Microflow
Systems Inc.

March 8th 2010
Dr. Andrew Rawicz
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Design Specification for Microflow's Networked Water Faucet System.

Dear Dr. Rawicz:

The attached document is intended to describe all of the design specifications for the networked water faucet system that is currently being developed by Microflow Systems Incorporated. Included in the document is the low level design of the entire system followed by the low level design of each component that makes up the faucet system.

Appropriate design requirements and specifications have been obtained through a comprehensive analysis of each component's function within the final working system. The networked water faucet system has been designed to be a green technology that will educate users of their water consumption by keeping track of their usage of water through faucets, as well as showerheads as a future offering. This type of water usage tracking is advantageous over traditional metering systems because it reports to the user their usage in real time, and it allows the user to track the water used voluntarily. Along with this immediate feedback, this system will also provide a continuously updated total of all the water used by the network of faucets (and showerheads in the future) in the household. The aim of this product is to create awareness of limited resources while encouraging the reduction of water waste, and in the ideal case the elimination of water waste.

Microflow Systems Incorporated is a start up Technology Company made up of the following four members: Kwang-young Lee (CFO), Sonca Teng (CEO), Micheal Hou (COO) and Aaron Marcano (CTO). The team at Microflow will use the attached design specifications as a reference to develop and test our proprietary networked water faucet system. The enclosed design specifications are subject to minor changes as the company moves forward with product development and testing.

Sincerely,

Sonca Teng
Chief Executive Officer
Microflow Systems, Inc.

Enclosure: *Design Specification for a Networked Water Faucet System*

Microflow
Systems Inc.

Design Specification for Microflow's Networked Water Faucet System

Submitted to: Dr. Andrew Rawicz – ENSC 440
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March 8th 2010

Executive Summary

Microflow's water metering system will function in ways that will raise people's awareness with respect to their water consumption on a daily basis. The main purposes of the networked device are to measure and display the water used currently and in total, then the water used will be broadcast to any other faucets in the network. By increasing awareness of water consumption within homes and businesses people can take steps to conserve limited fresh water resources. Water conservation is increasing in importance in areas of the world where there are limited fresh water resources. Regions of the world such as California and many cities in China, to name a few, face water deficits that will grow with population growth. This product is intended to raise awareness and educate people about how much fresh water they are using which will help them reduce their own water consumption. If people become educated about how much water they are using across all of their water faucets then this type of metering will raise awareness and highlight any potential areas of water waste. Awareness is the one thing Microflow feels has been missing with respect to water consumption. We believe it is the biggest thing that needs to be addressed when talking about conservation of water resources.

Microflow's faucets will have attached to them a PIC24 processor, RF transceiver module, water flow sensor, power supply, and an LCD to display water usage data. Each of these devices will need to be integrated into a single streamlined system through implementing software, hardware and mechanics. The attached document contains detailed design specifications explaining the design of the networked water faucet system being developed by Microflow. It explains everything from hardware pin assignments and electrical requirements to software standards and network security issues. The development stages for which the design specifications must be adhered to are the following:

- Software Development – LCD, Flow Sensor, Transceiver (system implementation)
- Software Development – Transceiver (program - wireless communication)
- Software Development – PIC (program - system integration)
- Hardware Development – LCD, Flow Sensor, Faucet (mechanical/electrical connection)
- Hardware Development – Transceiver, PIC (electrical pin connections/wiring)

Throughout the project the Microflow development teams will refer to the design specifications to make certain that all the design requirements are being met. With this goal in mind this document will be frequently referenced by hardware technicians and software programmers. The test case design run sheets will also be invaluable during product testing.

The design specifications have been written in compliance with laws, bylaws, codes and acts in accordance with North America's consumer product standards.

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Glossary

DC	Direct current
Flow Rate	Volume of fluid that flows past a cross section area per unit of time
ETSI	European Telecommunications Standards Institute
FDA	The United States Food and Drug Administration
FCC	The United States Government Federal Communications Commission
IC	Industry Canada
ISM	Industrial, scientific and medical
Kbps	Kilobits per second
LPM	Liters of fluid that flow through a cross section area per unit of time measured in minutes
MAC	Medium access control
MiWi	Short range, low power consumption, wireless networking protocol developed by Microchip Technology
Networked Water Faucet System	The product that Microflow is currently developing for water conservation, used in place of regular water faucets
P2P	peer-to-peer
PAN	Personal area network
PCB	Printed circuit board
PIC	Programmable interface controller
PSI	Pounds of fluid pressure per square inch of surface area
PHY	Physical layer
R&D	Research and development
SPI	Serial peripheral interface
WPANs	Wireless personal area networks

1. Introduction

The networked water faucet system is designed primarily as a water conservation device, however there are some additional uses for it. As an added benefit these faucets will also be accurate dispensers of water. This means that there will be no need to use a measuring cup for water because the faucets permit almost any volume of water to be dispensed. To be able to accurately and easily measure water into any container is convenient for cooking and baking purposes. Measuring the total amount of water used by one or multiple faucets will achieve the most important step toward conserving fresh water, awareness. The detailed design requirements for the networked water faucet system are contained in subsequent sections.

1.1 Scope

This document is primarily intended for internal use at Microflow to help with product development and maintenance. If approved by Microflow, any third party that requests the design specifications of the networked water faucet system shall be given access to them in softcopy form.

The following design specifications will provide quality assurance personnel with the central resource they need to carry out the test case execution process. At this time the test case design is complete and the run sheets, issue 3.1, have been included at the end of the document (Section 8).

1.2 Intended Audience

The design specifications will be used during R&D, manufacturing and testing stages and are meant to be a reference for Microflow personnel. The external audience will include legal representation, manufacturing contractors, product licensees and sales partners. In addition, external use of this document will be permitted to various standards organizations so they can verify, and then certify, that Microflow branded products are safe for public use.

2. System Overview

The Microflow networked faucet is a direct drop-in replacement for a standard household faucet. In order to encourage rapid adoption we have specified our system to operate in exactly the same fashion as any user would be accustomed to. The user interface is identical to that of a traditional faucet save for a backlit LCD display which must show both water usage for the current session, and total water usage throughout the day across the faucet network.

2.1 Conceptual Overview

A conceptual model of our faucet is shown below in Figure 1.

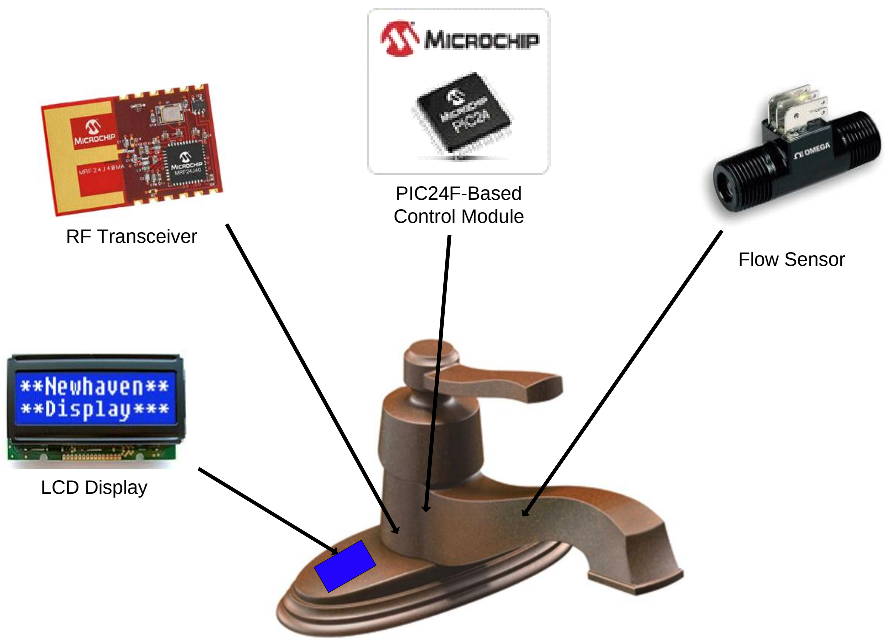

Figure 1 - Conceptual model.

As shown in figure 1, the primary components in our system are the LCD Display, the RF Transceiver, the PIC24F-Based Control Module, the Flow Sensor, and the Faucet. All of these components are not perceived by users, save for the LCD display and the faucet itself.

2.2 System Block Diagram

A high level system block diagram is shown below in Figure 2.

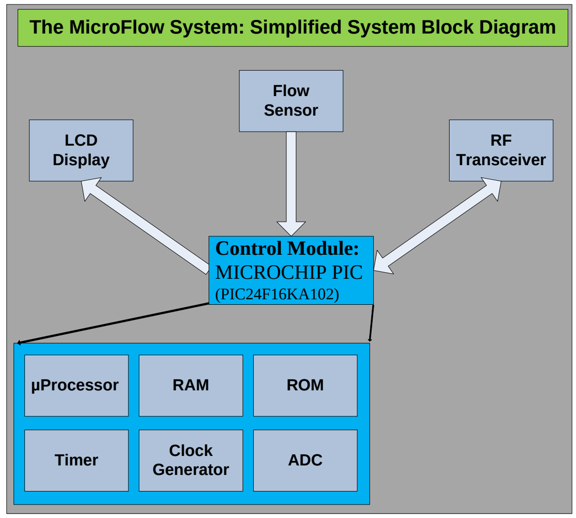

Figure 2 - System block diagram.

As shown in the system block diagram, the control module updates the LCD display module with state and water usage information, receives session water usage data from the flow sensor, and interacts with the RF transceiver. The control module needs to interface with these other components in order to: update nodes in the network, receive updates from other nodes, calculate and update the water usage dynamically, and then display the network water usage on the LCD.

2.3 Operation and User Interface

When the user turns on the faucet, water flows as it would in a traditional faucet [2]. However, with our faucet there is an LCD that gives water usage information for the immediate node in addition to all other nodes in the network.

The state diagram below in Figure 3 summarizes the system operation scheme for a single faucet.

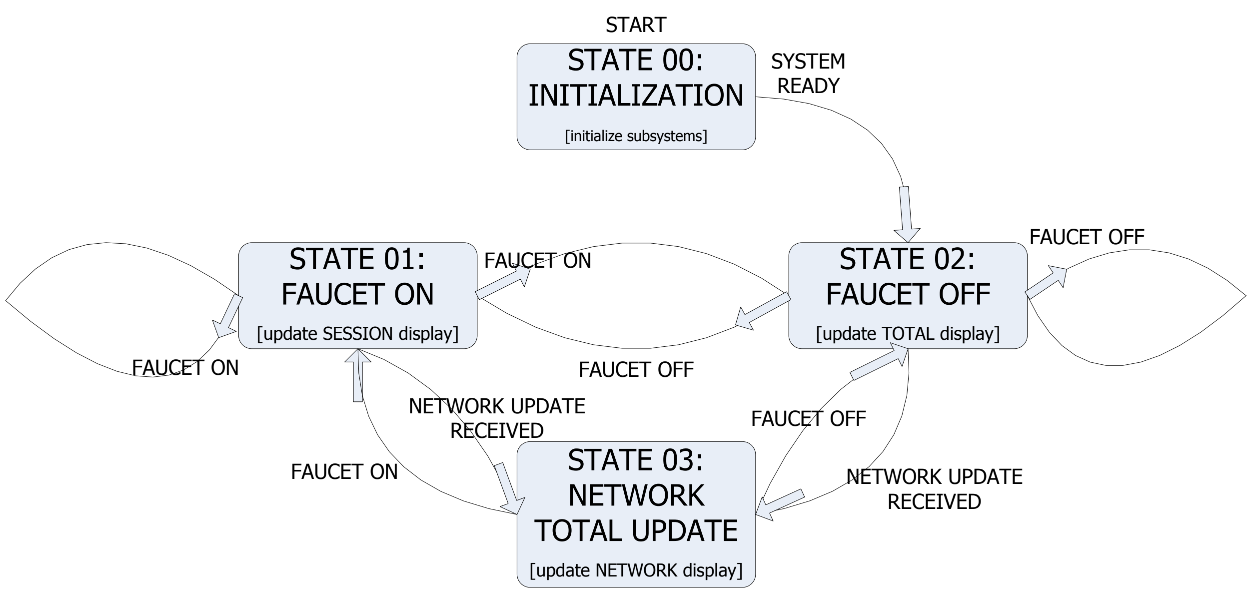

Figure 3 - System operation state machine.

The system begins in STATE 00:, the initialization state. Once the subsystems are first initialized and the system reports READY, STATE 02: "FAUCET OFF", is entered next by default. Now depending on whether the faucet is on or off at this point, the next state is determined.

While the water is running (STATE 01: FAUCET ON), the LCD Display on our faucet must give a readout as shown in Figure 4, updating both figures in real time as the water runs. The Session line reflects usage in mL as presently being used by the faucet in use, and network denotes the total water used in liters (L) across the network of Microflow faucets in within RF range.

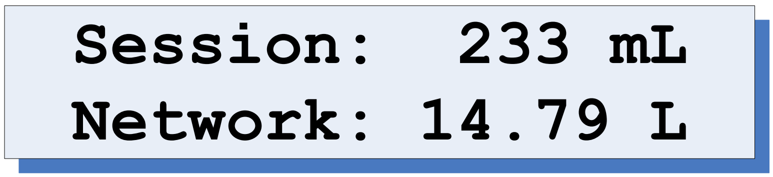

Figure 4 - LCD display – water running.

The flow sensor tracks the amount of water flowing through the faucet in real time, and updates the control module continuously. At the same time, the faucet receives updates of the total network water usage through the RF transceiver periodically, and updates the display accordingly. When this occurs, STATE 03: NETWORK TOTAL UPDATE is entered.

When the water is off (STATE 02: FAUCET OFF), the LCD display reverts to showing "Total" usage in L by the faucet in question, while the "Network" usage line shows the water use in L across the entire network, which updates in real time. This display mode is shown in Figure 5.

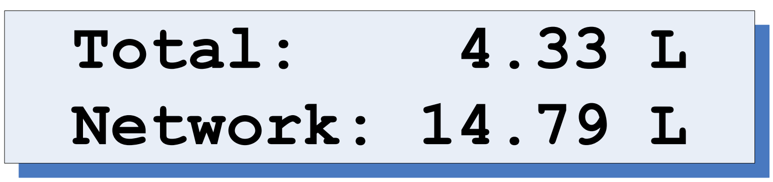

Figure 5 - LCD display – faucet not in use.

The control module simply updates the total individual faucet usage when the tap is shut off, and leaves this statistic displayed until the next time the system enters the faucet on state. Similarly, at any time, the faucet receives updates to the total network water usage through the RF transceiver periodically, and updates the display accordingly. When this occurs, STATE 03: NETWORK TOTAL UPDATE is entered.

For further details on the user interface, please see Section 7.

2.4 Wireless Networking

Further enhancing our technology is the wireless capability made possible by our RF transceiver. A wireless network *automatically* forms between faucets installed into the home, and an illustration of this is shown below in Figure 6.

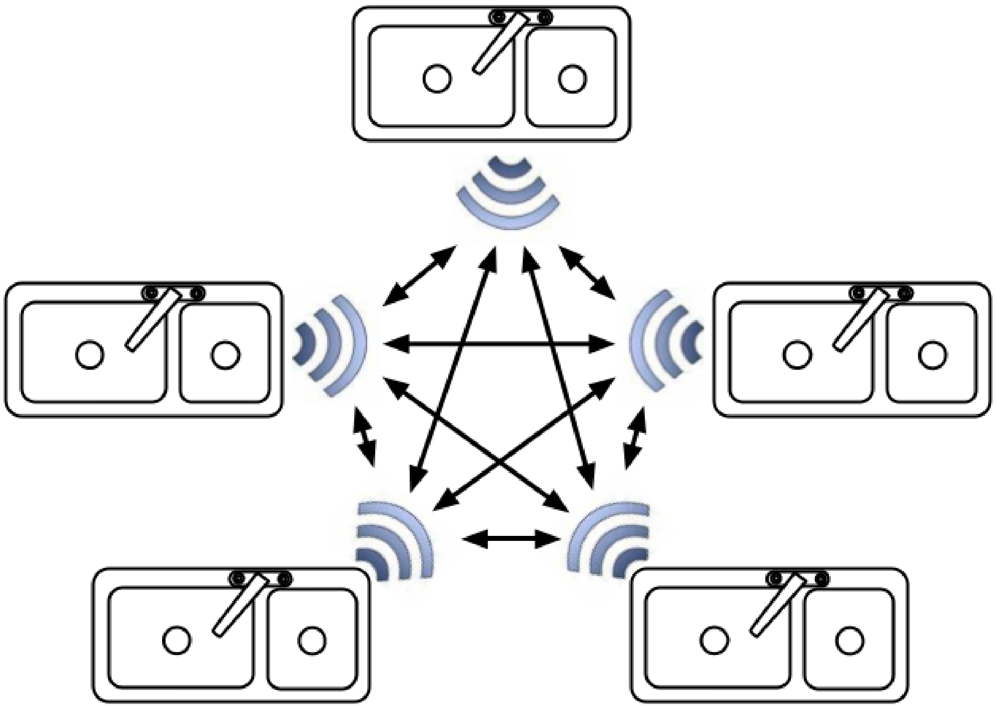

Figure 6 - Network model.

Once two or more Microflow faucets are present in the network, the individual control modules of each faucet process and calculate the total water usage of the network and the LCD's of every faucet are able to display this information to the user. There is no need for user intervention to initiate this networking process.

The wireless network engages the MiWi communication protocol, using small, low-power radios, based on IEEE 802.15.4-2006 standards for wireless devices developed by Microchip Technology. It is provided fully free of charge and royalty free for use with a Microchip PIC's. MiWi provides a low development cost and low memory footprint alternative to competing IEEE 802.15.4 based protocols, such as the ZigBee protocol [1].

3. PIC Design

3.1 PIC Application Overview

A PIC, or programmable interface controller, is used to control the various analog and digital devices within the faucet system. It will receive digital input from the flow sensor, control the LCD screen and interface with the wireless transceiver hardware and software.

3.2 PIC Hardware Design Specifications

To be capable of controlling all the external devices in the water faucet system, a PIC with a sufficient number of input/output pins, and the necessary communication peripherals was selected. More specifically, the wireless transceiver requires connection with SPI pins from the PIC to function properly.

The following table shows the number of connection pins and connection types required for the PIC to communicate with other devices in the system.

Table 1 – PIC connection requirements.

Device Name	Connection Type	Number of Connections
Wireless Transceiver	SPI	3
LCD Screen Control	Digital Output	6
LCD Backlight Control	Digital Output	1
Flow Sensor	Digital Input	1

For the LCD screen control, only 6 pins are required, (RS, E, 4-bit Data), since 4-bit mode has been chosen for its simplicity in wiring and software development, instead of 8 bit.

Other hardware requirement for the PIC was excellent processing power, DIP (dual inline pins) form-factor, low power requirement, and low cost per unit. These requirements were set to reduce development cost for the proof-of-concept model, and also for ease of in-circuit testing in a lab environment using a breadboard.

After extensive product search, from both MicroChip and Digikey websites, using the requirements stated previously, the PIC24F16KA102 family was chosen for its compact size, low power consumption, and various built-in modules with enough pin counts. Although not as powerful in processing power compared to other microcontrollers (scalable 8Mhz primary oscillator compared to others' 16 to 36Mhz primary oscillator), due to the relative simplicity of the system, its performance was acceptable for this application.

3.3 PIC Software Design Specifications

The PIC24F16KA102 family microprocessors can be programmed using MPLAB3 design software and a PICKit3 PIC programmer. The design software and the programmer translate C language into executable instruction sets inside the microprocessor. This enables high-level programming without extensive knowledge of the hardware inside the PIC. The following flow diagram in figure 7 shows the software execution overview.

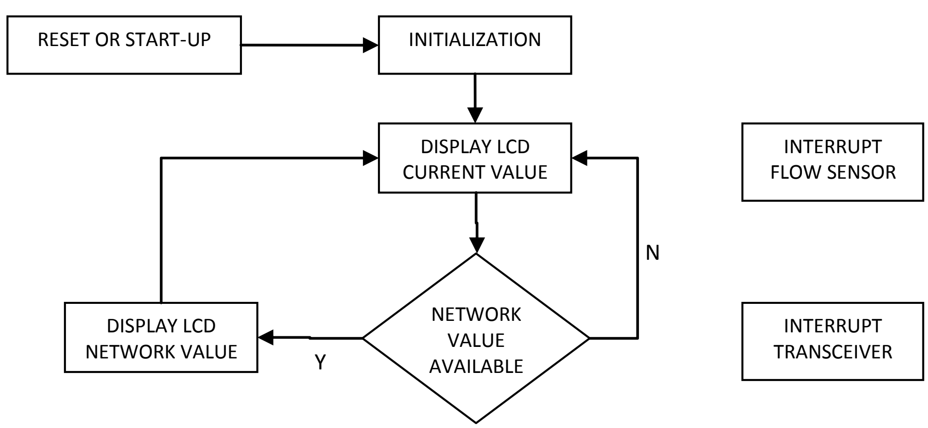

Figure 7 - Software process flow diagram.

The initialization stage will be entered either when the system starts or the hardware resets. In this stage, LCD will be initialized, the wireless transceiver will be initialized, all variable registers are reset, interrupt services for the flow sensor enabled, and wireless transceiver is set. After the initialization is complete, the LCD will display local water usage and network water usage if network is available, and do so in an infinite loop. While the LCD is displaying the appropriate values, two interrupt services are in stand-by, one for the flow sensor, and another for the wireless transceiver.

The interrupt for the flow sensor will increment the register value with current usage to reflect the water usage volume. It's connected to interrupt channel 0 pin for the PIC. Since the flow sensor generates a fixed number of square signals per liter, the PIC can keep track of the amount of water used by incrementing with every rising edge from the flow sensor. Because the sensor can output at maximum 500Hz frequency signal, this interrupt needs to be small and quick, and shouldn't take more than 2 milliseconds per register increment. By adjusting the scalar primary oscillator frequency, which dictates the processing speed, this can easily be achieved. Since keeping accurate value of water usage is important, the flow sensor has the highest user-settable interrupt priority.

Another source for interrupt is the wireless transceiver. This interrupt will fire when interrupt channel 1 receives a trigger signal from the transceiver upon receipt of an incoming packet. Once this packet is received, the software decodes the packet header to determine unit information and timing information, it then processes the packet data for updating of previous network water use statistics. These new statistics are then displayed to the LCD via the SPI bus.

3.3.1 Software Reliability

The software is programmed onto the program memory in the PIC. The memory has minimum memory hold time of 10,000 hours without reset. However, when an error occurs during software execution, such as primary oscillator failure, hardware reset will occur. The reset, however, will not erase the program memory.

Most foreseeable software errors, such as register overflow, interrupt timing, and module hardware failure, have been discussed and resolved during the programming and debugging stage. In future development, more error situations may reveal themselves and will be resolved as necessary.

3.3.2 Software Modularity

Due to the independent modular nature of the system, software can be developed separately for each hardware module or parts, and integrated into one system afterwards. With good programming practice, this will lead to well defined modular functions for each part of the system, which will result in better maintainability and expandability.

4. Transceiver Design

4.1 Transceiver Application Overview

This section of the design specifications will use information from the following documents: AN-1204(MiWi P2P), AN-1066(MiWi), SPI_39699b.pdf, 802.15.4-2006.pdf (IEEE), Microchip PIC24F16KA102 family data sheet, Microchip MRF24J40MA data sheet, MRF24J40.pdf, and Microchip's ZENA wireless network analyzer user's guide. Covered in the rest of the overview are the main characteristics of the design as they pertain to software implementation, and hardware connection of the transceiver module.

The transceiver modules used in this system will communicate over an RF between 2.405 GHz and 2.48 GHz ISM band [3]. Also, the transceiver shall send and receive data at a data rate not exceeding 250 Kbps [3]. Microchip's MRF24J40MA transceiver modules operate in the non-licensed 2.4 GHz frequency band and are FCC, IC and ETSI compliant [3].

When the transceivers are not actively communicating with each other they will enter sleep mode where they will consume approximately 2 µA of DC [3]. At full power the transceiver modules will consume approximately 23 mA of DC [3]. The software implementation of the faucets will be achieved by referencing Microchip's MiWi wireless networking protocol stack, this will minimize software development time and allow a quicker time to market. It should also be stated that every network compatible Microflow faucet can also be used individually without networking dependencies. A single faucet will manage the basic functions of monitoring and recording its own water use data that will be displayed on its LCD.

While Microflow is developing and testing the first networked water faucet system model we will be using the Zena network analyzer. This device was also purchased from Microchip and is designed to sniff any channel for transmitted MiWi packets. The analyzer will display the information via the wireless network analyzer's graphical interface. The Zena software comes with a customizable stack configuration for sniffing specific bands and a network traffic monitor display to show network topologies. With this device software developers can quickly and easily observe if and when messages are being sent across the network, this will then ensure packets are transmitted correctly and securely. Security of the network's data is an important area that is described in section 3.3 subsection of the transceiver module design.

4.2 Transceiver Hardware/Electrical Design Specifications

The Microchip RF transceiver module, model # MRF24J40MA, has 12 pins and a PCB antenna with a maximum 400 foot data transmission range [3]. The pin symbols are listed below along with the types and descriptions. The complete surface mountable transceiver measures at 17.8mm x 27.9 mm.

4.2.1 Transceiver Module Pins

Table 2 - Pin symbols and descriptions of Microchip's MRF24J40MA transceiver module [3].

PIN DESCRIPTION

Pin	Symbol	Type	Description
1	GND	Power	Ground
2	$\overline{RESET}$	DI	Global hardware Reset pin
3	WAKE	DI	External wake-up trigger
4	INT	DO	Interrupt pin to microcontroller
5	SDI	DI	Serial interface data input
6	SCK	DI	Serial interface clock
7	SDO	DO	Serial interface data output from MRF24J40
8	$\overline{CS}$	DI	Serial interface enable
9	NC	—	No connection (allow pin to float; do not connect signal)
10	VIN	Power	Power supply
11	GND	Ground	Ground
12	GND	Ground	Ground

Legend: Pin type abbreviation: D = Digital, I = Input, O = Output

Below is the diagram of the basic pin assignments required for the electrical connections between the transceiver module and the PIC24 family of processors. Re-stated, the three SPI pins handle data transmission between the two
components.

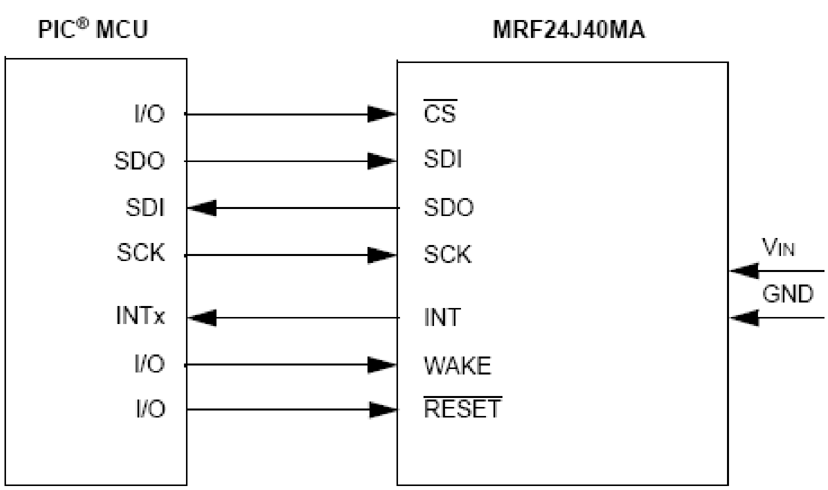

Figure 8 - PIC24 pins that will be attached to the MRF24J40MA transceiver module [3].

There are four synchronous SPI pins designated on the MRF24J40MA transceiver circuit, in this application we require the use of only the following 3 SPI pins: SDI1, SDO1 and pin SCK1. In total, this transceiver application will make use of the reset, interrupt, power supply, SPI, wake and SPI enable pins. The transceiver module will operate in standard mode and must be wired using the following pin mapping with the PIC24F16KA102 processor pins.

Table 3 - Serial peripheral pin assignments for transceiver communication with PIC24 processor.

Pin Symbol/Name	Pin Purpose	PIC Pin #	Notes:
SDI1	Serial Data Input	Pin 21	SPI input pin -Standard Mode
SDO1	Serial Data Output	Pin 24	SPI input pin -Standard Mode
SCK1	Shift Clock Input or Output	Pin 22	SPI input pin -Standard Mode
RESET	Reset Device	Pin 15	Conditional Reset
WAKE	Wake Device from Sleep	Pin 17	Exit sleep mode when no active messages
INT	Interrupt from Transmit/Receive	Pin 25	Interrupt for the transceiver
CS	Serial interface enable	Pin 18	Enable SPI pins
Vin	Power supply	-	2.4-3.6V (3.3V typical)
GND	Ground	-	Single ground pin only

4.2.2 Transceiver Component Overview

All of the major components of the transceiver are shown in the diagram below. The PHY layer is the component that is responsible for all controlling radio operations with all channels, most importantly sending and receiving packets or data frames. The MAC layer block is responsible for implementing application-appropriate security mechanisms (see section 4.3.4), as well as other transceiver management processes.

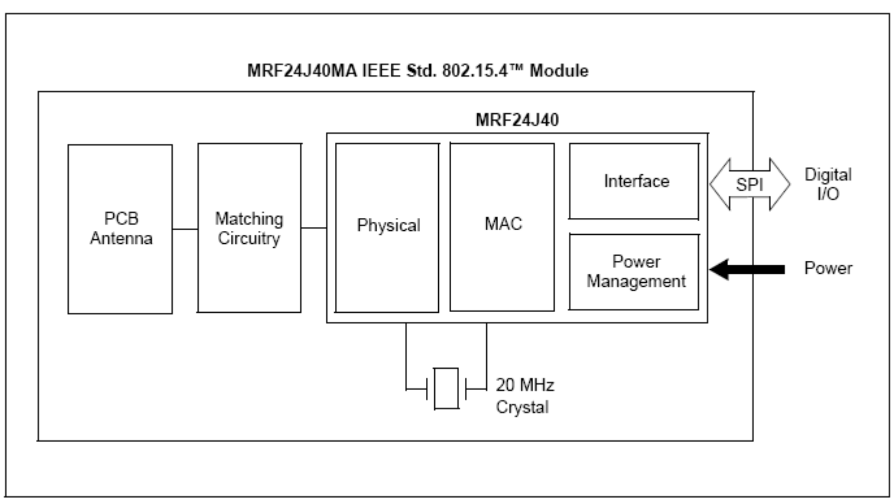

Figure 9 - Block diagram of the MRF24J40MA transceiver module layer and components [3].

Following the transceiver pin assignments, the 12 transceiver pin mapping is shown in the figure below.

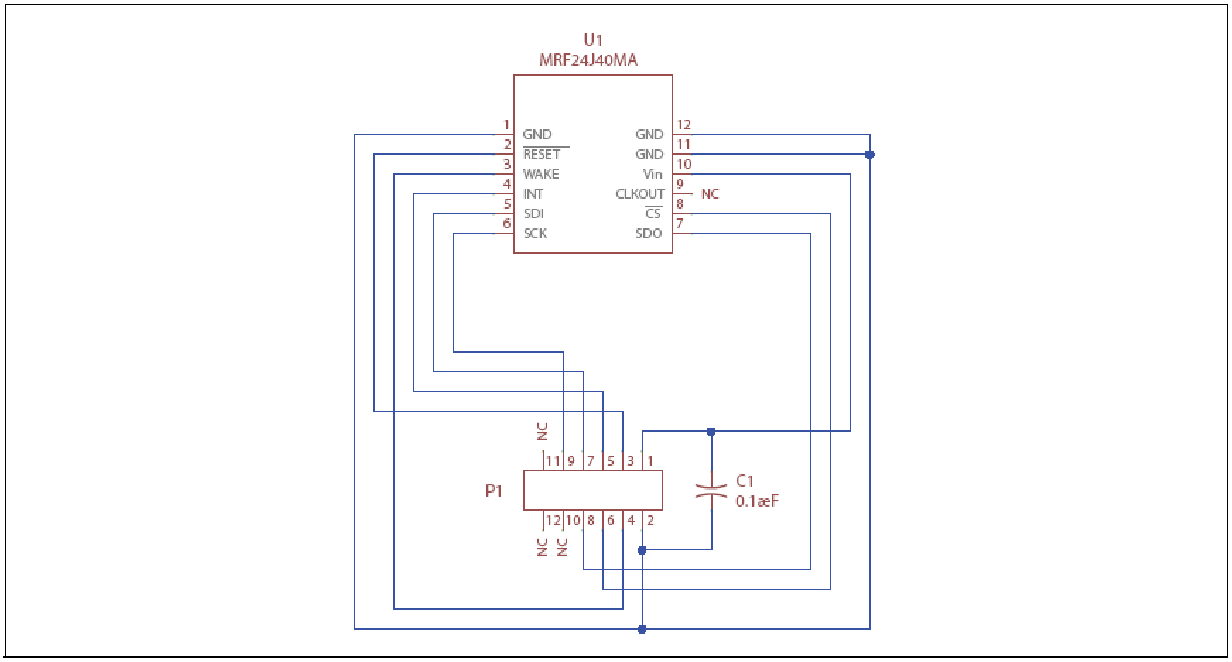

Figure 10 - Pin assignments from the MRF24J40MA transceiver hardware pins [4].

4.3 Transceiver Software Design Specifications

4.3.1 Transceiver Communications Software Overview

Faucets within established networks will use their transceiver modules to share information with other faucets. The software is being developed using Microchip's MPLAB IDE v8.43, and the finalized code will run on the PIC24F16KA102 processor. Pre-configuration of nodes needs to be minimal so the P2P network will be dynamically implemented for this application. The operating WPAN range is a maximum 400 foot distance between two communicating nodes, assuming RF signals are not being blocked.

Faucet nodes will form P2P communication links with other devices and use their long addresses to recognize each other. New nodes attempting to join an already established network will first perform an active scan. An active scan will determine an existing network's operating channel, signal strength and PAN identifier code. The maximum number of PAN's that a node can acquire is set with stack variable "ACTIVE_SCAN_RESULT_SIZE". If there are no nodes communicating within range, meaning the active scan fails to acquire at least one PAN identifier, then the node will run an energy scan to survey all 16 channels for the best channel. The gauge of the best channel is the channel with the least energy or noise on it. To implement the active scan feature "ENABLE_ACTIVE_SCAN" must be defined in the project file, P2PDefs.h [5]. To activate the Energy Scan feature within the program, "ENABLE_ENERGY_SCAN" must be defined in the header file P2PDefs.h [5]. The desired scan time can be set by the user as it is a user-designated parameter with the name "Scan_Time_Period". Once a faucet in the network successfully performs the first energy scan a PAN identifier will be available to other nodes attempting to join the cluster, via active scans. The channel number will now be selected for any future active scans performed by Microflow faucets within range.

The Microchip RF transceiver module, model # MRF24J40MA, will send and receive a faucet's water usage data to and from the rest of the faucets within a given WPAN. The maximum number of nodes able to connect to a single MiWi network is 1024; faucet nodes will be communicating over one of the possible 16 ISM channels, channels [11, 26] are available to the 2.4 GHz RF band. When two or more powered Microflow faucets are in close proximity to each other a single MiWi compliant network will be established automatically. As stated previously the networks formed are designed to be of P2P configuration. Each device will have equal access to the network as long as the selected channel is idle, and there are other nodes ready to transmit and receive data. The IEEE std. 802.15.4 (2006) compliant network has been utilized for this application; it is compatible with the MiWi wireless networking protocol developed by Microchip Technology. Once a network has been formed then standardized communication between two or more faucet nodes will be possible, the faucets can then update each other with their most recent water use data.

4.3.2 Transceiver Control Register Design

The Serial Peripheral Interface (SPI) registers shown below have the corresponding names and purposes. The SPI module is a serial interface used by the PIC24 processor family for simple communication with peripheral transceiver modules:

Table 4 – Transceiver control registers and transmit/receive buffers.

Register Name	Register Purpose	Notes
SPI1CON	Control register that configures SPI module for different modes of operation	16 bit memory mapped register
SPI1BUF	Buffer for sending and receiving data to/from the transceiver	Standard modes divides the buffer into two parts 1. SPIxTXB (Transmit) 2. SPIxRXB (Receive)
SPI1STAT	Provides the interface to control the transceiver module's modes of operation	Control and status register

> "The memory mapped register, SPIxBUF, is the SPI Data Receive/Transmit register. In Standard modes, the SPIxBUF register is actually comprised of two separate registers: the Transmit Buffer, SPIxTXB, and the Receive Buffer, SPIxRXB. These two unidirectional, 16-bit registers share the SFR address of SPIxBUF. If a user writes data to be transmitted to the SPIxBUF address, internally the data is written to the SPIxTXB register. Similarly, when the user reads the received data from SPIxBUF, internally the data is read from the SPIxRXB register" [6].

A summary of the transceiver module control registers is shown below in table 5, and the software development team will use this table as a quick reference for setting bits in the transceiver's control registers, to find buffer register addresses, and to locate the names of appropriate write/read bits in the SPI1STAT register. The SPI1STAT register controls the module's operation and has a bit that controls whether the SPI1CON register may be written to, the SPIxSTAT<15> bit must be cleared before modifying this register.

Table 5 – Transceiver module control register bit mapping [6].

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	All Resets
SPIxSTAT	SRMPT	SPIROV	SRXMPT	SISEL2	SISEL1	SISEL0	SPIxTBF	SPIxRBF	0000
SPIxCON1	SSEN	CKP	MSTEN	SPRE2	SPRE1	SPRE0	PPRE1	PPRE0	0000
SPIxCON2	—	—	—	—	—	—	SPIFE	SPIBEN	0000
SPIxBUF	SPIx Transmit and Receive Buffer								0000
PMD1	I2C1MD	U2MD	U1MD	SPI2MD	SPI1MD	—	—	ADCMD	0000
PMD2	—	—	—	OC5MD	OC4MD	OC3MD	OC2MD	OC1MD	0000
PMD3	CRCPMD	—	—	—	—	—	I2CMD	—	0000

Name	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8
SPIxSTAT	SPIEN	—	SPISIDL	—	—	SPIBEC2	SPIBEC1	SPIBEC0
SPIxCON1	—	—	—	DISSCK	DISSDO	MODE16	SMP	CKE
SPIxCON2	FRMEN	SPIFSD	SPIFPOL	—	—	—	—	—
SPIxBUF	SPIx Transmit and Receive Buffer							
PMD1	T5MD	T4MD	T3MD	T2MD	T1MD	—	—	—
PMD2	—	—	—	IC5MD	IC4MD	IC3MD	IC2MD	IC1MD
PMD3	—	—	—	—	—	CMPMD	RTCCMD	PMPMD

Legend: — = unimplemented, read as '0'. Reset values are shown in hexidecimal.

4.3.3 Transceiver Software Design

The following files and functions will be included in the C language project that will be compiled to produce the executable code for the networked water faucet's processor.

Table 6 – Header files, functions, and program files required for the transceiver module.

Header Files:	Program Files:	Transceiver Functions //description:

ConfigP2P.h
P2P.h
ConfigMRF24J40.h
MRF24J40.h
MSPI.h
ConfigApp.h
Transceivers.h
MCHP_MAC.h
P2PDefs.h
	MainP2P.c
	MRF24J40.c
	P2P.c
	MSPI.c
		InitMRF24J40 (); // initialize transceiver
		MiApp_NoiseDetection(); // search for least noise channel
		SetChannel(myChannel); // set the channel to operate
		AddConnection() // accept new P2P connection
		CreateNewConnection(2); // establish new connection
		SendPacket (); // send data over the SPI
		MiMAC_ReceivedPacket(); // check for packet
		MiMAC_DiscardPacket (); // discard the packet
		MiApp_FlushTx(); // flush the entire buffer
		MiApp_WriteData(); // write data to buffer
		MiApp_TransceiverPowerState()// put transceiver into //sleep or wake up mode

		MiApp_Unicast Address()// send address node a message
		MiApp_BroadcastPacket(); // broadcast message, all nodes
		PHYSetLongRAMAddr(); // set long address to write to
		PHYGetLongRAMAddr(); // read long address

4.3.4 Transceiver Communication Security

Every time the transceiver sends a packet, or data frame, to another transceiver it will also request an acknowledgement be sent from the receiving node to the sending node. This acknowledgement will help verify if the packet was received, but not necessarily if the packet was sent and received correctly. Security will be handled in a simple way that does not require too much power or processing time. There is a group key that will be assigned to each node when it associates with a cluster. The group key will be stored in the MAC layer in the designated auxiliary security header shown in figure 11.

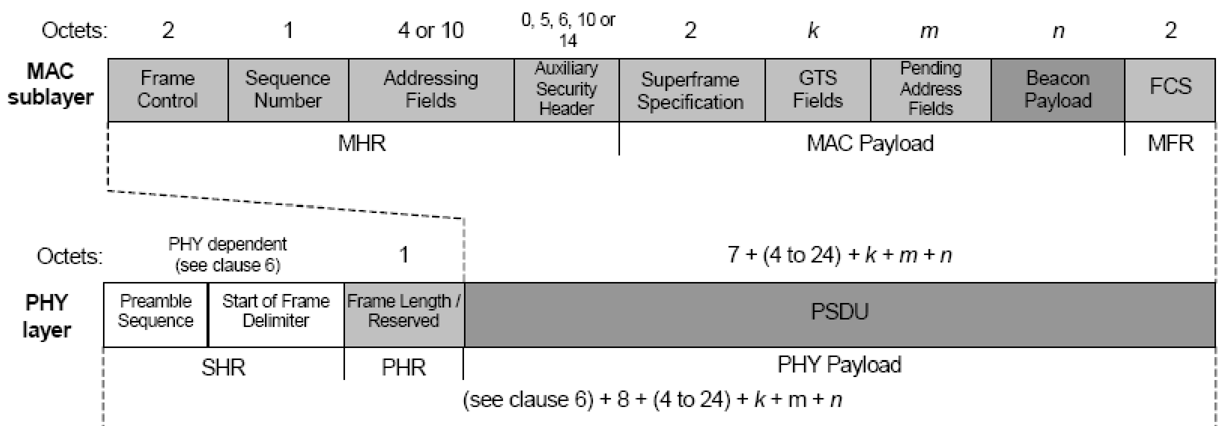

Figure 11 - MAC sub-layer format showing auxiliary security header [7].

4.3.5 Transceiver Communication MiWi P2P Wireless Packet Format and Software Flow

Before any packet information is sent over the SPI pins the Interrupt from radio is turned off before accessing the SPI and turned back on after accessing the SPI. We have therefore designed the software to attempt to send packets more than once, with timeout, to account for the possibility of a collision between outgoing and incoming messages. The packet format is shown below; packet component sizes are labeled in number of bytes.

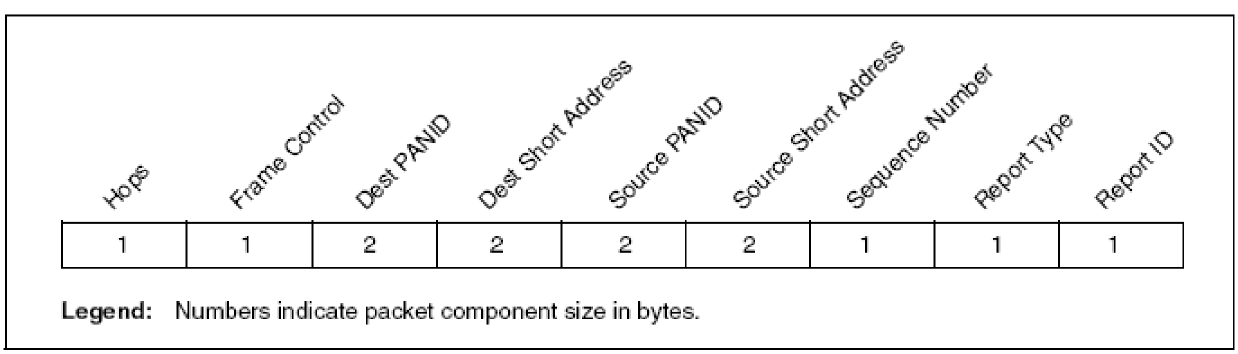

Figure 12 - Transceiver packet format [8].

The transceiver processes packets to send or receive data according to the flowchart in figure 13 below. If a packet is sent while the transceiver interrupt is off then the processor will make another attempt to send that packet at 30 second intervals until the message is successfully sent and an acknowledgement received. The sending transceiver must receive a positive acknowledgement before the packet stops being sent, or until time out. The flowchart below is applicable only when the transceiver is awake, not in sleep mode.

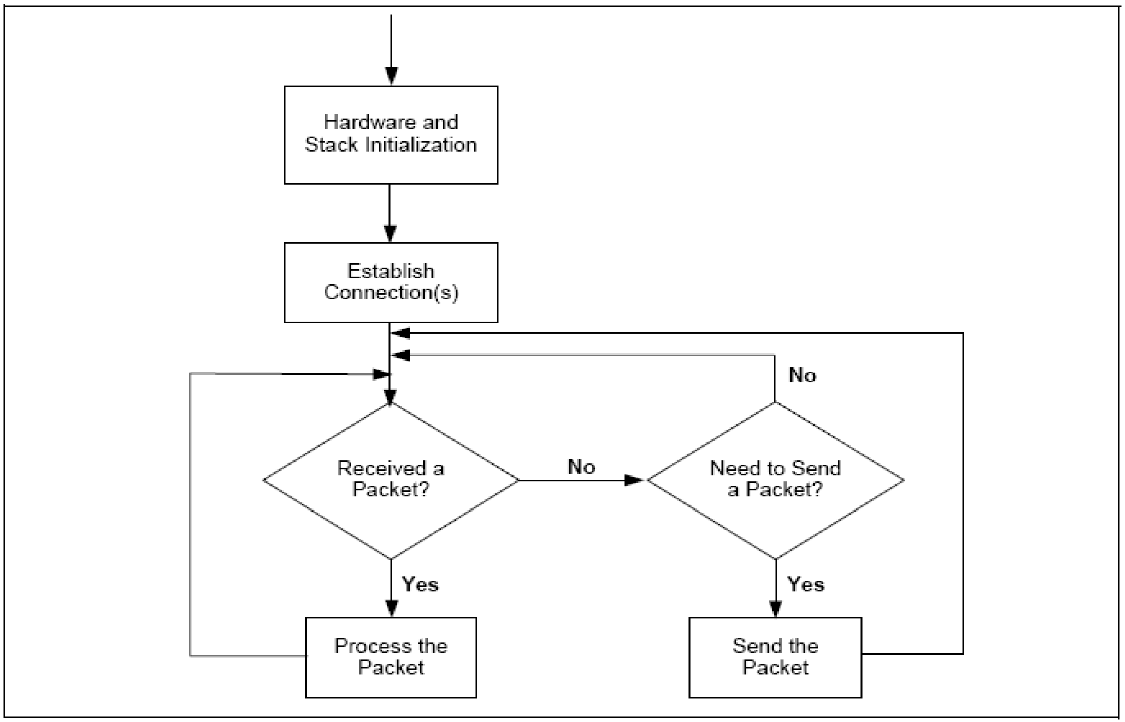

Figure 13 - MiWi P2P transceiver software flow chart [5].

5. Mechanical Design

5.1 Mechanical Design Overview

The networked water faucet system devices include three main hardware components. They are flow sensor, LCD unit, and the faucet itself. The hardware and electronic are integrated into the faucet for easy installation for end users. The electronic board and the LCD unit will be encased in their own waterproof plastic enclosure. Furthermore, the enclosure used will be form fitting to the module and it is transparent for the LCD unit to be visible. This section describes the mechanical design of each module by itself.

Below is a hardware block diagram for the system in its entirety.

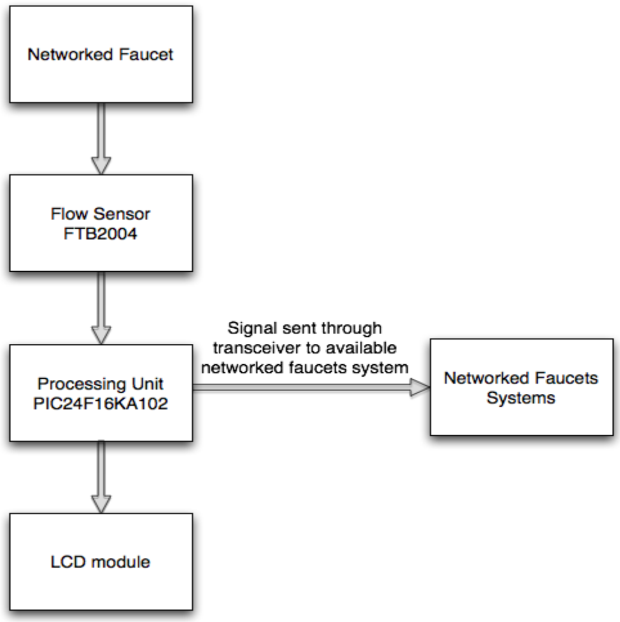

Figure 14 - Hardware Block Diagram

A three-dimensional model of the mechanical system is shown following.

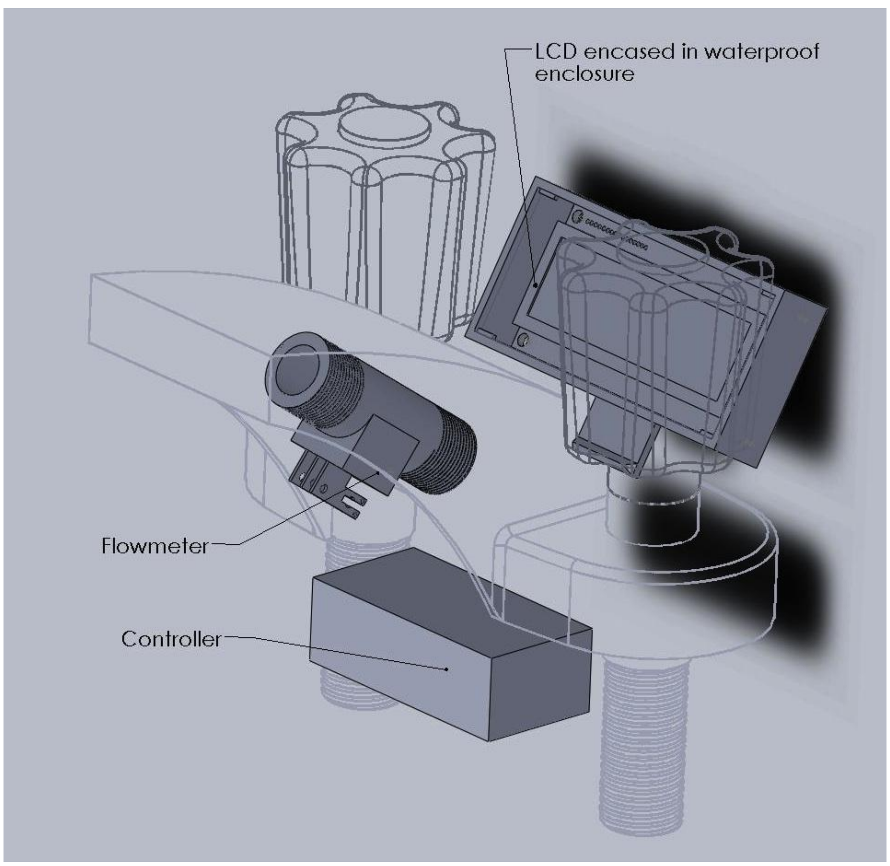

Figure 15 - Mechanical System Model

5.2 Faucet Mechanical Design

The faucet we choose for the prototype is made by Glacier Bay. It has two handles that each connects to the cold and hot water line. The water are then mixed in the Y pipe depends on the water volume set by rotating the knobs. The faucet is 160mm x 140mm x 75mm. The dimension is illustrated in the figure below.

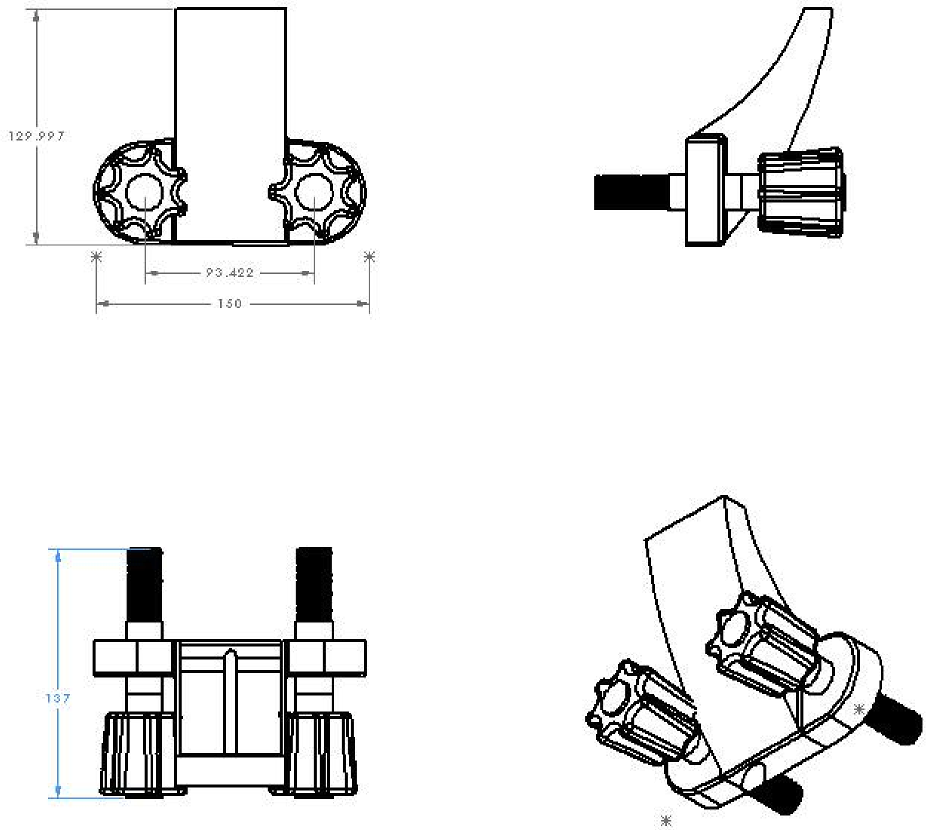

Figure 16 - Faucet dimensions and design rendering.

5.3 Flow Sensor Mechanical Design

The flow sensor we chose is the model FTB2004 purchased from Omega Engineering. The device is chosen for its dimension is small enough to fit inside the water faucet to connect the pipes. Inside the flow sensor, there is a propeller that rotates as water flow through. Every full rotation indicates 0.45mL of water volume, which is 2200 rotation for every liter [9]. The flow sensor has three metal contacts for the power supply, and transmits square wave pulses to the microcontroller via these contacts.

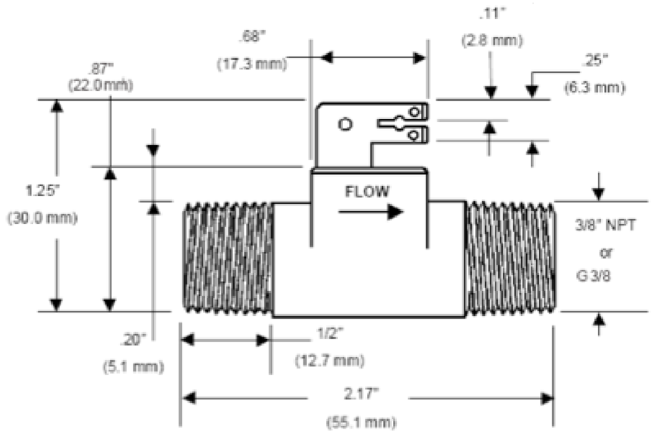

Figure 17 - Dimensions of the flow meter [9].

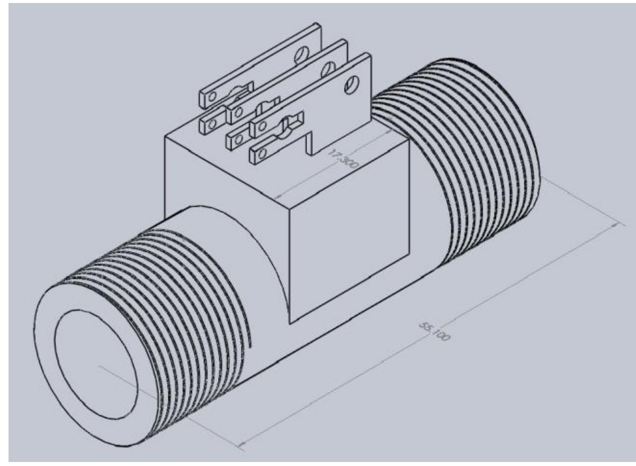

Figure 18 - Isometric view for the flow meter.

5.4 LCD Mechanical Design

We choose the Newhaven NHD-0216K1Z series for our LCD module. It displays two lines of sixteen characters and comes in different backlight colors. The module's dimension without the pin contact is 80mm x 35mm x 13.5mm. For the final product, the LCD will be encased in a transparent plastic casing to keep it away from humidity.

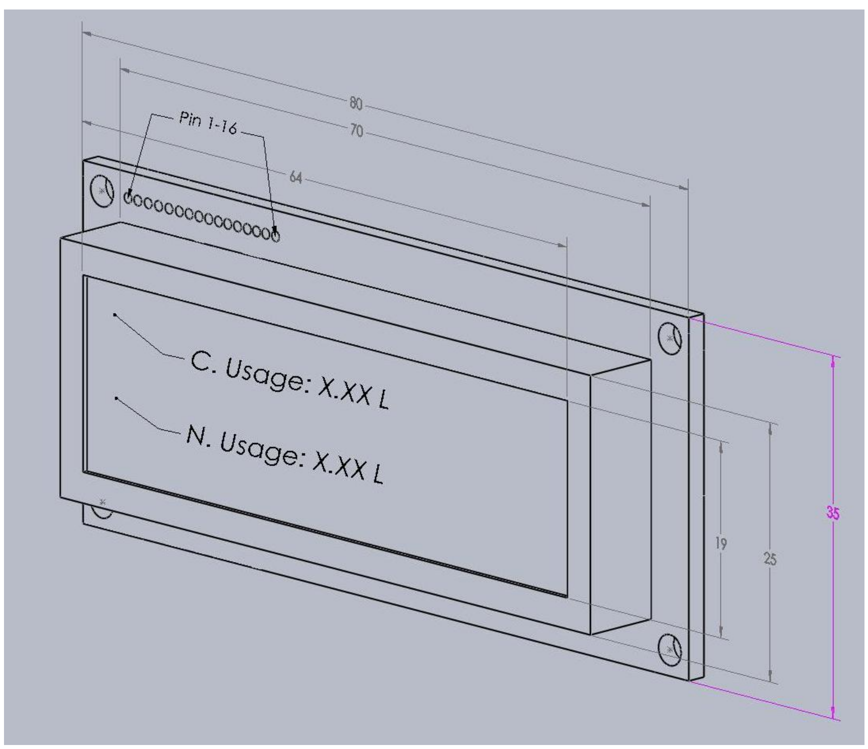

Figure 19 - Isometric view with dimension for the LCD module.

6. Electrical Design

6.1 Electrical Design Overview

The system's electronic system schematic is shown below. Our system features high efficiency of PIC pin-out use, and thus amount of wire routing, in order to facilitate an especially cost efficient end product.

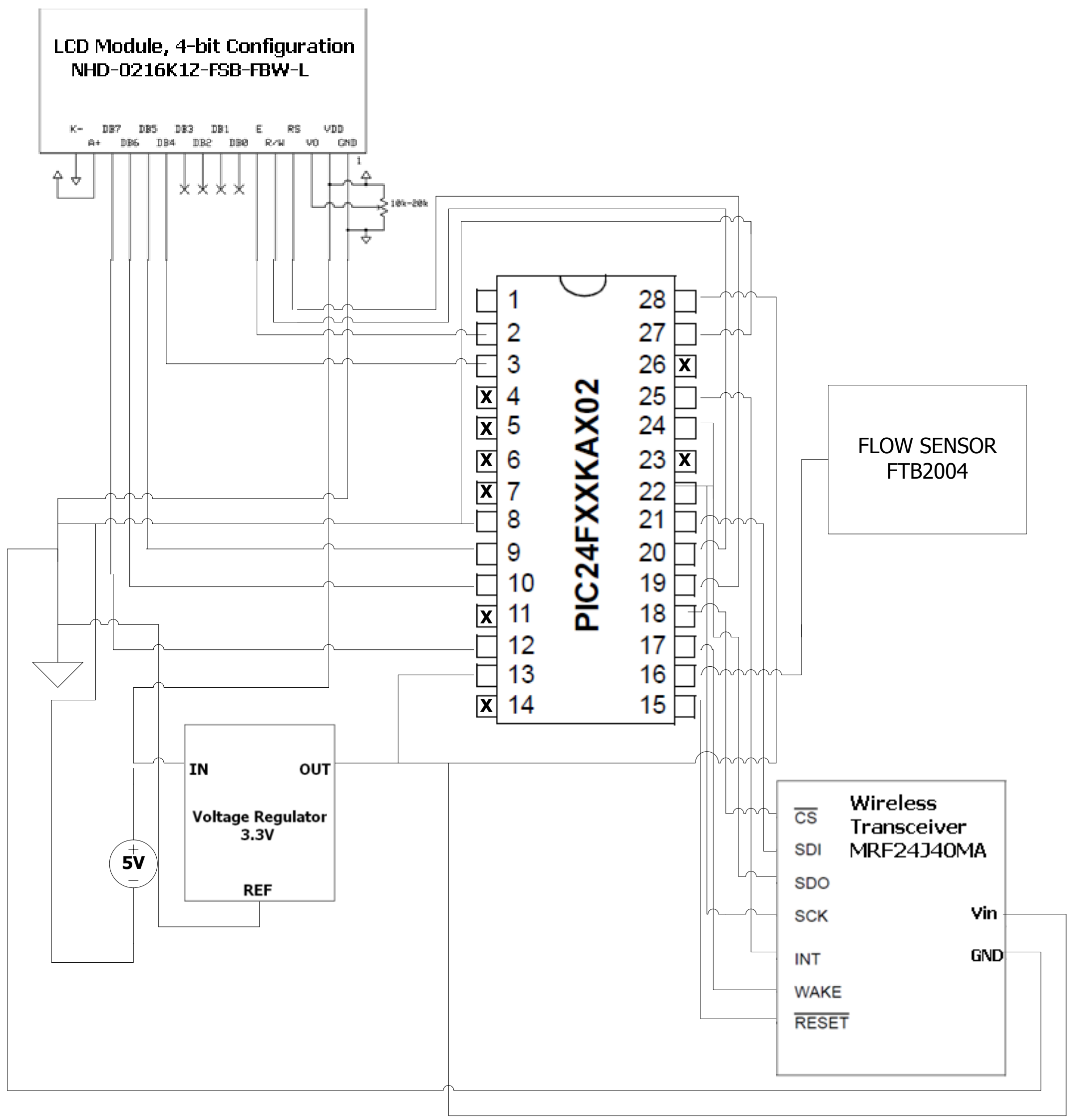

Figure 20 - System Electrical Design Overview

Five components make up the primary blocks of our system. These are the PIC24F Control Module, the Flow Sensor, the LCD Module, the 3.3V Voltage Regulator, and the Wireless Transceiver Module.

The PIC24F Control Module is a 28-pin version, and features a 16-bit embedded MCU. This is the central control and processing unit for our system. The PIC24F is fed by the 3.3V output of the voltage regulator, and has an available I/O and SPI bus for the various peripherals.

The LCD Module in 4-bit configuration, is connected to the PIC's I/O pins, as well as to an interrupt pin, and a direct connection to the 5V power source.

The Flow Sensor is connected to one of the I/O pins of the PIC Control Module.

Next, the Wireless Transceiver is connected to SPI bus of the PIC, as well as to the I/O pins, in addition to the 3.3V source and to ground.

Finally, the 3.3V Voltage Regulator is used to feed the variety of peripherals that do not take 5V, but rather 3.3V as their Vdd.

6.2 LCD Electrical Design

The Newhaven LCD requires 5V supply voltage and 0.5V to supply for contrast. Without the contrast, the characters will be hard to see. The LCD also requires a 5V supply voltage for the backlight.

Table 7 - LCD electrical characteristics [10].

Item	Symbol	Condition	Min.	Typ.	Max.	Unit
Operating Temperature Range	Top	Absolute Max	-20	-	+70	ºC
Storage Temperature Range	Tst	Absolute Max	-30	-	+80	ºC
Supply Voltage	VDD		4.7	5.0	5.5	V
Supply Current	IDD	Ta=25°C, VDD=5.0V	-	1.5	2.5	mA
Supply for LCD (contrast)	VDD-V0	Ta=25°C	-	4.5	-	V
"H" Level input	Vih		2.2	-	VDD	V
"L" Level input	Vil		0	-	0.6	V
"H" Level output	Voh		2.4	-	-	V
"L" Level output	Vol		-	-	0.4	V
Backlight Supply Voltage	Vled	-	-	5.0	-	V
Backlight Supply Current	Iled	Vled=5.0V	-	20	-	mA

Table 8 - LCD pin assignments [10].

Pin No.	Symbol	External Connection	Function Description
1	VSS	Power Supply	Ground
2	VDD	Power Supply	Supply Voltage for logic (+5.0V)
3	V0	Adj Power Supply	Power supply for contrast (approx. 0.5V)
4	RS	MPU	Register select signal. RS=0: Command, RS=1: Data
5	R/W	MPU	Read/Write select signal, R/W=1: Read R/W: =0: Write
6	E	MPU	Operation enable signal. Falling edge triggered.
7-10	DB0 – DB3	MPU	Four low order bi-directional three-state data bus lines. These four are not used during 4-bit operation.
11-14	DB4 – DB7	MPU	Four high order bi-directional three-state data bus lines.
15	LED+	Power Supply	Power supply for LED Backlight (+5.0V via on-board resistor)
16	LED-	Power Supply	Ground for Backlight

6.3 Flow Sensor Electrical Design

The flow sensor passes its electrical signal, generated voltage pulses, with the signal metal contacts on top of the sensor. The wiring diagram can be found in figure 20.

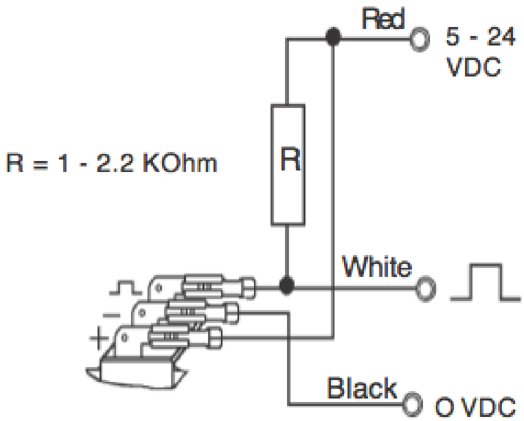

Figure 21 - Flow sensor wiring diagrams [9].

The flow sensor gives 2200 pulses per liter and its sensing behavior is summarized in figure 21 below. Each pulse is indicated when the sensor actuates with a square wave signal.

Part Numbers	Flow Ranges				Pulses		Frequency
	Normal		Extended				
3/8" NPT	GPM	LPM	GPM	LPM	Per Gallons	Per Liters	Output
FTB2004	.26 - 4	1 - 15	.07 - 5.3	.25 - 20	8300	2200	37 - 550 Hz

Figure 22 - Flow sensor flow rate to pulses [9].

Table 9 – Flow sensor specifications [9].

Specifications	
Wetted Parts	**Body:** Nylon 12/**Turbine:** Nylon 12 Composite/**Bearings:** PTFE/ 15% Graphite
Operating Pressure	200 psi
Burst Pressure	2500 psi
Operating Temperature	-4° to 212°F (-20° to 100°C)
Viscosity	32 to 81 SSU (.8 - 16 Centistokes)
Filter	< 50 Microns
Input Power	5-24 VDC @ 8 mA
Output	NPN Sinking Open Collector @ 50 mA, Max.
Accuracy	± 3% of Rdg. Normal Range
Repeatability	0.5% FS Normal Range
Electrical Connection	Spade Terminals .110/.248 X .031" (2.8/6.3 X .8 mm)

6.4 PIC Electrical Design

PIC24F16KA102 requires 3.3V for its power and its general electrical characteristic are summarized in the figure below.

Ambient temperature under bias .... -40°C to +125°C
Storage temperature .... -65°C to +150°C
Voltage on VDD with respect to VSS .... -0.3V to +5.0V
Voltage on any combined analog and digital pin, with respect to VSS .... -0.3V to (VDD + 0.3V)
Voltage on any digital only pin with respect to VSS .... -0.3V to (VDD + 0.3V)
Voltage on MCLR/VPP pin with respect to VSS .... -0.3V to +9.0V
Maximum current out of VSS pin .... 300 mA
Maximum current into VDD pin (1) .... 250 mA
Maximum output current sunk by any I/O pin .... 25 mA
Maximum output current sourced by any I/O pin .... 25 mA
Maximum current sunk by all ports .... 200 mA
Maximum current sourced by all ports (1) .... 200 mA

Figure 21 - PIC24F16KA102 electrical characteristics [11].

The microcontroller has 28 pins with various functions that can be enabled by software implementation and each of them is assigned in the figure below.

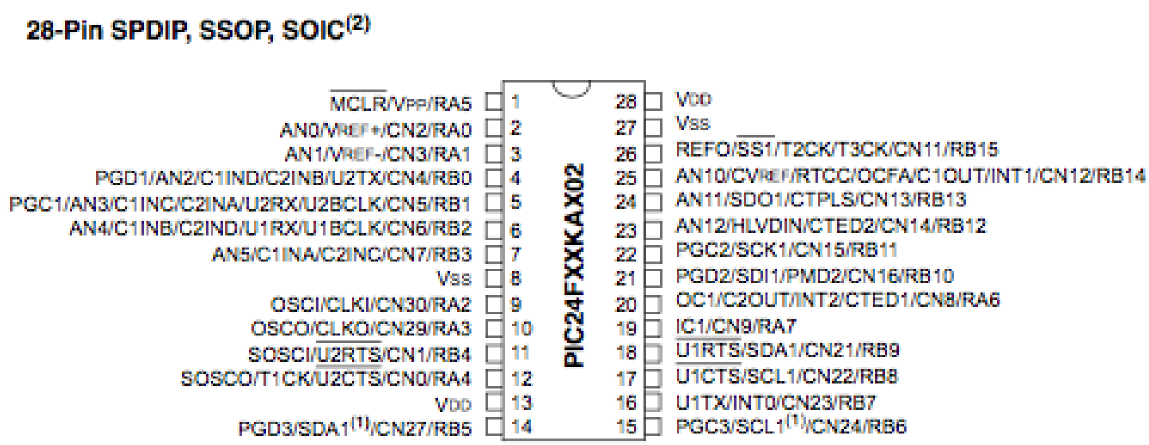

Figure 23 - PIC24F16KA102 pin assignments [11].

For the networked water faucet, we have defined and connected the microcontroller according to their function in the table below.

Table 10– Pin assignment for microcontroller.

Pin number	Function	Connected to
1	RA5	-
2	RA0	LCD E
3	RA1	LCD DB4
4	RB0	-
5	RB1	-

6	RB2	-
7	RB3	-
8	Vss	Ground
9	RA2	LCD DB5
10	RA3	LCD DB6
11	RB4	-
12	RA4	LCD DB7
13	Vdd	3.3 V Supply Rail
14	RB5	-
15	RB6	Transceiver Reset
16	RB7/INT0	Flow Sensor +
17	RB8	Transceiver Wake
18	RB9	Transceiver SPI Enable
19	RA7	LCD RS
20	RA6	LCD R/W
21	RB10	Transceiver Serial Data Input
22	RB11	Transceiver Shift Clock
23	RB12	-
24	RB13	Transceiver Serial Data Output
25	RB14	Transceiver Interrupt
26	RB15	-
27	Vss	Ground
28	Vdd	3.3 V Supply Rail

7. User Interface Design

In order to facilitate adoption of our new faucet solution, the UI employed in our system was deliberately designed to be near identical to that of a traditional faucet.

7.1 Daily Operation

From the user's perspective, the faucets will function entirely as a standard faucet normally would. It is our primary design goal to create an interface such that a guest with no prior knowledge or awareness of this product would be able to use it like any traditional faucet, with the one difference that they are able to monitor their water usage immediately via the LCD display. A user should never have to consult with a users' manual for any aspect of operation, or our intuitiveness target will not have been met. We will test for this using randomly sampled focus groups.

Display units (metric versus imperial), are within the firmware specifically for each market, and no setup is required.

Joining the existing wireless faucet network within the household is automatic and completely transparent to the user.

7.1.1 Faucet On

When the user turns the faucet on, water runs as it normally would in a standard faucet. The difference is that there is now an LCD display that lights up in "Impact Blue" (also available in "Radiance Orange" and "Eco Green"), with the following information shown for the Metric or Imperial market editions, where "mL" denotes milliliters, "L" denotes liters, "oz" denotes fluid ounces, and "g" denotes gallons.

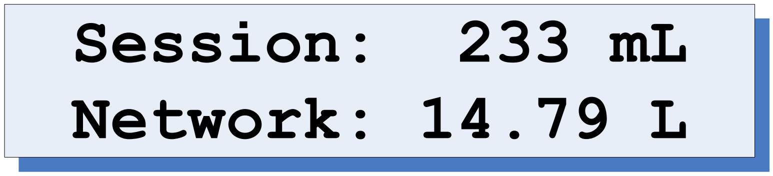

Figure 24 - PIC24F16KA102 pin assignments [11].

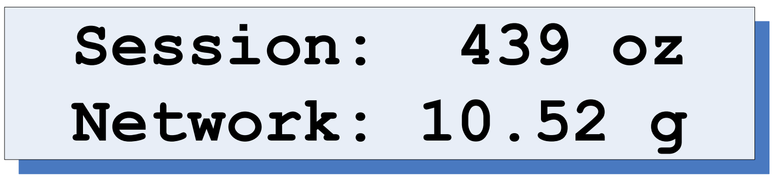

Figure 25 - Display of session usage, for imperial markets.

The session readout shows how much water is being used while the faucet has been running in current session. The Network readout shows how much water has been used to date across the entire network of faucets (and in the future, showerheads as well).

7.1.2 Faucet Off

Once the faucet is shut off, the display holds the backlight on for an additional five seconds, and displays the following information, for the Metric or Imperial markets, where "mL" denotes milliliters, "L" denotes liters, "oz" denotes fluid ounces, and "g" denotes gallons.

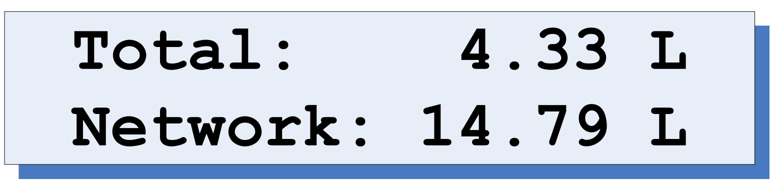

Figure 26 - Display of total usage, for metric markets

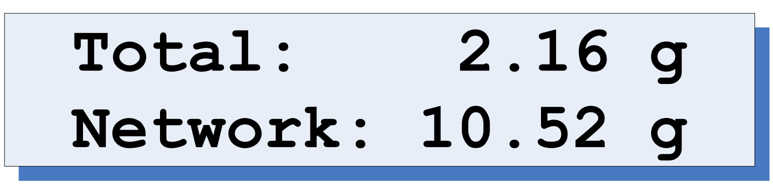

Figure 27 - Display of total usage, for imperial markets

The Total readout shows how much water has been used on this individual faucet for the day. The Network readout shows how much water has been used to date across the entire network of faucets (and in the future, showerheads as well).

7.2 Installation

The installation process would be in strict accordance to standard practice, except for one additional step where the user must insert the batteries. The battery installation procedure would involve placing three AAA batteries into a holder and snapping the cover closed, in exactly the same fashion that one would install batteries into a television remote control unit.

7.3 Maintenance

Mechanically, our faucet would require no different or additional maintenance from traditional faucets. Replacement of o-rings and other such wear-items in intervals of several years is expected.

The difference lies in having to replace the battery every six months, depending on duty level of usage. Future showerhead offerings will not require battery replacement at all, due to the consistency and magnitude of water displacement through the showerhead.

8. System Test Plan Design

The following is a test plan that has been designed to implement specific system testing for quality assurance. The testing steps and expected results must be accounted for during the system testing stages. Also, the actual test results must be recorded for the appropriate developer's reference needs. Ad-hoc testing and beta testing will follow QA required testing, run sheet Issue 3.1 provided below.

WATER FAUCET TESTING RUN SHEET (Issue 3.1): Microflow Systems Incorporated - Internal Use Only
Testing Date Started____________ Testing Date Completed______________ Page 1 of ___
Testing Location_________________________ Product Release/Version___________
Product Manufacture Date_______ Manufactured Batch #_____________Product P.O.#_______________
Tester Name(s) _________________________________ , ____

Run #:	**Steps to execute (Two faucet networked system):**	**Expected Results:**	**Actual/Summary of results:**
Networking Cases, Ensure Network Forms Correctly:			
31008	Power up faucet # 1, wait for active scan to fail and energy scan to succeed, estimated minimum wait time 5 minutes, power up faucet #2, wait for active scan to complete, minimum wait time 5 minutes	Check that the LCD is displaying the correct values as follow: Current Use = 0 L Total Use = 0 L	**Current Use** **Total Use** **Notes:** **PASS/FAIL #1** **PASS/FAIL #2**
31009	Power up faucet # 1, wait for active scan to fail and energy scan to succeed, estimated minimum wait time 5 minutes, power up faucet #2, wait for active scan	Both faucet network update times must not exceed 5 minutes from the time their	**Water Volume #2 -** **Notes:**

	to complete, minimum wait time 5 minutes, test network connection for faucet #2 by dispensing any amount, turn tap off, wait for faucet#1 LCD to update	respective dispensing stopped	**PASS/FAIL #1** **PASS/FAIL #2**
31010	Power up faucet # 1, wait for active scan to fail and energy scan to succeed, estimated minimum wait time 5 minutes, power up faucet #2, wait for active scan to complete, minimum wait time 5 minutes, test network connection for faucet #1 by dispensing any amount, turn tap off, wait for faucet#2 LCD to update	Both faucet network update times must not exceed 5 minutes from the time their respective dispensing stopped	**Water Volume #1 -** **Notes:** **PASS/FAIL #1** **PASS/FAIL #2**
Typical Use Cases, Ensure faucets Update Properly:			
31011	Turn on faucet # 1, fill measuring container with approx 250 mL of water, turn off faucet #1, start timer immediately, stop timer when faucet number 2 displays updated water usage at faucet #2 Check the Zena network analyzer display to ensure correct packet format and content	The faucet #2 update time should occur according to network conditions and must not exceed 5 minutes	**Update Time -** **Water Volume -** **Notes:** **PASS/FAIL -**
31012	Turn on faucet #1 and faucet #2 at the same time, fill a measuring container with 250 mL from each faucet at approximately the same time, turn off both faucets simultaneously, start timer and time how long it takes for each faucet to update Check the Zena network analyzer display to ensure correct packet format and content	Both faucet network update times must not exceed 5 minutes from the time their respective dispensing stopped	**Update Time #1 -** **Update Time #2 -** **Water Volume #1 -** **Water Volume #2 -** **Notes:** **PASS/FAIL #1** **PASS/FAIL #2**
31013	Turn on faucet #1, fill a measuring container with 250 mL, turn off faucet#1, before faucet #2 updates with usage data from faucet #1 dispense 250 mL from faucet #2 Check the Zena network analyzer display to ensure correct packet format and content	Both faucet network update times must not exceed 5 minutes from the time their respective dispensing stopped	**Update Time #1 -** **Update Time #2 -** **Water Volume #1 -** **Water Volume #2 -** **Notes:** **PASS/FAIL #1** **PASS/FAIL #2**

Secondary and Tertiary Testing:			
31014	Ad-Hoc Testing	Test system's limits and endpoints according to specification	**Results/Issues:**
31015	Beta testing	Microflow executive or employee test the device at home/office	**Results/Issues:**

9. Conclusion

This document has specified all of the design requirements for MSI networked water faucet system to function consistently, safely and in an appropriate manner. Also included above is the completed system test plan that must be executed during the quality assurance phase. With this document, Microflow Systems Incorporated will be able to design, construct and test our functioning model. Bringing our product to market in a relatively short amount of time is important to MSI, and we feel we have made design choices that reflect that goal.

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