Embedded System Design

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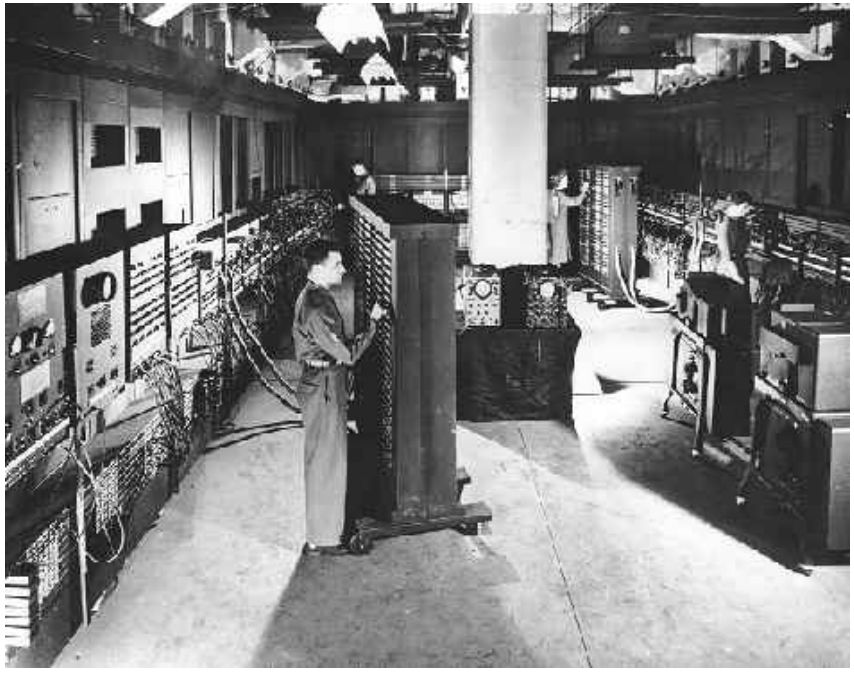
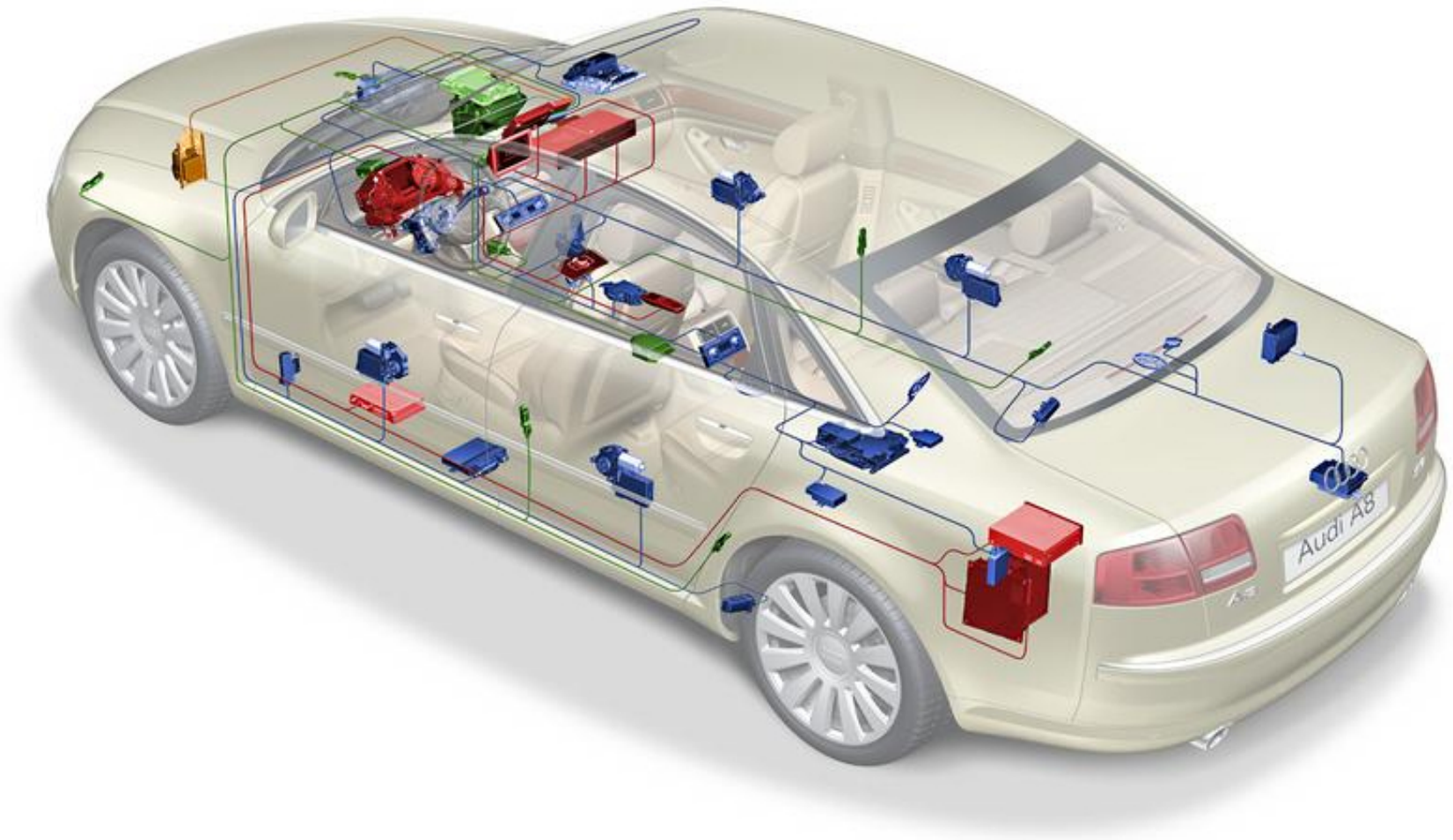
Columbia University

Spring 2014

Spot the Computer



Cars These Days...



Embedded Systems: Ubiquitous Computers

iPhone

Laser Keyboard

Nikon D300

Video Watch

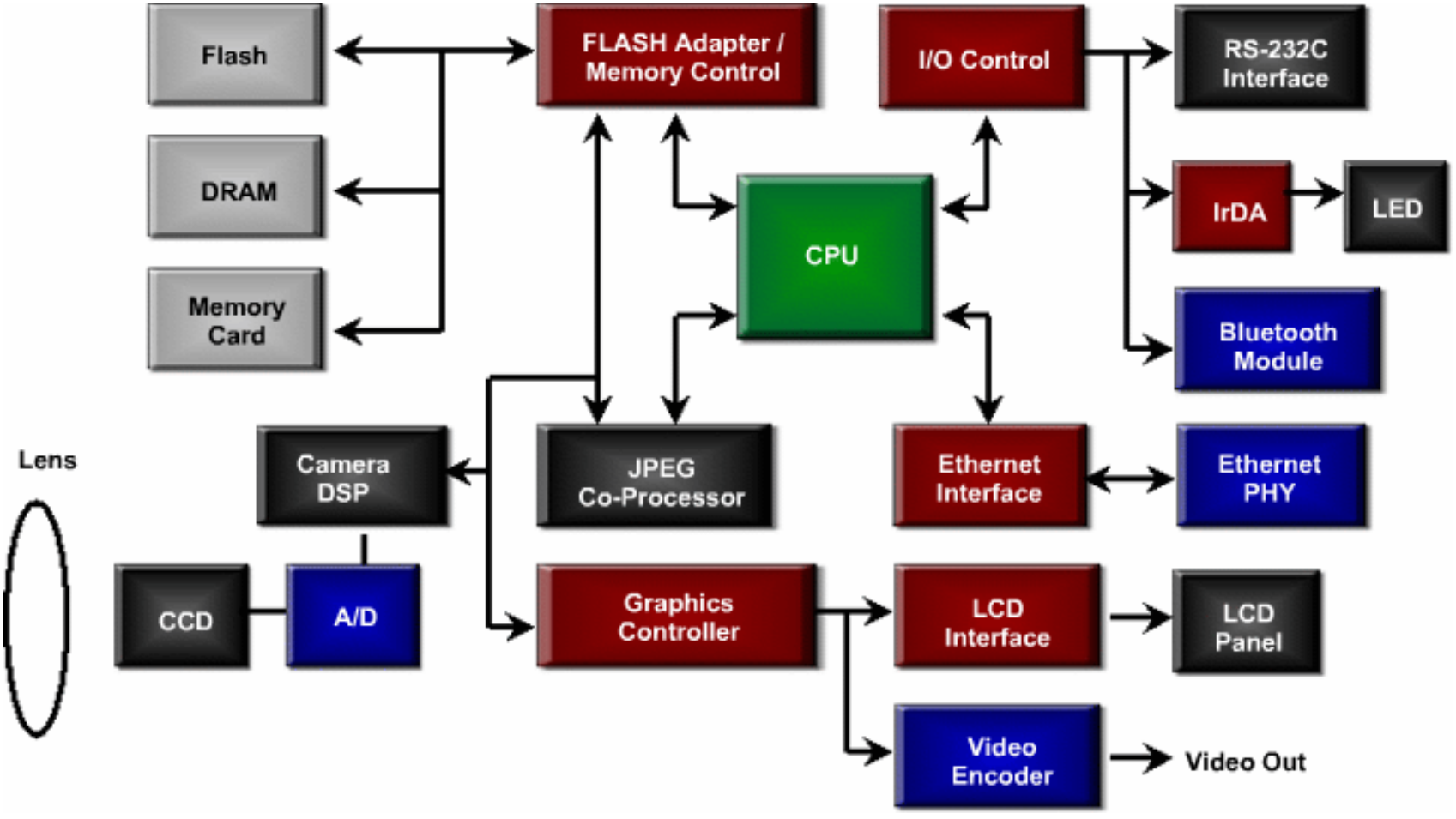
GPS

Playstation 3

PC Keyboard

SD Card

Inside a Digital Camera



Want an Optimal Device that Meets Constraints On

Price

Functionality

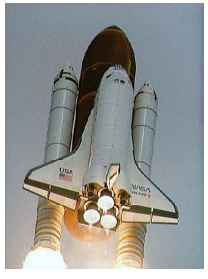
Performance

Size

Power

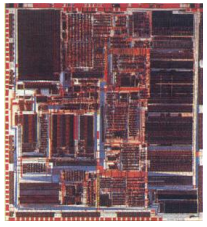
Time-to-market

Maintainability

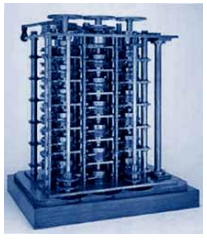


Safety

Embedded System Technologies



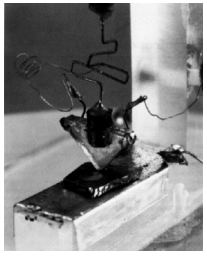
Integrated Circuits



Processing elements

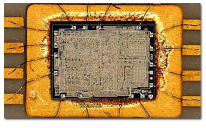
Design tools

IC Technology

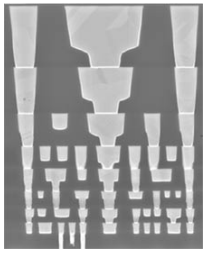


1947: First transistor (Shockley, Bell Labs)

1958: First integrated circuit (Kilby, TI)



1971: First microprocessor (4004: Intel)

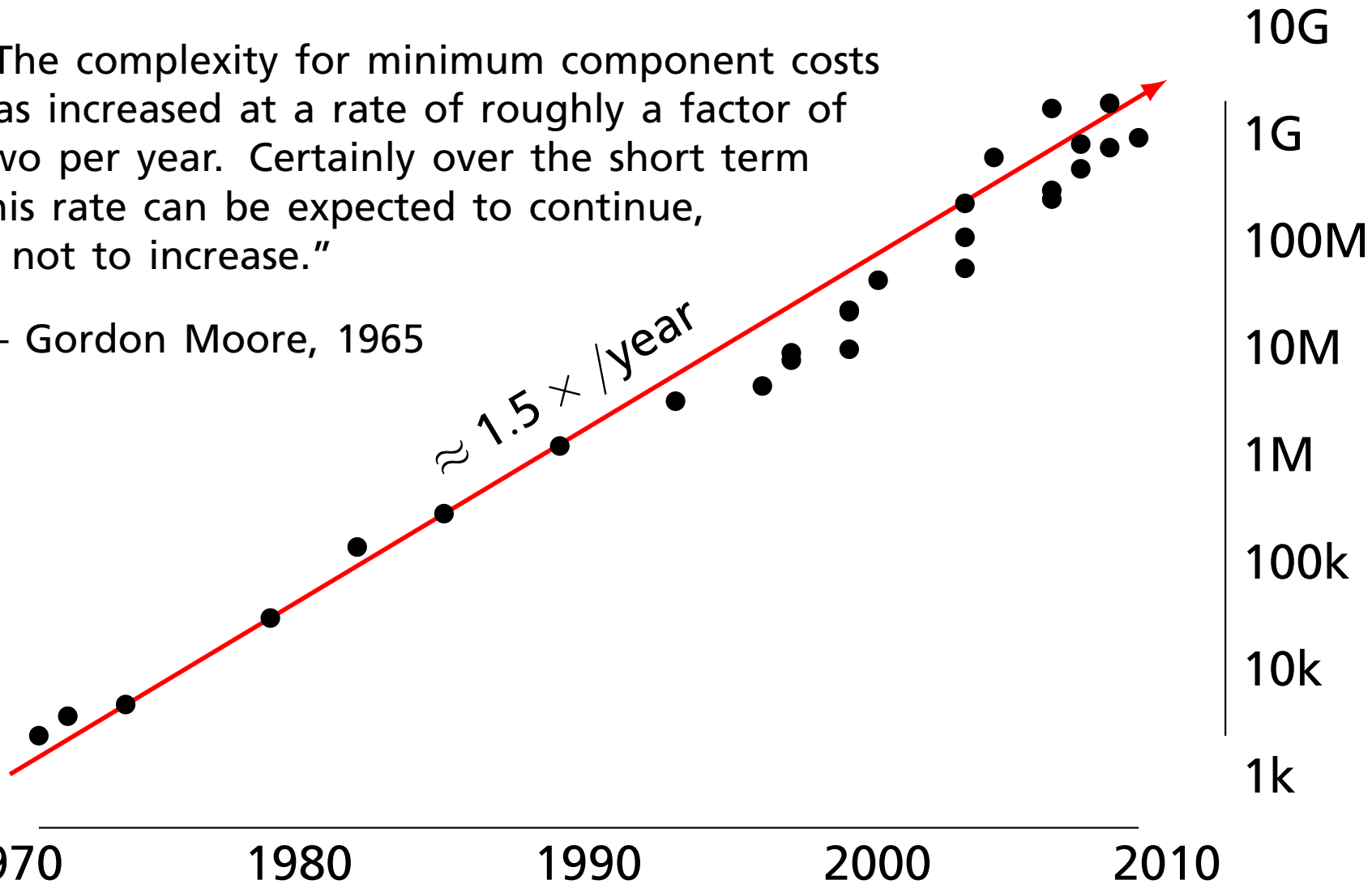


Today: ten wire layers, 28 nm features

Moore's Law: Transistors per chip

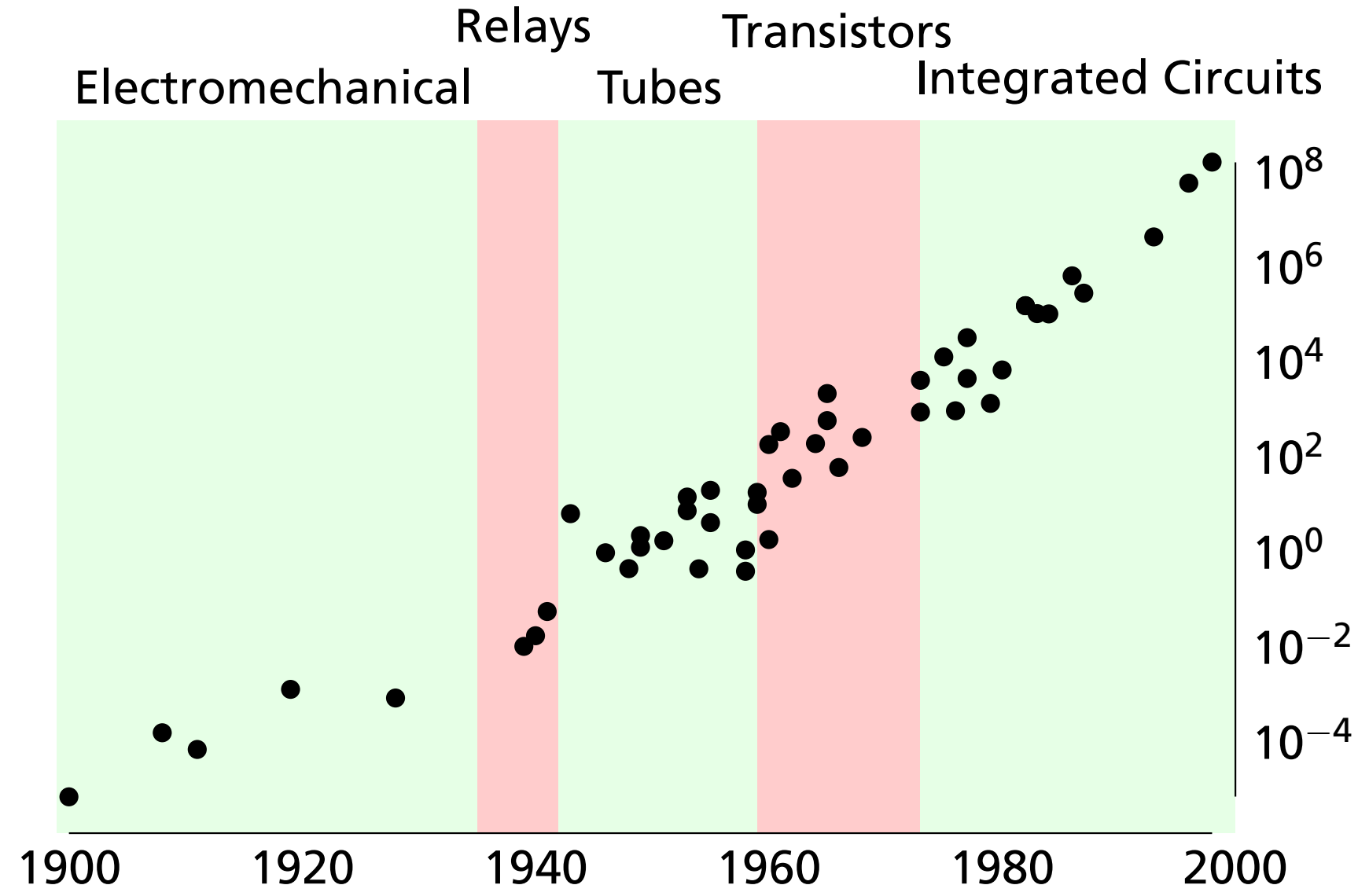
"The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase."

— Gordon Moore, 1965



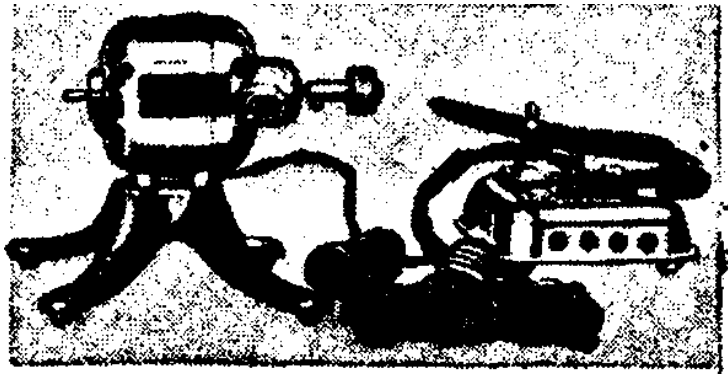
Source: Intel/Wikipedia

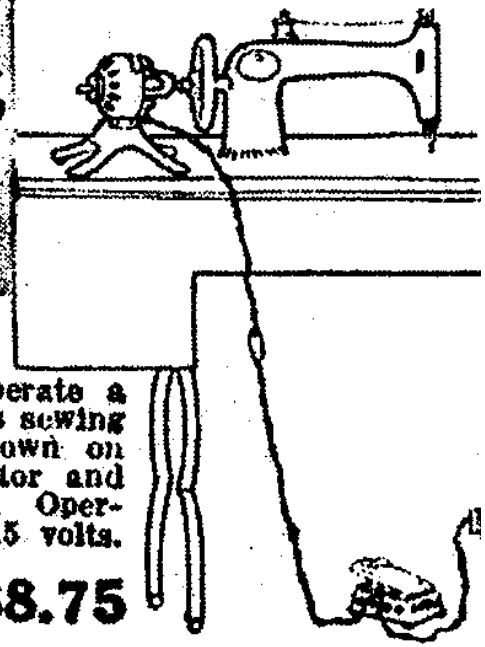
$1000 Buys You This Many Cycles per Second



Source: Ray Kurzweil, *The Age of Spiritual Machines*

1918 Sears Roebuck Catalog





Home Motor.

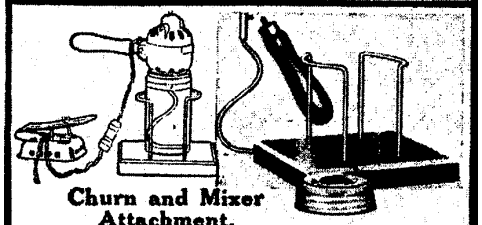
This motor, as shown above, will operate a sewing machine. Easily attached; makes sewing a pleasure. The many attachments shown on this page may be operated by this motor and help to lighten the burden of the home. Operates on usual city current of 105 to 115 volts. Shipping weight, about 5 pounds.

No. 57P7564 Price, complete, as shown..... **$8.75**

Beater Attachment.

Whips cream and beats eggs, and many other uses will be found for these attachments when used in connection with the Home Motor. Parts include the stand, handle and the beater. Shipping weight, about 14 ounces.

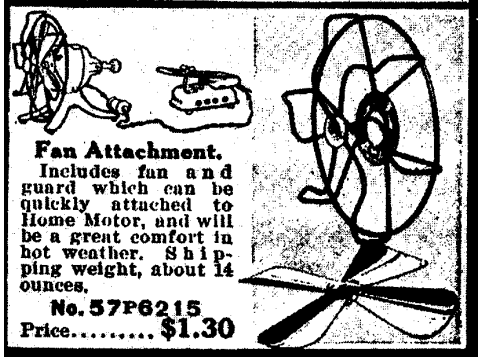
No. 57P7585 Price..... **$1.30**



Churn and Mixer Attachment.

Used in connection with the Home Motor, makes a small churn and mixer for which you will find many uses. The attachments include the base, supports, mixer, handle and special cover for jar. Shipping weight, about 1¾ pounds.

No. 57P7582 Price..... **$1.30**



Fan Attachment.

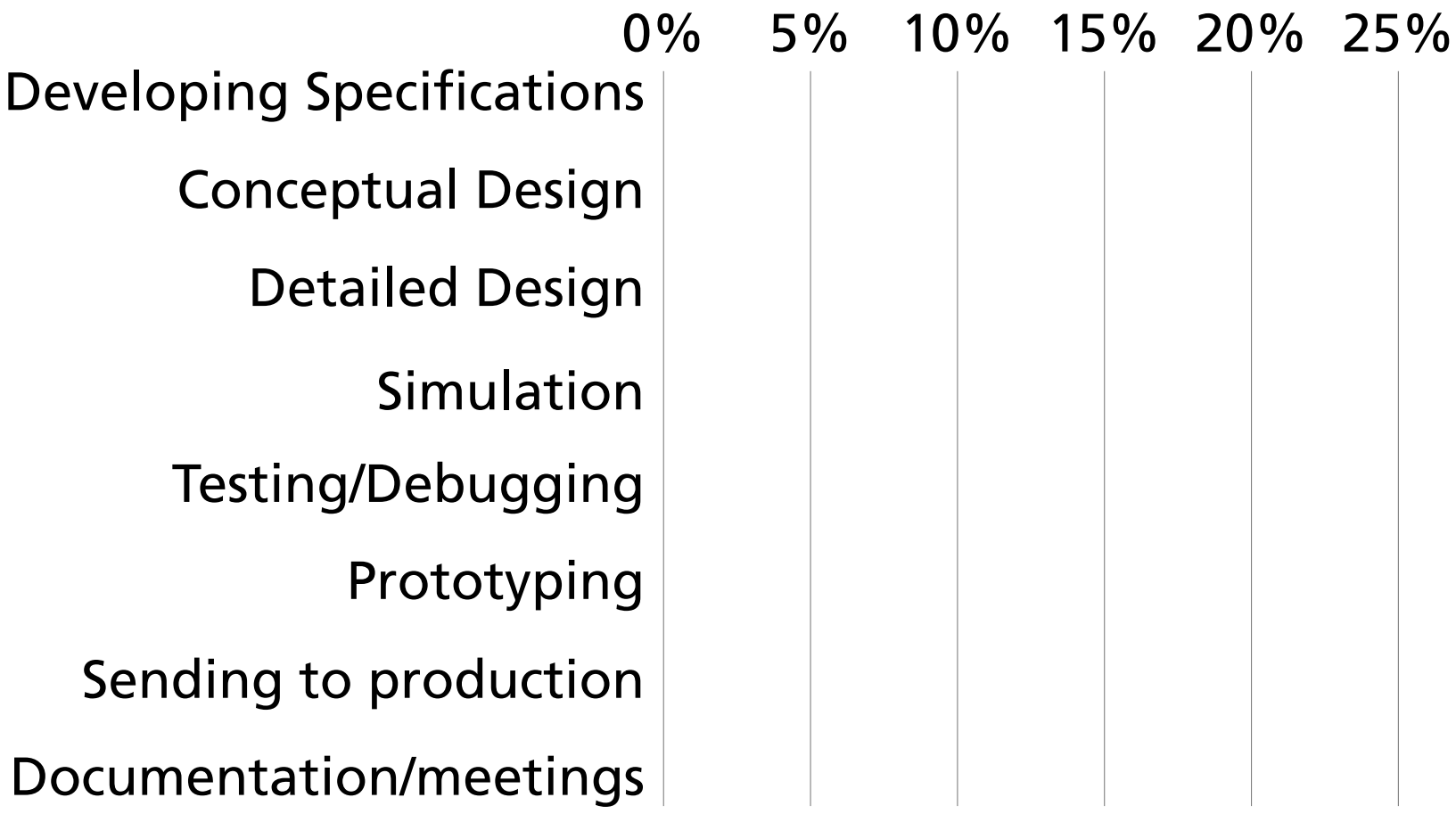
Includes fan and guard which can be quickly attached to Home Motor, and will be a great comfort in hot weather. Shipping weight, about 14 ounces.

No. 57P6215
Price..... **$1.30**

About $100 in today's dollars.

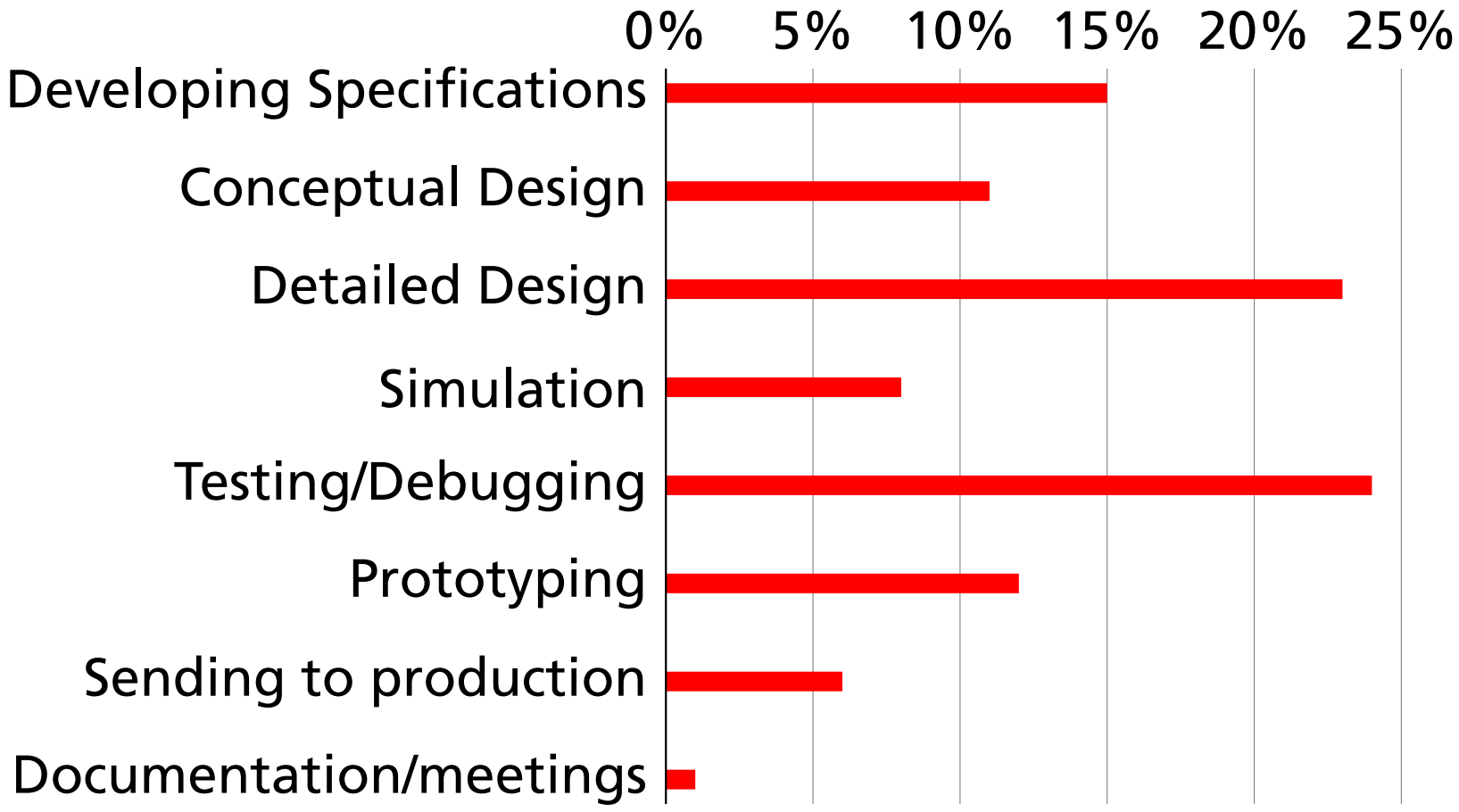
From Donald Norman, *The Invisible Computer*, 1998.

What Percentage of Time Do You Spend...



Source: 2009 Embedded Market Study

What Percentage of Time Do You Spend...



Source: 2009 Embedded Market Study

Does Your Current Project Contain FPGAs?

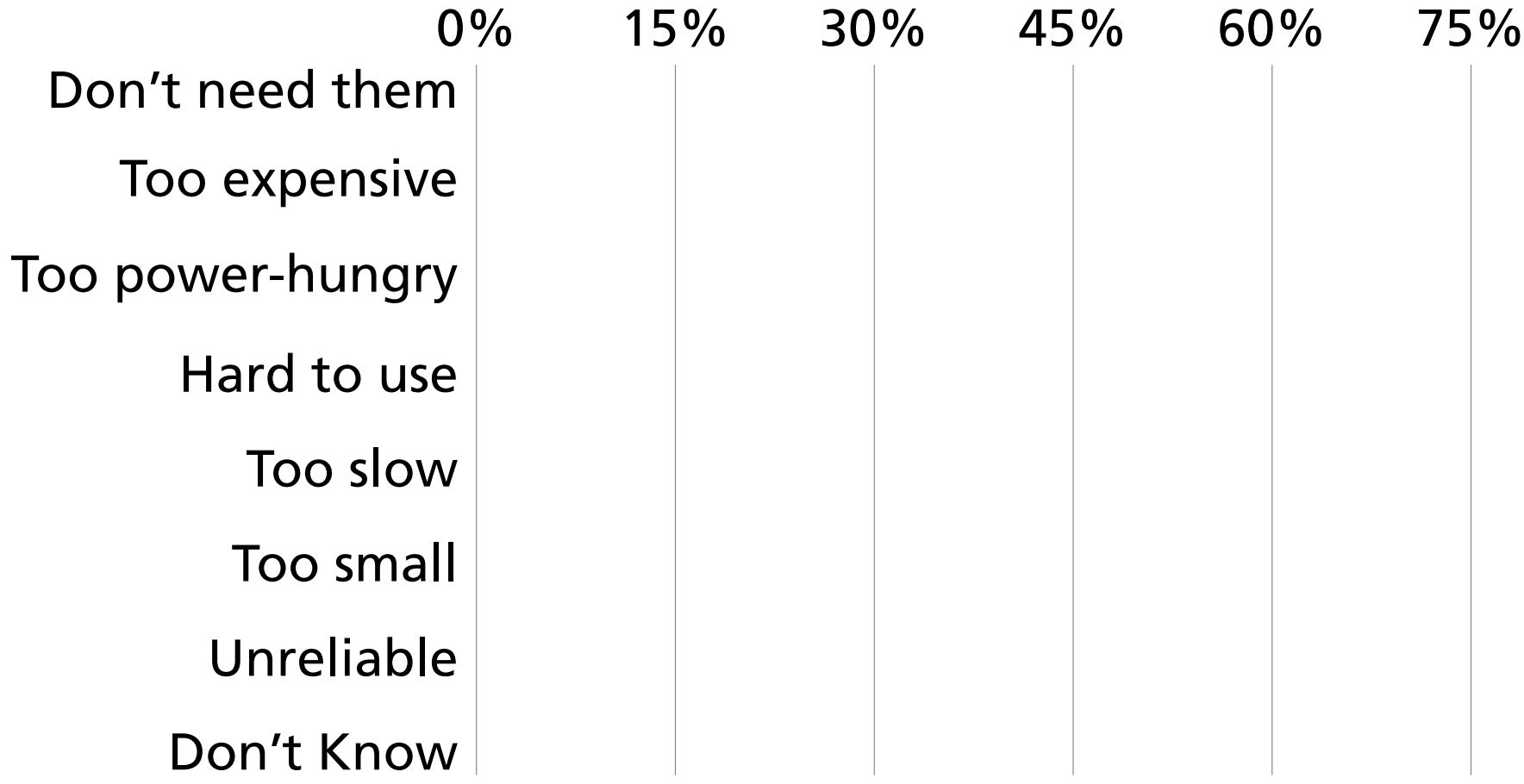
Does Your Current Project Contain FPGAs?

45% Yes

55% No

Source: 2009 Embedded Market Study

Why Won't Your *Next* Project Use FPGAs?



Source: 2009 Embedded Market Study

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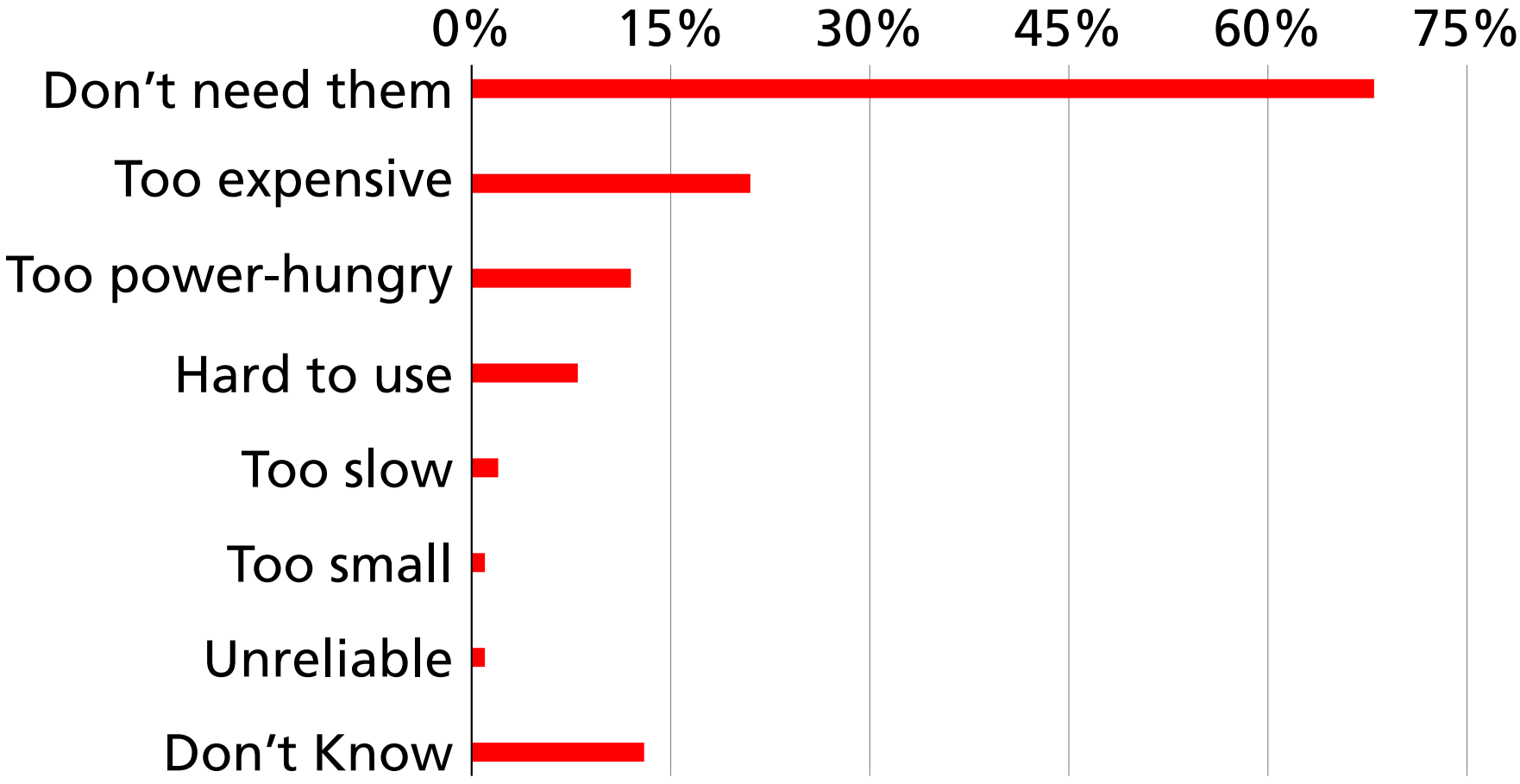
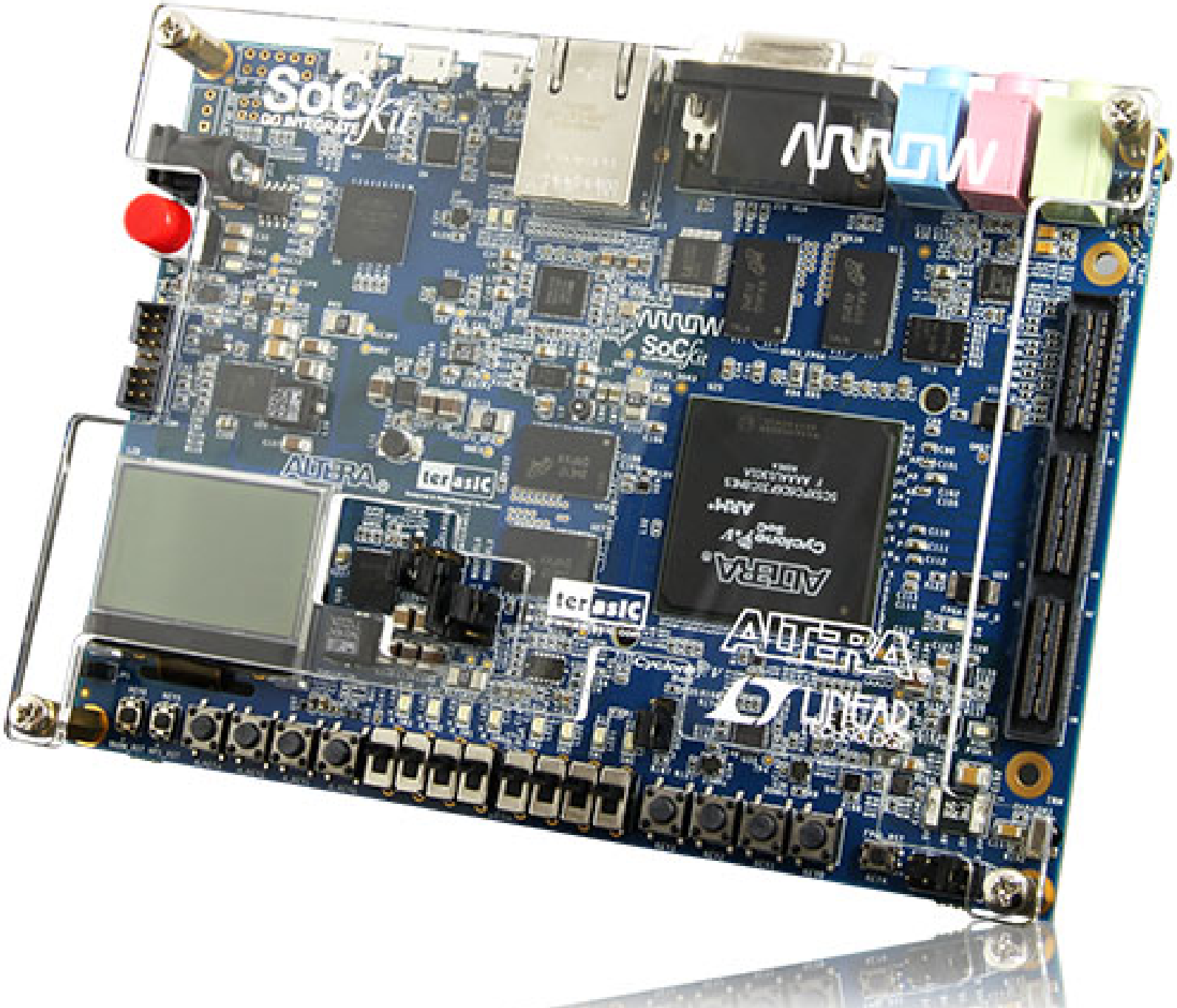
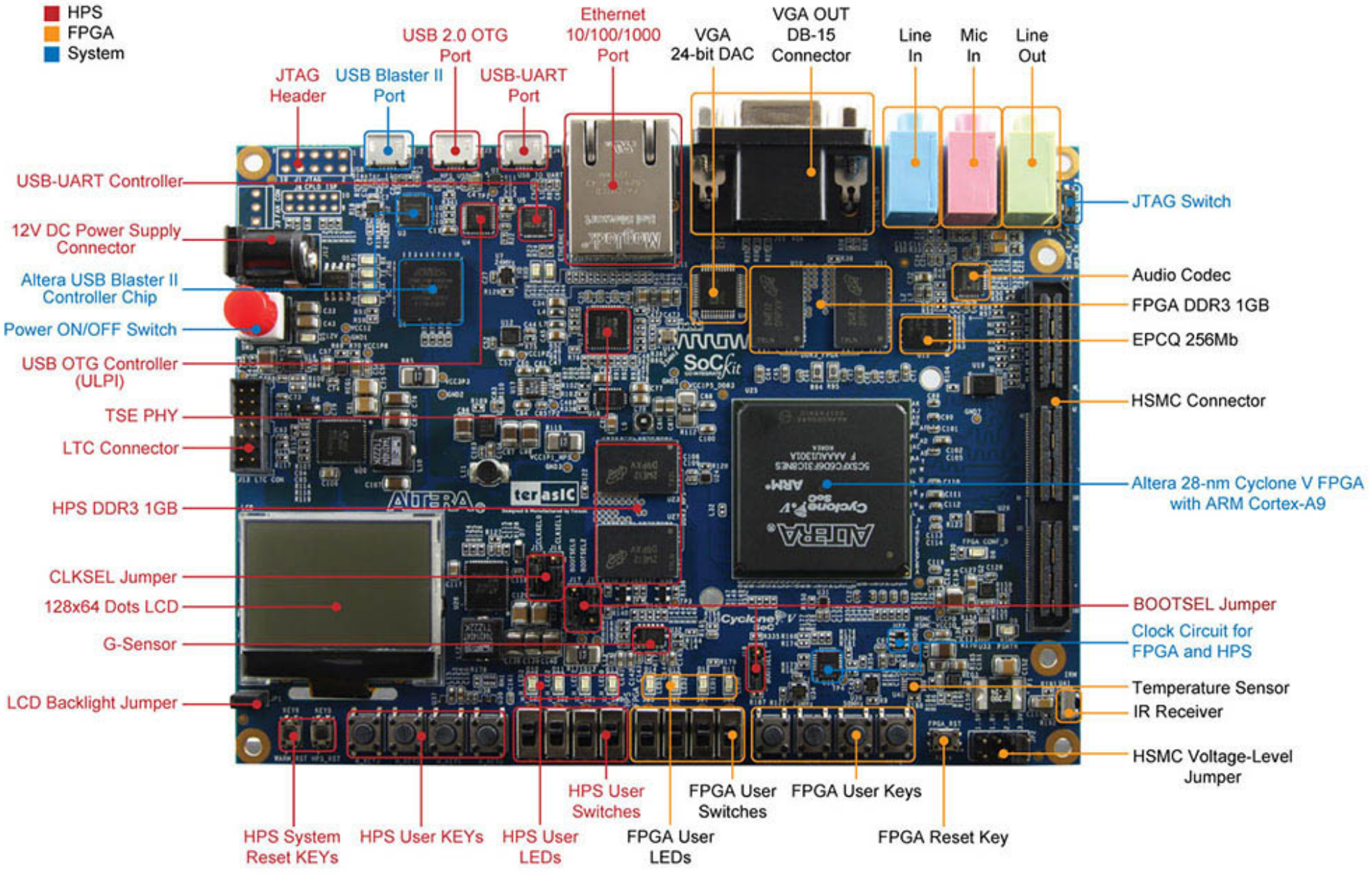


Source: 2009 Embedded Market Study

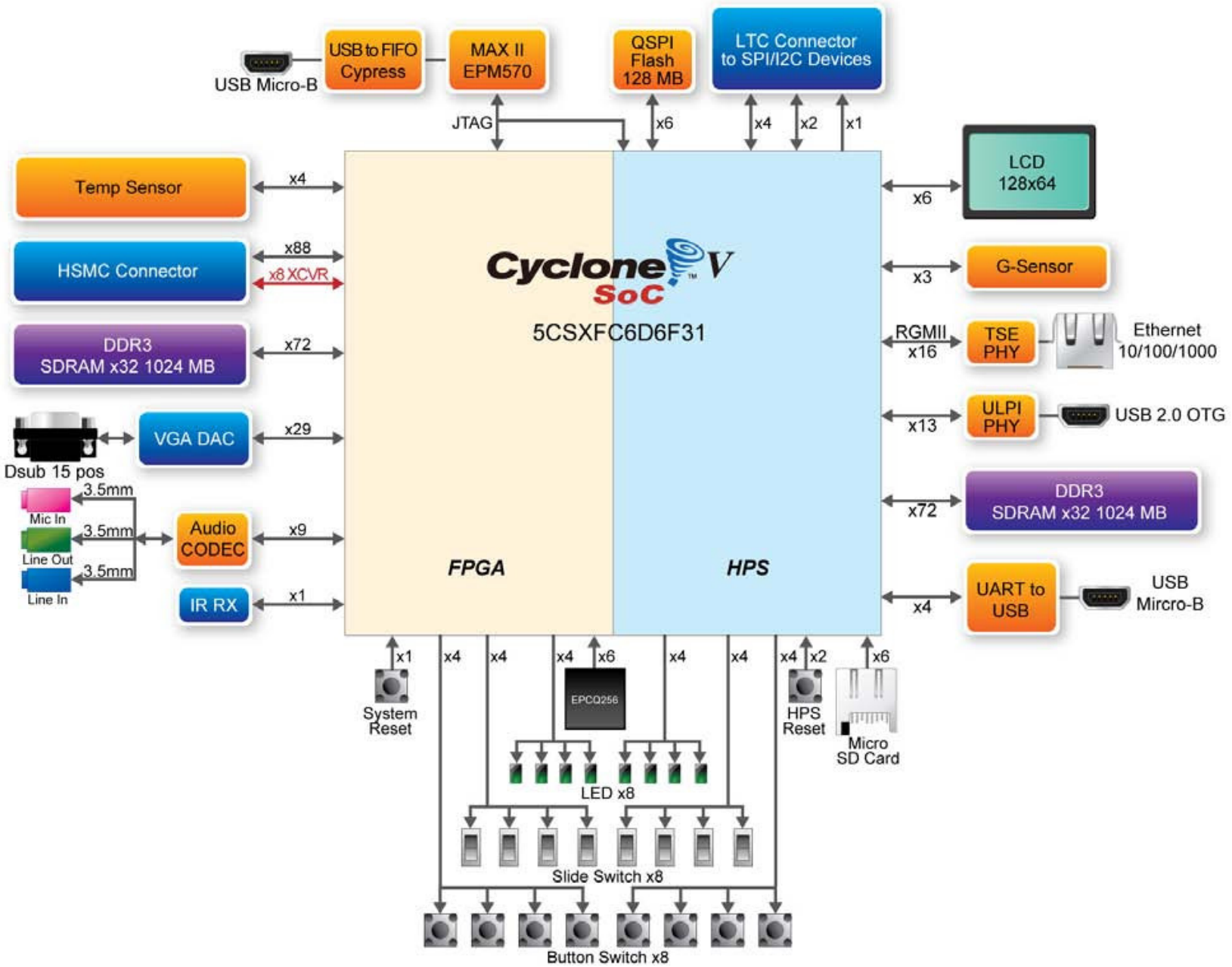
Your Nemesis: The SoCKit Board



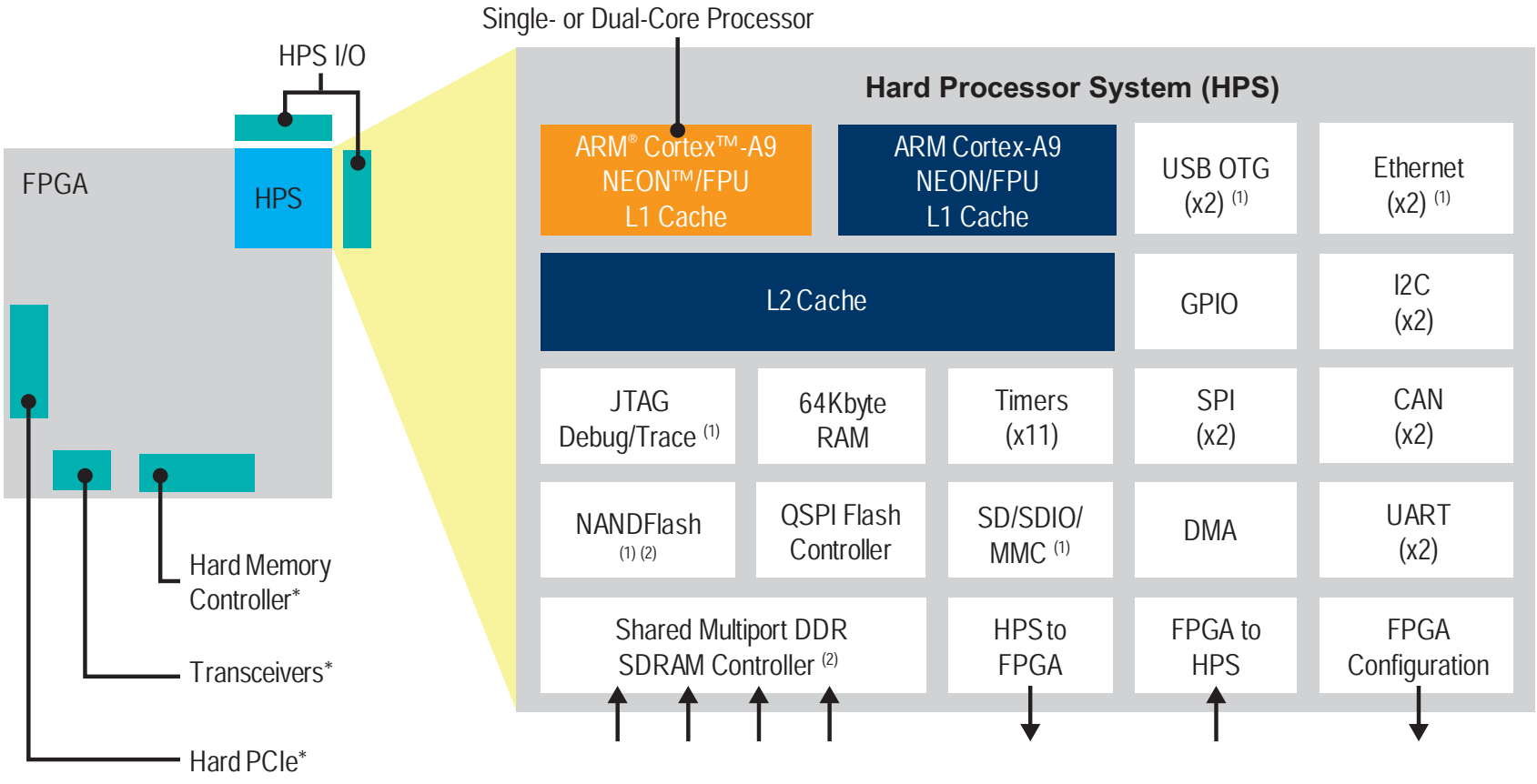
Components and Peripherals



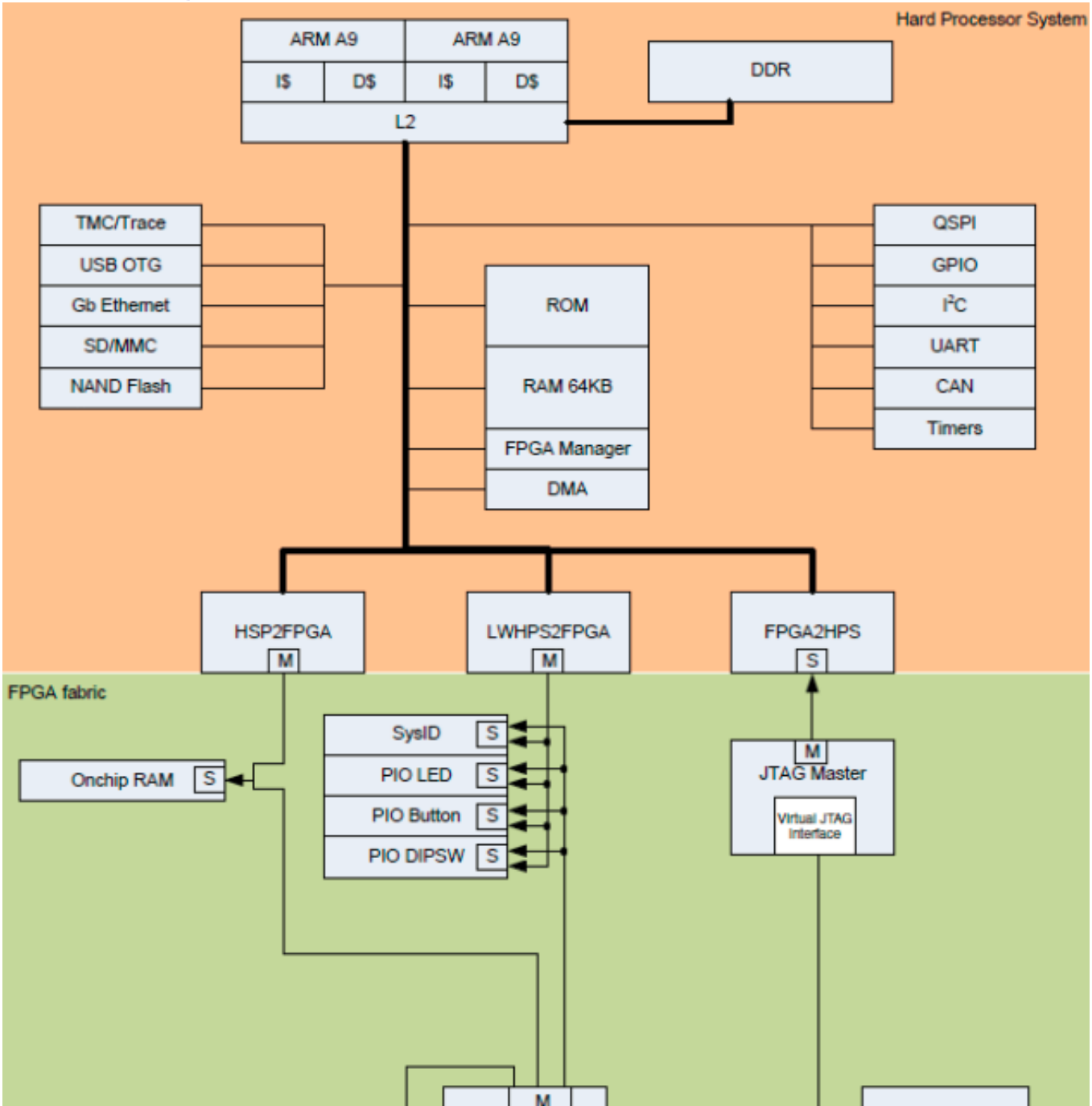
Dual ARM Cortex-A9 and Programmable Logic



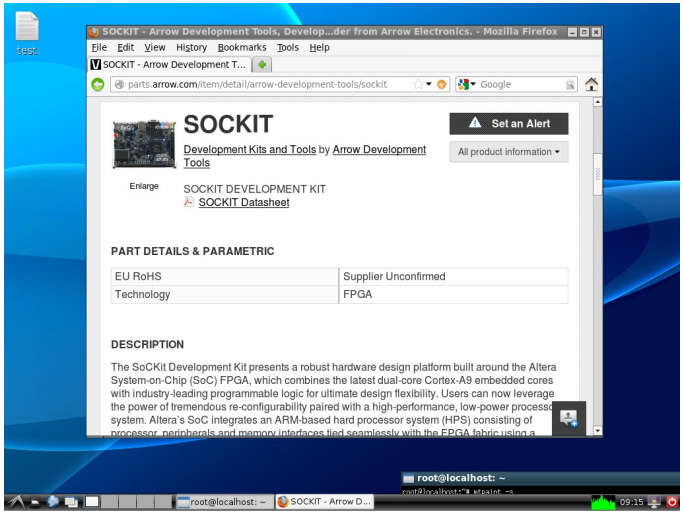
Inside the Cyclone V: Dual ARM processors + FPGA



An Example System



Linux + Custom Hardware



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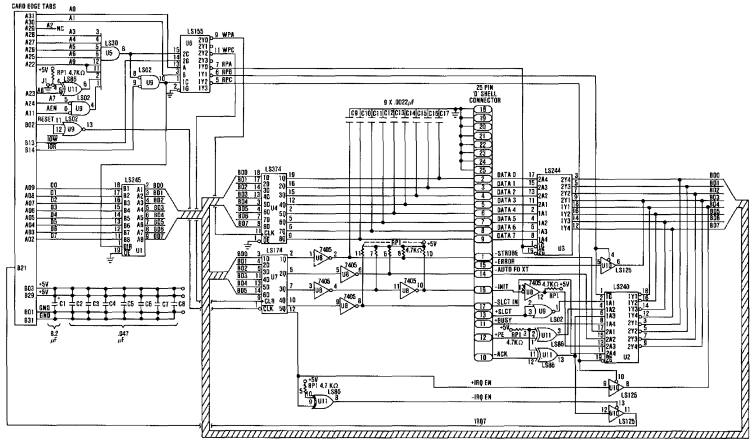


Class Structure

Three Introductory Labs: 2 weeks each
Work in pairs

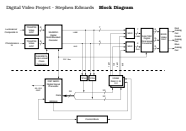
1. Hardware: Access, modify, and display memory
2. Software: A simple Internet chat client
3. HW + SW: A video bouncing ball

The project: **Design-your-own**
Work in groups of four (mostly)

Custom Project Ideas

Broadly: C + SystemVerilog + peripheral(s)

Video game (e.g., Pac-Man)



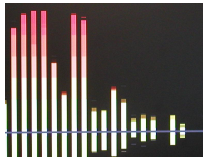
Video effects processor

Digital photo frame

Very fancy digital clock

More Ideas

Digital tone control



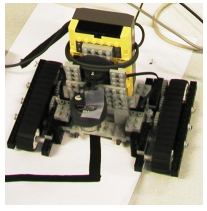
Real-time audio spectrum analyzer

Internet radio

Speech Synthesizer

Projects from 2004

MIDI synthesizer

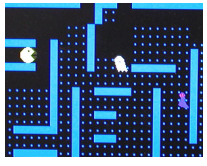


Line-following robot with video vision

SAE student vehicle telemetry system

Stereo video vision system

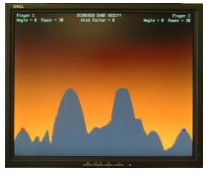
Internet video camera



Pac-man-like video game

Projects from 2005

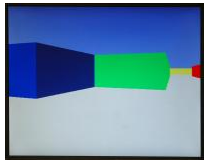
Scrabble Timer



Scorched Earth

SAE Auto Shifter

Internet Radio Broadcaster



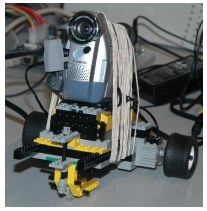
3D Maze Game

VoIP Telephone

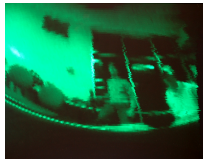
JPEG decoder

Rally-X video game

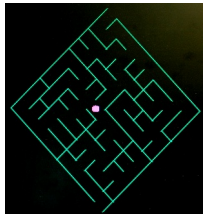
Projects from 2006



Video-guided Lego Robot

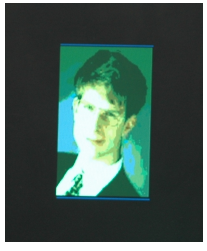


360° camera de-warper



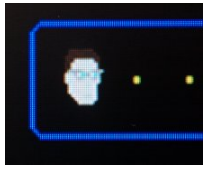
Videogame with accelerated line-drawing

Voice recorder

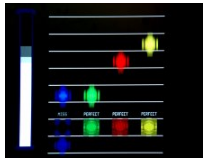


JPEG decoder

Projects from 2007



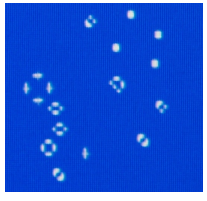
Pac-Edwards



Button Hero Videogame

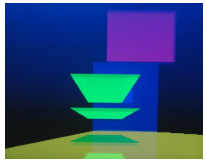
Digital Picture Frame: SD card with JPEG to VGA

Networked game of Clue

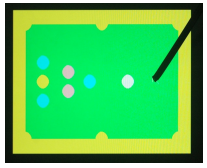


Conway's Game of Life (60 gps)

Projects from 2008

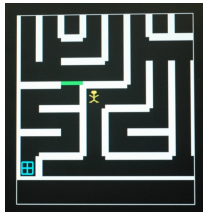


Real-time ray tracer



Video-camera-controlled pool game

Real-time video decryption



WiiMote-controlled maze game

Projects from 2009

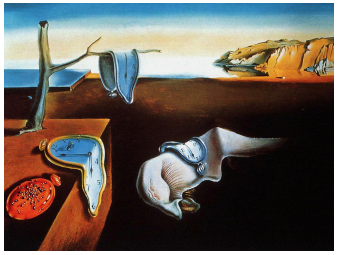
Lightsaber video overlay

Networked Video Phone

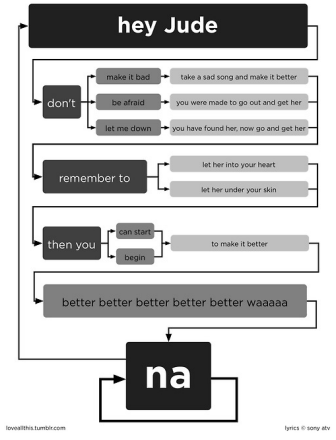
Sound-controlled videogame

Visual object tracker

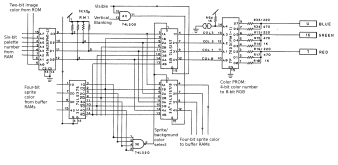
The Three Main Challenges of Embedded Systems



Coping with Real-World Sensor Data

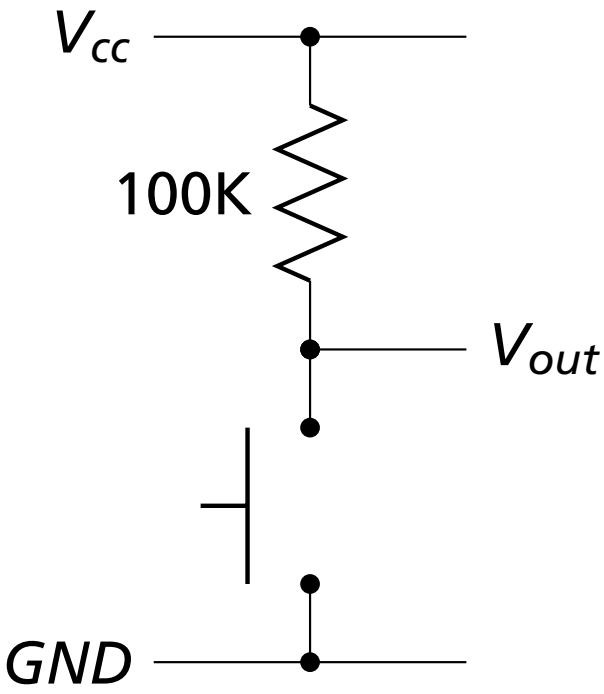


Algorithm Design

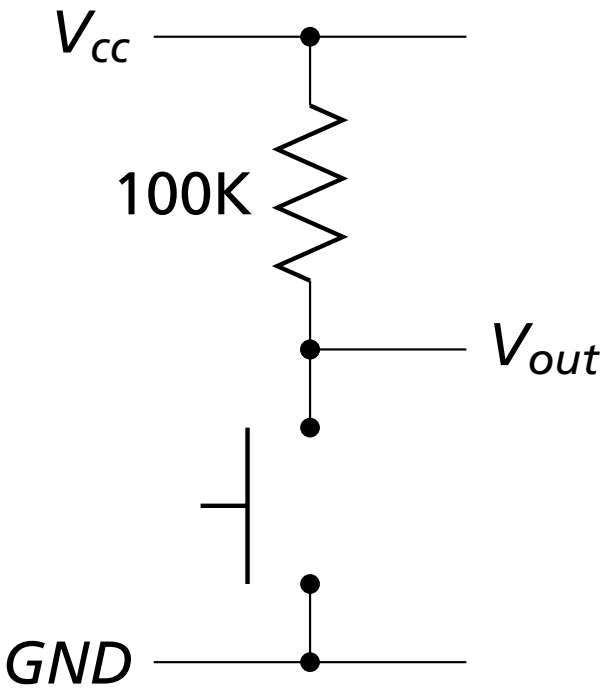


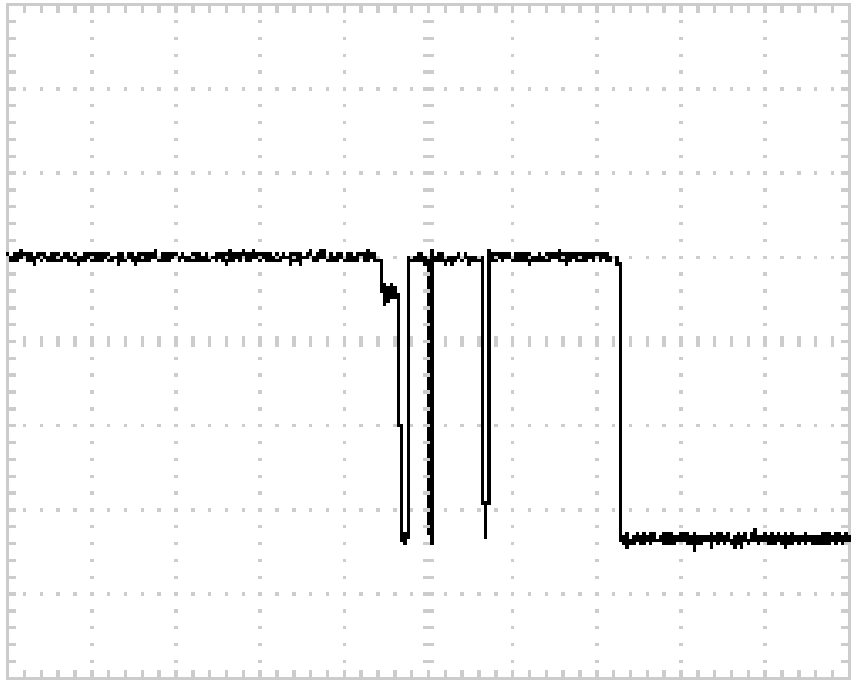
Implementation Details

What Happens When You Press the Switch?

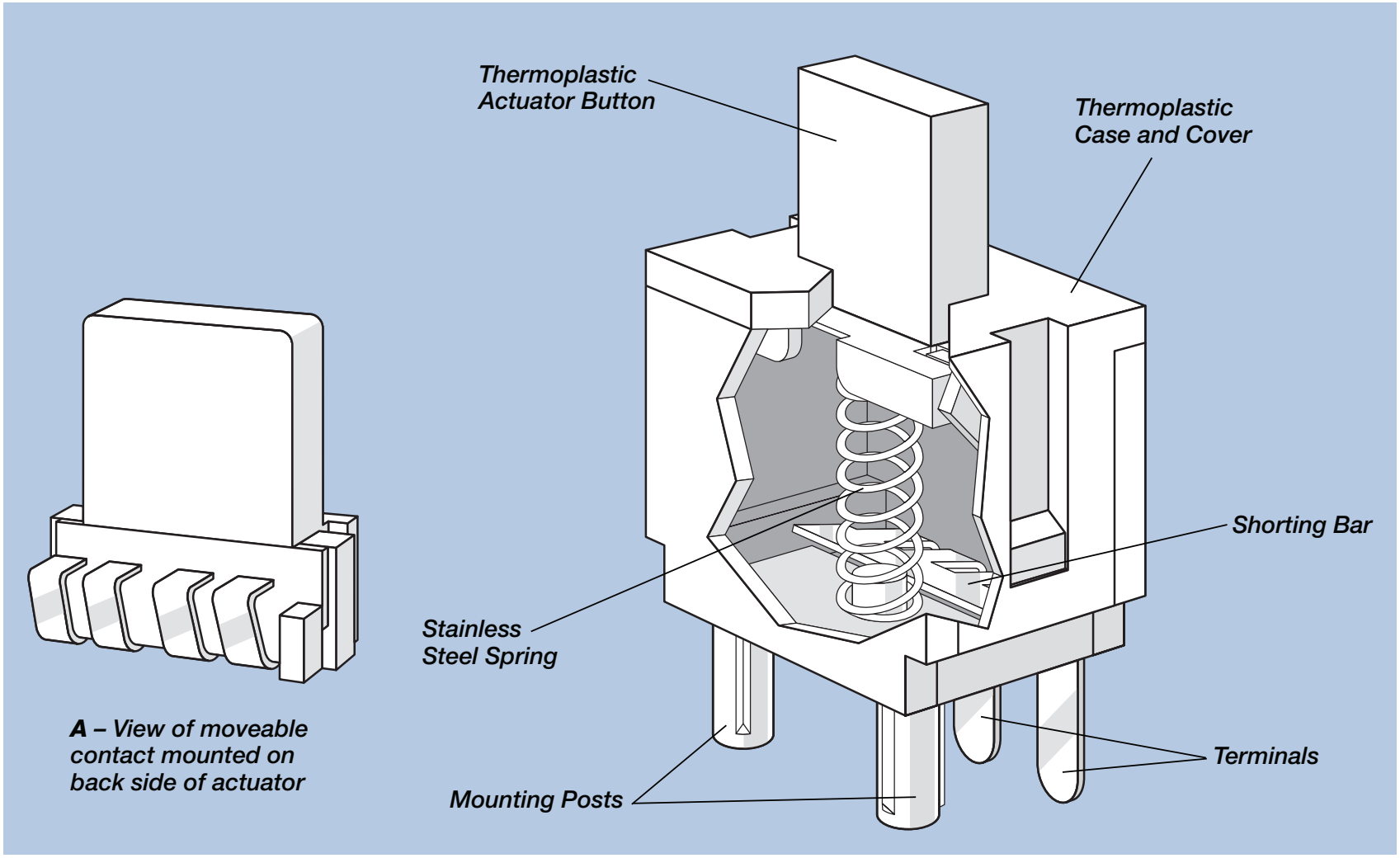


What Happens When You Press the Switch?



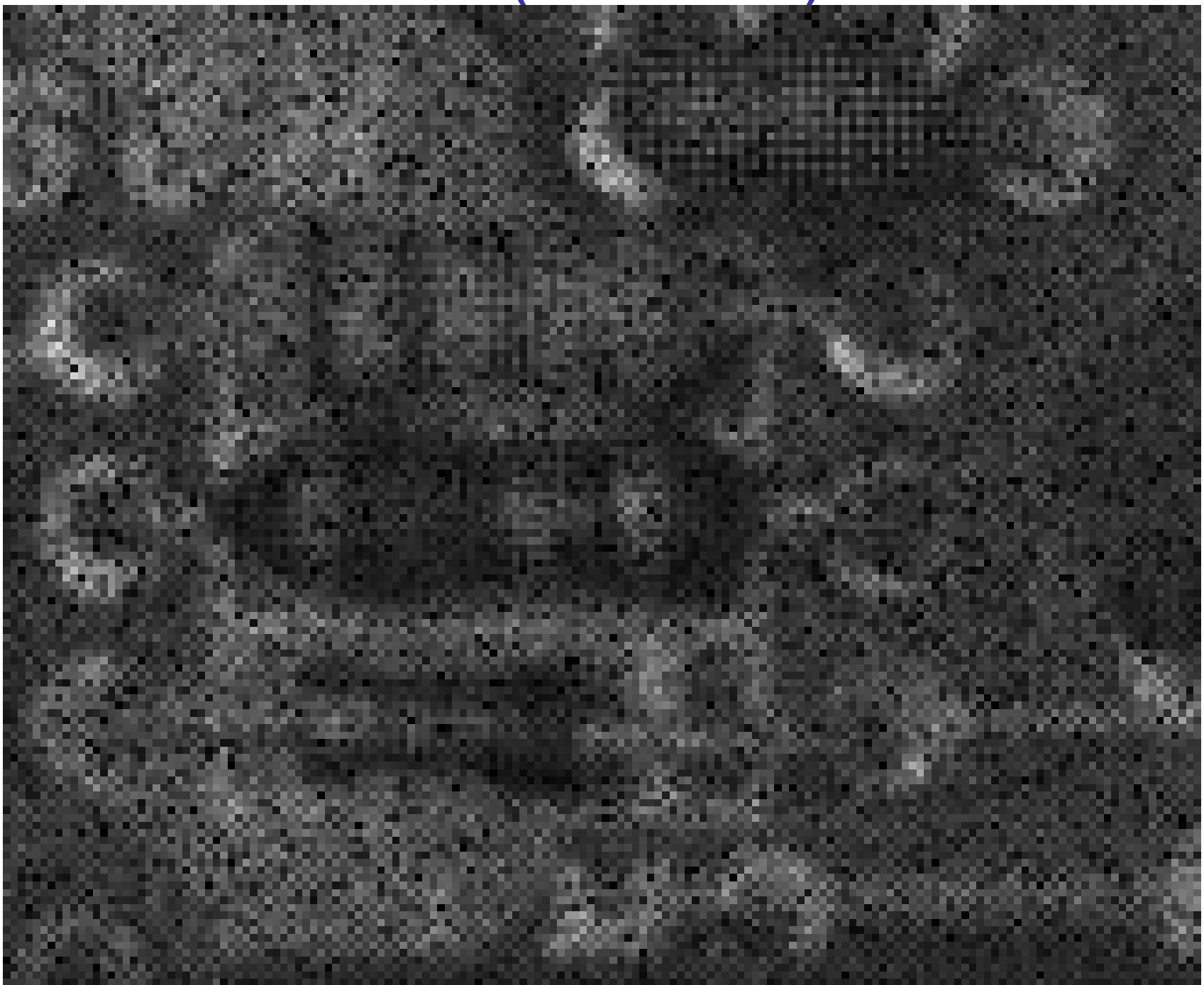


Inside a Pushbutton Switch

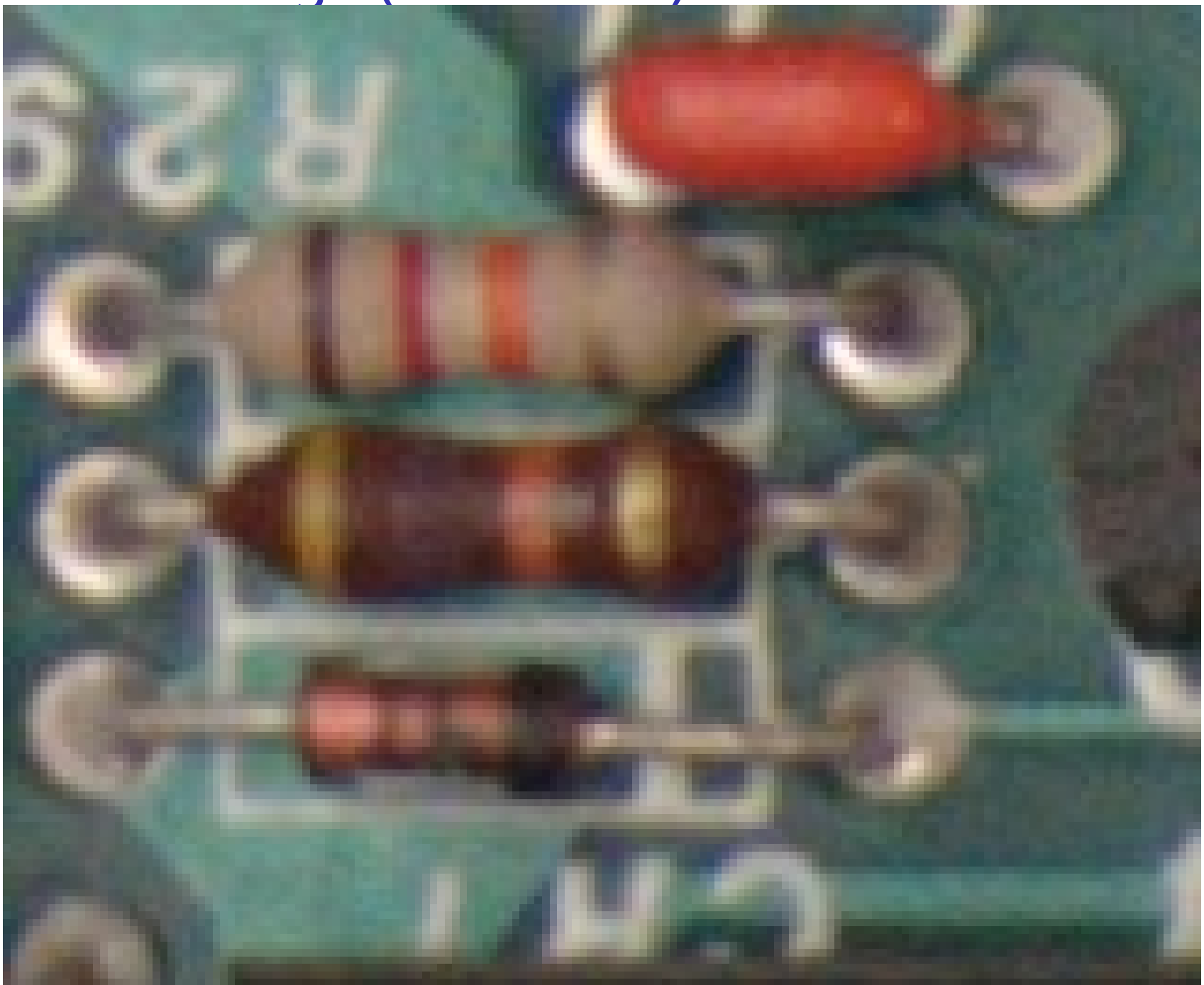


Source: Cherry CS series data sheet

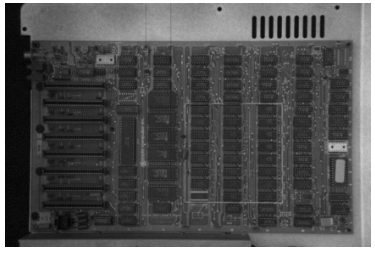
Raw Data from a CCD (zoomed in)



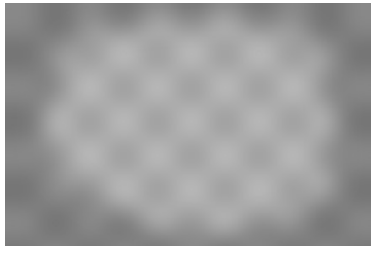
Corrected Image (zoomed in)

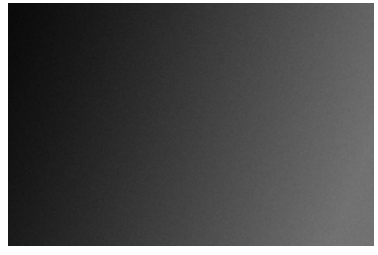


Correcting Data from CCDs



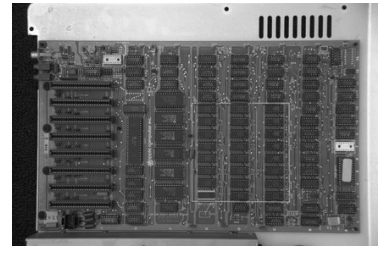
Raw Dark Frame



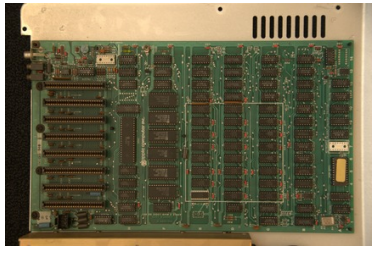


Flat Field Bias

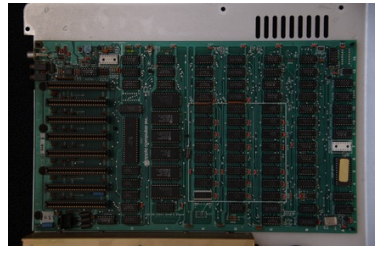
=



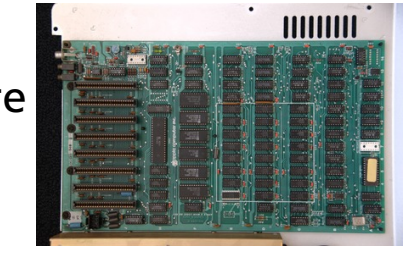
Color →



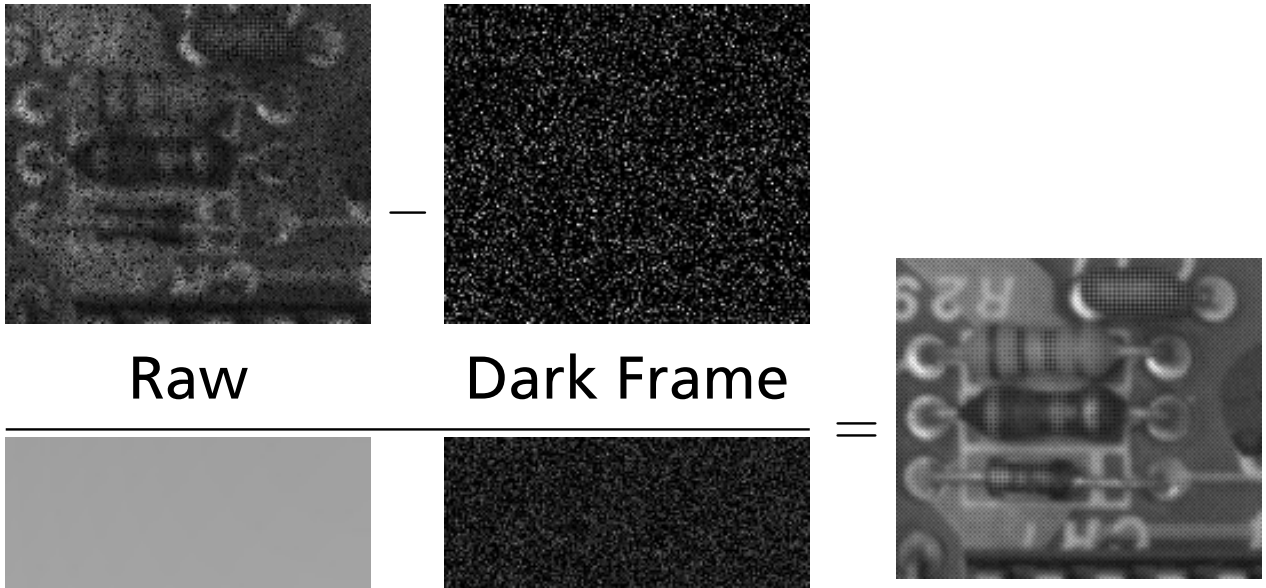
Temp. →

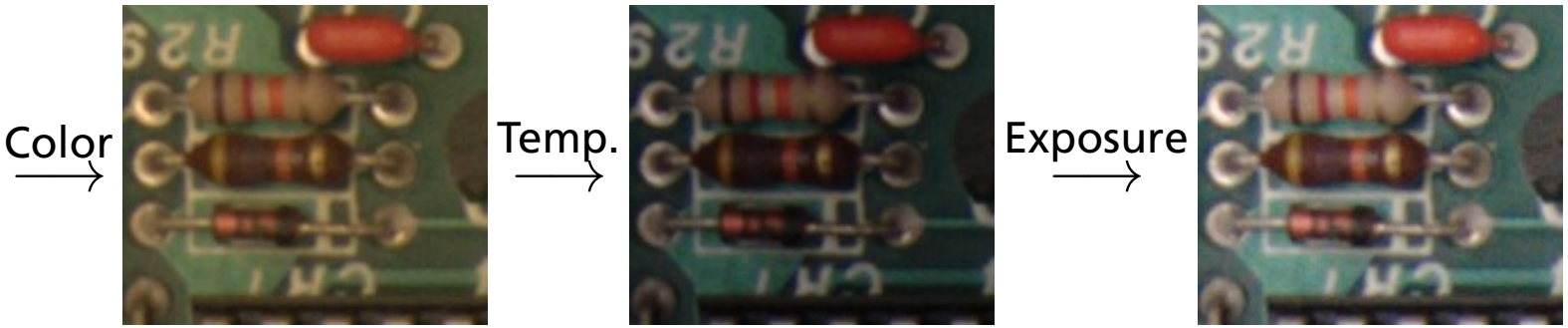


Exposure →



Correcting Data from CCDs





Where Does This Noise Come From?

Nikon D300: 23.6 mm $\times$ 15.8 mm
12.3 megapixel CMOS sensor

Pixels are 5.5 μm on a side

A/D sampling of 12 bits per pixel measures

ISO:	LO	200	400	800	1600	3200
G	7.1	5.5	2.7	1.3	0.65	0.33
B	5.8	4.6	2.3	1.1	0.55	0.27
R	4.7	4.5	2.2	1.1	0.54	0.26

The units: *electrons per ADU* (digital unit).

Emil Martinec, *A comparison of the Nikon D300 and Canon 40D sensors*, 2007.

Development Plan

1. Obtain some representative raw sensor data
2. Develop an algorithmic prototype using your favorite language (e.g., Java, C, Matlab)
3. Plan how to implement it
4. Implement while constantly testing