WiWe Moisture Sensor Final Report

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Contents

List of Figures

List of Tables

1 Executive Summary

The Wireless Wearable Moisture Sensor (WiWeMS) is an inexpensive radio frequency identification (RFID) system to quantitatively measure moisture and wirelessly send the data to a reader 3 to 5 meters away. Children of all ages and adults with enuresis struggle with incontinence. The WiWeMS monitoring system helps to solve this problem without using a battery or external antennas as other solutions have used in the past by using backscatter radio.

The current WiWeMS uses a flexible wetness sensor, a sensor board, and two antennas mounted on either side of the diaper. The flexible wetness sensor uses capacitive sensing to detect moisture and sits in absorptive material in the diaper. The sensor board measures the capacitance of the wetness sensor and converts the value to data for the antennas to backscatter to the reader.

The current prototype has been improved by developing a new technology to print silver ink on photo paper with an off-the-shelf inkjet printer to create flexible circuits. The new technology allows for rapid prototyping of the final design, a flexible inlay for the diaper.

The final WiWeMS uses two integrated circuits (ICs), two antennas, and a wetness sensor printed on a flexible substrate. The two antennas use spatial diversity to improve coverage when the child moves into different orientations such of lying on her back or lying on her side. The two ICs replace the sensor board but are very expensive to design and manufacture, so they will be implemented in the next phase of the project. After the development, the ICs only cost a few pennies each, so the final WiWeMS device is expected to cost less than $0.16 per inlay. After the ICs are manufactured, the medical testing trials could begin which include overnight hospital surveillance, home nocturnal void testing, and school for daily monitoring in the classroom.

The WiWeMS is currently protected under a provisional patent and a patent application was initiated due to the work performed under this grant.

2 Introduction

The purpose of the Wireless Wearable Moisture Sensor (WiWeMS) is to develop an inexpensive radio frequency identification (RFID) system to measure wetness quantitatively for patients or children with incontinence and wirelessly report the data to a nearby reader. This technical report summarizes work performed to this end under the 2012/2013 grant funded by Center for Pediatric Healthcare Technology Innovation (CPHTI).

2.1 Motivation

Incontinence can be a common problem for children of all ages. This report develops a prototype unit and a test plan for a wireless, battery-free moisture sensor for use in the detection and/or treatment of enuresis. The Wireless Wearable Moisture Sensor (WiWeMS) system allows remote monitoring of moisture with no on-board battery or power supply, making the cost of each sensor extraordinarily low (15 cents or less per device).

Devices to signal incontinence have proven useful in the immediate detection of a void. Often, these devices are attached to the child's undergarments and an alarm (sometimes accompanied by a vibration) is emitted to signal when a void begins to occur, so that a parent or trainer can immediately take the child to the toilet. Since these devices were first described in the research literature [3], updated versions have been created and shown to be effective [4] and the use of these systems has been extended to the treatment of other toileting problems such as nighttime incontinence [5].

A wireless system is more natural but has eluded successful deployment in clinical and home remedy markets. One problem is the perception associated with placing a conventional, free-running transmitter on the groin of a small child. Another significant hurdle is primarily technological: the electronics of detection and information relay must require such little power that it may operate from harvested RF energy rather than an expensive, non-disposable battery. Biosensors of the past have often been too large, cumbersome, and power-hungry to provide a convenient solution.

2.2 Comparison to Similar Current Systems

An important problem with the technology exists because the current models for the devices (Wetstop™, Malem™alarm, [6], [7]) include a wire that attaches the sensor in the child's undergarments to the alarm or a wire to an external antenna. This wire can prove quite problematic due to the presence of a cord and a clip-on alarm does not provide a comfortable solution for children of any age. Especially for children with developmental disabilities that engage in maladaptive forms of problem behaviors such as aggression and self-injury [8], significant physical consequences may occur (e.g., the wire may become wrapped around the child's body parts, the wire may be used as a tool for aggression against self or others) when such devices are integrated into behavioral protocols. Other current systems and solutions require someone to bring the reader within less than a meter of the tag for sensing wetness in diapers [9]. Systems that require a reader in close proximity to the tag can be difficult during implementation because someone has to actively check patients or children.

The WiWeMS system is a dramatic improvement on these other systems for these major reasons:

- No wires or external antennas
- Antenna diversity
- Backscatter communications
- Quantitative moisture information

Without wires or external antennas, the WiWeMS diaper is much more low-profile and unobtrusive for the patient than similar systems. Other solutions use external antennas to increase range, but the WiWeMS uses an antenna in the diaper on front and back which can attain or even exceed the range of other systems. In addition, using two antennas helps prevent detuning of the antennas due to a wet diaper and eliminate degradations due to orientation and position of the child. Backscatter communications requires no active transmitter on the diaper or on the child, so the amount of radiation density that the child is subjected to is reduced by orders of magnitudes [10]. Lastly, the quantitative moisture data enables reporting of how wet the diaper is. For doctors and parents, a small leak versus a full void is an important distinction.

2.3 How RFID Sensing Systems Work

RFID sensing systems use backscatter radio to communicate wirelessly between a tag and a reader by using reflections from the tag [11]. The reader transmits a continuous wave (CW) signal which propagates through the air to power and communicate with a tag. The tag receives the CW signal through an antenna to a switch and energy harvesting circuit.

The switch is controlled by a microcontroller unit on the tag to switch between a short and open (or other loads) which correspond to bits of -1 and 1. Since the short has a reflection coefficient of -1 and the open a coefficient of 1, data can be modulated onto the reflected signal which propagates back to the reader. Upon receiving the reflected signal, the reader demodulates the data and processes the baseband signal for a computer to display to the user.

The energy harvesting circuitry on the tag allows for operation of the tag without a battery by rectifying the incident CW signal. Although rectifying wireless signals to DC power is inefficient, the energy harvesting circuitry eliminates the need for a battery, but does reduce range by introducing a forward link limit instead of the link being limited by the signal-to-noise ratio at the reader (SNR). The forward link limit is the range limit of where the tag has enough power to turn on which is -20 dBm for most off-the-shelf RFID chips [2] [12].

2.3.1 Reduction of Incident Radiation

Backscatter systems are sufficient for wireless communication over short ranges (1 to 20 meters) and dramatically reduce the radiation incidence on a patient wearing a tag. Other previously developed systems use a transmitter on the patient that results in radiation orders of magnitude higher than the WiWe system [7].

The Federal Communications Commission (FCC) limits radiation by limiting the specific absorption ratio to $1.6W/kg$ which is calculated as shown in (1) [13]. SAR is directly proportional to the square of the electric field (E) and related to conductivity (σ) and mass density of tissue (ρ) [13]. The electric field values were calculated based on a dipole antenna 1 cm away from operator since all these communications devices are used in close proximity to a human. The dramatic reduction in electric field for backscatter radio is because there is no transmitter within 1 cm to the human body. The transmitter is assumed to be approximately 3 meters away (a low, conservative

Technology	TX Power	Freq.	**E-Field**	Avg. Range
Cell Phone	300 mW	1920 MHz	**3950 V/m**	800 m
Active RFID	3 mW	915 MHz	**1490 V/m**	3 m
Backscatter	1000 mW	915 MHz	**3 V/m**	3 m
WiFi	30 mW	2400 MHz	**800 V/m**	20 m
Bluetooth	3 mW	2400 MHz	**280 V/m**	1 m

Table 1: Comparison of various wireless technologies showing how backscatter communications reduces the electric field on the user by two orders of magnitude

estimate of a UHF RFID system), co-located as part of the reader. The additional distance reduces the electric field by orders of magnitude than other technologies. The disadvantage of backscatter is that range and data rates are limited, but for applications with low data rates, backscatter is ideal.

$$SAR = \frac{|E|^2\sigma}{\rho} \tag{1}$$

Table 2 shows that backscatter radio reduces the electric field by two orders of magnitude which reduces SAR by four orders of magnitude. Compared to other RFID solutions with active transmitters on the tag, there is an improvement of three orders of magnitude in electric field exposure to the patient. This improvement ensures that there is no harm to the patient due to high electric fields near the human body and makes the product more marketable. This is especially important for patients that may have sensitive internal electric devices such as pacemakers. In addition, the effects of high-level, non-ionizing radiation is still not fully understood especially for very young children during critical developmental stages [14]. By using backscatter radio, electric field exposure is reduced by two or more orders of magnitude depending on the technologies.

2.4 Frequency Selection of ISM Bands

In the early 1980s and 1990s, the Federal Communications Commission (FCC) allocated three bands that are useful candidates for WiWeMS communications: 902-928 MHZ, 2.4-2.4835 GHz, and 5.725-5.875 GHz [15]. These are called the industrial, scientific, and medical (ISM) bands and allow for unlicensed transmission provided that the power levels remain under certain levels, which are limited by the maximum effective isotropic radiated power (EIRP) at 36 dBm (4 Watts) [16].

The rules set by the FCC prevent operators from overpowering the spectrum and blocking others from communicating over this shared radio resource.

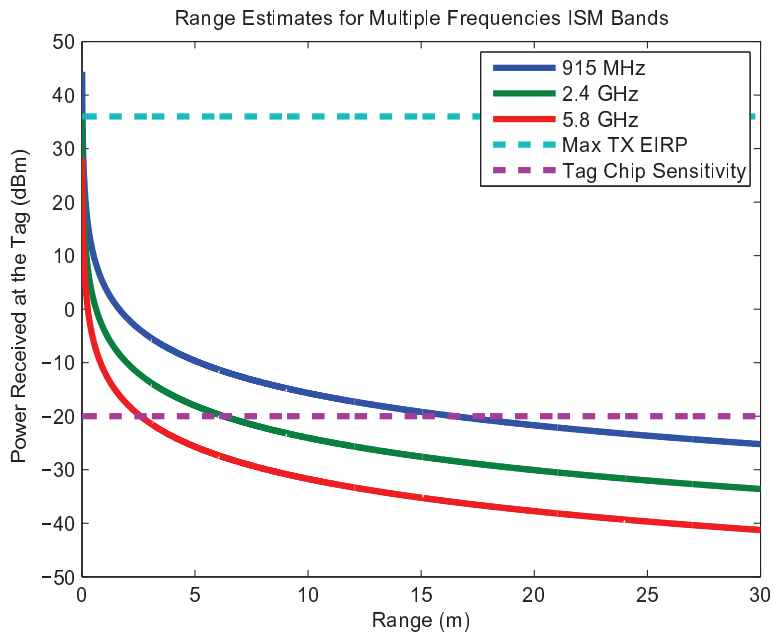

Figure 1: Range for different RFID frequencies for a chip with -20 dBm sensitivity

Although each ISM band limits the transmitted power to 36 dBm EIRP, the band chosen dramatically affects range and antenna size of the wireless system. As frequency increases, the path loss increases to limit the power input to the tag, but the antennas footprint decreases linearly with frequency. Figure 1 shows the power level received for each frequency over a variety of ranges assuming the receive antenna has 0 dBi gain; the antenna efficiencies are ideal, and multipath is minimal.

Off-the-shelf RFID chips such as Impinj's Monza^{TM}4 & 5 require -20 dBm power received in order to activate. Thus, a custom made IC for the WiWe sensor, if manufactured with a similar CMOS silicon process, should be able to attain a similar sensitivity [12]. With a -20 dBm sensitivity and 0 dBi antenna, in ideal conditions, a tag at 915 MHz has a read range of about 15 m, while the 2.4 GHz and 5.8 GHz have a read range of approximately of 6 m and 3 m respectively as shown in Figure 1. Clearly, 915 MHz is a superior choice to satisfy a long range, but, unfortunately, this requires a larger antenna than 2.4 GHz or 5.8 GHz. Although 5.8 GHz and 2.4 GHz have shorter ranges than 915 MHz, the FCC allows engineers to add 2 dB by increasing the gain of the antenna

by 3 dB and lowering the transmit power by 1 dB for fixed readers. The result of this change increases the range of the 5.8 GHz and 2.4 GHz systems slightly but still cannot cover the range of a 915 MHz system.

The result of this analysis shows using 915 MHz is the best solution and that a larger antenna is a necessary trade off in order to improve range of the tag but can be reduced by using different antenna designs.

2.5 Key Outcomes

The key outcomes of the development of the WiWeMS project discussed in this report are:

a. An initial tag prototype has been developed and implemented to sense wetness and backscatter data back to the reader at 5.8 GHz

b. An inkjet printing system has been developed to create flexible circuits quickly and cheaply by using silver nanoparticle ink

c. A flexible prototype of the final tag has been developed without the RFIC at 915 MHz by using the silver nanoparticle inkjet printing system

d. Dual antenna experiments in a dry and wet diaper have been taken and results show that dual antennas improve range for dry and wet diapers

e. A plausibility study for large scale production has been initiated and a cost basis researched

f. Initial medical trials have been discussed and are currently being developed

3 Current WiWe Moisture Sensor Prototype

This section discusses the current state of the WiWeMS tag. Currently, the tag operates at 5.8 GHz using a sensor board to control the sensing of moisture and backscatter communication while being powered by a small coin cell battery instead of energy harvesting circuitry. The operation frequency of 5.8 GHz for the initial prototype was chosen due to small antenna sizes and because the Propagation Group at Georgia Tech had already developed a reader at this frequency. The sensor board can also work passively (without a battery) at 5.8 GHz but can only get a range of approximately 1 m by using a 4 stage Dickson charge pump. In addition to the sensor board, the current WiWeMS also has a flexible wetness sensor and antennas on FR-4 printed circuit boards with switches to backscatter data. In the final design, the sensor board is replaced by a radio frequency identification chip to make the entire tag less expensive and smaller, but the overall block diagram and function does not change as shown in Figure 2.

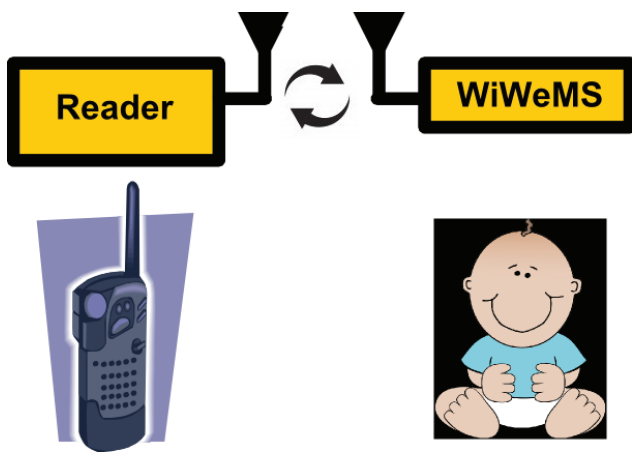

Figure 2: Overall block diagram for the WiWeMS with the reader wirelessly interrogating the WiWeMS inlaid in a diaper

3.1 Moisture Sensor

The moisture sensor is an interdigitated capacitor that uses a change in capacitance to measure moisture as small as 1 cc of water. Traditionally, this sensor is designed on FR-4 for a rigid sensor [17], but by implementing a similar design on a flexible substrate, a more conformable moisture sensor is possible. The measurement technique used by the sensor board to record the capacitance

of the sensor and the flexible moisture sensor is also discussed.

3.1.1 Flexible Sensor

The flexible moisture sensor is a simple design that uses two traces of interdigitated fingers to create a capacitor. As the more moisture gets on the sensor, the fields between the fingers pass through the water with a different dielectric constant than air. With a higher dielectric constant, the capacitance increases, so an increase in water on the moisture sensor results in higher capacitance.

The capacitance (C) of a moisture sensor can be calculated as shown in (2) where n is the number of teeth, a is the area of one tooth, d is the separation distance between opposing teeth, ϵ is the permittivity, and γ is the fringing factor ($>= 1$) [17]. The change in capacitance is due to moisture on the sensor which changes the dielectric constant or permittivity because the electric field lines pass through the water instead of through air. The sensitivity to water on the sensor can be altered by increasing the density of fingers or by increasing the thickness of the copper on the PCB to increase the area (a).

$$C \approx \frac{(n-1)\epsilon a \gamma}{d} \tag{2}$$

Traditional interdigitated capacitors on printed circuit boards are rigid and difficult to place in a diaper, but by using a similar design on a flexible substrate, the capacitive sensor is less sensitive but can easily fit in a diaper inlay. The flexible wetness sensors can be manufactured inexpensively using an inkjet printer, silver ink, and a flexible substrate. The flexible sensors are also sensitive to bending, but the degree of sensitivity depends on the geometry used for the sensor.

In order to manufacture the wetness sensors on a flexible substrate, an ink jet printer is used to print silver nanoparticles on to photo paper. After printing, the sensors must be sealed to prevent water from shorting out the fingers by laminating the sensors. Thinner lamination works better, because this allows the water to get closer to the spacing between the fingers where the highest density of electric fields are. In addition, the lamination allows for the flexible wetness sensor to be dried and reused after each test. Figure 3 shows how the lamination and silver deposit on to the flexible substrate and expresses why a thin laminate is helpful to keep the sensitivity of the sensor. For this particular sensor, a 1.5 mil lamination was used. Overall, the process of producing these

sensors is easy, inexpensive, and produces an effective, reusable sensor.

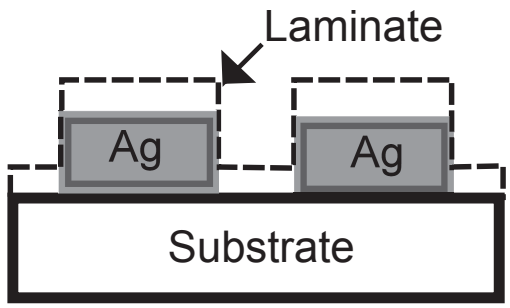

Figure 3: Flexible silver interdigited capacitor sensor stack up after printing and lamination

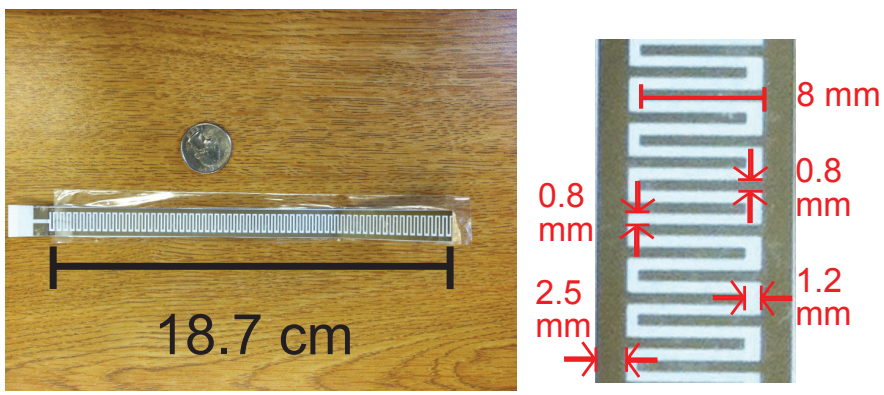

Figure 4: Flexible silver interdigitated capacitor sensor for sensing wetness containing 60 teeth on each side

Figure 4 shows an example of the flexible sensor after printing and lamination as well as the dimensions used for the sensor that was characterized while under test conditions shown in Figure 6. The capacitance is linearly related to the moisture as shown in Figure 5. This linear relationship is expected because capacitance is linearly related to relative permittivity. For the experiment, water was added to the diaper, the count was recorded 5 times, and the average value was plotted. The regression line had a coefficient of determination of 0.94 which shows a strong linear fit. To put the graph in perspective to the diaper application, a child at birth has a bladder capacity of 60 cc. As the child grows, starting at age 1, urologists use a rule-of-thumb to estimate bladder capacity by adding 1 to the age and multiplying by 30 [18]. This means by age 1 the infant has a capacity of 90 cc. Since the sensor can accurately sense from a few ccs to a saturation point (dependent on absorption material), the WiWeMS can depict how much the "child" has leaked or

if a complete void has occurred. If only a small drip occurs, the WiWeMS can precisely depict the level of wetness in the diaper instead of simply reporting if the diaper is wet or not as other systems do. The level of wetness is important information to prevent needlessly changing a diaper and for a doctor's diagnosis during observation.

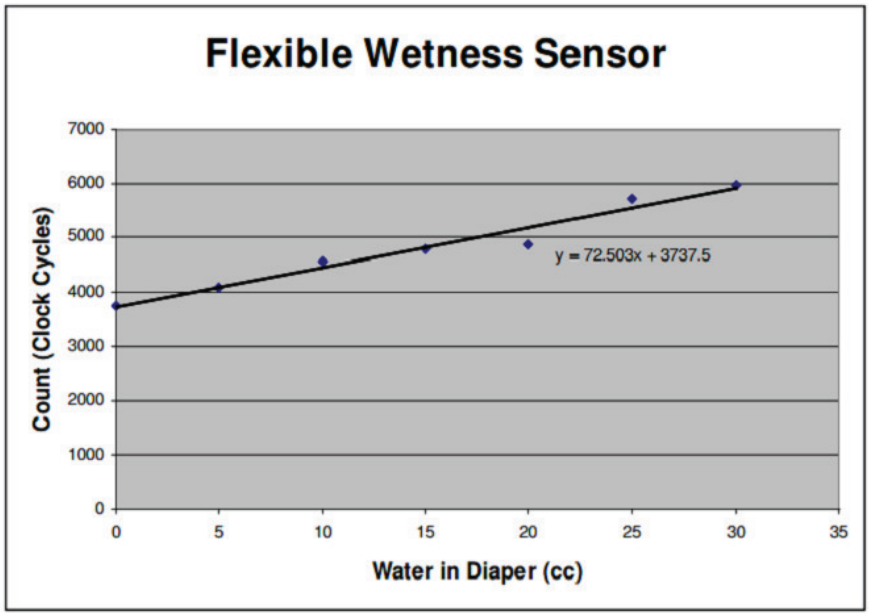

Figure 5: Linear relationship of clock count versus CCs of water placed into the diaper

3.1.2 Moisture Measurement Technique

The moisture measurement technique is simple and very effective, because it is a parallel resistor-capacitor (RC) circuit as shown in Figure 7. To measure how moist the sensor is, the RFIC uses a counter with a resistor in parallel to the sensing capacitor to count how long it takes for the DC circuit to reach steady state. The sensor board or RFIC in final production measures the time constant of the circuit, then reports the number of cycles that it took to get from the high digital voltage to a low voltage. Many applications in wireless sensing such as measuring wetness or gas presence use a capacitive based sensor that can easily be measured using this method [19].

The time constant measurement is performed by using a general input output pin and interrupts [19]. First, the general purpose input/output (GPIO) pin should be set to an output port and set to the high voltage. Secondly, enable the negative-edge interrupt, start a timer, and release the

Figure 6: Wetness sensor placed underneath absorbing material inside the diaper for characterization

GPIO by changing it to an input pin. Since the GPIO pin is now floating, the capacitive sensor (C_S) discharges through the resistor (R) and when the voltage level cross the low threshold, the interrupt stops a timer as shown in Figure 8. The timer value is approximately three time constants can be used to calculate capacitance based on (3) where C_S is the capacitance of the sensor, T_{timer} is the timer value, and R is the resistor value.

$$C_S = \frac{T_{timer}}{3R} \tag{3}$$

Figure 7: Microcontroller schematic for wetness sensor measurement using general input output pin (GPIO) where R is $3M\Omega$ and C_s is the variable capacitance of the wetness sensor

If the timer runs too quickly, it may overflow, but there are two solutions to avoid this situation. A overflow occurs when the count becomes higher than the maximum number supported by the 16 bit counter register in the timer on the microcontroller. If this occurs, the clock of the timer can

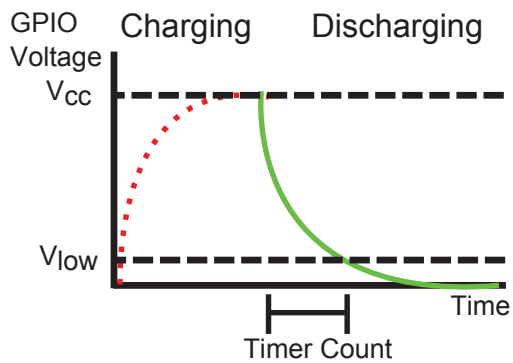

Figure 8: Time domain voltage plot of how the MCU measures the capacitance by measuring the time elapsed for the pin voltage to drop from high to low

be slowed to a lower frequency so it is able to count longer without overflowing, or the resistance can be reduced to reduce the time constant [19]. If the timer is not fast enough for the desired resolution, the timer clock frequency must be increased or the resistor size increased. In addition, if the resistor is not sufficiently large the leakage through the resistor during the charging period may alter the capacitance estimation.

3.2 Sensor Board

The current sensor board prototype of the WiWe wetness sensor is on a rigid FR-4 printed circuit board and does not use an integrated circuit (IC), because an IC is expensive for prototyping. The sensor board shown in Figure 9 is composed of discrete components and has been used for developmental purposes. Although the board is small (approximately as large as a quarter) and can be used with a patient, developing an IC will reduce cost, size, and ability to print the final product on a flexible inlay. The sensor board is composed of a microcontroller, programming pins, LEDs, interface to antennas/switches, and interface to moisture sensor.

3.2.1 Microcontroller

The microcontroller used for the sensor board was Texas Instruments MSP430F2132 for its low power operation, serial peripheral interface (SPI), and GPIO interrupt. The power consumption in active mode is only 550 μW and in sleep mode only consumes 1.54 μW. The SPI port is used to control the external switch that connects to the antenna to modulate data into the backscattered

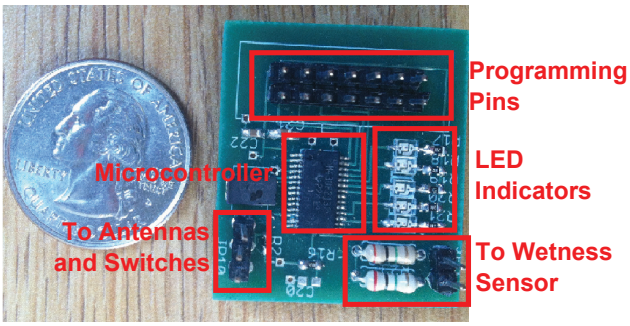

Figure 9: Sensor board that can sense capacitance of the wetness sensor and signal the switches to communicate wirelessly with the reader

signal. The slave in master out (SIMO) port of the SPI should be used to control the switch. The GPIO interrupt is used to measure the capacitance of the wetness. For initial prototype testing, the sensor board is powered by a small coin cell battery to emulate the type of range experienced by a sensitive RFIC harvesting energy wirelessly.

The microcontroller is programmed according to the following flow chart shown in Figure 11. The microcontroller turns on in the start up sequence that ensures the microntroller turned on correctly. If it did not, the MCU errors out. Otherwise, the MCU begins to sense moisture then checks for an overflow. If an overflow occurs, the MCU senses for moisture again until the overflow does not occur. After sensing moisture, the value is backscattered by the tag.

The backscatter data uses RFID protocol by sending the header, ID, data, and cyclical redundancy check (CRC). The header alerts the reader that it should start listening to bits that it receives. The ID tells the reader what tag is backscattering to it. The data contains information about how moist the sensor is and the CRC confirms that the correct data was sent. The backscattered data is shown in Figure 10 with the bit numbers labeled. The data is the count of how many cycles were measured during the capacitance measurement.

Figure 10: Backscattered data from the WiWeMS to the reader

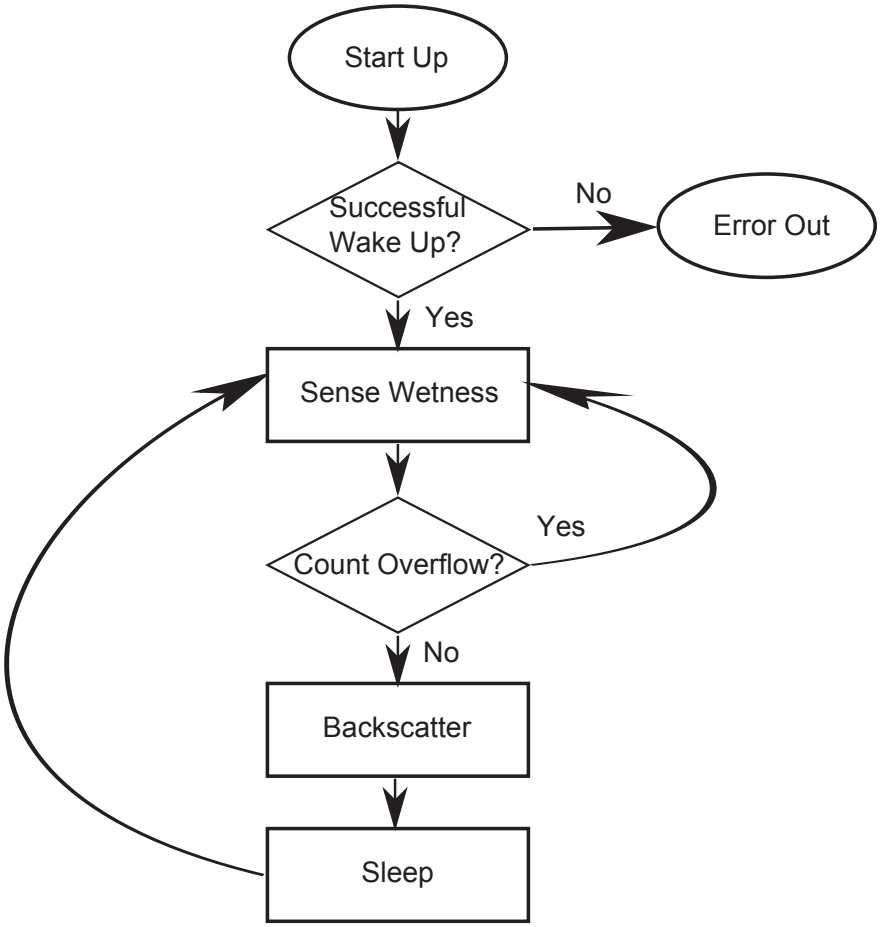

Figure 11: Flow chart showing the states that the microcontroller passes through to sense wetness and communicate with the reader wirelessly

3.2.2 Programming Pins

The programming pins are designed to interface with the MSP-FET430UIF USB debugger and programmer from Texas Instruments. The schematic for the connections to the MSP430F2132 can be found online for both the JTAG and Spy-Bi-Wire debugging selections. These pins may be removed after the programming is completed to ensure comfort for the patient. They must be reattached to make any modifications to the microcontroller code.

3.2.3 Interface to Switch and Antennas

The interface from the sensor board to the switches and antennas are vital since their relationship relays the data from the MCU back to the reader. As previously mentioned, the SPI SIMO port is

used to connect to the control pin of the switch. The only other pins required are V_{cc} and GND, therefore only three pins are required to output from the sensor board to the switch/antenna. Since no radio frequency signal is sent to the sensor board, there is no need to design for trace thickness or matching networks on the sensor board.

3.2.4 LEDs

The LEDs are not required in the final product but are very useful for development, debugging, and demonstration. In the current code on the MCU, the LEDs run a start up sequence to alert the user that the tag has been turned on. Then, the tag enters into sensing mode where it senses and backscatters the data..

3.2.5 Interface to Wetness Sensor

The sensor board interfaces with the wetness sensors through two pins. One is for ground and the other is the GPIO output with interrupt enabled on the MCU. On the sensor board, there are two 1.5 $M\Omega$ resistors in series and two pins to connect to the flexible wetness sensor.

3.3 Dual Antennas

The WiWe tag design uses two identical antennas printed on a flexible substrate mounted on the front and back of the child. By using dual antennas, the cost and complexity of design increases but there are many advantages:

- Possibility of a second moisture sensor
- Increased range
- Orientation tolerance

Previously, it was shown that 915 MHz was limited by -20 dBm sensitivity at about 15 m of range, but this range could be improved by using two antennas since each antenna only has to account for a half-space instead of the whole space. Traditionally, RFID uses a dipole to cover all space equally with one antenna. But, by using dual antennas, each one only has to cover half the space so higher gain antennas can be used to increase range.

In addition, each antenna has its own IC, so a second moisture sensor can be implemented inexpensively. The second wetness sensor can be used to improve the resolution of how wet the diaper is or locate where in the diaper the moisture occurs. The largest benefit is the tolerance to the child's orientation, since a child crawls, walks, rolls, and sleeps in different positions. With dual antennas, the child may be situated in any orientation without interrupting communication or limiting range as shown in Section 5.4.

4 Silver Nanoparticle Printing for Flexible Circuits

4.1 Equipment

Many techniques to print silver nanoparticles onto photo paper or other substrates require expensive printers or an oven to cure the ink, but, during this research, the Propagation Group developed our own inexpensive printing system with assistance from Dr. Yoshihiro Kawahara from University of Tokyo. This technique is dramatically faster than thermal curing techniques since the ink cures in air through a chemical process that begins after printing. With these capabilities, flexible sensors, antennas, and circuits can be quickly and cheaply produced for applications such as wearable circuits. The equipment required is:

- *Brother DCP-J140W Inkjet Printer* - The Brother printer currently (2013) costs $85.99 from Amazon and is very simple to install on to a computer by following the instructions. It prints up to 6000 by 1200 dots per inch (dpi) which ensures conductivity of the silver ink. If the resolution is too low, the ink may not dry properly and have no conductivity.

- *Refillable Empty Ink Cartridges for DCP-585CW DCP-J125* - The refillable cartridges cost only $15 on Amazon. These are empty ink cartridges that fit into the DCP-J140W and can be filled with silver ink easily with the provided syringe.

- *Mitubishi Imaging Inc. Silver Nanoparticle Ink (NBSIJ-FD02)* - The NBSIJ-FD02 ink is the magic in the process since it comes in liquid form but dries as conductive silver. It is availible in various sized bottles and costs $5 per 1 mL ordered. The ink must be stored in the refrigerator and lasts up to approximately 6 months. It can be ordered through Lee Ornati at Mitubishi Imaging [20].

- *Photopaper - Mitubishi Imaging Substrates or other photo paper* - The cost of photo paper varies on the quality that is purchased. The effects of different photo paper on the results have not been investigated. Currently, our system uses Mitubishi's substrates which come in different materials, thicknesses, and levels of opacity.

- *Conductive Epoxy* - Silver conductive epoxy costs $65 per two 7 gram tubes. The epoxy replaces solder since hot solder can destroy the photo paper or the silver ink. The conductive

epoxy comes in two tubes, one with metal and one with epoxy, which should be mixed together and then applied to the points where connections are required on the flexible circuit.

4.2 Procedure

To develop a flexible circuit silver printing system, the equipment must be purchased and the printer installed. Next, the cartridges must be filled with silver ink and the printer prepared for printing before any circuits can be developed.

4.2.1 Filling the Cartridges

In preparation for filling, the bottle of silver nanoparticle ink should be well shaken before beginning to ensure homogeneity. **For safety, gloves and goggles should be used. All activities with the ink other than printing should be done in a well ventilated area due to health risks.** The rest of the procedure should be followed in this order:

a. Begin by setting up your empty cartridges and removing the air plug (colored) and the refill plug (clear) shown in Figure 12.

b. Connect the syringe through the filter (supplied by Mitubishi) to the needle shown in Figure 13/.

c. Open the bottle of silver ink.

d. Insert the needle and withdraw about 10 mL of ink.

e. Insert the needle into one of the color cartridges (Y,C,M) through the refill hole.

f. Deposit the ink into the cartridge.

g. Replace the refill and air plugs for the cartridge.

h. Repeat for the other color cartridges (Y,C,M) but NOT for black since it is not used for printing. (5 mL ink may be inserted into the black cartridge just in case it is accidentally printed.)

i. Dispose of the filter, syringe, and needle.

j. Insert the filled cartridges into the printer and close the door to the cartridges.

k. If an error registers reading "not enough ink in the black cartridge", use a piece of black tape on the back of the cartridge under the black plastic bar. This will trick the optical sensor into reading the cartridge as sufficiently full.

l. The printer is ready to begin printing now.

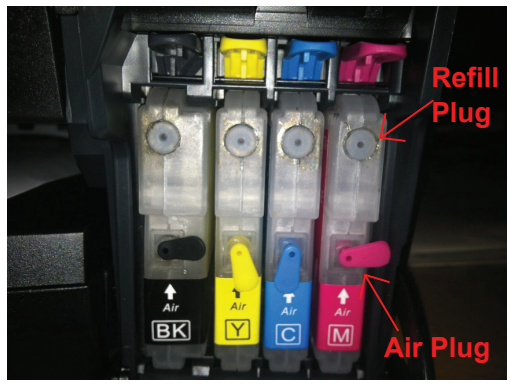

Figure 12: Ink cartridges mounted in the printer filled with silver ink with the air plug and refill plug in position

Figure 13: Syringe, needle, and filter used to fill the silver ink into the empty cartridges

4.2.2 Printer Settings

After the cartridges have been filled and loaded into the printer, the printing settings should be set for optimal conductivity of the silver on photo paper. Open the printer preferences and make the print quality set to Best and select Vivid printing as in Figure 14. Next, open the Advanced tab and select Color printing as in Figure 15. Finally, open the Color Settings and select Color Enhancement, Improve Pattern Printing, and set the Color Density to +2 as in Figure 16. Make sure the paper type is photo paper.

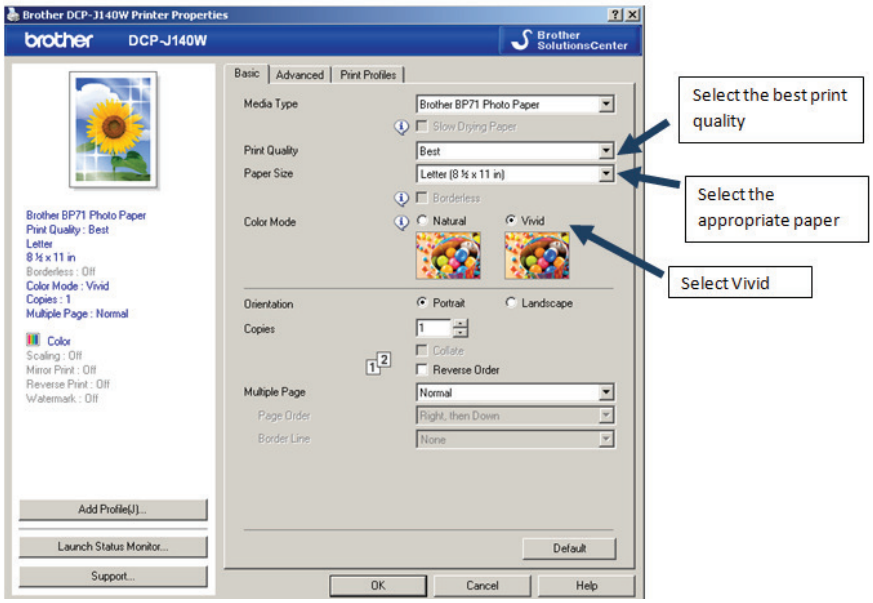

Figure 14: Printer preferences should be set to paper quality best and vivid

4.2.3 First Printing

With the ink successfully in the printer and the settings properly adjusted, the final step is to print out a test page. Turn on the printer and go to Menu then Ink then Test Print to print out a test page. Use photo paper for this as there will be excess ink between the new cartridges and the inkjet head. If colors are printed, there is still ink that needs to be purged from the printer which can be done by printing out black lines on regular (not photo) paper. Keep printing black lines out of the printer until the color lightens. You may want to use photo paper occasionally to see if conductivity exists. Be sure not to over print and waste silver ink. This may take 1 sheet of black

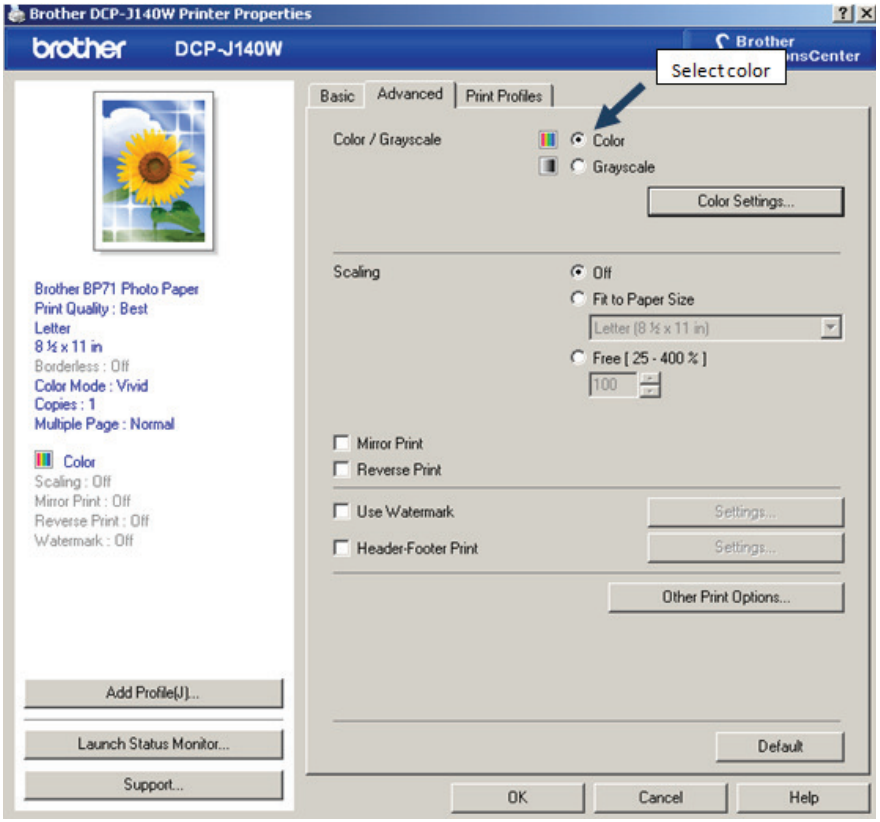

Figure 15: Color printing should be selected

lines or up to about 20 sheets depending on how much regular color ink was left in the printer and how large of lines you are printing.

Once the color ink is purged from the printer, print another test page on photo paper to ensure that each color is printing silver and has good conductivity. If not make sure there is enough ink and keep running Clean and Test Print from the Ink menu until the results are satisfactory. Remember when using the photo paper to insert it with glossy side *down* so it will print on the correct side. If printed on the incorrrect side, the ink will bleed over the paper and not dry properly.

4.3 915 MHz Antenna Example

A 915 MHz meandered line antenna was printed using the silver inkjet printer based on a design from [1]. The antenna was first simulated in CST Microwave Studio then exported to AutoCAD to print the correct dimensions. The CST simulation geometry and results are shown in Figure 17.

After CST simulation to show that the antenna is working as expected, the layout is exported

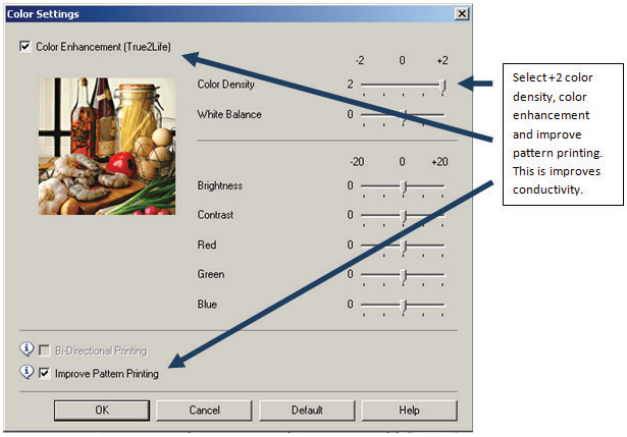

Figure 16: Color enhancement and improve print pattern should be selected and color density set to +2

to AutoCAD to be printed. To export to AutoCAD and print the layout to the proper dimensions, follow these steps:

a. In CST, select the entire antenna component.

b. Go to File, Export, and DXF File.

c. Save the file.

d. Now, import it up in AutoCAD.

e. Fill out the empty spaces by using the hatch function as in Figure 18.

f. Switch to the layout mode as shown in Figure 19.

g. Scale the layout properly for 1-to-1 printing as shown in Figure 20.

h. Finally, print the layout.

The flexible antenna is shown in Figure 21 with an SMA connector attached. *Do not use solder and a soldering iron to make connections.* The proper way to make electrically connections is using silver epoxy which is a mix of glue and silver and can be brushed on to attach the connector. Using hot glue is also useful for structural support.

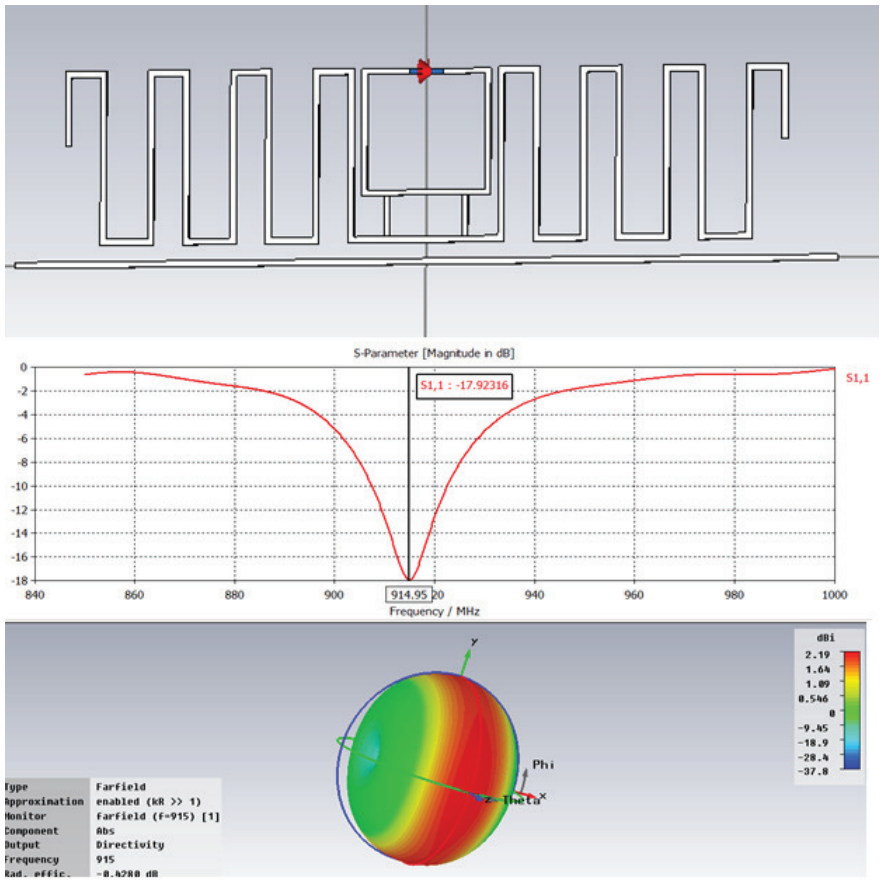

Figure 17: CST geometry, S11, and gain pattern for 915 MHz meandered dipole adapted from [1]

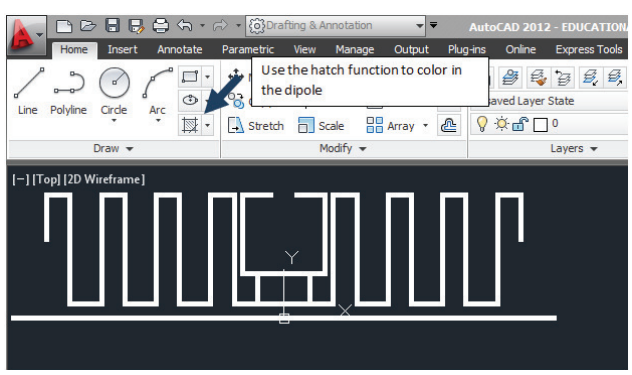

Figure 18: Filling empty space with the hatch tool in AutoCAD

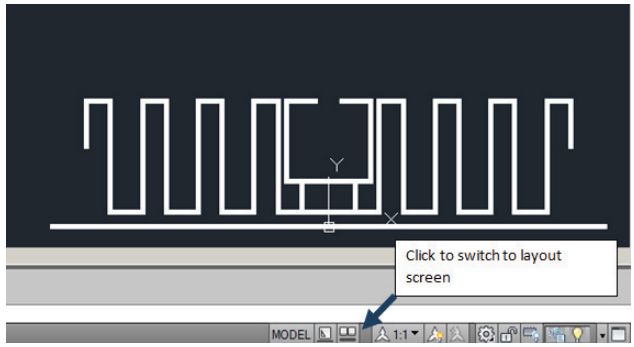

Figure 19: Switching AutoCAD to layout mode

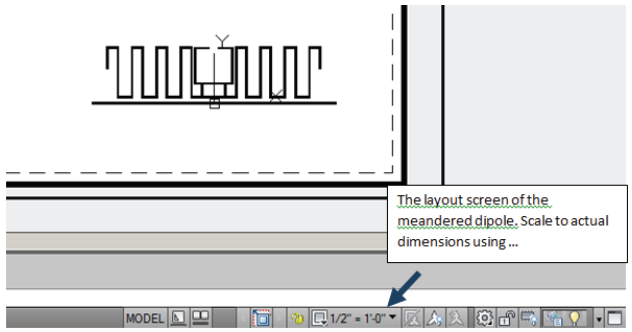

Figure 20: Scaling the drawing properly for printing

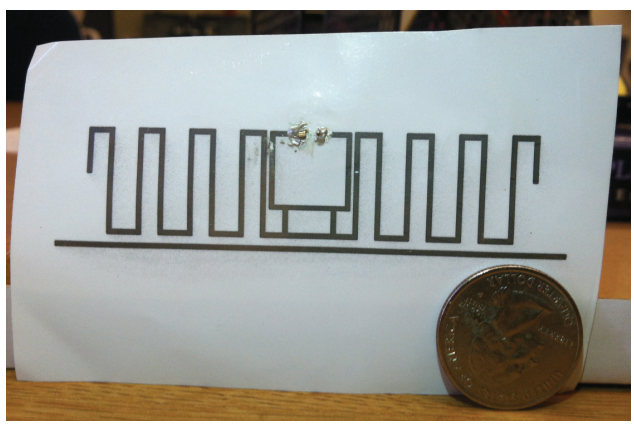

Figure 21: Flexible antenna resonant at 915 MHz printed from our inkjet setup (SMA connector behind connected with silver epoxy and hot glue)

5 Dual Antenna Measurement Plan

5.1 Setup Overview

For experimental verification, two patch antennas at 2.4 GHz made on rigid FR-4 printed circuit boards are tested in a diaper with one on front and one on back. Although 915 MHz is planned for the final product, 2.4 GHz was used to simplify testing. In the experiment, a continuous wave (CW) source with a 2.4 GHz patch antenna transmitting 36 dBm EIRP to model a reader is set up with the diaper set at various distances and orientations away from the reader as shown in Figure 22.

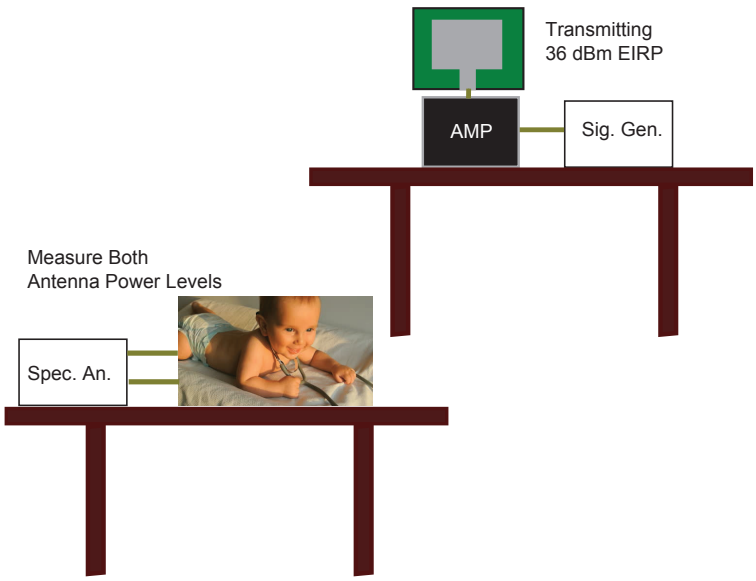

Figure 22: Experimental setup for dual antenna measurements with different orientation of the "child"

During this experiment, the "child" will be oriented different ways to simulate how a child sleeps and moves around. The variation in distances simulate the child moving around in the crib or on the floor which results in various power levels that can predict when outages will occur. An outage is defined as power levels dropping under the sensitivity of the RFID chip (-20 dBm). At 915 MHz longer ranges are possible as explained previously than 2.4 GHz.

5.2 Equipment

The dual antenna measurement system used a signal generator, amplifier, antennas, and a spectrum analyzer to measure power levels.

a. *Signal Generator* - Agilent Technologies - E8247C PSG CW - 250 kHz to 20 GHz

b. *Amplifier* - Mini-Circuits - ZVE-8G - 2000 to 8000 MHz

c. *Spectrum Analyzer* - Agilent E4407B - 9 kHz to 26.5 GHz - ESA-E Series - Center Frequency = 2.4 GHz, Span = 1 MHz, Res BW and Video BW on Auto

5.3 Antennas

The antennas used were fabricated on FR-4 substrate, designed for 2.4 GHz, and matched with a quarter wave transformer to 50 Ω. When connected to the vector network analyzer, the antenna showed resonance at 2.4 GHz with -13 dB returns loss. The simulation in CST Microwave Studio showed a peak gain of the patches to be 6 dB. The antennas used for the diaper and the transmitter are shown in Figure 23. The antennas were mounted inside the diaper on the front and back on the child similar to where the inlay would sit for the final WiWeMS product in the diaper.

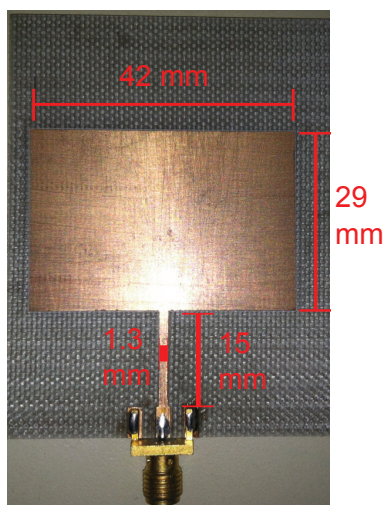

Figure 23: For all antennas in the experiment, copies of the patch antenna shown here were used for the transmitter and the front and back antennas on the model

5.4 Diaper and Baby Model

The baby is modeled with a water bottle as the body is as much as 75% water for a new born infant [21]. A diaper is placed on the water bottle as fitted on a child as shown in Figure 24. The orientations tested in the set up were the child lying on her back, the child lying on her side, and the child sitting up as shown in Figure 25. These are three common positions for an infant to be sleeping or playing.

Figure 24: Wetness measurement setup showing the diaper holding the sensor with a water bottle half full (modeling a child) connected through the sensor board to the computer

Figure 25: Orientations of how the tests were performed for a baby lying on her back, lying on her side, and sitting

After the various distances are tested with a dry diaper, 1 pint of water was added to the front of the diaper and the measurements were retaken. Tap water was used to simulate urine which is not ideal due to the salt content in urine. The water does demonstrates the effect that a lossy dieletric material can have on detuning of RFID antennas in a diaper setting and the reliability

improvement achievable by the dual antennas. The diaper used was a Size One Publix brand that is made for babies 8 to 14 lbs with a soft, stretchable tab, Dry-Lock enhanced and leakage protection.

6 Dual Antenna Measurement Results and Discussions

The results of the dual antenna experiment showed that using two antennas on opposite sides of the child improved coverage and range than just a single antenna. In addition, after wetting the diaper, the antenna that remained mostly dry aimed away from the transmitter sometimes was able to receive more power than the wet antenna facing the transmitter due to multipath in the room. Overall, the dual antenna technique increases range and makes the entire system more tolerant to the childs orientation but does increase the cost of a tag. For the WiWeMS, this improvement makes it a better option than current state of the art technologies.

6.1 2.4 GHz Results

6.1.1 Lying on Back Data

When the child is lying on her back, the front antenna performed much better than the back antenna by 10 dB throughout the various ranges which is expected since the front antenna is aimed into the air and the back antenna is aimed onto the table or crib as in Figure 26. With the front antenna, the range of operation at 2.4 GHz is about 2 meters.

When water was poured down the front of the diaper, the front antenna's performance degraded significantly even to the point where the back antenna performed better at various distances. The estimated range is approximately equal for both the wet front antenna and the dry back antenna at 1.4 meters.

If the child was lying on her stomach, the back antenna gives the system an additional 1 meter of range at 2.4 GHz or a 100% improvement over a single front antenna.

6.1.2 Sitting Data

When the child is sitting looking at the reader, the front antenna performed very well with an estimated range of 4 meters while the back antenna was limited around 1 meters of range. These are expected results since the front antenna faces the reader and the back antenna aimed away from the reader. If the child faced the other direction (away from the reader), a single front antenna would only attain 1 meter of range but the dual antenna system gets 4 meters of range, a 400% improvement.

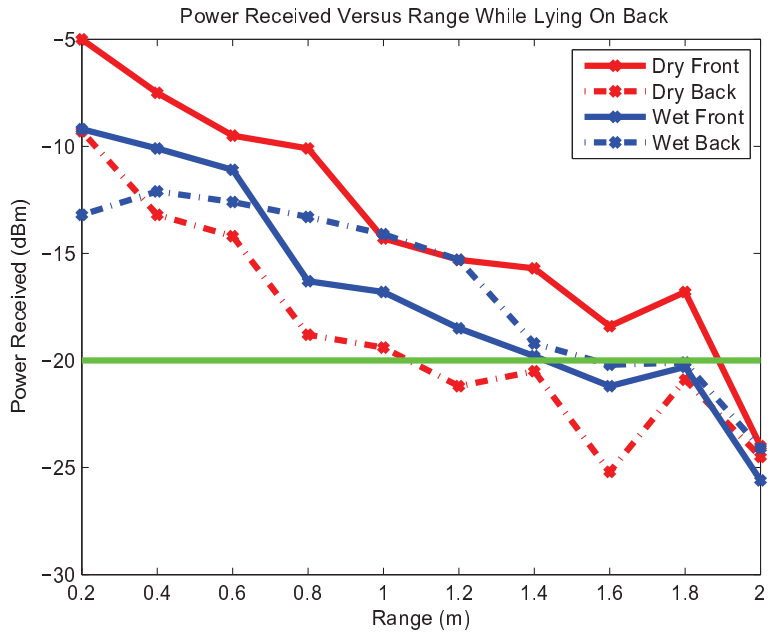

Figure 26: Power levels received by each of the dual antennas when the child is oriented lying on her back

When the pint of water was added to the front of the diaper, the front antenna detuned and worked dramatically worse limiting the range to 2 meters for an RFID chip, but still remained better than the dry back antenna.

6.1.3 Lying on Side Data

The final setup revealed the most beneficial use of the dual antenna technique when the child was lying on her side and neither antenna was aimed towards the reader. In this experiment, both front and back antennas performed equally as well with a range of around 2 meters as expected due to symmetry of the setup.

After wetting the front of the diaper with water, the front antenna detuned dramatically causing the range to drop to about 1.2 meters, but the back antenna maintained the range of 2 meters since it was not detuned by the water. If a single front antenna were used instead of the dual antenna, half the range would be lost due to the child's void onto the antenna.

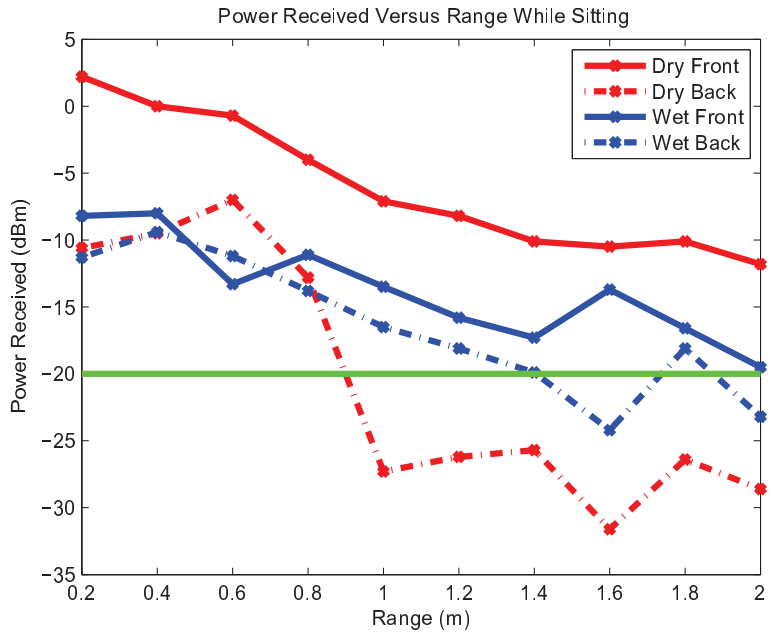

Figure 27: Power levels received by each of the dual antennas when the child is oriented seated

6.2 Data Summary

In summary, the dual antennas never degrade the power levels received by the RFID chips, but do make large improvements when the child is sitting facing away from the reader by 400% and when the child is sleeping on her stomach by 100%. After the child has a void and the front antenna is wet, the dual techniques improves the same positions as the dry case but also improves while the child is oriented on her side. The dual antenna technique either matches the performance of a single antenna or improves the performance by at least 100% depending on the orientation.

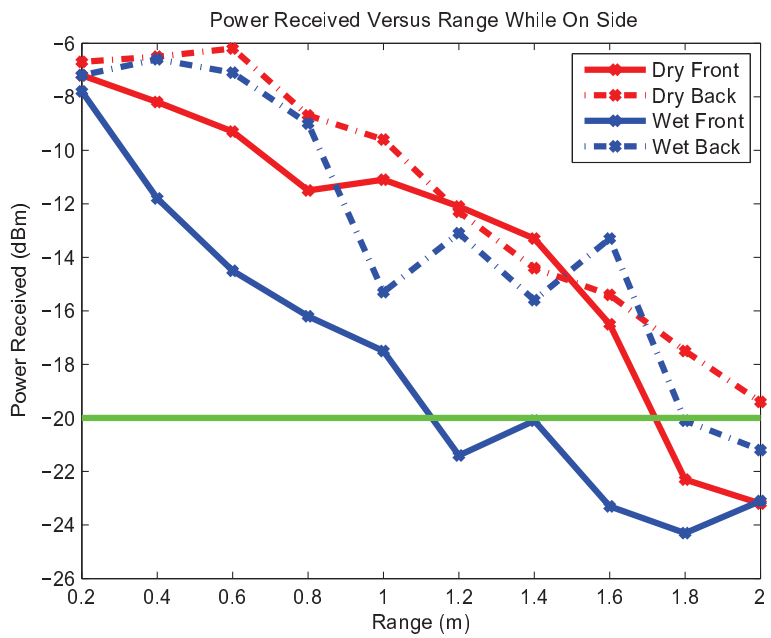

Figure 28: Power levels received by each of the dual antennas when the child is oriented lying on her side

Dry Antennas in Diaper **Orientation**	**Single Front Antenna**	**Dual Antennas**	**Range Improvement**
Lying On Back	2 m	2 m	0%
Lying On Stomach	1 m	2 m	100%
Sitting Towards Reader	4 m	4 m	0%
Sitting Away From Reader	1 m	4 m	400%
Lying On Side	2 m	2 m	0%
Wet Antennas in Diaper **Orientation**	**Single Front Antenna**	**Dual Antennas**	**Range Improvement**
Lying On Back	1.5 m	1.5 m	0%
Lying On Stomach	1 m	2 m	100%
Sitting Towards Reader	2 m	2 m	0%
Sitting Away From Reader	1 m	4 m	400%
Lying On Side	1 m	2 m	200%

Table 2: Comparison of received power level with various child's orientations with a single front antenna versus dual antennas during dry and wet conditions

7 Final WiWe Sensor Plan

7.1 Final System Overview

For the final product of the WiWe sensor, the sensor board will be replaced with two radio frequency identification integrated circuits (RFIC). The final design plan for the WiWe wetness sensor is a passive wireless backscatter communication system that is composed of two flexible antennas, a flexible capacitive moisture sensor as previously shown, and two radio frequency identification (RFID) integrated circuits (IC). The antennas and wetness sensor are printed on a flexible substrate similar to photo paper using silver nanoparticle ink to create the inlay which can simply be slid into a diaper. The RFIC is implemented to replace the sensor board as shown in the current prototype section and make the entire system dramatically cheaper.

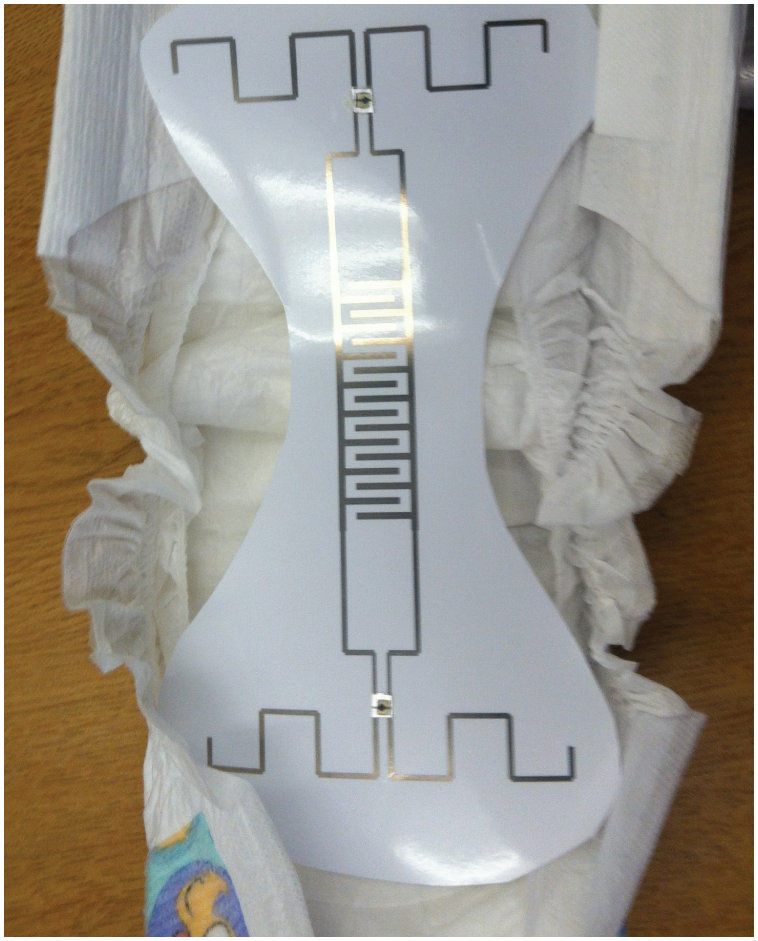

Figure 29: The mock-up inlay for 915 MHz WiWeMS final product tag in diaper

7.2 Radio Frequency Integrated Circuit (RFIC)

The RFIC is used in most RFID systems with an antenna, but these RFICs do not have capabilities to measure capacitive sensors. In order to include wetness sensing, a custom RFIC has been developed which can be costly for initial development. The RFID IC contains most basic blocks from a Gen 2 RFID chip but needs to include sensing capability which may be included in the not-yet-developed Gen 3 protocol. The RFIC functional layout should look something similar to the block diagram in Figure 30.

Approximately half of the area of the integrated circuit is used for logic in order to transmit the proper bits from the IC [2]. The next largest section of the chip is for energy harvesting and energy storage, but this area can be reduced if need by using an external capacitor [2]. For the WiWe moisture sensor, the external capacitor can be printed on the flexible substrate from the silver ink. These decisions and sizes of section can be better determined by a RFIC designer, since the WiWe chip may need more room for logic to sense the wetness. Since cost is directly related to the size of the chip, printing external capacitors on the flexible substrate may result in a less expensive overall product.

The initial development of the chip requires the development of a mask and to receive several devices for testing. After initial development, the costs can drop down to $0.03 per chip for mass-production [22].

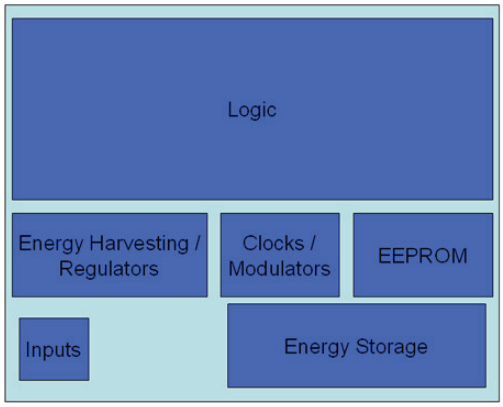

Figure 30: Layout of approximate space required for each sub-system of RFIC (adapted from [2])

Product	Cost
RFIC (x2)	\$0.033(2) = \$0.066
Flexible Substrate per tag	\$0.02
Silver ink per tag	\$0.07
Total	**\$0.156**

Table 3: Expected costs per tag for each component

7.3 Large Scale Cost Analysis

The overall cost per sensor is estimated to be \$0.16 based on the cost of silver ink, flexible substrates, and the RFICs. In 2003 for large scale RFIC production, RFID integrated circuits (IC) could be made for as little as \$0.03 per chip by using flip chip methodology [22].

The flexible substrate cost per tag is predicted by using the cost \$14 for a 300 pages of a photo paper by Hammermill and estimating that three tags could be placed on the same sheet. With these numbers, each substrate should cost about \$0.02 each. As for the silver ink made by Mitsubishi Imaging, the ink costs \$5 per milliliter which seems like a high price but only 0.02 mL is used per square centimeter of printing [20]. The estimated cost for 1 sq. cm of silver ink is \$0.10, but this made even cheaper by using copper or aluminum transfers onto flexible substrates.

7.4 Medical Testing Trials

There are a few different medical trials that can be performed using this technology:

a. In an overnight stay at a hospital for surveillance and detection of nocturnal voids

b. At home in a bed or crib testing for nocturnal voids with a portable reader

c. At school or day care, a reader can be put discreetly in a classroom to monitor daytime voids

Dr. Andrew Kirsch's urology office will decide what trials are the most useful and how to implement the tests. They will clarify how the trials are to be executed and conclusions that can be drawn from each.

8 Conclusions and Future Features

This grant has funded a prototype of the WiWeMS, a new system for rapid prototyping flexible tags, and an inlay ready for RFIC placement. The current 5.8 GHz WiWEMS tag and reader from the Propagation Group at Georgia Tech have shown that the WiWeMS system works passively at a limited range of 1 meter, which will be increased by moving to a 915 MHz operating frequency. A new flexible tag printer has been developed to rapidly prototype new flexible tags. The mock-up of the inlay has been printed which is only missing RFICs to be operational at 915 MHz. The final WiWeMS sensor will use two RFICs, two flexible antennas, and a flexible wetness sensor and a small reader at 915 MHz. The system is expected to have a range around 5 meters and sense wetness dynamically down to 1 cc with the reusable flexible sensor. The cost has been estimated to be about $0.16 per tag when implemented with RFICs and the inlay in mass production.

The focus of the future will be on developing a 915 MHz RFIC that is capable of measuring capacitance of a wetness sensor and backscatter the information to a reader. In addition, a low profile 915 MHz reader will be developed to interrogate the WiWeMS along with an app to relay the data to a parent or doctor.

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9 Appendices

9.1 Work Resulting from Center for Pedatric Healthcare Technology Innovation Grant

a. B. R. Marshall and G. D. Durgin. Electromagnetic Field Analysis of Near Body Wireless Technologies, Pedatric Surgery and Technology Research Day 2012 at Emory University, Atlanta, Georgia.

b. B. R. Marshall and G. D. Durgin. Staggered Pattern Charge Collector Design and Optimization, Radio Wireless Week 2013, Austin, Texas.

c. B. R. Marshall and G. D. Durgin. RFID Single and Dual Tag Performance Near Various Media, IEEE RFID 2013, Orlando, Flordia.

d. B. R. Marshall and G. D. Durgin. Staggered Pattern Charge Collection: Antenna Technique to Improve RF Energy Harvesting, IEEE RFID 2013, Orlando, Flordia.

e. D. A. Apatira, S. T. Hepner, K. A. Kizirian, K. M. Berman, B. R. Marshall, and G. D. Durgin. Detuning of 2.4 GHz and 5.8 GHz RFID Antennas in RF Harsh environments, Opportunity Research Scholars 2013, Atlanta, Georgia.

f. B. R. Marshall, C. R. Valenta, and G. D. Durgin. DC Power Pattern Analysis of N-by-N Staggered Pattern Charge Collector and N^2 Rectenna Array, IEEE Wireless Power Transfer Conference 2013, Perugia, Italy.

9.2 Microcontroller Board Schematic

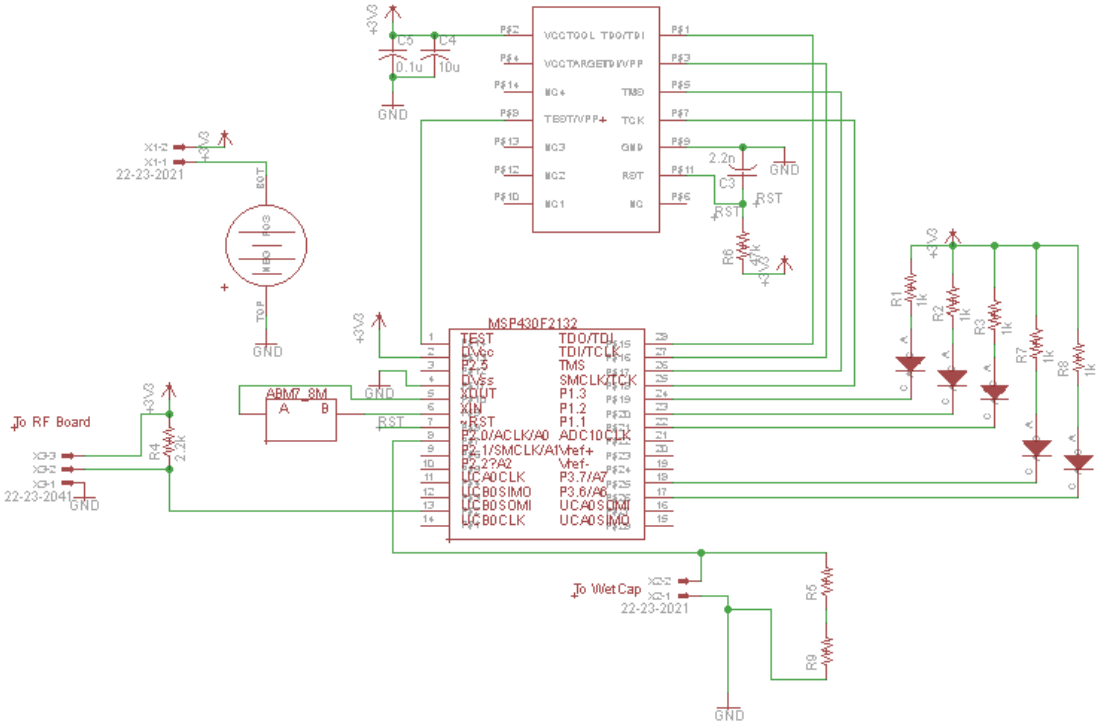

Figure 31: Schematic of the MCU Board

9.3 RF Board Schematic

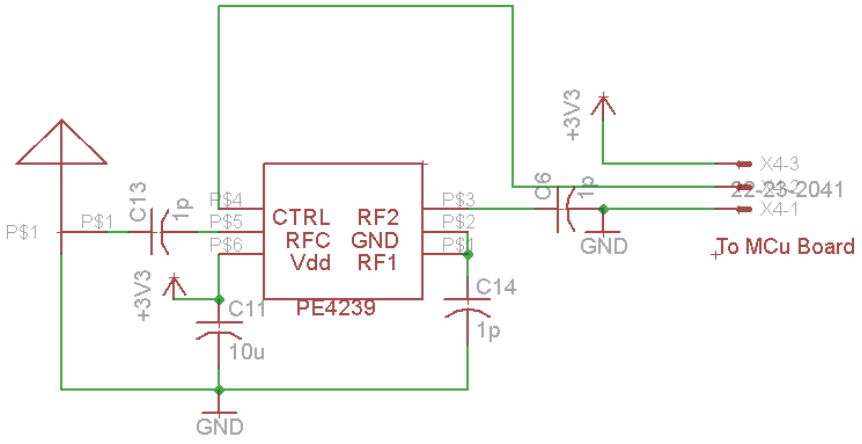

Figure 32: Schematic of the RF Board

9.4 MCU Code

```
#include "msp430f2132.h"

#define POLYVAL 0x8C
unsigned int finalCount;
unsigned int wet;
unsigned int j;
unsigned int overflow;
unsigned int caught;
unsigned char buffer[7] ={0};
//unsigned int 8MHzCountMultiplier = 41;



void startUp(void)
{
    WDTCTL = WDTPW + WDTHOLD;

    //LED INTRODUCTION ROUTINE
    //Set P1 to output for 1.1, 1.2, 1.3
    P1OUT|=BIT1+BIT2+BIT3;
    P3OUT|=BIT6+BIT7;
    P1DIR|=BIT1+BIT2+BIT3;

    P3DIR|=BIT6+BIT7;

   P3SEL |= BIT1;  //For SPI on Pin 3.1
```

```
    P1OUT&=~BIT3;
    __delay_cycles(1000000);
    P1OUT|=BIT3;
    P1OUT&=~BIT2;
    __delay_cycles(1000000);
    P1OUT|=BIT2;
    P1OUT&=~BIT1;
    __delay_cycles(1000000);
    P1OUT|=BIT1;
    P3OUT&=~BIT7;
     __delay_cycles(1000000);
    P3OUT|=BIT7;
    P3OUT&=~BIT6;
     __delay_cycles(1000000);
    P3OUT|=BIT6;

    //Set Header
    buffer[0]=0xA4;
    buffer[1]=0x89;
    buffer[2]=0xAE;
    //Set ID
    buffer[3]=0x11;
    buffer[4]=0x11;

}
```

```
//CRC CALCULATION
unsigned char calc_crc(unsigned int start,unsigned int end)
{
 unsigned char crc=0,c;
 int i;
 while (start<=end) {
 c= buffer[start];
 for(i=0;i<8;i++) {
  if((crc ^ c) & 1) crc=(crc>>1)^POLYVAL;
  else crc>>=1;
  c>>=1;
 }
 start++;
 }
 return(crc);
}//CRC CALCULATION


void transmit(int data)
{
//            P3DIR=BIT1;
//            P3OUT=BIT1;
           buffer[5]=data;
          //calc CRC
           buffer[6]=calc_crc(3,5); //ID + 1 byte
           UCB0CTL1 |= UCSWRST;
           UCB0CTL0 = UCMST+UCSYNC+UCMSB+UCMODE_0;                          // SPI master mode
           UCB0CTL1 = UCSSEL_1+ UCSWRST;                // intialize SPI, clk=ACLK
           UCB0CTL1 &= ~UCSWRST;
```

```
//Ensure Reader is ready
  //Header
     UCB0TXBUF=buffer[0];
     while(!(UCB0TXIFG & IFG2))
     {
     }
     UCB0TXBUF=buffer[1];
     while(!(UCB0TXIFG & IFG2))
     {
     }
     UCB0TXBUF=buffer[2];
     while(!(UCB0TXIFG & IFG2))
     {
     }
    //ID
     UCB0TXBUF=buffer[3];
     while(!(UCB0TXIFG & IFG2))
     {
     }
     UCB0TXBUF=buffer[4];
     while(!(UCB0TXIFG & IFG2))
     {
     }

    //Data
     UCB0TXBUF=buffer[5];
     while(!(UCB0TXIFG & IFG2))
     {
     }
```

```
                //CRC

                UCB0TXBUF=buffer[6];
                while(!(UCB0TXIFG & IFG2))
                {
                }

}



int measureCap()
{
     //CLOCK SETUP

    //DCOCTL = CALDCO_1MHZ; // Set DCO to 1 MHz
    BCSCTL1=XT2OFF+XTS+DIVA_3; // Sets XT1 to HF mode, Turns off XT2, Sets DCO to 1MHz, // ACLK
    BCSCTL2|=DIVM_3+SELM_3+SELS+DIVS_0;
    BCSCTL3= LFXT1S_2+XCAP_1; // 1pF XT1 load, XT1 set to support up to 16MHZ osc.

    finalCount=0;
    overflow=0;
    caught=0;

    //Clear OFIFG flag untill it remains clear
    IFG1 &= ~OFIFG;
    while (IFG1 & OFIFG){IFG1 &= ~OFIFG;}
```

```
    P2DIR|=BIT0; //Set cap bit to output
    P2OUT|=BIT0; //Sets P2.1 to high voltage
    __delay_cycles(1000000);
    P2IFG&=~BIT0; //Clears flag
    P2IES|=BIT0; //Sets negative edge (high to low) flag set
    P2IE|=BIT0; //Enables P2

    //TIMER A
    TACTL|=TACLR; //Clears the timer
    TACTL&=~TACLR; //releases clear

    //GET READY
    TACCTL0|=CCIE;
    _BIS_SR(GIE);

    TACTL=TASSEL_2+ID_0+MC_2; //STARTS CLOCK COUNTING UP WOOO HOOOOO
    P2DIR&=~BIT0; //Sets P2.1 to input // GO GO GO GO
    while(caught==0); //WAITING

    //FOR DIAPER SENSOR
//    if(finalCount<1500)
//    {
//      return 1;
//    }
//    else if(finalCount>=1500 & finalCount <3000)
//    {
//      return 2;
//    }
```

```
//   else if(finalCount>=3000 & finalCount <5000)
//    {
//      return 3;
//    }
//    else if(finalCount>=5000 & finalCount <7000)
//    {
//      return 4;
//    }
//     else if(finalCount>=7000)
//    {
//      return 5;
//    }


        //FOR FLEXIBLE
    if(finalCount<1500)
    {
      return 1;
    }
    else if(finalCount>=1500 & finalCount <3000)
    {
      return 2;
    }
   else if(finalCount>=3000 & finalCount <5000)
    {
      return 3;
    }
    else if(finalCount>=5000 & finalCount <7000)
    {
      return 4;
    }
```

```
     else
    {
      return 5;
    }



    //FOR OTHER
//       if(finalCount<2400)
//    {
//      return 1;
//    }
//    else if(finalCount>=2400 & finalCount <3000)
//    {
//      return 2;
//    }
//   else if(finalCount>=3000 & finalCount <3400)
//    {
//      return 3;
//    }
//    else if(finalCount>=3400 & finalCount <4000)
//    {
//      return 4;
//    }
//     else if(finalCount>=4000)
//    {
//      return 5;
//    }
}

#pragma vector = TIMER0_A0_VECTOR
```

```
__interrupt void TimerA_Overflow(void)
{
    overflow++;
    //TACTL&=~TAIFG;
    TACCTL0&=~CCIFG;
    return;
}

#pragma vector = PORT2_VECTOR
__interrupt void grabCount_int(void)
{
    finalCount=TAR;
    caught=1;
    TACTL&=MC_0;
    TACTL|=TACLR; //Clears the timer
    P2IFG&=~BIT0;



}



void main( void )
{
    // Stop watchdog timer to prevent time out reset
    startUp();
    j=2;
    while(j>1)
    {
      wet=measureCap();
```

```
P1OUT|=BIT1+BIT2+BIT3;
P3OUT|=BIT6+BIT7;
P1DIR|=BIT1+BIT2+BIT3;

P3DIR|=BIT6+BIT7;

  if(wet==1)
  {
    P1OUT&=~BIT3;
    P1OUT|=BIT2;
    P1OUT|=BIT1;
    P3OUT|=BIT7;
    P3OUT|=BIT6;
  }
  else if(wet==2)
  {
    P1OUT&=~BIT3;
    P1OUT&=~BIT2;
    P1OUT|=BIT1;
    P3OUT|=BIT7;
    P3OUT|=BIT6;
  }
  else if (wet==3)
  {
    P1OUT&=~BIT3;
    P1OUT&=~BIT2;
    P1OUT&=~BIT1;
    P3OUT|=BIT7;
    P3OUT|=BIT6;
```

```
      }
      else if(wet==4)
      {
        P1OUT&=~BIT3;
        P1OUT&=~BIT2;
        P1OUT&=~BIT1;
        P3OUT&=~BIT7;
        P3OUT|=BIT6;
      }
      else if(wet==5)
      {
        P1OUT&=~BIT3;
        P1OUT&=~BIT2;
        P1OUT&=~BIT1;
        P3OUT&=~BIT7;
        P3OUT&=~BIT6;
      }
      else
      {
      }

      transmit(wet);
    }

}
```