EECS 452 – Project Hardware Possibilities

- This lecture is focused on programmable and non-programmable devices for potential project use.

- Projects are not restricted to using C5515/DE2-70. What are some alternatives?

- This is an awareness building lecture. It is not comprehensive. Other choices exist.

- There has been an explosive growth of programmable/configurable devices. How to choose?

The good news about computers is that they do what you tell them to do. The bad news is that they do what you tell them to do. — Ted Nelson

If you can get your hands on the part, it's obsolete. — anon

Nothing is more difficult, and therefore more precious, than to be able to decide. — Napoleon Bonaparte

Before we start ...

In today's world there exist many, moderately powerful, very low cost, single board computers that one can use to self-educate. When doing DSP one very often wants/needs to generate an observe signals. The cost of the needed equipment can greatly dwarf the board cost. However, the cost of "equipment" is dropping. Consider the Digilent *Analog Discovery*.

Designed in cooperation with:
ANALOG DEVICES   XILINX.
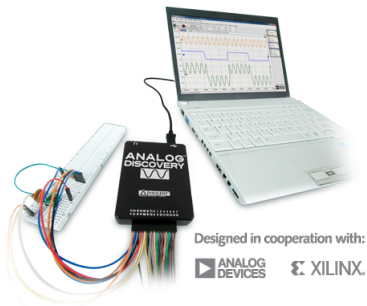
From a Digilent web page.

▶ $159 academic
▶ 2-channel oscilloscope
▶ 2-channel waveform generator
▶ 16-channel logic analyzer
▶ 16-channel digital pattern generator
▶ Spectrum Analyzer
▶ Network Analyzer
▶ Voltmeter
▶ Digital I/O
▶ ≈$220 with bells and whistles

Risk and other

▶ The safest choice in implementing your project is to make use of the C5515 and/or DE2-70 (or DE0-nano). However, it might be that they are not suitable or your team would like to stretch a bit.

▶ Choosing other than the C5515/DE2-70 opens the door for having a "growth" experience. (You might have one anyway!) Worthwhile, but ....

▶ If using Linux, make sure it supports the devices (e.g., SPI) as well as the functions (e.g., slave mode) that you need.

▶ The C5515 does not support SPI slave mode. If using with a FPGA and needing slave mode, consider implementing via I2S slave mode. The C5515 does need any special timing, the I2S slave is done using edges independent of clock timing.

▶ If your project needs a stray A/D, 10 or 16 bits, hung onto something, consider using a MSP430F2012 or MSP430F2013.

▶ Start simple, add complexity in steps.

▶ Identify what you don't know and start early to remedy.

Outline

- "Traditional" microcomputers
  - TI C5505 and C5515
  - TI Piccolo and Delfino
  - TI MSP430
  - Other: PIC and Arduino

- ARM System on Chip (SOC)
  - Raspberry Pi
  - BeagleBone Black
  - Cubieboard
  - Wandboard
  - Other: UDOO, Olimex A20, MarS

- FPGA
  - Altera DE2/DE270/DE0 nano, mini Altera
  - Xilinx BASYS, Spartan 3 Starter Board

Outline – continued

- Cameras
    - bullet
    - CMOS
    - Raspberry Pi

- Wireless
    - XBee
    - Bluetooth
    - ZigBee
    - TI RF2500 (?)

- Devices and sensors
    - PMods
    - FT232R/H RS-232 interfaces
   - Sparkfun and Adafruit breakout boards
    - Other breakout boards

"Traditional" microcomputers

- ▶ The list here is pretty much TI-centric.
- ▶ Programmed via PC using Code Composer Studio.
- ▶ C5505 and C5515
  - ‣ 100MHz to 120 MHz clock.
  - ‣ Optimized for doing DSP.
  - ‣ 160K 16-bits memory on chip.
- ▶ F2807 (fixed-point) and F28335 (floating point)
  - ‣ Up to 150 MHz clock.
  - ‣ High speed A/D, dual channel track and hold.
  - ‣ Limited on chip memory 32K.
- ▶ MSP430
  - ‣ Ultra-low power.
  - ‣ Small amount of RAM, larger amount of EEPROM.
  - ‣ Low cost.
  - ‣ Range of models available.
- ▶ other–Arduino

C5505 and C5515 eZdsp
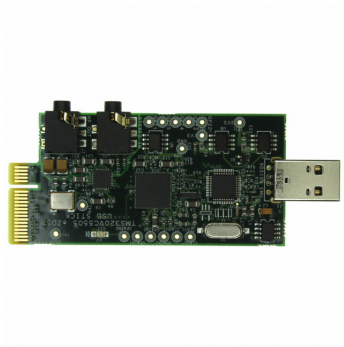
TI, 16-bit, fixed point, 160K on-chip memory, nominal clock of 100 MHz, CODEC. C5515 is used in EECS 452 lab. Targeted at DSP applications.

From Google Images.

C5505 and C5515 comments

- ▶ Both boards, nominally, can be operated executing one instruction per clock cycle.

- ▶ Both can be booted out of on-board EEPROM. Stand alone operation is possible.

- ▶ Our C5505s can be operated at 100 MHz, maybe faster.

- ▶ The C5515 can be operated at 120 MHz.

- ▶ Our C5505 break out board layout is a bit klutzy and can be redone if needed. This is complicated by a design error on the early C5505 boards, no mating connector exists.

- ▶ The CODECs used on these boards are very complex, essentially DSP systems in their own right.

- ▶ For many projects a 8 kHz sample rate is quite adequate. I have the C5515 CODEC code changes needed to operate using a 8 kHz sample rate.
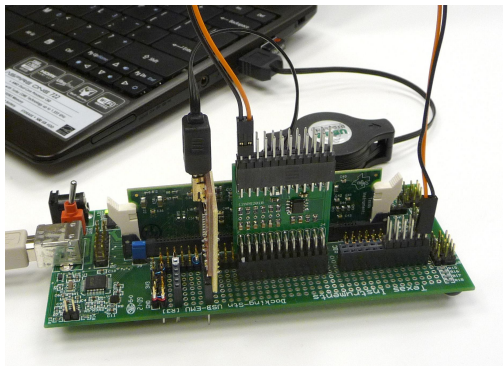
F28027 Piccolo

USB JTAG Interface & Power   On-board USB JTAG Emulation   Peripheral Header Pins
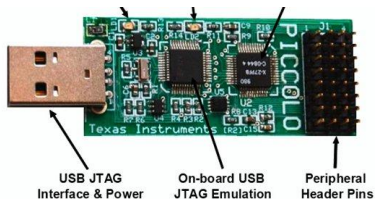
A few years ago three sopho-more EECS students used a USB Piccolo to enter a competition and won $3000.
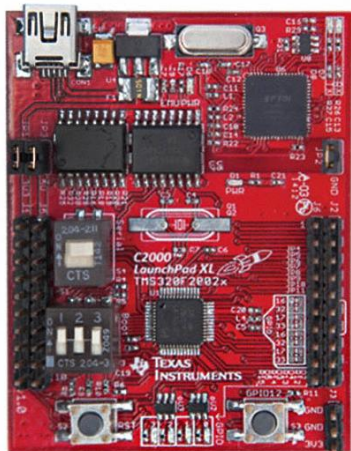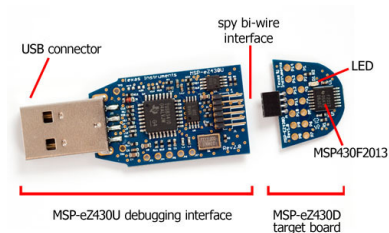
From TI web pages.

F28335 Experimenter Kit

Uses TI F28335, *Delfino* chip. 150 MHz clock. Floating point. 12.5 MHz A/D, 12-bits. 34K 16-bit word RAM. 256K EPROM. Added PWM D/A.

MSP430

On board A/D, no multiplier, SPI, around 64 16-bit data words, reasonable sized program EEPROM.

From Google Images.

MSP430 comments

- ▸ TI's low cost, fixed-point, ultra low power chips.
- ▸ Often used as smart components.
- ▸ Many variations are available. Least expensive unit costs around $0.25 in quantity.
- ▸ Typically max clock of 16 MHz, units available with clocks up to 25 MHz. Can be self clocked. Often clocked using a 32 KHz wristwatch crystal.
- ▸ Smaller units have 64 words of 16-bit RAM and use EEPROM for code.
- ▸ Some units have hardware multipliers.
- ▸ MSP430F2012 has 8 ch 10-bit ADC, I^2C/SPI, $0.95.
- ▸ MSP430F2013 has 4 ch 16-bit (slow) ADC, I^2C/SPI, $1.35.
- ▸ Did I mention that many variations are available?

Other TI boards on-hand

- BeagleBoard-XM, $149. High end single board Linux system. (2)
- TMDSMEVM3530-L Development Kit ($1795), media & LCD screen.
- OMAP-L138 DSP+ARM9 Development Kit $195, C6000+ARM9, com. (2)
- TMDS1MTRPFCKIT C2000 Microcontroller Development Tool, $432. Motor control. Has heavy duty power drive capability.
- TMDSPREX28335 C2000 Microcontroller Development Tool, $186. F28335 controlCART and baseboard.
- TMS320DM6437 Video Development Platform $579. C6000 with video coders and decoders. TI's DaVinci.

Donated by TI.

Pic and Arduino

Disclaimer: I've not worked with either. Many students have. Both are wildly popular.

PIC

- ▶ Scads of variations and packages are available.
- ▶ Often used as smart components.

Arduino

- ▶ Microcomputer board system targeted at the education and hobby markets. Used extensively in robot projects.
- ▶ Arduino boards are typically expandable using pluggable *shields*.
- ▶ 32-bit version recently became available.
- ▶ An embedded Arduino board is available for the Raspberry Pi.
- ▶ The UDOO combines a ARM i.MX6 with and Arduino.
- ▶ My youngest grandson built a robot controlled by an Arduino in third grade.

System on Chip (SoC)

- ► Today's technology allows building "complete" microcomputer systems on a chip (SoC). Though, the DRAM is almost always external.

- ► The performance of these SoCs rivals that of the INTEL/AMD processors used in PCs not so long ago.

- ► The major source of SoC designs is ARM holdings. Manufacturers can license a SoC design, have it converted into silicon using a silicon foundry and build it into their products.

- ► These SoCs are typically programmed using Android and Linux. Android appears to be far the more prevalent.

- ► Today, one can purchase, in large quantity, a very powerful, low power, 32-bit dual core processor chip including a graphics processing unit (GPU) for about $7 in large quantity.

- ► Basically, Linux systems are becoming components.

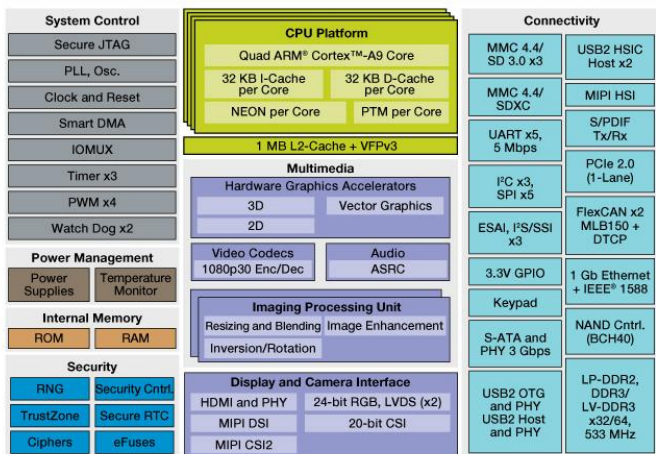# SoC example

i.MX 6Quad Applications Processor Block Diagram

System Control
- Secure JTAG
- PLL, Osc.
- Clock and Reset
- Smart DMA
- IOMUX
- Timer x3
- PWM x4
- Watch Dog x2

Power Management
- Power Supplies
- Temperature Monitor

Internal Memory
- ROM
- RAM

Security
- RNG
- Security Cntrl.
- TrustZone
- Secure RTC
- Ciphers
- eFuses

CPU Platform
- Quad ARM® Cortex™-A9 Core
- 32 KB I-Cache per Core
- 32 KB D-Cache per Core
- NEON per Core
- PTM per Core
- 1 MB L2-Cache + VFPv3

Multimedia
- Hardware Graphics Accelerators
  - 3D
  - Vector Graphics
  - 2D
- Video Codecs 1080p30 Enc/Dec
- Audio ASRC

Imaging Processing Unit
- Resizing and Blending
- Image Enhancement
- Inversion/Rotation

Display and Camera Interface
- HDMI and PHY
- 24-bit RGB, LVDS (x2)
- MIPI DSI
- 20-bit CSI
- MIPI CSI2

Connectivity
- MMC 4.4/ SD 3.0 x3
- USB2 HSIC Host x2
- MMC 4.4/ SDXC
- MIPI HSI
- UART x5, 5 Mbps
- S/PDIF Tx/Rx
- I²C x3, SPI x5
- PCIe 2.0 (1-Lane)
- ESAI, I²S/SSI x3
- FlexCAN x2 MLB150 + DTCP
- 3.3V GPIO
- 1 Gb Ethernet + IEEE® 1588
- Keypad
- S-ATA and PHY 3 Gbps
- NAND Cntrl. (BCH40)
- USB2 OTG and PHY USB2 Host and PHY
- LP-DDR2, DDR3/ LV-DDR3 x32/64, 533 MHz

Image from Freescale.

A confluence

- Effects of Moore's law on what can be implemented in silicon.
- ARM SoC designs.
- Availability of silicon foundries.
- Low manufacturing costs (e.g., in China).
- Apple's creation of the iPhone, etc.
- Availability of open source software (Android, Linux, etc.).
- The Raspberry Pi.
- Intel is moving into the "maker" market.

How does using SoCs relate to doing DSP?

- ▸ These SoCs are being built into cell phones, note pads, video streams, eye glasses, etc. They are being used in embedded applications where a desktop or laptop is too big, heavy and too costly.

- ▸ SoC boards are often used to make robotic devices.

- ▸ Are used to implement interaction with an environment through sensors and add *intelligence* to devices.

- ▸ Many SoCs have built in audio CODECs, grapic processing units, video streamers and peripheral interfaces (e.g., SPI, I2C, I2S, UART, USB, ethernet, touch screens).

- ▸ "Complete" PC like systems based on a SoC can be purchased for as little as $25 and can be comparable in size to a credit card. They can typically fit into a shirt pocket or, in the case of the Beaglebone Black, an Altoids' tin. Intel's Edison system (available this summer) is the same size as an SD card.

Embedded Linux examples

Image from Nest Labs.

- ► Learning thermostat.
- ► Access remotely.
- ► Linux based.
- ► Nest Labs bought by Google.

Image from Belkin.

- ► Internet enabled slow cooker.
- ► Part of the Belkin WeMo collection.
- ► Linux based?

Image from RPi foundatation.
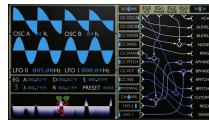
- ► RPi homebrew sound synthesizer
- ► Linux based.
- ► RPi forum member Omenie.

Intel's Edison is here!

- Announced at CES January 2014.
- Dual core (x86 and MCU) Quark processor.
- 500 MHz clock.
- 2x UART, 2x I2C, 1x I2S, 12x GPIO.
- Wifi (802.ii a/b/g/n and Bluetooth 4.0.
- MCU for handling IO and ?.
- System memory: 1 GB LPDRR3.
- Yocto 1.6 Linux.
- Storage: 4 GB eMMC Flash.
- Dimensions 35.5 Œ 25.0 Œ 3.9 mm
- Targeted at wearable applications (e.g., remote baby vital signs monitor).

Some ARM based systems

- Raspberry Pi, Broadcom.
- Beaglebone Black, uses TI chip.
- Olimex A10 (Lime) and A20 boards.
- Cubieboard, Allwinner A10, A20.
- UDOO. Freescale single to quad plus Arduino.
- Wandboard, Freescale I.MX6 single to quad core.
- Odroid–U3.
- MarS board. Freescale I.MX6, full dual core.
- Altera ARM/FPGA, combined on one chip (lacks GPU).
- Beagleboard-XM, uses TI chip.

The good news is that one has choices. The bad news is that one needs to choose.

Other ARM based boards

- www.olimex.com sells various ARM boards as well as boards that use other (non-arm) processors. Check this site out.

- There are a number of Android based, stick and pad, systems that can be hacked to run using Linux. These generally are self-contained with minimal "pin" access. See www.miniand.com for some examples. This site is also a good place to order Cubieboards from.

- ARM based boards seem to keep popping on Kickstarter. A good site to use to learn when these pop up is www.linuxgizmos.com/.

- There also exist a number of additional ARM design manufacturers that use the chips in-house or primarily target large volume buyers.

My ARM SOC hands-on experience

- ▶ Raspberry Pi (Broadcom).
- ▶ BeagleBone Black (TI).
- ▶ Cubieboard A10 (Allwinner).
- ▶ UDOO I.MX6 quad core (Freescale, Kickstarter project)
- ▶ Wandboard I.MX6 dual lite (Freescale).

My depth of experience is fairly shallow.

Comments on ARM devices/boards

- Low cost manufacturing capability in China coupled with Kickstarter/Indegogo financing allows almost anyone to try their hand a producing a low cost computer.

- ARM devices are typically targeted at Android. Linux use typically is not a priority. TI and Freescale are sort of exceptions. Read this as "when using Linux, expect a growth experience".

- Low volume/low cost boards seem to use Allwinner, Freescale and TI devices.

- $100 or less boards seem to have hit a marketplace "sweet spot".

- Products are presently in their Burgess Shale state. Great diversity presently exists. Extinctions are to come. Choose carefully.

- With these boards expect lots of DYI growth experiences. The RPi, which is the lowest of the low cost, is an exception.

Raspberry Pi

http://www.raspberrypi.org

- ▶ Essentially started the low cost Linux box *craze.*
- ▶ $25 and $35 models available.
- ▶ Over 2 million sold in less than two years of availability.
- ▶ Large ecosystem and vibrant user community.

Raspberry Pi Foundation

RPi overhead costs

- SD card used as virtual disk drive.
- Monitor . . . unless using remote access.
- Mouse and keyboard . . . unless using remote access.
- 5 Volt power module.
- USB cables, HDMI cable.
- Case?

Comments:

- I use a Logictech wireless keyboard and mouse with a unifying USB receiver. Frees up a USB slot.
- I use a USB 4-port hub both as a hub and to power the RPi (chosen to be able to do so). System only needs one power module.
- I use high speed Sandisk 32 GB SD cards. Overkill, but . . . .

Raspberry Pi comments

- Created by a charity in England.
- First available at end of February 2012.
- In Fall 2012 term one EECS 452 used a RPi, Seymour project. In Winter 2013 term, five EECS 452 projects used a RPi. In Fall 2013 term three of five projects used a RPi.
- Chip is essentially a GPU with an ARM processor added.
- Uses older ARM processor design (ARMv6), 32-bit.
- Has floating point hardware.
- Primary OS is Rasbian, a Debian Linux variant.
- Model-A has 256 MB RAM, Model-B has 512 MB ram.
- Nominally uses 700 MHz clock. I run my unit(s) at 900 MHz.
- Supports 1080P display (1920×1080).
- RPi is moving from X11 to Wayland to speed up the desktop.
- SD card connector is **fragile**, be careful.

Raspberry Pi ecosystem

In addition to USB wireless boards, cables, power units, USB hubs, cases
and the like there are available various boards and devices intended for
use with the Raspberry Pi.

- ▸ 5M pixel camera ($25.00).
- ▸ Gertboard I/O Expansion Board ($49.99).
- ▸ Humble Pi Prototyping Board ($7.99).
- ▸ Pi-Face Digital Interface Board ($39.99).
- ▸ Raspberry Pi Prototyping Plate Kit ($12.99).
- ▸ Slice of Pi Prototyping Board ($7.99).
- ▸ Embedded Pi (32-bit Arduino add on) ($33.99).

These pretty much can be found at the MCMelectronics and Adafruit and
web sites.

Raspberry Pi software

- ▶ Primary OS is Raspbian a Debian Linux derivative.
- ▶ Raspbian includes a free version of Wolfram's Mathematica as well as a programmable version of Minecraft.
- ▶ A other OS variants exist as well. See the RPi download page for more information.
- ▶ A common use is as a XMBC (open source home theater) box.
- ▶ RPi uses ARMv6 processor with floating point hardware. The other Linux boards listed in the following slides typically use the ARMv7 with floating point hardware.
- ▶ Essentially the entire Debian software repository is available.
- ▶ Have tested Libre Office (similar to MS Office), Octave (similar to MATLAB) and many other applications.

Raspberry Pi references

In addition to copious (overwhelming?) web pages there are books (35, my last Amazon count, Sept 2013) and a magazine devoted to the Raspberry Pi (another magazine is in the works).

- ▶ *Raspberry Pi User Guide*, Upton and Halfacree, Wiley.
- ▶ *Raspberry Pi for Dummies*, McManus and Cook, For Dummies.
- ▶ *Programming the Raspberry Pi: Getting Started with Python*, Monk, Tab.
- ▶ *Getting Started with Raspberry Pi*, Richardson and Wallace, O'Reilly.
- ▶ *Learn Raspberry Pi with Linux*, Membrey and Hows, Springer.
- ▶ *Raspberry Pi Projects for the Evil Genius*, Norris, McGraw-Hill.
- ▶ *The MagPi*, `http://www.themagpi.com/`. A RPi focused magazine. Available in hardcopy form as well as PDF form (free).

Why use a board other than the RPi?

- ▶ Need speed improvement and/or more memory.
- ▶ Peripheral support.
- ▶ Need additional GPIO pins.
- ▶ Likely not because of cost.

My original interest in the RPi was to generate displays for C5515/FPGA programs. Display commands would be sent to the RPi via FT232R USB/UART device. The RPi would use OpenGL ES or OpenVG to render on a standard monitor.

BeagleBone Black

http://beagleboard.org/Products/
BeagleBoneBlack
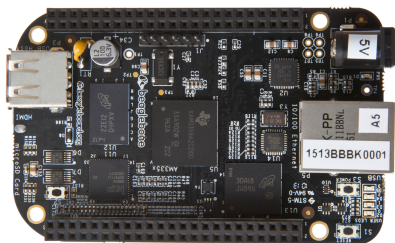
- Second generation BeagleBone. Improvements: has more memory (512 MB), is faster (1 GHz) and costs less ($45).
- Over 188k sold as of 9/18/2014 (since April 2013).
- Open source/design.
- Based on TI's AM335x 1GHz ARM® Cortex-A8 chip.

Beaglebone Black comments

- ► Targeted at hobbyists and developers.
- ► Companies that need large quantities can/should meet their own needs. All the artwork, etc. is available at no cost.
- ► Sockets use 0.1" spacing.
- ► Extenable using "capes" that can be stacked up to four deep.
- ► Uses micro-HDMI connector, max resolution is 1280×1024.
- ► Has access to more "pins" than does the RPi.
- ► Single core, 1 GHz, 512 MB RAM, floating point, 2×46 headers.
- ► Has graphics acceleration (not a GPU?). Promised to be supported maybe this fall.
- ► Comes with Angstrom Linux installed.

Beaglebone Black capes

http://beagleboardtoys.info/index.php?title=Main_Page

- Three sizes of LCD display and touchscreen available.
    - 3.5", 320×480, $69.95.
    - 4.3", 480×272, $79 (BB-View).
    - 7", 800×480, $119 (BB-View).

- Battery supply cape is available.

- Available from Mouser, Digikey, MCM Electronics, etc.

- Not all original BeagleBone capes are presently supported on the BBB.
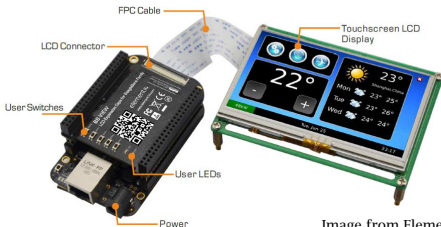
Image from Element 14.

BeagleBone Example

http://www.oz9aec.net/
index.php/beaglebone/
480-rtlizer
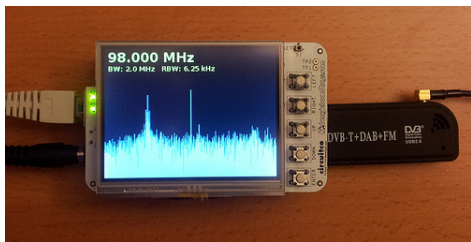
- ▶ Beagle bone using touch screen cape for display.
- ▶ Uses a TV like RF dongle and generates spectra in real time.
- ▶ Also see http://www.youtube.com/watch?v=6YhrKMBrJ2g.

A10 Cubieboard
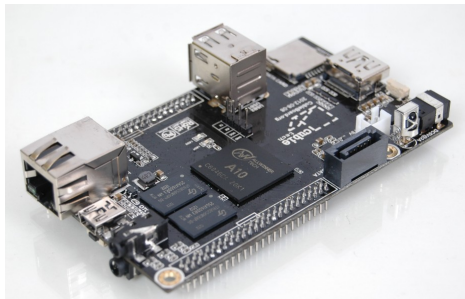
http://www.cubieboard.org
Originally an Indiegogo project.

- ▶ Allwinner A10, 1 GB, 1 GHz, $49.
- ▶ Dual core A20 version available, $59.
- ▶ 2mm pin spacing (ouch!).
- ▶ A20, 2 GB CubieTruck is also available.

Image from cubieboard.org.

Cubieboard comments

- Supports line in and line out. Lacks microphone in.
- Was available starting about December 2012.
- I bought my A10 unit via Indiegogo.
- I had struggles getting Linux with GPU support running. Still not quite sure that every thing works correctly.
- Several problems went away after switching to Debian from Linaro.
- Allwinner A10/A20 Linux support is maturing.
- Fedora is available for both the A10 and A20 versions.
- Current background struggle is "simultaneous" line-in and line-out support, a Linux problem rather than a Cubie problem.

UDOO

http://www.udoo.org

A Kickstarter project.

- ▶ Combines a one to four core i.MX6 with a 32-bit Arduino processor.
- ▶ Supports standard Arduino shields.
- ▶ Available around September/October 2013.

UDOO board comments

- ▶ Was heavily over supported on Kickstarter.
- ▶ I purchased a quad core unit on Kickstarter.
- ▶ Combines i.MX6 with 32-bit Arduino on one circuit board.
- ▶ Has microphone in and line out. Lacks line in!!!
- ▶ I have GPU problems under Ubuntu 12.04 (armel).
- ▶ Debian (armhf) is available. GPU support is in alpha.

Wandboard

http://www.wandboard.org

- ▶ i.MX6 (one, two or four cores) on daughter board. Uses a baseboard for making connections.
- ▶ Includes wireless.
- ▶ Was available starting about May 2013 from distributors such as Digikey.

Wandboard comments

- Open source hardware. Core group is very professional.

- Industrial quality (built like a tank). Carrier board and processor board. Can buy processor board in 10-packs.

- Supports microphone in, line in and line out.

- Available from distributers such as Digikey.

- Included in U-Boot source code. All versions included in the Linux kernel starting with 3.8.12.

- Dual core board uses the "lite" i.MX6 version.

- Early adopter. Early support was Ubuntu 11.10 which displayed a "I'm obsolete, update" message when loaded. Updating was a growth experience and broke the GPU support.

- GPU support presently only available for ARM soft floating point.

- Software is maturing. Using Robert C. Nelson's Debian (no GPU support).

- Ubuntu 12.04 LTS is now available. (7/20/2013 .. I can't make use of 1080p or LXDE desktop.) (1/7/2014 .. newest Ubuntu and Yocto don't seem to work on my board.)

Olimex A20-OLinuXino-MICRO-4GB

https://www.olimex.com/
Products/OLinuXino/A20/
A20-OLinuXino-MICRO-4GB/
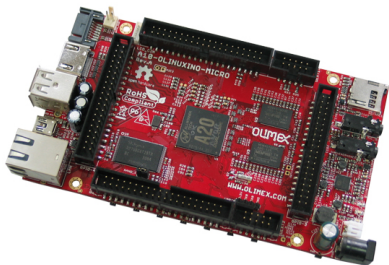
- ▶ Was available starting about June 2013. Cost: ≈ $89.
- ▶ Dual core A20 Allwinner ARM chip, 1 GB DDR3 RAM.
- ▶ Microphone in, headphone out.
- ▶ Connector pin spacing is 0.1" (?).
- ▶ Power: 6-16 VDC.

Image from Olimex web site.

Olimex A10-OLinuXino-LIME
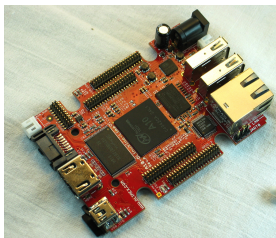
https://www.olimex.com/
Products/OLinuXino/A10/
A10-OLinuXino-LIME/
open-source-hardware

- Available starting December 2013. Cost: ≈ $42.
- Case is available.
- Single core A10 Allwinner ARM chip, 512 MB DDR3 RAM.
- Dual core A20 version is planned.
- 160 GPIOs.
- Connector pin spacing is 0.05" .
- Power: 5 VDC.

Image from Olimex web site.

Odriod–U3
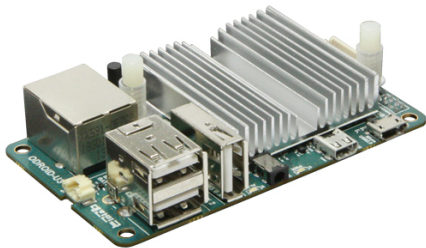
http://hardkernel.com/
main/products/prdt_info.
php

- Available starting mid January 2014.
- 1.7 GHz quad-core Samsung ARM chip, 2 GB RAM.
- Includes mike in, stereo out.
- Cost: $59 (community edition).
- IO expander board available.

Image from Hardkernel web site.

MarS Board

http://www.embest-tech.
com/shop/product/
mars-board.html

- ▶ Was available starting about July 2013.
- ▶ Dual (non-lite) i.MX6 ARM chip.
- ▶ Distributer (Embest in England) designed.
- ▶ Cost: $99.

Intel Galileo

http://www.mouser.
com/new/Intel/
intel-galileo-development-board/
?gclid=
COPr3Lbn07sCFdBlOgod01IAPA
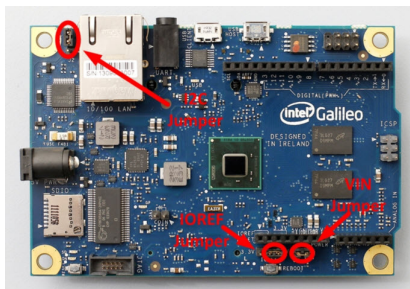
- ▶ Available starting about December 2013.
- ▶ Intel Quark SoC X1000. 400 MHz, 32-bit Pentium level.
- ▶ 512KB SRAM, 256MB DRAM
- ▶ Hardware and software compatible with Arduino shields.
- ▶ Supports 3.3V and 5V shields.
- ▶ Cost: $69.

Image from http://www.mouser.com/new/Intel/intel-galileo-development-board/.

Linux comments

- ▶ The SoC devices are normally targeted at Android applications (high volume sales). Linux operation tends to be an enthusiast use (because it can be done).

- ▶ Linux support is by community. If a community does not form around the board that you select, or if they wander away, good luck. The main components needing support are the boot (configuration and timings) and the GPU/VCU.

- ▶ Need to configure Linux for a particular chip and board. The boards do not include a BIOS. Memory timings and peripheral choices likely will differ between boards.

- ▶ Different chip suppliers tend to obtain their GPU designs from differing sources. The available support can be an important factor when selecting a SoC.

- ▶ These boards listed here generally do NOT have a real time clock (RTC). The time/date needs to be either entered manually or obtained via a network time server (this assumes a net connection).

GPU notes

- ▶ Broadcom supplies hard float drivers for the RPi. They just work.
- ▶ Allwinner A10, A20 use ARM Mali-xxx GPUs. Drivers are easily installed.
- ▶ Open source drivers for Mali are being worked on.
- ▶ i.MX6 uses Vivanti xxx GPUs. Driver installation presently is a bit of a mystery to me.
- ▶ Soft floating point Vivanti Linux drivers are available. Hard float drivers are in alpha (I'm running such on my quad core UDOO). Available hf Vivante suport for OpenGL is claimed to be not so good.
- ▶ GPU drivers for the BBB are not presently available (maybe available this spring?).
- ▶ Test programs include glxgears, glxgears-es, glmark2, glmark2-es2, etc. I use *Big Buck Bunny* to test VPUs.

My current Linux preferences

- ▶ Debian using the LXDE desktop.
- ▶ Leafpad as the editor.
- ▶ PCManFM as the file manager.
- ▶ Midori and/or Iceweasel as the browser.

- ▶ Using the FT232R board (UART to USB), I have used the RPi as a display generator for the C5515. Plotted real time spectra and transfer function measurements. (My original application goal.)
- ▶ Have not made use of any GPIO operations. I've been testing units as if a desktop.
- ▶ Testing GPU performances using es2gear/glxgear and glmark2/xxx.
- ▶ I'm using my Wandboard as a headless Torrent Bit Sync cloud. Access is via ssh.

Linux or bare metal?

- ▶ Doing real-time using Linux isn't all that easy.

- ▶ Arduino boards appear to be frequently used to add processing and I/O support to a Linux board.

- ▶ Another example is the XMOS starter kit which has a RPi connection built in. It should be possible to use this connection with other boards, possibly with an adapter.

- ▶ Altera and Xilinx make ARM SoC chips that include a FPGA interfaced to the ARM processor.

- ▶ I think I see a trend.

STM32F407 Discovery

My board du jour. Being used in ENGIN 100 section 850.

- ▶ 32-bit core.
- ▶ 168 MHz max clock.
- ▶ Floating point.
- ▶ Includes DSP instructions.
- ▶ Single cycle multiply.
- ▶ 1 MB flash, 192KB SRAM.
- ▶ Flash memory execution accelerator.
- ▶ Three 12-bit ADCs, 2.5 MSPS.
- ▶ Two 12-bit DACs, ≈1MSPS
- ▶ Multiple: GPIO, SPI, I2C and UART).
- ▶ 3-axis accelerometer.
- ▶ And, much, much more.
- ▶ $14.90.
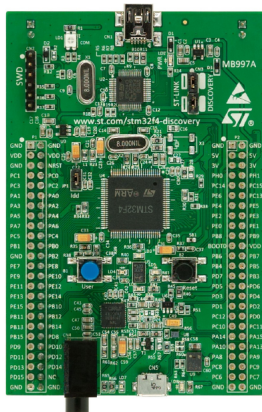
Infineon XMC 2Go

- Infineon XMC1100 ARM Cortex-M0
- 32-bit core.
- 32 MHz max clock.
- Single cycle multiply.
- 64KB flash, 16KB SRAM.
- 6-channel 12-bit A/D, 2000 ksps.
- GPIO, SPI, I2C, I2S and UART.
- 4 16-bit timers.
- Two 8 bit header connectors.
- Includes programmer/debugger.
- $6.75 (Mouser).
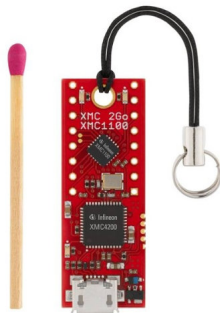
Olimex PIC32-PINGUINO-MICRO

- ▶ 32-bit core with 5 stage pipeline.
- ▶ 80 MHz max clock.
- ▶ Single cycle multiply.
- ▶ 256KB flash, 32KB SRAM.
- ▶ Upto 16-channel 10-bit A/D, 1000 ksps.
- ▶ GPIO, SPI(2), I2C(2) and UART(2).
- ▶ Support for one Olimex UEXT module.
- ▶ Dual register set for fast context switching.
- ▶ $16.30.
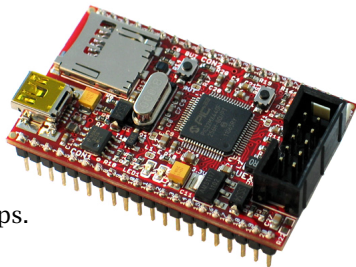
Freescale FRDM-KL25Z

- Freescale MKL25Z128VLK4 MCU
- 48 MHz max clock.
- 128KB flash, 16KB SRAM.
- Tri-color RGB LED.
- Capacitive touch slider.
- GPIO, UART (1), SPI(2). I2C(2).
- 16-bit A/D (sample rates?).
- 12-bit D/A.
- Optimized for low power operation.
- Arduino pin compatible.
- $12.95.

XMOS StartKIT
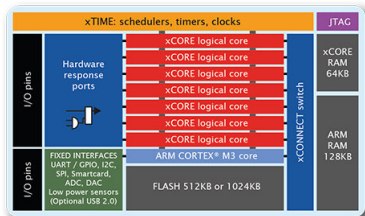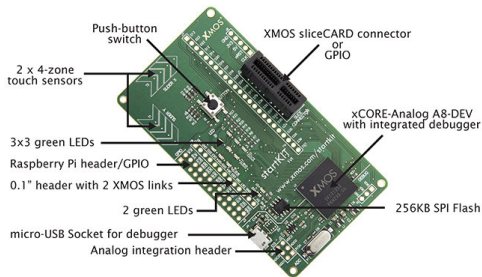
- ▶ 8 cores. 500 MIPs total. Instruction set includes DSP instructions.
- ▶ 12-bit A/D, 1 MSPS, 4 multiplexed channels.
- ▶ $14.99 from Digikey. Two stereo CODEC sliceCARD: $40.
- ▶ Will have to add needed connectors. How to power?

Available/affordable FPGA boards

- Terasic/Altera DE0-Nano.
- Terasic/Altera DE2.
- Terasic/Altera DE2-70.
- Arrow/Altera BeMicro SDK.
- EP2C5T144 Altera mini-development board.

- Digilent/Xilinx BASYS2.
- Digilent/Xilinx NEXYS2.
- Digilent/Xilinx S3E Starter Board.
- Digilent/Xilinx S3 Starter Board.
- NuHorizons/Xilinx S3A DSP board.
- Avnet Spartan-3A Evaluation Kit.
- Mojo V3 Spartan 6 board.

How to choose?

Most of these have at least one on-hand. Not all are EECS452 owned but are available for loan. There are other boards (e.g., DE0, DE1, etc.) that might be more suitable for a project and fit within that project's budget.

Terasic DE2 and DE2-70
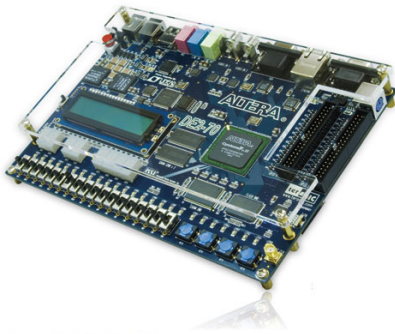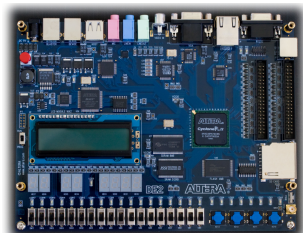
DE2 is used in EECS 270 and DE2-70 is used in EECS 452.

Approaching (attained?) obsolesce.

From Google Images.

Terasic DE0-Nano

http://www.terasic.com.tw/cgi-bin/page/archive.pl?Language=English&CategoryNo=139&No=593
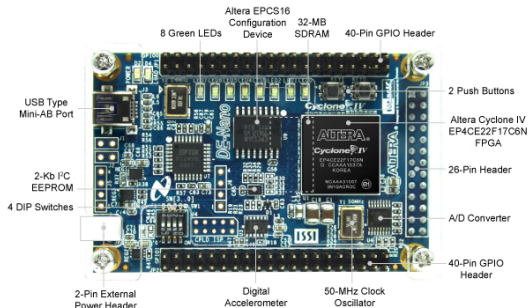
- ▶ 22,230 LEs, 32 MB SDRAM, $79.
- ▶ 40-pin headers can match those on DE2-70.
- ▶ Has been used in past EECS 452 projects.
- ▶ Have a couple of units on-hand.
- ▶ Built in USB-blaster.

DE0-Nano caution

- There have been at least two versions.
- The older version used a 16M EEPROM. The newer uses a larger EEPROM.
- Their might also be other differences.
- I think that EECS452 has one older unit.

Comments on DE2, DE2-70 and DE0-Nano

The DE0-Nano, DE2 and DE2-70 are *moderately* compatible.

- ▶ The DE2x boards use a Cyclone II FPGA. The DE0-Nano uses a Cyclone IV. Likely a good idea to regenerate wizard generated elements when moving between II and IV.
- ▶ The DE2x has M4K memory blocks. The DE0-Nano has M9K.
- ▶ DE2x 40-pin connectors have 32 GPIO pins each. The DE0-Nano has 34 GPIO pins. Can match 32 pins but the names differ.
- ▶ When plugging in cables keep track of where pin 1 on the connector is and where cable pin 1 (red line) is. The DE2-Nano is not well marked.
- ▶ The same 32Mbyte SDRAM chip is used on all three boards. The available 4-port SDRAM support should run all three. (Likely need to regenerate the FIFO and PLL wizard generated modules.)

Memory caution

The Terasic boards uniformly include SDRAM. I've been using a four port module that is used on their non-NIOS VGA demonstrations. It is mostly intended for steaming types of applications. If you are using a NIOS soft core then more general support is included in the NIOS support. Some form of pages pseudo static RAM is available on some of the Terasic boards. Finding open (free) support modules for DRR and DRR2 SDRAM memory has been a problem.

The Digilent boards have varying types of memory. The SRAM on the Spartan-3 Starter Board is particularly straight forward to work with. Working with the other types is likely to provide a growth experience.

If on-board memory will suffice, use it.

Arrow/Terasic Altera SoCKit
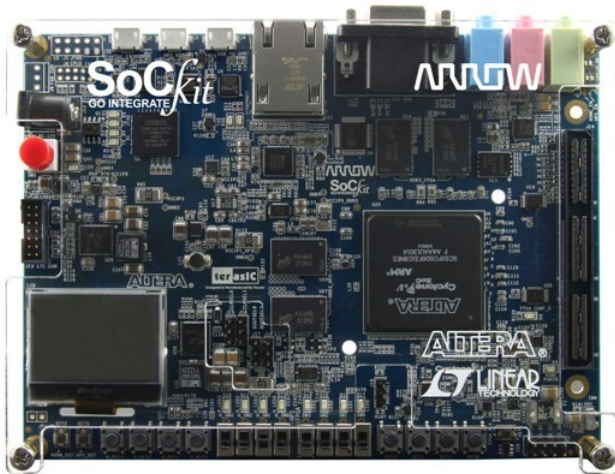
▶ Combines Altera FPGA with ARM processor.

SoCKkit block diagram

SoCKit comments

- FPGA/ARB chip created because of Altera customer interest.
- SoCKit is a development/test platform.
- Combines FPGA and dual core ARM processor on one chip.
- FPGA is Cyclone V with 110 k LEs.
- Two banks of low-power DDR3 memory.
- Graphic 128×64) LCD, SPI interface.
- VGA and Audio connections.
- 3-axis digital accelerometer and temperature sensor.
- Uses ARM tools as well as Quartus tools.
- Need to understand both tool sets.
- Does not include hard GPU. Soft version is available.
- $249.
- Not for the faint of heart.
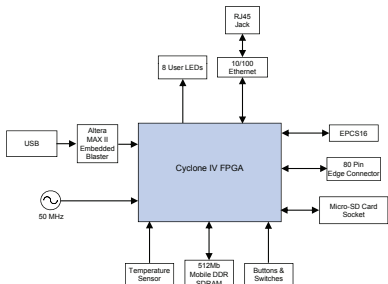
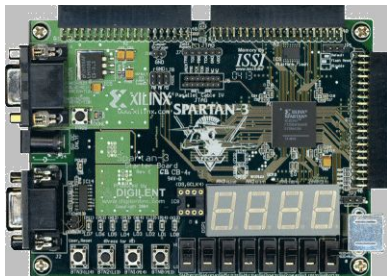Meant to showcase the Altera NIOS soft core. Expander board available.

From Arrow/Google site.

BASYS2
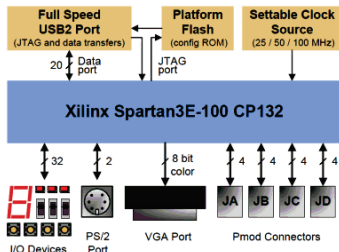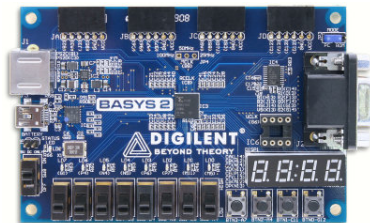
- Excellent for doing DYI learning. Free ISE web edition is available.
- 100K and 250K gate versions available.
- Uses Xilinx Spartan-3E device.
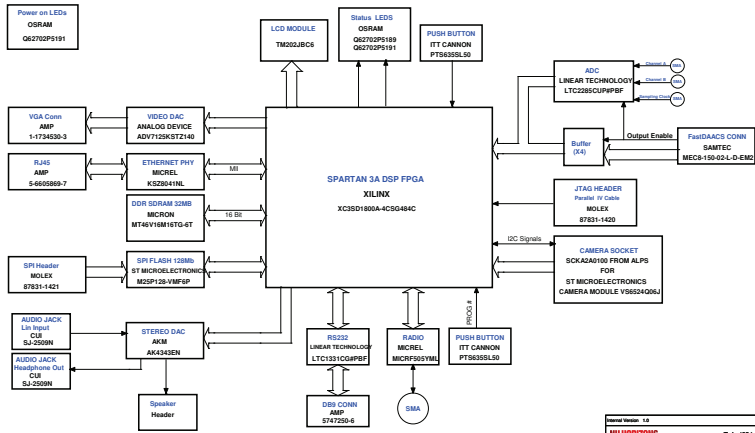- $89 (standard), $64.99 (academic), $49.00 (student).

From Digilent Inc web site.

Spartan 3 Starter Board
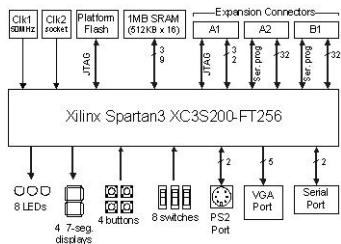
- ▶ Used for several semesters in EECS 452 (now obsolete). We have several units available.
- ▶ Uses Xilinx XC2S200 FPGA, 4,320 logic cell equivalents, 216K bits block RAM, 12 18 × 18 multipliers, lots of I/O pins.
- ▶ Board has 1 MB SRAM (easy to use).

Nu Horizons Spartan 3A DSP

From Nu Horizons schematics.

# Avnet Spartan-3A Evaluation Kit

- ▶ Xilinx XC3S400A-4FTG256C Spartan-3A FPGA
- ▶ Four LEDs
- ▶ Four CapSense switches
- ▶ I2C temperature sensor
- ▶ Two 6-pin expansion headers
- ▶ 20 x 2, 0.1-inch user I/O header
- ▶ 4 MB Spansion Parallel Flash
- ▶ 128 Mb Spansion SPI Flash
- ▶ USB-UART bridge
- ▶ I2C port
- ▶ SPI and BPI configuration
- ▶ Xilinx JTAG interface
- ▶ FPGA configuration via PSoC
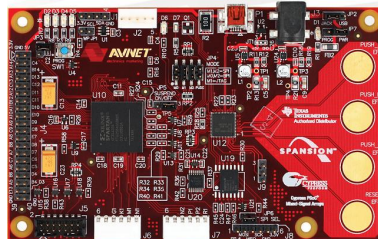
Costs $49.   Image from Google Images.
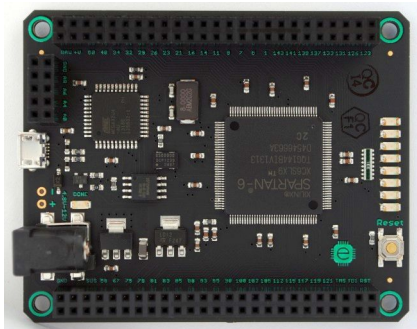
Mini Altera Cyclone II development board
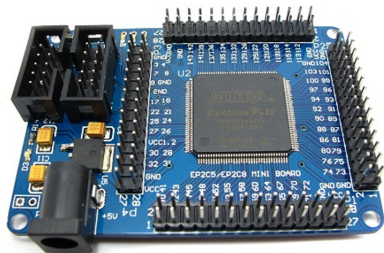
EP2C5T144 Altera Cyclone II

Can order through Amazon.com

- ▶ FPGA and serial boot EEPROM only!
- ▶ Various sources, nominal cost $29.90.
- ▶ Buy with USB-blaster for about $14.90 more.
- ▶ Have not experimented with.
- ▶ Mine arrived from China in less than 2 weeks.

Mojo V3 development board (Xilinx)

Xilinx Spartan 6 XC6SLX6

- www.embeddedmicro.com/development-boards/mojo-v3.html
- Cost $74.95. Available from Sparkfun.
- Have not experimented with (don't have one).

FPGA comments

- These are low cost boards!

- Typically 50 Mz clocks are used. I've been able to operate some at 75 MHz and 100 MHz using a PLL. Doing so requires care in design and HDL coding.

- These boards demonstrate the design flexibility obtainable with a FPGA. They do not demonstrate the performance levels attainable with more expensive devices.

- With design/implementation flexibility comes a significant amount of design responsibility.

- Worldwide, about half of FPGA designs use Verilog and about half use VHDL.

- Xlinx has the largest FPGA market share followed by Altera.

Video

DE2/DE2-70 support NTSC (RCA) video input and VGA RGB output.

EECS 452 has four NTSC bullet cameras. Low cost CMOS NTSC cameras can be purchased for about $30-$40.

DE0-Nano/DE2/DE2-70 digital CMOS camera and (usable) RGB output.

Uses Omnivision OV7670. Have BW version? Were supposed to be color, might be color. Development support is a work in progress.

DE0-Nano/DE2/DE2-70 support Terasic 5M pixel camera board.
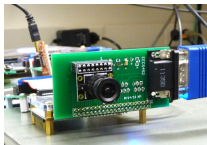
Comparison images

Bullet camera on DE2-70.

CMOS camera on DE0-Nano.

Cameras were positioned side-by-side. Captured to a PC using a FT232R 6-pin board on a DEx breakout board. MATLAB script used to view and convert to PNG. IrfanView was used to convert the PNG files to PDF.

Video comparison comments

- ▶ Bullet camera needs a supply 9 to 12 Volts DC. The CMOS camera uses 3.3V from the DEx 40-pin connector.

- ▶ Both images are 640×480 pixels. (For the bullet camera these are the center 640 from 732).

- ▶ 640×480 is not a large number of pixels when viewed on a 17" or 19" monitor. Many applications can live with fewer. Consider sub-sampling to 320×240 or fewer.

- ▶ The CMOS camera lens is on the telephoto side of life. The lens on the bullet is more wide angle.

- ▶ Neither is all that sharp. The bullet camera image feels "better".

- ▶ The CMOS camera has some sort of noise pattern. This might be residue on the sensor surface. Will try to clean.

- ▶ Have two pin compatible CMOS (hopefully color) cameras on order. Lens should have much wider angle of view. Likely here early October.

RPi camera board

- ▶ 5 Megapixel (2592×1944 static), fixed focus, pin hole.
- ▶ Supports 1080p30, 720p60 and 640×480p60/90 video.
- ▶ Supported in Raspbian, $25.

Wireless

- I've shown a few somewhat different wireless devices. The XBee and ZigBee units have found use in projects.

- Projects have also made use of other TI wireless products and devices from Sparkfun.

- There also wireless PMod modules that one might want to consider. These include WiFi, Bluetooth, IEEE 802.15 transceiver, etc. See the Digilent web site.

XBee
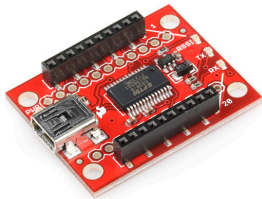
- ▶ Low cost, ≈ $23. Other antennae available.
- ▶ Can be used as "straight through" UART.
- ▶ Various carrier boards available from Sparkfun.
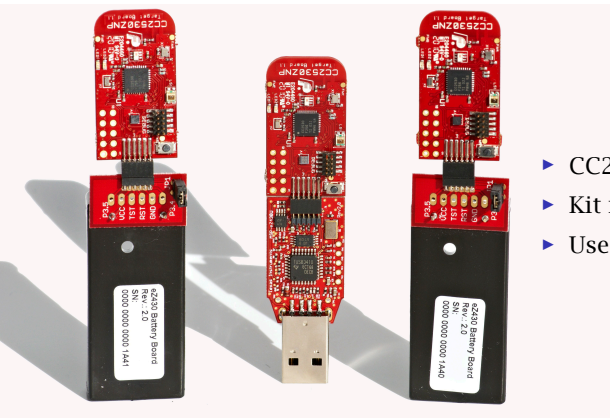- ▶ Slice of Pi prototype board supports the XBee.

Bluetooth

- UART to Bluetooth serial cable replacement.
- 2400 to 115200 bps.
- Sparkfun unit can be powered from 3.3V to 6V.
- NOT RS232!
- Built in antenna.
- Distance: 18m.

Image from Sparkfun.

TI ZigBee and other protocols

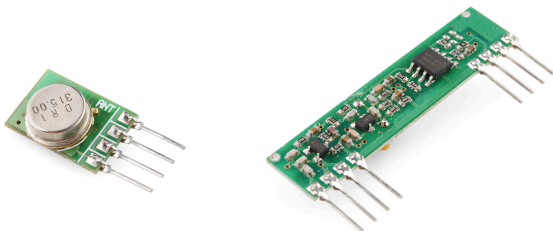- ▸ CC2530ZDK shown.
- ▸ Kit is $299.
- ▸ Uses MSP430 as microcomputer.

RF Link modules

- ▶ Half duplex, transmitter on left, receiver on right.
- ▶ Low cost, $3.95 xmtr, $4.95 rcvr. Use with microcomputer (MSP430 would be a good choice).
- ▶ Simple amplitude shift keying, noisy, 4800 bps, max range of about 500 ft (optimistic). 5V.
- ▶ Tutorials and application notes available.
- ▶ Various frequencies boards available from Sparkfun.

Places to find parts, sensors and devices

- Adafruit, www.adafruit.com.
- Sparkfun, www.sparkfun.com.
- Digikey, www.digikey.com.
- Mouser, www.mouser.com.
- MCM Electronics, http://www.mcmelectronics.com/.
- Use web searches to locate other sources.

MCM has an excellent RPi section. They are located in Dayton Ohio and we have, on occassion, placed an order early in the morning and received the shipment the next day.

Adafruit also has a strong RPi presence.

Digilent Pmod boards

The Digilent Pmod peripheral modules are targeted at the Digilent FPGA boards, but will work with our DE2-70 adapter board. The adapter board should also work with most all Terasic DE boards.

There are currently over 64 Pmod boards available. Included are:

Organic LED Graphic Display	802.11b/g/n WiFi Interface
Bluetooth Interface	Network Interface Controller
IEEE 802.15 RF transceiver	Wireless Radio Transceiver
USB to UART Interface	Character LCD, parallel Interface
16 Button Keypad	3-axis Accelometer
3-axis Accelerometer	H-bridge for servo drive

http://www.digilentinc.com/Products/Catalog.cfm?NavPath=2,401&Cat=9

Freescale sensor board
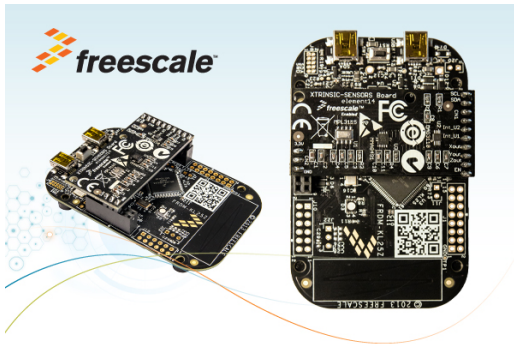
http://www.newark.com/
freescale-semiconductor/
xtrinsic-sensors-evk/
eval-kit-xtrinsic-sensor/
dp/69W6392?Ntt=69W6392&et_
cid=22834257&et_rid=3553579&
Linkid=-FREESCALE_XTRINSIC_
SENSOR&CMP=EMC-22834257

▶ Precise altitude/pressure sensor, 3-D magnetic sensor, 3-axis accelerometer, development platform, $26.99.

Whatevers

- Rhumba
- Kinect
- Left over robot bits and pieces.
- Battery packs that generate 5 Volts.

Tools

DSP and FPGA

- ▶ For commercial use expect to pay several thousands of dollars.
- ▶ For low end devices there typically free "web" editions.
    - ▶ TI — Code Composer Studio.
    - ▶ Altera — Quartus II.
    - ▶ Xilinx — ISE.
- ▶ Each has Windows and Linux version available.
- ▶ On Windows it is safest to install as Administrator.

Linux

- ▶ Pick products that have a large and interested community.

Some general comments

▶ Most of these boards are powered using 5 Volts. This is usually regulated down to 3.3 Volts and/or lower.

▶ Some boards are powered by 6 to 15 Volts (e.g., DE2-70, UDOO). I've tried to mark the power module supply voltages in the lab. CHECK before using!

▶ We have several DC/DC converter units that take 2 AA cells and generate 5 Volts adequate to power most of the ARM and FPGA boards.

▶ The logic lines on most (all?) of our ARM and FPGA boards are **NOT** 5 Volt tolerant!!!!

▶ Multiple ARM cores should generate additional heat. Where are the heat sinks?

Some additional boards on hand

Recently TI donated a number of boards to EECS 452. These included:

- ▶ Beagleboard-xM (2).
- ▶

These presently remain untested but are available for project use.

Ending comments

It's a big world out there. There are many other choices beyond what I've shown. It makes sense to use what you know, however, feel free to search out other choices.

- ▶ From previous semester students, **"Start early and run hard"**.
- ▶ **Begin by using MATLAB to develop your design.** If you can't get your basic project running using MATLAB, at least conceptually, you are not likely to be successful using "real hardware."
- ▶ Generally, the final result is a **proof of concept**.
- ▶ **Involve the use of DSP**.
- ▶ **Make a good case for how your project could lead to a commercial product.** What distinguishes it from existing similar products, etc. Could you convince a venture capitalist to give your team serious money to move your project onto the next step?
- ▶ **Backup frequently.** Things happen (and have).

Ending comments continued

- Almost of our boards do **NOT** have 5 Volt tolerant inputs!

- The OV7670 camera board by itself supply voltage must be less than 3 Volts. My adapter board has a voltage regulator that drops the FPGA 3.3 Volt supply to 2.8 Volts.

- The FPGA display support for the OV7670 seems to work well. Having problems with setting control parameter values.

- Documentation is in progress but in fairly rough form.

    - email: metzger@umich.edu.
    - Office: 4236 EECS.
    - Lab: 4343 EECS.
    - Hours: open door, walk-in.