Ultrasonic range finding

THERE ARE A SET OF 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)
- Set the type to "clock" and the output to PP.
- Click on the "edit" icon next to the "+" and "-". Select "parameters" and change the frequency to 40 kHz and the duty cycle to 50%.
- "+Add" and then "Signal".
- Select DIO 1 (Digital Input/Output Channel 1)
- Set the type to "clock" and the output to PP.
- Click on the "edit" icon, select "parameters" and set frequency to 20 **Hz** (NOT kHz!) and duty cycle to 2 %.

When you click run, you can plug the output wire for DIO channel 0 (simply labeled "0" on the Analog Discovery) directly into measurement channel 1 and check that the scope measurement shows what you would expect. Check DIO zero as well.

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, the wire for DIO 1 into pin 2, and pin 3 will be the output. The chip will AND the two signals.

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.

The result, if you measure the output on pin 3 of SN74ATC08 should look like the signal in Figure 1. Note: for some reason that is not fully understood, if you measure the output of the SN74ATC08 not attached to anything, you may get something odd. The output of the chip should be connected to the ultrasound transducer before you check to make sure the output is working. You should 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.

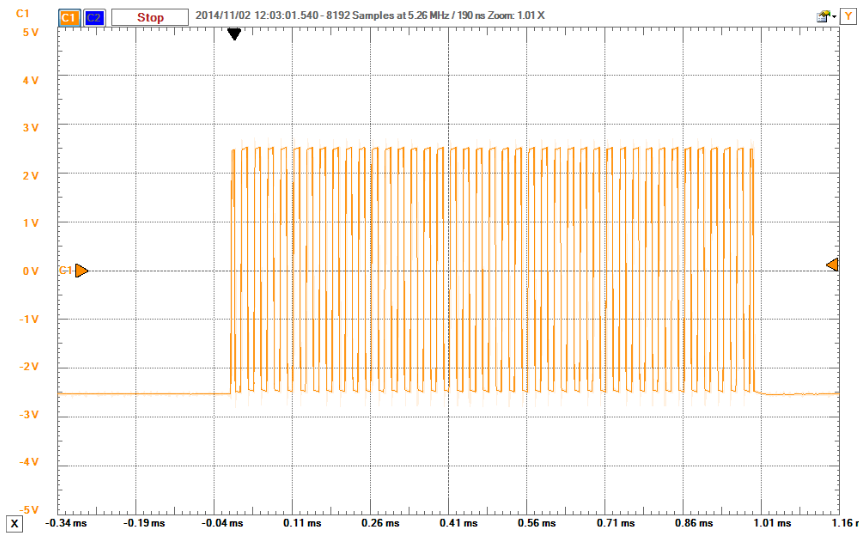

Figure 1: Example of the measured transmit signal. The 1 ms pulse has a 40 kHz carrier wave.

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 on 40 kHz
- 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 in frequency above and below the 40 kHz pass-band, the output should fall by a factor of 100.
- The circuit should amplify signals at 40 kHz by a factor of about 1000 (60 dB).
- Your circuit elements should progressively amplify the signal – don't try to get the whole factor of 1000 gain in one shot.
- The output of the circuit should be centered at 2.5V. Reference all your high pass filters and op-amp circuits to 2.5V.

We will have analyzed a circuit in Monday's class that will work quite nicely, so you may want to start by looking at your notes from class. The circuit shown in class can amplify and band-pass. Sketch out the circuit that you want to build before going to the breadboard. We cannot help you debug your experiment if we don't know what you are trying to build. Also, the internet (and the last lab) may point you to the Sallen-Key topology (we will not have done this in class on Monday). We would recommend AVOIDING this circuit, as there can be some subtle instability issues.

Once you have your circuit designed and built, you should test it with the Network Analyzer. Temporarily disconnect the ultrasonic transducer acting as the 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 a 10 mV signal and a gain of 1000, the 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 at higher frequencies. 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:

Aim your transducer at a wall. Sound travels about 1 foot per millisecond, so you should see an echo from the wall that should correspond to the distance the signal traveled (there and back). In the classroom, the floor tiles are conveniently 1 foot square. You can place your setup and laptop on a rolling cart. Walk in 1 foot increments starting from 2 feet, to about as far as you can go and still get a reasonable reflection (should have no problem getting 10-20 ft). Sample data for one ping is shown in Figure 3.

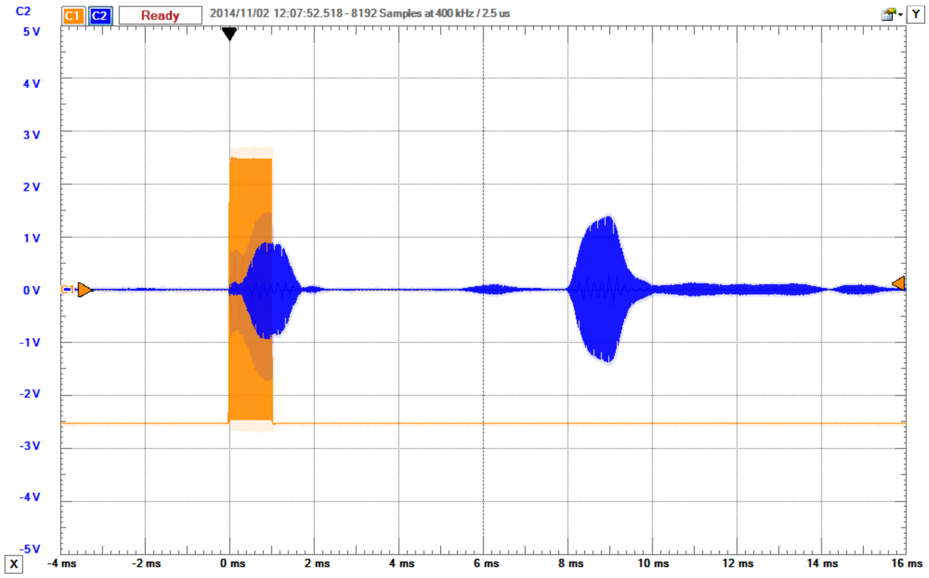

Figure 3: Sample data. The orange is the transmit signal and the blue is the received. In this case there is about 8 ms between transmitted and received signal, indicating the pulse traveled about 9 ft, or the wall is 4.5 feet away.

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! 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) A measured Bode plot for your complete receiver circuit. You DO NOT need to compare to the analytical solution this week, we will really start to analyze these circuits in next Monday's class. If you want to try and compare to the prediction, be our guest!
3) Take a picture of your final, breadboarded circuit. It should be compact and pretty.
4) 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.
5) 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!).

PLEASE KEEP YOUR LAB REPORT CONCISE. DO NOT REPORT EVERY SINGLE DETAIL YOU DID. Above there are requests for 5 figures. Keep your lab report focused on these 5 figures. We have not quite gotten to the point of analyzing these op-amp filters in class, so you do not need to analyze your filter just yet.