THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

SCHOOL OF ENGINEERING AND APPLIED SCIENCE
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
ECE 2110: CIRCUIT THEORY LABORATORY

Experiment #12:
Final Project Preparation Lab 2 – Active Filter and LED Display Design

EQUIPMENT

Lab Equipment	Equipment Description
(1) DC Power Supply	Supplied by the AD2 and the KLY-2402000 Power Supply
(1) Function Generator	Supplied by the AD2
(1) Digital Multimeter (DMM)	Harbor Freight Model 63759 Handheld Digital Multimeter
(1) Digital Oscilloscope	Supplied by the AD2
(1) Breadboard	Prototype Breadboard
(1) Test Leads	Banana to Alligator Lead Set
1/8" Headphone Jack	iPod to Breadboard Audio Adapter
1/8" Headphone Cable	Stereo Audio Cable
Music Source	

Table 1 – Equipment List

COMPONENTS

Type	Value	Symbol Name	Multisim Part	Description
Resistor	--- Ω	R	Basic/Resistor	Various Values
Capacitor	--- F	C	Basic/Capacitor	Various Values
LED Bar	---	---	LED/Bar_LED_Red_Ten	Bar of 10 Red LEDs
Op-Amp	LM741	LM741	Basic/Analog/OpAmp/741	---
Power Amp	LM386	LM386	---	Audio Amplifier
Speaker	6Ω	---	---	18W Speaker

Table 2 – Component List

OBJECTIVES

- Discuss the high-level system design for the final project
- Design, build, and measure a band-pass filter using LM741s and an LM386
- Attach a music signal to your band-pass filter system and a speaker to hear how your system sounds
- Design, build, and measure an LED Display that monitors volume of a signal

INTRODUCTION

This lab will detail the design of the final project specified on the lab website (see the lab webpage, look under: Projects → Final Project.pdf)

Final Project Overview

The range of human hearing stretches from **20Hz to 20kHz**. Lower frequencies we often call the "**bass**" tones and high frequencies are often called the "**treble**" tones. In a single audio speaker there are typically two separate speakers, one to handle the bass (called the woofer) and one to handle the treble (called the tweeter).

In this lab, we would like to design a system that amplifies music (ranging from 20Hz to 20kHz) from an iPod or other music source (e.g. computer or phone). We would also like to separate the bass and the treble of the music and send it to two separate speakers. The speakers you have available in your kit handle frequencies from **15Hz to 10kHz**. With that in mind, if we consider the frequency band from **150Hz to 5kHz the "bass"** and the frequency band from **5kHz to 10kHz the "treble,"** we begin to see a perfect application of active band-pass filters!

Overall, the system we would like to design will have a block diagram that looks like the following:
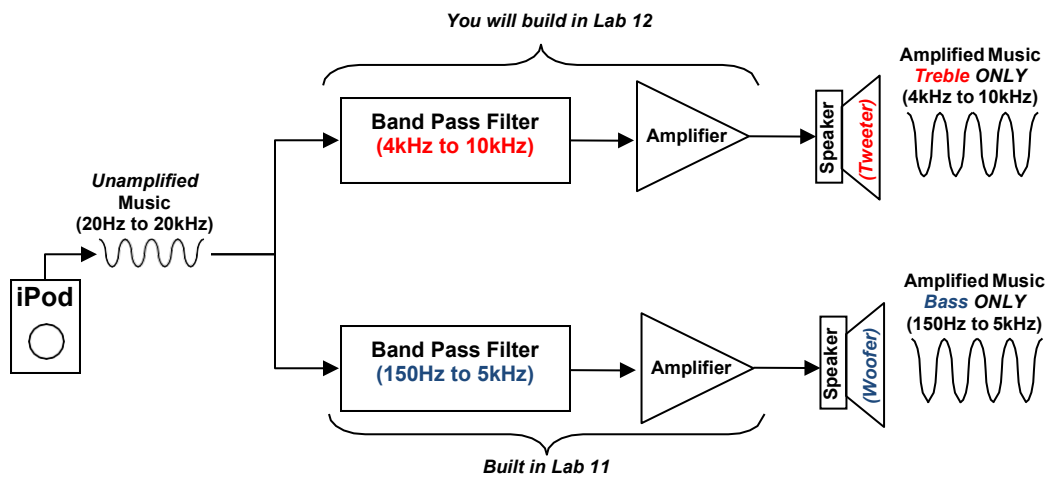

Figure 1 – iPod Docking Station Block Diagram

In Lab 11, you built a band-pass filter with a gain of -10, with a bandwidth ranging from 150Hz to 5kHz. In Part IV of Lab 11, you swapped the 3rd stage of your band-pass filter for an audio power amplifier. This brought the gain of the band-pass filter to +20. What you built not only filtered frequencies, but it also amplified those frequencies. This band-pass filter will serve as the "bass" channel for the iPod docking station we are going to build.

PRELAB

Part I – Active Band-Pass Filter Design (Treble)

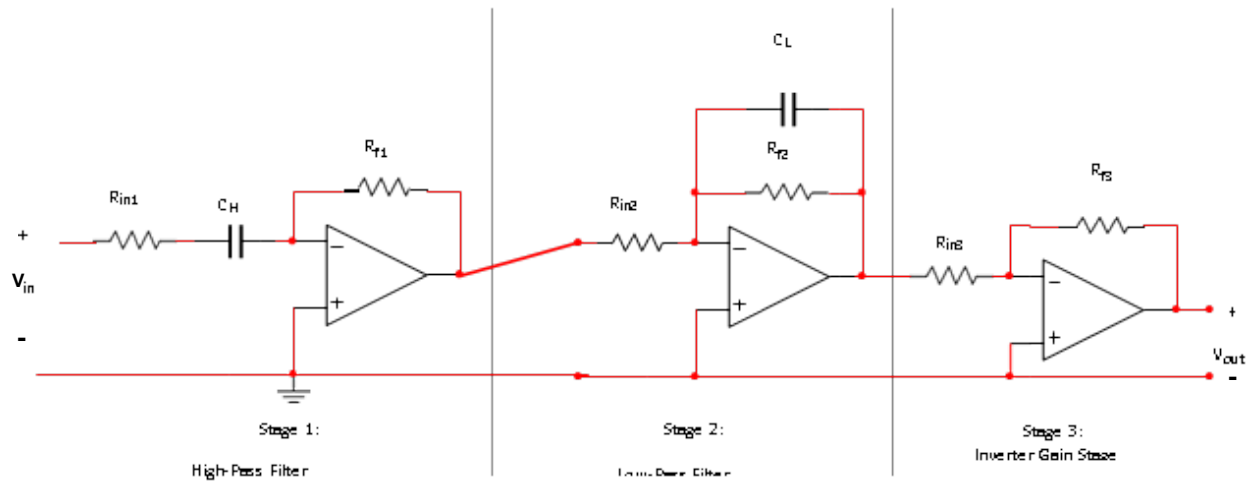**Figure P.1.1 – Active Band-Pass Filter with Gain Stage**

1. Using the procedure discussed in Lab 11, **design** an active band-pass filter for the "**treble** channel" for the iPod docking station in **Figure 1**. Set the gain in the 3rd stage to be -10 (using an inverting amplifier as the 3rd stage as you did in Lab 11). Set the lower cut-off frequency to be **4kHz** and an upper cutoff frequency of **10kHz**. Use an input voltage of 300mV$_{rms}$ and a load resistor of value 1kΩ.

   Note: When choosing resistor values to set the gain for each stage, be certain to keep them in the high kΩ range. Also look at your parts list and make certain you have the capacitors necessary to build your band-pass filter. If you do not, you can raise or lower your resistance values until you reach capacitance values available in your kit.

   Turn in: Your calculations, the Multisim schematic, and Multisim simulation results showing V$_{out}$ (in Volts) across the load resistor versus time at 7kHz. And a 2nd simulation showing V$_{out}$/V$_{in}$ (in dB) versus frequency (from 3kHz to 11kHz). Identify the -3dB cutoff points.

2. **Download** the following tones to your computer from the lab website (look under the final project specification):

   50Hz, 150Hz, 1kHz, 2kHz, 3kHz, 4kHz, 5kHz, 6kHz, 8kHz, 10kHz, 11kHz.

Part II – LED Display

For our iPod docking station, we would like to add a display panel that shows how the music signal amplitude goes up and down as the music is playing. This is typically called a "VU meter" in audio equipment terminology. We will use op-amp comparators to compare the music to a known voltage level and an LED on the output of the comparator to "light-up" when the music reaches a certain amplitude. In this section of the prelab, you will design a voltage ladder that will provide reference voltages for the comparator amps that we will use to light-up the LEDs.

Voltage Ladder:

In Lab 4, you designed a voltage ladder (shown in **Figure P.2.1**). As part of this design, you used the concept of voltage division to select resistors to produce specific node voltages.
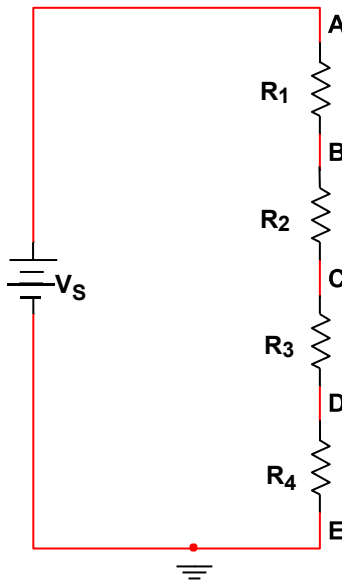

Figure P.2.1 – Voltage Ladder Design

1. **Design** a voltage ladder with the following specifications:

   - **Power Supply: 4V (±5%)**
   - **V_A:**   4V ±5%
   - **V_B:**   3V ±5%
   - **V_C:**   2V ±5%
   - **V_D:**   1V ±5%

   Rule of Thumb*: Always use resistors on the order of kΩ, unless the specifications necessitate that you use smaller or larger resistors.*

   <u>**Turn in**</u>: Your calculations, a Multisim schematic, and Multisim simulation showing the node voltages.

Music Comparator:

In Lab 7, you built and tested several op-amp circuits. One of those circuits was a comparator (shown in **Figure P.2.2**). The comparator op-amp circuit accepts two voltages (V_1 and V_2) on the non-inverting and inverting inputs (pins 3 and 2 on an LM741). If V_1 is larger than V_2, then the voltage on the output of the comparator (pin 6 on an LM741) will be raised to the positive voltage supply voltage (V_{CC+}). If V_2 is larger than V_1, then the voltage on the output of the comparator will be pulled down to the negative voltage supply voltage (V_{CC-}).
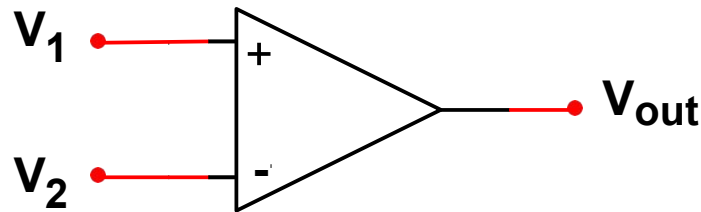

Figure P.2.2 – Comparator Op-Amp Circuit

If we represent music with a sine wave (see **Figure P.2.3** below), we would like to build a system that compares that sine wave to various known voltages. For instance, if we have a sine wave that has a voltage that varies between 0V and 5V, we would like to know when that sine wave reaches 1V, 2V, 3V, and 4V.
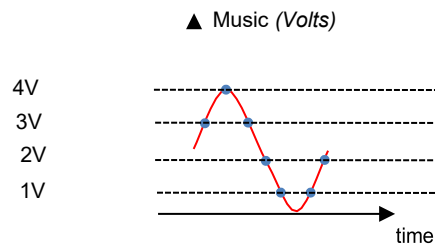

Figure P.2.3 – Comparing Music to Known Voltages

You have designed a voltage ladder to generate the known voltages (1V, 2V, 3V, and 4V) from a 12V supply. If we used Multisim to create a voltage source that produced a sine wave with a 2V amplitude and a +2V offset, we would have a sine wave like the one shown in **Figure P.2.3**. Connecting the sine wave voltage source to the input of a comparator op-amp, and the known voltage from a "rung" on the voltage ladder (say the node where the voltage = 1V), we could compare the sine wave to the known voltage of 1V. When the sine wave reaches 1V, the comparator would output 5V. If the sine wave falls below 1V, the comparator would output -5V. With this technique in mind, we could use four comparators to compare the sine wave to the four known voltages from the voltage ladder.

1. **Design** and **simulate** a circuit that compares an input voltage to each of the node voltages (reference voltages) from the voltage ladder that you designed earlier, simultaneously. The design will require multiple comparators. The comparator assigned to a specific reference voltage **should output a positive voltage if the input voltage is larger than that reference voltage**, and a **negative voltage otherwise**. The positive and negative supply voltages for the op-amps should be 12V and -12V.

   Note: In the lab you will design the final part of this circuit, attaching the output of the comparator circuits you have designed to LEDs. They will light up when the music reaches the known voltage levels you have set up.
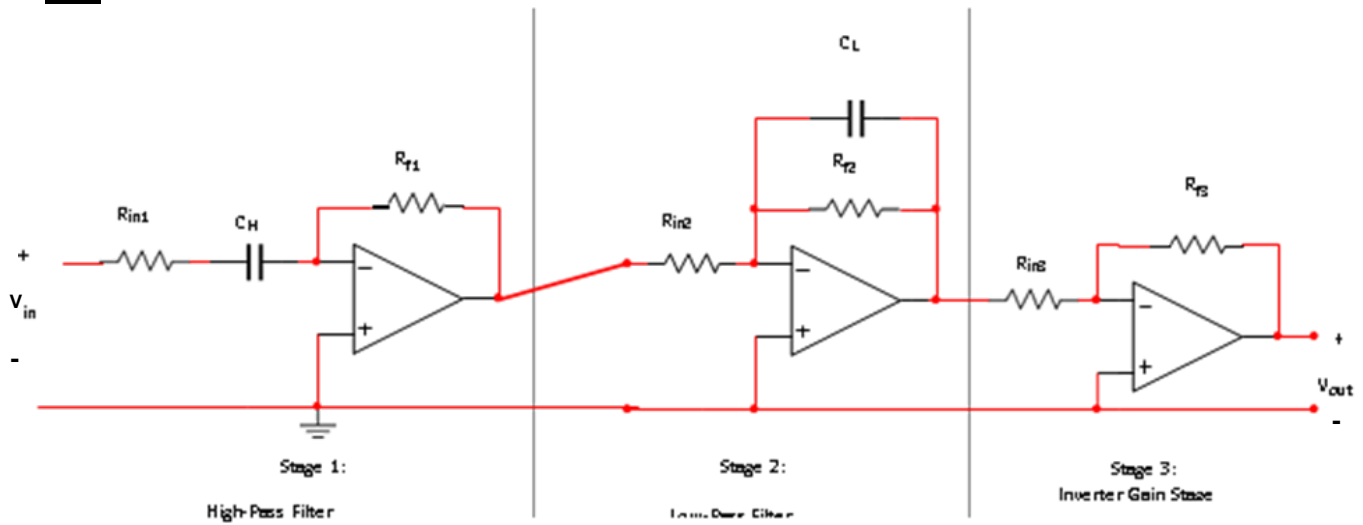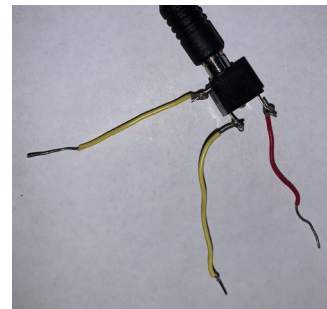
ECE 2110: Circuit Theory

LAB

Figure 1.1 – Active Band-Pass Filter with Gain Stage

1. **Build** the active band-pass filter on a breadboard.
    *   **DC Supply Voltage (V$_{CC+}$ and V$_{CC-}$): ±12V Generated by the DC Power Supplies.**
    *   **V$_{in}$: Audio output from PC or Phone**
    *   **Load: 1kΩ**
2. The figure to the right shows how to attach the **1/8" headphone cable** to your breadboard as the input to your band-pass filter. The two yellow wires are the left and right audio wires, and the black wire is ground.
3. **Connect** the local PC (or your iPod) to the 1/8" headphone cable.
4. **Download** the music tones (from the lab website) onto the local PC (or your iPod).
*   **Use** this as V$_{in}$ instead of the function generator.
5. **Measure V$_{out}$** using the DMM or Oscilloscope (RMS voltage) across the 1kΩ load at the following frequencies: 3kHz, 4kHz, 6kHz, 8kHz, 10kHz, 11kHz
6. **Using** the peak output voltage of V$_{out}$, **calculate** the **peak power dissipated** by the 1kΩ load resistor at each frequency.
7. **Calculate** the current drawn by the 1kΩ load resistor at the peak output power in each case.
8. **Record** these values in **Table 1.1**.
9. **Adjust** the **frequency** of the function generator until you find the **exact -3dB frequencies**.

Frequency	V$_{in}$ (rms)		V$_{out}$ (rms)		Gain (V$_{out}$/V$_{in}$)		P$_{out}$ (peak)		I$_{out}$ (peak)	
	Sim.	Meas.	Sim.	Meas.	Sim.	Meas.	Sim.	Meas.	Sim.	Meas.
3kHz										
4kHz										
6kHz										
8kHz										
10kHz										
11kHz										
	Lower -3dB		**Upper -3dB**							
Simulated										
Measured										
Error										

Table 1.1 – Band-Pass Filter Output Characteristics with 1kΩ Load

Part II – Active Band-Pass Filter with Small Load

1. For the band-pass filter you have simulated and measured, **calculate** the amount of current a 6Ω load would draw at the **highest value** of **V$_{out}$** you recorded in **Table 1.1**.
   a. **What** is the value in **mA**? Include this in your lab write-up
   b. **Can** the LM741 op-amp provide this much current to a **6Ω load**?
      i. **Download** the LM741 specification sheet from the lab website.
      ii. **Look** for the electrical parameter: "**Output Short Circuit Current**"
      iii. **Is** this value **more** or **less** than the amount of current a 6Ω load would draw?
   c. **Replace** the 1kΩ load in your **Multisim** simulation with a **6Ω load**.
      i. **Run** an AC Analysis from **10Hz** to **6kHz**. **Measure V$_{out}$** (in RMS voltage) across the 6Ω load at the following frequencies: 10Hz, 150Hz, 1kHz, 4kHz, 5kHz, 6kHz
      ii. **What** do you notice about your results?
2. From Step 1 you should realize that the **LM741 cannot support a small load** like 6Ω.
   a. We **need an amplifier** for the 3rd stage of our band-pass filter that can provide enough current to our 6Ω load.
   b. For this, we will replace Stage 3 of our amplifier with a power amplifier called the **LM386**.
      i. The **LM386 is not an op-amp**. It is a self-contained amplifier that can provide a great deal of current to **small loads**.
      ii. **Download** the LM386 specification sheet from the lab website.
3. On page 5 of the LM386 specification sheet a sample configuration is shown.
   a. **Replace** the **3rd stage** of your amplifier with this sample configuration.
   b. Instead of a 6Ω load, use the **speaker** provided in your kit.
4. **Measure V$_{out}$** using the DMM or Oscilloscope (RMS voltage) across the speaker at the following frequencies: 10Hz, 150Hz, 1kHz, 4kHz, 5kHz, 6kHz
5. **Using** the peak output voltage of V$_{out}$, **calculate** the **peak power dissipated** by the speaker at each frequency.
6. **Calculate** the current drawn by the speaker at the peak output power in each case.
7. **Record** these values in **Table 2.1**.
8. **Adjust** the **frequency** of the function generator until you find the **exact -3dB frequencies** (upper and lower) of the filter, where $V_{out} = \frac{1}{\sqrt{2}} * (maxV_{out})$.

Frequency	V$_{in}$ (rms)		V$_{out}$ (rms)		Gain (V$_{out}$/V$_{in}$)		P$_{out}$ (peak)		I$_{out}$ (peak)	
	Sim.	*Meas.*	*Sim.*	*Meas.*	*Sim.*	*Meas.*	*Sim.*	*Meas.*	*Sim.*	*Meas.*
3kHz										
4kHz										
6kHz										
8kHz										
10kHz										
11kHz										
	Lower -3dB		*Upper -3dB*							
Simulated										
Measured										
Error										

Table 2.1 – Band-Pass Filter Output Characteristics with 6Ω Load

Part III – Building and testing the LED Display

In Lab 2, you were introduced to light-emitting diodes (LEDs). You saw that an LED emits light when a large enough current passes through it in the direction of anode to cathode. For individual LEDs, it is standard for the longer wire to be the anode. For packages containing multiple LEDs, you must reference the datasheet to determine the pin labels. **Figure 3.1** shows the circuit diagram for the LED bars provided in your parts kit (pin 1 of the LED bar is indicated by the notch removed from the corner of the bar). The line in the LED symbol indicates the cathode.
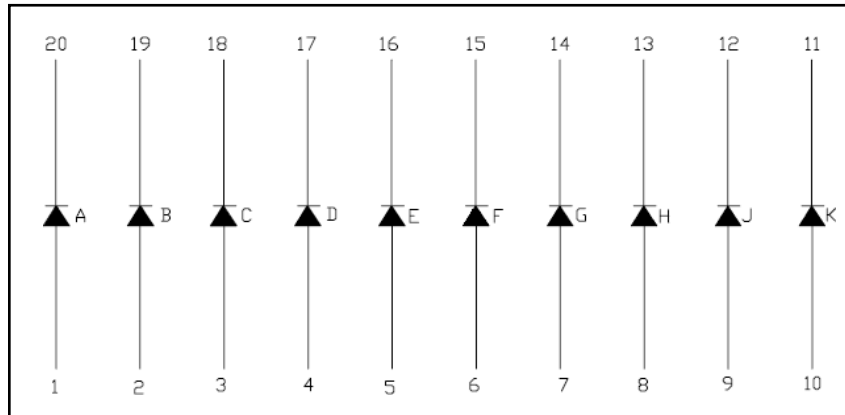

Figure 3.1 – LED Bar Circuit Diagram

LEDs often require that a resistor be placed in series with them in order to limit the amount of current that can pass through them. For the purpose of designing a circuit containing an LED, you should reference the LED's datasheet to determine the maximum current that can pass through it and the nominal voltage drop across it (**100mA** and **2V**, in the case of the LED bars included in the kit). The voltage not dropped across the LED will be dropped across the resistor. Therefore, its resistance should be selected such that the current flowing through the resistor (same amount of current flowing through the LED) is less than the maximum amount tolerated by the LED.

1. **Build** the voltage ladder comparator circuit you designed in the **Prelab**.
2. **Add** an LED to the output of each comparator (use the LED bar in your kit).
3. **Choose** the right resistor value so that the LED does not burn out.
    Hint: Is the maximum current that the LM741 can output large enough to justify current-limiting resistors for the LEDs? Look at the LM741 spec sheet on the lab website to determine its maximum output current.
4. **Connect** a 5V$_{pp}$, 10Hz sine wave as the input to the display circuit that you just built. **Verify** that it produces a periodic pattern of lights ranging from zero to four LEDs illuminated and back.
    *   **1 LED lights up when an input voltage is larger than 1V**
    *   **2 LEDs light up when the input voltage is larger than 2V**
    *   **3 LEDs light up when the input voltage is larger than 3V**
    *   **4 LEDs light up when the input voltage is larger than 4V**
5. **How** can you attach this LED display to your active band-pass filter from to have it show the amplitude of your music?

POST-LAB ANALYSIS

There is no required lab report for Lab 12; however, if you would like to earn some **extra credit**, you may submit a formal lab report for this lab. You will need this data to create your final report for the final project. During the next lab, you will demonstrate your complete iPod docking station. You will also be expected to present an oral PowerPoint presentation detailing your design. Finally, a formal written report will be due. Your GTA will discuss the due dates for each of these.

At this point, you should now have a basic working iPod docking station. To complete it, you will need to assemble:

- The **band-pass filter** from Lab 11 and Lab 12 to have both a **bass** and **treble** channel driving the **two separate speakers**

- A volume control knob that controls the volume on each channel
    - **Where** would you put a potentiometer (e.g. volume control knob) in your circuit to adjust the output of your amplifier?

- The **LED display** that shows the amplitude of the music signal

Ways to make your iPod docking station better:
- In these labs we have used 1st order filters to make the band-pass filters
    - You could use **2nd order filters** to increase the selectivity of the filters and make the music sound "crisper"
    - Designing a 2nd order filter is discussed in your textbook
- **Enclose your system** in a "Project Enclosure" box. These are sold at your local RadioShack or by various online merchants.
- Remember, **any improvement** you make (better filter, etc), you **must include simulations** for it and be able to **explain how it works and how you designed it** (even analysis) in your presentation and final report. **Never build something you do not understand!**