BICYCLE TIRE PRESSURE MONITOR SYSTEM

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Abstract

The designed system was intended to monitor the pressure in each tire of a bicycle and wirelessly transmit pressure measurements to a unit on the handlebars, which would display real time pressure values on an LCD. The final system was not functioning fully as intended due to component failure. However, enough functionality was operational to establish the proof of concept, and with further testing and replacement of the damaged component the system could be completed as specified in the performance requirements.

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1. Introduction

Riding a bicycle with under-inflated or leaky tires can reduce traction and cause faster tire deterioration, but tire pressure monitoring systems are currently unavailable for bicyclists. Therefore, a system that monitors the pressure and rate of change of pressure for the rider can inform the rider of unfavorable riding conditions can reduce risk of injury to the rider. The system consists of three main parts: two sensor modules and the display module, as shown in figure 1.1.

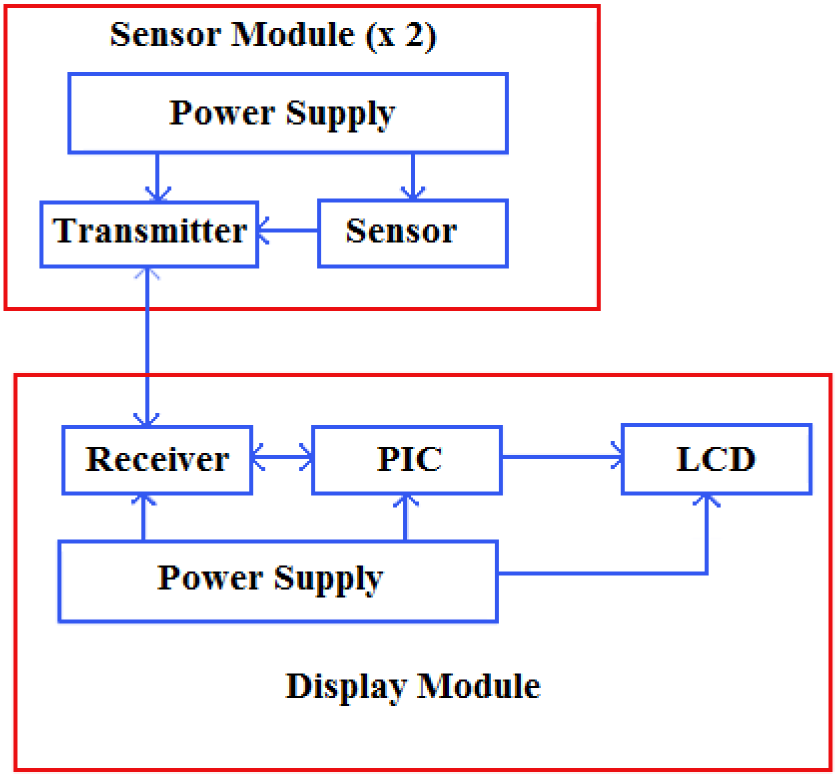

Figure 1.1 Full system block diagram

The sensor modules digitize the pressure measured by the sensor, check if the measurement is below the 25PSI threshold or if the pressure has changed by at least 3PSI since the last measurement, and serially transmit the measured pressure and warning flags to the display module. The display module then serially receives the data and updates the LCD as necessary.

The display was originally to be implemented as a bank of LEDs, but was upgraded to an LCD for the sake of a more user friendly and meaningful display. The receiver and transmitters were also originally intended to be transceivers to allow for two-way communication between the modules, but the power required to sustain that system would have been too great for our intended battery power supplies, and therefore they were changed to the final receiver and transmitter components.

It is required that the pressure measurement be accurate to within 10% of the actual pressure in the tire, that the transmitted signal be strong enough to be received up to four feet away, and that all three modules be power efficient enough to last with one 3 Volt coin battery without requiring battery replacement for at least four months.

2 Design

The main choice that could have potentially been implemented differently was the choice to use an RF link between the display module and sensor modules. One of the first ideas was to instead use a slip-ring to feed a wire from the sensors on the wheels to the handlebars. However, due to the spokes and bike frame this was deemed impractical, and if selected this would have greatly increased the difficulty of installing the system, which was not desired.

The use of a force sensor to measure the pressure indirectly could also have been implemented differently. However, because most bicycle tires have tubes it would be a non-trivial task to insert a pressure sensor into the tube and somehow retrieve measurements from the sensor while also somehow resealing the point of entry in the tube.

2.1 Sensor Module

The sensor modules are each made up of a force sensor, battery, operational amplifier in a non-inverting amplifier topology, PIC microprocessor, transmitter chip and antenna, as shown in figures 2.1 and 2.2. The force sensor is placed on the inside of the tire rim, such that the force of the tire tube is pressing upon the sensing area. With variable pressure, variable force will be absorbed by the sensor, which is itself part of the resistor network in the non-inverting amplifier topology. The variable resistance of the sensor is thereby converted into a variable voltage, which the PIC digitizes and serially transmits via the transmitter chip and antenna. The most important factors of the sensor module's operation for successful operation of the system are the accurate analog-to-digital conversion of the amplifier output and a consistent relationship between force applied to the sensor and resistance provided by the sensor.

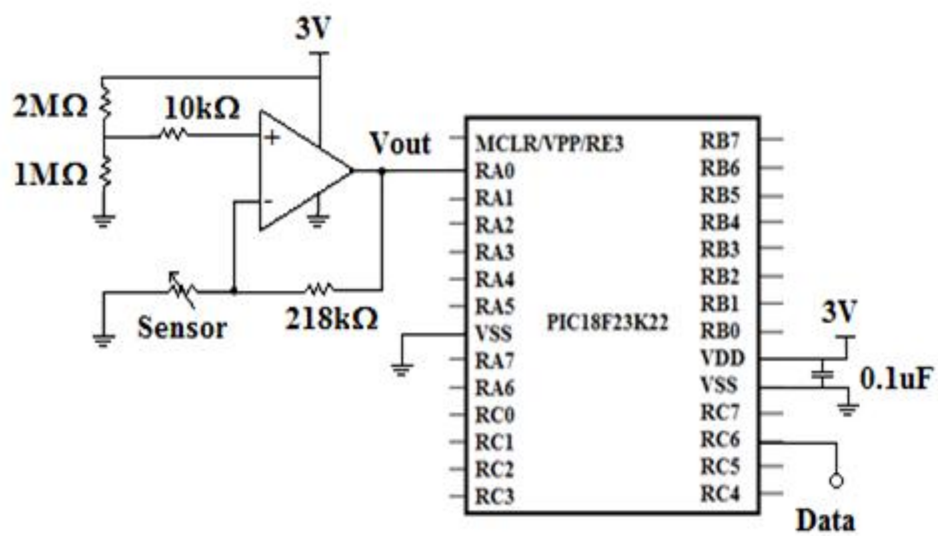

Figure 2. 1 The sensor, non-inverting amplifier and PIC of the sensor module

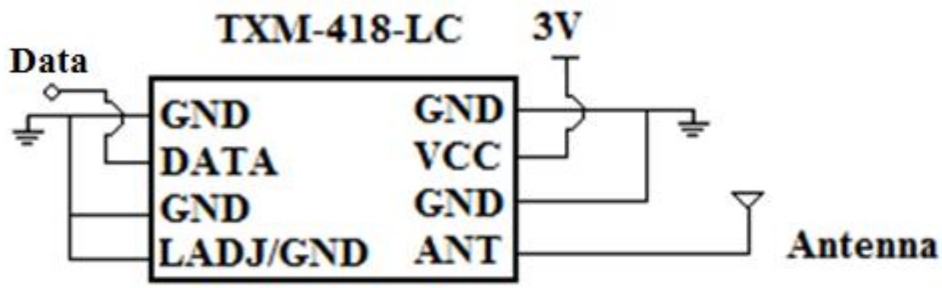

Figure 2. 2 The transmitter and antenna of the sensor module

2.1.1 Sensor

The sensor block of the sensor module, shown in figure 2.1, consists of the force sensor, non-inverting amplifier, and PIC. The Parallax Flexiforce sensor was chosen as a force sensor because of its flexibility and incredibly small profile, allowing for very easy insertion into the rim of the wheel without damaging the sensor or deforming the tire. A non-inverting amplifier is the method prescribed by the sensor datasheet for converting the variable resistance into a variable voltage, although the resistance values were calculated to fit the specific needs of this application.

Before the resistance values could be calculated, the sensor had to be characterized. By varying the pressure and measuring the resistance of the force sensor we established the relationship between pressure and resistance described by formulas 2.1 and 2.2.

$$R = 343.776 - 3.274 * P \; for \; P \geq 45PSI \tag{2.1}$$
$$R = 862.835 - 14.70 * P \; for \; 25PSI \leq P < 45PSI \tag{2.2}$$

The voltage divider occurring at the ‘+’ terminal of the operational amplifier serves to provide a range of output voltages within 0V – 3V, because this is the voltage range the ADC of the PIC is limited to. A 1V input voltage was arbitrarily chosen as a starting point to allow for the calculation of the feedback resistance, and bias resistances in the megaohm range were chosen so that they would draw very little current from the battery. Using this input voltage, the lowest and highest resistances observed (143kΩ), and equation 2.3, which gives the output voltage given a sensor resistance R, the feedback resistance can be calculated.

$$V = 1 + \frac{R_f}{R} \tag{2.3}$$

Namely, the feedback resistance must be at most 286kΩ, and the larger the feedback resistance the larger the output voltage range will be, giving a finer resolution for the ADC. Therefore, given the resistors available in the lab, a feedback resistance of 218kΩ was chosen, giving a final output voltage expression of equation 2.4 (assuming R is in kΩ).

$$V = 1 + \frac{218}{R} \tag{2.4}$$

The PIC was then programmed to convert the voltage from analog to digital, and using equations 2.4, 2.2 and 2.1 convert this measurement into a pressure value. The pressure value is then compared to 40 PSI, which is the lower bound of the suggested pressure range for our tire, and the last pressure measurement. In order to prevent false positives, if the pressure is not already in the low region and is measured to be below 40PSI or if it has changed by more than 3 PSI since the last measurement, then the pressure is remeasured twice and a new pressure value is generated by averaging these three pressures, then the comparisons are made again. The PIC then outputs the data and warning bits serially to the transmitter via the PIC's UART.

The PIC chosen is the PIC18F23K22. This specific PIC was selected because it is a low power PIC that can operate at 3V, it has both ADC and UART pins, which are required for the program as explained above, and because they were readily available.

2.1.2 Transmitter

The transmitter block of the sensor module, shown in figure 2.2, consists of the LINX transmitter chip and antenna. The chip is designed to operate at 418MHz and transmits digital data via on-off keying.

418MHz was a choice among three frequencies: 315MHz, 418MHz, and 433MHz. The 315MHz chips were disregarded because the frequencies around 315MHz are allocated to mobile communications by the FCC, and it is desirable to reduce possible interference sources. Of the two remaining possibilities, 418MHz chips were readily available, and therefore 418MHz was chosen.

2.1.3 Power Source

The sensor modules are supplied power via 3V coin batteries – one battery per module. 3V batteries were chosen because they provide the lowest voltage that can provide sufficient power to all of the components and for their relatively small size.

2.2 Display Module

The display unit consists of a PIC microprocessor (figure 2.3), LCD(figure 2.4), battery, receiver chip (figure 2.5), and antenna. The antenna and receiver chip receive the transmitted pressure measurements, which the PIC serially receives. The PIC stores the pressure measurements and controls the LCD, displaying the current measurements and instead alerting the rider to unfavorable conditions by display "check tire" when pressure falls below 25PSI or if pressure has changed by more than 3 PSI since the last measurement. The ability to display the correct values via the LCD and the successful serial receiving of data are the most crucial aspects of the display unit's operation.

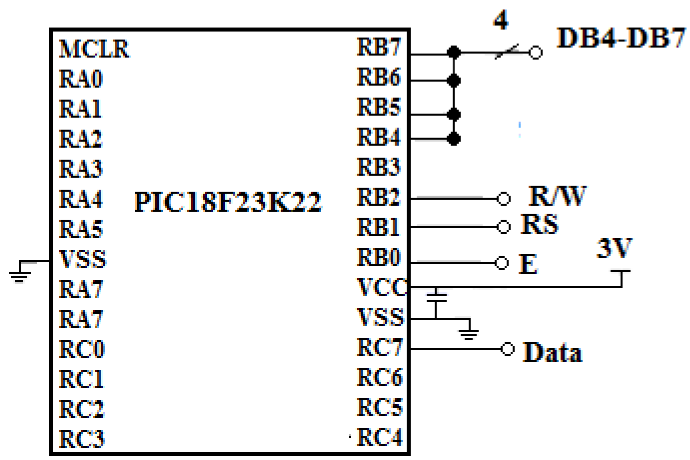

Figure 2. 3 The display module PIC

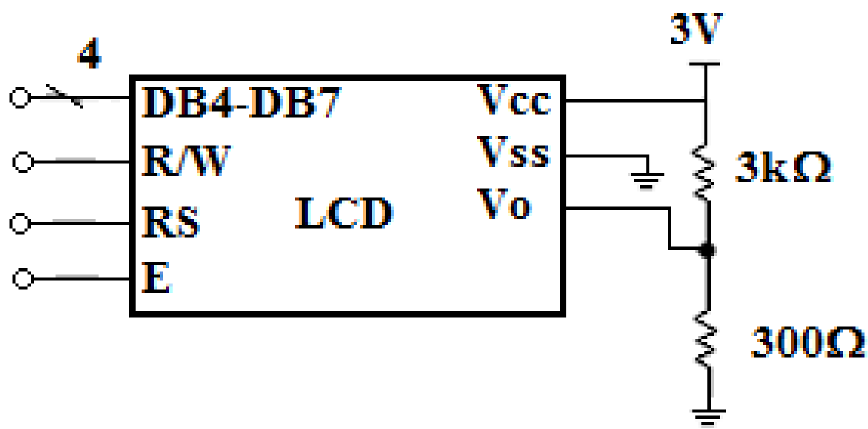

Figure 2. 4 Display module LCD

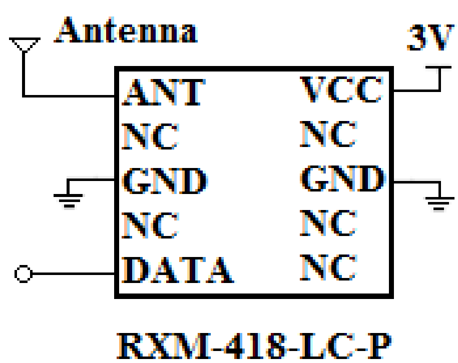

Figure 2. 5 Reciever chip and antenna

2.2.1 PIC microprocessor

The PIC is the same model as the PICs used for the sensor modules for the same reasons. This PIC receives the data from the receiver chip via the UART and stores the pressure measurement. The LCD is then updated to show the new measurement to the rider.

2.2.2 LCD

The specific LCD used is an NHD-0208AZ-RN-YBW-3V, because it is an LCD capable of operating at 3V.

2.2.3 Receiver

The receiver is the 418MHz receiver chip designed to be paired with the selected transmitter, and it was selected for the same reasons.

2.2.4 Power Supply

See 2.1.3.

3. Design Verification

When the entire system was assembled the LCD was observed and nothing was displayed.it did not function as intended. By tracing through the circuit, component by component, it was found that the RF link was not functioning properly, and specifically that the receiver chip had been damaged to the point of non-operation, most likely during the soldering process.

3.1 Sensor Module

The sensor module was tested first by attempting to read the received bits from the receiver chip. When that failed, the sensor was hardwired directly to the proto-board such that the PICkit 2 could read in the transmitted values and display them on the computer monitor.

3.1.1 Sensors

The most extensively tested components were the sensors. This is because it was vital that a material be found that gave sufficient sensitivity in output resistance when placed between the sensor and the tire tube. An extra material was required because the sensor on its own was not sensitive enough to the force of the tire to provide a sufficiently large range of resistances. Various types of rubber and plastic were tried, before the sensor and a Q-tip head were placed between two metal plates, which gave the best sensitivity of all the trials. This setup provided the data shown in figure 3.1 when tested. Figure 3.1 also shows the best fit lines that defined equations 2.1 and 2.2.

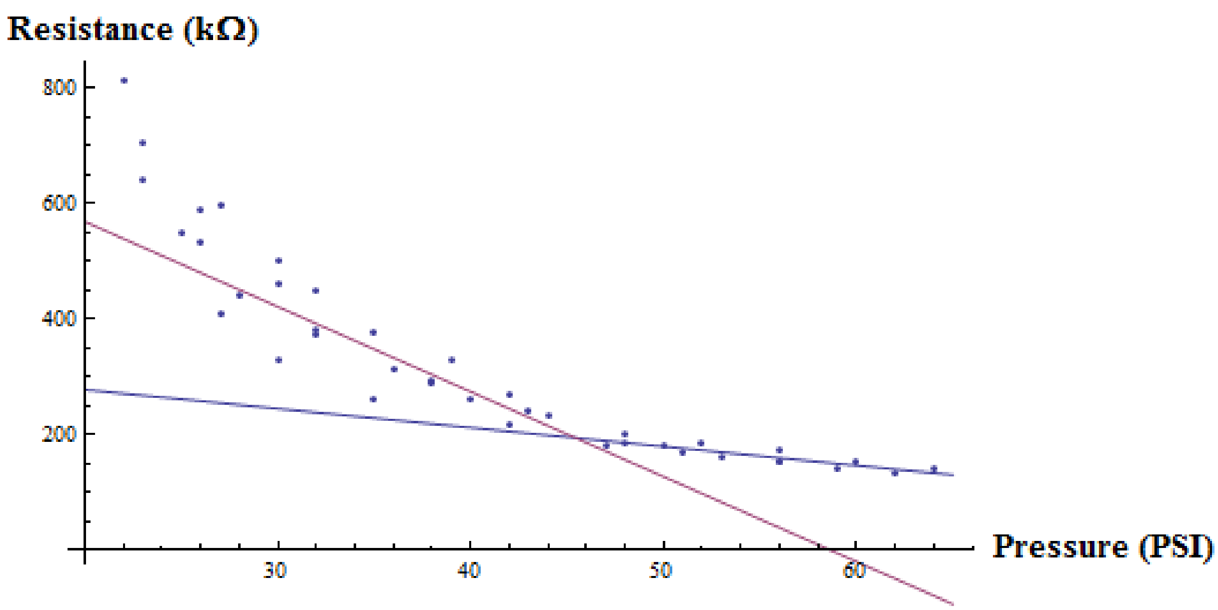

Figure 3. 1 Sensor data and best fit lines

With equations 2.1 and 2.2, the pressure can be calculated from a measured resistance, and after varying the pressure between 30 and 65 PSI the calculated pressure was always within 2PSI of the actual measured pressure, which satisfies the 10% accuracy requirement.

Using the PICkit2 and hardwiring the serial data output to the proto-board, the serial output could be observed on the computer monitor. This was successful at first, but eventually the output stopped changing with the pressure. It was later discovered that the sensor leads had broken loose and were no longer electrically connected to the board, hence the unchanging values.

3.1.2 Transmitter

The transmitter was originally allowed to transmit to the receiver chip, however, after it was discovered that the receiver chip was damaged, the accuracy of the transmitted signal was essentially untestable. To discover if the transmitted signal was too weak to be received, the receiver antenna was connected to a vector signal analyzer, while the transmitter was placed four feet away. The observed power at 418MHz was -40.4dBm, well above the -95dBm specified sensitivity of the receiver chip. It was at this point that it was determined that the receiver chip had been damaged beyond operation.

3.1.3 Power Supply

It was discovered that both batteries were supplying less power to the sensor circuits than the requirements dictated: 2.88V and 2.95V compared to the expected 3V ±0.1%.

3.2 Display Module

Testing the display module independently consisted of running a test program on the PIC to display "hello" on the top line of the LCD and "world" on the bottom line, which was accomplished.

3.2.1 PIC

The PIC successfully controlled the LCD, as described above. However, the PIC was unable to correctly receive data 100% of the time. It was discovered that sometimes the data was sometimes shifted to the left by 1 bit upon read in. This was caused when the UART failed to correctly synchronize with the incoming data.

3.2.2 Receiver

The receiver module was working correctly on the proto-board, however, it was found that at some point - most likely during soldering - the receiver chip had been damaged beyond operation. Due to this, the receiver portion of the project failed all tests.

3.2.3 LCD

By changing the test program used to display "hello world" a variety of alphanumerical symbols were properly displayed on the LCD, proving its ability to properly respond to the PIC's control signals.

3.2.4 Power supply

Unlike the sensor batteries, the battery supplying power to the display module was within the expected voltage range with 3.01V. This is because the display circuit drew less current than the sensor circuits, causing the internal battery resistance to deteriorate the supply voltage by a smaller amount.

4. Costs

4.1 Parts

Table 1 Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
PIC18F23K22	Microchip	2.66	1.73	7.98
LM358AN/S	Fairchild Semiconductor	0.46	0.10912	0.92
NHD-0208AZ-RN-YBW-3V-ND	New Haven Display	8.25	5.94	8.25
TXM-418-LC	LINX	6.42	5.775	12.84
RXM-418-LC-P	LINX	13.56	9.7632	13.56
ANT-418-HESM	LINX	1.04	0.45	3.12
P5.1BACT-ND	Panasonic-ECG	0.09	0.00992	0.18
1MAACT-ND	Yageo	0.31	0.05085	0.62
P220KBACT-ND	Panasonic-ECG	0.09	0.00992	0.18
P3.0KW-1BK-ND	Panasonic-ECG	0.34	0.03024	0.09
P300BACT-ND	Panasonic-ECG	0.09	0.00992	0.09
P10KW-2BK-ND	Panasonic-ECG	0.43	0.03844	0.86
490-5369-ND	Murata Electronics North America	0.19	0.0798	0.57
796136-1	TE Connectivity	1.592	1.08927	4.776
SY189-ND	FDK America	0.41	0.20508	1.23
Total				**52.27**

4.2 Labor

Table 2 Labor Costs

Person	Hours Spent	Hourly Wage($/hr)	Total Wagex2.5($)
Michael McDowall	250	40	25,000
Bryan Rafferty	250	40	25,000
Total(x2.5)			**50,000**

5. Conclusion

5.1 Accomplishments

Although the full system was not functional in the end, many components were functional, and this has served as a powerful learning experience. Among the functional parts of the project was the very consistent relationship between pressure and resistance, which allowed for very accurate calculation of the pressure. This proves the proof of our concept, and eliminated any concerns regarding the potential accuracy of the force sensor.

The display module PIC was also able to print to the LCD. There were many trials to get the LCD functional and it required much more time than anticipated, so the final accomplishment was very rewarding.

Finally, the transmitted signal had more than enough power to be received, had the receiver chip not been damaged. The strength of the RF link was another concern during the design phase, but as before, that concern was silenced by the promising VSA measurements.

5.2 Uncertainties

The failures and mistakes served as lessons as well. The underestimation of the time required to program the PICs lead to the project falling behind early on, and the schedule never fully caught up.

The mistakes in the layout of the display PCB also showed the importance of thinking ahead to the next step while still working on the task at hand, this can make things much easier down the road.

5.3 Ethical considerations

The only relevant ethical consideration is to ensure that the power output by the sensor transmitters is within the legal limit established by the FCC.

5.4 Future work

If the receiver chip were replaced further testing could perfect the receiving algorithm. Once the receiving algorithm is perfected, the full system would essentially be at operating specifications. At this point casings could be designed and built for the modules and attached full time to a bicycle.

References

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Appendix A Requirement and Verification Table

Table 3 System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Power Supply a. All three power supply units will provide within 0.1% of 3V and 100 µA to their respective circuits.	1. Verification a. Display Battery : 3.01V, 10mV ripple b. Sensor 1 Battery: 2.88V, 16mV ripple c. Sensor 2 Battery: 2.95, 8mV ripple	N
2. The sensors will output a series of bits corresponding to within 10% of the correct pressure value.Subrequirement a. Both flexiforce sensors should have resistance values that correspond to within 10% of the expected value. b. The Microcontroller serial outputs will properly output the A/D converted sensor voltage and the necessary warning flags.	2. Verification a. Within 2PSI of the correct value for all trials b. Passed until sensor broke loose.	Y
3. The transmitter module must emit a signal that is without errors and strong enough to be received by the handlebar unit. a. The transmitted signal must have a power of at least -90dBm 4 feet away from the transmitter. b. The transmitter must output the correct signal to the antenna that corresponds to the input data.	3. Verification a. Received power: -40.4dBm b. See verification 2.b	Y
4. The proper control signals for the LCD will be generated by the PIC for a given serial input to the RX pin.	4. The received series was sometimes shifted one bit to the left during read in, causing incorrect values to be displayed.	N

5. The LCD must display the correct information corresponding to its control inputs.	5. “hello” was printed on the top line of the LCD and ”world” was printed on the bottom line.	Y