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Industrial Wireless Communication System for Notification

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**INDUSTRIAL WIRELESS COMMUNICATION
SYSTEM FOR NOTIFICATION**

ECE 4820 – Electrical and Computer Engineering Design II
Dated: April 26, 2013

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Abstract

An industrial wireless communication system for short structured messages was needed to support lean manufacturing environments. While first generation prototypes of end devices were previously constructed for the network, it lacked the range, robustness and battery operation desired. The advances made in the new system incorporate multiple small rechargeable user modules that communicate with and through one or more higher powered fixed location message router stations. This configuration ensures that wireless signal integrity is maintained throughout an industrial facility, and that the messages are successfully sent and received. XBee wireless transceivers were imbedded onto the router to enable communication between devices and router. The router stations use higher power ISM band Digi's Xtend RF modems for router-to-router station communications. The configuration of the nodes ensures that wireless signal integrity is maintained throughout an industrial or manufacturing facility and that the messages are successfully sent and received. Embedded software in the user modules and router stations ensure robust communications in the presence of high power transient RF noise often found in manufacturing environments by repeating message transmission until a successful response is received.

1. INTRODUCTION

1.1. Need statement

Manufacturing facilities require sturdy methods of communications. While conventional methods such as Bluetooth could be used, they require a continuum of data to establish network. In environments with thick concrete walls, large volumes of metallic equipment and other magnetic interfering factors, these methods are at a sore disadvantage. Such mechanical and electromagnetic interferences also tamper and dull signals from the more robust radio frequency networks along the distance it covers. Flexibility of system installation is also a concern in manufacturing facilities looking to for minimally invasive upgrades. Any major alterations would cost large facilities a lot of money as well as be time consuming.

In order to attend to the special needs of manufacturing facilities, a router which supports the pre-existing RF communication network is designed that can navigate its way around these hindrances.

1.2. Project Specifications

1. Functional requirements

1.1. Efficient communication

1.1.1. The system must support the relay of electronic messages between network devices in an industrial environment.

1.1.1.1. It must be able to transmit and receive messages to and from their intended recipients.

1.1.1.2. The network must allow expandability of the network to cover the entirety of any single building industrial facility.

- 1.1.1.3. The system must adhere to an already existing network protocol.
 - 1.1.2. Data passed externally through the network must support AES Encryption; 128-bit or 256-bit to maintain security of network.
 - 1.1.3. Data Transmission must contain error checking.
- 1.2. Any electronic device must run 24/7 with a lifetime of at least 6 months.
- 2. Physical Requirements
 - 2.1. The total weight any individual hardware module must be less than 2 lbs.
 - 2.2. Any non-commercial equipment must be able to maintain functionality after drops from 30 inches onto concrete floors.
 - 2.3. Designed hardware with a case must be accessible with a standard size screwdriver.
 - 2.4. Designed hardware must be contained in enclosures that are resistant to fine particulate and water resistant.
 - 2.5. Excluding any external antenna, no case should exceed dimensions of 20 cm wide, 20 cm long and 10 cm tall.
 - 2.6. Hardware modules must be designed with consideration to minimize size, weight, and cost without compromising on required functionality.
- 3. Electronic Hardware Design Requirements
 - 3.1. Resistors and capacitor elements should be larger than the size of 1206 type resistors, or (3.2 mm × 1.6 mm) when possible.
 - 3.2. Must have visual status indicator for users to quickly assess certain status states
 - 3.2.1. Must indicate when functioning properly.
 - 3.2.2. Must indicate when device is in a startup configuration state.
 - 3.2.3. Must indicate when there is a critical failure when possible.
 - 3.3 If device variants are developed, a single common PCB must be designed to support component differences on the board.

3.4 Any electrical communication device must exclusively utilize RS232 ports for wired I/O.

3.5 The network must support the receiving and transmitting of messages from an XBee Pro RF transceiver.

3.6 No single hardware unit should contain more than \$500 in components.

These specifications have been constructed from need statement and input from Dr. Bazuin. Dr. Bazuin has required that any PCB designed with variant configurations of hardware. This means that the board has to accommodate exchangeable circuit elements, and designed to support extra I/O. To simplify design, RS232 was given as the required type of I/O cable. Physical requirements were constructed to define the minimum standards of our design goals.

1.1. Project Sponsor

This project was sponsored by the Lee Honors College, WMU, who provided the funds needed for this project. Another sponsor of this project was Dr. Bradley J. Bazuin of the College of Engineering and Applied Sciences at Western Michigan University. Dr. Bazuin provided access to the RFID laboratory located in room A-216, located in Parkview campus of WMU, and resources within the laboratory. Throughout the development of this project, Dr. Bazuin acted as the technical mentor, sharing his knowledge and experience with wireless embedded systems.

2. ALTERNATE SOLUTIONS

There were several alternative solutions that could be implemented to facilitate communication between router nodes. A wired connection could have allowed high bandwidth communication between router nodes. The use of other popular industrial network protocols could have been used for real-time communication. Such fieldbus protocols include Profibus DP, DeviceNet, and Profinet.

Though industrial communication networks did exist prior to the proposed solution, the following reasons were deemed favorable to choose the communication protocols that are used in the project:

- Flexibility to tailor a protocol to suit the needs of the project could be easily done using an unlicensed frequency band. The Xbee Pro uses an ISM 2.4 GHz band (IEEE 802.11a) which uses frequencies reserved for industrial, scientific and manufacturing; while the Xtend uses a Digimesh protocol uses a 900 MHz band (IEEE 802.11b).
- Relatively easy nature of designing a protocol using an unlicensed band as opposed to following procedures defined by licensed bands such as Bluetooth (IEEE 802.16).

Low urgency of the message allows the use of a low bandwidth, which spares the message from interference from higher bandwidth data flow.

3. DESIGN CONCEPT

The goal of the project was to develop a backbone for a wireless communication network to extend its range of communication. The proposed system would route messages from a 2.4 GHz low-powered pre-existing wireless network through to a 900 MHz higher powered wireless network. Routers with dual transceivers were responsible for carrying on this function. The routing devices assisting these communications have three major hardware functions: two power transceivers and hardware to support the operations of the transceiver. Local communication between the hand-held devices and the routers will be done by using a low powered radio frequency transceiver called an XBee Pro S1 (ISM 2.4 GHz). For longer communications beyond the coverage of the XBee, a high powered 900 MHz XTend modems will be connected to the router device.

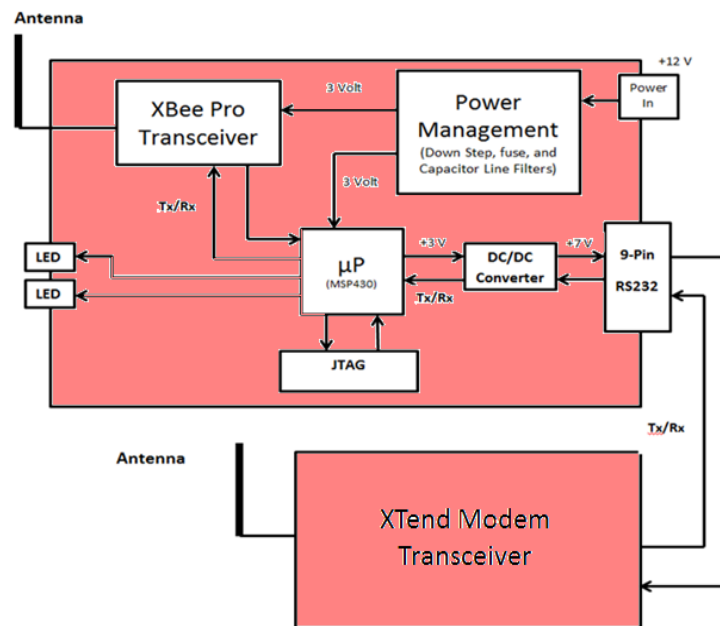


Figure 1- Block diagram showing Design Concept

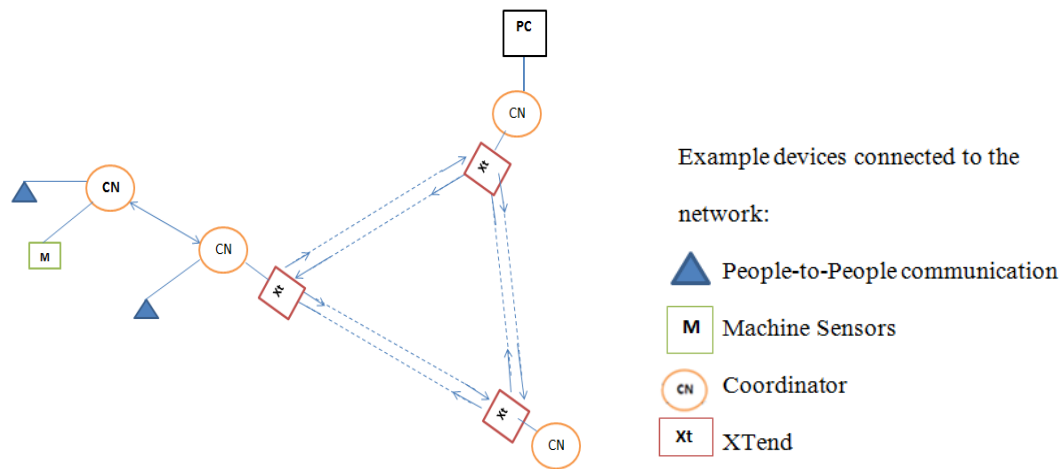


Figure 2- System architecture

The system architecture depicted above shows the interactions between the different devices in the network. The routers will be connected to it a long-range transceiver which will pick messages that need to be transmitted. The successive transceiver will receive the message and pass it on to the short-range transceiver to hand it over to its local end device.

4. ENGINEERING DESIGN

The major components of the design have been discussed in the following section. Software aspects have also been explained.

4.1. Hardware

4.1.1. Short-Range Communication



Figure 3- XBee Pro Module

Devices that communicate locally within the network use low powered transceivers called the XBee Pro (Series 1). The routing node is imbedded with an XBee Pro S1 to retrieve and transmit data to these devices.

The XBee Pro S1 supports a generic IEEE 802.15.4 ZigBee communication protocol. It is powered directly through the PCB, and interface with the board's microcontroller via standard UART communication. Figure 3, which was sampled from the XBee Pro product manual, outlines the system's UART data flow.

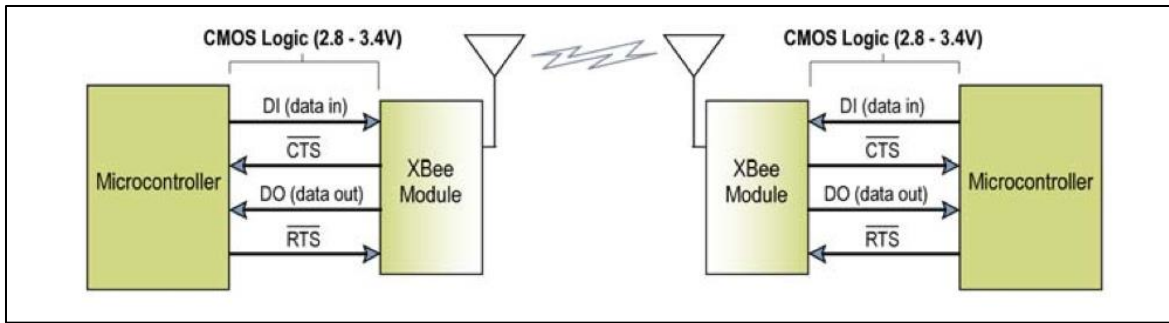
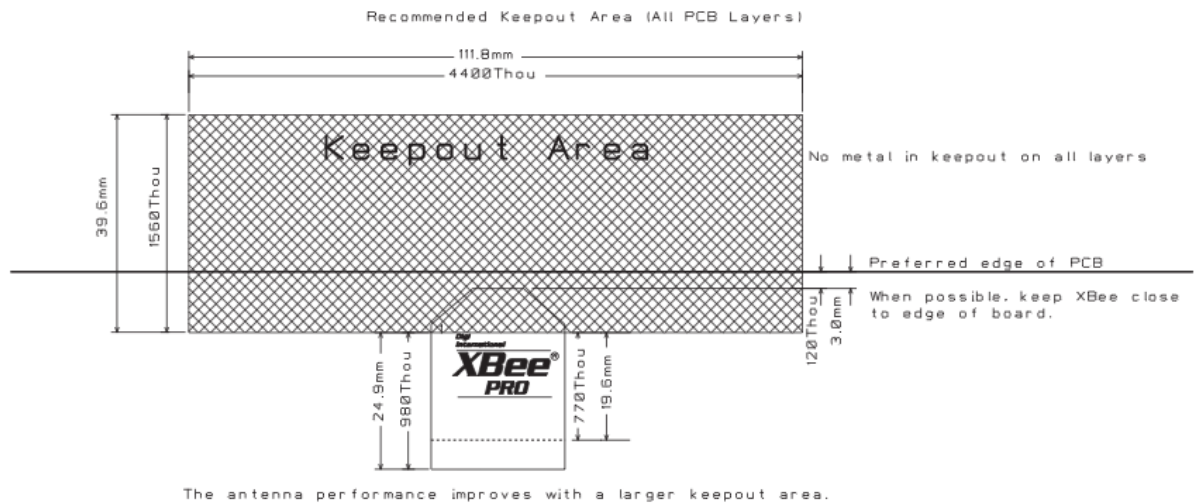


Figure 4- Node to node communication through XBee Pro modules

The XBee Pro S1 variant used for this project includes a RFSMA antenna which will be fitted externally on the side of the PCB enclosure. For optimal antenna performance, the XBee Pro S1 is designed to fit at an edge of the enclosure away from any metallic material. To accommodate suggestions from the transceiver's data manual, the antenna and the XBee Pro are placed on the opposite side of the power input and D-sub connectors.

The XBee Pro S1 meets specifications to communicate with existing XBee Pro S1 devices. This communication is rated up to 100 feet indoors, and relies on a secondary higher power transceiver for longer range communication.



Notes:

1. Non-metal enclosures are recommended. For metal enclosures, an external antenna should be used.
2. Metal chassis or mounting structures in the keepout area should be at least 1 inch (2.54 cm) from antenna.
3. Maximize distance between antenna and metal objects that might be mounted in keepout area.
4. These keepout area guidelines do not apply for Wire Whip antennas or external RF connectors. Wire Whip antennas radiate best over the center of a ground plane.

Figure 5- Recommended keep-out Area

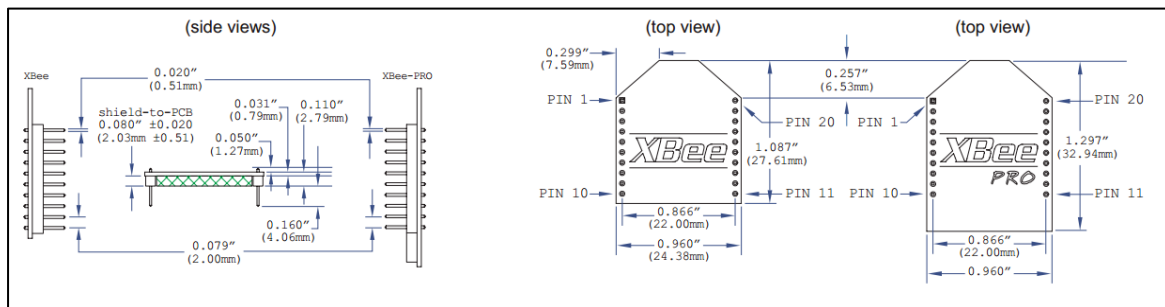


Figure 6- XBee Pro S1 Mechanical Drawing

4.1.2 Long-range Communication



Figure 7- XTend RF module

As mentioned earlier, long range transceivers were needed to communicate beyond the range of the XBee Pro S1. The transceivers used for this purposed were the XTend modems. The Xtend modems were connected externally to the router device through an RS232 cable.

The high powered XTend modem is rated at 3000 feet indoors, and operates at the ISM 900 MHz band . It follows the Digimesh protocol which supports sleeping routers for power-sensitive applications. More importantly, the protocol supports an advanced dense mesh network, thus allowing the flexibility of expanding the network when the need arises.

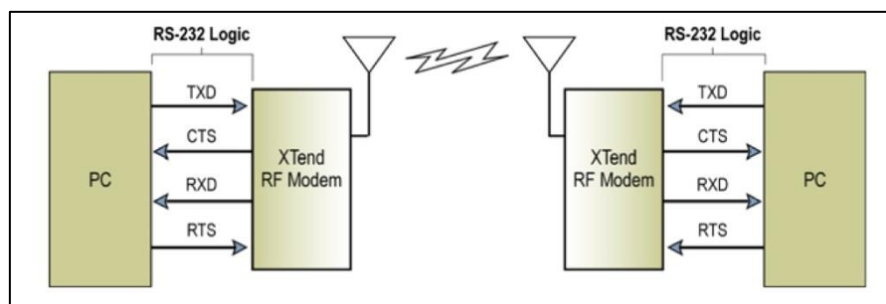


Figure 8- RS-232 data flow

The baud rate, which is the data rate of a modem, is rated at 9600 bps . The microcontroller is configured to match the modems baud rate. The table below shows the settings

of the XTend RF modem that needs to match with the host port for successful UART communication.

Parameter Setting	XTend RF Modem Default Parameter Value	
Baud (Serial Data Rate)	9600 bps	(BR parameter = 3)
Number of Data Bits	8	(NB parameter = 0)
Parity	None	(NB parameter = 0)
Number of Stop Bits	1	(NB parameter = 0)

Table 1- Critical values for successful communication

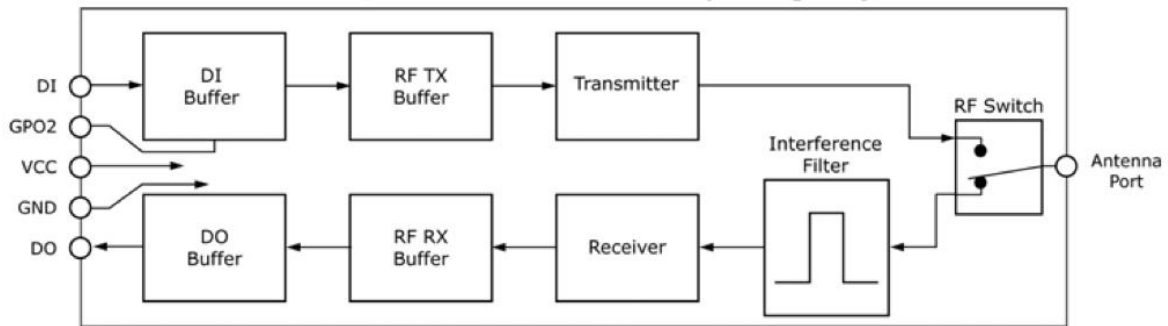


Figure 9- Data flow within the XTend RF modem

While the modem is receiving data, other serial data queued is stored in the DI buffer. The DI buffer can handle up 2.1 KB of data. The modem transmits data out via the DO buffer, which stores data up to 2.1 KB till the transceivers have the chance to transmit it. The RF transceivers work in three modes: Receiving, Transmitting and Idle. It exchanges information in the form of RF packets between modems.

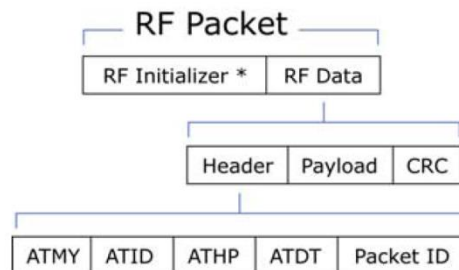


Figure 10- RF Packet Components

The Cyclic Redundancy Check (CRC) is added at the end of the RF package by the transmitting modem to allow the receiving modem to verify the integrity of the message and provide built-in error checking.

4.1.3. Microcontroller



Figure 11- MSP430F5418A

Since the two transceivers implement two different messaging protocols, a microcontroller is required to facilitate the communication between them. The microcontroller used in this project is the MSP430F5418A, a member of the Texas Instruments MSP430 family. The MSP430 family is of ultralow-power microcontrollers which are optimized to achieve extended battery life in portable measurement applications. The MSP430F5418A was mainly chosen for its large information memory (flash) of 128 KB and 16 KB RAM. [17] The large memory allows storing the program in it. The chosen microcontroller also features three UART ports. The ports were used one each for the transceivers and one as a PC terminal to acquire data logs.

DEVICE SIGNAL	BSL FUNCTION
$\overline{\text{RST}}/\text{NM}/\text{SBWTDIO}$	Entry sequence signal
TEST/SBWTK	Entry sequence signal
P1.1	Data transmit
P1.2	Data receive
VCC	Power supply
VSS	Ground supply

Table 2- Bootstrap Loader Signals

The Bootstrap Loader (BSL) in the microcontroller enables the user to program the flash memory or RAM using UART serial interface. The above table shows that the usage of the BSL requires four pins. The Universal Asynchronous Receiver/Transmitter (UART) is commonly used in conjunction with communications standards and is commonly included in microcontrollers.

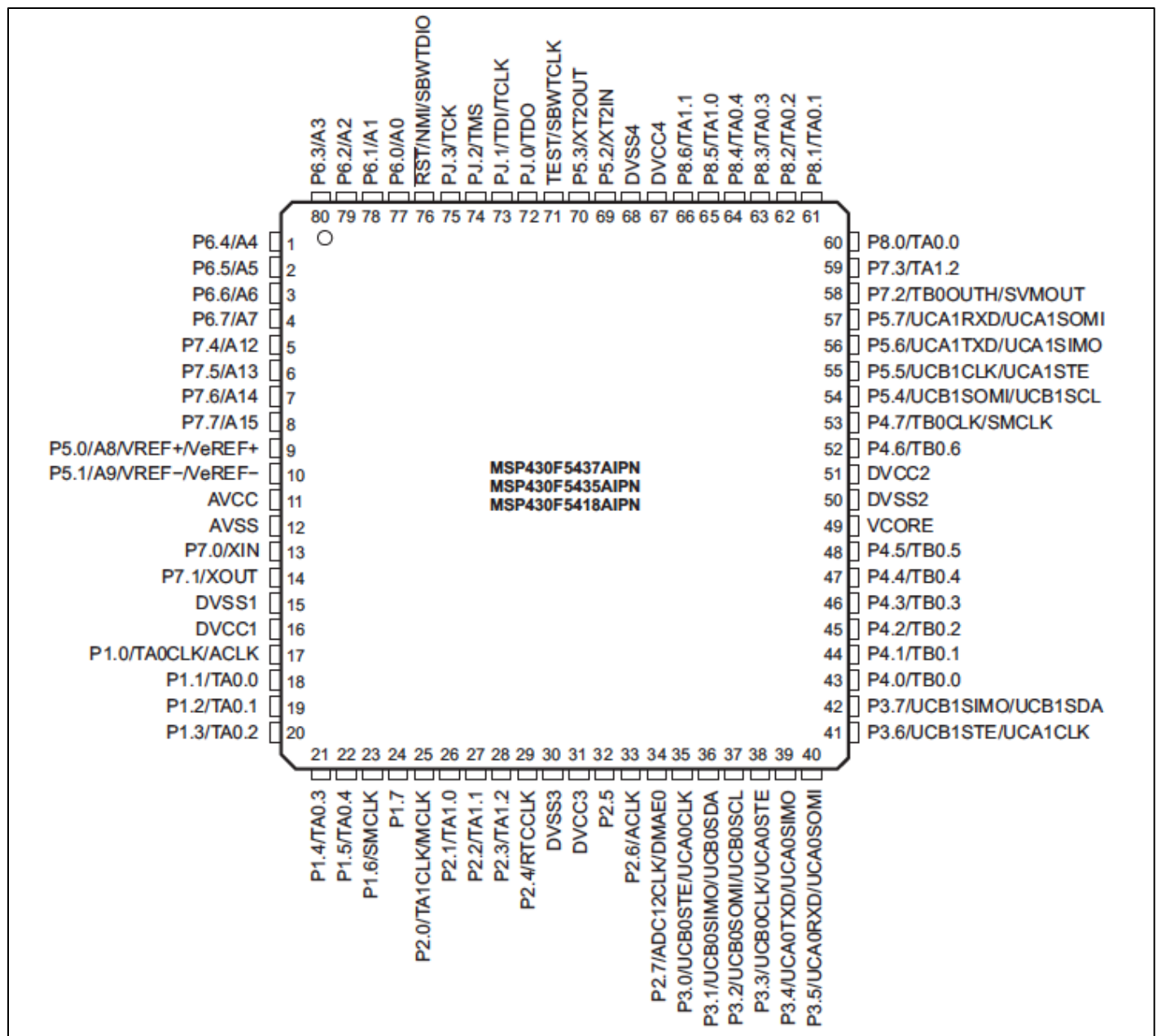


Figure 12- MSP430F5418A Pin Configuration

The microcontroller interacts with the XTend through an RS232 interfacing protocol via an RS232 transceiver. The IC transceiver bus used in the routing node is called ICL3222.

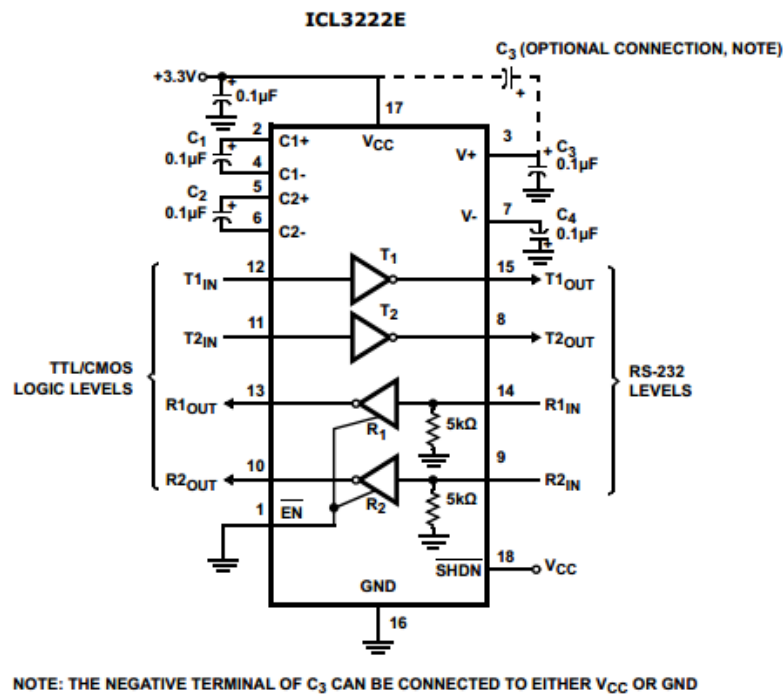


Figure 13- ICL3222 typical operating circuit

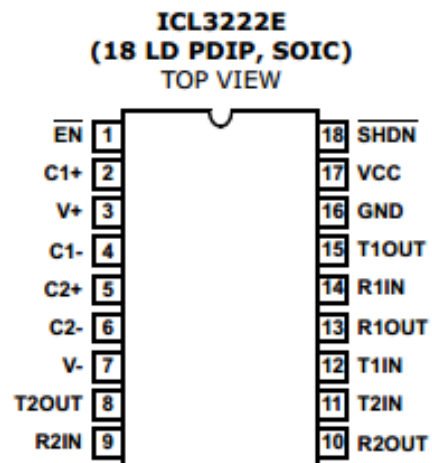


Figure 14- ICL3222 pin configuration

4.1.4. Power Management

In order to reduce power consumed for ecological as well as economic reasons, low-powered modules were incorporated wherever possible. The ultra-low powered MSP430 microcontroller, rated at 3.3V, uses 230 $\mu\text{A}/\text{MHz}$ at 8MHz in its active mode. The XBee Pro S1 which is also a low powered module rated at 3.3V uses 250mA while transmitting messages and 55mA while receiving. To support the power needs of these modules on the PCB, a power management circuit was constructed. The circuit included a buck converter from Linear Technology called LT1776.

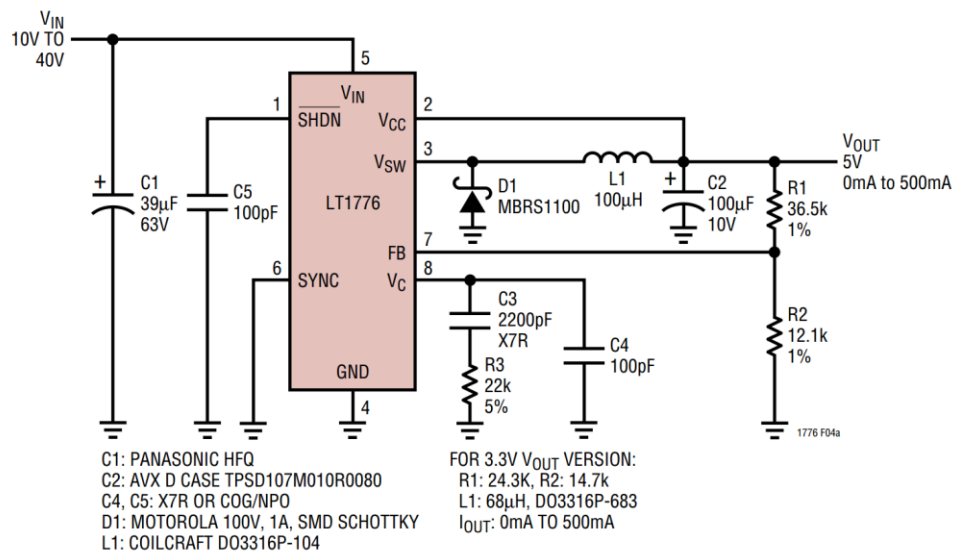


Figure 15- LT1776 from data sheet

The input voltage is drawn from a wall socket adapter of 9 VDC.

4.2. Software

The primary objective of this section is to outline the states of operation within the microcontroller's software, and describe a simplified IP protocol used to test communication. First generation software was developed to validate developed hardware and demonstrate a proof of concept design. This software was created on Texas Instruments IDE called Code Composer Studio. The C code was developed specifically for the MSP4305438A.

4.2.1. Initialization

To facilitate the transfer of messages across the network, the microcontroller needs to initialize internal hardware modules, input-output pins and software variables. These configurations occur in one organized state called Initialization. Within Initialization, UART configuration for XTend, Xbee, and PC console occur. Initializations of a real time counter module within the MSP430 and LED lights also occur. Within the initialization state, interrupt routines are disabled to allow the system to fully initialize before reacting to external signals. The initialization flow chart below illustrates the specific components that are configured.

Each of the three UART ports is configured to communicate at a 9600 buadrate calculated from the SMCLK at 1 MHz. The defined default UART data format consists of 8 data bits, no parity bits, and 1 stop bit. It should be noted for future development, that the end hardware connected to each of the UART ports can support higher baud rates; the Xbee Pro S1 being the slowest at a 250 Kbps data transfer.

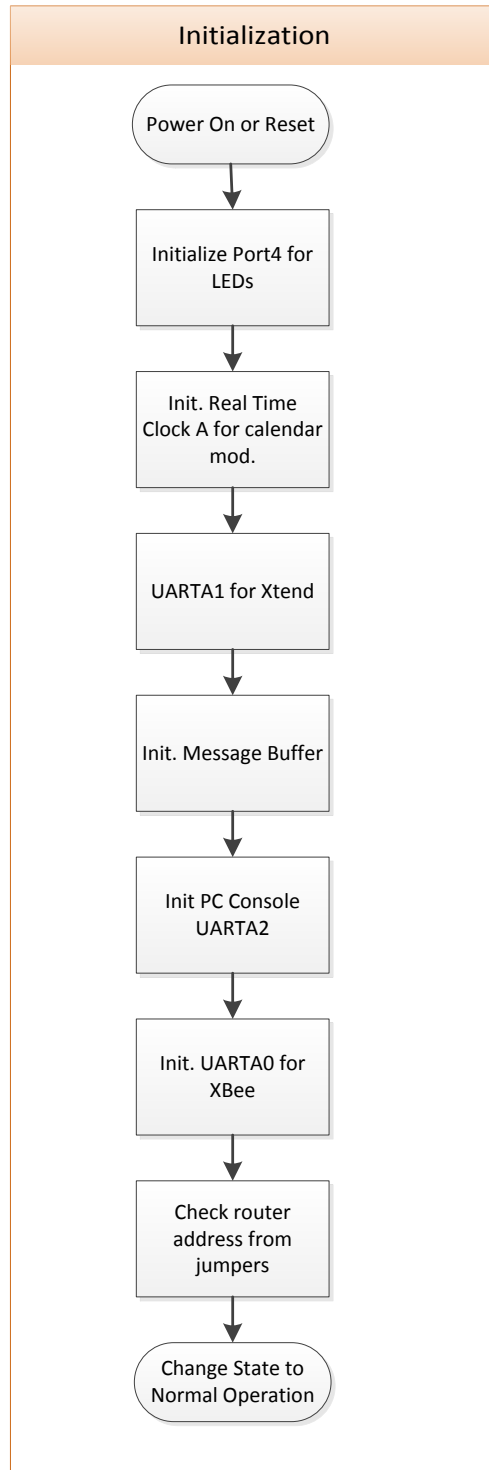


Figure 16- Initialization State Flowchart

4.2.2. Normal Operation

The primary state of operation is the NormalOp state, which is where the router periodically checks if interrupt flags were raised and handles each of the flags. Normal operation contains functions that handle managing internal logging data, detecting UART communication from both XTend and XBee, and interpreting how to handle message transfer. Below, in Figure 18, a software flow chart of this state can be observed. When a message is received from the Xbee Pro module and relayed to the microprocessor, a UART receive interrupt is triggered, raising the Xbee receive flag. When the message has been received, a message handling flag is raised indicating that there is a message in the buffer that needs to be analyzed. The message handling condition is the only condition which is not triggered by an interrupt.

Normal Op

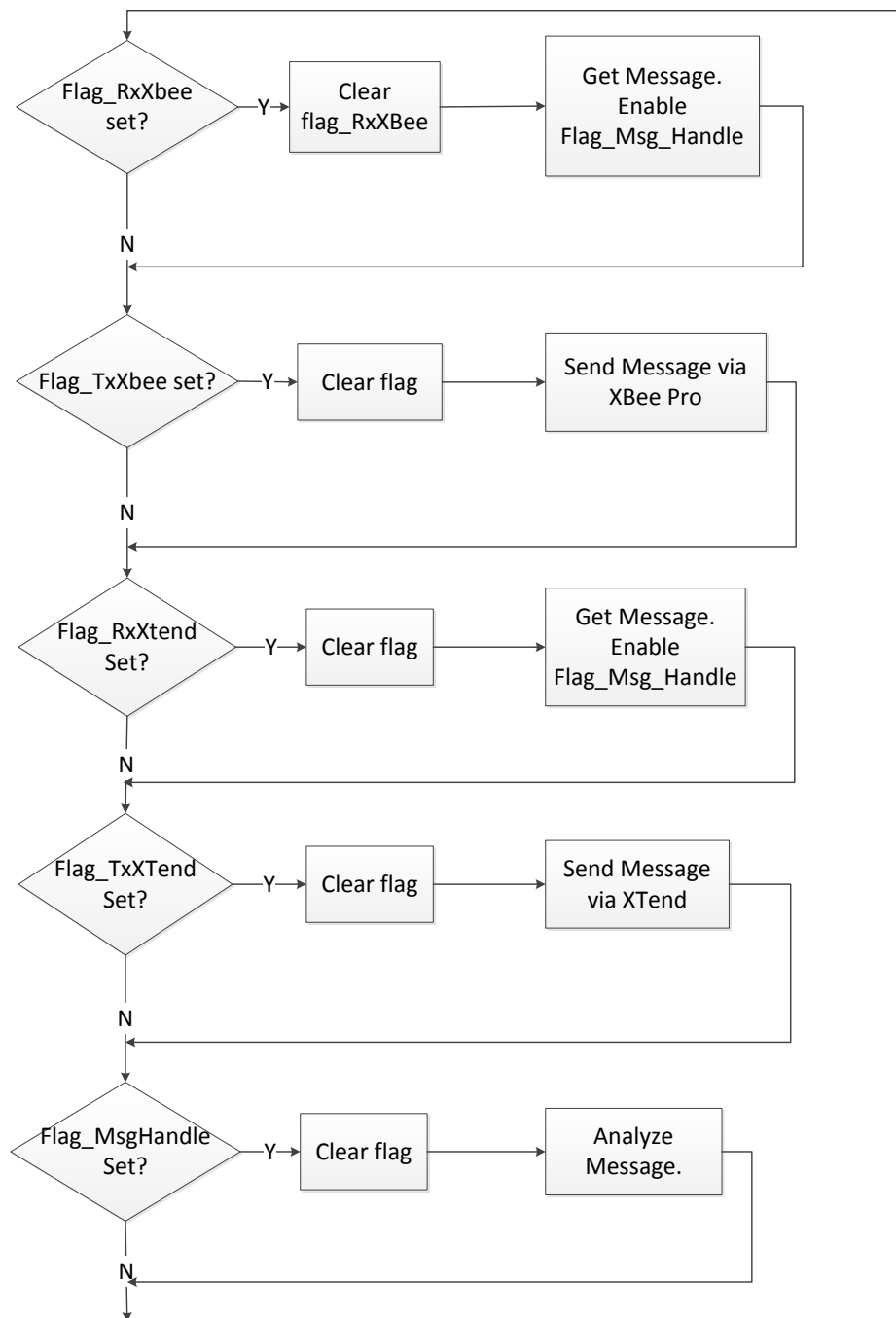


Figure 17- Normal Op State Flowchart

4.2.3. Rx-Tx Communication

Code that handles the Xbee, Xtend , and PC Console are organized into separate c files. Each of these files contains very similar generic functions. They all include a initialization function for the UART pins, a get character function, and put character function. Uniquely the Xtend and Xbee files contain functions to send and receive messages, while the PC Console files contains printf capability.

4.2.4. Message Protocol

To organize the necessary information to transmit and receive messages across the wireless network, a message format was developed. This format is an 8 byte packet of information which contains sender address, receiver address, data length space, reserved space, 2 data bytes and a place for CRC information. The table below outlines the bit organization of the message.

	Bits							
	7	6	5	4	3	2	1	0
Byte 1	Recipient ID 15 - 8							
Byte 2	Recipient ID 7-0							
Byte 3	Sender ID 15-8							
Byte 4	Sender ID 7-0							
Byte 5	Data Length				SFC			
Byte 6	data byte 1							
Byte 7	data byte 2							
Byte 8	CRC							

Figure 18: Router device PCB layout – Screen capture from PCB123

5. PROTOTYPE CONSTRUCTION

Though no mathematical models were applied directly, component values and its corresponding circuitry used were from information found in the datasheets.

A printed circuit board designing program called PCB123 was used to design the schematic and the layout of the board. Schematic sheets have been included in Appendix A. The following screen capture is the router's completed PCB layout in PCB123.

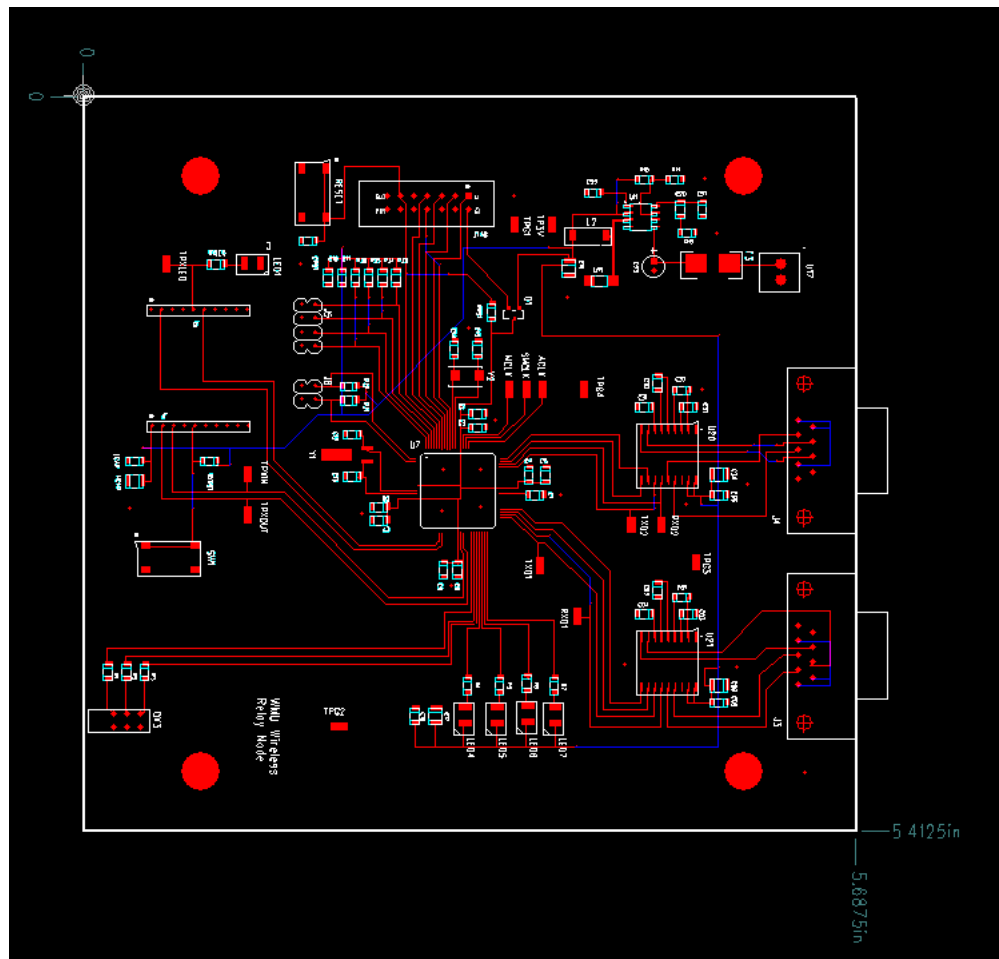


Figure 19: Router device PCB layout – Screen capture from PCB123

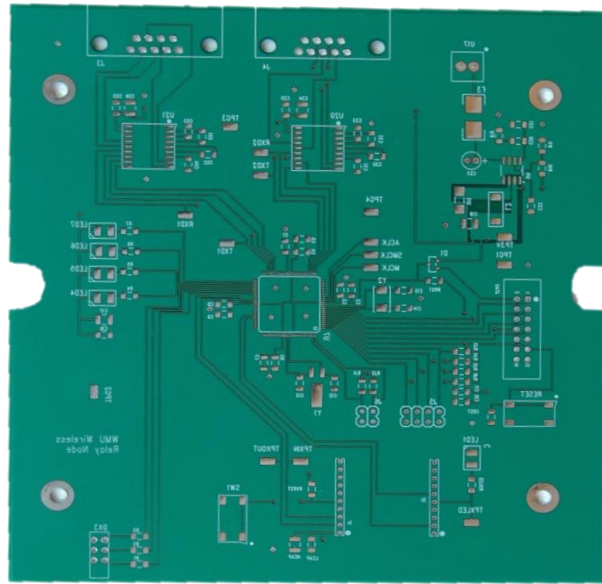


Figure 20: Router PCB

The board was then fabricated, and had holes drilled to fit it into its enclosure.

The components were finally hand-soldered onto the board. Majority of the capacitors and resistors used were of the 1206 package.

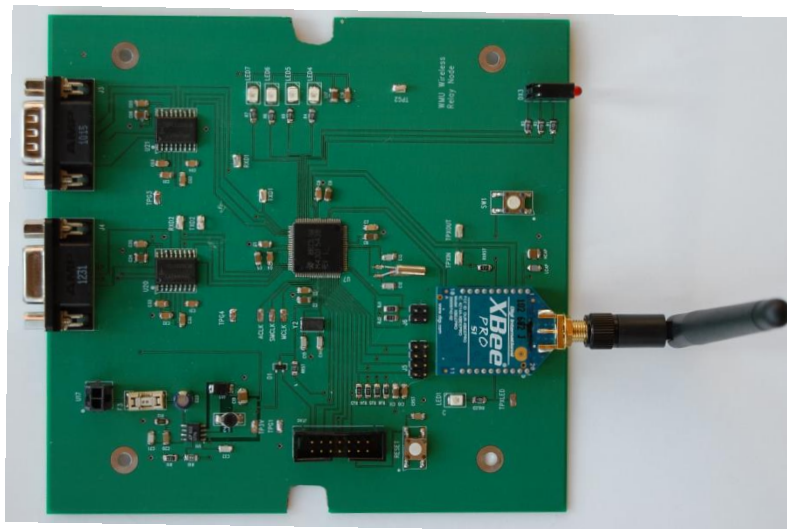


Figure 21: Router PCB completed with soldered components

The software was programmed in Texas Instrument's Code Composer Studio in C language. The printouts of the .c files of the code have been added to Appendix B. Example codes for MSP430x54xx family, available on the Ti website, were studied, edited and adapted to perform functions needed for the project.

6. Testing & results

X-CTU Software was used to create message packages to be sent between the devices for testing. The first step in the testing procedure was testing the XBee Pro S1, which was done by connecting demo board to a computer, and having X-CTU send the message packages through the cable. By having another board connected to a laptop, the message is delivered through the XBee Pro S1. As a result, a maximum distance of 245 ft of communication between the XBees was achieved.

The second step was to test the range of the XTend. The range was tested through connecting one XTend to a computer, and plugging the second one into the wall. A serial loop back adapter was used to test the range, where the first XTend sends the message, and by having the serial loop back adapter, a confirmation of the message delivery is achieved. As a result of this step, a maximum distance of 565 ft of communication between the XTends was achieved.

The final step was to test the range of the network, by connecting the XTend to the XBee and to the board. The message packages were sent from the first board to the XBee and then to the XTend. The message is then sent to the other board through the XTend, which sends it to the XBee and so. By doing this, a maximum distance of 750 of communication was achieved.

Figure 24 shows a comparison between the distances of communication achieved through the three steps of testing. The range of the router network was three times greater than the range of the XBee.

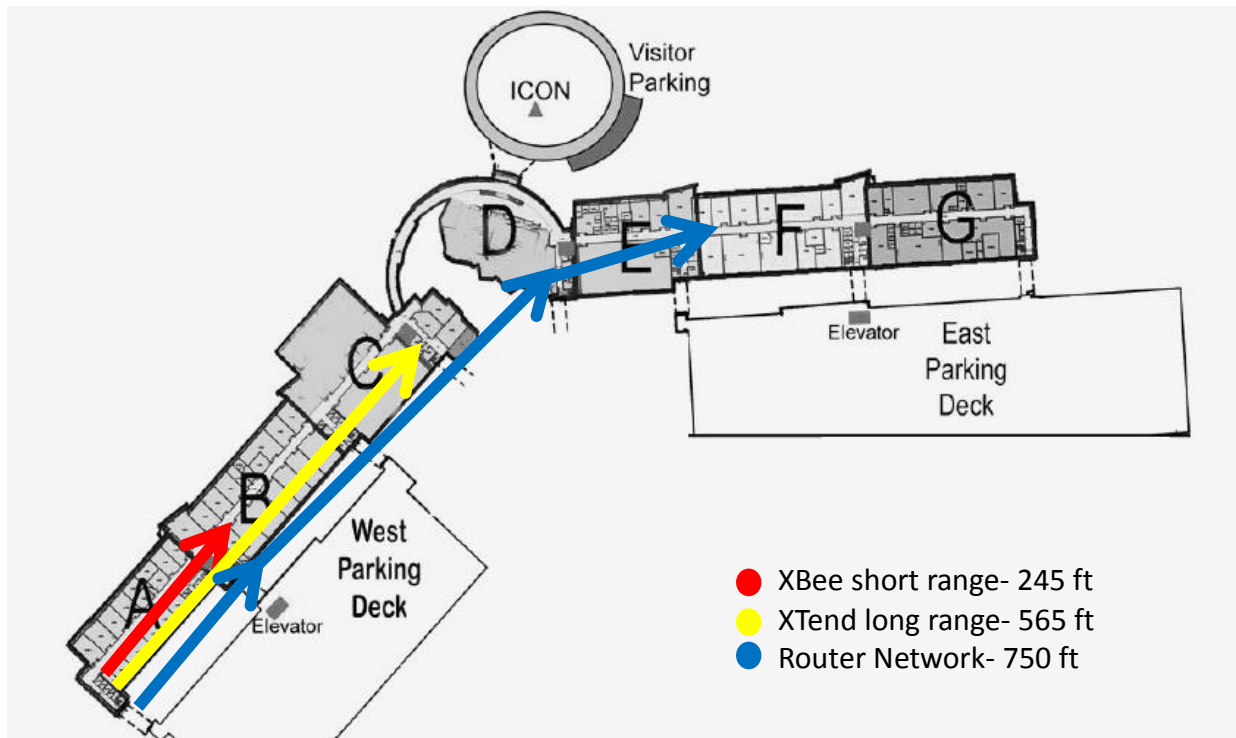


Figure 22: Comparison of communication coverage

7. PARTS LIST

Quantity - 1 Board	Part Number	Description	Manufacturer	Distributor	Price-One	Order Quantity	Price
14	399-1248-1-ND	CAP CER 0.1UF 50V 20% X7R 1206	Kemet	Digikey	0.11	63	6.93
4	399-3525-1-ND	CAP CER 10UF 16V 10% X7R 1206	Kemet	Digikey	0.4	18	7.2
4	399-1197-1-ND	CAP CERAMIC 22PF 50V NP0 1206	Kemet	Digikey	0.19	18	3.42
2	478-1519-1-ND	CAP CER 2200PF 100V 10% X7R 1206	Kemet	Digikey	0.28	9	2.52
1	399-3498-1-ND	CAP CER .47UF 50V X7R 1206	Kemet	Digikey	0.34	5	1.53
2	478-1444-1-ND	CAP CERM 100PF 5% 100V NP0 1206	AVX Corporation	Digikey	0.49	9	4.41
1	399-1190-1-ND	CAP CER 8.2PF 50V NP0 1206	Kemet	Digikey	0.36	5	1.62
1	399-3076-1-ND	CAP CER 1UF 50V 10% X7R 1210	Kemet	Digikey	0.5	5	2.25
1	399-4697-1-ND	CAP CERAMIC 100 UF 6.3V X5R 1210	Kemet	Digikey	0.94	5	4.23
2	399-5509-1-ND	CAP CER 10UF 35V X5R 1210	Kemet	Digikey	0.88	9	7.92
1	MSP430F5418A	MSP430F548A 16-Bit Ultra-Low-Power Microcontroller, 256KB Flash, 16KB RAM, 12 Bit ADC, 4 USCI's, 32-bit	Texas Instruments	Texas Instruments	Free	5	
2	EG1868CT-ND	TL3301NF260QG SWITCH TACT 6MM 260 GF SMT	E-Switch	Digikey	0.43	9	3.87
1	BAT54-FDICT-ND	DIODE SCHOTTKY DUAL 30 V SCOT23-3	Diodes Inc		0.16	5	0.72
1	30314-6002HB-ND	CONN HEADER 14POS DL STR GOLD	3M	Digikey	1.39	5	6.255
2	311-0.0ERCT-ND	RES 0.0 OHM 1/4W 5% 1206 SMD	Yageo	Digikey	0.1	9	0.9
1	P24.3KFCT-ND	RES 24.3K OHM 1/4W 1% 1206 SMD	Panasonic-ECG	Digikey	0.1	5	0.45
1	RHM22.0KAICT-ND	RES 22.0K OHM 1/4W 1% 1206 SMD	Rohm Semiconductor	Digikey	0.2	5	0.9
1	P12.1KFCT-ND	RES 12.1K OHM 1/4W 1% 1206 SMD	Panasonic-ECG	Digikey	0.1	5	0.45
8	311-470FRCT-ND	RES 470 OHM 1/4W 1% 1206 SMD	Yageo	Digikey	0.1	36	3.6
1	350-1755-ND	Three LED Lights Strip	Dialight	Digikey	3.31	5	14.895
5	475-1180-1-ND	LED SRED 630 NM CLEAR 2-PLCC SMD	OSRAM	Digikey	0.16	23	3.6
1	WM2648-ND	CONN HEADER 2POS 3MM	MOLEX INC	Digikey	0.9	5	4.05
1	DO1608C-683MLB	INDUCTOR 68uH	Coilcraft	Coilcraft	Free	5	
1	P10291-ND	39UF 35V HFQ ALUM RADIAL CAP	Panasonic-ECG	Digikey	0.49	5	2.205
1	F1222CT-ND	FUSE FAST 125 VAC,125 VDC 1A SMD	Littlefuse Inc	Digikey	2.37	5	10.665
1	10BQ100PBFACT-ND	DIODE SCHOTTKY 100V 1A SMB	Vishay/Semiconductors	Digikey	0.64	5	2.88
1	LT1776CS8	IC SW REG STEP-DOWN HI-EFF 86OIC	Linear Technology	Linear Technology	Free	5	Free
1	XC983CT-ND	ECX-64AEN CRYSTAL 16.000 MHZ SERIES SMD	ECS INC	Digikey	3.68	5	16.56
1	XC1911CT-ND	CRYSTAL 32.768 KHZ 12.5PF SMD	ECS INC	Digikey	0.94	5	4.23
2	SAM1234-10-ND	CONN RCPT 2MM 10POS SGL VERT PCB	Samtec Inc	Digikey	2.86	9	25.74
2	ICL3222EIB	IC TXRX RS-232 3-5.5V ESD 18SOIC	Intersil	Bazuin	Free	9	
1	AE9869-ND	RS232 Cable	Assmann WSW Components	Digikey	3	5	13.5
2	XBP24-BSIT-004-ND	MODULE XBEE PRO ZNET 2.5 W/RPSMA	Digi International /Maxstream	Digikey	36	9	324
1	A35105-ND	CONN D-SUB PLUG/MALE R/A 9POS GOLD/FL	TE Connectivity	Digikey	1.18	5	5.31
1	A35107-ND	D89 Female Right Angle	TE Connectivity	Digikey	1.87	5	8.415
1	OR1105-ND	Generic Fuse	Omron Electronics	Digikey	0.15	5	0.675
1	XG8T-0231-ND	Generic Fuse	Omron Electronics	Digikey	0.13	5	0.585

8. APPLICABILITY

The network is a robust system that can function in environments affected by electromagnetic interferences. This particular project is designed to handle short message communications through a defined set of point-to-point one liners, and to facilitate just-in-time deliveries. The proposed router addition would offer flexibility to the network, and so is highly useful in large facilities. The system can be used for inventory monitoring, and can be expanded to include advance features, such as machine operations status and diagnostics.

9. FUTURE DEVELOPMENT

Now that the prototype of the router's PCB has been successfully tested, plans for a smaller board based on the proposed design can be made. A smaller two sided PCB can be developed, which will reduce the surface area by greater than 50%. A smaller PCB can also be established by using smaller passive components. Another development that can be done is developing current end node devices that support this network. The XTend and XBee have advanced commands which were not used in this project due to the lack of time; therefore, future investigation in these advanced commands settings could enable higher bandwidth communication and encryption.

10. RESOURCES

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APPENDIX A

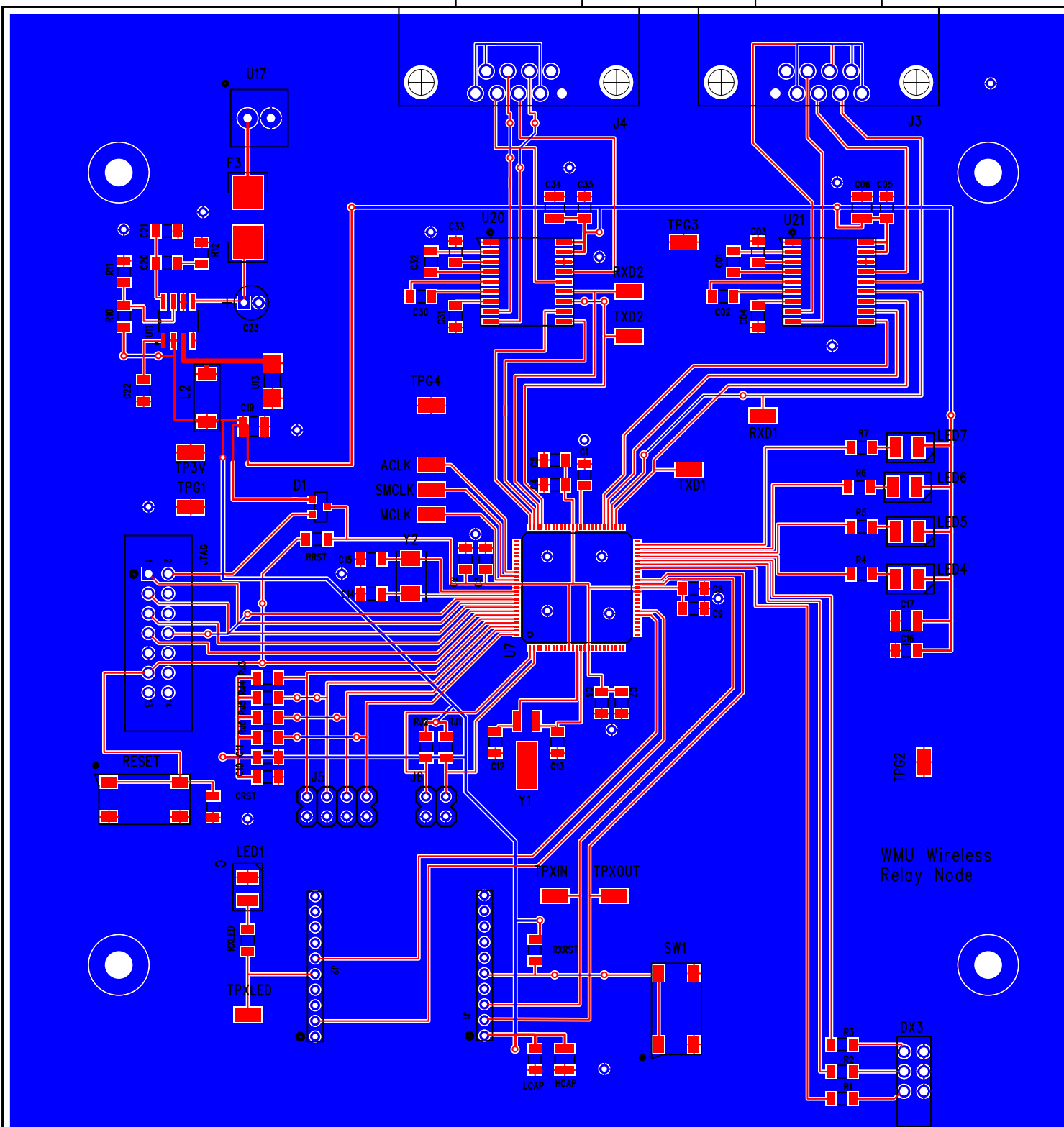
Schematic Drawings

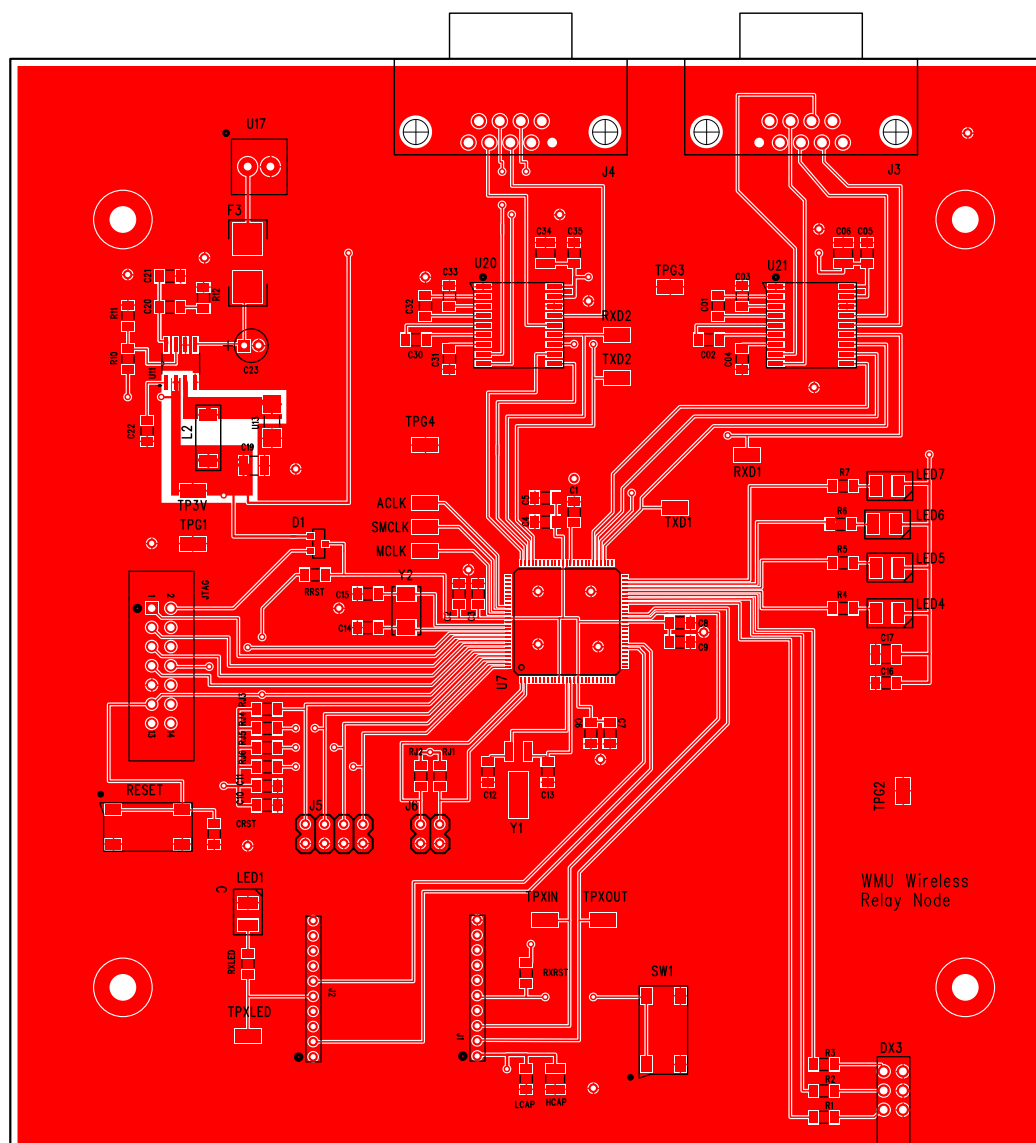
APPENDIX B

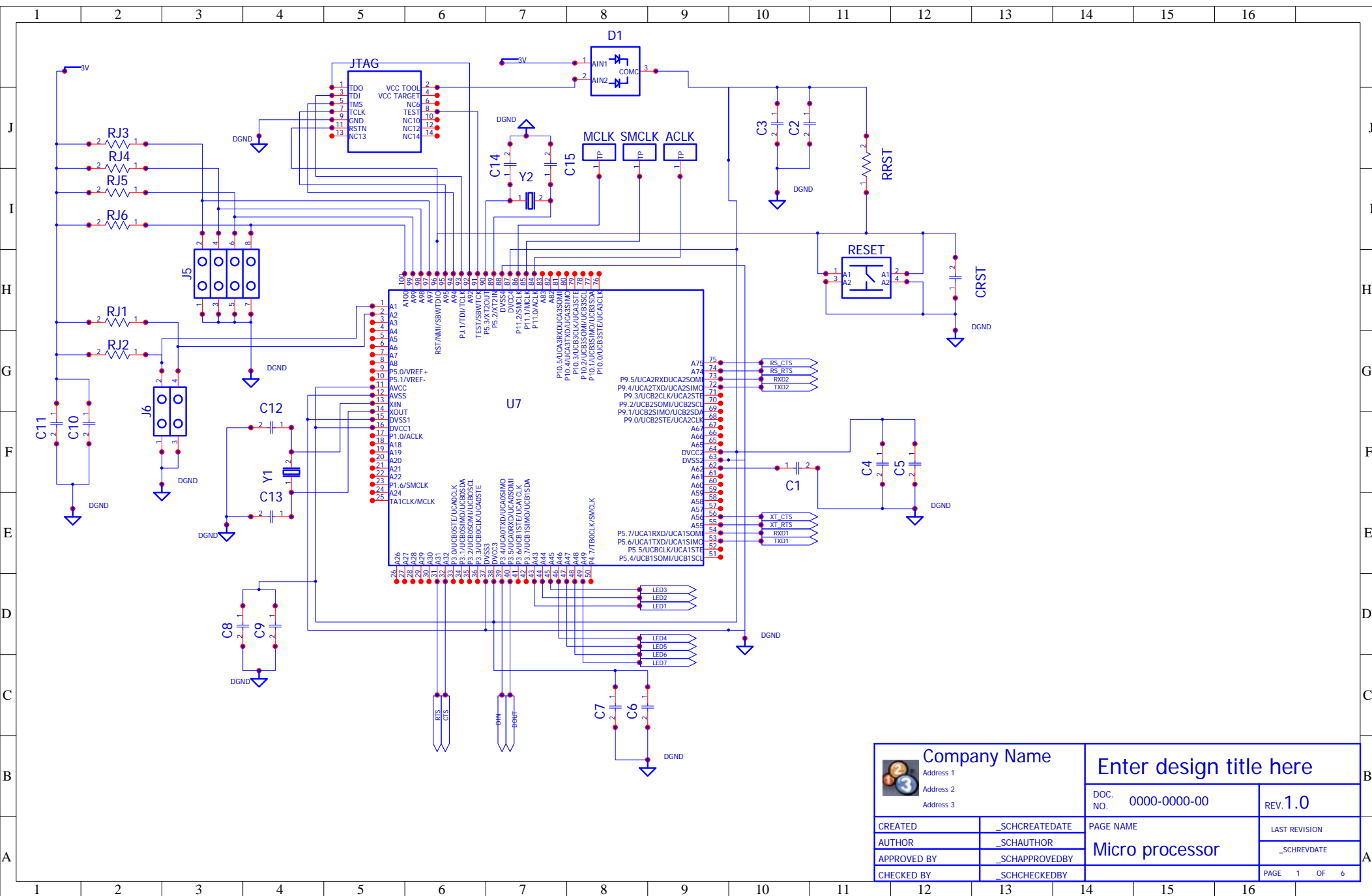
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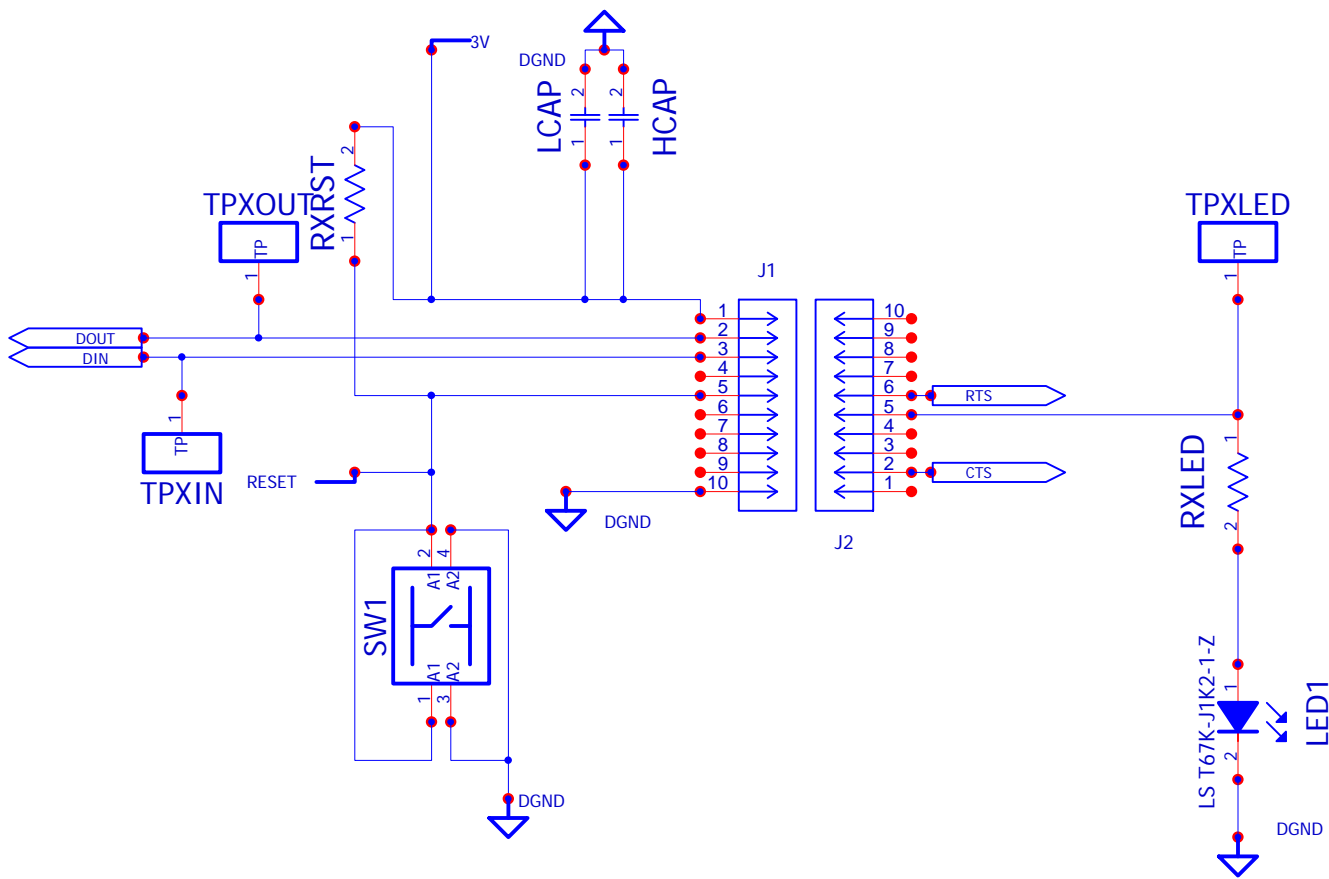
APPENDIX C

Datasheets

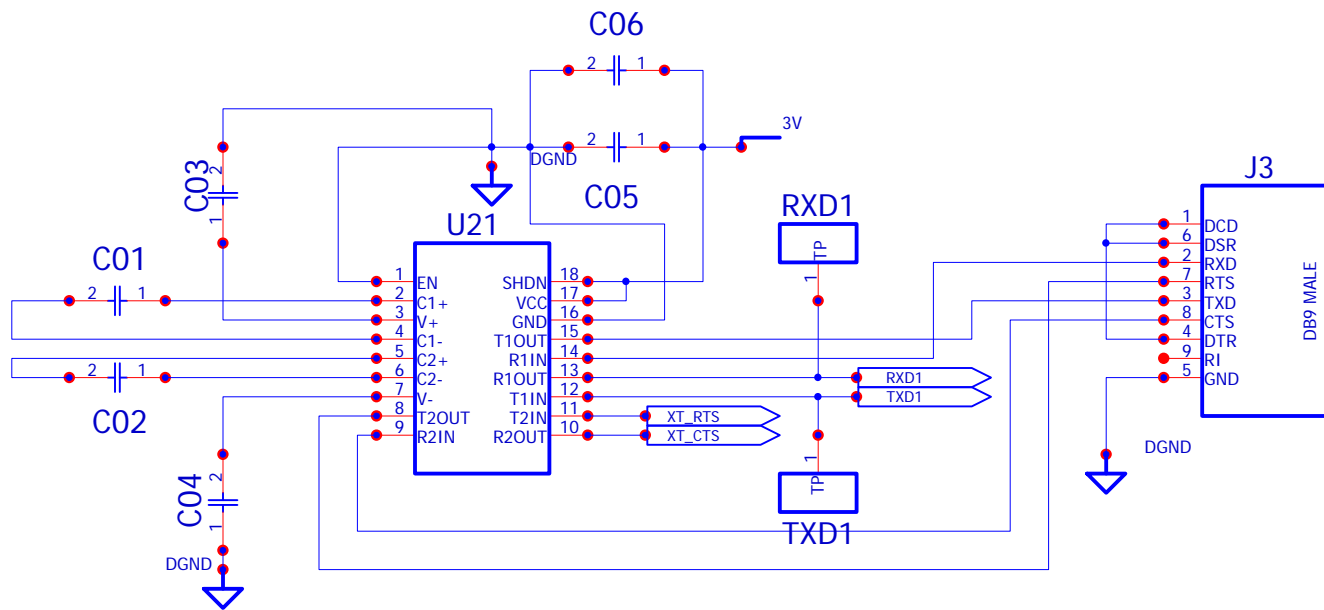





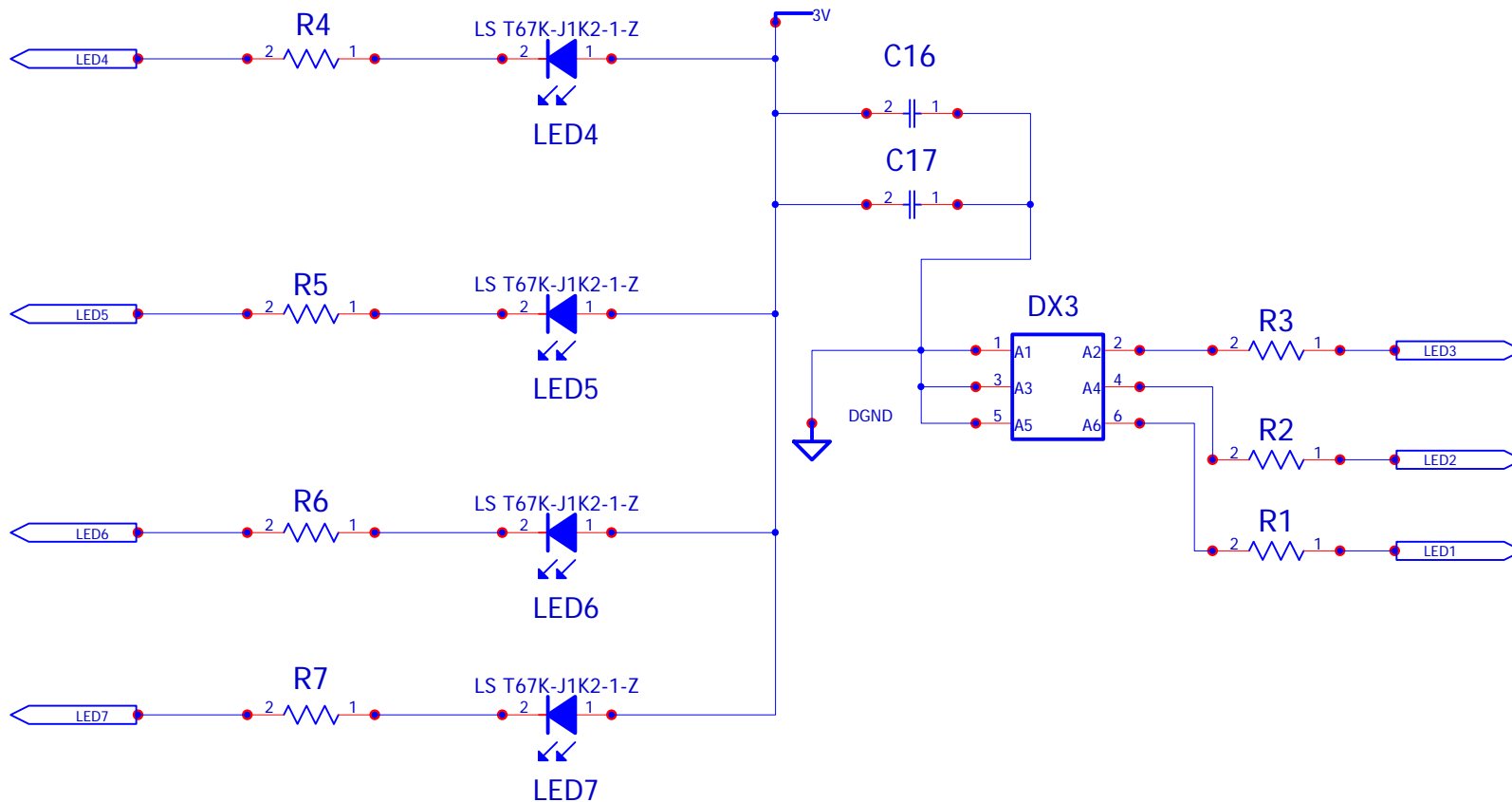





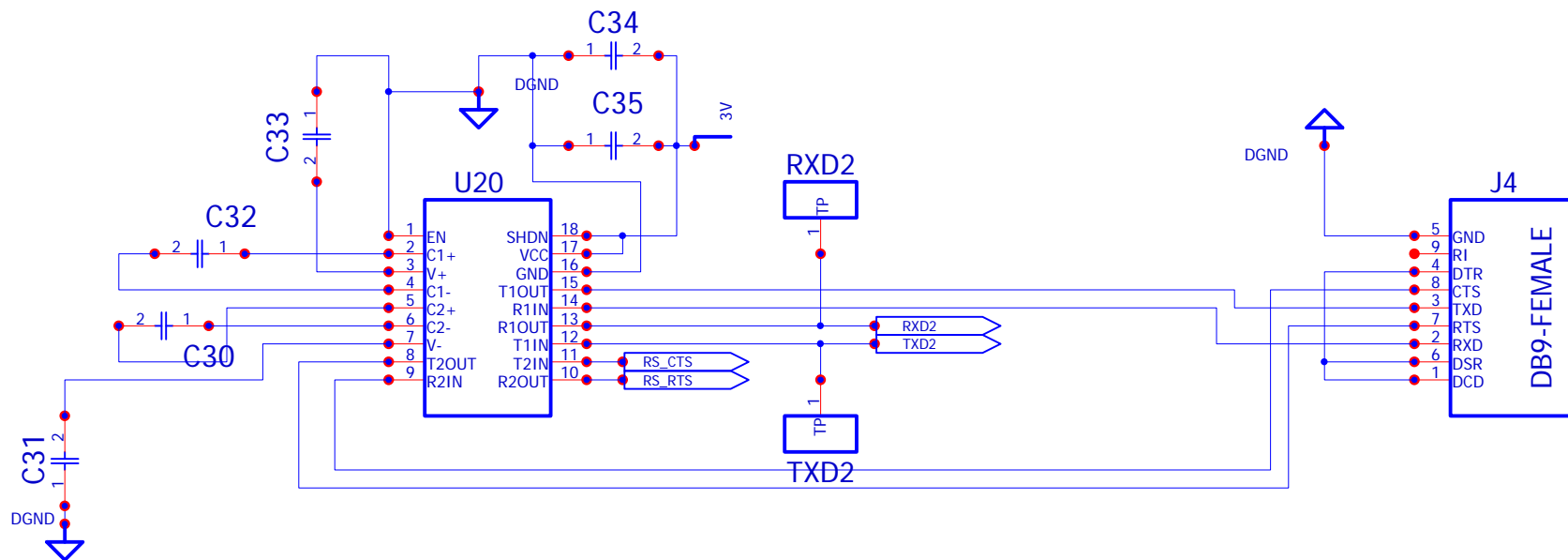
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