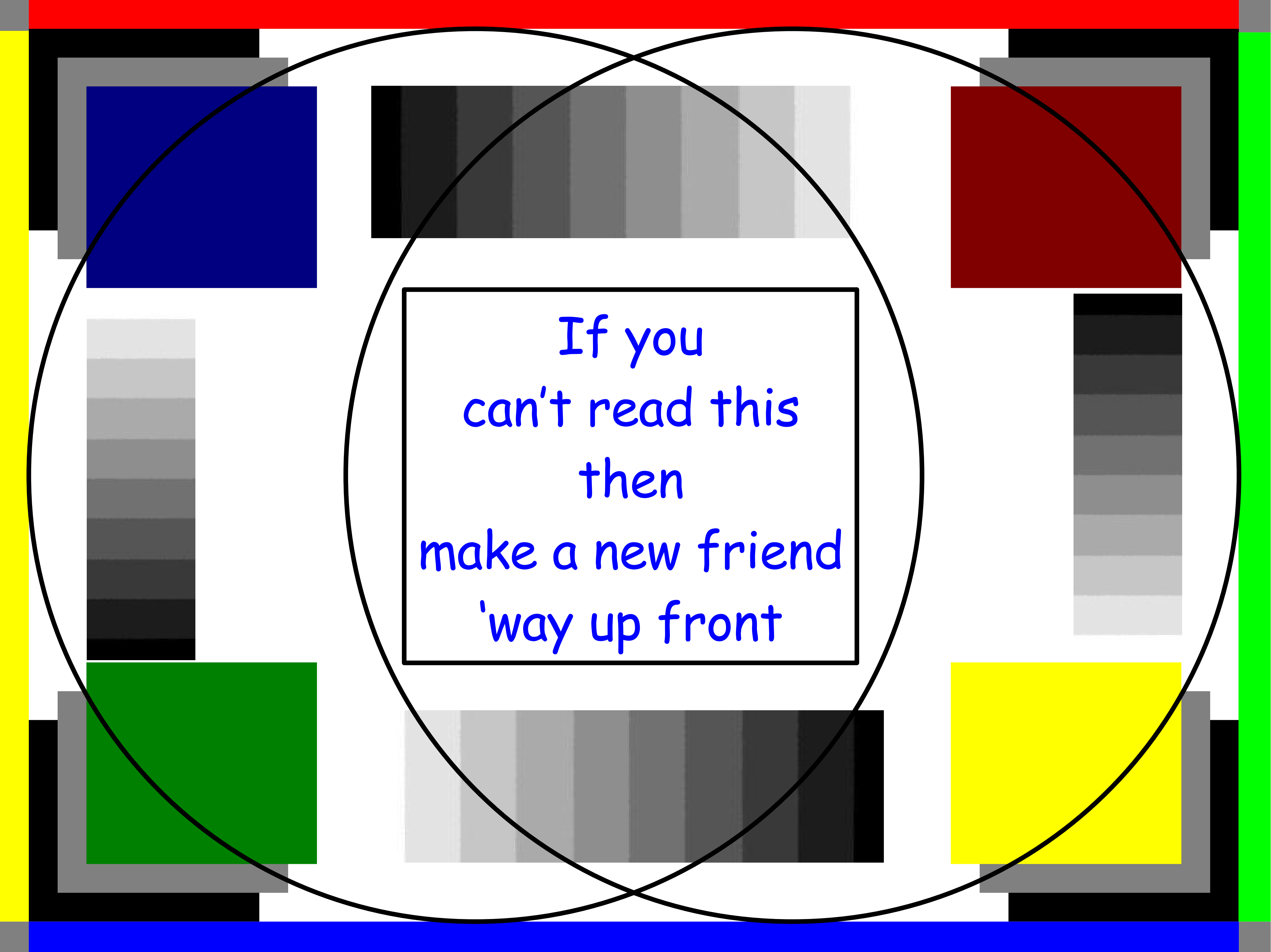


If you
can't read this
then
make a new friend
'way up front

Making Chips

~

TUX in the Machine Shop

Ed Nisley
September 2007
MHVLUG Poughkeepsie

Upcoming Events

Motivational Pictures

Machine shops & milling machines
Computer Numerical Control
Numbers and where to get them
Machine (non-PC) programming

Stepper motors & step timing
Real-time Operating Systems
Why Linux?

Show-n-Tell

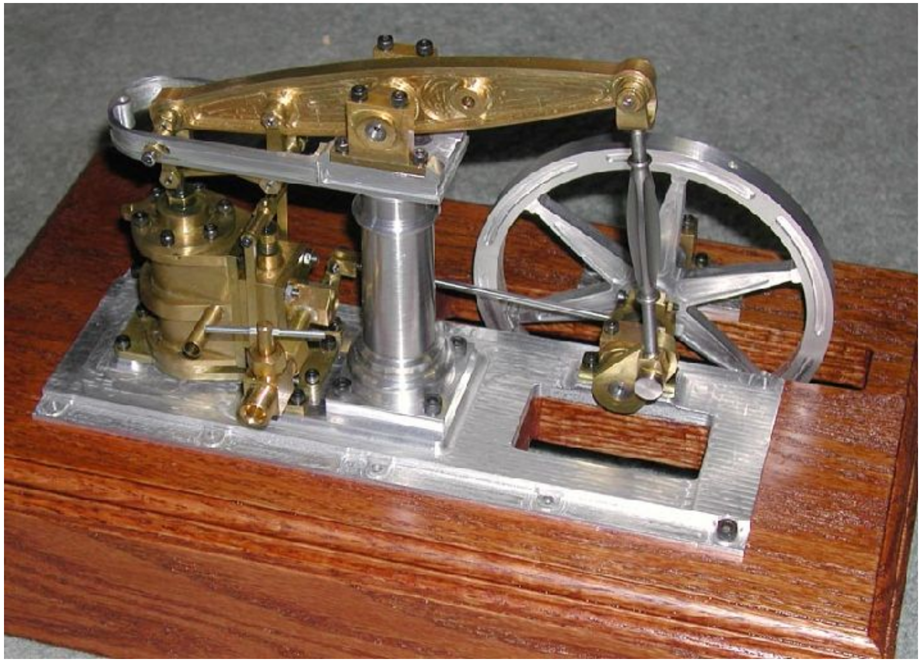
* Must *

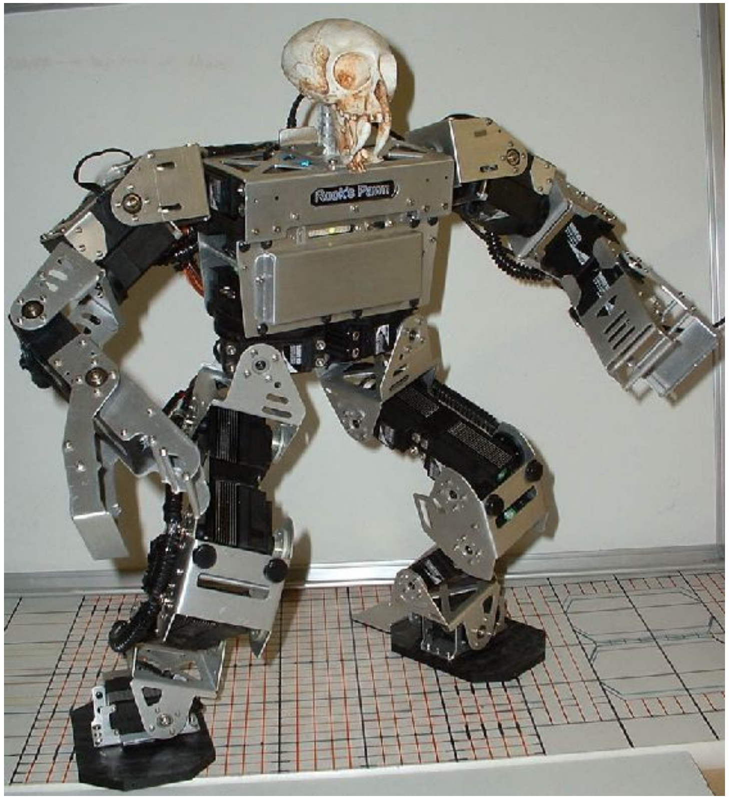
* Make *

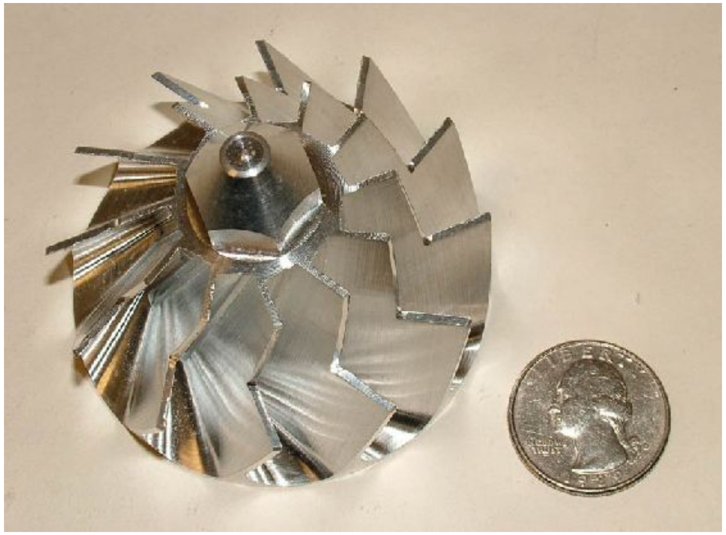
* Shiny *

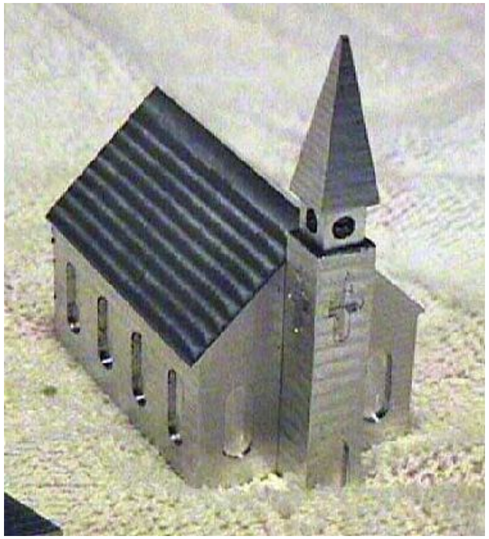
* Objects *

http://statmandesigns.com

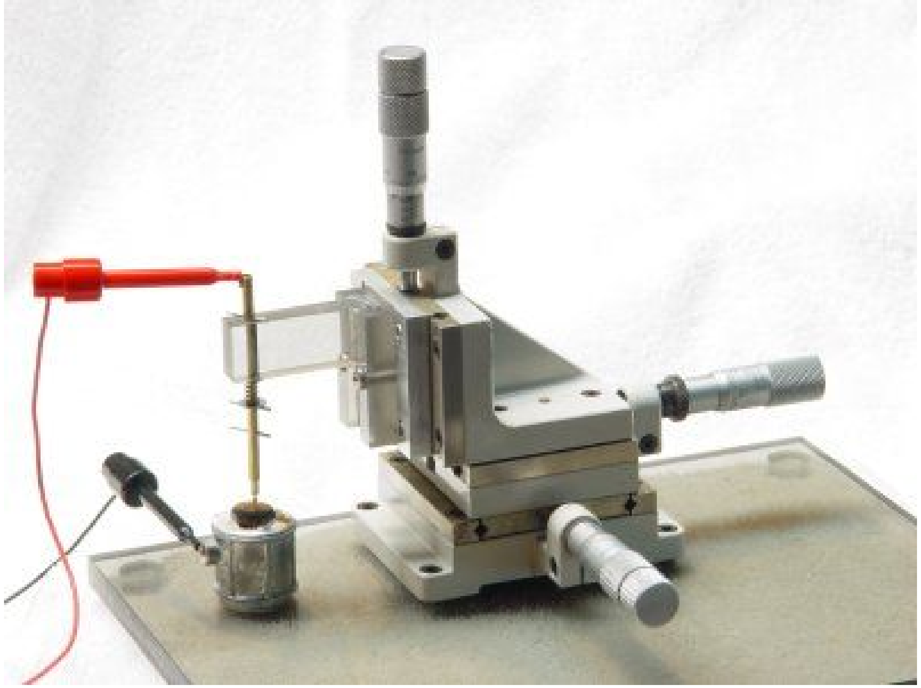


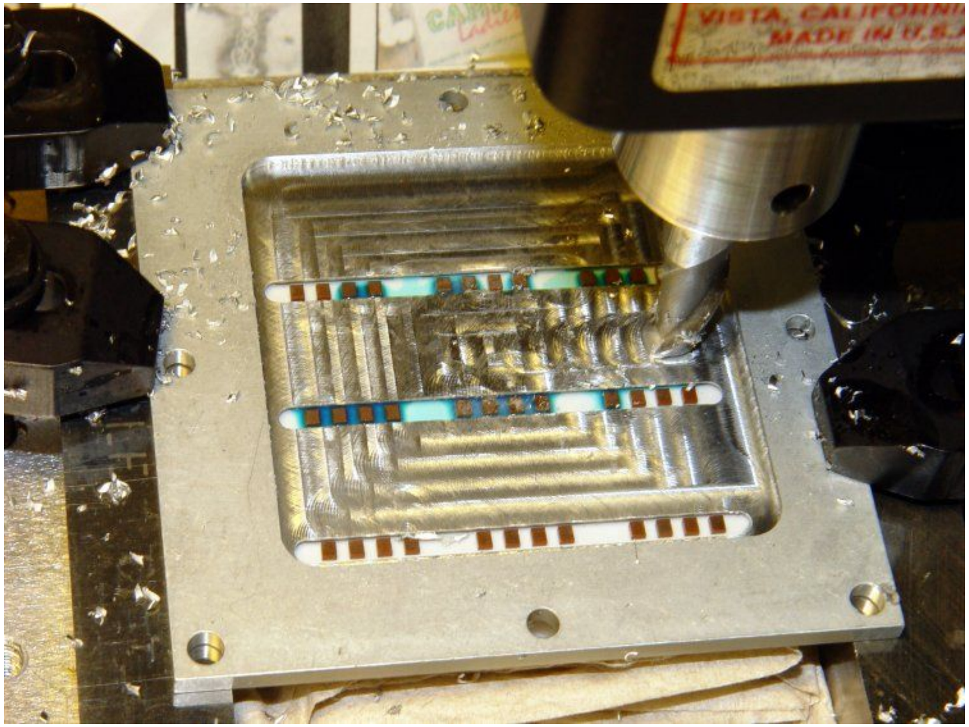


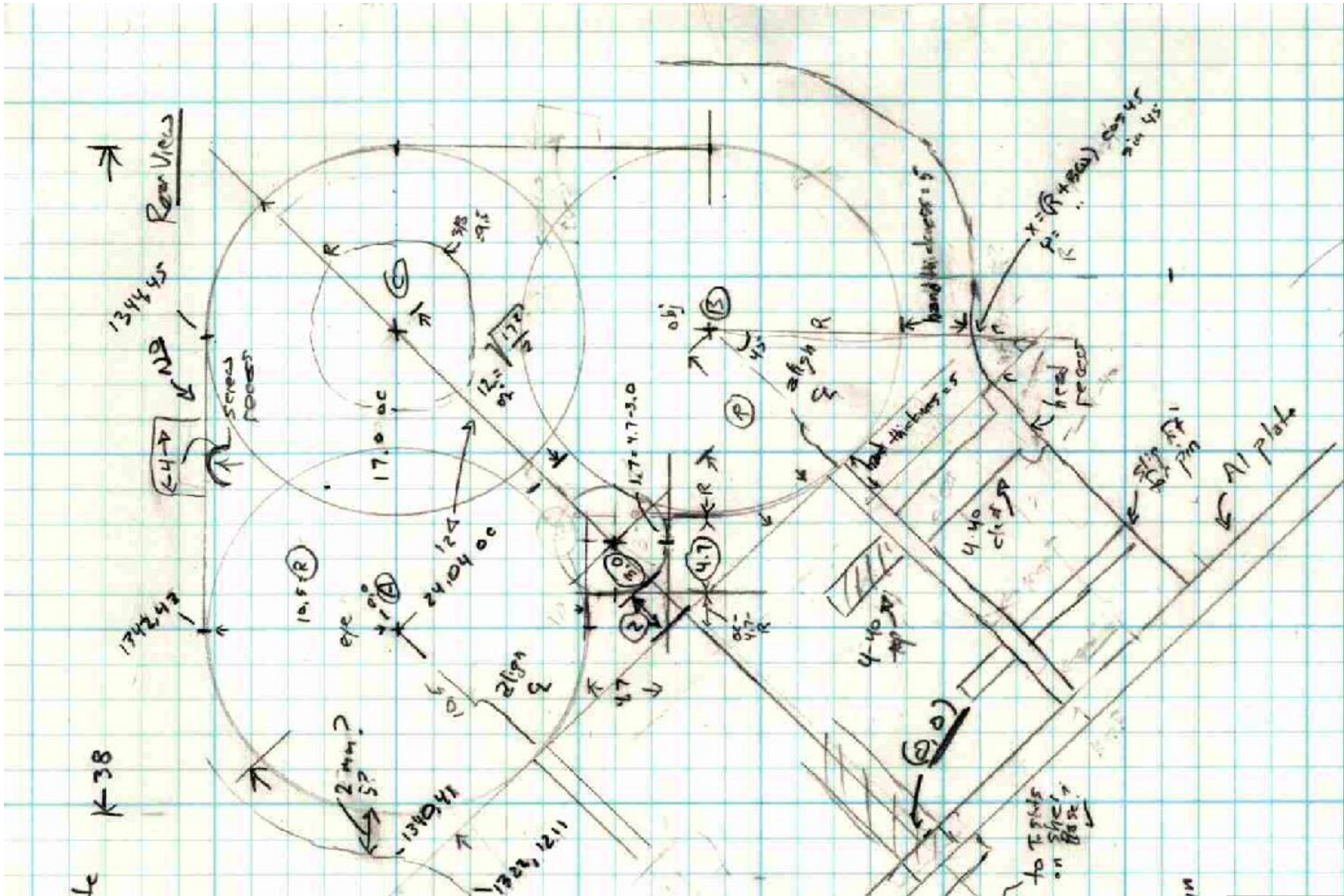




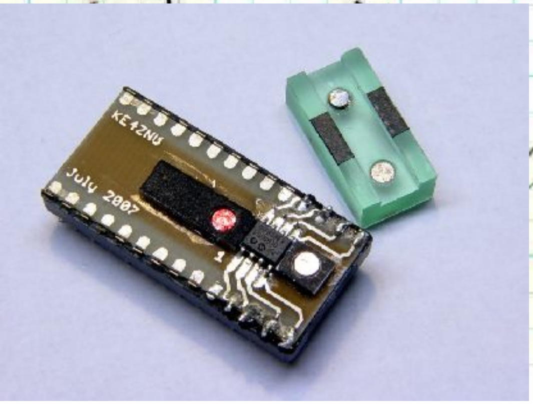
http://sherline.com/CNCproj.htm




VISTA, CALIFORNI
MADE IN U.S.A

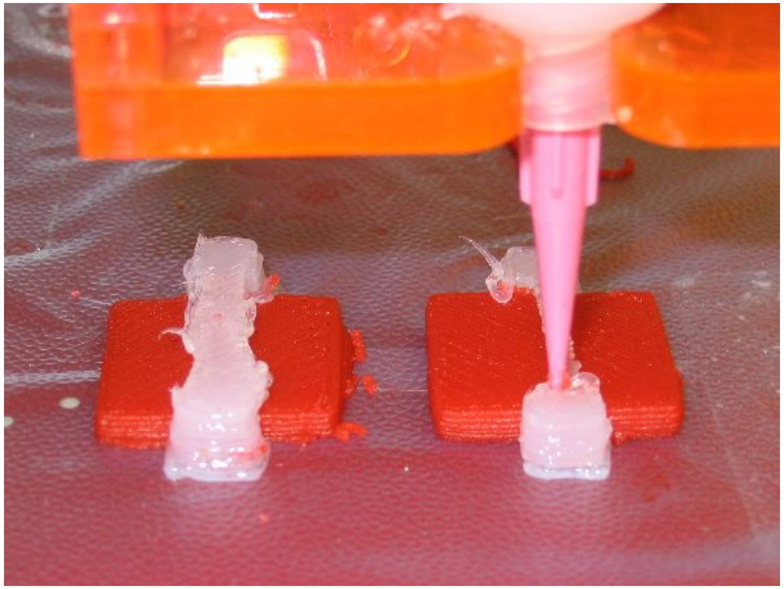

Rear View
1344,45
1342,48
1349,48
1328,12,11
eye
obj
17.0 oc
24.04 oc
align ℄
head thickness = 5
4-40 clear
Al plate
K-38
2 mm?

DIAMOND
ANTENNA

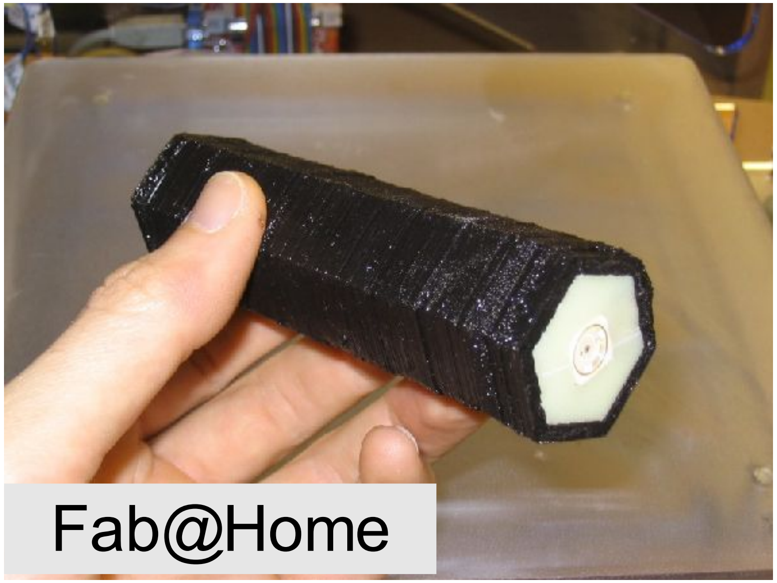

KE4ZNU
July 2007

CM 1 2 3 4

Not *Squishy* Objects

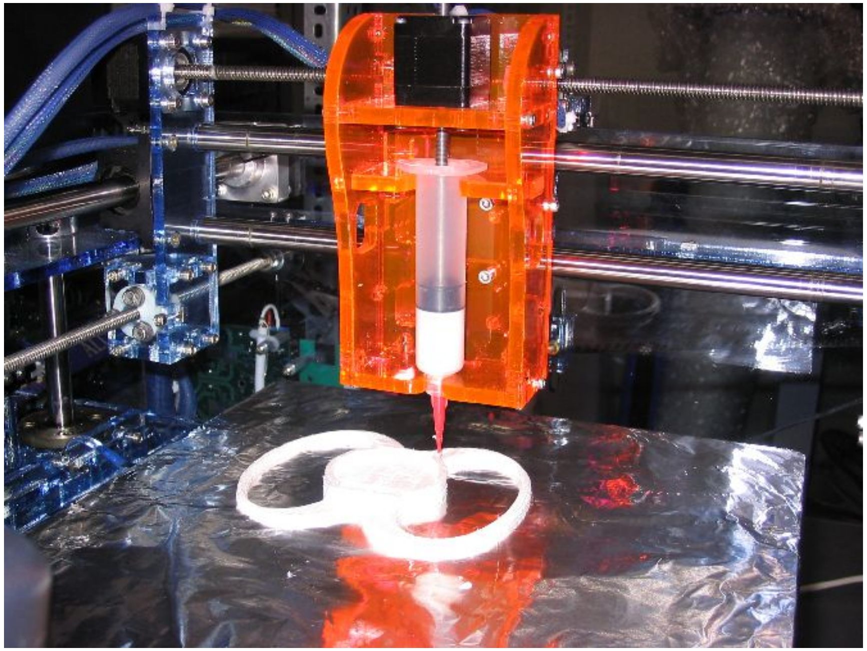


Silicone
snot
bridge

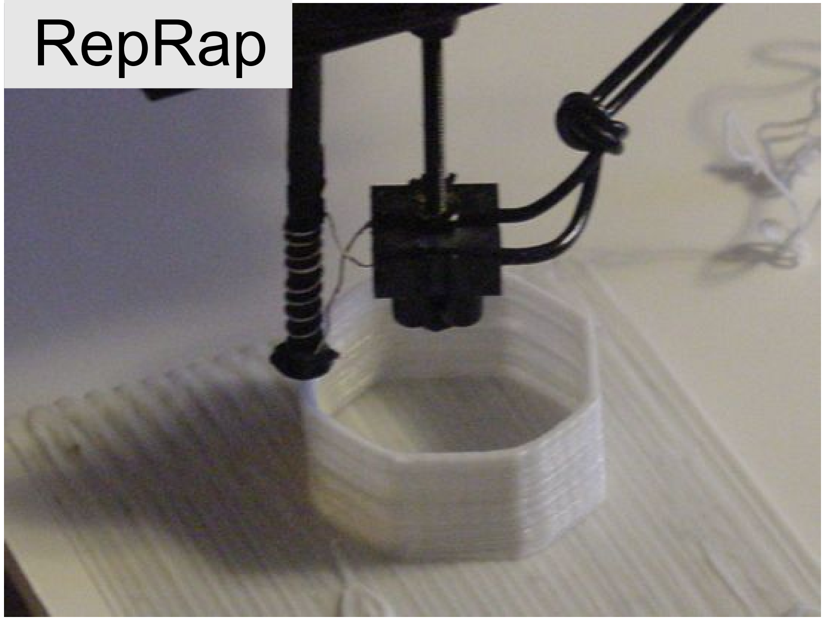


Silicone
snot
+ epoxy
LED light

Fab@Home



Band
over
watch



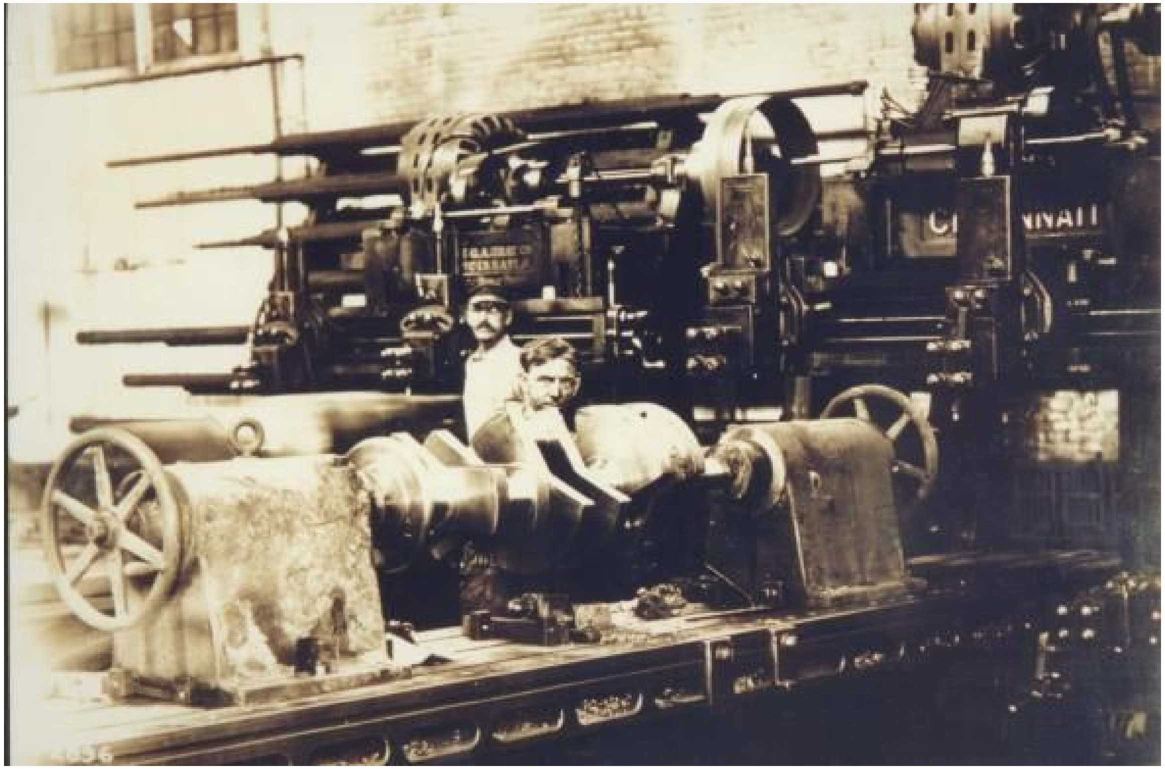
RepRap

Shotglass

Machine Shop

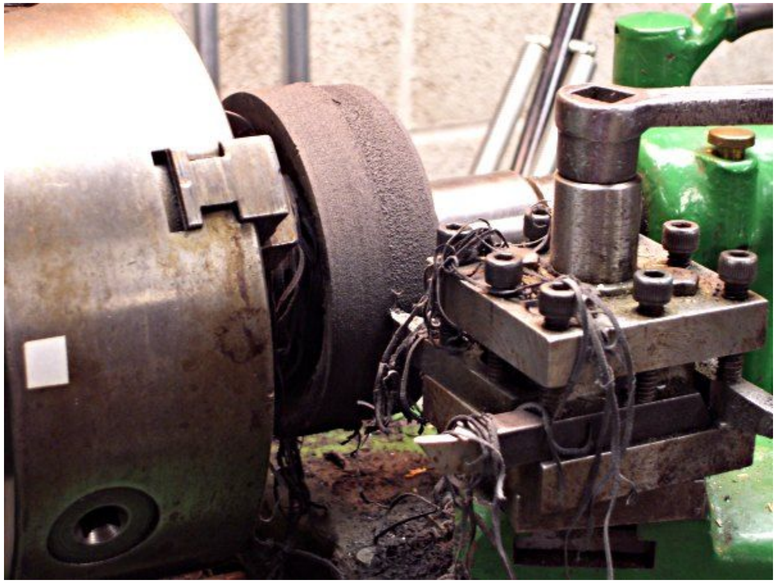
A room, building, or company where machining is done is called a machine shop.

Wikipedia



http://www.explorepahistory.com/displayimage.pl

Machine Shop

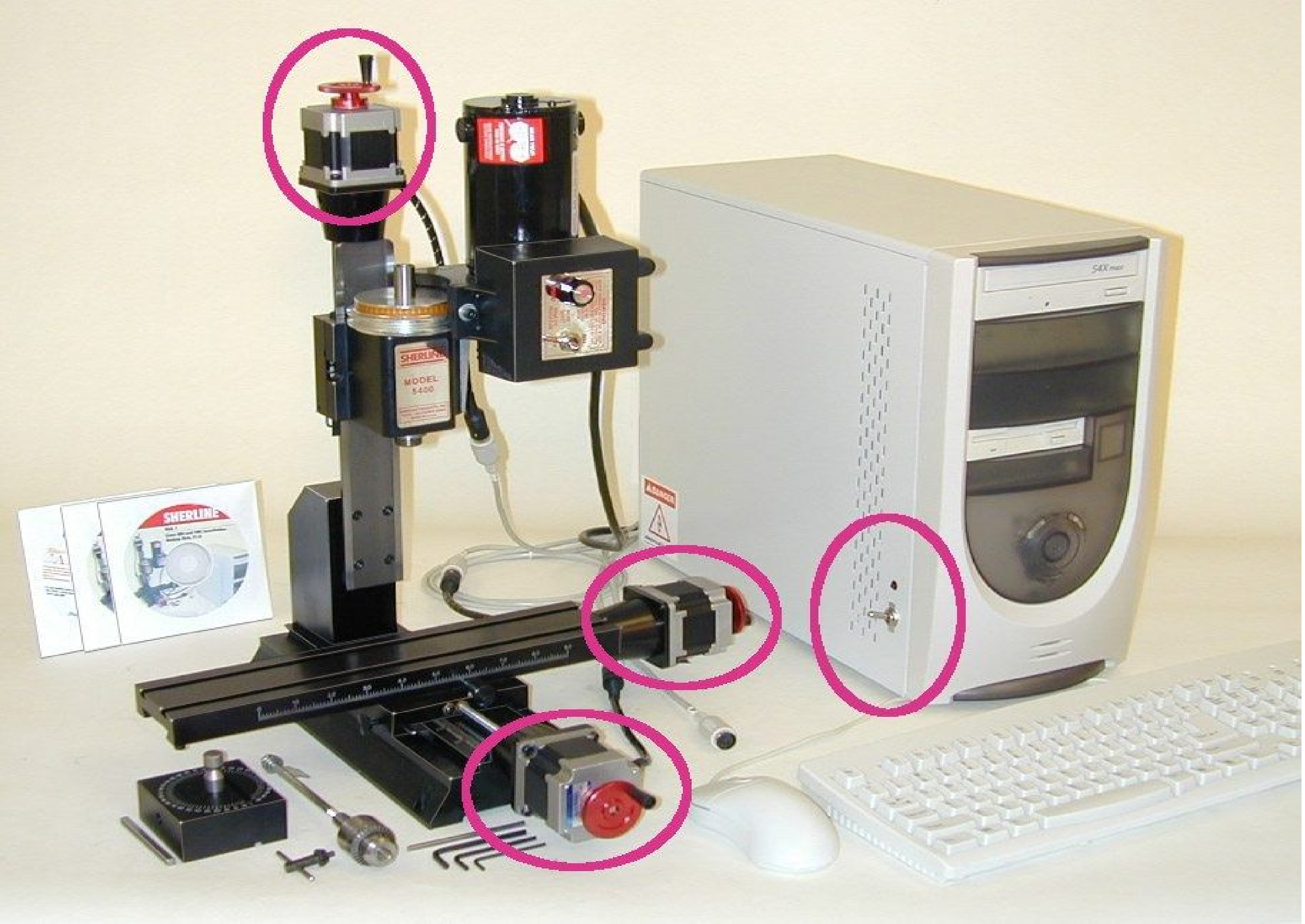


Hey, kids,
try this
at home!

Milling Machine

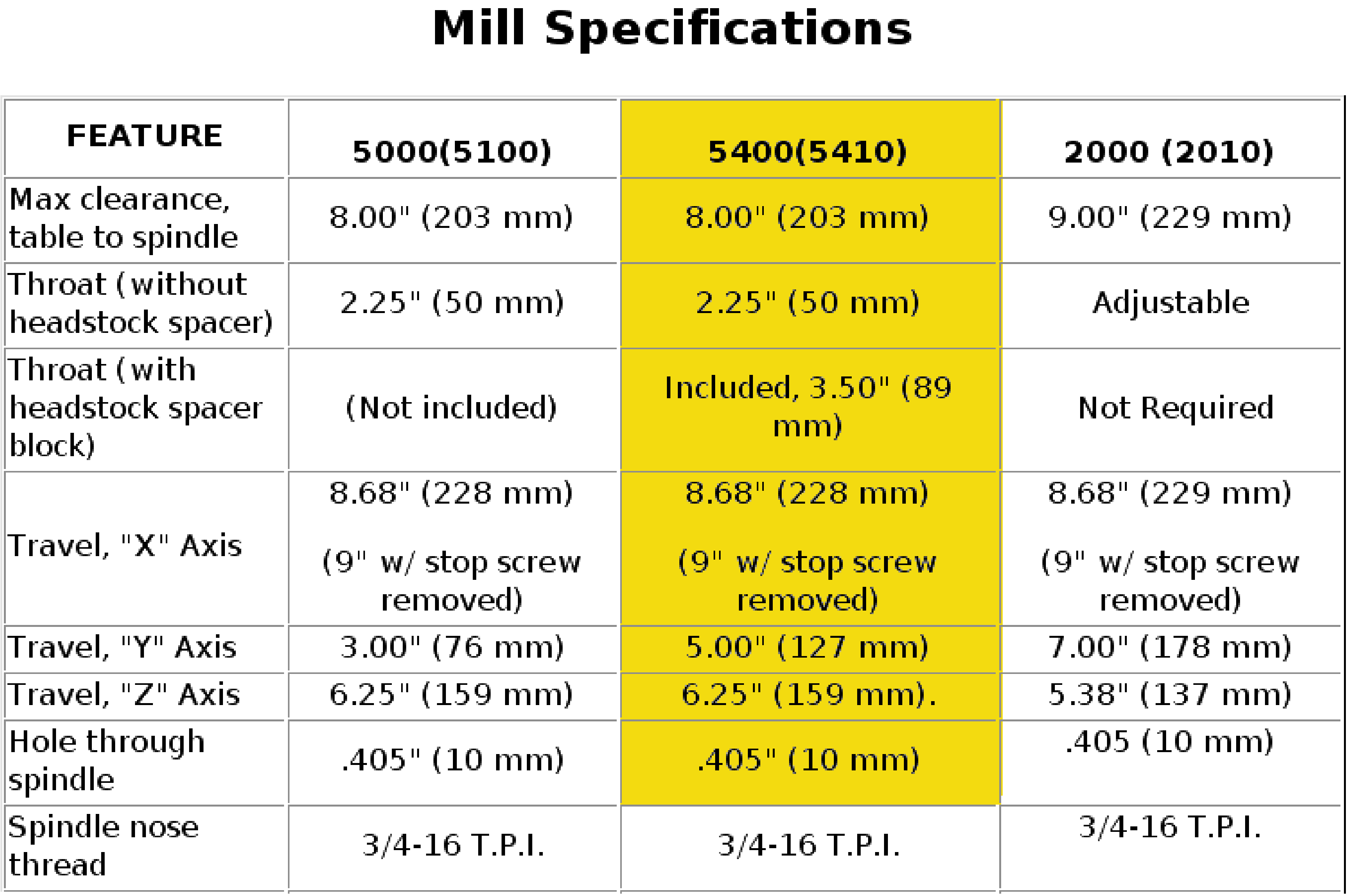
http://www.iwsteamrailway.co.uk/pages/locos/mt_2002.htm

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 workpiece must be

- Utterly lacking overhang
- Clamped downward
- Fairly durable

You can't make

- Sharp concave XY corners

Small Projects

Why not just buy a new door latch?

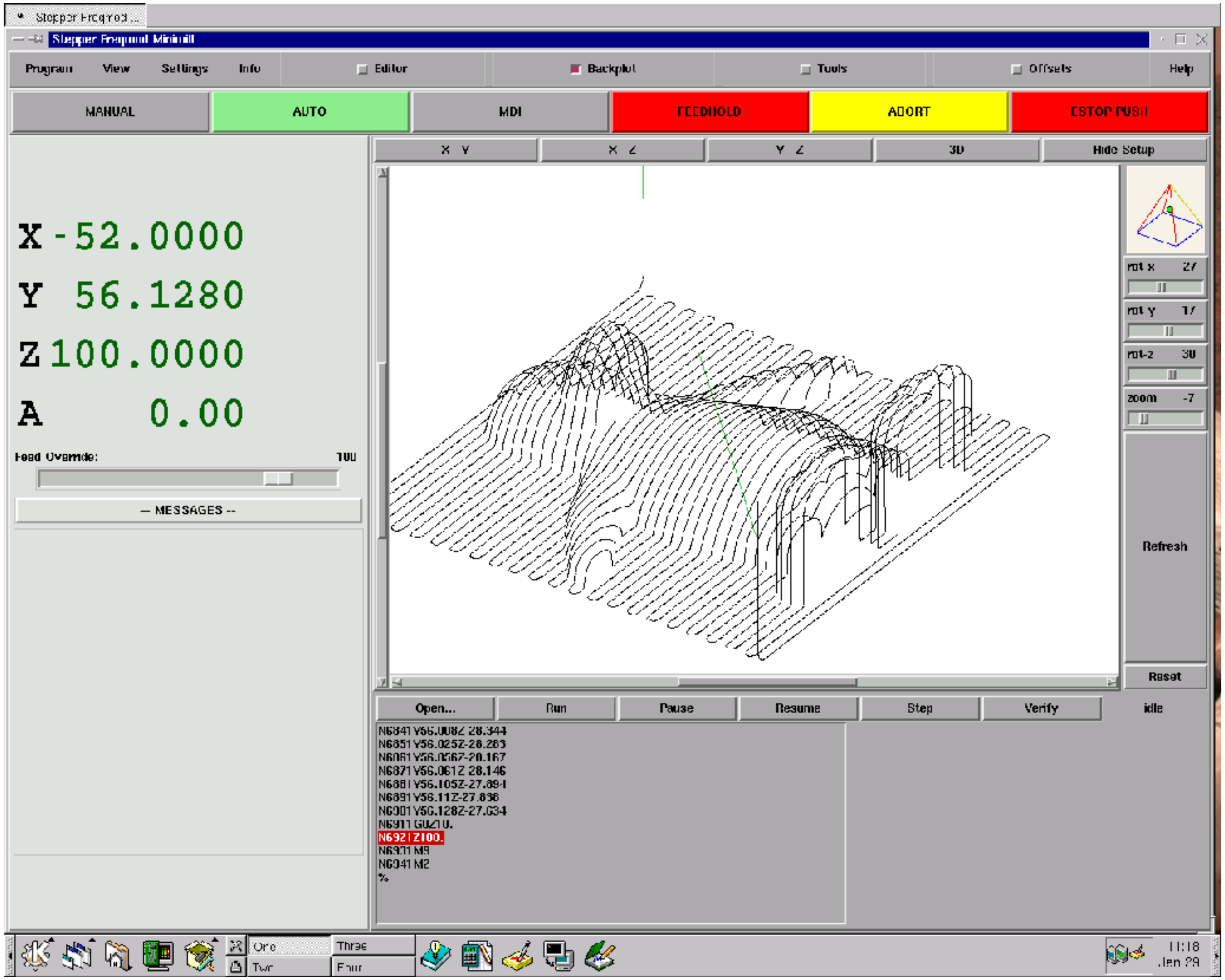
I did, but it didn't fit. No surprise...

Just Draw What You Want?

http://www.auma.com/

For Some Drawings, Maybe

"Chips"
~
LinuxCNC
Mascot



```
X -52.0000
Y  56.1280
Z 100.0000
A     0.00
```

Feed Override: 100

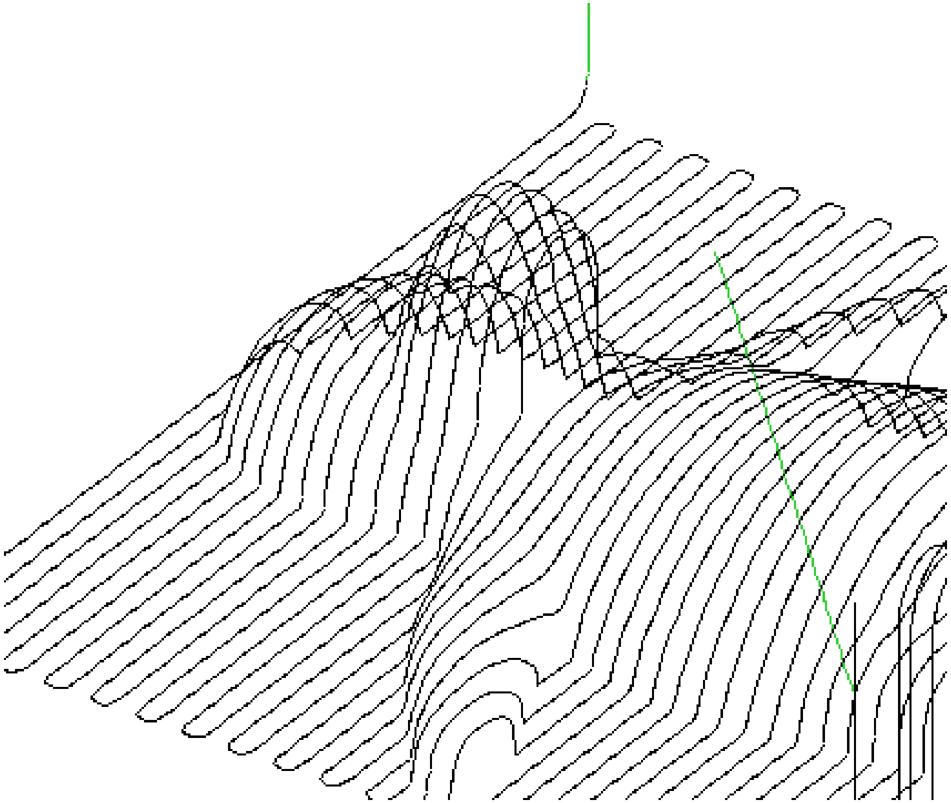
rot x 27
rot y 17
rot z 30
zoom -7

idle

```
N6841 Y56.008Z 28.344
N6851 Y56.025Z-28.263
N6861 Y56.056Z-28.167
N6871 Y56.061Z 28.146
N6881 Y56.105Z-27.894
N6891 Y56.11Z-27.836
N6901 Y56.128Z-27.634
N6911 G0Z10.
N6921 Z100.
N6931 M9
N6941 M2
%
```

G-Code = Coordinates

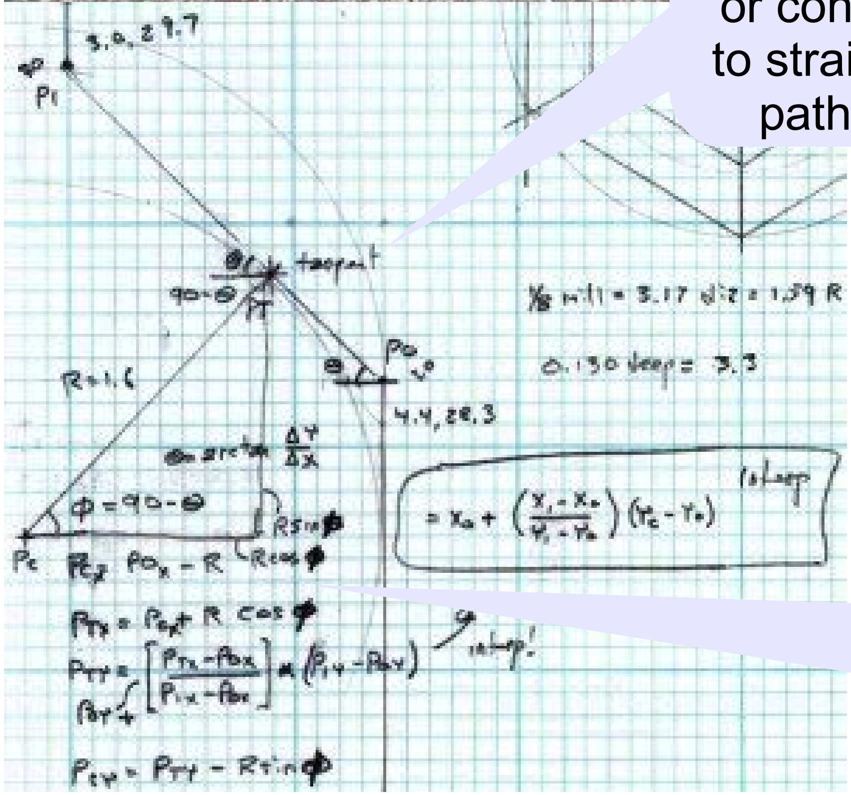
```
%
N05 ( This program is copyright of Rab Gordon, Gary Drew, and Paul Corner.)
N10 ( It is released here under a GPL without warranty to do with as you may.)
N15 ( The part is cut from a 100x100x50mm block with the zero point at the )
N20 ( center top of the block. Cutter is a 10mm ball nose. )
N30G21
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 ...

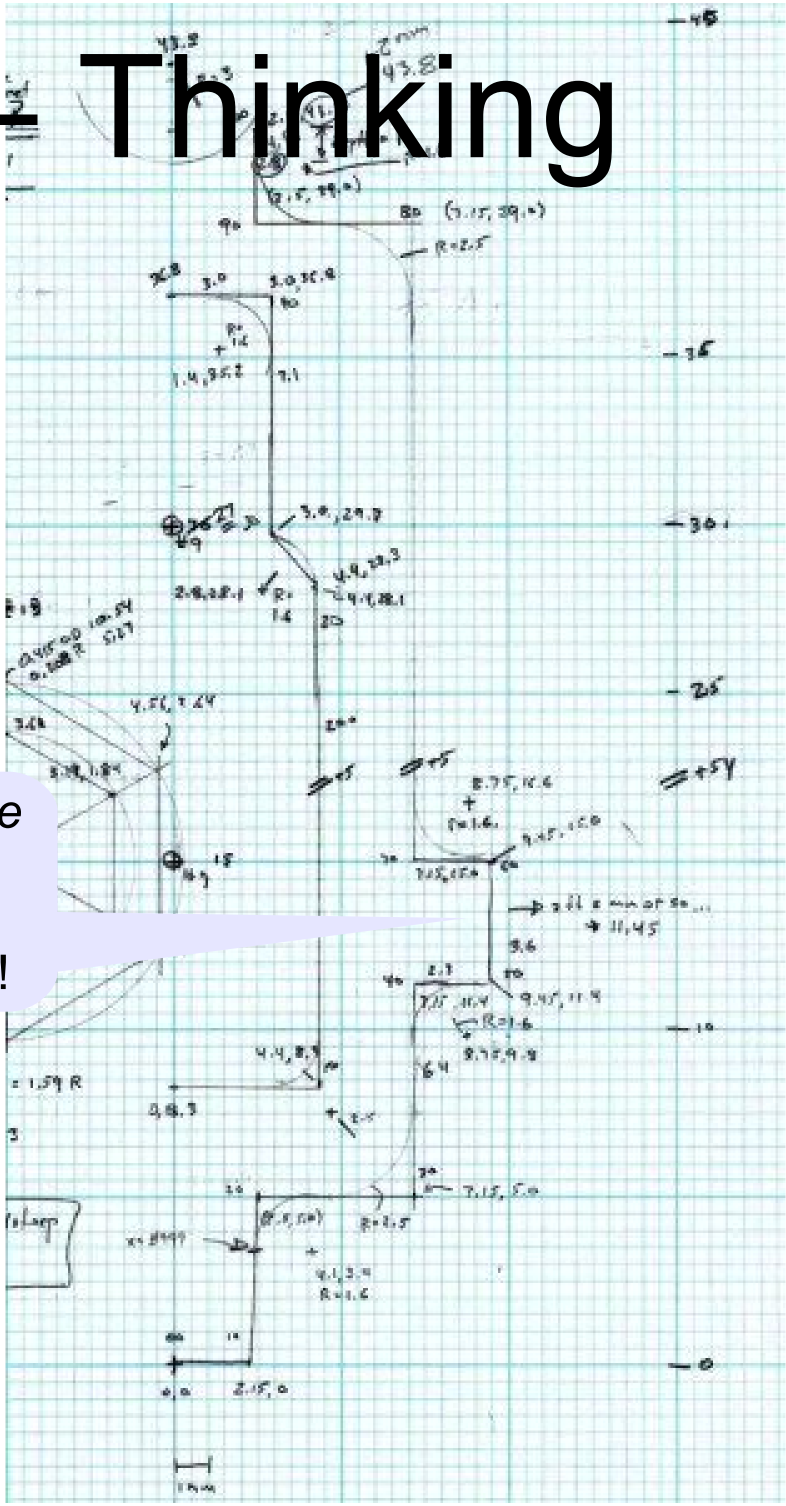
Door Latch Pull – Thinking

You must have numbers for those fancy CAD drawings!



All circular paths must be tangent or convex to straight paths

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



Where *are* all these points? Measure!

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!

Pre-processor (python?) 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 now supports programming constructs!

G-Code

All the charm of machine-code programming

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 non-standard feature set...

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
=
Your inputs

Door Latch Pull – Main Loop

Woot!

```
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
```

Door Latch Pull – Cutting!

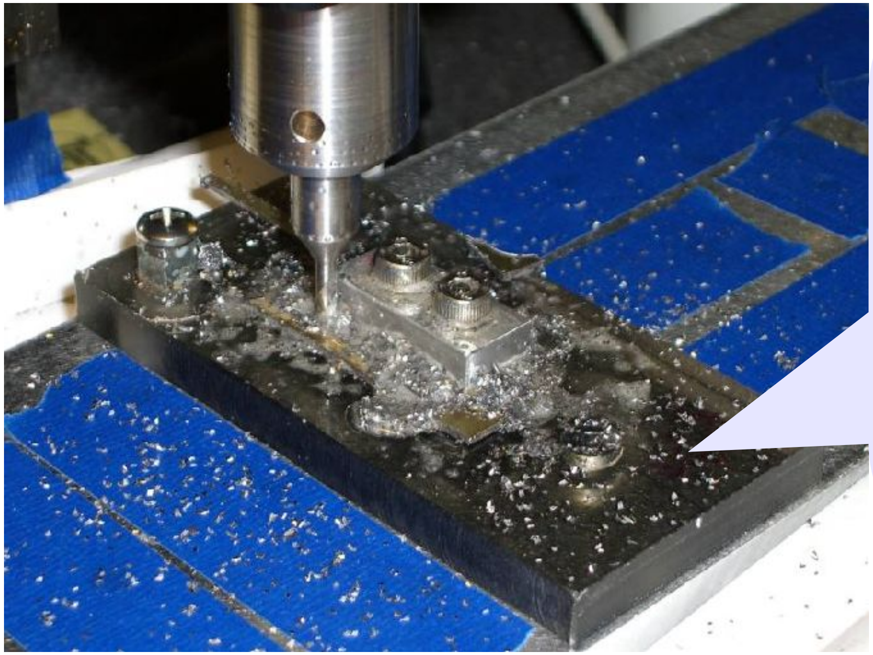
```
O100 SUB
G1 X[0-[#2010 - #1200]] Y#2011 Z#1                (ramp down along slot bottom)
G2 X[0-#2010] Y[#2011 + #1200] I0 J#1200          ( ... LL corner)
#800 = [90 - ATAN [#2031 - #2021] / [#2020 - #2030]] (angle: fillet arc ctr to tangent pt)
#802 = [#2020 - #1200]                            (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 to LR corner)
G2 X[#2010 - #1200] Y#2011 I[0-#1200] J0          (fill
G1 X#2000 Y#2001                                  (re
O100 ENDSUB
```

Linear

Circular

Calculate coordinates based on geometry & measurements

Real-world I/O



First, you must make the fixture

G-code must clear the clamps!

Bottom Line

“CNC” machining requires *Numbers*

Numbers

▼

Coordinates

▼

Tool Path

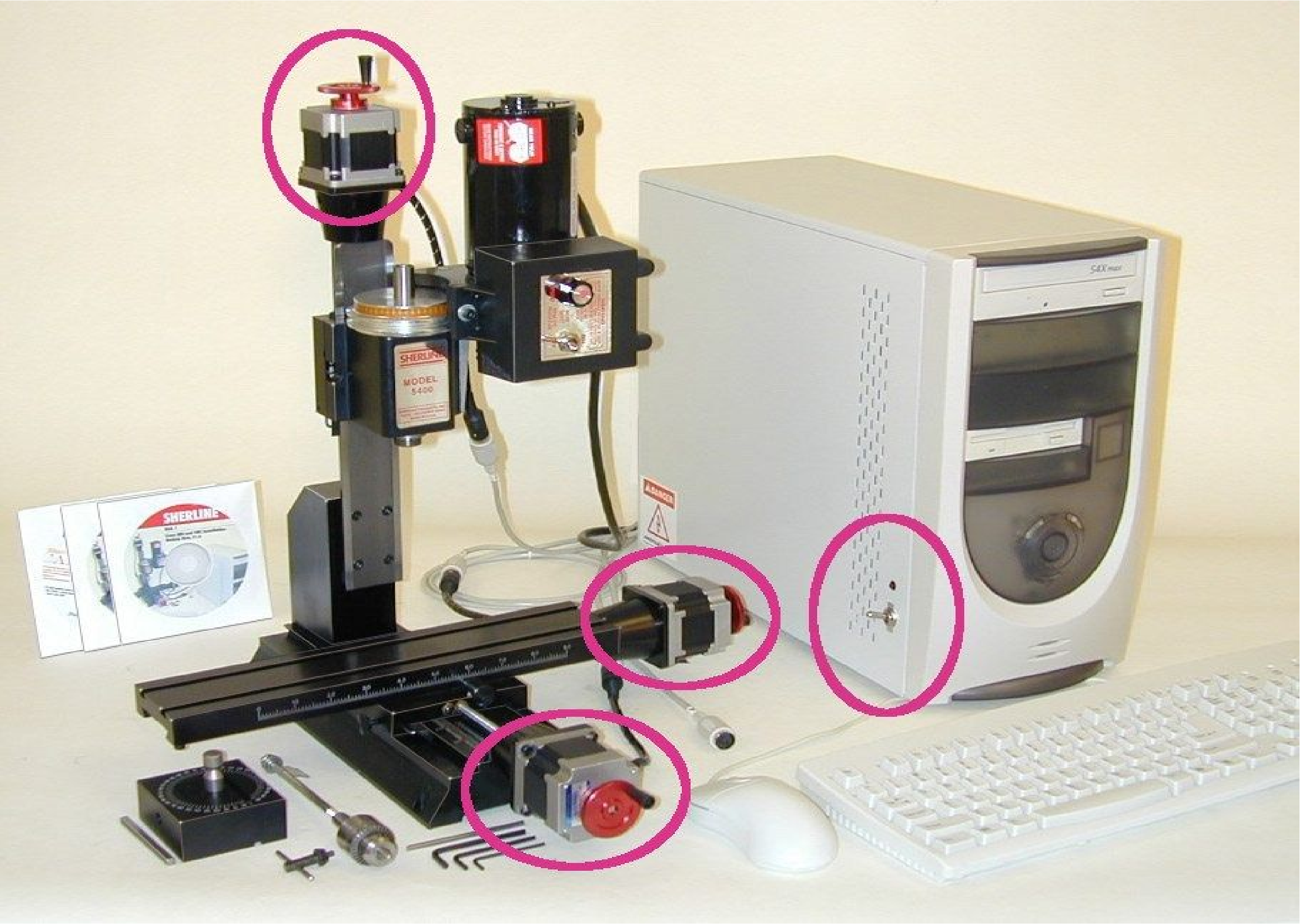
▼

Motion Control

▼

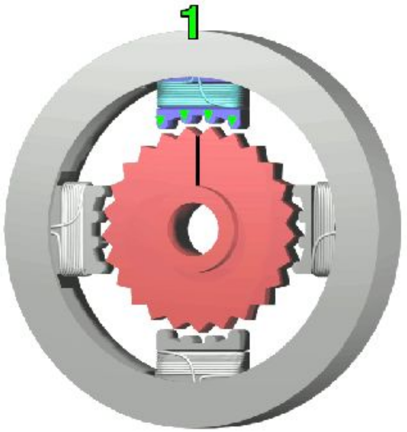
Motor Drive

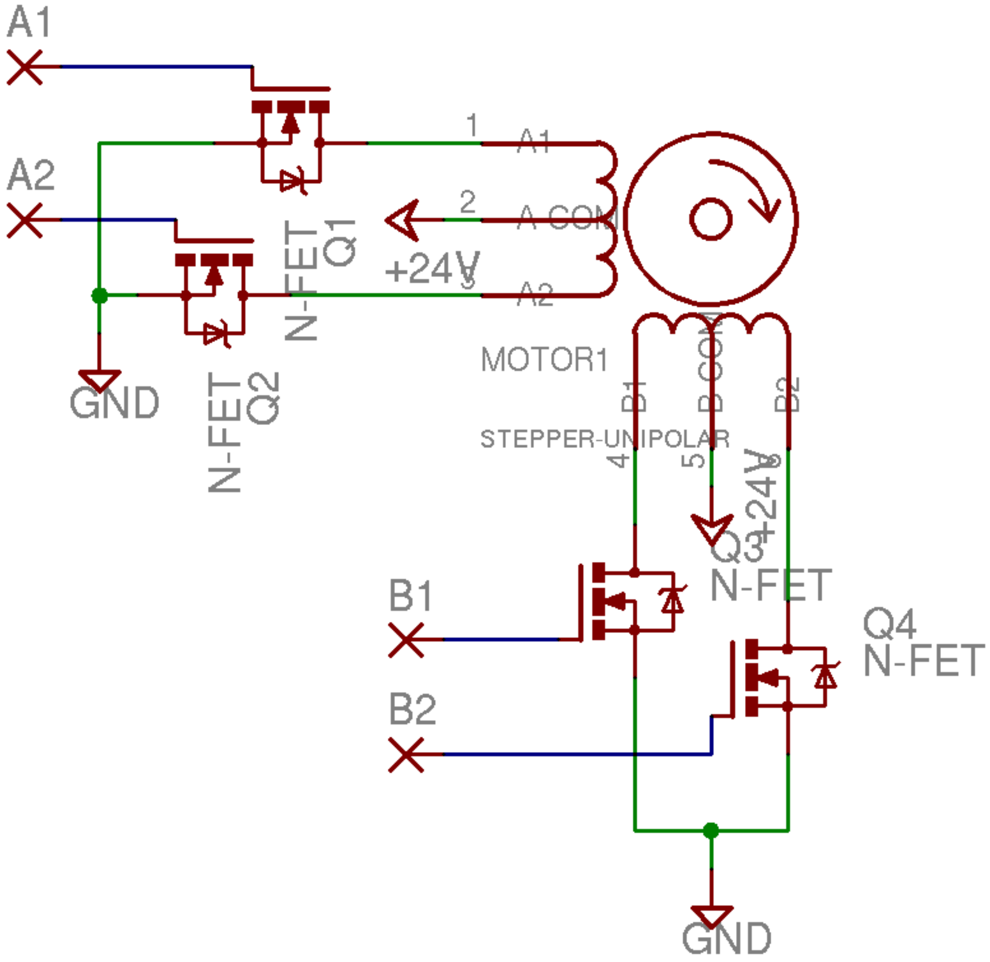
Stepper Motors

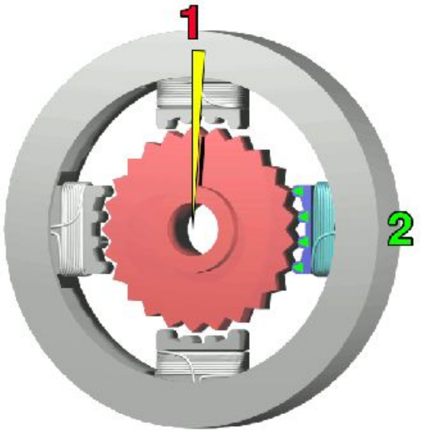


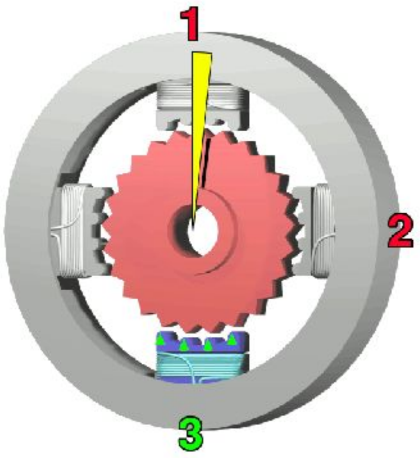
http://sherline.com/CNCmenu.htm

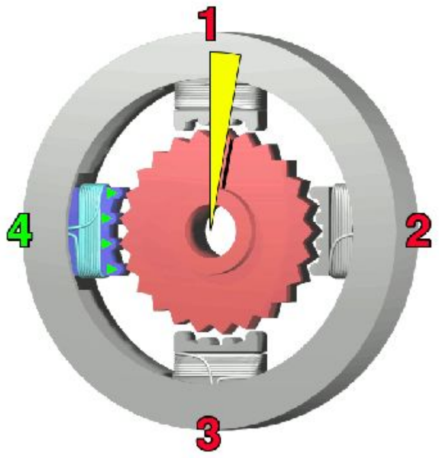
Stepper Motor





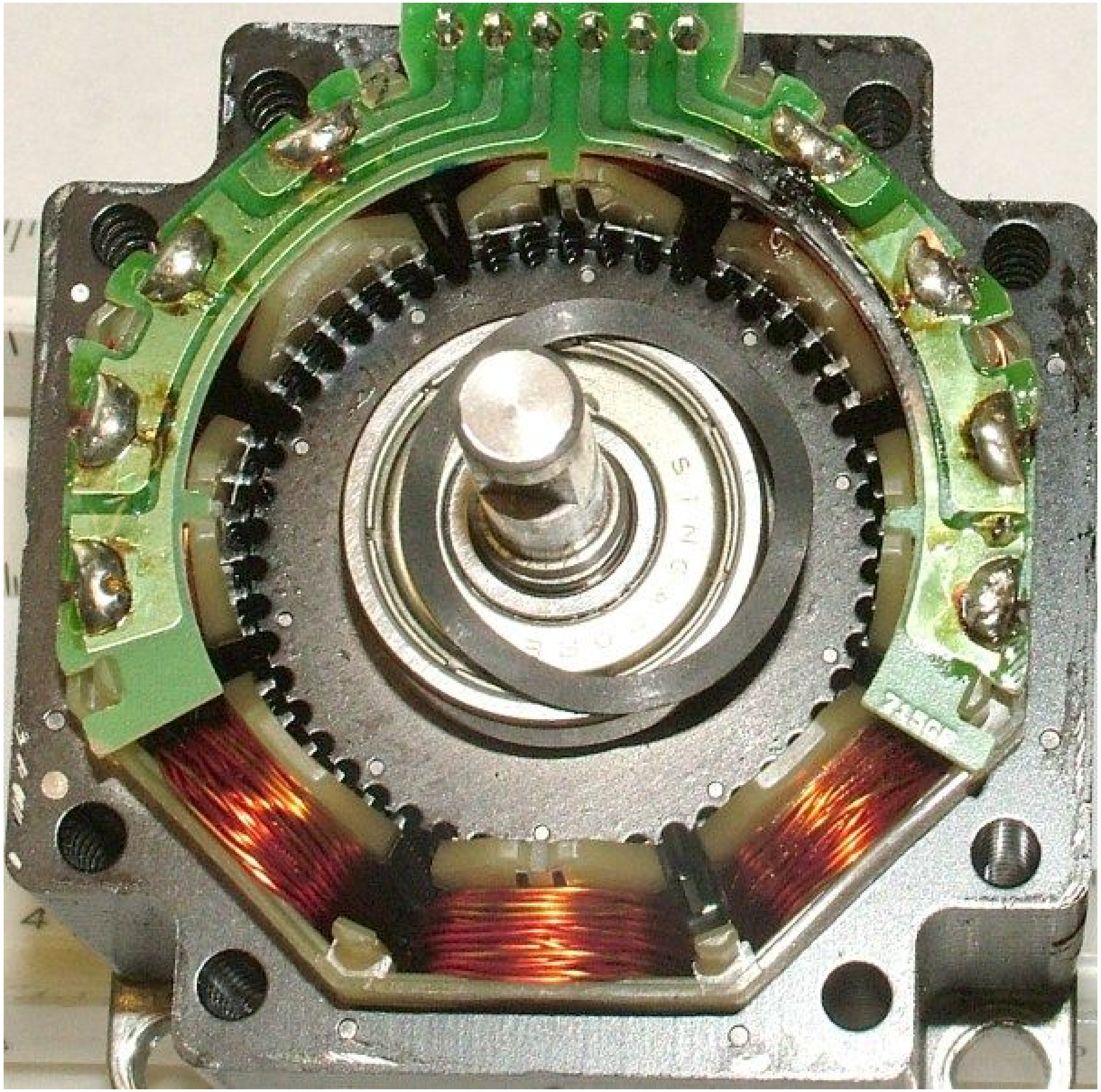


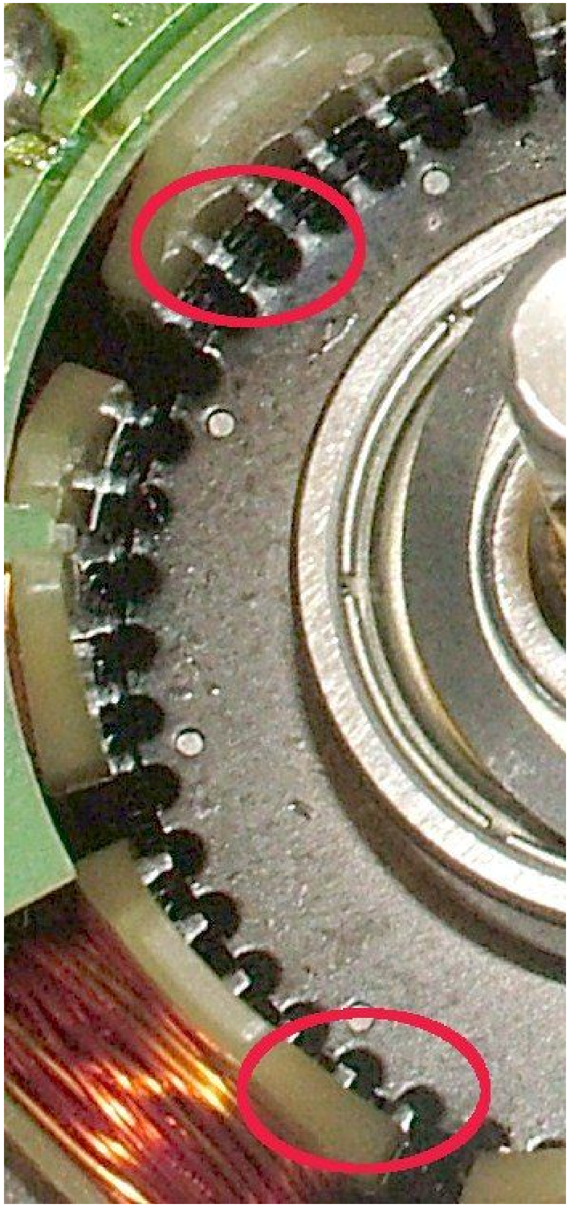




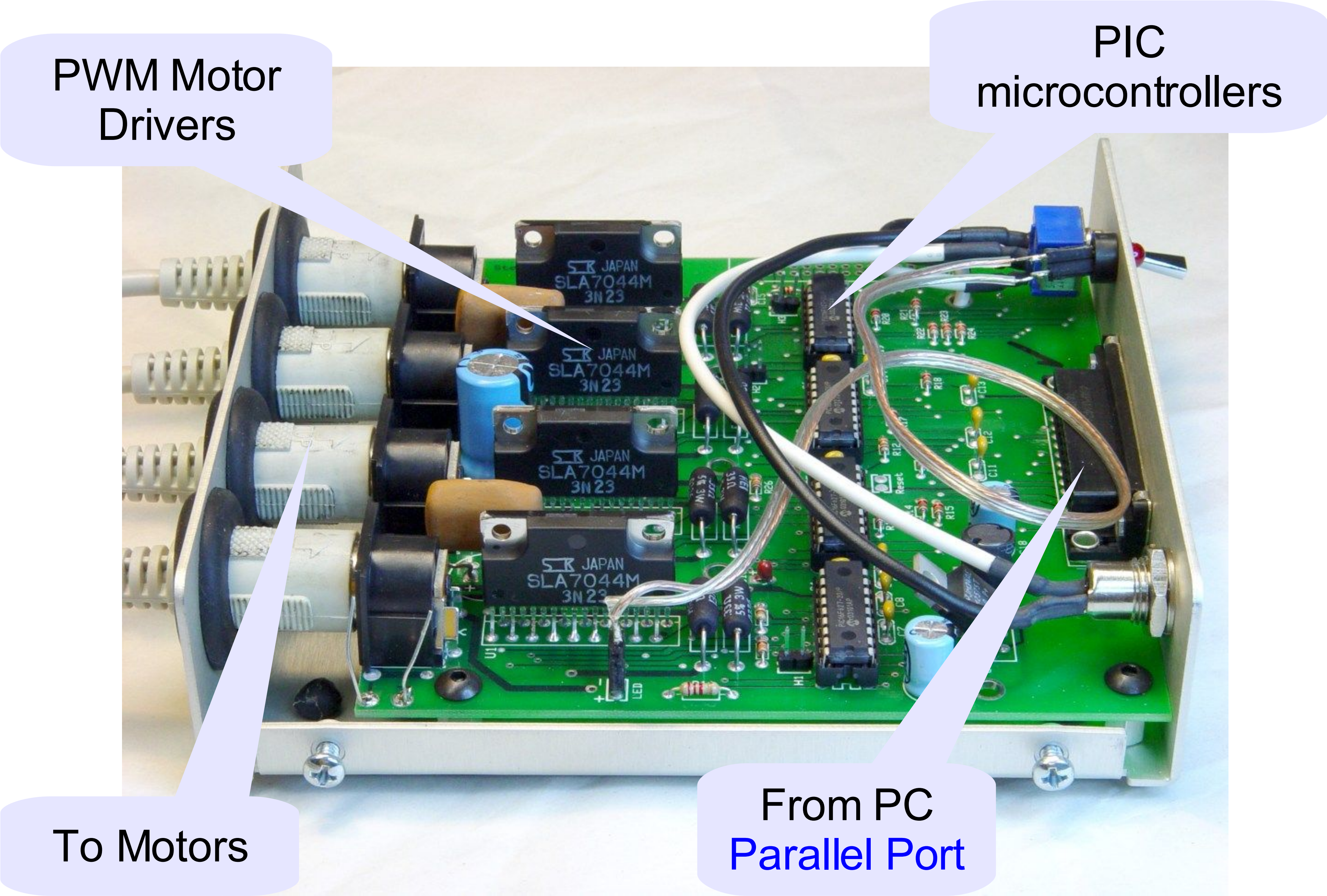
http://en.wikipedia.org/wiki/Stepper_motor

Stepper Steps





Stepper Motor Controller



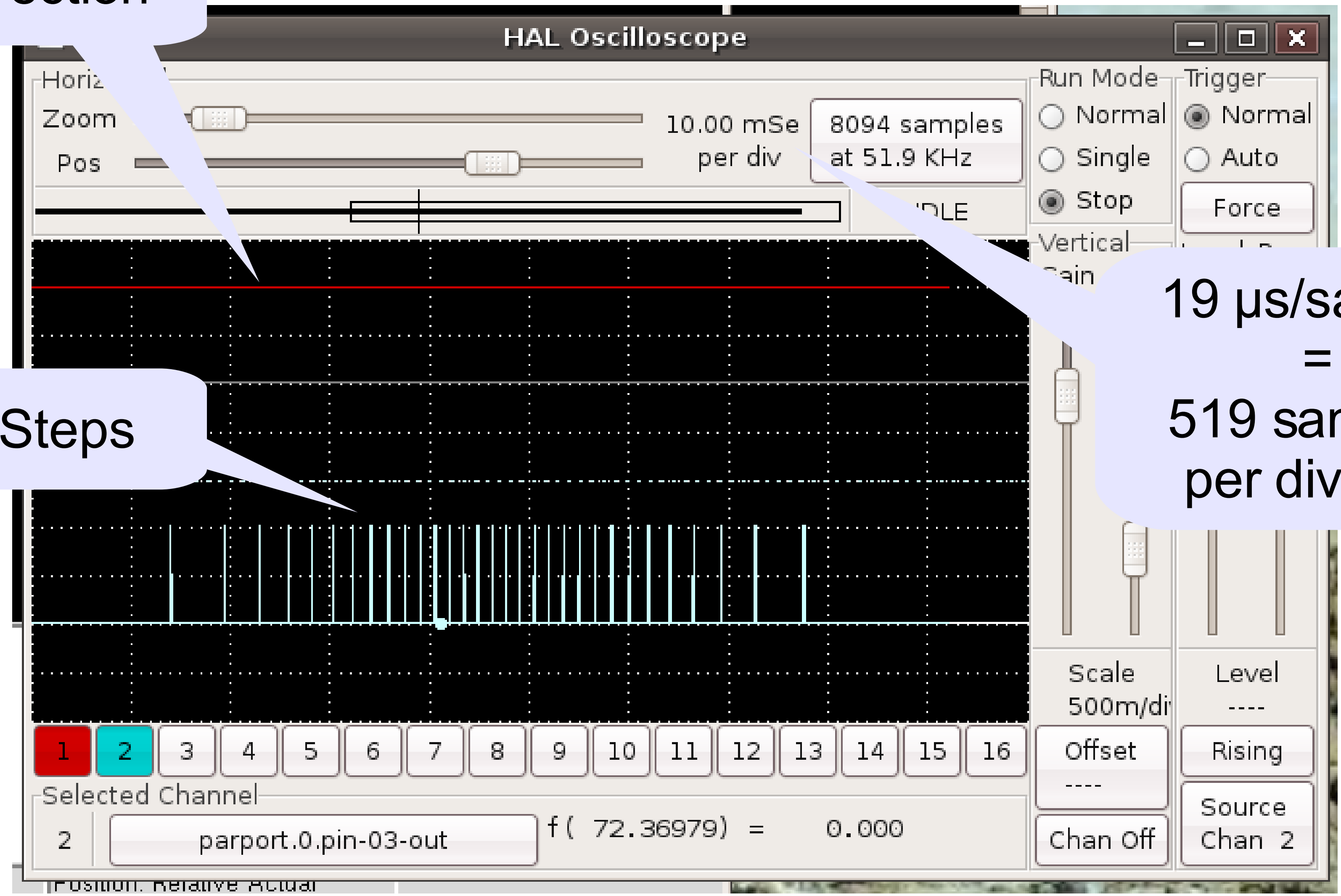
PWM Motor Drivers

PIC microcontrollers

To Motors

From PC Parallel Port

Stepping Pulses



2 parport.0.pin-03-out f(72.36979) = 0.000

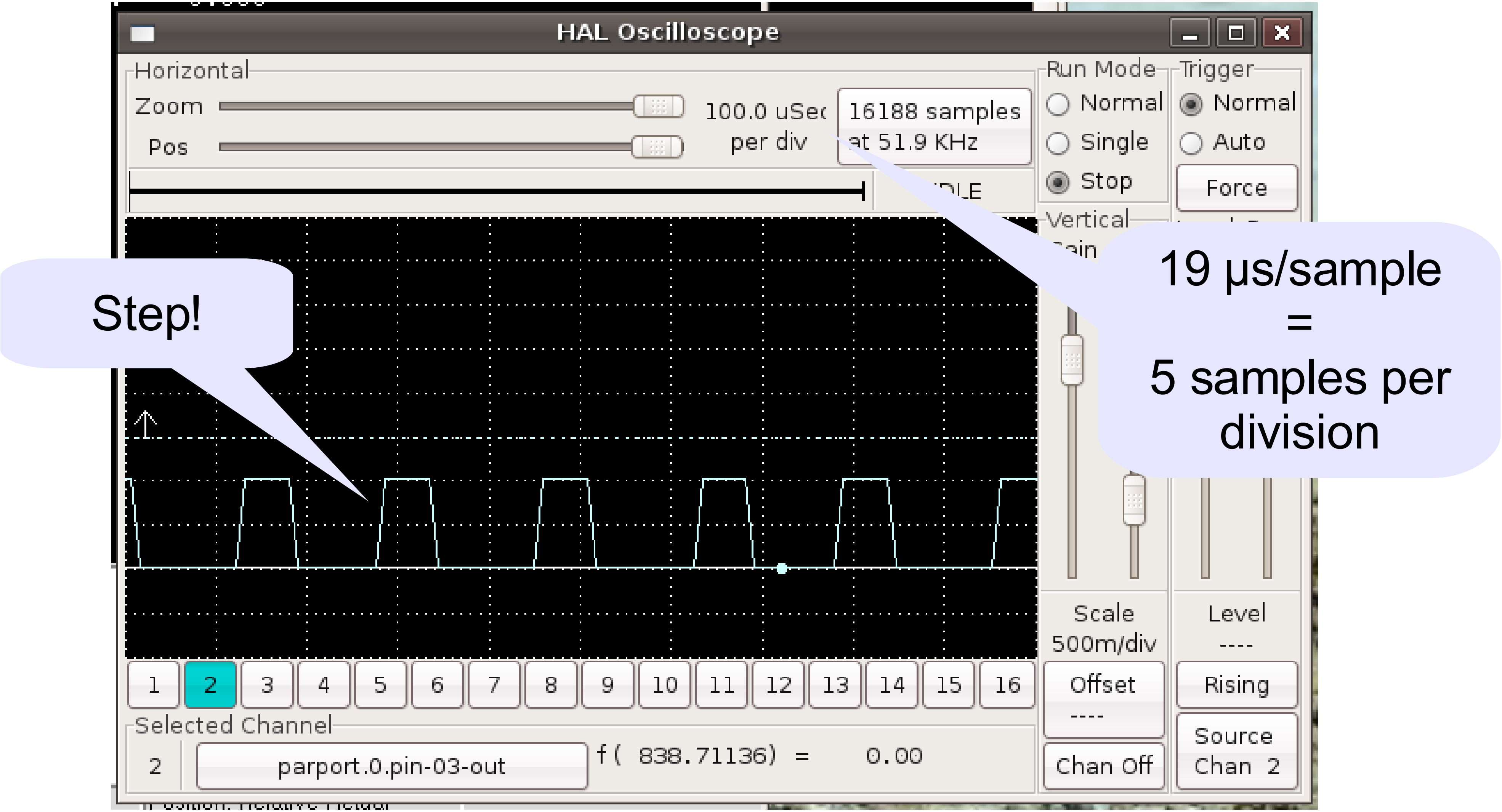
Direction

Steps

19 µs/sample = 519 samples per division

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

Stepping Speed



100.0 uSec per div

16188 samples at 51.9 KHz

Run Mode: ○ Normal ○ Single ● Stop

Trigger: ● Normal ○ Auto

Scale 500m/div

Offset ----

Level ----

Source Chan 2

Selected Channel: 2 parport.0.pin-03-out f(838.71136) = 0.00

Step!

19 µs/sample = 5 samples per division

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!

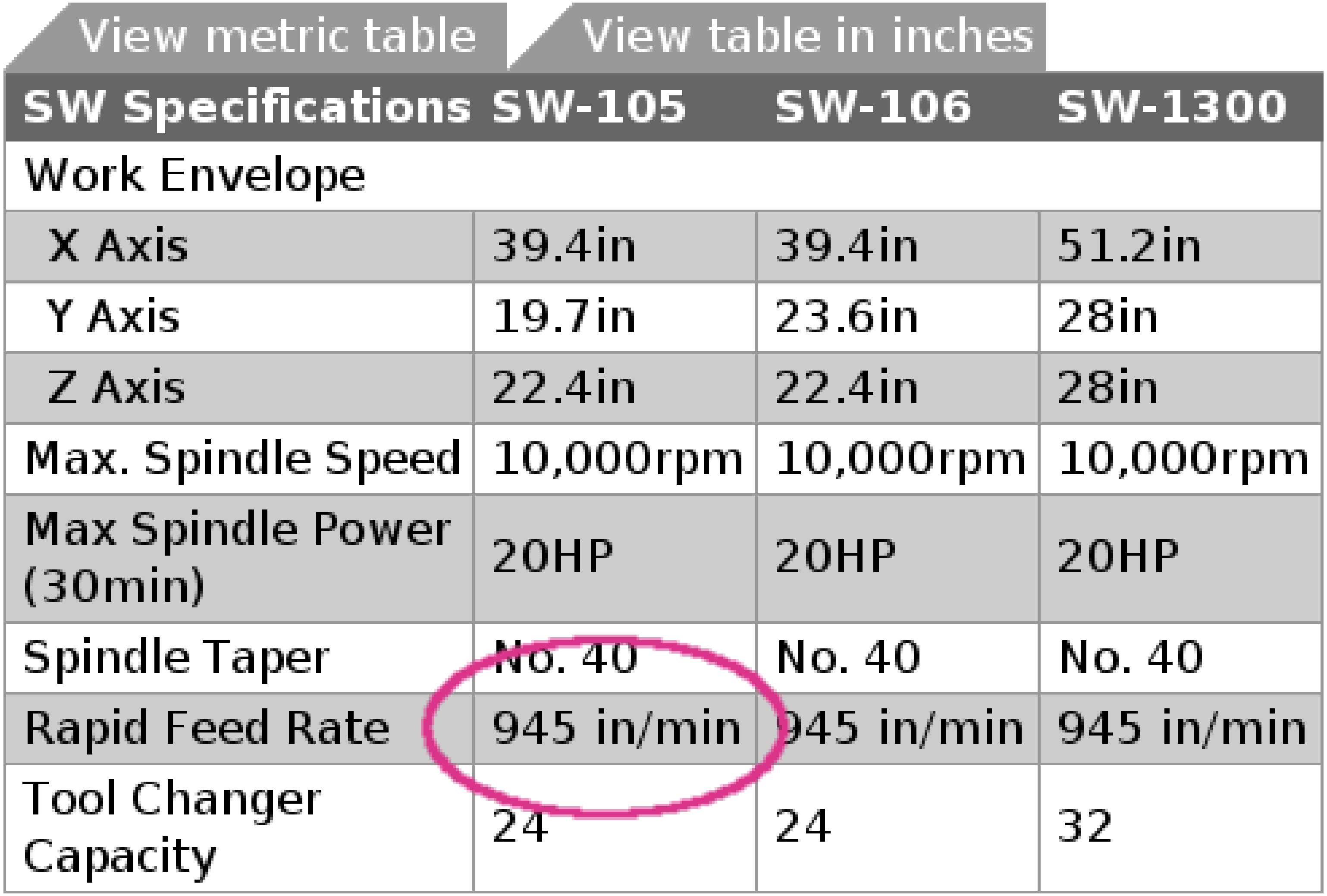
●

It's a config file setting

●

Speeds for cutting metal are much lower!

Speed Matters



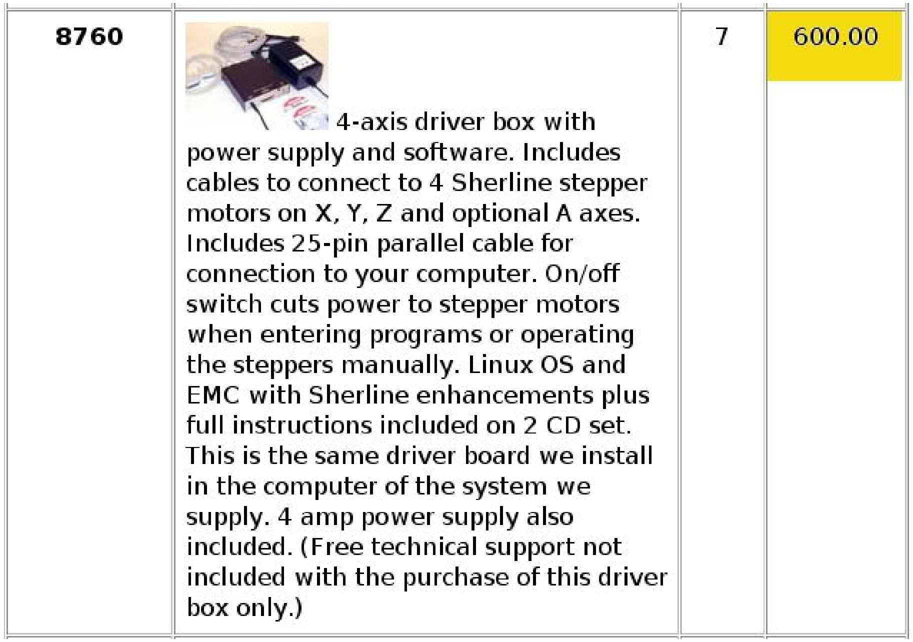
SW Specifications	SW-105	SW-106	SW-1300
Work Envelope			
X Axis	39.4in	39.4in	51.2in
Y Axis	19.7in	23.6in	28in
Z Axis	22.4in	22.4in	28in
Max. Spindle Speed	10,000rpm	10,000rpm	10,000rpm
Max Spindle Power (30min)	20HP	20HP	20HP
Spindle Taper	No. 40	No. 40	No. 40
Rapid Feed Rate	945 in/min	945 in/min	945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

That's 15 in/s = 244 kHz = 4 µs/step... for my setup

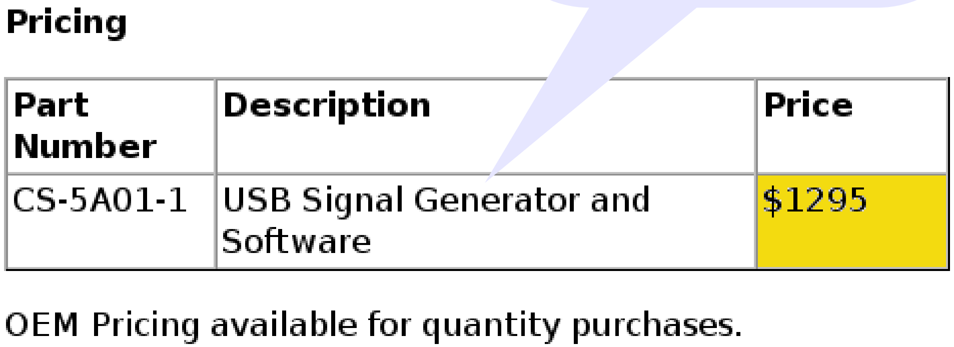
www.milltechcnc.com/sw.html

Motor Control / Driver Boxes

Motor power drivers not included!



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



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

Real Time Software

The right answer

at the wrong time

is wrong

Real Time Linux

Kernel preemption – now in mainline code

- “Soft real time” preemption
- Unbounded latency, no matter what
- Sorta-kinda OK for millisecond-scale timing

Hypervisor Real-time kernel – RTAI

- IRQ → “Hard real time” task handling
- Entire Linux kernel runs as background task
- Guaranteed microsecond-scale latency

RT(?) Kernel Preemption

"In Linux, the kernel code
for switching keyboard capslock and numlock
waits for an acknowledgment
from the keyboard."

The Design and Implementation of RealTime Schedulers in REDLinux
Lin and Wang

Proceedings of the IEEE - July 2003

Kernel Preemption

Oops...

a.k.a: “Stuff happens”

No matter how clever you (think you) are

Kernel Preemption

Mechanical equipment is unsympathetic

Hard RT Hypervisor

Real-time code is hard

sooo...

Put only simple operations in RT tasks

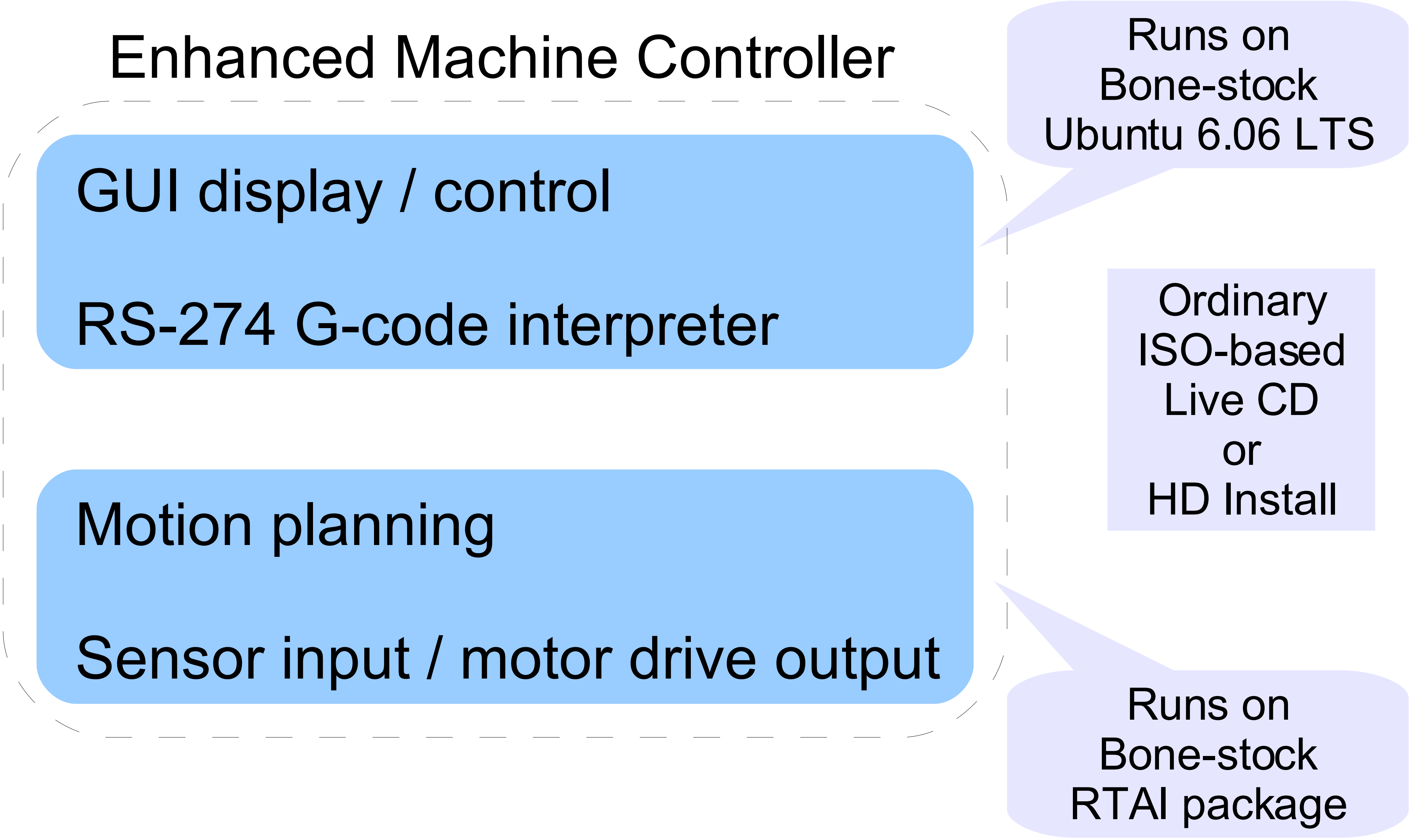
Hard RT Hypervisor

Real-time tasks mostly do I/O
I/O is relatively slow

Userspace ↔ FIFO / vars ↔ RT

RT must never, ever spin on a lock!

Software Stack



Enhanced Machine Controller

GUI display / control

RS-274 G-code interpreter

Motion planning

Sensor input / motor drive output

Runs on
Bone-stock
Ubuntu 6.06 LTS

Ordinary
ISO-based
Live CD
or
HD Install

Runs on
Bone-stock
RTAI package

Timing Parameters

RT kernel timer period depends on crystal!

dmesg

```
CPU: Intel(R) Pentium(R) 4 CPU 2.40GHz stepping 07
RTAI[sched_lxrt]:
Linux timer freq = 1000 (Hz), CPU freq = 2392347000 hz.
timer setup = 2010 ns, resched latency = 2688 ns.
```

Shortest EMC task period, ns

Sherline.ini

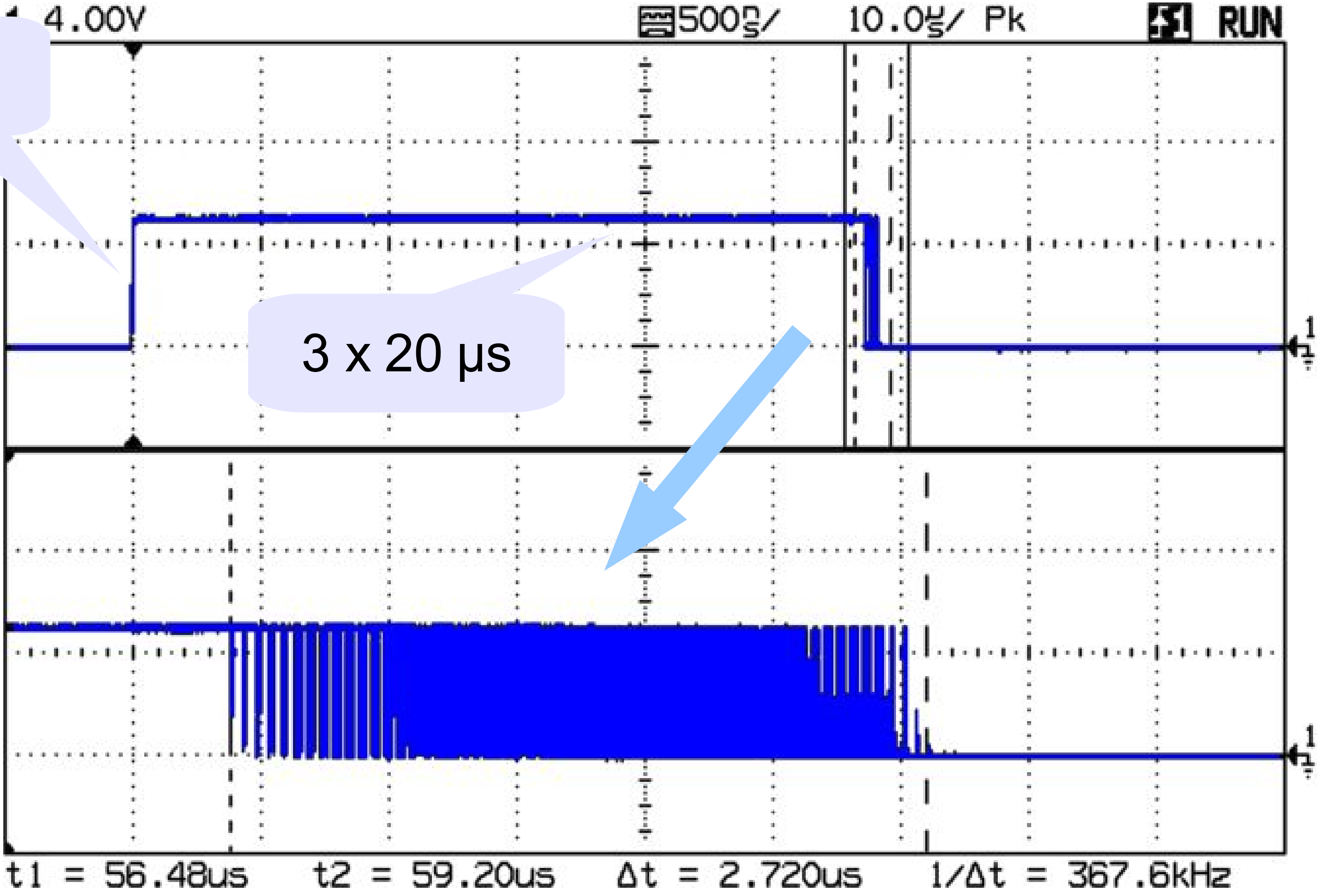
```
BASE_PERIOD = 20000
```

Shortest X-axis pulse (3 high + 4 low) x BASE_PERIOD

Sherline.hal

```
setp stepgen.0.steplen 3
setp stepgen.0.stepspace 4
```

Timing Jitter



Step!

3 x 20 µs

Average ≈ 58 µs

Slightly > 1 RT IRQ period

Timing Jitter

Sherline fast-traverse = 24 in/min ► 6 KHz

6 KHz ► 160 µs/step

3 µs jitter ≈ 2% error

Pretty good for pure software...

Real-Time Pulse Generation

Non-RT OS cannot generate precision pulses

Use hardware or RTOS

Which adds a **major** per-unit cost

Increase retail price

Which limits market appeal

Badness

Why Linux?

P/N 8540 - Model 5400
mill, computer, drivers,
stepper motors & software
$2450

MSRP

http://sherline.com/8540pg.htm

FlashCut CNC
Sherline Mill Retrofit Kit
$1795
+ Mill & motor adapters + PC
+ Windows = $954 + 200?
$2800 (?)

‘Nuff said

http://discountcampus.com/store/dpp_flashcut.htm

Why Linux?

Hardware vendors *looove* FOSS

because

It’s free-as-in-beer

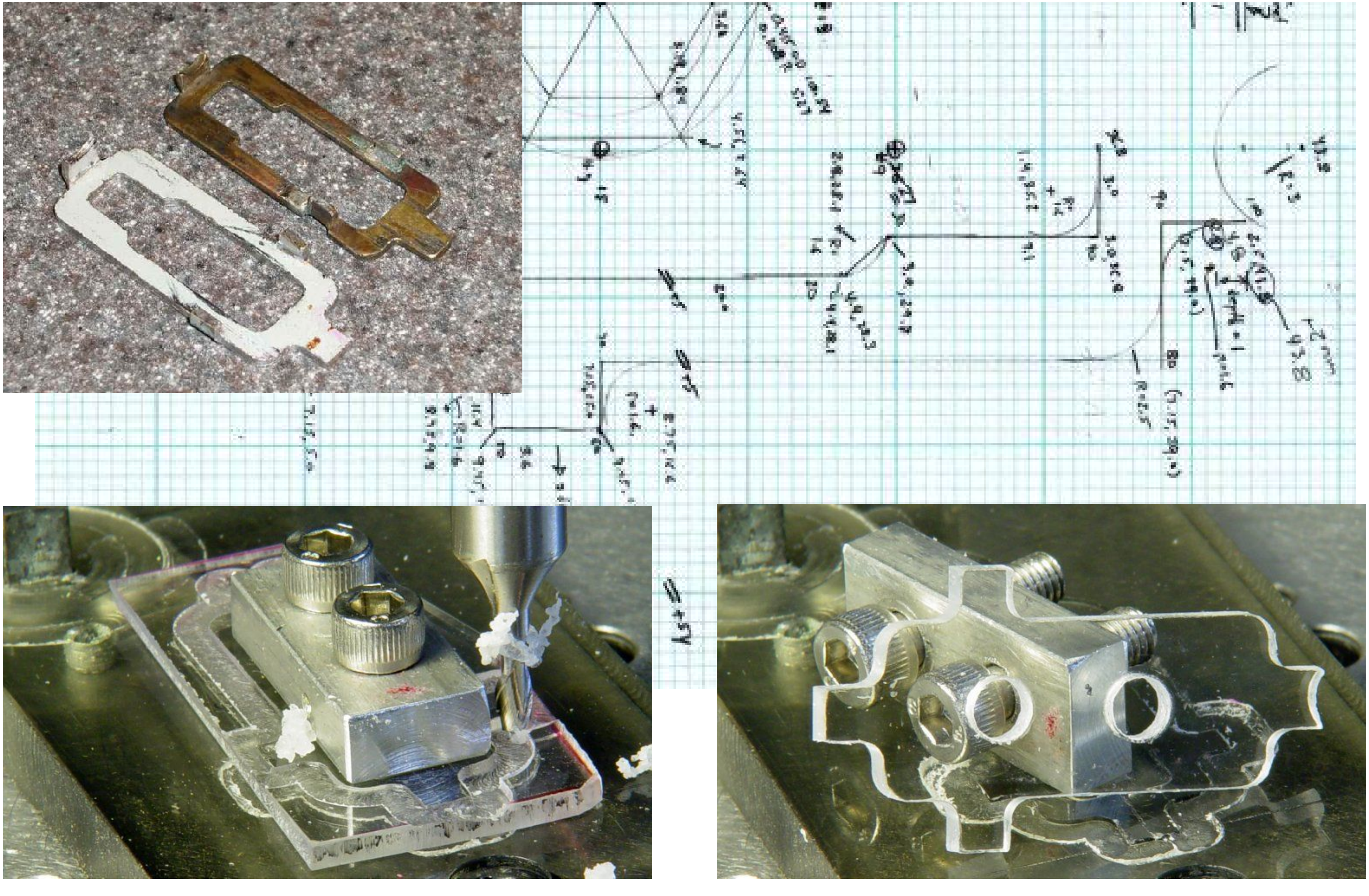
and

It’s (just barely) good enough

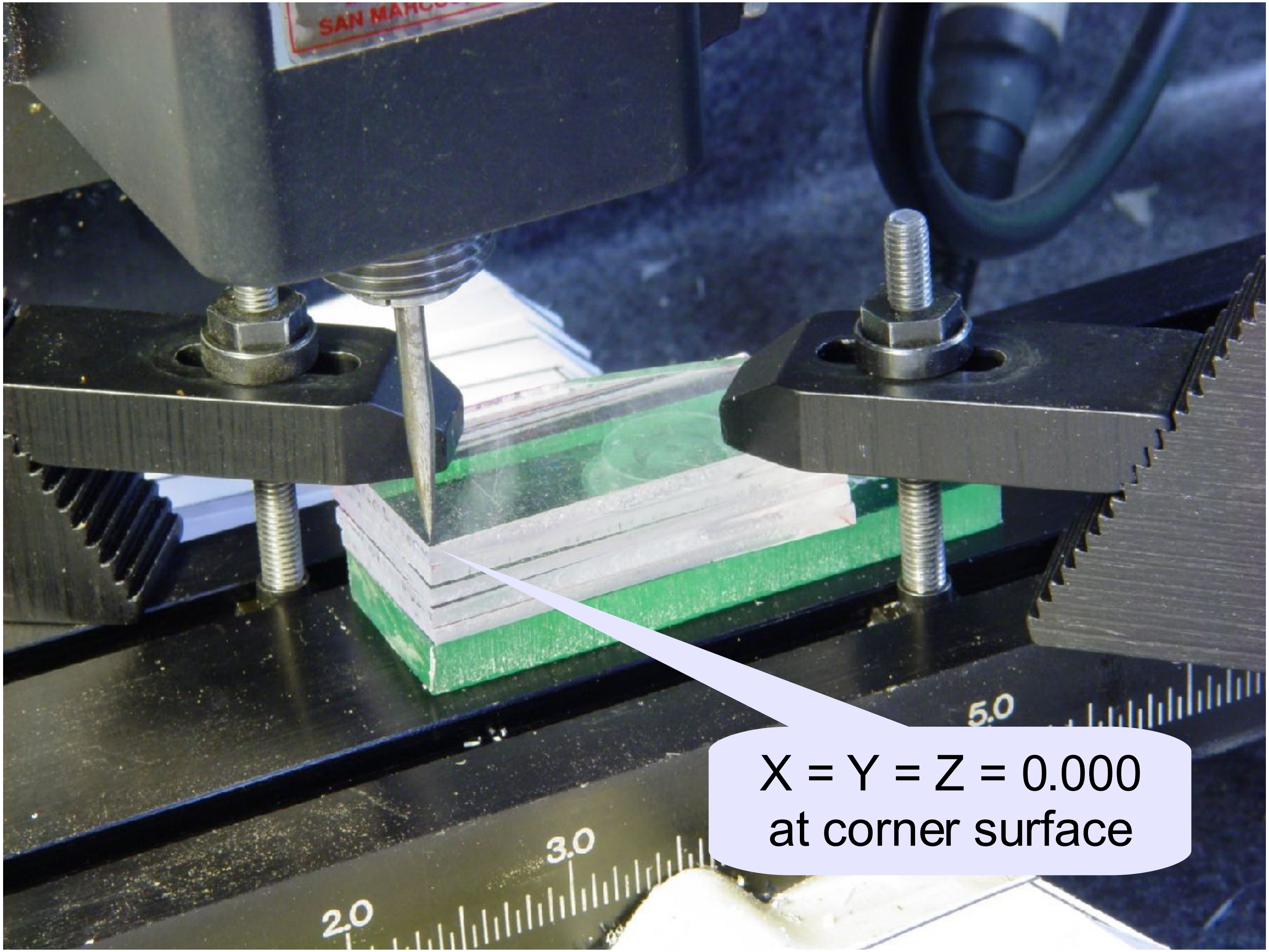
Why Linux?

Get over it

Demo Madness

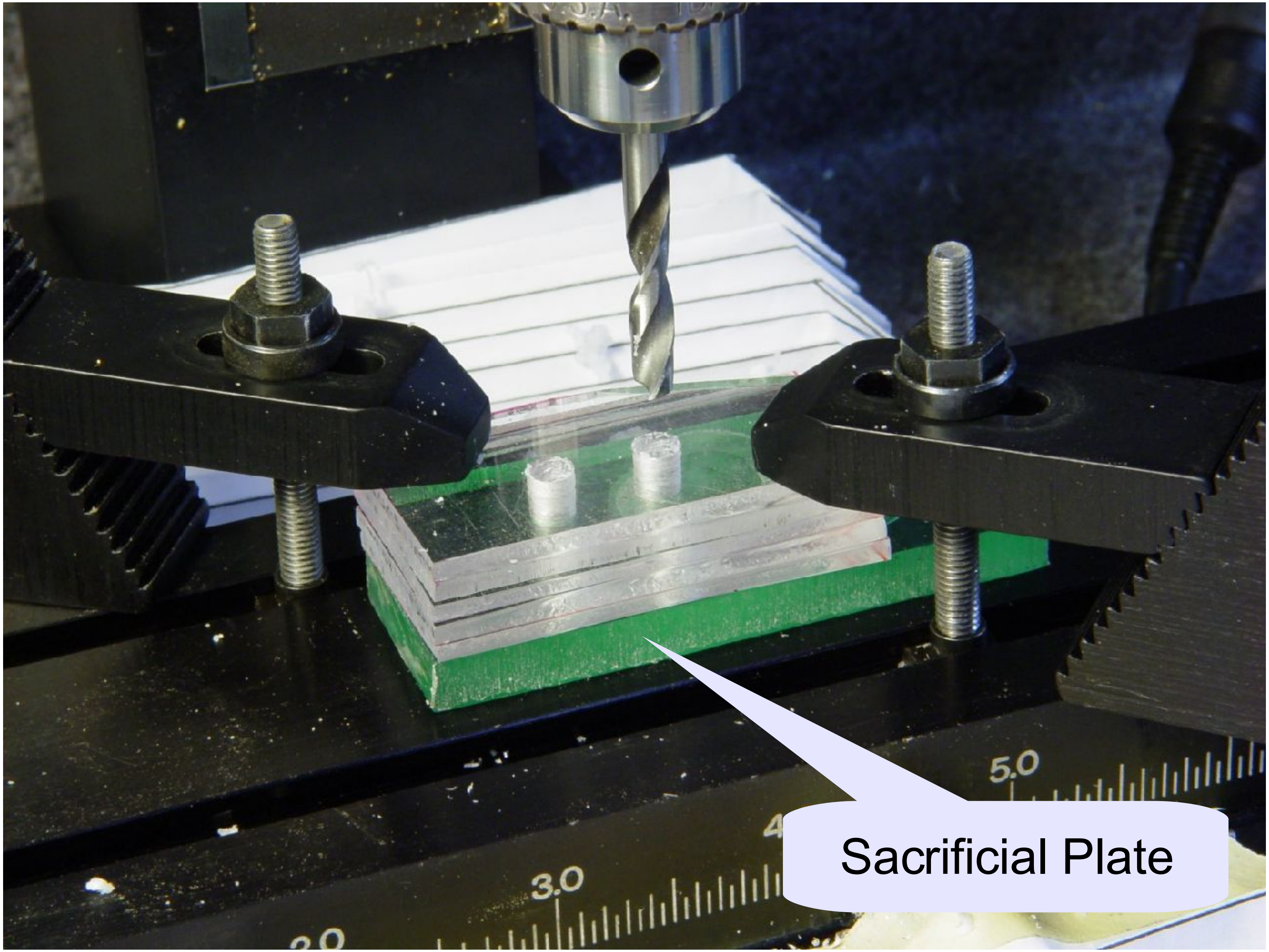


Locate Origin



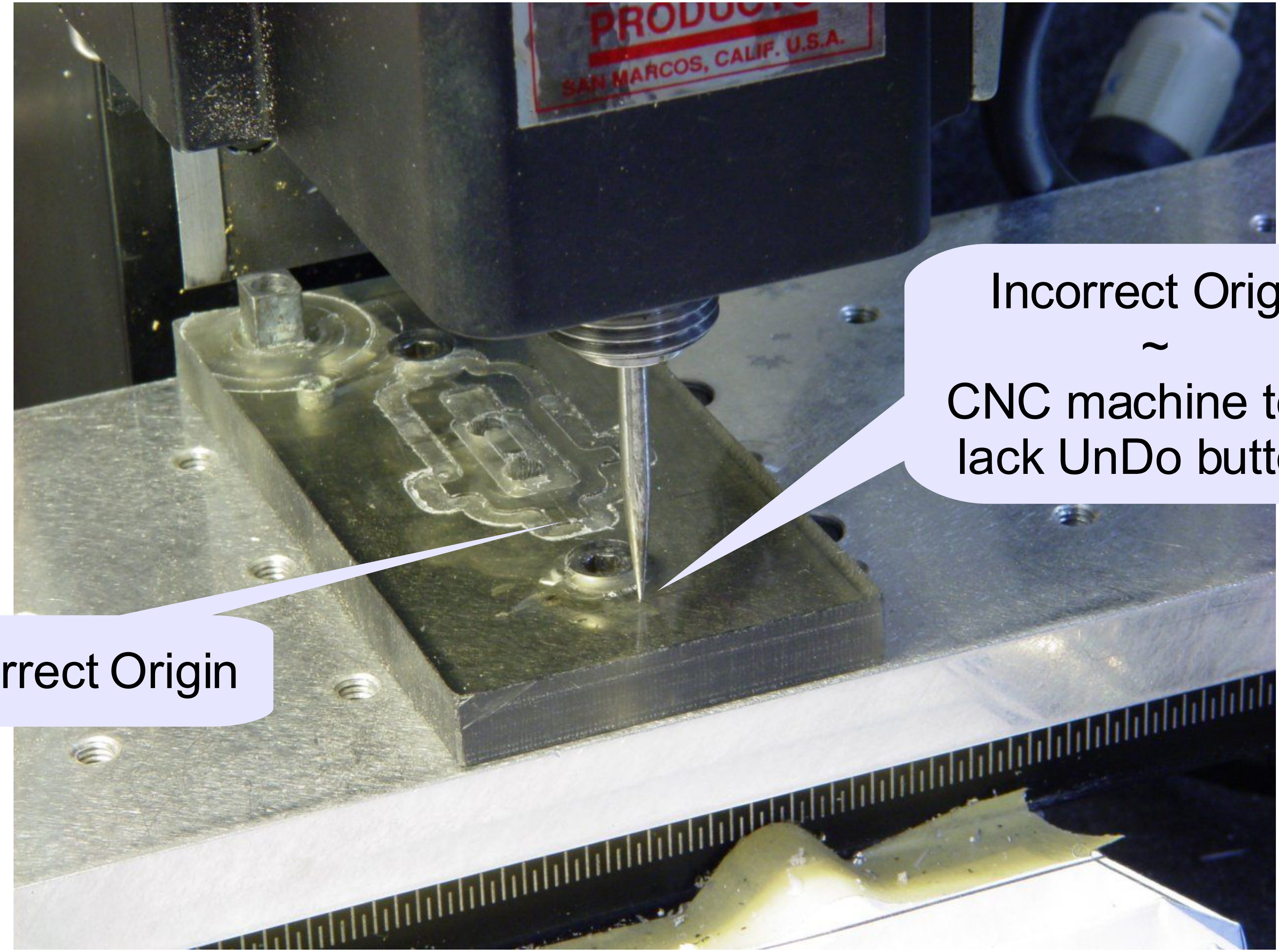
X = Y = Z = 0.000
at corner surface

Drill Clamping Holes



Sacrificial Plate

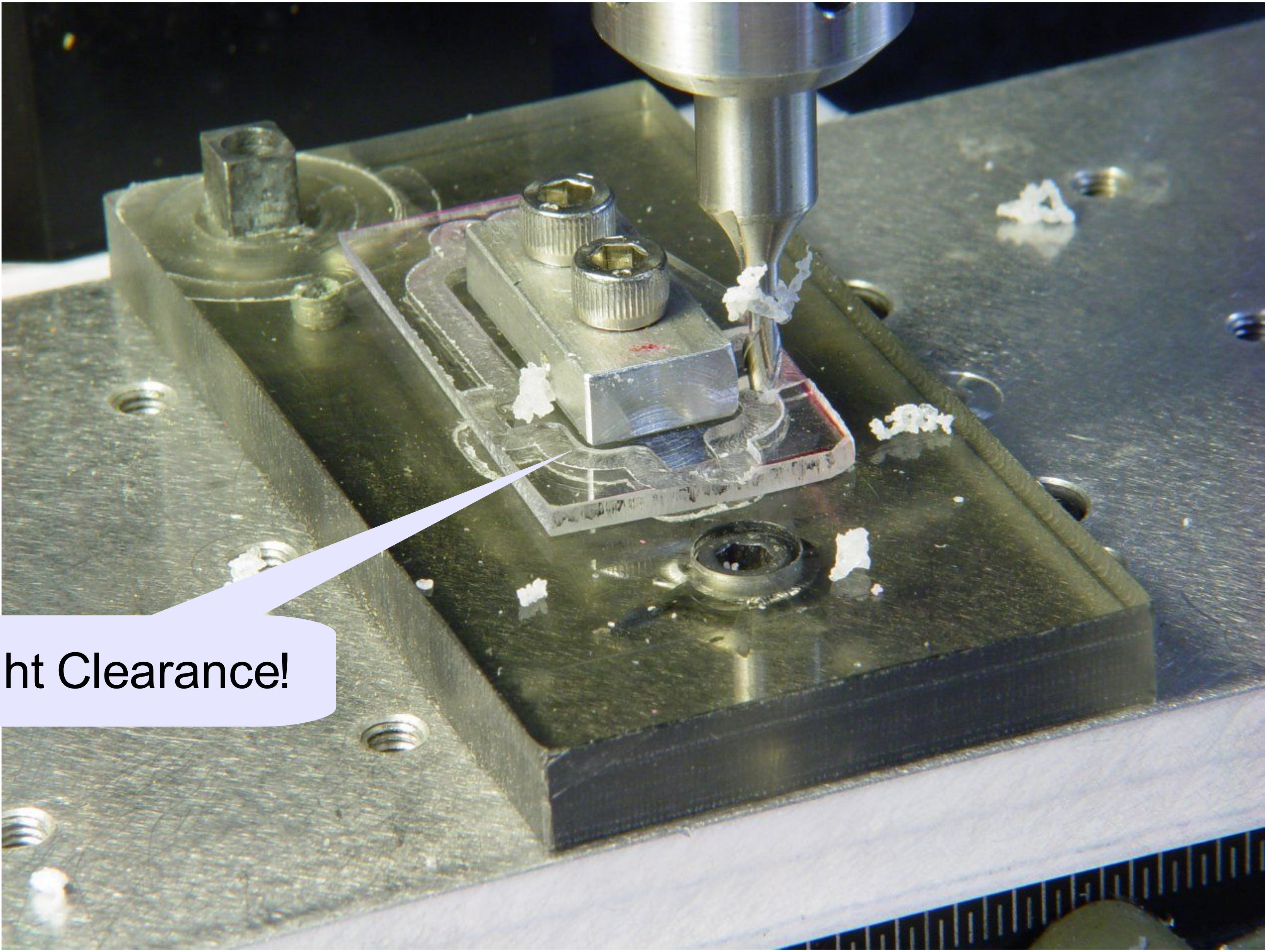
Locate Fixture Origin



Incorrect Origin
~
CNC machine tools lack UnDo buttons

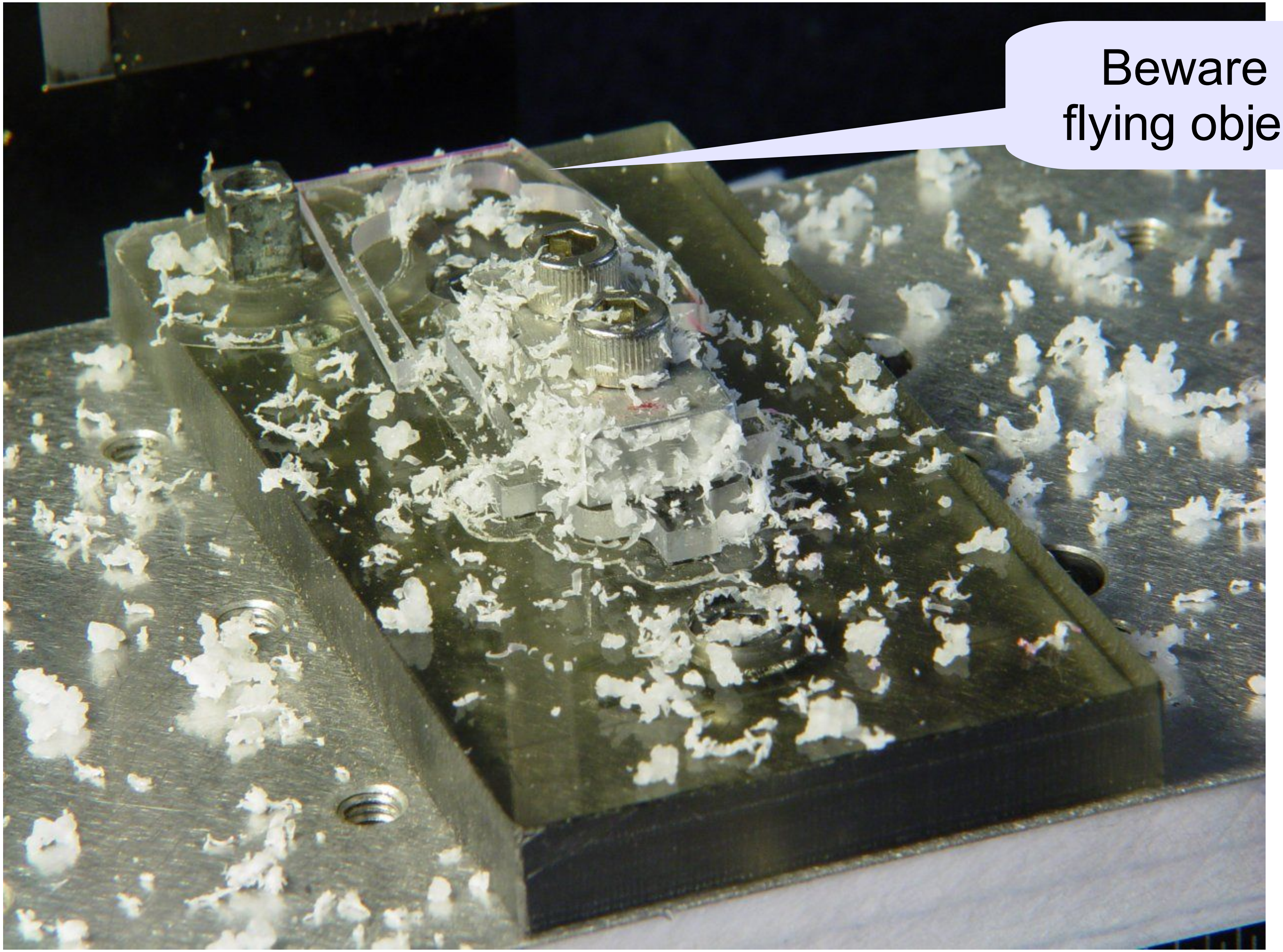
Correct Origin

Outside Cutting



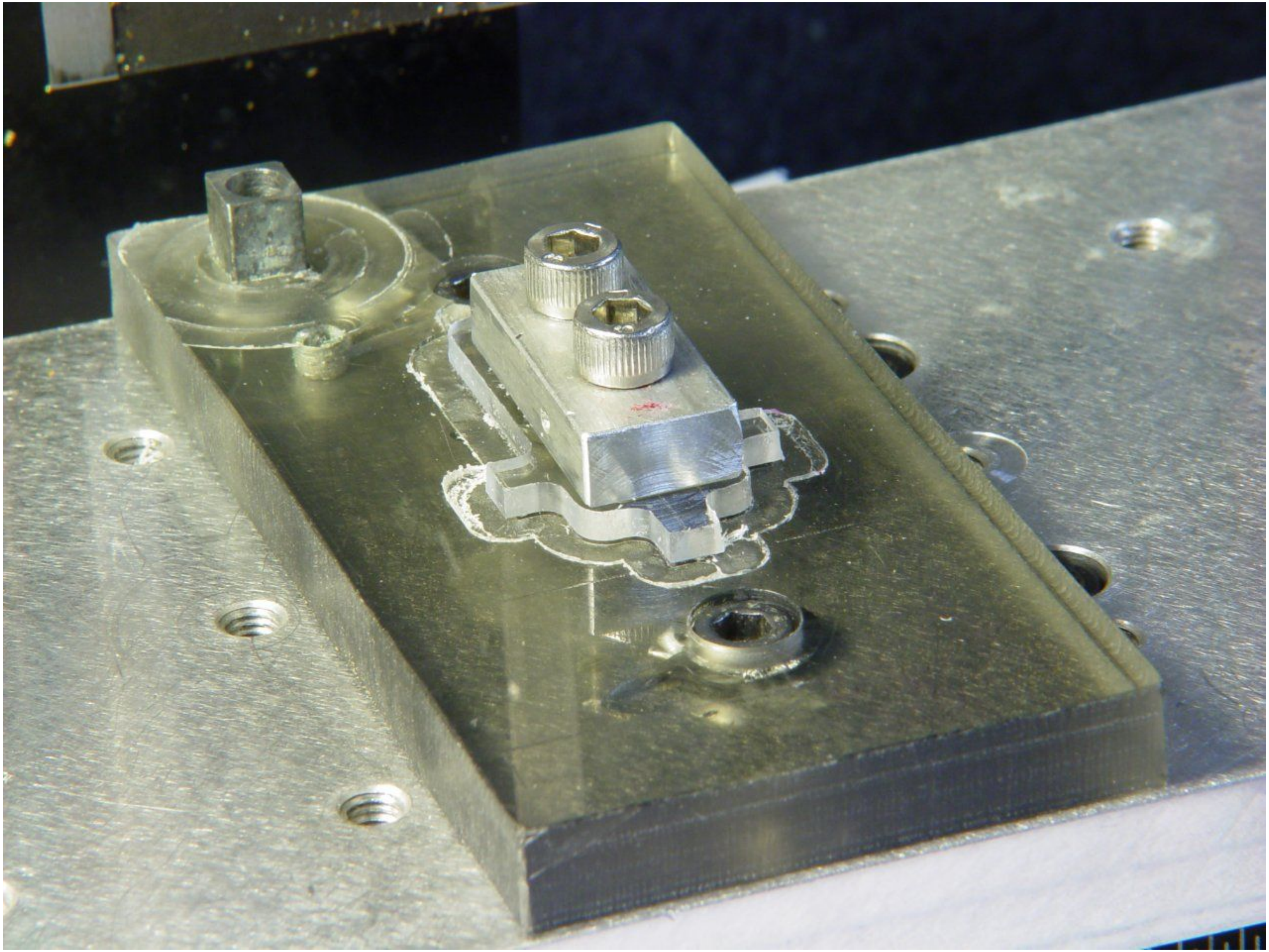
Tight Clearance!

Chips Aplenty

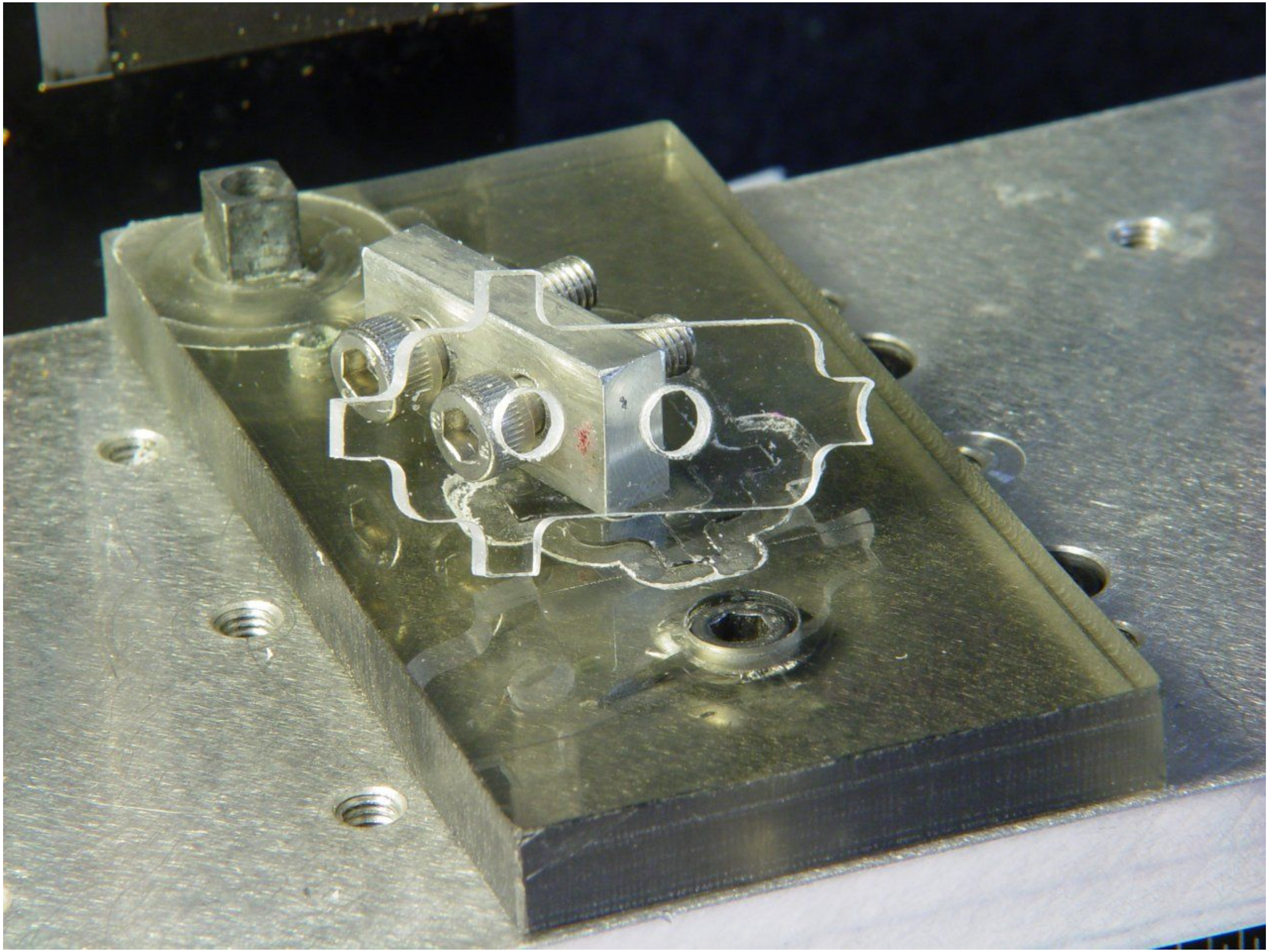


Beware of flying objects!

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

RealTime Application Interface for Linux
https://www.rtai.org

Non-shiny Things
www.fabathome.org
http://reprap.org

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

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The rest are mine

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Ed Nisley

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

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

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

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

Dr. Dobb’s Journal
Embedded Space (2001-2006) - All things embedded
Nisley’s Notebook (2006-2007) - Where hardware & software collide