# DEVELOPMENT OF MEASURING TEMPERATURE CHANGE FOR WATER QUALITY INDEX IN UMP LAKE, PEKAN CAMPUS.

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# DEVELOPMENT OF MEASURING TEMPERATURE CHANGE FOR WATER QUALITY INDEX IN UMP LAKE, PEKAN CAMPUS.

MUHAMMAD ZAIFULFAZLI BIN ZAILANI

Thesis submitted in fulfilment of the requirements

for the award of the degree of

Bachelor of Electrical Engineering (Electronic)

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Specially dedicated to

My beloved Parents, brother and sister, and to all my friends.

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# ABSTRACT

This project proposed a development of temperature changing measuring system for water quality index in UMP Lake, Pekan Campus. Temperature is one of nine critical water qualities and environmental parameter because it governs the kinds and types of aquatic life, regulates the maximum dissolved oxygen. With respect to chemical and biological reactions, when the water temperature is increased, the rate of chemical and metabolic reactions will also increase. This project will use Graphic User Interface (GUI) of Visual Basic, the software will be the data storage which save all the data measured by the temperature sensor. The temperature sensor will send a feedback through ZigBee Compatible Wireless device. The current technology in adopting wireless terminal technology for instrumentation directly leads to efficient process. In a warm water streams, the temperatures should not exceed 89 degrees Fahrenheit. Cold water streams should not exceed 68 degrees Fahrenheit. The expected result is the sensor will monitor the temperature in UMP Lake and send the data to the software. If the sensor detect the water temperatures exceed 89 degrees Fahrenheit, or 68 degrees Fahrenheit in cold water stream, it will send a warning signal to the computer through the wireless device.

# ABSTRAK

Projek ini mencadangkan satu perkembangan/pembaharuan mengenai kaedah penyukatan perubahan suhu untuk kualiti indeks air di Tasik UMP, Kampus Pekan. Suhu merupakan salah satu daripada sembilan kualiti air yang kritikal dan merupakan parameter alam sekitar/ sekeliling kerana ia mengawal jenis-jenis hidupan akuatik, di mana ia turut mengawal keterlarutan kuantiti oksigen yang maksimum di dalam air. Berdasarkan tindak balas kimia dan biologi, apabila suhu air dinaikkan, kadar tindak balas kimia dan metabolisme juga turut meningkan. Projek ini akan menggunakan Graphic User Interface (GUI) daripada Visual Basic, di mana perisian komputer ini akan menyimpan kesemua data yang diukur melalui pengesan suhu. Pengesan suhu tersebut akan menghantar maklum balas melalui alat ZigBee Compatible Wireless. Teknologi semasa dalam mengadaptasi teknologi peralatan tanpa wayar untuk peralatan sememangnya membawa ke arah proses yang lebih berkesan. Di dalam aliran air sejuk, suhu tersebut sepatutnya tidak melebihi 89 darjah Fahrenheit. Keputusan yang diramal ialah pengesan tersebut akan memantau suhu di Tasik UMP dan menghantar data kepada perisian computer tersebut. Jika pengesan tersebut mengesan suhu air melebihi 89 darjah Fahrenheit atau 68 darjah Fahrenheit pada aliran air sejuk, ia akan menghantar isyarat amaran pada komputer melalui alat tanpa wayar tersebut.

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# LIST OF SYMBOLS

| | |
|---|---|
| mA | Miliampere |
| mV | MiliVolts |
| ms | Miliseconds |
| °C | Degree Celcius |
| V | Volts |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AD | Analog to Digital |
| ADC | Analog to Digital Converter |
| ANN | Artificial Neural Network |
| CD | Compact Disc |
| CDMA | Code Division Multiple Access |
| COM | Component Object Model |
| FSK | Frequency Shift Keying |
| GSM | Global System Communication for Mobile Phone |
| GPRS | General Packet Radio Service |
| HART | Highway Addressable Remote Transducer |
| IDE | Integrated development environment |
| IEEE | Institute of Electrical and Electronics Engineers |
| I\O | Input Output |
| LCD | Liquid Crystal Display |
| OEM | Original Equipment Manufacturer |
| PIC | Peripheral Interface Controller |
| PC | Personal Computer |
| RF | Radio frequency |
| RS | Radio Signal |
| UMP | Universiti Malaysia Pahang |
| USB | Universal Serial Bus |
| VB | Visual Basic |
| VPN | Virtual Private Network |
| WHAN | wireless home area networks |
| WLAN | Wireless local area network |
| WPAN | Wireless personal area networking |
| WQI | Water Quality Index |
| WSN | Wireless System Network |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Project Background

Water quality measurements fall into three broad categories which is physical characteristic, chemical characteristic and biological characteristic. Water temperature measurement is categories under physical characteristic. Temperature is one of the critical water quality and environmental parameter because it governs the kinds and types of aquatic life, regulates the maximum dissolved oxygen concentration of the water, rate of photosynthesis of plants, metabolic rates of animals, the sensitivity of organisms to toxic wastes, parasites and diseases, and influences the rate of chemical and biological reactions.[3] With respect to chemical and biological reactions, when the water temperature is increased, the rate of chemical and metabolic reactions will also increase.[1] Thermal pollution is an increase in water temperature caused by adding relatively warm water to cooler stream water. The cutting down of trees that shade a lake will expose it to sunlight and increase temperature. Measurement of temperature change can help detect sources of thermal pollution and suggest the size of habitat for organisms that are more sensitive to temperature variation.

## 1.2 Introduction to the Project

In this project, wireless technology will be use to transfer the data taken from the sensor to the computer. It is an improvement from the previous wiring technology which is expensive due to the wiring installation and maintenance. Wireless technology also allow otherwise impossible sensor applications, such as monitoring dangerous, hazardous, unwired or remote areas and locations. Wireless technologies have been under rapid development during recent years. Types of wireless technologies being developed range from simple infrared light for short-range, point-to-point communications, to wireless personal area network (WPAN) for short range, point-to multi-point communications, such as Bluetooth and ZigBee, to mid-range, multi-hop wireless local area network (WLAN), to long-distance cellular phone systems, such as GSM/GPRS and CDMA.[4]

Hence, this project is an improvement for the wiring water temperature measuring system by using wireless technology and it will also calculate the water quality index (WQI). WQI is a 100 point scale that summarizes results from a total of nine different measurements when complete (refer to table 1). The point is calculated from the change of water temperature. Finally, if the sensor detected the water temperatures exceed 89 degrees Fahrenheit, or 68 degrees Fahrenheit in cold water stream, it will send a warning signal to the computer through the wireless device.

This project will be using the Visual Basic software to interface the ZigBee receiver and the computer to display the temperature data. Visual Basic (VB) is also considered a relatively easy to learn and use programming language, because of its graphical development features and BASIC heritage.[7] Visual Basic is user friendly software and it also has simple applications. Hence, Visual Basic is suitable software to be used for this project because this software is for a beginner programmer.

Table 1 : Water Quality Index (WQI) Legend

| The value different | QUALITY |
|---|---|
| 0 | Excellence |
| 5 | Good |
| 10 | Medium |
| 20 | Bad |
| 20 and above | Very Bad |

## 1.3 Problem Statement

Problems of water quality have been a factor in determining human welfare. At present, continuous monitoring of drinking water and wastewater quality at most treatment plants is applied in Europe, North America and Japan. In China, online monitoring installations have been constructed for several large rivers, such as the Huanghe River and the Huaihe River, to provide real-time information to support environmental protection decision-makers.[2] There are nine factors in water quality index measurement but this project only focus on the temperature measurement. Often summer heat can cause fish kills in ponds because high temperatures reduce available oxygen in the water.[1] Therefore this system can avoid this problem occur in our country by measuring the water temperature and calculate the changes in temperature to get the water quality index.

Due to the rapid developments in the miniaturization of electronic devices and wireless communication technology have led to the emergence of WSN.[6] The wireless technology are more practical that the wiring technology. The previous technology, they using wire as a medium to send a data or information which is expensive due to the maintenance and also wiring installation.

Nowadays, it is also a difficult job to put the sensor and collect the data near the lake during bad weather or monitoring dangerous, hazardous, unwired or remote areas and locations. By implement the wireless instrument in this system, it allows impossible sensor applications.

## 1.4 Objectives

The main objectives of this project are design a wireless temperature measuring system for water quality index at UMP lake, Pekan. While measuring the water temperature, the system will calculate the water quality index base on temperature. The specific objectives of this project are listed below:

i. Develop a wireless temperature measurement system in UMP Lake.
ii. Develop software for the temperature measurement system and also calculate the WQI for the lake.
iii. Measure and monitoring the temperature from UMP Lake using wireless network system ZigBee.

## 1.5 Scope of Project

Scope of this project is to determine the lake temperature using the temperature sensor and display the data in the computer. The data will be display at the computer screen and the system will calculate the lake water WQI if there is a change in the water temperature. It will also give an alert if the water temperature exceed to the dangerous level and also if the water quality index give a bad feedback water quality.

This system is using the wireless instruments as the interface between the hardware and the software. Hence, by using the wireless technology such as ZigBee for this project, it can reduce the cost taken when developing this project. This method will be used so that the data can be taken at certain or dangerous place without risking our safety and make our work more easy than before.

# CHAPTER 2

# LITERATURE REVIEW

This chapter focused on the literature review for main component in this project. The main component is described based on the findings from journal or articles during the completion of this project.

## 2.1 XBee-PRO® OEM RF Modules

ZigBee is a new type of WPAN based on the IEEE 802.15.4-2003 standard for wireless home area networks (WHANs) which widely used by industry nowadays. Zigbee wireless mesh technology has been developed to address sensor and control applications with its promise of robust and reliable, self-configuring and self-healing networks that provide a simple, cost-effective and battery-efficient approach to adding wireless to any application, mobile, fixed or portable. ZigBee devices bring simple, effective wireless connectivity to low-rate sensors and control devices at an effective cost. ZigBee is widely use nowadays in industry for monitoring, data collection, surveillance and medical telemetry.

This new wireless technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPAN, such as Bluetooth. ZigBee is targeted at radio-frequency (RF) applications that require a low data rate, low power usage, and secure networking. It is also easy to deploy, low cost, and can be used globally. The low cost allows the technology to be widely deployed in wireless control and monitoring applications such as for this project which is to monitor the water temperature. The low power usage allows longer life with smaller batteries and it also have a high connection range.

XBee-PRO® OEM RF Modules (figure 2.1) will be used as the wireless network system in this project. It is one type of the ZigBee which were engineered to meet IEEE 802.15.4 standards and support the unique needs of low-cost, low-power wireless sensor networks. XBee-PRO® OEM RF Modules are the most advanced ZigBee modules available in the XBee footprint and are ideal for deployment in ZigBee networks.[9]

The modules require minimal power and provide reliable delivery of data between devices. The modules operate within the ISM 2.4 GHz frequency band and are pin-for-pin compatible with each other. With advanced mesh networking functionality, XBee and XBee-PRO modules improve data traffic management, allow for greater node density, and provide OEMs with the ability to change firmware remotely with over-the-air updates.[9]


Figure 2.1: XBee-PRO® OEM RF Modules

The XBee-PRO RF Module were designed to mount into a receptacle (socket) and therefore does not require any soldering when mounting it to a board as it shown in figure 2.2. The XBee Development Kits contain RS-232 and USB interface boards which use two 20-pin receptacles to receive modules. The mechanical and ZigBee-mesh drawing of XBee-PRO RF Module are shown below in figure 2.3 and figure 2.4 respectively.

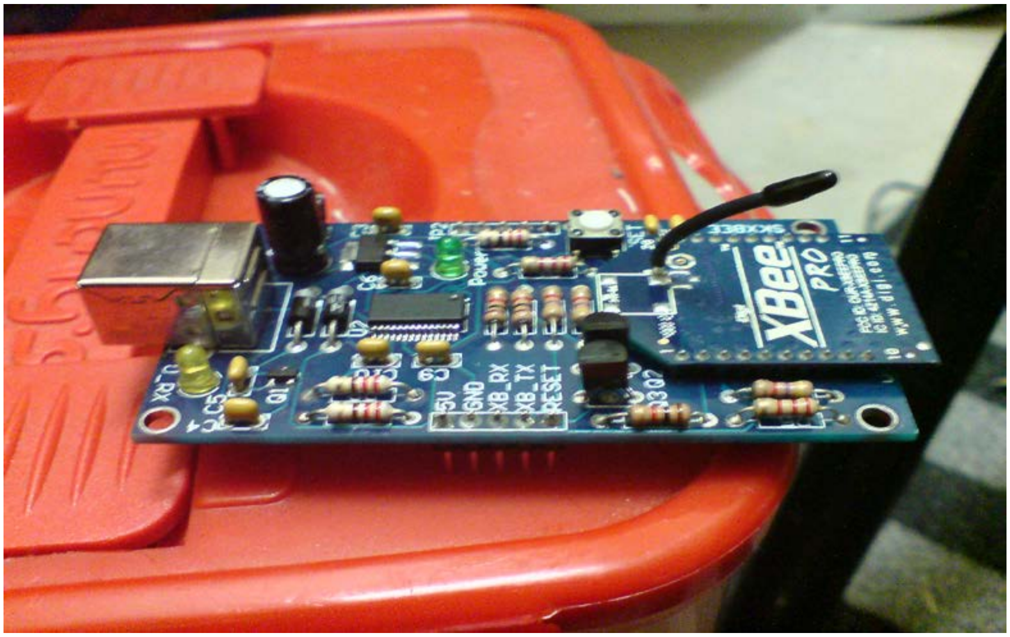


Figure 2.2: A receptacle (socket) for XBee-PRO RF Module

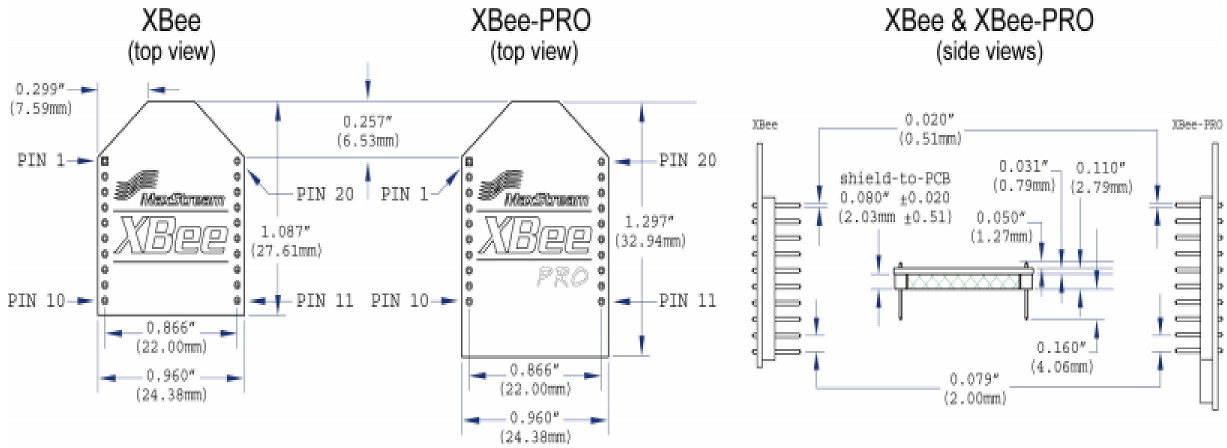


Figure 2.3: The mechanical drawing of XBee-PRO RF Module

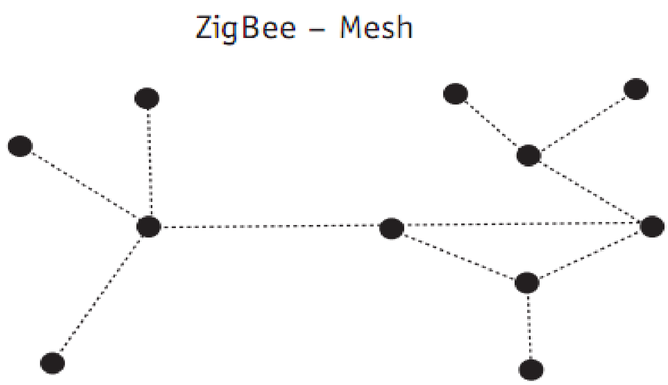


Figure 2.4: ZigBee-mesh

## 2.2 Thermocouple Type K

Thermocouple is a type of temperature sensor which widely used for measurement, control and also to convert heat to electrical power. It is a device which has a junction between two different metals that produces a voltage related to a temperature difference. They are cheap, interchangeable, have standard connectors and can measure a wide range of temperatures. Thermocouples are widely used in science and industry applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. The main limitation is accuracy, system errors of less than 1°C can be difficult to achieve.

Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage. Different alloys are used for different temperature ranges. Properties such as resistance to corrosion may also be important when choosing a type of thermocouple. Where the measurement point is far from the measuring instrument, the intermediate connection can be made by extension wires which are less costly than the materials used to make the sensor. Thermocouples are usually standardized against a reference temperature of 0 degrees Celsius practical instruments use electronic methods of cold-junction compensation to adjust for varying temperature at the instrument terminals. Electronic instruments can also compensate for the varying characteristics of the thermocouple, and so improve the precision and accuracy of measurements.[7]

Type-K thermocouple will be used in this project to measure and monitoring the water temperature. A K type thermocouple is the most popular and uses nickel-chromium and nickel-aluminium alloys to generate voltage. It is low cost and, owing to its popularity, it is available in a wide variety of probes. Thermocouples are available in the -200°C to +1200°C range. Sensitivity is approx 41uV/°C.[10] Type-K thermocouple is shown below in figure 2.5.

Figure 2.5: Thermocouple Type-K

## 2.3 Temperature Transmitter

A temperature transmitter as shown in figure 2.6 is a device used to sense a temperature and transmit an output representative of the sensed temperature. Process control transmitters are used to measure process parameters in a process control system. Temperature transmitters are used in controlling industrial processes by sensing a temperature of the process and transmitting the information to a remote location.

Figure 2.6: Temperature transmitter

The transmitter injects a current into the temperature sensor and the resultant voltage drop across the temperature sensor is used to measure resistance. The voltage is converted into a digital format using an analog to digital converter and provided to a microprocessor. The microprocessor converts the measured voltage into a digital value representative of temperature. The temperature transmitter generally includes a housing and a temperature probe which attaches to the housing. In order to monitor a process temperature, the transmitter includes a sensor, such as the thermocouple type-K in this project.

A thermocouple provides a voltage in response to a temperature change. Typically, the temperature transmitter is located in a remote location and coupled to a control room over a 4-20 mA current loop. A temperature sensor is placed in the process fluid and provides an output related to temperature of the process fluid.

## 2.4 Emerson Model 375 HART Communicator

The HART Communicator as shown in figure 2.9 is a hand-held interface that provides a common communication Link to all HART-compatible, microprocessor-based instruments. The HART Communicator can interface with a transmitter from the control room, the instrument site, or any wiring termination point in the loop through the rear connection panel (Figure1-2). To interface, connect the HART Communicator with the appropriate Connectors in parallel with the instrument or load resistor. All connections are non-polarized. When connecting to a PC, use the PC Communication Adapter to connect to the Communicator’s serial port. Figure 2.7 shown the HART Communicator and figure 2.8 shown illustrate typical wiring connections between the HART Communicator and any compatible device.


Figure 2.7: HART Communicator Device

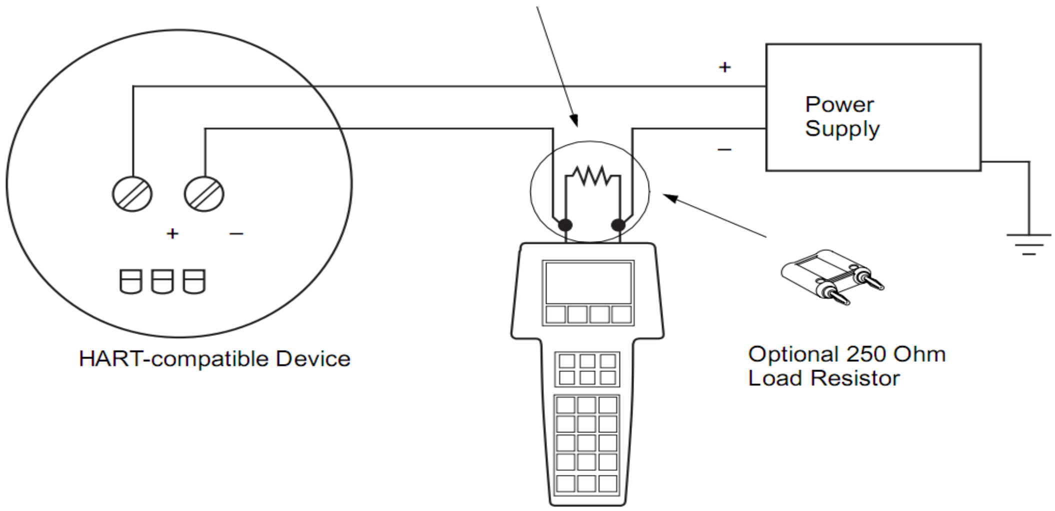


Figure 2.8: Connection between HART and any compatible device

The majority of installed instruments are now digital instruments. Most of these use the HART protocol. The HART protocol uses 1200 baud Frequency Shift Keying (FSK) based on the Bell 202 standard to superimpose digital information on the conventional 4 to 2OmA analogue signal. Maintained by an independent organisation, the HART Communication Foundation, the HART protocol is an industry standard developed to define the communications protocol between intelligent field devices and a control system. HART is the most widely used digital communication protocol in the process industries, with over eight million HART field instruments installed in over 100,000 plants worldwide, HART:

- Is supported by all of the major vendor of process field instrument.
- Preserves present control strategies by allowing traditional 4 to 20mA signal to co-exist with digital communication on existing two-wire loops.
- Is compatible with traditional analogue devices.
- Provides important information for installation and maintenance, such as Tag-IDs, measured values, range and span data, product information and diagnostics.
- Can support cabling savings through use of multidrop network.
- Reduces operation costs, through improved management and utilization of smart instrument network.

## 2.5 Research or Finding Materials which related to the project.

In China, online monitoring installations have been constructed for several large rivers, such as the Huanghe River and the Huaihe River, to provide real-time information to support environmental protection decision-makers. In this article, water quality remote monitoring systems using CDMA service combined with IPsec-based virtual private network (VPN) function were developed for constructing a wireless sensing network in countrywide scale. The researcher developed an online water quality monitoring system for intensive fish culture in China, which combined web-server-embedded technology with mobile telecommunication technology. Integrated with a forecasting model on the basis of artificial neural networks (ANN), the system is able to provide real-time information and the dynamical trend of the water quality at different monitoring sites. [1] This showed that monitoring the WQI is an important thing to make sure the water supply is clean and non-toxic. Hence, this method should be used to monitor the WQI in Malaysia water supply. For the WQI, the researcher using seven type of measurement such as temperature, pH, dissolve oxygen and others. The researcher also used more advance wireless system than ZigBee which is been used in this project, the CDMA service combined with IPsec-based virtual private network (VPN) function were developed for constructing a wireless sensing network in countrywide scale, same fixture as the GSM.

According to the book Field Manual for Water Quality Monitoring[2], the National Sanitation Foundation surveyed 142 people representing a wide range of positions at the local, state, and national level about 35 water quality tests for possible inclusion in an index. In this journal, the researcher used nine factors to calculate the WQI for the water supply. Nine factors (temperature, pH dissolved oxygen, turbidity, fecal coliform, biochemical oxygen, total phosphates, nitrates, total suspended solids) were chosen and some were judged more important than others, so a weighted mean is used to combine the values. Temperature is a critical water quality and environmental parameter because it governs the kinds and types of aquatic life, regulates the maximum dissolved oxygen concentration of the water, and influences the rate of chemical and biological reactions. It is also showed that temperature is a critical water quality because regulates the maximum dissolved oxygen concentration of the water and also give support to the aquatic life. The WQI calculation for the temperature factor in this project will be refers to the graph (as shown in figure 2.9) from this journal by using Visual Basic software.

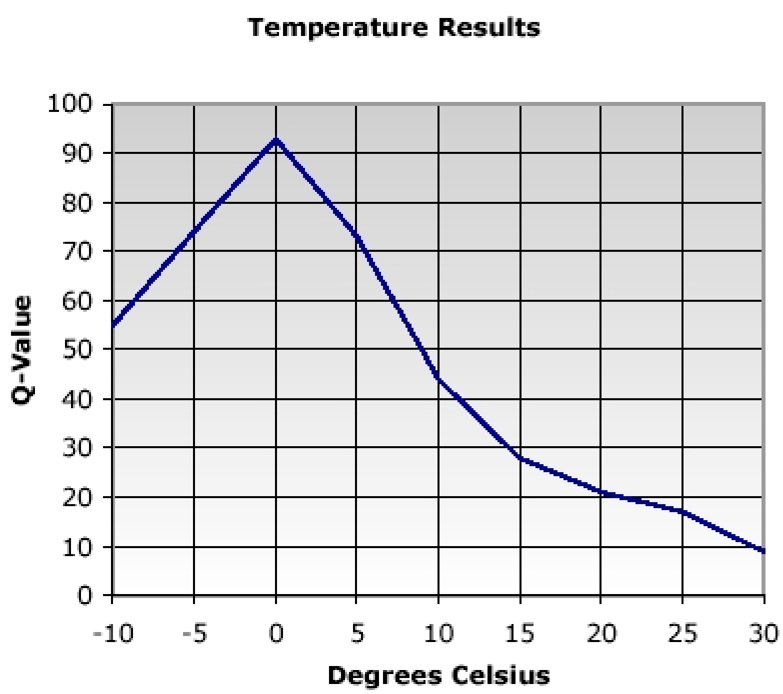


Figure 2.9: The WQI for Temperature Measurement

From the thesis titled Temperature Measurement system,[11] the PIC16F877 was used to control the transmitter and receiver module. The PIC also been used to control the LCD which display the temperature reading. This project objective is to monitor a room temperature. The project used integrated-circuit temperature, LMD35DZ (figure 2.10) to read the temperature room. This temperature sensor may detect over -55ºC to 150 ºC temperature range and suitable for the scope of project which temperature range is from 0ºC to 60ºC. It can be used with single power supplies, or with plus and minus supplies. It can be supplied from 4 to 30V. It is also directly supplied with 5V from voltage regulator.[9] This type of temperature sensor is not suitable to use in this project because it is not a type of water temperature sensor. This project used thermocouple type-K which is more suitable to measure the water temperature.[11]


Figure 2.10: Temperature Sensor type LMD35DZ

From the thesis done by Mohd Azizul Ghafur Bin Rahimi, titled Temperature Monitoring system, PIC16F877 was also used to analyze data and to control the transmitter and receiver module where in this thesis, the researcher was using Radio Frequency (RF) to transmit the data. The use of radio frequency in monitoring the temperature are said to be more precise and reliable. The project that use the application of RF by using RF transmitter and RF receiver to monitor the temperature in the roof. It was known that when the temperature outside the house is rising, the area the sealed like in the roof will cumulate heat. So, in order to ensure that the temperature in that area do not rise so high that will make house resident feel not comfortable, sensor will detect the temperature and fan will do the job in stabilized the temperature. ZigBee will be use in this project instead of RF module because the Zigbee transmit data even faster that the RF. RF also can be interrupt when another RF signal appear in the same location, but ZigBee cannot be interrupt. ZigBee module also easier to interface with the software rather than the RF.

# CHAPTER 3

# METHODOLOGY

## 3.1 Hardware

### 3.1.1 Temperature Sensor (Thermocouple Type-K)

The thermocouple type-k is a type of temperature sensor which produce an output signal via milivolts. In this project, this sensor will measure the water temperature and will send the analog signal to the microcontroller. The thermocouple will connect with the temperature transmitter to convert the signal from voltage to current, since its easier for the ZigBee module to read the data in current rather than voltage because the voltage from the thermocouple is to low (mV). The thermocouple and the transmitter will work with 24 volt of power supply.

### 3.1.2 XBee-PRO® OEM RF transmitter and receiver Modules.

Figure 3.1 shows that how the ZigBee sensor network working when transferring a data. ZigBee sensor network using radio wave to transfer the data and the range the ZigBee module can be connected depend on the frequency of the radio wave itself. Basically, to transferring a data, it needs two ZigBee module which is the transmitter and the receiver part. Hence, in this project two module of ZigBee will be used as the transmitter which is connected to the sensor and the transmitter, and the other one is the receiver which connected directly to the PC. The transmission between the ZigBee are shown in figure 3.2.

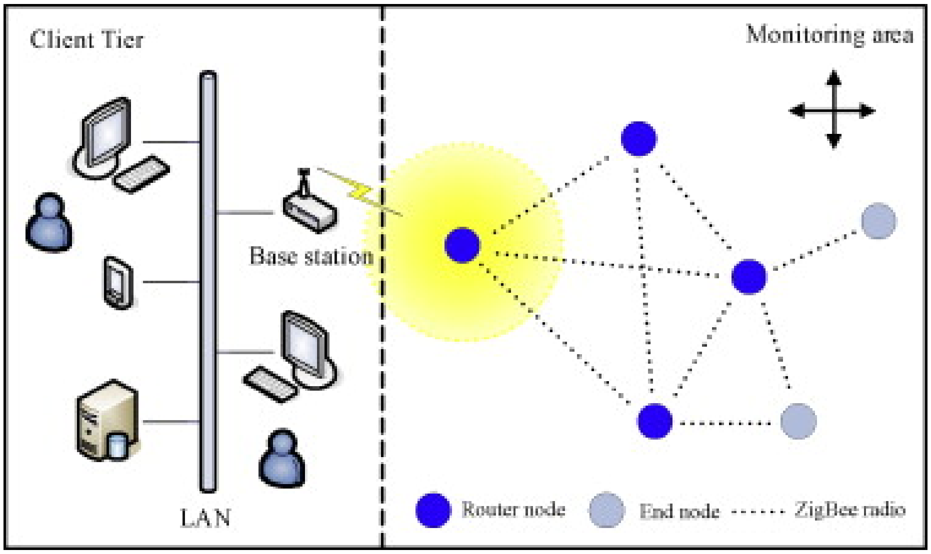


Figure 3.1: Basic strategy of the ZigBee-based sensor network **[8]**

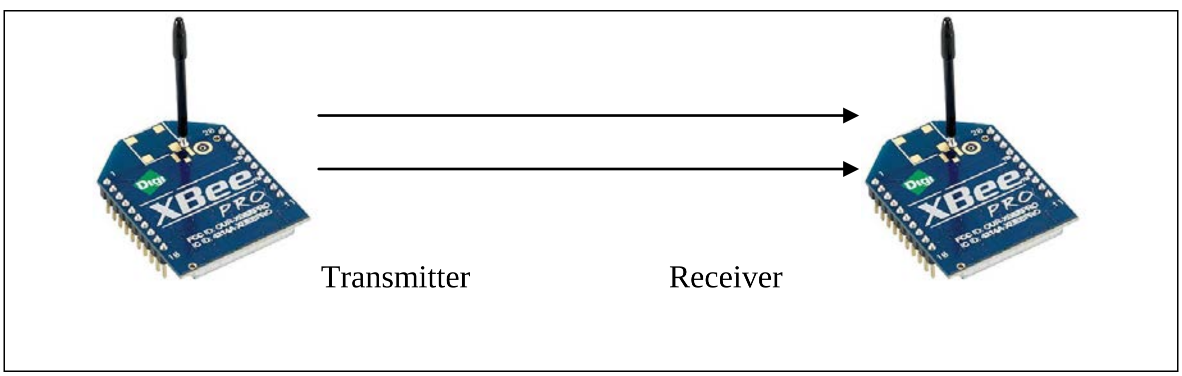


Figure 3.2: ZigBee wireless system transmission

The ZigBee transmitter will receive the digital data from the microcontroller and it will send the data through the wireless signal and it will be receive by the ZigBee receiver. This ZigBee module need 5Volt of power supply and as for the receiver module, it can directly connect through USB cable to the computer to turn it on. The Zigbee modules also must be setup first before interface with PC. The X-CTU driver will be use to setup both receiver and tramitter module. Both modules need to be program using the X-CTU driver so the data can be transmit and receive smoothly without an error. Then, the ZigBee receiver also will be interface with the computer software which in this case, Visual Basic.

The ZigBee module will also be the ADC (analog to digital converter) link to convert analog signal from transmitter into digital signal. The signal will be convert to digital by the ZigBee transmitter before transmit the signal to Zigbee receiver and the PC will read the data signal via USB port. Pin 20 will be use as the ADC because pin 20 supports the analog and digital I/O. By using X-CTU software, pin 20 can used as several function which is ADC, digital input, digital Output low and digital output high. Setting the AT command, ATDn=2 to set pin 20 as the ADC line support. The function of other ZigBee pin can be seen in figure 3.3.

| Pin # | Name | Direction | Description |
|---|---|---|---|
| 1 | VCC | - | Power supply |
| 2 | DOUT | Output | UART Data Out |
| 3 | DIN / CONFIG | Input | UART Data In |
| 4 | DO8* | Output | Digital Output 8 |
| 5 | RESET | Input | Module Reset (reset pulse must be at least 200 ns) |
| 6 | PWM0 / RSSI | Output | PWM Output 0 / RX Signal Strength Indicator |
| 7 | PWM1 | Output | PWM Output 1 |
| 8 | [reserved] | - | Do not connect |
| 9 | DTR / SLEEP_RQ / DI8 | Input | Pin Sleep Control Line or Digital Input 8 |
| 10 | GND | - | Ground |
| 11 | AD4 / DIO4 | Either | Analog Input 4 or Digital I/O 4 |
| 12 | CTS / DIO7 | Either | Clear-to-Send Flow Control or Digital I/O 7 |
| 13 | ON / SLEEP | Output | Module Status Indicator |
| 14 | VREF | Input | Voltage Reference for A/D Inputs |
| 15 | Associate / AD5 / DIO5 | Either | Associated Indicator, Analog Input 5 or Digital I/O 5 |
| 16 | RTS / AD6 / DIO6 | Either | Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6 |
| 17 | AD3 / DIO3 | Either | Analog Input 3 or Digital I/O 3 |
| 18 | AD2 / DIO2 | Either | Analog Input 2 or Digital I/O 2 |
| 19 | AD1 / DIO1 | Either | Analog Input 1 or Digital I/O 1 |
| 20 | AD0 / DIO0 | Either | Analog Input 0 or Digital I/O 0 |

Table 3.1: Pin Assignments for XBee and Xbee Pro modules

### 3.1.3 Emerson Model 375 HART Communicator

The HART Communicator can interface with a transmitter from the control room, the instrument site, or any wiring termination point in the loop through the rear connection panel. The connection between the HART communicator and the transmitter shows in figure 2.8. HART Communicator uses the Bell202 frequency shift key (FSK) technique of high-frequency digital signals super imposed on a standard transmitter current loop of 4–20mA. Because the total high frequency signal voltage added to the loop amounts to zero, communication to and from a HART compatible device does not disturb the 4–20mA signal. Devices which support the HART protocol are grouped into master (host) and slave (field) devices. Master devices include handheld terminals as well as PC-based workplaces, e.g.in the control room. HART slave devices, on the other hand, include sensors, transmitters and various actuators. The variety ranges from two-wire and four-wire devices to intrinsically safe versions for use in hazardous environments.

The HART data is super imposed on the 4 to 20mA signal via a FSK modem. This enables the devices to communicate digitally using the HART protocol, while analog signal transmission takes place at the same time. In this project, the main function of the HART is to set the range of the temperature sensor which will be read by the transmitter to 0°C minimum until 100°C maximum to be compatible with water temperature. The HART communicator also used to check if there is an error in a transmitter when we connect with a sensor. The HART Communicator is generally used in two environments offline (not connected to a device) and online (connected to a device).

## 3.2 Software

### 3.2.1 Microsoft Visual Studio 2008

Microsoft Visual Studio is an integrated development environment (IDE) from Microsot. It can be used to develop console and graphical user interface applications along with Windows Forms applications, web sites, web applications, and web services in both native code together with managed code for all platforms supported by Microsoft Windows. Microsoft Visual Studio 2008 as shown in figure 3.3 below was released on 19 November 2007.[7]

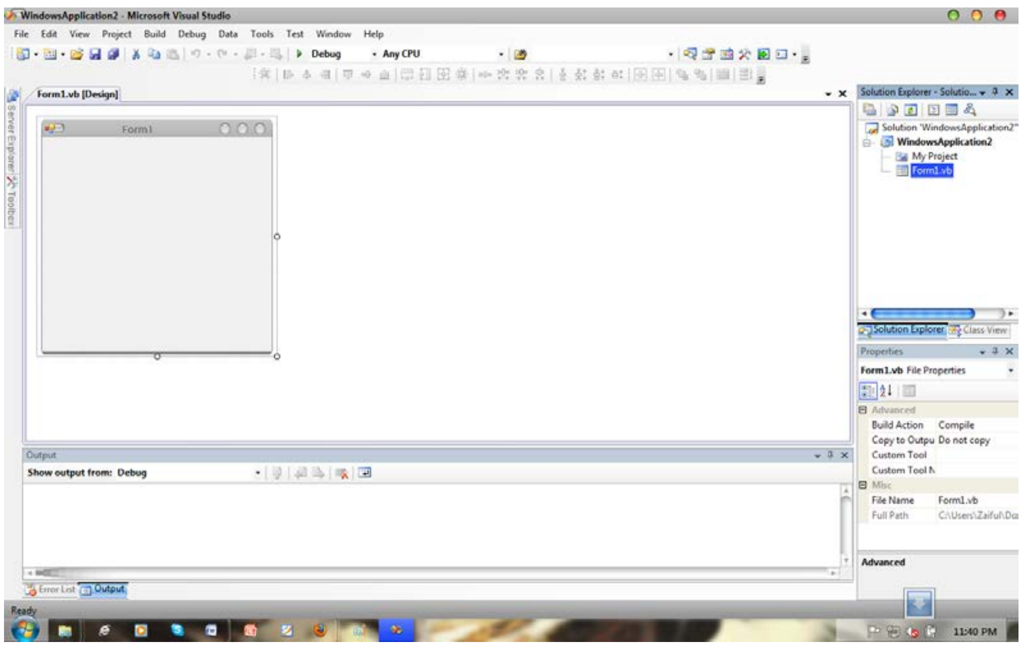


Figure 3.3: The Main form of Visual Studio 2008

In this project, Microsoft Visual Studio 2008 will be use to interface the data between ZigBee receiver module and the Personal Computer (PC). Microsoft Visual Studio 2008 according to Microsoft, is to provide streamlined, easy-to-use and easy-to-learn IDEs for users other than professional software developers, such as hobbyists and students. The first versions of Visual Studio 2005 Express were released on October 2005 and the Service Pack 1 versions were released on December 2006.

The data from the ZigBee receiver will be send to the PC and the data will be translate and read by the Visual Studio 2008 software. The software will display the temperature of the water and monitor the measurement. In this project, the software will be program to monitor the temperature and also calculate the WQI for the water. If there is a change in the water temperature, the software will calculate the value of the WQI based on the graph shown in figure 1 in the literature review part.

For the programming part, the command will be used IF and ELSE IF command. The smaller the different between present value and past value, the higher quality of WQI it will get. If the values reach the very bad level, the software will give us a warning about the WQI value. The program are based on the table 1 which shown as it shown in chapter 1.

### 3.2.2 X-CTU (XCTU) software

X-CTU is a Windows-based application provided by Digi. This program was designed to interact with the firmware files found on Digi's RF products and to provide a simple-to use graphical user interface to them. X-CTU is designed to function with all Windows-based computers running Microsoft Windows 98 SE and above. X-CTU can either be downloaded from Digi's Web site or an installation CD.

When launched, you will see four tabs across the top of the program (see Figure 3.4). Each of these tabs has a different function.

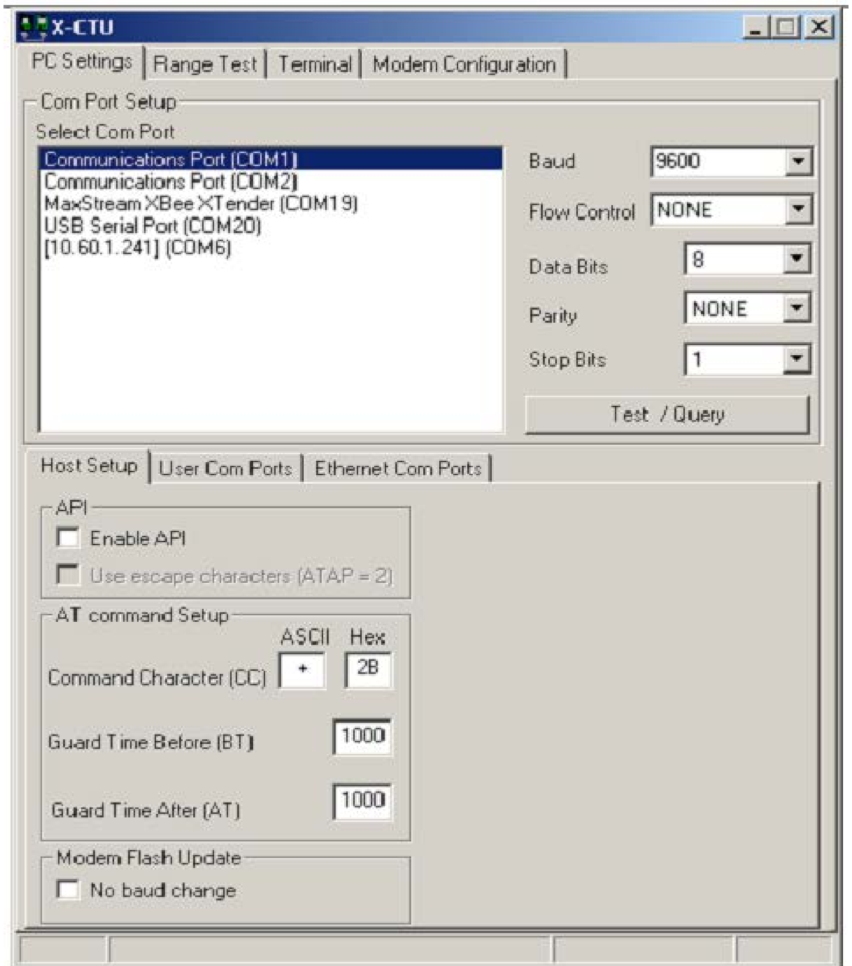


Figure 3.4: The PC Setting form

The first tab is the PC Setting allows a customer to select the desired COM port and configure that port to fit the radios settings. To change any of the above settings, select the pull down menu on the left of the value and select the desired setting. To enter a non-standard baud rate, type the baud rate into the baud rate box to the left. The Test / Query button is used to test the selected COM port and PC settings. If the settings and COM port are correct, you will receive a response similar to the one depicted in Figure 3.5 below.


Figure 3.5: Com Test Form

The second tab is the Range Test (see figure 3.6) which allows a customer to perform a range test between two ZigBee modules. The range test tab is designed to verify the range of the radio link by sending a user-specified data packet and verifying the response packet is the same, within the time specified.

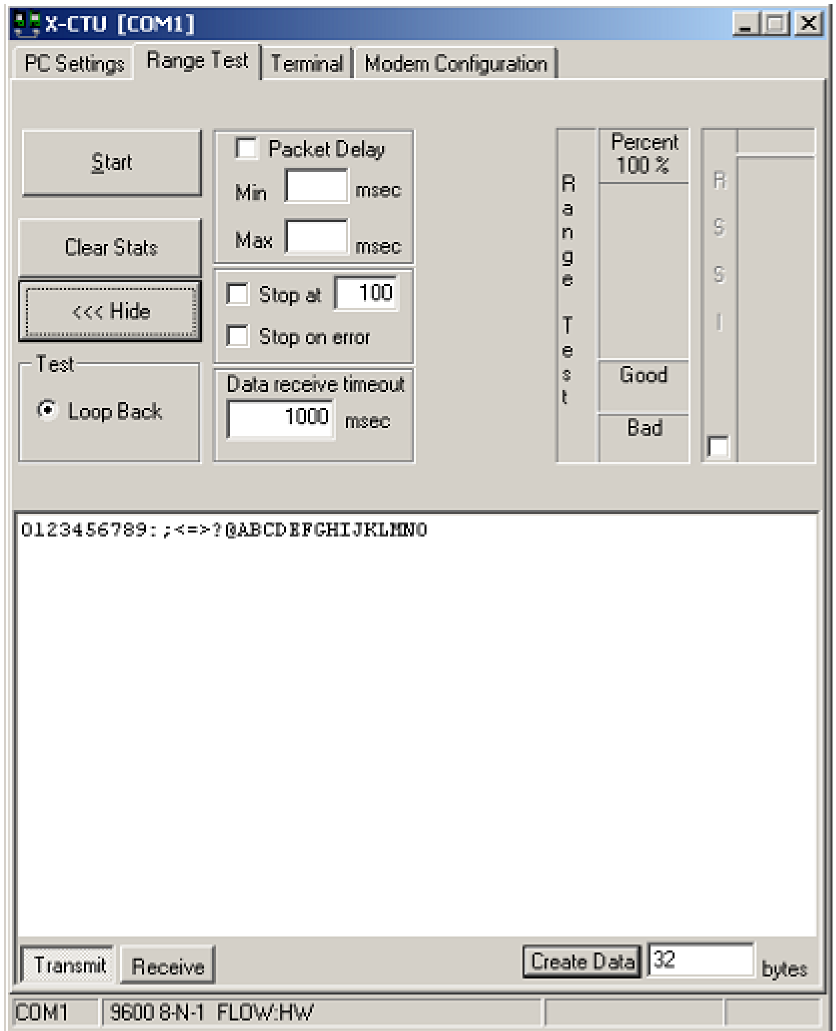


Figure 3.6: Range Test Form

Then is the Terminal tab which allows access to the computers COM port with a terminal emulation program. This tab also allows the ability to access the ZigBee mudule firmware using AT commands. The Terminal tab has three basic functions:

- Terminal emulator
- Ability to send and receive predefined data pacts (Assemble packet)
- Ability to send and receive data in Hex and ASCII formats (Show/Hide hex)

The main white portion of this tab is where most of the communications information will occur while using X-CTU as a terminal emulator. The text in blue is what has been typed in and directed out to the radio's serial port while the red text is the incoming data from the radio's serial port (see Figure 3.7).

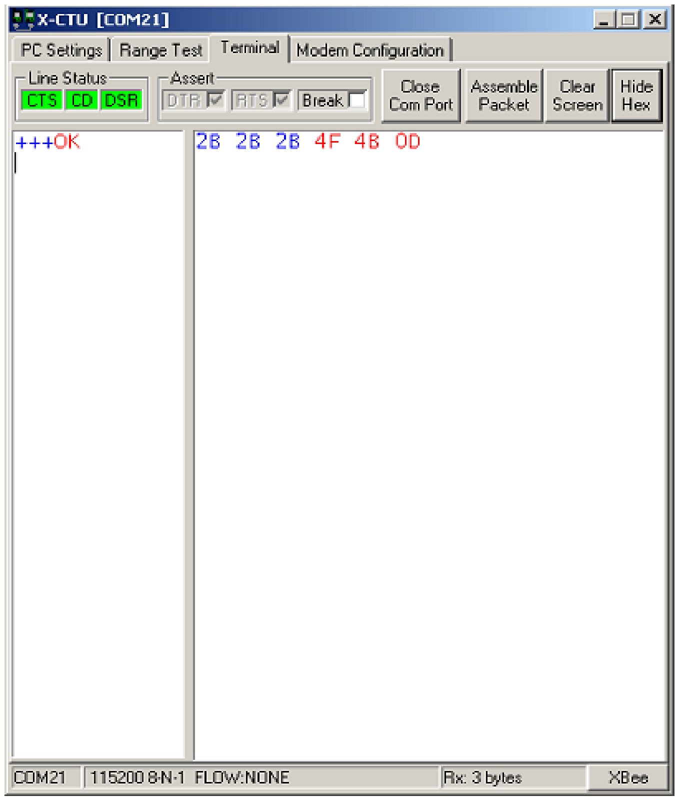


Figure 3.7: Terminal Form

Last but not least, the modern configuration which allows the ability to program the radios' firmware settings via a graphical user interface. This tab also allows customers the ability to change firmware versions. The Modem configuration tab has four basic functions, which are:

1: Provide a Graphical User Interface with a radio's firmware

2: Read and Write firmware to the radio's microcontroller

3: Download updated firmware files from either the web or from a compressed file

4: Saving or loading a modem profile

To read the ZigBee firmware, first connect the Zigbee module to the interface board and connect this assembly to the PC's corresponding port which in this case via USB port. On the Modem Configuration tab, select "Read" from the Modem Parameters and Firmware section (see Figure 3.8).

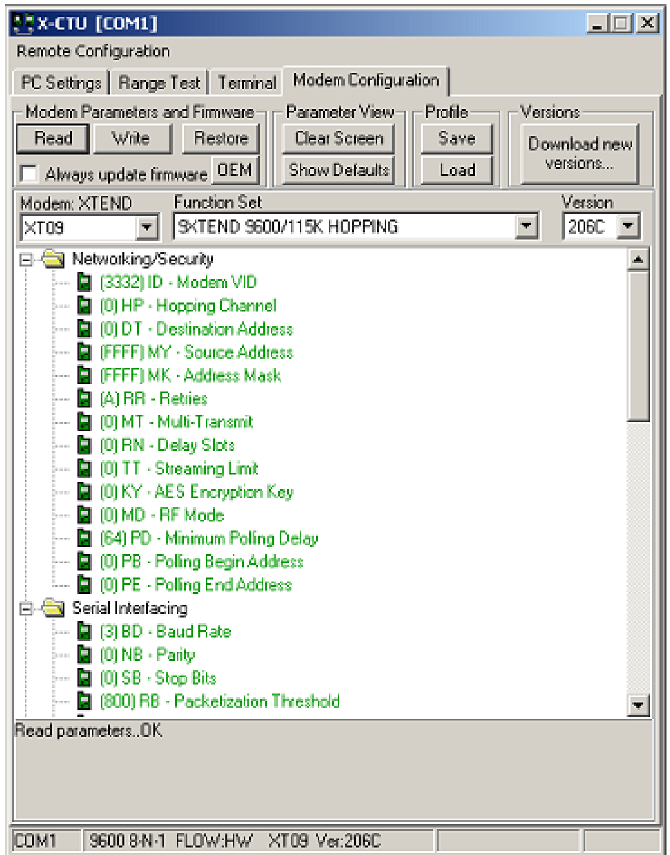


Figure 3.8: Modern Configuration Form

To connect between two Zigbee module, the destination address low (DL) and 16-bit Source Address (MY) must be set in both Zigbee modules. As an example for a simple A/D (Analog to digital) link, a pair of RF modules could be set as follows:

Remote Configuration (Transmit)

DL = 0x1234

MY = 0x5678

D0 = 2

D1 = 2

IR = 0x14

IT = 5

Base Configuration (Receive)

DL = 0x5678

MY = 0x1234

P0 = 2

P1 = 2

IU = 1

IA = 0x5678 (or 0xFFFF)

These settings configure the remote module to sample AD0 and AD1 once each every 20 ms. It then buffers 5 samples each before sending them back to the base module. The base should then receive a 32-Byte transmission (20 Bytes data and 12 Bytes framing) every 100 ms.

### 3.2.3 Overall System Process

First, the temperature sensor will read the water temperature at the lake. Then the analog data from the temperature sensor will be converted to digital data via PIC microcontroller. Next, the digital will be send to the zigbee transmitter and it will send the data through wireless network to the zigbee receiver. Then, the data will be sent to the PC and the temperature data will be display on the screen using Visual Basic software. The software will monitor the lake water temperature and if there is a change in the temperature reading, the software will calculate the WQI for the lake base on the graph from figure 2.9. The system also will give an alert to the user if the temperature or the WQI exceed to the dangerous level. The connection between the instruments are shown in figure 3.10.

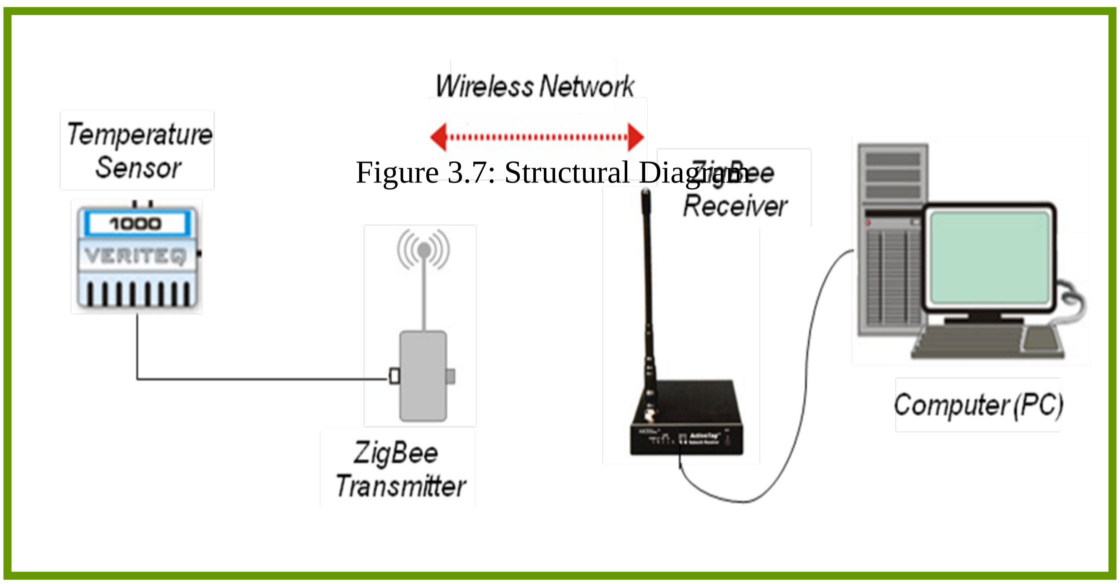


Figure 3.7: Structural Diagram

Figure 3.9: The connection between the instruments

## 3.4 Flow Chart

Figure 3.8 describe the flow about this project and also what was done in the process to achieve project objectives.

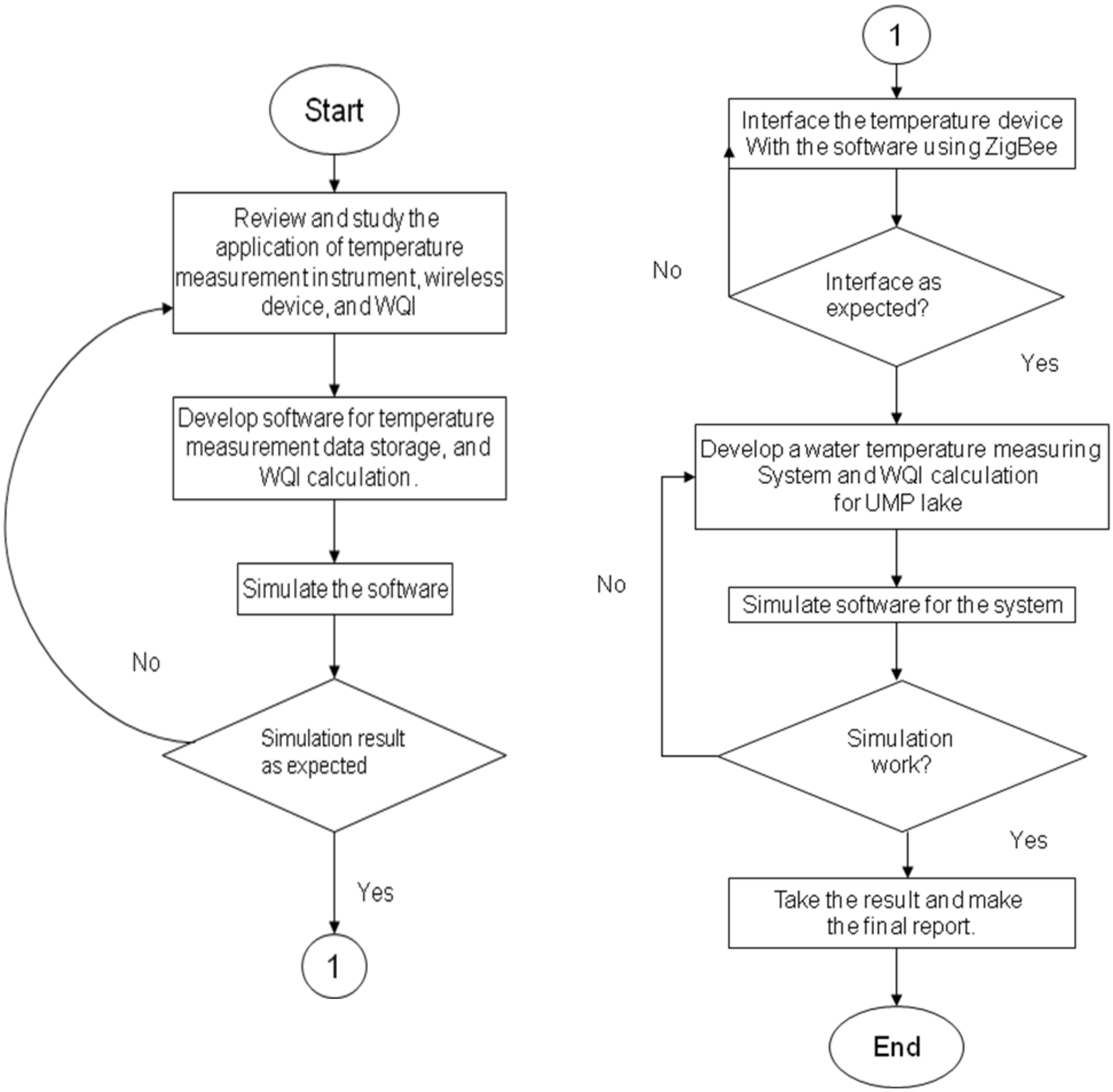


Figure 3.10 : Project Flow Chart

# CHAPTER 4

## 4.1 Result and Discussion

The results of the GUIs are shown below in figure 4.1 until 4.5. The software run exactly as expected and the WQI calculate were accurate base on the graph figure in literature review part (figure 2.9). The calculation run automatically and the data will be read when the progress bar 1 end and the progress bar 2 start to move, and vice versa. The software will give a sign of warning if the WQI exceed to the dangerous level. This GUI also provides date and time to know the time the data have been taken. The date and the automatic calculation can be done using timer form as shown in figure 4.5.

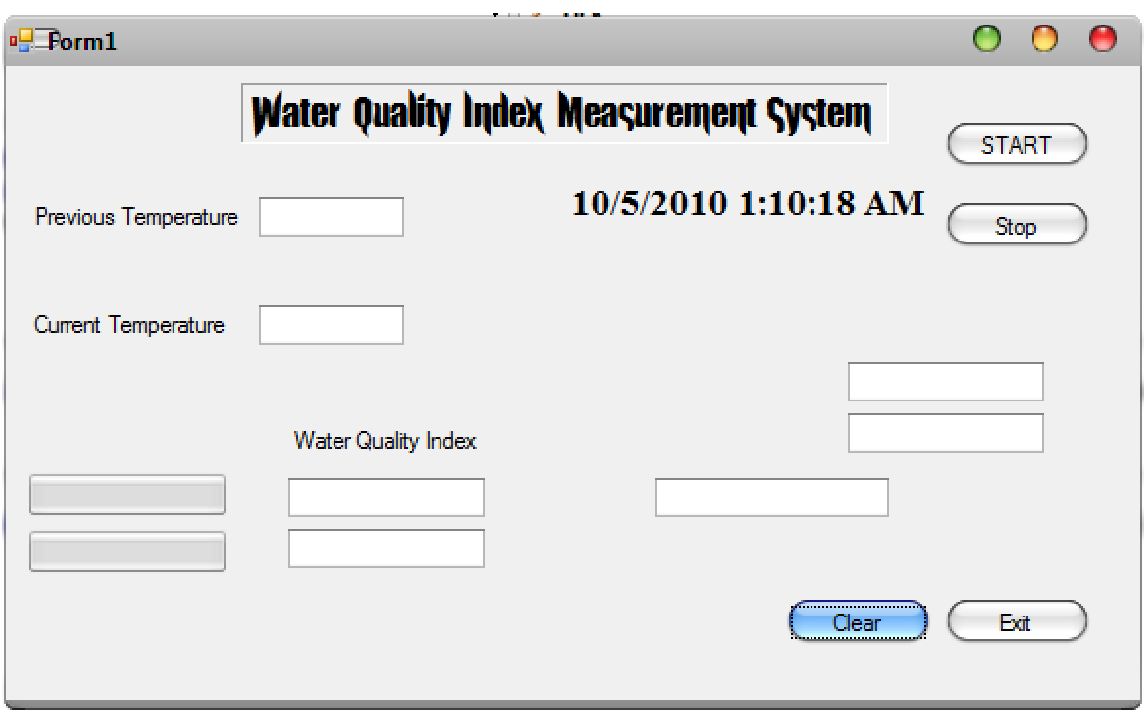


Figure 4.1: Front Page of GUI

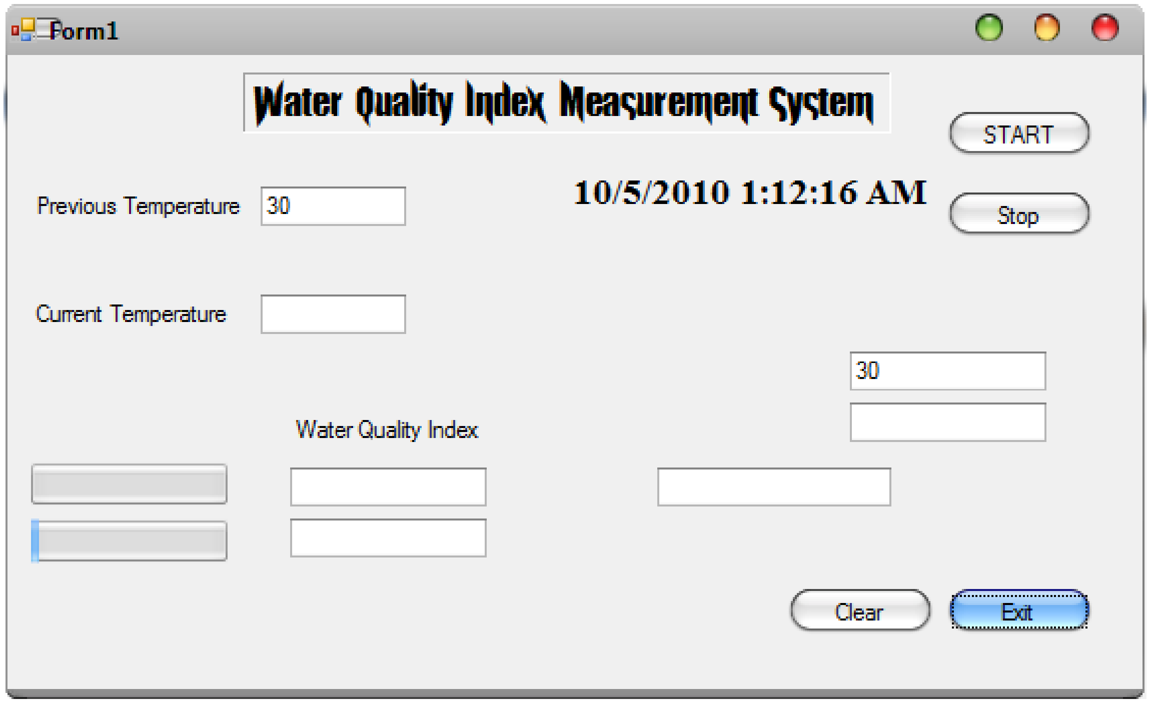


Figure 4.2: The reading of the 1st data

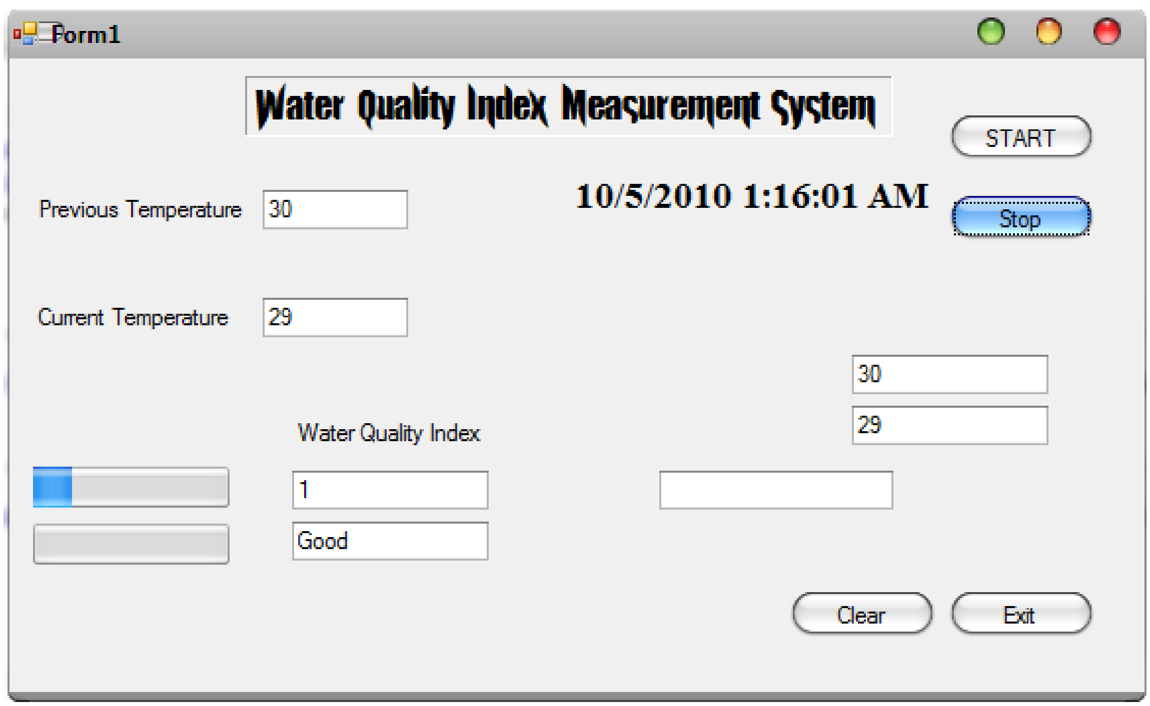


Figure 4.3: The reading of the 2nd data and the WQI calculation result

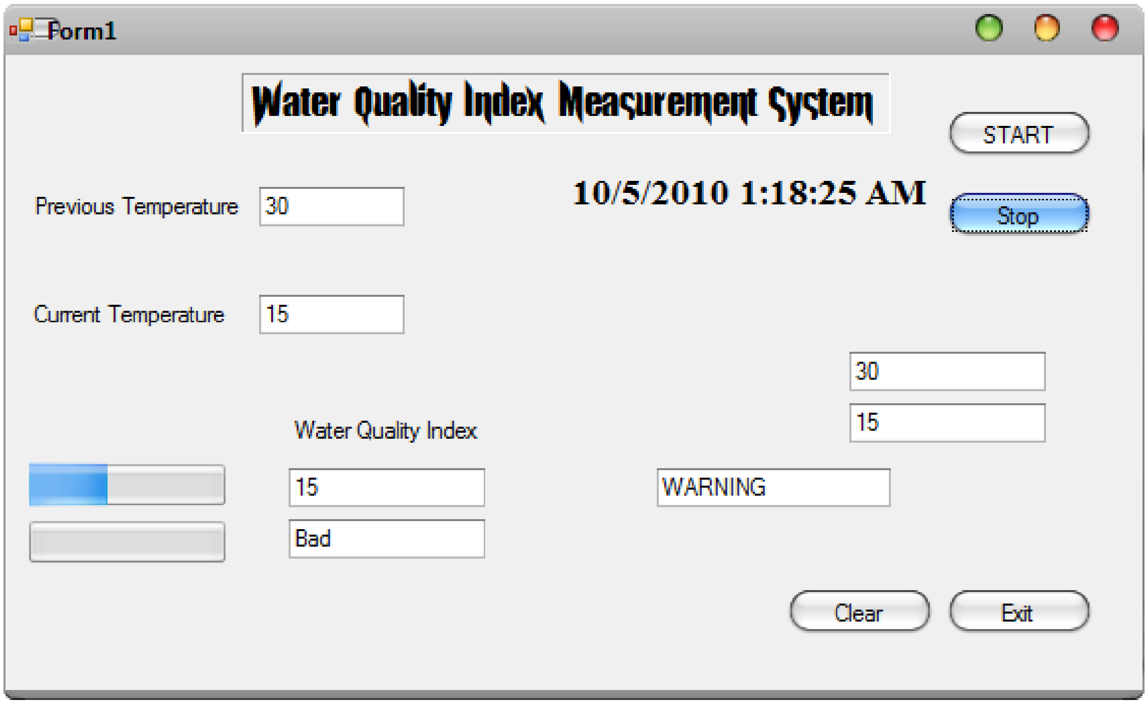


Figure 4.4: The result for Warning WQI

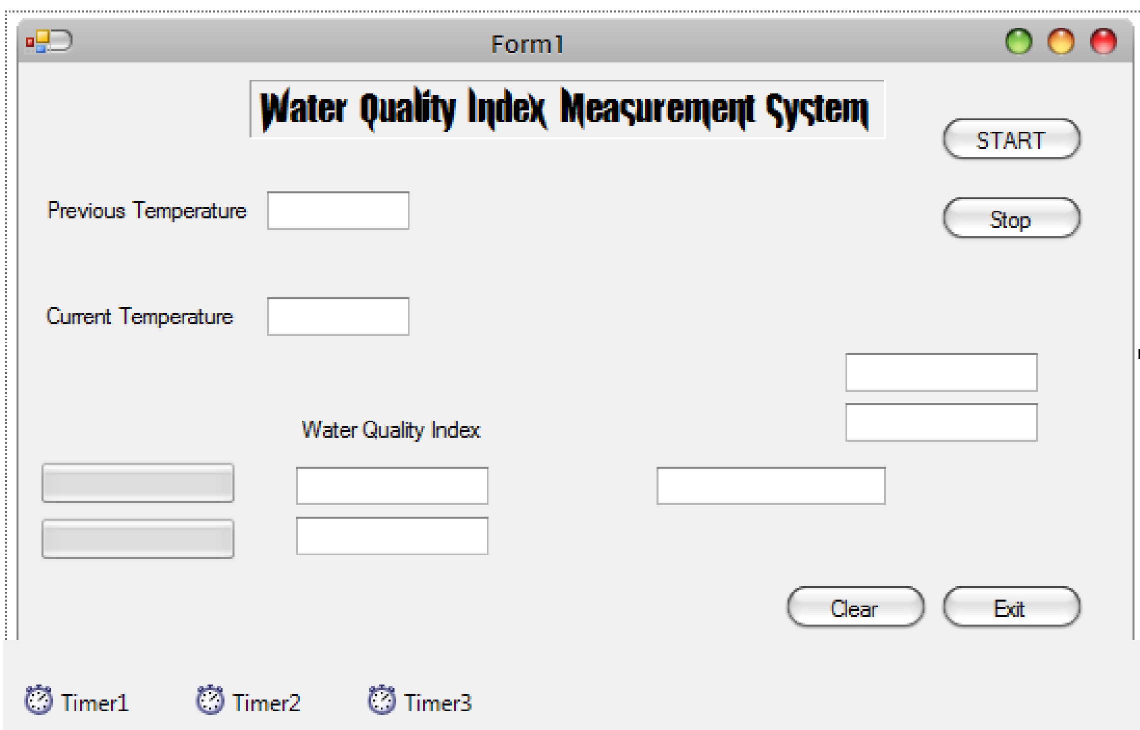


Figure 4.5: The GUI form with Timer

The temperature of the water from UMP lake will be taken six times during working hour which is between 8am to 5pm. The data saved include the time and date which the data have been taken, and also the WQI of the water as in figure 4.6. The data will be saved to excel format automatically when six reading have been taken from the sensor. The data also can be saved during the process which mean if there is only three data needed for the user, click the save button at the third reading to saved the data manually. The example of the data saved in excel format are in figure 4.7 and figure 4.8.

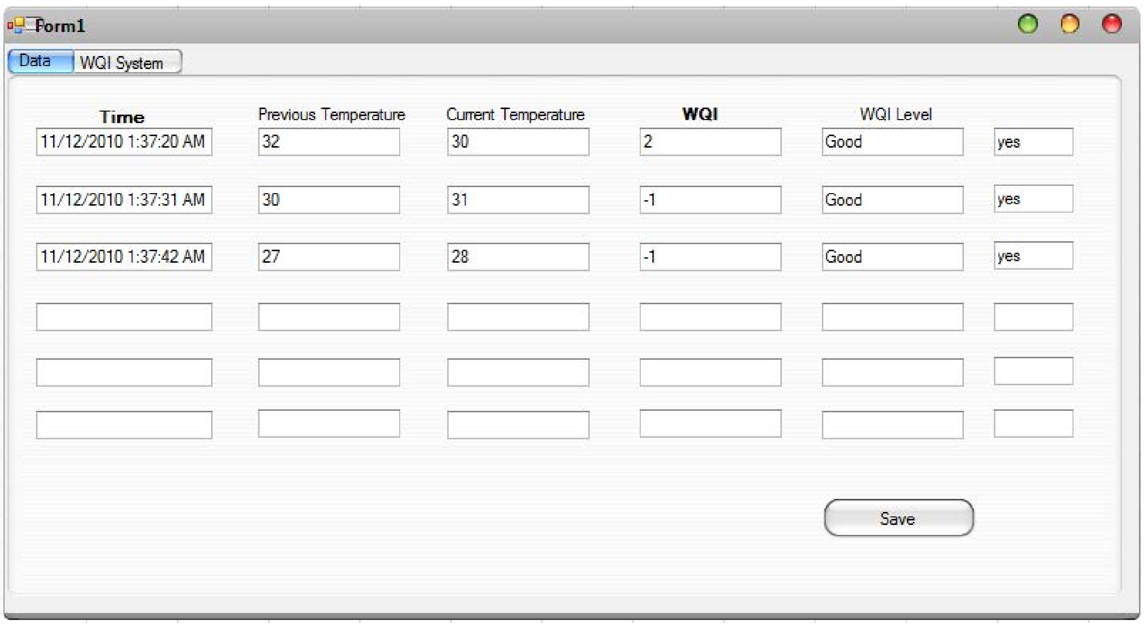


Figure 4.6: Temperature and WQI data recorded Form

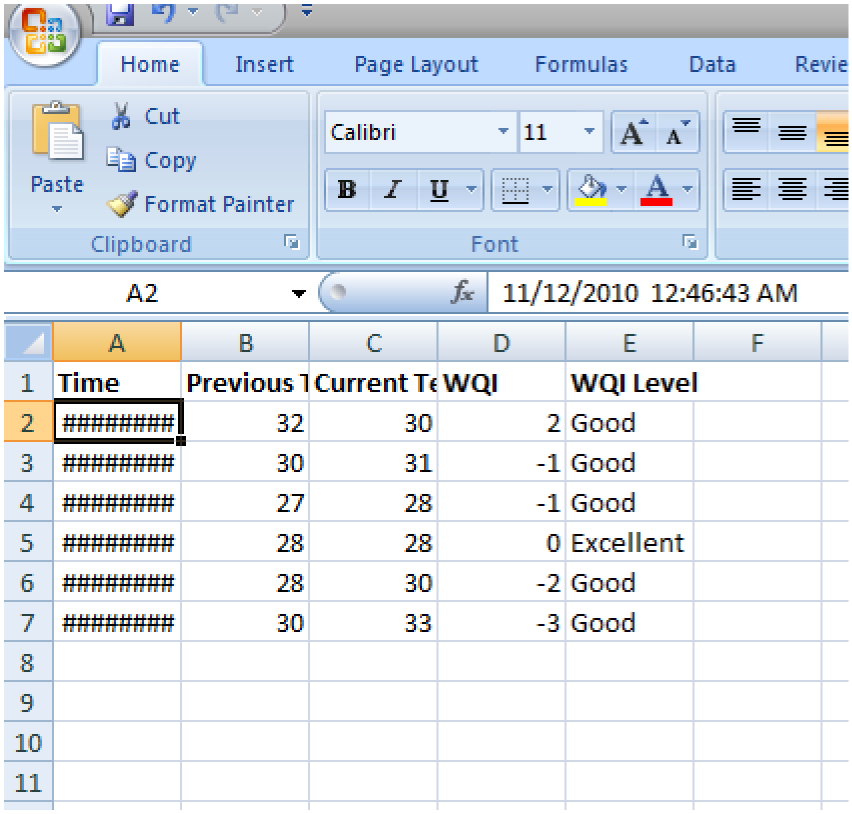


Figure 4.7: Data in Excel

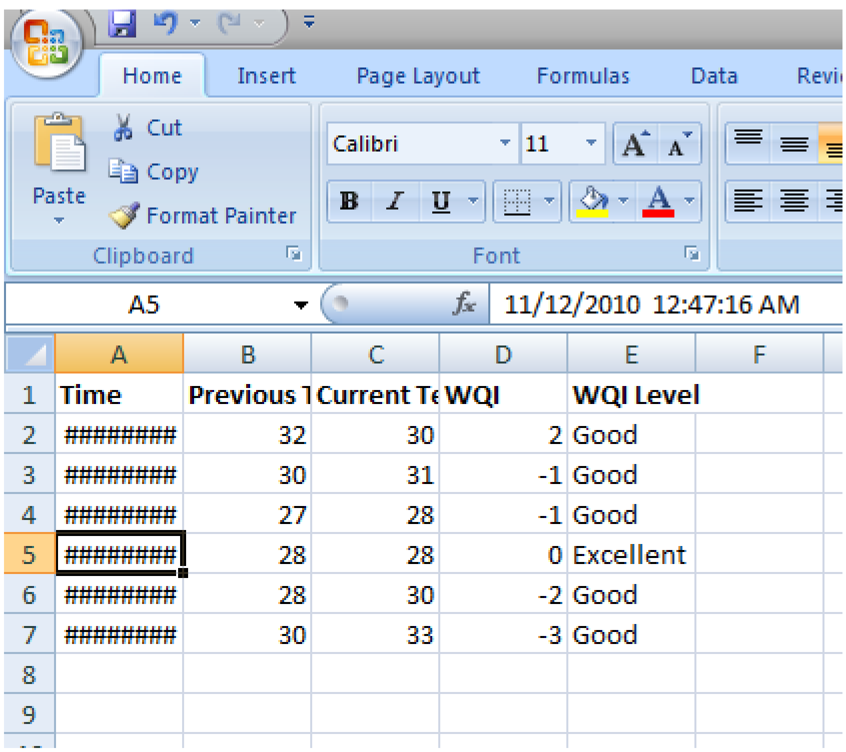


Figure 4.8: Data save in Excel

From the six reading which been taken, a graph will be compute from the reading to show the different of WQI and also the temperature of the UMP lake water in six different reading. The WQI and temperature reading graph showed in figure 4.9 and figure 4.10 below.

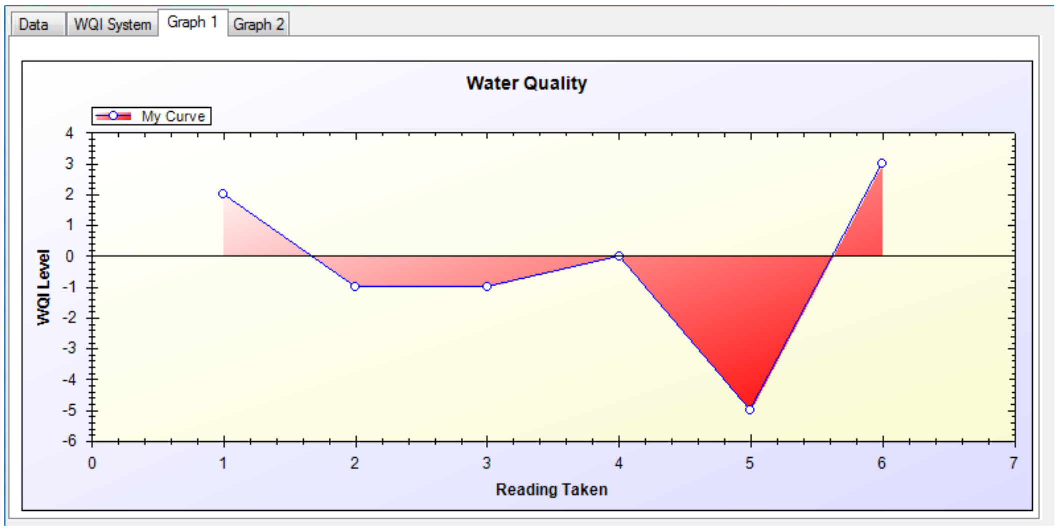


Figure 4.9: WQI Graph

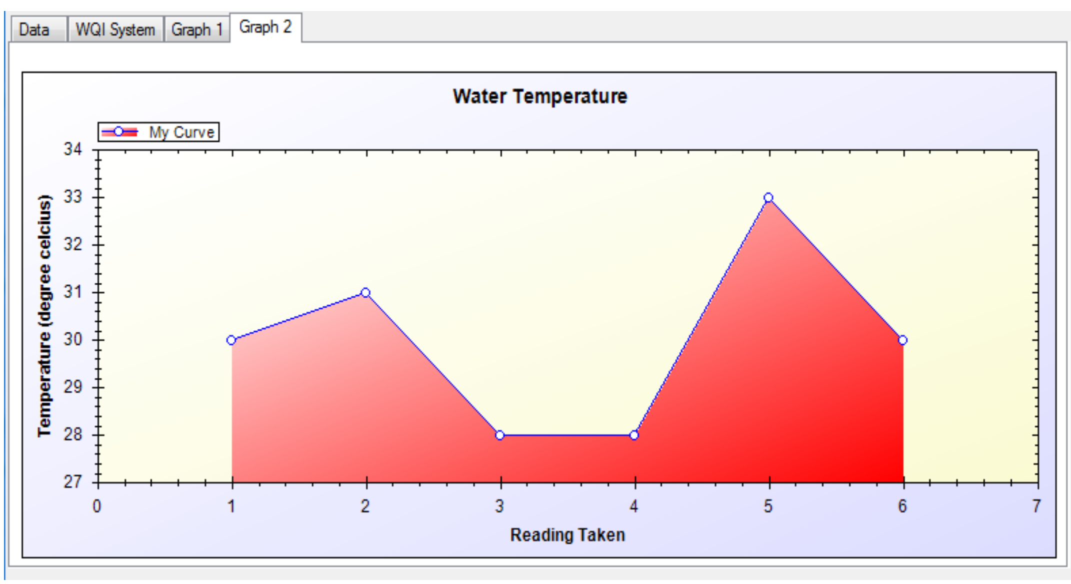


Figure 4.10: Temperature reading graph

# Chapter 6

# Conclusion and Recommendation

## 6.1 Conclusion

The main objective of this project is to develop a wireless temperature measurement system as well as calculate the WQI in UMP Lake. As the conclusion of this project, the temperature data can be transfer to the computer through wireless network. Then, the analog signal from temperature sensor can be converted to digital using ZigBee ADC (analog to digital) line support so it can be read by the Zigbee transmitter. The signal from Zigbee transmitter will be sent to Zigbee receiver.

Then, the data will be display at the computer screen by using the Visual Basic software. By using the Visual Basic software, the WQI of UMP Lake can be calculated while monitoring the lake temperature. The system will give an alert if the temperature exceed to the dangerous level. This wireless temperature monitoring system can be used for impossible sensor applications such as to monitor temperature at some place which difficult for human to reach.

## 6.2 Problem Encountered

When carrying out this project, there are a few problems that had been encountered in order to achieve the objectives, such as:

i) Window Vista and Window 7 limitation

Nowadays, most of the Personal Computer and Laptop were using window 7 or window vista as the operating system. This system are the newest window produced by Microsoft for use on personal computers, including home and business desktops, laptops, netbooks, tablet PCs, and media center PCs. However, some software such as X-CTU (Zigbee wireless system driver) is not incompatible with window 7 or window vista. Its only can be used with window XP. There is the X-CTU driver which compatible with window 7, but it is hard to find.

ii) Limited Budget

This system can be more efficient if the XBee-PRO XSC is use as the wireless transmitter and receiver modules. XBee-PRO XSC are extended-range 900 MHz embedded wireless solutions providing end-point connectivity to devices. These modules are capable of deploying point-to-point, peer-to-peer and point-to-multipoint networks. Designed for maximum range, the XBee-PRO XSC is ideal for solutions where RF penetration and absolute transmission distance are paramount to the application. The outdoor range of signal can go up to 15miles (24KM) with high gain antenna which suitable to use as wireless modules for this project which involve a high distance location. However, the price is too expensive which exceed the budget given. Hence, the XBee-PRO OEM RF modules have been chosen as the wireless modules which have a range only up to 1 mile (outdoor range).

## 6.3 Recommendation

For further research, there are several recommendation to enhance and improve the system, such as:

i) Use Window XP

At the beginning of the project, Window XP must be install to the PC that will be use in this project. Most of the software or the drivers that will be use in this project are more compatible with window XP rather than window 7 or window vista. Hence to prevent from the driver or the software cannot be use on the PC which will delay the project, window XP is recommended as the operating system in the PC.

ii) Use the XBee-PRO XSC

This system can be upgrade by using XBee-PRO XSC as the wireless transmitter and receiver modules in this project. XBee-PRO XSC is more efficient device than XBee-PRO OEM RF because it's have a high outdoor signal range which suitable to use for this project.

iii) Implement the project with more sensors

The WQI originally involve 9 different measurements such as pH, dissolved oxygen, turbidity, fecal coliform, biochemical oxygen, total phosphates, nitrates, and total suspended solid. So, the project can be implemented on bigger range by using the sensors from all 9 measurement of the WQI to get the more precise result. For example, we can add pH sensors to check the pH water quality of UMP Lake and combine the calculation with the temperature measurement to get better result of WQI.

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# APPENDIX A

## Visual Basic Programming

```vb
'Exit Button
        Dim StMsg As String
        Dim inResult As Integer
        Dim oExcel As Object
        Dim oBook As Object
        StMsg = "Betul ke nak keluar?"
        inResult = MsgBox(StMsg, vbYesNo + vbQuestion, "close conformation")
        If inResult = vbYes Then
            Close()
        Else : Return

        End If



'1st Reading at timer
        Dim A As Double
        Label6.Text = System.DateTime.Now
        ProgressBar1.Value += 10
        Timer3.Enabled = False

        If ProgressBar1.Value = 100 Then
            A = TextBox6.Text
            TextBox1.Text = A
            Timer2.Enabled = True
            Timer1.Enabled = False
            ProgressBar1.Value = 0

        End If



'2nd reading at timer
        Dim B As Double
        ProgressBar2.Value += 2

        If ProgressBar2.Value = 100 Then
            B = TextBox6.Text
            TextBox2.Text = B
            Timer3.Enabled = True
            Timer2.Enabled = False
            ProgressBar2.Value = 0

        End If
```

```
'Start Button
        SerialPort1.Open()
        SerialPort1.ReadByte()

        Timer1.Enabled = True
        Timer19.Enabled = True
        ProgressBar1.Enabled = True
        ProgressBar2.Enabled = True


        'Start a new workbook in Excel
        oExcel = CreateObject("Excel.Application")
        oBook = oExcel.Workbooks.Add



'WQI Reading
        TextBox3.Text = TextBox1.Text - TextBox2.Text

        If TextBox3.Text = 0 Then
            TextBox4.Text = "Excellent"
            TextBox5.Text = ""
        ElseIf TextBox3.Text <= 5 And TextBox3.Text >= -5 Then
            TextBox4.Text = "Good"
            TextBox5.Text = ""
        ElseIf TextBox3.Text <= 10 And TextBox3.Text >= -10 Then
            TextBox4.Text = "Everage"
            TextBox5.Text = ""
        ElseIf TextBox3.Text <= 20 And TextBox3.Text >= -20 Then
            TextBox4.Text = "Bad"
            TextBox5.Text = "WARNING"
        Else : TextBox4.Text = "Very Bad"
            TextBox5.Text = "WARNING"
        End If

        TextBox8.Text = Label6.Text
        TextBox9.Text = TextBox1.Text
        TextBox10.Text = TextBox2.Text
        TextBox11.Text = TextBox3.Text
        TextBox32.Text = TextBox4.Text
        TextBox38.Text = "yes"

        If TextBox38.Text = "yes" Then
            Timer4.Enabled = True
            Timer1.Enabled = False
            Timer2.Enabled = False
        End If
```

```
'Save In Excel
        'Add data to cells of the first worksheet in the new workbook
        oSheet = oBook.Worksheets(1)
        oSheet.Range("A1").Value = "Time"
        oSheet.Range("B1").Value = "Previous Temperature"
        oSheet.Range("C1").Value = "Current Temperature"
        oSheet.Range("D1").Value = "WQI"
        oSheet.Range("E1").Value = "WQI Level"
        oSheet.Range("A1:B1:C1:D1:E1").Font.Bold = True
        oSheet.Range("A2").Value = TextBox8.Text
        oSheet.Range("B2").Value = TextBox9.Text
        oSheet.Range("C2").Value = TextBox10.Text
        oSheet.Range("D2").Value = TextBox11.Text
        oSheet.Range("E2").Value = TextBox32.Text
        oSheet.Range("A3").Value = TextBox12.Text
        oSheet.Range("B3").Value = TextBox14.Text
        oSheet.Range("C3").Value = TextBox13.Text
        oSheet.Range("D3").Value = TextBox15.Text
        oSheet.Range("E3").Value = TextBox33.Text
        oSheet.Range("A4").Value = TextBox16.Text
        oSheet.Range("B4").Value = TextBox18.Text
        oSheet.Range("C4").Value = TextBox19.Text
        oSheet.Range("D4").Value = TextBox17.Text
        oSheet.Range("E4").Value = TextBox34.Text
        oSheet.Range("A5").Value = TextBox20.Text
        oSheet.Range("B5").Value = TextBox24.Text
        oSheet.Range("C5").Value = TextBox23.Text
        oSheet.Range("D5").Value = TextBox21.Text
        oSheet.Range("E5").Value = TextBox35.Text
        oSheet.Range("A6").Value = TextBox22.Text
        oSheet.Range("B6").Value = TextBox27.Text
        oSheet.Range("C6").Value = TextBox26.Text
        oSheet.Range("D6").Value = TextBox25.Text
        oSheet.Range("E6").Value = TextBox36.Text
        oSheet.Range("A7").Value = TextBox28.Text
        oSheet.Range("B7").Value = TextBox31.Text
        oSheet.Range("C7").Value = TextBox30.Text
        oSheet.Range("D7").Value = TextBox29.Text
        oSheet.Range("E7").Value = TextBox37.Text


        'Save the Workbook and Quit Excel
        oBook.SaveAs("C:\Users\Zaiful\Documents\Book1.xlsx")
        oExcel.Quit()
```

```
'CODING GRAPH
            Dim myPane As GraphPane = zg1.GraphPane

            ' Set the title and axis labels
            myPane.Title.Text = "Water Quality"
            myPane.XAxis.Title.Text = "Reading Taken"
            myPane.YAxis.Title.Text = "WQI Level"

            ' Make up some data arrays based on the Sine function
            Dim list As New PointPairList()
            'list.Add(TextBox8.Text, TextBox11.Text)
            Dim x As Double, y As Double, i As Integer
            For i = 0 To 5
                x = i + 1
                If x = 1 Then
                    y = TextBox11.Text
                ElseIf x = 2 Then
                    y = TextBox15.Text
                ElseIf x = 3 Then
                    y = TextBox17.Text
                ElseIf x = 4 Then
                    y = TextBox21.Text
                ElseIf x = 5 Then
                    y = TextBox25.Text
                ElseIf x = 6 Then
                    y = TextBox29.Text
                End If
                list.Add(x, y)
            Next i

            ' Generate a blue curve with circle symbols, and "My Curve 2" in
the legend
            Dim myCurve As LineItem = myPane.AddCurve("My Curve", list,
Color.Blue, SymbolType.Circle)
            ' Fill the area under the curve with a white-red gradient at 45
degrees
            myCurve.Line.Fill = New Fill(Color.White, Color.Red, 45.0F)
            ' Make the symbols opaque by filling them with white
            myCurve.Symbol.Fill = New Fill(Color.White)

            ' Fill the axis background with a color gradient
            myPane.Chart.Fill = New Fill(Color.White,
Color.LightGoldenrodYellow, 45.0F)

            ' Fill the pane background with a color gradient
            myPane.Fill = New Fill(Color.White, Color.FromArgb(220, 220,
255), 45.0F)

            ' Calculate the Axis Scale Ranges
            zg1.AxisChange()
```

```
'Serial Port Reading
      If SerialPort1.ReadByte = 0 Then
          TextBox6.Text = SerialPort1.ReadByte
      Else : Timer21.Enabled = False
      End If
      Timer21.Enabled = False
```

# APPENDIX B

## X-CTU Configuration & Test Utility Software

# X-CTU
# Configuration & Test Utility Software

## User's Guide

## Contents




Technical Support:

Online support: http://www.digi.com/support/eservice/login.jsp

Phone: (801) 765-9885



90001003_A

2008.08.20

## Introduction

This User's Guide is intended to discuss the functions of Digi's X-CTU software utility. Each function will be discussed in detail allowing a better understanding of the program and how it can be used.

X-CTU is a Windows-based application provided by Digi. This program was designed to interact with the firmware files found on Digi's RF products and to provide a simple-to-use graphical user interface to them.

X-CTU is designed to function with all Windows-based computers running Microsoft Windows 98 SE and above. X-CTU can either be downloaded from Digi's Web site or an installation CD. When properly installed it can be launched by clicking on the icon on the PC desktop (see Figure 1) or selecting from the Start menu (see Figure 2).

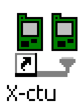



Figure 1


Figure 2

When launched, you will see four tabs across the top of the program (see Figure 3). Each of these tabs has a different function. The four tabs are:

**PC Settings**: Allows a customer to select the desired COM port and configure that port to fit the radios settings.

**Range Test**: Allows a customer to perform a range test between two radios.

**Terminal**: Allows access to the computers COM port with a terminal emulation program. This tab also allows the ability to access the radios' firmware using AT commands (for a complete listing of the radios' AT commands, please see the product manuals available online).

**Modem Configuration**: Allows the ability to program the radios' firmware settings via a graphical user interface. This tab also allows customers the ability to change firmware versions.

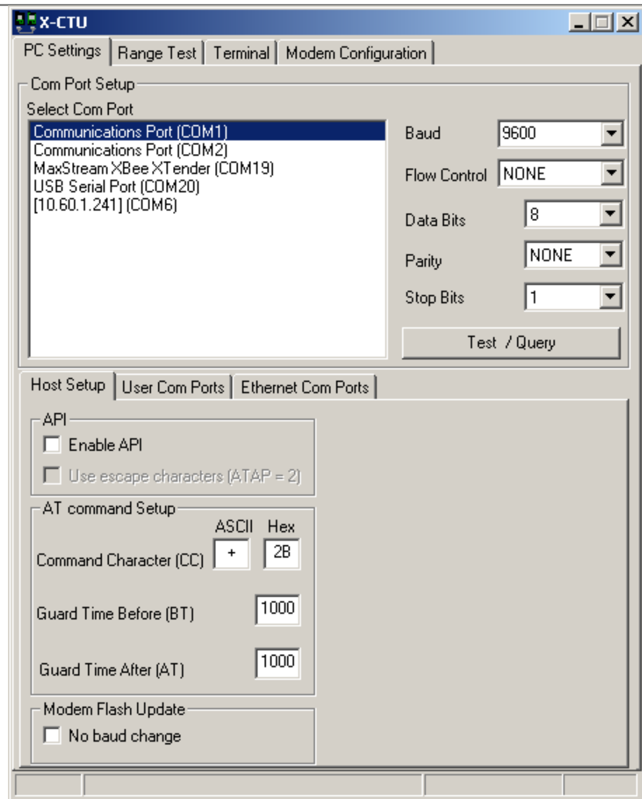



Figure 3

## PC Settings Tab

When the program is launched, the default tab selected is the "PC Settings" tab. The PC Settings tab is broken down into three basic areas: The COM port setup, the Host Setup, and the User Com ports.

**COM port setup:**

The PC settings tab allows the user to select a COM port and configure the selected COM port settings when accessing the port. Some of these settings include:

| | |
|---|---|
| Baud Rate: | Both standard and non-standard |
| Flow Control: | Hardware, Software (Xon/Xoff), None |
| Data bits: | 4, 5, 6, 7, and 8 data bits |
| Parity: | None, Odd, Even, Mark and Space |
| Stop bit: | 1, 1.5, and 2 |

To change any of the above settings, select the pull down menu on the left of the value and select the desired setting. To enter a non-standard baud rate, type the baud rate into the baud rate box to the left.

The **Test / Query** button is used to test the selected COM port and PC settings. If the settings and COM port are correct, you will receive a response similar to the one depicted in Figure 4 below.

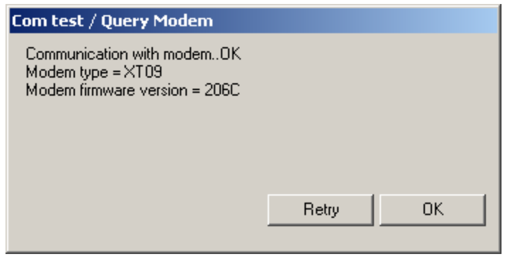



Figure 4

**Host Setup:**

The Host Setup tab allows the user to configure how the X-CTU program is to interface with a radio's firmware. This includes determining whether API or AT command mode will be used to access the module's firmware as well as the proper command mode character and sequence.

By default, the Host Settings are as follows:

| | |
|---|---|
| API mode: | not enabled (Not checked) |
| Command mode Character: | + (ACSII) 2B (Hex). |
| Before Guard Time: | 1000 (1 Sec) |
| After Guard Time: | 1000 (1 Sec) |

This is the default value of our radios. If this is not the value of the AT, BT, or GT commands of the connected radio, enter the respective value here.

**User COM ports:**

The user COM port option allows the user to "Add" or "Delete" a user-created COM port. This is only for temporary use. Once the program has closed, the user-created COM port will disappear and is no longer accessible to the program.

## Range Test Tab

The range test tab is designed to verify the range of the radio link by sending a user-specified data packet and verifying the response packet is the same, within the time specified. For performing a standard range test, please follow the steps found in most Quick Start or Getting Started Guides that ship with the product.

**Packet Data and Size**

By default, the size of the data packet sent is 32 bytes. This data packet specified can be adjusted in either size or the text sent.

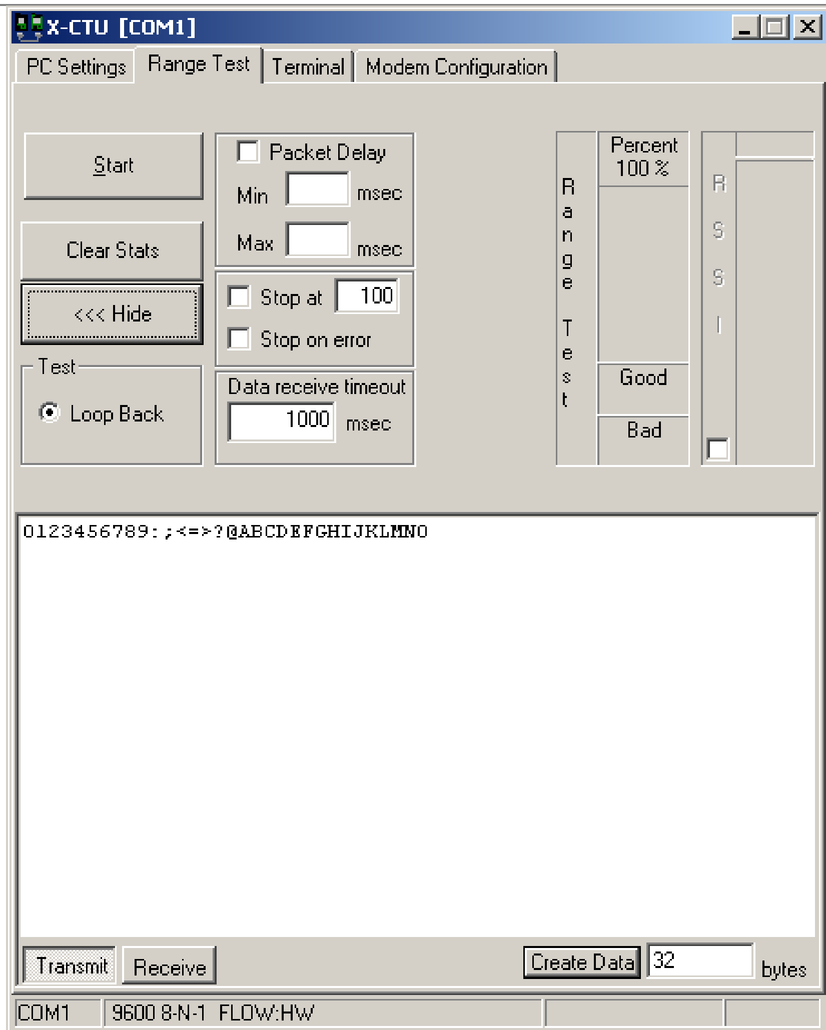



Figure 5

To modify the size of the packet sent, change the value next to the "Create Data" box and click on the "Create Data" button (see Figure 5). If you want to change the data sent, delete the text in the transmit window and place in your desired text.

By modifying the text, data packet size, packet delay and the data receive timeout; the user is able to simulate a wide range of scenarios.

**RSSI:**

The RSSI option of the X-CTU allows the user to see the RSSI (Received Signal Strength Indicator) of a received packet when performing a range test.

**API Function:**

The X-CTU also allows the user to test the API function of a radio during a range test.

To perform a range test with the API function of the radio, follow the steps outlined below:

1: Configure the Base with API enabled and a unique 16 bit or 64 bit source address.
2: Configure the remote radio with a unique source address and set the Destination address to equal the Base radio's source address.
3: Enable the API option of the X-CTU on the PC Settings tab and connect the base radio to the PC (See Figure 3).
4: Connect the red loopback adapter to the remote radio and place them a distance apart.
5: Enter either the 16 bit or 64 bit destination address of the remote radio into the Destination Address box on the Range Test tab (See figure 6).
6: Create a data packet of your choosing by typing in the data in the Transmit box
7: To start a Range test, click on Start.

You will notice the TX failures, Purge, CCA, and ACK messages will increment accordingly while the range test is performed.

To stop a range test, click on the Stop button.

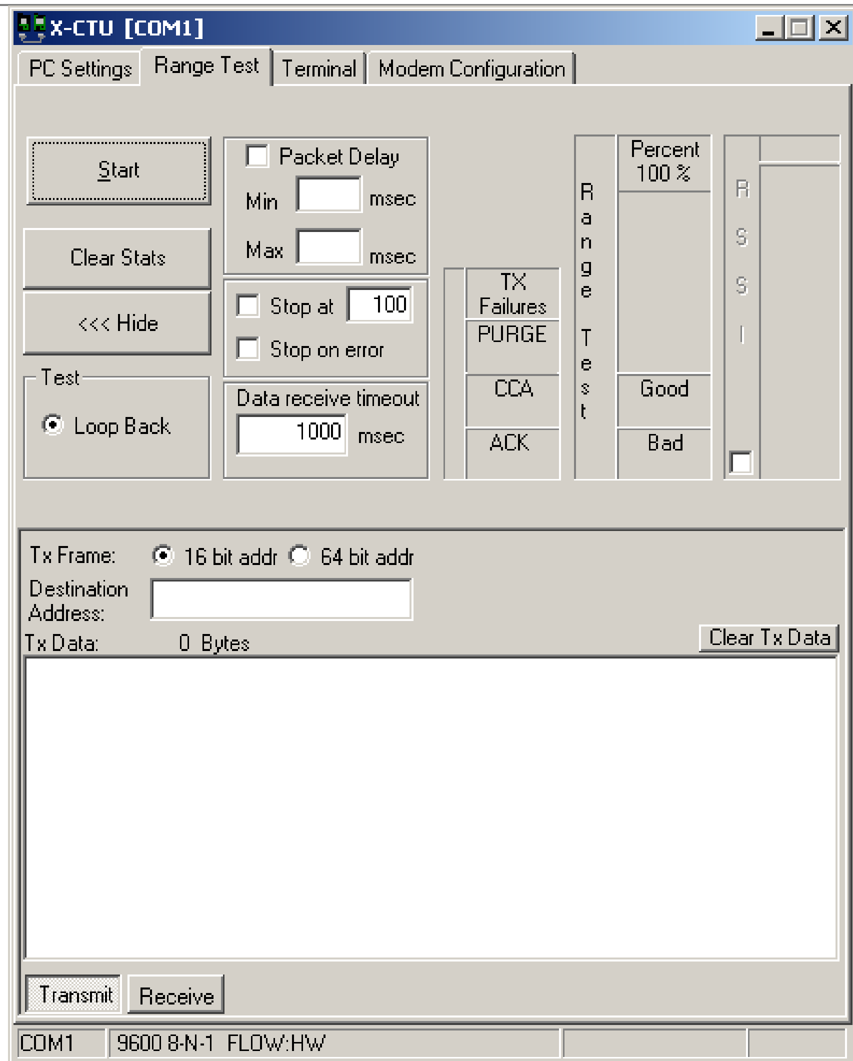



Figure 6

## The Terminal Tab

The Terminal tab has three basic functions:

Terminal emulator

Ability to send and receive predefined data pacts (Assemble packet)

Ability to send and receive data in Hex and ASCII formats (Show/Hide hex)

### The main terminal window

The main white portion of this tab is where most of the communications information will occur while using X-CTU as a terminal emulator. The text in blue is what has been typed in and directed out to the radio's serial port while the red text is the incoming data from the radio's serial port (see Figure 7).

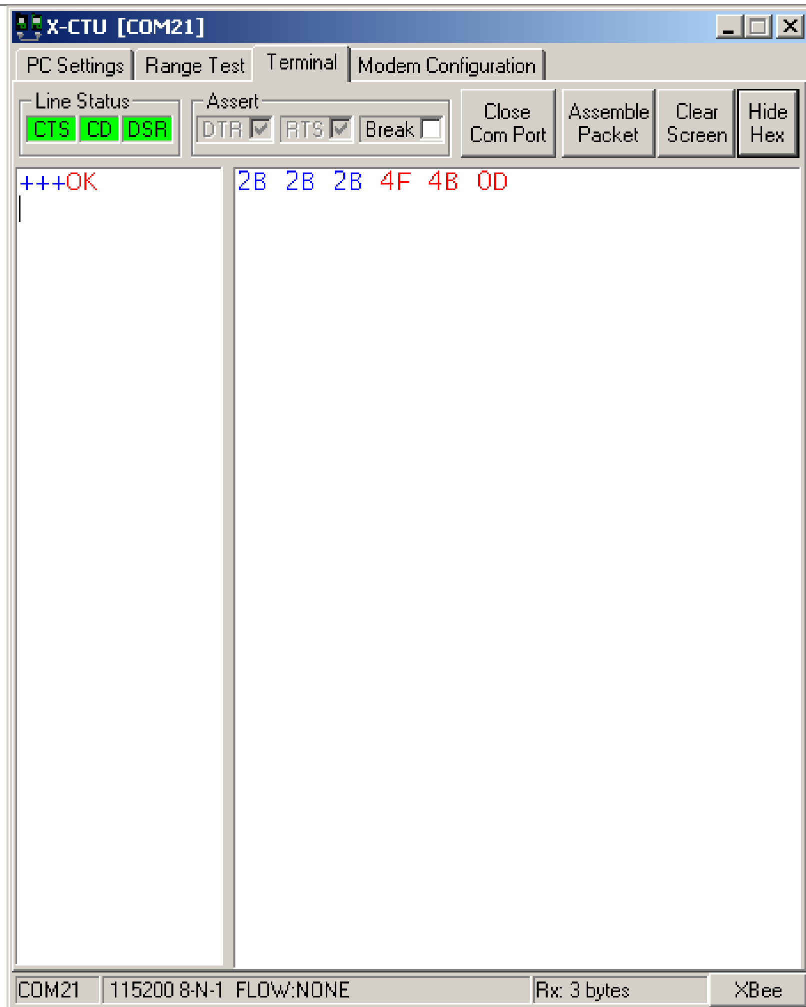



Figure 7

**Assemble Packet**

The Assemble Packet option on the Terminal tab is designed to allow the user to assemble a data packet in either ASCII or Hex characters. This is accomplished by selecting the Assemble packet window and choosing either ASCII (default) or Hex. Once selected, the data packet is assembled by typing in the desired characters as depicted in Figure 8.

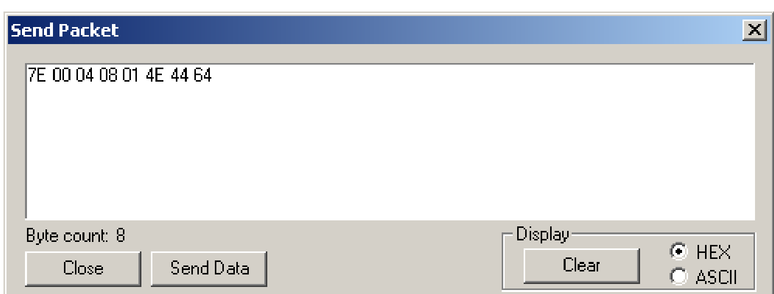



Figure 8

The **Line Status** indicators depicted in Figure 5 shows the status of the RS-232 hardware flow control lines. Green indicates the line is asserted while black indicates de-asserted.

The **Break** option is for engaging the serial line break. This can be accomplished by checking or asserting the Break option. Asserting the Break will place the DI line high and prevent data from being sent to the radio.

## Modem Configuration tab

The Modem configuration tab has four basic functions:

1: Provide a Graphical User Interface with a radio's firmware
2: Read and Write firmware to the radio's microcontroller
3: Download updated firmware files from either the web or from a compressed file
4: Saving or loading a modem profile

### Reading a radio's firmware

To read a radio's firmware, follow the steps outlined below:

1: Connect the radio module to the interface board and connect this assembly or a packaged radio (PKG) to the PC's corresponding port (IE: USB, RS232, Ethernet etc.).
2: Set the PC Settings tab (see Figure 3) to the radio's default settings.
3: On the Modem Configuration tab, select "Read" from the Modem Parameters and Firmware section (see Figure 9).

### Making changes to a radio's firmware

Once the radio's firmware has been read, the configuration settings are displayed in three colors (see Figure 10):

Black – not settable or read-only
Green – Default value
Blue – User-specified

To modify any of the user-settable parameters, click on the associated command and type in the new value for that parameter. For ease of understanding a specific command, once the command is selected, a quick description along with its limits is provided at the bottom of the screen. Once all of the new values have been entered, the new values are ready to be saved to the radio's non-volatile memory.

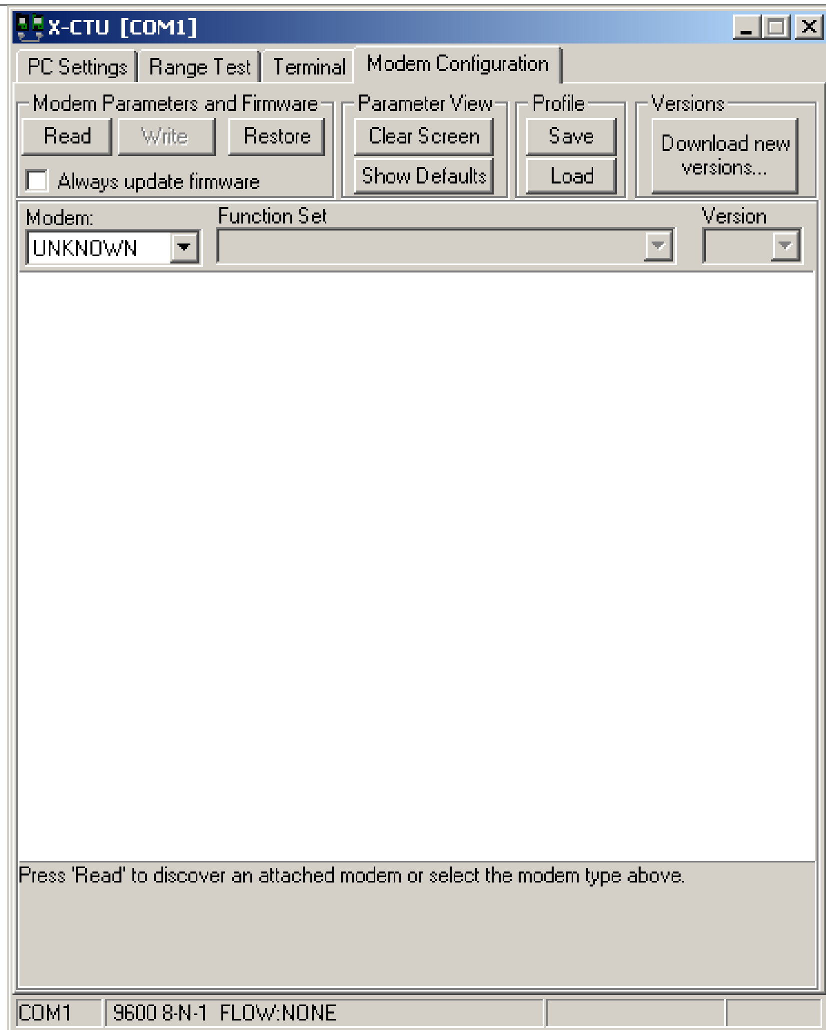



Figure 9

## Writing firmware to the Radio

To write the parameter changes to the radio's non-volatile memory, click on the Write button located in the Modem Parameters and Firmware section (see Figure 10)

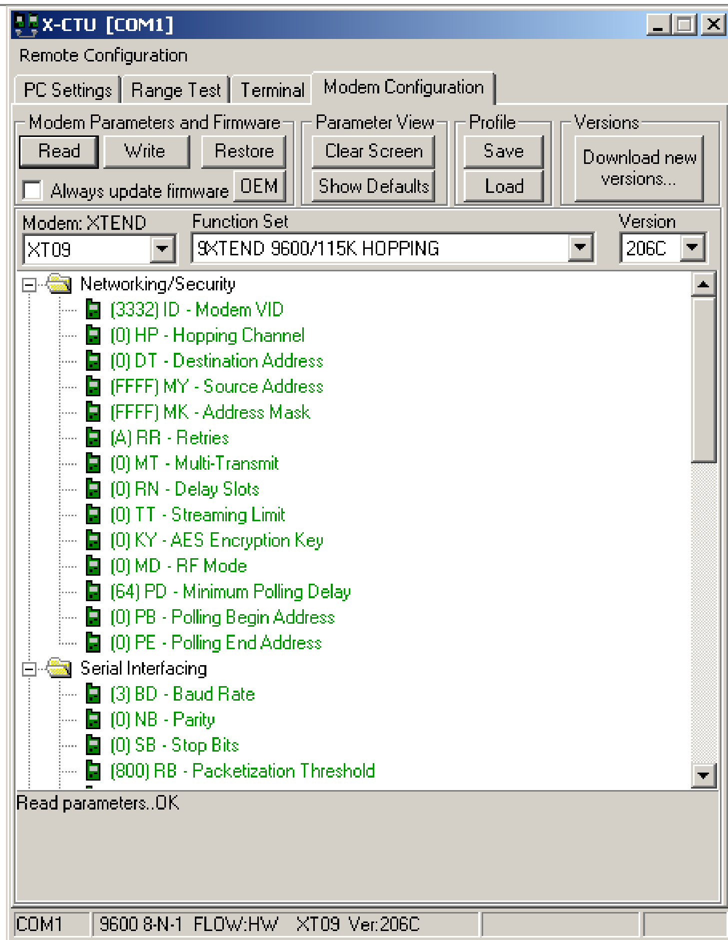



Figure 10

Downloading Updated Firmware Files

Another function of the Modem Configuration tab is allowing the user to download updated firmware files from either the web or install them from a disk or CD. This is accomplished by following the steps below:

1: Click on the Download New Versions… option under the Version section

2a: Click on Web for downloading new firmware files from the web

2b: Click on the File when installing compressed firmware files from a CD or saved file (see Figures 11 and 12)

 2bi: Browse to the location the file is saved at and click on Open (see Figure 13)

3: Click on OK and Done when prompted

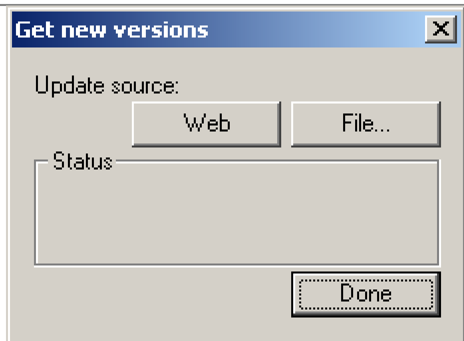



Figure 11

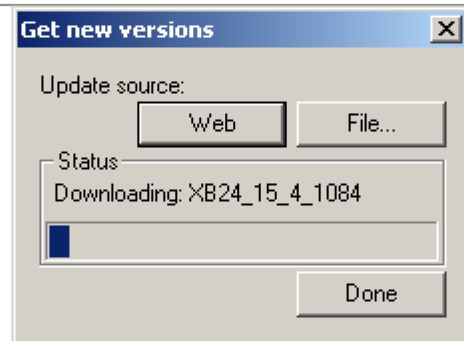



Figure 12

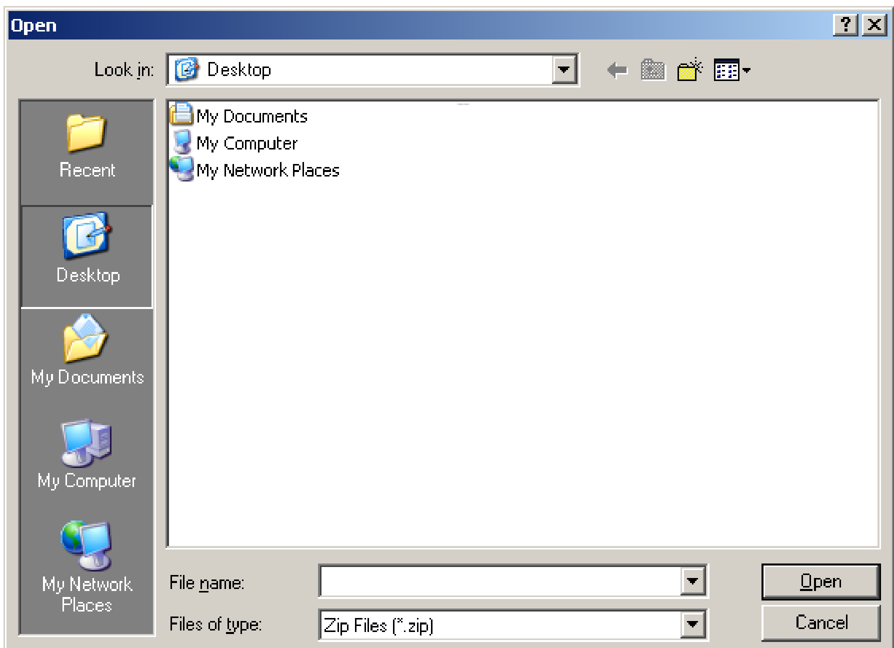



Figure 13

## Modem Profiles

The X-CTU has the ability to save and write saved modem profiles or configuration to the radio. This function is useful in a production environment when the same parameters need to be set on multiple radios.

How to save a profile:

1: Set the desired settings within the radio's firmware as described in the Making changes to the radios firmware section
2: Click Save in the Profile section
3: Type in the desired name of this profile in the File Name box (see Figure 14)
4: Browse to the location where you wish to save your profile
5: Click Save

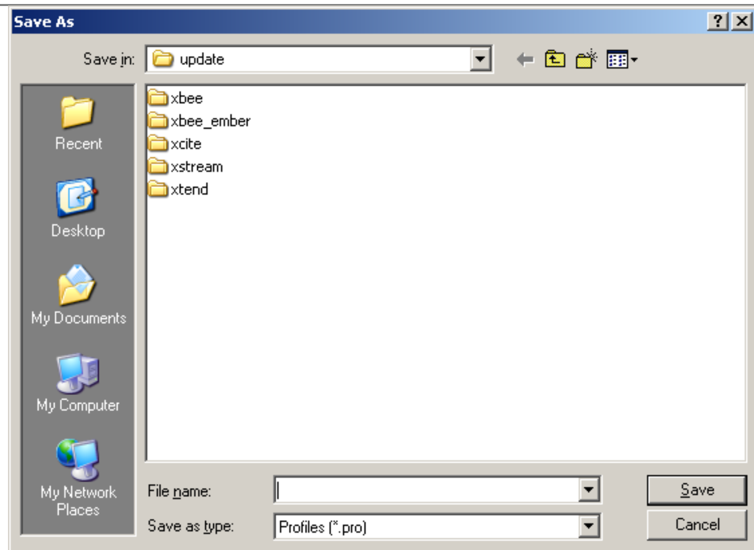



Figure 14

How to load a saved profile:

1: Click on Load from the profile section
2: Browse to the location of the file and click on the desired file (see Figure 15)
3: Click Open

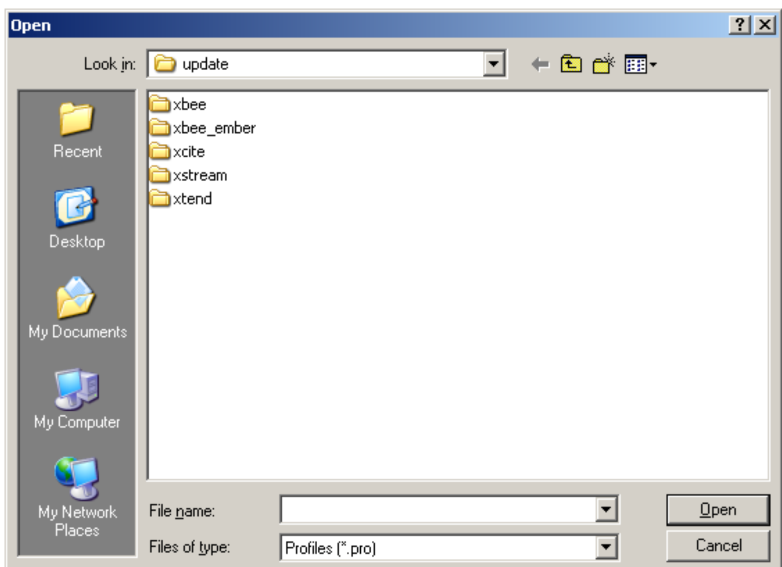



Figure 15

To save the loaded profile to the radio once you have loaded the file, follow the steps outlined in the Writing firmware to the radio section above.

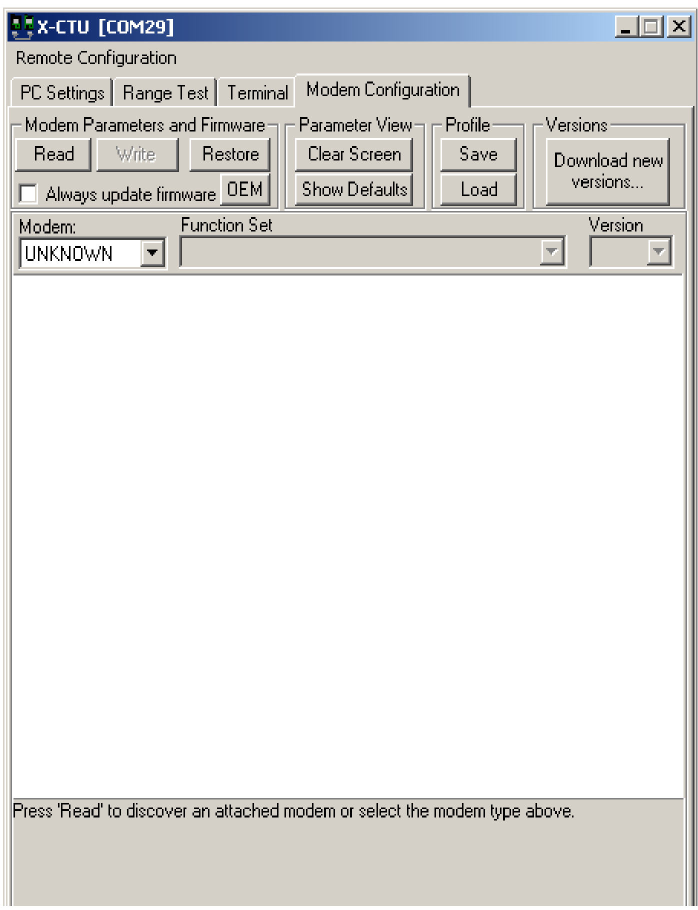
To find out how to load the saved profiles in a production environment from a DOS prompt, please follow the steps outlined in Digi's online Knowledgebase at http://www.maxstream.net/support/knowledgebase/article.php?kb=126

XBee 802.15.4 modules with firmware version 1xCx and above, XBee ZNet 2.5 modules, and XBee ZB modules offer the ability to be configured with over the air commands. With the addition of this new feature, the user is able to configure remote radio parameters with X-CTU or API packets. To use the remote configuration tool, the following is required:

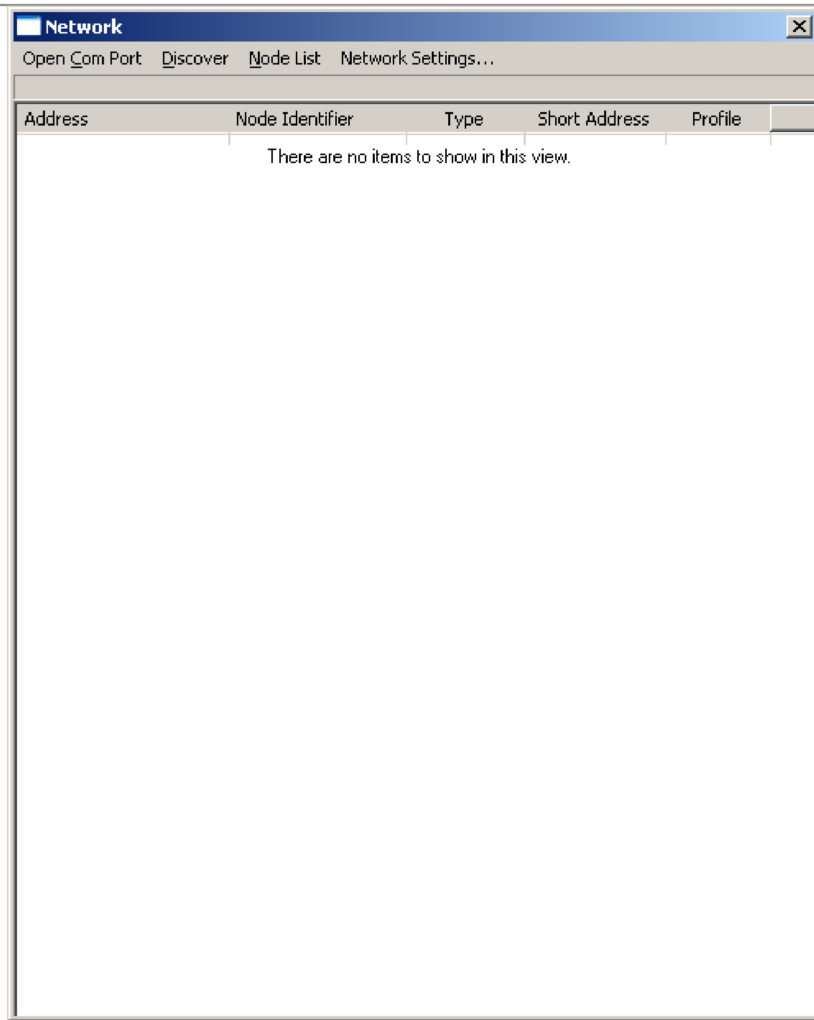
- The radio connected to the PC must be in API mode
- The remote radio must be associated or within range of the base radio

To access remote radios through X-CTU's Modem Configuration tab, perform the steps below:

- Enable API on the PC Settings tab
- Verify the COM port selection and settings
- On the Modem Configuration tab, select the Remote Configuration option on the top left corner of the program




- Select Open Com port
- Select Discover




- Select the desired modem from the discovered node list
- On the Modem configuration tab, select Read

The remote radio's configuration is now displayed on the Modem Configuration tab. At this point, the same options exist with respect to Read and Write parameter changes. Please note that the ability to change firmware versions is still limited to the radio's UART.

To clear the discovered node list, click on Node List and Clear.

The Node List option provides several additional options, including:

- Ability to print the discovered list
- Ability to remove a specific node from a list
- Ability to add additional nodes that have not been discovered
- Save the Node List
- Load a saved Node List
- Select/filter All, Routers, or End nodes

For specific questions related to the X-CTU configuration and test utility software, please contact our Support department, Mon – Fri, 8am – 5pm U.S. Mountain Time:

US and Canada Toll free:
(866)765-9885

Local or International calls:
(801) 765-9885

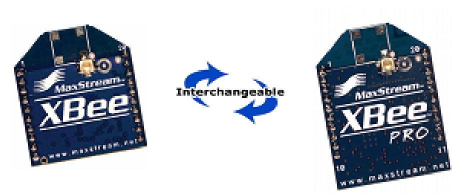
Online support: http://www.digi.com/support/eservice/login.jsp

# APPENDIX C

# XBee®/XBee-PRO OEM RF Modules Manual

# XBee®/XBee-PRO® OEM RF Modules






**Product Manual v1.xCx - 802.15.4 Protocol**

For OEM RF Module Part Numbers: XB24-...-001, XBP24-...-001

**IEEE® 802.15.4 OEM RF Modules by Digi International**


Digi International Inc.
11001 Bren Road East
Minnetonka, MN 55343
877 912-3444 or 952 912-3444
http://www.digi.com



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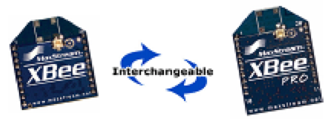
2008.09.04

# 1. XBee®/XBee-PRO OEM RF Modules

The XBee and XBee-PRO OEM RF Modules were engineered to meet IEEE 802.15.4 standards and support the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power and provide reliable delivery of data between devices.

The modules operate within the ISM 2.4 GHz frequency band and are pin-for-pin compatible with each other.




## Key Features

**Long Range Data Integrity**

**XBee**

- Indoor/Urban: up to 100' (30 m)
- Outdoor line-of-sight: up to 300' (90 m)
- Transmit Power: 1 mW (0 dBm)
- Receiver Sensitivity: -92 dBm

**XBee-PRO**

- Indoor/Urban: up to 300' (90 m), 200' (60 m) for International variant
- Outdoor line-of-sight: up to 1 mile (1600 m), 2500' (750 m) for International variant
- Transmit Power: 63mW (18dBm), 10mW (10dBm) for International variant
- Receiver Sensitivity: -100 dBm

RF Data Rate: 250,000 bps

**Advanced Networking & Security**

Retries and Acknowledgements

DSSS (Direct Sequence Spread Spectrum)

Each direct sequence channels has over 65,000 unique network addresses available

Source/Destination Addressing

Unicast & Broadcast Communications

Point-to-point, point-to-multipoint and peer-to-peer topologies supported

**Low Power**

**XBee**

- TX Peak Current: 45 mA (@3.3 V)
- RX Current: 50 mA (@3.3 V)
- Power-down Current: < 10 µA

**XBee-PRO**

- TX Peak Current: 250mA (150mA for international variant)
- TX Peak Current (RPSMA module only): 340mA (180mA for international varian
- RX Current: 55 mA (@3.3 V)
- Power-down Current: < 10 µA

**ADC and I/O line support**

Analog-to-digital conversion, Digital I/O

I/O Line Passing

**Easy-to-Use**

No configuration necessary for out-of box RF communications

Free X-CTU Software (Testing and configuration software)

AT and API Command Modes for configuring module parameters

Extensive command set

Small form factor

## Worldwide Acceptance

**FCC Approval** (USA) Refer to Appendix A [p63] for FCC Requirements. Systems that contain XBee®/XBee-PRO RF Modules inherit Digi Certifications.

ISM (Industrial, Scientific & Medical) **2.4 GHz frequency band**

Manufactured under **ISO 9001:2000** registered standards

XBee®/XBee-PRO RF Modules aare optimized for use in the United States, Canada, Australia, Israel, Japan, and Europe. Contact Digi for complete list of government agency approvals.

## Specifications

Table 1-01. Specifications of the XBee®/XBee-PRO OEM RF Modules

| Specification | XBee | XBee-PRO |
|---|---|---|
| **Performance** | | |
| Indoor/Urban Range | Up to 100 ft (30 m) | Up to 300 ft. (90 m), up to 200 ft (60 m) International variant |
| Outdoor RF line-of-sight Range | Up to 300 ft (90 m) | Up to 1 mile (1600 m), up to 2500 ft (750 m) international variant |
| Transmit Power Output (software selectable) | 1mW (0 dBm) | 63mW (18dBm)*<br>10mW (10 dBm) for International variant |
| RF Data Rate | 250,000 bps | 250,000 bps |
| Serial Interface Data Rate (software selectable) | 1200 bps - 250 kbps (non-standard baud rates also supported) | 1200 bps - 250 kbps (non-standard baud rates also supported) |
| Receiver Sensitivity | -92 dBm (1% packet error rate) | -100 dBm (1% packet error rate) |
| **Power Requirements** | | |
| Supply Voltage | 2.8 – 3.4 V | 2.8 – 3.4 V |
| Transmit Current (typical) | 45mA (@ 3.3 V) | 250mA (@3.3 V) (150mA for international variant)<br>RPSMA module only: 340mA (@3.3 V) (180mA for international variant) |
| Idle / Receive Current (typical) | 50mA (@ 3.3 V) | 55mA (@ 3.3 V) |
| Power-down Current | < 10 µA | < 10 µA |
| **General** | | |
| Operating Frequency | ISM 2.4 GHz | ISM 2.4 GHz |
| Dimensions | 0.960" x 1.087" (2.438cm x 2.761cm) | 0.960" x 1.297" (2.438cm x 3.294cm) |
| Operating Temperature | -40 to 85º C (industrial) | -40 to 85º C (industrial) |
| Antenna Options | Integrated Whip, Chip or U.FL Connector, RPSMA Connector | Integrated Whip, Chip or U.FL Connector, RPSMA Connector |
| **Networking & Security** | | |
| Supported Network Topologies | Point-to-point, Point-to-multipoint & Peer-to-peer | |
| Number of Channels (software selectable) | 16 Direct Sequence Channels | 12 Direct Sequence Channels |
| Addressing Options | PAN ID, Channel and Addresses | PAN ID, Channel and Addresses |
| **Agency Approvals** | | |
| United States (FCC Part 15.247) | OUR-XBEE | OUR-XBEEPRO |
| Industry Canada (IC) | 4214A XBEE | 4214A XBEEPRO |
| Europe (CE) | ETSI | ETSI (Max. 10 dBm transmit power output)* |
| Japan | R201WW07215214 | R201WW08215111* (Max. 10 dBm transmit power output)** |
| Australia | C-Tick | C-Tick |

* When operating in Europe, XBee-PRO 802.15.4 modules must operate at or below a transmit power output level of 10dBm. Customers have two choices for transmitting at or below 10dBm:

a. Order the standard XBee-PRO module and change the PL command to "0" (10dBm),

b. Order the International variant of the XBee-PRO module, which has a maximum transmit output power of 10dBm (@ PL=4).

Additionally, European regulations stipulate an EIRP power maximum of 12.86 dBm (19 mW) for the XBee-PRO and 12.11 dBm for the XBee when integrating antennas.

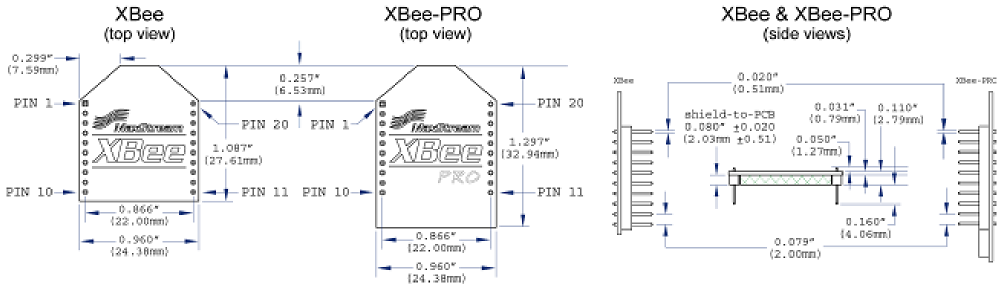
** When operating in Japan, only the International variant of the XBee-PRO 802.15.4 module is approved for use.

Antenna Options: The ranges specified are typical when using the integrated Whip (1.5 dBi) and Dipole (2.1 dBi) antennas. The Chip antenna option provides advantages in its form factor; however, it typically yields shorter range than the

Whip and Dipole antenna options when transmitting outdoors.For more information, refer to the "XBee Antennas" Knowledgebase Article located on Digi's Support Web site

## Mechanical Drawings

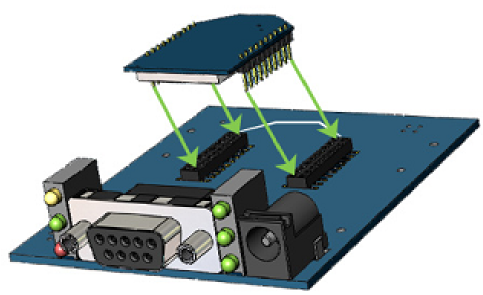
**Figure 1-01. Mechanical drawings of the XBee®/XBee-PRO OEM RF Modules (antenna options not shown)**
The XBee and XBee-PRO RF Modules are pin-for-pin compatible.




## Mounting Considerations

The XBee®/XBee-PRO RF Module was designed to mount into a receptacle (socket) and therefore does not require any soldering when mounting it to a board. The XBee Development Kits contain RS-232 and USB interface boards which use two 20-pin receptacles to receive modules.

**Figure 1-02. XBee Module Mounting to an RS-232 Interface Board.**



The receptacles used on Digi development boards are manufactured by Century Interconnect. Several other manufacturers provide comparable mounting solutions; however, Digi currently uses the following receptacles:

- Through-hole single-row receptacles -
  Samtec P/N: MMS-110-01-L-SV (or equivalent)
- Surface-mount double-row receptacles -
  Century Interconnect P/N: CPRMSL20-D-0-1 (or equivalent)
- Surface-mount single-row receptacles -
  Samtec P/N: SMM-110-02-SM-S

Digi also recommends printing an outline of the module on the board to indicate the orientation the module should be mounted.

## Pin Signals

**Figure 1-03. XBee®/XBee-PRO RF Module Pin Numbers**

(top sides shown - shields on bottom)

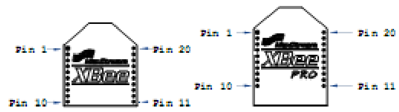



**Table 1-02. Pin Assignments for the XBee and XBee-PRO Modules**
(Low-asserted signals are distinguished with a horizontal line above signal name.)

| Pin # | Name | Direction | Description |
|---|---|---|---|
| 1 | VCC | - | Power supply |
| 2 | DOUT | Output | UART Data Out |
| 3 | DIN / CONFIG | Input | UART Data In |
| 4 | DO8* | Output | Digital Output 8 |
| 5 | RESET | Input | Module Reset (reset pulse must be at least 200 ns) |
| 6 | PWM0 / RSSI | Output | PWM Output 0 / RX Signal Strength Indicator |
| 7 | PWM1 | Output | PWM Output 1 |
| 8 | [reserved] | - | Do not connect |
| 9 | DTR / SLEEP_RQ / DI8 | Input | Pin Sleep Control Line or Digital Input 8 |
| 10 | GND | - | Ground |
| 11 | AD4 / DIO4 | Either | Analog Input 4 or Digital I/O 4 |
| 12 | CTS / DIO7 | Either | Clear-to-Send Flow Control or Digital I/O 7 |
| 13 | ON / SLEEP | Output | Module Status Indicator |
| 14 | VREF | Input | Voltage Reference for A/D Inputs |
| 15 | Associate / AD5 / DIO5 | Either | Associated Indicator, Analog Input 5 or Digital I/O 5 |
| 16 | RTS / AD6 / DIO6 | Either | Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6 |
| 17 | AD3 / DIO3 | Either | Analog Input 3 or Digital I/O 3 |
| 18 | AD2 / DIO2 | Either | Analog Input 2 or Digital I/O 2 |
| 19 | AD1 / DIO1 | Either | Analog Input 1 or Digital I/O 1 |
| 20 | AD0 / DIO0 | Either | Analog Input 0 or Digital I/O 0 |

* Function is not supported at the time of this release

**Design Notes:**

- Minimum connections: VCC, GND, DOUT & DIN
- Minimum connections for updating firmware: VCC, GND, DIN, DOUT, RTS & DTR
- Signal Direction is specified with respect to the module
- Module includes a 50k Ω pull-up resistor attached to RESET
- Several of the input pull-ups can be configured using the PR command
- Unused pins should be left disconnected

# Electrical Characteristics

Table 1-03. DC Characteristics (VCC = 2.8 - 3.4 VDC)

| Symbol | Characteristic | Condition | Min | Typical | | Max | Unit |
|---|---|---|---|---|---|---|---|
| $V_{IL}$ | Input Low Voltage | All Digital Inputs | - | - | | 0.35 * VCC | V |
| $V_{IH}$ | Input High Voltage | All Digital Inputs | 0.7 * VCC | - | | - | V |
| $V_{OL}$ | Output Low Voltage | $I_{OL}$ = 2 mA, VCC >= 2.7 V | - | - | | 0.5 | V |
| $V_{OH}$ | Output High Voltage | $I_{OH}$ = -2 mA, VCC >= 2.7 V | VCC - 0.5 | - | | - | V |
| $II_{IN}$ | Input Leakage Current | $V_{IN}$ = VCC or GND, all inputs, per pin | - | 0.025 | | 1 | µA |
| $II_{OZ}$ | High Impedance Leakage Current | $V_{IN}$ = VCC or GND, all I/O High-Z, per pin | - | 0.025 | | 1 | µA |
| TX | Transmit Current | VCC = 3.3 V | - | 45 (XBee) | 215, 140 (PRO, Int) | - | mA |
| RX | Receive Current | VCC = 3.3 V | - | 50 (XBee) | 55 (PRO) | - | mA |
| PWR-DWN | Power-down Current | SM parameter = 1 | - | < 10 | | - | µA |

Table 1-04. ADC Characteristics (Operating)

| Symbol | Characteristic | Condition | Min | Typical | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{REFH}$ | VREF - Analog-to-Digital converter reference range | | 2.08 | - | $V_{DDAD}$ | V |
| $I_{REF}$ | VREF - Reference Supply Current | Enabled | - | 200 | - | µA |
| | | Disabled or Sleep Mode | - | < 0.01 | 0.02 | µA |
| $V_{INDC}$ | Analog Input Voltage[1] | | $V_{SSAD}$ - 0.3 | - | $V_{DDAD}$ + 0.3 | V |

1. Maximum electrical operating range, not valid conversion range.

Table 1-05. ADC Timing/Performance Characteristics[1]

| Symbol | Characteristic | Condition | Min | Typical | Max | Unit |
|---|---|---|---|---|---|---|
| $R_{AS}$ | Source Impedance at Input[2] | | - | - | 10 | kΩ |
| $V_{AIN}$ | Analog Input Voltage[3] | | $V_{REFL}$ | | $V_{REFH}$ | V |
| RES | Ideal Resolution (1 LSB)[4] | 2.08V ≤ $V_{DDAD}$ ≤ 3.6V | 2.031 | - | 3.516 | mV |
| DNL | Differential Non-linearity[5] | | - | ±0.5 | ±1.0 | LSB |
| INL | Integral Non-linearity[6] | | - | ±0.5 | ±1.0 | LSB |
| $E_{ZS}$ | Zero-scale Error[7] | | - | ±0.4 | ±1.0 | LSB |
| $F_{FS}$ | Full-scale Error[8] | | - | ±0.4 | ±1.0 | LSB |
| $E_{IL}$ | Input Leakage Error[9] | | - | ±0.05 | ±5.0 | LSB |
| $E_{TU}$ | Total Unadjusted Error[10] | | - | ±1.1 | ±2.5 | LSB |

1. All ACCURACY numbers are based on processor and system being in WAIT state (very little activity and no IO switching) and that adequate low-pass filtering is present on analog input pins (filter with 0.01 µF to 0.1 µF capacitor between analog input and VREFL). Failure to observe these guidelines may result in system or microcontroller noise causing accuracy errors which will vary based on board layout and the type and magnitude of the activity.
Data transmission and reception during data conversion may cause some degradation of these specifications, depending on the number and timing of packets. It is advisable to test the ADCs in your installation if best accuracy is required.
2. $R_{AS}$ is the real portion of the impedance of the network driving the analog input pin. Values greater than this amount may not fully charge the input circuitry of the ATD resulting in accuracy error.
3. Analog input must be between $V_{REFL}$ and $V_{REFH}$ for valid conversion. Values greater than $V_{REFH}$ will convert to $3FF.
4. The resolution is the ideal step size or 1LSB = $(V_{REFH}–V_{REFL})/1024$
5. Differential non-linearity is the difference between the current code width and the ideal code width (1LSB). The current code width is the difference in the transition voltages to and from the current code.
6. Integral non-linearity is the difference between the transition voltage to the current code and the adjusted ideal transition voltage for the current code. The adjusted ideal transition voltage is $(Current Code–1/2)*(1/((V_{REFH}+E_{FS})–(V_{REFL}+E_{ZS})))$.
7. Zero-scale error is the difference between the transition to the first valid code and the ideal transition to that code. The Ideal transition voltage to a given code is $(Code–1/2)*(1/(V_{REFH}–V_{REFL}))$.
8. Full-scale error is the difference between the transition to the last valid code and the ideal transition to that code. The ideal transition voltage to a given code is $(Code–1/2)*(1/(V_{REFH}–V_{REFL}))$.
9. Input leakage error is error due to input leakage across the real portion of the impedance of the network driving the analog pin. Reducing the impedance of the network reduces this error.
10. Total unadjusted error is the difference between the transition voltage to the current code and the ideal straight-line transfer function. This measure of error includes inherent quantization error (1/2LSB) and circuit error (differential, integral, zero-scale, and full-scale) error. The specified value of $E_{TU}$ assumes zero $E_{IL}$ (no leakage or zero real source impedance).

## ADC and Digital I/O Line Support

The XBee®/XBee-PRO RF Modules support ADC (Analog-to-digital conversion) and digital I/O line passing. The following pins support multiple functions:

**Table 2-01. Pin functions and their associated pin numbers and commands**
AD = Analog-to-Digital Converter, DIO = Digital Input/Output
Pin functions not applicable to this section are denoted within (parenthesis).

| Pin Function | Pin# | AT Command |
|---|---|---|
| AD0 / DIO0 | 20 | D0 |
| AD1 / DIO1 | 19 | D1 |
| AD2 / DIO2 | 18 | D2 |
| AD3 / DIO3 / (COORD_SEL) | 17 | D3 |
| AD4 / DIO4 | 11 | D4 |
| AD5 / DIO5 / (ASSOCIATE) | 15 | D5 |
| DIO6 / (RTS) | 16 | D6 |
| DIO7 / (CTS) | 12 | D7 |
| DI8 / (DTR) / (Sleep_RQ) | 9 | D8 |

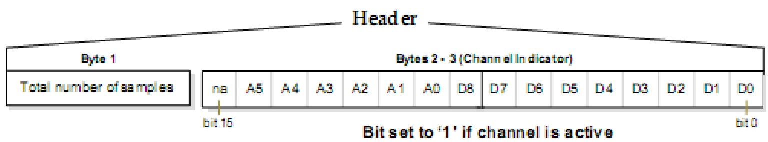
To enable ADC and DIO pin functions:

| | |
|---|---|
| For ADC Support: | Set ATDn = 2 |
| For Digital Input support: | Set ATDn = 3 |
| For Digital Output Low support: | Set ATDn = 4 |
| For Digital Output High support: | Set ATDn = 5 |

### I/O Data Format

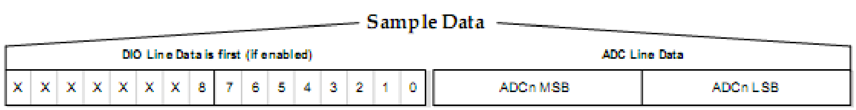
I/O data begins with a header. The first byte of the header defines the number of samples forthcoming. The last 2 bytes of the header (Channel Indicator) define which inputs are active. Each bit represents either a DIO line or ADC channel.

**Figure 2-04. Header**




Sample data follows the header and the channel indicator frame is used to determine how to read the sample data. If any of the DIO lines are enabled, the first 2 bytes are the DIO sample. The ADC data follows. ADC channel data is represented as an unsigned 10-bit value right-justified on a 16- bit boundary.

**Figure 2-05. Sample Data**



## I/O Line Passing

Virtual wires can be set up between XBee®/XBee-PRO Modules. When an RF data packet is received that contains I/O data, the receiving module can be setup to update any enabled outputs (PWM and DIO) based on the data it receives.

Note that I/O lines are mapped in pairs. For example: AD0 can only update PWM0 and DI5 can only update DO5. The default setup is for outputs not to be updated, which results in the I/O data being sent out the UART (refer to the IU (Enable I/O Output) command). To enable the outputs to be updated, the IA (I/O Input Address) parameter must be setup with the address of the module that has the appropriate inputs enabled. This effectively binds the outputs to a particular module's input. This does not affect the ability of the module to receive I/O line data from other modules - only its ability to update enabled outputs. The IA parameter can also be setup to accept I/O data for output changes from any module by setting the IA parameter to 0xFFFF.

When outputs are changed from their non-active state, the module can be setup to return the output level to it non-active state. The timers are set using the Tn (Dn Output Timer) and PT (PWM Output Timeout) commands. The timers are reset every time a valid I/O packet (passed IA check) is received. The IC (Change Detect) and IR (Sample Rate) parameters can be setup to keep the output set to their active output if the system needs more time than the timers can handle.

Note: DI8 cannot be used for I/O line passing.

**Applicable Commands:** IA (I/O Input Address), Tn (Dn Output Timeout), P0 (PWM0 Configuration), P1 (PWM1 Configuration), M0 (PWM0 Output Level), M1 (PWM1 Output Level), PT (PWM Output Timeout), RP (RSSSI PWM Timer)

## Configuration Example

As an example for a simple A/D link, a pair of RF modules could be set as follows:

| **Remote Configuration** | **Base Configuration** |
|---|---|
| DL = 0x1234 | DL = 0x5678 |
| MY = 0x5678 | MY = 0x1234 |
| D0 = 2 | P0 = 2 |
| D1 = 2 | P1 = 2 |
| IR = 0x14 | IU = 1 |
| IT = 5 | IA = 0x5678 (or 0xFFFF) |

These settings configure the remote module to sample AD0 and AD1 once each every 20 ms. It then buffers 5 samples each before sending them back to the base module. The base should then receive a 32-Byte transmission (20 Bytes data and 12 Bytes framing) every 100 ms.

## Command Mode

To modify or read RF Module parameters, the module must first enter into Command Mode - a state in which incoming characters are interpreted as commands. Two Command Mode options are supported: AT Command Mode [refer to section below] and API Command Mode [p56].

### AT Command Mode

**To Enter AT Command Mode:**

Send the 3-character command sequence "+++" and observe guard times before and after the command characters. [Refer to the "Default AT Command Mode Sequence" below.]

Default AT Command Mode Sequence (for transition to Command Mode):

- No characters sent for one second [GT (Guard Times) parameter = 0x3E8]
- Input three plus characters ("+++") within one second [CC (Command Sequence Character) parameter = 0x2B.]
- No characters sent for one second [GT (Guard Times) parameter = 0x3E8]

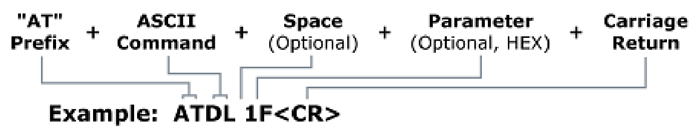
All of the parameter values in the sequence can be modified to reflect user preferences.

NOTE: Failure to enter AT Command Mode is most commonly due to baud rate mismatch. Ensure the 'Baud' setting on the "PC Settings" tab matches the interface data rate of the RF module. By default, the BD parameter = 3 (9600 bps).

**To Send AT Commands:**

Send AT commands and parameters using the syntax shown below.

Figure 2-08. Syntax for sending AT Commands




To read a parameter value stored in the RF module's register, omit the parameter field.

The preceding example would change the RF module Destination Address (Low) to "0x1F". To store the new value to non-volatile (long term) memory, subsequently send the WR (Write) command.

For modified parameter values to persist in the module's registry after a reset, changes must be saved to non-volatile memory using the WR (Write) Command. Otherwise, parameters are restored to previously saved values after the module is reset.

**System Response.** When a command is sent to the module, the module will parse and execute the command. Upon successful execution of a command, the module returns an "OK" message. If execution of a command results in an error, the module returns an "ERROR" message.

**To Exit AT Command Mode:**

1. Send the ATCN (Exit Command Mode) command (followed by a carriage return).

   [OR]

2. If no valid AT Commands are received within the time specified by CT (Command Mode Timeout) Command, the RF module automatically returns to Idle Mode.

For an example of programming the RF module using AT Commands and descriptions of each configurable parameter, refer to the RF Module Configuration chapter [p25].

# 3. RF Module Configuration

## Programming the RF Module

Refer to the Command Mode section [p24] for more information about entering Command Mode, sending AT commands and exiting Command Mode. For information regarding module programming using API Mode, refer to the API Operation sections [p56].

### Programming Examples

Refer to the 'X-CTU' section of the Development Guide [Appendix B] for more information regarding the X-CTU configuration software.

**Setup**

The programming examples in this section require the installation of Digi's X-CTU Software and a serial connection to a PC. (Digi stocks RS-232 and USB boards to facilitate interfacing with a PC.)

1. Install Digi's X-CTU Software to a PC by double-clicking the "setup_X-CTU.exe" file. (The file is located on the Digi CD and under the 'Software' section of the following web page: www.digi.com/support)
2. Mount the RF module to an interface board, then connect the module assembly to a PC.
3. Launch the X-CTU Software and select the 'PC Settings' tab. Verify the baud and parity settings of the Com Port match those of the RF module.

NOTE: Failure to enter AT Command Mode is most commonly due to baud rate mismatch. Ensure the 'Baud' setting on the 'PC Settings' tab matches the interface data rate of the RF module. By default, the BD parameter = 3 (which corresponds to 9600 bps).

**Sample Configuration: Modify RF Module Destination Address**

Example: Utilize the X-CTU "Terminal" tab to change the RF module's DL (Destination Address Low) parameter and save the new address to non-volatile memory.

After establishing a serial connection between the RF module and a PC [refer to the 'Setup' section above], select the "Terminal" tab of the X-CTU Software and enter the following command lines ('CR' stands for carriage return):

Method 1 (One line per command)

| **Send AT Command** | **System Response** |
|---|---|
| +++ | OK <CR> (Enter into Command Mode) |
| ATDL <Enter> | {current value} <CR> (Read Destination Address Low) |
| ATDL1A0D <Enter> | OK <CR> (Modify Destination Address Low) |
| ATWR <Enter> | OK <CR> (Write to non-volatile memory) |
| ATCN <Enter> | OK <CR> (Exit Command Mode) |

Method 2 (Multiple commands on one line)

| **Send AT Command** | **System Response** |
|---|---|
| +++ | OK <CR> (Enter into Command Mode) |
| ATDL <Enter> | {current value} <CR> (Read Destination Address Low) |
| ATDL1A0D,WR,CN <Enter> | OK<CR> OK<CR> OK<CR> |

**Sample Configuration: Restore RF Module Defaults**

Example: Utilize the X-CTU "Modem Configuration" tab to restore default parameter values.

After establishing a connection between the module and a PC [refer to the 'Setup' section above], select the "Modem Configuration" tab of the X-CTU Software.

1. Select the 'Read' button.
2. Select the 'Restore' button.

### D0 - D4 (DIOn Configuration) Commands

<I/O Settings> The D0, D1, D2, D3 and D4 commands are used to select/read the behavior of their respective AD/DIO lines (pins 20, 19, 18, 17 and 11 respectively).

Options include:

- Analog-to-digital converter
- Digital input
- Digital output

AT Commands: ATD0, ATD1, ATD2, ATD3, ATD4

Parameter Range: 0 - 5

| Parameter | Configuration |
|---|---|
| 0 | Disabled |
| 1 | n/a |
| 2 | ADC |
| 3 | DI |
| 4 | DO low |
| 5 | DO high |

Default Parameter Value: 0

Minimum Firmware Version Required: 1.x.A0

### D5 (DIO5 Configuration) Command

<I/O Settings> The D5 command is used to select/read the behavior of the DIO5 line (pin 15).

Options include:

- Associated Indicator (LED blinks when the module is associated)
- Analog-to-digital converter
- Digital input
- Digital output

AT Command: ATD5

Parameter Range: 0 - 5

| Parameter | Configuration |
|---|---|
| 0 | Disabled |
| 1 | Associated Indicator |
| 2 | ADC |
| 3 | DI |
| 4 | DO low |
| 5 | DO high |

Default Parameter Value: 1

Parameters 2-5 supported as of firmware version 1.xA0

### D6 (DIO6 Configuration) Command

<I/O Settings> The D6 command is used to select/read the behavior of the DIO6 line (pin 16). Options include:

- RTS flow control
- Analog-to-digital converter
- Digital input
- Digital output

AT Command: ATD6

Parameter Range: 0 - 5

| Parameter | Configuration |
|---|---|
| 0 | Disabled |
| 1 | RTS Flow Control |
| 2 | n/a |
| 3 | DI |
| 4 | DO low |
| 5 | DO high |

Default Parameter Value: 0

Parameters 3-5 supported as of firmware version 1.xA0

# API Operation

By default, XBee®/XBee-PRO RF Modules act as a serial line replacement (Transparent Operation) - all UART data received through the DI pin is queued up for RF transmission. When the module receives an RF packet, the data is sent out the DO pin with no additional information.

Inherent to Transparent Operation are the following behaviors:

- If module parameter registers are to be set or queried, a special operation is required for transitioning the module into Command Mode.
- In point-to-multipoint systems, the application must send extra information so that the receiving module(s) can distinguish between data coming from different remotes.

As an alternative to the default Transparent Operation, API (Application Programming Interface) Operations are available. API operation requires that communication with the module be done through a structured interface (data is communicated in frames in a defined order). The API specifies how commands, command responses and module status messages are sent and received from the module using a UART Data Frame.

## API Frame Specifications

Two API modes are supported and both can be enabled using the AP (API Enable) command. Use the following AP parameter values to configure the module to operate in a particular mode:

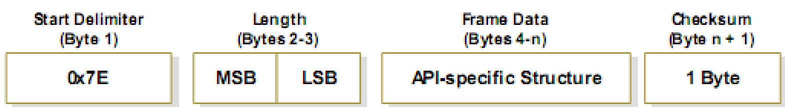
- AP = 0 (default): Transparent Operation (UART Serial line replacement) API modes are disabled.
- AP = 1: API Operation
- AP = 2: API Operation (with escaped characters)

Any data received prior to the start delimiter is silently discarded. If the frame is not received correctly or if the checksum fails, the data is silently discarded.

### API Operation (AP parameter = 1)

When this API mode is enabled (AP = 1), the UART data frame structure is defined as follows:

Figure 3-01. UART Data Frame Structure:

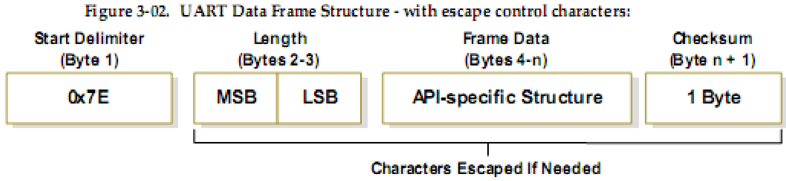



MSB = Most Significant Byte, LSB = Least Significant Byte

### API Operation - with Escape Characters (AP parameter = 2)

When this API mode is enabled (AP = 2), the UART data frame structure is defined as follows:

Figure 3-02. UART Data Frame Structure - with escape control characters:




MSB = Most Significant Byte, LSB = Least Significant Byte

**Escape characters**. When sending or receiving a UART data frame, specific data values must be escaped (flagged) so they do not interfere with the UART or UART data frame operation. To escape an interfering data byte, insert 0x7D and follow it with the byte to be escaped XOR'd with 0x20.

**Data bytes that need to be escaped:**

- 0x7E – Frame Delimiter
- 0x7D – Escape
- 0x11 – XON
- 0x13 – XOFF

**Example -** Raw UART Data Frame (before escaping interfering bytes):
0x7E 0x00 0x02 0x23 0x11 0xCB

0x11 needs to be escaped which results in the following frame:
0x7E 0x00 0x02 0x23 0x7D 0x31 0xCB

Note: In the above example, the length of the raw data (excluding the checksum) is 0x0002 and the checksum of the non-escaped data (excluding frame delimiter and length) is calculated as: 0xFF - (0x23 + 0x11) = (0xFF - 0x34) = 0xCB.

### Checksum

To test data integrity, a checksum is calculated and verified on non-escaped data.

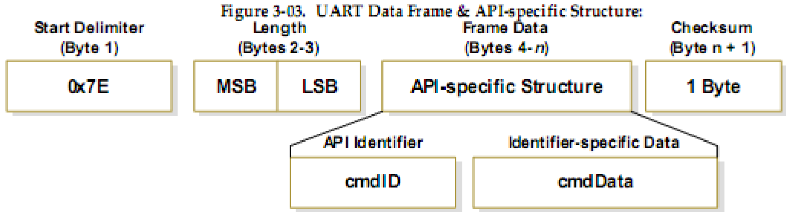
**To calculate**: Not including frame delimiters and length, add all bytes keeping only the lowest 8 bits of the result and subtract from 0xFF.

**To verify**: Add all bytes (include checksum, but not the delimiter and length). If the checksum is correct, the sum will equal 0xFF.

## API Types

Frame data of the UART data frame forms an API-specific structure as follows:

Figure 3-03. UART Data Frame & API-specific Structure:

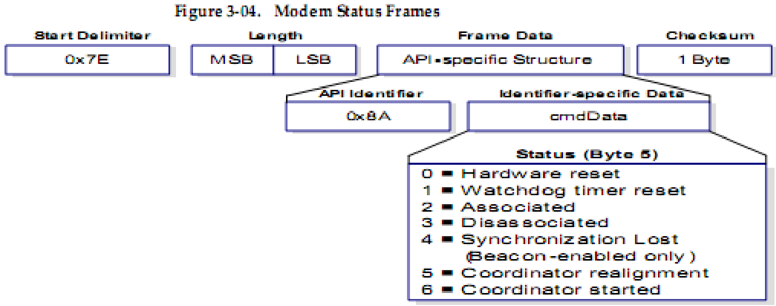



The cmdID frame (API-identifier) indicates which API messages will be contained in the cmdData frame (Identifier-specific data). Refer to the sections that follow for more information regarding the supported API types. Note that multi-byte values are sent big endian.

### Modem Status

API Identifier: 0x8A
RF module status messages are sent from the module in response to specific conditions.

Figure 3-04. Modem Status Frames



### AT Command

API Identifier Value: 0x08

The "AT Command" API type allows for module parameters to be queried or set. When using this command ID, new parameter values are applied immediately. This includes any register set with the "AT Command - Queue Parameter Value" (0x09) API type.

**Figure 3-05. AT Command Frames**

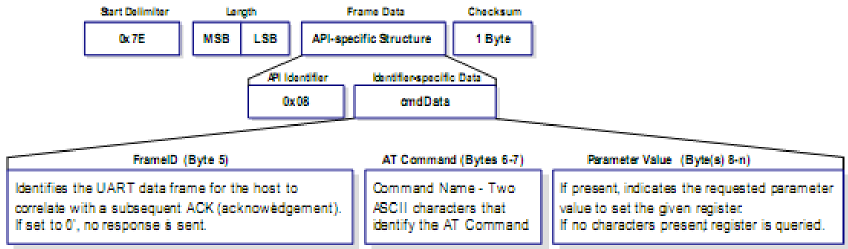
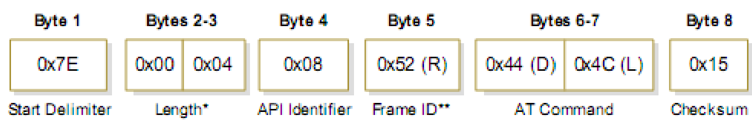


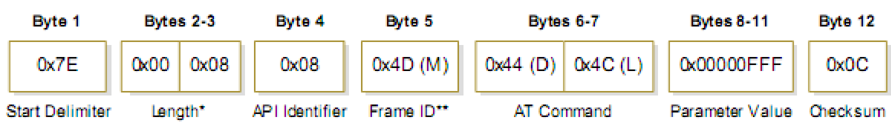

**Figure 3-06. Example: API frames when reading the DL parameter value of the module.**




* *Length [Bytes] = API Identifier + Frame ID + AT Command*

** *"R" value was arbitrarily selected.*

**Figure 3-07. Example: API frames when modifying the DL parameter value of the module.**




* *Length [Bytes] = API Identifier + Frame ID + AT Command + Parameter Value*

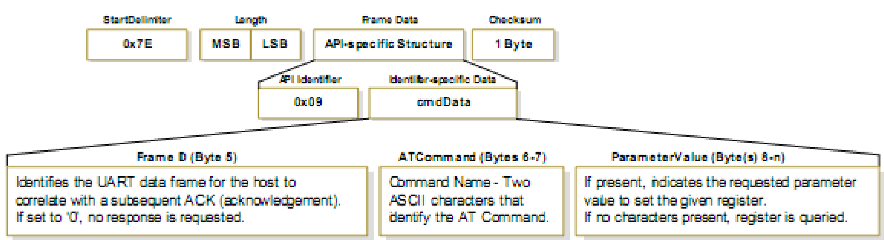
** *"M" value was arbitrarily selected.*

### AT Command - Queue Parameter Value

API Identifier Value: 0x09

This API type allows module parameters to be queried or set. In contrast to the "AT Command" API type, new parameter values are queued and not applied until either the "AT Command" (0x08) API type or the AC (Apply Changes) command is issued. Register queries (reading parameter values) are returned immediately.

**Figure 3-08. AT Command Frames**
**(Note that frames are identical to the "AT Command" API type except for the API identifier.)**



## AT Command Response

API Identifier Value: 0x88

Response to previous command.

In response to an AT Command message, the module will send an AT Command Response message. Some commands will send back multiple frames (for example, the ND (Node Discover) and AS (Active Scan) commands). These commands will end by sending a frame with a status of ATCMD_OK and no cmdData.

Figure 3-09. AT Command Response Frames.

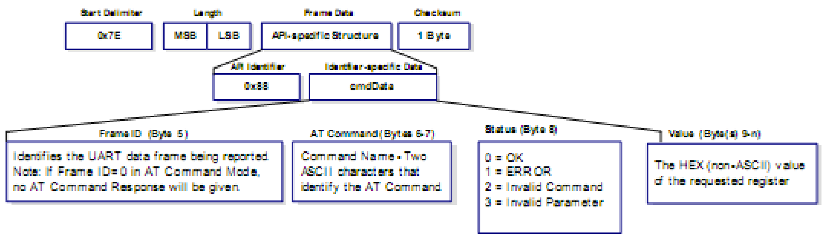
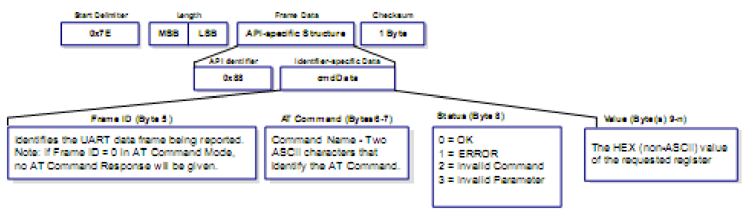



Figure 3-10. AT Command Response Frames.

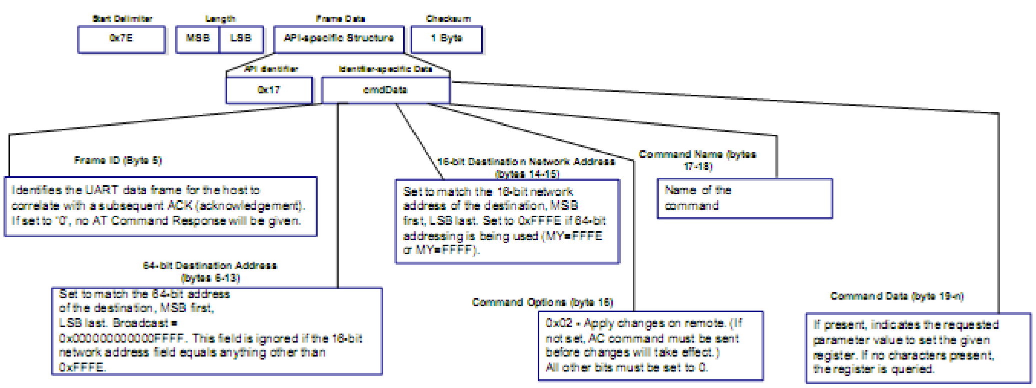



## Remote AT Command Request

API Identifier Value: 0x17

Allows for module parameter registers on a remote device to be queried or set

Figure 3-11. Remote AT Command Request

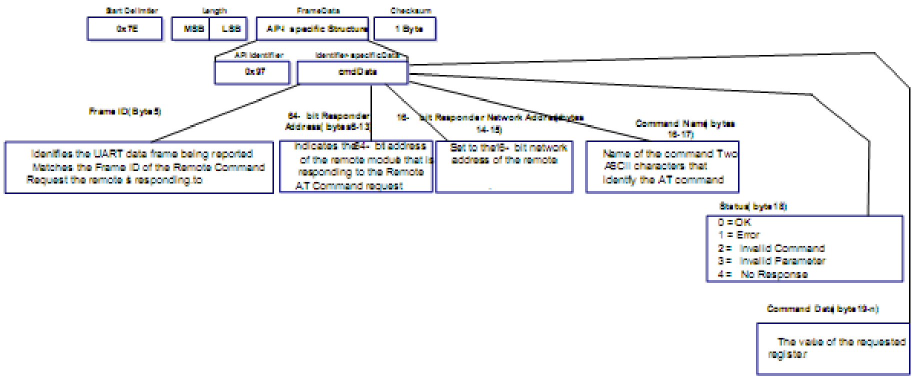


### Remote Command Response

API Identifier Value: 0x97

If a module receives a remote command response RF data frame in response to a Remote AT Command Request, the module will send a Remote AT Command Response message out the UART. Some commands may send back multiple frames--for example, Node Discover (ND) command.

**Figure 3-12. Remote AT Command Response.**

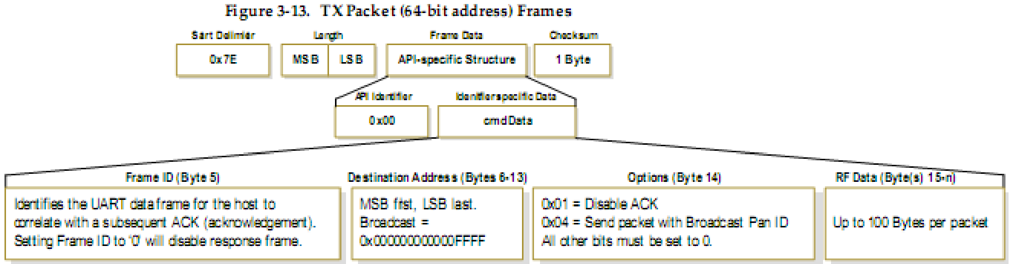



### TX (Transmit) Request: 64-bit address

API Identifier Value: 0x00

A TX Request message will cause the module to send RF Data as an RF Packet.

**Figure 3-13. TX Packet (64-bit address) Frames**

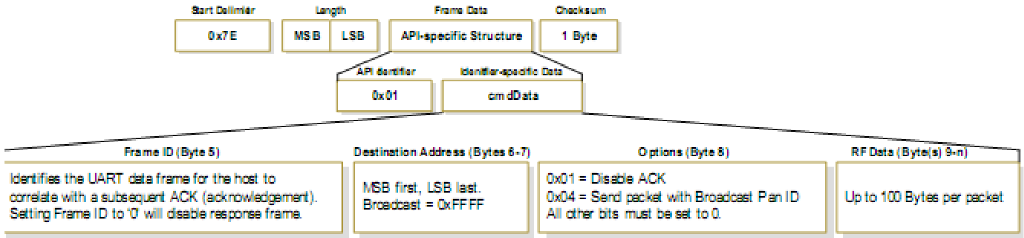


### TX (Transmit) Request: 16-bit address

API Identifier Value: 0x01

A TX Request message will cause the module to send RF Data as an RF Packet.

**Figure 3-14. TX Packet (16-bit address) Frames**

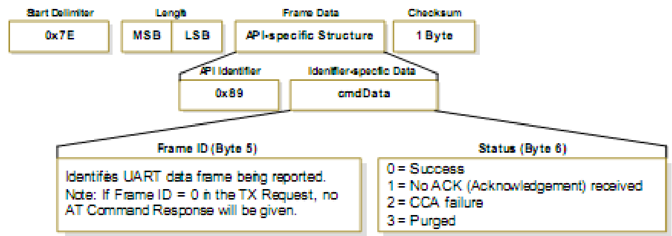


### TX (Transmit) Status

API Identifier Value: 0x89

When a TX Request is completed, the module sends a TX Status message. This message will indicate if the packet was transmitted successfully or if there was a failure.

Figure 3-15. TX Status Frames




NOTES:

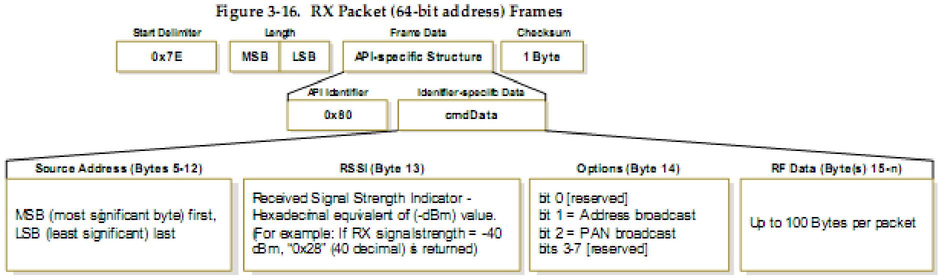
- "STATUS = 1" occurs when all retries are expired and no ACK is received.
- If transmitter broadcasts (destination address = 0x000000000000FFFF), only "STATUS = 0 or 2" will be returned.
- "STATUS = 3" occurs when Coordinator times out of an indirect transmission. Timeout is defined as (2.5 x SP (Cyclic Sleep Period) parameter value).

### RX (Receive) Packet: 64-bit Address

API Identifier Value: 0x80

When the module receives an RF packet, it is sent out the UART using this message type.

Figure 3-16. RX Packet (64-bit address) Frames

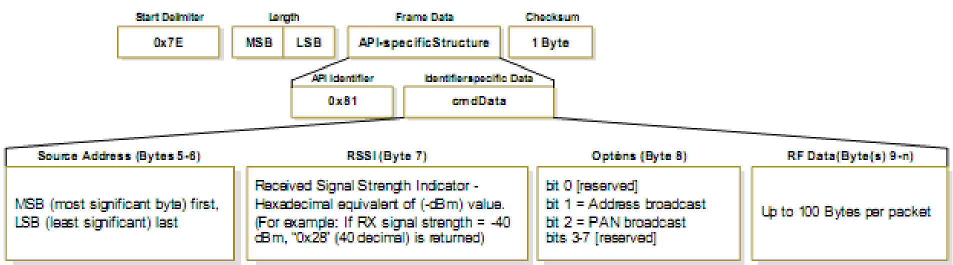



### RX (Receive) Packet: 16-bit Address

API Identifier Value: 0x81

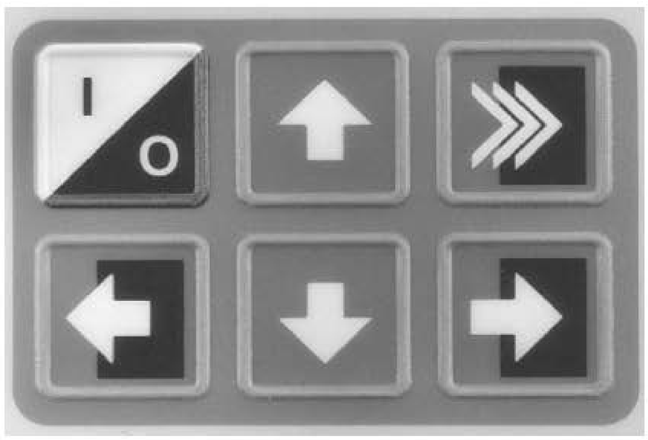
When the module receives an RF packet, it is sent out the UART using this message type.

Figure 3-17. RX Packet (16-bit address) Frames



MAN 4275A00
PN: 00275-8026-0001
English
July 2000

# HART® Communicator



FISHER-ROSEMOUNT™

# Product Manual for the HART Communicator

**NOTICE**

Read this manual before working with this product. For personal and system safety, and for optimum product performance, make sure you thoroughly understand the contents before using or servicing this product.

For equipment service needs, contact the nearest product representative.



**Fisher-Rosemount**
8301 Cameron Road
Austin, TX 78754 USA
Technical Support: 1-800-833-8314
or (512) 832-3774
Service: 1-800-654-7768
www.hartcommunicator.com

FISHER-ROSEMOUNT™

MAN 4275A00 AW# 000701

# SECTION 1

# The HART® Communicator

## INTRODUCTION

The HART (Highway Addressable Remote Transducer) Communicator (**Figure 1-1**) is a hand-held interface that provides a common communication link to all HART-compatible, microprocessor-based instruments.

**Section 1** discusses the HART Communicator Connections, Liquid Crystal Display, Keypad, Offline and Online menu, Battery Pack, Memory Module, data pack 100, Maintenance, and Year 2000 Compatibility. It also includes short overviews on some of the Communicator's functionality.

**Section 2** describes tasks that are common to Fisher-Rosemount's HART devices and includes some of the common screen displays.

**Section 3** displays typical examples of menu trees specific to Fisher-Rosemount products.

Your HART Communicator interfaces with any HART-compatible device from any wiring termination point using a 4–20 mA loop, provided a minimum load resistance of 250 ohms is present between the Communicator and the power supply. Your HART Communicator uses the Bell 202 frequency shift key (FSK) technique of high-frequency digital signals superimposed on a standard transmitter current loop of 4–20 mA. Because the total high-frequency signal voltage added to the loop amounts to zero, communication to and from a HART-compatible device does not disturb the 4–20 mA signal.

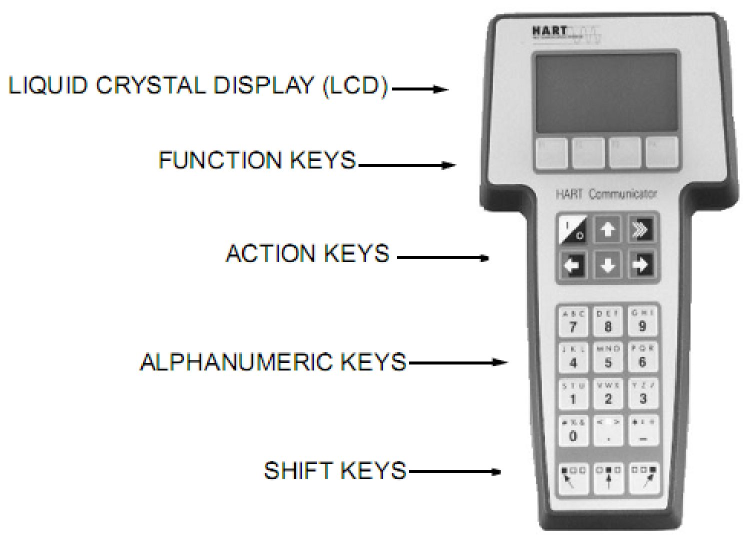



FIGURE 1-1. The HART Communicator.

## HART COMMUNICATOR CONNECTIONS

The HART Communicator can interface with a transmitter from the control room, the instrument site, or any wiring termination point in the loop through the rear connection panel (**Figure 1-2**).

To interface, connect the HART Communicator with the appropriate connectors in parallel with the instrument or load resistor. All connections are non-polarized. When connecting to a PC, you must use the PC Communication Adapter to connect to the Communicator's serial port. See **Listen for PC Menu on page 1-26** for more information and **Appendix B** for a complete list of parts.

For intrinsically safe Canadian Standards Association (CSA) and Factory Mutual (FM) wiring connections, see **Appendix C**.

> **⚠WARNING**
>
> Explosions can result in death or serious injury. Do not connect to the serial port or NiCad recharger jack in an explosive atmosphere.

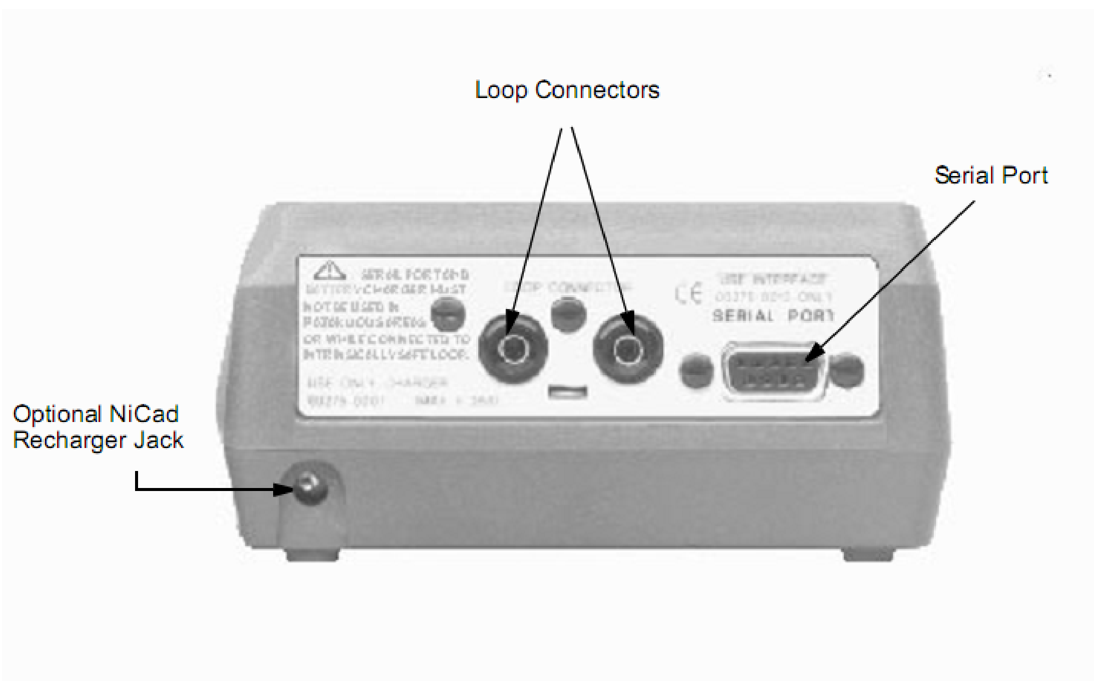



FIGURE 1-2. Rear Connection Panel with NiCad Recharger Jack.

**NOTE**: For the HART Communicator to function properly, a minimum of 250 ohms resistance *must be* present in the loop. The HART Communicator does not measure loop current directly.

**Figure 1-3** and **Figure 1-4** illustrate typical wiring connections between the HART Communicator and any compatible device.

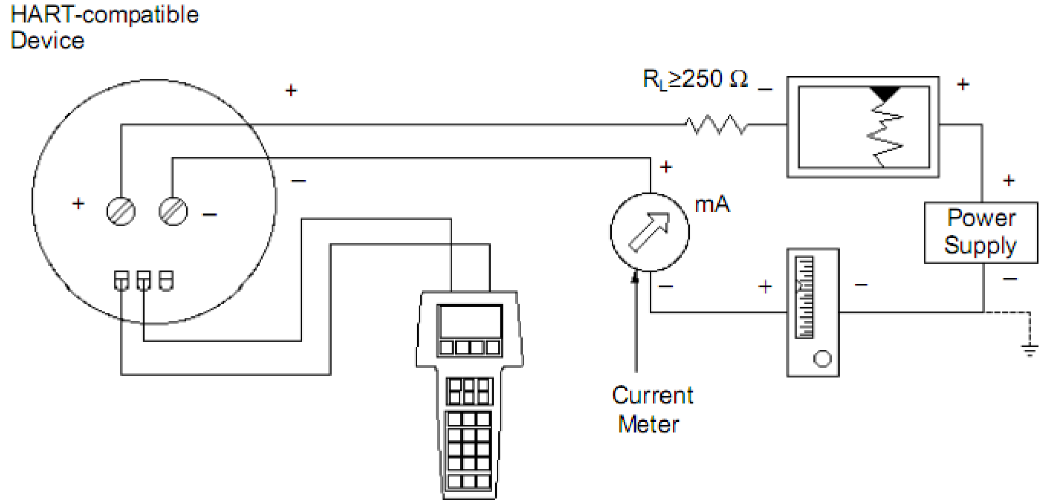



FIGURE 1-3. Connecting to the Transmitter Comm Terminals.

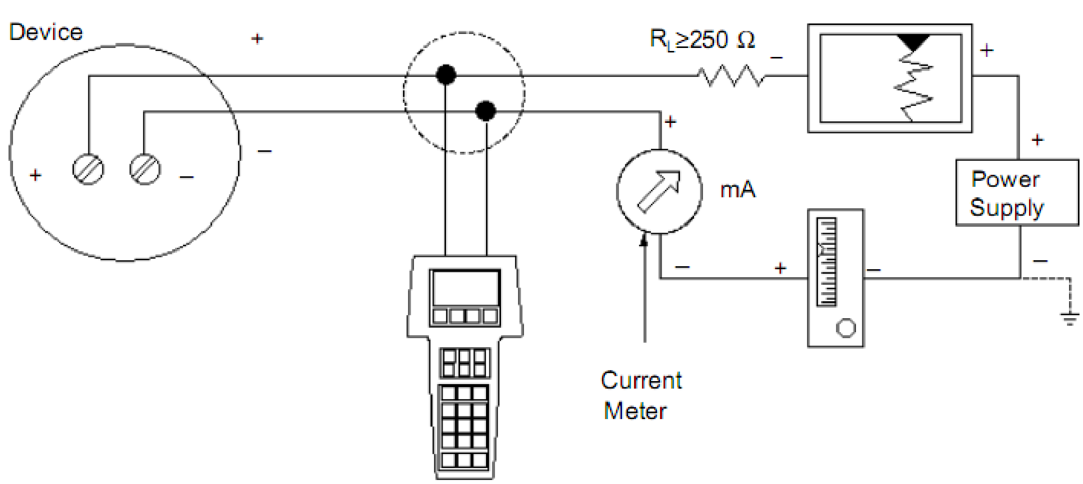



FIGURE 1-4. Connecting the HART Communicator to the Loop.

| ⚠WARNING |
| --- |
| Explosions can result in death or serious injury. Before connecting the HART Communicator in an explosive atmosphere, make sure the instruments in the loop are installed in accordance with intrinsically safe or nonincendive field wiring practices. For intrinsically safe CSA and FM wiring connections, see Appendix C. |

**Figure 1-5** shows how to connect the optional 250 ohm load resistor.

**NOTE:** To temporarily install the optional 250 ohm Load Resistor:
1. Insert the load resistor into the lead set jacks.
2. Open the loop to allow connection of the resistor in series in the loop.
3. Close the loop using the lead set connectors.

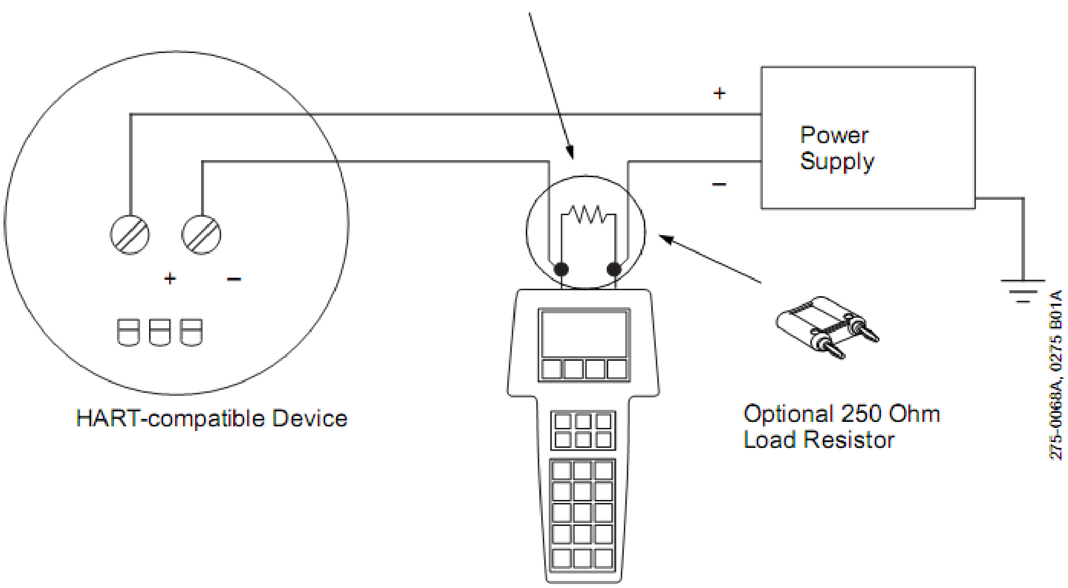



FIGURE 1-5. Connecting the HART Communicator with the Load Resistor.

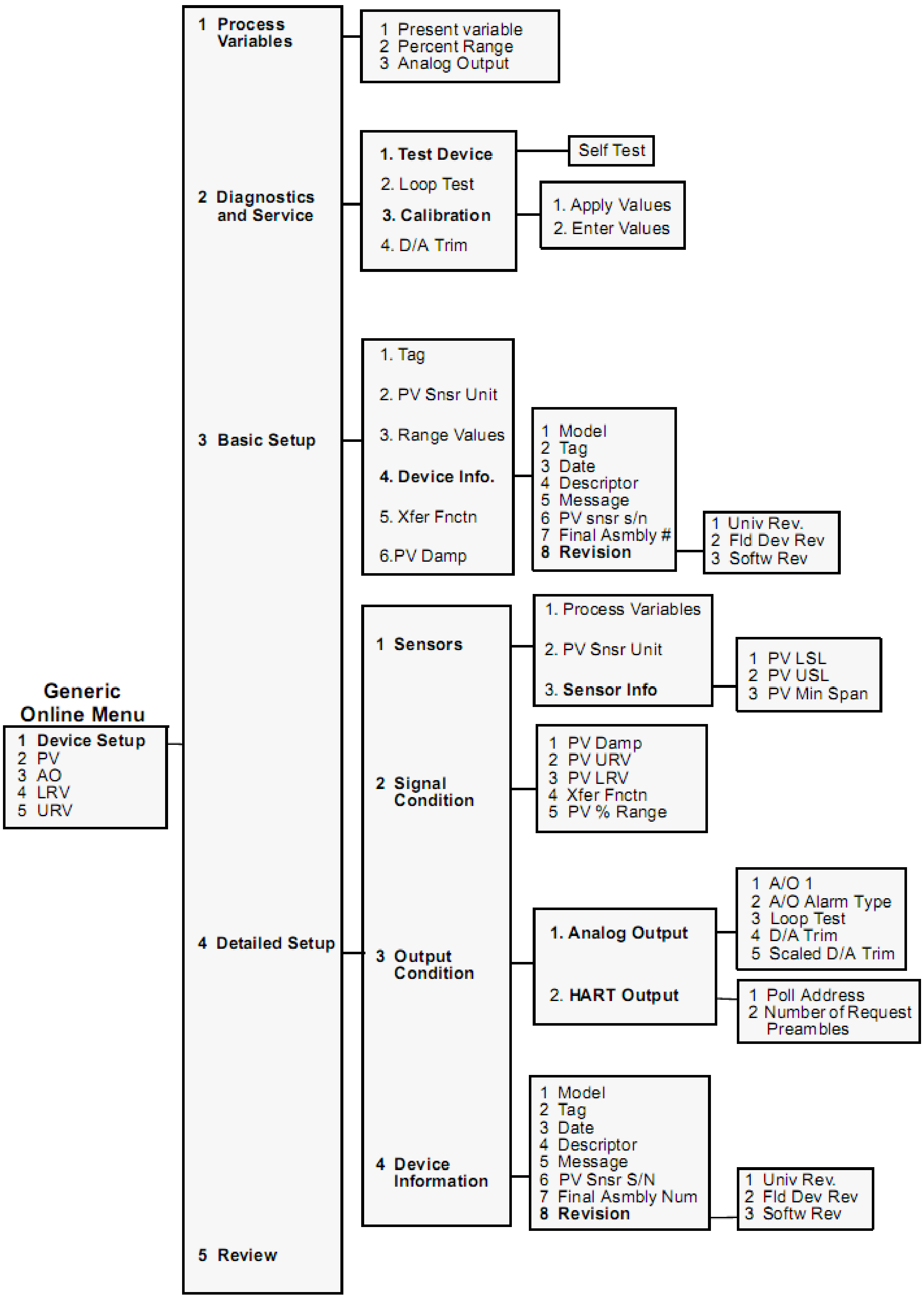
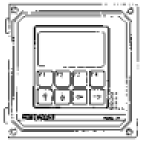
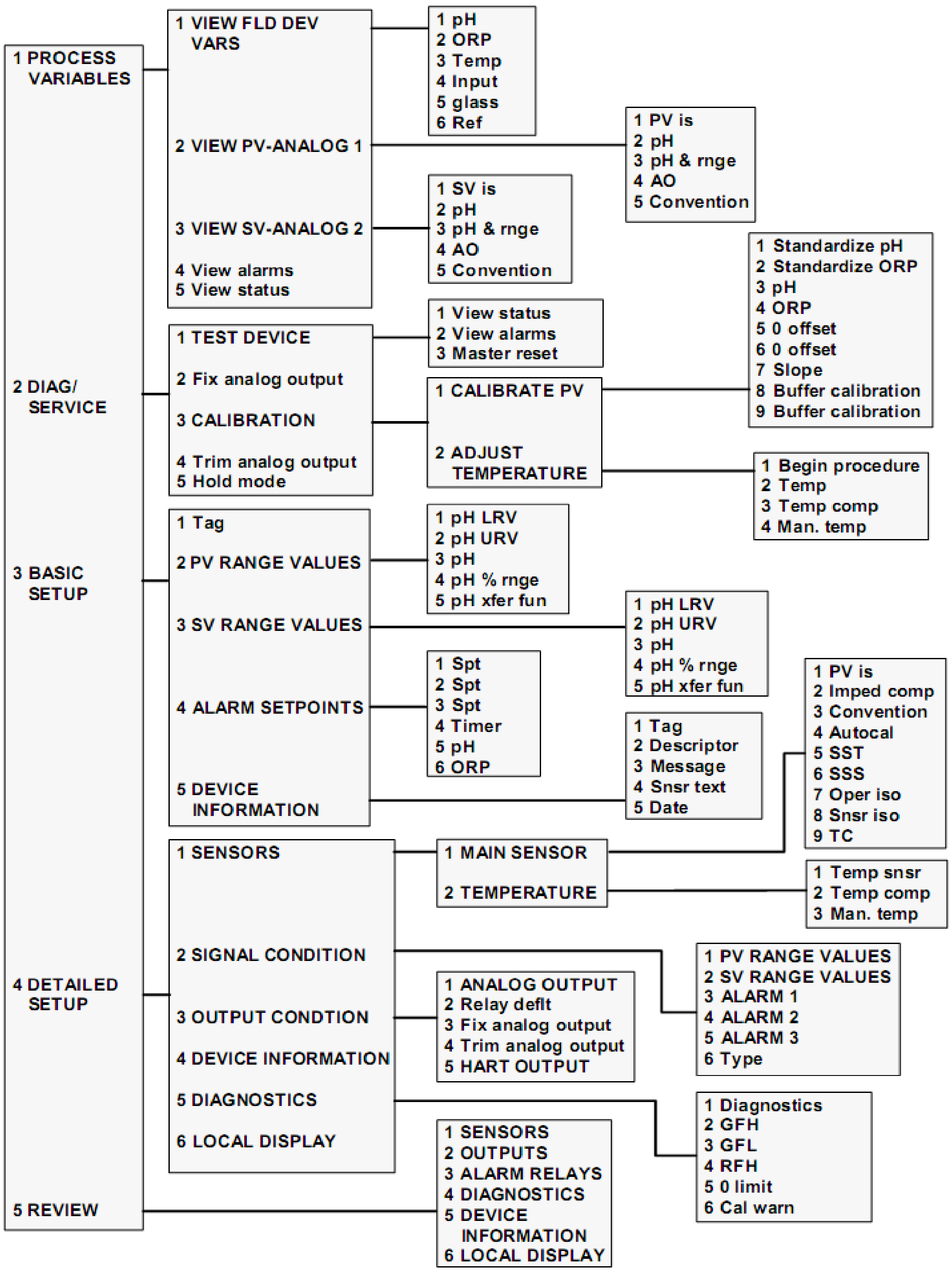
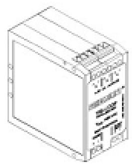



FIGURE 1-22. Generic Online Menu Tree.

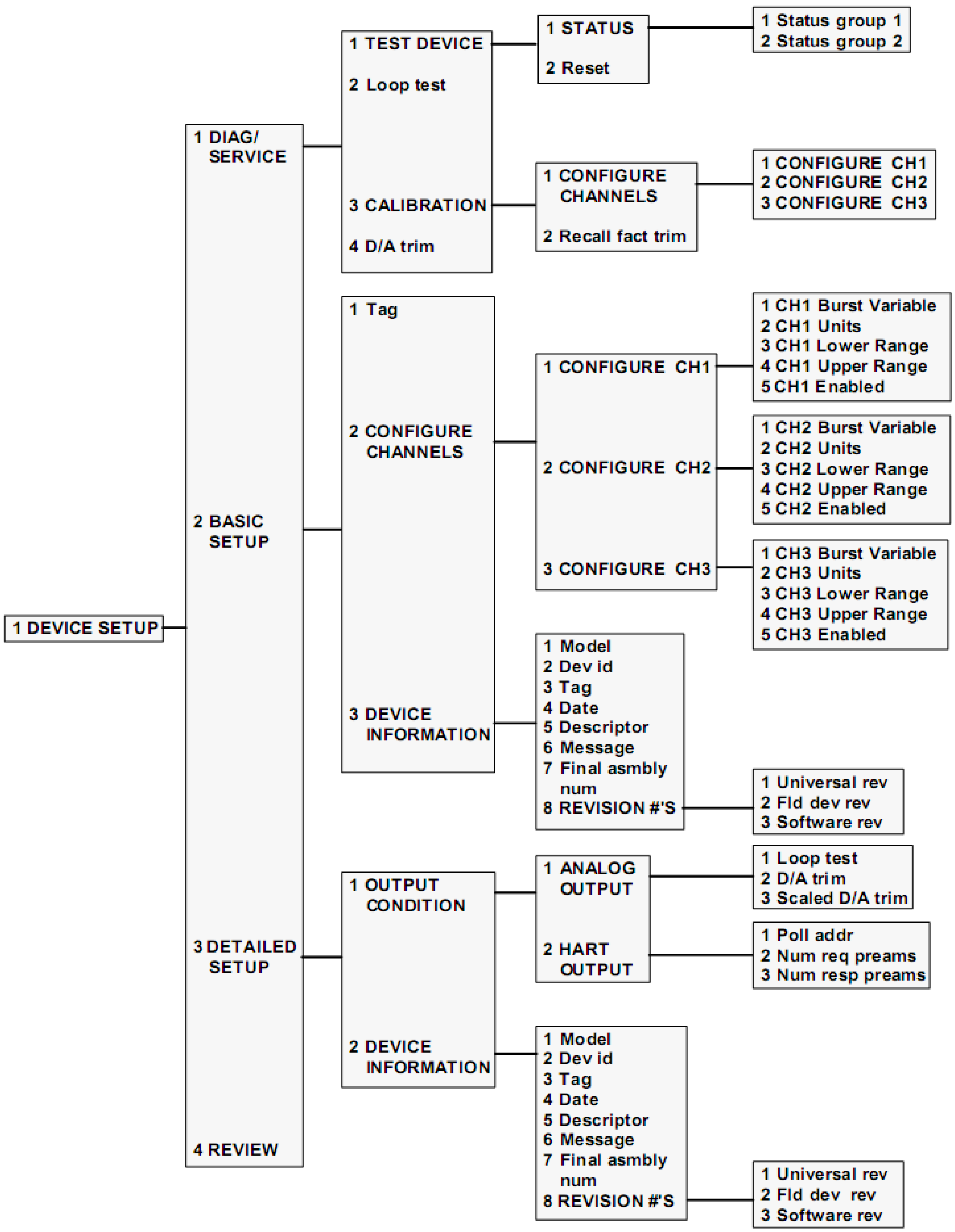


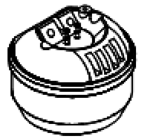
# Model 54pH/ORP Transmitter



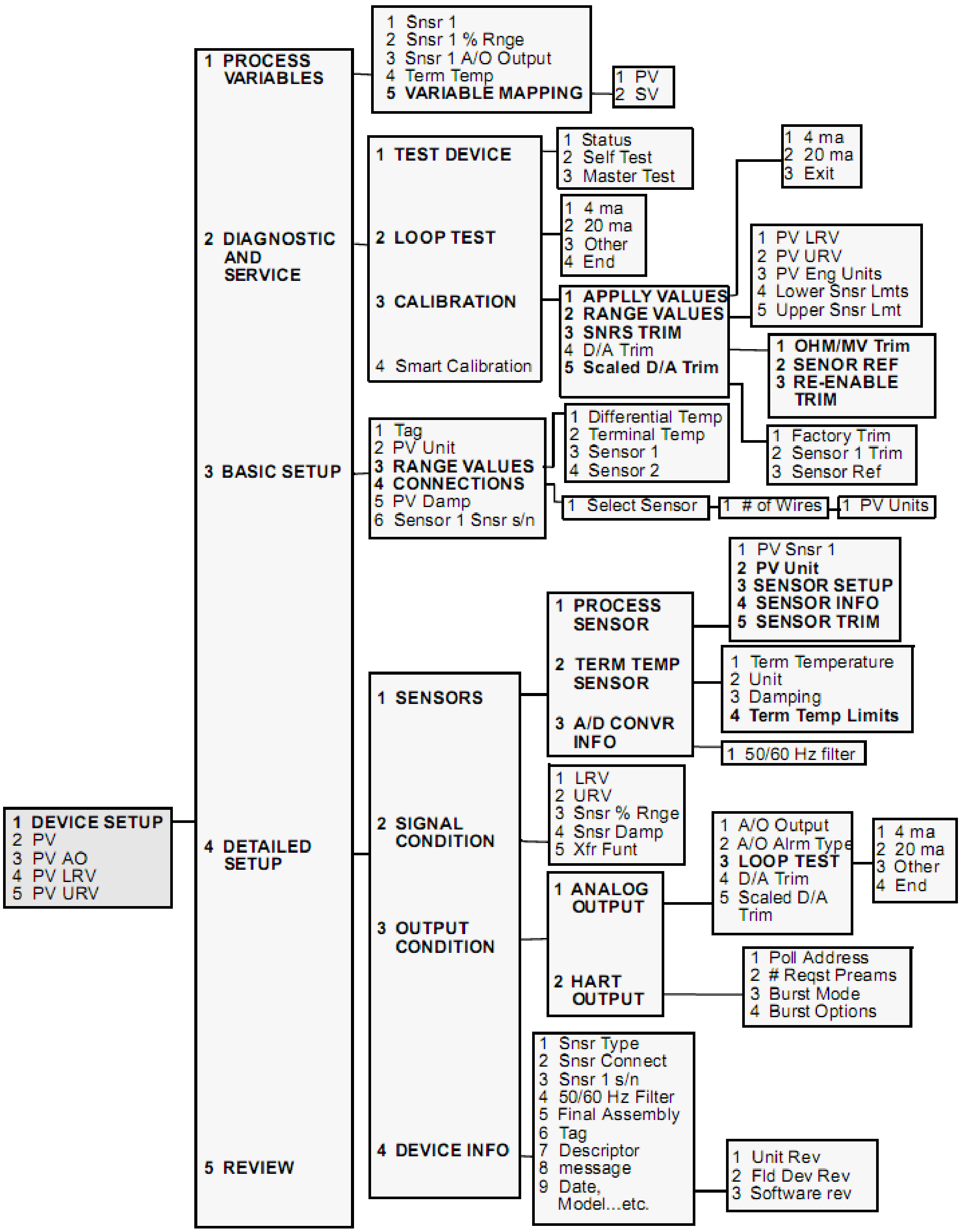


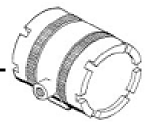
# Model 333 HART® Tri-Loop Converter





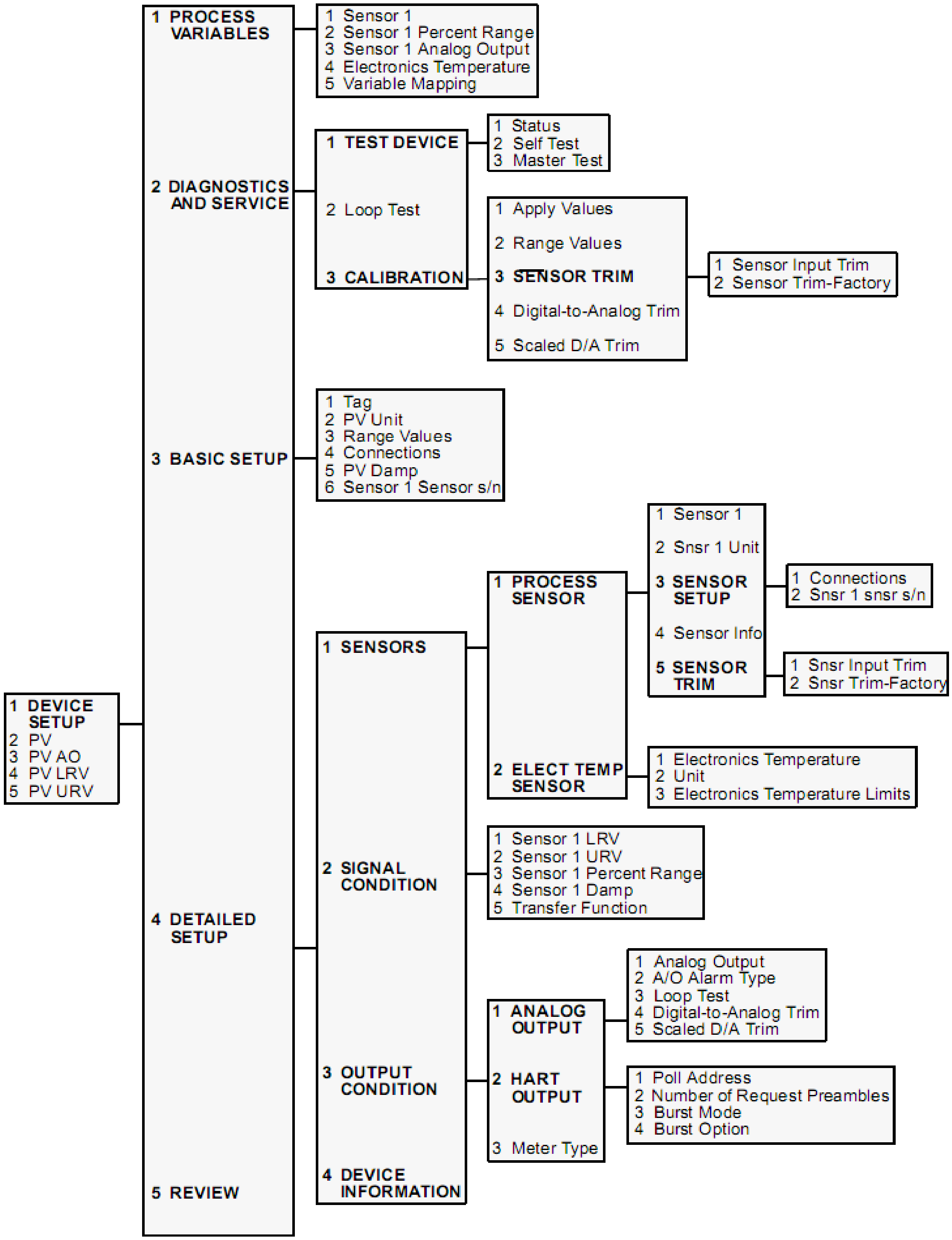
# Model 644 Temperature Transmitter

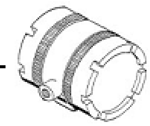




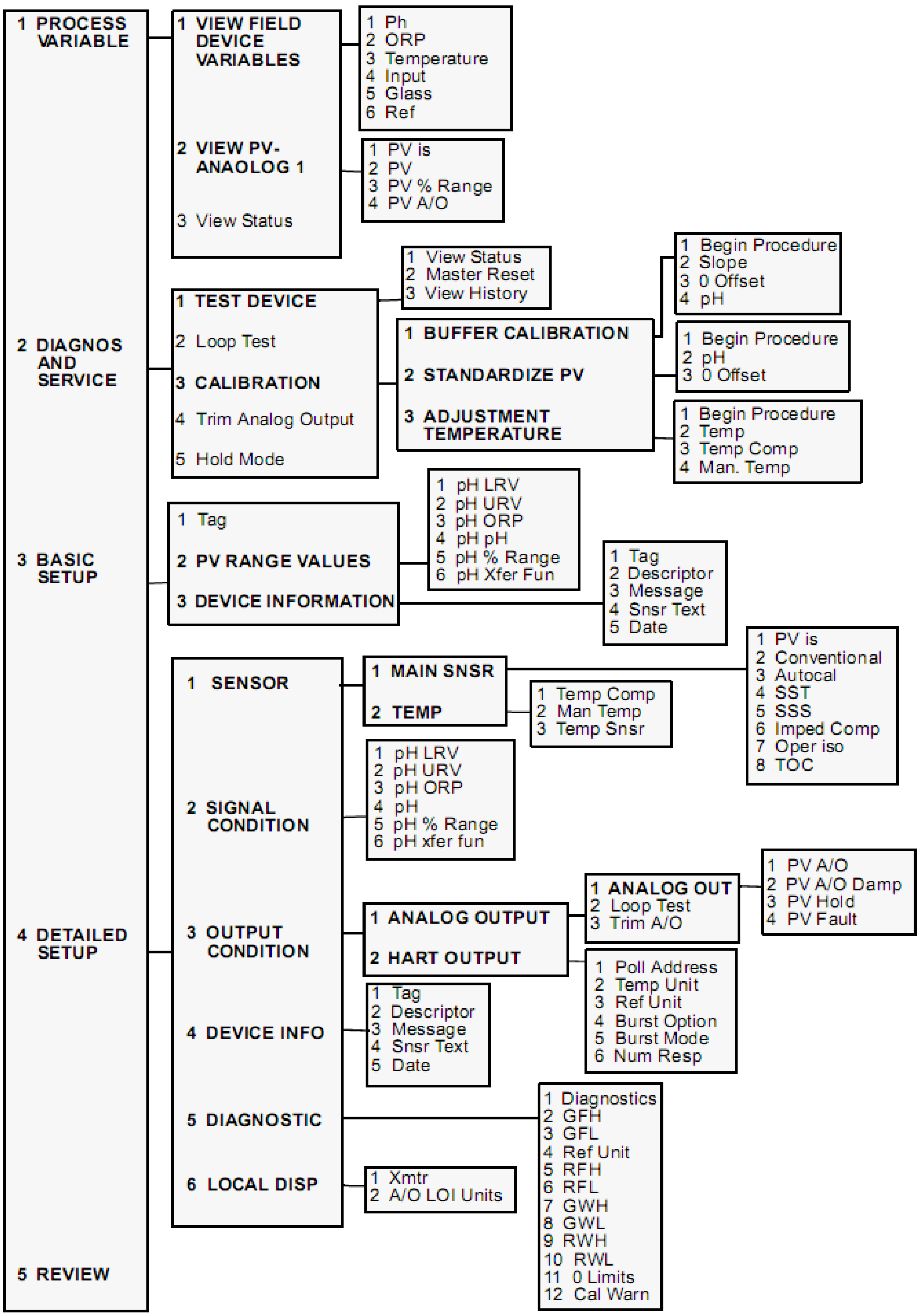
# Model 2081pH Transmitter

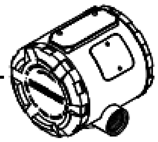
- **1 PROCESS VARIABLE**
  - **1 VIEW FIELD DEVICE VARIABLES**
    - 1 pH
    - 2 Temperature
    - 3 Input
  - **2 VIEW PV-ANAOLOG 1**
    - 1 PV is
    - 2 PV pH
    - 3 PV % Range
    - 4 PV A/O
  - 3 View Status
- **2 DIAGNOS AND SERVICE**
  - **1 TEST/STATUS**
    - 1 View Status
    - 2 Master Reset
  - 2 Loop Test
  - **3 CALIBRATION**
    - **1 BUFFER CALIBRATION**
      - 1 Begin Procedure
      - 2 Slope
      - 3 pH
    - **2 STANDARDIZE ph**
      - 1 Begin Procedure
      - 2 pH
    - **3 ADJUST TEMPERATURE**
      - 1 Begin Procedure
      - 2 Temp
      - 3 Temp Comp
      - 4 Man. Temp
  - 4 Trim Analog Output
- **3 BASIC SETUP**
  - 1 Tag
  - **2 PV RANGE VALUES**
    - 1 PV LRV
    - 2 PV URV
    - 3 PV Damp
    - 4 PV pH
    - 5 PV % Range
    - 6 Xfer Fun
  - **3 DEVICE INFORMATION**
    - 1 Tag
    - 2 Descriptor
    - 3 Message
    - 4 Snsr Text
    - 5 Date
- **4 DETAILED SETUP**
  - **1 SENSOR**
    - 1 Temp Comp
    - 2 Man. Comp
  - **2 SIGNAL CONDITION**
    - 1 pH LRV
    - 2 pH URV
    - 3 pH Damp
    - 4 pH
    - 5 pH % Range
    - 6 pH xfer fun
  - **3 OUTPUT CONDITION**
    - **1 ANALOG OUTPUT**
      - 1 PV A/O
      - 2 Loop Test
      - 3 Trim Analog Output
    - **2 HART OUTPUT**
      - 1 Poll Address
      - 2 Temp Unit
      - 3 Burst Option
      - 4 Burst Mode
  - **4 DEVICE INFO**
    - 1 Tag
    - 2 Descriptor
    - 3 Message
    - 4 Date
    - 5 Snsr Text
    - 6 Burst Mode
    - 7 Burst Option
    - 8 Num Req Preams
    - 9 Write Protect
    - 10 Distributor
    - 11 Manufacturer
    - 12 Model
    - 13 etc.
- **5 REVIEW**


1 PROCESS VARIABLES
1 Sensor 1
2 Sensor 1 Percent Range
3 Sensor 1 Analog Output
4 Electronics Temperature
5 Variable Mapping
2 DIAGNOSTICS AND SERVICE
1 TEST DEVICE
1 Status
2 Self Test
3 Master Test
2 Loop Test
3 CALIBRATION
1 Apply Values
2 Range Values
3 SENSOR TRIM
1 Sensor Input Trim
2 Sensor Trim-Factory
4 Digital-to-Analog Trim
5 Scaled D/A Trim
3 BASIC SETUP
1 Tag
2 PV Unit
3 Range Values
4 Connections
5 PV Damp
6 Sensor 1 Sensor s/n
1 DEVICE SETUP
2 PV
3 PV AO
4 PV LRV
5 PV URV
4 DETAILED SETUP
1 SENSORS
1 PROCESS SENSOR
1 Sensor 1
2 Snsr 1 Unit
3 SENSOR SETUP
1 Connections
2 Snsr 1 snsr s/n
4 Sensor Info
5 SENSOR TRIM
1 Snsr Input Trim
2 Snsr Trim-Factory
2 ELECT TEMP SENSOR
1 Electronics Temperature
2 Unit
3 Electronics Temperature Limits
2 SIGNAL CONDITION
1 Sensor 1 LRV
2 Sensor 1 URV
3 Sensor 1 Percent Range
4 Sensor 1 Damp
5 Transfer Function
3 OUTPUT CONDITION
1 ANALOG OUTPUT
1 Analog Output
2 A/O Alarm Type
3 Loop Test
4 Digital-to-Analog Trim
5 Scaled D/A Trim
2 HART OUTPUT
1 Poll Address
2 Number of Request Preambles
3 Burst Mode
4 Burst Option
3 Meter Type
4 DEVICE INFORMATION
5 REVIEW



# Model 3081pH Transmitter





# Model 3244 Temperature Transmitter