ENGR 1121 Lab 5
Ultrasonic Range Finder

February 24, 2014

In this lab, you will design and build an ultrasonic range finder that is capable of measuring the distance to an object by emitting a brief burst of ultrasound and measuring the time it takes for an echo to return. This lab will be a two-week lab; you will need to submit a single lab report at the end of the two weeks. You are free to decide how to break it up between the two weeks, but we suggest that you at least complete the design and characterization of the receiver circuit during the first week. Please note that we do not have enough ultrasonic transducer boards for every student in the class to have his or her own, so they will need to remain in AC 428. Please return them to the box on the front table when you are done working in the lab.

The basic circuit that you will be designing and building in this lab is shown in Figure 1. You will be using your Arduino to generate the short (i.e. 0.5-ms) burst of ultrasound at 40kHz twenty times per second. You will find a sketch called `ping.ino` on the course website to generate such a signal on pin 2 of the digital header. The transmitter circuit that you will use is quite simple, with pin 2 directly driving an ultrasonic transducer, as shown in Figure 1a. The receiver circuit, shown in Figure 1b, is somewhat more complex, comprising an ultrasonic transducer connected to a bandpass filter/amplifier circuit that you will need to design and characterize. Your filter/amplifier circuit needs to have a passband gain of about 60dB (i.e. 1000). Its passband should be roughly centered on 40kHz and it should have at least a second-order (i.e. 40dB/decade) roll off on either side of the passband. As in our previous labs, the zero level of the filter should be 2.5V. Unlike in previous labs, we are not going to provide you with the circuit. You will need to design it to meet the specifications just provided. Please note that you will not be able to use the AD623 instrumentation amplifier, because it is not fast enough to deal with the 40-kHz ultrasonic signals that we will be using. You should be able to design a viable circuit using two or three op-amp stages similar to the ones that we used in Lab 4. You should not attempt to get all of the gain in a single stage; rather, you should break it up and distribute it across the two or three stages of your circuit.

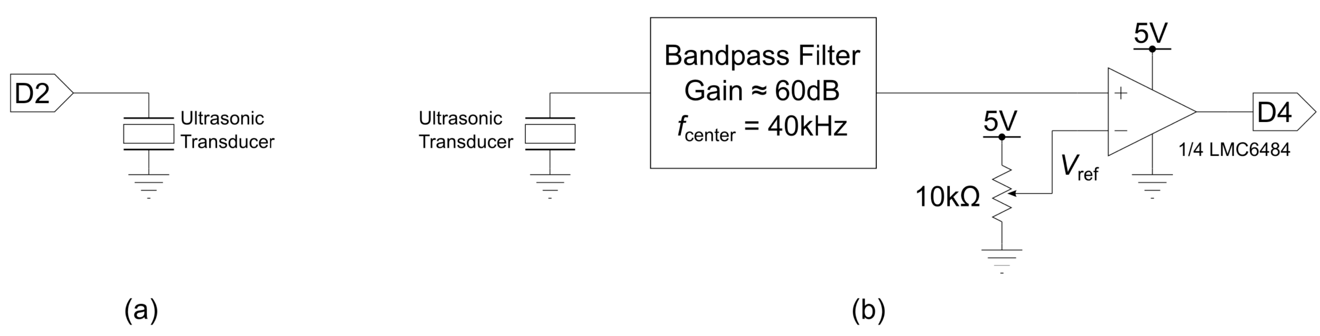

Figure 1. Ultrasonic range finder circuitry. (a) Transmitter circuit with digital pin 2 of the Arduino directly driving an ultrasonic transducer. (b) Receiver circuit with an ultrasonic transducer connected to a bandpass filter/amplifier circuit, which, in turn, drives an op amp to generate a digital signal to feed into digital pin 4 of the Arduino. Your bandpass filter/amplifier circuit needs to have a passband gain of about 60dB (i.e. 1000), a passband centered around 40kHz, and at least a second-order (i.e. 40dB/decade) roll off on both sides of the passband.

As shown in Figure 1b, the output of your bandpass filter/amplifier will drive a final op amp, which we will use as a comparator to make a clean digital signal that can be fed into a digital input pin on the Arduino. The 10-kΩ trimpot provides an adjustable threshold voltage level that controls the minimum received amplitude that will make it through to the Arduino. The whole receiver circuit, including the final comparator stage should fit on a single LMC6484 chip. Your first task should be to design your bandpass filter/amplifier circuit. Before you connect them together, you should construct each stage and characterize its frequency response independently with your Analog Discovery's network analyzer instrument.

Next, you should download the `ping.ino` sketch from the course website and upload it to your Ardunio. You should also obtain an ultrasonic transducer board and connect it to your receiver circuit and to pin 2 of the Arduino as shown in Figure 1. We suggest that you power your Arduino from your USB cable and that you power your receiver circuit by connecting GND and 5V on the Arduino's power header to the 5V and 0V power busses of your solderless breadboard using hookup wire. You should have the little power supply board that you build during the first week of classes (with no USB cable or wall wart plugged into it) plugged into your breadboard in order to generate the 2.5-V mid-rail voltage for your bandpass filter/amplifier circuit. Observe the transmitted signal (digital pin 2) and the received signal (digital pin 4) using with your Analog Discovery's oscilloscope. Measure the time delay between the transmitted and received signals (time of flight) as a function of distance to target for at least 10 different distances. Produce a calibration curve showing time of flight as a function of distance for your ultrasonic range finder. Is the curve linear? If so, is the slope of the best-fit line reasonable? What would you expect the slope to be?

Finally, modify the basic `ping.ino` sketch to measure the delay between the transmitted and received signals and print the delay in microseconds to the serial port. To do so, you will at least need to do the following:

1. Initialize the serial port.
2. Set up pin 4 of the digital header as an input.
3. Record the time that the signal is transmitted (using the `micros()` function)
4. Listen for a received signal on pin 4, recording the time (using the `micros()` function) that an echo is first received and printing the time difference to the serial port.

You might also want to consider adding a reasonable time out (e.g. 20ms) to your sketch, in the event that no echo is received. We realize that some of you may have very little programming experience. We are here to help, as are your NINJAs. The modifications that you will need to do are not very complicated and you have a couple of weeks to do the assignment. When you have your modified sketch working, produce a calibration curve with the delay measured by the Arduino. Plot this calibration curve on the same axes as the one you made using the Analog Discovery. Do the two curves agree?

Deliverables

1. A circuit schematic showing your bandpass filter/amplifier design and a brief description of your design approach.

2. Experimental Bode plots showing the frequency response of each stage of your bandpass filter/amplifier.

3. Calibration curve(s) with at least 10 points showing time of flight (measured using the Analog Discovery and the Arduino) as a function of distance along with comments on the form of the relationship between the two variables.

4. Listing of modified Arduino sketch.

5. Photograph of your ultrasonic range finder.

Grading

20 points total for everything correct.

1. 3 points total for bandpass filter/amplifier schematic. A scan of a neat hand-drawn schematic is acceptable. All component values should be clearly labeled.

2. 2 points total for brief description of bandpass filter/amplifier design approach.

3. 4 points total for experimental Bode plots of the individual bandpass filter/amplifier stages.

4. 6 points total for calibration curve(s) and comments on the form of the relationship.

5. 4 points total for modified Arduino sketch.

6. 1 point for a picture of the circuit.