`-camera`	`/dev/video0`, a camera number, an `http://` JPEG address, or `file:<path>`
`-list-cameras`	List the V4L2 cameras
`-feed`	Draw speed in mm/min (default 3000)
`-park`, `-scan-twice`, `-split`	Scan settings: park the gantry, two pictures, the join row
`-lens`	Fit the lens distortion (6 or more points)
`-addr`	The address of the plotstudio page (default `127.0.0.1:8780`)
`-data`	The folder for the calibration and the library

Files of the repository

Path	Content
`README.md`	The short introduction and the quick start
`docs/guide/`	The chapters of this guide
`docs/penplotter-guide.pdf`	This guide as one PDF (`tools/guide`)
`docs/bom.md`, `docs/wiring.md`, `docs/network-api.md`, `docs/studio.md`, `docs/printdeck.md`	Reference documents
`docs/REVIEW-integration.md`	The cross-track review
`hardware/shape.py`, `parts.py`, `model.py`	The printed parts in build123d, the fit check, the exports
`hardware/make.sh`	Builds, checks, slices and documents all parts
`hardware/stl/`, `hardware/cad/`	The STL files in print orientation, and the STEP files
`hardware/stl/frame.json`	The machine geometry for the simulator and plotstudio
`hardware/penplotter-build-guide.pdf`	The step-by-step build guide for the hardware
`hardware/REVIEW.md`, `hardware/MEASURE.md`	The hardware review, the measurements to take
`firmware/config/`	All machine values
`firmware/gcode/`, `planner/`, `stepgen/`	The portable firmware core (no `machine` import)
`firmware/mini/`	The small controller for the stock board
`firmware/board/mega/`, `firmware/cmd/mega/`	The stock board code (pins, step timer, servo, LCD, knob, EEPROM) and its main program

Path	Content
`firmware/controller/`, `ui/`, `settings/`, `netapi/`	The full controller for a Pico W board. This build does not use it.
`firmware/board/pico/`, `firmware/cmd/pico/`	The Pico and Pico W board code and its main program. This build does not use it.
`sim/`	The simulator backend; `sim/web/` the 3D window and the LCD window
`studio/`	Plotstudio: `geom`, `svg`, `plan`, `serial`, `netlink`, `camera`, `app`, `web`
`integrations/printdeck/`	The Printdeck package and `printdeck.patch`. It needs a Pico W board.
`samples/`	`square.gcode`, `test-drawing.gcode`, `blueprint.gcode`, the six-pen test `mandala.gcode` (`samples/mandala`) and their generators
`tools/progress/`	The progress site
`tools/guide/`	The generator of `docs/penplotter-guide.pdf`