Arduino Survival Guide
Workshop Edition
~
Helping Your Arduino Survive *You*

Ed Nisley • KE4ZNU
ed.nisley@pobox.com
softsolder.com

~

CNC Workshop
TechShop Detroit
June 2015

Bring This Stuff With You

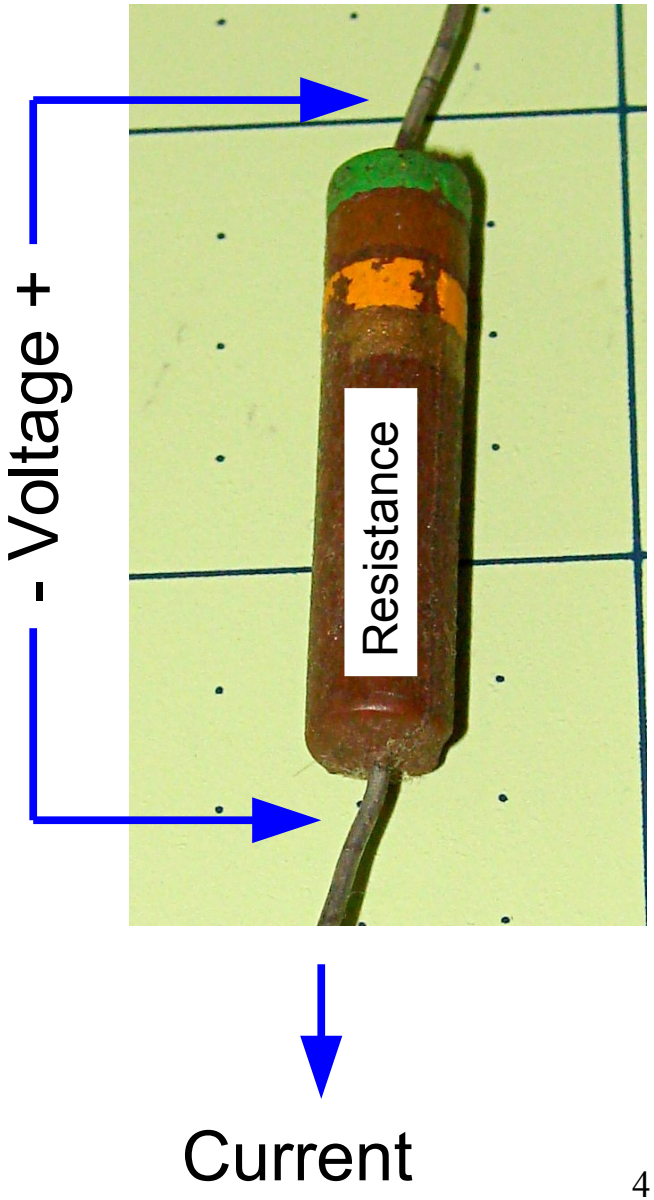
- Laptop (with Arduino board + USB cable!)
  - Arduino IDE installed & tested
- Digital Multimeter
  - Volt • Amp • Ohm (optional: Freq • Diode • Cap • Induct)
  - Two (or more!) meters = better
- Scientific Calculator (√ power log engineering)
- Power strip / short extension cord
- Useful, but not absolutely essential
  - Solderless breadboard / ProtoScrewShield
  - Soldering iron & suchlike

The Big Picture

- Arduino stuff
  - It's a PCB with known pin layout & spacing
  - Atmel Atmega168 / 328 µC + USB Interface
  - Power Source: USB or DC wall wart
  - Digital & analog I/O pins
- Your stuff
  - Draws power (ideally 5 V, maybe 12 V, or ...)
  - Connects to µC I/O pins (5 V only!)
  - Must play well with Arduino

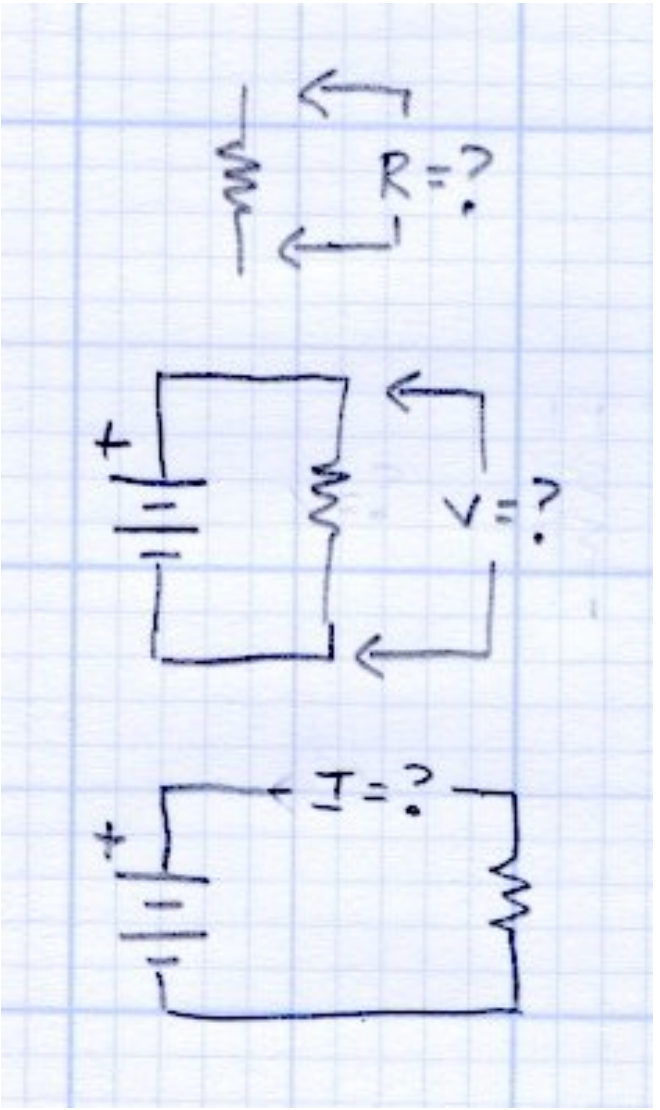
The Fundamental Units

- E = voltage: volt V
  - Millivolt 1 mV = 0.001 V
- I = current: ampere A
  - Milliampere 1 mA = 0.001 A
- R = resistance: ohm Ω
  - Kilohm 1 kΩ = 1000 Ω



Lab: Measure Resistor Circuit

- Set meter to Ω = ohms
  - Measure resistance
- Set meter to V = volts
  - Measure voltage
- Set meter to A = amps
  - (Re-plug leads?)
  - Measure current
  - (Re-plug leads?)



One Rule To Bind Them All

- Ohm's Law
  - I = E / R (know R, measure E, get current!)
  - E = I • R
  - R = E / I
- Most useful with resistors = known resistance
- You need a calculator and a multimeter ... *now*!

Lab: Verify Ohm's Law

- Using your measured values
  - Does measured voltage = (current x resistance)?
  - Does measured current = (voltage / resistance)?
  - Does measured resistance = (voltage / current)?
- How close did you come?
  - Percentage vs. absolute error
- What are the most accurate measurements?

The Power Rule

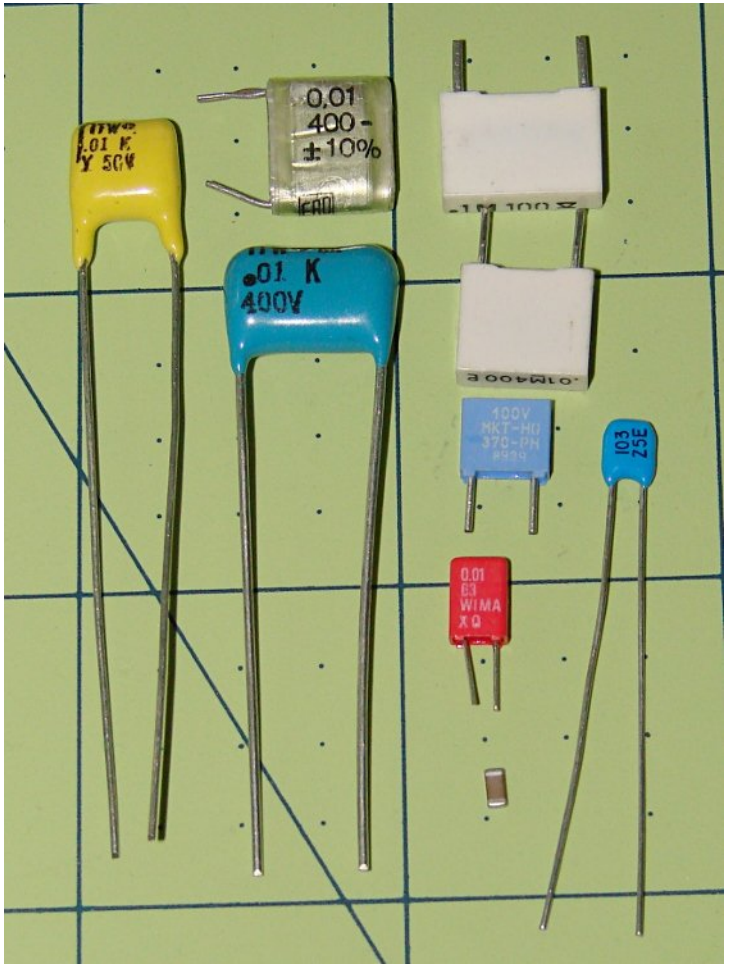
- Power dissipated in *resistors*
  - $P = I^2 \bullet R$
  - $P = E^2 / R$
    - You know R, so just measure E across resistor
- Power dissipated in *anything*
  - $P = E \bullet I$
  - If there's an R in series, measure E to find I...
- P = power: W watt
  - Milliwatt 1 mW = 0.001 W

Lab: Calculate Power

- Using your measured values
- Calculate power dissipated in resistor
  - Power = voltage x current
  - Power = voltage^2 / resistance
  - Power = current^2 x resistance
- How close are those three values?
  - Percentage vs. absolute error

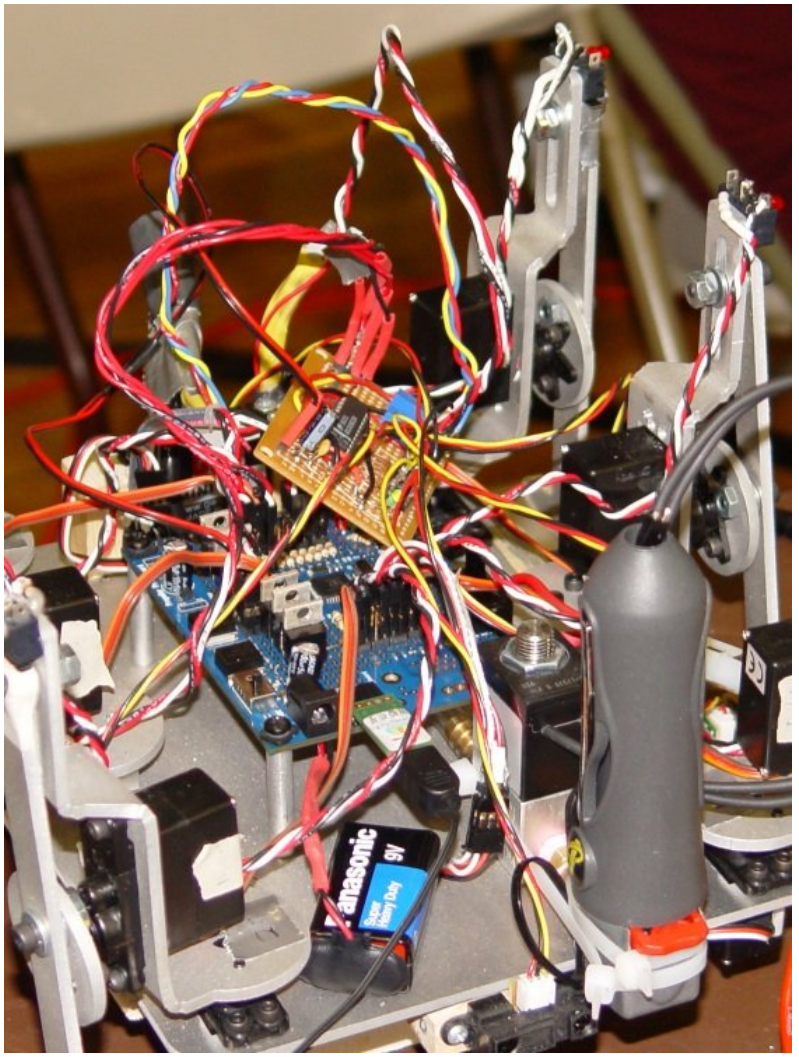
Capacitance

- C = capacitance: farad F
  - Millifarad
    - 1 mF = 0.001 F = 10^{-3} F
  - Microfarad
    - 1 µF = 0.000 001 F = 10^{-6} F
  - Nanofarad
    - 1 nF = 0.000 000 001 F = 10^{-9} F
  - Picofarad
    - 1 pF = 0.000 000 000 001 F = 10^{-12} F



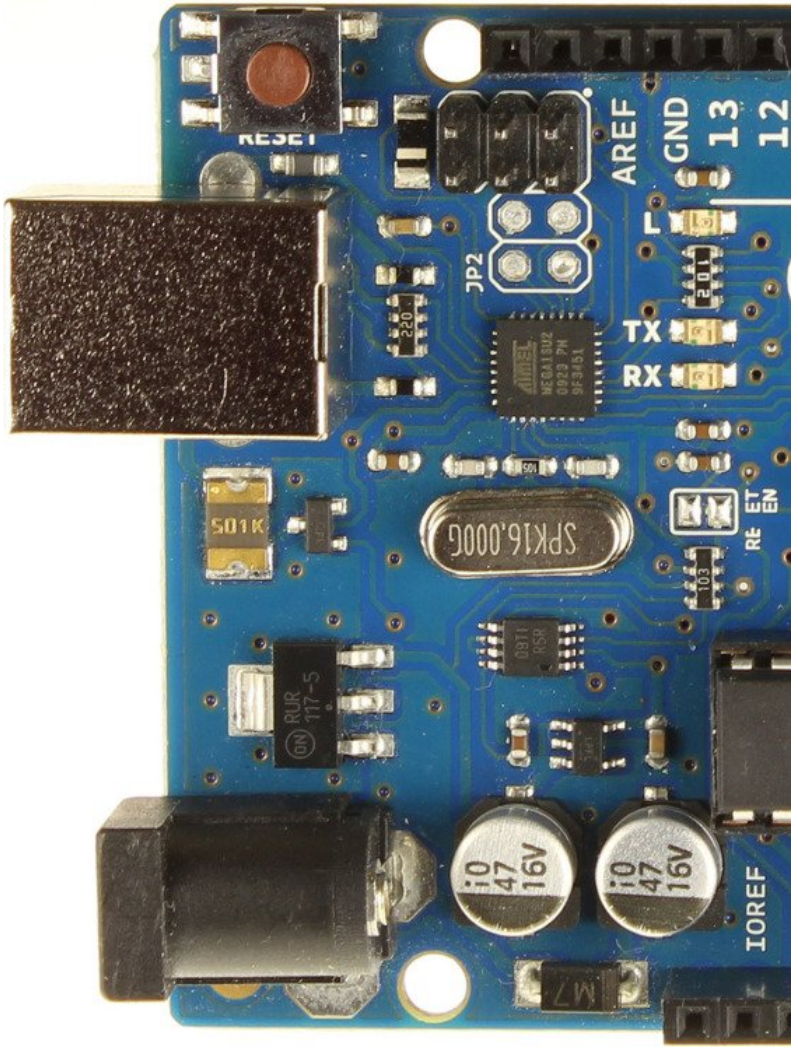
Circuit Construction

- Use a solid breadboard
- If it *can* move, *stop it...*
- Good connections FTW!
  - Power
  - Ground
  - Signal
- Build it right the first time
  - Or do it over and over ...
- Current > 1 A = think hard!



Power Supply

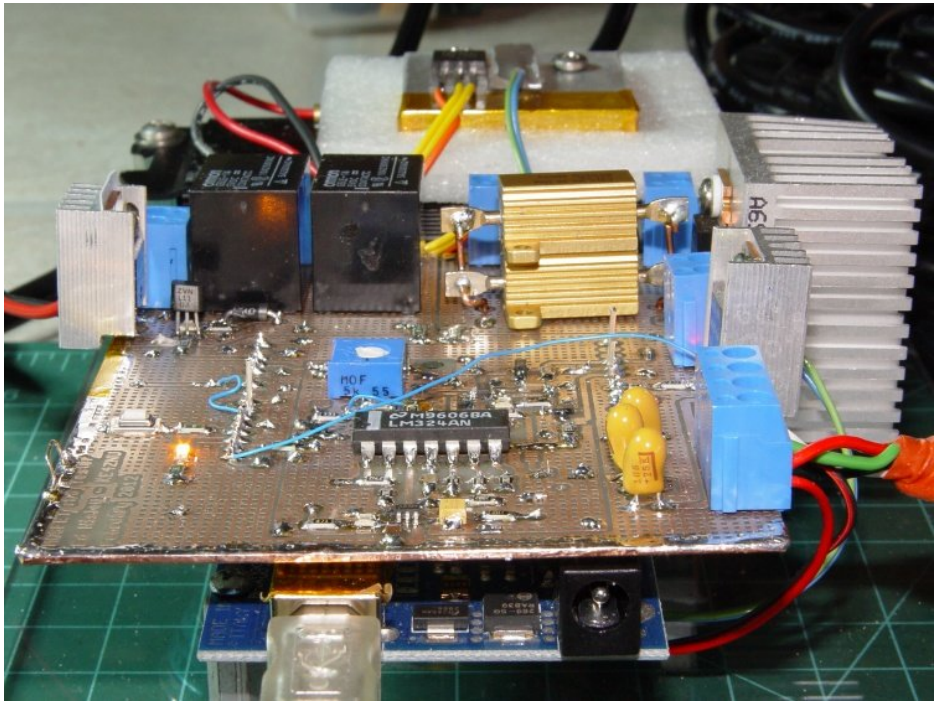
- USB Supply ≠ 5.0 V
  - Measure actual voltage!
  - Draw < 200 mA from port
    - Max ≈ 500 mA, usually
- Wall Wart V_{EXT} ≤ 12 V
  - Loose wire? µC dies > 5 V!
  - Less heat @ V_{EXT} = 9 V
    - Keep regulator << 500 mW
    - Power P = (V_{EXT} - 5) * I



http://arduino.cc/en/Main/ArduinoBoardUno

Ground (a.k.a. Common)

- Reference = 0 V
- Sum of all currents
- AC + DC Signals
- Difficult to get right
  - High current = trouble
- Vital for good signals
  - Glitches & intermittents
- Impossible to fix later
  - Daisy chain = death

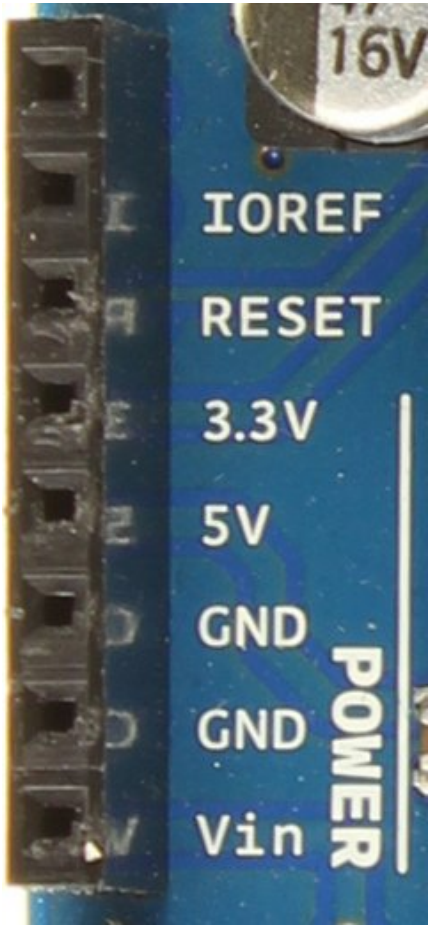


MOSFET $R_{DS(on)}$ Tester
PCB has four ground planes

http://softsolder.com/2012/02/23/mosfet-rds-pcb/

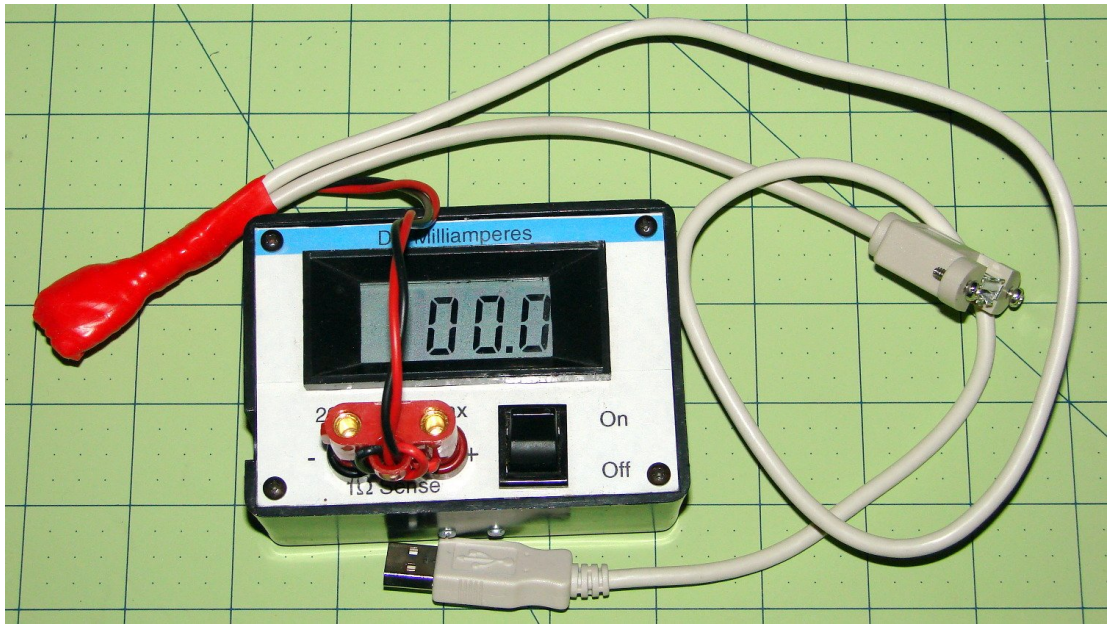
Lab: Arduino Supply Voltages

- Meter (-) terminal to GND pin
  - Measure Vin (from supply)
  - Measure 5V (= “5V”)
  - Measure 3.3V (= “3.3V”)
- If using external supply...
  - Measure V_{EXT} at source



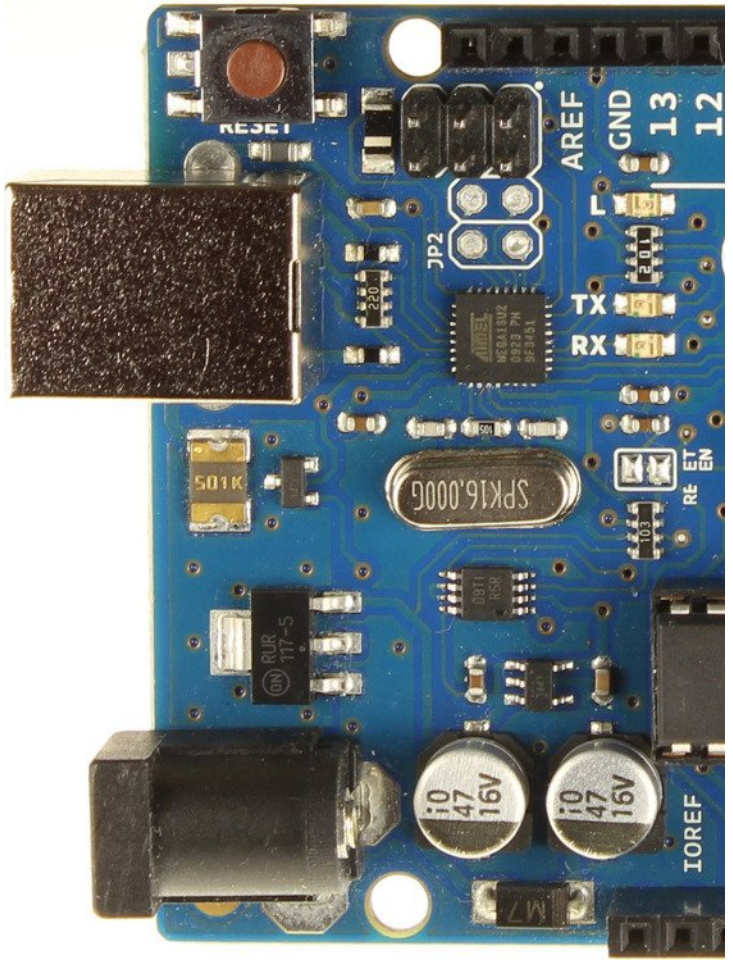
Lab: Arduino Supply Current

- Measure current from supply
  - USB needs inline tap
  - Wall wart can be cut & spliced
  - Cheap USB inline volt/ammeter



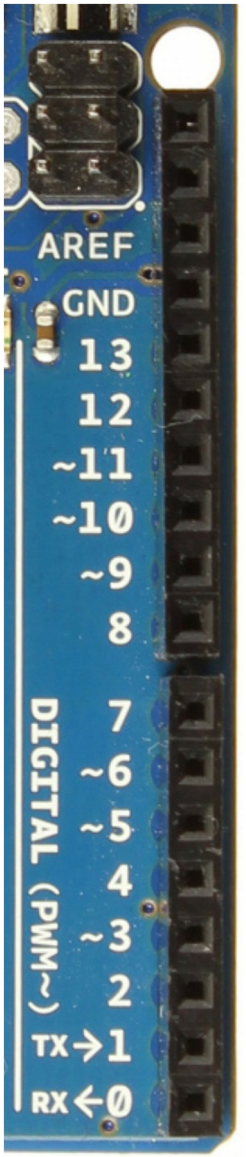
Lab: Calculate Arduino Power

- Total power
  - “Vin” x supply current
- Regulator power
  - (“Vin” – “5V”) x supply current
  - Is it < 500 mW?
- Board power
  - “5V” x supply current
- Compare all those powers



Digital Input Pins

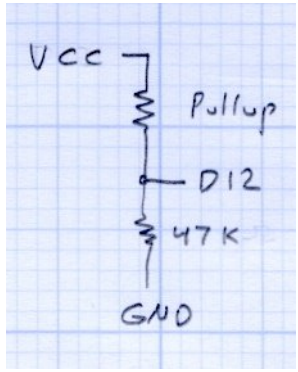
- All pins are inputs before `setup()`
  - `pinMode(2,INPUT)`
- Enable internal pullup resistors (always?)
  - `pinMode(2,INPUT_PULLUP)`
  - `digitalWrite(2,HIGH)`
- *Do not* depend on pullup resistor value
  - Min 20 kΩ – what everyone assumes it is
  - Max 50 kΩ – what it might actually be
- `digitalRead(2)`

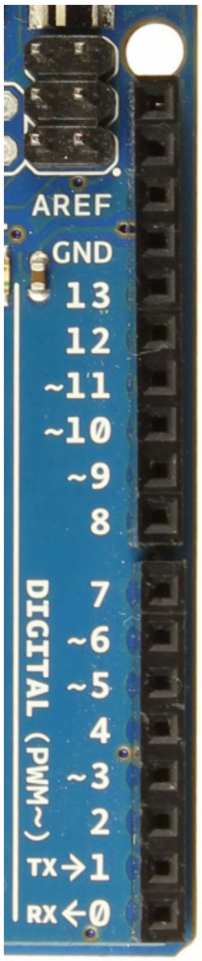


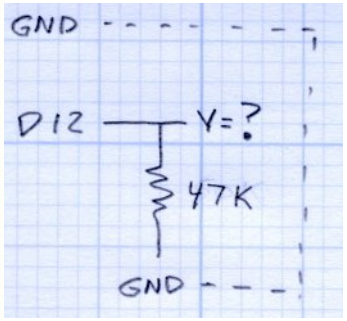
http://arduino.cc/en/Tutorial/DigitalPins
http://arduino.cc/en/Reference/DigitalRead

Lab: Measure Arduino Pullup

- Insert 47 kΩ resistor: D12 - GND
- pinMode(12,INPUT_PULLUP)
  - Modify Blink example!
- Measure V across resistor
- Compute:
  - Current through resistor: I = E / R
  - Voltage across pullup: “5V” - V
  - Pullup resistance
    - Know voltage & current: R = E / I
- Is pullup ≥ 20 kΩ and ≤ 50 kΩ?

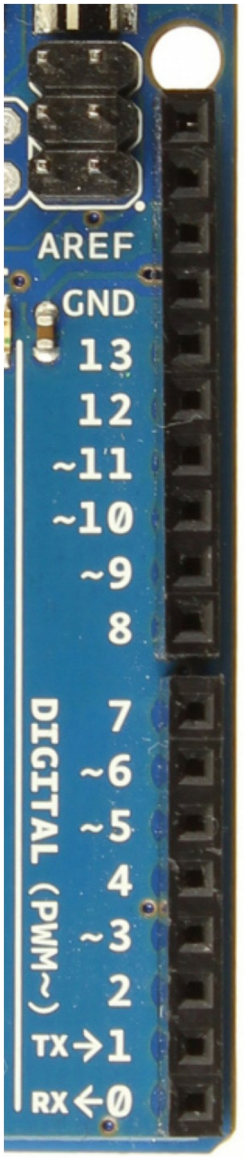






Digital Output Pins

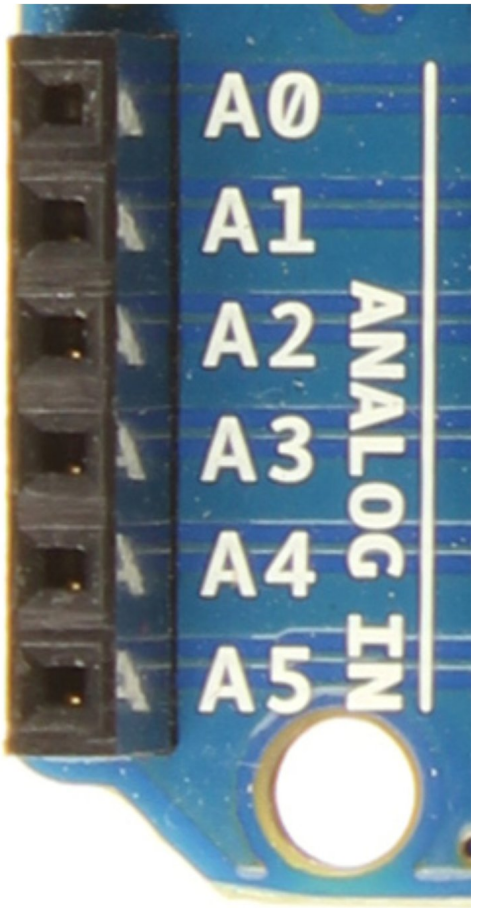
- Configure pins for output in `setup()`
  - `pinMode(2,OUTPUT)`
- Outputs `HIGH` = 5 V or `LOW` = 0 V
  - Depends on load: measure!
- Current ≤ 40 mA / pin = *absolute max*
  - Happiness ↑↑ for current ≤ 20 mA
  - Enough for one standard LED...
- Maximum total µC current ≤ 200 mA
  - Draw *much* less than that: ≤ 100 mA max



http://arduino.cc/en/Tutorial/DigitalPins
http://arduino.cc/en/Reference/DigitalWrite

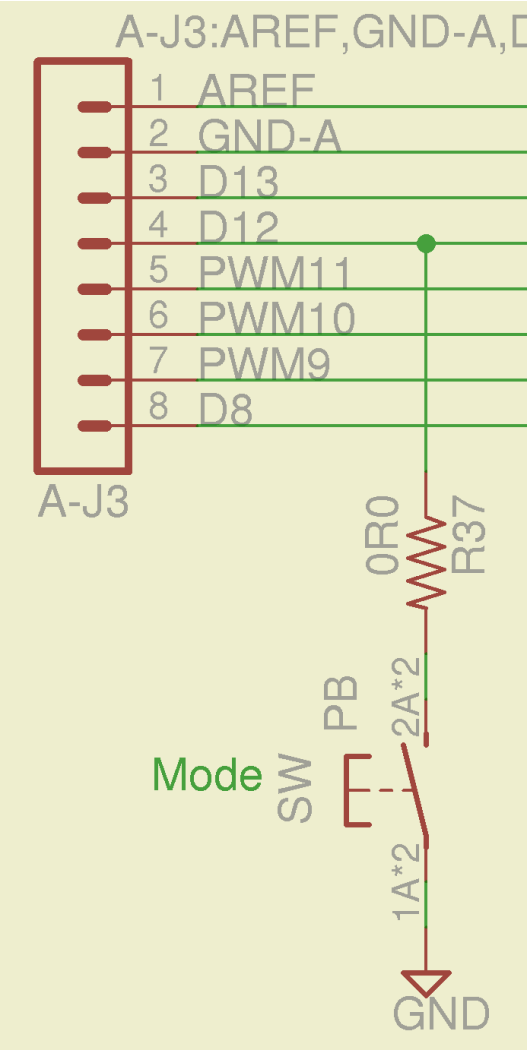
Additional Digital I/O Pins!

- Reconfigure Analog Input pins
  - `pinMode(A0,INPUT_PULLUP)`
  - `pinMode(A0,OUTPUT)`
- The usual digital functions
  - `digitalWrite(A0,LOW)`
  - `digitalRead(A0)`
- No analog *output*
  - ~~`analogWrite(A0,128)`~~



Switch Inputs

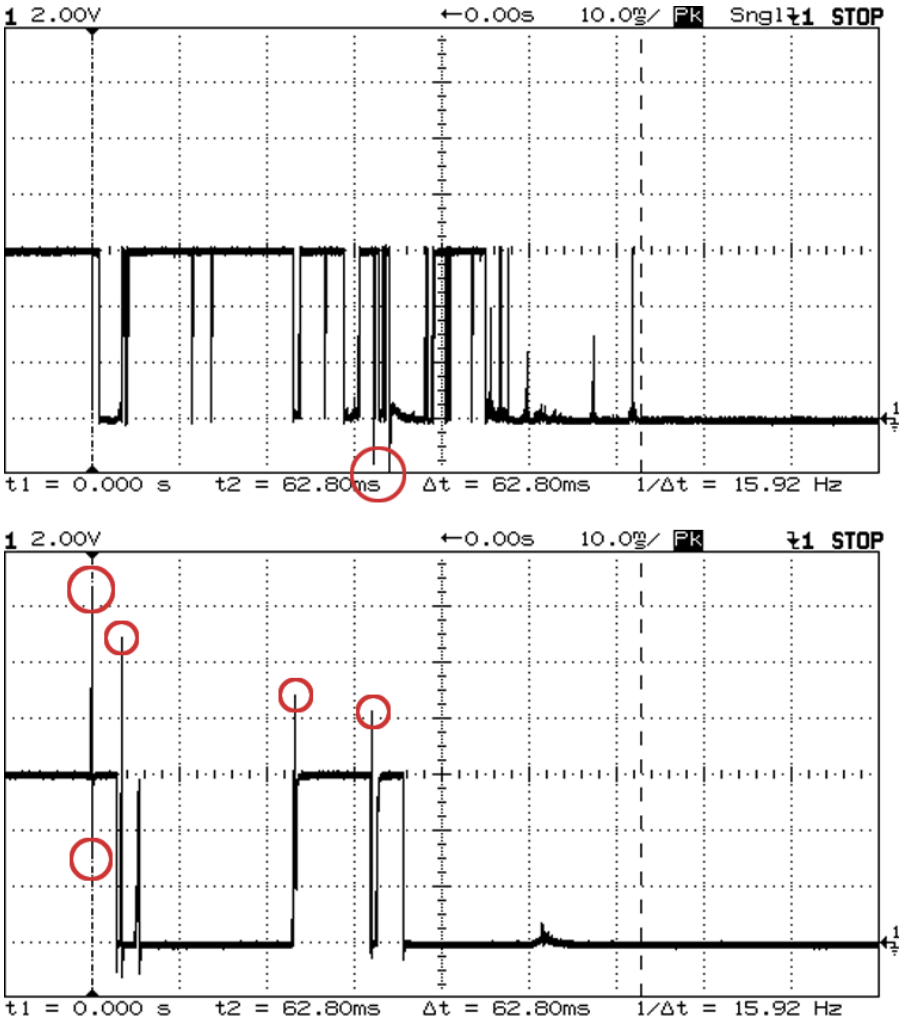
- Connect input pin to ground
  - This kills output pins = HIGH
  - Add 1 kΩ series R for protection?
- Enable internal pullup
  - `pinMode(12,INPUT_PULLUP)`
- Add external pullup ≈ 10 kΩ
- Pin states track *voltages*
  - Closed = pushed = `LOW` = `false`
  - Open = released = `HIGH` = `true`



http://arduino.cc/en/Reference/DigitalRead

Switch Contact Bounce

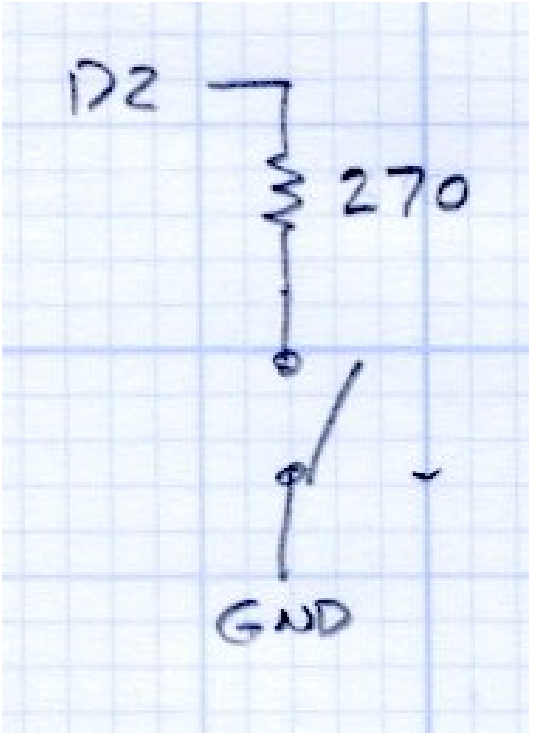
- Glitches galore!
  - Time scale = 10 ms/div
  - Unpredictable events
- Add parallel C = bad
  - Resonant with stray L
  - Voltage spikes!
- Use e.g. Bounce library
  - Don't roll your own
- Plan for the worst case



https://en.wikipedia.org/wiki/Switch#Contact_bounce
http://arduino.cc/playground/Code/Bounce

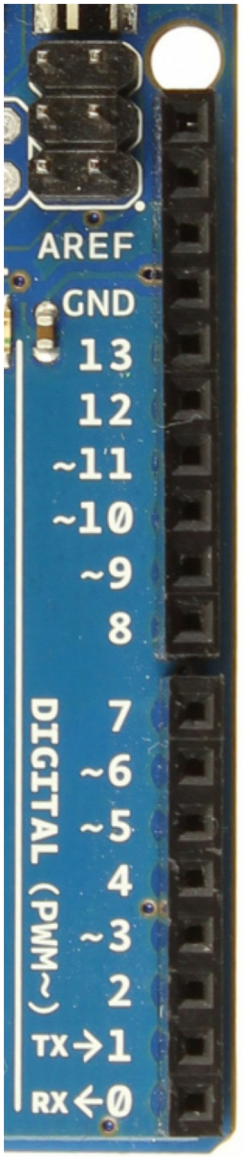
Lab: Measure Contact Bounce

- Use a grotty switch!
- pinMode(2,INPUT_PULLUP)
- Loop 1 second while testing D2
  - Hint: millis() + 1000
  - Hint: D2 != previous value?
  - Count each change
- Print/clear total every second
- Bonus
  - External Interrupt on D2 edge
  - Pin-change interrupt



“Analog” Output

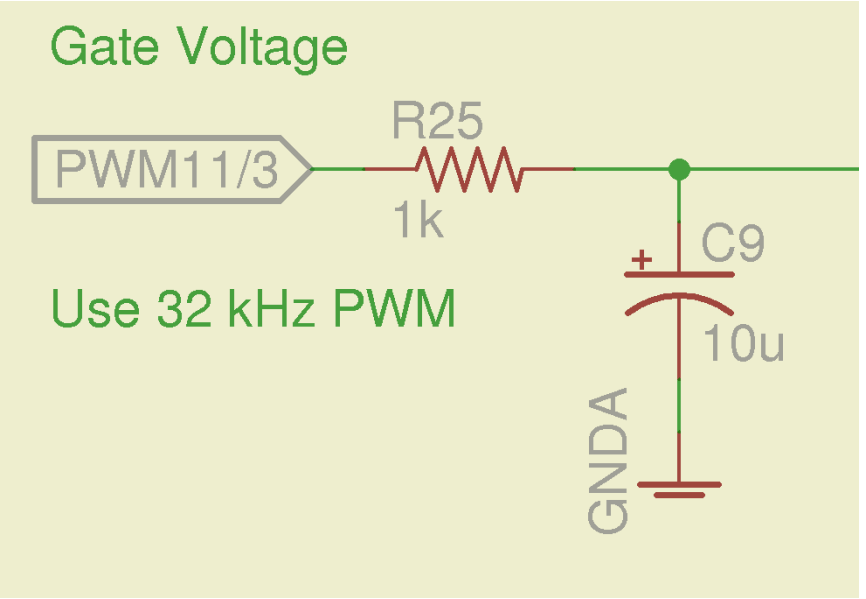
- It’s not *analog*, it’s *digital* ...
  - PWM = Pulse Width Modulation
  - Output pins 3, 5, 6, 9, 10, 11 *only*
- `analogWrite(3,100)`
  - Minimum = 0 → 0 V (steady, per load)
  - Maximum = 255 → 5 V (steady, per load)
  - 0 < “analog PWM” < 255 → pulses (*duh*)
- PWM frequency ≈ 488 & 976 Hz
  - Direct LED drive works fine



http://arduino.cc/en/Reference/AnalogWrite
http://arduino.cc/en/Tutorial/PWM

Real Analog Output

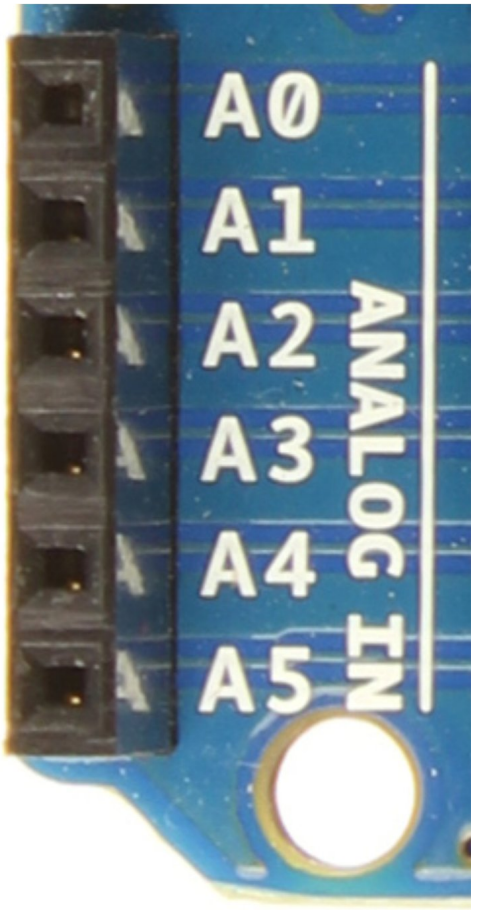
- Filter PWM → Analog
  - Simple RC filter OK
  - R•C >> 1/(2π•PWM freq)
  - C can become nasty big
  - ↑↑ PWM freq = ↓↓ C
- Analog buffer / op amp
  - Minimal load = good
  - Voltage scaling
- Wall wart = stable V (*duh)*



http://arduino.cc/en/Tutorial/PWM
http://softsolder.com/2009/02/21/changing-the-arduino-pwm-frequency/
http://softsolder.com/2009/03/04/arduino-fast-pwm-faster/

Analog Input

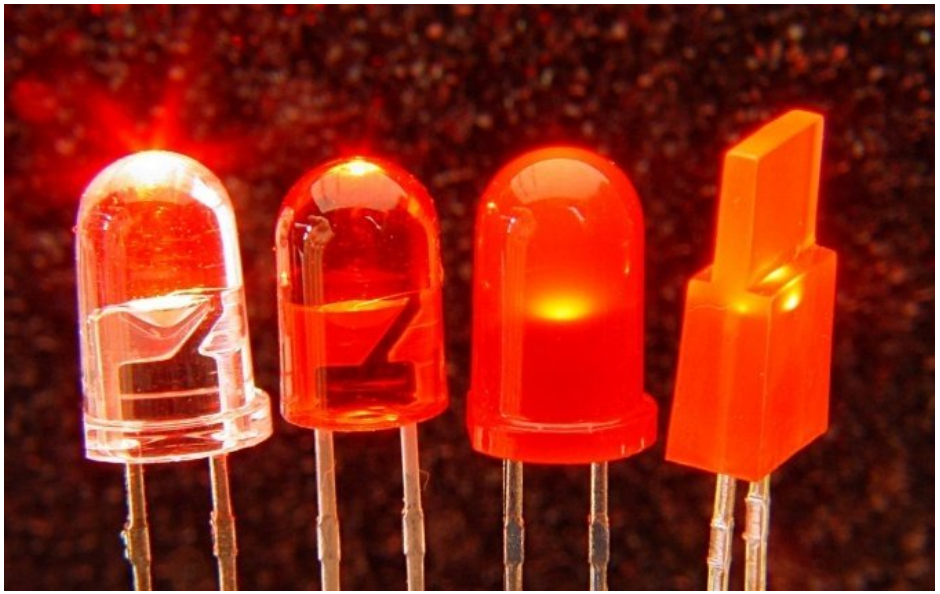
- analogRead(A0)
  - Minimum 0 = 0V
  - Maximum 1023 = “5V” (pretty close)
  - Depends on actual supply voltage!
    - Value = 1023 * (V / AREF)
- Wall wart = stable AREF = (*duh*)
- 0 V ≤ [Analog voltage] ≤ 5 V
- Avoid digital pin output before AI
- Average several AI readings?



http://arduino.cc/en/Tutorial/AnalogInputPins
http://arduino.cc/en/Reference/AnalogReference

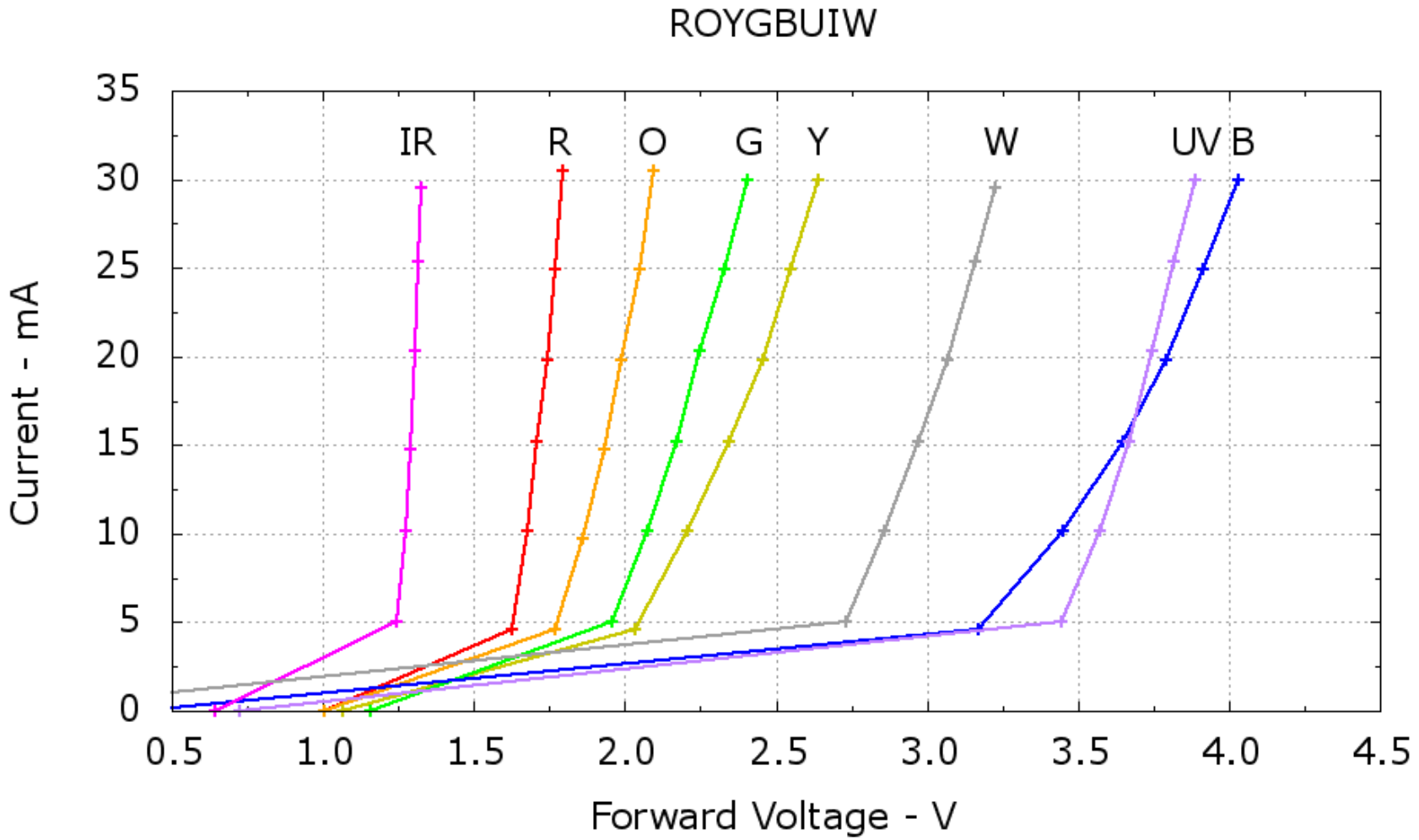
Single LED

- Assume 20 mA max
  - *Continuous*, not *peak*
  - 10 mA = bright enough
  - Do you know different?
- Forward voltage drop
  - Red - orange = 2 V
  - Yellow - green = 2.5 V
  - Blue & white = 3.5 V
- Arduino = one LED / pin
  - Pin = 5 V & 20 mA maximum



https://en.wikipedia.org/wiki/LED_circuit

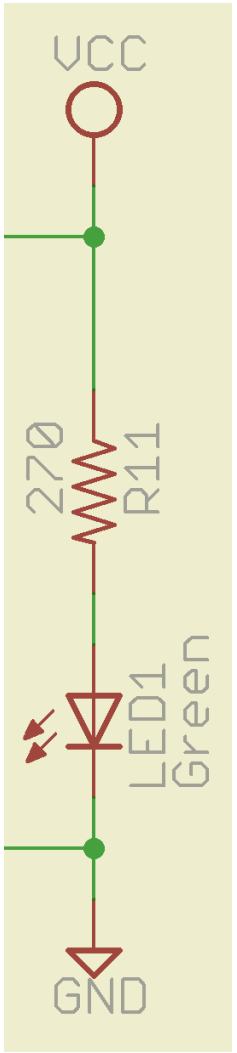
LED Forward Voltage vs. Color



http://softsolder.com/2013/04/02/led-forward-voltages-vs-color/

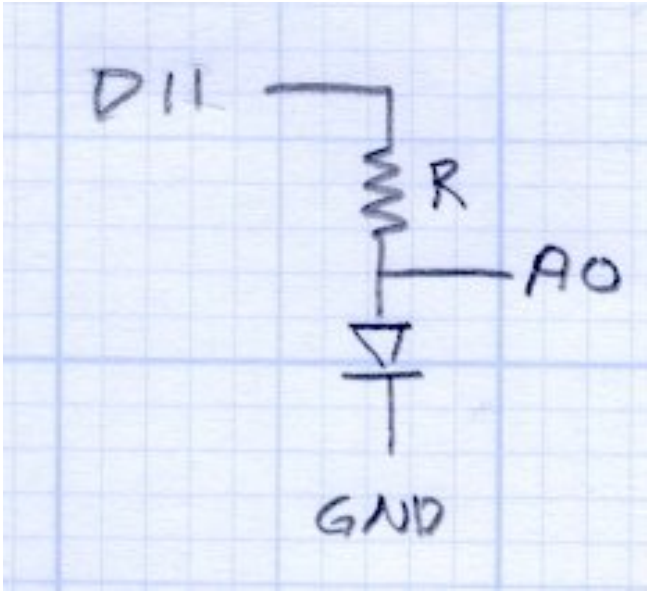
Single LED Resistor

- Resistor limits LED current
  - This is not optional!
- Ohm's Law for resistor: $R = V_R / I$
  - Want current I = 10 mA (< 20 mA, OK?)
    - Same as LED because they're in series
  - Voltage = $V_{CC} - V_{LED}$ = "5V" – 1.8 V = 3.2 V
    - V_{LED} varies with color, so be careful!
  - Resistance = R = V / I = 3.2 / 0.01 = 320 Ω
  - Round up to next standard value = 330 Ω
- Measure actual V_R to verify: $I = V_R / R$



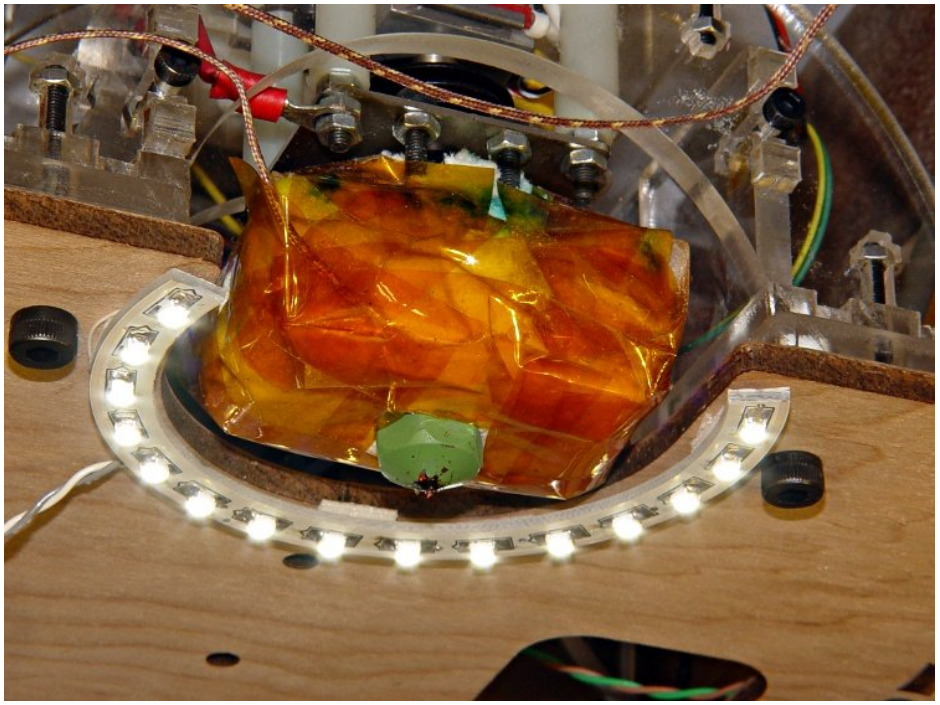
Lab: Measure LED Voltage

- LED
  - Pick a color
  - Use R = 270 Ω? (compute current)
- Program
  - pinMode(11,OUTPUT)
  - digitalWrite(11,HIGH)
  - Print analogRead(A0)
  - Compute actual voltage
- Bonus
  - Compute LED current
  - Compute LED power



LED Strips & Rings

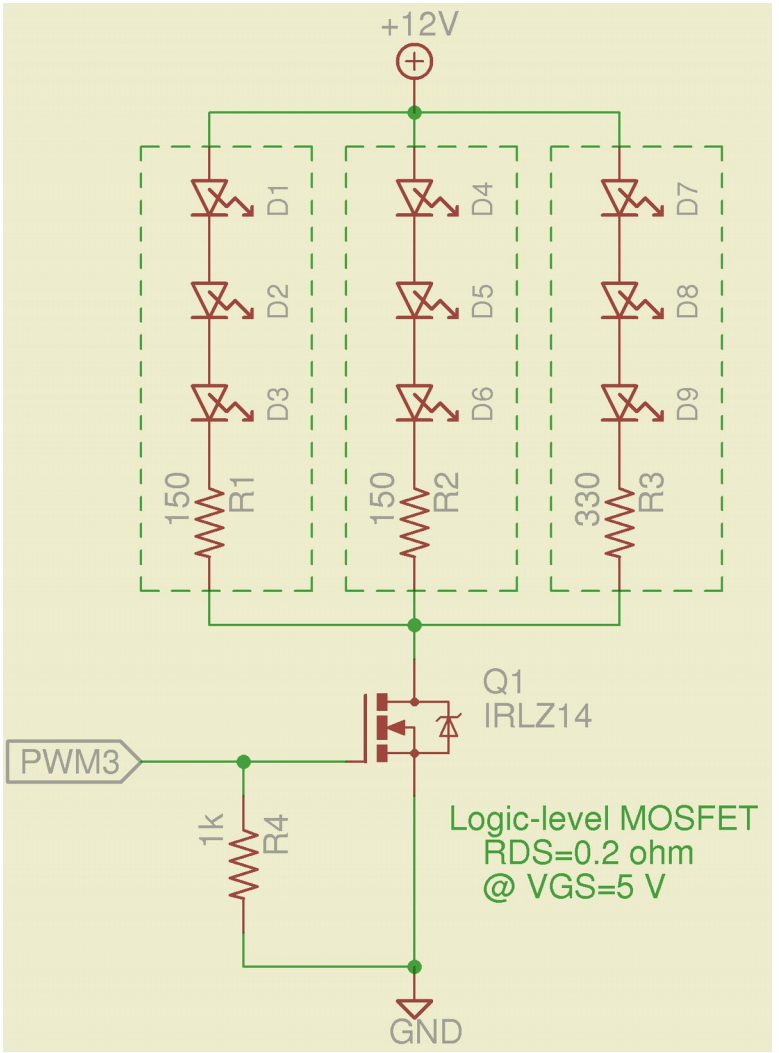
- 3 LEDs + R / section
  - I = 20 mA typical
  - V = 12 V supply
  - Sections in parallel
- Cannot use µC pin (!)
  - MOSFET driver?
- RGB LEDs = 3 strings
  - Different resistors!
  - Measure V_R to find I



http://softsolder.com/2011/05/25/thing-o-matic-led-lighting-upgrade/

LED Strip Driver

- 3 LED sections = 60 mA
- Logic-level MOSFET
- Must have gate pulldown R
  - Override µC internal pullup
- More sections = heatsink!
  - MOSFET $P = I^2 \bullet R_{DS}$
- May need RC snubber
  - Stray inductance (!)



http://softsolder.com/2009/03/06/rc-snubber-resonant-design/

Other Gotchas

- Motors
  - DC – H-bridge driver
  - Steppers – microstep
  - Servo – PWM
- Noisemakers
  - Piezo
  - Speaker
- Keyboard / Keypads
- Thermistors
- SPI / I^2C / OWP chips
- LCD Panels
- LED Char / Dot Matrix
- EEPROM / SD Data
- Ethernet / WiFi
- Zigbee / XBee
- Accelerometers
- ...

Everything Else

Is

A Simple Matter of Software

More Info

arduino.cc/en/Reference/HomePage
www.ladyada.net/learn/arduino/index.html
todbot.com/blog/spookyarduino/
www.sparkfun.com/tutorials

and, of course ...
softsolder.com/tag/arduino/

Copyright-ish Stuff

Some web images probably copyrighted, but
shown & attributed here under “fair use”
[whatever that is]

The rest is my own work

•

Ed Nisley

Say “NISS-lee”, although we're on the half-essed branch of the tree

Engineer (ex PE), Hardware Hacker, Programmer, Author

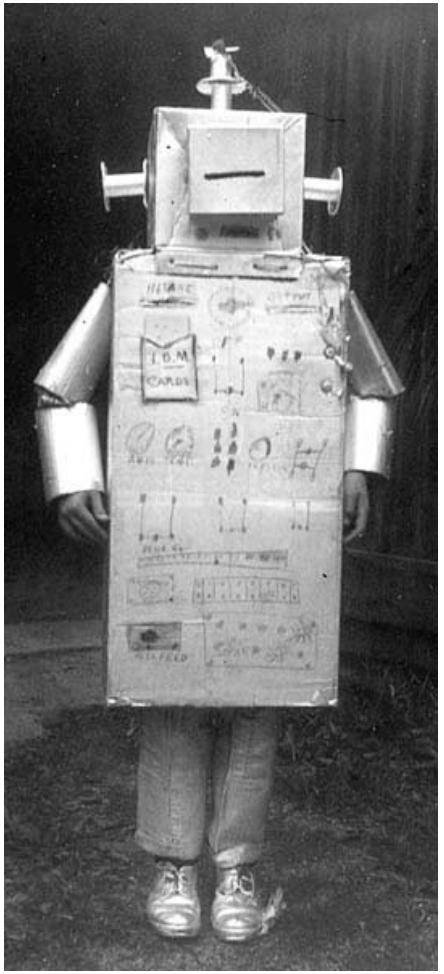
The Embedded PC's ISA Bus: Firmware, Gadgets, Practical Tricks

Circuit Cellar www.circuitcellar.com
- Firmware Furnace (1988-1996) - Nasty, grubby hardware bashing
- Above the Ground Plane (2001 ...) - Analog and RF stuff

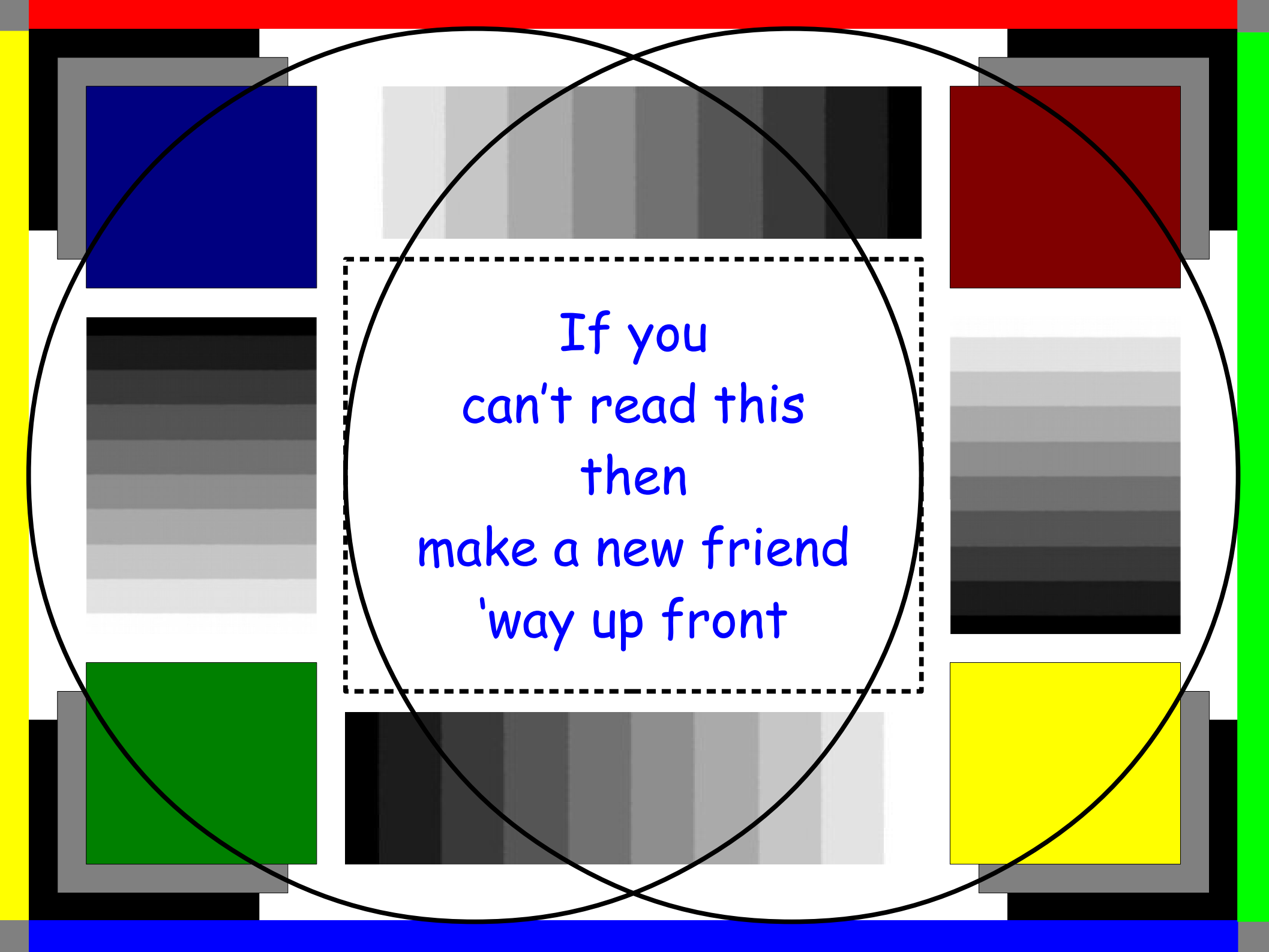
Digital Machinist www.homeshopmachinist.net
- Along the G-Code Way (2008 ...) - G-Code, math, 3D printing

Dr. Dobb’s Journal www.ddj.com
- Embedded Space (2001-2006) - All things embedded
- Nisley’s Notebook (2006-2007) - Hardware & software collisions

My Blog: The Smell of Molten Projects in the Morning
softsolder.com



September 1962


If you
can't read this
then
make a new friend
'way up front