Team: May14-11
Final Senior Design Report
Detection of MCLR by Capacitance Measurement
4/23/14

Authors:
David Callen
Danielle Kimler
Watson Mulder

Problem Statement

A type of bacteria called cyanobacteria, colloquially known as blue green algae, can be found in fresh water sources all over the world. The cyanobacteria can reproduce rapidly in a blooming period. During the bloom the bacteria can secrete toxins, which can be harmful to aquatic life, humans, and other mammals. In our project we are concerned with a particular toxin called Microcystin-LR (MCLR) which can damage a mammal's liver.

Cyanobacteria is causing problems here in the Midwest. It has affected water sources for people and livestock as well as swimming areas. Currently the methods for detecting the presence of MCLR are slow and expensive. For instance, if a farmer's cow gets sick and he/she suspects that it is because of a cyanobacteria bloom in a pond that the livestock drink form, he/she can take a sample of the water and send it to a lab to be analyzed.

There are several problems with the existing test method. The first is the slow turnaround of the process. It takes at least a week for someone to send a sample of water to a lab where it is analyzed and results are sent back. In the end the analysis may not help because cyanobacteria blooms can run their course in just a couple days. The device that is used in labs to detect MCLR is large and cumbersome so it is not practical to bring on site. Finally, the current measurement devices are too expensive and require too much technical knowledge for the average individual to justify owning it.

Our Solution

The struggle that Midwestern farmers are experiencing to get fast, reliable, inexpensive test results suggests a need for a device that can test their water for the bacteria. Our system aims to provide a quick, accurate, and substantially less expensive method that the average user can easily operate.

The proposed system needs to detect the capacitance change seen by an electrode in the presence of Microcystin-LR. The device should take advantage of a study done regarding the relationship between MCLR and electrode capacitance.

Project Standards

Because our project involves the detection of a toxin, we have several standards to consider—especially related to human and animal safety. We also need to consider environmental standards, as our device will be used outdoors in fresh water sources.

With regards to the human health standard, we are looking to the World Health Organization's MCLR concentration requirement. Citing their webpage here, there is a requirement of less than 1 µg/liter for drinking water. There is also a limit on daily intake, which is 0.04 µg/kg of body weight. These standards are quite strict, so we want to make sure we are detecting MCLR below this level to ensure human safety.

We also need to abide by the Environmental Protection Agency's emission standards. Some of these are as obvious as avoiding lead-based materials, and other are more subtle (such as the frequency spectrum we can use).

Other than the more biological standards are the standards we need to abide by as engineers. IEEE has a whole set of standards, and we need to consider a few categories: impedance measurement, PCB design/layout, electrode fabrication, and testing schemes. This guides us in our development of the product.

Project Design

The final form of our solution consists of two parts: a timer circuit and electrochemical probes. The timer circuit design utilizes a 555 timer as the basis of an oscillator that relates capacitance with frequency. As the capacitance under test changes, the signal takes different amounts of time to charge and discharge, and we detect this change by observing the corresponding change in the frequency of oscillation of the 555's square wave output. We measure the period of the wave by programming an MSP430 to capture the value of a 16 MHz counter on each rising edge for 50 cycles. These values represent the number of clock counts taken to fully charge the capacitance. The captured values are averaged and outputted to the user through a computer.

For full implementation, the electrochemical probes are used as the capacitance under test, and they can be placed in MCLR solutions. Depending on the concentration, the capacitance of our probes will drop relative to the amount of toxin present. (The more MCLR in the solution, the larger the magnitude of the drop). Together, the timer circuit and the electrochemical probes can be used to determine a relationship between MCLR concentration and capacitance change.

We had to design the layout of our timer circuit so that it could be fabricated. Before we were able to do this, we had to learn a software tool to create it with. We ended up choosing Eagle for this task. After familiarizing ourselves with the program, we created a digital schematic that is pictured below.

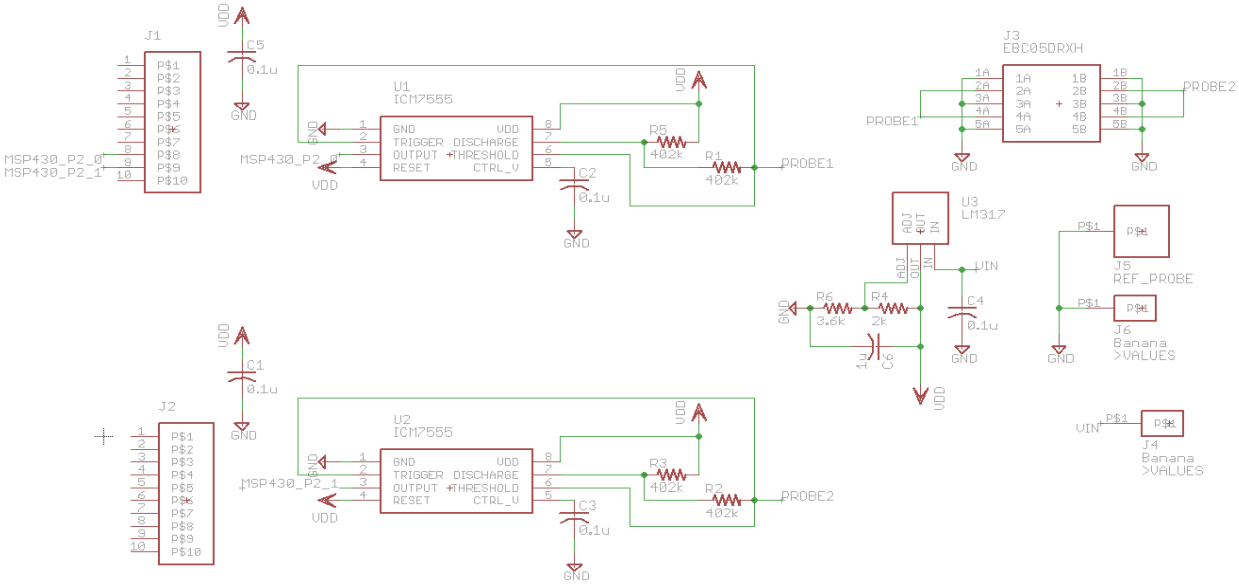


Figure 1: Eagle Schematic of Timer Circuit.

Once the schematic was finished, we laid the circuit out on a PCB and sent it off to be fabricated. The PCB layout of the timer circuit is pictured below. We soldered all of the components onto the board once it was sent back from the fabrication house.

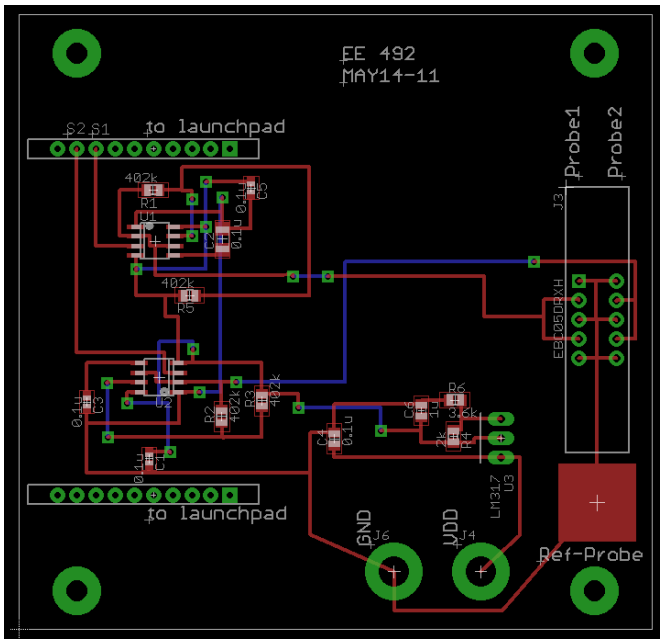


Figure 2: PCB Layout of Timer Circuit.

Circuit Testing

Setup/Process

Breadboard Testing

The original test setup consisted of our circuit built on a breadboard, with the measured capacitance made up of a group of individual capacitors together in parallel along two rails of the breadboard. This setup was used in order to prototype our circuit before fabrication. In order to simulate different capacitance changes of the electrodes, we plugged and unplugged individual 10 pF capacitors along the two rails. The input voltage of 5V DC was plugged into two other rails.

The actual testing process would be initiated by running the code on the computer using CCS v.5 to make the MSP430 begin capturing period counts. When finished with the measurement, the values were outputted to the computer terminal via the Tera Term program. When the values popped up on the computer screen, they were copied and pasted into Microsoft Excel for data analysis.

This setup worked to an extent, but the results were decided to be not entirely satisfactory, as could be expected in a prototype. We observed 5 to 10% error throughout the measurement, as shown in the plot. This was partly due to noise and imprecise connections in the breadboard, and in greater part due to the changing parasitics of the measured capacitors as they were plugged in and unplugged.

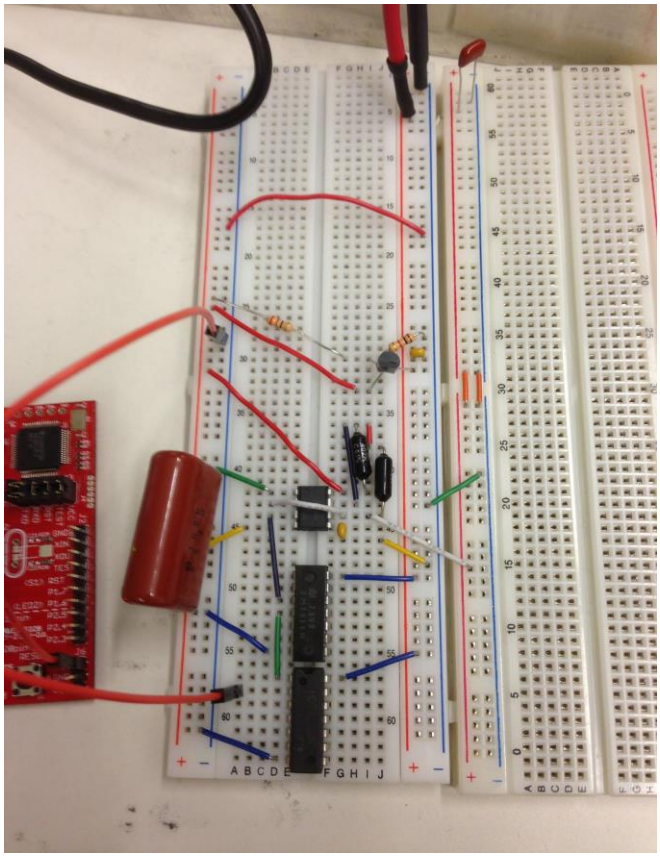


Figure 3: Initial Breadboard Setup of Timer Circuit Used for Testing.

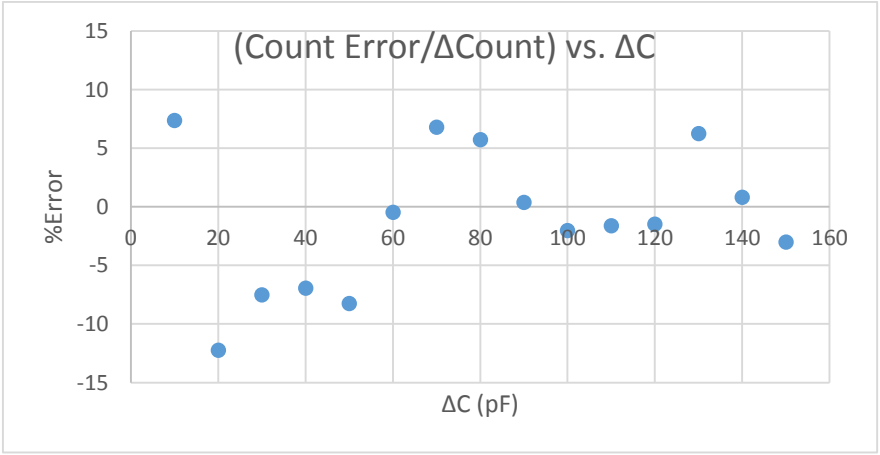


Figure 4: Example of Error Encountered in Breadboarded Circuit.

PCB Testing, Capacitors on Breadboard

When our PCB was fabricated, we used it instead of the breadboard circuit. We soldered all the components to the board and soldered wires leading to the breadboard rails which contained the individual capacitors to be measured.

The procedure for this setup was exactly the same as before: press the button on the Launchpad to obtain counted values, and plug/unplug capacitors to simulate capacitive change, as shown in the figure below. Unfortunately, the problems with changing breadboard parasitics continued to cause variation in the data. We formulated a plan to deal with this problem: use a switched capacitor array.

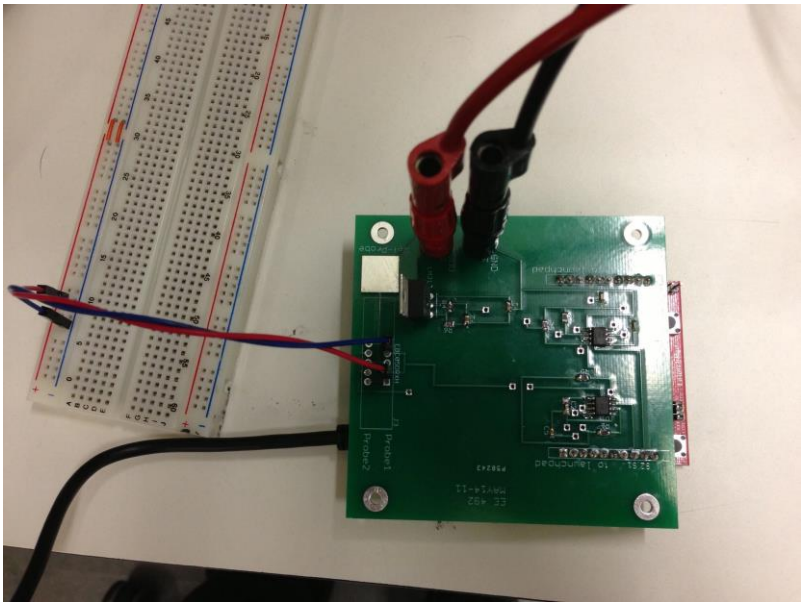


Figure 5: Fabricated Timer Circuit Measuring Capacitance in a Breadboard.

PCB Testing, Capacitors in Switched Array

We fabricated a switched capacitor array in-house to aid in the testing. With the introduction of this array, we were able to do away with the changing parasitics of the breadboard. It consists of many capacitors in parallel and a switch for each capacitor, so that we can add or subtract capacitance to get changing capacitance values. The layout for this circuit that we created (also utilizing Eagle) is pictured below.

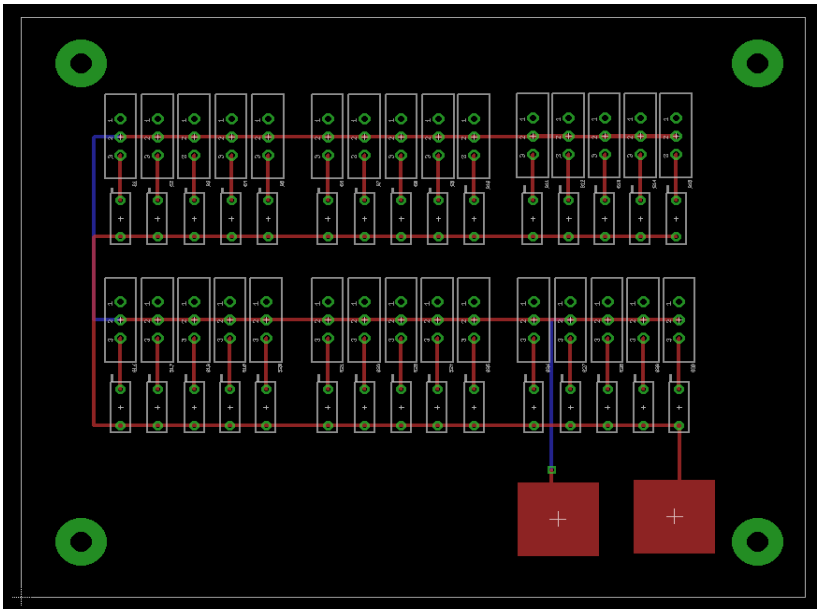


Figure 6: PCB Layout of Capacitor Bank Circuit.

The procedure remained the same as before, except that instead of plugging and unplugging capacitors, we would flip switches on the capacitor array board. The only difficult-to-control variable that remained was that the temperature drift due to air convection in the ambient environment seemed to have some effect on the output of the 555 timer. We attempted to minimize this by keeping the circuit in a box during measurements.

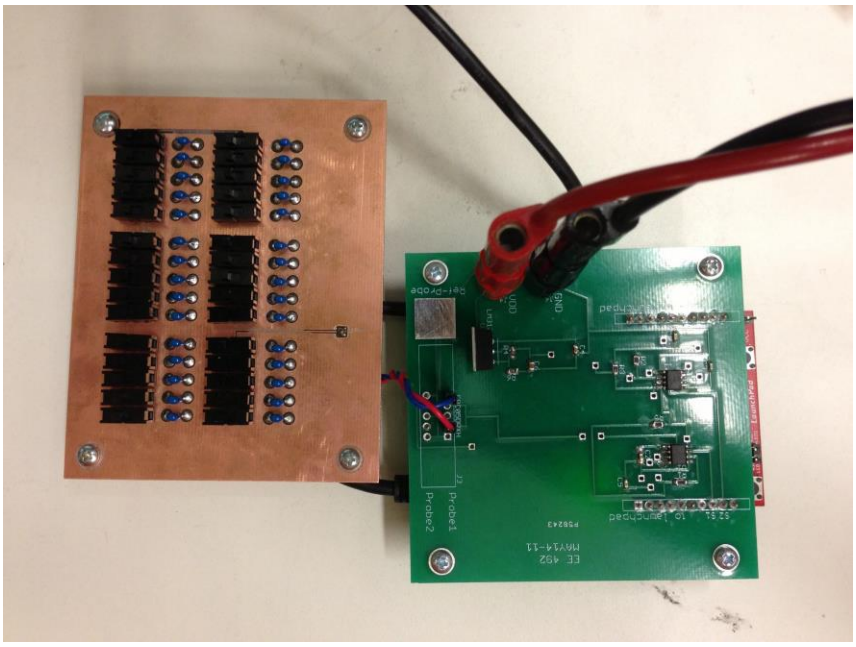


Figure 7: Fabricated Timer Circuit Measuring Capacitance from our Fabricated Capacitor Bank.

Measurement Results

Below are some of the experimental results obtained using our circuit. The count (which is an indicator of the frequency) and the capacitance have a linear relationship with one another. We demonstrated this linear proportionality as shown in the graph below.

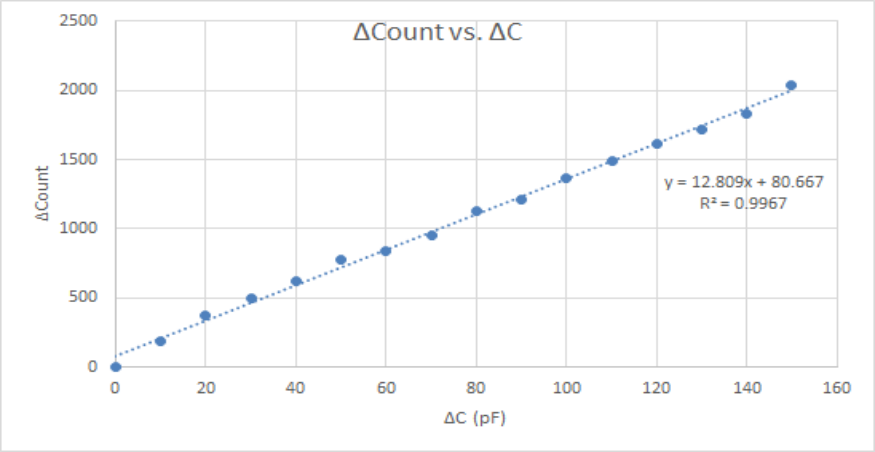


Figure 8: Change in Count as a Function of Changing Capacitance.

To further validate our measurements, we also verified the operation of the circuit against an LCR meter. The following is a plot correlating the count with the readout from the LCR meter. For the circle data points, the values were measured with the timer circuit while increasing the capacitance, then measured with the LCR meter while decreasing the capacitance. For the triangle data points, the LCR meter was used while increasing the capacitance, and the timer circuit was used while decreasing. The slight variations are attributed to temperature drift during the measurement.

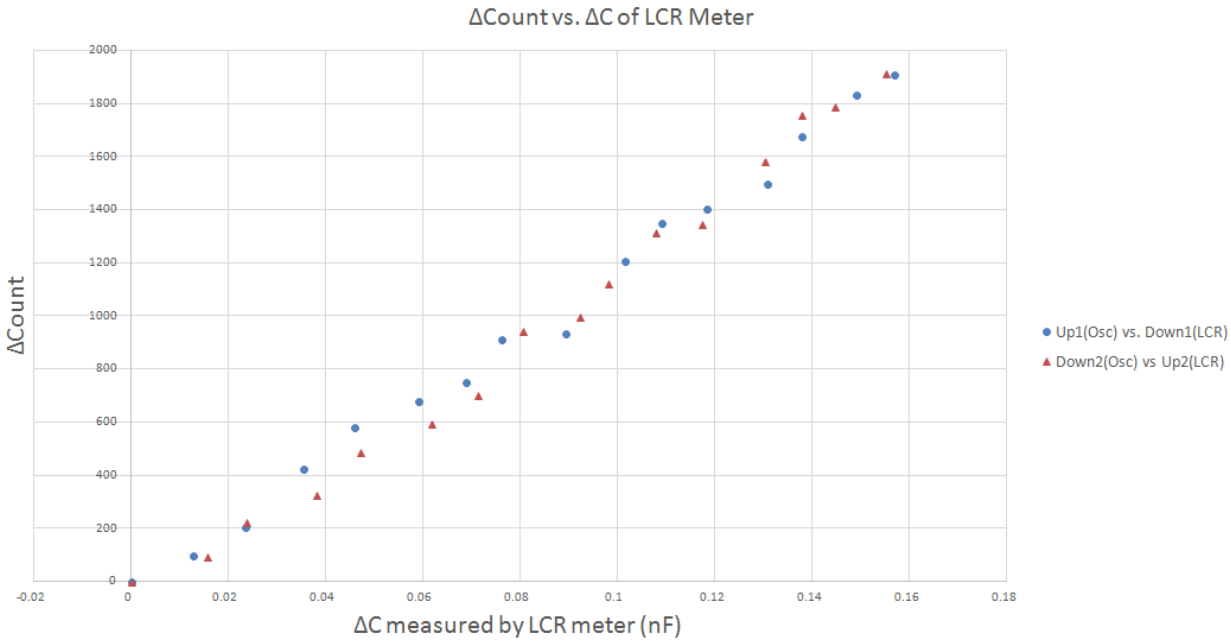


Figure 9: Counter Value as a Function of Capacitance measured by an LCR meter.

Electrode Testing

Experiment 1
March 12, 2014

Setup

The Princeton Applied Research Parstat 2273 Advanced Electrochemical System was used for measurements.

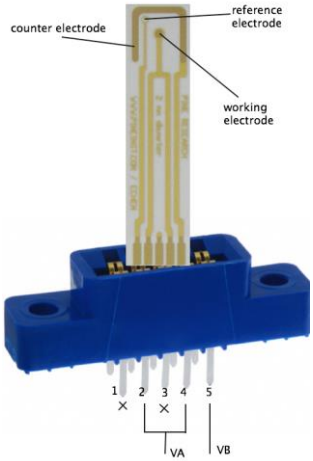


Figure 10 - A representative model of the electrode testing chip. VA and VB leads are treated as the high and low side of a capacitor, respectively.

Measurements

The first measurement taken was that of the wiring of the electrode system (with no electrode attached). This was done by both shorting and opening the wiring connections.

The measurements were taken using **10Hz measurement frequency at 50mV RMS**.
In order to short the system, a small piece of wire was placed on the connection chip between the working and counter lead. Because the counter electrode was tied the reference, this effectively short-circuited the set-up.

Next the system was measured with an open circuit set-up. The results are below. The resistance was found to be about 0.2 ohms with a phase angle of 0 degrees.

Next an electrode fabricated with MCLR-antibody was measured under open conditions without any water or solution (dry).

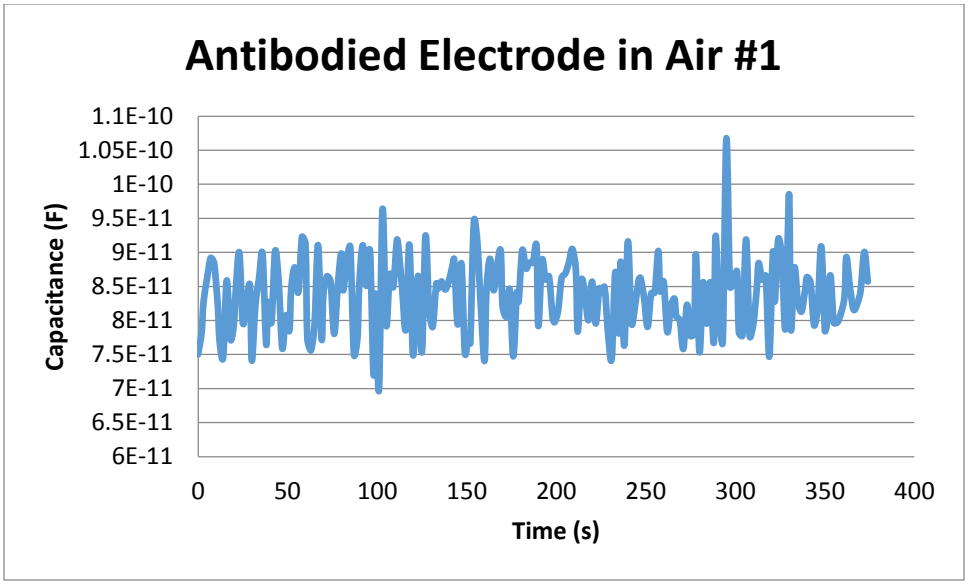
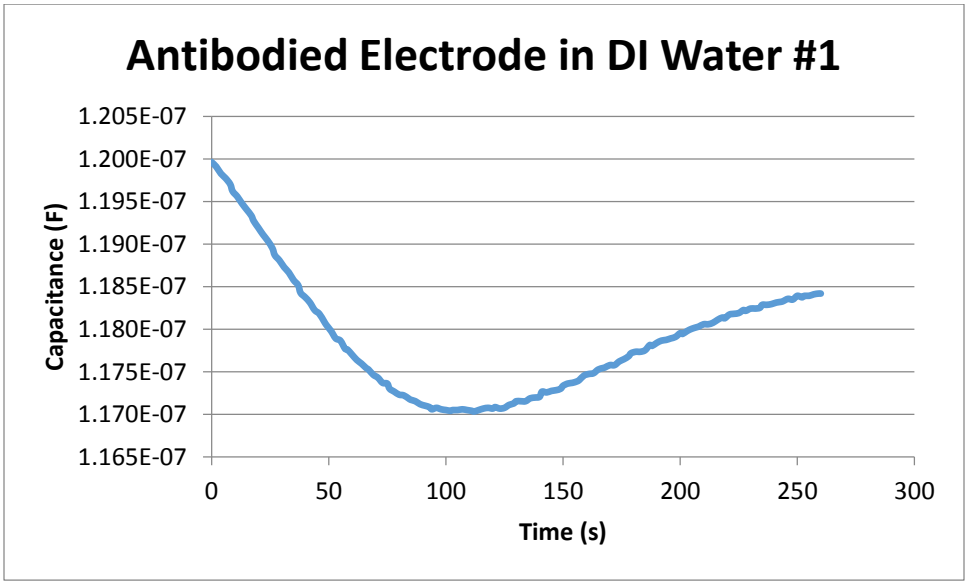
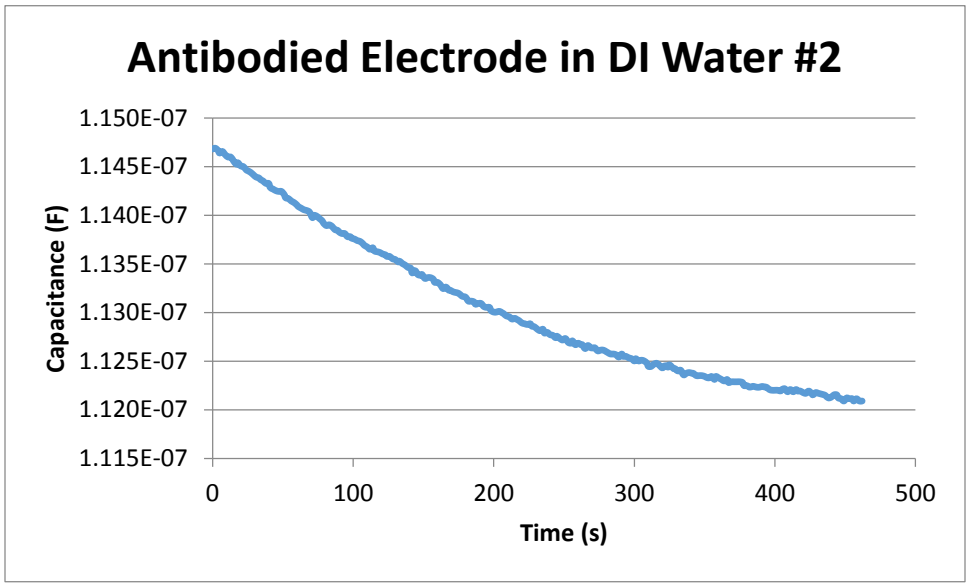
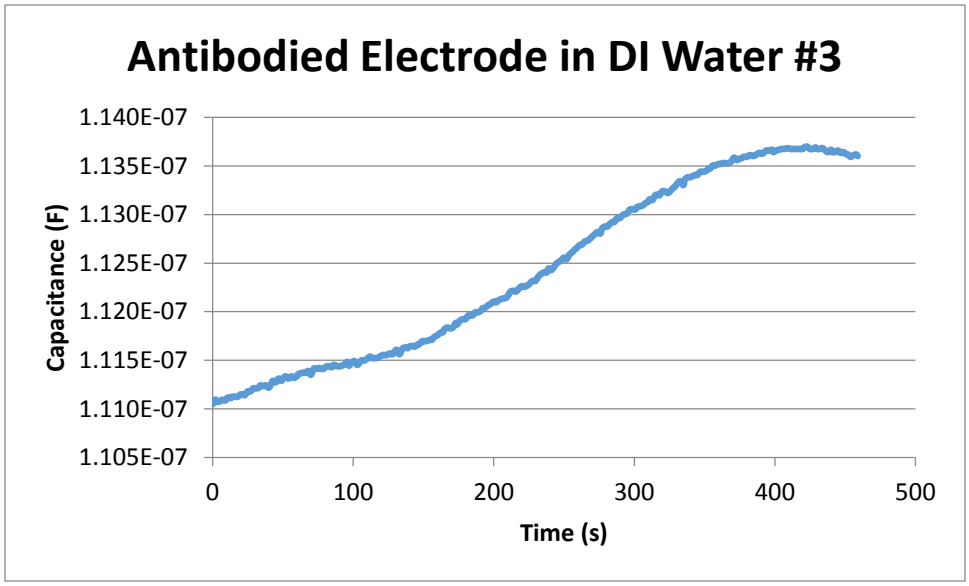


Figure 11 - Capacitance vs. time for antibodied electrode in air, trial 1.

After the dry measurements were taken, the electrode was submerged in deionized water at room temperature. Four measurements were done consecutively to determine the capacitance of the electrode while submerged. The results are shown below.




Antibodied Electrode in DI Water #2
1.150E-07
1.145E-07
1.140E-07
1.135E-07
1.130E-07
1.125E-07
1.120E-07
1.115E-07
Capacitance (F)
0
100
200
300
400
500
Time (s)


Antibodied Electrode in DI Water #3
1.140E-07
1.135E-07
1.130E-07
1.125E-07
1.120E-07
1.115E-07
1.110E-07
1.105E-07
Capacitance (F)
0
100
200
300
400
500
Time (s)

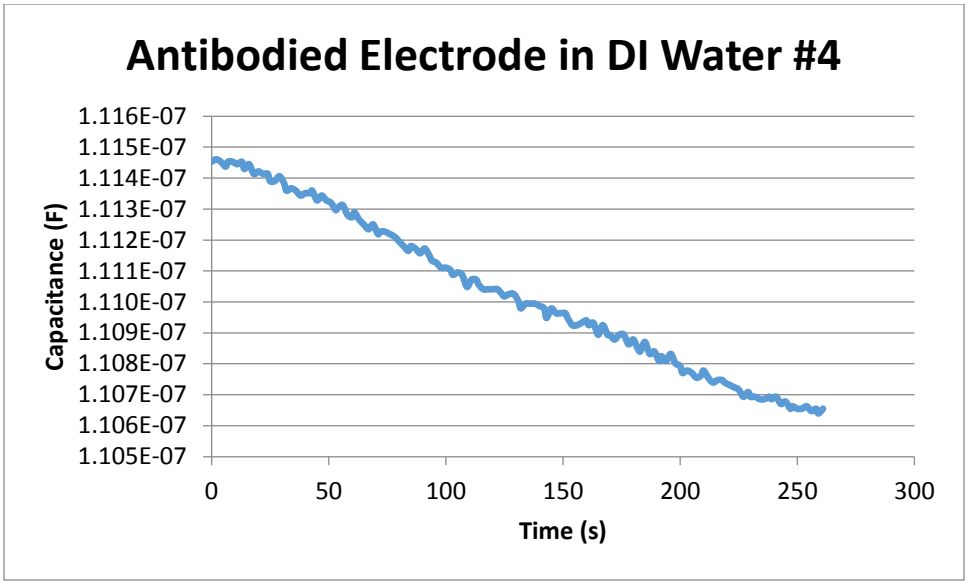


Figure 12 (4 figures) - Data from 4 sequential tests with the same electrode in deionized water. There was a lot of fluctuation present from trial to trial.

It appears that a relatively tangible capacitance fluctuation takes place while in the deionized water. Other solutions should be tested and considered.

After the 4th test, the electrode was removed from the water and placed in an empty beaker. It was then measured again under dry conditions.

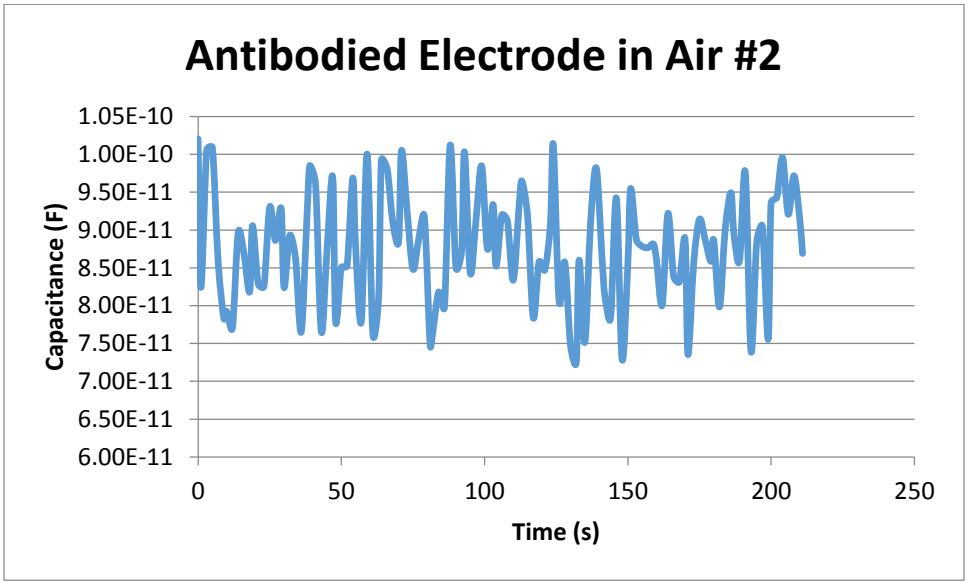


Figure 13 – Capacitance vs. time for antibodied electrode in air, trial 2.

It appeared to have capacitance values fairly consistent with the original readings. None of the previous measurements included the reference electrode.

Next, a solution of 4ug/L MCLR was used for measurement. The electrode was placed in a 20mL vial containing 15mL of the solution (reference electrode attached). The first test ran for 300 seconds and capacitance was measured.

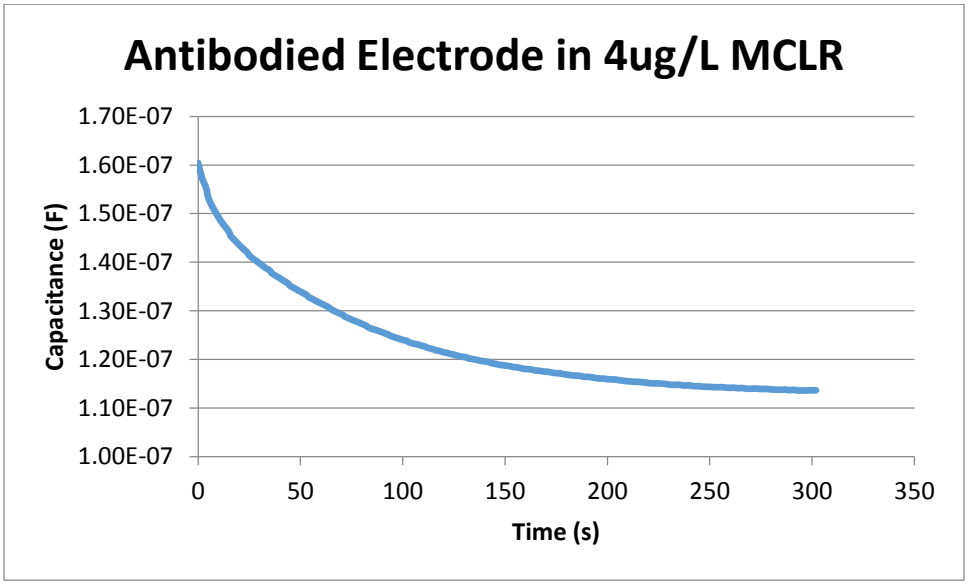


Figure 14 – Capacitance vs. time for 4ug/L solution with antibodied electrode.

The overall change from the measurement start time to the measurement end time was a drop of 46.8 nF.

After this measurement, the electrode was removed from the vial containing MCLR and rinsed in DI water for about 10 seconds. This was done by submersion and a gentle swirl. The electrode was then placed in a pH2.5 HCl solution for 30 seconds. It was gently swirled in the mixture for this 30 seconds. Finally, it took a short (~4 second) re-submersion in DI water.

After the attempted regeneration, the capacitance was measured again using the same 4ug/L MCLR solution.

This measurement only yielded a 1.06nF drop in capacitance. It is clear that 30 seconds is not enough time to regenerate the antibody completely. The starting capacitance was in the 115nF range, while the previous experiment started at 160nF.

The electrode took a 30 second rinse in DI water before being submerged in the 2.5pH HCl solution for 1 minute. It was swirled for 30 seconds and then left to rest in the beaker for the final 30 seconds. It finally took a quick dip in DI water (<4 seconds) and was placed in the 4ug/L solution again.

After 300 seconds the electrode was placed in a dry beaker and was still measured. This resulted in approximately zero capacitance (the reference electrode was left in place).

The 300 second measurement time showed an initial rise in capacitance. Once it hit the peak value, it dropped about 1.63nF. It started around 122nF this time.

The electrode was rinsed in DI water briefly before taking a 2 minute bath in HCl. It then was briefly rinsed in DI water before being placed in a 15mL solution of 1ug/L MCLR.

This experiment showed a capacitance drop (after initial rise) of 0.5nF. While this is a lesser drop than with the 4ug/L experiments, it's unclear whether this is due to a lower concentration or a need for better regeneration methods.

Experiment 2
March 30, 2014

The second experiment was also conducted at the MRC, but this time it involved 2 new electrodes (fabricated in the same batch as experiment 1's electrode). Unfortunately, the same experiment environment was not available, so tests were done in a different room. This experiment was primarily to investigate the repeatability of the capacitance drop between electrodes with the same surface chemistry, in the same concentration.

For each electrode, preliminary tests were done to examine their capacitance in air and deionized water. Then, each was placed in a 1ug/L solution for 300 measurements, roughly 1 second apart. Because the protocol had not been created yet, the electrodes were not placed in an HCl solution, but briefly rinsed with DI water before being dried and placed in a marked envelope.

At the end of this experiment, an electrode with no MCLR antibody was also tested in the 1ug/L solution. Unfortunately these results showed an almost shorted circuit, indicating that the test set-up may have been compromised. Because of the tight schedule of the MRC staff aiding with the experiment tasks, we were unable to acquire any further data on the non-antibodied electrode. It is certainly something for the next group to investigate, along with an effective antibody regeneration solution/schema.

The testing protocol that was followed is listed below.

Testing Protocol
Setup
Connect electrode B to measurement device (no reference electrode)
Prepare data collection for a 1 minute dry run
Place electrode in special cap in a dry vial
Collect ~200mL of deionized water, place some in a small rinse beaker

Electrode A
Dry
Perform a 1 minute dry measurement without the reference electrode
Copy data into excel worksheet
Set up a new 1 minute measurement
Connect reference electrode
Perform a 1 minute dry measurement WITH the reference electrode

Copy data into new excel worksheet
Set up a new 1 minute measurement

Wet
Place the electrode in a vial with ~25mL deionized water
Perform a 1 minute wet measurement in deionized water #1
Copy data into Excel

Set up a new 1 minute measurement
Perform a 1 minute wet measurement in deionized water #2
Copy data into Excel
Set up a new 5 minute experiment

MCLR
Place electrode A in a ~15mL solution of 1ug/L MCLR
Perform a 5 minute wet measurement with 1 ug/L MCLR
Copy data into Excel
Prepare a new 5 minute measurement
Rinse electrode A in deionized water
Dry carefully with wipes
Place in a marked envelope so as to not confuse with others

Electrode B
Place electrode B in the same solution
Perform a 5 minute measurement
Copy data into excel
Rinse electrode B with deionized water
Dry carefully with wipes
Place in a marked envelope so as to not confuse with others

Wet
Place the electrode in a vial with ~25mL deionized water
Perform a 1 minute wet measurement in deionized water #1
Copy data into Excel

MCLR
Place electrode A in a ~15mL solution of 1ug/L MCLR
Perform a 5 minute wet measurement with 1 ug/L MCLR
Copy data into Excel
Prepare a new 5 minute measurement
Rinse electrode A in deionized water
Dry carefully with wipes
Place in a marked envelope so as to not confuse with others

Non-Antibody Electrode A

Place non-antibody electrode A in the same 1ug/L solution
Perform a 5 minute measurement
Copy data into excel
Rinse non-antibody electrode A in deionized water
Dry carefully with wipes
Place in a marked envelope so as to not confuse with others

Clean up
Pour remaining deionized water down the sink
Place the reference electrode in its KCl solution and cap as tightly as possible
Cap 1 ug/L MCLR solution and place in container
Save Excel workbook to flash drive

Results of Experiment 2

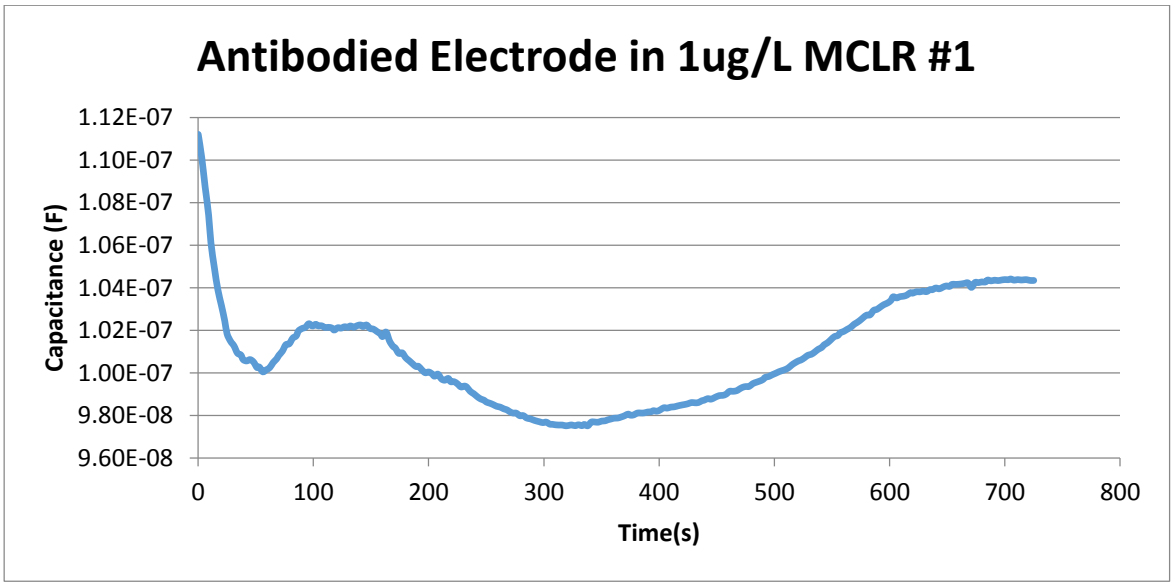


Figure 15 – Electrode A capacitance versus time results. Electrode A's data seemed promising at first, but then began to act strangely. It is unclear whether the small, crowded room the measurements took place in had any effect on this. It is also possible that fabrication inconsistencies were present. The capacitance drop of the portion that behaved as expected was 10.7nF.

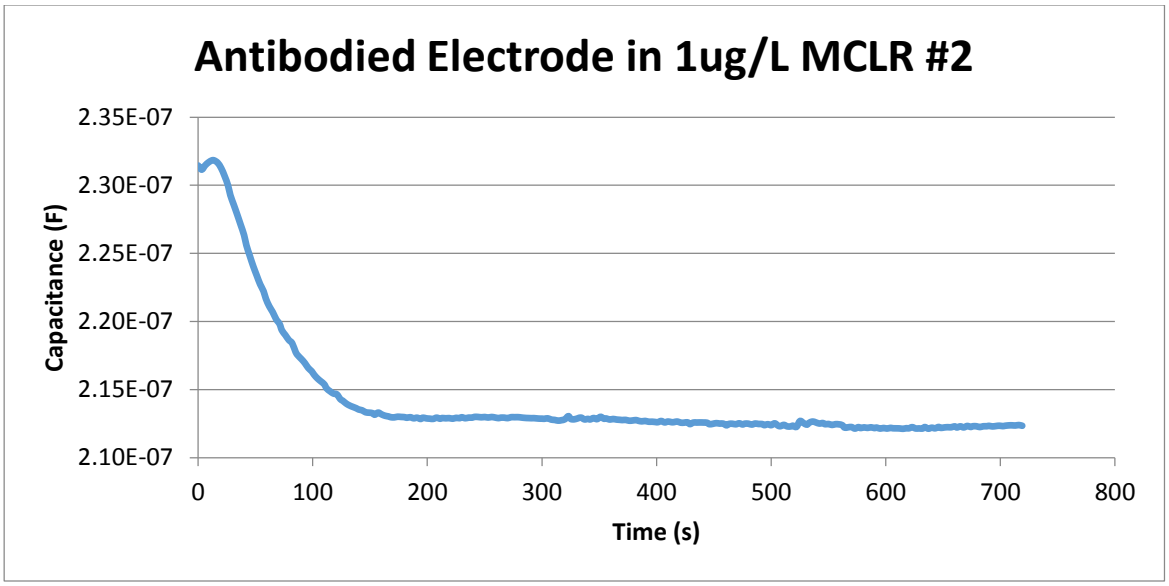


Figure 16 - Non-antibody electrode capacitance versus time results. Electrode B performed as hypothesized: the capacitance dropped fairly consistently, then leveled off. This capacitance drop was also smaller than the drop seen in the 4ug/L solution. The value of the capacitance drop was 19.09nF.

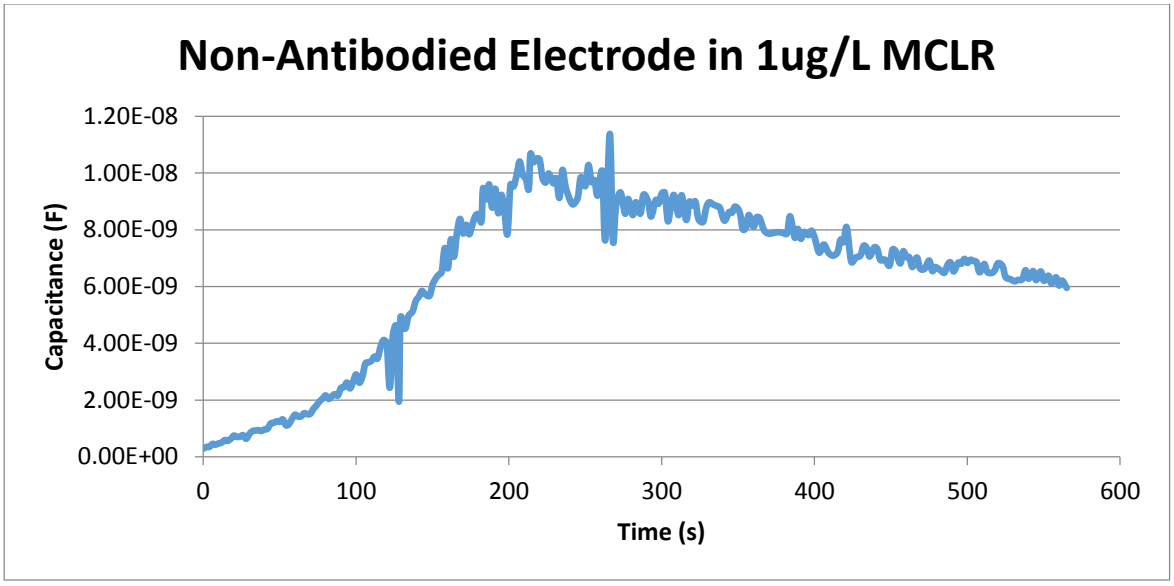


Figure 17 – Non-antibody electrode capacitance versus time results. These results weren't as clean as hoped: for some reason it started at almost zero capacitance, then grew for a while. After its growth stage, it did display a capacitance drop. The fluctuation could be due to many factors, such as experiment set up or ambient conditions.

Turnover Details

Due to the long-term nature of the project, many details have been left for an additional team to complete in the future. All valuable work completed this year has been organized and labeled for hand-off, including code, schematics, layouts, experiment instructions, and other relevant documentation. Specific details are below.

Layout, Schematic
All Eagle files have been labeled thoroughly with part numbers, pin locations, etc. They were electronically organized and placed in an online storage system accessible to advisers and graduate members.

Electrode Fabrication
All surface chemistry will continue to be handled by the Smith group in the ISU Chemistry Department. Materials (including chemicals, equipment, and additional electrodes) have already been purchased and will be used in future experiments.

Electrode Testing
All testing documentation has been electronically organized and submitted to the online storage system. Instructions regarding dilution preparation, electrode testing procedure, and software data templates have been included.

Prior Work
All work, including work related to scrapped endeavors, has been categorized and labeled for potential future reference. This includes MATLAB code, calculations, weekly reports, and reference papers (such as journal articles).

Appendix I - Operation Manual

Timer Circuit Operation

One of the best qualities of the timer circuit setup is the simplicity with which it can be operated. There are only a few steps needed to use the system:

- First, hook up (or solder) the capacitance to be measured between the 555 timer's pin 7 and ground.
- Then, plug in the supply voltage cables to the power and ground banana connections.
- Next, plug the MSP430 Launchpad into a USB port on the computer being used.
- Open the Tera Term application and select the option for "UART: MSP430 Application" to establish the UART connection.
- If the MSP430 is not already programmed, then you need only to compile and run the measurement program code, using CCS v5 for instance.
- Turn on the 5V power supply.
- The system is now ready for measurements. You now need only to press the button on the Launchpad.
- If the system is hooked up correctly, the green LED will flash several times when the button is pushed, to indicate measurements are being taken.
- When the measurements are complete, then the red LED will light, and the values will pop up in the Tera Term terminal. Congratulations, you've done it!

Electrode Test Setup Operation

Refer to the electrode testing procedure as described in the testing process section above.

Appendix II - Initial Design

During the first semester of our senior design course, we devoted many hours to an initial design that was later handed off to a Huanhuan Zhang (a graduate student we worked with). After the handoff, we refocused our efforts on the current timer circuit design discussed earlier in our report. Even though the task of refining this design was given to Huanhuan, we still played a role in preparing the circuit layout.

Our initial design consisted of a probe that was dipped in a water sample. The probes was connected to an impedance analyzing circuit which was controlled and measured by a microcontroller interface. The user would give input to the device through buttons connected to the microcontroller and receive feedback on the LCD screen.

Our device was centered around an impedance measurement circuit. The impedance measurement module was based on the balancing a bridge of impedances so that the voltage across the bridge approaches zero. The bridge had two sides each with a top and bottom impedance. The top impedance block on both sides is an electrode (one is painted with MCLR antibody and one is not). On the bottom, one of the branches is set to a fixed impedance and the other is an impedance that the microcontroller tunes. Again the branch with the adjustable impedance will be tuned until the voltage difference between the node between the bottom and top impedance branch on the left and on the right approaches zero.

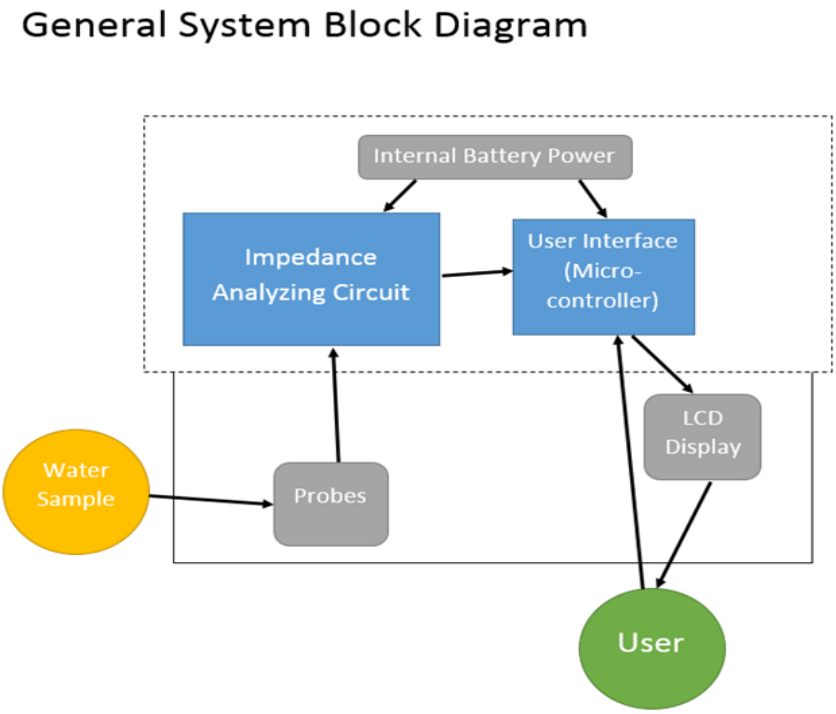


Figure 18: Block Diagram of Our Initial System.

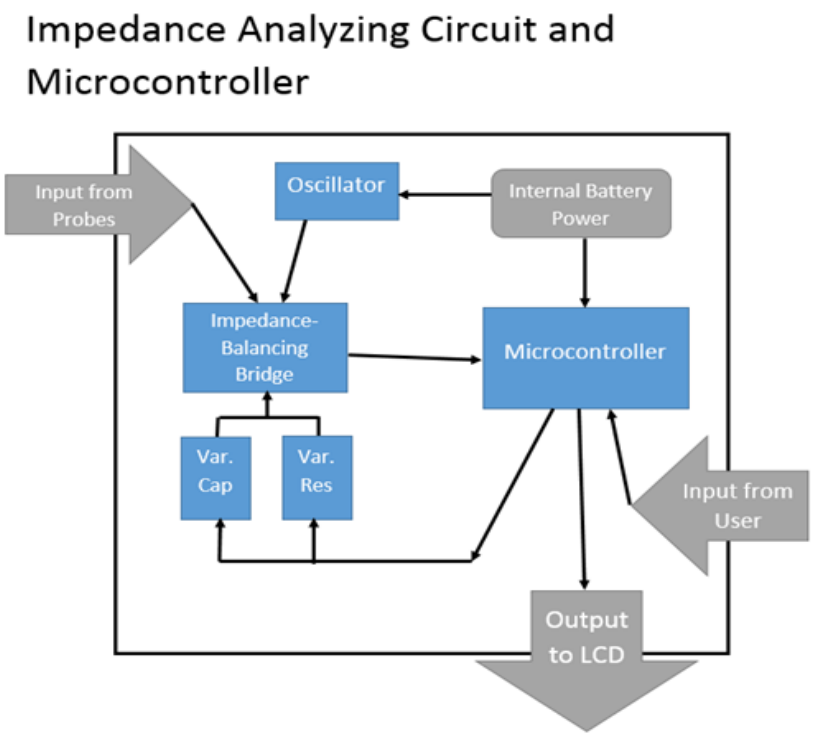


Figure 19: Block Diagram of the Impedance Analyzing Circuitry Including the Microcontroller.

Appendix III - Dilution Preparation

Supplies

5 volumetric flasks, 50mL
1 volumetric flask, 10mL
1 volumetric flask, 250mL (100mL for higher initial concentration)
10 small plastic vials, ~5mL
1 electronic pipet (disposable plastic tips)

Set up

The vial of 10ug solid MCLR was placed in a centrifuge and balanced by a small vial of similar size. The centrifuge was run at 2000rpm for 10 minutes.

After centrifuge, 1mL of methanol and 1mL of deionized water was added to the MCLR vial via measurement needle. This 2mL of liquid was considered in other dilution calculations, and was used to promote mixing. The MCLR solution was swirled using a vibration mixer and then added to a 10mL volumetric flask.

Deionized water was added to the volumetric flask until the 10mL line was reached. This resulted in 10mL of a 1000ug/L solution.

The 10mL was poured into a small beaker (150mL) and an electronic pipet was used to divide this solution into ten 1mL stock solutions. 9 were placed in small, plastic containers with lids and placed in a freezer in the VetMed building (contact Dwayne Schrunk, (515) 294-1215, duey@iastate.edu for room location).

The remaining 1mL of stock solution was used to create dilutions for the first MCLR experiment.

Procedure

The 1mL of 1000ug/L MCLR was poured into a 250mL volumetric flask, and deionized water was added until the 250mL line was reached. This resulted in 250mL of a 4ug/L solution. 15mL of this was poured into the first test vial.

Next, 12.5mL of the 4ug/L solution was measured using an electronic pipet (because they are limited to 10mL, two 6.25mL samples were taken) and placed in a 50mL volumetric flask. The flask was filled with deionized water until the 50mL line was reached.

This resulted in 50mL of a 1ug/L solution. 15mL of this solution was placed in the second test vial.

12.5mL of this dilution was measured by the same method as previously noted. The same process was repeated using clean 50mL volumetric flasks and fresh pipet nozzles each time. The basic process was:

1. Measure 12.5 mL of current dilution into empty, clean 50mL volumetric flask
2. Replace plastic nozzle, dispose of used nozzle

3. Add water to 50mL fill line of volumetric flask
4. Pour off ~15mL solution into test vial
5. Measure 12.5 mL for the next dilution

The remaining amount of the original 4ug/L solution and the final solution were placed in a waste beaker and was tagged using the appropriate protocol.

Results

Five 15mL solutions with the following dilutions:

4ug/L
1ug/L
0.25 ug/L
0.0625 ug/L
0.015625 ug/L

Appendix IV – Code

```
/*
-------------------------------------------------------------------------------
 * This program scans 50 samples on Port2.0 of MSP430 and dumps their pulse widths.
 * Platform         :   TI MSP-EXP430G2 Launchpad running MSP430G2553
 * Software Suite   :   Code Compose Studio,  Version: 4.2.3.00004
-------------------------------------------------------------------------------
 */

#include <msp430g2553.h>
#include <stdbool.h>
////////////////Defines///////////////
#define LED1        BIT6
#define LED0        BIT0
#define DAT         BIT0 //P2.0   //input signal port
#define VCC         BIT5 //P1.5
#define GND         BIT4 //P1.4
char charbuffer[8];
int i=0;
int j=0;
unsigned int capture_array[51];             // RAM array for captures
int tick=0;
int cap=0;
int pre_cap=0;
int first_pulse=0;

////////////////Function Protos///////////////
void TX(char *tx_message);
static char *i2a(unsigned i, char *a, unsigned r);
char *itoa(int i, char *a, int r);


static char *i2a(unsigned i, char *a, unsigned r)
{
    if (i/r > 0) a = i2a(i/r,a,r);
    *a = "0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZ"[i%r];
    return a+1;
}

char *itoa(int i, char *a, int r)
{
    if ((r < 2) || (r > 36)) r = 10;
    if (i < 0)
    {
        *a = '-';
        *i2a(-(unsigned)i,a+1,r) = 0;
    }
    else *i2a(i,a,r) = 0;
    return a;
}

void TX(char *tx_message)
{
```

```
    unsigned int i=0; //Define end of string loop int
    char *message; // message variable
    unsigned int message_num; // define ascii int version variable
    message = tx_message; // move tx_message into message
    while(1)
    {
        if(message[i]==0) // If end of input string is reached, break loop.
        {break;}
        message_num = (int)message[i]; //Cast string char into a int variable
        UCA0TXBUF = message_num; // write INT to TX buffer
        i++; // increase string index
        __delay_cycles(10000); //transmission delay
        if(i>50) //prevent infinite transmit
        {
            P1OUT |= (LED1+LED0);
            break;
        }
    } // End TX Main While Loop
} // End TX Function

int main(void)
{ WDTCTL = WDTPW + WDTHOLD; // Stop watchdog timer
    //setup clock to 1MHZ
    BCSCTL1 = CALBC1_16MHZ;            // Set DCO to 1MHz
    DCOCTL = CALDCO_16MHZ;
    ////////////////USCI setup////////////////
    P1SEL = BIT1 + BIT2;            // Set P1.1 to RXD and P1.2 to TXD
    P1SEL2 = BIT1 + BIT2;            //
    UCA0CTL1 |= UCSSEL_2;            // Have USCI use SMCLK AKA 1MHz main CLK
    UCA0BR0 = 104;                  // Baud: 9600, N= CLK/Baud, N= 10^6 / 9600
    UCA0BR1 = 0;                   // Set upper half of baud select to 0
    UCA0MCTL = UCBRS_1;               // Modulation UCBRSx = 1
    UCA0CTL1 &= ~UCSWRST;             // Start USCI
    ////////////////General GPIO Defines////////////////
    P1DIR |= (LED0 + LED1+GND+VCC); //define output ports
    P1OUT &= ~(LED0 + LED1+GND); //turn ports low
    P1OUT|=VCC;
    P2IE |= DAT;
    P2IFG &= ~DAT;
    P2SEL = DAT;                              // Set P1.1 to TA0
    /////////////////SETUP TIMER
    TA1CCTL0 = CM_2 + SCS + CCIS_0 + CAP + CCIE; // falling edge + CCI0A (P2.0)// +
Capture Mode + Interrupt
    TA1CTL = TASSEL_2 + MC_2;                  // SMCLK + Continuous Mode
    __enable_interrupt();
    for(;;)
    {

    }
}

// Timer1 interrupt service routine
#pragma vector=TIMER1_A0_VECTOR
__interrupt void TIMER1(void)
{
```

```
    if (first_pulse==0)
        {
            pre_cap=TA1CCR0;
            first_pulse=1;
            goto here; //break from interrupt service routine
        }

    tick = TA1CCR0;
    cap = tick- pre_cap;
    capture_array[i]=cap;
    i++;
    if (i == 30)
    {
        P1OUT^=LED0;//toggle led
        //turnoff timer 1
        TA1CTL = MC_0;
        //dump samples
        //setup clock to 1MHZ
           BCSCTL1 = CALBC1_1MHZ;            // Set DCO to 1MHz
           DCOCTL = CALDCO_1MHZ;
        for (j=0;j<=i;j++) //exclude bit0 as it is most likely erroneous
        {
  //          itoa(j, charbuffer, 10);
  //          TX(charbuffer);
  //          TX("-->");
            itoa(capture_array[j], charbuffer, 10);
            TX(charbuffer);
   //         TX("\r\n");
        }
        TX("------------------\r\n");
        first_pulse=0;
        i=0;
        //start timer
        TA1CCTL0 |= CM_1;
        TA1CTL = TASSEL_2 + MC_2;                  // SMCLK + Continuous Mode
    }
    pre_cap = tick;                        // store this capture value
    here:
    P1OUT^=LED1;
}
```