Intro to Electronics and Circuit Building

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Class Outline - Lecture

1. Basic Electricity
2. Electronic Components
3. Microcontroller Intro
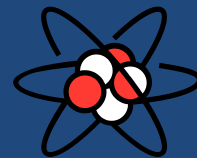4. Danger Shield & Components

Class Outline - Lab

1. Soldering Intro
2. Assembling Danger Shield Kit
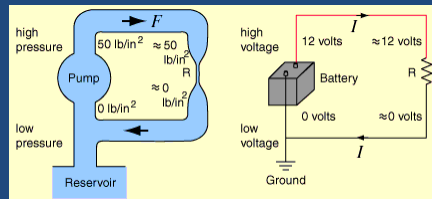
Basic Electricity - Outline

- Electrons
- Conductors and Insulators
- Models
- Voltage
- Current
- Resistance
- Ohm's Law
- Power
- Series Circuits
- Parallel Circuits
- Digital vs. Analog

Basic Electricity - Electrons

- In the atom-as-solar-system model, Electrons are the "planets" orbiting the central nucleus "Sun"
- Electrons are charged (negative by convention) - think magnets
  - Can be moved around by electric fields
  - They repel each other so it takes energy to pack them together
- Electricity is moving electrons
- Important quantities:
  - Electrical current = rate electrons are flowing
  - Electromotive Force (EMF aka Voltage) = force making them move

Basic Electricity –
Conductors and Insulators

- In **conductors**, the electrons are loosely attached to the atoms and can be easily moved from place to place by applying a force
  - Examples: Copper, Silver, Black carbon
- In **insulators**, the electrons are tightly attached to the atoms and can't be moved around
  - Examples: Air, glass, plastic, Diamond
- Huge difference in conductivity makes it easy to control where electricity goes:
  Copper:Plastic = 600000000000000000000000000000:1
- Wrapping conductor in insulator gives us wires

Basic Electricity – Models

- One way to think of electricity is "balls in a tube" model
- Tube is conductor, balls are electrons
- Pushing a ball in one end makes a different ball pop out the other end
- This happens instantaneously, but a given ball doesn't travel very fast
- Voltage = force pushing ball into tube
- Current = numbers of balls per second going by a point in the tube

Basic Electricity – Models

- Also popular is the water flow model:
  - Tube is wire, water is electricity
  - Voltage/EMF = water pressure forcing water through tube
  - Current = volume of water going through the pipe
  - Power supply = Pump =; Resistance = Narrowing in pipe or Turbine load
- However, a difference in conductors and insulators:
  - Cut a pipe and water goes everywhere
  - Cut a wire and the flow stops – no where for electricity to go
- **Electrical circuits are complete circles – must be a path for electrons to return to source in the steady state**
  - Antennas can use the earth ground as a path

Basic Electricity – Voltage

- Electro-motive force (EMF) makes electrons move in a conductor
- EMF is aka Voltage and is measured in Volts:
  - AA cell = 1.5 Volts   -- Cell phone charger = 5 Volts
  - Wall power is 120Vac   -- Power transmission lines = 110,000V
- $1/1000^{th}$ of a Volt is a milliVolt = 1mV
- Voltage is a relative measurement between two points
  - Voltage is signed – positive and negative relative to reference
  - The earth is often assumed to be one reference point – "Ground"
  - Can measure by touching voltmeter probes to two conductors in a circuit without affecting circuit much
- DC = direct current – Voltage doesn't change with time
  - Used in most electronic projects
- AC = alternating current – Voltage changes level and polarity over time (sine wave)
  - What comes out of the wall sockets; cycles polarity 60 times/sec
  - Makes calculations more complex – overlap integrals

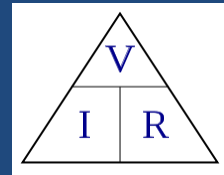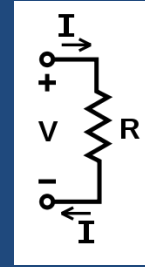# Basic Electricity – Current

- Current is the rate at which electricity flows – electrons/sec
- Current is measured in Amperes aka Amps (A). 1A = 1 Coulomb of charge/second = 6.24*10^18 electrons/sec
- 1/1000th of an Amp = 1 milliAmp = 1mA
- 1/1,000,000th of an Amp = 1 microamp = 1uA
- Typical current consumptions:
  - Single LED lamp = 20 mA   -- 7W night light = 58 mA
  - 60W light bulb = 500mA = 0.5A   -- 1200W heater = 10A
  - Max home wiring current = 15-20A   -- Car starter = 80-160A
- Typically need to open circuit and insert meter to measure
  - Meter inserts small resistance into circuit
  - Can measure magnetically with clamp-on meter

Basic Electricity – Resistance

- The amount of current that flows through many materials is proportional to the voltage across them – is **linear**
  - Twice the voltage gives twice the current, etc.
- The ratio of Voltage to Current is the *Resistance*; this can be a constant over a very large range of currents and voltages
- Resistance is measured in Ohms (Ω) - 1Ω resistance gives 1A of current with 1V across it
  - 1000 Ω = 1 kiloOhm = 1 KΩ = 1 K (say "one kay" resistance)
  - 1,000,000 Ω = 1 megaOhm = 1 MΩ = 1 M (say "one meg")
- Energy lost in a resistance is converted into heat

Basic Electricity – Ohm's Law

- *Ohm's Law* relates the voltage (V), current (I) and resistance (R) of a circuit element: **V = I * R**
- Can be rearranged to solve for any quantity when the other two are known: **I = V / R** and **R = V / I**
- Example 1: How much current will flow through a 24Ω resistance with a 12V battery across it? Current **I = V/R** = 12V / 24Ω = 0.5 Amps
- Example 2: How much resistance do you need to limit current to 250mA from a 5V power source? Resistance **R = V/I** = 5V / 0.25A = 20 Ω
- Pyramid figure helps recollection – cover missing quantity to see how to calculate it

Basic Electricity – Power

- **Power** P is the product of Voltage (V) and Current (I):
  P = V * I
- Power is measured in Watts:
  - 1V * 1A = 1 Watt
  - [Watts]= [Joules /second]
- Circuits may transform voltage <=> current, but power is conserved (unless energy is being stored)
  - Efficiency is (PowerOut / PowerIn)
- Example 1: Calculate power delivered by a 12V source supplying 1.5A current:
  P = V * I = 12 * 1.5 = 18 Watts
- Example 2: Calculate current in a 60W light bulb driven by 120V:
  I = P / V = 60W / 120V = 0.5 A
- Can use Ohm's law to calculate Power when two of (V, I, R) are known
- Example 3: Calculate power dissipated in an R=20Ω resistance carrying a current I=0.5A:
  P = V*I = (I*R)*I = (0.5*0.5)*20 = 5W
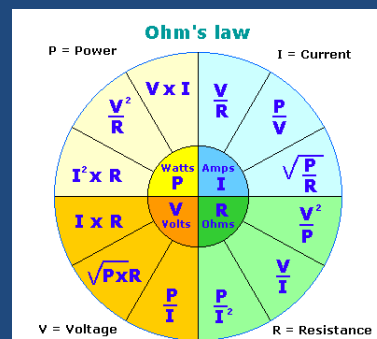
Basic Electricity – Series Circuits

- In series circuits, multiple components are connected one after another in a line.
- Same current flows through all components in the series
- Voltage across entire series is sum of voltage on each components
- Series resistance add:
  Rtotal = R1 + R2 + … + Rn

Series resistors

$$R_{equivalent} = R_1 + R_2$$
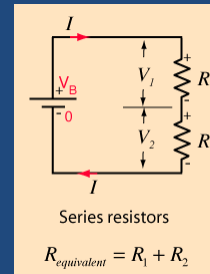
Basic Electricity – Parallel Circuits

- In parallel circuits, multiple components are connected across the same set of terminals
- Same voltage is applied to each component
- Each component can have a different current
- Total current is sum of current in each component
- Two equal resistances in parallel have ½ the net resistance; three have 1/3
- Parallel conductances add, so net resistance follows:
  1/Rnet = 1/R1 + 1/R2 + … + 1/Rn
- Can break down more complex circuits into series and parallel segments and compute total response.

Parallel resistors

$$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2}$$
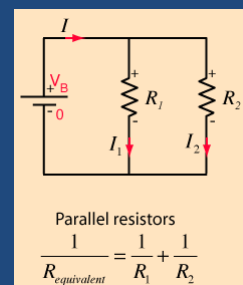
Basic Electricity – LED examples

- You want to drive a blue LED which takes I=20mA at V_L=3.5V from a V_S=5V power supply. What load resistance R do you need?
  - We want the resistor to drop (5V - 3.5V) = 1.5Volts at 20mA. So using Ohm's Law:
    R= $(V_S – V_L)/I$ = 1.5V/0.02 = 75Ω
- What power rating is needed for the resistor?
  - Power = V*I = 1.5 * 0.02 = 0.03W; 1/8W is okay

- You want to drive three high power LEDs (0.35A at 3.5V) from a 12V supply. What load resistance do you need?
  - Resistor drops 12V – 3*3.5V = 1.5V at 350mA. So R = V/I = 1.5/0.35 = 4.3Ω
- Power check:
 - P = V*I = 1.5V * 0.35A = 0.525W; use a 1W resistor
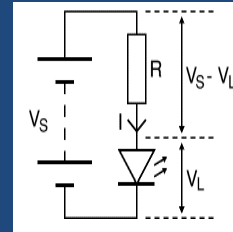
Electronic Components - Outline

1. Schematic Diagrams
2. Switches
3. Resistors
4. Capacitors
5. Inductors
6. Relays
7. Diodes
8. LEDs
9. Transistors

Schematic Diagrams

- **Schematic diagrams** show details of circuit parts and wiring connections
- Reading them takes some experience but they are ultimate reference for circuit
- Most circuit components have standard symbols
  - Component schematic symbols shown on slides
  - Integrated circuits are often just rectangles with lots of pins and labels – no symbols
- Wires indicated by lines; dots show connection when lines cross
- Power supply voltage (eg V+ or Vcc) shown on top, ground (GND) at bottom
  - But connections often shown as symbols not wires to reduce clutter nowadays
- Flow of signal usually from left to right
  - But circuits often broken up into blocks now
- Text labels also used to reduce clutter; wires connect terminals with same text label
- Labels list part number (Letter+Number) and component values (resistance, voltage)
- On more complicated parts, pins are labelled with function and pin number

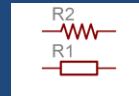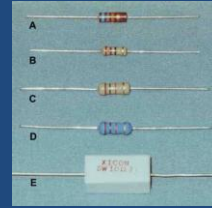Figure 22. Temperature Sensor Simplified Equivalent Circuit
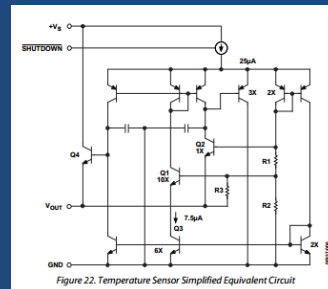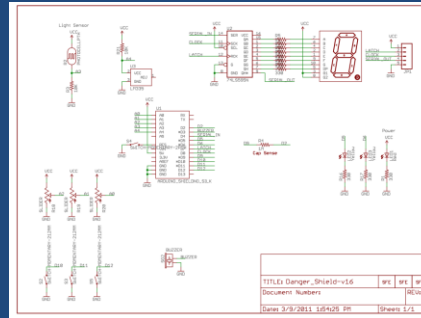
Electronic Components - Switches

- Switches allow people to control the flow of electricity
- Rated for current capacity and voltage (AC and DC ratings can differ)
- Can be N.O.=normally open (no connection when not activated) or N.C.=normally closed (connection until activated)
- Can be momentary (activated only when pushed), latching (stays where pushed), or toggle (push-on, push-off)
- Multiple **Poles** switch independent circuits; Multiple **Throws** connect to different terminals
- Example: DPDT = double-pole double-throw = two circuits, two connections each
- Thousands of choices – pick high quality, robust switches for public art

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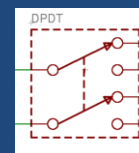
Electronic Components - Resistors

- Resistors introduce a constant amount of resistance into a circuit
- Used to drop voltages, limit current flows, and set time constants
- Different values of resistance, tolerance, and power dissipation:
  - Resistance 0.1Ω to 30 MΩ; smaller value steps for better tolerances
  - Tolerance 10%, 5% (usual), 1% (precision)
  - Power 1/8W, 1/4W, 1/2W (big) and up
- Must check power dissipation at worst case (and heat has to go somewhere)
- Uses color code to indicate values:
   Blk=0 Brn=1 Red=2 Org=3 Yel=4
   Grn=5 Blu=6 Vio=7 Gry=8 Wht=9
- Potentiometers (or "Pots") can be used as variable resistors or voltage dividers
 - Turn knob on circular pots or move slider on linear pots to adjust

Electronic Components - Capacitors

- Capacitors store energy in electric field between conductor plates
- Voltage increases as charge builds up
- Tend to reduce variations in voltage
- Used to filter power supplies, block DC voltages, and set time constants
- Different values of capacity, voltage
  - Capacity in Farads (F) ranges from 10 pF to 10F (supercap) but microFarad (uF) typical
  - Working voltage – leave margin!
- Different types for different uses:
  - Cheap ceramic for power decouping
  - Large value electrolytic and tantalum
  - Plastic dielectric for audio
- Larger values often have wide tolerances (+/- 50%) and leakage – doesn't matter for filtering but don't use in audio
- Larger values are polarized (have positive and negative pins) - don't hook up wrong!
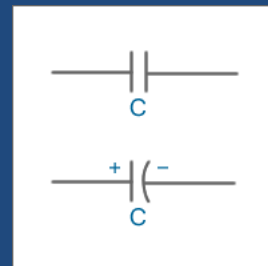
Electronic Components - Inductors

- Inductors store energy in magnetic field around coil of wire
- Works to reduce variations in current flow
- Used in power supplies, interference reduction, and audio filters
- Different values of inductance, resistance, and current capacity
  - Inductance in Henrys (H), typically mH
- Resistance, current capacity, and magnetic properties differ by device and manufacturer
  - Not generic; circuits often specify specific model of devices
- Some inductors look like resistors and use color codes – see chart
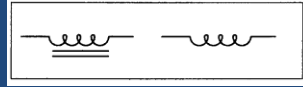
INDUCTOR COLOR GUIDE
Result Is In µH

4-BAND-CODE   270µH ± 5%

COLOR	1st BAND	2nd BAND	MULTIPLIER	TOLERANCE
BLACK	0	0	1	± 20%
BROWN	1	1	10	Military ± 1%
RED	2	2	100	Military ± 2%
ORANGE	3	3	1,000	Military ± 3%
YELLOW	4	4	10,000	Military ± 4%
GREEN	5	5		
BLUE	6	6		
VIOLET	7	7		
GREY	8	8		
WHITE	9	9		
NONE				Military ± 20%
GOLD			0.1 / Mil. Dec. Pt.	Both ± 5%
SILVER			0.01	Both ±10%

Military Identifier   6.8µH ± 10%
MILITARY CODE

Electronix Express / RSR   1-800-972-2225
http://www.elexp.com   In NJ 732-381-8020

Electronic Components - Relays

- Relays use magnetic field from current in coil to move switch contacts
- Low voltage and currents can switch higher ones; Isolates drive circuit from load for safety
- Used for controlling line power and switching audio signals
- Different drive voltages and currents, switch voltages and currents, and configurations
  - Example: 5V @100mA drive switches 2A @ 120Vac with DPDT contacts
- Need "snubber diode" across coil to prevent damage from inductive pulse
- Solid-state relays work similarly but use semiconductor devices to switch:
  - Require less drive power so good for ICs
 - Are very robust and reliable; cost more
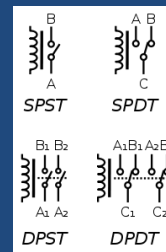
Electronic Components - Diodes

- Semiconductor device allows current to flow only one way
- To conduct current (="forward bias"), **anode** is at a more positive voltage than **cathode**
  - When "forward biased," current flows with voltage drop of ~0.6V
  - Open circuit (some leakage) when reverse biased
- Used in power supplies and protection ckts
- Rated for reverse voltage, current capacity, capacitance, and switching speed
- Different types (Schottky, germanium) have lower voltage drops – use less 'on' power
- Need to be oriented correctly in circuit
  - Cathode (negative) side has a band
- Other devices like LEDs, solar cells, and photodetectors are also diodes
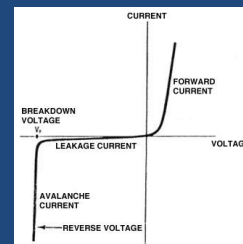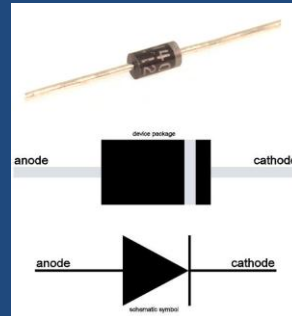
Electronic Components - LEDs

- LEDs = Light Emitting Diodes – put out light proportional to forward-biased current
- Long lifetimes and low voltages and currents compared to incandescent bulbs
- Used in indicators, lighting, remote controls
- Narrow band colors from IR->Visible->UV
  - Also broad white and pink etc. using phosphors
- Forward voltage drops from 1.5—3.5V depending on color:
  - IR 1.5V; Red/Orange/Yellow 2V, Green/Blue 3.3V
- Typical currents of 20mA for indicators and 0.35A – 1A for high power sources
- Usually need current limiting resistor in series
- Lensed packages give range of output angles; diffused plastic emits all directions
- Can turn on and off rapidly which allows pulse-width modulation control of brightness
- Available in digits, alphanumerics, 1D and 2D arrays, bulbs, strips…choices are endless
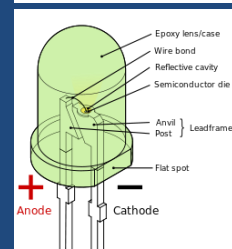
Electronic Components - Transistors

- Transistors are voltage or current amplifiers or switches
- Two common types operate differently:
  - Bipolar transistors are current amplifiers
  - MOSFET transistors control current flow with input voltage
- Individual transistors used for power supplies, changing voltage levels, or driving outputs with more current or voltage
  - E.g. LEDs, relays, solenoids, motors
- Designing analog amplifiers gets complex
- Can use MOSFETs as switches without knowing too much about them:
  - Control terminal (gate) polarity and threshold voltage
  - Max current and voltage
  - "On" resistance and power dissipation
- FETs are static sensitive – keep leads shorted and handle carefully after assembly
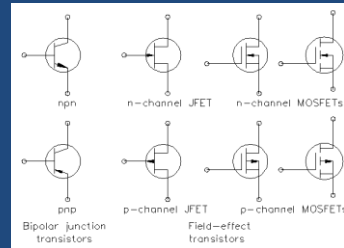

Microcontroller Electronics - Outline

- Microcontrollers
- Analog and Digital signals
- AVR Microcontroller I/O Pins

Danger Shield Kit - Outline

- Danger Shield
- Danger Shield Inputs
- Danger Shield Outputs
- Intro to Soldering
- Soldering – Fixing mistakes
- Danger Shield Kit
- Danger Shield Kit Assembly
- Danger Shield Kit Testing

Microcontrollers

- Entire computer system on a single chip:
  - CPU and registers, Program memory, Computation memory, Non-volatile memory, I/O drivers, digitizers (ADC), analog output (PWM and DAC) clock, programming, and debugging
  - Speeds of 8 to 166 MHz (fast as 90's desktops)
  - 8, 16, and 32 bit processors
  - Yours for $1 and up!
- Can have extremely low power consumption
  - 20 uA at 1MHz – can run 13 years on AA battery!
- Can pick what each connection pin does for maximum flexibility
  - Input or Output, Analog or Digital
  - Many special functions for specific applications
  - Can have up to 144 pins (but harder to solder)
  - Must learn details of registers to configure – read 500 pages of documentation, or use Arduino!
- Arduino uses 8-bit Atmel AVR microcontrollers
  - 5V power supply (but can run from 1.8V-5V)
  - 28 pin package for ease of soldering and testing
  - 16 MHz clock = 16 Million instructions per second
  - 32 Kbyte program memory, 2 Kbyte data memory
  - 14 digital and 6 analog I/Os on Arduino board
  - Later classes will talk more about configuring and programming the Arduino microcontroller board
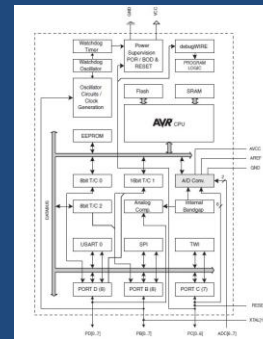
| Pin			Pin
(PCINT14/RESET) PC6	1	28	PC5 (ADC5/SCL/PCINT13)
(PCINT16/RXD) PD0	2	27	PC4 (ADC4/SDA/PCINT12)
(PCINT17/TXD) PD1	3	26	PC3 (ADC3/PCINT11)
(PCINT18/INT0) PD2	4	25	PC2 (ADC2/PCINT10)
(PCINT19/OC2B/INT1) PD3	5	24	PC1 (ADC1/PCINT9)
(PCINT20/XCK/T0) PD4	6	23	PC0 (ADC0/PCINT8)
VCC	7	22	GND
GND	8	21	AREF
(PCINT6/XTAL1/TOSC1) PB6	9	20	AVCC
(PCINT7/XTAL2/TOSC2) PB7	10	19	PB5 (SCK/PCINT5)
(PCINT21/OC0B/T1) PD5	11	18	PB4 (MISO/PCINT4)
(PCINT22/OC0A/AIN0) PD6	12	17	PB3 (MOSI/OC2A/PCINT3)
(PCINT23/AIN1) PD7	13	16	PB2 (SS/OC1B/PCINT2)
(PCINT0/CLKO/ICP1) PB0	14	15	PB1 (OC1A/PCINT1)

Analog and Digital Signals

- **Digital** I/Os sense or transmit one bit of information
  - 0 or 1, on or off, True or False, switch pushed or not pushed, signal at high or low level
  - Zero represented as low voltage (near Ground or 0V)
  - One represented has high voltage (near power supply voltage, +5V for Arduino)
  - Values near high or low levels are just the same as ideal levels
    - Allows digital circuits to be more tolerant of noise
  - Can abstract away electronic details, allows for very complex systems
  - Can represent more levels by grouping I/O pins or transmitting bits in time sequence
- **Analog** I/Os have continuously varying values over some range
  - The Real World is analog – even digital signals
  - Voltage or current in a circuit node can represent some continuous physical quantity
  - Any level over some range is possible
  - Small changes in level are meaningful – no margin for noise or errors
  - Different circuit components and design techniques needed for analog signals
    - Circuits are simpler in function but much more exacting in performance than digital
- Need to be able to convert between the two words
  - Analog to Digital Converters (ADCs) are circuits that find digital values of continuous signals
  - Digital to Analog Converters (DACs) turn digital numbers into analog values (voltage or current)
  - Number of bits of digital output determines precision of answer
  - Trade off between precision and speed and power used

AVR Microcontroller I/O Pins

- Digital Pin Input Mode
  - Digital Input returns 0 or 1 based on voltage level at pin
  - Can select high impedance input so it doesn't draw a lot of current from circuit
  - Or can connect internal 20KΩ pull-up resistor to +V so switch can be wired to ground
    - This is how Arduino will read push-button switches on Danger Shield
- Digital Pin Output Modes
  - Can set pins to output digital (0=0V, 1=5V) signal
  - AVR chip can accept or supply ~20mA to drive LEDs etc.
- Analog Pin Input Mode
  - AVR chip converts analog voltage on pin to digital value using Analog to Digital Converter
  - 10-bit digital resolution maps 0-5V to 0-1023
  - Single ADC shared between six pins
  - Takes ~100 microseconds to read level – 10 KHz updates
- Analog Pin Output Mode – Pulse-width Modulated digital signal
  - Arduino microcontroller doesn't have true Digital to Analog Converter (DAC) output
  - Outputs a 490 Hz pulse train that is high from 0-100% of the time
  - 8-bit resolution gives 256 analog levels
  - Digital PWM signal good for driving LEDs and heaters etc (with output driver circuit)
  - Can low-pass filter digital output to give actual analog voltage if needed
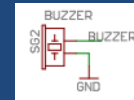
Danger Shield
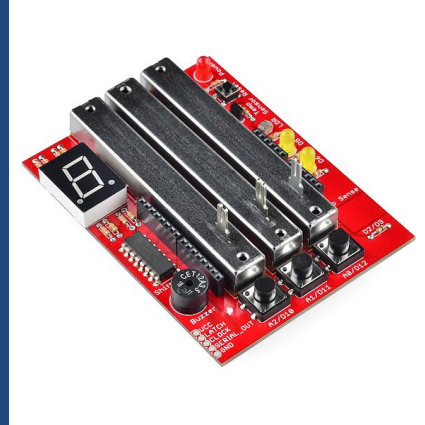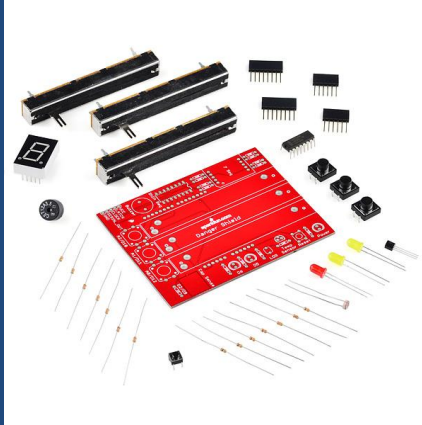
- The **Danger Shield** is an add-on board for an Arduino microcontroller board that offers a variety of inputs and output devices for interacting with a user
- We will use it as the control console for the Arduino and Processing application developed in later classes
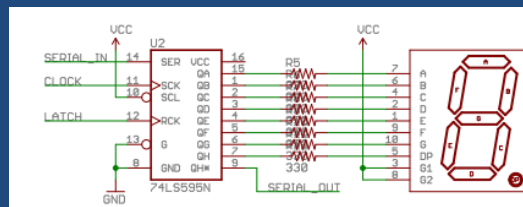
Danger Shield Inputs

- Two LEDs on Digital PWM outputs D5, D6
  - Can turn LEDs on and off with digital outputs
  - Can also vary brightness by Pulse-Width Modulation (PWM) of digital outputs using Analog Output function
- Piezoelectric transducer on Digital output D3
  - Can use as speaker by driving with digital output waveform
  - Can use as 'knock detector' by configuring as input and looking for voltage spikes due to impacts

7-segment LED by shift register on D4, D8, D7
  - 74HC595 shift register chip allows 3 output pins (clock, data, latch) to control state of 8 LED segments
  - LED state sent one bit at a time
  - Programming more complex

Danger Shield Outputs

- 3 Push-button switches – Digital inputs D10, D11, D12
  - Switches connect Arduino pins and circuit ground (low level)
  - Can read state of switch as digital input if internal uC pullup used
  - Reads digital zero (low level) when button pressed; high (1) otherwise
- 3 Linear potentiometers – Analog inputs A0, A1, A2
  - Resistor connected between +5V power and 0V ground
  - Slider position selects voltage (0-5V) that goes to Analog input pin
  - Arduino Analog-to-Digital Converter (ADC) converts to 0-1023 value
- Temperature sensor – Analog input A4
  - Uses integrated circuit (IC) chip to measure temperature to +/-1C
  - Output voltage = (Temp in degC)/100 + 0.5V
  - Can read voltage with Analog input pin and convert to temperature
- Light sensor – Analog input A3
  - Changes resistance from 10KW (in dark) to 1KW (in light)
  - Put in series with 10KW resistor to make voltage divider
  - Analog input reads ~2.5V in dark, increasing with light level
- Also (not used in our project)
  - Capacitive sensor pad
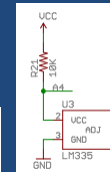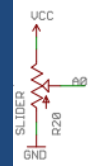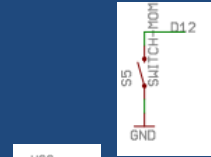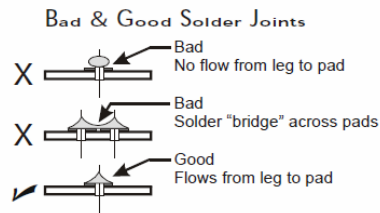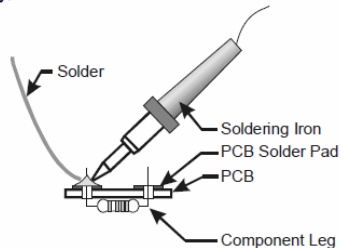
Soldering - Introduction

- Soldering makes good electrical contacts by melting a low-melting-point conductive metal into the gaps between two conductors
  - Liquid solder 'wets' conductors and flows into gaps
- Use **soldering iron** to heat up conductors, then melt solder onto them
  - Don't apply solder to iron directly if possible
  - However, some solder on iron helps heat transfer
- Apply heat for no longer than needed for good solder joint
  - Too much heat can cook components and lift circuit board pads
- Different solders are available, but leaded solder is easiest to use
  - Melts at lower temps and good joints are shiny
  - Wash hands after finished soldering!
  - Lead-free solder must be used for products sold in US and EU
  - Don't use plumbing solder – acid core will destroy circuits!
- Look for soldering iron with temperature regulation
  - Not just fixed or adjustable heating power – Radio Shack $6 irons
  - Costs $40-$100 for a good iron
    - More heating power will let you work more quickly, heat components for short times

Soldering - Introduction

Soldering Tutorial

The most important skill needed to successfully construct your device is soldering. Make sure you start by using electronics solder, not plumber's solder. The main trick to getting a successful solder connection is to heat the junction up before applying the solder to the heated area. Do NOT try to melt some solder onto the tip of the iron and smear it onto the joint - you won't get a strong joint. You're a roboticist, not a painter!

If the heat is applied unevenly, you will get solder blobs (see below). To better apply heat, keep your soldering iron tip clean by wiping it frequently on a damp sponge or cloth. The tip should always be shiny, and not covered in tarnish and burned crud (don't burn crud - bad!).

Solder

Soldering Iron
PCB Solder Pad
PCB

Component Leg

Bad & Good Solder Joints

X — Bad No flow from leg to pad

X — Bad Solder "bridge" across pads

✓ — Good Flows from leg to pad

Remember to take your time. Don't rush. It's almost impossible to "burn up" these parts!

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Soldering – Step by Step

1. Cut two pieces of wire and strip 1" off ends
2. Twist wires together to make mechanical joint
3. Clean soldering iron tip and apply a bit of new solder for good heat transfer
4. Touch iron to twisted joint and heat both wires
5. Couple seconds later, touch end of solder to hot joint (but not iron tip) and let it melt into joint
6. When area between wires is filled (but not too much solder on wire surfaces), remove solder, and then iron seconds later
7. Let cool and inspect your work
8. Can reheat to melt and reflow solder if lumpy or cold joint
9. Try it a couple more times for practice!

Soldering – Fixing Mistakes

Tools and techniques for fixing soldering mistakes:

- Can often just wipe away too much solder using a clean iron tip – board is treated to repel solder between pins
- Sacrificing part – many electronic parts are cheap enough you can just cut them out of the circuit and pull the leads out with a pliers
  - Easier to remove pins one at a time than multiples
  - Cut them close to the part body to maximize length
  - Grab lead with needle-nose pliers and pull while heating reverse with iron
- Use "solder sucker" to vacuum off solder from joint while melted
  - Also use to clean out holes once part is removed
- Also can remove solder using wick or braid
  - Mesh of fine copper wire coated with flux
  - Liquid solder wicks into braid when heated
  - Takes a lot of heat; can cook parts (or fingers!)
- Use hot air rework tool to heat all pins at once with stream of hot air, so part can be removed
  - Especially useful for surface-mount parts
  - Costs $200-300

Danger Shield – Kit Intro

- General plan is to solder components onto board in shortest to tallest order.
  - This lets you flip board over and rest on tallest components while soldering them
- Some pins will need much more time with iron before solder melts – these are connected to ground plane and you are heating large area of copper. Be patient and check for good joints.
- When hand soldering a circuit board it is often hard to keep multi-lead components flat on board when you flip it over to solder
  - Solder one lead first, then push part towards board with fingers while melting solder connection – this will allow part to become seated
  - Remove heat and hold part against board until solder freezes
  - Solder the rest of the pins once alignment looks good
  - Be careful not to touch pin that is soldered while you are heating it! Usually package won't get too hot, but be aware and only touch plastic cases not metal parts
- Identify resistors (may need magnification)
  - 2X 10KΩ (Brown Black Orange Gold)
  - 1X 1MΩ (Brown Black Green Gold)
  - 11X 330Ω (Orange Orange Brown Gold)

Danger Shield – Assembly plan

1. Resistors
   1. Bend resistor leads in right angle at body
   2. Insert into holes (orientation doesn't matter) and bend leads outward to hold in place
   3. When all done, flip board and solder joints in back
   4. Clip off excess leads on back side
2. LDR and Temp sensor
   1. Bend middle lead of temp sensor toward rounded side and push leads into holes
3. Small switch
4. IC
   1. May need to bend pins in slightly to fit both sides into holes – do on table
   2. Find notch on package and insert correctly
   3. Solder one lead and check that IC is flush with board – reflow if needed
   4. Solder rest of leads
5. Socket headers – Hardest step, important to have them aligned right
   1. Solder one pin only at first, then reflow and push socket against board
   2. When all four are in (by one pin only), test fit to Arduino board. Adjust if needed by melting solder and tilting socket.
   3. When all pins fit into Arduino sockets, solder rest of pins to circuit board

Danger Shield – Assembly plan

6. LEDs
   1. Match flat side of LED to flat outline on board when inserting
7. Big switches
   1. Solder one lead first and then reflow while pushing on switch to make sure it is flat on board
   2. Then solder rest of pins
8. Buzzer
   1. Plus lead goes on right side (not how picture shows)
   2. Solder one lead first, then reflow and flatten device before soldering other lead
9. LED digit
   1. Note flat corner of device and insert correctly
   2. Solder single lead first, then reflow while pressing LED flat against board
   3. Then solder the rest of the leads
10. Potentiometer sliders
    1. Put all three in but only solder one lead on each; remelt and adjust
    2. Holes are big and need lots of solder – may take a while to heat and fill

Danger Shield – Testing

- When done, inspect all joints on solder side carefully
  - Look for shorts between pins and remove excess solder
  - Look for pins with gaps in solder, reheat and add more
  - Look for solder joints with rough, non-shiny surfaces and reflow
- We will have Arduino running test program on laptop PC
  - Plug Danger Shield into Arduino sockets and run program