E40M
LEDs, Time Multiplexing
Reading

• Course Reader 2.6 – LEDs

• Course Reader 5.8 - Multiplexing

• LEDs
  – https://learn.adafruit.com/all-about-leds
  – http://dangerousprototypes.com/docs/
    Basic_Light_Emitting_Diode_guide

• LED Multiplexing
  – http://www.instructables.com/id/Multiplexing-with-Arduino-and-
    the-74HC595/step1/What-Is-Multiplexing/
LED Cube – Project #3

• In the next several lectures, we’ll study

• Concepts
  – Coding
  – Light
  – Sound
  – Transforms/equalizers

• Devices
  – LEDs
  – Analog to digital converters

Music responsive LED Cube

https://www.youtube.com/watch?v=FRXDTiOHFII&feature=youtu.be
What is Light?

- It is an electromagnetic wave
  - Speed of light, \( c = 3 \times 10^8 \text{ m/s} \)
  - Frequency = \( c/\lambda \)
- Part of electromagnetic spectrum:
- All waves transport power

(https://science.hq.nasa.gov/kids/imagers//ems/index.html)
Quantum Mechanics - Photons

• Just when it looked like things would be simple
  – In Quantum Mechanics light not always a wave
  – It is also carried by particles called photons

• Each photon has a precise energy
  – Set by the wavelength
  – \( E = \frac{hc}{\lambda}; \) where \( h \) is Planck’s constant = 6.6E-34 Jsec

• It will be useful to calculate energy in eV (electron volts)
  – This is the energy needed to move one electron, one volt
  – \( q \times 1V = 1.6E-19 \) J
  – \( hc = 1.24ev-\mu m \)
Energy of Photons

- Visible light = 0.63\(\mu\)m (red), 0.55\(\mu\)m (green), 0.47\(\mu\)m (blue)
  - Infrared lights, used in remotes are around 1\(\mu\)m

- The energy of these photons range from
  - 1.2eV for infrared
  - 2.0eV for red
  - 2.3eV for green
  - 2.6 eV for blue

- We have sensors that can detect single photons
  - And light really is quantized
Energy of Photons

\[ f = \frac{c}{\lambda}, \quad E = \frac{hc}{\lambda} = \frac{1.24 \text{eV}}{\lambda (\mu \text{m})} \]

- Current drops 2.3 volts across diode and green photons are emitted.
- Green photons strike a diode, current and up to 2.3 volts can be generated.
Light Measurements

• Total light emitted is measured in lumens
  – Comparing light bulbs compares lumen output
  – 60Watt bulb is about 800 lumens

• Illumination on a surface is in lux
  – Lumens/m$^2$
  – 300 lux - Office lighting
  – 10k lux - Full sunlight (not direct)
  – 32k – 100k lux - Direct sunlight

• At green (550nm), 680 lux = 1W/m$^2$
  – Other freq require less lux for 1W/m$^2$
When Light is Absorbed By a Material

• It transfers its energy to the material
  – While the energy of each photon is small
  – The energy flux can be large

• In most cases this energy is converted to heat
  – That is why you feel warm in dark clothes
    • They absorb the sunlight and convert it into heat
  – Can generate energy this way
    • Heat rocks, boil water, generate steam, turn turbines

• In special situations (a.k.a diodes)
  – Can directly generate electricity with some of the energy
LEDs
Generating Light from Electricity

- Use heat
- Use plasma
LEDs

- How do we get different colors?
- How does this relate to a solar cell which operates in reverse?
LED Operation

• When current flows through a diode
  – There is a voltage drop across the diode
    • This drop depends on the material
  – Device consumes energy
    • iV

• For many materials this energy is converted into heat
  – Silicon, for example

• For some materials
  – “Direct band-gap” materials
  – This energy can emit a photon
LED Voltage Drop and Color

- The color of the photon depends on energy
- The energy available depends on the voltage
  - Each electron that flows can create one photon
    - If it takes two, the two have to happen at the same time (unlikely)
  - $V_f$ for a blue LED is larger than for a Red LED
FYI – How Do Light Emitting Diodes and Solar Cells Actually Work?

- Red/orange/green LEDs have been used in small displays for 30 years. Nakamura’s invention of InGaN LEDs has dramatically changed the lighting world – not only creating blue LEDs for full color displays, but creating the possibility of solid state lighting.

White LEDs utilize blue emission of GaN or InGaN to excite fluorescence in a phosphor which emits yellow light. Blue + yellow appears white to the eye. Alternatively, phosphors are used that emit green and red. Blue + green + red = white.
Using LEDs

• They are diodes
  – Current only flows in one direction
  – Voltage not very sensitive to current
    • Often have an internal resistance

• You should use external resistance to limit current
  – Set current at around 20mA (30mA max)
  – Voltage drop across diode is 2-3V
  – Voltage drop across resistor is 3-2V if driven from 5V supply
  – \( R = \frac{V}{I} = \frac{3V}{20mA} = 150\Omega; \frac{2V}{20mA} = 100\Omega \)
    • And the Arduino pin has a resistance of 30\( \Omega \)
Using LEDs in Simple Circuits

- Always use a series R with an LED

- Do not wire LEDs in parallel

- Series connection is fine with a higher V
LED CUBE
LED Cube

• You are building a 4 x 4 x 4 cube of LEDs

• You can choose
  – Red, Green, Blue, White
  – Or can mix it up

• Two challenges
  – How to control 64 lights?
  – How to build something
    • With 64 elements
      – That is a lot of soldering
      – A little planning will go a long way

• Friday’s prelab lecture will discuss soldering strategies.
The Control Problem

• Our cube has 64 lights
  – We would like to allow any combinations of lights to be on
    • So you can create any light pattern that you would like
  – If every light is independent
    • Need at least one bit per light (on, off)
    • State of lights is 64 bits (4x4x4 array)

• Our computer only has around 20 digital output pins
  – And 20 is less than 64.
  – Need to communicate 64 bits over 20 pins.

• How are we going to do this?
PIN MULTIPLEXING
Solving the Pin Problem

• The pin problem is very common
  – Your keyboard has many keys
    • But not that many wires that connect it to a computer
  – Your display has millions of pixels
    • And the cable has only a few wires

• Clearly need to get more than 1 bit/wire
  – The way computers do it is serial communication
  – Transmit different bits at different times
Serial Communication

- Also called
  - Time division multiplexing
  - Or just multiplexing

- Heavily used
  - Ethernet
  - Serial ports
  - USB (universal serial bus)
  - I²C, SPI, HDMI, JTAG, etc.
Serial to Parallel Converters

- If you use a string of memory cells can get all the bits
  - Load each memory cell at the “right” time
Dealing With Lights and Switches

• Serial communication works well between two chips
  – And there are some LEDs that have a chip packaged w/ them
    • But not most

• LEDs and switches don’t have memory to store information
  – So simple serial communication doesn’t work

• Use the fact that humans are slow (in computer time)
Optical Persistence

• We can take advantage of the fact that our eyes are “slow”

• If we turn an LED ON and OFF faster than our eyes can “see” then we will perceive a constant light intensity.
  – The flicker fusion rate is around 30Hz
  – Your eye averages the signal

• Electronics takes advantage of the fact that your eyes are slow
  – Creates more outputs than wires
  – Creates analog light output values on digital pins
Basic Approach

• If I have many lights, I don’t need to turn them all on at once
  – I can create different slots in each time period
    • Say I created 8 slots
      – Then I only need to light 64 / 8 lights in each slot

• But how do I get the right lights to light up at the right time?
  – Leverage the diode nature of the LED
LED Wiring Diagram
LED Wiring Diagram - EveryCircuit
LED Array Wiring Diagram
Testing Our Understanding

- If we use time division multiplexing to drive the LED array
  - How do you light up the red LEDs?
  - How many time slots?
Driving the LED Cube

- Friday’s prelab lecture will discuss how to physically construct the cube and how to electrically drive it from your Arduino using the multiplexing methods we discussed today.
Learning Objectives

- Understand that some diodes can produce light from electricity
  - Color is related to the diodes forward voltage
    - 2V (red) to 3V (green and blue)
  - And be able to use LED lights in your design
    - Limit current through diode to 20-40mA

- Understand it is possible to control $N^2$ lights
  - Using only 2N wires
  - Scan/drive a row at a time