Embedded System Design

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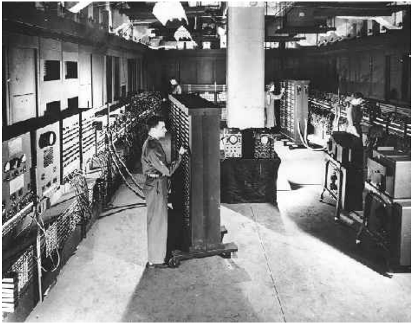
Columbia University

Spring 2011

Spot the Computer



Embedded Systems: Ubiquitous Computers

iPhone

Laser Keyboard

Nikon D300

Video Watch

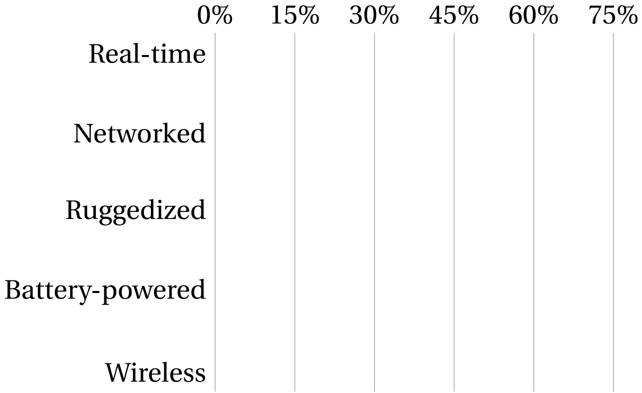
GPS

Playstation 3

PC Keyboard

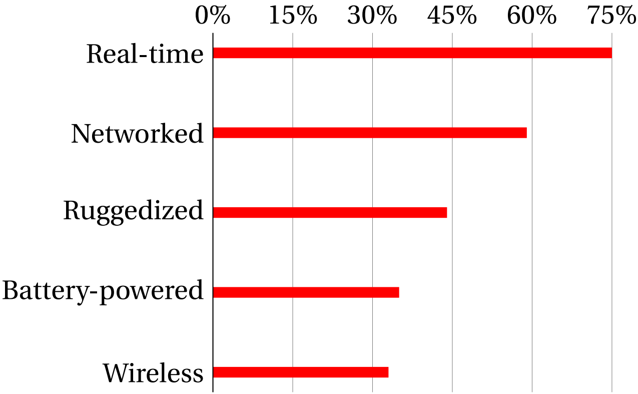
SD Card

Is Your Current Embedded Project...



Source: 2009 Embedded Market Study

Is Your Current Embedded Project...



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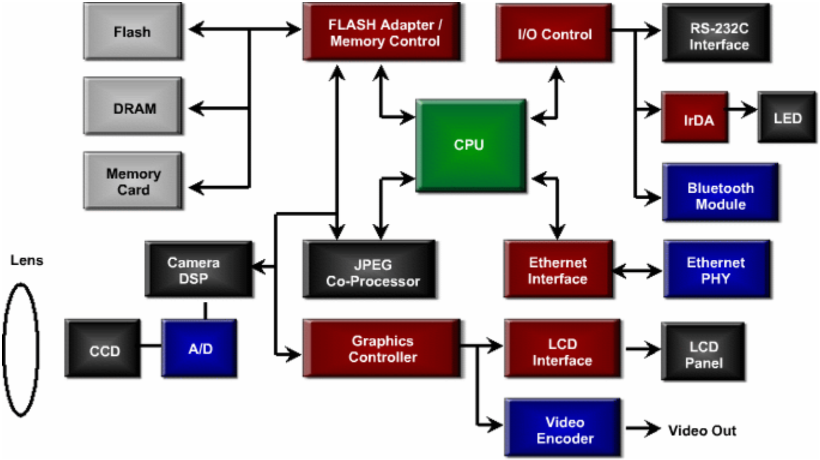
Digital Camera Block Diagram



Design An Optimal Device that Meets Constraints On


Price


Performance

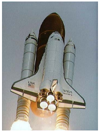

Power


Maintainability

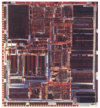

Functionality

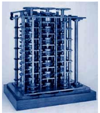

Size


Time-to-market


Safety

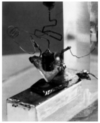
Embedded System Technologies


Integrated Circuits

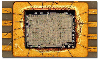

Processing elements

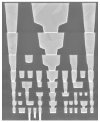

Design tools

IC Technology

 1947: First transistor (Shockley, Bell Labs)

 1958: First integrated circuit (Kilby, TI)

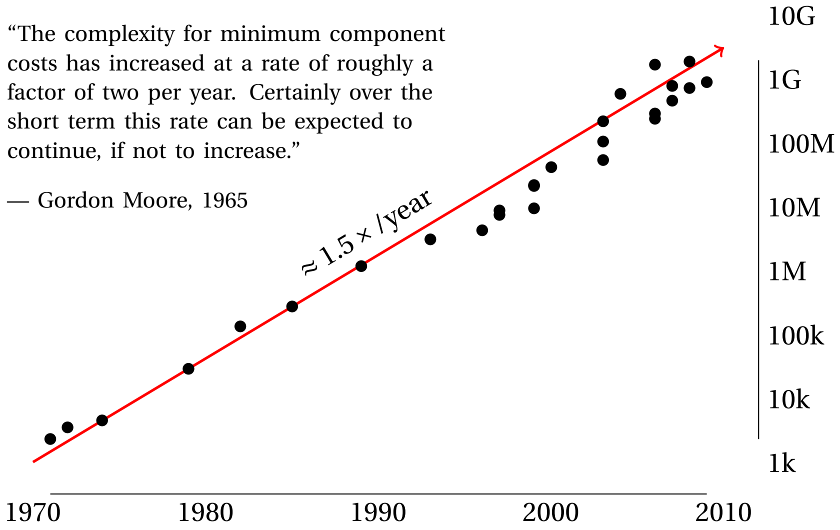
 1971: First microprocessor (4004: Intel)

 Today: eight wire layers, 45 nm features

Moore's Law: Transistors per chip

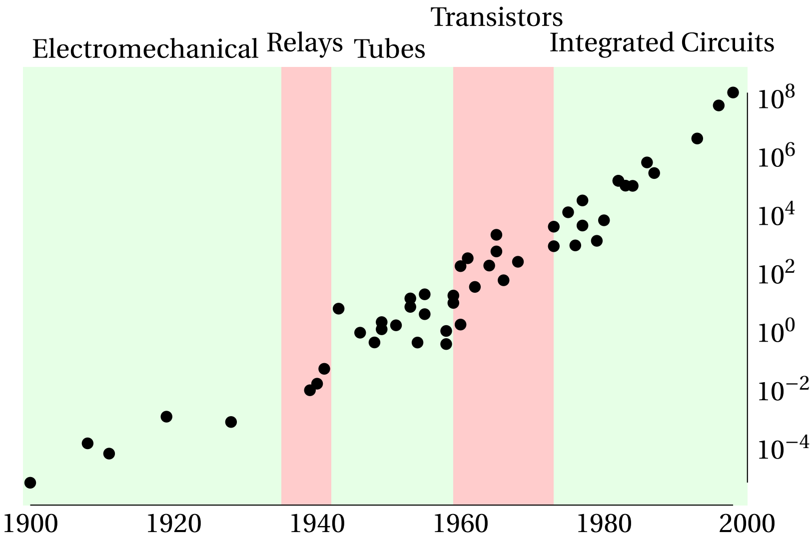
"The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase."

— Gordon Moore, 1965



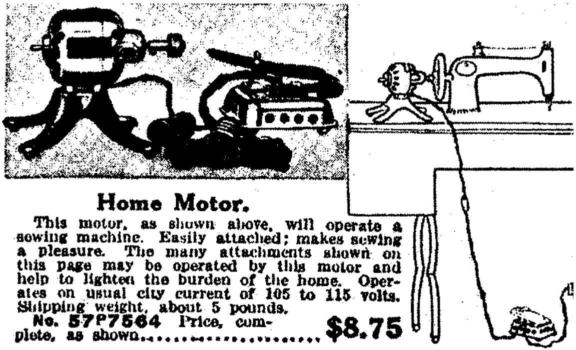
Source: Intel/Wikipedia

$1000 Buys You This Many CPS



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

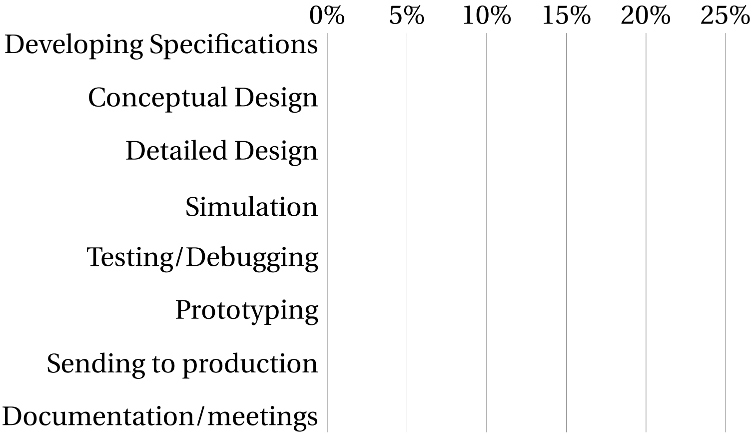
1918 Sears Roebuck Catalog



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

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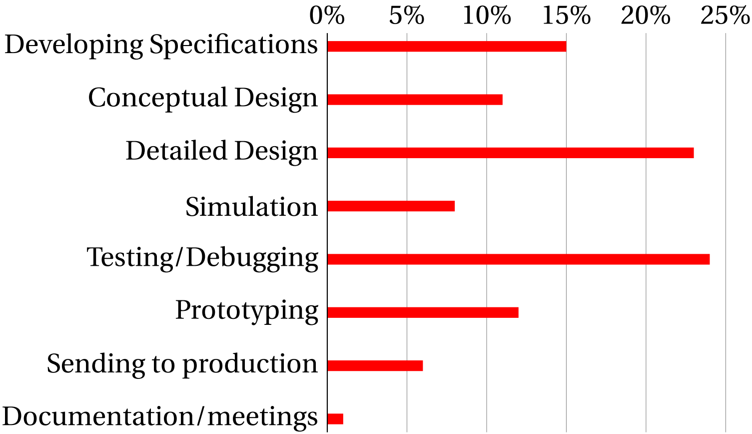
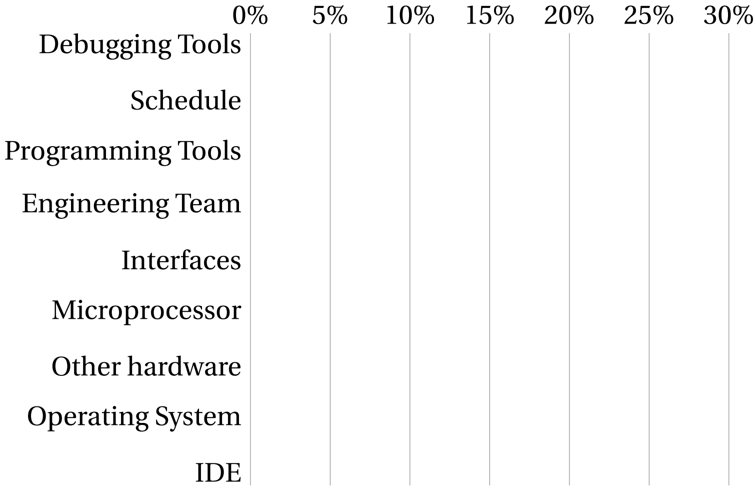


Source: 2009 Embedded Market Study

If You Could Improve One Thing...



Source: 2009 Embedded Market Study

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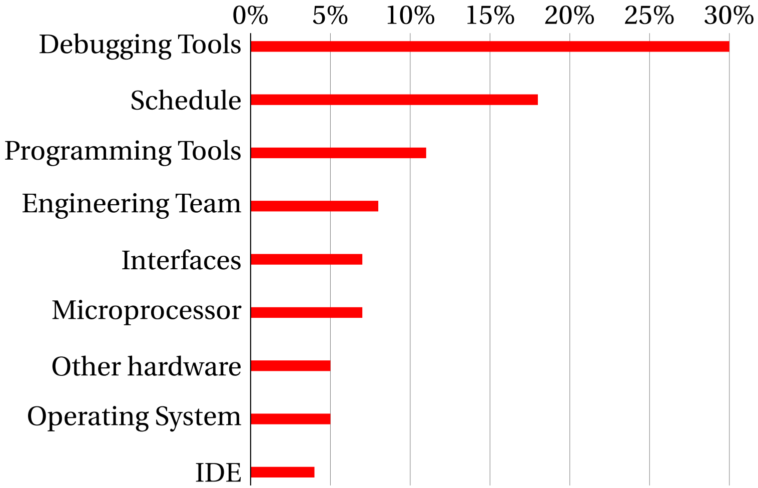
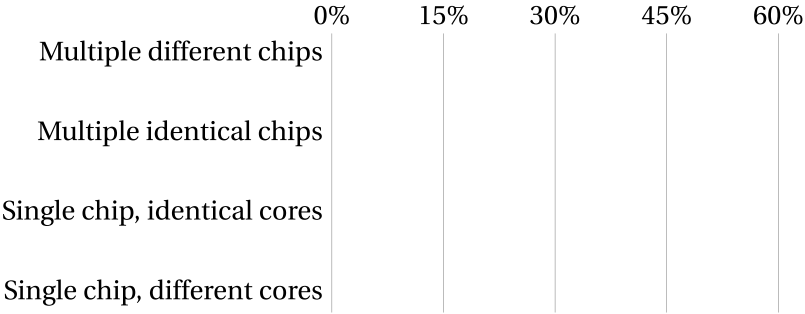


Source: 2009 Embedded Market Study

If Your System Has More Than One Processor, Does It Use…



Source: 2009 Embedded Market Study

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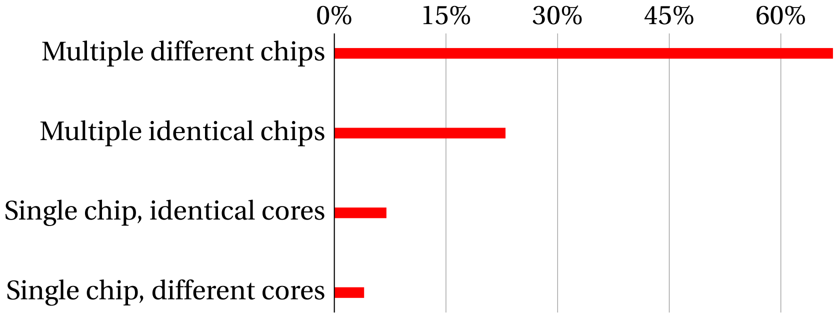


Source: 2009 Embedded Market Study

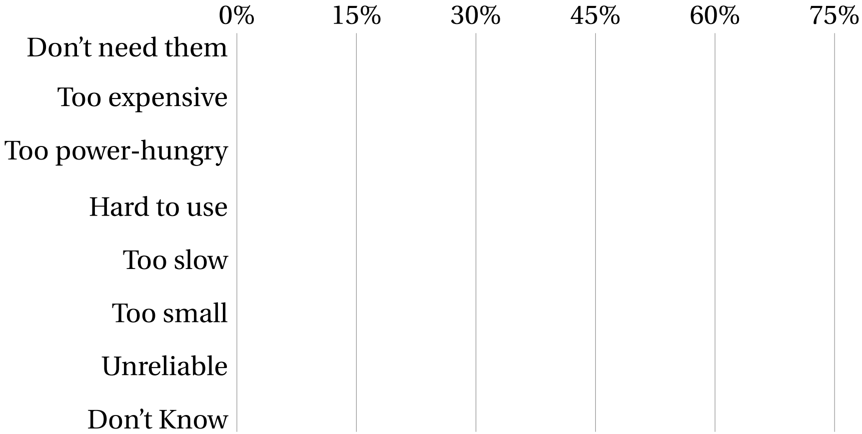
Does Your Current Project Contain FPGAs?

Does Your Current Project Contain FPGAs?

45%	Yes
55%	No

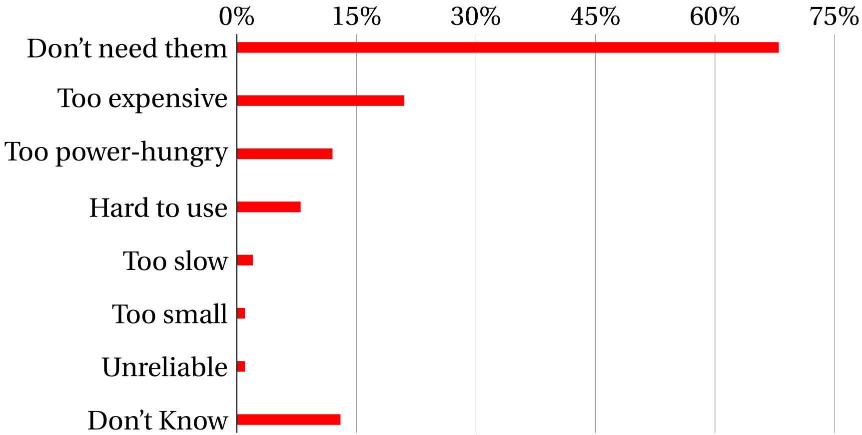
Source: 2009 Embedded Market Study

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



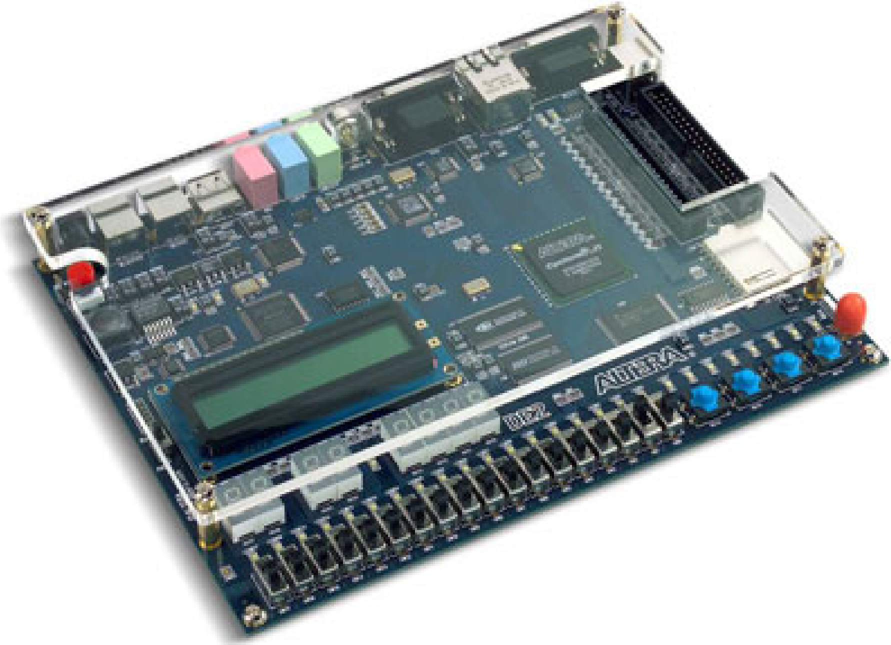
Source: 2009 Embedded Market Study

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

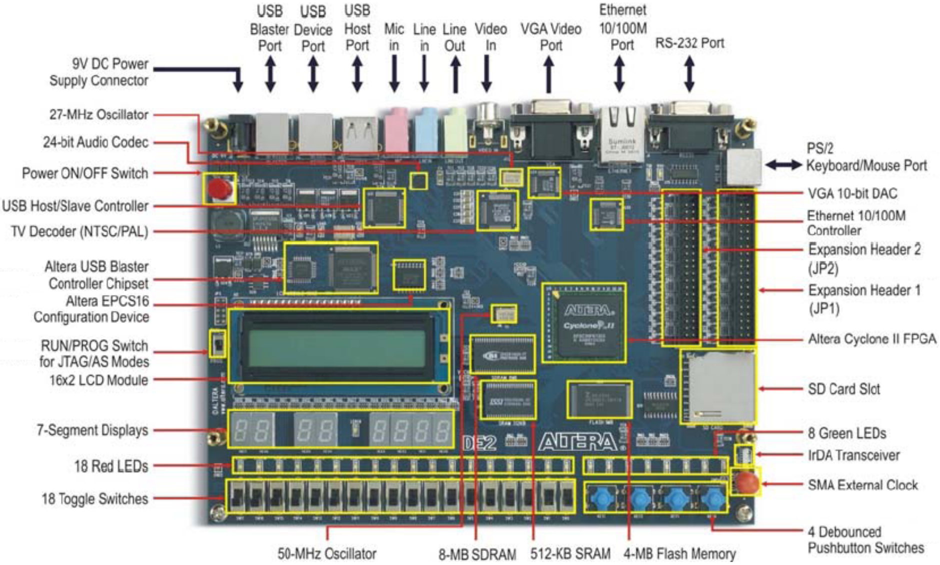


Source: 2009 Embedded Market Study

Your Nemesis: The Altera DE2



DE2 Peripherals



Class Structure

Three Introductory Labs: 2 weeks each

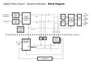
1. Access, modify, and display memory in VHDL
2. An Ethernet chat client (software only)
3. Either
   - an FM audio synthesizer; or
   - a video bouncing ball.

The project: **Design-your-own**

Custom Project Ideas

Broadly: C + VHDL + peripheral(s)

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



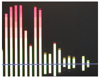
Video effects processor

Digital photo frame

Very fancy digital clock

More Ideas

Digital tone control



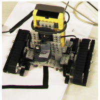
Real-time audio spectrum analyzer

Internet radio

Speech Synthesizer

Projects from 2004

MIDI synthesizer

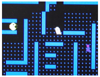


Line-following robot with video vision

SAE student vehicle telemetry system

Stereo video vision system

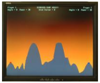
Internet video camera



Pac-man-like video game

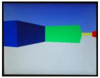
Projects from 2005


Scrabble Timer


Scorched Earth

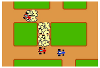

SAE Auto Shifter


Internet Radio Broadcaster

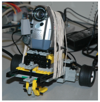

3D Maze Game


VoIP Telephone

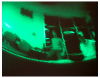

JPEG decoder


Rally-X video game

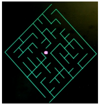
Projects from 2006



Video-guided Lego Robot

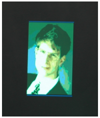


360° camera de-warper



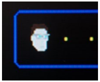
Videogame with accelerated line-drawing

Voice recorder

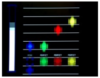


JPEG decoder

Projects from 2007



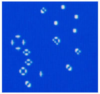
Pac-Edwards



Button Hero Videogame

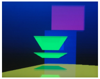
Digital Picture Frame: SD card with JPEG to VGA

Networked game of Clue

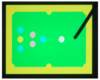


Conway's Game of Life (60 gps)

Projects from 2008

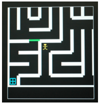


Real-time ray tracer



Video-camera-controlled pool game

Real-time video decryption



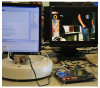
WiiMote-controlled maze game

Projects from 2009

Lightsaber video overlay

Networked Video Phone

Sound-controlled videogame

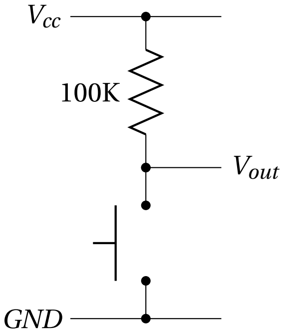


Visual object tracker

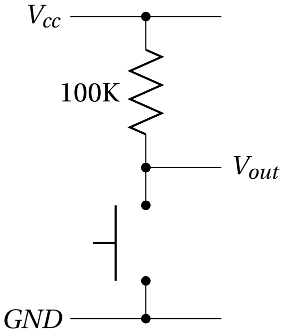
The Three Main Challenges of Embedded Systems

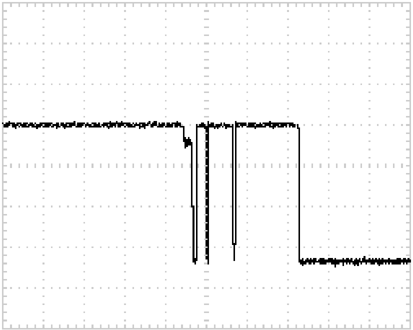
- Coping with Real-world Sensor Data
- Algorithm Design
- Implementation Details

What Does this Circuit Do When You Press the Switch?

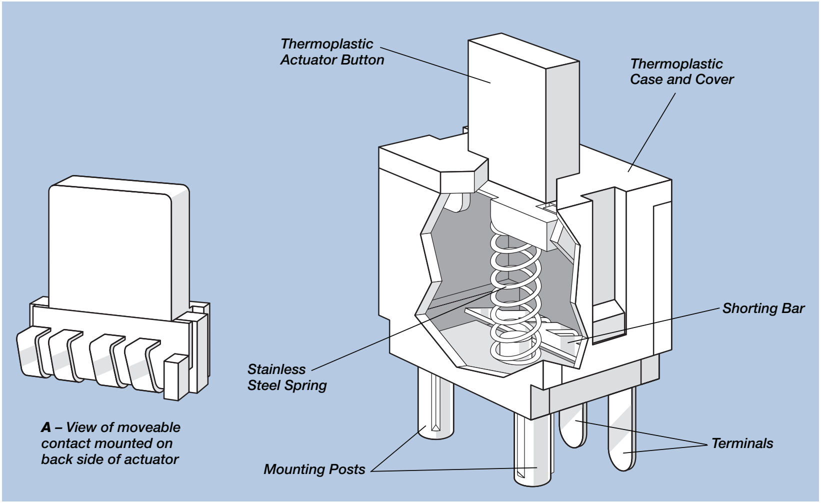


What Does this Circuit Do When You Press the Switch?



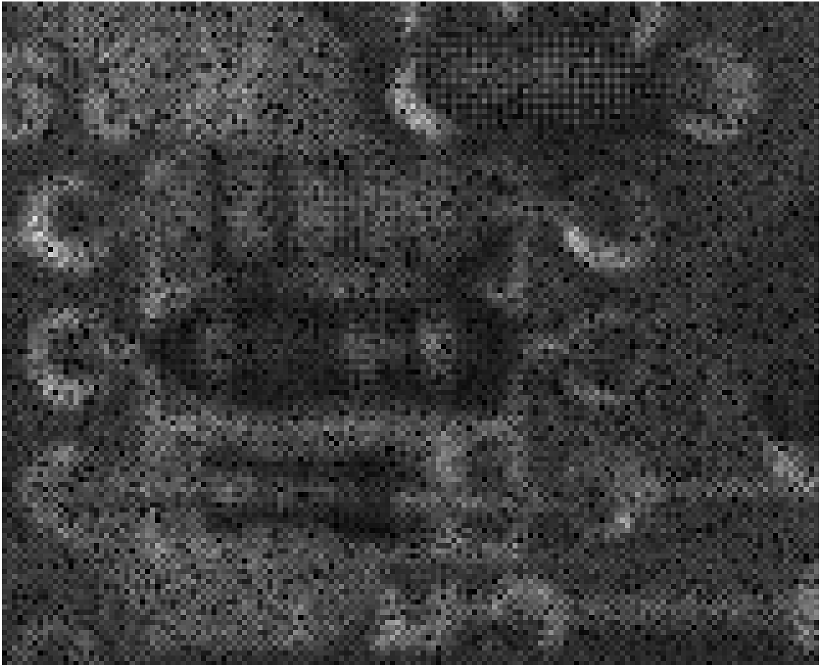


Inside a Pushbutton Switch

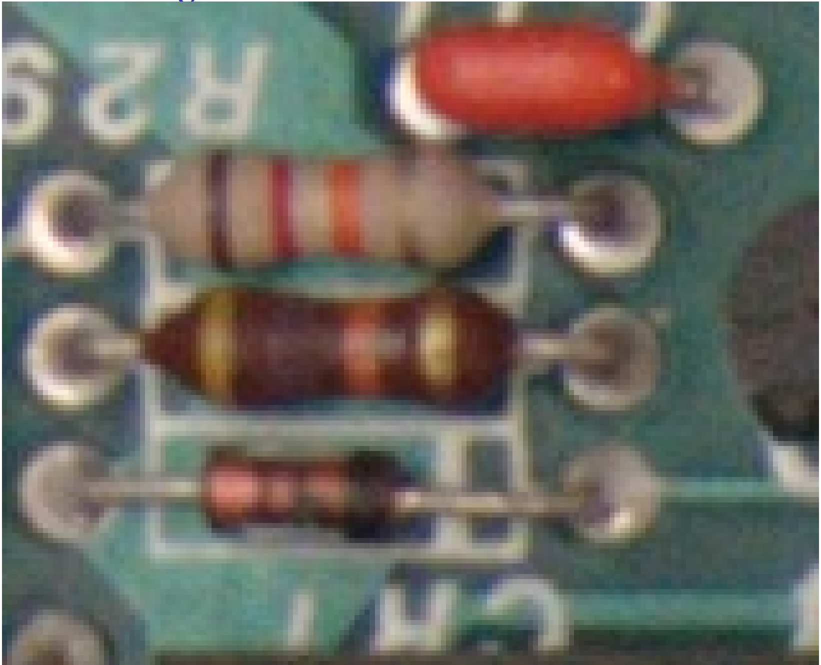


Source: Cheery CS series data sheet

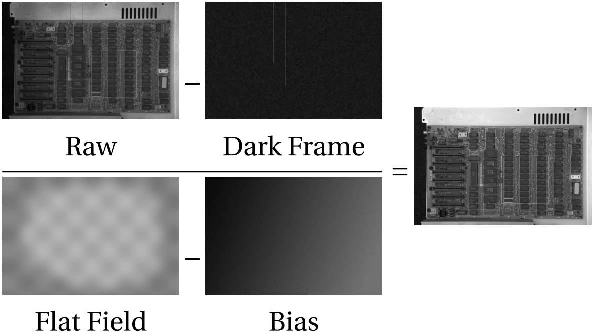
Raw Data from a CCD (zoomed in)

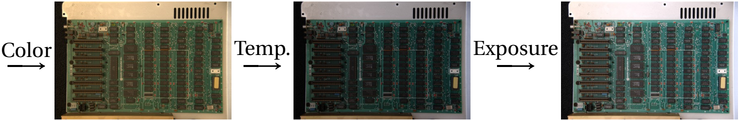


Corrected Image (zoomed in)



Correcting Data from CCDs





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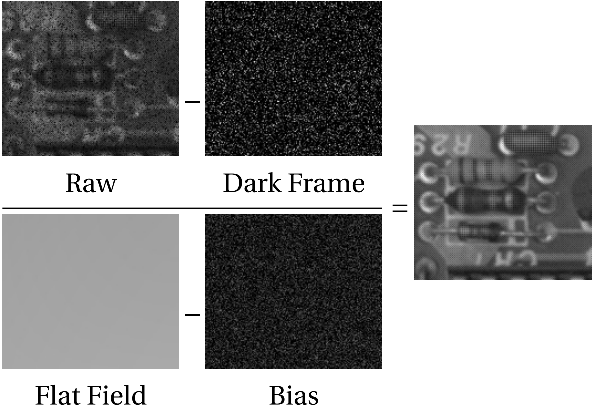
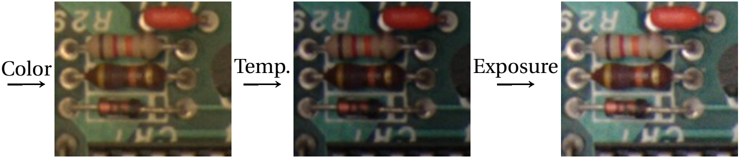
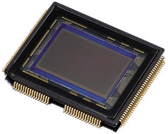




Where Does This Noise Come From?

Digital camera sensors are remarkably sensitive.
My high-end Nikon D300 has a 23.6 mm × 15.8 mm 12.3 megapixel CMOS sensor whose pixels are 5.5 μm on a side. When each pixel is sampled with the 12-bit A/D converter, the sensor efficiency is



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