Why CNC?

~

An Introduction

Ed Nisley • KE4ZNU
January 2008
Cabin Fever Expo
York PA

* Must *
* Make *
* Shiny *
* Objects *

Upcoming Events

Things to do with CNC

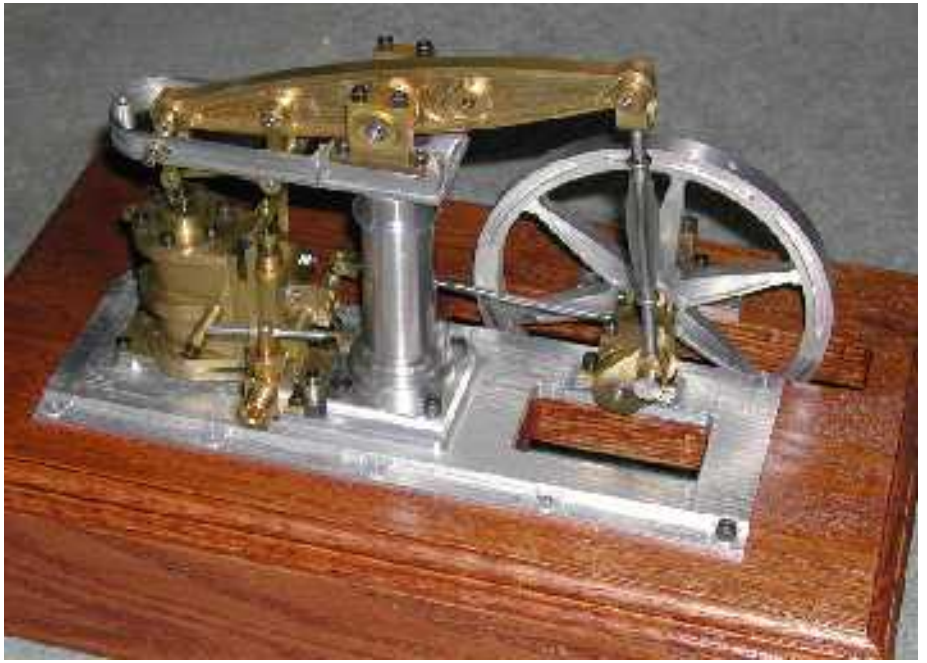
Machine shops & milling machines
Computer Numerical Control
Numbers and where to find them

G-Code programming
Stepper motors & step timing

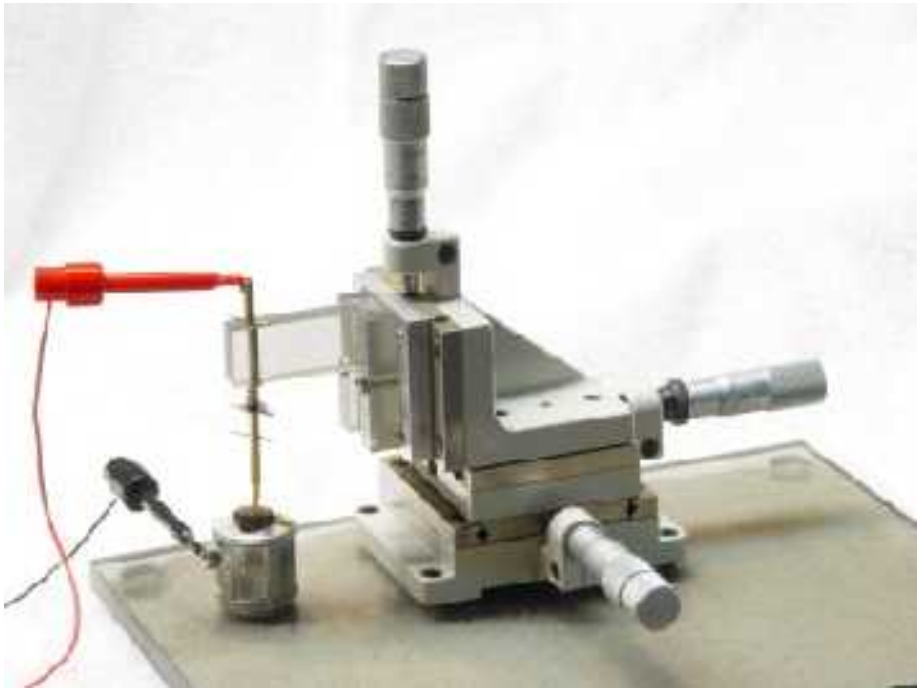
Useful (?) household (?) projects

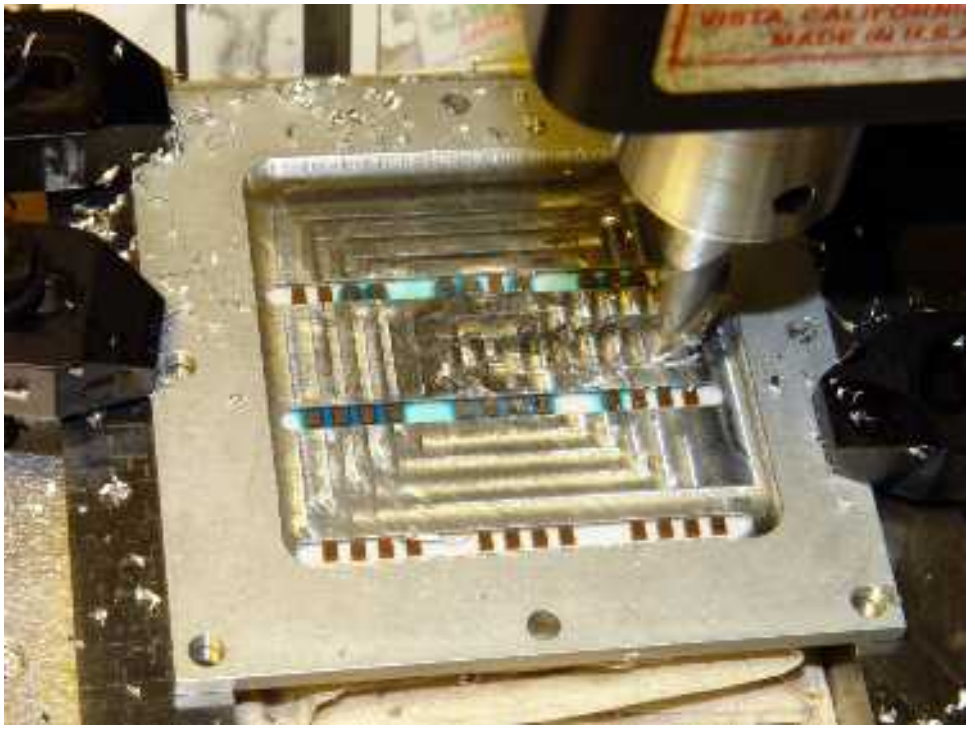
Live-fire Show-n-Tell Demo Madness

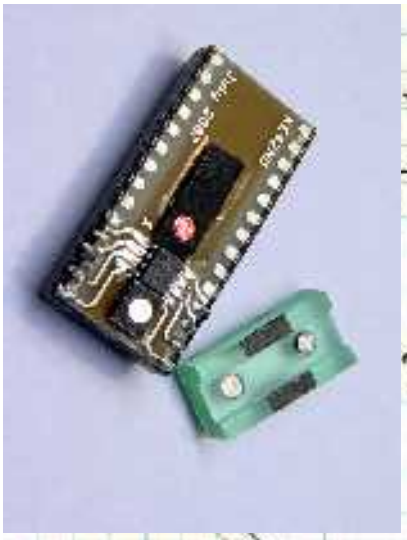
http://statmandesigns.com



http://sherline.com/CNCproj.htm

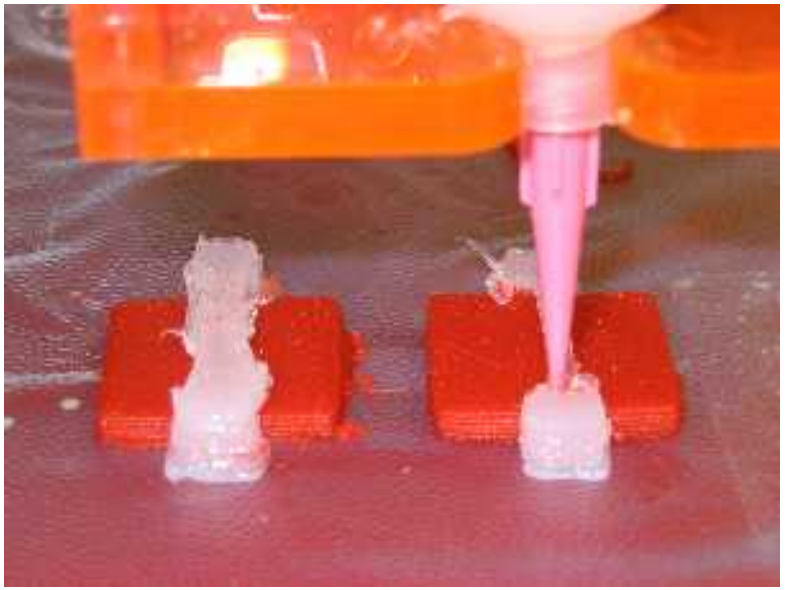







CM 1 2 3 4

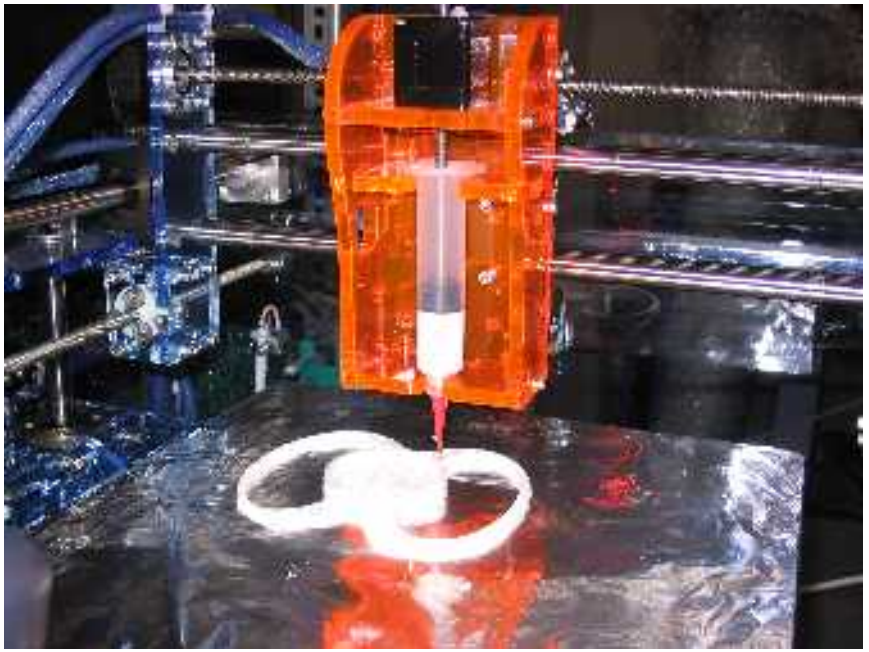
Not *Squishy* Objects



Silicone
snot
bridge

Silicone
snot
+ epoxy
LED light

Fab@Home



Band
over
watch

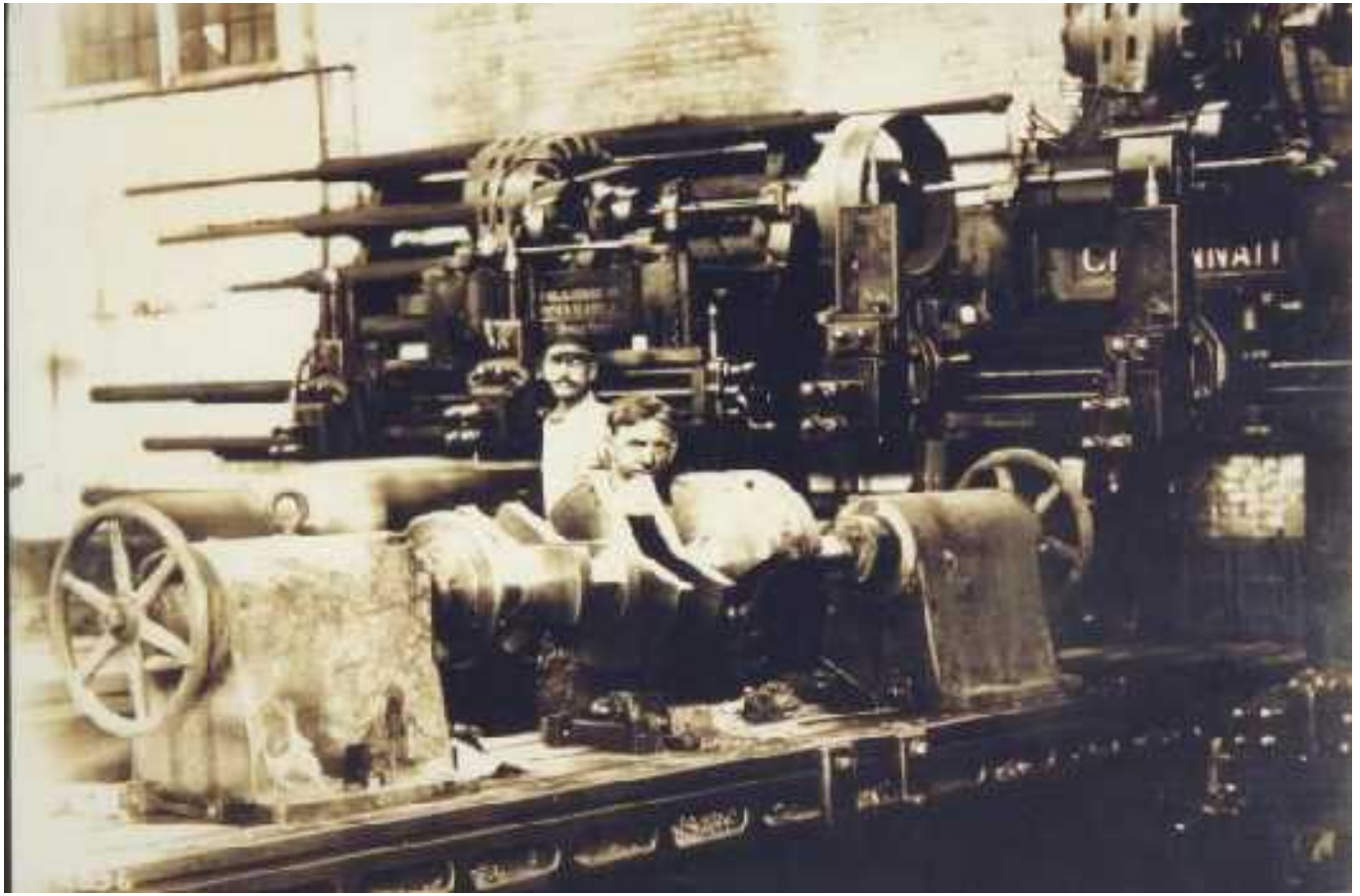
Shotglass

RepRap

Machine Shop

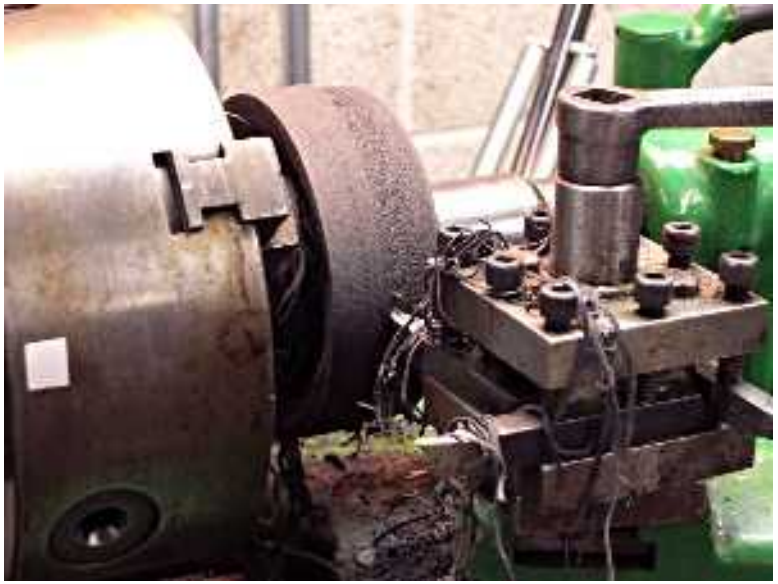
A room, building, or company where machining is done is called a machine shop.

Wikipedia



http://www.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

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?

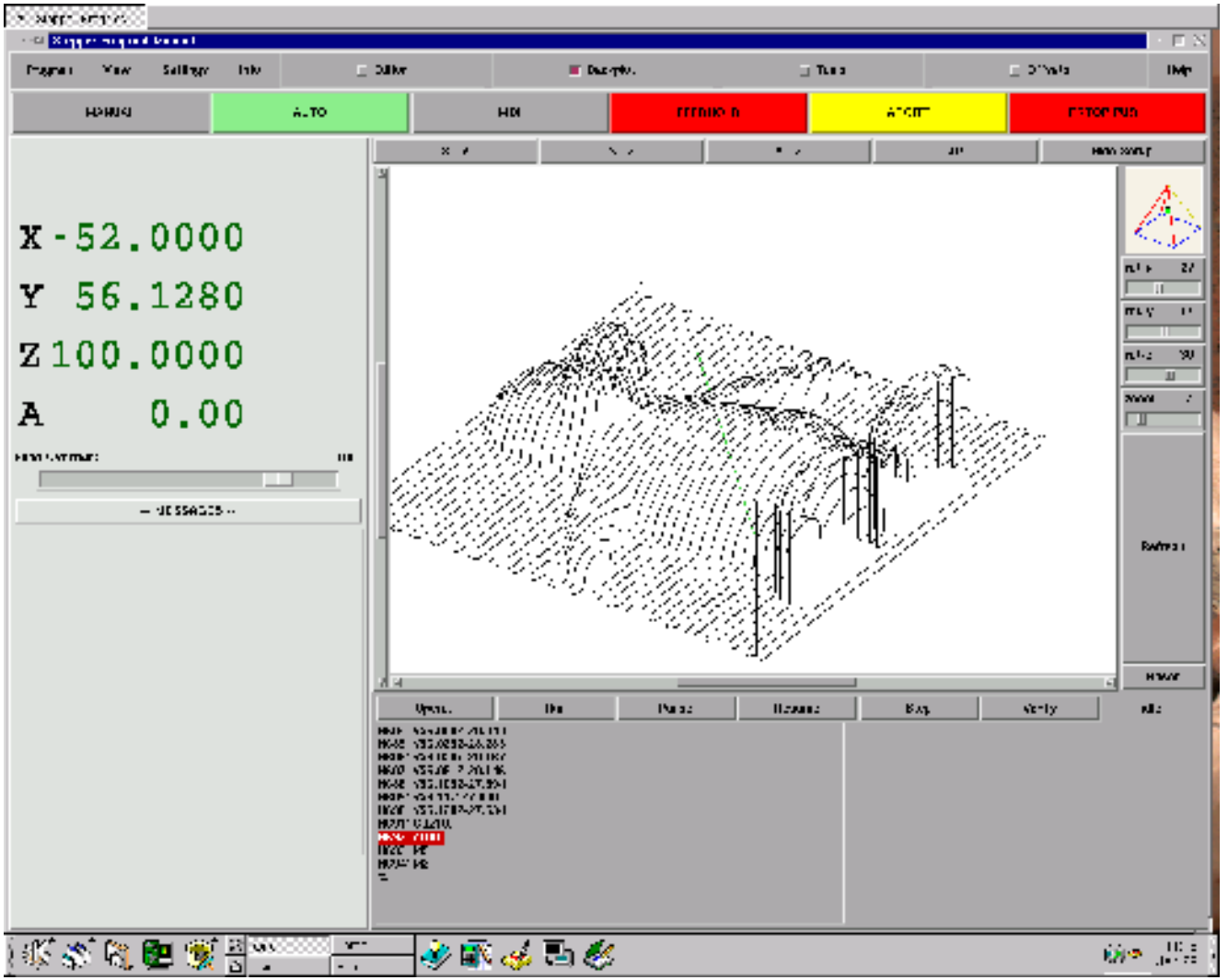
I did, but it didn't fit… S*urprise!*

Just Draw What You Want?

http://www.auma.com

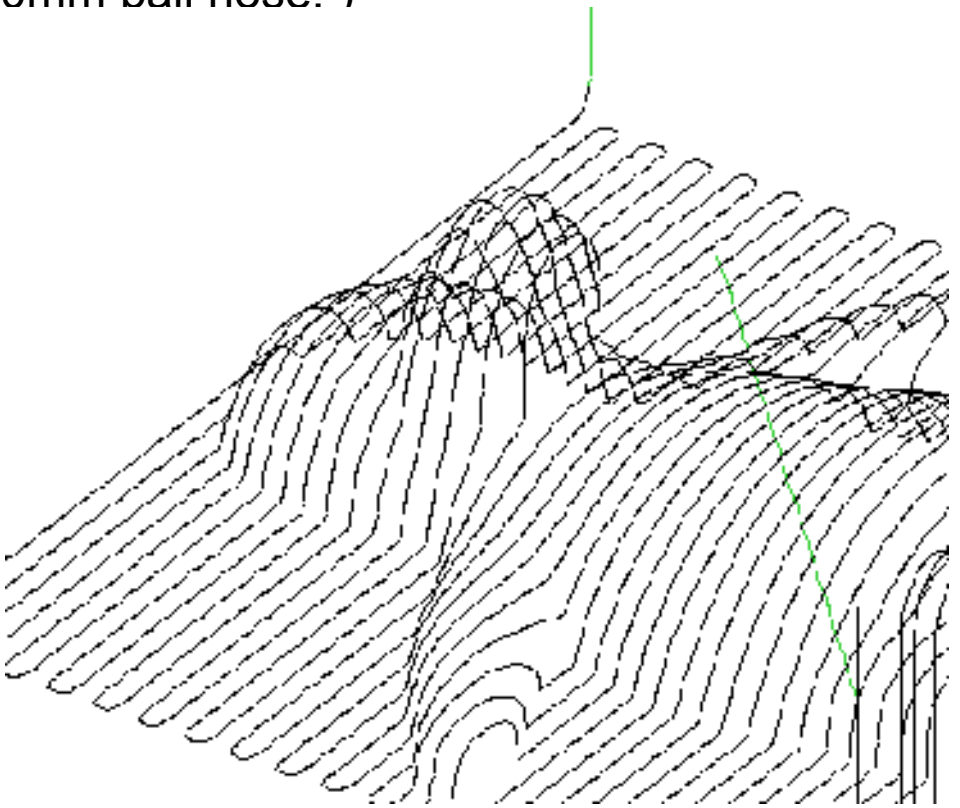
For Some Drawings, Maybe

"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 ...

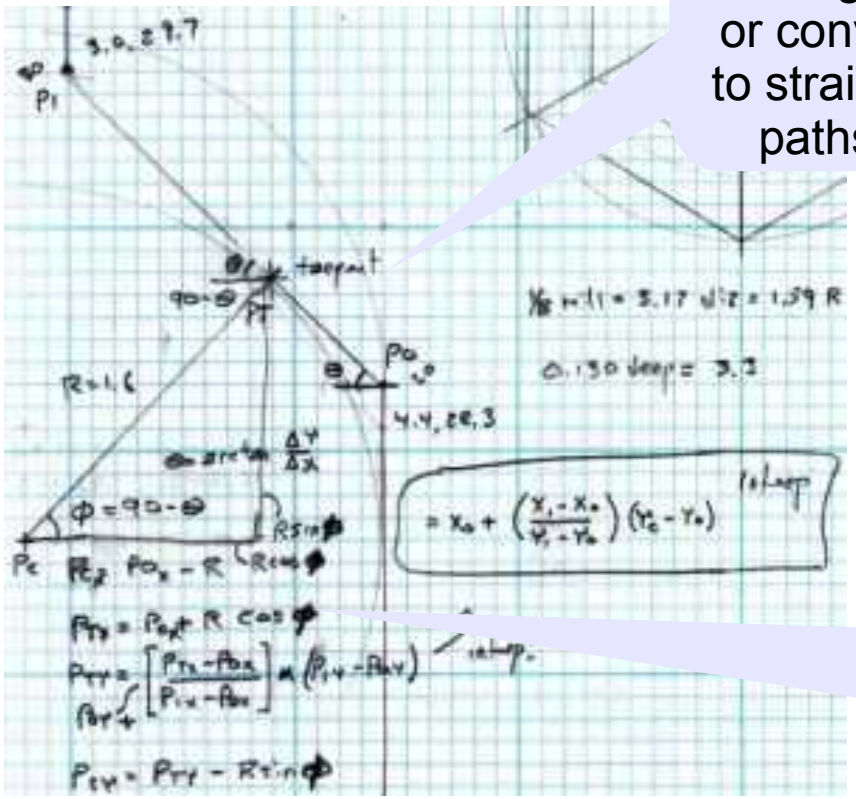
Door Latch Pull

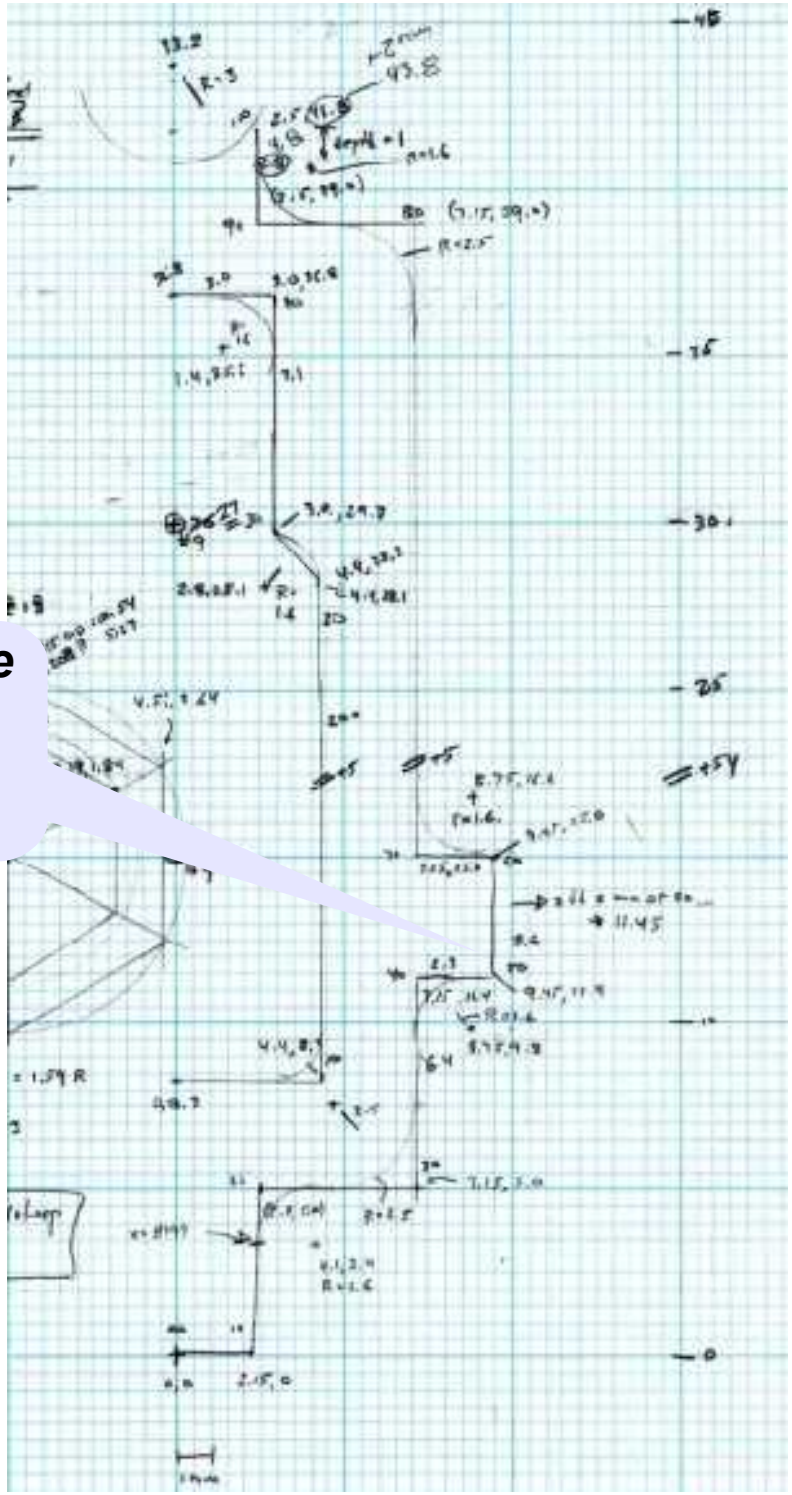
You must have numbers for those fancy CAD drawings!

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

EMC’s G-Code now supports 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...

Extensions for loops, routines, conditionals
- A major set of non-standard EMC 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                               (pass counter - start at surface)
#901 = 0.00                            (initial Z)

O200 DO                                (mill outline)

O100 CALL [#901]                       (do a pass around the outline)

#900 = [#900 + 1]                      (tick loop counter)
#901 = [#901 - #1133]                  (next Z level)

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
```

Looping!

Subroutine to handle one pass

Variable holds Z-axis depth

Door Latch Pull – Cutting!

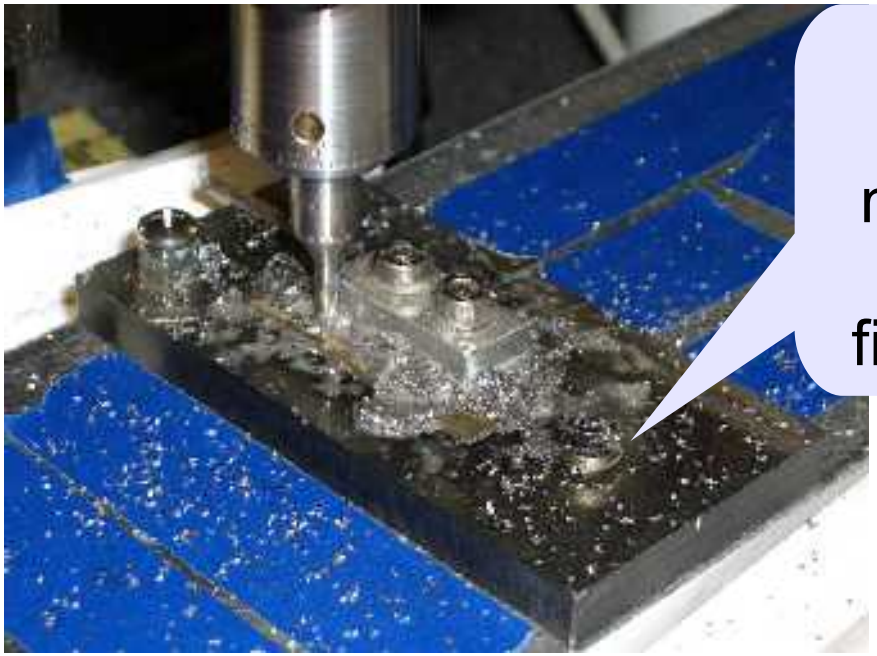
```
O100 SUB
G1 X[0-[#2010 - #1200]] Y#2011 Z#1                          (ramp down along slot bottom)
G2 X[0-#2010] Y[#2011 + #1200] I0 J#1200                    ( ... LL corner)
#800 = [90 - ATAN [#2031 - #2021] / [#2030 - #2020]]        (angle: fillet arc ctr to tangent pt)
#802 = [#2020 - #1200]                                      (fillet arc center X)
#804 = [#802 + [#1200 * COS[#800]]]                         (tangent pt X)
O020 CALL [#804] [#2020] [#2021] [#2030] [#2031]            (tangent pt Y in #999)
#805 = [#999 - [#1200 * SIN[#800]]]                         (fillet arc center Y)
G1 X[0-#2020] Y[#805]                                       (slot side L to fillet start)
G2 X[0-#804] Y#999 I#1200 J0                                (fillet)
G1 X[0-#2030] Y#2031                                        (fillet to neck)
G1 X[0-#2040] Y[#2041 - #1200]                              (neck L)
G2 X[0-[#2040 - #1200]] Y#2041 I#1200 J0                    (fillet to top)
G1 X[#2040 - #1200] Y#2041                                  (across the top to UR fillet)
G2 X#2040 Y[#2041 - #1200] I0 J[0-#1200]                    (fillet to neck)
G1 X#2030 Y#2031                                            (neck R)
G1 X#804 Y#999                                              (neck to fillet)
G2 X#2020 Y#805 I[0-[#1200 * COS[#800]]] J[0-[#1200 * SIN[#800]]]    (fillet to slot R)
G1 X#2010 Y[#2011 + #1200]                                  (slot
G2 X[#2010 - #1200] Y#2011 I[0-#1200] J0                    (
G1 X#2000 Y#2001                                            (ret
O100 ENDSUB
```

Linear

Circular

Calculate coordinates based on geometry & measurements

Real-world I/O



First you make the fixture

G-code must miss the clamps!

Bottom Line

CNC machining requires ***Numbers***

Numbers

▼

Coordinates

▼

Tool Path

▼

Motion Control

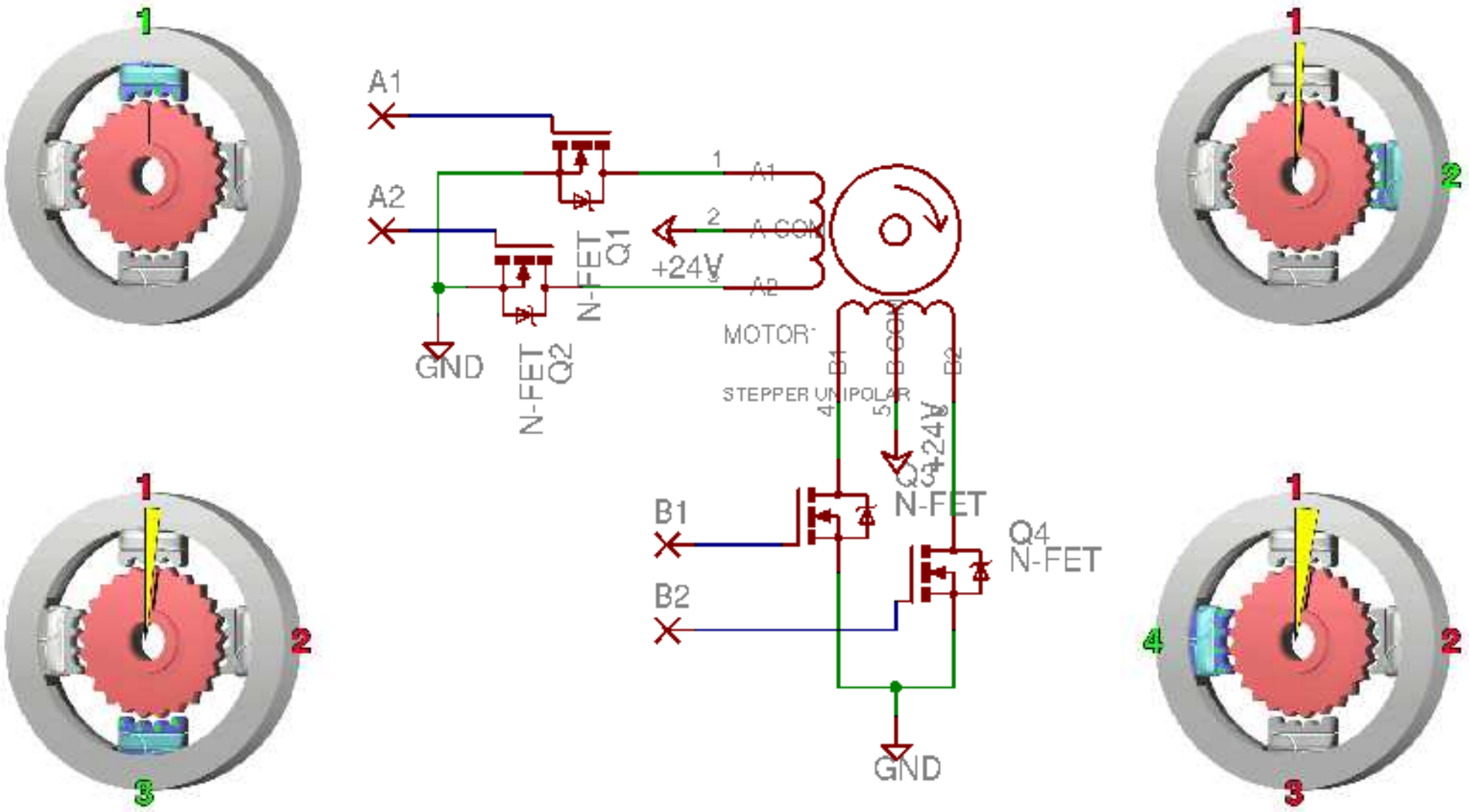
▼

Motor Drive

Stepper Motors

http://sherline.com/CNCmenu.htm

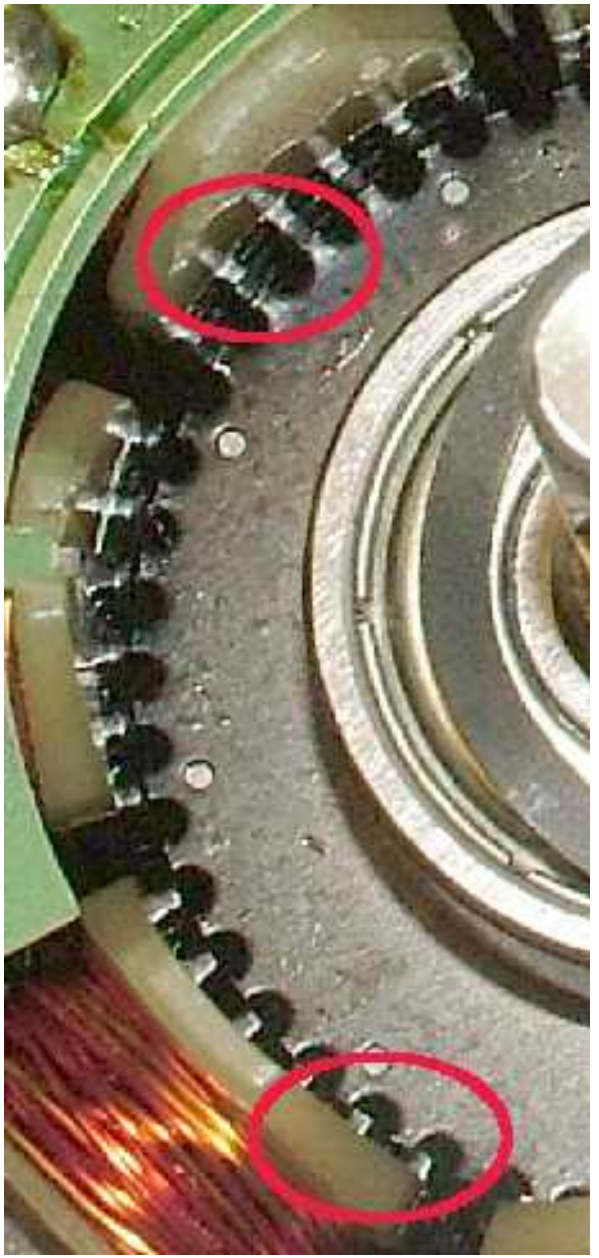
Stepper Motor



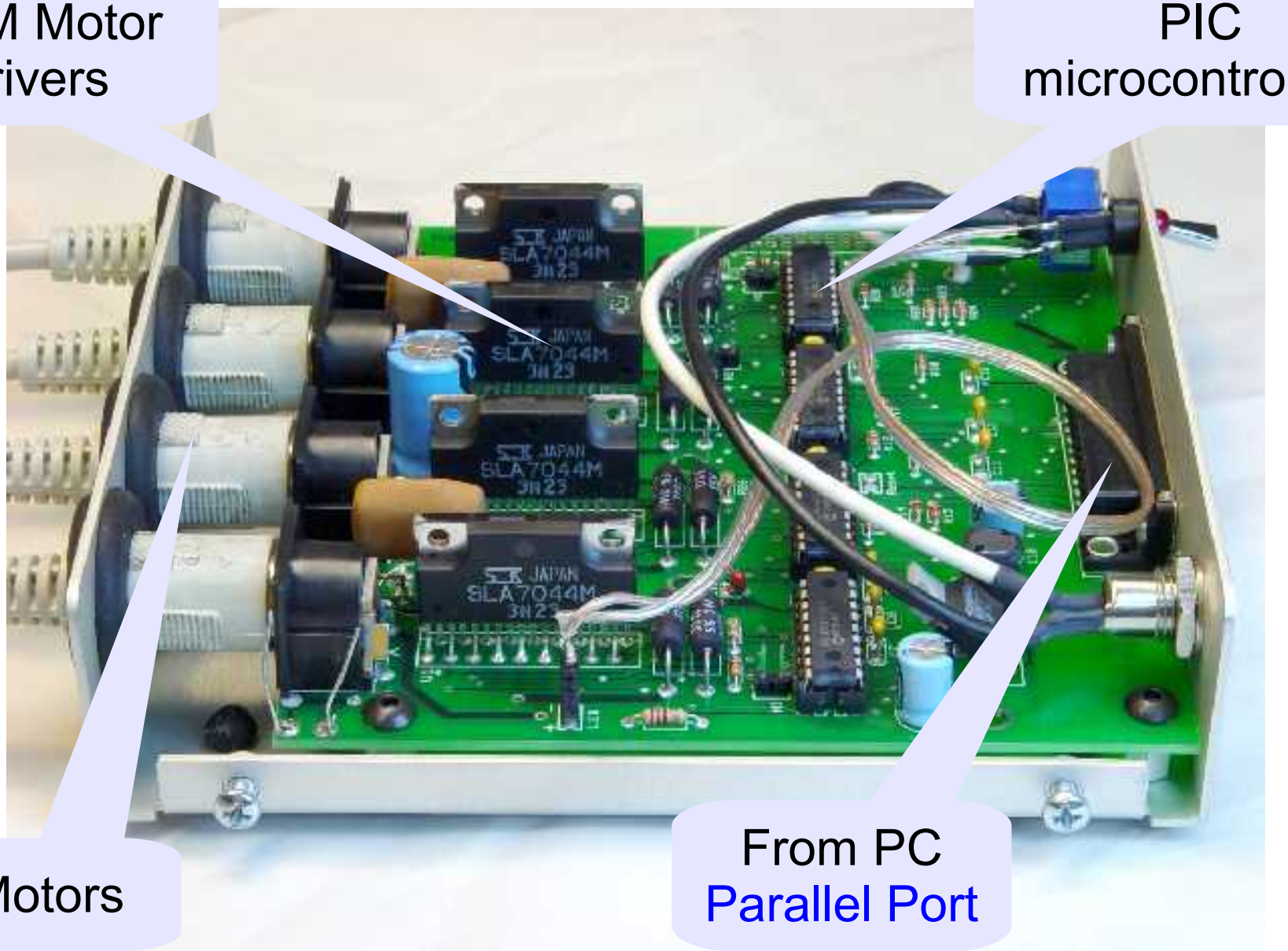
http://en.wikipedia.org/wiki/Stepper_motor

Stepper Motor

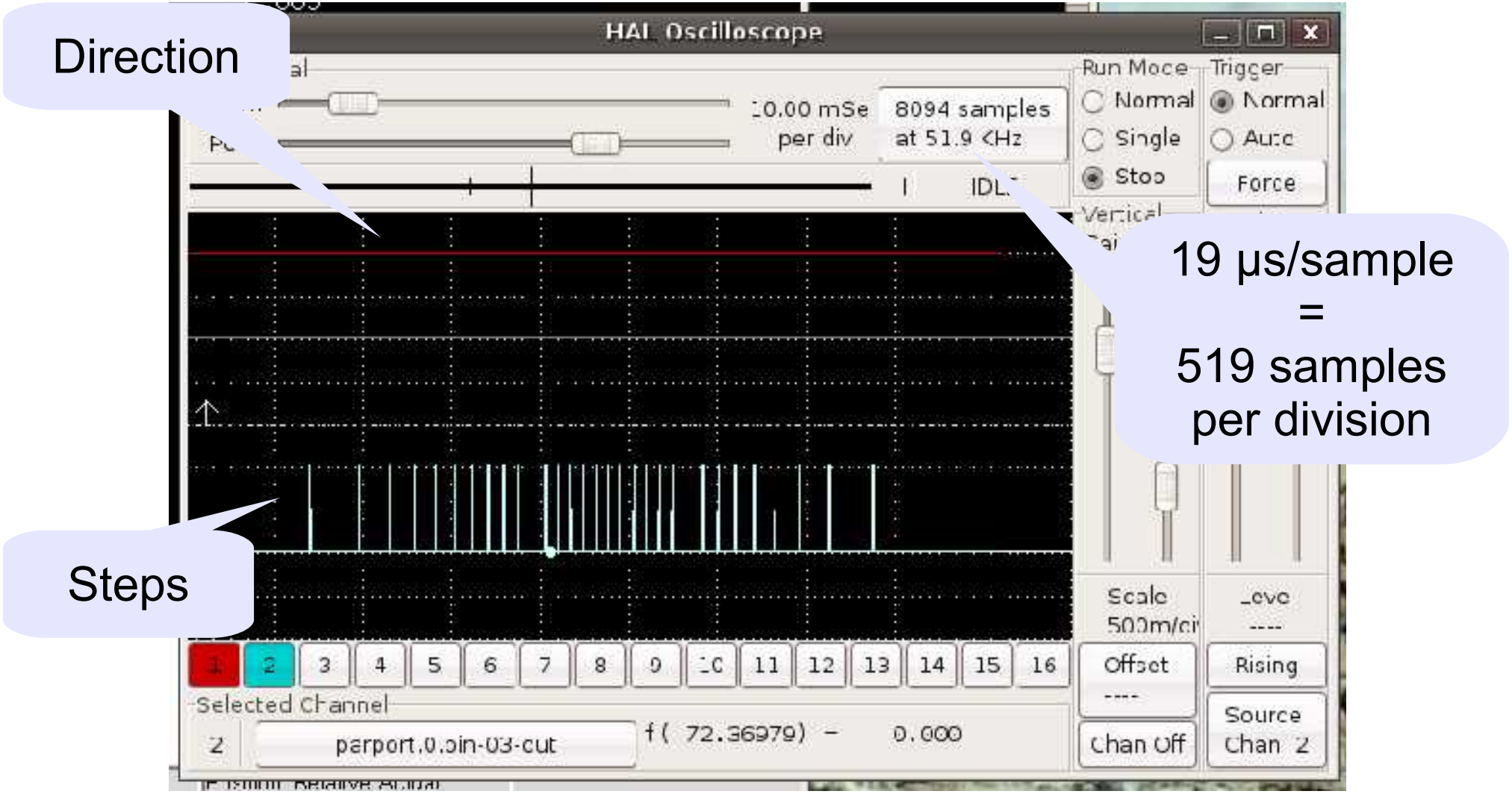
Photos by Craig Libuse, Sherline



Stepper Motor Controller

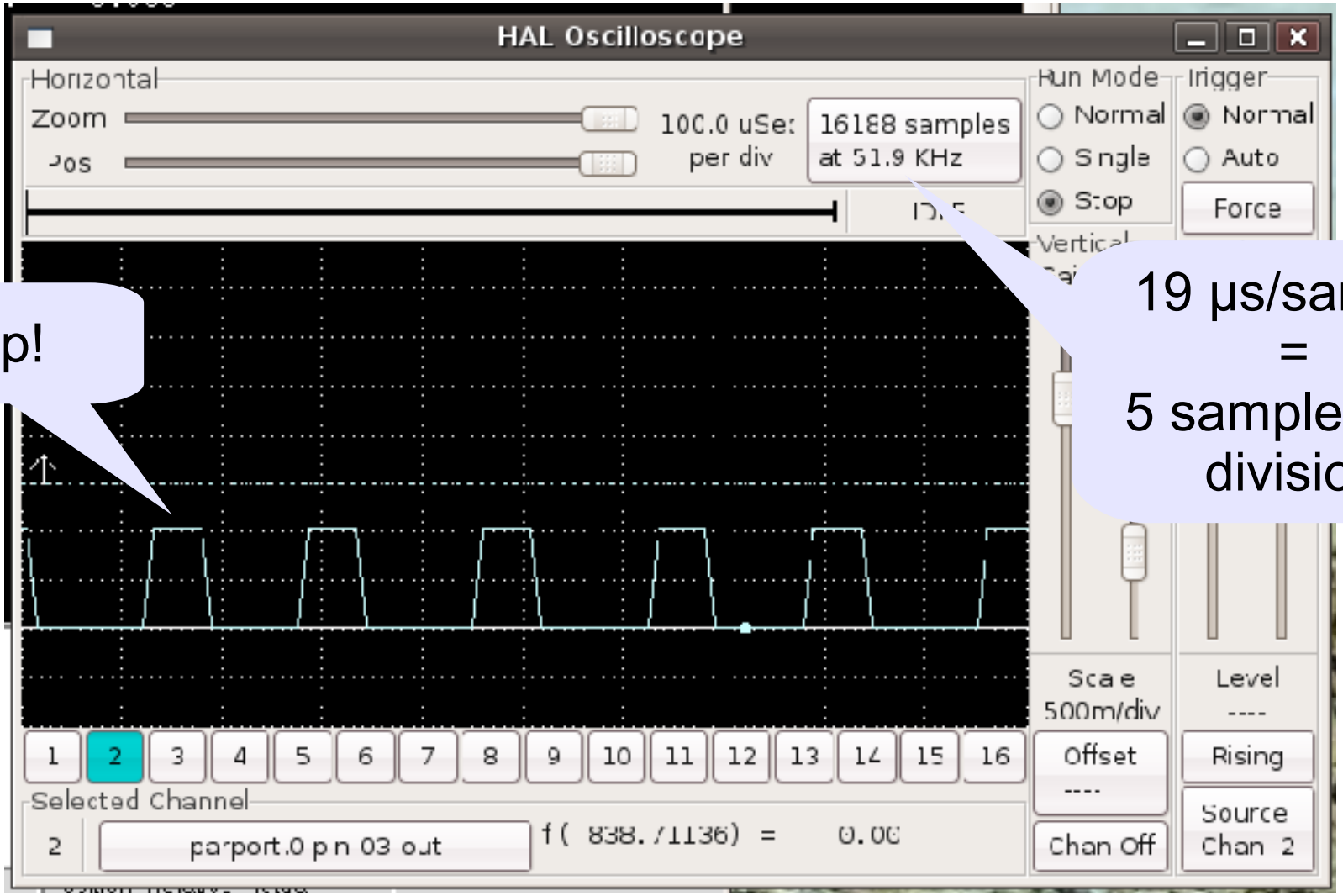


Stepping Pulses



0.05 mm = 0.002 in / 31 steps ► 1.6 µm/step = 63 µ·in/step

Stepping Speed



5 steps in 8.2x100 µs = 160 µs/step = 6 kHz

Speed Matters

63 µ·in/step x 6000 step/s = 0.38 in/s = 23 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 be15 in/s = 244 kHz = 4 µs/step... for my setup

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://sherline.com/CNCprices.htm

Home Shop Projects

Mostly flat

- More or less 2½ D

Simple geometry

- Straight lines
- Circular arcs

Low precision

- ≤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

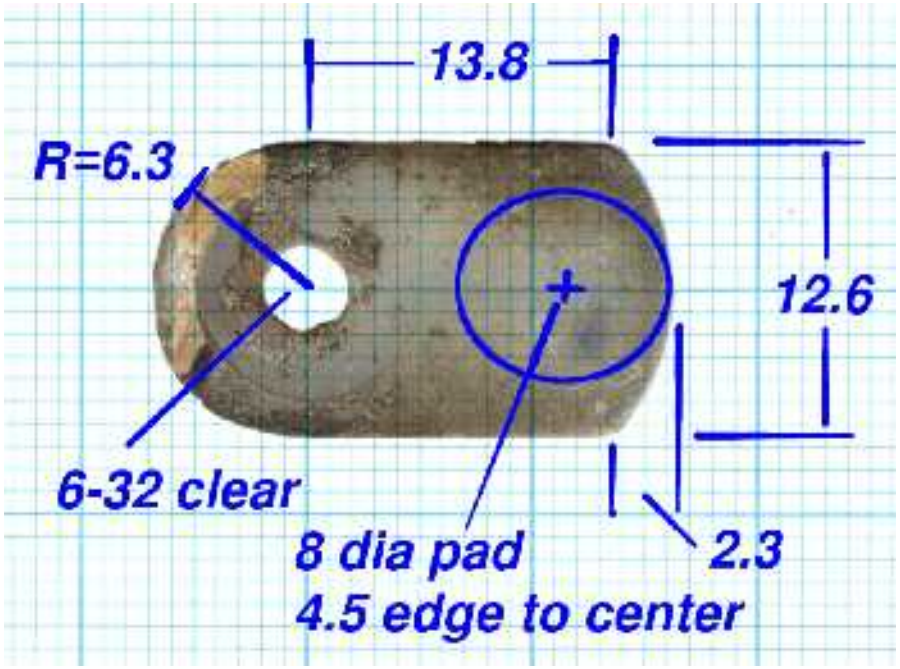
Replacement windows?
- $1000… more or less

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

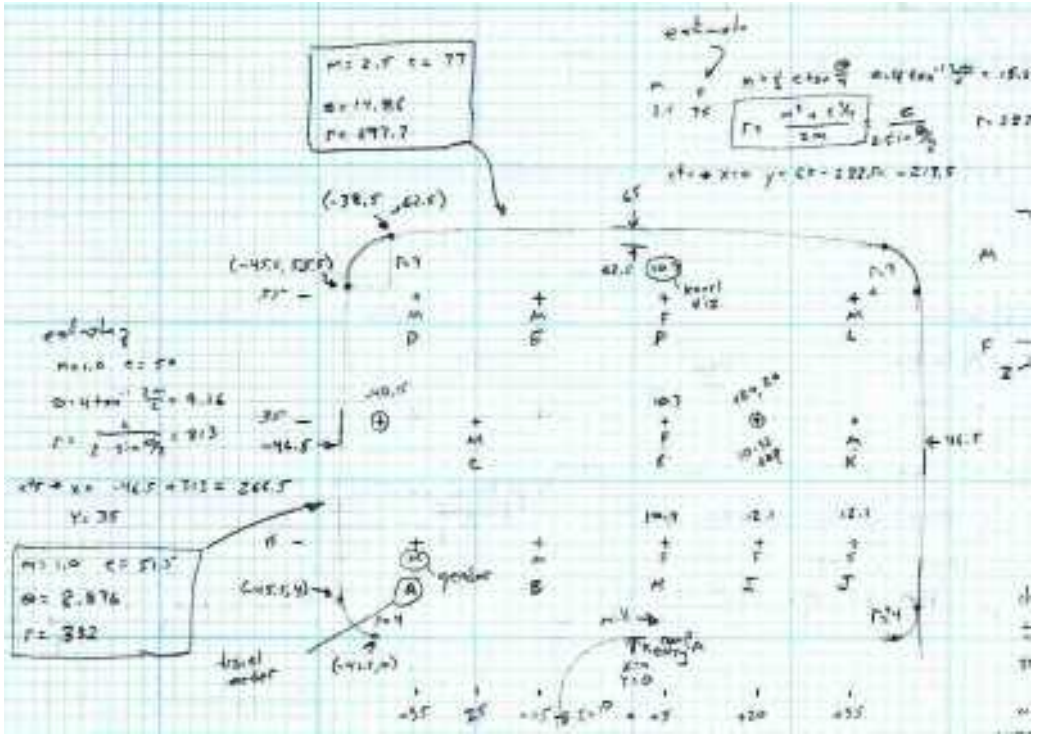
Amateur radio “go-kit” toolbox

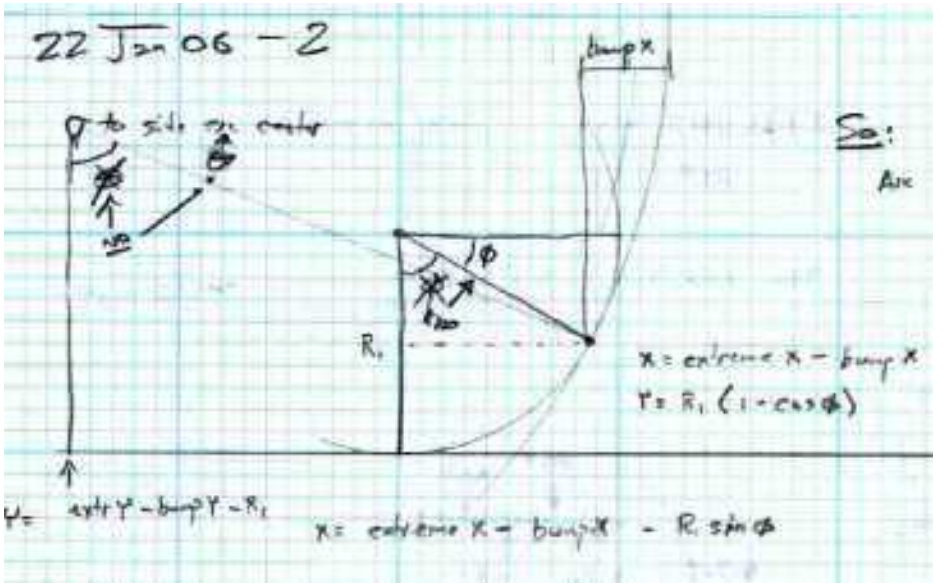
Adapters hide in the clutter

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

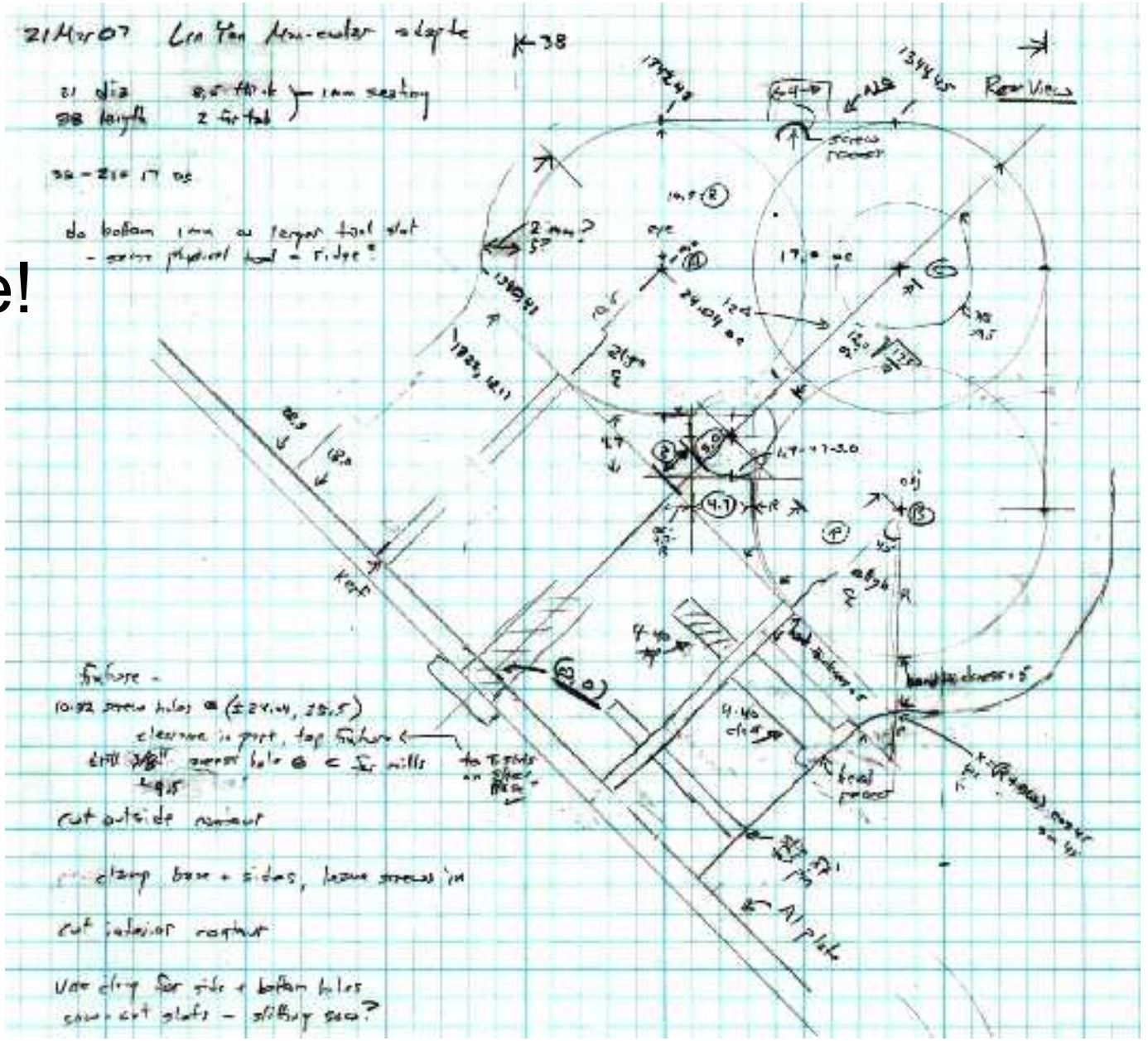
Monocular
- 8x telescope
- 20x microscope
- Light & compact

Digital Camera + lens
- 114 mm → 912 mm
- f/5.1 → f/41 (ouch)
- Best for sunny scenes!

Camera Monocular Mount

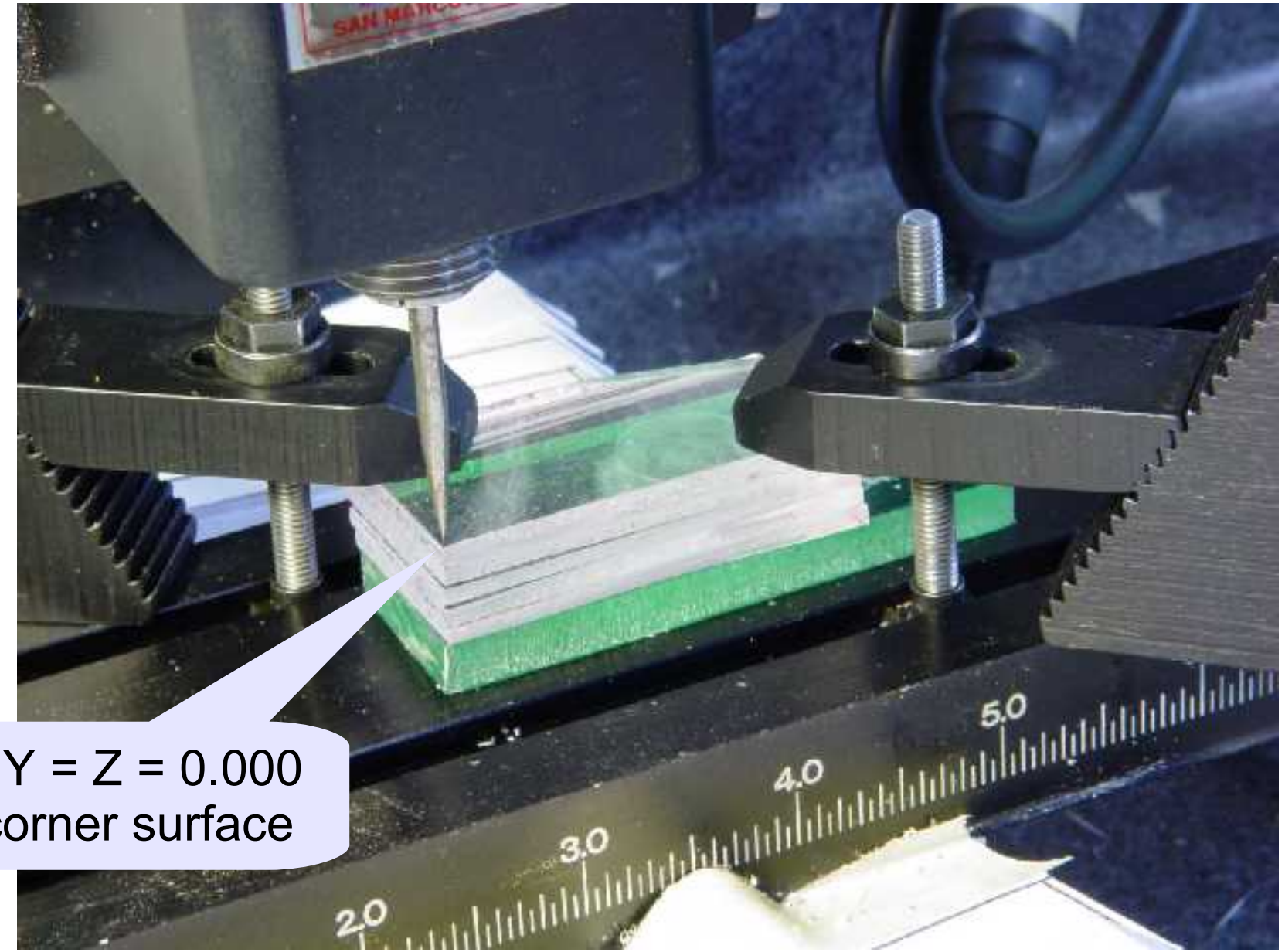
Simple Layout

- Circular arcs
- Right angles
- Polycarbonate!



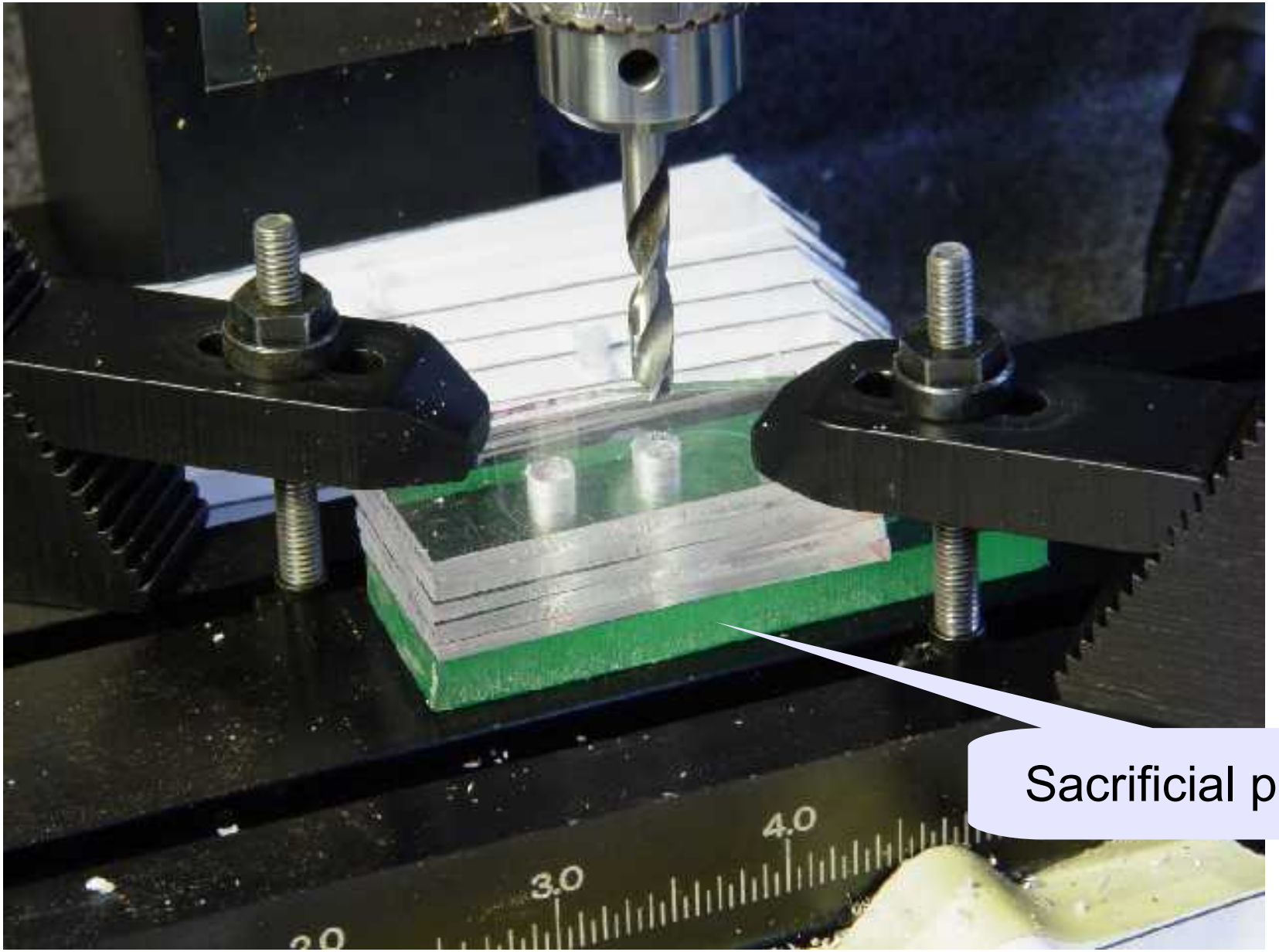
Demo Madness

Locate Origin

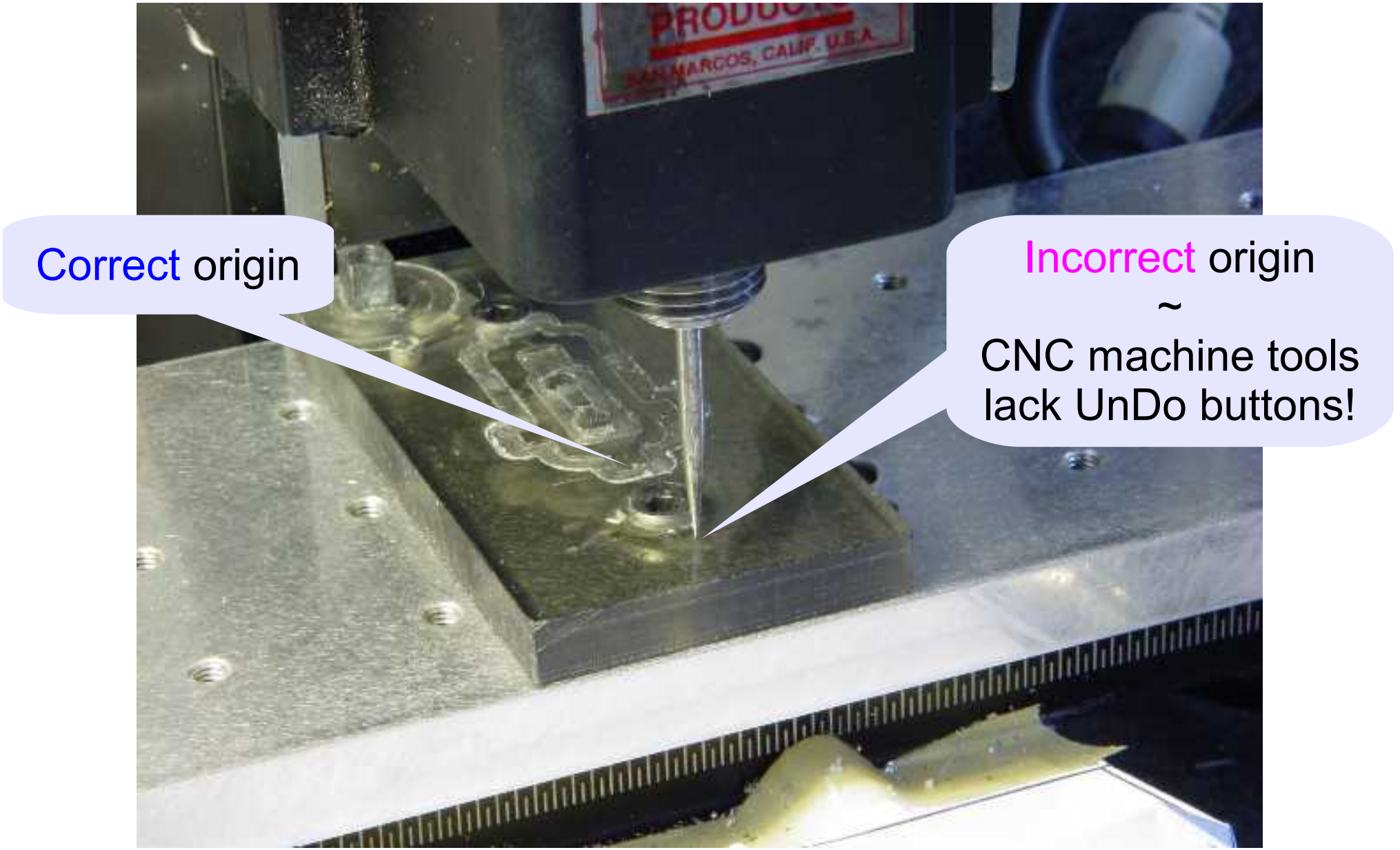


X = Y = Z = 0.000
at corner surface

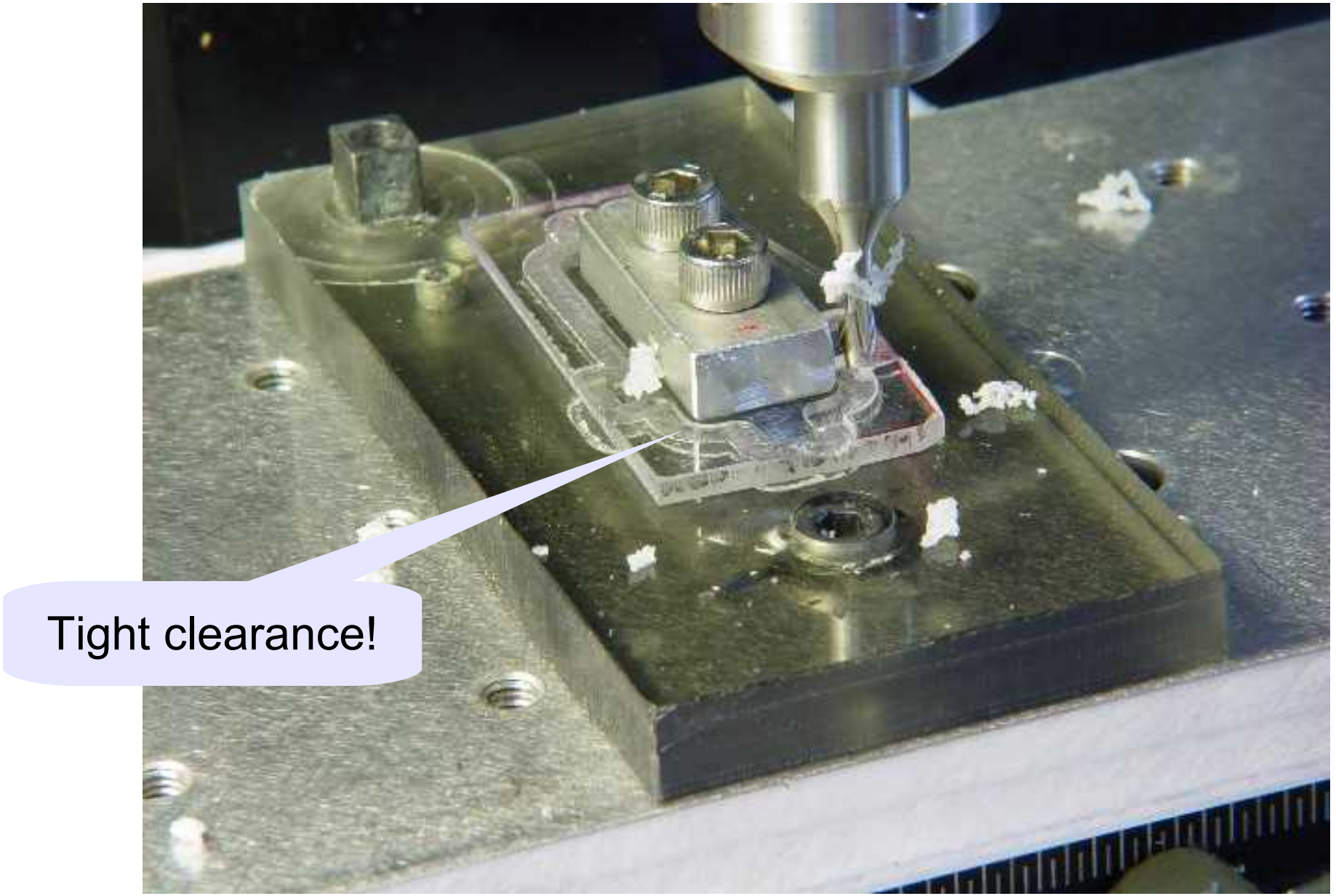
Drill Clamping Holes



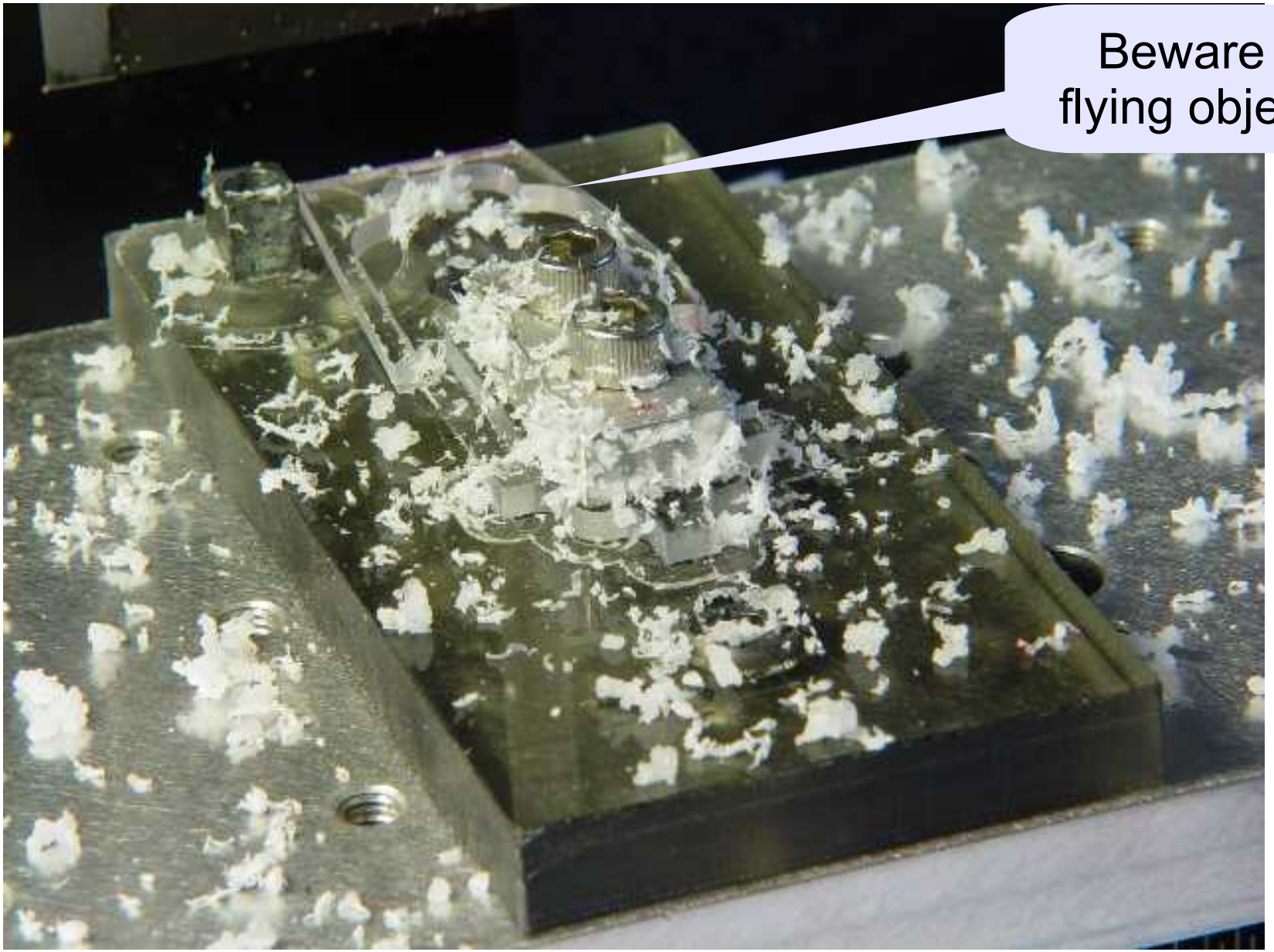
Locate Fixture Origin



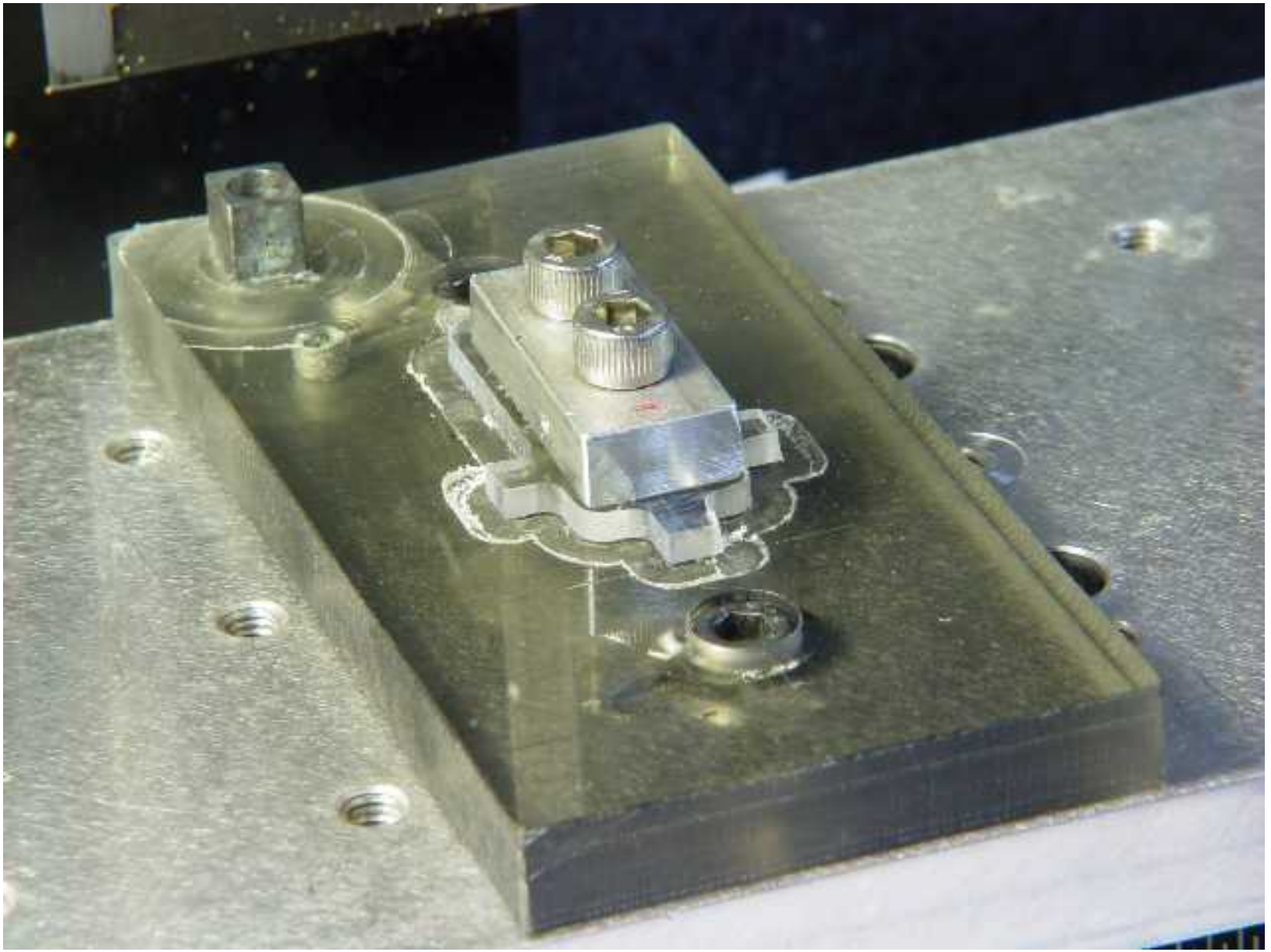
Outside Cutting



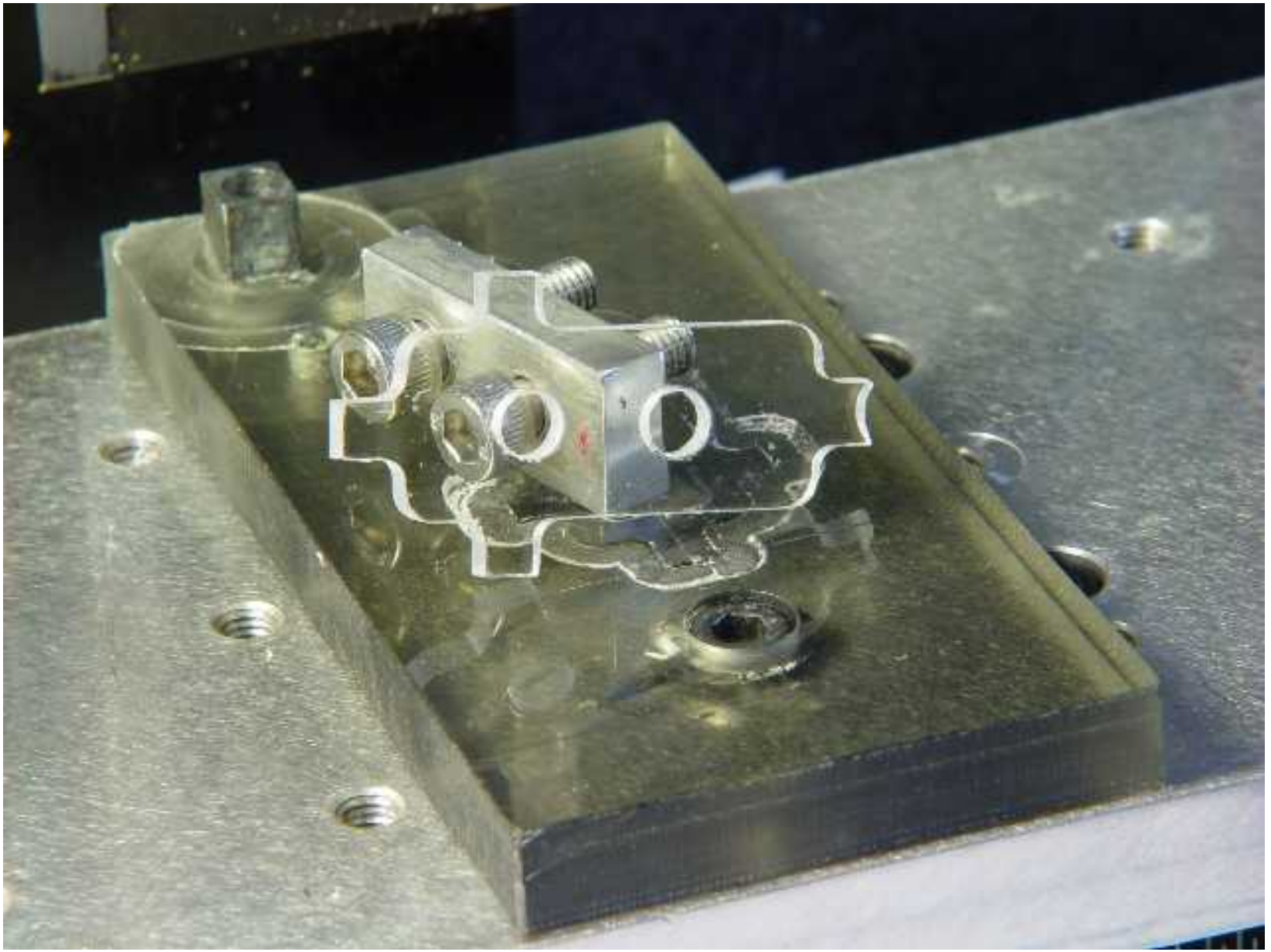
Chips Aplenty



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://reprap.org

Naval Safety Center
http://www.safetycenter.navy.mil/photo/default.htm

Copyright-ish Stuff

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Ed Nisley

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

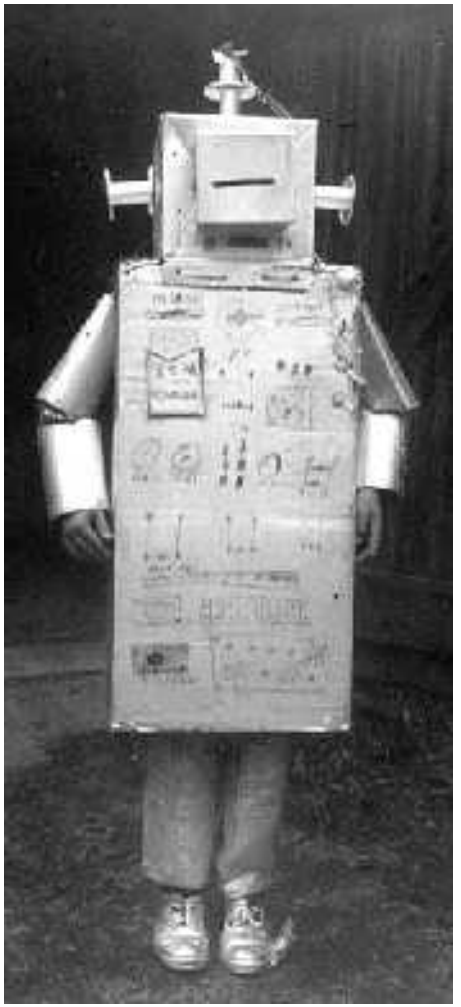
Engineer (ex PE), Hardware Hacker, Programmer, Author

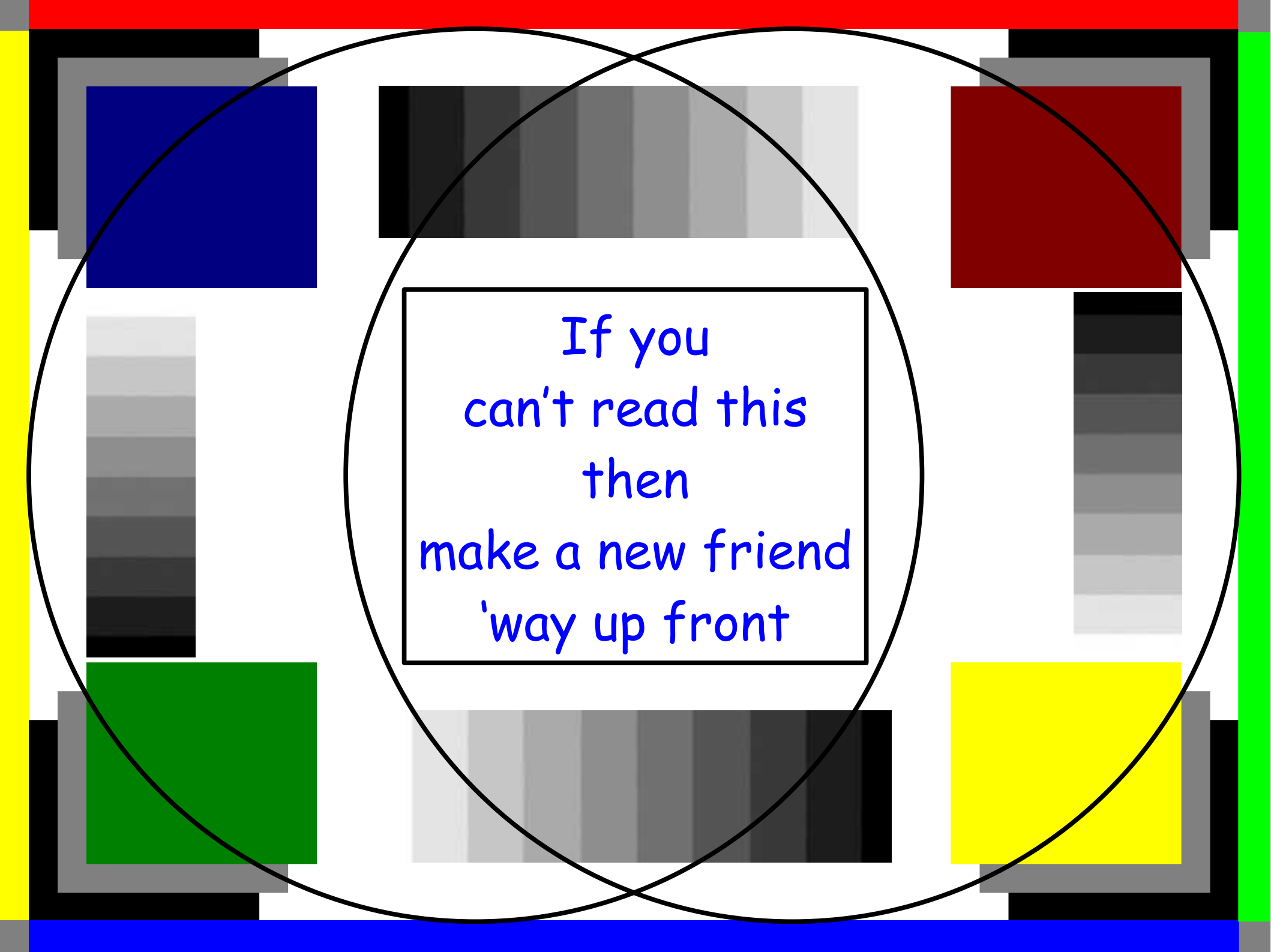
The Embedded PC's ISA Bus: Firmware, Gadgets, Practical Tricks

Circuit Cellar www.circuitcellar.com
- Firmware Furnace (1988-1996) - Nasty, grubby hardware bashing
- Above the Ground Plane (2001...) - Analog and RF electronics

Dr. Dobb’s Journal www.ddj.com
- Embedded Space (2001-2006) - All things embedded
- Nisley’s Notebook (2006-2007) - Hardware & software collisions

Digital Machinist www.homeshopmachinist.net
- Along the G-Code Way (2008-) - G-Code and mathematics

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'way up front