# Ultrasonic Range Finding

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November 17, 2017

**Abstract**

The purpose of this lab is to build a circuit capable of measuring distance with an ultrasonic sensor and active filters.

## 1 Description

In this lab, a ranging finding device was constructed with an ultrasonic transducer. The transducer had a transmitter for sending the ultrasound and a receiver for detecting the ultrasound that bounced off objects in its way. Circuit wise, the transmitter was connected to an AND gate that took two inputs - a 20Hz square wave and a 40kHz square wave. The resulting effect would be 20Hz blips of 40kHz ultrasound.

On the receiver side, op-amps and a instrumentation amplifier were used to filter out the signal at 40kHz and amplify the signal by roughly 1000 times. The detailed circuit construction was left to the students. The circuit and corresponding resistor and capacitor values I chose are shown in the schematic below. The range finding data was recorded in the end by measuring the time it took for the receiver to detect the echo at a given location.

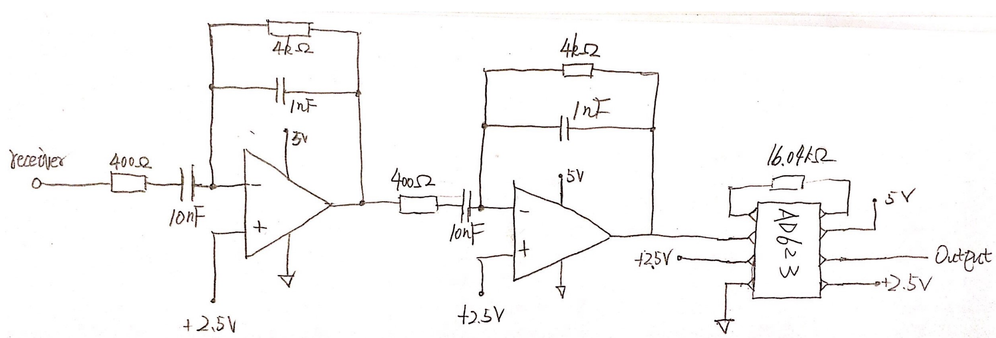


Figure 1: The receiver circuit.

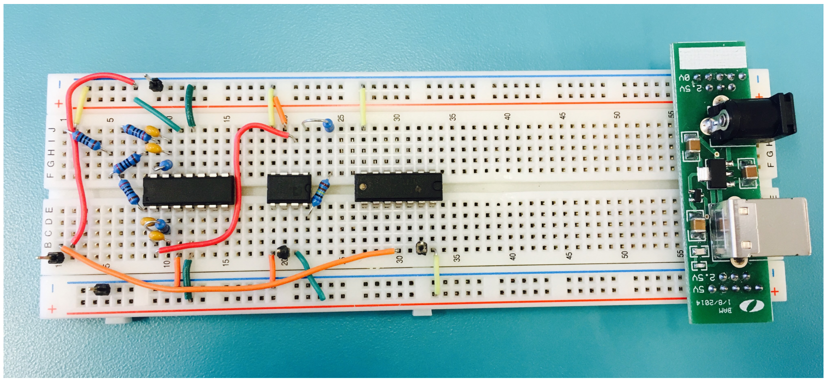

Figure 2: The breadboard setup of the circuit.

## 2 Evidence

To test the function of the receiver circuit, Network Analyzer of Analog Discovery was used to input sinusoidal signal of $10^3$ Hz to $10^6$ Hz, and the resulting Bode plot is shown in Figure 3.

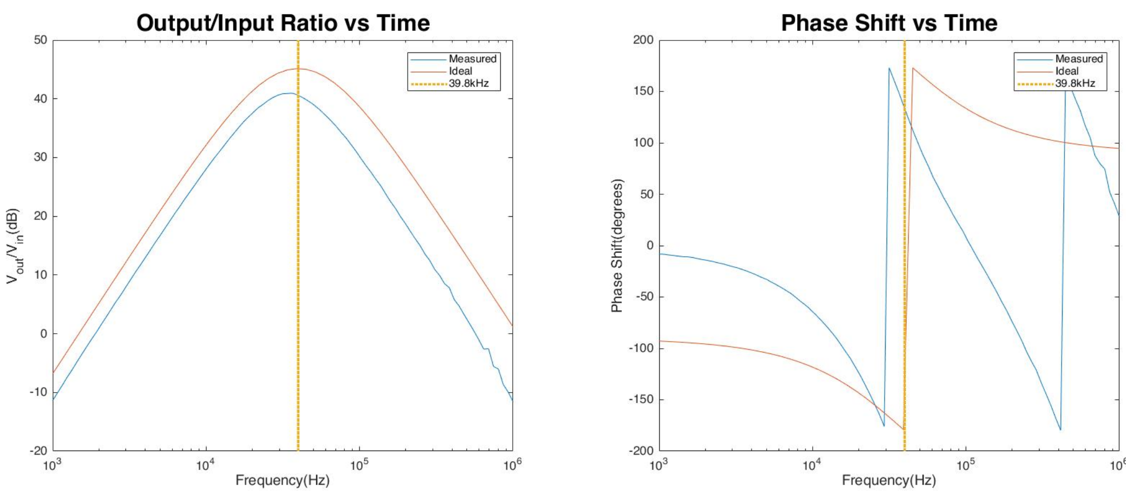


Figure 3: Bode Plot for the receiver circuit

Put together, the transmitter signal and the receiver signal would look like Figure 4. The known distance in this case is 1.75 ft as shown in the figure.

Table One provided the data on the time it took for the echo to reach the receiver at a known distance. A scatter plot of the data is also shown in Figure 4.

Table 1: Time at Known Distances

| **Distance(ft)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Time(ms)** | 2.01 | 3.99 | 5.80 | 7.49 | 9.44 | 11.36 | 13.13 | 15.01 | 16.86 | 18.58 |

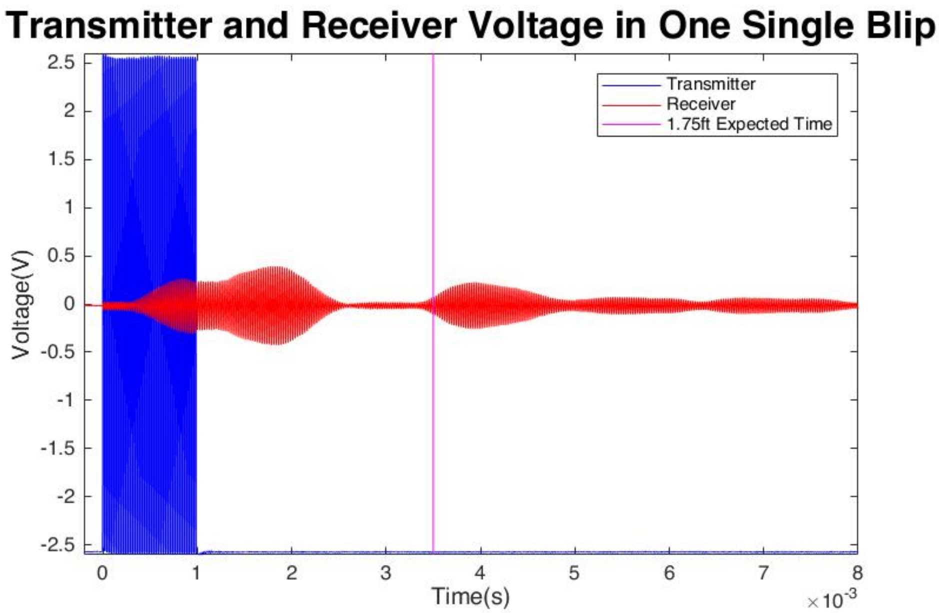


Figure 4: One Single Blip of the transmitter and the response on the receiver.

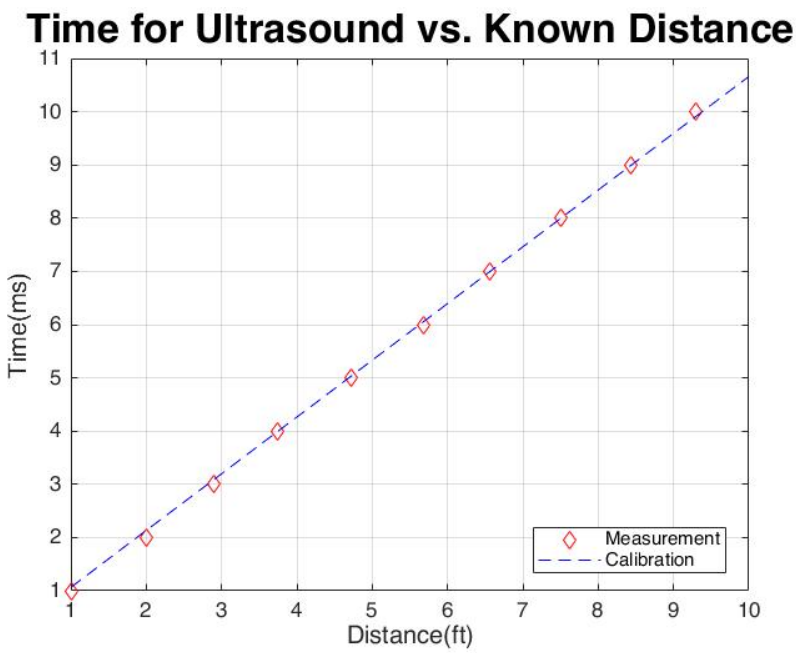


Figure 5: Each red diamond represents the time it took for the receiver to detect a response at a known distance.

# 3 Interpretation

The selections of resistors and capacitors should preserve signals around 40kHz and attenuate signals at other frequencies. The type of active filter arrangement I used is a combination of a amplifier, a low pass and a high pass filter that can be modeled with the following equation:

$$\frac{V_{out}}{V_{in}} = -\frac{R2}{R1} \times \frac{1}{1 + jR_2C_2\omega} \times \frac{jR_1C_1\omega}{1 + jR_1C_1\omega} \tag{1}$$

where Subscript 1 denotes components that lead to the negative input of a op-amp and Subscript 2 denotes components that bridge across the negative input and the output.

The selections shown in the schematic would result in the following cut-off frequency:

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 400\Omega \times 10nF} = \frac{1}{2\pi \times 4000\Omega \times 1nF} = 397.89kHz \tag{2}$$

and an amplification of:

$$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_1} = \frac{4000\Omega}{400\Omega} = 10 \tag{3}$$

Even though a cut-off frequency this close to the targeted frequency could attenuate the desired signal, every other frequency would be attenuate more, so such selections were still highly functional. Finally, 16.04 $k\Omega$ resistor bridged across Pin 1 and Pin 8 of the instrumentation amplifier to achieve further amplification without peaking the signal out at 5V:

$$G = \frac{100k\Omega}{16.04k\Omega} + 1 = 7.2344 \tag{4}$$

$$G_T = 10 \times 10 \times 7.2344 = 723.44 \tag{5}$$

The bode plot of the receiver circuit was shown in Figure 4. In the Output/Input ratio vs. Time plot, the shape of the measurement data fits the mathematical model very well, even though the whole curve seems to be shifted to the left and downward. The same shift in the frequency response can be observed in the phase shift, too. These variations are probably due to the tolerance of the capacitors and resistors. However, the right half of the phase shift plot sees a large deviation from the predicted behavior. That is probably a result of Analog Discovery's limitation in figuring out a signal that was so attenuated at such a high frequency.

The scatter plot looks to be strongly linear and increase in a way that fits to rough 1 ft/ms for sound accordingly as the distance were farther away. The calibration line in Figure 5 is:

$$distance = 1.066 \times time \tag{6}$$

I would trust the ultrasonic range finder well, especially in close ranges. Not only did the range finder proves to be quite reliable within ten feet, but the echo signal became weaker and weaker as the known distance grow larger, making its ability of long range findings questionable.