University of Minnesota

Department of Electrical and Computer Engineering

Handheld Bio-Sensing System

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Executive Summary

It is estimated that in the year 2012, over 500,000[1] people worldwide will die due to one or more forms of cancer. Research shows that the number of deaths can be greatly reduced when early detection followed by therapy is exercised. Our team is part of a project that attempts to reduce this staggering number by detecting cancer cells at an earlier stage.

A bench-top system has been developed that makes use of advanced magnetic sensors for early cancer cell detection. The electrical system supporting the sensors uses large and expensive equipment, making it unfeasible for real world testing applications. Our team has been further developing a design started by the previous year's team. The design attempts to tackle this feasibility issue by reducing the size and cost of the system.

The previous team's design uses a low resolution microprocessor along with external Integrated Circuits (ICs) for signal generation and detection. The lower resolution signal generation introduces higher than desirable noise corruption, and the serial communication with external ICs reduces the speed of the overall system. The previous team also designed a high current driving power amplifier, but it was found to overheat after a short time of operation resulting in its output amplitude drifting.

Our team takes advantage of a Digital Signal Processing (DSP) microcontroller with built in signal generation and detection capability. This improves Signal to Noise (SNR) performance and reduces the stress on the processor, by using higher resolution signal generation and eliminating serial communication. The team also improved the tracing and component placement on the Amplifier PCB in order to increase efficiency and reduce drifting due to overheating. Finally, a User Interface is used to carry out efficient amplitude extraction and frequency analysis in order to display the results of the test underway.

Our design is incorporated with the magnetic sensors to achieve the overall goal of early cancer cell detection. The sinusoidal signal from the microcontroller is fed to the amplifier, which provides the required current amplification. This amplified current generates the

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[1] National Cancer Institute, SEER Fact Sheet: All Sites

magnetic field required by the Giant magneto-resistive (GMR) sensors responsible for detecting the cancer cells. The microcontroller also monitors the stability and integrity of the magnetic field generating current, and provides the required correction when drifting from the nominal value is detected.

The microcontroller and amplifier sub-systems have been tested and evaluated separately. Signal generation and detection with the desired bandwidth and amplification with little drift indicate good progress, but the team also recognizes that further work needs to be done. Improvements that may further solidify the design include:

- Integrating the Microcontroller and Amplifier PCBs into a single PCB to reduce number of connections, thus reducing electrical noise throughout the system.
- Implement a Lock-in Amplifier[2] on the DSP microcontroller, allowing higher accuracy detection of the magnetic field current
- Provide a user interface (LCD/Touchscreen) that is integrated to the rest of the design.

GMR Technology Background

The GMR sensor is a device that changes its resistance based on alignment of adjacent ferromagnetic layers when exposed to a magnetic field. This technology is not only widely used today in computer hard drives but also has demonstrated great potential in biological devices, such as biochips and highly sensitive biosensors. As biological molecules are attached to the sensor's layer, a change in resistance can be detected when other molecules are attached to the molecules place on the sensor. Professor Wang's group at the University of Minnesota has developed such a system, which uses GMR bio-sensors in a 64 node array. When biological samples with antibodies are attached to the sensor array, the antigens in the samples will react with antibodies and change the resistance of that sensor. This method is highly precise to measure biological samples to a level that cannot be inexpensively done with normal lab

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[2] Lock-in Amplifier: Can extract a signal of known frequency from an extremely noisy environment

procedures. Therefore, the device provides a means to detect diseases and conditions at an earlier and more treatable stage.

Keywords and Acronyms

These are acronyms and keywords used throughout the document.

GMR	Giant Magneto-resistance
DSP	Digital Signal Processing
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
DAQ	Data Acquisition System
UART	Universal Asynchronous Receiver Transmitter
PA	Power Amplifier
UI	User Interface
FFT	Fast Fourier Transform
PCB	Printed Circuit Board

Customer Needs

A list of the required functionalities and their respective priorities has been tabulated on Table 1 below.

#	Required needs	Priority[3]
1	Reduce overall system electrical noise	1
2	Generate 2 digital sinusoidal signal	1
3	Read and process signal from the coil	1
4	Design Power amplifier	1
5	Design and integrate overall design on a small scale PCB	1
6	Successfully run overall system for at least 1 hour	2
7	Integrate signal to/from sensor in overall design	3
8	Integrate a user interface capable of controlling and displaying overall system	4

Table 1: Customer needs

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[3] Highest Priority: 1
Lowest Priority: 4

Design Specifications

A table listing the design specification for each requirement is also tabulated on Table 2.

#	Req #	Metric	Units	Ideal Value	Acceptable	Priority[4]
1	1,2,3	SNR at microcontroller/ADC	dB	> 80	75dB	1
2	2,3,4	Signal bandwidth	kHz	5.0	4.8< f < 6.0	1
3	4	Power amplifier AC current	mA	1000	750	1
4	4	DC offset current	mA	250	220	1
5	5	PCB size	cm^2	120	160	1
6	6	System run time	mins	60	45	2

Table 2: Design specs

Concept Design

A system block representation of our design is shown in Figure 1. The system consists of three major blocks.

1. **Power Amplifier**: This block is used to drive a 1.0A AC current to the magnetic coil on the Sensor PCB. The magnetic coil generates the magnetic field required by the GMR sensor.
2. **Microcontroller**: This block generates two signals used as inputs to the power amplifier block and the sensor. In addition, it monitors the power amplifier output and provides amplitude correction when drifting is detected.
3. **User Interface**: This block displays the power amplifier data sent from the microcontroller on a screen. It also carries out amplitude and frequency computations and sends the data back to the microcontroller.

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[4] Highest Priority: 1
Lowest Priority: 2

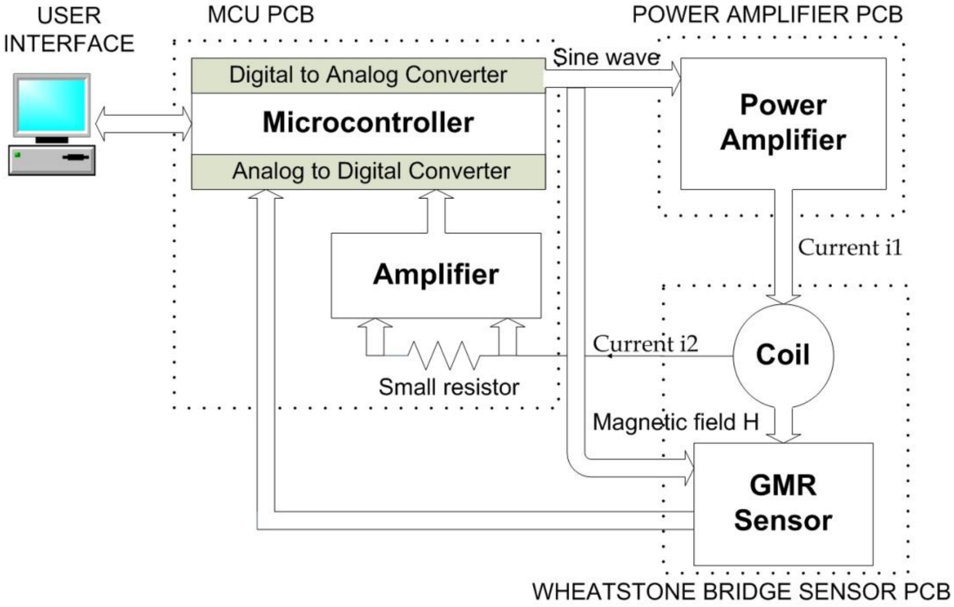

Fig 1: System block diagram

Power Amplifier and PCBs Detailed Design

The hardware design had two major parts:

1. Design and fabricate the power amplifier circuit
2. Fabricate the micro-controller circuit board

Each part was designed with a slightly different level of emphasis, and the details are summarized in the sections below.

Power Amplifier

The emphasis of designing the power amplifier circuit board was making the board highly unsusceptible to electrical noise. The goal was to achieve a Signal-to-Noise Ratio (SNR) of no less than 80dB.

$$SNR = 20\log_{10}\left(\frac{V_{signal}}{V_{Noise}}\right) > \quad 80dB$$

The power amplifier should also be able to provide an AC current of 1.0A to the load, and be able to do so for at least one hour.

To achieve the 80dB SNR, the design was started by finding a power amplifier chip capable of providing a theoretical SNR much higher than 80dB, while being capable of sourcing high current. This superior quality of the chip would give us a buffer to tolerate noise coming from other sources (i.e. noise from the surrounding space). The LT1210 Current Feedback Amplifier from Linear Technology is rated at a minimum 116dB SNR and a 2.0A[5] nominal maximum output current, which is well over our requirements. Also, to help limit the noise of the power amplifier, it was decided to use the minimum supply voltages of ±5V. The tolerance of the resistors used in this circuit was not considered and eventually resulted in a lower SNR. The resistors were selected based only on the amplifier gain ratio. Our amplifier design was a traditional negative feedback amplifier as shown in Figure 2 below.

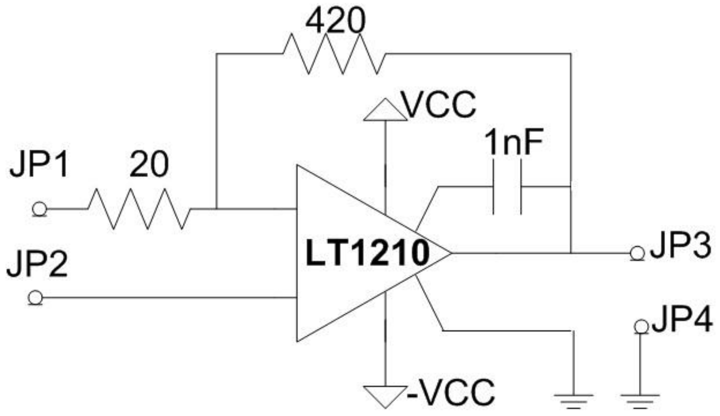

Fig 2. Schematic of the Power Amplifier Circuit

Tests of this circuit on a breadboard proved that the LT1210 chip can support 1.0A of AC current. The SNR on the bread board testing circuit was about 56.5dB, which was determined as a fair value considering the configuration on a bread board introduces high electrical noise.

The environment noise on a PCB board is primarily present in the form of eddy current. A shielding concept was used to filter out the noise from these sources. The shielding was done in a form of a ground trace surrounding the input and the output signal traces as shown in

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[5] 2A value directly cited from the LT1210 datasheet and 116dB SNR were calculated based on the parameters SPOT NOISE (nV/√Hz OR pA/√Hz) graph from the datasheet and the 5kHz input signal frequency

Figure 3. A surrounding ground panel around the edge of the PCB board was also used to conduct the eddy current away from the components.

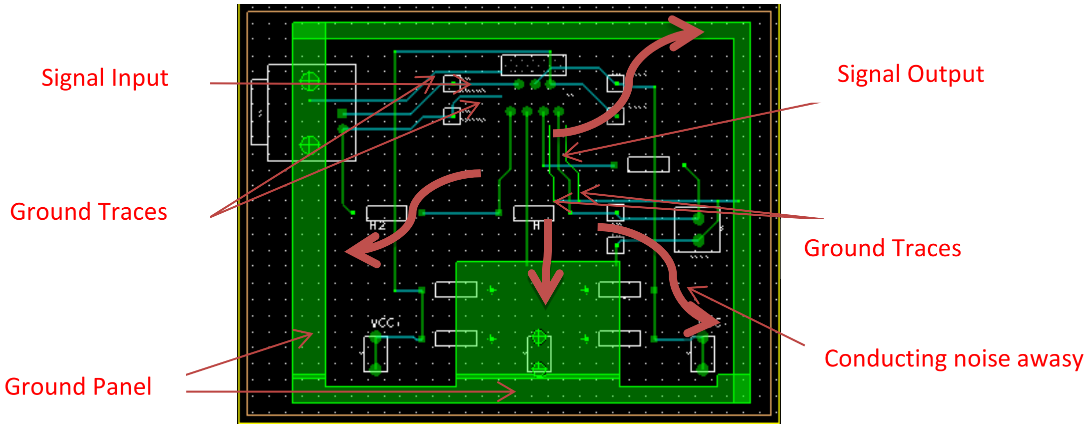


Fig 3. PCB of the Power Amplifier Circuit

Prototype testing

After soldering the fabricated PCB board and related components, a prototype test with the set up shown in Figure 4 was performed.

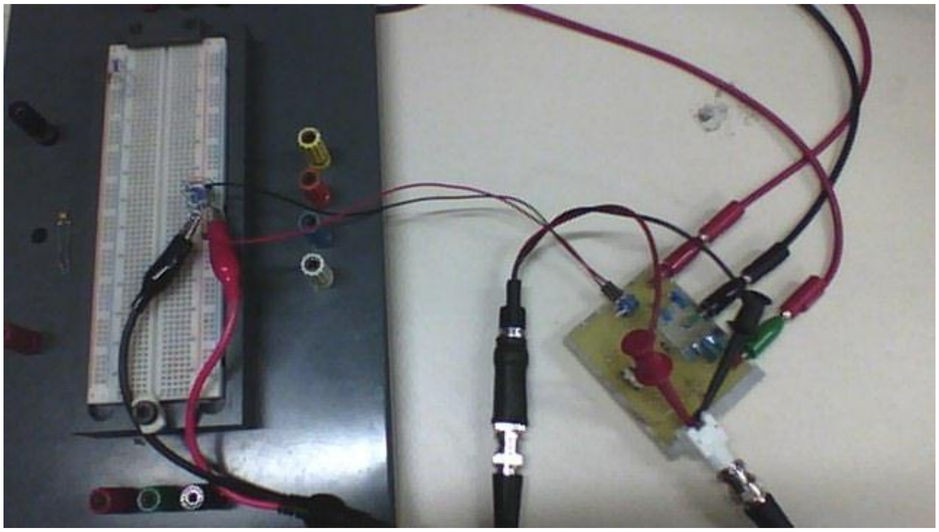


Fig 4. Amplifier Testing Set Up

Load: Four 10Ω resistors in parallel with a 0.3mH inductance. The combination gives a reactive load of 1.69Ω and 0.3mH.

Input Signal: A Function Generator with an input sine wave signal of 100mV peak-to-peak at 5 kHz frequency.

Output Signal: The oscilloscope showed that the output signal was a 5 kHz sine wave with 2.4V peak-to-peak voltage. The RMS value of the 2.4V is about 1.67V. This ensures that we are able to supply the load with a 1.0A AC current.

Testing Result: Due to lack of equipment accurate enough to measure the precise oscillation of the output voltage signal, the shape of the signal waveform on the oscilloscope was used to estimate the SNR. This was done by using the maximum zoom on the oscilloscope and observing the oscillations of peak point of the waveform to estimate the range of the peak voltage, as shown in Figure 5. This figure shows the screen shot of the input and output signals displaced on the oscilloscope when the amplifier turned on for the first 10 minutes. The yellow line represents the output signal with the blue line representing the input.

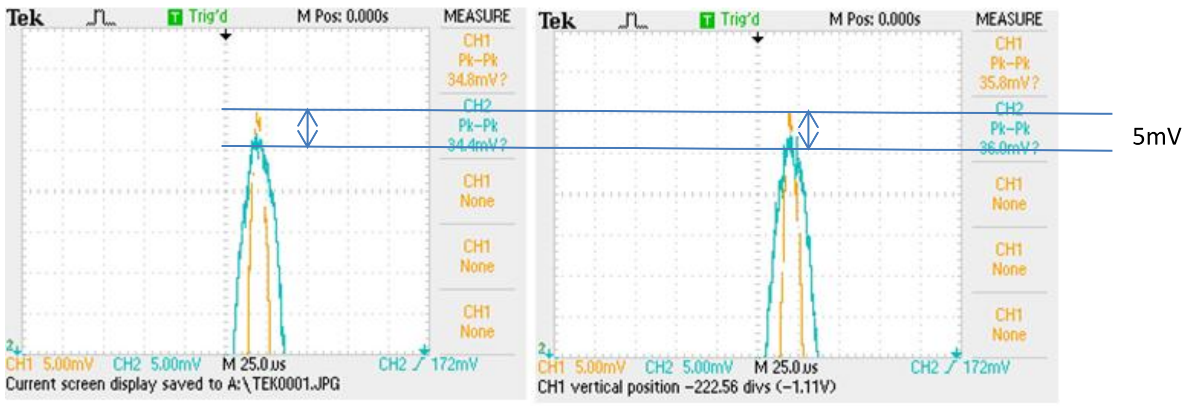


Fig 5. The Screen Shot of the input and output signals at the first 10 minutes

From Figure 5, it estimated that the oscillation of the output signal was around 5mV and the oscillation of the input signal was around 2.5mV. Therefore the SNR was found as

$$SNR = 20\log_{10}\left(\frac{2.4\ V}{5.0\ mV}\right) = 53.6\ dB$$

Considering this is a rough estimate and that that the input signal also had noise comparable to the out signal, the SNR could be significantly larger than 53.6dB.

The results after one hour of non-stop operation are shown in Figure 6 (10us time-scale) with no distinguishable difference from the output signal shown in Figure 5 above (25us time-scale).

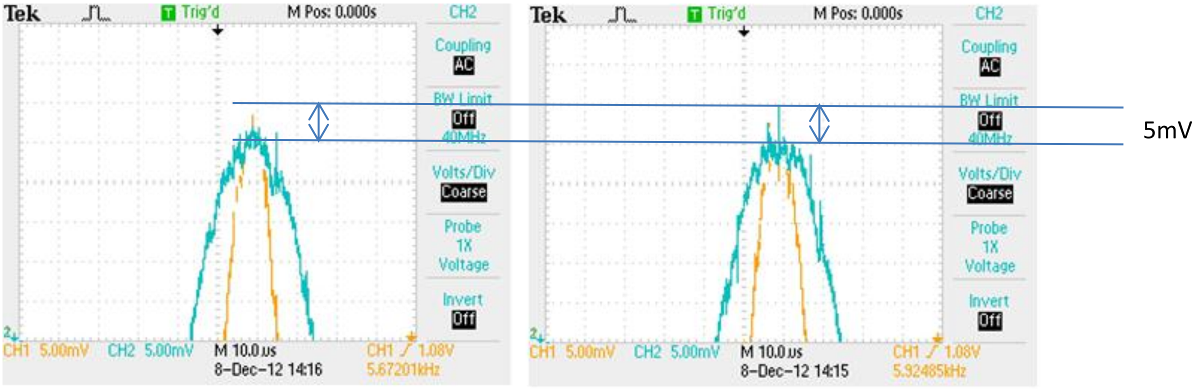


Figure 6. The Screen Shot of the input and output signals after 1hour

This shows that the power amplifier is capable of running for at least 1 hour under normal working conditions. Additional tests with the right equipment are needed to be carried out for more accurate SNR measurement.

Microcontroller PCB Design

The microcontroller PCB was designed to support the functions of the microcontroller and its external peripherals. These include but are not limited to:

1. Battery powered
2. Have on board programming and debugging capability
3. Provide the minimum hardware requirements of the microcontroller
4. Provide interfaces for various signals

A low electrical noise feature was considered throughout the design process. To ensure all the traces were properly shielded from environmental noise, whole ground panels were applied through the entire board as shown in Figures ***7a*** and ***7b***. This was possible because the micro-controller board does not have high frequency signals and does not need large currents to flow through the board.

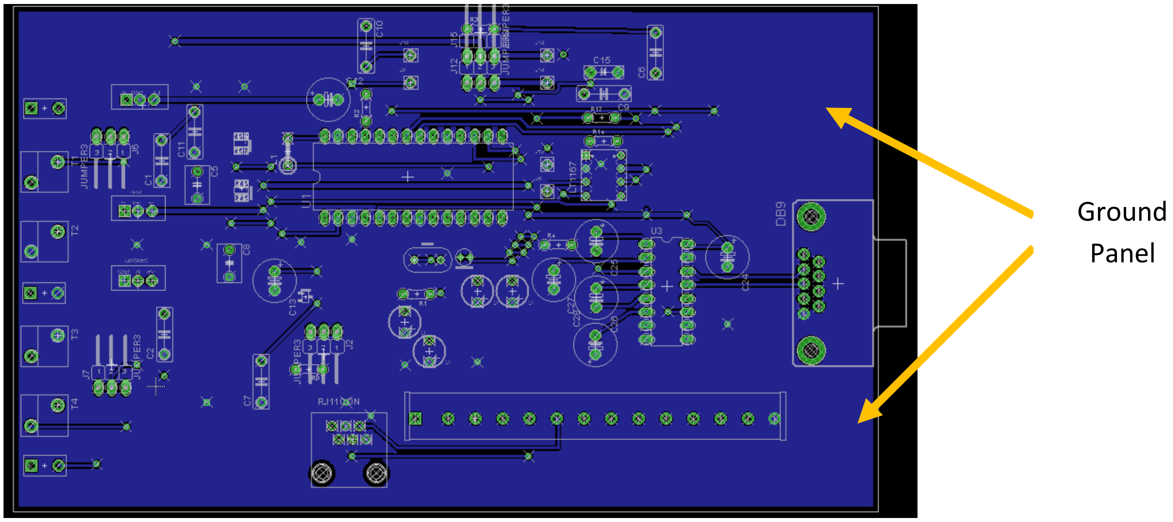


Fig 7(a). Bottom part of the PCB board

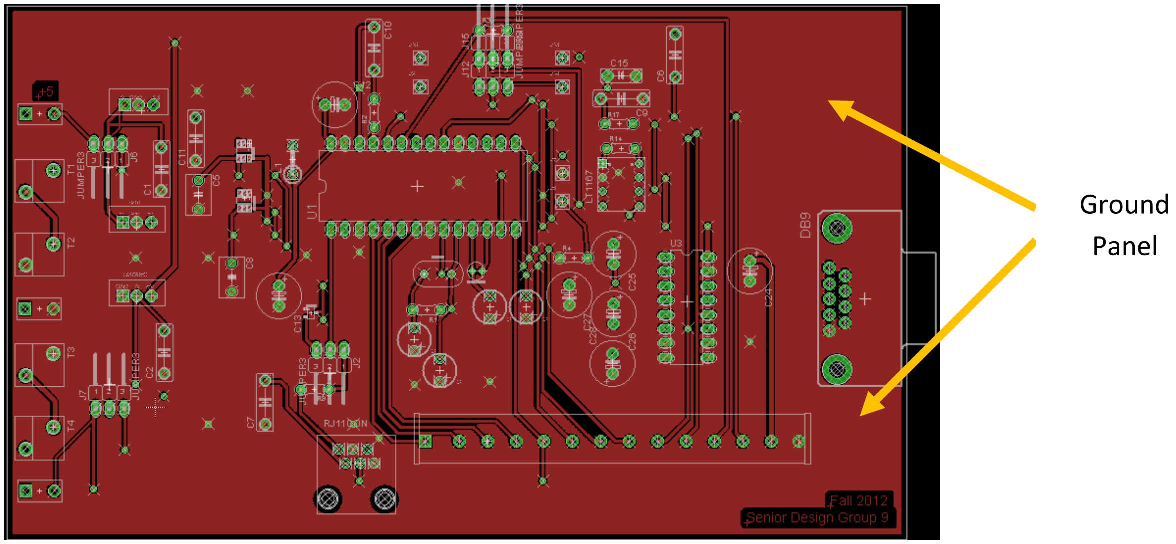


Fig 7(b). Top part of the PCB board

Due to the large number of components on the microcontroller board, the work was divided among two team members. The symbols and footprints were designed by one person while the other team member was in charge of the layout. This decision later brought serious problems to the board design, which eventually led to a non-functional PCB. The major mistakes are summarized below in an order of the most serious error to the least harmful.

1. Footprint mismatch

This mistake made some of the devices on the PCB unusable. An example is shown in Figure 8 below where pins 4 and 6 were in opposite places. This effectively reversed the input and output pins of the chip making it unusable on the PCB board.

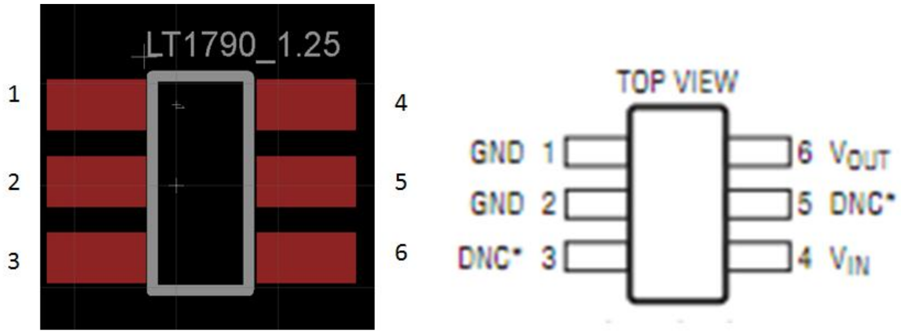
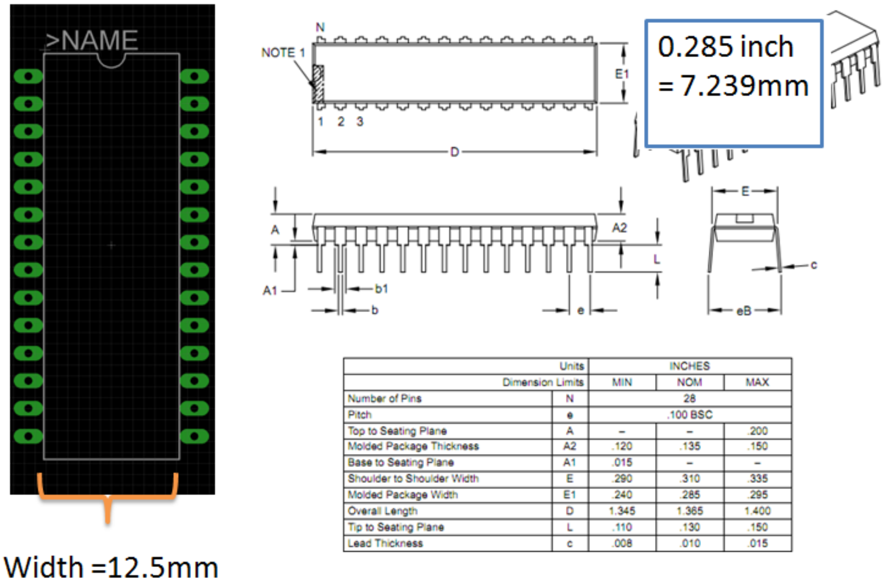


Fig 8. Mismatch of footprint numbering

2. IC dimensions mismatch

This problem was not a fatal problem since most circuit components were through-holes. The pins were bent and soldered on the board to make it work, but this could lower the quality of the connections especially with high frequency components such as oscillators. Figure 9 shows the dimension mismatch of the microcontroller package.

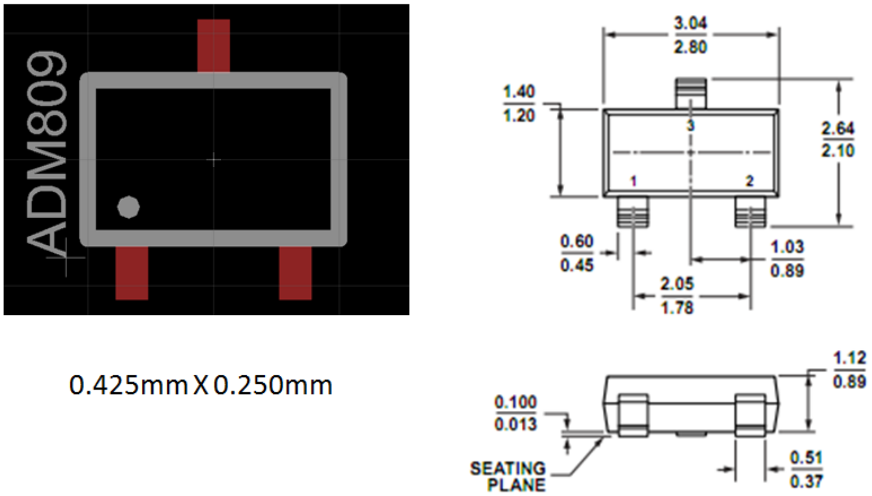


		Units	INCHES	
Dimension Limits		MIN	NOM	MAX
Number of Pins	N		28	
Pitch	e		.100 BSC	
Top to Seating Plane	A	–	–	.200
Molded Package Thickness	A2	.120	.135	.150
Base to Seating Plane	A1	.015	–	–
Shoulder to Shoulder Width	E	.290	.310	.335
Molded Package Width	E1	.240	.285	.295
Overall Length	D	1.345	1.365	1.400
Tip to Seating Plane	L	.110	.130	.150
Lead Thickness	c	.008	.010	.015

Fig 9. The width of the footprint (12.5mm) is much larger than the device width (7.24mm)

3. Footprint pad size

The soldering pads on some surface mount components were made too small. This made the components extremely hard to manually solder on to the board. Figure 10 shows the pad-size comparison between the footprint on the PCB and the device datasheet.



0.425mm X 0.250mm

Fig 10. The pads of the footprint were too small compared to the actual device

Because of the mistakes specified above, the microcontroller board was unusable. Therefore all tests on the microcontroller were performed using the Explorer-16 development board from Microchip. These mistakes are well documented for the next group of students working on the project.

Microcontroller Firmware Detailed Design

The current bench-top system uses an expensive multi-function data acquisition (DAQ) system for signal generation and detection. In this project, we focused on the specific functions performed by the DAQ in this system in order to replicate them with a much lower cost overhead. Recognizing that only a very small portion of the DAQ processing capability was being used, we focused on the specific tasks being performed and developed an application specific solution. We utilized a digital signal processing microcontroller from Microchip’s dsPIC33F family, to implement the signal generation and detection currently carried out by the DAQ.

The overall operation of the microcontroller can be described with the block diagram shown In Figure 11.

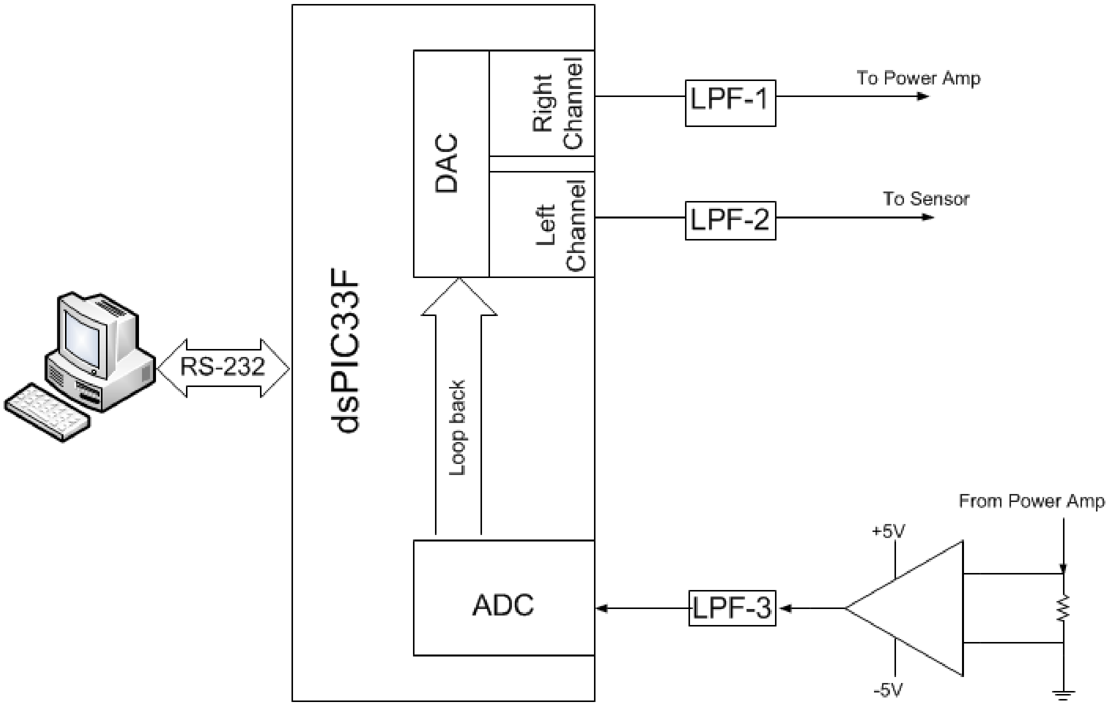


Fig 11. Microcontroller System block

The four major functions of the microcontroller are

1. Signal generation with Digital to Analog Conversion (DAC)
2. Monitor Power Amplifier (PA) output amplitude with Analog to Digital Conversion (ADC)
3. Serial communication with the User Interface (UI)
4. Provide a feedback loop between the ADC and DAC

The microcontroller uses built in DAC modules to generate two independent sinusoidal signals used as inputs for the Power Amplifier and the Sensor array. The output amplitude of the power amplifier is monitored by the microcontroller using the built in ADC module. This data is serially transmitted and made available for display on the UI. A feedback loop is provided from the ADC to the DAC to compensate for any power amplifier amplitude drift detected. The detailed functions, analysis and design of these four functions are described in the sections below.

DAC design

The microcontroller has a built in 16-bit resolution DAC module with two independent channels capable of generating independent frequency analog signals. Both the Right and Left Channels of the DAC generate a sinusoidal signal with frequencies ranging from 1kHz to 5kHz. Both signals are independent of each other, and can operate at separate frequencies.

To generate the sinusoidal signals, we created a sine-lookup table with a total of 1000 elements. We continuously sample the elements of this lookup table to generate the desired sinusoidal signals. In order to reduce high frequency components and increase SNR rating at the output of the DAC, we use the maximum sampling rate of 100ksps available from the microcontroller.

Using this 1000 element table and a sampling rate of 100ksps, we generate a sinusoidal signal of only 287Hz frequency. To generate the desired frequencies, we up-sample our table using an up-sampling factor L. The number of elements sampled for each up-sampling factor and the corresponding frequency output is shown in Table 3.

L	Sampled elements	$DAC\ frequency$
1	1000	287 Hz
4	250	1.13 kHz
8	125	2.24 kHz
12	83	3.43 kHz
16	62	4.64 kHz
20	50	5.71 kHz

Table 3. DAC output frequency

The amplitude of the sinusoidal signal from the DAC has a peak to peak value of 1.4V with a 1.5V DC offset (max of 2.2V and min of 0.8V). This peak to peak amplitude can be controlled with a simple integer division followed by a multiplication, thus providing the Power Amplifier with the required input. The maximum amplitude value of 2.2V is represented with the decimal value of 32,767. To generate the 1V peak to peak voltage required by the Power Amplifier, we need to multiply this decimal value by

$$F = \frac{1}{1.4} = 0.7$$

From this we obtain a new maximum decimal value of

$$D = \frac{32{,}767}{10} \times 7 = 22{,}937$$

ADC design

In order to process the data in discrete time, we perform periodic sampling of the continuous signal through a built in 12-bit resolution A/D converter. The input is a sinusoidal signal with frequencies ranging from 1.15kHz to 5.74kHz.

In order to avoid aliased samples of our signal, we must sample at a minimum of twice the maximum input frequency.

$$f_{sample,min} = 2.BW\_max$$

$$f_{sample,min} = 2 \times 5.74kHz$$

$$f_{sample,min} = 11.48kHz = 11.48\ kS/s$$

Using a system clock frequency of 36.85MHz we set the ADC clock period to 814.11ns. This gives us a total conversion time of

$$T_{conv-total} = 2T_{AD} + T_{samp} + T_{conv}$$

$$T_{conv-total} = 2T_{AD} + 6T_{AD} + 14T_{AD} = 17.91\mu s$$

Which corresponds to a sampling frequency of

$$F_{conv-total} = \frac{1}{T_{conv-total}} = 55.83\ kHz$$

This is well over the required Nyquist sampling frequency of 11.48kHz. Sampling at such a high rate ensures that aliasing will not occur and avoids the need of using anti-aliasing filters.

The number of samples can be computed as

$$Samples\ per\ period = Signal\ Period \times F_{conv-total}$$

The minimum number of samples occurs for the case of 5kHz signal frequency

$$Samples\ per\ period = \frac{1}{5kHz} \times 55{,}830 \frac{samples}{sec}$$

$$Samples\ per\ period \cong 11$$

A/D converter's output is a quantized signal that is represented by a digital value equivalent to the number of bits of the converter. In order to achieve higher resolution, a small reference voltage is desirable. The minimum reference voltage allowed by our system is 2.5V. The ADC module being used offers an option of 10-bit or 12-bit conversion. In order to achieve higher resolution, the 12-bit system is chosen, and the voltage resolution achieved is

$$V_{Resolution} = \left(\frac{V_{Ref,min}}{2^n}\right)$$

$$V_{Resolution} = \frac{2.5\ V}{2^{12}} = \ 610.35\ \mu V$$ [6]

Serial communication with UI

RS-232 serial communication creates a link between the microcontroller and the User Interface. The Power Amplifier data read by the ADC is transferred and displayed on the User Interface in real time. The microcontroller also receives frequency control commands and the calculated amplitude data from the User Interface via this link.

A high baud rate of 921,600 was chosen in order to increase the number of ADC samples sent to the UI. Each sample from the ADC is sent to the UI in a packet of 16-bits, thus sample transfer rate is

$$Sample\ transfer\ rate = \frac{Baudrate}{bits\ per\ sample}$$

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[6] n is the number of bits

$$= \frac{921{,}600\ b/sec}{16b/sample}$$

$$= 57{,}600\ samples/sec$$

The microcontroller also receives commands to control the DAC frequency from the UI. Five options are selectable per channel. Each channel frequency is individually controlled using a custom communication protocol.

Feedback loop

The feedback loop is a link between the data collected by the ADC and the output of the DAC. Our design collects the power amplifier amplitude data through the ADC and passes this data to the User Interface as indicated above. Overtime, rise in temperature of the power amplifier may result in amplitude drifting. The user interface performs the amplitude extraction with IQ demodulation algorithm and reports the results back to the microcontroller. Amplitude drifting is monitored in increments of 2.5% from the nominal value, at which the output amplitude of the DAC is increased to compensate for the drifting.

Since the power amplifier voltage gain is 20x, for every 2.5% amplitude drift of the power amplifier, the DAC output is increased by 0.125%.

$$DAC_{out} = \frac{2.5\%}{20} = 0.125\%$$

If the current DAC output was a 1V peak-to-peak signal, when a 2.5% amplitude drift is detected it must be increased to

$$DAC_{increase} = 1V(1 + 0.00125) = 1.00125V$$

Therefore the new maximum decimal value of the lookup table is determined as

$$F = \frac{1.00125}{1.4} = 0.7152$$

$$D = 32{,}767 \times F = \left(\frac{32{,}767}{1000}\right) \times 715$$

$$D = 23{,}428$$

Due to memory space restrictions, the amplitude extraction computation is currently performed outside the microcontroller. Future designs, should include access to an external flash memory (EEPROM) for this computation to be performed within the microcontroller.

Microcontroller Prototype Analysis

DAC Analysis

The majority of the microcontroller testing was performed on the Explorer-16 development board available from Microchip. To ensure that the 80dB system SNR was met, the SNR at the signal generation had to be high enough to avoid noise propagation. We tested this by generating a 1.23V peak to peak amplitude signal at 1.13kHz frequency, and taking 206 samples out of which we computed the mean and standard deviation.

$$Mean = \frac{1}{N} . \sum_{i=1}^{N} DAC\_sample_i = 1.230268\ V$$

$$Std.Dev = \sqrt{\frac{1}{N} . \sum_{i=1}^{N} (DAC_{sample_i} - Mean)^2} = 0.226 \times 10^{-3}$$

$$SNR = 20 \log_{10} \left(\frac{Mean}{Std.Dev} \right) = \mathbf{74.72\ dB}$$

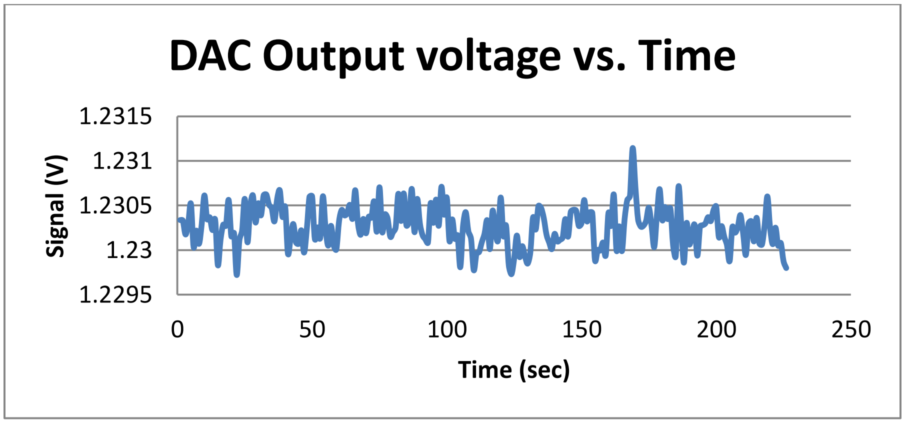


Fig 12. DAC output samples data

ADC Analysis

The ADC quantization noise was analyzed by modeling the error as additive noise. Using a statistical model, we determined the quantization SNR to be

$$SNR_Q = 10\log_{10}\left(\frac{\sigma_x^2}{\sigma_e^2}\right)$$

Where

$$\sigma_e^2 = \frac{2^{-2B}.X_m^2}{12} = \frac{2^{-2\times 11}.(2.5^2)}{12} = 1.24 \times 10^{-7}W$$

And

$$\sigma_x^2 = \frac{1}{2}\left(0.5V_{p-p}\right)^2 = 0.78125\ W$$

Therefore the quantization SNR_Q is

$$SNR_Q = 10\log_{10}\left(\frac{0.78125}{1.24\times 10^{-7}}\right) = \boldsymbol{68\ dB}$$

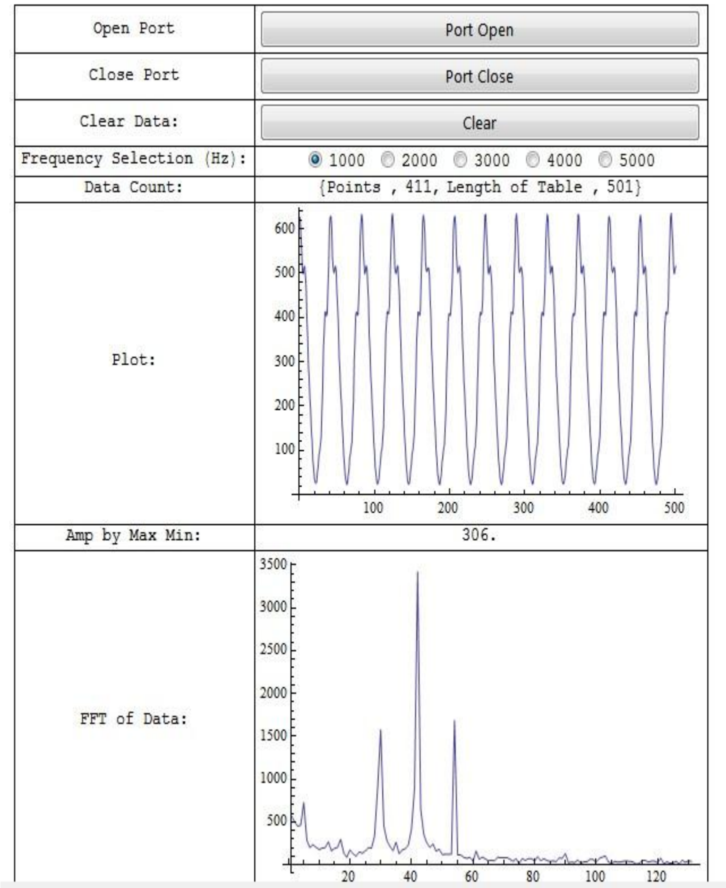
User Interface (UI)

The User Interface of the GMR bio-sensing system is used to display the results of the current test underway. By designing a custom interface, we have a high level of flexibility in implementing the sub-functions of the interface. This in turn gives us an interface that best fits the functionality of the overall product.

Several tools such as MATLAB, LabVIEW, Visual Studio and Wolfram Mathematica were considered in implementing the UI. This design chose Wolfram Mathematica as the development platform for its flexibility of programming, high integration with other programming environment, high computation abilities, and friendly user graphical interface. The UI can be provided as software in the final product. Wolfram Math Player is a Mathematica reader that would allow users to interact with our programmed interface window.

Design Description

The UI displays the power amplifier output data received from the microcontroller ADC. The data from the microcontroller is received via a 1.0 Mbps serial link implemented using the UART protocol. The data is dynamically displayed in real time in a form of a continuous plot. The power peak of the incoming data is also computed using FFT and displayed on another window. The UI also computes the amplitude of the incoming signal and sends the information back to the microcontroller. Finally, the UI allows the user to control the frequency of the signal generated by the two channels of the microcontroller in order to test for different antigens/antibodies.



Frequency Selection (Hz): ● 1000 ○ 2000 ○ 3000 ○ 4000 ○ 5000

Data Count: {Points , 411, Length of Table , 501}

Amp by Max Min: 306.

Fig 13. Interface Overview

Signal Reception

Mathematica does not support low-level serial communication in a direct way, but through a NETLink Package, .NET functions could be called in Mathematica, hence we created .NET serial port class for serial communication.

Frequency Analysis

When data is collected from the serial port, they are assembled into integers and put into a list. The signal from both sensor and coil are sinusoid waves of mix of several sinusoid waves. An FFT is performed for each 500 samples of collected data and the detected frequencies are displayed in real time.

Amplitude Control

Another function of the software is to close the feedback loop with the microcontroller board. Since temperature change may affect the output amplitude of the power amplifier, the amplitude of the signal is constantly monitored. The amplitude extraction is achieved using IQ demodulation technique. The incoming signal from the ADC has a form of

$$ADC_{in} = A\cos(\omega t + \phi)$$

Because the frequency of the incoming signal is known to be one of the 5 values ranging from 1.15kHz to 5.74kHz, we can use in-phase and quadrature components with the same frequency

$$In\,phase = \cos(\omega t) \qquad and \qquad Quadrature = \sin(\omega t)$$

Multiplying ADC_in by both the in-phase and quadrature components, and taking the mean results in the removal of the higher frequency components.

$$I = mean[A.\cos(\omega t + \phi) \times \cos(\omega t)]$$
$$Q = mean[A.\cos(\omega t + \phi) \times \sin(\omega t)]$$

The amplitude is then deduced from both the I and Q components as

$$Amplitude = 2 \times \sqrt{I^2 + Q^2}$$

This was found to be a very efficient method of amplitude extraction as the computation can be done by taking only 10 samples from a period of a signal, thus reducing the load on the processing unit.

Display

The data from the microcontroller and all computation results are displayed on user friendly separate windows. The current data displayed on the User Interface include

i. Real-time signal from ADC

ii. Real-time frequency analysis

iii. Frequency selection of signal generation

iv. Amplitude extraction results

Conclusion

Budget

The design was given a budget of no more than $300. All design techniques and component selection were done to achieve highest performance with lowest cost. The cost of both the Power amplifier and the microcontroller PCBs together was less than $155.

1. Power Amplifier overall cost: $74.82
2. Microcontroller overall cost: $75.70

The BOM for both these PCBs can be found in the Appendix at the end of this document. Other testing prototyping expenses resulted in the final overall cost of $211.

Design process

The team had a clear timeline for each part of the system, and followed through with the plans for the most part. The timeline set by the team at the beginning of the semester can be found in the Appendix at the end of the document.

The concept of design, design implementation, and prototype testing followed through with the schedule. However, the time taken by PCB design and testing was not carefully implemented which resulted in the delay of the PCB fabrication.

Results and Future Improvements

Overall the Handheld Bio-sensing System team achieved most of the design specification goals. Each product design specification and whether it was met or not is displayed on Table 4 below

#	**Required needs**	**Met**	**Not Met**
1	Reduce overall system noise		**X**
2	Generate digital sinusoidal signal	**X**	
3	Read and process signal from the coil	**X**	
4	Design Power amplifier	**X**	
5	Design and integrate overall design on a small scale PCB		**X**
6	Successfully run overall system for at least 2 hours	**X**	
7	Integrate signal to/from sensor in overall design	**X**	
8	Integrate a user interface capable of controlling and displaying overall system	**X**	

Table 4. Achievements vs. original PDS

The main outcomes of this project are

1. A Power Amplifier circuit capable of generating a 1.0A AC current to drive the magnetic coil.
2. A digital signal processing system capable of generating sinusoidal signals and monitoring the power amplifier output amplitude.
3. Software for frequency analysis, signal processing, and user interface

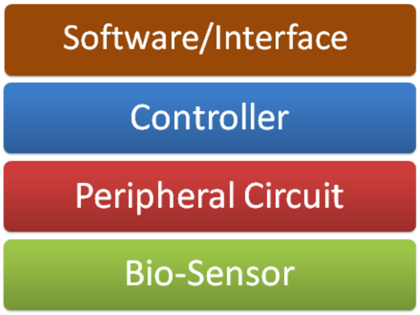


Fig 14. Layers of Bio-sensing system

Some of the weaknesses of the design that can be improved by the next group include

1. Unreliable SNR measurements due to lack of proper equipment. The current measurements rate the microcontroller DAC at 74.13dB and the power amplifier at 53.6dB SNR. The SNR across the entire system should also be measured for higher accuracy.
2. The microcontroller PCB design contained numerous mistakes that are well documented and can be easily corrected.
3. An isolation buffer should have been included between the microcontroller and the power amplifier.
4. Power dissipation analysis should be done on the power amplifier and the required heat-sink mounted to avoid amplitude drifting due to overheating.

References

Y. Li, Y. Jing, X.Yao, B. Srinivasan, Y. Xu, Ch.Xing, J-P Wang, “Biomarkers Identification and Detection Based on GMR Sensor and Sub 13 nm Magnetic Nanoparticles”, 31st Annual International Conference of the IEEE EMBS Minneapolis, Minnesota, USA, September 2-6, 2009

LT1210 Current Feedback Amplifier dataseet

LT1210
Datasheet.pdf

dsPIC33FJ128GP804 Datasheet

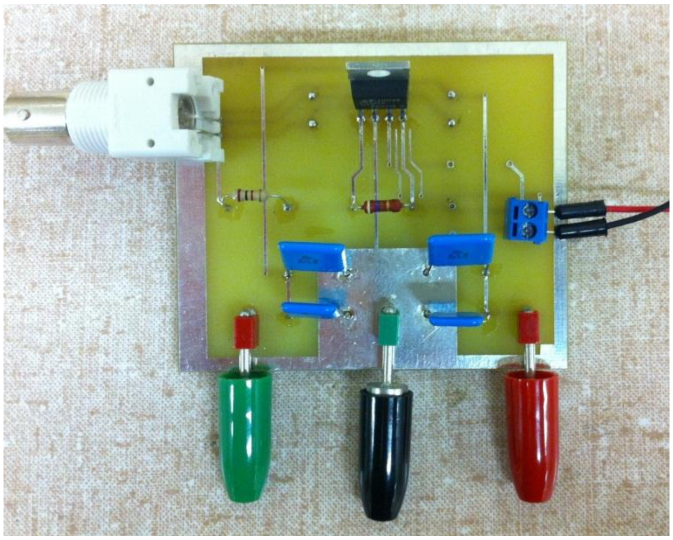
dsPIC33 Data
Sheet.pdf

NI Developer Zone: What is I/Q Data?

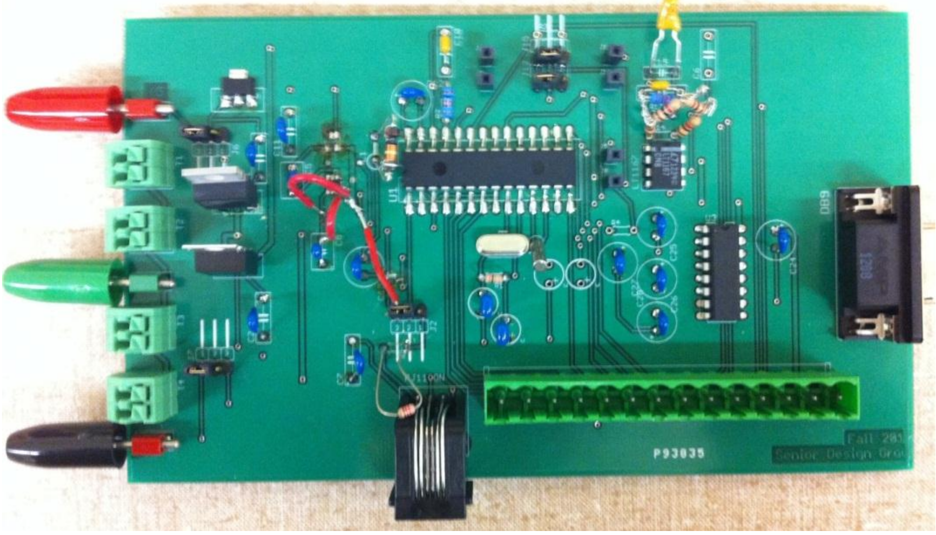
http://www.ni.com/white-paper/4805/en

Appendix

Populated Power amplifier PCB



Populated Microcontroller PCB



Relevant Documents

1. Timeline

Team 9
TIMELINE.docx

2. Power Amplifier and Microcontroller BOM

Team 9 BOM.xlsx