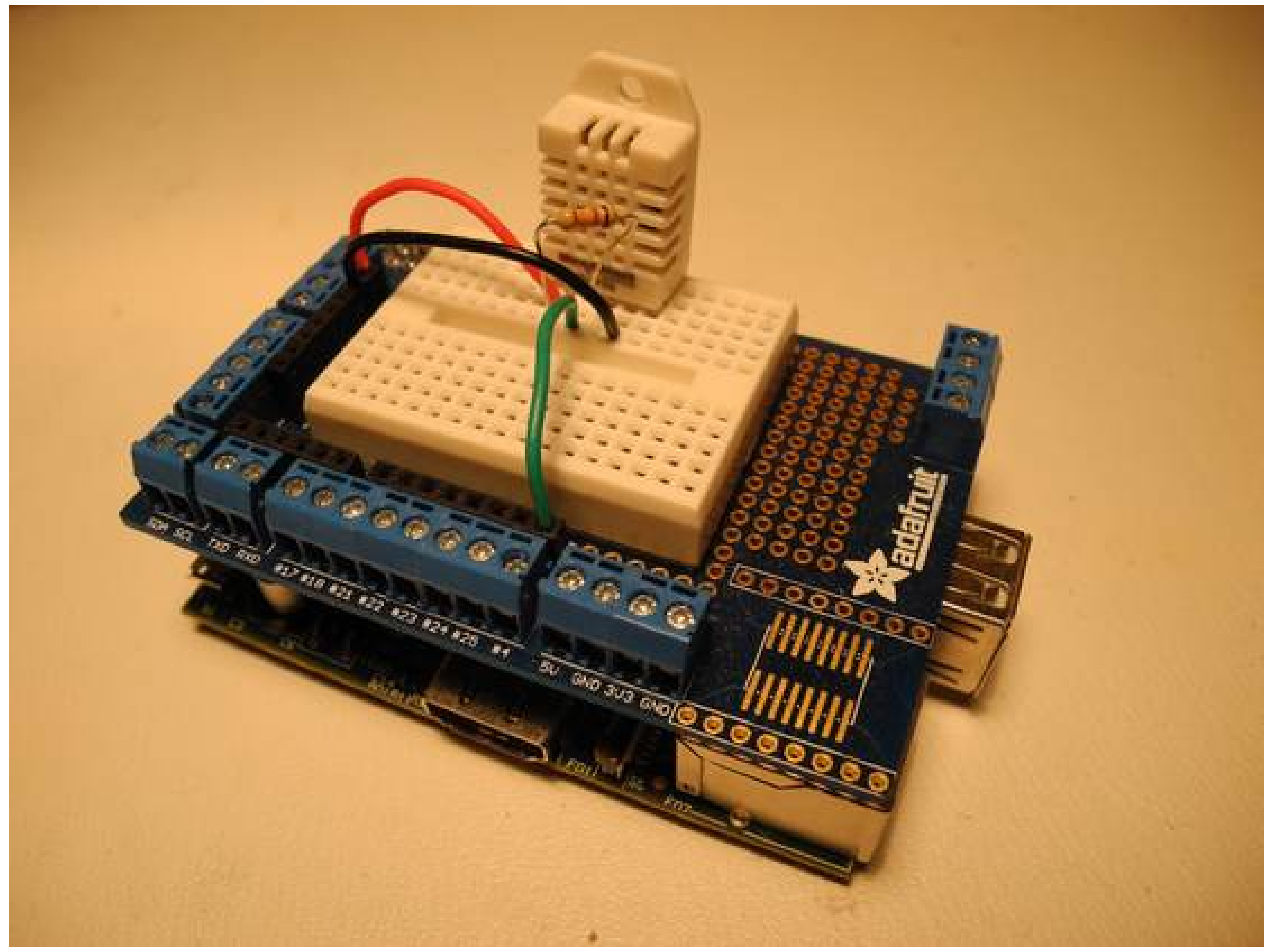
DEVELOPER DAYS 2014 EUROPE



Low-Level Hardware Programming for Non-Electrical Engineers

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Agenda

- About the Speaker
- Introduction
- Some History
- Safety
- Some Basics
- Hardware Interfaces
- Sensors and Other Devices
- Embedded Development Platforms
- Relevant Qt APIs
- Linux Drivers and APIs
- Tips
- Gotchas
- References

About The Speaker

- Jeff Tranter <jtranter@ics.com>
- Qt Consulting manager at Integrated Computer Solutions, Inc.
- Based in Ottawa, Canada
- Used Qt since 1.x
- Originally educated as Electrical Engineer

Introduction

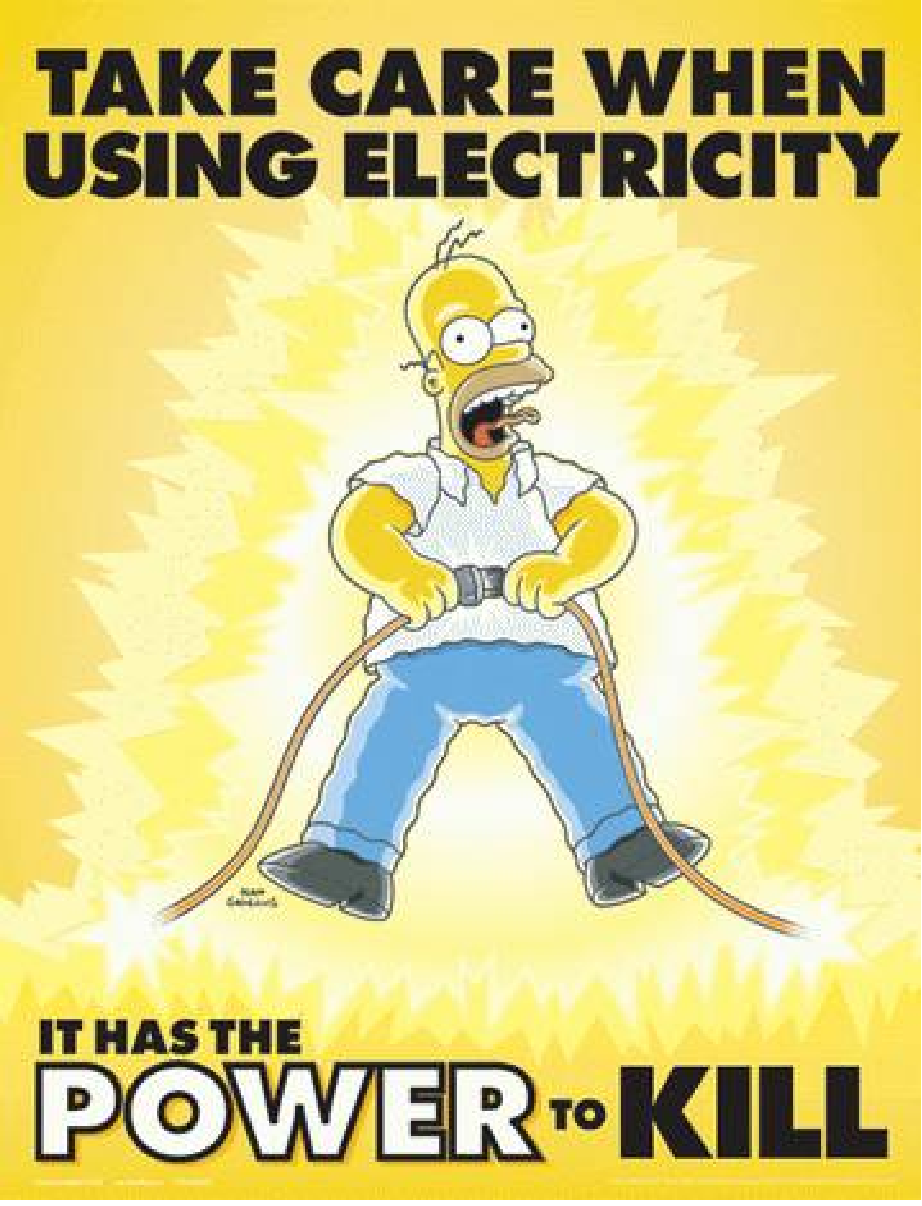
Some History

- 1970s: Hard-coded logic
- 1980s: 8-bit microprocessors (assembler)
- Today: 64-bit, multicore, 3D, etc. (high-level languages)

- This presentation won't cover:
  - Programming languages other than C/C++
  - Much systems other than embedded Linux
  - Video, sound
  - Building embedded software: cross-compilation, debugging, etc.

A Few Words About Safety

- High voltage
- High current (e.g. batteries)
- High temperature (e.g. soldering)
- Eye protection (solder, clip leads)
- Chemicals

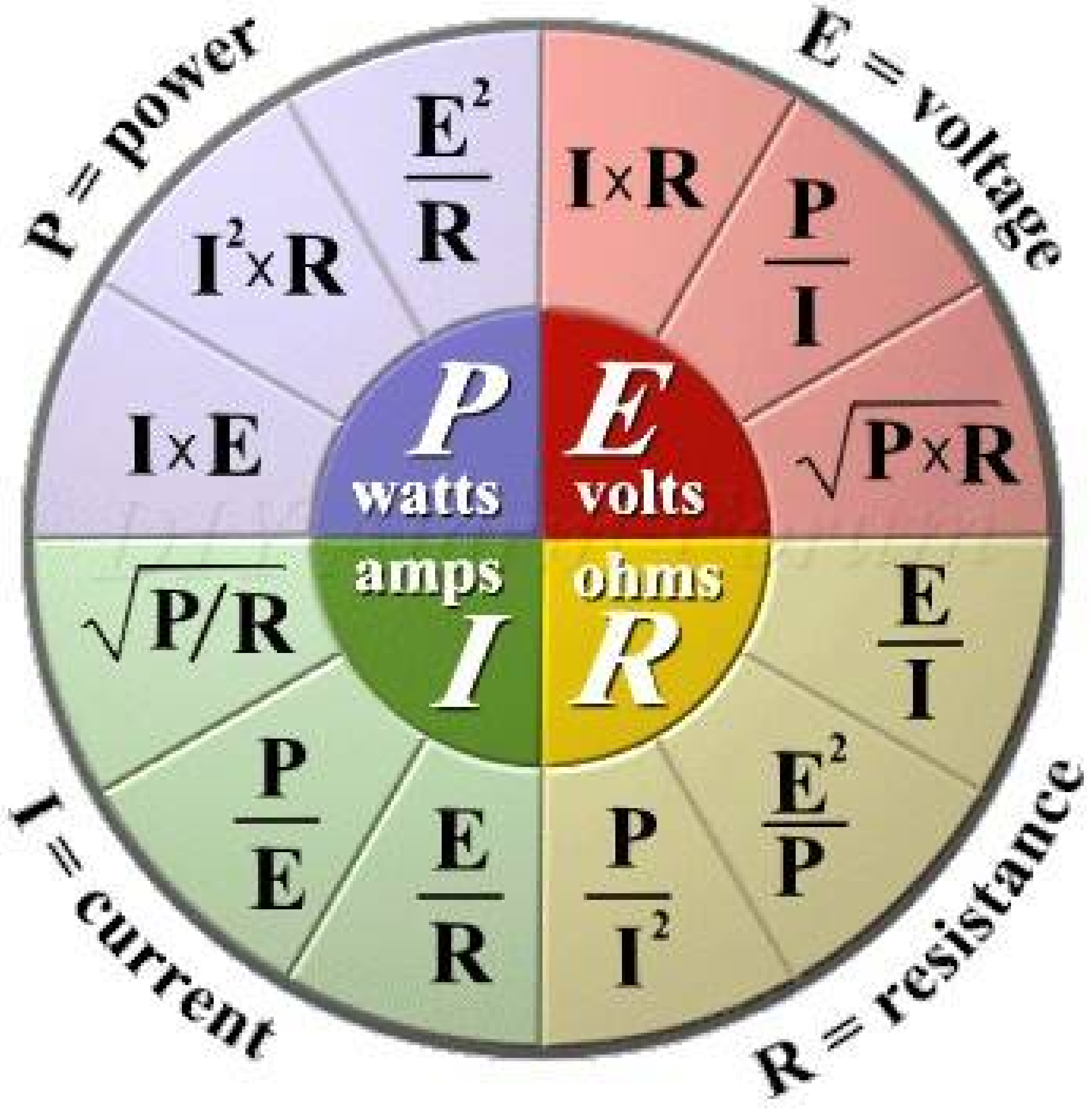


ESD

- Electrostatic discharge, i.e. static electricity
- Many devices can be damaged by high voltages from static
- Use static safe packaging, work mat, wrist strap, soldering iron

Some Basics

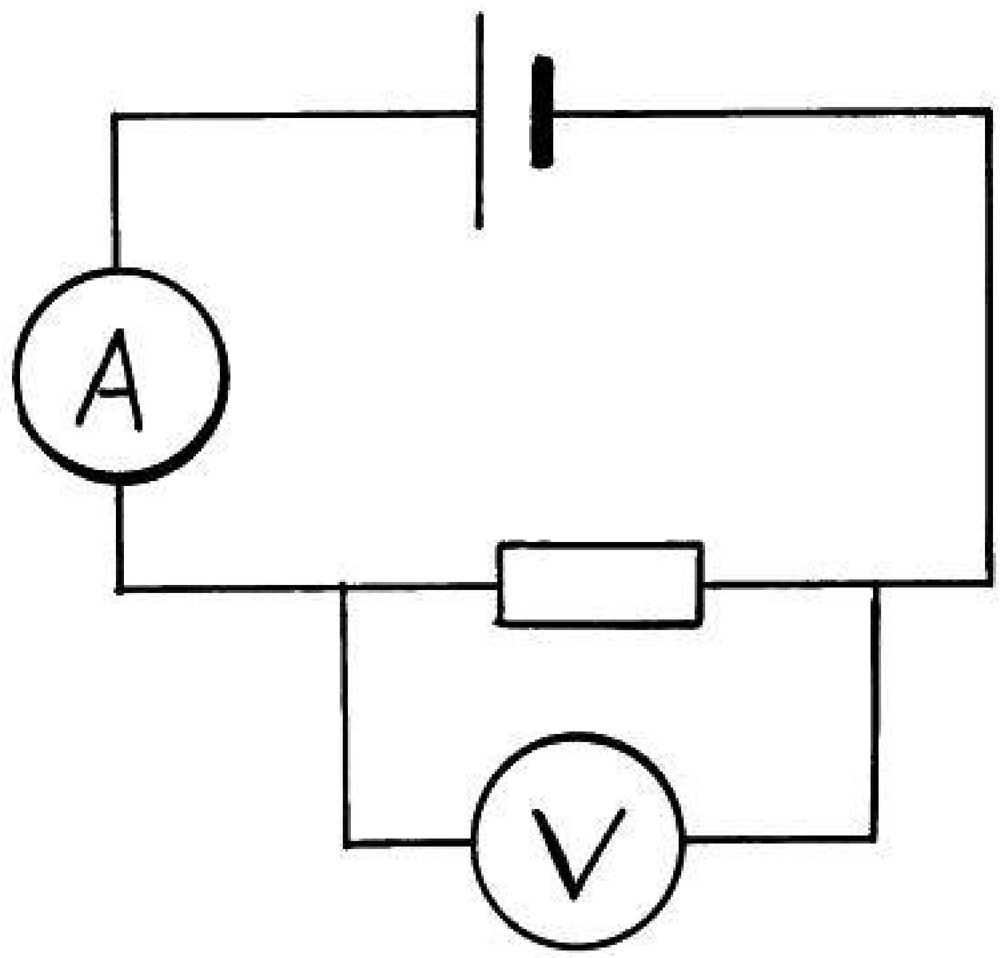
- Ohms Law: I = V / R (sometimes E)
- Power P = V x I



Measuring

Measuring (e.g. with a multimeter)

- Voltage - in parallel (across)
- Current - in series (break the circuit)
- Resistance - out of circuit, powered off

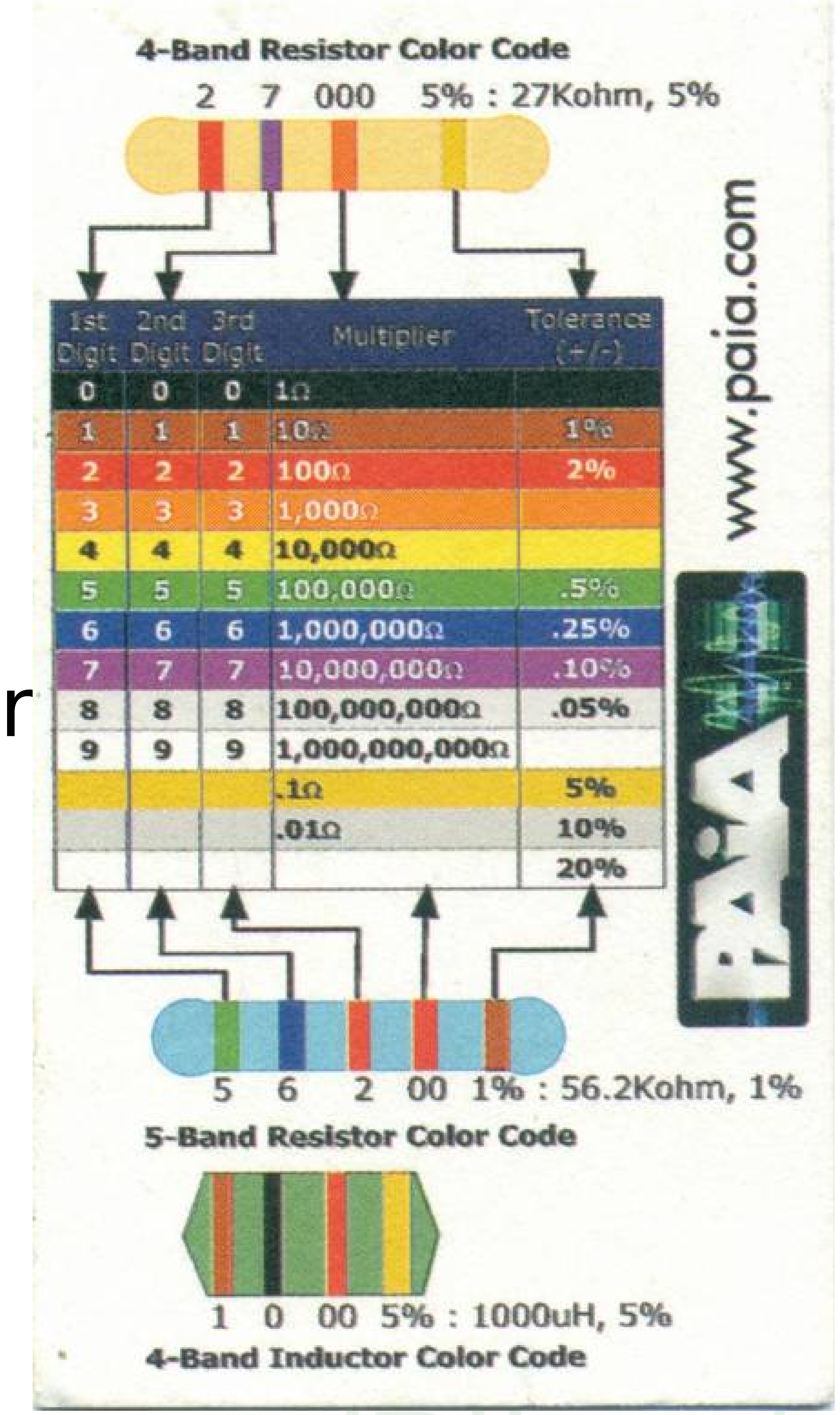


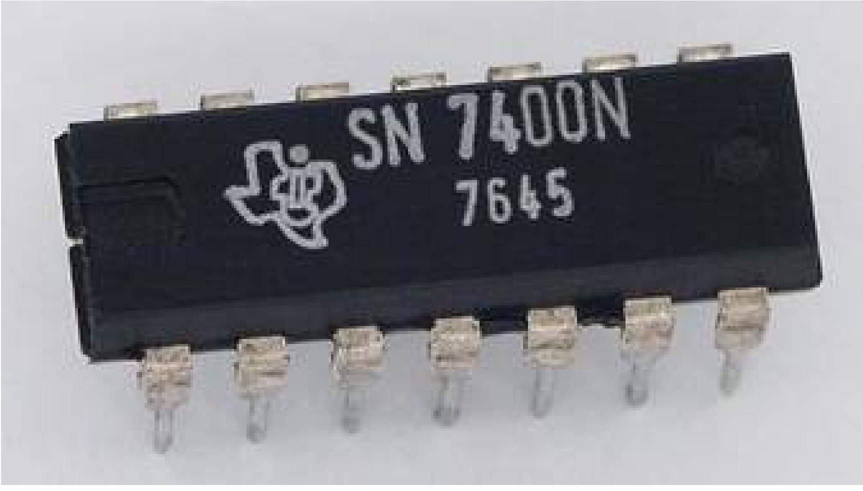
Common Electronic Components

- Passive components:
  - resistor unit: Ohm (kilohm, megohm)
  - capacitor unit: Farad (μF, nF, pF)
  - inductor unit: Henry (μH, mH)
- Active components:
  - vacuum tube (valve)
  - diode/LED
  - transistor (many types)
  - ICs (many types)

Common Electronic Components

- Components identified by:
  - part identifier (e.g. 7400)
  - value (e.g. 1000 ohms)
  - power rating (e.g. 1 watt)
  - voltage rating (e.g. 10 VDC)
- Component values marked using colour codes or number conventions





Common Metric Prefixes

Name	Prefix	Multiplier
Pico	p	10^{-12}
Nano	n	10^{-9}
Micro	µ	10^{-6}
Milli	m	10^{-3}
Kilo	k	10^{3}
Mega	M	10^{6}
Giga	G	10^{9}
Tera	T	10^{12}

Digital versus Analog

- **Digital**: represent values/numbers using discrete voltages
- Modern computers generally use binary, two values, 1/0, true false
- Value represented as a voltage within a range, dependent on technology used
- e.g. standard TTL logic - 0 to 0.4V is false, 2.6 to 5.0V is true

Digital versus Analog

- **Analog**: can take any value within a continuous range
- Digital to Analog (D/A) and Analog to Digital (A/D) conversion processes can convert
- Conversion between the two is not perfect
- Key factors are sample rate (samples/sec) and sample size (bits)
- e.g. Audio CD: 16 bit sample size, 44100 bits per second sample rate

Hardware Interfaces - Processor Terminology

Hardware Interfaces - Processor Terminology

- **CPU**: Central Processing Unit. Hardware within a computer that carries out the instructions of a computer program.
- **Microprocessor**: Incorporates the functions of a computer's central processing unit (CPU) on a single integrated circuit.
- **Microcontroller**: Small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals.
- **SOC**: System On a Chip; integrated circuit that integrates all components of a computer or other electronic system into a single chip.

Hardware Interfaces - Processor Terminology

- **SOM**: System on Module (SOM), a type of single-board computer (SBC).
- **SiP**: System In Package (SiP), also known as a Chip Stack MCM. A number of integrated circuits enclosed in a single module (package).
- **DSP**: Specialized microprocessor optimized for the needs of digital signal processing.
- **GPU**: Graphics Processing Unit, specialized CPU designed to rapidly manipulate and alter memory to accelerate the creation of images in a frame buffer intended for output to a display

Hardware Interfaces - Memory

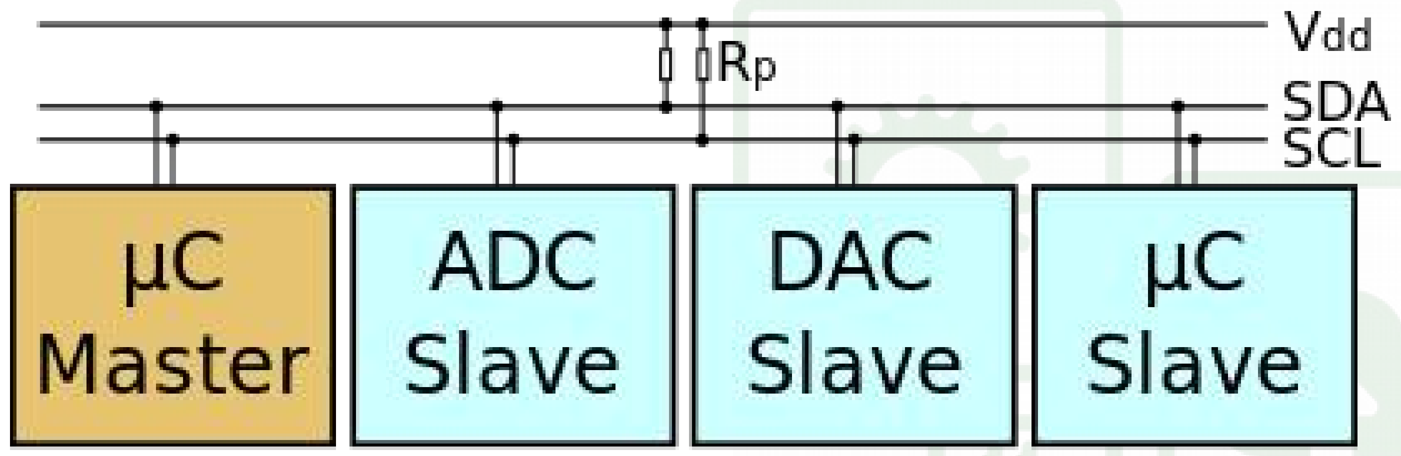
- RAM, DRAM, Static RAM
- ROM, PROM, EPROM, EEPROM
- Flash memory: NAND, NOR

Hardware Interfaces - Simple I/O

- Inputs
- Outputs
- Bi-directional
- Tri-state (high-Z), pull-up, pull-down
- Open collector/open drain
- Analog
- Digital
- PWM

Hardware Interfaces - I²C

- I²C (Inter-Integrated Circuit), pronounced I-squared-C or I-two-C
- Multi-master, multi-slave, single-ended, serial computer bus invented by Philips Semiconductor
- Used for attaching low-speed peripherals to computer motherboards and embedded systems
- Uses two bidirectional open-drain lines, Serial Data Line (SDA) and Serial Clock Line (SCL), pulled up with resistors.
- Typical voltages used are 5V or 3V, although other voltages are permitted
- Will cover programming under Linux later

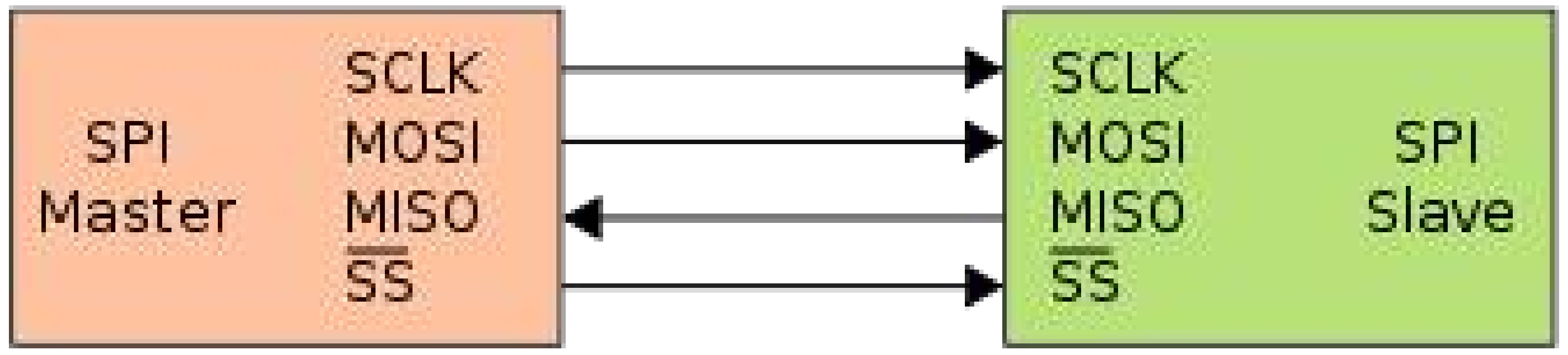


Hardware Interfaces - SMBus

- System Management Bus (SMBus or SMB)
- Simple single-ended two-wire bus for lightweight communication
- Commonly found on PC motherboards for communication with power management
- Derived from I²C
- Defined by Intel in 1995

Hardware Interfaces - SPI

- Serial Peripheral Interface or SPI bus
- Also known as SSI (Synchronous Serial Interface)
- Full duplex, synchronous, serial data link
- Four-wire serial bus
- Often used with sensors and SD cards
- Devices communicate in master/slave mode
- Multiple slave devices are allowed with individual slave select lines



Hardware Interfaces - GPIO

- General-Purpose Input/Output
- Generic pin that can be controlled by user at run time
- Typically can be programmed as input or output
- May support tri-state, pull-up pull-down, PWM, etc.
- Supported by e.g. Arduino, BeagleBone, Raspberry Pi

Hardware Interfaces - USB

- Ubiquitous
- Latest spec is 3.1
- Sometimes used (only) for power
- See later for some gotchas

Hardware Interfaces - IEEE-488/GP-IB/HP-IB

Hardware Interfaces - IEEE-488/GP-IB/HP-IB

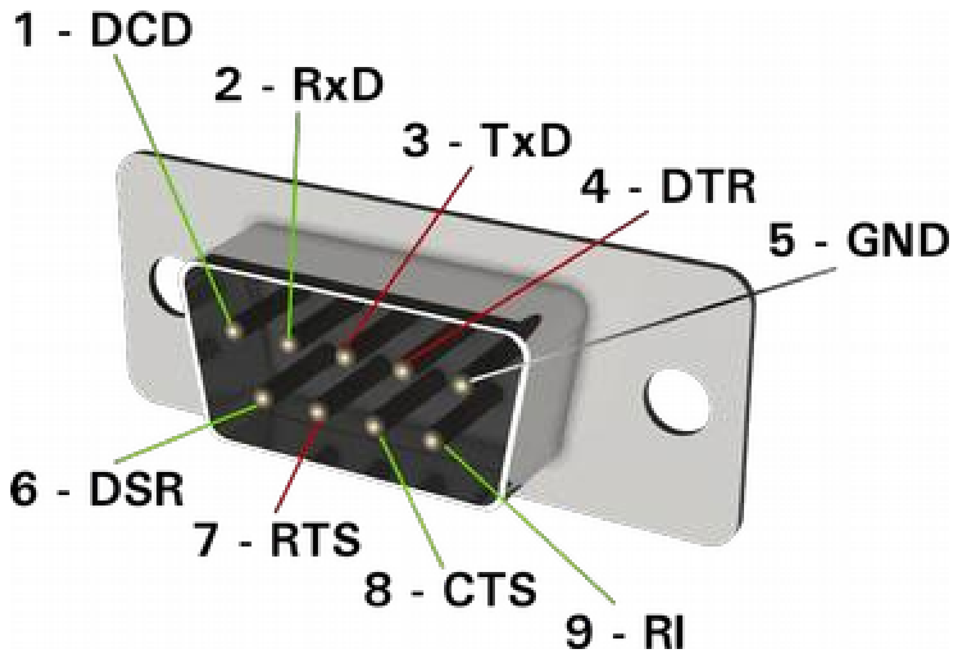
- Short-range digital communications bus
- Created in the late 1960s by Hewlett-Packard for use with automated test equipment
- Expensive connectors and cables
- Now mostly replaced by more recent standards such as USB, FireWire, Ethernet

Hardware Interfaces - MODBUS

- Serial communications protocol
- Originally developed by Modicon for use with programmable logic controllers (PLCs)
- Commonly used for connecting industrial electronic devices
- Used in supervisory control and data acquisition (SCADA) systems
- Enables communication among many (approx. 240) devices connected to same network

Serial/UART RS-232/RS-422/RS-485

- Asynchronous serial interfaces, send one bit at a time
- Need to agree on baud rate, data bits, start/stop bits, parity
- RS-232 uses voltage levels of +/- 3-15V
- RS-422 is differential signalling, longer distance
- RS-485 supports multi-point
- Some USB devices are serial devices (e.g. FTDI)
- On newer computers can use USB to serial converter



Hardware Interfaces - Parallel Ports

- As a generic term, means port with multiple data bits (as opposed to single bit serial)
- Typically data and handshaking lines as well
- In the past referred to a standard Centronics/IEEE-1284 PC printer port, now mostly obsolete

Hardware Interfaces - JTAG

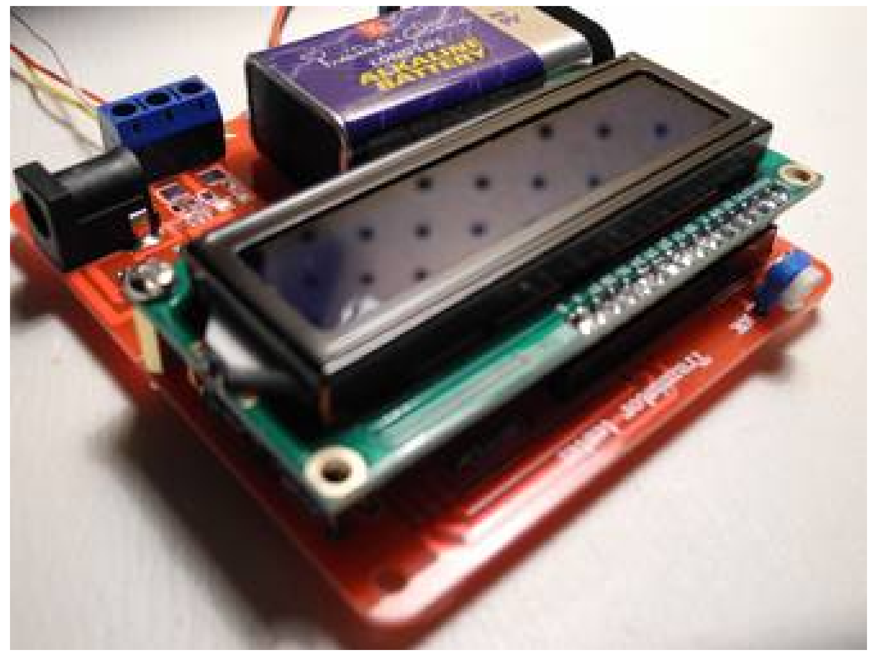
- Joint Test Action Group
- Common name for IEEE 1149.1 Standard Test Access Port and Boundary-Scan Architecture
- Initially intended for testing printed circuit boards using boundary scan (still widely used for this)
- Also used for IC debug ports
- Most embedded processors implement JTAG
- Supports operations like single stepping and breakpointing (in hardware)

Hardware Interfaces - 1-Wire

- Device communications bus system designed by Dallas Semiconductor (sometimes called Dallas 1 Wire)
- Provides low-speed data, signalling, and power over a single signal
- Master and slave devices
- Similar to I²C, but with lower data rates and longer range
- Typically used to communicate with small inexpensive devices such as digital thermometers and weather instruments
- Only two wires: data and ground. Device also powered by data line.
- Can be supported on Linux using GPIO and bit banging
- OWFS One Wire File System provides library and utilities for Linux and other platforms (owfs.org)

Hardware Interfaces - HD44780 LCD

Hardware Interfaces - HD44780 LCD



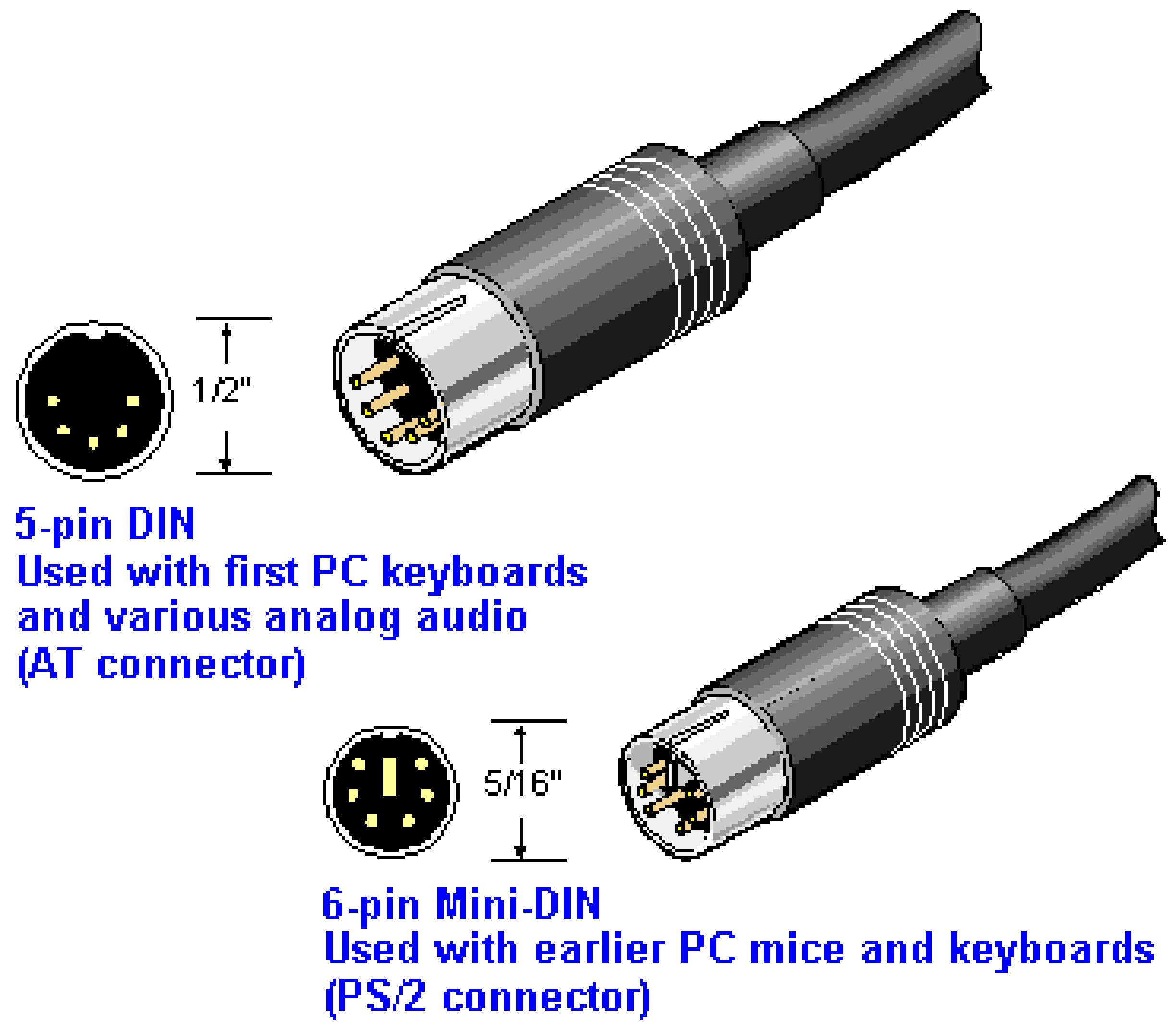
- One of the most common dot matrix LCD display controllers
- Simple interface that can be connected to a general purpose microcontroller or microprocessor
- Many manufacturers make compatible displays
- Can display ASCII characters, Japanese Kana characters, and some symbols
- Low cost (under US$20)
- Typically 2 line by 16 or up to 80 characters
- 16 pin connector, 4 or 8 data bits
- Various drivers/libraries available for Linux if you don't want to code it all yourself

Hardware Interfaces - MIDI

- Musical Instrument Digital Interface
- Standard protocol, interface, and connector for electronic musical instruments
- Carries event messages that specify notation, pitch and velocity
- Also used for lighting
- Supports multiple devices
- A single MIDI link can carry up to sixteen channels of information
- Standardized in 1983
- Mostly used by professional musicians

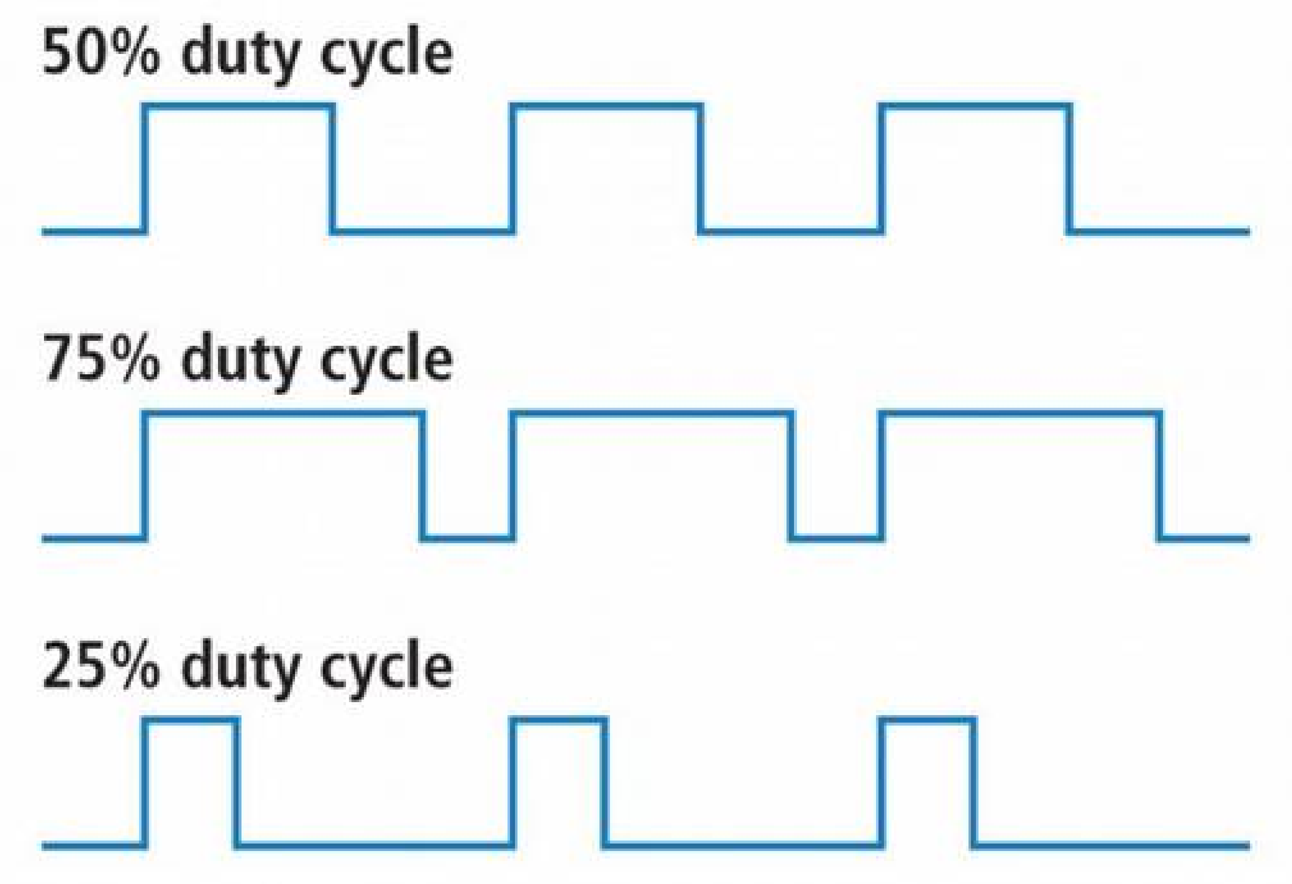
Hardware Interfaces - PC Keyboard

- Original PC/XT/AT (5-pin DIN)
- PS/2 (6-pin mini-DIN)
- USB (USB type A)
- (first 2) protocols can be implemented by bit banging



Hardware Interfaces - PWM

- Pulse Width Modulation
- Can be used for D/A conversion
- Some devices use PWM for control
- Can be done in software with GPIO pins
- Some GPIO pins have direct hardware support for PWM



Hardware Interfaces - Stepper Motors

- Brushless DC electric motor that divides a full rotation into a number of equal steps
- Motor's position can then be commanded to move and hold at one of these steps without any feedback sensor
- Unipolar and bipolar types
- Typically need driver circuit for suitable voltage/current
- Read/write heads of hard and floppy disk drives typically use this
- Easy to control using Arduino

Hardware Interfaces - Servos

- Usually refers to hobby servo motors developed for radio control
- Small, low-cost, mass-produced actuators used for radio control and small-scale robotics
- Standard three-wire connection: two wires for a DC power supply and one for control
- Position controlled using a PWM signal
- Directly supported by Arduino (without additional hardware)

Hardware Interfaces - DSI/CSI

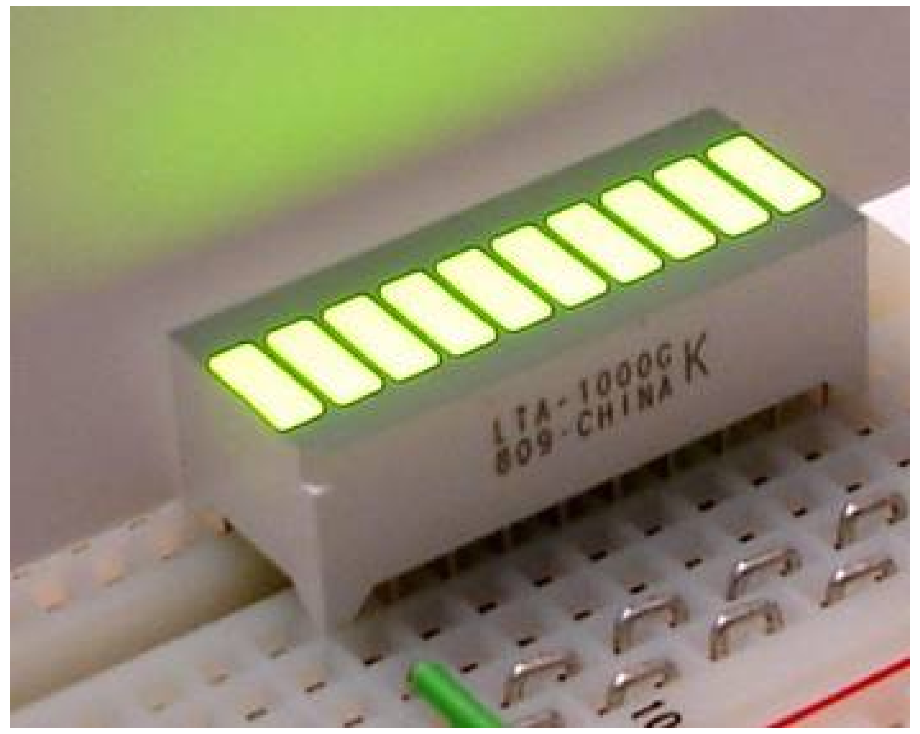
- Display Serial Interface
- Camera Serial Interface
- Specifications by the Mobile Industry Processor Interface (MIPI) Alliance
- DSI for LCD displays
- CSI for cameras
- Serial bus and a communication protocol between host and device
- Both are present on Raspberry Pi but currently no open source drivers

Sensors and Related Devices

- IR transmitters/receivers
- Sensors for physical values: temperature, light intensity, air pressure, humidity, pH, radiation, motion, proximity, radiation, sound, touch, etc.
- Accelerometers
- Output: light (LED), sound (speaker, piezo), motion (motor, stepper)
- GPS
- Commonly interface using analog, digital, I^2C etc.
- See, e.g. http://www.adafruit.com/categories/35

Displays

- LEDs: discrete, bargraph, matrix, 7-segment
- LCD: numeric, text, bitmapped graphics
- Video: VGA, composite, HDMI, etc.



Real-Time Considerations

- System is real-time if correctness of an operation depends on the *time* in which it is performed
- Classified by the consequence of missing a deadline
- *Hard real-time*: missing a deadline is a total system failure
- *Soft real-time*: usefulness/quality of service degrades after missing deadline
- Supported by an RTOS (Real-Time Operating System)
- Standard Linux is not an RTOS

Approaches for Supporting Real-Time

- Set priority, scheduling policy (e.g. Linux/POSIX: setpriority, sched_setscheduler)
- Implement in kernel
- Real-time add-ons (e.g. for Linux)
- True RTOS (e.g. QNX)
- Offload to other hardware like microcontroller or PIC

Embedded Development Platforms

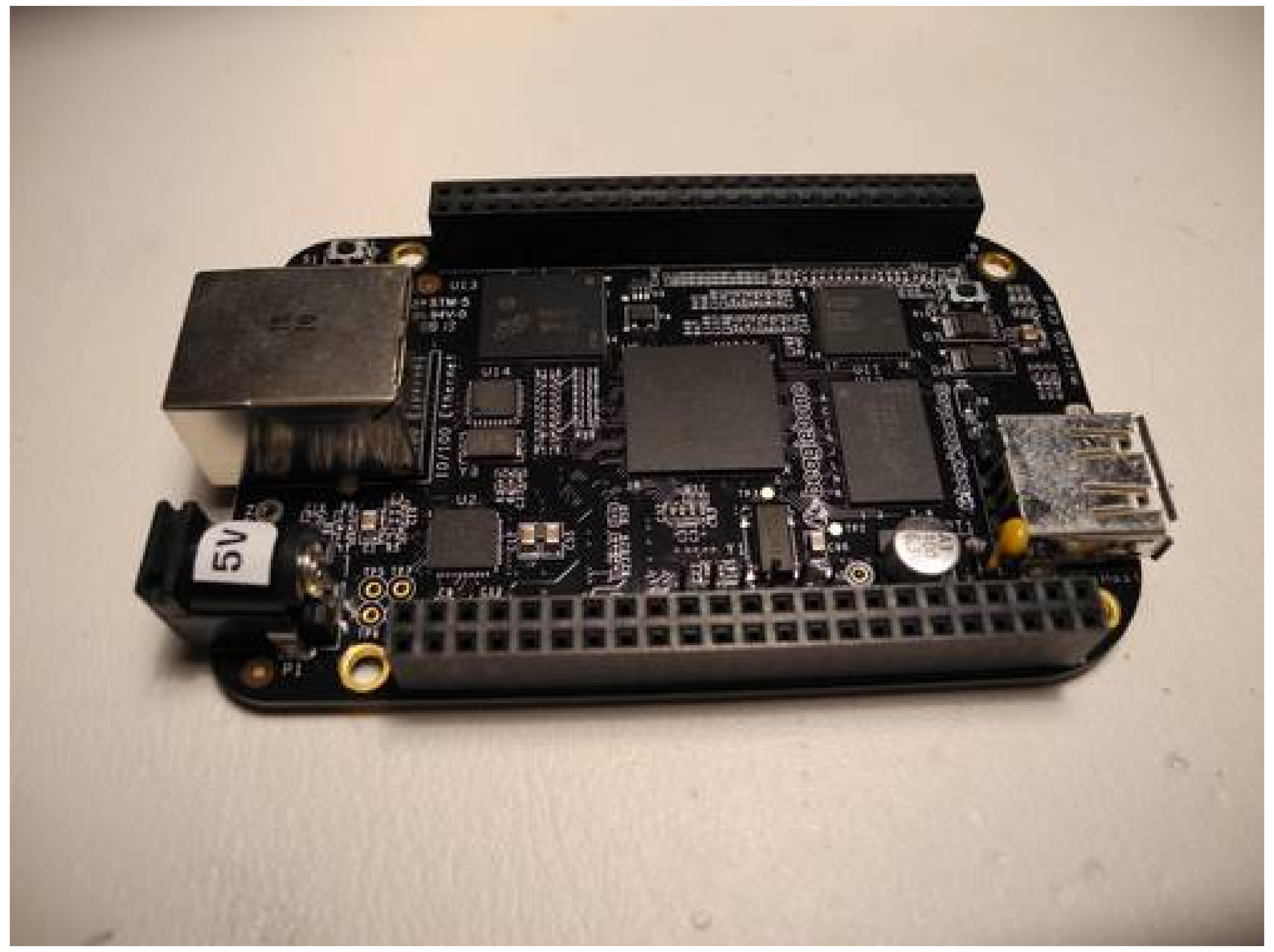
- Many to choose from
- Most vendors have evaluation boards
- Some popular ones:
  - Raspberry Pi
  - BeagleBoard/BeagleBone
  - Intel NUC, Edison
  - Arduino

Raspberry Pi

Raspberry Pi

- Developed as low-cost platform for education
- Broadcom SOC (700 MHz ARM)
- Supports various OSes including Linux
- USB, SD card, Ethernet, audio out, composite and HDMI video
- Micro USB power
- Model A: US$25, 256MB RAM, 1 USB
- Model B: US$35, 512MB RAM, 2 USB
- Model B+: lower power (3W), 4 USB, microSD, more GPIO
- Compute Module: DIMM form factor, suitable for OEM, more GPIO

BeagleBoard/BeagleBone



- Open source SBC from TI and Digi-Key and Farnell/Element14
- OMAP3530 SOC (ARM)
- 600 MHZ to 1 GHz clock speed
- 128MB to 52MB RAM
- USB On-The-Go, DVI-D, PC audio, SDHC, JTAG, HDMI
- Accelerated 2D, 3D, OpenGL ES 2.0
- On-board and SD/MMC flash
- Cost $45 to $149
- Models: BeagleBoard, BeagleBoard-xM, BeagleBone, BeagleBone Black
- Run various operating systems including Linux and Android
- Add-on "capes"

Intel Offerings

NUC:

•Next Unit of Computing (NUC)

•small form factor PC designed by Intel

Galileo:

•Arduino-compatible development boards based on x86

•Compatible with Arduino IDE and shields

Edison:

•Small computer for wearable devices

MinnowBoard:

•Low-cost Atom board

Texas Instruments Offerings

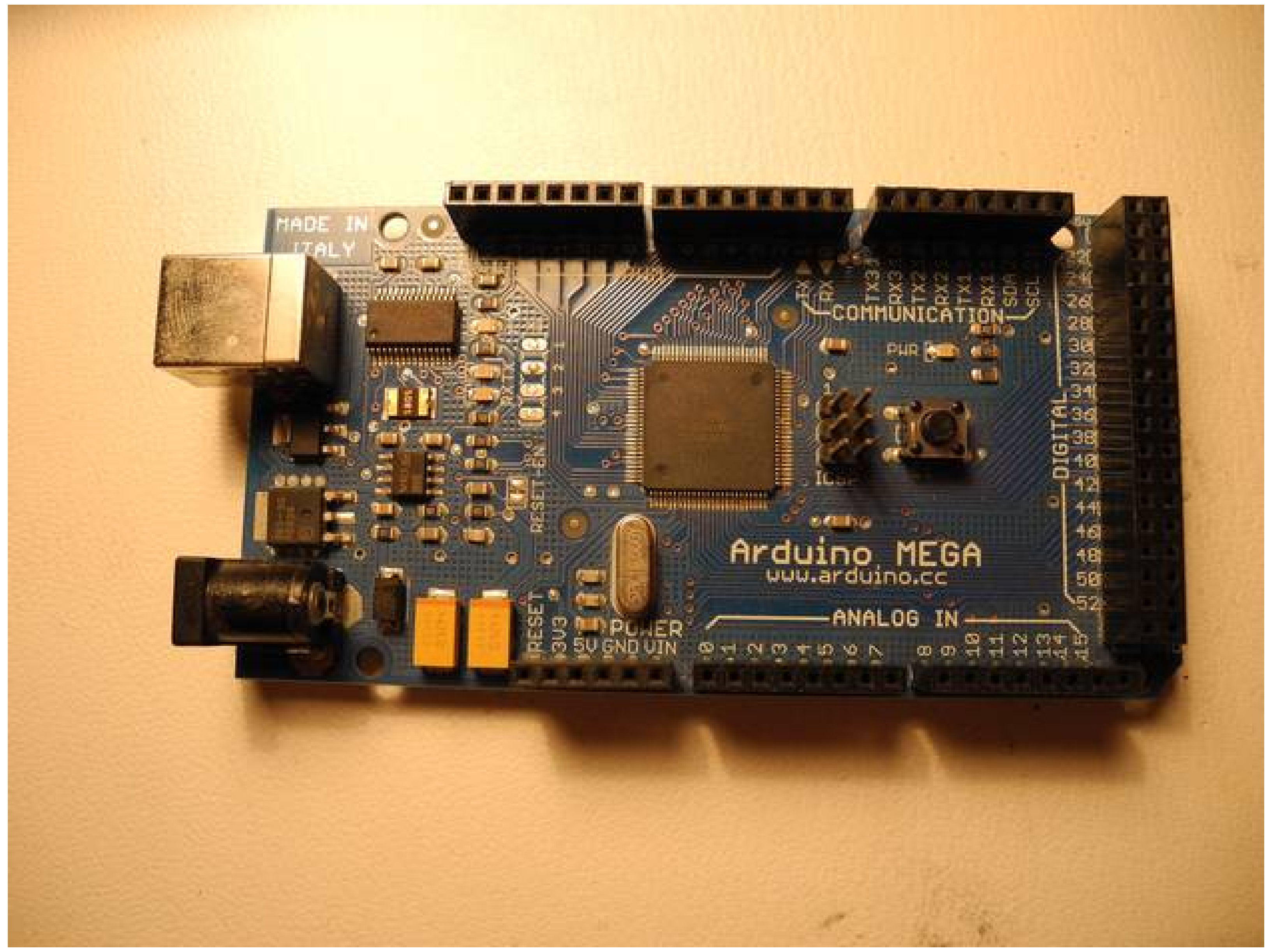
Texas Instruments Offerings

- e.g. Sitara ARM AM335X Starter Kit

Arduino

Arduino

- Family of open source single board microcontrollers
- Most use 8-bit Atmel AVR processors
- No operating system per se



Arduino

Highly popular due to "perfect storm" of:

- Low cost (clones under US$10)
- Ease and speed of programming (easy to use IDE, high-level language based on simplified C++)
- Many programming tutorials, examples, libraries
- Large user base
- Digital and analog inputs/outputs
- Many add-on "shields"

Arduino

Code Example

```
#define LED_PIN 13

void setup() {
  pinMode(LED_PIN, OUTPUT); // Enable pin 13 for digital output
}

void loop() {
  digitalWrite(LED_PIN, HIGH); // Turn on the LED
  delay(1000); // Wait one second (1000 milliseconds)
  digitalWrite(LED_PIN, LOW); // Turn off the LED
  delay(1000); // Wait one second
}
```

Relevant Qt APIs

Several Qt modules fit category of low-level hardware:

- Serial Port
- Networking
- BlueTooth
- Location/Positioning API (GPS, Wi-Fi)
- Sensors (accelerometer, compass, etc.)

Linux Drivers and APIs

- Will cover I^2C, SPI, GPIO
- Can use these from user space
- In some cases may want to write kernel code
- Kernel pros: access to kernel interfaces such as IRQ handlers or other layers of the driver stack
- Kernel cons: harder to write and debug, error can crash entire machine

Linux Drivers and APIs - I²C

- Kernel-level drivers make I²C interfaces look like standard Linux character devices.
- Devices are /dev/i2c-*n* where *n* is adaptor number starting from 0
- Also see /sys/class/i2c-adapter
- Linux i2c-tools package provides useful utilities like "i2cdetect".
- Can program using standard system calls open(), ioctl(), read(), write()

Linux Drivers and APIs - I²C

- Also higher level SMBus commands defined in <linux/i2c-dev.h>
- (SMBus is a subset of I²C, with a stricter protocol definition)

```
 __s32 i2c_smbus_write_quick(int file, __u8 value);
  __s32 i2c_smbus_read_byte(int file);
  __s32 i2c_smbus_write_byte(int file, __u8 value);
  __s32 i2c_smbus_read_byte_data(int file, __u8 command);
  __s32 i2c_smbus_write_byte_data(int file, __u8 command, __u8 value);
  __s32 i2c_smbus_read_word_data(int file, __u8 command);
  __s32 i2c_smbus_write_word_data(int file, __u8 command, __u16 value);
  __s32 i2c_smbus_process_call(int file, __u8 command, __u16 value);
  __s32 i2c_smbus_read_block_data(int file, __u8 command, __u8 *values);
  __s32 i2c_smbus_write_block_data(int file, __u8 command, __u8 length, __u8
*values);
```

Linux Drivers and APIs - I^2C

- On some platforms, like Raspberry Pi, may need to manually load the relevant kernel drivers, e.g. "sudo modprobe i2c-dev" and set permissions if you need to access them as non-root user, e.g. "sudo chmod o+rw /dev/i2c*"
- Can put a script in /etc/rc.local to do this on boot up
- See https://www.kernel.org/doc/Documentation/i2c/dev-interface

Linux Drivers and APIs - SPI

- Appear as character devices.
- Creates character device nodes at /dev/spidev*B*.*C* where:
  - *B* is the SPI bus (master) number
  - *C* is the chip-select number of specific SPI slave
- SPI devices have a limited user space API, supporting basic half-duplex read() and write() access to SPI slave devices.
- Using ioctl() requests, full duplex transfers and device I/O configuration are also available

Linux Drivers and APIs - SPI

- read() for read only SPI transaction, with a single chip-select activation
- write() for write only SPI transaction, with a single chip-select activation
- Defined in <linux/spi/spidev.h>
- See https://www.kernel.org/doc/Documentation/spi/spidev

Linux Drivers and APIs - GPIO

- Linux has unified driver for GPIO on different platforms
- Often GPIO pins can also be I^{2}C, SPI, PWM, UART, etc. depending on how programmed
- Typically can control on a per pin basis: pin direction (input or output), read inputs, write to outputs, and maybe pullup, pulldown, open collector, and enable interrupts
- Typically need to run as root or change permissions on device files
- See https://www.kernel.org/doc/Documentation/gpio/
- Different ways to control

Linux Drivers and APIs - GPIO

- **Method 1: Kernel system calls**
- #include <linux/gpio.h>
- Old, deprecated integer-based interface
- New, preferred descriptor-based interface
- Examples:
  - int gpio_get_value(unsigned int gpio);
  - void gpio_set_value(unsigned int gpio, int value);

Linux Drivers and APIs - GPIO

- **Method 2: Sysfs**
- Can be controlled via sysfs interface under /sys/class/gpio
- Need to "export" pin that you want to use by writing pin number to /sys/class/gpio/export
- Will see /sys/class/gpio/gpio*N* appear
- Write to /sys/class/gpio/unexport to free when done
- Set direction by writing "in" or "out" to /sys/class/gpio/gpio*N*/direction
- Set value by writing "0" or "1" to /sys/class/gpio/gpioN/value
- Read value from /sys/class/gpio/gpio*N*/value
- Info about GPIO controllers in /sys/class/gpio/gpiochip*N*/

Linux Drivers and APIs - GPIO

- Raspberry Pi example (shell script):

```
#!/bin/sh
echo "4" > /sys/class/gpio/export
echo "out" > /sys/class/gpio/gpio4/direction
echo "1" > /sys/class/gpio/gpio4/value
cat /sys/class/gpio/gpio4/value
echo "4" > /sys/class/gpio/unexport
```

Linux Drivers and APIs - GPIO

- **Method 3: Memory Mapped**
- Works on devices where GPIO hardware is memory mapped e.g. Raspberry Pi
- Hardware specific, but very fast
- Steps:
  - Open /dev/mem
  - Call mmap() to get pointer to appropriate physical memory
  - Close /dev/vmem
  - Access memory as a volatile unsigned * (macros can make it easier)
- Examples (with macros) exist for Raspberry Pi: http://elinux.org/RPi_Low-level_peripherals#C

Linux Drivers and APIs - GPIO

- **Method 4: Kernel Driver**
- For maximum performance and flexibility, write customer kernel level code
- As mentioned earlier, provides access to kernel interfaces such as IRQ handlers or other layers of the driver stack and gives you control over preemption.
- Typically an order of magnitude harder than user space code to write and debug; errors can crash entire machine.

GPIO - Libraries

- Various libraries available
- WiringPi is a Linux Raspberry Pi library that is mostly compatible with Arduino: http://wiringpi.com
- Also supports serial, SPI, I^2C
- e.g.

```
pinMode(0, OUTPUT);    // aka BCM_GPIO pin 17
digitalWrite(0, 1);    // On
delay(500);            // mS
digitalWrite(0, 0);    // Off
delay(500);
```

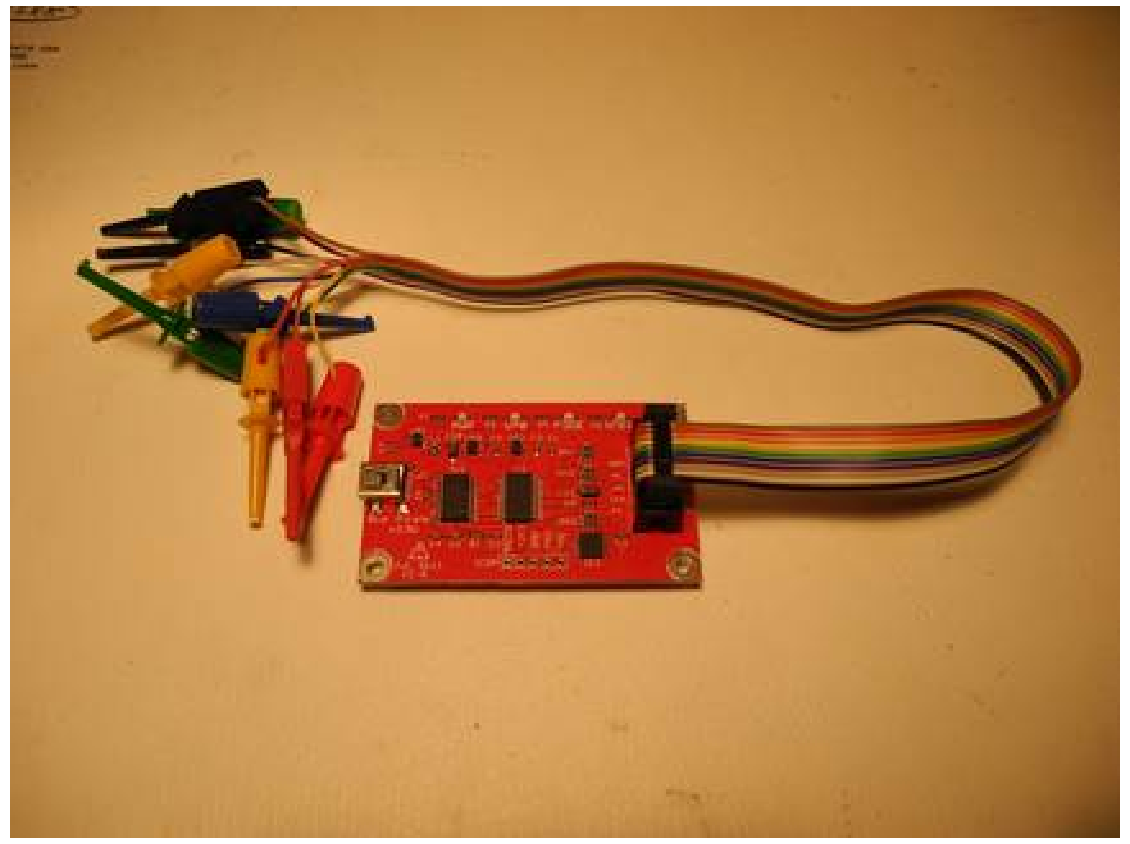
Tips

- Tools:
- Small wire cutters, pliers, strippers
- Magnifier
- Temperature controlled soldering station, solder
- Desoldering tool (braid, pump)
- Heat gun

Soldering

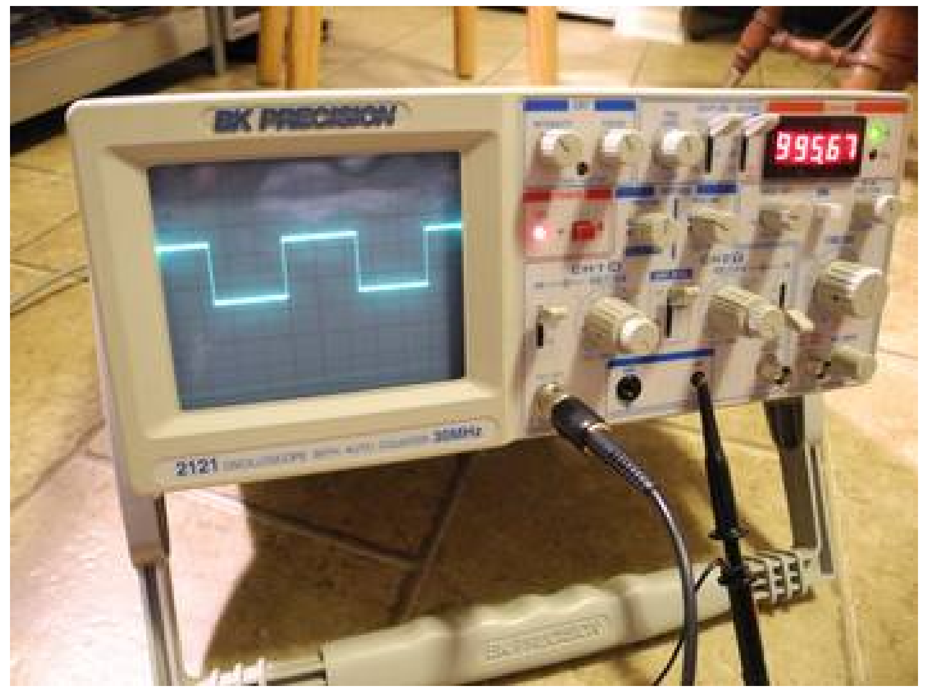
- Not hard, but requires practice
- Use proper iron and solder
- It is possible to hand solder the larger SMT parts
- Can even do reflow using toaster oven and controller
- Lots of good YouTube videos
- Recommend the "Soldering is Easy" comic book:
  http://mightyohm.com/blog/2011/04/soldering-is-easy-comic-book/

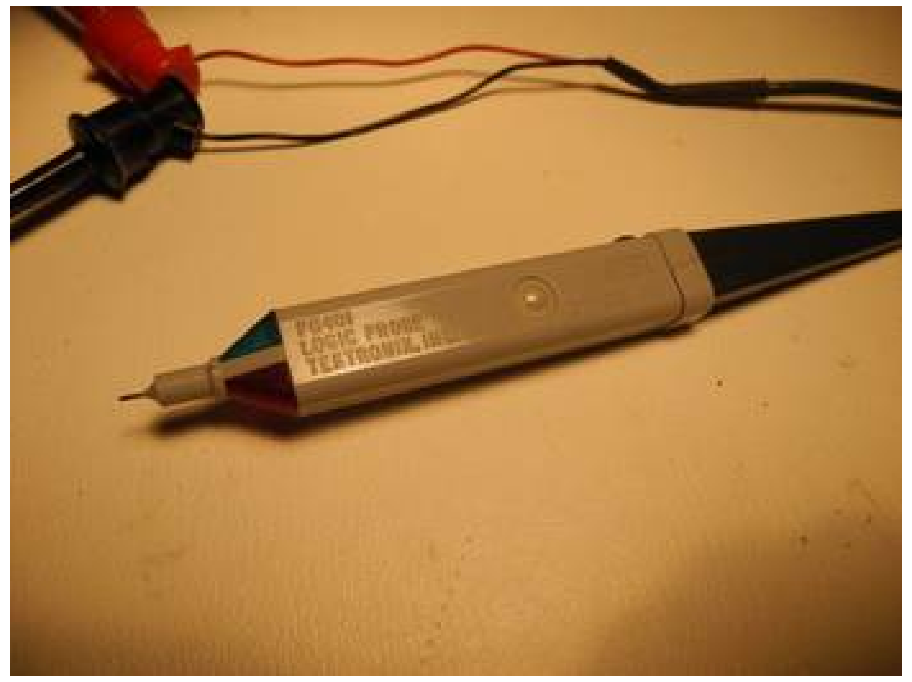
Test Equipment



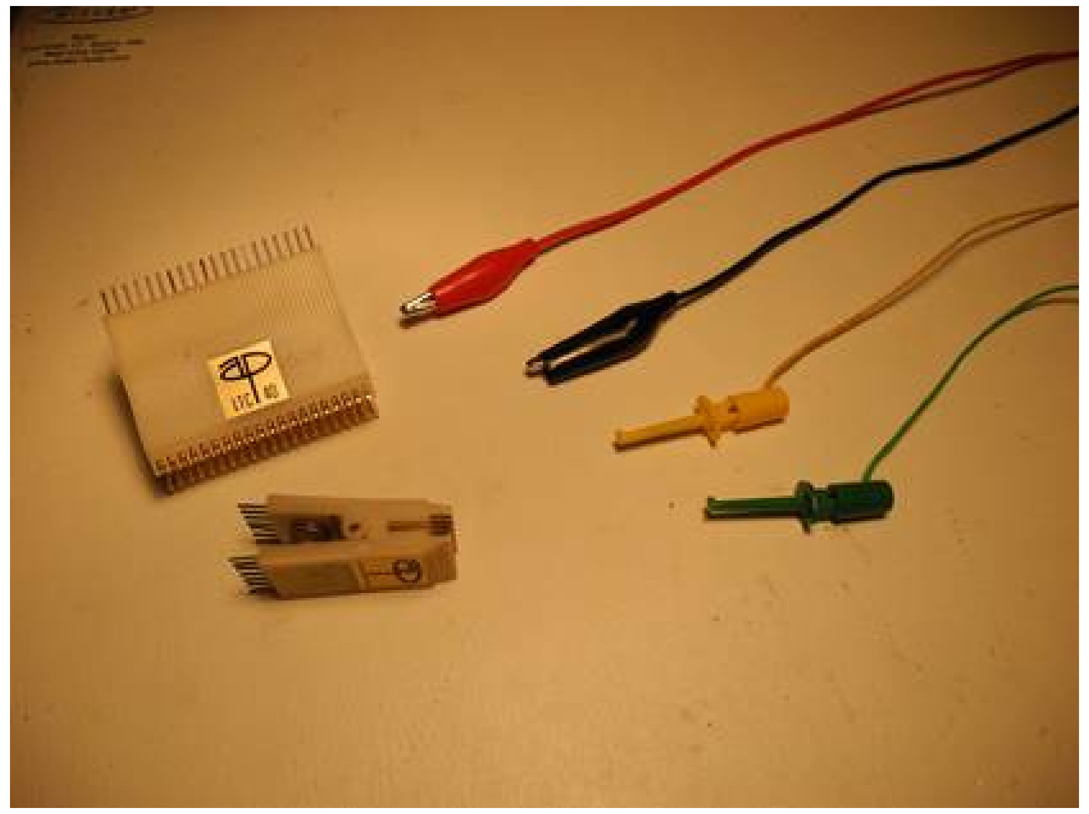
Test Equipment:

- DMM (very inexpensive)
- DC power supply, e.g. +/-5V, +/-12V, 0-30V
- Logic probe
- FTDI friend
- Bus Pirate
- Oscilloscope (analogue or digital, wide price range)





Tips

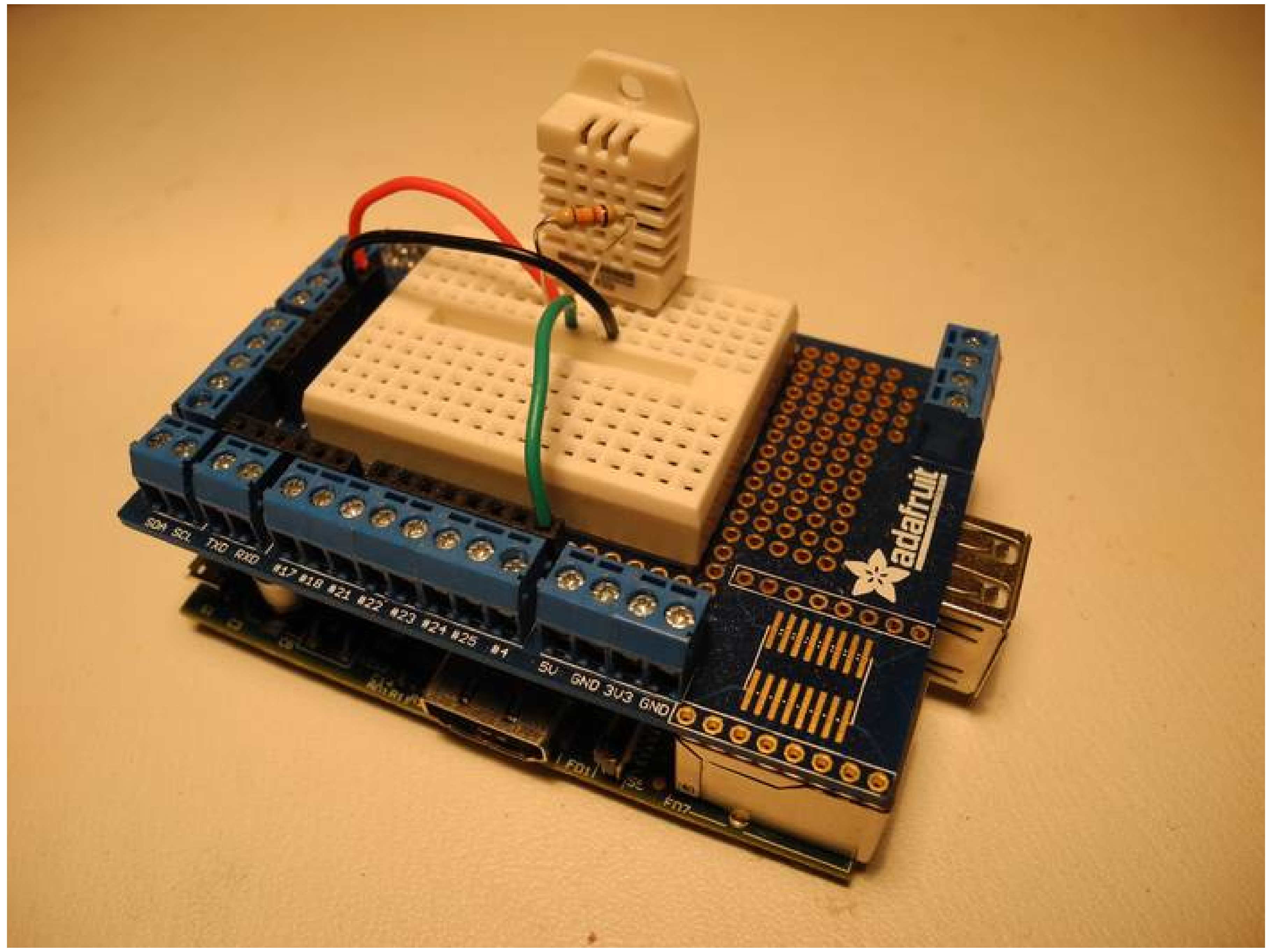


- Parts:
  - resistors
  - capacitors
- Miscellaneous:
  - hookup wire (solid for solderless breadboards)
  - clip leads (including small ones for IC pins)
  - DIP clips
  - good collection of cables and adaptors (USB, serial, header connectors)
  - proto boards (wireless breadboard)
  - SD/microSD cards, adaptors

Tips

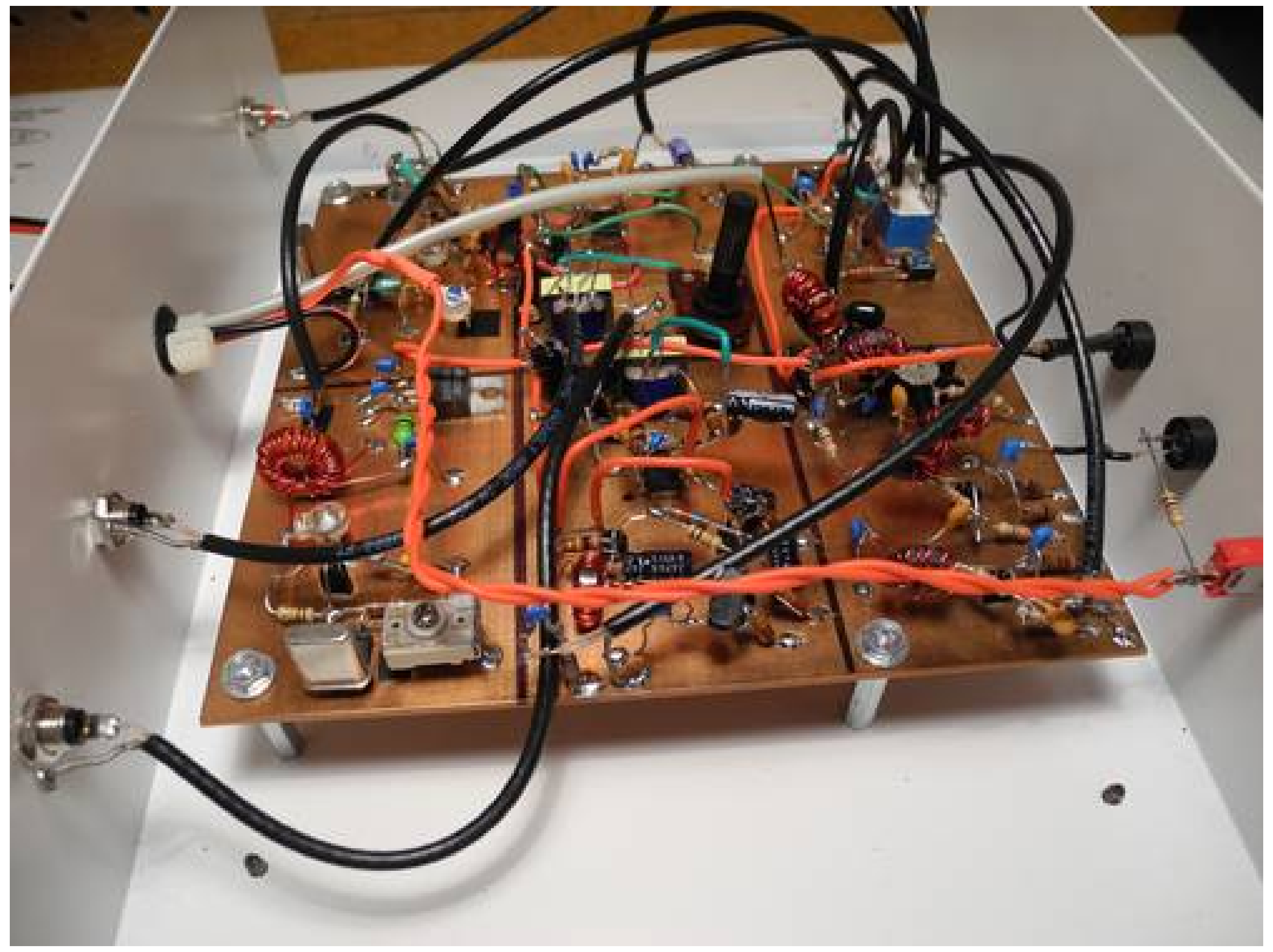
Getting Started

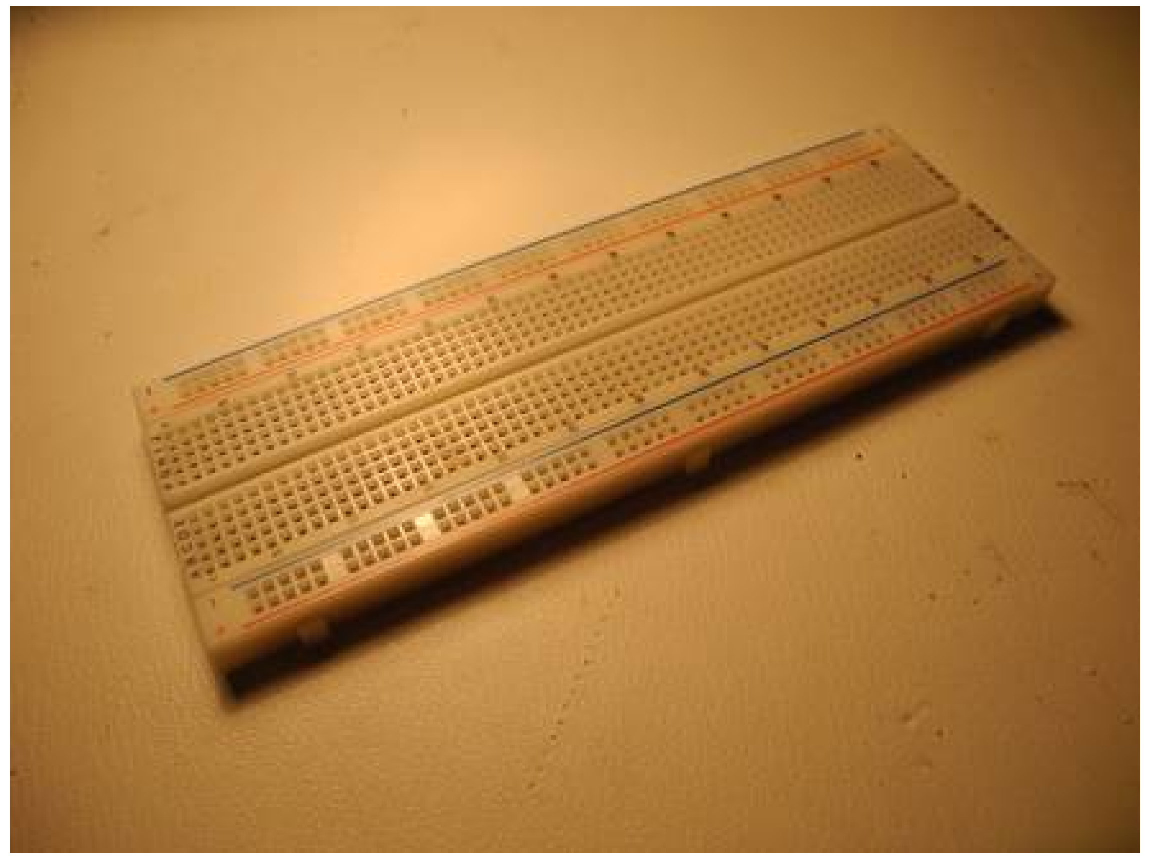
- Buy a low-cost board like Raspberry Pi, BeagleBoard or Arduino and spend some time with it.
- Start with a flashing LED and then progress to more complex work

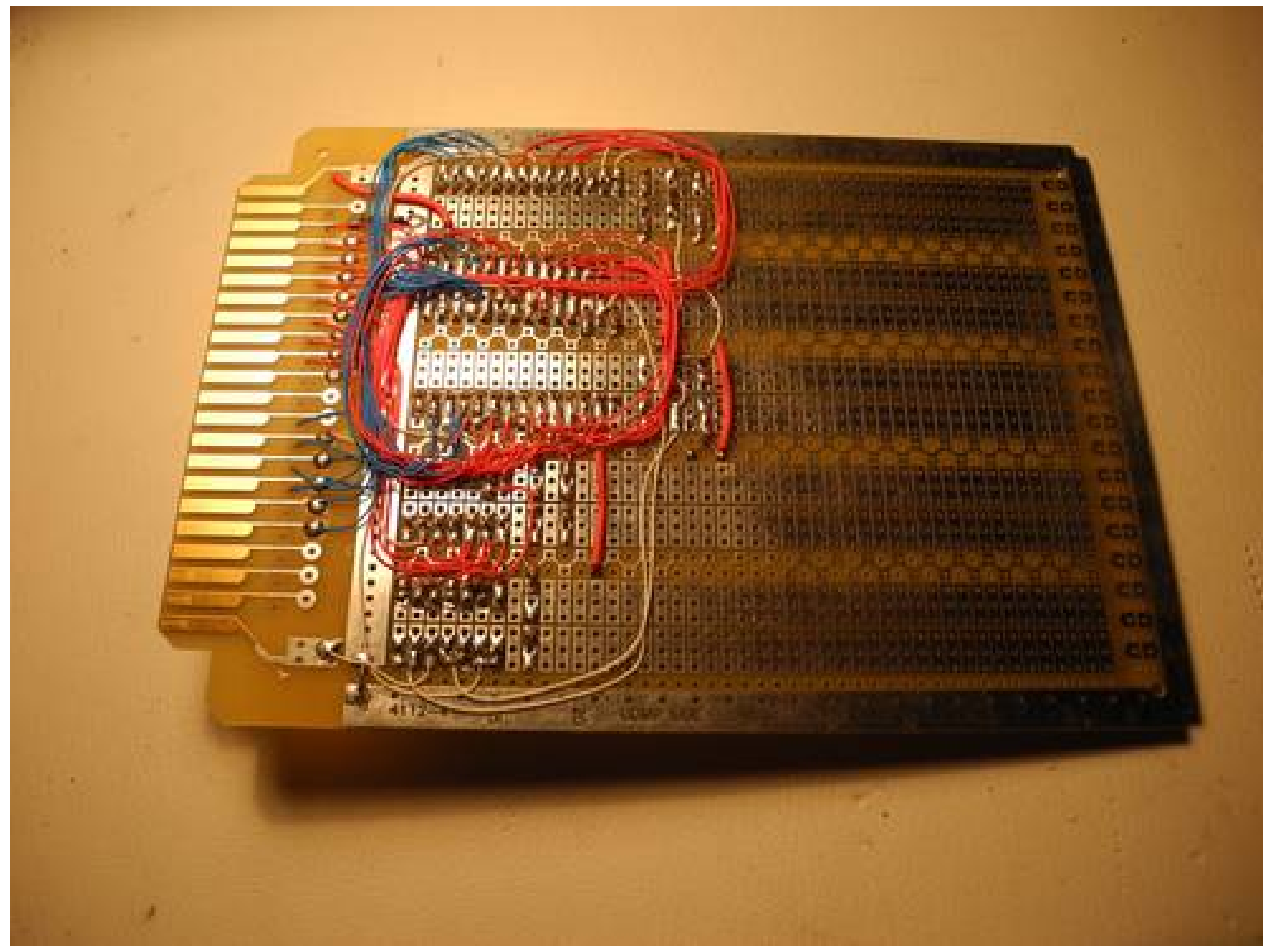


Hardware Construction Methods

- Breadboards
- Protoboards
- Wirewrapping
- Veroboard
- Ugly style, Manhattan
- PCBs
- SMT versus through-hole







Gotchas

- Device power: 3.3V versus 5V (or less). Beware of cheap power supplies.
- Serial ports: RS-232 versus TTL (or other) levels. DTE/DCE, hardware handshaking, different connectors.
- USB: Different connectors. Some USB ports are for power only. Host versus device. Power capability (don't exceed). hubs.
- ESD/static

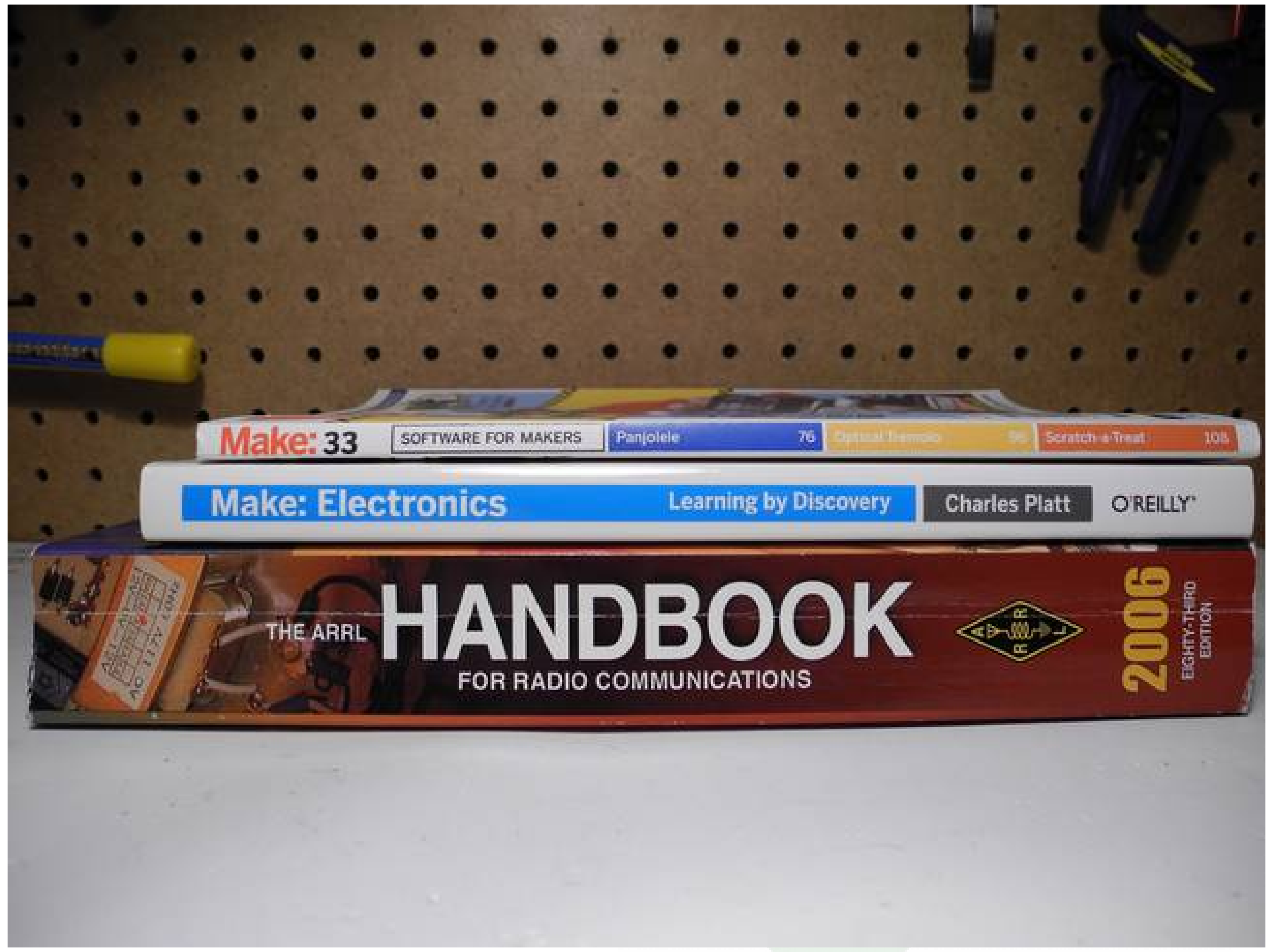
References - Websites

- EEVBlog (YouTube, eevblog.com)
- Hack A Day (hackaday.com)
- Wikipedia has articles on most buses, protocols, etc.

References

References - Books

- Make: Electronics
- ARRL Handbook for Radio Communications
- Hacking the XBox, Andrew "Bunny" Huang
- Make magazine



References - Suppliers

- AdaFruit (adafruit.com)
- Amazon (amazon.com)
- Digi-key (digikey.com)
- Farnell/Element 14 (farnell.com)
- Jameco (jameco.com)
- Maker Shed (makershed.com)
- Mouser (mouser.com)
- SparkFun (sparkfun.com)

The End

- Thank you for attending
- Questions?