Computing From Scratch

Building a Computer from Switches on Up

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OpenWest Conference
Thursday, May 7th, 2015

Outline

Motivation

My Motivation

- A Desire to Explore Ternary Logic
- Wanted to see actual ternary logic circuits!
- Understand Optimizations
- Grand "Impossible" Desire: An actual silicon computer
- A Focus on Electronics

Motivation

A Brief Contrast: NAND to Tetris in 12 Steps

- Focus on Computer Design, from gates to OS to application
- No Electronic Circuitry — Everything simulated
- Skips flip-flops and system clocks
- Avoids Optimizations

`http://www.nand2tetris.org`

Elements of Computing Systems, by Noam Nisan and Shimon Schocken

Motivation

Some Interesting Results

- I learned how to design a computer
- Ironically, I still don't know what working ternary circuits would look like...
- I discovered all sorts of fun circuit design techniques!
- I learned that anyone can do this!

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Some Interesting Results

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- I discovered all sorts of fun circuit design techniques!
- I learned that anyone can do this!
- I experienced firsthand that transistors stop working when they release their "magic smoke"

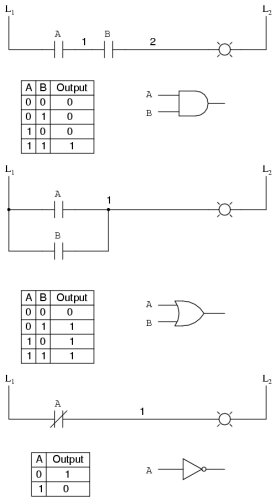
Motivation

In this presentation, I will focus on *building* a computer. I will discuss *designing* a computer at the Provo Linux User's Group on Tuesday, May 19. That presentation will likely be called "Ternary Logic and Computer Design".

Outline

Types of Logic (Circuitry)

Relay Logic

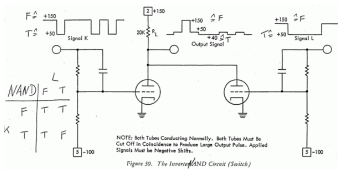


Harry Porter's Relay Computer (http://web.cecs.pdx.edu/~harry/Relay/index.html)

http://www.allaboutcircuits.com/vol_4/chpt_6/2.html

Types of Logic (Circuitry)

Vacuum Tube Logic



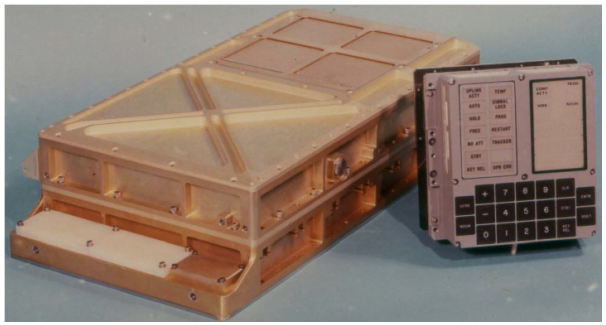
Setun Ternary Computer (http://en.wikipedia.org/wiki/Ternary_computer)

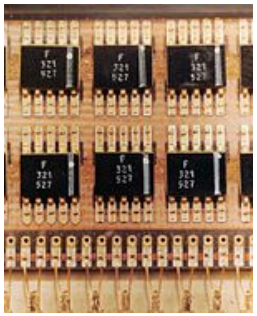
http://en.wikipedia.org/wiki/Vacuum_tube

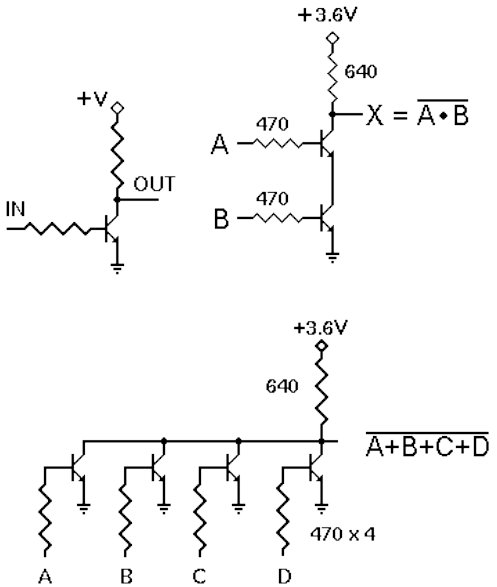
http://www.qrp.gr/technology/logic.htm

Types of Logic (Circuitry)

Resistor-Transistor Logic





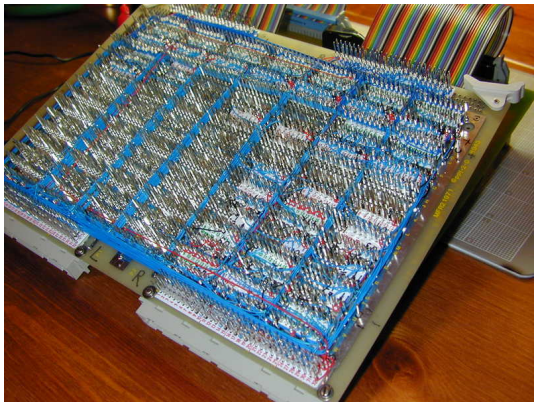


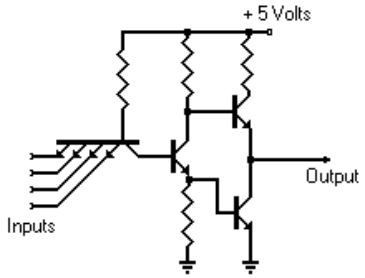
Apollo Guidance Computer (http://en.wikipedia.org/wiki/Apollo_Guidance_Computer)

http://www.play-hookey.com/digital_electronics/rtl_gates.html

Types of Logic (Circuitry)

Transistor-Transistor Logic





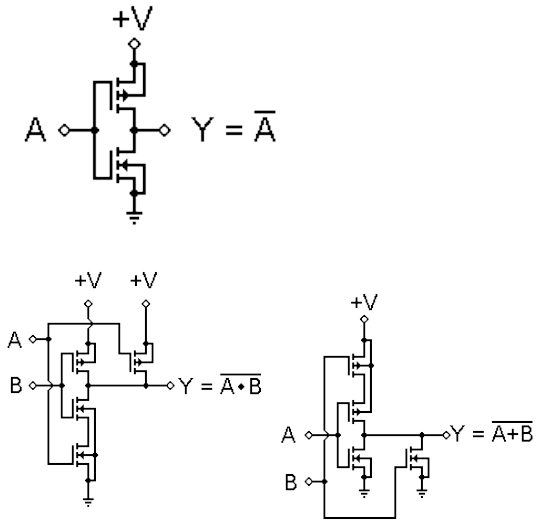
Mark 1 FORTH Computer (http://www.aholme.co.uk/Mk1/Architecture.htm)

Magic 1 (http://www.homebrewcpu.com)

(http://mail.humber.ca/~mike.crompton/logic5.html)

Types of Logic (Circuitry)

CMOS Logic



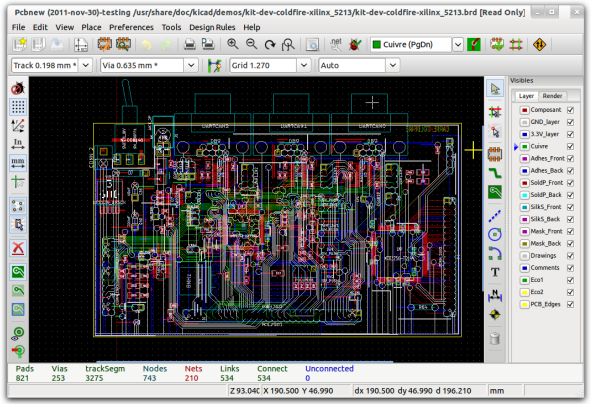
Altara Stratix IV FPGA (http://en.wikipedia.org/wiki/Stratix)

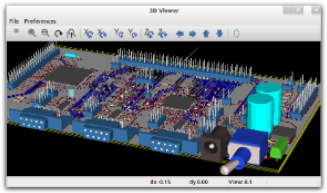
http://www.play-hookey.com/digital_electronics/cmos_gates.html

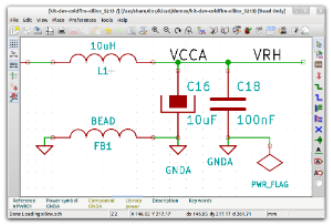
Outline

Open Source Circuit Design

KiCAD







- Schematics
- Printed circuit boards (multiple layers)
- Components
- Solder masks
- Silk Screens

http://www.kicad-pcb.org/display/KICAD/KiCad+EDA+Software+Suite

Open Source Circuit Design

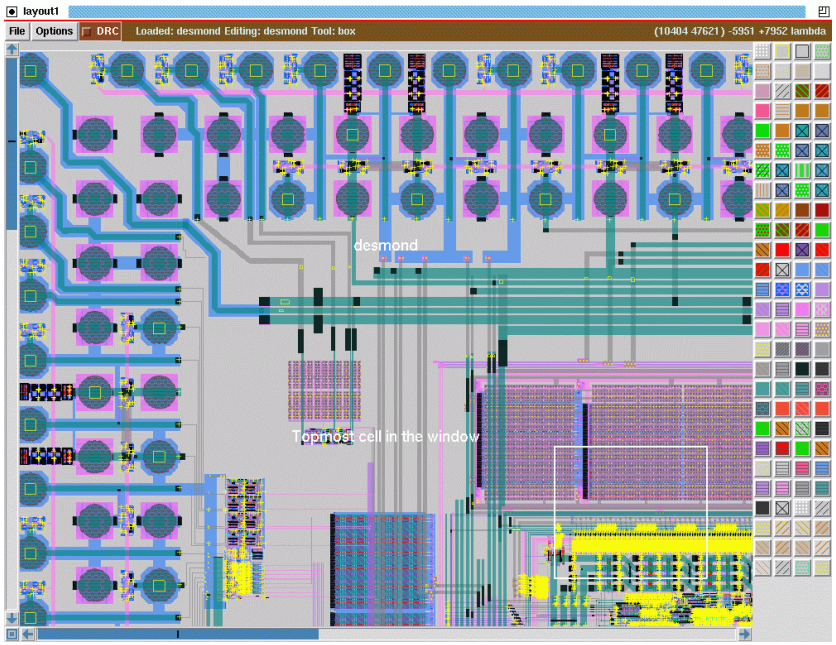
SPICE

- Circuit simulation (voltage and temperature)
- Command Line Interface
- Bewildering selection of GUI wrappers
- I don't know if it "plays nicely" with KiCAD...

http://bwrcs.eecs.berkeley.edu/Classes/IcBook/SPICE/

Open Source Circuit Design

Magic VLSI



- VLSI layout tool for silicon chips
- Originally written in the 1980's
- Popular with universities and small companies

`http://opencircuitdesign.com/magic/`

Note that `http://opencircuitdesign.com` hosts other useful FOSS electronics design programs as well...

Open Source Circuit Design

FPGA (Field Programmable Gate Array) Tools

- Icarus Verilog for Verilog simulation

  `http://iverilog.icarus.com/`

- GHDL for VHDL simulation

  `http://home.gna.org/ghdl/`

- FreeHDL for VHDL simulation

  `http://freehdl.seul.org/`

- Specific FPGAs typically need vendor-specific software (not likely FOSS)

Outline

Circuit Creation Techniques

Components by the Reel

Bipolar Transistors

3,000 parts per reel at $0.047 per part for $141.00 per reel (6,000 tranistors per reel)

MOSFET Transistors

8,000 parts per reel at $0.063 per part for $504.00 per reel (16,000 transistors per reel)

Resistors

4.7kΩ or 10kΩ — 10,000 parts per reel at $0.003 per reel for $30.00 per reel

Capacitors

68pF — 3,000 parts per reel at $0.03 per part for $90.00 per reel

PC Boards

double-sided 11.8 in × 11.8 in at $19.95 per board or $179.50 for 10 boards

`http://www.mouser.com` `http://www.jameco.com`

Circuit Creation Techniques

Iron-On Laser-Printed Templates

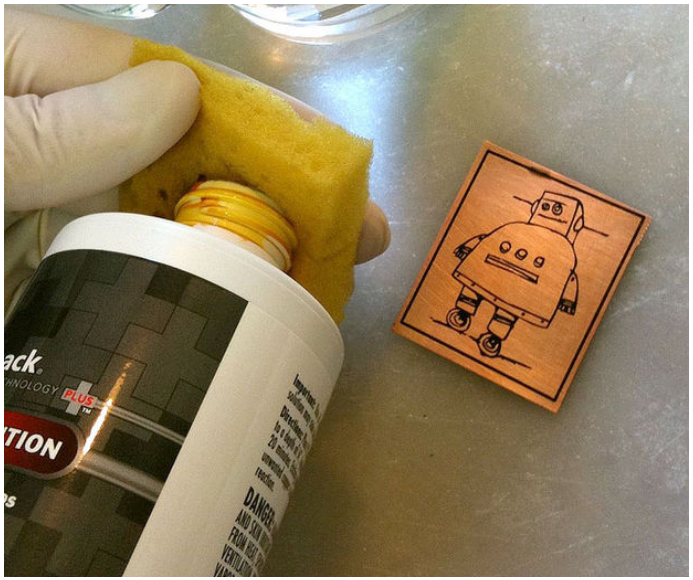
- Laser print tracings onto glossy magazine paper
- Iron on tracings
- Gently wash off glossy paper
- Etch and gently sand off toner!

http://hackaday.com/2008/07/28/how-to-etch-a-single-sided-pcb/

Circuit Creation Techniques

Interesting Options for Etching

Sponged Ferric Chloride



Copper Chloride in Aqueous Hydrochloric Acid

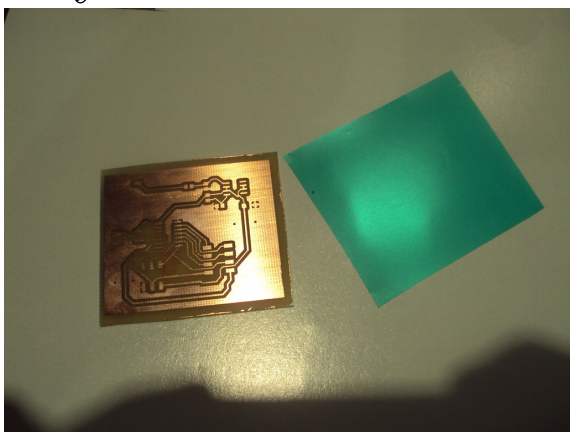
http://www.instructables.com/id/Sponge-Ferric-Chloride-Method-Etch-Circuit-Bo/

http://www.instructables.com/id/Stop-using-Ferric-Chloride-etchant!--A-better-etc

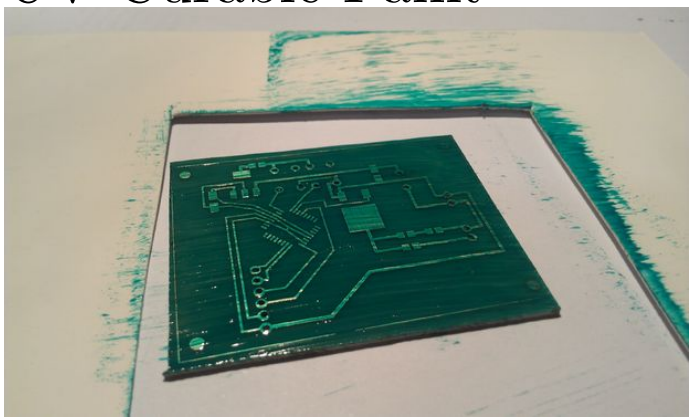
Circuit Creation Techniques

Solder Mask Techniques

Dry Film



UV Curable Paint



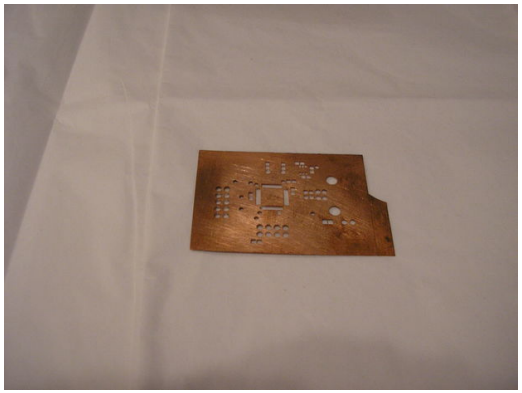
http://www.instructables.com/id/Dry-Film-Solder-Mask

http://www.instructables.com/id/Professional-Home-Brew-PCB-Creating-a-solder-mask

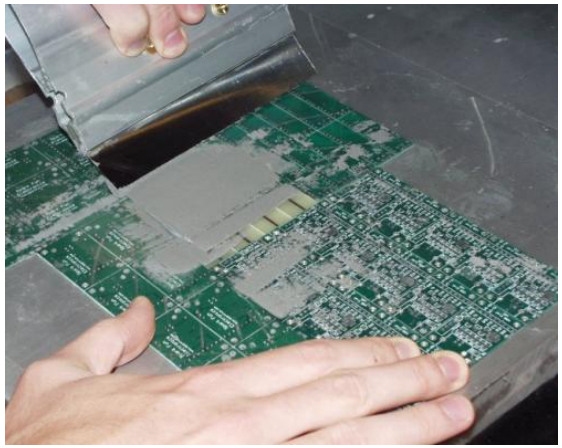
Circuit Creation Techniques

Solder Stencils and Paste

Stencil Etching



Applying Solder Paste



NOTE: These steps are somewhat optional. (The alternative is toothpicks.)

`http://www.instructables.com/id/Making-stencils-for-solder-paste-at-home`

`https://www.sparkfun.com/tutorials/58`

Circuit Creation Techniques

Silk Screen Fun! (Entirely Optional ;-)

Why silk screen?

- Looks “professional”
- Helps with diagnostics
- Educational

http://www.instructables.com/id/Screen-Printing%3a-Cheap%2c-Dirty%2c-and-At-Home

Circuit Creation Techniques

Surface Mount Soldering!

Reflow Station

Reflow Skillet

https://www.sparkfun.com/tutorials/59

Outline

Conclusions

- The cost? Estimated $2,000 to $5,000. Somewhat expensive. . . but within reach!
- Surface mounted electronics is surprisingly simple
- I think I would like to build a computer someday

Conclusions

- The cost? Estimated $2,000 to $5,000. Somewhat expensive. . . but within reach!
- Surface mounted electronics is surprisingly simple
- I think I would like to build a computer someday (Sigh: time and money. . .)

Questions

Any Questions?