NEONUR: A FEEDING DEVICE FOR PREMATURE NEONATAL NURSING

NSF Summer Undergraduate Fellowship in Sensor Technologies
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ABSTRACT

Premature infants lack the ability to communicate verbally; therefore doctors who care for them need tools to measure their health, particularly their ability to nourish themselves adequately. These measurements need to be obtained in a variety of locations, such as intensive care nurseries and in homes. The bulky size and tethered nature of current devices measuring infant feeding make such monitoring too difficult. Nurses doing research at the Children's Hospital of Philadelphia (CHOP) have requested the University of Pennsylvania School of Engineering to develop a device that will meet the needs of CHOP nursing researchers. During the 2007-2008 academic year, University of Pennsylvania Seniors Leslie Chen and Preeti Rajendran have worked on developing a prototype for a new system that has progressed to the troubleshooting phase. In particular, problems with the on board FLASH memory chip persist. This summer, functionality of data acquisition, data amplification, and Enhanced Universal Synchronous Asynchronous Receiver Transmitter (EUSART) communication between the microcontroller and a personal computer have been tested, modified and are now confirmed to be functioning properly. There is still a need for more testing before a prototype will be ready for further testing and optimization.

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1. INTRODUCTION

1.1. Motivation

In the United States in 2006 over half a million babies were born prematurely. [1] Researchers in the Department of Nursing at the Children's Hospital of Philadelphia (CHOP) are studying the development of the feeding instinct and sucking abilities of ill and premature neonates. To monitor the babies' sucking ability, researchers have been using a device that measures the flow of milk through a bottle to the infant. Measurement of infant sucking behavior is important in determining infant health, as it is a critical function leading to growth and development. [2]

The researchers at CHOP have been using a device that requires the complicated assembly of many parts and time-consuming cleaning after each use. In addition, the device that is currently in use consists of a large, expensive processing unit that must be connected by a wire to a feeding apparatus. This impairs the ability of researchers to maneuver and orient the device as needed, so measurements are difficult to obtain in the real settings in which these infants will need to nourish themselves adequately. Furthermore, the poor maneuverability and the complex process of preparing the current device for each use introduce significant human error into the data.

A prototype NeoNur device has been developed up to the debugging stage. The electrical circuit consists of a pressure sensor, a PIC microcontroller, an instrumentation amplifier, and a FLASH memory chip, along with a battery, resistors, capacitors, pins to program the PIC microcontroller, and pins to communicate with a computer. Using this system, the device is designed to collect inputs from a pressure sensor, process them, and save them to the FLASH memory chip. Upon request, the device would then retrieve that information and send it to a computer. According to calculations made by a University of Pennsylvania senior design team for the 2007-2008 academic year, the device is designed to cost a maximum of $170 per unit, while the equipment that is currently in use costs almost $5000.00.

1.2. Goals

This past academic year, a senior design team at University of Pennsylvania worked on the NeoNur device and has developed software and hardware to the troubleshooting phase. The goals for the summer of 2008 were:

1. Identifying which parts of the design are functioning properly
2. Determining the sources of error in hardware and software
3. Implementing a simple solution to correct these problems.

2. BACKGROUND

2.1. Previous Devices

In the early 1960's researchers at the University of Pennsylvania School of Medicine developed an apparatus to measure infant feeding behavior. Using the device, researchers found that healthy babies produced pressures between 0 and -300mmHg compared to atmospheric pressure. [3] The device used (Figure 1) is composed of a burette with a stopper in the top filled with formula, milk, or other nutritious fluid, that is connected by a capillary tube to a pressure transducer and a nipple, from which the infant sucks the fluid. The pressure transducer is then connected to an amplifier that sends information to a recorder. While this device successfully measured feeding, the process was unnatural, as the infant had to lie on his or her back with the nipple in its mouth instead of being held in a more upright position as occurs while feeding from a bottle or from a breast.

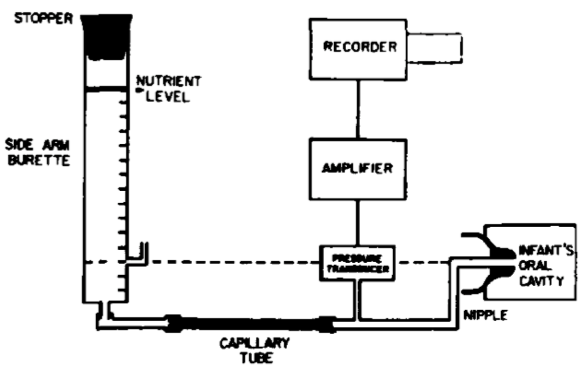


Figure 1: Kron apparatus for measuring newborn sucking behavior

Reuben E. Kron and Mitchell Litt further developed the idea of making a device to measure feeding in the early 1990's. The device that resulted is the apparatus that is currently being used by researchers at CHOP. It was an improvement over the previously used device in that it made feeding much more natural, as the neonates could be held while being fed, instead of having to lie on their backs. However, the wires still got in the way. Figure 2 demonstrates that the device currently in use at CHOP has a processing unit as well as a bottle with the sensory electronics contained in the upper portion. It is large and bulky, the bottle is tethered to the processing unit, and the system as a whole is not easily transportable.

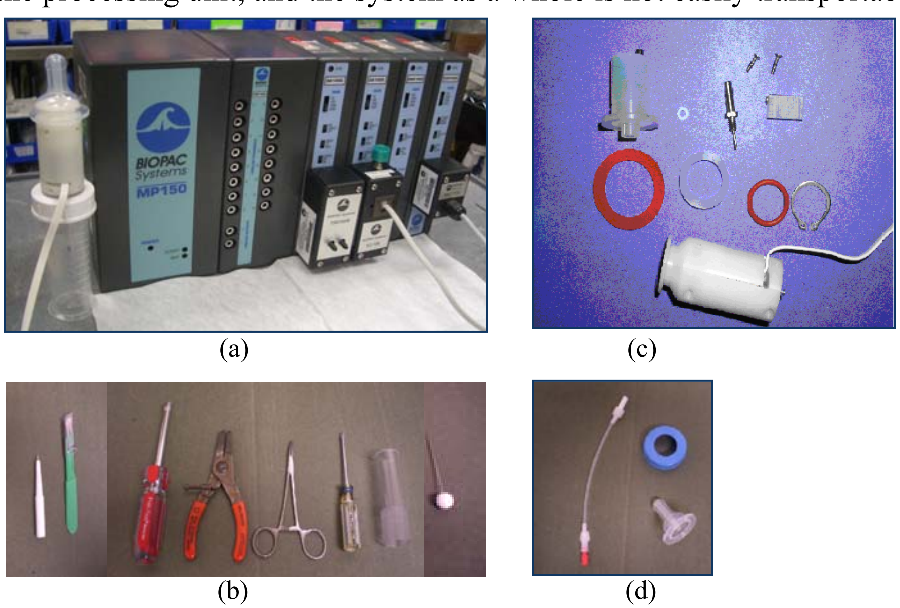


Figure 2: The bulky processing unit (a), the 8 tools used to assemble and disassemble the device (b), and the 14 parts of the bottle (c,d), of the current device being used at CHOP

It requires eight tools to disassemble the device for cleaning in between uses, and the bottle breaks up into many small pieces. Disassembling, cleaning and reassembling the current device takes approximately 35 minutes and it is a complex and confusing process that has introduced error into the calculations and measurements taken by the device.

A team from Houston, Texas developed another apparatus in 2001 that is based on the same principles as the previous devices (Figure 3). A nipple is connected to a pressure transducer via a capillary tube, which then outputs data to a signal processor connected to a chart recorder. [4]

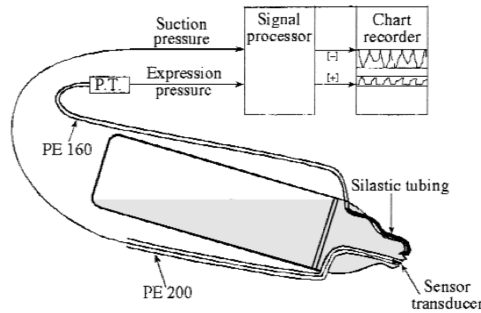


Figure 3: Device developed in Texas

None of the previous devices have managed to implement a wireless system or made the apparatus user-friendly. Additionally, none of the other devices have the capability to integrate other vital signs into the measurements collected, showing the interaction between other body functions, such as breathing, and neonatal feeding.

2.2. Scientific Principles Behind Design

The NeoNur design is based on the Hagen-Poiseuille equation, which states that the volumetric flow rate of a liquid through a pipe is proportional to the pressure differential at either end of that pipe. Since volumetric flow is constant in a continuous pipe, with atmospheric pressure on one end of the tube, the pressure at any point in the tube with respect to atmospheric pressure is proportional to the pressure created within the feeding infant’s mouth with respect to atmospheric pressure. Since the infants’ ability to create negative pressure is necessary for normal feeding, measuring pressure in the milk is desirable.

The pressure transducer uses piezoresistors arranged in a Wheatstone bridge. When a voltage is placed across two opposite corners of the Wheatstone bridge, the voltage difference across the other two corners is proportional to the pressure deforming the piezoresistive elements.

3. TESTING THE PRESSURE TRANSDUCER

Qualitative testing showed that the pressure transducer was functional. Because there were no devices available to create a preset or known level of pressure, one node of the pressure sensor was connected to ground, and the opposite node was connected to a power source set to 3V. Sucking on the tube connected to pressure sensor resulted in the voltage across the other two nodes increasing above zero volts; blowing through the same tube caused the voltage to drop below zero.

4. TESTING THE INSTRUMENTATION AMPLIFIER

Multiple tests of the instrumental amplifier led to the conclusion that the instrumental amplifier is functional. In all tests performed specifically on the instrumental amplifier,

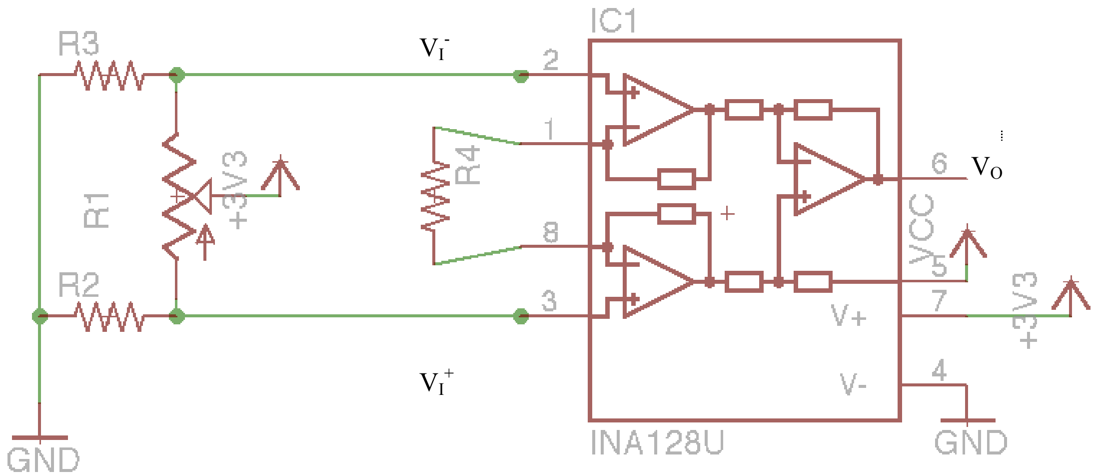


Figure 4: The Circuit test the amplifier. R_1=92.5kΩ, R_2=R_3=98.7kΩ, R_4=R_G.

the circuit depicted in Figure 4 was used. The amplifier used the INA128U by Burr-Brown Products from Texas Instruments. Signal amplification can be controlled by selecting a resistor value, R_G, that goes across pins 1 and 8 of the chip.

In testing, researchers found that babies produce no more than 300 mmHg of negative pressure [3]. Because the pressure sensor being used is rated at a sensitivity of 5µV/mmHg/V, and because the pressure sensor will be powered by 3V, the maximum voltage coming from the pressure sensor would be 4.5mV. To insure a margin of safety, a maximum voltage of up to 5mV was assumed. The input range of the ADC of the microcontroller is 3.2mV to 3.0 V. A gain between 200 and 300 would result in a maximum voltage between 2.15V and 2.75V.

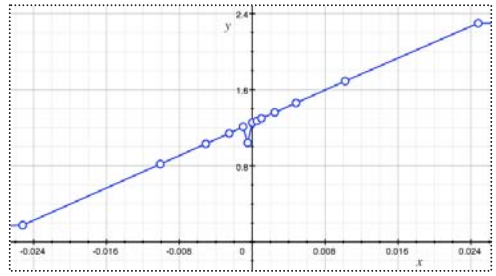
4.1. INA128 Test 1

The first test of the amplifier used the R_G value from the circuit from the beginning of the debugging phase of the project. This R_G value was 997Ω≈1kΩ; however, as the data in Table 1 and Figure 5 show, the gain is much lower than expected, at 40 to 50 in the range of operation.

Table 1

V_I (mV)	V_O (V)	V_O-V_{REF} (V)	G
1,440	2.31	1.06	0.736
959	2.31	1.06	1.11
514	2.30	1.05	2.04
249	2.30	1.05	4.22
99.4	2.30	1.05	10.6
50.6	2.30	1.05	20.75
24.8†	2.30	1.05	42.3
10.2†	1.69	0.44	43.1
4.91*†	1.46	0.21	43.7
2.46*,†	1.36	0.11	44.7
1.01*†	1.30	0.05	47.5
0.500*†	1.27	0.02	40
0.00*†	1.25	0.00	N/A
-0.498*‡	1.04	-0.21	422
-1.01*,†	1.21	-0.04	39.6
-2.53*,†	1.14	-0.11	43.5
-5.10*,†	1.03	-0.22	43.1
-10.1†	0.819	-0.431	42.7
-25.2†	0.176	-1.07	42.6
-50.1	0.0802	-1.1698	23.3
-100.	0.0830	-1.167	11.7
-250.	0.0897	-1.1603	4.64
-501	0.0960	-1.154	2.30
-1000	0.105	-1.146	1.15
-1440	0.104	-1.146	0.796

(a)



(b)

Figure 5: Graph of data from Table 1 (a), and the linear region therein (b).

* In range of operation
† In linear region
‡ Outlier

The average gain within the range of operation was 43.0. As a result, the choice of R_G is clearly incorrect. The calculation that R_G ought to be around 1 kΩ was made based on a previous circuit that used the INA122 differential amplifier, and had not been updated when the INA128 instrumentation amplifier was implemented. As a result, the gain equation used had been:

$$G = 5 + (200\ k\Omega / R_G)$$

but gain equation for the instrumentation amplifier is:

$$G = 1 + (50\ k\Omega / R_G)$$

As a result, the 1 kΩ resistor was replaced with one with a value of 270 Ω.

4.2. INA128 Test 2

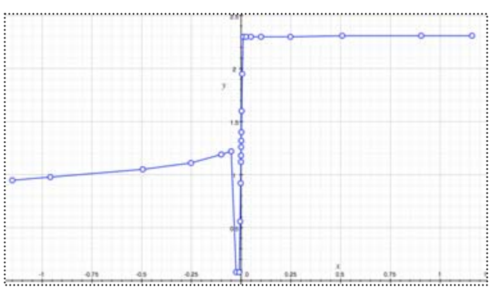
For the second Test of the instrumentation amplifier, a 270 Ω resistor was used for R_G, in order to yield a gain of about 190. The results are shown in Table 2 and in Figure 6. While the gain increased significantly, testing had been done on a breadboard, and the circuit needed to be implemented using surface-mount resistors. Since there were no 270

Ω surface mount resistors available, testing needed to confirm that the amplifier functioned with a 240 Ω resistor soldered onto a test board.

Table 2

V_I(mV)	V_O(V)	V_O-V_{Ref}(mV)	G
-1,150	0.947	-308	0.268
-959	0.977	-278	0.290
-494	1.05	-202	0.409
-252	1.11	-140	0.556
-100	1.19	-688	0.688
-49.9	1.22	-358	0.717
-25.1	0.0801	-1,170	46.6
-9.82	0.0798	-1,170	119
-5.08[†]	0.559	-695	136
-2.47[†]	0.919	-336	136
-1.00[†]	1,12	-131	131
-0.550[†]	1.18	-70.5	128
0.003[†]	1.26	3.49	1160[*]
0.490[†]	1.32	69.8	142
1.05[†]	1.40	146	139
2.50[†]	1.60	346	138
5.07[†]	1.95	701	138
11.0	2.30	1,050	95.5
25.1	2.30	1,050	41.8
49.0	2.30	1,050	21.4
100.	2.30	1,050	10.5
248	2.30	1,050	4.23
508	2.31	1,060	2.07
905	2.31	1,060	1.16
1,160	2.31	1,060	0.914

[*] In range of operation
[†] In linear region
[‡] Outlier



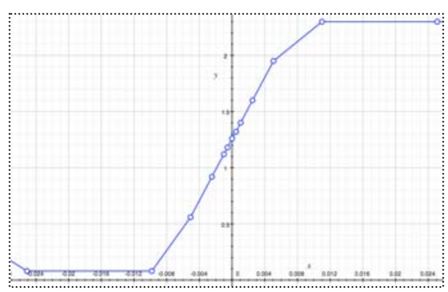


Figure 6: Graph of V_O from Table 2. All points (top) and relevant area (bottom)

4.3. INA128 Test 3

The third test of the instrumentation amplifier used the test board and sockets. Plugging only instrumentation amplifier into the test board yielded the results in Table 3 and Figure 7.

Table 3

V_I (mV)	V_O (mV)	V_O-V_{Ref} (mV)	G
-104	88.0	-1,157	11.1
-11.6	82.3	-1,162.7	100
-1.48*	1,020	-225	152
0	1,245	0	N/A
1.09*	1,400	155	142
2.34*	1,590	345	147
4.60*	1,940	695	151
10.2	2,300	1,055	103
98.9	2,300	1,055	10.7

*Range of Operation

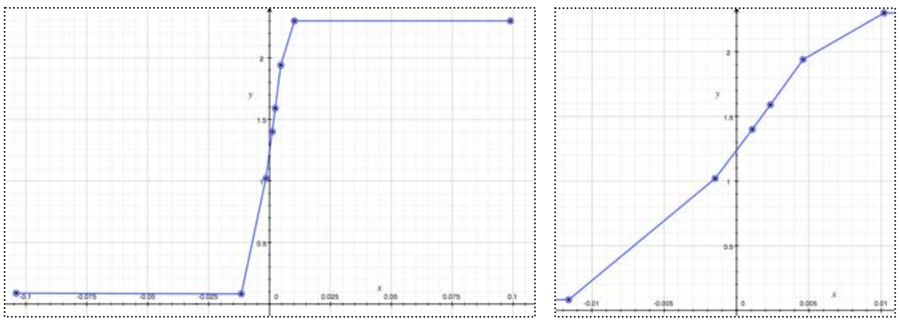
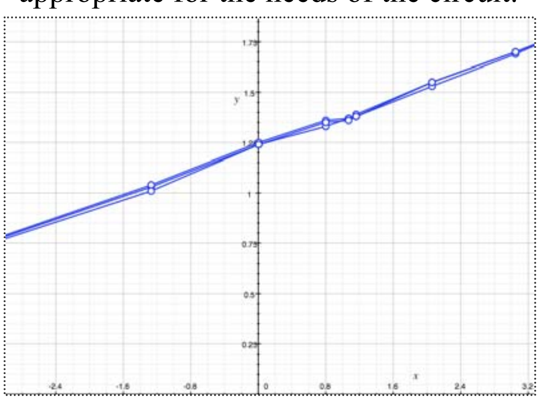


Figure 7: The full result (left) and the range of operation (right) from the data in Table 3

4.4. INA128 Test 4

In order to check consistent performance using different chips, 3 different INA128U chips were tested side-by-side. The results in Figure 8 show that all three chips followed almost the exact same path. The amplification and exact values that the test yielded were appropriate for the needs of the circuit.



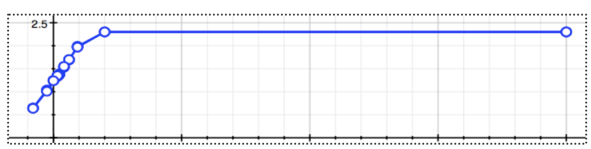


Figure 8: The full range (above) and range of operation (left) graphs for the multiple INA128 test

5. TESTING THE MICROCONTROLLER

Three aspects of the microcontroller had to be tested: the ADC input, the EUSART asynchronous communication with an external computer, and serial communication with a FLASH memory chip.

5.1. Testing the ADC

The first part of the microcontroller tested was the analog to digital converter. A sinusoidal signal was sent into the ADC port of the microcontroller. The microcontroller was programmed to take the digital conversion of the signal and to output it serially to one of its pins. Figure 9 shows the analog to digital converter functioning properly.

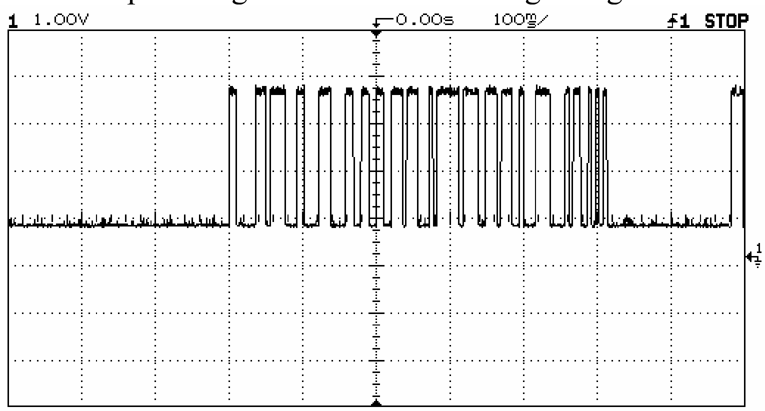


Figure 9: Output from the ADC test

5.2. Testing the EUSART

The second part of the microcontroller that was tested was the EUSART communication between the computer and the microcontroller. Initial testing (Figure 10) showed that the computer successfully sent information to the microcontroller; however, the microcontroller was not able to store that information. In order to solve this problem, a header was used. The header allowed the computer to display the internal workings of the microcontroller. With the help of the header it was found that there were problems with the wiring of the test board. The circuit was designed such that the microcontroller and the computer were connected output-to-output and input-to-input, so that neither was receiving information that the other was transmitting. After soldering extra pins and inverting the EUSART cable, the problems with wiring were solved. Appropriate

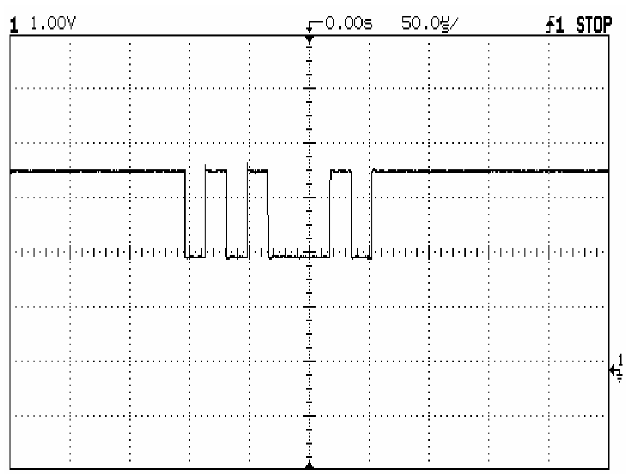


Figure 10: Transmission of an ASCII 'E'. The signal reads 0/1010 0010/1 = start/0x45/stop. 0x45 = 'E', and is sent LSB

changes were made to the schematic of the circuit so that future circuits will be functional without soldering in extra wires. Thus, the EUSART connection with the computer was shown to be functional.

5.3. Testing the SSP

The last element in the circuit that was tested was SSP communication between the microcontroller and the FLASH memory chip. SSP communication from the microcontroller to the FLASH appeared to be successful; however, using a header will be necessary to confirm that information is properly received and stored. The functionality of the header requires it to be powered by the computer, which is only able to output 5V, a voltage that would damage the FLASH memory chip. In order to use the FLASH and the header at the same time, a voltage converter needs to be assembled to protect the FLASH and to raise the output voltage of the FLASH to 5V. Development of such a voltage converter is underway, and will be completed soon. The serial communication is functional; however, the accuracy of the information sent to and from the FLASH is not yet confirmed.

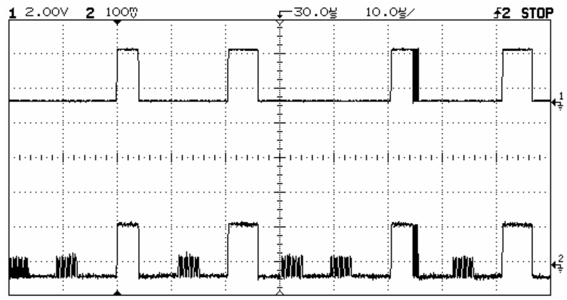


Figure 11: When the chip select signal (top) is high, the signal to the FLASH (bottom) stays high, but when the chip select signal is low, data is transferred to the FLASH

6. CONCLUSIONS

The entire circuit has not yet been tested, but finishing testing is well within sight. It will still be necessary to calibrate the device, and ensure that the pressure readings are accurate. One major reason to do so is because the INA128 testing was not done using the microcontroller. Reading outputs through the microcontroller is a better method for testing the amplifier because it provides a true measurement of what is being recorded. Additionally, testing while using the actual program that will ultimately run in the device needs to be completed. Figuring out how to progress through the routine of feeding the infants is necessary. Ultimately, the feeding device is on its way to completion.

7. NOMENCLATURE

ADC	Analog-to Digital Converter
EUSART	Enhanced Universal Synchronous/Asynchronous Receiver/Transmitter
LSB	Least Significant Bit
MSB	Most Significant Bit
SSP	Synchronous Serial Port

8. HARDWARE

Microcontroller: PIC16F690 SOIC by Microchip
Instrumentation Amplifier: INA128U by Burr-Brown of Texas Instruments
FLASH: S25FL016A by Spansion
Pressure Sensor: Various

9. ACKNOWLEDGMENTS

I would like to thank Dr. Jay Zemel for being a helpful and supportive advisor, answering numerous questions, explaining the concepts involved in designing the device. Dr. Zemel provided guidance through the obstacles I faced doing my research, and made my work possible. I would also like to thank Sanket Doshi greatly; working in the lab with me, he was an excellent go-to-guy every day. I would not have been able to accomplish what I have without his help. I would also like to thank Leslie Chen and Preeti Rajendran for laying the groundwork and providing resources for my work this summer. Also, thank you to the RCA laboratory for allowing me to use their resources. Thanks are also due to Dr. Jan Van der Spiegel, and everyone else that organized SUNFEST 2008, for creating such an incredible opportunity and an outstanding program. Finally I would like to thank the National Science Foundation for funding the SUNFEST program, and for giving young engineering and science students, like myself, opportunities to conduct research as undergraduates.

10. REFERENCES

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11. APPENDIX Schematic of Information Flow Through Hardware