An Autonomous ‘Pinger Tester’ to Verify the Operation of Bycatch-Reducing Acoustic Pingers for Marine Mammal-Fishery Interactions

Sabrina G. Liao
Advisors: Douglas Nowacek, Associate Professor, Electrical and Computer Engineering (ECE)
& Nicholas School of the Environment
&
Matthew S. Reynolds, Assistant Professor, ECE

Pratt Undergraduate Research Fellows Project, Spring 2011
Duke University

1 Abstract

In an effort to reduce by-catch of dolphins, porpoises, and other marine mammals as well as decrease the frequency of damaged fish and fishnets, fisheries attach pingers to the nets they lay out. These pingers are marine mammal acoustic alarm devices, with common frequencies of 10kHz and 70kHz. The human ear can ostensibly hear up to 20kHz, so the need for a 70 kHz pinger tester is evident. However, 10kHz is already past the most sensitive frequency range of human hearing, and thus, even if the 10kHz pingers emit a sound signifying their functionality, the factors working against its detection (e.g. wind, waves, ship's motor) necessitates a tester for it, and there is yet to be a low-cost option. In addition, as the batteries die, the signal amplitude will decrease, complicating detection.

This project focused on the design and construction of a pinger tester that will clearly signify the presence or lack of a pinger signal at 10kHz and 70kHz by displaying a green or red light, respectively as well as a bar graph to indicate the signal strength. These indicators would then alert fishers to the need for pinger replacements, thereby reducing the amount of unnecessary deaths and net damage.

Since the pinger testers will be used in relatively rough conditions, the different components of the pinger tester must be constructed robustly. Based off of testing done on an initial design on a protoboard, a basic prototype was built as a proof of concept. Further work to be done includes establishing the range of distances in which a hydrophone should be placed for optimal pinger testing as well as the incorporation of the peak-level detector, which was tested in the protoboard stage but left out of the basic prototype. The long-term goal of the continuation of this project is to produce an inexpensive and rugged working pinger tester option that fisheries can consider using so that unnecessary bycatch and damage due to non-working pingers will be precluded.

2 Introduction

Ever since awareness was raised on behalf of the cetaceans, which had comprised the majority of the marine mammal bycatch that resulted due to the actions of U.S. fisheries (and of the cetaceans, most consisted of dolphins and porpoises), efforts to reduce the number of marine mammal bycatch have gained steam, especially with the 1994 U.S. Marine Mammal Protection Act amendments. There is increasing admission of the fact that bycatch is the main threat to the survival and health of the populations of whale, dolphin, and porpoise species, and that extinction could be the end result if practices are not changed or implemented that would hinder the deaths and damages of such animals [1]. Among the different ways bycatch occur, gillnets were the major players, and so gillnet-related changes in fishing practices tended to bring about the most effective outcomes [2]. In the years after 1994, studies revealed a substantial decrease (92%) in the number of bycatch, which correlated to the active implementation of acoustic alarms, also known as pingers, in the late 1990's [1]. Since then, various companies have begun developing innovative pinger models and improving upon them.

With the emergence of pingers, however, there arose a need for a way to detect their functionality since many pingers do not come with their own detectors or indicators of when the pingers should be replaced. Pingers that are no longer effective (i.e. batteries have died or provide insufficient power to have an acceptably strong signal) affect both the bycatch and the fisheries negatively – the bycatch caught in the nets usually die or are injured, and as a result of having the bycatch trapped in but attempting to escape from the nets, the nets and target fish become damaged in the process. It is therefore important to be aware of when pingers need to be replaced. Current ‘pinger receivers’ or ‘pinger locators’ offer multiple functions to ensure flexibility of use, but these inevitably push the cost of these pinger detectors higher, which can run from the hundreds into the thousands of dollars [3]. The extravagant prices make them an unviable option for fisheries to use to test the status of their pingers.

This project aims to provide an economical alternative to the complete lack of testers at all in the form of a handheld ‘pinger tester’ with very limited and specific functions, namely the detection of 10kHz and 70kHz pinger signals as well as a display of the signal strength. The choice to design the device around these two frequencies is due to the availability of and easy access to the prevalent Fumunda pingers, which operate at 10kHz and 70kHz (a 3kHz pinger has also just recently been put on the market). The 10kHz frequency is known to have the longest record of successfully decreasing dolphin and porpoise bycatch and has long range [4]; the 70kHz frequency was most likely chosen because it falls within the echolocation range of many cetaceans [5][6]. Due to the fact that humans cannot hear above 70kHz, the 70kHz detector on the pinger tester is clearly necessary. The 10kHz detector is included as well because though that frequency is audible to the human ear, the combination of being outside the most sensitive range (for humans) of 1 to 4 kHz and the factors acting against the audible detection of the pinger in use at sea is cause for the addition of that detector [7]. Furthermore, there needs to be a consistent and accurate way to measure the signal strength to determine whether replacements for the pinger batteries need to be purchased and inserted rather than a simple ‘hear by ear.’ The pinger tester provides one solution. Designing around the Fumunda pingers is a good choice because they were produced with the intent to make implementation as simple and cost-effective as possible for the fisheries (e.g. easily replaced batteries, durable, light, small, no need to remove when setting and dragging net), making their pingers the option that is more likely to be chosen, and thus the pinger tester that comes out of this project would be most appropriate [4].

3 Design

3.1 Components

The LM567CN Tone Decoder was chosen to be the basis of the frequency detectors owing to its low cost, relatively simple circuitry, and match of desired functionality, which is to drive a load when it detects a persistent frequency within the range controlled by the external components connected to it [8]. An LED was wired to the output since it serves as a very simple and clear visual indicator of detection. Green was arbitrarily decided upon to denote the presence of a 70kHz signal, and red for the presence of a 10kHz signal. Another addition is the 0.1uF capacitor inserted between the signal and the input pin of the decoder to smooth out the signal. The particular setup of the Tone Decoder employed is shown below (Fig. 1) where input is the pinger signal.

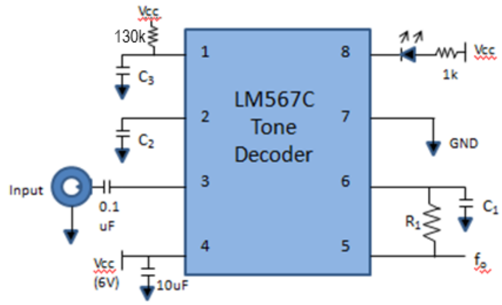


Figure 1: The LM567C/LM567CN Tone Decoder setup as frequency detector

The design equations provided with the Tone Decoder's documentation guided the selection of the external filter and timing elements. Equations 1 to 4 comprise the equations, with 2 and 3 resulting from additional information from the included Bandwidth vs. Input Signal Amplitude graph. f_c is the center frequency to be identified, so 10kHz or 70kHz in this case.

$$f_o = \frac{1}{1.1R_1C_1} \tag{1}$$

For Bandwidth (BW) of 15%: $f_oC_2 \approx 0.8*10^3$ (2)

For Bandwidth (BW) of 5%: $f_oC_2 \approx 10*10^3$ (3)

$$C_3 = 2C_2 \tag{4}$$

The main determinant for which values were selected, after preliminary calculations of and changes to the theoretical values based on recommendations from the data sheet, was availability [in the laboratory] of such values since the focus is to first build a few prototypes to demonstrate a proof of concept. In regards to the bandwidth of the frequency range (in % of f_c) that the detectors would pick up, there was no immediate data for the frequency tolerances of the pingers, and thus the ranges were simply chosen to allow a roughly 1.5kHz margin for the 10kHz pinger and a margin of error of a few kHz for the 70kHz pinger.

To display the relative strength of the pinger signal, the LM3915 Dot/Bar Display Driver in conjunction with a 10-Segment LED bar graph were chosen [9][10]. The LM3915 Display Driver was configured to work as a 0V to 10V Log Bar Display for range, which was facilitated by its versatility. The bar graph was an ideal substitute to a conventional meter because of its faster response and better durability. As with the frequency detectors, a 0.1uF capacitor was added between the signal and the input pin to the display driver. Another minor alteration, which is reflected in Figure 2, was the 150k resistor that pulled the input to the driver to ground in order that the LED bar graph would have none of the LEDs light up when a signal was not sensed (without it, the LEDs remained high by default).

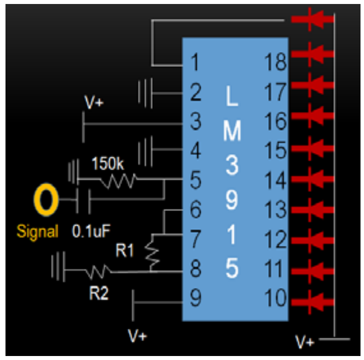
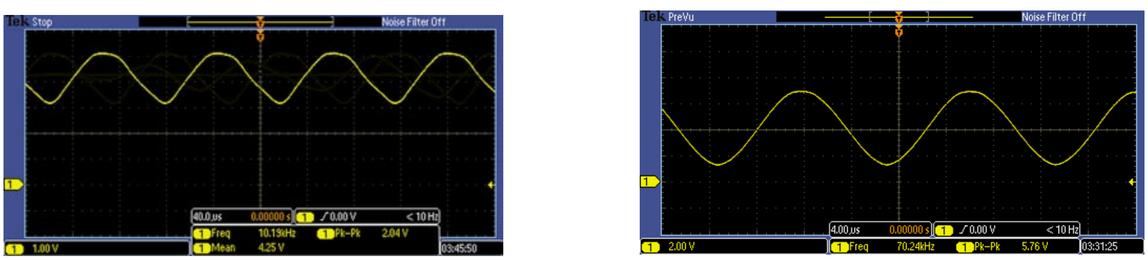


Figure 2: The tailored LM3915 Bar Display Driver

Only one equation was necessary for the application the driver would be used as, and it is shown below.

$$V_{ref} = 1.25V(1 + \frac{R_2}{R_1}) + R_2 * 80\mu A \tag{5}$$

To determine what the reference voltage (V_{ref}) should be, the pinger signals had to be measured for their approximate voltage amplitudes. Using an oscilloscope and a hydrophone with a pre-amp, plots of the pinger signals were obtained (Fig. 3).



(a) (b)

Figure 3: (a) Vpp of 10kHz pinger is ~2V; (b) Vpp of 70kHz pinger is ~6V

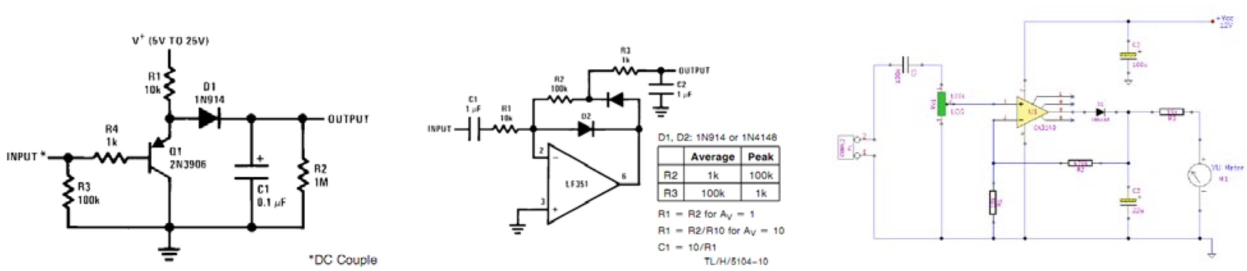
Because the LM3915 only responds to the positive half-cycles, V_{ref} must be at least half of the maximum voltage detected between the two signals, which would be 3V since the greater 70kHz signal is roughly 6V. The V_{ref} was then set to be 4V to allow for unexpectedly larger signals. There are variants of the op-amps and IC's we use that would take less power to operate, but they are more expensive, so the afore-mentioned components are our final choices

3.2 Initial Protoboard Trial

Placing all the components on a protoboard revealed the differences between theoretically ideal values and experimentally more suitable ones due to deviations from nominal settings. The bandwidths were not as large as anticipated (7% for 10kHz, 4% for 70kHz), but the margin still seemed reasonable, so the elements affecting those values were left unchanged. The center frequencies were also not quite right, but that is very possibly due to not having the exact values needed. Since there is more flexibility in picking resistor values than in picking different capacitors, a potentiometer was used to find the values that would in reality result in center frequencies at 10kHz and 70kHz.

On contemplating whether efforts to integrate a hydrophone into the prototype design should be made or not, factors such as cost, space and placement, versatility. Simply including a hydrophone in the design would significantly increase the cost of a pinger tester, but not necessarily increase its value to the same extent as a more complete pinger tester. If the goal is to make the pinger tester compact and thus have only the hydrophone head sticking out of the device, the hydrophone and the battery powering it would require the enclosure to be larger in order to provide adequate additional internal space. Having this setup would also necessitate a waterproof enclosure since the hydrophone receiver must be submerged to accurately pick up the pinger signals. Leaving the hydrophone out of the design specifications allows the potential customer (presumably someone affiliated with a fishery) to plug into the pinger tester whatever hydrophone is already available, and using the combined specifications of the hydrophone and tester, determine the acceptability of the signal strength.

In an effort to have a more stable and steady display for the signal strength, various peak detector models were evaluated. The first two came from the display driver's own data sheet [9], while the last came from an outside source [11]. The first model tested was the Half-Wave Peak Detector (Fig. 4a) since the goal is to have the simplest circuit using parts, which are already available. This gave an offset of 4 LEDs and did not prevent the display from flickering. It was surmised that the cause was having the C_1 capacitor and R_2 resistor of the peak detector in parallel with the 150k resistor that's already connected to the display driver. Observing a slower discharge of the display after taking out the 150k resistor confirmed the hypothesis. However, the offset remained a problem due to the uneven drops in voltages across the transistor and diode. Unsuccessful attempts to even them out (e.g. replacing the diode with a transistor) led to the testing of another model, the Precision Half-Wave Rectifier (Fig. 4b). Although the model called for a LF351 op-amp (single supply), the only op-amp that was most similar to it and available at the time was a dual supply op-amp and caused the circuit to behave unexpectedly. A third model was chosen as a last resort, the Audio Peak Level Meter (Fig. 4c). Initially, its inclusion made the signal strength bar graph much too sensitive, so many elements had to be replaced. The best, but still not perfect, configuration was with the addition of a 470k resistor in series with the capacitor to the positive input of the op-amp and of a 270k resistor going into the negative input. Due to the timing constraints for perfecting a peak detector and lack of a dire need for it, one was not included in the final prototype, but perhaps the next version of this prototype will be able to incorporate the results of this experimentation.



(a) (b) (c)

Figure 4: (a) Half-Wave Peak Detector; (b) Precision Half-Wave Rectifier; (c) Audio Peak Level Meter

3.3 Printed Circuit Board (PCB)

The schematic in Figure 5 displays all the main components as well as auxiliary ones such as the power LED indicator, the capacitor that is meant to keep the power supply 'clean' and not too affected by the noise that would result from the LEDs' switching between the on and off states, power terminals to which the battery would be connected, the audio jack for the hydrophone input, the power switch, and the drill holes to attach the PCB to the enclosure.

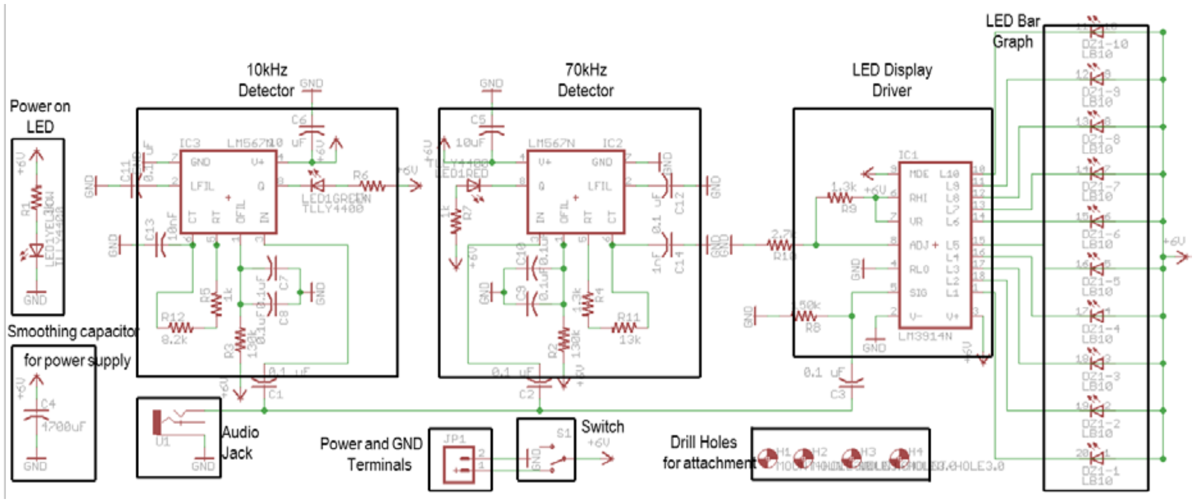


Figure 5: Schematic of entire pinger tester

Before laying out the parts on a board, a box enclosure had to be selected first. The few sought after features were a relatively small size for ergonomic reasons, simple and flat for easy adaptation, and clear documentation of all the different dimensions of the box, which would need to have the capacity to hold 4 AA batteries. A suitable candidate was found in the 90-series of Box Enclosures, Inc. [12]. Having decided on a box, the dimensions of the PCB were subsequently determined to be 2.6 in. x 2.7 in. The general look of the final product from the outside served as the foundation for the placement of components. The PCB was laid out using Eagle Cad software, and the final board layout is shown below (Fig. 6).

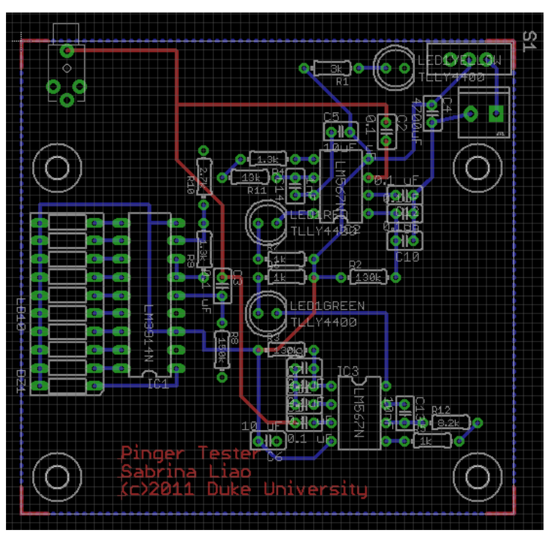


Figure 6: PCB for pinger tester

When the board arrived, and everything was soldered on, further testing demonstrated once again that 'ideal' and even experimentally obtained trial values do not always guarantee expected performance. The bandwidths and center frequencies had shifted again, so values had to be tweaked once more: the 1.3k resistor for the 70kHz detector was replaced with a 1.8k resistor, and the 1k resistor for the 10kHz detector was replaced with a 2.2k resistor. Those changes brought the center frequencies closer to their nominal frequencies. In the hopes of increasing the bandwidth for the 10kHz detector since its bandwidth seemed so tight, a capacitor with smaller capacitance (22nF) was soldered in place of the original C_2, 0.1uF capacitor, but there was no considerable difference. A reduction of the capacitance C_2 for the 70kHz detector would ostensibly have no considerable change as well. It was realized that such a large 4700uF smoothing capacitor for the power supply was not necessary, and so a smaller 100uF capacitor took its place. Various measurements were taken using the oscilloscope and function generator to document the product details: frequency detector output vs. input frequency (Fig. 7), frequency detector output vs. input signal amplitude (Fig. 7), bar graph calibration per LED at both frequencies (Fig. 8), and power consumption when not detecting pingers, and as a function of LEDs lit (Fig. 8). The max input signal amplitude for each detector tested was based off of the average signal amplitude of the respective sample pingers.

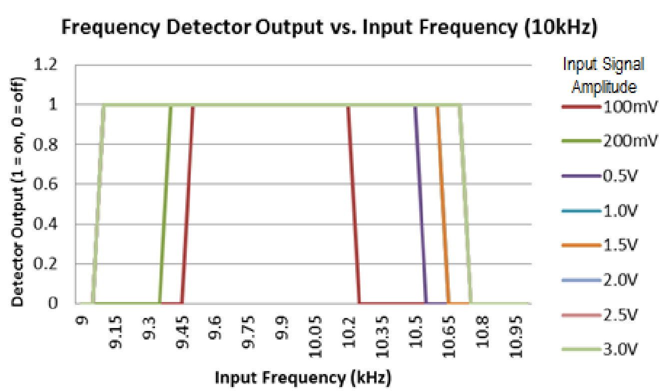


Figure 7a: Frequency Detector Output vs. Input Frequency according to Input Signal Amplitude for the 10kHz Detector

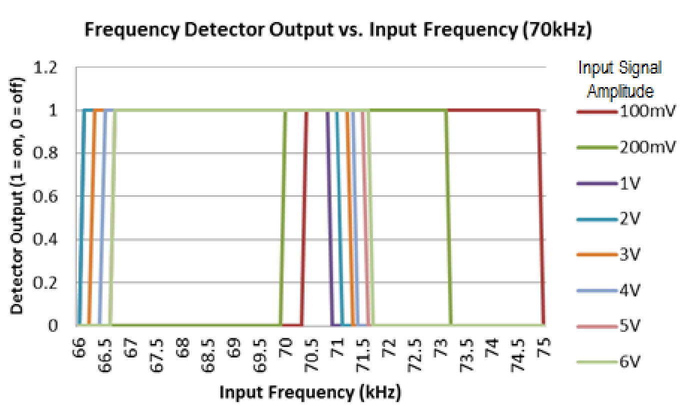


Figure 7b: Frequency Detector Output vs. Input Frequency according to Input Signal Amplitude for the 70kHz Detector

LEDs lit	Bar graph Calibration for each LED		Voltage Drop (V)	Current Drawn (I)	Power Consumed (P = I*V)
None	-		6V	21mA	126mW
1	350mV		6V	32mA	192mW
2	490mV		6V	37mA	222mW
3	690mV		6V	42mA	252mW
4	960mV		6V	48mA	288mW
5	1.3V		6V	55mA	330mW
6	1.7V		6V	63mA	378mW
7	2.3V		6V	71mA	426mW
8	3.1V		6V	78mA	468mW
9	4.3V		6V	87mA	522mW
10	5.9V		6V	89mA	534mW

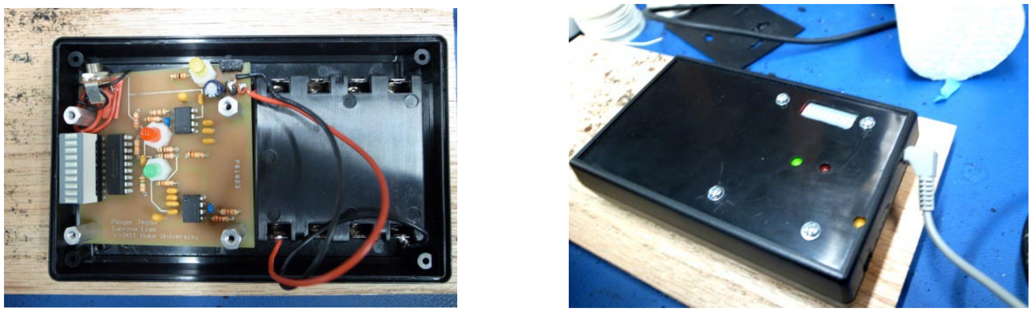
Figure 8a: Calibration and Power Consumed as a function of LEDs lit for 10kHz Detector

LEDs lit	Bar graph Calibration for each LED		Voltage Drawn (V)	Current Drawn (I)	Power Consumed (P = I*V)
None	-		6V	21mA	126mW
1	370mV		6V	33mA	198mW
2	510mV		6V	37mA	222mW
3	710mV		6V	42mA	252mW
4	970mV		6V	43mA	258mW
5	1.4V		6V	46mA	276mW
6	6V		6V	46mA	276mW
7	*		-	-	-
8	*		-	-	-
9	*		-	-	-
10	*		-	-	-

Figure 8a: Calibration and Power Consumed as a function of LEDs lit for 70kHz Detector
*There was unstable flickering for the 7^{th} and higher LEDs, so data for those were not included

3.4 Resulting Prototype

Since the hydrophone was already determined to not be included, incorporating a 9V battery was not necessary, and 4 AA batteries were the easy choice for the power supply as the protoboard had been working on such a supply during the design process. With the minimal current draw of about 20mA and a peak current draw of about 90mA, the average current draw is 55mA. The capacity of a 1.5V AA battery is ~2750 mA*hr., which means the pinger tester could operate for 50 hours before needing new batteries [13]. After the PCB was attached and all the holes for the LEDs, bar graph, switch, and audio jack were made to the enclosure, the pinger tester prototype was complete (Fig. 9).



(a) (b)

Figure 9: (a) Internal view of final pinger tester prototype; (b) External view of pinger tester

If we were to build 1000 of these pinger tester devices, the total cost of the entire device is estimated to be a little over $10, a significant difference from other pinger receivers that can run into the hundreds and even thousands. Being so simple yet helpful and inexpensive, the pinger tester becomes a viable and attractive product for customers such as fisheries.

	Price	Quantity	Total Cost
Tone Decoder	0.783/each	2	1.566
Dot/Bar Display Driver	1.334/each	1	1.334
10-segment LED Display	0.693/each	1	0.693
PCB	1.49/each	1	1.49
Box enclosure	4.73/each	1	4.73
Misc. LEDs and capacitors* (estimate)			0.5
		Total cost:	10.513

Figure 10: Cost of one pinger tester assuming mass distribution of the devices

4 Conclusion

A prototype of a low-cost and easy to use pinger tester was successfully designed and built. A small PCB contained all the circuitry and indicators needed for its functionality. With no built-in hydrophone, the pinger tester can be manufactured and distributed at a much lower price while allowing fisheries to use what hydrophone equipment is already available. Operating on 4 AA batteries, the pinger tester can operate for an average of 50 work hours before requiring battery replacements. Further studies can be executed to determine whether the visual indicators of signal presence and strength do indeed decrease instances of bycatch and net damage by discovering which pingers are failing earlier.

5 Acknowledgements

I would like to thank Professor Doug Nowacek for the original idea and funding and equipment used for the initial implementation of this project using a DSK development kit. I would also like to thank Professor Matt Reynolds for his patience and extremely good guidance and assistance in the new implementation of the project using analog circuits and for purchasing the necessary components for the prototype-designing process. I appreciate the grad students in Professor Reynolds lab – although they were not involved with my project, they were always friendly and willing to lend a hand in whatever way they could. And finally, I thank Dean Absher for allowing me the opportunity to explore research and for being flexible in allowing me to re-evaluate the project's direction when things seemed to hit a wall.

References

[1] Andrew J. Read, Phebe Drinker, and Simon Northridge, *Bycatch of Marine Mammals in U.S. and Global Fisheries*, Vol. 20. Beaufort, NC: Society of Conservation Biology, 2006, 163-169.

[2] Stephen M. Dawson, Andrew Read, and Elisabeth Slooten, *Pingers, Porpoises and Power: Uncertainties with Using Pingers to Reduce Bycatch of Small Cetaceans*. Great Britain: Elsevier Science Ltd, 1998, 141-146.

[3] Detector Electronics Corp., “Metaldetector.com,” 2003, http://www.metaldetector.cc/index.asp?PageAction=VIEWCATS&Category=80, May 2010.

[4] Fumunda Marine, “How Fumunda Pingers Work,” 2009, http://www.fumunda.com/how, May 2010.

[5] Seaworld, Inc., “Communication and Echolocation,” 2002, http://www.seaworld.org/infobooks/bottlenose/echodol.html, Apr. 2011.

[6] Darlene R. Ketten, “Cetacean Ears,” in *Hearing by Whales and Dolphins*, Whitlow W.L. Au, Arthur N. Popper, and Richard R. Fay, Ed. New York: Springer-Verlag New York Inc., 2000, 43-48.

[7].Steven W. Smith, Ph.D., “Audio Processing,” in *The Scientist and Engineer’s Guide to Digital Signal Processing*, California Technical Publishing, 2007, http://www.dspguide.com/ch22/1.htm, Apr. 2011.

[8] National Semiconductor, “LM567/LM567C Tone Decoder,” National Semiconductor, 2003, http://www.national.com/ds/LM/LM567.pdf.

[9] National Semiconductor, “LM3915 Dot/Bar Display Driver,” National Semiconductor, 1995, http://media.digikey.com/pdf/Data%20Sheets/National%20Semiconductor%20PDFs/LM3915(Feb95).pdf.

[10] Kingbright, “10 Segment Bar Graph Array,” Kingbright, 2011, http://www.us.kingbright.com/images/catalog/SPEC/DC10SRWA.pdf.

[11] Andy Collinson, “Audio Peak Level Meter,” http://www.zen22142.zen.co.uk/Circuits/Audio/palm.htm, Feb. 2011.

[12] Box Enclosures, Inc., “90-Series,” Box Enclosures, Inc., 2004, http://www.boxenclosures.com/technical_drawings/90series.pdf, Mar. 2011.

[13] Energizer Holdings, Inc., “Energizer E91,” Energizer Holdings, Inc., http://data.energizer.com/PDFs/E91.pdf, Feb. 2011.