EE 109 Unit 17 - Pulse Width Modulation

17.2 Power

- Recall (or learn) that Power is a measure of:
  - ______________________
  - In an electronic circuit, \( P = \) ______________
    - Power = Current & Voltage (each may be __________ w/ time)
  - A circuit that draws a constant 2 mA of current at a constant 5V would consume __________
  - Since voltage and current may change rapidly, it is often helpful to calculate the average power
    - Just sum the total power and divide by the total time

\[
P = \frac{1}{T} \int_0^T P(t) dt
\]

- Average Power

\[
I = 1A
\]

17.3 Output Devices

- What do the following have in common?
  - Servo motor that can rotate to any angle w/in 180 degrees
  - ______________________
    - ______________________ with various power levels
- They are controlled by Pulse Width Modulation (PWM)
  - Usually a 3-pin interface: Power (Vcc), GND, PWM Signal

17.4 Duty Cycle

- A pulse is just a short window of time when a signal is 'on'
- We could repeat the pulse at some regular period, \( T \)
- We define the duty cycle as
  - Duty Cycle % = ______________________

\[
\text{Duty Cycle} = \frac{T}{T} \times 100\%
\]

\[
\text{Duty Cycle} = \frac{T}{T} \times 100\%
\]

\[
\text{Duty Cycle} = \frac{T}{T} \times 100\%
\]
Power & Duty Cycle

- When we light up an LED we often just turn a PORTxx output 'on' and leave it 'on'
  - This supplies the ____________ power possible to the LED
- We could _________ the output at some duty cycle (say 50%) at a fast rate
  - Fast so that the human eye can't _________________
  - Average power would be ½ the original always 'on' power
  - Result would be a ________________

In-Class Activity

- Write a program with a loop that turns on the LED (PORT B5) for x milliseconds and then turns it off for 100-x milliseconds
  - Initially set x = 100
  - Now set x = 50
  - Now set x = 20
  - Now set x = 10
  - Now set x = 2
- Notice result may be non-linear
- A similar tactic is used in your ______________ when you want to cook something at __________ etc. power.

PWM

- Modulation refers to ____________ a value based on some ____________ (i.e. changing one signal based on another)
- Pulse width modulation refers to modifying the width of a pulse based on another signal
- It can be used to _______________ one signal into another
  - Example below of sine wave represented as pulses w/ different widths
- Or it can just be used to alter average power as in the last activity

Simple Digital-To-Analog

- Connecting a PWM output to a resistor-capacitor circuit as shown causes the voltage at Vc to "integrate" the digital PWM signal (charge the capacitor)
  - Analogy: Imagine you have a leaky bucket (i.e. capacitor) and you want to produce a variable level (i.e. ____________) of water by only turning the hose (___________ output) on or off

\[
\begin{align*}
V_{PWM} & \quad 5V \\
V_c & \quad 0V \\
& \quad 5V \\
& \quad 0V \\
& \quad 0V
\end{align*}
\]
Servo Motors

- Many embedded systems use servo motors to move or rotate mechanical devices
- Most servo motors use some form of pulse width modulation to control the direction and speed of their rotation
- 2 Kinds
  - __________ servo motors: can only rotate through a certain _____ (usually 180 degrees)
  - ____________: can keep spinning round and round while pulses are provided

Standard Servo Motor

- Pulse width determines ______________ of servo motor
- Must continue to give pulses for the duration of time it takes to ________________
- No pulses = ______________

Continuous Servo Motors

- Pulse width determines ______________ of rotation
- Controlled via PWM (Pulse Width Modulation)
  - Short pulse = Rotate one direction
  - Medium pulse = Stop
  - Long pulse = Rotate other direction

Implementing PWM

- Can use delays or timers to make your own pulse signals
- Most microcontrollers have hardware to automatically generate PWM signals based on the contents of some control registers
- Many microcontrollers use the Timers to also serve as PWM signals
  - Recall the timer module gave us a counter that would increment until it hit some 'modulus' (MAX) count which would cause it to restart and also generate an interrupt
Using Timers for PWM

- For PWM we can use that counter to just count 0 to some MAX count making the:
  - PWM output = '1' while the count < threshold (OCRxx) and
  - PWM output = '0' when the count >= modulus (OCRxx)

PWM Control Registers

- In this slide packet we will use the 8-bit Timer/Counter0 rather than the 16-bit Timer/Counter1
- Refer to Timer Slides w/ following additions
  - Set WGM0[2:0] bits for Fast PWM mode as opposed to CTC
  - Timer/Counter0 can produce two PWM outputs on Arduino pins D5 and D6, each with its own threshold value, so you need to pick which one you want to use
    - Bits COM0A[1:0] and threshold register OCRA control operation of output D6 (PORTD6)
    - Bits COM0B[1:0] and threshold register OCRB control operation of output D5 (PORTD5)

See datasheet, textbook or other documentation for further explanation

PWM Output 1

PWM Output 2

Exercise

- Try to use PWM to make your LED glow at various brightness levels similar to what you did earlier with normal digital I/O
A BRIEF SUMMARY

Review of some key concepts from the first half of the semester and revisit what CECS prepares you to do in the future....

A Few Big Ideas 1

- ___________________________ bits in a register tells the hardware what to do and when (this is SW interacting with HW)
- ___________ matters
  - Your software is executing ___________ compared to how fast a human can do something
  - You can use that to your advantage: blinking an LED at a fast rate can give the illusion it’s always on but just more dim
  - Or it can work to your disadvantage: One button press may look like ___________ because a loop may see one press on multiple iterations.
  - We must write our software with this in mind

A Few Big Ideas 2

- Clocking or enables are necessary to say ___________
  - Digital signals are always 1's and 0's so just looking at the bits doesn't tell us how many we have
  - We usually need ____________ (pulses) to tell the hardware when we want it to grab the data

Just looking at this set of digital values, are we sending 0101 once, twice, three times, how many? Once because we use the clock/enable to indicate that. But without the clock we’d have no clue how many times we are trying to write 0101.

A Few Big Ideas 3

- External events happen _______________ with your software (don't know "when" something has happened)
  - Your software program is the brains for how to process information but it doesn't magically know "when" something has happened?
  - We have to keep checking it (polling) or
  - Hardware designers built "interrupt" mechanisms to help
- Many tasks can be done in _______________; SW may be easier to code/use but HW provides parallelism
  - A 0.1 second timer can be done in SW using delays but then software can’t do much else
  - Or in HW using timers allowing SW to do other tasks
Remember Day 1

- Computer engineering prepares you for a broad set of fields
  - You could work in the SW industry
  - You could work in the HW industry
  - You will be most qualified for jobs that combine that knowledge
- We've been focused on the software/hardware interaction embodied in embedded systems

You Can Do That...

Cloud & Distributed Computing
(CyberPhysical, Databases, Data Mining, etc.)

Applications
(AI, Robotics, Graphics, Mobile)

Systems & Networking
(Embedded Systems, Networks)

What we've been focusing on thus far

Architecture
(Processor & Embedded HW)

Devices & Integrated Circuits
(Semiconductors & Fabrication)

Dive Into a SmartPhone

- Here's a picture of what's inside the iPhone™ 6
- Both sides of the circuit board are populated with chips

What's Inside Your SmartPhone

- What's inside an iPhone™ 6?
- Microcontrollers/microprocessors
  - Apple A8 APL1011 SoC + Elpida 1 GB LPDDR3 RAM
  - SoC = __________________...Not just a processor but a processor with custom hardware to do specialized tasks...on-board graphics processor in this case
  - NXP LPC18B1UK ARM Cortex-M3 Microcontrollers
  - Similar on-board I/O modules as the ____________. Take a look...
- Modem + Amplifiers + Transceivers for wireless communication
  - Qualcomm MDM9625M LTE Modem + many others

http://www.techinsights.com/teardown.com/apple-iphone-6/
What's Inside?

- A gyroscope, accelerometer, and touchscreen
  - InvenSense MP67B 6-axis gyroscope and accelerometer combo
  - Broadcom BCM5976 Touchscreen Controller
  - Both use some form of _____________________ to sense motion or touch
- Memory Storage
  - SK Hynix H2JTDG8UD1BMS 128 Gb (16 GB) NAND Flash
- Other specialized HW I/O modules
  - Murata 339S0228 Wi-Fi Module
  - Qualcomm PM8019 power management IC
  - Cirrus Logic 338S1201 audio codec

http://www.techinsights.com/teardown.com/apple-iphone-6/

Computer Engineering & HW

- Computer engineering prepares you to work in jobs that design these kinds of systems by:
  - Learning how to design digital circuits using logic gates [AND, OR, NOT] (EE 154 and EE 254 Digital System Design)
  - Learning how to optimize processors to execute software as efficiently as possible (EE 457 Computer Architecture)
  - Learn how to assemble many HW pieces (processor cores, RAM, specialized HW) to form systems-on-chip (EE 454L – SoC Design)
  - Learn some of the physics and science of fabricating these designs on silicon (EE 277L and EE 477L VLSI Design)

http://www.anandtech.com/show/8562/chipworks-a8

Die Photo of the Apple A8 SoC Processor