

# Why CNC?

~

## An Introduction

Ed Nisley • KE4ZNU

<http://softsolder.com>

January 2011  
Cabin Fever Expo  
York PA



\* Must \*

\* Make \*

\* Shiny \*

\* Objects \*

# Upcoming Events

Things to do with CNC

Machine shops & milling machines

Computer Numerical Control

Numbers and where to find them

G-Code programming

Stepper motors & step timing

Useful (?) household (?) projects (!)

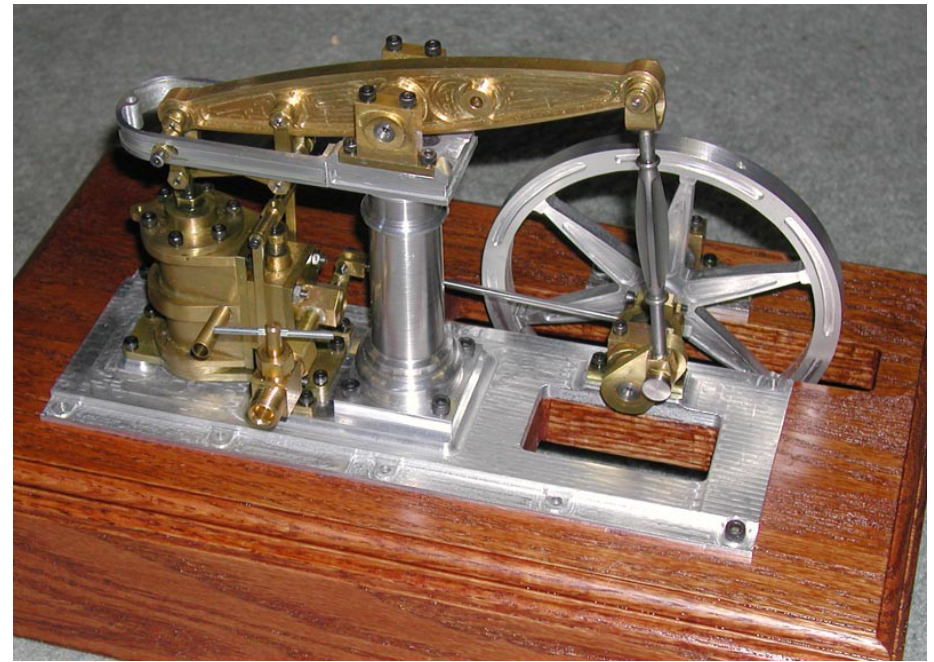
*See it in action at the CNC Exhibit!*



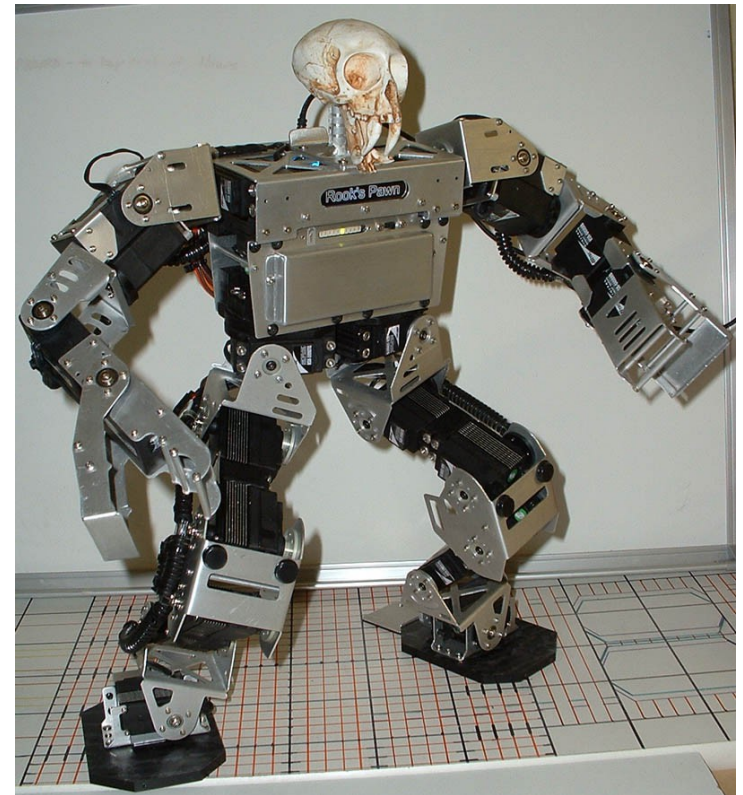
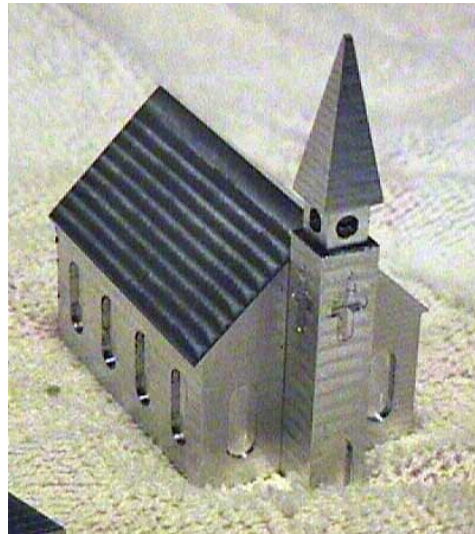
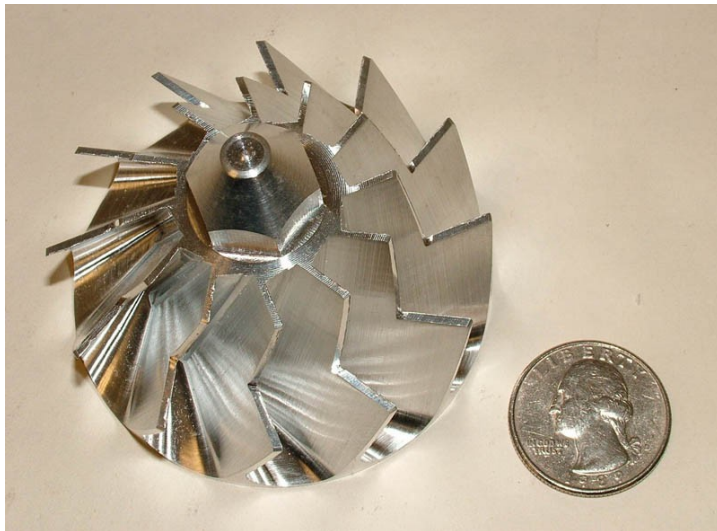




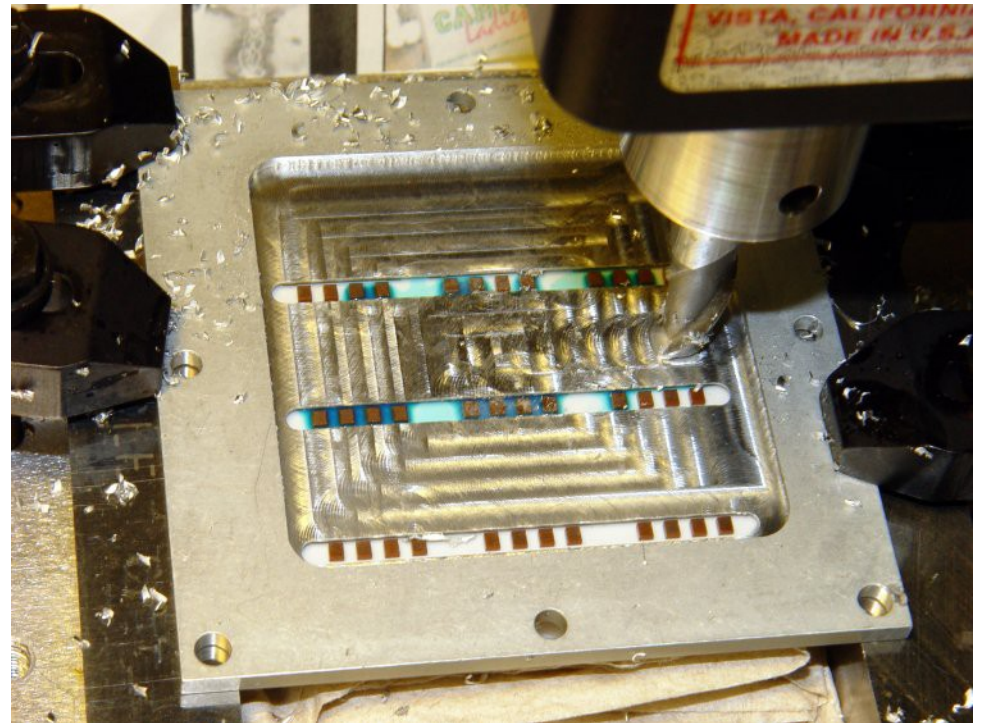
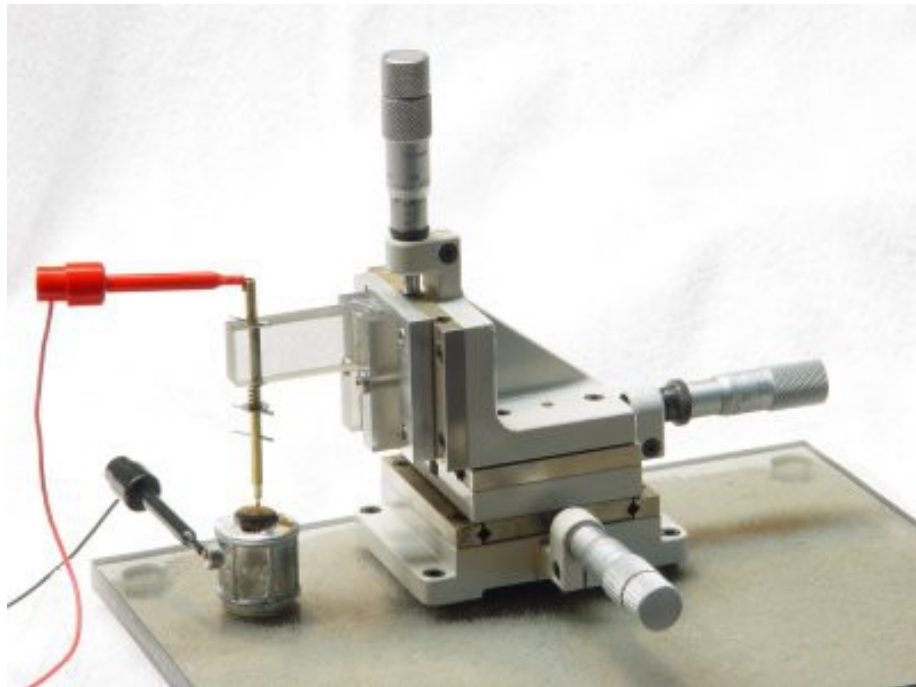
<http://statmandesigns.com>



<http://sherline.com/CNCproj.htm>





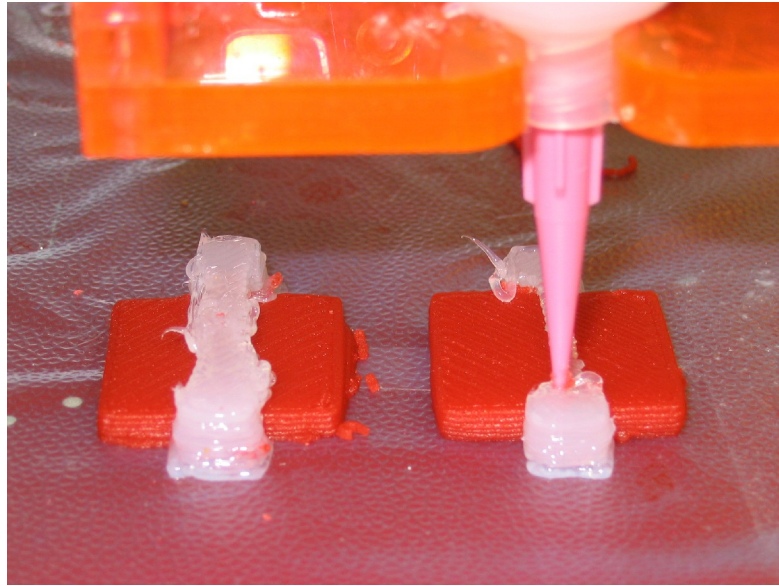






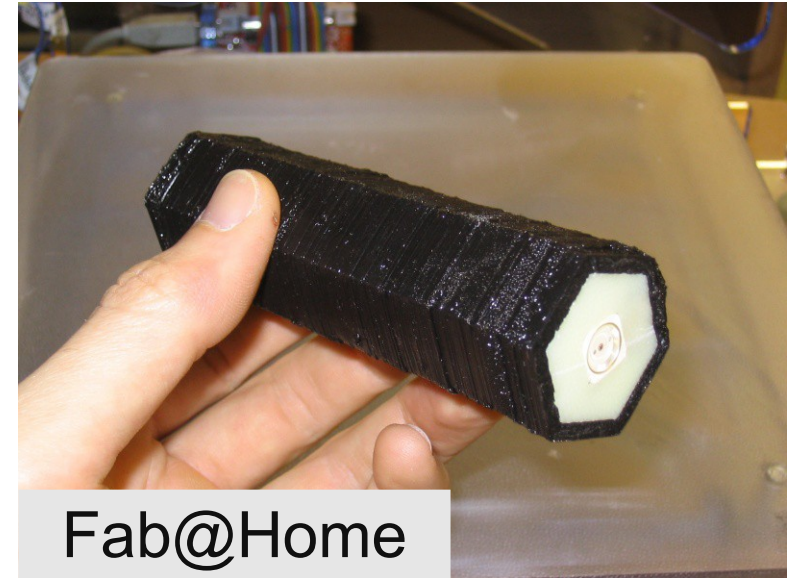


# Not *Squishy* Objects

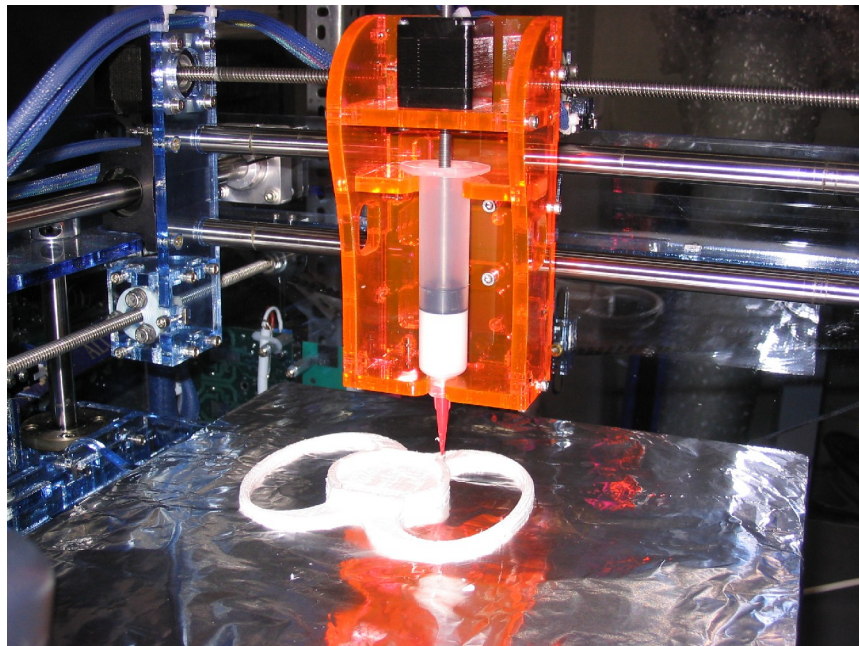


Silicone  
snot  
bridge

Silicone  
snot  
+ epoxy  
LED light



Fab@Home



Band  
over  
watch

Shotglass



RepRap



# Machine Shop

A room, building, or company where machining is done is called a machine shop.

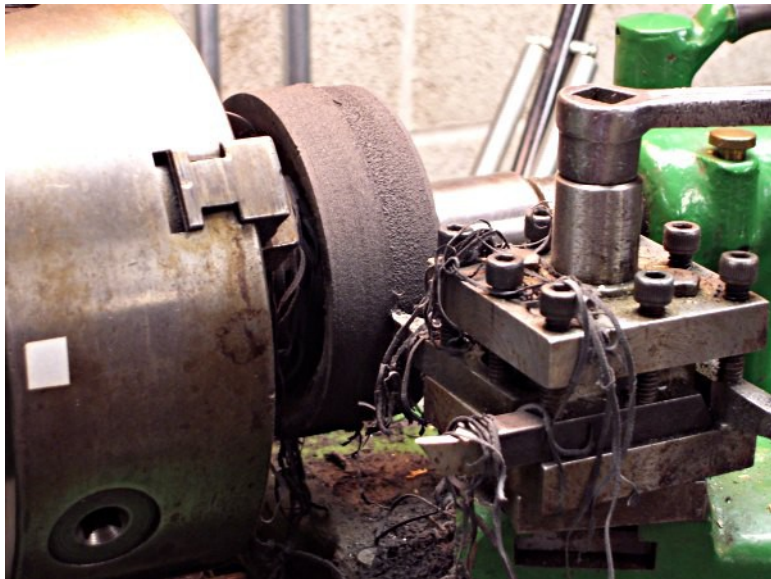
Wikipedia



<http://explorepahistory.com/displayimage.php?imgId=3523>



# Machine Shop



Hey, kids,  
try this  
at home!





# Milling Machines



[http://www.iwsteamrailway.co.uk/pages/locos/mt\\_2002.htm](http://www.iwsteamrailway.co.uk/pages/locos/mt_2002.htm)





# Sherline CNC Milling Machine



<http://sherline.com/CNCmenu.htm>

# Size Matters

## Mill Specifications

FEATURE	5000(5100)	5400(5410)	2000 (2010)
Max clearance, table to spindle	8.00" (203 mm)	8.00" (203 mm)	9.00" (229 mm)
Throat (without headstock spacer)	2.25" (50 mm)	2.25" (50 mm)	Adjustable
Throat (with headstock spacer block)	(Not included)	Included, 3.50" (89 mm)	Not Required
Travel, "X" Axis	8.68" (228 mm) (9" w/ stop screw removed)	8.68" (228 mm) (9" w/ stop screw removed)	8.68" (229 mm) (9" w/ stop screw removed)
Travel, "Y" Axis	3.00" (76 mm)	5.00" (127 mm)	7.00" (178 mm)
Travel, "Z" Axis	6.25" (159 mm)	6.25" (159 mm).	5.38" (137 mm)
Hole through spindle	.405" (10 mm)	.405" (10 mm)	.405 (10 mm)
Spindle nose thread	3/4-16 T.P.I.	3/4-16 T.P.I.	3/4-16 T.P.I.

<http://sherline.com/specs.htm>

# Shape Matters

***Given* that the mill has**

- Table moving in X & Y
- Cutter moving in Z

***Then* the workpiece must be**

- Utterly lacking overhang
- Clamped downward
- Fairly durable

***You can't* cut**

- Sharp concave XY corners
- Features smaller than cutter





# Small Projects



Well, why not just buy a new door latch?

I did, but it didn't fit... *Surprise!*

# Just Draw What You Want?

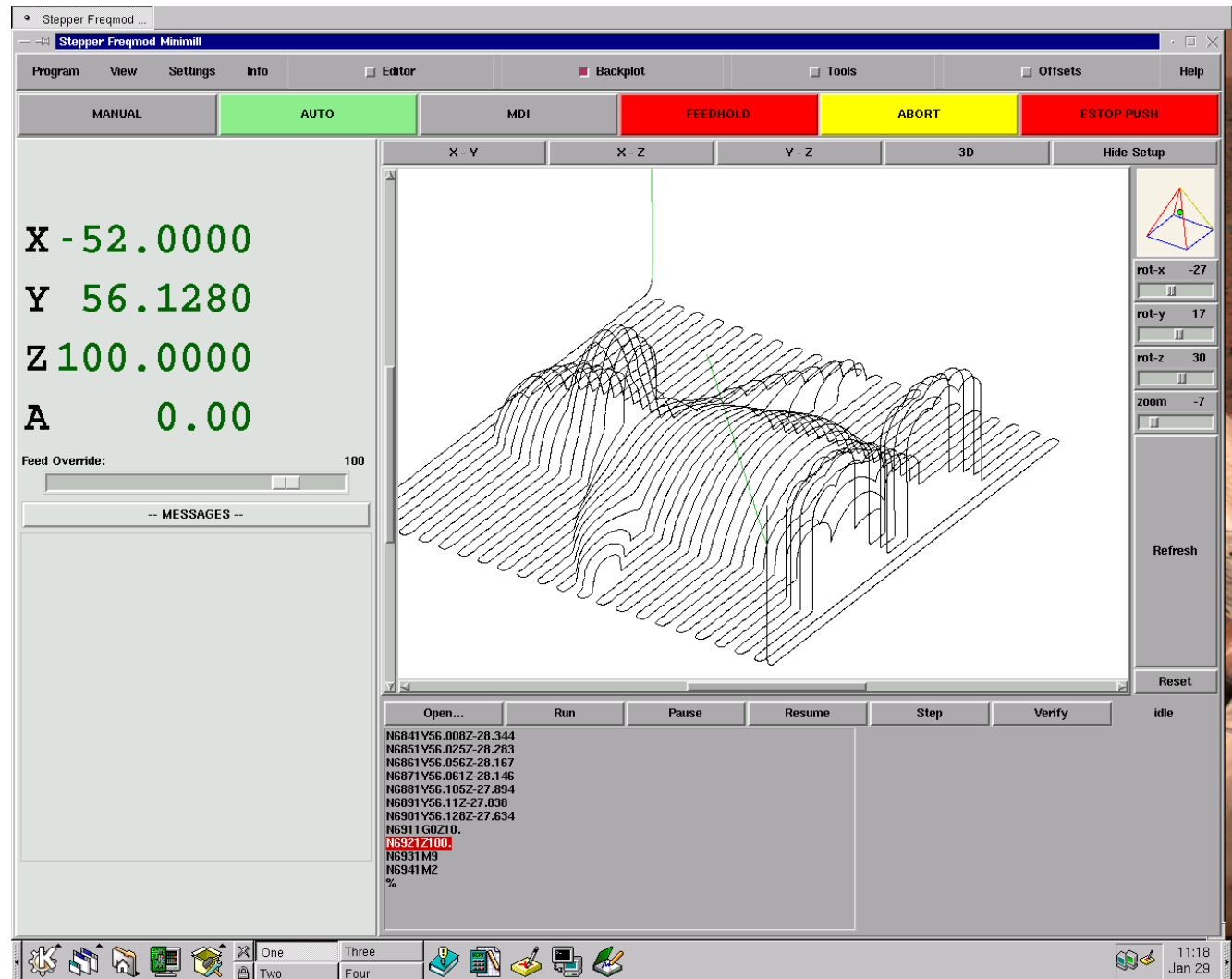


<http://www.auma.com>

# For Some Drawings, Maybe



“Chips”  
~  
LinuxCNC  
Mascot





# G-Code = Coordinates

%

N05 ( This program is copyright of Rab Gordon, Gary Drew, and Paul Corner.)

N10 ( It is released here under a GPL without warranty to do with as you may.)

N15 ( The part is cut from a 100x100x50mm block with the zero point at the )

N20 ( center top of the block. Cutter is a 10mm ball nose. )

N30G21

N40G90

N50T1M6

N60M8

N70S1600M3

N80G0X53.Y-56.128

N90Z10.

N100Z-25.372

N110G1Z-27.372F225

N120Y-56.12Z-27.725

N130Y-56.105Z-27.894

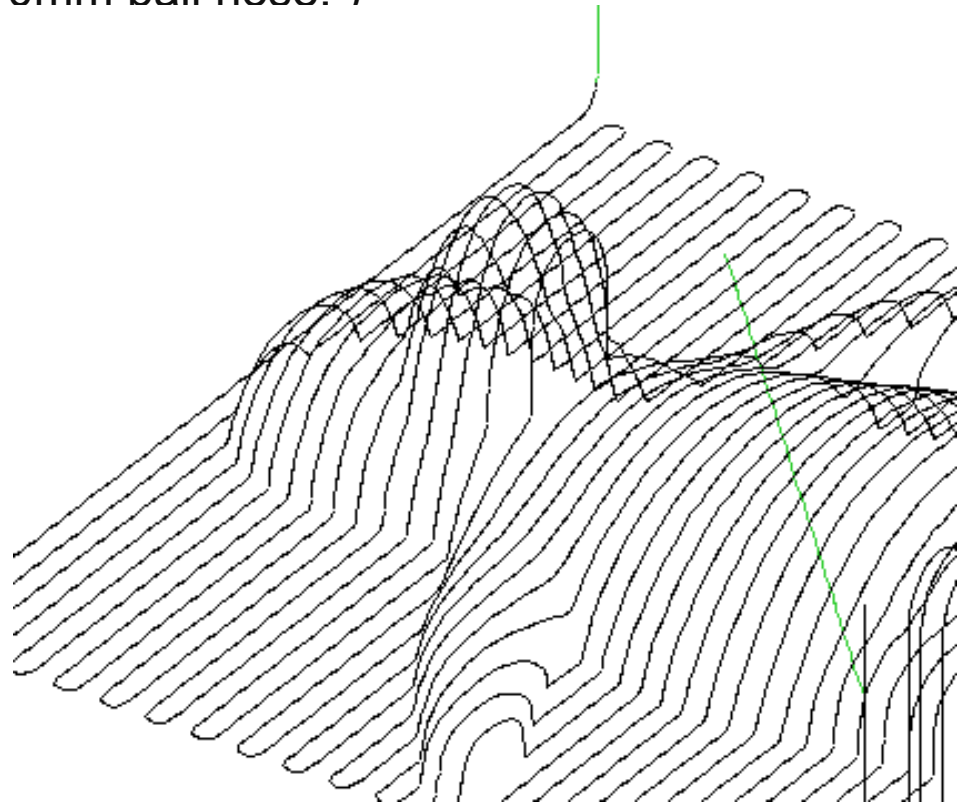
N140Y-56.06Z-28.152

N150Y-56.051Z-28.184

N160Y-55.992Z-28.405

N170Y-55.902Z-28.651

N180Y-55.792Z-28.888



... and much, much more ...

# Door Latch Pull

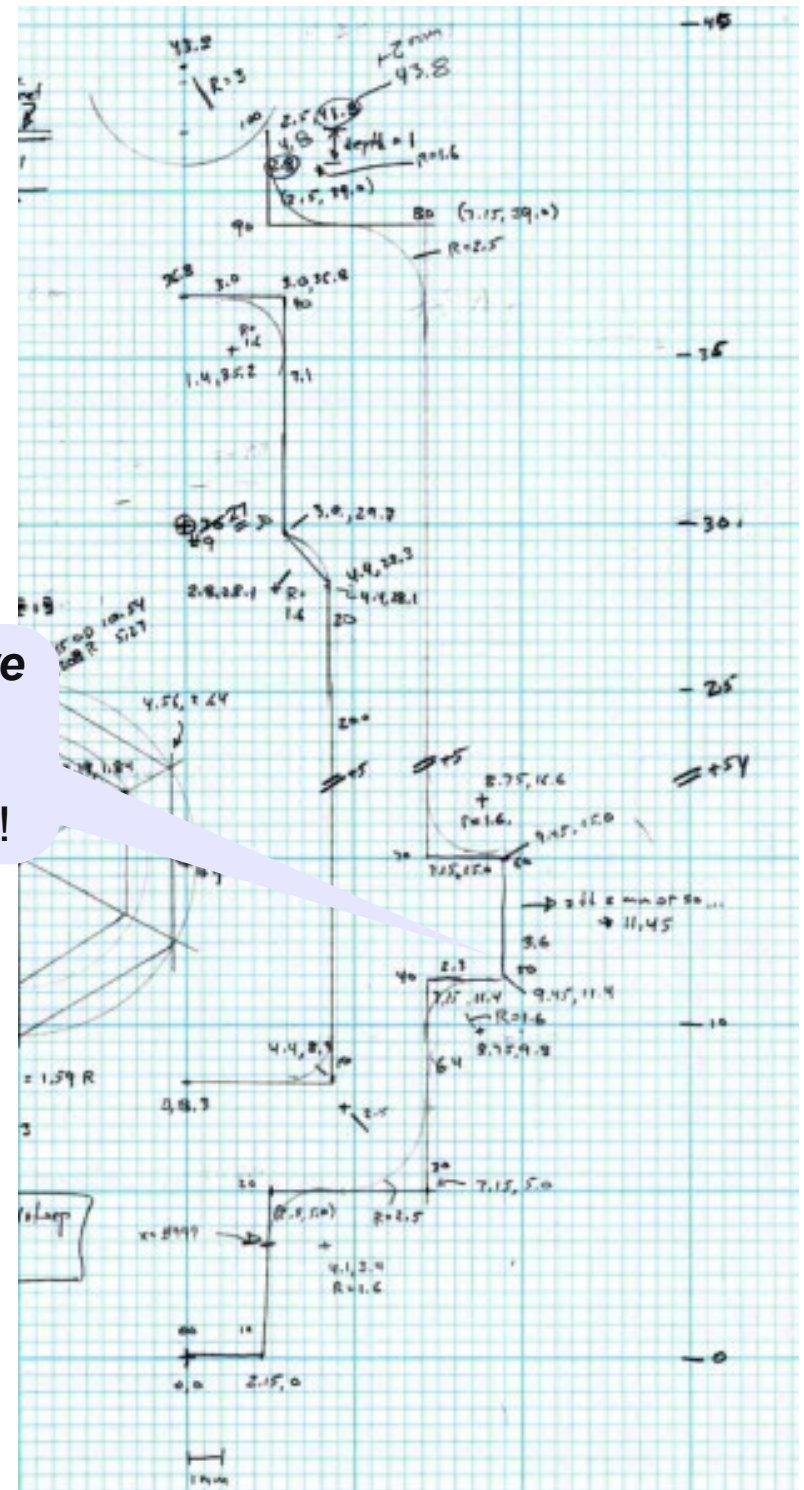
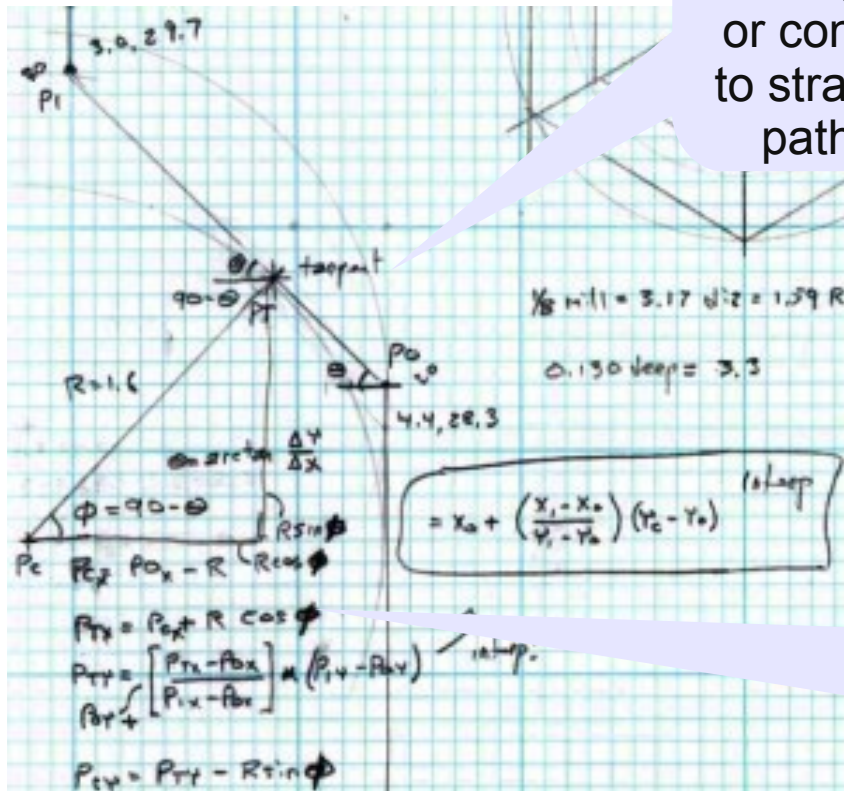


You must have numbers for those fancy CAD drawings!

All circular paths must be tangent or convex to straight paths

Where ***are***  
all these  
points?  
Measure!

Dust off your  
high-school  
trigonometry  
& algebra...





# Problem

What happens when a coordinate changes?

*It could happen...*

Design changes in real projects

For me: part doesn't quite fit  
(worn parts, bad measurements)

Design by successive approximation

# Solution(s)

Parametric CAD drawings?

If you can afford those programs, great!

“Wizard” program that spits out G-code?

It's been done, but you get stale G-code

G-code “programs” based on measurements?

Requires programming language

Which G-code *really* isn't:

Can't do much without iteration & logic

*But: EMC's G-Code supports real programming!*



# G-Code

All the charm of computer machine language

Some of assembly language's user-friendliness

Now with a dash of Pascal!

## Dialects

RS274D	current “standard” language
RS274X	Gerber PCB artwork
RS274NGC	NIST extensions
RS274?	whatever the EMC crew is up to

# G-Code Big Picture

Assembly language programming for machines

Move the cutting tool in 9-dimensional space

**XYZ** ABC UVW (*you don't want to know*)

Linear & circular motion interpolation

Speed control in 6-space w/ per-axis limits

Machine control

Spindle, coolant, clamps, tool changer...

Programming: loops, subroutines, if-then-else

A major set of **non-standard** language features



# Door Latch Pull - Numbers

#1110 =	$[0.125 * 25.4]$	(cutter diameter, inches -> mm)
#1111 =	$[0.0005 * 25.4]$	(chip load, inches/tooth -> mm/tooth)
#1112 =	2	(number of teeth)
#1113 =	1	(tool slot holding this cutter)

-- *and much, much, **much** more like that* --

(Part corner coordinates)  
(Long body axis parallel to Y, "near" is to front of table = low Y)  
(Symmetrical about Y axis, all in X+ range)  
( X = even, Y=odd)  
(Inside material contour, X+ half)

#2000 =	0.00	(center of bottom)
#2001 =	8.30	
#2010 =	4.40	(LR corner)
#2011 =	8.30	
#2020 =	4.40	(start of neckdown)
#2021 =	28.30	
#2030 =	3.00	(end of neckdown)
#2031 =	29.70	
#2040 =	3.00	(UR corner)
#2041 =	36.80	

“Parameters”  
=  
“Variables”  
from  
Measurements  
or  
Calculations

# Door Latch Pull – Main Loop

G0 Z#1004

(to traverse level)

#900 = 0

#901 = 0.00

Looping!

(pass counter - start at surface)  
(initial Z)

O200 DO

(mill outline)

Subroutine  
to handle  
one pass

O100 CALL [#901]

(do a pass around the outline)

#900 = [#900 + 1]

(tick loop counter)

#901 = [#901 - #1133]

(next Z level)

Variable  
holds Z-  
axis depth

O200 WHILE [#900 LE #1132]

(mill outline)

G1 X[0-[#2010 - #1200]] Y#2011

(trim final ramp)

M5

(spindle off)

G0 Z#1002

(get air)

G40

(cutter comp off)

G0 X#1000 Y#1001

(return home)

(msg,Done!)

M30

# Door Latch Pull – Cutting!

O100 SUB

G1 X[0-[#2010 - #1200]] Y#2011 Z#1

G2 X[0-#2010] Y[#2011 + #1200] I0 J#1200

#800 = [90 - ATAN [#2031 - #2021] / [#2000 - #2001]] (ramp down along slot bottom)  
( ... LL corner)

#802 = [#2020 - #1200]

#804 = [#802 + [#1200 \* COS[#800]]]

O020 CALL [#804] [#2020] [#2021] [#2030] [#2031] (angle: fillet arc ctr to tangent pt)

#805 = [#999 - [#1200 \* SIN[#800]]]

G1 X[0-#2020] Y[#805]

G2 X[0-#804] Y#999 I#1200 J0 (fillet arc center X)

G1 X[0-#2030] Y#2031 (tangent pt X)

G1 X[0-#2040] Y[#2041 - #1200]

G2 X[0-[#2040 - #1200]] Y#2041 I#1200 J0 (tangent pt Y in #999)

G1 X[#2040 - #1200] Y#2041 (fillet arc center Y)

G2 X#2040 Y[#2041 - #1200] I0 J[0-#1200]

G1 X#2030 Y#2031 (slot side L to fillet start)

G1 X#804 Y#999 (fillet)

G2 X#2020 Y#805 I[0-[#1200 \* COS[#800]]] J[0-[#1200 \* SIN[#800]]] (fillet to neck)

G1 X#2010 Y[#2011 + #1200]

G2 X[#2010 - #1200] Y#2011 I[0-#1200] J0 (neck L)

G1 X#2000 Y#2001 (fillet to top)

O100 ENDSUB (across the top to UR fillet)

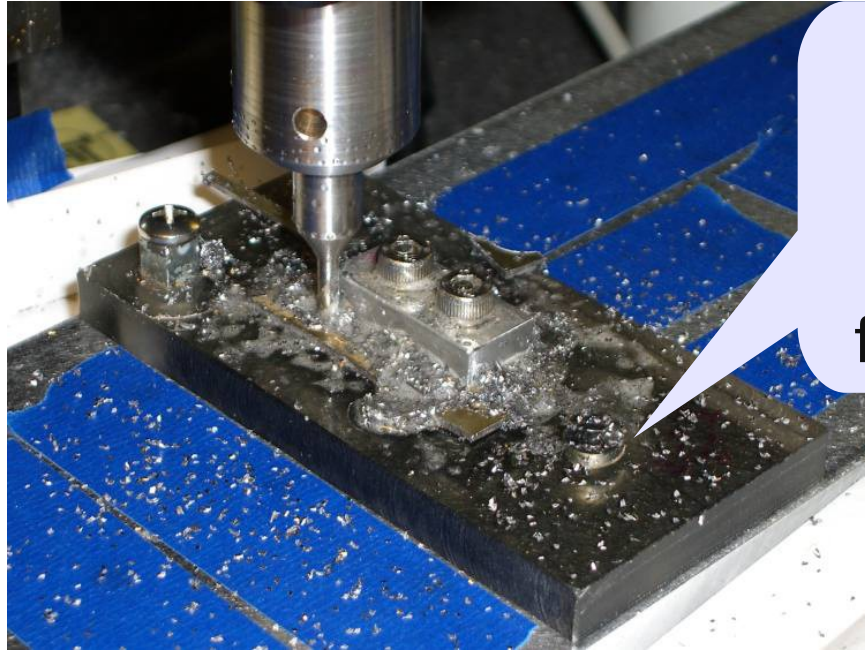
Linear

Circular

Calculate  
coordinates based  
on geometry &  
measurements



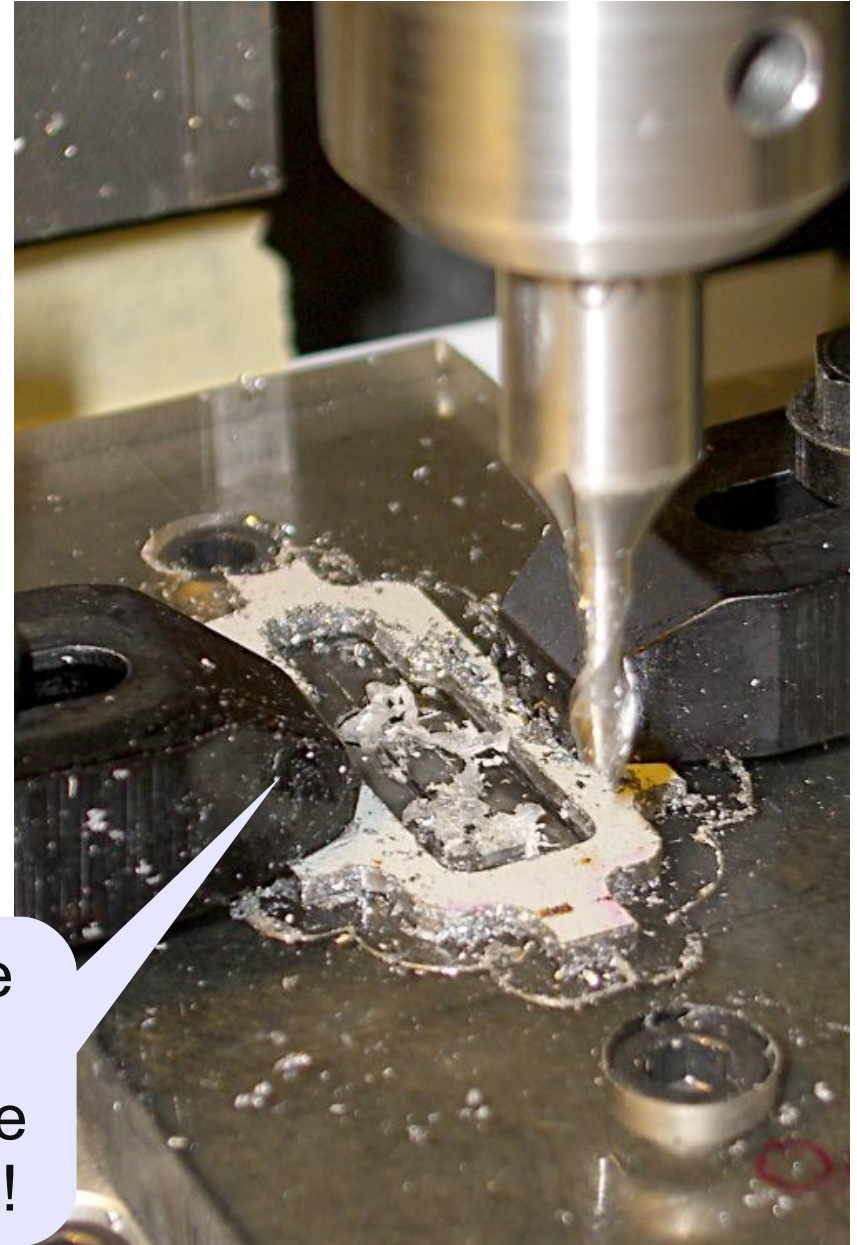
# Real-world I/O



First  
you  
make  
the  
fixture

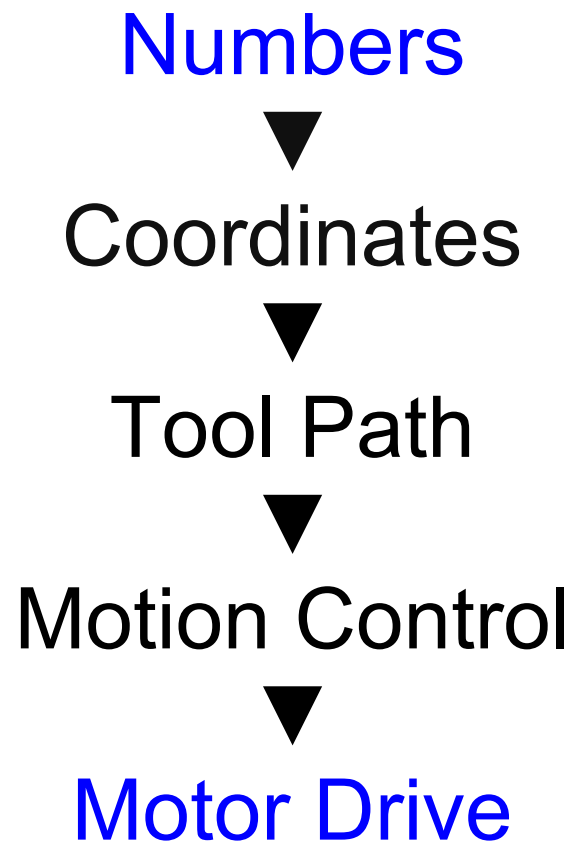


G-code  
must  
miss the  
clamps!



# The Big Picture

**C****N****C** machining requires *Numbers*



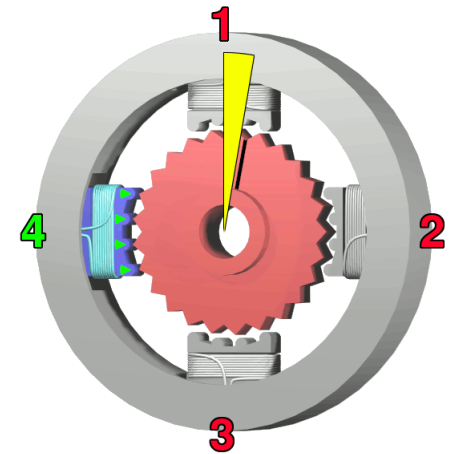
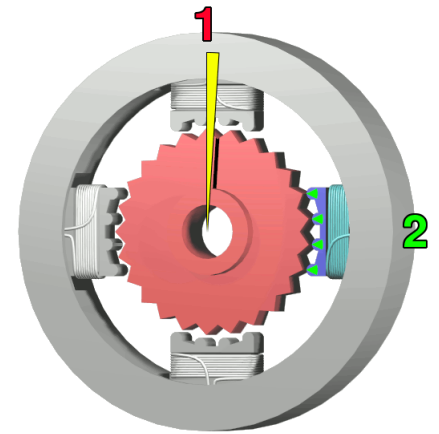
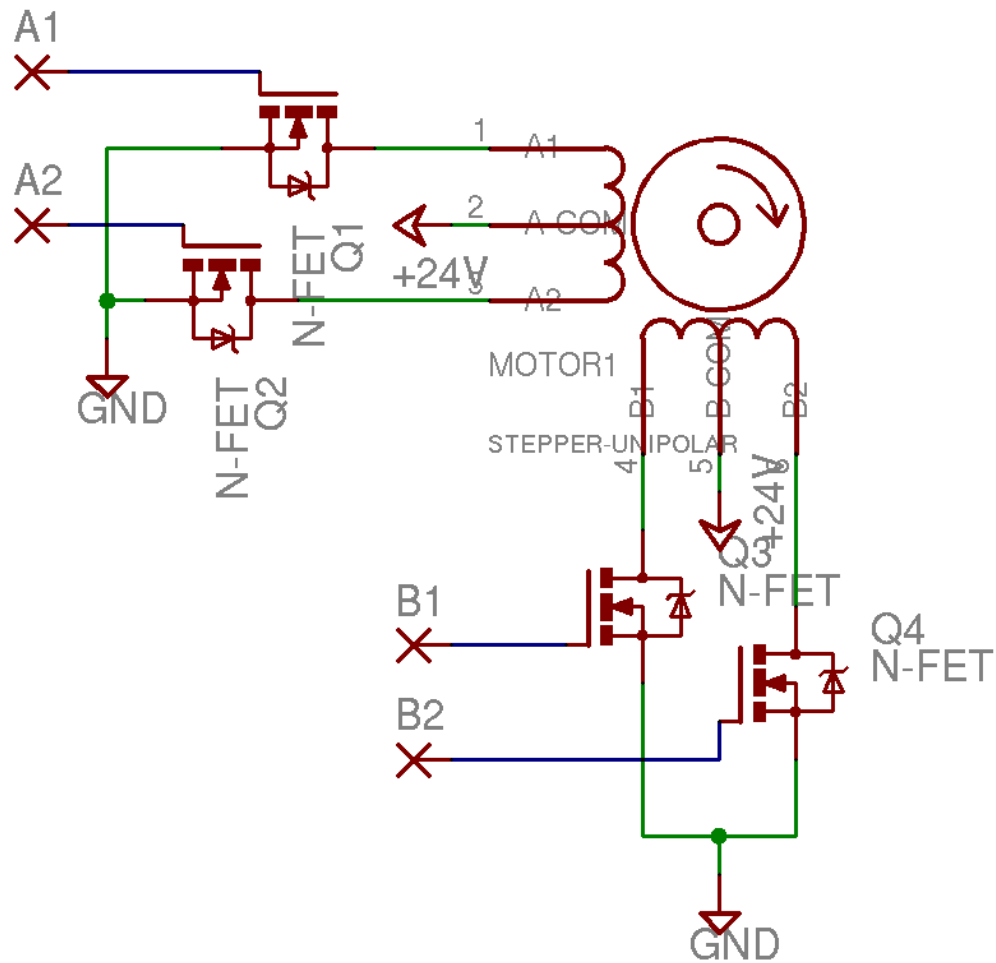
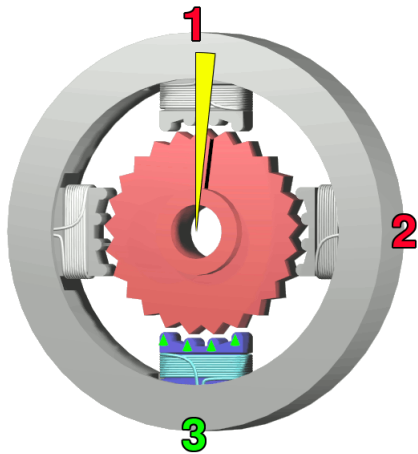
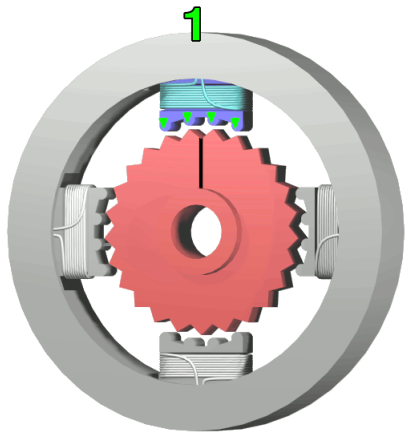


# Stepper Motors



<http://sherline.com/CNCmenu.htm>

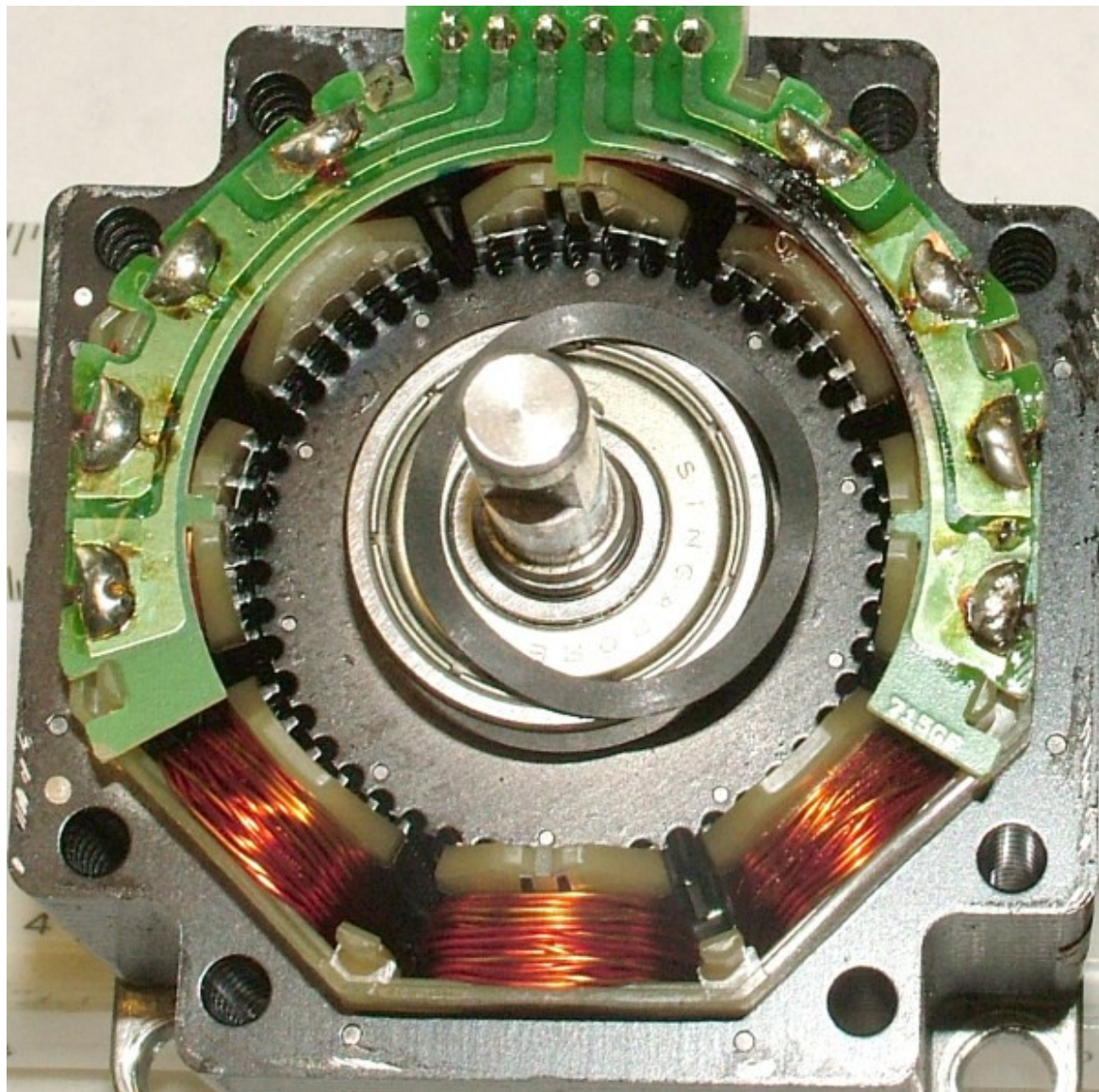
# Stepper Motor



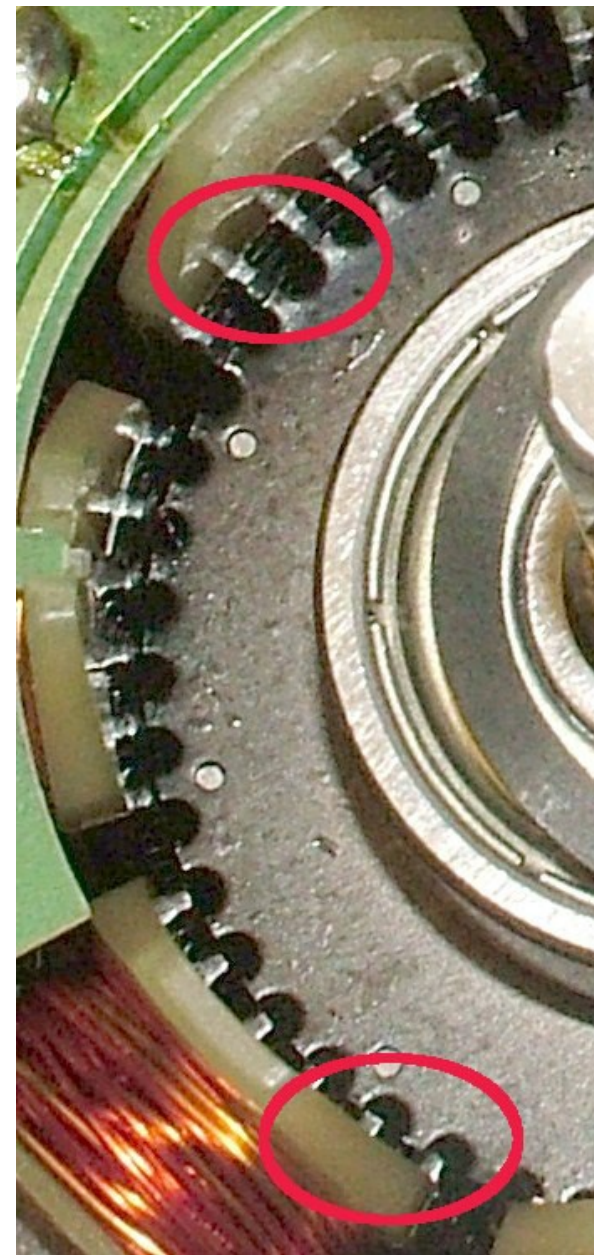
[http://en.wikipedia.org/wiki/Stepper\\_motor](http://en.wikipedia.org/wiki/Stepper_motor)



# Stepper Motor



Photos by Craig Libuse, Sherline

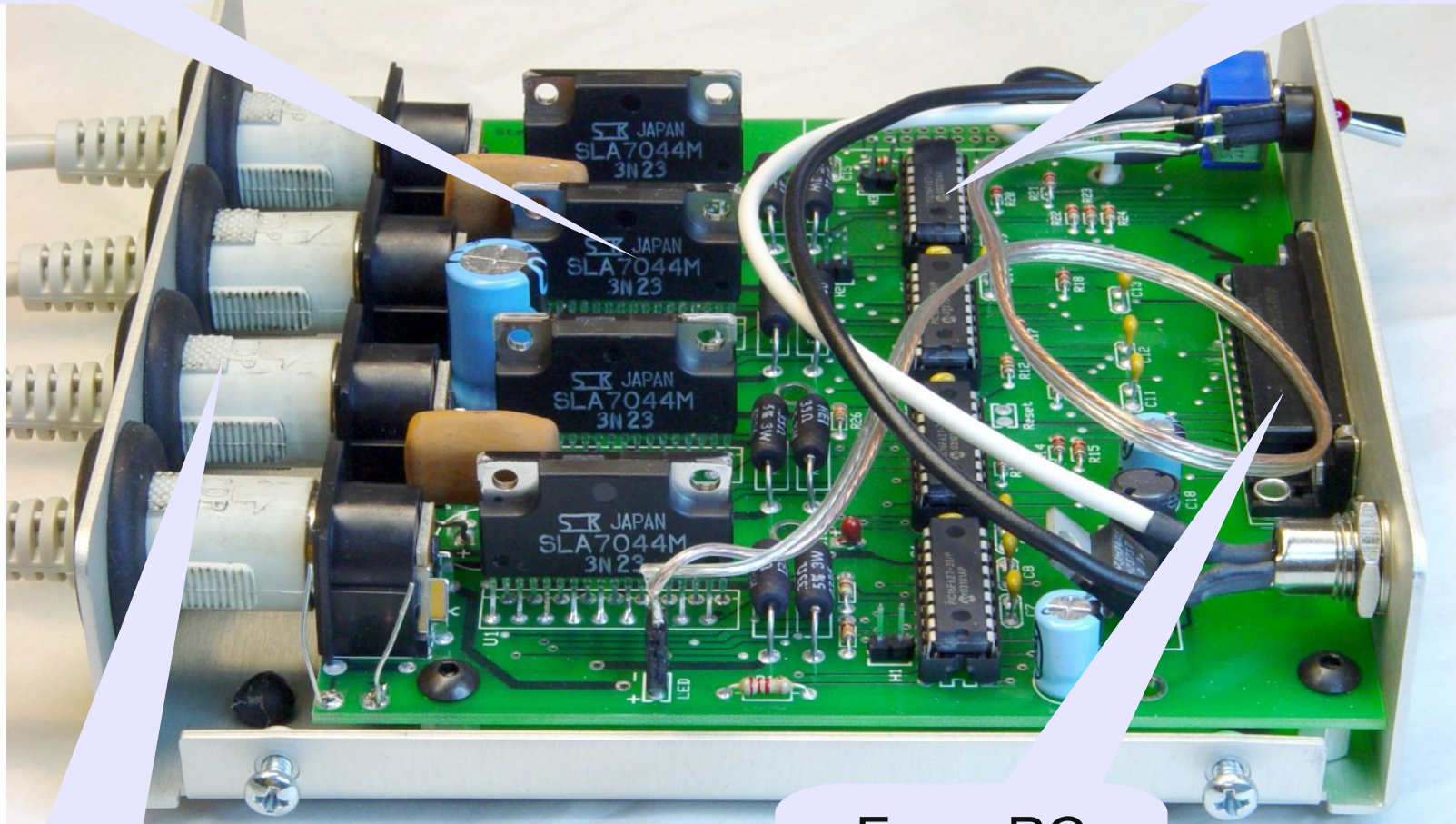




# Stepper Motor Controller

PWM Motor Drivers

PIC microcontrollers

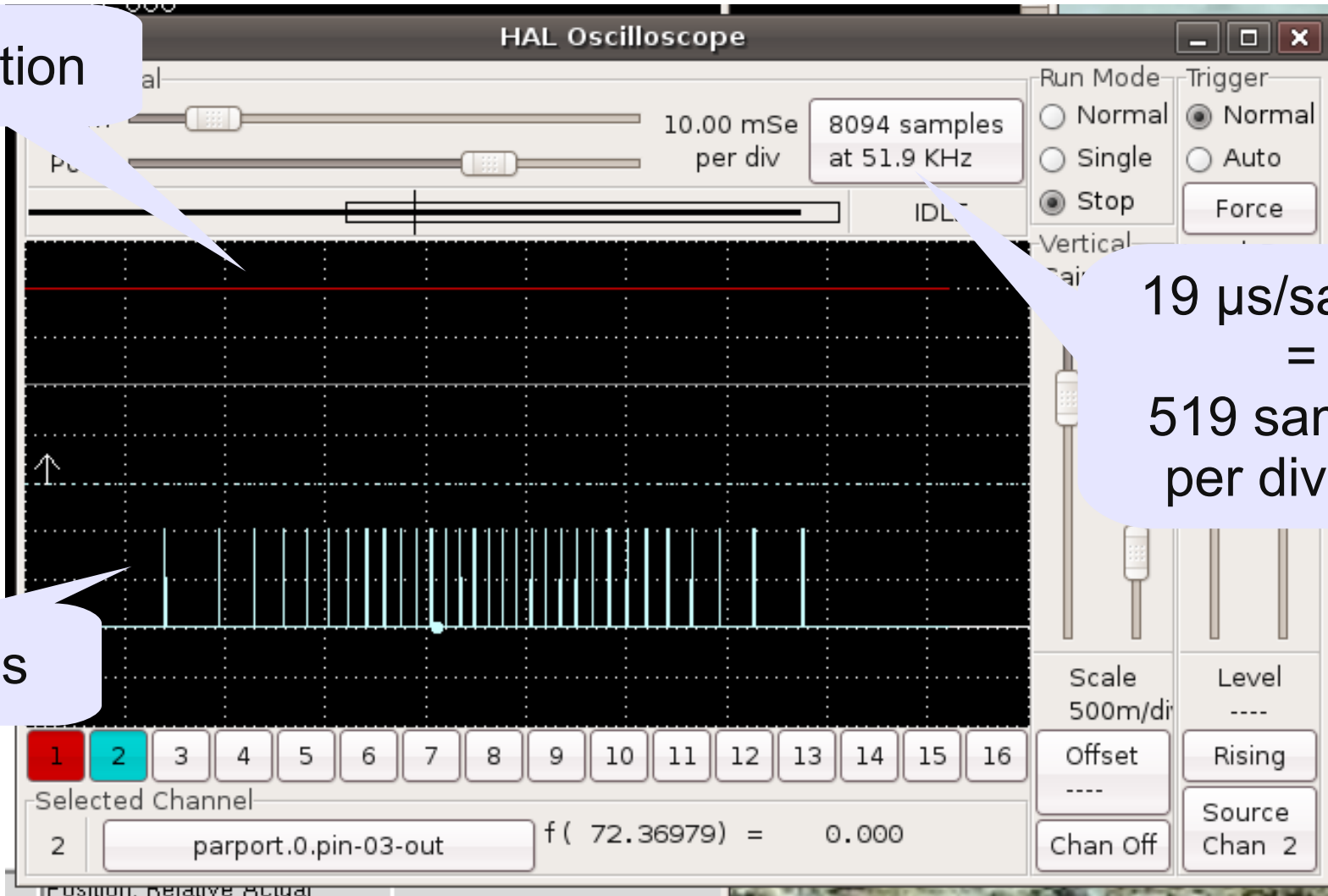


To Motors

From PC  
Parallel Port

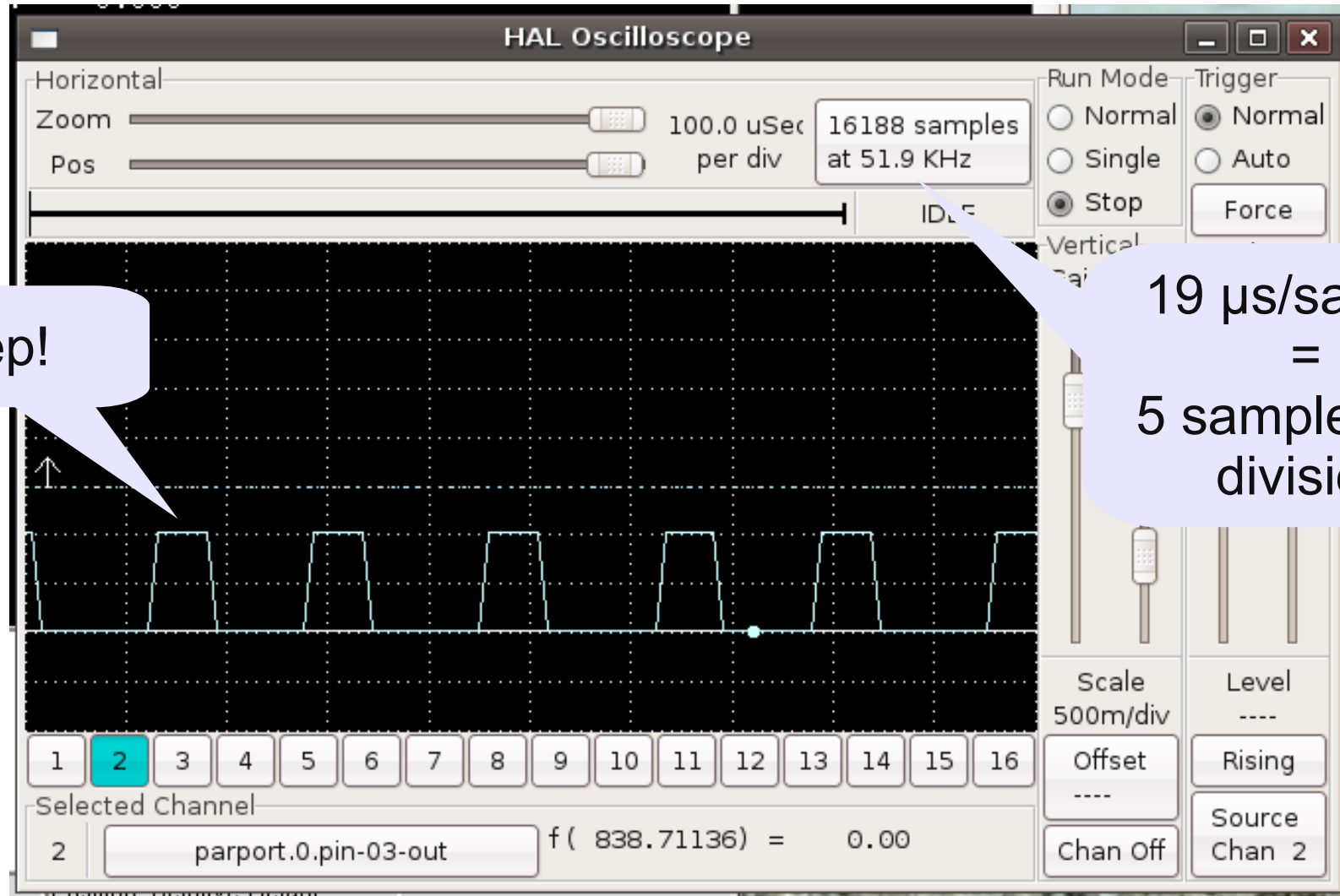


# Stepping Pulses



0.05 mm = 0.002 in / 31 steps ► 1.6  $\mu$ m/step = 63  $\mu$ ·in/step

# Stepping Speed



5 steps in  $8.2 \times 100 \mu\text{s} = 160 \mu\text{s/step} = 6 \text{ kHz}$

# Speed Matters

$63 \mu\text{-in/step} \times 6000 \text{ step/s} = 0.38 \text{ in/s} = 23 \text{ in/min}$

That's about as fast as a Sherline can move!



It's a config file setting



Speeds while cutting metal are *much* lower!



# Speed Matters

View metric table		View table in inches	
SW Specifications	SW-105	SW-106	SW-1300
Work Envelope			
X Axis	39.4in	39.4in	51.2in
Y Axis	19.7in	23.6in	28in
Z Axis	22.4in	22.4in	28in
Max. Spindle Speed	10,000rpm	10,000rpm	10,000rpm
Max Spindle Power (30min)	20HP	20HP	20HP
Spindle Taper	No. 40	No. 40	No. 40
Rapid Feed Rate	945 in/min	945 in/min	945 in/min
Tool Changer Capacity	24	24	32

That'd be  $15 \text{ in/s} = 244 \text{ kHz} = 4 \mu\text{s/step}$ ... for my setup  
[www.milltechcnc.com/sw.html](http://www.milltechcnc.com/sw.html)

# Motor Control / Driver Boxes



8760



4-axis driver box with power supply and software. Includes cables to connect to 4 Sherline stepper motors on X, Y, Z and optional A axes. Includes 25-pin parallel cable for connection to your computer. On/off switch cuts power to stepper motors when entering programs or operating the steppers manually. Linux OS and EMC with Sherline enhancements plus full instructions included on 2 CD set. This is the same driver board we install in the computer of the system we supply. 4 amp power supply also included. (Free technical support not included with the purchase of this driver box only.)

7

600.00



Motor power drivers not included!

## Pricing

Part Number	Description	Price
CS-5A01-1	USB Signal Generator and Software	\$1295

OEM Pricing available for quantity purchases.

[www.flashcutcnc.com/html/new\\_USB.html](http://www.flashcutcnc.com/html/new_USB.html)

<http://sherline.com/CNCprices.htm>

# Home Shop Projects

## Mostly flat

- More or less 2½ D

## Simple geometry

- Straight lines
- Circular arcs

## Low precision

- $\leq 0.005$  inch is perfection

## Simple surface finish

- As-machined or paint-to-cover: “used-car shine”





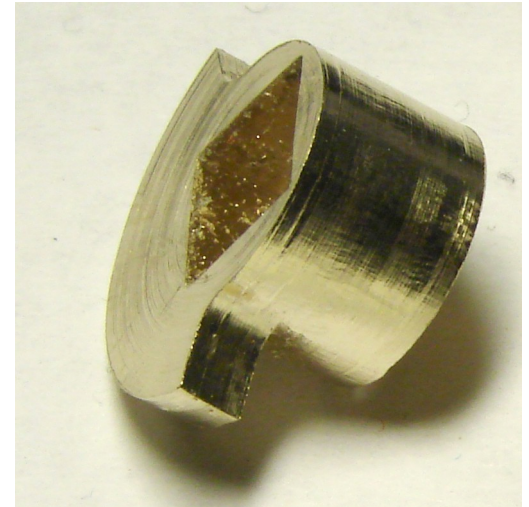
# Why This Works

## Old products have simple designs

- Non-CNC production machinery
- Screw-machine, stampings, turnings

## Bash to fit, file to hide...

- Don't (try to) do it all with CNC
- A manual lathe is helpful



## Just Do It!

- Start simple: machining is hard enough
- With CNC, you can *quickly* make “another one”

# Storm Window Clips

## Anderson Awning Windows

- State-of-the-art, circa 1955
- Glass storm panes held in by nylon clips
- Sun and weather are *very* unkind to plastic

## Replacement windows?

- \$1000... more or less
- *For each window*

## Easy to reproduce

- If you're not fussy
- Oh, that scalloped fin!



# Storm Window Clips

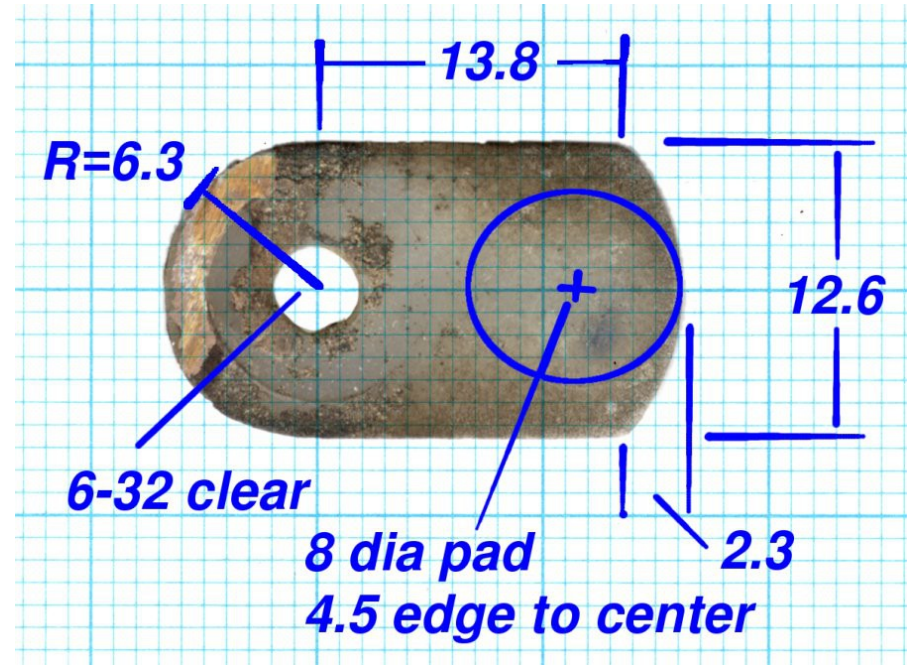
## Simple design

- Straight edges
- Half-circle
- Circular arc
- Mounting hole

## Easy fixture

- Add a second hole to prevent spinning
- Hold it down with 6-32 machine screw

So... why bother with CNC?





# Storm Window Clips

(22 windows)  $\times$  (4 or 5 clips each)





# Storm Window Clips

Fixture array?

- Copy & paste
- G54-G59.3
  - Only 9 spots
- “O-word” loop

EMC changes!

- 2005: Copy
- 2007: Loop

Pick your poison



# RF Adapter Holder



Amateur radio “go-kit” toolbox

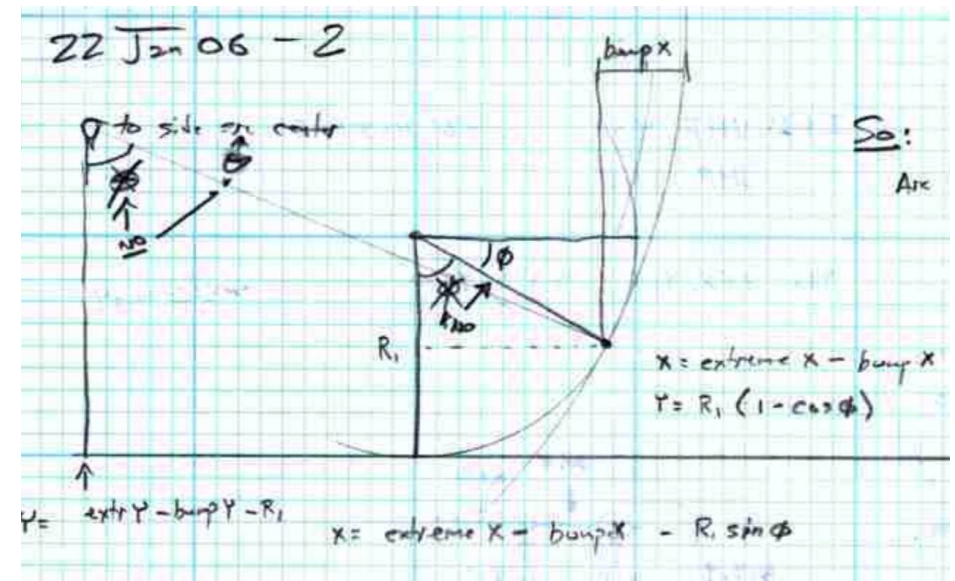
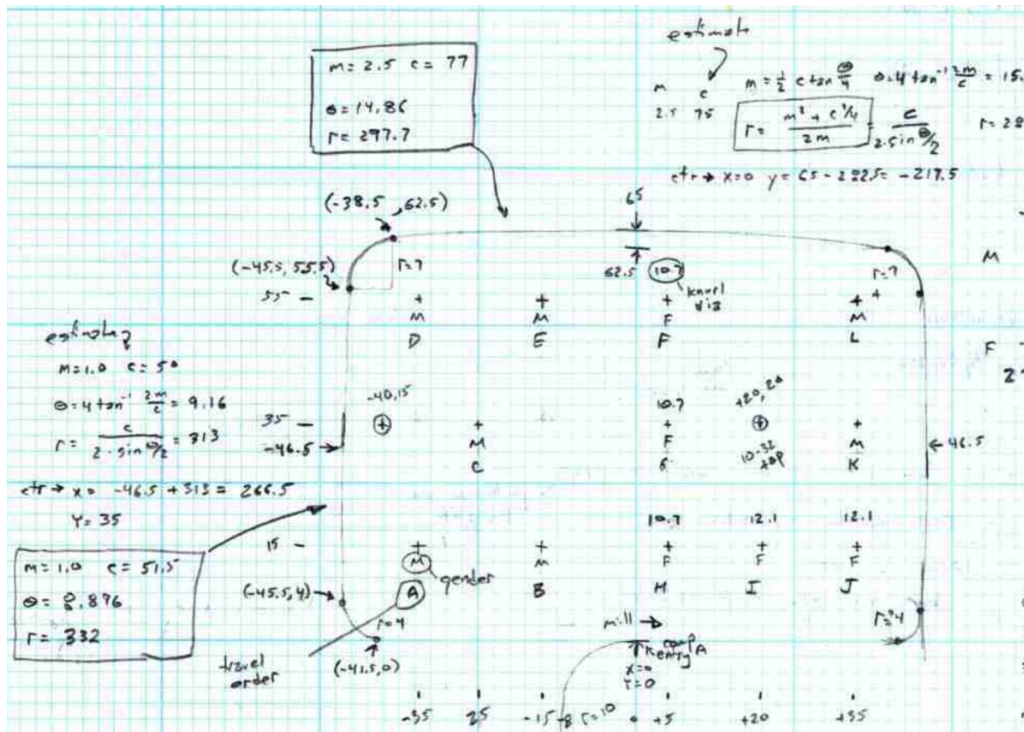
Adapters hide in the clutter

*Who borrowed that adapter?*



# RF Adapter Holder

Faired corners to match box  
Weeks to find trivial equation  
Machining was easy after that!  
*The first one didn't fit...*



# Recumbent Bike Chain Idler

## Original design

- Aluminum sprocket
- Teeny steel balls
- Plastic race insert (???)

## Improvements

- Aluminum sprocket
- Large cartridge bearing
- Bushing to match original shaft

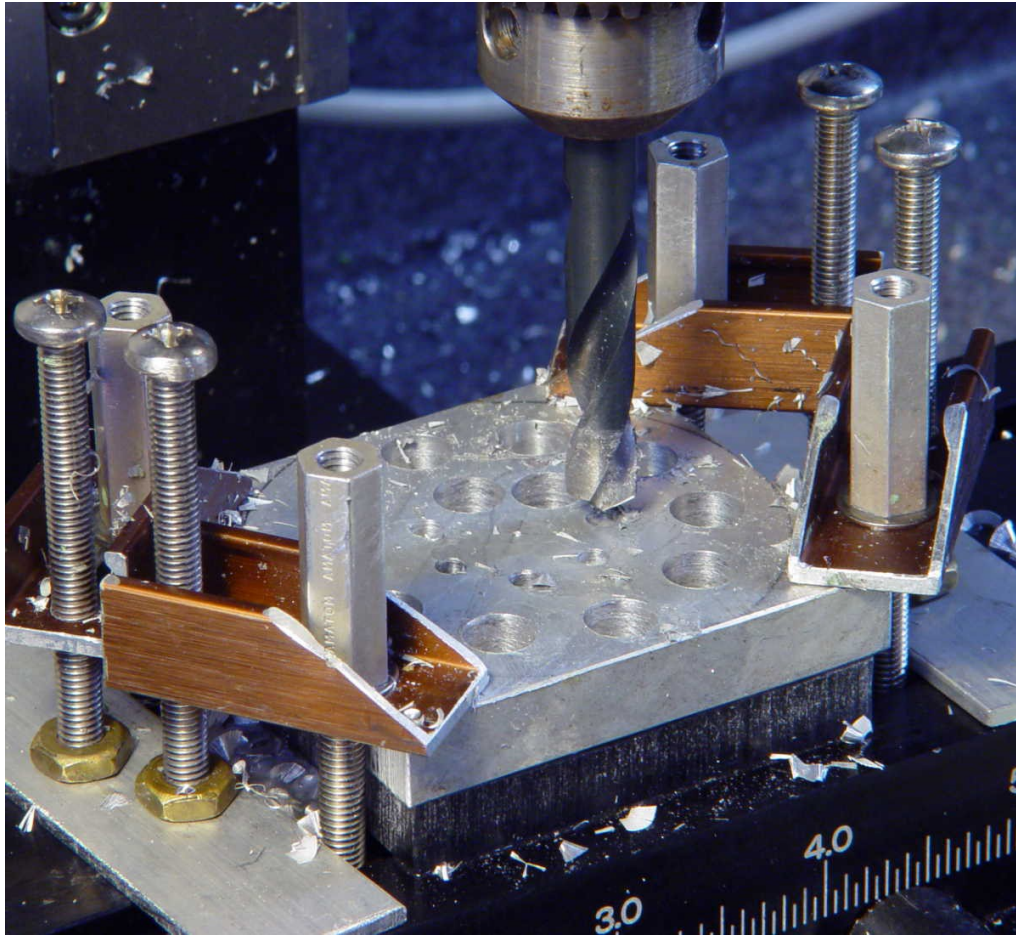
## Do it manually?

- (2 idlers) x (3 bikes)



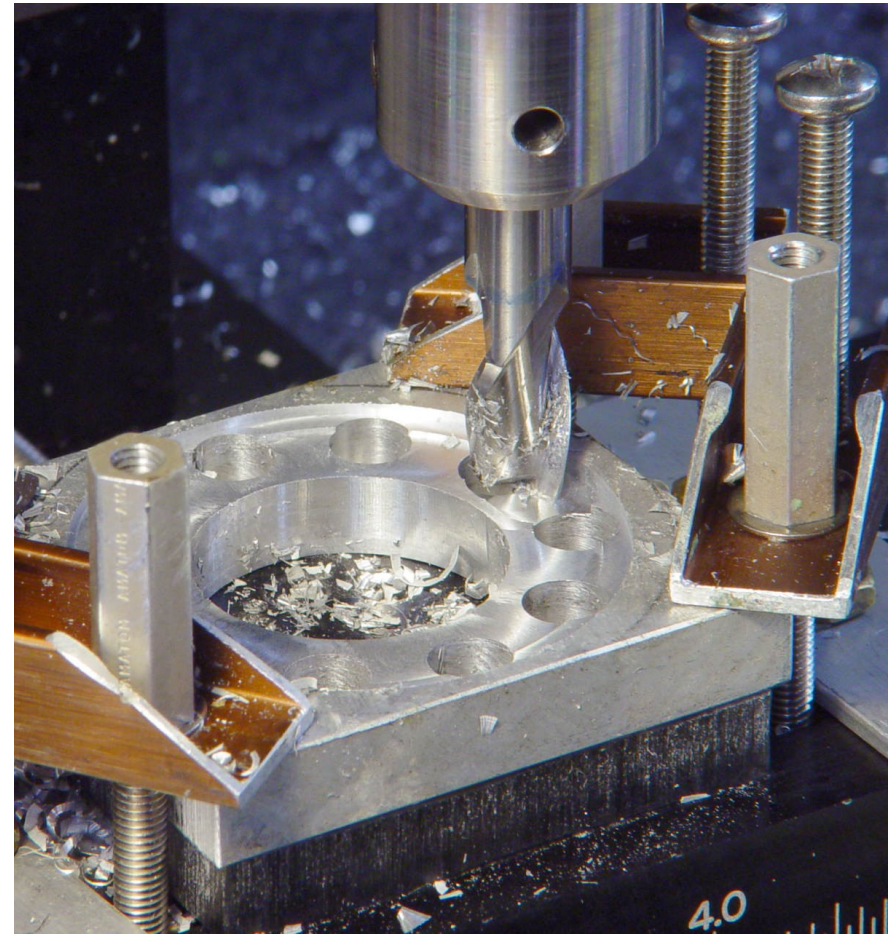


# Recumbent Bike Chain Idler



## Drilling

- Chain roller positions
- Hub area cleanout



## Milling

- Circular interpolation!
- Many Z-axis levels

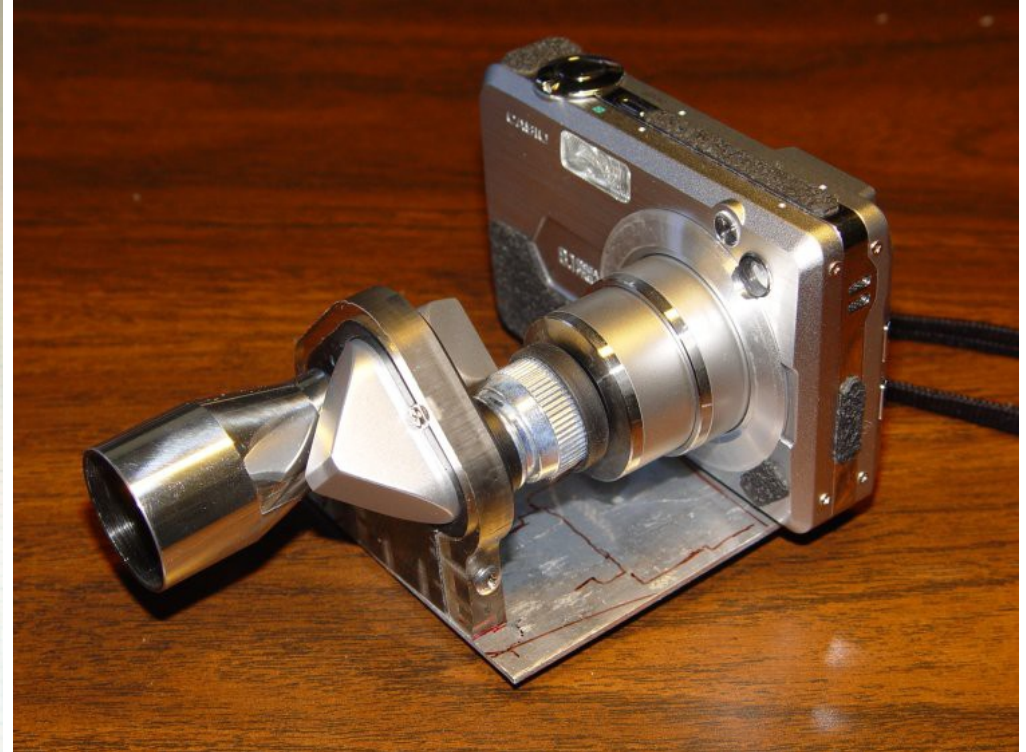


# Camera Monocular Mount



## Monocular

- 8x telescope
- 20x microscope
- Light & compact



## Digital Camera + lens

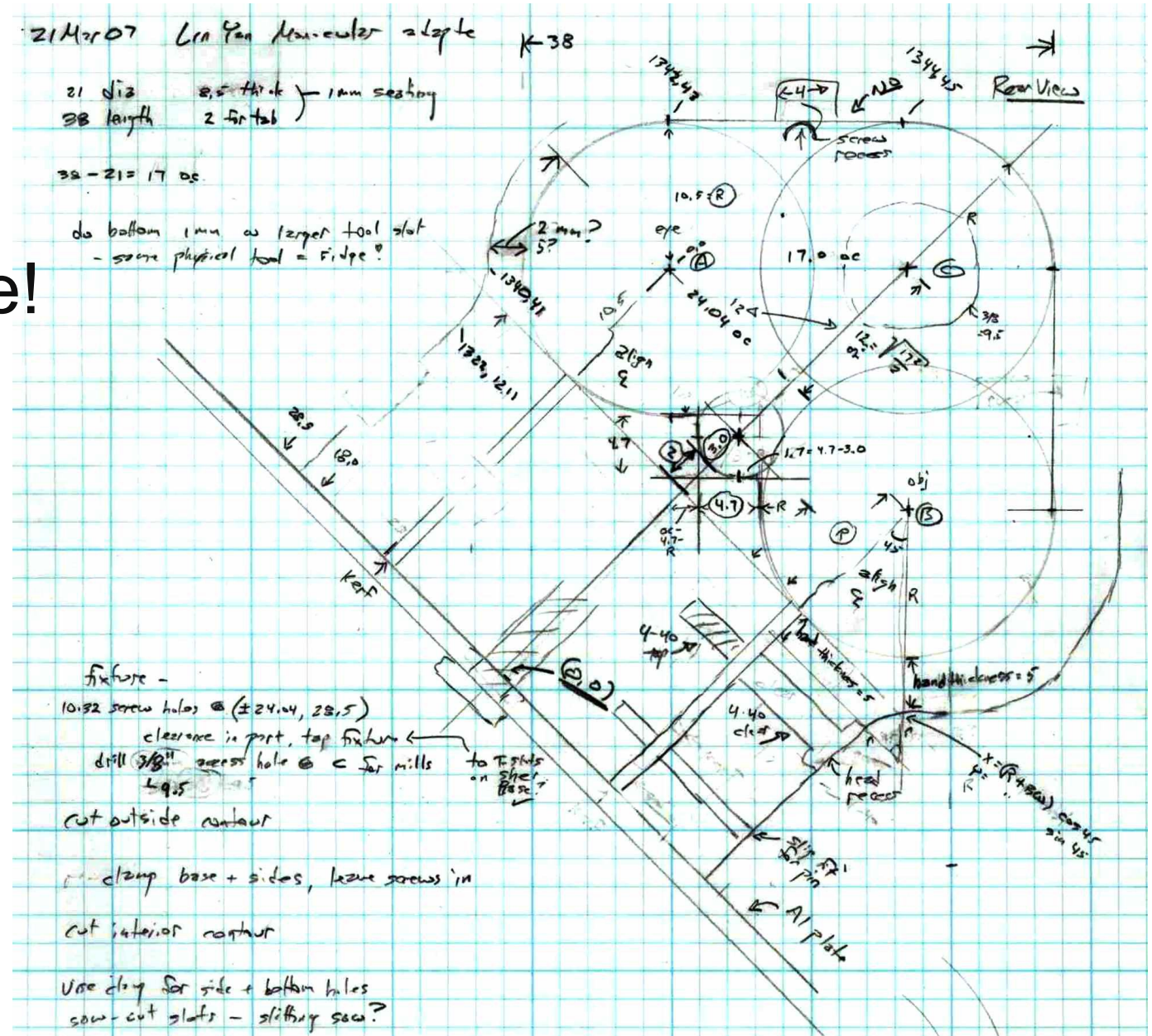
- 114 mm  $\rightarrow$  912 mm
- f/5.1  $\rightarrow$  f/41 (ouch)
- Best for sunny scenes!



# Camera Monocular Mount

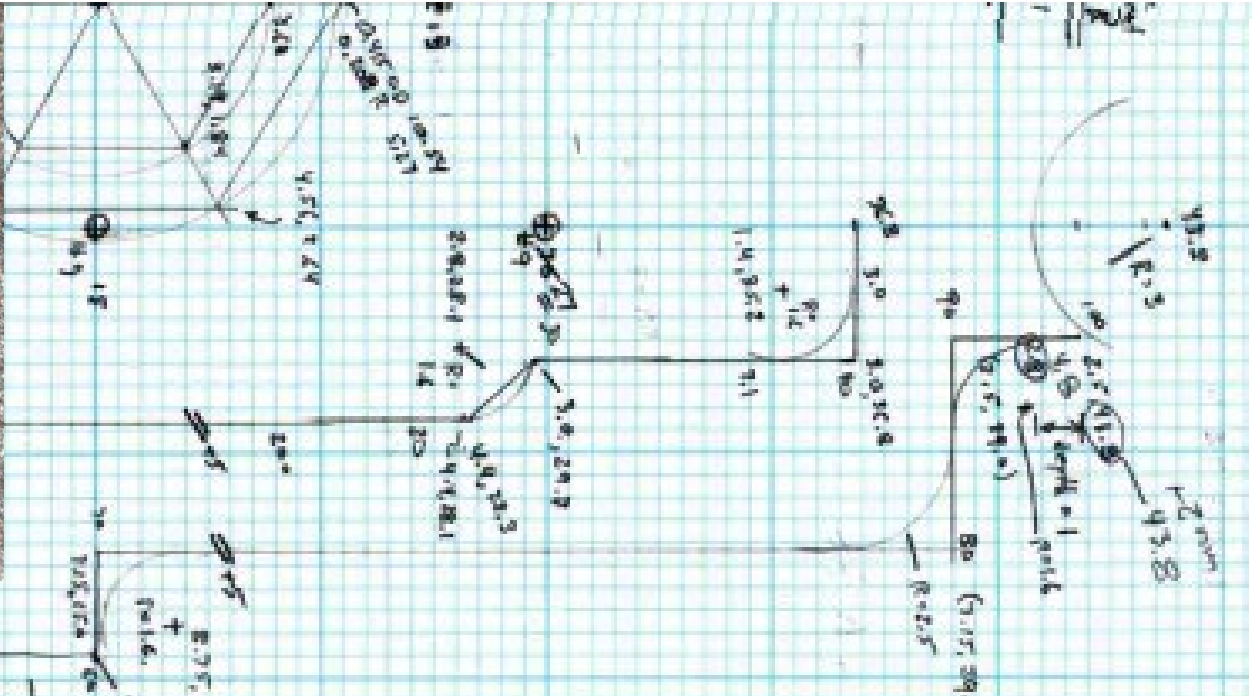
# Simple Layout

- Circular arcs
- Right angles
- Polycarbonate!



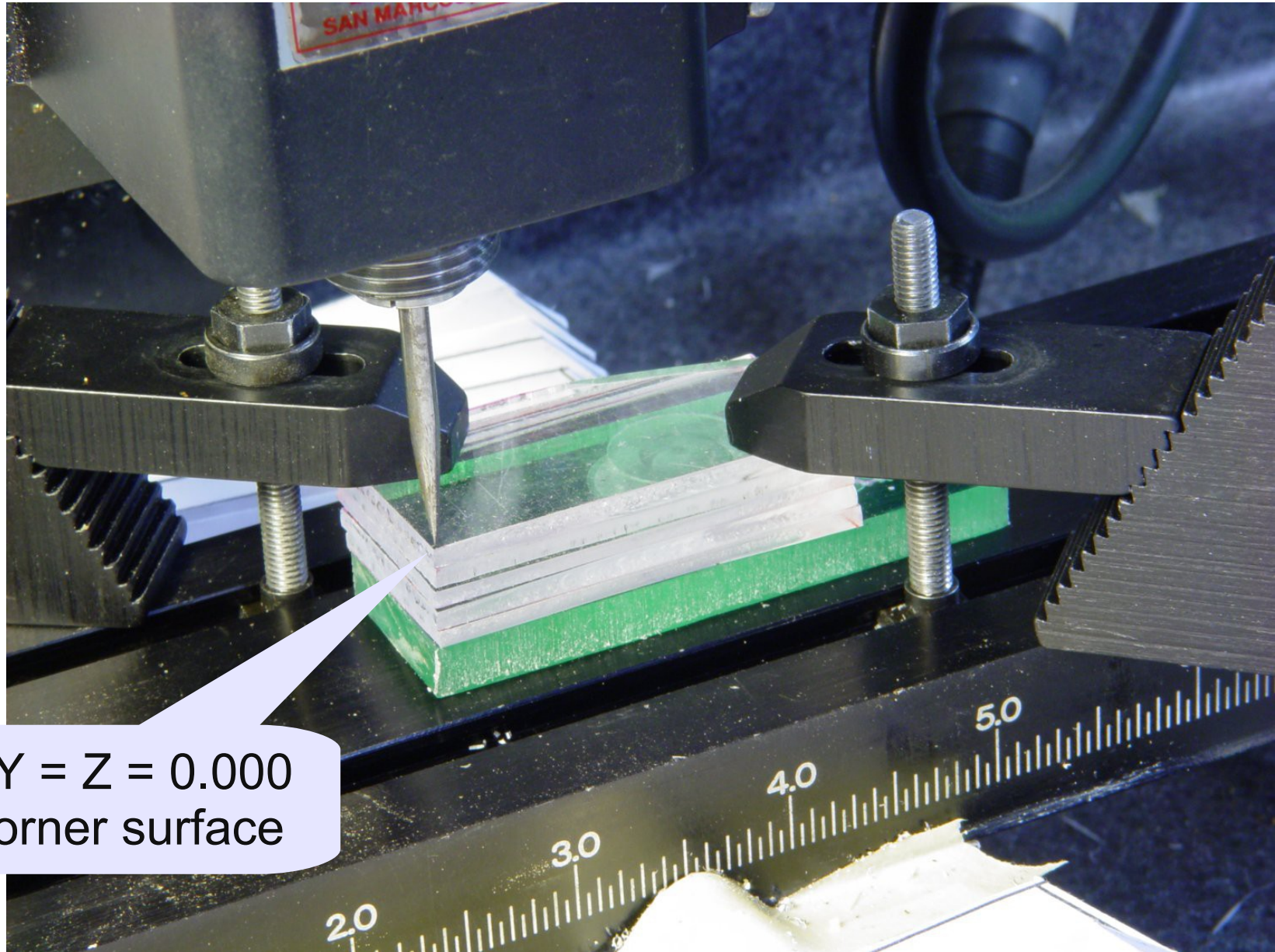


# Demo Madness





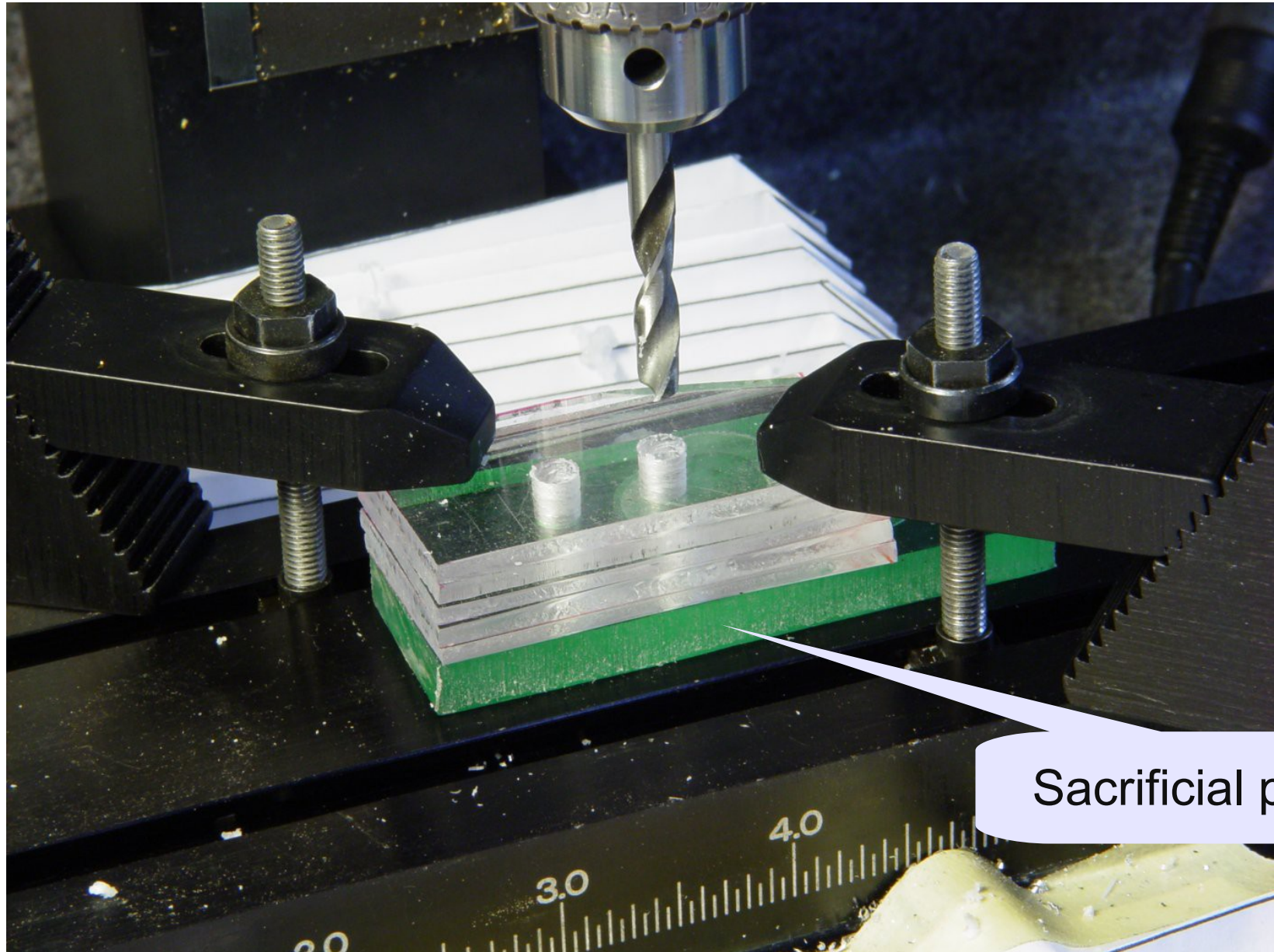
# Locate Origin



$X = Y = Z = 0.000$   
at corner surface



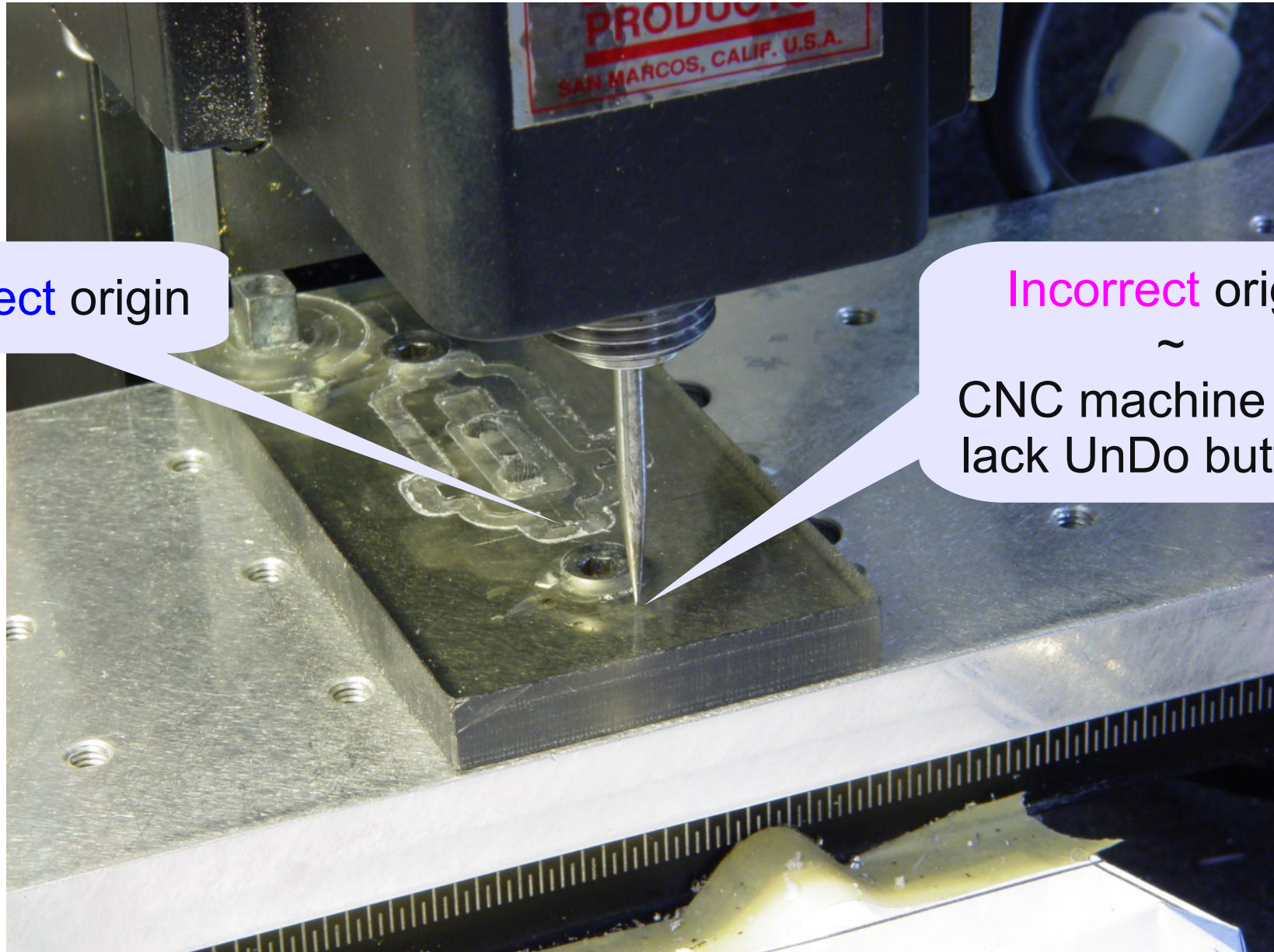
# Drill Clamping Holes



Sacrificial plate



# Locate Fixture Origin



Correct origin

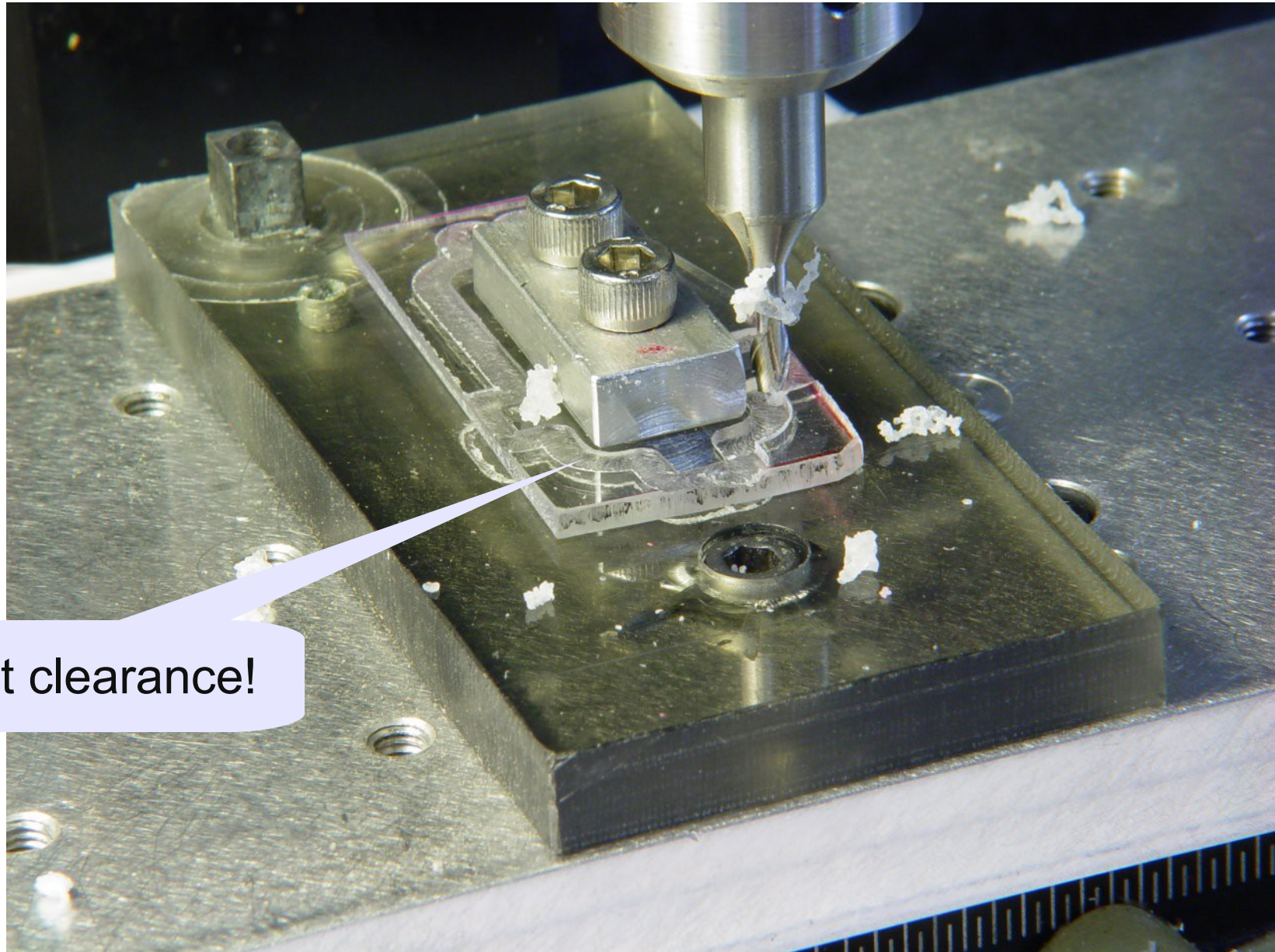
Incorrect origin

~

CNC machine tools  
lack UnDo buttons!



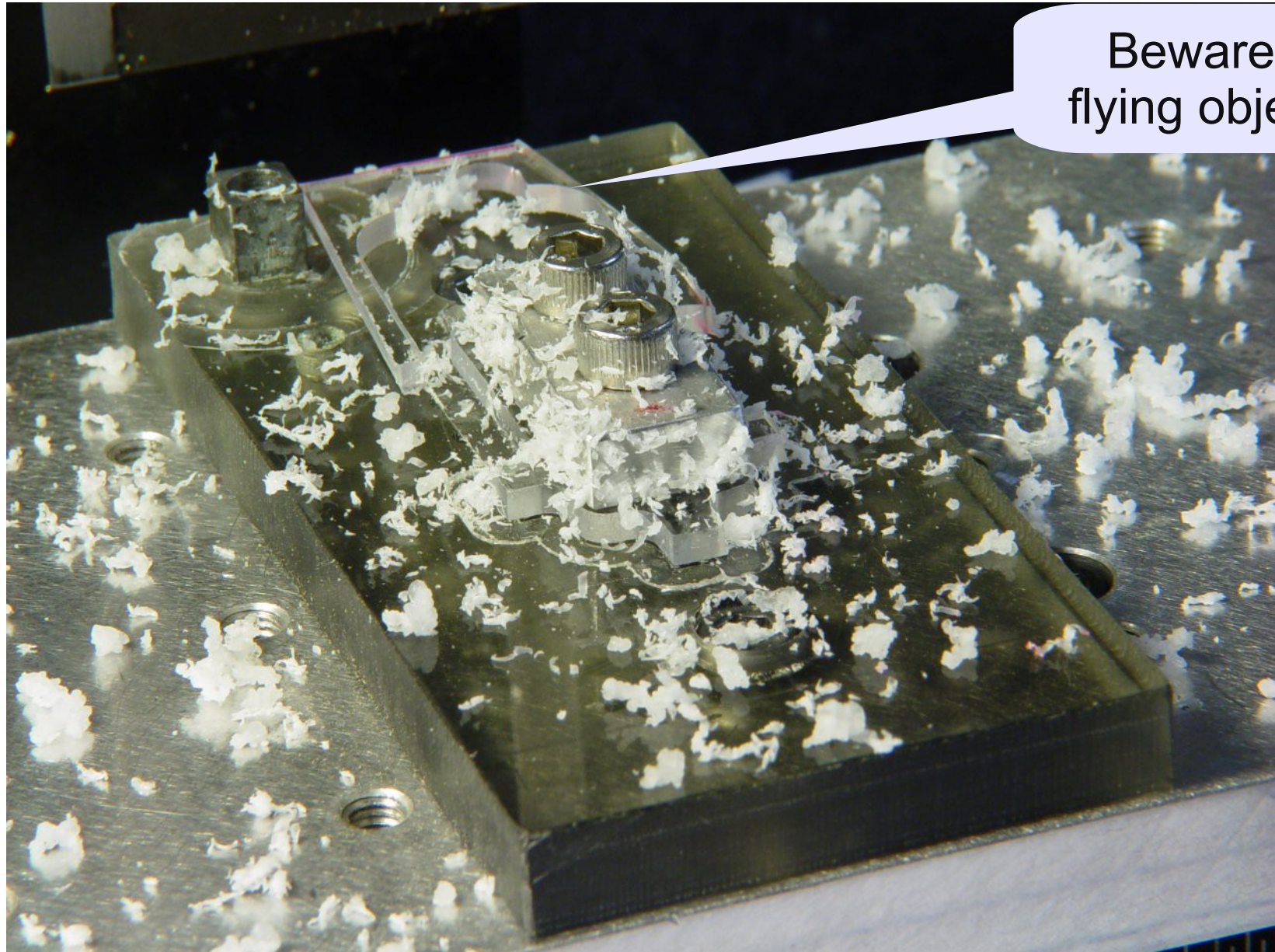
# Outside Cutting



Tight clearance!



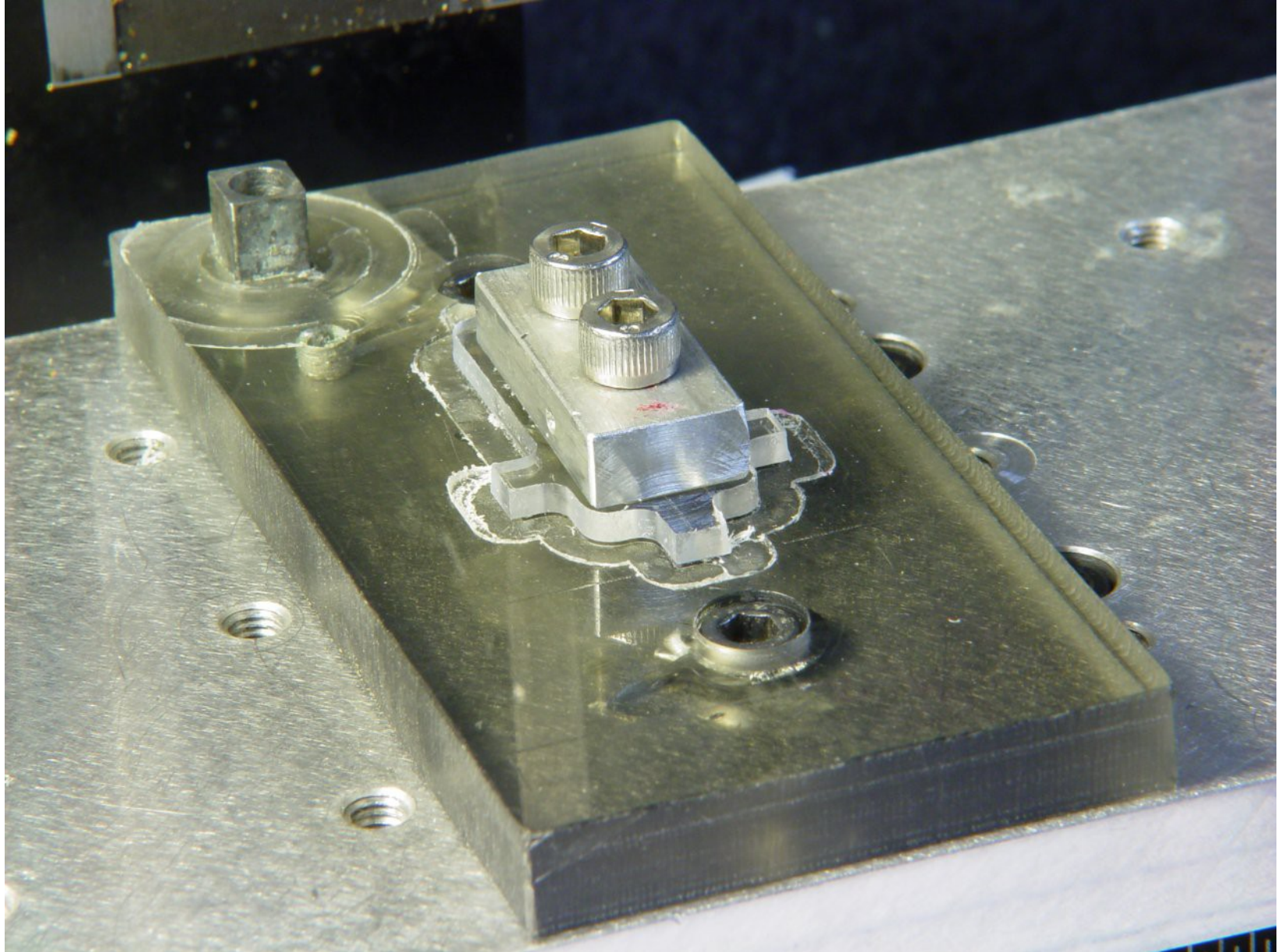
# Chips Aplenty



Beware of  
flying objects!

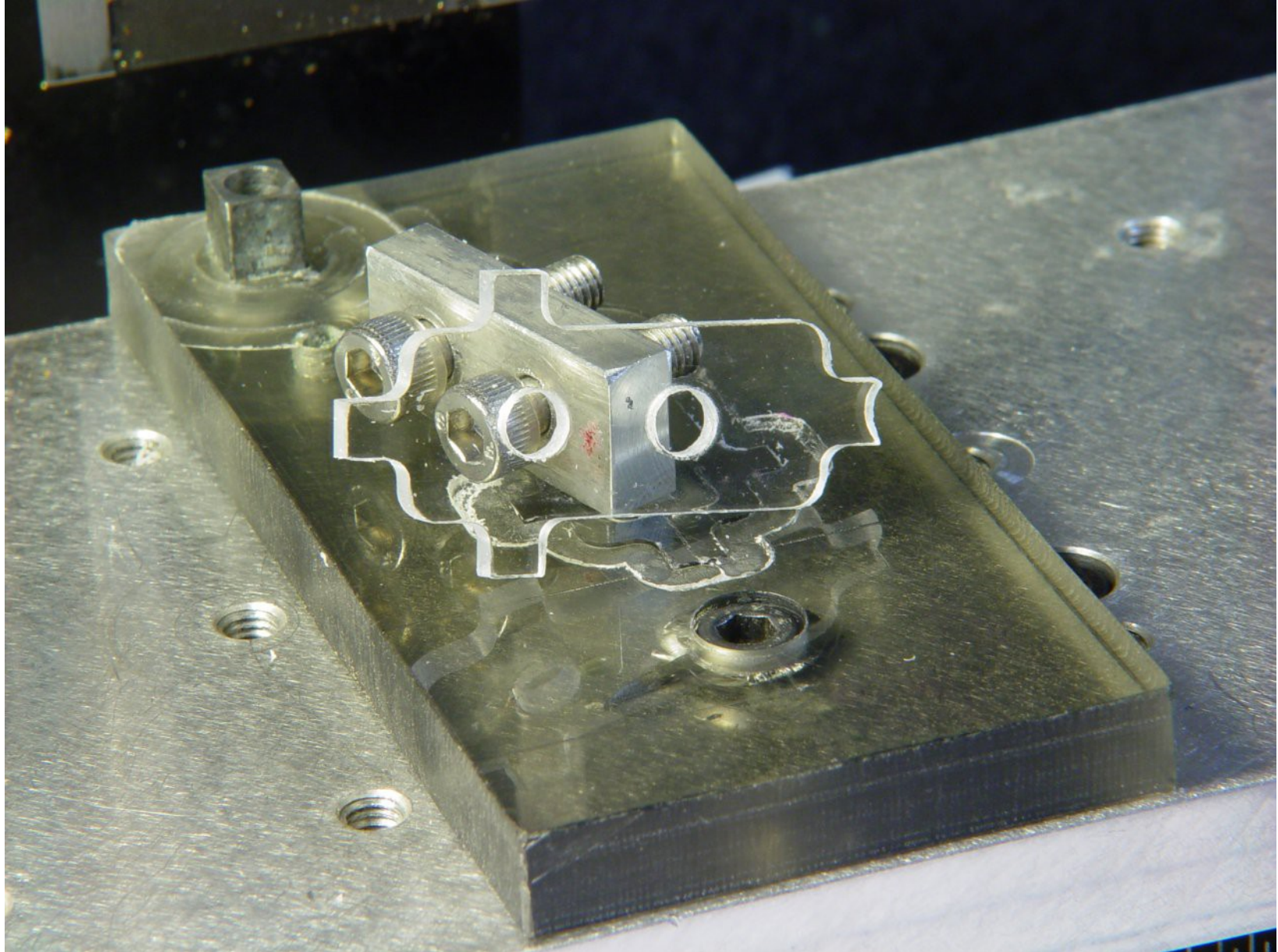


# Some Deft Vacuum Work





# Outside Done!



# Places To Go

Wikipedia CNC article

<http://en.wikipedia.org/wiki/Cnc>

Nice CNC setup & info

<http://www.irritatedvowel.com/Railroad/Workshop/SherlineCNC.aspx>

Sherline Products

<http://sherline.com>

Enhanced Machine Controller Project

<http://linuxcnc.org>

Flashcut CNC

<http://www.flashcutcnc.com>

Non-shiny Things

[www.fabathome.org](http://www.fabathome.org)

<http://reprap.org>

Naval Safety Center

<http://www.safetycenter.navy.mil/photo/default.htm>



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# Ed Nisley

Say “NISS-lee”, although we're the half-essed branch of the tree

Engineer (ex PE), Hardware Hacker, Programmer, Author

The Embedded PC's ISA Bus: Firmware, Gadgets, Practical Tricks

Circuit Cellar [www.circuitcellar.com](http://www.circuitcellar.com)

Firmware Furnace (1988-1996) - Nasty, grubby hardware bashing

Above the Ground Plane (2001...) - Analog and RF electronics

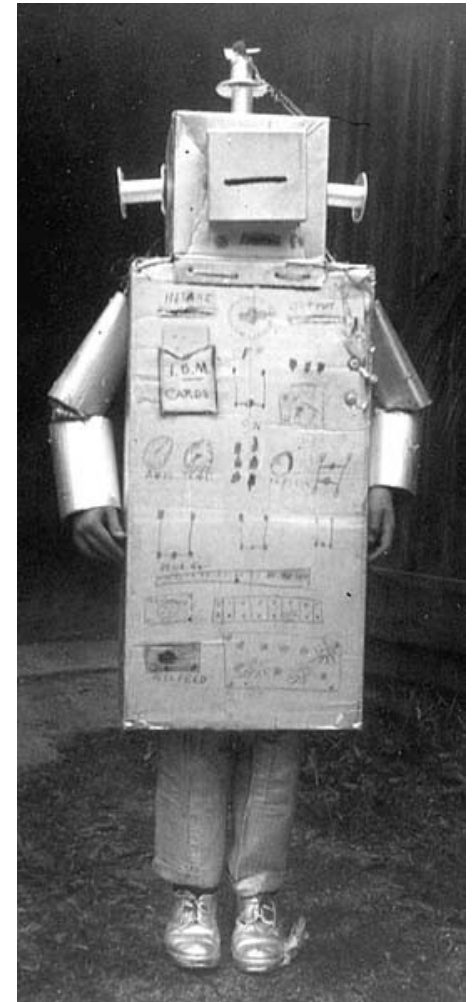
Dr. Dobb's Journal [www.ddj.com](http://www.ddj.com)

Embedded Space (2001-2006) - All things embedded

Nisley's Notebook (2006-2007) - Hardware & software collisions

Digital Machinist [www.homesopmachinist.net](http://www.homesopmachinist.net)

Along the G-Code Way (2008-) - G-Code and mathematics





The background is a complex abstract composition. It features a large black circle centered on the page. Inside this circle is a white rectangular box with a black border, containing the text. Surrounding the circle are various geometric shapes: a blue square in the top-left, a red square in the top-right, a green square in the bottom-left, and a yellow square in the bottom-right. There are also several grayscale gradient bars of different orientations (horizontal and vertical) and colors (blue, red, green, yellow) scattered around the central circle. The entire image is framed by a thick black border.

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