Ultrasonic range finding

THERE ARE 25 ULTRASONIC TRANSDUCER BOARDS TO BE SHARED AMONG THE SECTIONS FOR THIS LAB. THESE BOARDS MUST EITHER STAY IN AC428 OR MAY BE USED IN THE HALLWAY OUTSIDE THE ROOM FOR TESTING. PLEASE DO NOT STEAL OUR TRANSDUCER BOARDS!

In this lab you will design and build an ultrasonic range finder capable of measuring distance by emitting a brief burst of ultrasound and measuring the time it takes for an echo to return. The transmitter will send out a short burst pulse (about 1ms long) at the transducer's operating frequency of 40 kHz. The receiver will find the reflected acoustic signal, then filter and amplify this signal. From the time difference in the transmitted and received acoustic signals, you can find the distance to the object. We use the same type of transducer to transmit and receive the signal. You will build two circuit systems, the transmitter and receiver. We will provide the transmit circuit where the signal is created using the digital pins on the Analog Discovery. You will need to design the receiver circuit.

Transmitter

To create the output signal, open "Patterns" on the digital side of the main Analog Discovery window. To create the signal, you need a 40 Khz signal which runs for about 1 ms and then pauses for several ms before sending the next ping. To create such a signal,

- Click "+Add" and then "Signal".
- Select DIO 0 (Digital Input/Output Channel 0)
- Double click on DIO 0 which you just added.
- Set the type to "clock", the frequency to 40 kHz, the duty cycle to 50%, and the output to PP.
- "+Add" and then "Signal".
- Select DIO 1 (Digital Input/Output Channel 1)
- Double click on DIO 1 which you just added.
- Set the type to "clock", the frequency to 20 Hz, the duty cycle to 2 %, and the output to PP.

Now get one of the logic gates, the Texas Instruments SN74ATC08. Put the chip on your breadboard. You can look at the pin diagram on the datasheet. 5 Volts will go to pin 14, ground will go to pin 7. The chip has 4 logic gates on it. You only need one of them. You can put the wire for DIO channel 0 (simply labeled "0" on the Analog Discovery) into pin 1, DIO 1 into pin 2, and pin 3 will be the output. The chip will AND the two signals. The result, if you measure the output on pin 3 of SN74ATC08 should look like the signal in Figure 1. You will see a 40 kHz square wave which is on for about 1 ms. Once you get the receiver working, you may elect to adjust the length of the 1 ms pulse, which can be done by editing the duty cycle on DIO 1.

Plug the transmitter/receiver board into your breadboard – on the opposite end from the power connector such that the pins connected to the transducers straddle the middle break in your breadboard. Face the transducers outward from your breadboard. The transducers are the same so you may select whatever is convenient to be the transmitter. Notice that each transducer has 2 sets of three pins. The extra pins are for stability. One set of three pins should be connected to the output of the SN74ATC08 and the other set of three pins should be connected to ground.

Figure 1: Example of the measured transmit signal. The 1 ms pulse has a 40 kHz carrier wave.

Figure 2: The transducer board for the ultrasound experiment. The transmitter and receiver are the same. The gap in the pins on the lefthand picture should straddle the middle break of your breadboard. On the right hand picture, the pins on one row should be connected to ground and the other row to either the output of the transmitter or the input of the receiver. The transducers have no preferred electrical orientation.

Receiver

It is up to you to design the receiver circuit. The basic connection is that one side of the receiver transducer is connected to ground and the other will be the input to your circuit. Your filter and amplifier circuit should have the following (approximate) properties:

- The circuit should have a band-pass filter centered at 40 kHz.
- The circuit should amplify signals at 40 kHz by a factor of about 1000 (60 dB).
- Your circuit elements show progressively amplify the signal – don't try get the whole factor of 1000 gain in one shot.
- The filter should have at least a second order roll-off above and below 40 kHz. By second order, we mean that for every factor of 10 change in frequency above and below the 40 kHz pass-band, the output should fall by a factor of 100.

- The output of the circuit should be centered at 2.5V.

We will have analyzed such circuits in Monday's class, so you may want to start by looking at your notes from that class. Sketch out the circuit that you want to build before building it. We cannot help you debug your experiment if we don't know what you are trying to build.

Once you have your circuit designed and built, you should test it with the Network Analyzer. Temporarily disconnect the ultrasonic receiver and connect channel 1 of the Waveform Generator to your circuit. Create a Bode plot by setting the output to be offset by 2.5 V and the amplitude to be 10 mV. Note that for 10 mV signal a circuit will saturate since the op-amps can't go above 5 volts. The Bode plot will saturate when 10 mV is amplified by a factor of 250 or about 50 dB.

Depending on your circuit, you may find that the measured Bode plot deviates from what is predicted. If you have a lot of gain in a single stage of the circuit, the deviation is likely due to the speed of the op-amp. We will discuss the op-amp dynamics next week in class. For now, if your measured Bode plot is not centered at the design frequency, you can simply adjust the resistor values a bit to push you into the proper frequency range. **You will need to save a final Bode plot for your receiver circuit.**

Range Experiment:

In the classroom, we will mark off with masking tape 1 foot increments from one of the walls. Walk in 1-2 ft increments starting from 2 ft, to about as far as you can go and still get a reasonable reflection (should have no problem getting 10-20 ft). For longer distances you may need to adjust the frequency of your repeating pulse in DIO 1 so there is adequate time to receive your signal back before the next ping is sent. Sample data for one ping is shown in Figure 3.

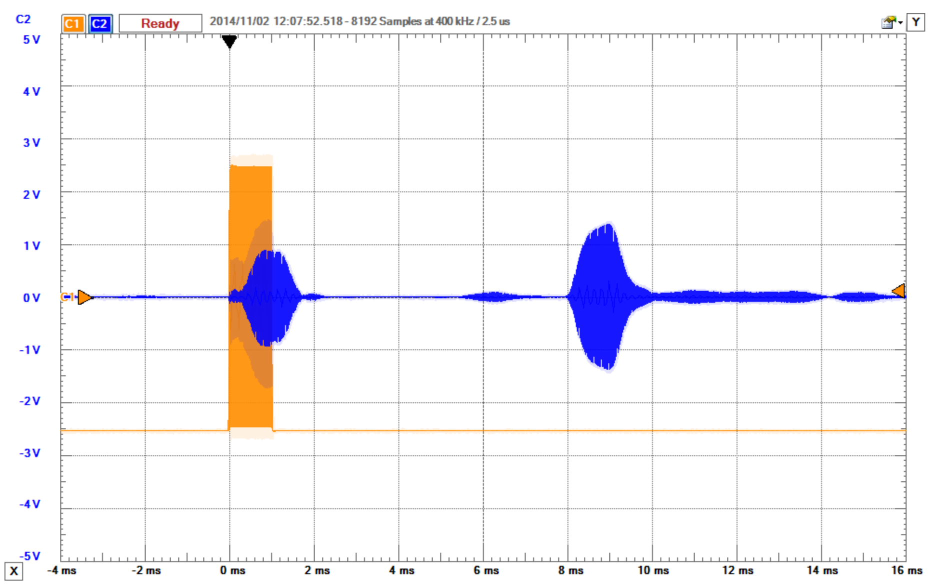

Figure 3: Sample data. The orange is the transmit signal and the blue is the received. In this case there is about 8 ms between transmitted and received signal, indicating the pulse traveled about 9 ft, or the wall is 4.5 feet away.

You might need to conduct your experiment in the hallway with a tape measure – if too many people are in the lab running their transmitters at the same time! It will probably work best to set your laptop and equipment on the floor, or a rolling desk. Repeat this for 10 distances. It is not that important what the exact distances are, but that you know them from the markings on the floor or that measured them with a tape measure. Plot all your data as known distance versus distance inferred from your circuit measurement.

Deliverables

1) A schematic of your received circuit.
2) The analysis of your receiver circuit using complex impedances.
3) A comparison between the measured and predicted Bode plot for your receiver circuit.
4) Take a picture of your final, breadboarded circuit. It should be compact and pretty.
5) Show representative data from a single blip with the transmitted and received signal on a single plot. Denote on the graph the time where the echo would be expected to be returned from the known distance to the wall.
6) Show a single plot measured distance from your ultrasonic range finder vs. the known distance. Plot all your data as points on a scatter plot. Comment on how well your range finder works (is it linear, does it give the correct result). Comment on to what accuracy you would trust your range finder (this is an estimate, we have not discussed statistically how to make these judgments in a more formal way!).