Wireless Blood Pressure and Pulse Rate Monitoring Device Using ZigBee Technology

by

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A Design Report Submitted to the School of Electrical Engineering, Electronics Engineering, and Computer Engineering in Fulfillment of the Requirements for the Degree

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Approval Sheet

Mapua Institute of Technology
School of EECE

This is to certify that we have supervised the preparation of and read the design report prepared by **Arjie Ray G. Dela Silva, Leonard M. Fernandez, Renson T. Gilo, Angeline M. Maguirang and Konica M. Supleo** entitled **Wireless Blood Pressure and Pulse Rate Monitoring Device Using ZigBee Technology** and that the said report has been submitted for final examination by the Oral Examination Committee.

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As members of the Oral Examination Committee, we certify that we have examined the design report, presented before the committee on **December 3, 2009**, and hereby recommended that it be accepted as fulfilment of the design requirement for the degree in **Bachelor of Science in Computer Engineering.**

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ABSTRACT

The design is intended for medical purposes, specifically, monitoring pulse rate and blood pressure. The design is capable of transfering the measured data to a host device such as computers through the use of ZigBee technology. The device includes software that reads the data being taken by the receiver. The study will aid in solving the problem of medical practitioners regarding the use of traditional method when assessing and monitoring pulse rate and blood pressure. The design comprises of digital blood pressure meter and a pulse rate measuring device. For the blood pressure, pressure sensor was used, while for the pulse rate, a light dependent resistor was used. The design allows fast method of monitoring blood pressure and pulse rate. Data are transmitted wirelessly and can be interfaced to the computer allowing fast transmission from a distance. This was proven by tests conducted during the research.

Keywords: Blood Pressure, Pressure Sensor, Pulse Rate, ZigBee

Chapter 1

DESIGN BACKGROUND AND INTRODUCTION

This chapter provides a general overview of the design project. The background of the design, the statement of the problem, the objectives, the significance and impact of the design, the scope and delimitations, and definition of terms, are presented.

The Design Setting or Frame of Reference

Pulse rate detection practice has been present for centuries which are done for diagnostic purposes. Further improvements of pulse rate monitoring continue but the principles are still the same and it is mostly intended to provide a reliable and convenient way of measurement. Pulse rate monitoring had already been attributed to the prevention of further escalation or diseases such as Congenital Heart Disease and other chronic heart ailments.

Blood pressure measurement was first monitored by the Egyptians through the simple palpation of the pulse. Blood pressure measurement is heading towards reliable data reading and noninvasive approach into taking measurements. Innovations were already done to develop a much accurate and, at the same time, convenient device to assess ones blood pressure.

Wireless Medical Technologies work on the basis of wireless communications, wireless applications, and other wireless technologies. Existing

Wireless Medical Technologies include Wireless Networking Technologies, Wireless Home Medical Equipment, Wireless Point-of-Care Systems, Wireless Remote Monitoring Systems, and Data Management Systems and Software (Infiniti Research Limited 2009/01).

The convergence of technology and medicine has produced a new way of medical practice and this is termed as telemedicine. From the common prefix of "tele" which means distant or far, the basic idea of telemedicine is health care or medical assessment taken from some distant location via telecommunication technologies (Stapic, et al. 2008). This system is aided with tools that make health assessment from a distant possible. These tools are called health monitoring equipments and are worn by the patient. Such equipments are then capable of transmitting the health status or data of the patient to a network for analysis and collection.

The implementation of new health care deliveries, such as telemedicine, will gradually increase the value of clinical health data and will thus create an incentive for collection and proliferation of health information electronically within and between medical organizations (OTA-ITC-624 pg.8).

Background

According to the World Health Organization (WHO), cardiovascular diseases cause 17.5 million deaths every year. Considered as one of the three major deaths in the world, Cardiovascular diseases are caused by disorders of the heart and blood vessels, and include coronary heart disease (heart attacks), cerebrovascular disease (stroke), raised blood pressure (hypertension), tachycardia (increased pulse rate), bradycardia (slow heart rate), peripheral artery disease, rheumatic heart disease, congenital heart disease and heart failure. The proliferation of such diseases and different disorders has now become an alarming issue and due to this problem, there arises a need for better diagnostic methods and tools. Chronic disorders are well treated if monitoring a patient's health can be analyzed in real-time even without the presence of a nurse or a doctor.

The design is intended for monitoring a patient's pulse rate and blood pressure. In comparison with the traditional or conventional tools already present which are used in the medical field, specifically the sphygmomanometer and the stethoscope, the design presents an innovation by combining the monitoring of the pulse rate and blood pressure into a single device and it is incorporated with a wireless technology, ZigBee. The design is also capable of interfacing data and result from the device to a PC monitor.

Basically, the design comprises of a digital blood pressure meter and a pulse rate sensor for pulse rate reading which can be used interchangeably through the design's accompanying software. For communication purposes, the ZigBee technology will be used for wireless data transmission between the device and the host PC.

Statement of the Problem

The study will address the problem of medical practitioners such as doctors and nurses in relieving the contemporary and native methods by improving the way medical data is taken. At present times, the nurse or doctor will attend to the patient and do some monitoring with conventional tools. After the monitoring is done, the results are written on a record sheet then transferred for further reference. This is done for each of the patient present in a medical area or in a hospital. As one can see, having a medical personnel attend to each of the patients will require time and is quite cumbersome especially to those who are in public hospitals.

The monitored data, on the other hand, can be inaccurate because the result of the reading will depend on the person who uses the traditional sphygmomanometer. The problem in it is the difficulty in using the traditional device, especially in hearing the beat for systolic and diastolic pressure as well as reading the gauge. Moreover, the process used by the medical practitioners in determining person's pulse rate is somewhat imprecise since the measurement depends on the number of pulse beats the medical practitioner can hear.

Furthermore, the manual recording of monitored data will be difficult to sort and organize. With the aid of the design project, monitoring of blood pressure and pulse rate of patients will be made through the use of a wireless device which is also interfaced to a PC. This method will greatly aid the doctors in their medical assistance to patients conveniently, in a way that the attendant will no longer bring record sheets along with them all the time since the design is capable of interfacing obtained data to host PC by means of the ZigBee protocol.

Objective of the Design

General Objective:

The general objective of the design is to develop a system that could aid and improve the traditional ways of assessing and monitoring blood pressure and pulse rate of medical practitioner towards his or her patients through the use of a wireless blood pressure and pulse rate health monitoring technology.

Specific Objectives:

To create a ZigBee based health monitoring system that is interfaced to a personal computer, and

To test, perform and compare measurements between devices.

Significance and Impact of the Design

The conceptualization of the design is based on the need to further improve the way medical practices are done. The beneficiaries of this innovation will benefit medical practitioners and patients. The prevalent methods being used before are likely to have suffered inefficiencies and the introduction of the new methods will greatly improve the way medical service is given. For the time being, such systems are already present but a need to improve is evident. Present systems tend to suffer inefficiency brought by issues regarding security, power consumption and ease of device usage not easily present on older wireless monitoring systems. Although the cost of such systems will inevitably be a little higher than the previous systems, the advantages will likely outweigh such small differences. This system is aimed to assist doctors and any others in the health industry. The study is relevant that it can enhance the way wireless health monitoring devices are used. Usage of the tools with the ZigBee modules for data transmission has a possibility to have a longer battery life which could provide more service hours to both the doctor and the patient. Critical usage of the monitoring devices involved medical relief missions and the role of these devices are considerably important. Therefore the service time of a device is a great concern. Furthermore, as the findings taken by the monitoring tools concerning the blood pressure and pulse rate data can be transferred to a computer, data storage and retrieval systems can be implemented so that the findings can assist related future cases which can ensure fast recovery for the patient and less time for the doctors. This will also allow them to have more time to diagnose other patients who are in need of medical services.

For global impact of the design, this would greatly help in the spreading of awareness of possible risk in one's health. In addition to that, it can persuade others to do some improvements concerning medical matters. Furthermore, because data is already present in its digital form, collaborative works between medical practitioners from different parts of the world can be implemented for studies on specific diseases.

Scope and Delimitations

Scope

The scope of the system involves the use of a digital device comprising of both blood pressure and pulse rate for the health monitoring of the patient. The device uses ZigBee technology for wireless data transmission.

A personal computer is used by the system to handle data storage and display taken from the ZigBee devices and is therefore well suited to read the data being taken by the receiving end. Raw data being taken by the device will now be transmitted to the receiver of the Zigbee. Then it will be displayed in the host PC monitor using software which reads the data being taken by the ZigBee receiver connected to the serial port. The software is also capable of checking the connection between the transmitter and the receiver side of the ZigBee.

Delimitations

The device is designed to monitor one's pulse rate and blood pressure. The blood pressure and pulse rate can not be measured simultaneously and is done one at a time. For data displays, a computer is used, in which a receiving ZigBee end device is attached. To view the data being obtained by the device, accompanying software is needed to be installed on the PC to be able to view the data from the ZigBee receiver. Also, database is not present in the design to record every single data since it is only capable of transferring the last value read by the device and therefore, have no way of retrieving the previous data but to measure again. The device will not function properly if the blood pressure and pulse rate monitoring device go beyond the allowable transmission range of the ZigBee, which are 40m for indoors with interferences and 120m for outdoors with a clear line-of-sight. The sphygmomanometer can handle about 200mmHg; whereas the wireless device could only handle up to 170mmHg. The design is only intended for one transmitter and one receiver. It is primarily intended for human use only. Some discrepancies in data reading of the blood pressure device may be observed due to its digital nature, wherein the measurements are derived from the readings.

Definition of Terms

Block Diagram. This term refers to a diagram represented by blocks connected by lines that show the relationships of the blocks (S.M.H. Collin; "Dictionary of Computing 5th edition")

Blood Pressure. It is the force of blood against the walls of the arteries caused when the heart pumps blood to the body parts. (Oxford Publishing; "Concise Medical Dictionary 6th edition")

Brachial Point. This refers to the point along the arm where the pulse in the arterial veins is strong and can be easily felt (Oxford Publishing; "Concise Medical Dictionary 6th edition")

Diastolic Pressure. It is the least amount of pressure exerted on arterial walls, which occurs when the heart is at rest between ventricular contractions (Turner, J., IU Center for Sports Medicine)

Flowchart. It is a diagram that shows step by step progression through a system using connecting lines and set of symbols (Gary J. Bronson; "C++ for Engineers and Scientists")

Graphical User Interface (GUI). This is a user interface that allows the user to activate operating system commands by clicking in a desktop icon using a pointing device such as mouse (Ida M. Flynn and Ann McIver McHoes; "Understanding Operating System 4th edition")

Hardware. It is the physical machine and its components, including main memory, I/O devices, I/O channels, direct access storage devices and the central processing unit (Ida M. Flynn and Ann McIver McHoes; "Understanding Operating System 4th edition")

Health Care. It refers to the prevention, treatment, and management of illness and the preservation of mental and physical well-being (The American Heritage® Medical Dictionary, 2007)

Interrupt. It is a useful way to grab the processor's attention, get it to perform a special task, and then resume execution from the point where it left off (James L. Antonakos; "The Intel Microprocessor Family: Hardware and Software Principles and Applications")

Light Emitting Diode (LED). It refers to a diode that gives out light or infrared rays when electrons enter holes as current flows through the diode (Neil Ardley; "Concise Encyclopedia Science")

Light Dependent Resistor (LDR). It is a variable resistor whose value decreases with increasing light intensity (Encarta Online Encyclopedia)

millimeter of Mercury (mmHg). It refers to the unit of measurement of pressure; a pressure of 1mmHg is that exerted by a column of mercury 1 millimeter high (Neil Ardley; "Concise Encyclopedia Science")

Microcontroller. It is a souped-up microprocessors with built-in features such as RAM, ROM, interval timers, parallel I/O ports, and even A/D converters (James L. Antonakos; "The Intel Microprocessor Family: Hardware and Software Principles and Applications")

Network. It refers to a system of interconnected computer systems and peripheral devices that exchange information within one another (Ida M. Flynn and Ann McIver McHoes; "Understanding Operating System 4th edition")

Operational Amplifier (OPAMP). It is an electronic unit that behaves like a voltage-controlled voltage source (Charles K. Alexander and Matthew N.O. Sadiku; "Fundamentals of Electric Circuit 3rd edition")

Printed Circuit Board (PCB). It is an insulating material used as base, into which conductive material strips are printed (Babak Kia, 2005)

Pulse. It refers to the rhythmic expansion and contraction of an artery caused by impact of blood pumped by the heart (National Health and Nutrition Examination Survey III by Westat, Inc)

Relay. It refers to an electrical switch that opens and closes under the control of another electrical circuit; electrical device that switches on and off (Neil Ardley; "Concise Encyclopedia Science")

Systolic Pressure. It is the highest point of pressure on arterial walls when the ventricles contract. (Turner, J. , IU Center for Sports Medicine)

Schematic Diagram. It refers to a diagram that represents the elements of a system using graphical symbols instead of realistic ones (S.M.H. Collin; Dictionary of Computing 5th edition)

Stethoscope. It is an instrument used for listening sound within the body (National Health and Nutrition Examination Survey III by Westat, Inc.)

Telemedicine. It is the employment of data transfer pertaining to medical from one location to another via electronic communication means for the provision of healthcare and/or education for the purpose of a fast recuperation.
(Max E. Stachura, MD and Elena V. Khasanshina, MD, PhD; "Telehomecare and Remote Monitoring: An outcomes overview")

Transformer. It refers to a device employing the principle of mutual induction to convert variations of current in a primary circuit into variations of voltage & current in a secondary circuit; a device that changes the voltage and current of an electrical supply (Neil Ardley; "Concise Encyclopedia Science")

Voltage. The energy required to move a unit charge through an element, measured in volts (V) (Charles K. Alexander and Matthew N.O. Sadiku; "Fundamentals of Electric Circuit 3rd edition")

Wireless Technology. It refers to a method of transmission that does not use wires or cables to connect both ends (Campus Information Technologies and Educational Services – University of Illinois)

ZigBee. It is a low-cost wireless system that provides low data-rate, low power consumption and has low current drain (Kinney,P., 2003)

Chapter 2

REVIEW OF RELATED LITERATURE AND STUDIES

This chapter contains related studies in relation to the design which help in understanding the related topics and the design itself.

As stated in the article entitled Health Care Online, the health care industry has been experiencing great innovations and some of these are due to the introduction of tools that aid the medical practitioners to assess patients from a distance. This method, through the use of such tools as discussed by Stapic in one of his studies, is referred to as Telemedicine and is defined as, "the use of electronic information and telecommunication technologies to share medical knowledge and provide care over a distance". Telemedicine systems are used to transfer bodily vital signs or a patient's status. These systems employ communication interface to a PC which allows the health personnel for a systematic collection and analysis of data. The significance of the system to the medical field, especially in long-term health supervision and chronic disease management is high. These new practice in health care delivery are further improving the way how health information are being collected and disseminated from within and between medical organizations. Enhancements in patient diagnosis brought by the availability of results from various data in gathered related cases using this system are promising.

A study made by Hoang denotes that health monitoring systems those being used in the telemedicine processes are typically made up of sensors and control devices. Sensors pick up the data of some health conditions into raw data that is then sent to the control device for processing. An appropriate action such as alerts, database storage, analyses and extraction of relevant information follows after the system initiated its use. This suggests that a typical health monitoring system is primarily made up of sensors, control devices and outputs such as a display or any certain computer response.

Many studies were already done based from various implementation of wireless health monitoring technologies. One of the studies led by Strömmer has shown that irDA, WLAN and Bluetooth, to name a few, have already been focused upon for wireless implementation. Each wireless system has different drawbacks and advantages to each other. The common factors that outweigh each system from another are price, interference issues, power consumption, security and usage complexities among other.

This project is intended to build a wireless pulse rate and blood pressure monitoring system using ZigBee as its means for data to be transferred wirelessly. Like its conventional medical monitoring tools equivalent, this project proposal is also meant to monitor the status of a patient but with wireless capability and pc interfacing improvement.

Using a wireless scheme for its data transfer, such systems are prone to errors due to noise caused by the environment. To minimize errors in data representations, the data being read from the monitoring devices will undergo filtering using a program based filter algorithms through the interfaced PC which also servers as the control. Implementation of needed data communication protocols required for the ZigBee devices will be considered in the interfacing.

Health monitoring tools are meant to be wearable devices for the use of a patient, therefore, some considerations of the project proposal design is based on this.

Finally, the main goal of this project proposal is to provide an almost real-time monitoring of the pulse rate and blood pressure of the patient.

Determining the method to be used in blood pressure and pulse rate monitoring system has great effect on the system's accuracy. Alvin Hopkinson, an author, explained that the success in controlling high blood pressure is ensured by keeping a record of pulse rates, weight loss or even the waistline. Tracking the progress involves monitoring as to what the heart is doing. Hence, one way of assessing the improvement of high blood pressure is via pulse rates. To determine high blood pressure, pulse rates can be taken from any part of the body with the wrist as the most preferred.

According to Xiaohui Li, Kangling Fang, Jinguang Gu and Liang Zhang entitled An Improved ZigBee Routing Strategy for Monitoring System, many ZigBee monitoring systems have been developed such as health monitoring, power monitoring, greenhouse monitoring and animal presence monitoring. The goal of these monitoring applications is low energy consumption for constantly monitoring. ZigBee offers a practical application solution coupled with low rate, low cost, low energy consumption characteristics for Wireless Sensor Networks. For constantly monitoring situation, the energy consumption is priority. In order to store the monitoring information into the database and provide interactive operations, the coordinator communicates with the personal computer through the RS-232 port. The management software on the personal computer can differentiate the requirements in the monitoring system. The ZigBee routers play the role of associating with other routers and sensor nodes as well as routing the messages within the network. The sensor nodes which are corresponding to the ZigBee end devices are equipped with a certain sensor to collect data from the environment. This Zigbee technology will be used for wireless data transfers between the sensors and the target device.

In the research done by Jung Han Choi*, Member, IEEE*, and Dong Kyun Kim entitled A Remote Compact Sensor for the Real-Time Monitoring of Human Heartbeat and Respiration Rate, they stated that the remote monitoring of human cardiac and respiratory activities are desirable since they help treat patients in emergency circumstances.

Presently, most commercial sensors have to be attached to the human body. It is inconvenient to use in daily life. The researchers stated that the remote sensor can be equipped in the home for long-period monitoring of the patient and in the bed for managing comfortable sleeping. If the sensor is applied to mobile application, the sensor needs to be portable and compact to maintain the accuracy of the detection.

Figure 2.1 Functional Block Diagram of the Developed Sensor

In conclusion, the heartbeat and respiration information can be obtained at a distance of 0.5 m with the developed sensor system. The measured heart beat signal was compared with the output signal of the commercial fingertip sensor. The comparison result shows excellent agreement, which validates the performance of the developed sensor system.

The researchers considered the study since it uses or applies the concept or real time monitoring system. Real time monitoring is very crucial in design projects especially if the intended use or application needs a fast yet accurate response. Not only the concept of real time monitoring is considered but also the use of sensor in monitoring one's vital parts, specifically, the heart beat and respiration rate.

Chapter 3

DESIGN PROCEDURE

This chapter gives a narrative procedures used in the development of the design. It includes the discussion of the block diagrams, schematic diagrams and flowcharts.

Data Gathering Procedure and Designing

This part initiates the study of the researchers. Procedures pertaining to the development of the design are discussed. Concepts regarding how the prototype will be constructed are dependent on what can be applied to ensure the construction of the prototype.

From the data gathered by the researchers, a design of the system is proposed as follows:

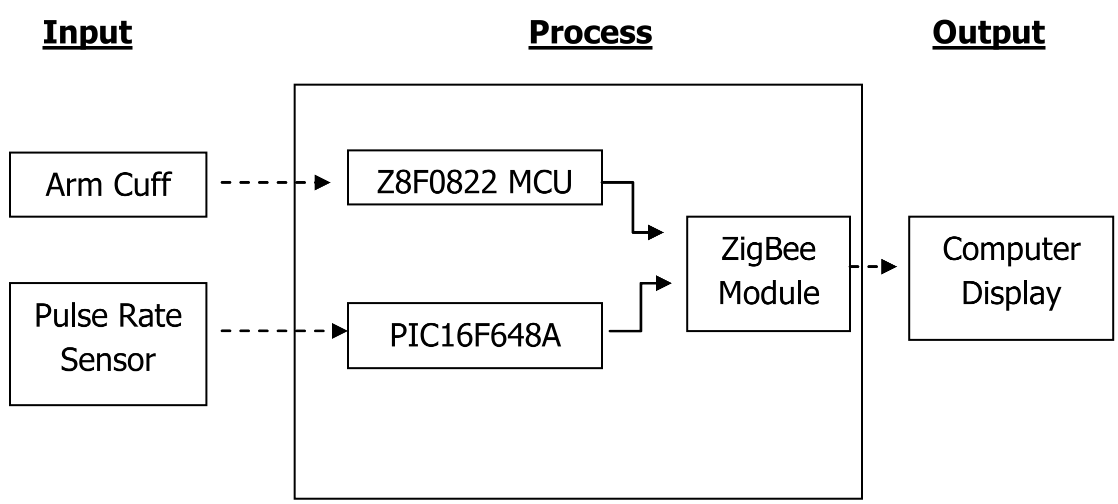


Figure 3.1 Block Diagram

In Figure 3.1, the design is divided into 3 parts which are categorized as input, process and output. The design is also composed of different parts which operate within the system to provide a specific function. The input part of the system is responsible for the assessment of the blood pressure and pulse rate of the patient.

In taking the blood pressure of the patient, the arm cuff is first worn by the patient on his arm near the brachial pulse point. Constriction of the arm takes places within a pressure range of 160 – 200mmHg by pumping air in the arm cuff which then blocks the blood vessels. As the air is slowly released from the constriction of the arm, the pressure sensor then operates by sensing the magnitude of oscillations caused by the blood as it begins to flow back into the arm. Small blood flow oscillations start to manifest when the air pressure in the cuff concurs with the systolic blood pressure. The blood pressure is then taken by the determination of the systolic blood pressure characterized by an increase in the amplitude of oscillations while the diastolic blood pressure value is determined by the detection of pulses which are leveling off. These detected pulses are converted to voltage signals by the pressure sensor which are proportional to the derived systolic and diastolic pressures.

The pulse rate measurement portion of the system works by detecting the varying opaqueness of the blood from the fingertip of the patient. A pair of Light

Dependent Resistor and a LED is used to determine whether blood has moved in the finger by determining a slight blockade of light from the LDR and the LED. This pulse is detected by amplifying the signal from the change of voltage brought by the LDR and by the OPAMP. The detection of pulse is calibrated using the variable resistors. The detected values are then handled by the program in the microcontroller.

The process step involves the manipulation of the data for computation, storage and transfer processes. The Zilog MCU handles the data provided by the blood pressure sensor for processing while the PIC16F84A MCU handles the measurement for the pulse rate. The wireless transfer of data to the ZigBee modules is also provided by the MCUs. Provisions were made to have a means of transferring the computed data through the use of the serial port (RS-232) using a MAX232 driver for data verification in comparison to the values received by the ZigBee.

The output portion of the system involves the screen display of the PC for viewing the data being shown in the GUI of the installed software. This is done by setting the program to read from the serial port of the PC in which the ZigBee receiver is connected and is interfaced to the PC by means of a MAX232 serial driver.

Schematic Diagrams

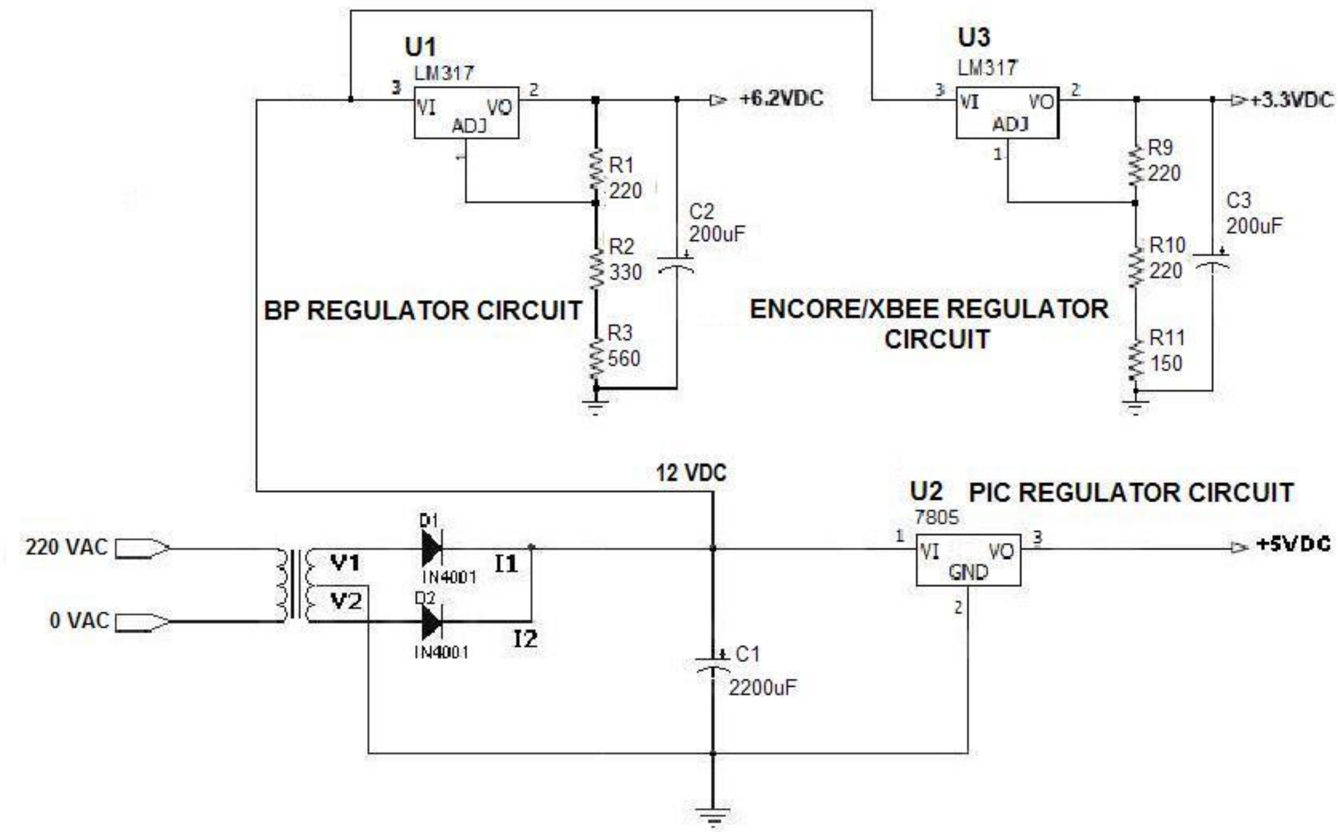


Figure 3.2 Schematic Diagram of Power Supply

Figure 3.2 is the schematic diagram for the power supply of the circuit. The power of the main circuit comes from the direct electric AC supply and is converted to a DC voltage through the use of the power supply circuit. This power supply circuit converts the AC characteristics of the voltage to a DC type through the process of full-wave rectification. The transformer on the left side of the diagram converts first the 220V AC to a 12V AC by stepping down the voltage through its coil windings. The transformer that is used in the design has a primary winding voltage of 220 volts and having a secondary nominal rating voltage of 12 volts. The current rating of the transformer is 400mA. The type of the transformer used in the design is center tap. The capacitor which is placed after the diodes filters any unwanted ripple voltage from the power supply to ensure the proper voltage requirements of the components. The design of the power supply was considered by first determining the required ratings of the components for a center tap type full wave rectifier. The center tap transformer has a secondary voltage rating (Vo) of 12 and output current (Io) of 400 mA. In finding the PIV (Peak Inverse Voltage) to determine the values of the needed Rectifier Diodes, the Vrms is needed and is computed using the formula:

$$C = (Io / 1.5) \times (1/\text{rectified frequency}).$$

With a value of 400mA and rectified frequency of 120Hz, the capacitor value is 0.0022133 Farad or 2213 microfarad which is close to the standard 2200 uF.

Each part of the circuit has different voltage requirements. For a constant voltage supply of 5V, the 7805 Fixed Voltage Regulator IC is used. For the other circuit that requires a different voltage supply, the LM317 Adjustable Voltage Regulator is used. The values to find the required LM317 output voltage are determined using the formula

$$V_{out} = 1.25\,(1 + (R2 + R3) / R1) = 6.2\text{ V}$$

for the 6.2 V output. For the 3.3 V output, the computation used is:

$$V_{out} = 1.25\,(1 + (R10 + R11) / R9) = 3.3\text{ V}$$

The LM317 uses bypass capacitors with values of 200 uF to improve the transient response of the power supply. The voltage of the LM317 with the output of 6.2 V is being supplied to the Blood Pressure Sensor System and the Relay switch. The LM317 with the output of 3.3 V is being used by the Zilog Microcontroller and the ZigBee Module. The output voltage of the 7805 is supplied to the pulse rate sensor system, the PIC Microcontroller and the max232 dual EIA-232 driver.

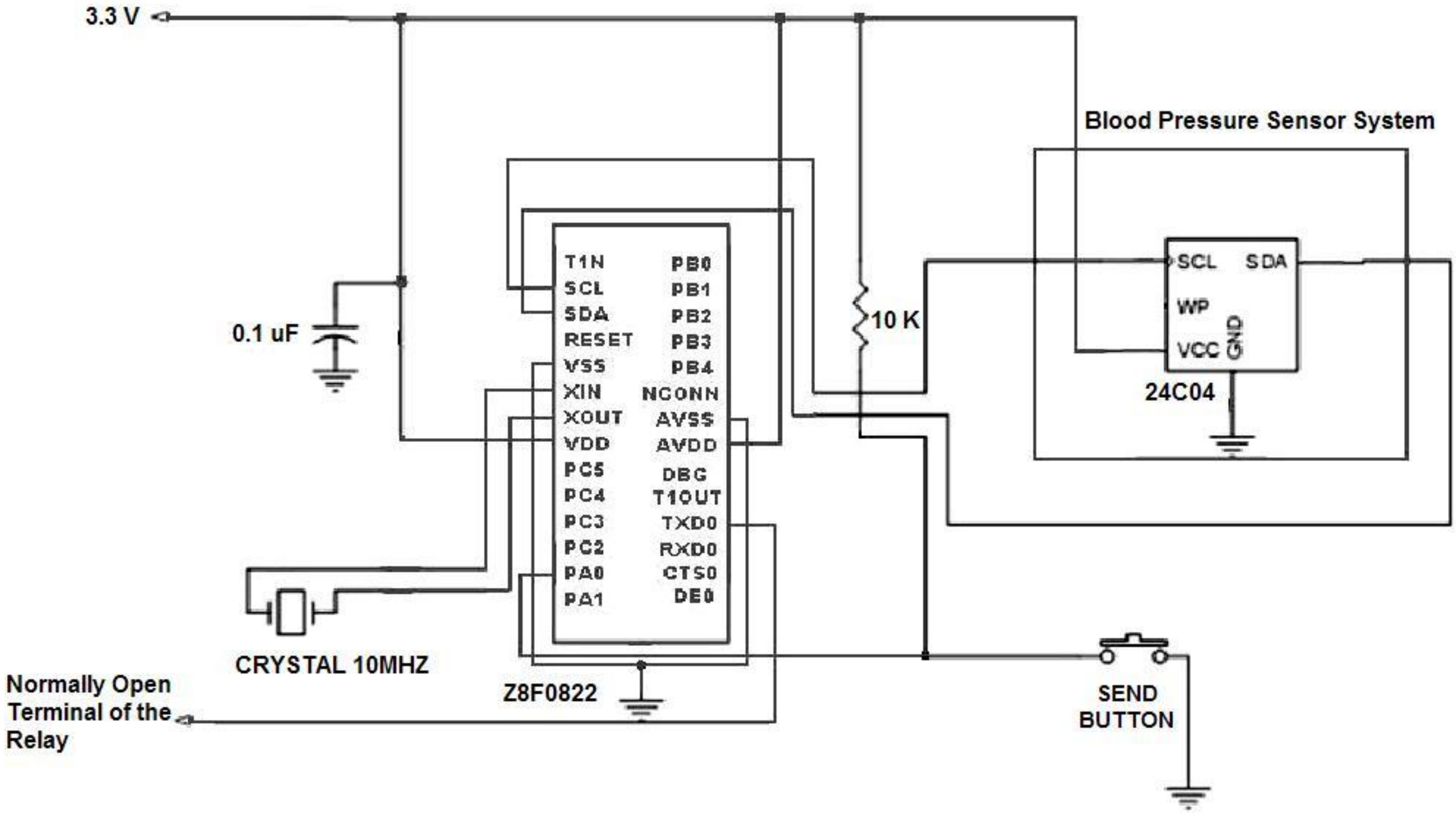


Figure 3.3 Schematic Diagram of Blood Pressure System

Figure 3.3 shows the schematic for the blood pressure system. The blood pressure sensor system obtains data from its pressure sensor and automatically saves the result of derived values into its 24C04 4kbit EEPROM IC. The Zilog Microcontroller uses the I^2C Protocol to read the values from the 24C04. The SDA and SCL pins of the Zilog MCU are connected to the respective SDA and SCL pins of the EEPROM. The Zilog MCU is clocked at 10MHz using a crystal oscillator connected to its XIN and XOUT pins. A push button with a pull down resistor value of 10k is connected to the General I/O Pin Port A0 of the Zilog MCU for the initiation of an interrupt in the sending of data for wireless transmission. A 3.3V supply voltage is connected to the Vdd of the Zilog MCU with a 0.1 microfarad bypass capacitor. The Avss and Vss pins of the MCU are connected to a common ground.

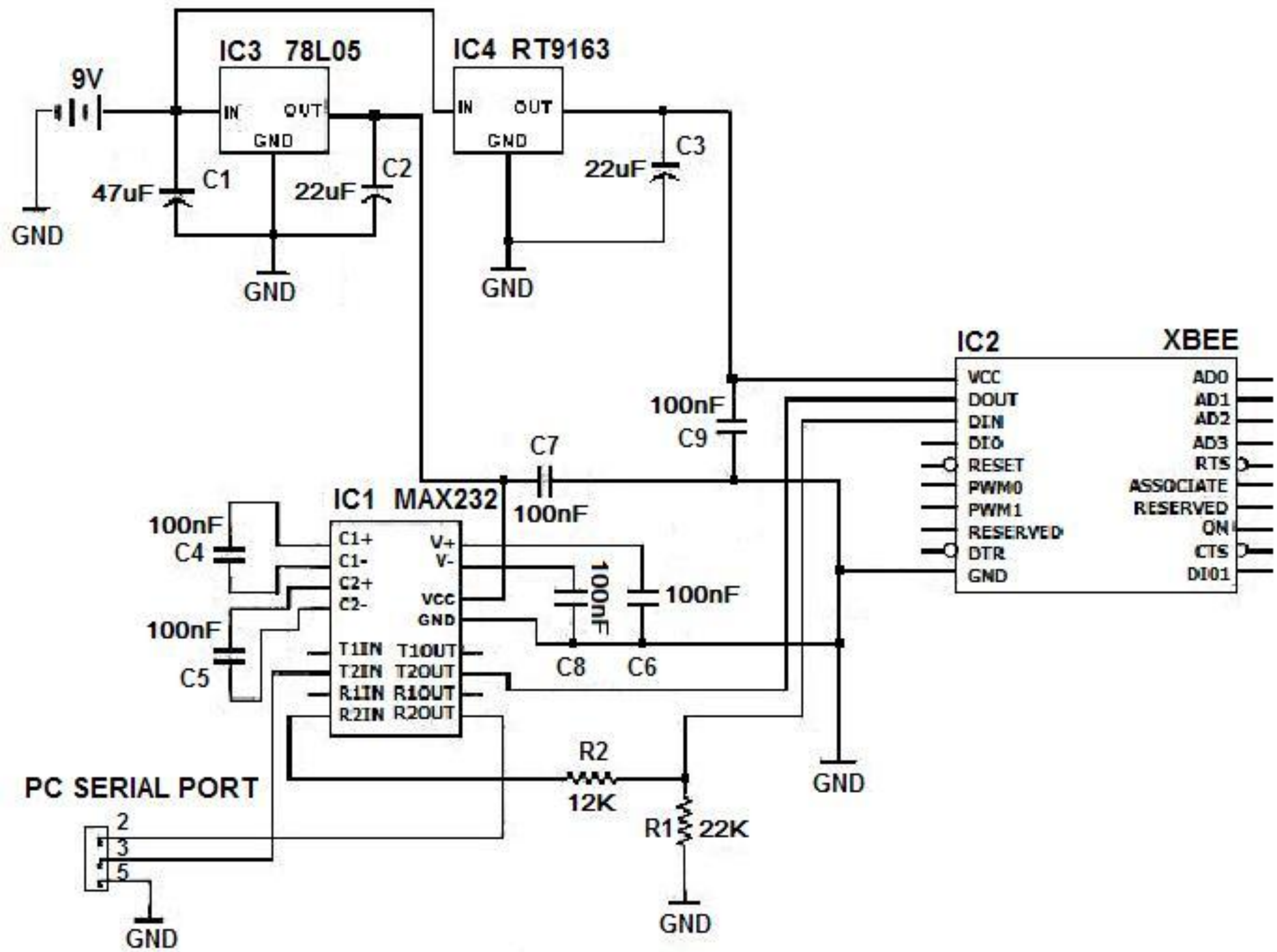


Figure 3.4 Schematic Diagram of ZigBee Receiver

The receiver part of the system consists of the ZigBee module (IC2), the max232 (IC1) driver for the interfacing of the device to the serial port, the 7805 5v power regulator (IC3) for the max232 and the rt9163 3.3V power regulator for the ZigBee. The receiver works by first using the ZigBee module to receive any data from the ZigBee module in the sensor side of the system. If any data is detected, the ZigBee module automatically sends the data received to the max232 driver to be interfaced to the serial port of the PC through the DOUT PIN of the ZigBee to the R2IN pin of the max232 driver. The Pin DIN of the ZigBee is held low to disable the data transmission capability of the ZigBee. The Max232 driver outputs the TIA/EIA-232 compatible signals form the ZigBee to its R2OUT Pin of the Max232 driver. The power supply of each part of the receiver is taken from a 9V battery supply. The voltages are further broken down into 5V for the max232 which is fed to its VCC pin using the lm7805 IC for 5V regulation. For the power supply of the ZigBee, the voltage is regulated using the rt9163 3.3V regulator IC. Bypass capacitors of 100 nF were connected to the C1+/-, C2+/- and Vs +/- of the max232 IC as specified in its datasheet under application information. The 470 uF capacitor after the 9V battery is placed to reject any ripple voltage that may occur. Values of 22uF were used for each voltage regulator to improve its output transient response.

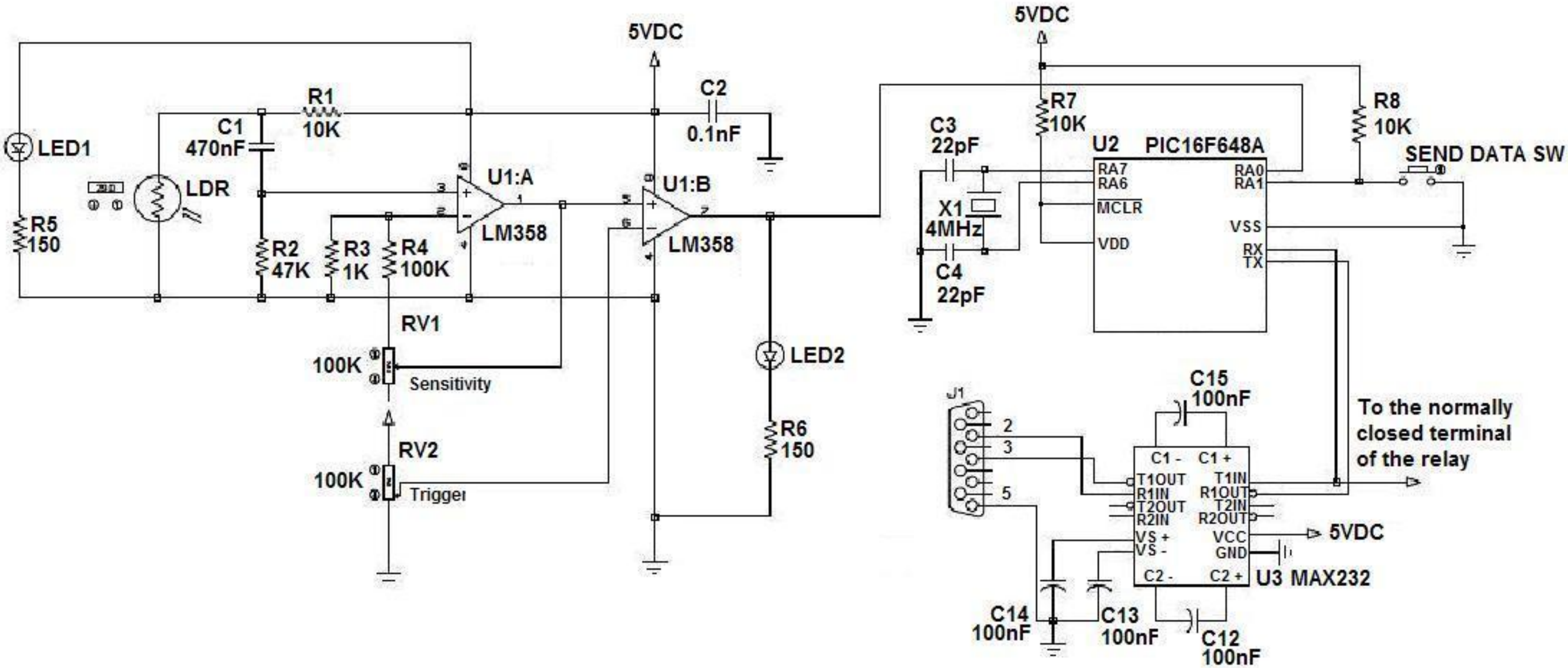


Figure 3.5 Schematic of Pulse Rate and Serial Port Driver

The pulse rate sensor circuitry uses a pair of LDR and LED to detect the blood pulse from the finger.

The sensor part of the pulse rate system is composed of a pair of Red LED and a Light Dependent Resistor (LDR). The pulse rate system uses a LM358 IC to amplify the detected pulses, checks the signal for a valid pulse and send the signals directly to the PIC microcontroller. The leftmost OPAMP in Figure 3.5 is configured as a Non-Inverting Amplifier to amplify the signals of pulse from the finger of the patient. The change in voltage brought by the change in resistance of the LDR determines whether a pulse has passed the finger or not. The change in voltage signal is small so that an amplifier circuit is used to strengthen the weak pulse signal. The detected pulse is an alternating signal as the voltage fluctuates from its base voltage to a slight difference increase when a pulse is detected. The circuit employs a simple low pass filter at the non-inverting input of the OPAMP that acts as an amplifier. This filter allows small frequencies to pass and rejects any higher frequency value. The formula used in computing for the sampling frequency is:

$$f_c = 1/(2\pi RC)$$

The value of R1 is set to 10kΩ while the value of capacitor was set to 470nF. The computed value for fc is 34 Hz.

The voltage gain of the amplifier OPAMP is set to Av = 201 using the formula:

$$Av = 1 + (R2 / R1)$$

The R1 in the equation is the R3 in the circuit with a value of 1k and is connected between the inverting terminal of the OPAMP and the common ground. R2 is composed of the RV1 and R4 in the circuit which is a resistor with a value of 100kΩ and a 100kΩ potentiometer. Potentiometers are included in the configuration of the OPAMP to calibrate the sensitivity of the system to detect a pulse. Using the set voltage gain, the Vout in the OPAMP can be computed using the formula Vout = Av x Vin. The 47kΩ resistor placed between the non-inverting terminal of the OPAMP and ground serves as a compensation resistor to correct voltage error caused by input bias current.

The second OPAMP is configured as a non-inverting comparator. The reference voltage that determines a valid pulse signal is the voltage in the trigger potentiometer. In this comparator setup, when the voltage from the non-inverting input exceeds the reference voltage which is applied to the inverting input, the output switches from low (0 V) to high (positive saturation). The PIC MCU accepts signals as TTL logical 0 for 0.8 V and below and a logical 1 value for 2V and above. The detected valid pulse signal goes to the GIO pin Port A0 of the PIC. Each LED in the pulse rate sensor system uses a 150Ω current limiting resistor designated as R5 and R6.

The PIC microcontroller computes the total pulse of the person in a given time through the program in the microcontroller. The PIC MCU is clocked at 4

MHz using a crystal oscillator paired with bypass capacitors whose values are 22pF connected to its OSC1 and OSC2 pins. The push button switch is connected to the Port A5 of the PIC MCU and along with a 10k pull down resistor. A MAX232 serial port driver is allows the transfer of data directly to the serial port of the host PC. The pin 4 Master Clear of the PIC is held high with a pull-up resistor of 10k. The PIC MCU uses its USART (Universal Synchronous/Asynchronous Receiver/Transmitter) pin TX to transfer the data serially to the ZigBee module device and the max232. The output of pin TX is connected to the normally closed terminal of the relay before reaching the PIN DIN of the ZigBee.

Bypass capacitors of 100 nF are connected to the C1+/-, C2+/- and Vs +/- of the max232 IC as specified in its datasheet under application information.

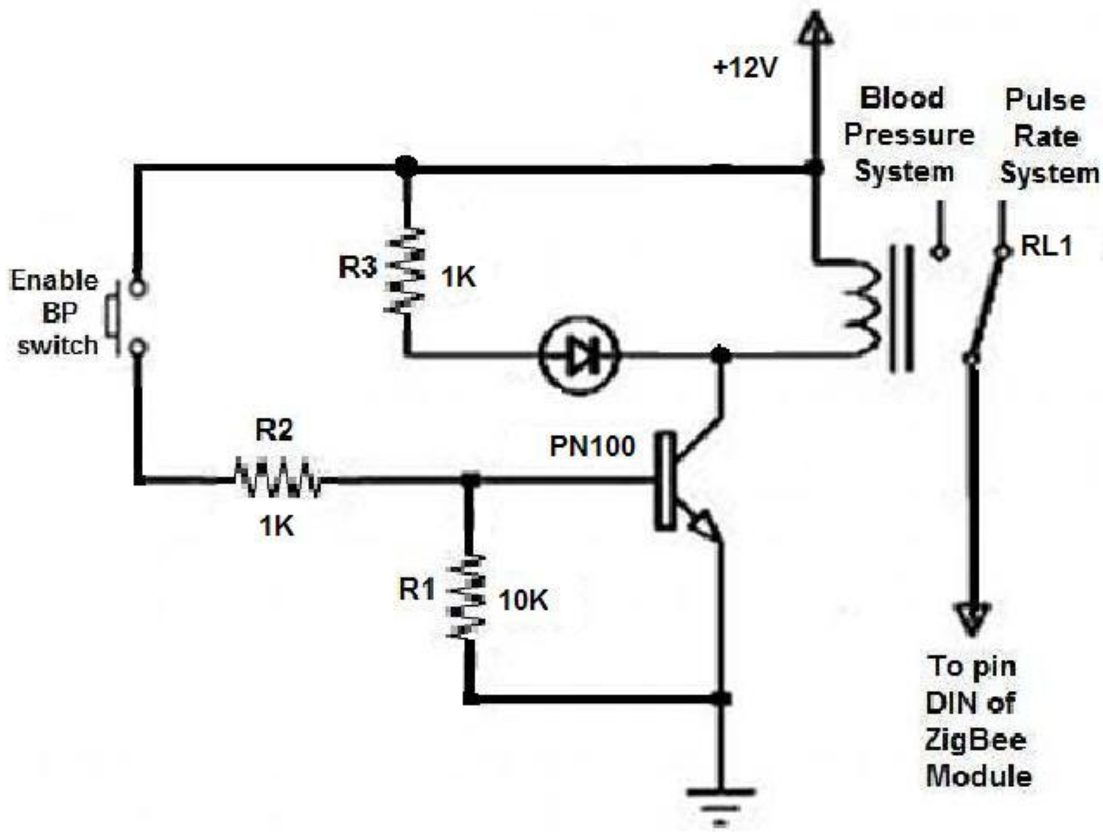


Figure 3.6 Schematic Diagram of the Relay Switch and Driver

Figure 3.6 shows the schematic diagram for the relay driver. The whole system operates by either selecting the blood pressure measurement system or the pulse rate measurement system. The data signals for each are confined in their respective modular systems and must be multiplexed to be transferred to a single ZigBee transmitter device for data transfer. The researchers have chosen the use of a relay as a switch to select either the data coming to the pulse rate system or the blood pressure system. The Relay driver is configured by making the transistor to act as a switch. To do this, the transistor must be put in a saturation state to further drive the relay. Knowing the needed load current for the device to be turned on and the minimum hfe of a transistor, the minimum base current to saturate the transistor can be known. The needed current of the relay to be switched is 100mA and the minimum hfe of the transistor is 100, the minimum base current can be solved using the equation:

Minimum base current = load current / transistor hfe

The equation yields a value of 1 mA. To ensure that the transistor is always saturated, an added 30% to the computed base current is made. The minimum base current then becomes 1.3 mA. The computation for the resistor R1 is computed using the formula:

R1 = Supply Voltage /(Maximum Current Required A/ Minimum HFE * Minimum Base current mA)

R1 = 12 volts / ((0.1 A / 100) * 1.3 mA)

R1 = 9230.7 Ω ≈ 10 KΩ

The R2 resistor is a base resistor which is used to prevent excessive base current going to the transistor. The R3 resistor was used as a current limiting resistor to the “Enable BP” LED. The purpose of the “Enable BP” switch is to activate the relay by shorting R1 to the positive end of the supply to select either the pulse rate system or the blood pressure system. The pulse rate system is connected to the common closed terminal of the relay and the blood pressure system is in the common open terminal of the relay. The output of the relay is connected to the DIN of the ZigBee module.

PCB Layout

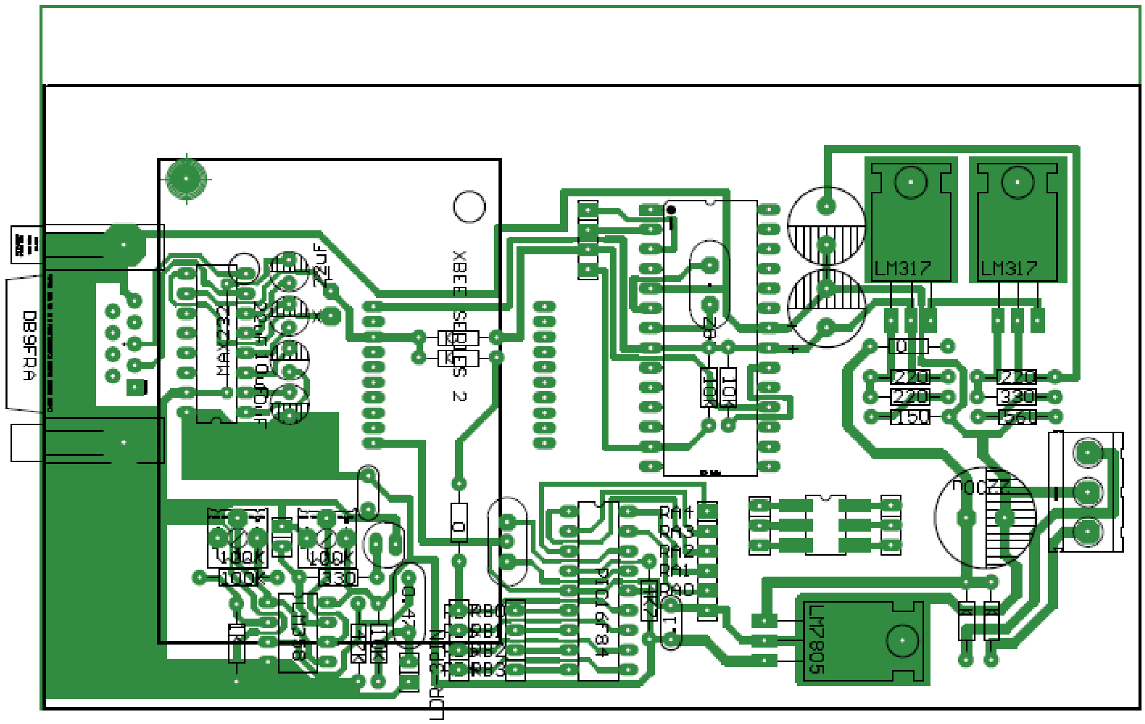


Figure 3.7 PCB Layout

Figure 3.7 shows the PCB layout for the main circuit of the design. The software used to develop this layout is the PCB wizard.

System Components

Quantity	Item Name	Description
3	Resistor	150 Ω
1	Resistor	47 kΩ
3	Resistor	1kΩ
1	Resistor	100kΩ
5	Resistor	10kΩ
3	Resistor	220Ω
1	Resistor	330Ω
1	Resistor	560Ω
1	Resistor	12kΩ
1	Resistor	22kΩ
1	LDR	Light Dependent Resistor
2	LED	Light- Emitting Diode

1	LM358	Dual Operational Amplifier
1	PIC16F648A	CMOS FLASH-based 8-bit microcontroller
1	Z8F0822	Zilog FLASH-based 8-bit microcontroller
1	Crystal Oscillator	4Mhz
1	Crystal Oscillator	10Mhz
1	24c04	4 kbit serial bus eeprom
2	Serial Connector	9-pin female serial connector
2	MAX232	Dual EIA-232 Drivers/Receivers
2	lm317	3-Terminal Positive Adjustable Regulator
2	ZigBee	XB24-z7uit-004 ZigBee Module
1	rt9163	3.3v voltage regulator
1	LM7805	5v voltage regulator
2	variable resistors	100kΩ
1	Capacitor	0.1nF
1	Capacitor	470nF
2	Capacitor	22pF
7	Capacitor	100nF
2	Capacitor	470uF
3	Capacitor	22uF
1	Capacitor	0.1uF
1	NPN Transistor	PN100 NPN General Purpose Amplifier
2	Rectifier Diode	1N4001 Rectifier
1	Relay	General Single Pole Double Throw Relay

Table 3.1 System Components

Software

Software is used in the construction of the design which involves the development of the GUI program and the programming of the microcontrollers. In the programming of the microcontrollers, compilers and burners are used for each. The program code for the PIC16F648A was made using the PICBASIC compiler. The program was burned using parallel PIC burner software from Oshonsoft. The Zilog was programmed using a Z8 C compiler and was burned using Zilog Developer Suite II. To design the PCB layout of the hardware, PCB wizard software was used.

The system employs a GUI program to display the result to a host PC taken by the device from the patient. The program to develop the GUI program is Visual Basic 6. The GUI development software is used because it has a ready built-in code for coordinating with devices which are interfaced to a serial port.

System Flowchart

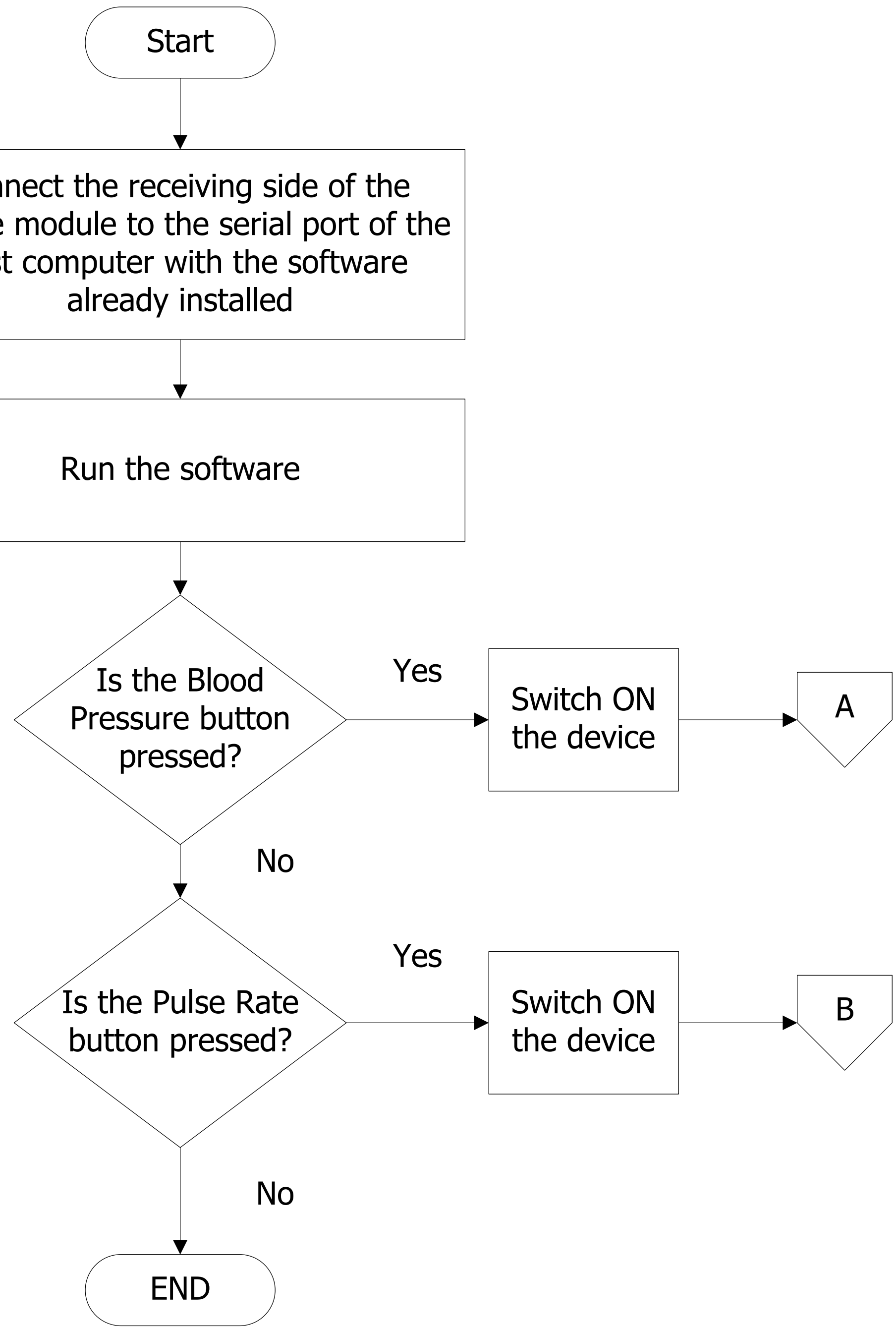


Figure 3.8 System Flowchart

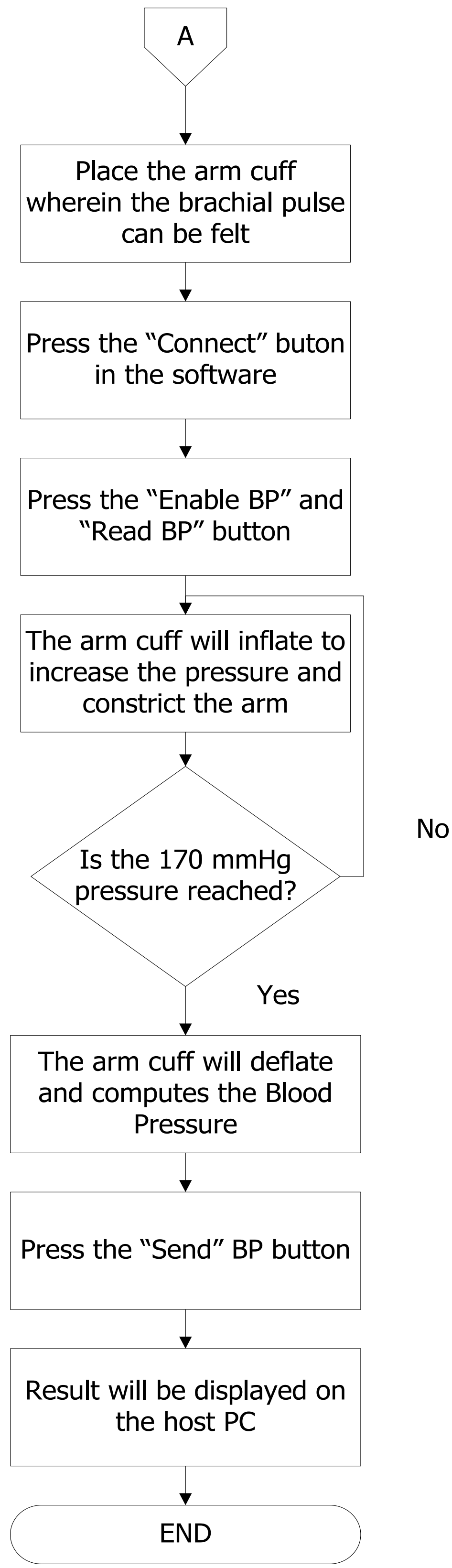


Figure 3.9 System Flowchart for the Blood Pressure

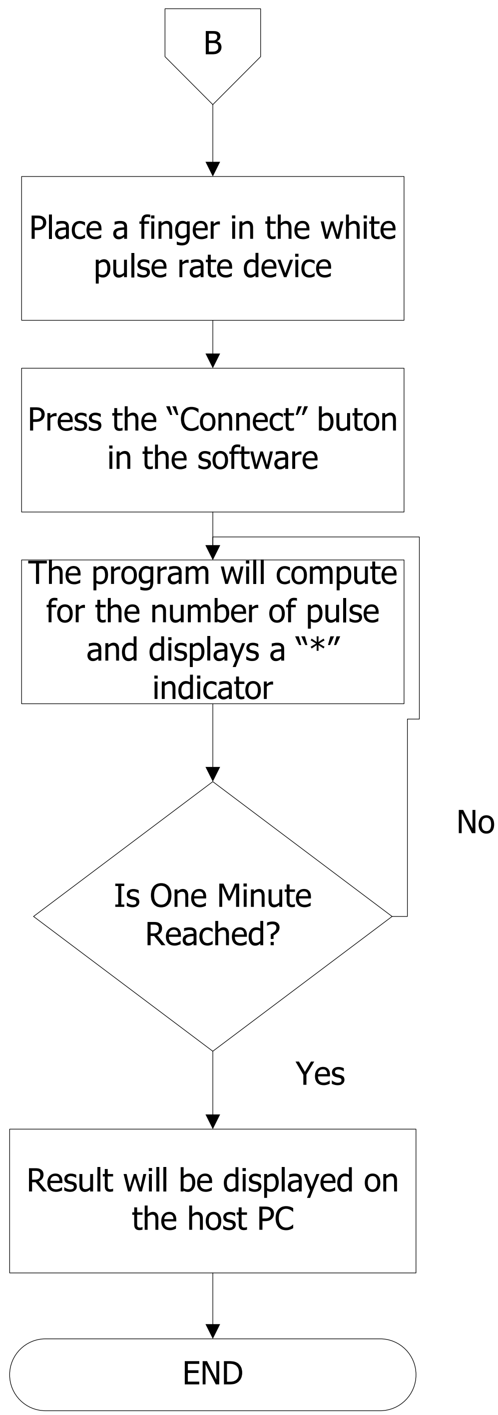


Figure 3.10 System Flowchart for the Pulse Rate

Design Procedure

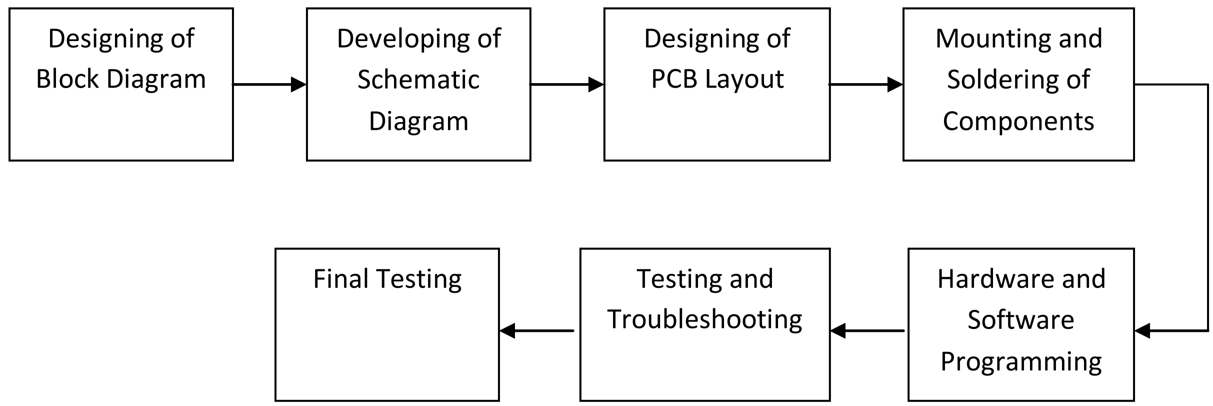


Figure 3.11 Design Procedure Diagram

The first step in the development of the prototype is the designing of the block diagram. The design's block diagram comprises of the input (arm cuff and pulse rate sensor), process (microcontroller and ZigBee module) and output (computer display). After designing the system's block diagram the next step will be the developing of the schematic diagram. The schematic diagram is based from the block diagram. Data sheets of every component were considered to prevent damage to the components and to the system. The PCB design is the next step before the placing of the components. The PCB wizard was used to develop the desirable circuit design. In PCB design, not only the paths of the wiring connecting the various components are important, but also the orientation of the components. High heat producing components should be placed as far as possible from heat sensitive components. After the PCB design layout was developed, the mounting and soldering of components comes next. A soldered connection when properly done offers better electrical conductivity and can withstand greater physical stress and corrosion. Hardware and Software programming comes after the mounting and soldering of components. For the hardware part, PIC basic was the programming used for our PIC16F648A and for the software part, Visual Basic was used. After the group has assembled the design, then comes the testing part. Testing of the design was done to determine possible errors. Immediately after the errors have been determined, troubleshooting and debugging were done to eliminate such errors. The last test is the final testing. It was made to ensure that the design is final and has already met the desired objectives.

Program Flowchart

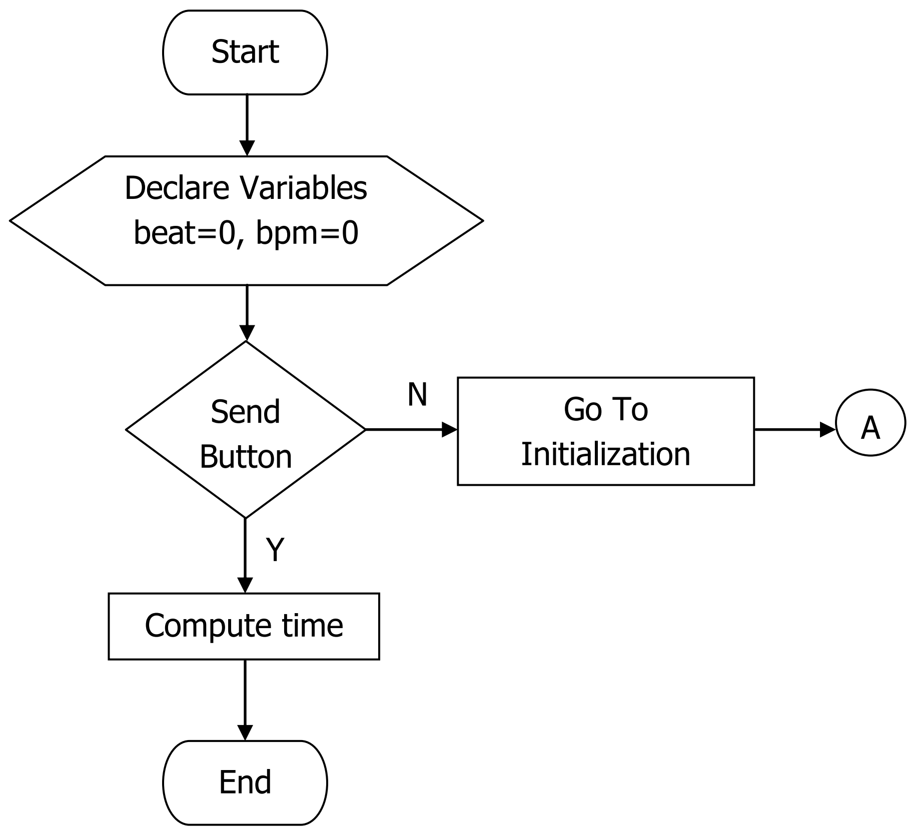
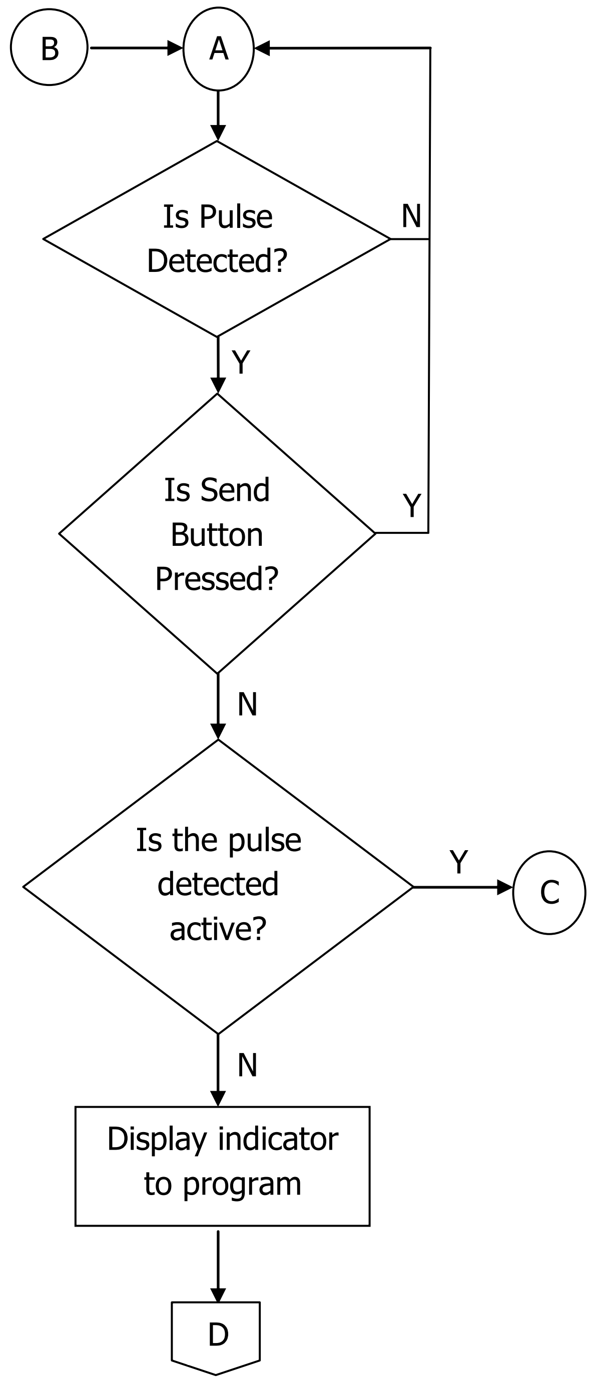
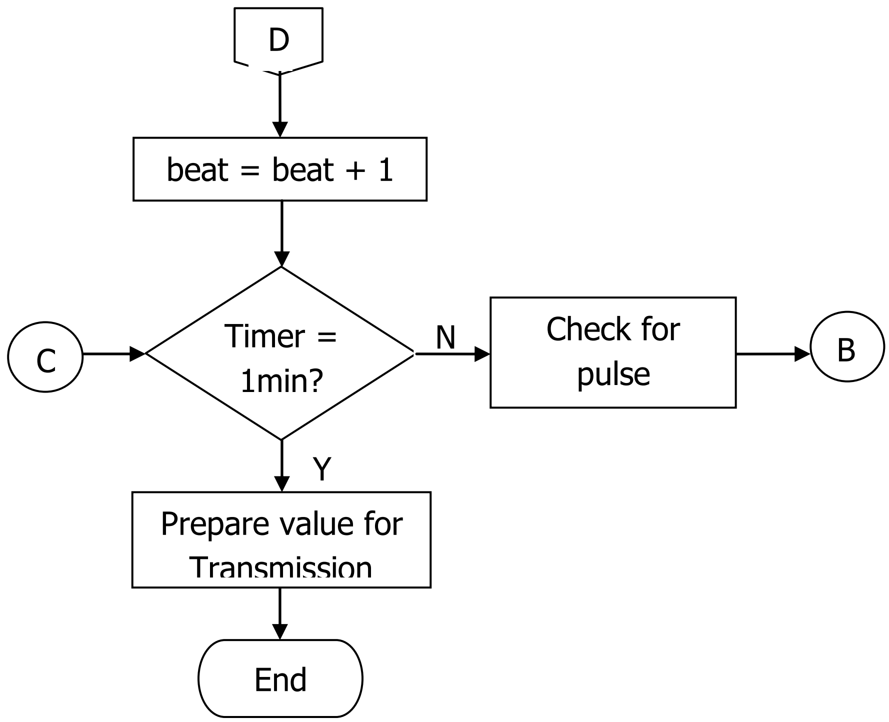


Figure 3.12 Program Flowchart



B
A
Is Pulse Detected?
N
Y
Is Send Button Pressed?
Y
N
Is the pulse detected active?
Y
C
N
Display indicator to program
D



This flowchart illustrates the operation of the program for the pulse rate sensing of the system. The program starts by declaring the needed variables to be used. The code then constantly checks whether the user has pressed the send button. If the button has not been pressed, the program initializes the variables to its default value and checks for any incoming pulse. This prevents the user to send the stored data repeatedly to the program in the PC. For a valid active pulse, the system will flash an asterisk indicator in the GUI program to show pulse rate detection while the counters are being incremented. The program will loop back to the pulse detection and continues to count the pulses for one minute. If the program has reached one minute, the value is then stored and waits for the user to press the send button to transfer the data wirelessly to the receiver which is then displayed on the GUI.

Chapter 4

TESTING, PRESENTATION AND INTERPRETATION OF DATA

This chapter gives details on how the system was tested in relation to the objectives stated in the first chapter.

In order to determine the consistency of the prototype, testing was done after the prototype has been assembled. A testing was also done in order to prove that the objectives were attained. Before testing for each procedure, the following steps must be completed.

1. Turn on the computer and run the Blood Pressure and Pulse Rate Monitoring Program,
2. Connect the receiver side of the ZigBee module to the serial port of the host computer,
3. Turn on the Blood Pressure and Pulse Rate Monitoring Device,
4. Select either "Blood Pressure" or "Pulse Rate"; and
5. Click the "Connect" button.

After these steps were ensured, the first thing to be tested is the maximum amount of pressure that the arm cuff can handle. The sphygmomanometer can handle about 200mmHg; whereas the wireless device could only handle up to 170mmHg.

Once determined, blood pressure and pulse rate are now ready to be measured. Measurements were done one at a time. Since the system is wireless, blood pressure and pulse rate readings can be transmitted and displayed to the host device using the ZigBee module. Once the data was measured, the user must press the "Send" button to transfer the data to the host device.

Readings in relation with distance covered

Distance	Is reading sent?	Distance	Is reading sent?
0m	Yes	60m	Yes
10m	Yes	70m	Yes
20m	Yes	80m	Yes
30m	Yes	90m	Yes
40m	Yes	100m	Yes
50m	Yes	Above 100m	No

Table 4.1 Blood Pressure and Pulse Rate Readings in relation with distance covered

Table 4.1 deals on the Blood Pressure and Pulse Rate readings in relation to the distance covered. The testing took place in an open area wherein the person to be monitored assumes a comfortable sitting position with the forearm supported at the level of the heart and the palm of the hand turned upwards. The host is fixed in one area whereas the person's distance from the host device is varied.

The distances used for the particular testing are from 0 meter – 110 meters. In every test, the distance varies 10 meters. The readings obtained from the tests show that the data could be sent at approximately 100m. Above from 100m, the data could not be read in the device. When the data is not read or the pressure exceeds 170mmHg, there will be no value displayed on the software and the word "STATUS" will blink. Hence, no status will be displayed on the software.

Comparison of readings between different devices

Person	**Sphygmomanometer**		**Digital Monitoring Device**		**Wireless Monitoring Device**	
	Blood Pressure	**Pulse Rate**	**Blood Pressure**	**Pulse Rate**	**Blood Pressure**	**Pulse Rate**
A	120/80	70	116/71	70	118/73	73
B	120/70	75	115/62	73	116/69	74

C	100/80	84	106/76	81	115/80	85
D	130/80	85	130/90	89	137/91	88
E	110/80	82	113/72	80	112/72	83

Table 4.2 Sphygmomanometer, Digital and Wireless Monitoring Device Comparison

Sphygmomanometer is a device used for several years to measure blood pressures and pulse rates. It is of great importance to perform a comparison between the sphygmomanometer and wireless blood pressure and pulse rate monitoring device to measure the credibility of the design. With the aid of a nurse, blood pressures and pulse rates of different individuals was measured. The results were reflected on table 4.2.

Blood pressure and pulse rate of five different individuals were obtained in this particular test. Test using sphygmomanometer was done with the aid of a nurse since nurses have a lot more knowledge in measuring using the traditional method. The accuracy of the measurements in this method depends on the ability of the person measuring it. While testing the digital and wireless monitoring device was done by the research team, it was found out that, using this device requires less effort and less complicated compared to the traditional one.

As seen in Table 4.2, the readings of both blood pressure and pulse rate in sphygmomanometer and wireless monitoring device showed minimal discrepancy. The discrepancy may be due to the inaccuracy of the readings by the wireless monitoring device. The wireless monitoring devices do not actually measure the blood pressure but derives the readings. The wireless device usually follows an algorithm in which it derives the readings from the highest values (systolic) down to the lowest values (diastolic) and averages them.

Chapter 5

CONCLUSION AND RECOMMENDATION

This chapter gives the overall conclusion of the design, which addresses the objectives of the design.

Conclusion

A Wireless Blood Pressure and Pulse Rate monitoring device using ZigBee technology that could remotely measure and monitor blood pressure and pulse rate was designed, constructed and implemented. The design allows ease of use and fast method of monitoring blood pressure and pulse rate for patients because data are transmitted wirelessly and can be interfaced to a computer allowing fast transmission from a distance and permits further evaluation of data. Tests made support this fact. The design will also aid the medical practitioners for cases of isolated patients that need continuous monitoring. The data from the patients can be easily accessed using a central computer which handles the information.

Wireless blood pressure and pulse rate monitoring system can be implemented by using ZigBee technology. The measured blood pressure and pulse rate can be transmitted wirelessly to the receiver with high accuracy. Only small discrepancies between the measurement of mercury based sphygmomanometer and the designed system were noted. This is based on the results of the tests done. This shows that wireless blood pressure and pulse rate monitoring system using ZigBee is a reliable way to measure blood pressure and pulse rate. The result of the monitoring device can be displayed using a personal computer by interfacing the ZigBee receiver module to the host computer via serial port.

Recommendation

The design can be improved by adding a database on its application software to help keep records of data for comparison of results. The database would allow flexibility by recording or deleting blood pressure and pulse rate results for future use or reference. Increasing the number of ZigBee modules connecting to the host computer is recommended to maximize the networking capability of ZigBee and will allow simultaneous monitoring of multiple patients. This is because multiple ZigBee transmitters can connect to a single receiver. Automation of the blood pressure and pulse rate monitoring could be added. This can be done by integrating an automatic and continuous measurement of pulse rate and blood pressure in a given time that can be set by a timer. For additional functionality of the design, ECG or Electrocardiogram can be added. It is a diagnostic tool that measures and records the electrical activities of the heart in great detail.

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Hoang, Doan. (2007). Wireless technologies and architectures for health. *Proceedings of the First International Conference on the Digital Society (ICDS'07)*

APPENDIX A

Program Listing

```
Device 16F628

Declare Xtal = 4

Hserial_Baud = 9600

Hserial_RCSTA = %10010000

Hserial_TXSTA = %00100100

Hserial_Clear = On

All_Digital = TRUE


TRISA =%00011

TRISB=%01000000


 Dim WRD As Word

 Dim beat As Byte

 Dim bpm  As Word


 Dim uS As Word

 Dim mS As Word

 Dim S As Word

 Symbol GIE = INTCON.7

 Symbol TMR0_uS = 512

 Symbol TMR0_Enable = INTCON.5

 Symbol TMR0_Overflow = INTCON.2
```

```
Symbol pulse = PORTA.0

Clear WRD
beat = 0
bpm = 0

Clear PORTA
Clear PORTB

On_Interrupt Int_Sub
GoTo Initialization
Int_Sub:
        GIE = 0
        If TMR0_Overflow = 1 And TMR0_Enable = 1 Then
          TMR0_Overflow = 0
          uS = uS + TMR0_uS
          If uS >= 1500 Then
                uS = uS - 1500
                mS = mS + 1
                If mS >= 1000 Then
```

```
                mS = mS - 1000
                S = S + 1
            EndIf
        EndIf
    EndIf
    GIE = 1
    Context Restore

Initialization:
    TMR0_Enable = 0
    uS = 0
    mS = 0
    S = 0
    OPTION_REG.0 = 0
    OPTION_REG.1 = 0
    OPTION_REG.2 = 0
    OPTION_REG.5 = 0
    TMR0 = 0
    TMR0_Enable = 1
    GIE = 1

check_pulse:
```

```
    If PORTA.1 = 0 Then
         DelayMS 250
        GoTo pulse_on
    EndIf
    GoTo check_pulse
pulse_on:
    If PORTA.1 = 0 Then
         DelayMS 250
    beat =0
    bpm  =0
    WRD = 0
        GoTo pulse_on
    EndIf

    If pulse = 1 Then
    HSerOut ["*",13]
    beat = beat + 1
    WRD = WRD + 1
    DelayMS 150

    While pulse = 1
```

```
    Wend
    HSerOut [" ",13]
    EndIf

    If S > 60 Then
    S = 0
    HSerOut [Dec beat]
    DelayMS 500

    beat =0
    bpm  =0
    WRD = 0
    GoTo check_pulse    '
    EndIf

    GoTo pulse_on
disp1:

     HSerOut [Dec beat]
     Return
```

```
Device Z8F0822
#include <eZ8.h>
#include <sio.h>
#include <string.h>
#include <stdlib.h>
int loc=0;
char ren;
char dat1;

char dat2;
char msg[100];
unsigned char num1;
unsigned char num2;
unsigned char num3;
char outstr[20];

#include "i2c.h"
void sleep (char x)
{
unsigned int y;
        while(x)
        {
```

```
            for(y=0;y!=0xffff;y++);
            x--;
        }
}

#pragma interrupt
void isr_uart0_rx(void)
{
   ren=getch();
}
void init_uart0(void)
{
   init_uart(_UART0,_DEFFREQ, 9600);
   select_port(_UART0);
       SET_VECTOR(UART0_RX, isr_uart0_rx);
       IRQ0ENH |= 0x10;
       IRQ0ENL |= 0x10;
}
void main (void)
{
```

```
DI();
//OSCCTL=0x80;
PADD=0xff;
init_uart0();
EI();
sleep(4);
while(1)
{




    sleep(40);

    loc=2047;
    while(readI2C(0,loc)==0xFF)
    {
        loc--;
        if(loc==0) break;
    }
    loc-=3;
    ren=0;
```

```
for(ren=0;ren!=4;ren++)
{
        msg[ren]=readI2C(0,loc);
        loc++;
}
putch('D');

putch('A');

putch('T');

putch('A');

putch(msg[0]);

putch(msg[2]);

putch(msg[3]);


//sleep(40);
```

APPENDIX B

Datasheets

XBee™ ZNet 2.5/XBee-PRO™ ZNet 2.5 OEM RF Modules

XBee ZNet 2.5/XBee PRO Znet 2.5 OEM RF Modules

ZigBee™ Networks

RF Module Operation

RF Module Configuration

Appendices

Product Manual v1.x.4x - *ZigBee* Protocol

For OEM RF Module Part Numbers: XB24-BxIT-00x

ZigBee OEM RF Modules by Digi International

Firmware Versions: 1.0xx - Coordinator, Transparent Operation
1.1xx - Coordinator, API Operation
1.2xx - Router, End Device, Transparent Operation
1.3xx - Router, End Device, API Operation

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

90000866_C
2/11/2008

1. Overview

The XBee/XBee-PRO ZNet 2.5 OEM (formerly known as Series 2 and Series 2 PRO) RF Modules were engineered to operate within the ZigBee protocol 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 remote devices.

The modules operate within the ISM 2.4 GHz frequency band and are compatible with the following:

- XBee RS-232 Adapter
- XBee RS-232 PH (Power Harvester) Adapter
- XBee RS-485 Adapter
- XBee Analog I/O Adapter
- XBee Digital I/O Adapter
- XBee Sensor Adapter
- XBee USB Adapter
- XStick
- ConnectPort X Gateways
- XBee Wall Router.

1.1. Key Features

High Performance, Low Cost

- Indoor/Urban: up to 300' (100 m)
- Outdoor line-of-sight: up to 1 mile (1.6 km)
- Transmit Power Output: 100 mW (20 dBm) EIRP
- Receiver Sensitivity: -102 dBm

RF Data Rate: 250,000 bps

Advanced Networking & Security

Retries and Acknowledgements

DSSS (Direct Sequence Spread Spectrum)

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

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

Self-routing, self-healing and fault-tolerant mesh networking

Low Power

XBee PRO ZNet 2.5

- TX Current: 295 mA (@3.3 V)
- RX Current: 45 mA (@3.3 V)
- Power-down Current: < 1 µA @ 25°C

Easy-to-Use

No configuration necessary for out-of box RF communications

AT and API Command Modes for configuring module parameters

Small form factor

Extensive command set

Free X-CTU Software (Testing and configuration software)

Free & Unlimited Technical Support

1.1.1. Worldwide Acceptance

FCC Approval (USA) Refer to Appendix A [p50] for FCC Requirements.
Systems that contain XBee /XBee-PRO ZNet 2.5 RF Modules inherit Digi Certifications.

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

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

XBee /XBee-PRO ZNet 2.5 RF Modules are optimized for use in **US**, **Canada**, **Australia, Israel and Europe** (contact MaxStream for complete list of agency approvals).

1.2. Specifications

Table 1-01. Specifications of the XBee /XBee-PRO ZNet 2.5 OEM RF Module

Specification	XBee ZNet 2.5	XBee PRO ZNet 2.5
Performance		
Indoor/Urban Range	up to 133 ft. (40 m)	up to 300 ft. (100 m)
Outdoor RF line-of-sight Range	up to 400 ft. (120 m)	up to 1 mile (1.6 km)
Transmit Power Output	2mW (+3dBm), boost mode enabled 1.25mW (+1dBm), boost mode disabled	63mW (+18 dBm) 10mW (+10 dBm) for International variant
RF Data Rate	250,000 bps	250,000 bps
Serial Interface Data Rate (software selectable)	1200 - 230400 bps (non-standard baud rates also supported)	1200 - 230400 bps (non-standard baud rates also supported)
Receiver Sensitivity	-96 dBm, boost mode enabled -95 dBm, boost mode disabled	-102 dBm

Table 1-01. Specifications of the XBee /XBee-PRO ZNet 2.5 OEM RF Module

Specification	XBee ZNet 2.5	XBee PRO ZNet 2.5
Power Requirements		
Supply Voltage	2.1 - 3.6 V	3.0 - 3.4 V
Operating Current (Transmit, max output power)	40mA (@ 3.3 V, boost mode enabled) 35mA (@ 3.3 V, boost mode disabled)	295mA (@3.3 V)
Operating Current (Receive))	40mA (@ 3.3 V, boost mode enabled) 38mA (@ 3.3 V, boost mode disabled)	45 mA (@3.3 V)
Idle Current (Receiver off)	15mA	15mA
Power-down Current	< 1 uA @ 25^{o}C	< 1 uA @ 25^{o}C
General		
Operating Frequency Band	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, RPSMA, or U.FL Connector*	Integrated Whip, Chip, RPSMA, or U.FL Connector*
Networking & Security		
Supported Network Topologies	Point-to-point, Point-to-multipoint, Peer-to-peer, and Mesh	Point-to-point, Point-to-multipoint, Peer-to-peer, and Mesh
Number of Channels	16 Direct Sequence Channels	13 Direct Sequence Channels
Addressing Options	PAN ID and Addresses, Cluster IDs and Endpoints (optional)	PAN ID and Addresses, Cluster IDs and Endpoints (optional)
Agency Approvals		
United States (FCC Part 15.247)	OUR-XBEE2	MCQ-XBEEPRO2
Industry Canada (IC)	4214A-XBEE2	1846A-XBEEPRO2
Europe (CE)	ETSI	ETSI
RoHS	Compliant	Compliant

1.3. Mechanical Drawings

Figure 1-01. Mechanical drawings of the XBee /XBee-PRO ZNet 2.5 OEM RF Modules (antenna options not shown)

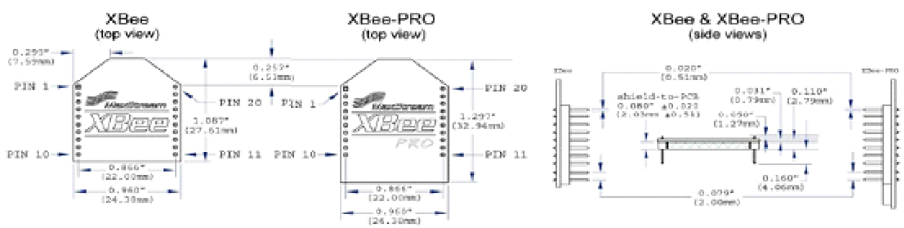
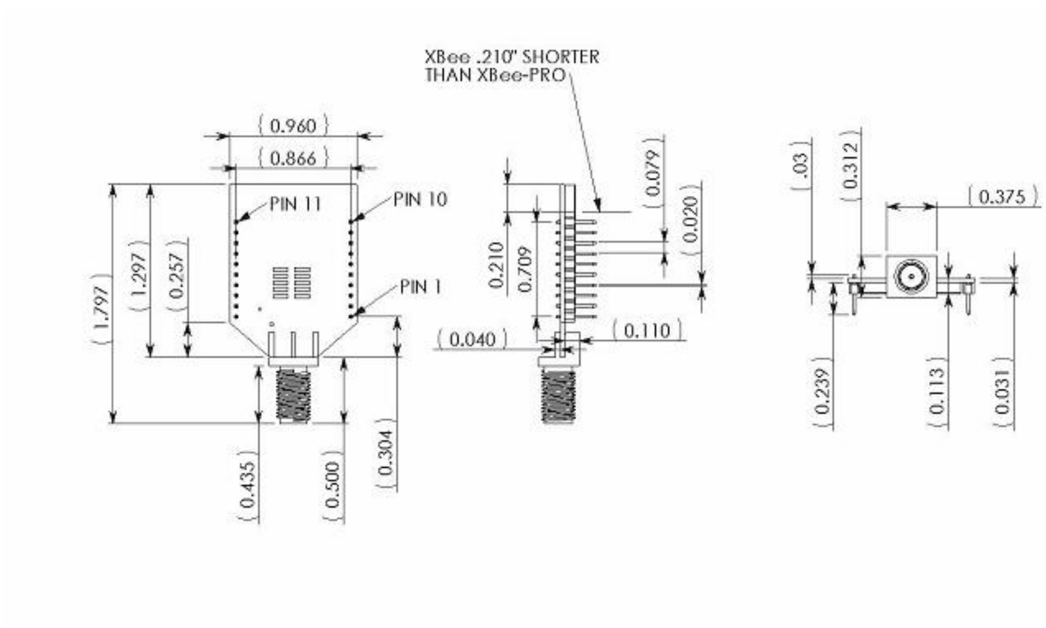


Figure 1-02. Mechanical Drawings for the RPSMA Variant



1.5. Pin Signals

Figure 1-04. XBee /XBee-PRO ZNet 2.5 RF Module Pin Number
(top sides shown - shields on bottom)

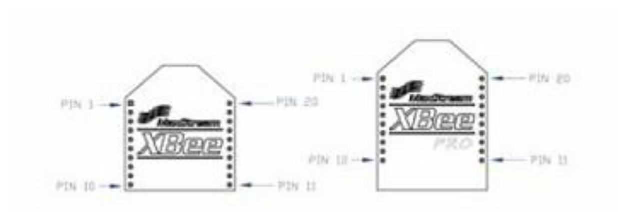


Table 1-02. Pin Assignments for the XBee PRO ZNet 2.5 Modules
(Low-asserted signals are distinguished with a horizontal line above signal name.)

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / CONFIG	Input	UART Data In
4	DIO12	Either	Digital I/O 12
5	RESET	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI / DIO10	Either	PWM Output 0 / RX Signal Strength Indicator / Digital IO
7	PWM / DIO11	Either	Digital I/O 11
8	[reserved]	-	Do not connect
9	DTR / SLEEP_RQ/ DIO8	Either	Pin Sleep Control Line or Digital IO 8
10	GND	-	Ground
11	DIO4	Either	Digital I/O 4
12	CTS / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / SLEEP / DIO9	Output	Module Status Indicator or Digital I/O 9
14	[reserved]	-	Do not connect
15	Associate / DIO5	Either	Associated Indicator, Digital I/O 5
16	RTS / DIO6	Either	Request-to-Send Flow Control, 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 / Commissioning Button	Either	Analog Input 0, Digital IO 0, or Commissioning Button

Design Notes:

- Minimum connections: VCC, GND, DOUT & DIN
- Minimum connections to support serial firmware upgrades: VCC, GND, DIN, DOUT, RTS & DTR
- Signal Direction is specified with respect to the module
- Module includes a 30k Ohm resistor attached to RESET
- Several of the input pull-ups can be configured using the PR command
- Unused pins should be left disconnected
- Pin 20 can be connected to a push button (pin grounded when closed) to support the commissioning push button functionality. See "Commissioning Pushbutton and Associate LED" for details.

1.6. Electrical Characteristics

Table 1-03. DC Characteristics of the XBee PRO ZNet 2.5 (VCC = 3.0 - 3.4 VDC).

Symbol	Parameter	Condition	Min	Typical	Max	Units
VIL	Input Low Voltage	All Digital Inputs	-	-	0.2 * VCC	V
V_{IH}	Input High Voltage	All Digital Inputs	0.8 * VCC	-	-	V
V_{OL}	Output Low Voltage	I_{OL} = 2 mA, VCC >= 2.7 V	-	-	0.18*VCC	V
V_{OH}	Output High Voltage	I_{OH} = -2 mA, VCC >= 2.7 V	0.82*VCC	-	-	V
I_{IN}	Input Leakage Current	V_{IN} = VCC or GND, all inputs, per pin	-	-	0.5uA	uA

2. RF Module Operation

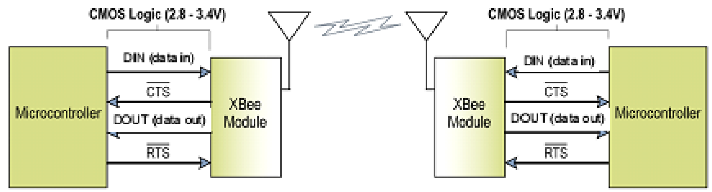
2.1. Serial Communications

The XBee ZNet 2.5 OEM RF Modules interface to a host device through a logic-level asynchronous serial port. Through its serial port, the module can communicate with any logic and voltage compatible UART; or through a level translator to any serial device (For example: Through a Digi proprietary RS-232 or USB interface board).

2.1.1. UART Data Flow

Devices that have a UART interface can connect directly to the pins of the RF module as shown in the figure below.

Figure 2-01. System Data Flow Diagram in a UART-interfaced environment
(Low-asserted signals distinguished with horizontal line over signal name.)

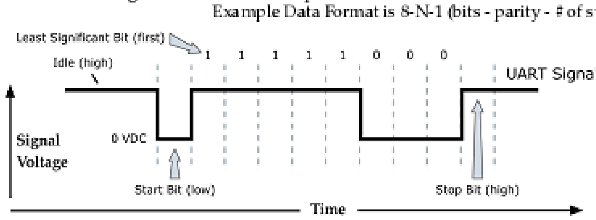


Serial Data

Data enters the module UART through the DIN (pin 3) as an asynchronous serial signal. The signal should idle high when no data is being transmitted.

Each data byte consists of a start bit (low), 8 data bits (least significant bit first) and a stop bit (high). The following figure illustrates the serial bit pattern of data passing through the module.

Figure 2-02. UART data packet 0x1F (decimal number "31") as transmitted through the RF module
Example Data Format is 8-N-1 (bits - parity - # of stop bits)

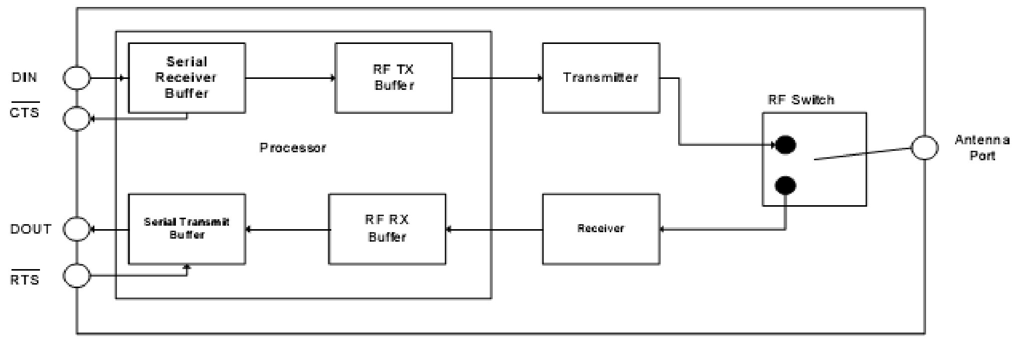


The module UART performs tasks, such as timing and parity checking, that are needed for data communications. Serial communications depend on the two UARTs to be configured with compatible settings (baud rate, parity, start bits, stop bits, data bits).

2.1.2. Serial Buffers

The XBee ZNet 2.5 modules maintain small buffers to collect received serial and RF data, which is illustrated in the figure below. The serial receive buffer collects incoming serial characters and holds them until they can be processed. The serial transmit buffer collects data that is received via the RF link that will be transmitted out the UART.

Figure 2-03. Internal Data Flow Diagram



Serial Receive Buffer

When serial data enters the RF module through the DIN Pin (pin 3), the data is stored in the serial receive buffer until it can be processed. Under certain conditions, the module may not be able to process data in the serial receive buffer immediately. If large amounts of serial data are sent to the module, $\overline{CTS}$ flow control may be required to avoid overflowing the serial receive buffer.

Cases in which the serial receive buffer may become full and possibly overflow:

1. If the module is receiving a continuous stream of RF data, the data in the serial receive buffer will not be transmitted until the module is no longer receiving RF data.

2. If the module is transmitting an RF data packet, the module may need to discover the destination address or establish a route to the destination. After transmitting the data, the module may need to retransmit the data if an acknowledgment is not received, or if the transmission is a broadcast. These issues could delay the processing of data in the serial receive buffer.

Serial Transmit Buffer

When RF data is received, the data is moved into the serial transmit buffer and sent out the UART. If the serial transmit buffer becomes full enough such that all data in a received RF packet won't fit in the serial transmit buffer, the entire RF data packet is dropped.

Cases in which the serial transmit buffer may become full resulting in dropped RF packets

1. If the RF data rate is set higher than the interface data rate of the module, the module could receive data faster than it can send the data to the host.

2. If the host does not allow the module to transmit data out from the serial transmit buffer because of being held off by hardware flow control.

2.1.3. Serial Flow Control

The $\overline{RTS}$ and $\overline{CTS}$ module pins can be used to provide $\overline{RTS}$ and/or $\overline{CTS}$ flow control. $\overline{CTS}$ flow control provides an indication to the host to stop sending serial data to the module. RTS flow control allows the host to signal the module to not send data in the serial transmit buffer out the uart. $\overline{RTS}$ and $\overline{CTS}$ flow control are enabled using the D6 and D7 commands.

$\overline{CTS}$ Flow Control

If $\overline{CTS}$ flow control is enabled (D7 command), when the serial receive buffer is 17 bytes away from being full, the module de-asserts $\overline{CTS}$ (sets it high) to signal to the host device to stop sending serial data. $\overline{CTS}$ is re-asserted after the serial receive buffer has 34 bytes of space.

$\overline{\text{RTS}}$ Flow Control

If RTS flow control is enabled (D6 command), data in the serial transmit buffer will not be sent out the DOUT pin as long as $\overline{\text{RTS}}$ is de-asserted (set high). The host device should not de-assert $\overline{\text{RTS}}$ for long periods of time to avoid filling the serial transmit buffer. If an RF data packet is received, and the serial transmit buffer does not have enough space for all of the data bytes, the entire RF data packet will be discarded.

2.1.4. Serial Interface Protocols

The XBee modules support both transparent and API (Application Programming Interface) serial interfaces.

Transparent Operation

When operating in transparent mode, the modules act as a serial line replacement. All UART data received through the DIN pin is queued up for RF transmission. When RF data is received, the data is sent out through the DOUT pin. The module configuration parameters are configured using the AT command mode interface.

Data is buffered in the serial receive buffer until one of the following causes the data to be packetized and transmitted:

1. No serial characters are received for the amount of time determined by the RO (Packetization Timeout) parameter. If RO = 0, packetization begins when a character is received.

2. Maximum number of characters that will fit in an RF packet is received (72 bytes).

3. The Command Mode Sequence (GT + CC + GT) is received. Any character buffered in the serial receive buffer before the sequence is transmitted.

RF modules that contain the following firmware versions will support Transparent Mode:
1.0xx (coordinator) and 1.2xx (router/end device).

API Operation

API operation is an alternative to transparent operation. The frame-based API extends the level to which a host application can interact with the networking capabilities of the module. When in API mode, all data entering and leaving the module is contained in frames that define operations or events within the module.

Transmit Data Frames (received through the DIN pin (pin 3)) include:

- RF Transmit Data Frame
- Command Frame (equivalent to AT commands)

Receive Data Frames (sent out the DOUT pin (pin 2)) include:

- RF-received data frame
- Command response
- Event notifications such as reset, associate, disassociate, etc.

The API provides alternative means of configuring modules and routing data at the host application layer. A host application can send data frames to the module that contain address and payload information instead of using command mode to modify addresses. The module will send data frames to the application containing status packets; as well as source, and payload information from received data packets.

The API operation option facilitates many operations such as the examples cited below:

->Transmitting data to multiple destinations without entering Command Mode

->Receive success/failure status of each transmitted RF packet

->Identify the source address of each received packet

RF modules that contain the following firmware versions will support API operation: 1.1xx (coordinator) and 1.3xx (router/end device).

2.2. Modes of Operation

2.2.1. Idle Mode

When not receiving or transmitting data, the RF module is in Idle Mode. During Idle Mode, the RF module is also checking for valid RF data. The module shifts into the other modes of operation under the following conditions:

- Transmit Mode (Serial data in the serial receive buffer is ready to be packetized)
- Receive Mode (Valid RF data is received through the antenna)
- Sleep Mode (End Devices only)
- Command Mode (Command Mode Sequence is issued)

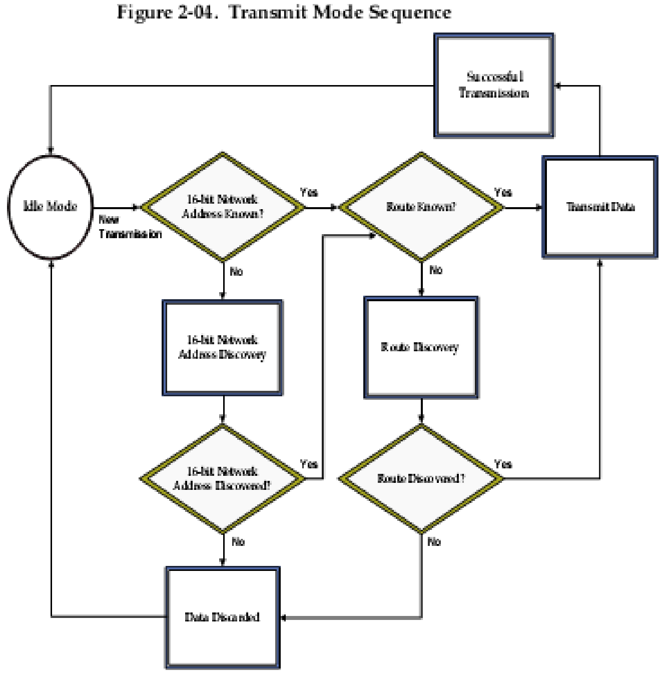
2.2.2. Transmit Mode

When serial data is received and is ready for packetization, the RF module will exit Idle Mode and attempt to transmit the data. The destination address determines which node(s) will receive the data.

Prior to transmitting the data, the module ensures that a 16-bit network address and route to the destination node have been established.

If the destination 16-bit network address is not known, network address discovery will take place. If a route is not known, route discovery will take place for the purpose of establishing a route to the destination node. If a module with a matching network address is not discovered, the packet is discarded. The data will be transmitted once a route is established. If route discovery fails to establish a route, the packet will be discarded.

Figure 2-04. Transmit Mode Sequence



When data is transmitted from one node to another, a network-level acknowledgement is transmitted back across the established route to the source node. This acknowledgement packet indicates to the source node that the data packet was received by the destination node. If a network acknowledgement is not received, the source node will re-transmit the data.

It is possible in rare circumstances for the destination to receive a data packet, but for the source to not receive the network acknowledgment. In this case, the source will retransmit the data, which could cause the destination to receive the same data packet multiple times. The XBee ZNet 2.5 modules do not filter out duplicate packets. The application should include provisions to address this potential issue

See Data Transmission and Routing in chapter 3 for more information.

2.2.3. Receive Mode

If a valid RF packet is received, the data is transferred to the serial transmit buffer.

2.2.4. Command Mode

To modify or read RF Module parameters, the module must first enter into Command Mode - a state in which incoming serial characters are interpreted as commands. Refer to the API Mode section in Chapter 7 for an alternate means of configuring modules.

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]

Once the AT command mode sequence has been issued, the module sends an "OK\r" out the DOUT pin. The "OK\r" characters can be delayed if the module has not finished transmitting received serial data.

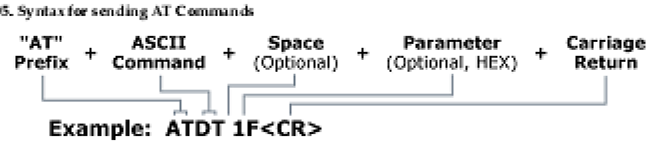
When command mode has been entered, the command mode timer is started (CT command), and the module is able to receive AT commands on the DIN pin.

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. By default, the BD (Baud Rate) parameter = 3 (9600 bps).

To Send AT Commands:
Send AT commands and parameters using the syntax shown below.

Figure 2-05. 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.

Command 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.

Applying Command Changes

Any changes made to the configuration command registers through AT commands will not take effect until the changes are applied. For example, sending the BD command to change the baud rate will not change the actual baud rate until changes are applied. Changes can be applied in one of the following ways:

- The AC (Apply Changes) command is issued.
- AT command mode is exited.

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 "Examples" and "XBee ZNet 2.5 Command Reference Tables" chapters.

2.2.5. Sleep Mode

Sleep modes allow the RF module to enter states of low power consumption when not in use. The XBee ZNet 2.5 OEM RF modules support both pin sleep (sleep mode entered on pin transition) and cyclic sleep (module sleeps for a fixed time). XBee ZNet 2.5 sleep modes are discussed in detail in section 5.3.

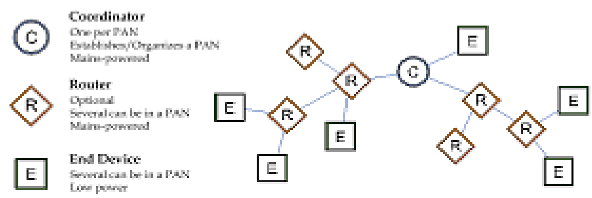
3. ZigBee Networks

3.1. ZigBee Network Formation

Zigbee networks are called personal area networks (PAN). Each network contains a 16-bit identifier called a PAN ID.

ZigBee defines three different device types – coordinator, router, and end device. An example of such a network is shown below.

Figure 3-01. Node Types / Sample of a Basic ZigBee Network Topology



Coordinator – Responsible for selecting the channel and PAN ID. The coordinator starts a new PAN. Once it has started a PAN, the coordinator can allow routers and end devices to join the PAN. The coordinator can transmit and receive RF data transmissions, and it can assist in routing data through the mesh network. Coordinators are not intended to be battery-powered devices. Since the coordinator must be able to allow joins and/or route data, it should be mains powered.

Router – A router must join a ZigBee PAN before it can operate. After joining a PAN, the router can allow other routers and end devices to join the PAN. The router can also transmit and receive RF data transmissions, and it can route data packets through the network. Since routers can allow joins and participate in routing data, routers cannot sleep and should be mains powered.

End Device – An end device must join a ZigBee PAN, similar to a router. The end device, however, cannot allow other devices to join the PAN, nor can it assist in routing data through the network. An end device can transmit or receive RF data transmissions. End devices are intended to be battery powered devices. Since the end device may sleep, the router or coordinator that allows the end device to join must collect all data packets intended for the end device, and buffer them until the end device wakes and is able to receive them. The router or coordinator that allowed the end device to join and that manages RF data on behalf of the end device is known as the end device's parent. The end device is considered a child of its parent.

3.2. ZigBee PANs

ZigBee networks are formed when a coordinator first selects a channel and PAN ID. After the coordinator has started the PAN, routers and end devices may join the PAN. The PAN ID is selected by the coordinator when it starts the PAN. Routers and end devices become a part of the PAN (and inherit the coordinator's PAN ID) when they join a PAN.

ZigBee supports mesh routing in the network, allowing data packets to traverse multiple nodes (multiple "hops") in order to reach the destination node. This allows ZigBee nodes to be spread out over a large region, and still support communications amongst all devices in the network.

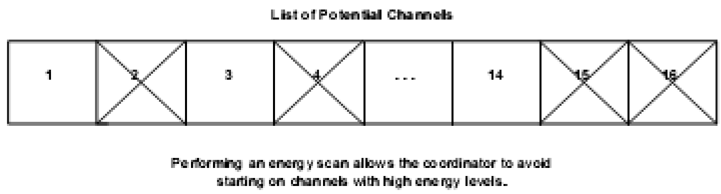
All devices in a ZigBee network receive a 16-bit address (network address) when they join a PAN. The 16-bit address of the coordinator is always 0.

3.2.1. Starting a PAN

Since the coordinator is responsible for starting a ZigBee network, all ZigBee networks must have a coordinator present initially. To start a PAN, the coordinator performs a series of scans to discover the level of RF activity on different channels (energy scan), and to discover any nearby operating PANs (PAN scan). Energy Scan

When a coordinator comes up for the first time, it performs an energy scan on multiple channels (frequencies) to detect energy levels on each channel. Channels with excessive detected energy levels are removed from its list of potential channels to start on.

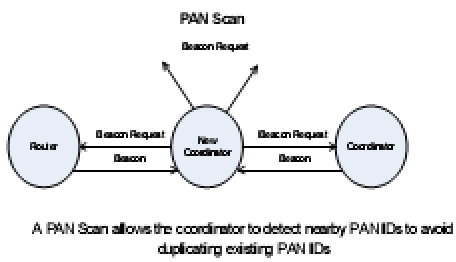
Figure 3-02. Potential Channels



PAN Scan

When the energy scan completes, the coordinator scans the remaining quiet channels (found in the energy scan) for existing PANs. To do this, the coordinator sends a broadcast, one-hop beacon request. Any nearby coordinators and routers will respond to the beacon request by sending a beacon frame back to the coordinator. The beacon frame contains information about the PAN the sender is on, including the PAN identifier (PAN ID), and whether or not the device is allowing joining. (The PAN scan is more commonly called an active scan or a beacon scan.)

Figure 3-03. PAN Scans



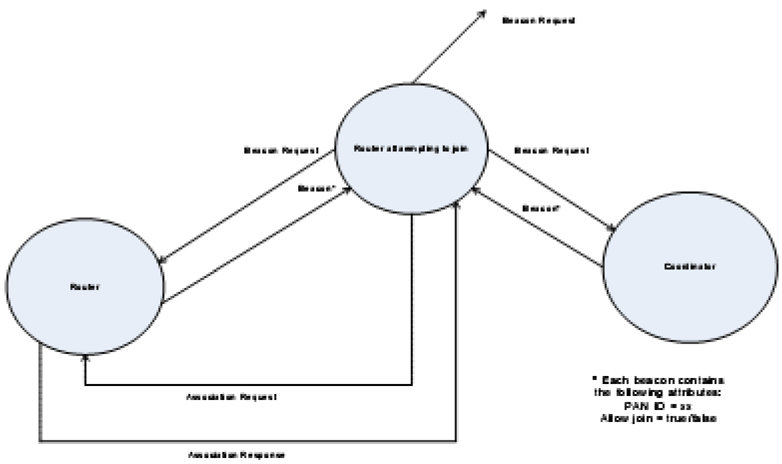
Once the coordinator has completed the energy and PAN scans, it parses all received beacons and attempts to start on an unused PAN ID and channel. When the coordinator starts a PAN, it can then allow routers and/or end devices to join the PAN. A coordinator retains the channel and PAN ID attributes through power cycle or reset events.

3.3. Joining a PAN

Router and end device types must discover and join a ZigBee PAN. To do this, they first issue a PAN scan, just like the coordinator does when it starts a PAN. From the PAN scan, the router or end device receives a list of beacons from nearby ZigBee devices. The router or end device parses this list to find a valid ZigBee network to join.

Routers and end devices can be configured to join any ZigBee PAN, or to only join a PAN with a certain PAN ID. However, they must always find a coordinator or router that is allowing joins.

Figure 3-04. Joining a PAN



A router or end device sends a beacon request to discover nearby Zigbee networks. If a device is found that is operating on a valid Zigbee network, that is allowing joins, the router or end device sends an association request to that device to attempt to join the network

Once a joining device (router or end device) discovers a device operating on a valid ZigBee network that is allowing joining, it attempts to join the PAN by sending an association request to that device.

3.3.1. Allowing Joining

The coordinator and all routers can allow new routers and end devices to join to them. Whether or not a particular coordinator or router will allow a new device to join depends upon two things:

- its permit-joining attribute (if joins are allowed)
- the number of end device children it already has

Permit-Joining Attribute

The coordinator and all routers have a permit-joining attribute. This attribute on a coordinator and any joined routers can be configured to always allow joins, allow joins for a short time, or to not allow any more joins. In order for a new device to join the network, this attribute must be set on a nearby device such that joins are enabled.

End Device Children

Since end devices rely on their parent router or coordinator to buffer incoming RF packets, the coordinator and each router can support a finite number of end device children. Once that number of end devices has joined a particular router or coordinator, the device can no longer allow end devices to join to it.

3.3.2. Security

If security is enabled, the coordinator will start up using a 128-bit AES encryption key. Only devices that have the same security key can communicate on the PAN. Routers and end devices that will join a secure PAN must obtain the correct security key. The security key can be obtained in one of two ways:

- pre-installation
- key is received over-the-air (in the clear) during joining

3.4. ZigBee Network Communications

Zigbee supports device addressing and application layer addressing. Device addressing specifies the destination address of the device a packet is destined to. Application layer addressing indicates a particular application recipient, known as a Zigbee endpoint, along with a message type field called a Cluster ID.

3.4.1. ZigBee Device Addressing

The 802.15.4 protocol upon which the ZigBee protocol is built specifies two address types:

- 16-bit network addresses
- 64-bit Addresses

16-bit Network Addresses

A 16-bit network address is assigned to a node when the node joins a network. The network address is unique to each node in the network. However, network addresses are not static - it can change.

The following two conditions will cause a node to receive a new network address:

1. If an end device cannot communicate with its parent it may need to leave the network and rejoin to find a new parent.
2. If the device type changes from router to end device, or vice-versa, the device will leave the network and rejoin as the new device type.

ZigBee requires that data be sent to the 16-bit network address of the destination device. This requires that the 16-bit address be discovered before transmitting data. See 3.2.3 Network Address Discovery for more information.

64-bit Addresses

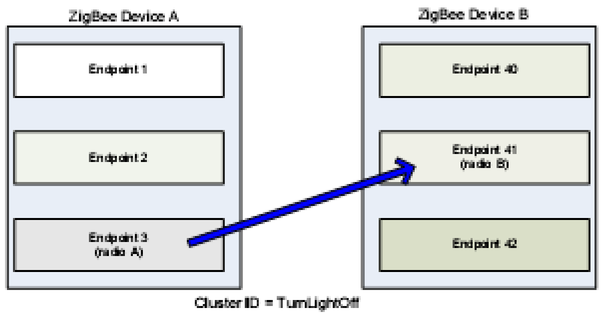
Each node contains a unique 64-bit address. The 64-bit address uniquely identifies a node and is permanent.

3.4.2. ZigBee Application-layer Addressing

The ZigBee application layers define endpoints and cluster identifiers (cluster IDs) that are used to address individual services or applications on a device. An endpoint is a distinct task or application that runs on a ZigBee device, similar to a TCP port. Each ZigBee device may support one or more endpoints. Cluster IDs define a particular function or action on a device. Cluster IDs in the ZigBee home controls lighting profile, for example, would include actions such as "TurnLightOn", "TurnLightOff", "DimLight", etc.

Suppose a single radio controls a light dimmer and one or more light switches. The dimmer and switches could be assigned to different endpoint values. To send a message to the dimmer, a remote radio would transmit a message to the dimmer endpoint on the radio. In this example, the radio might support cluster IDs to "TurnLightOn", "TurnLightOff", or "DimLight". Thus, for radio A to turn off a light on radio B, radio A would send a transmission to the light switch endpoint on radio B, using cluster ID "TurnLightOff". This is shown in the figure below.

Figure 3-05. ZigBee Layer-Addressing Example



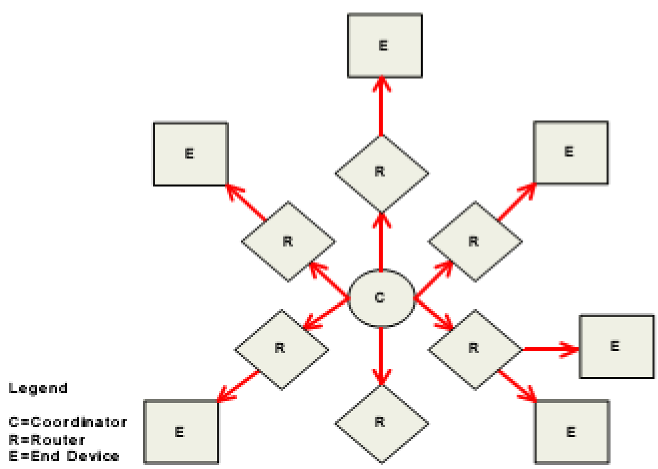
3.4.3. Data Transmission and Routing

All data packets are addressed using both device and application layer addressing fields. Data can be sent as a broadcast, or unicast transmission.

Broadcast Transmissions

Broadcast transmissions within the ZigBee protocol are intended to be propagated throughout the entire network such that all nodes receive the transmission. To accomplish this, all devices that receive a broadcast transmission will retransmit the packet 3 times.

Figure 3-06. Broadcast Data Transmission



Each node that transmits the broadcast will also create an entry in a local broadcast transmission table. This entry is used to keep track of each received broadcast packet to ensure the packets are not endlessly transmitted. Each entry persists for 8 seconds. The broadcast transmission table holds 8 entries.

For each broadcast transmission, the ZigBee stack must reserve buffer space for a copy of the data packet. This copy is used to retransmit the packet as needed.Large broadcast packets will require more buffer space.

Since broadcast transmissions are retransmitted by each device in the network, broadcast messages should be used sparingly.

Unicast Transmissions

Unicast ZigBee transmissions are always addressed to the 16-bit address of the destination device. However, only the 64-bit address of a device is permanent; the 16-bit address can change. Therefore, ZigBee devices may employ network address discovery to identify the current 16-bit address that corresponds to a known 64-bit address, and route discovery to establish a route.

Network Address Discovery

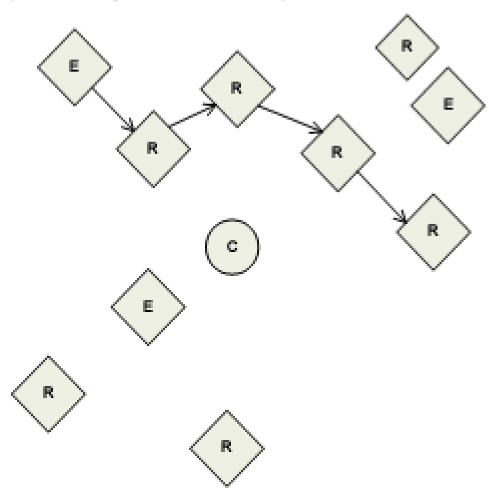
Data transmissions are always sent to the 16-bit network address of the destination device. However, since the 64-bit address is unique to each device and is generally known, ZigBee devices must discover the network address that was assigned to a particular device when it joined the PAN before they can transmit data.

To do this, the device initiating a transmission sends a broadcast network address discovery transmission throughout the network. This packet contains the 64-bit address of the device the initiator needs to send data to. Devices that receive this broadcast transmission check to see if their 64-bit address matches the 64-bit address contained in the broadcast transmission. If the addresses match, the device sends a response packet back to the initiator, providing the network address of the device with the matching 64-bit address. When this response is received, the initiator can then transmit data.

Route Discovery

ZigBee employs mesh routing to establish a route between the source device and the destination. Mesh routing allows data packets to traverse multiple nodes (hops) in a network to route data from a source to a destination. Routers and coordinators can participate in establishing routes between source and destination devices using a process called route discovery. The Route discovery process is based on the AODV (Ad-hoc On-demand Distance Vector routing) protocol.

Figure 3-07. Sample Transmission Through a Mesh Network



AODV (Ad-hoc On-demand Distance Vector) Routing Algorithm

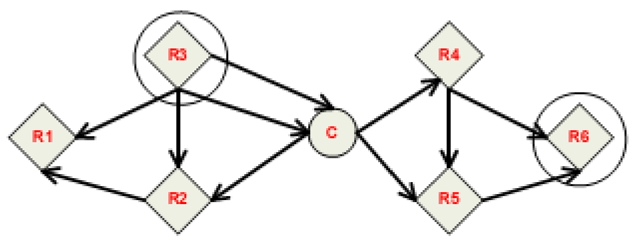
Routing under the AODV protocol is accomplished using tables in each node that store the next hop (intermediary node between source and destination nodes) for a destination node. If a next hop is not known, route discovery must take place in order to find a path. Since only a limited number of routes can be stored on a Router, route discovery will take place more often on a large network with communication between many different nodes.

Table 3-01.

Node	Destination Address	Next Hop Address
R3	Router 6	Coordinator
C	Router 6	Router 5
R5	Router 6	Router 6

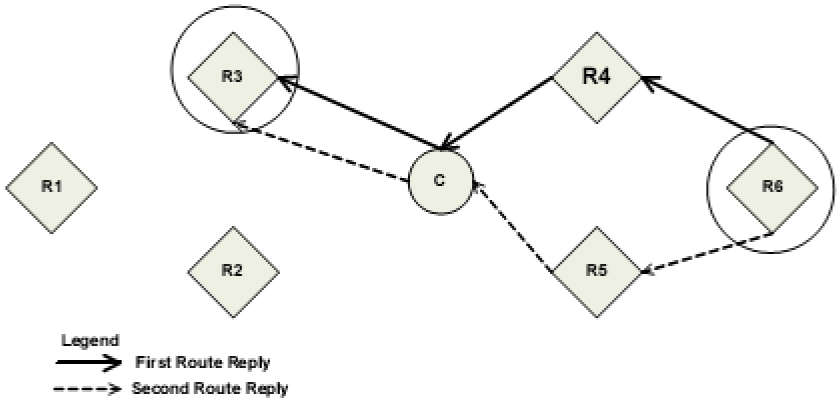
When a source node must discover a route to a destination node, it sends a broadcast route request command. The route request command contains the source network address, the destination network address and a path cost field (a metric for measuring route quality). As the route request command is propagated through the network (refer to the Broadcast Transmission), each node that re-broadcasts the message updates the path cost field and creates a temporary entry in its route discovery table.

Figure 3-08. Sample Route Request (Broadcast) Transmission Where R3 is Trying to Discover a Route to R6



When the destination node receives a route request, it compares the 'path cost' field against previously received route request commands. If the path cost stored in the route request is better than any previously received, the destination node will transmit a route reply packet to the node that originated the route request. Intermediate nodes receive and forward the route reply packet to the source node (the node that originated route request).

Figure 3-09. Route Reply Sample Route Reply (Unicast) Where R6 Sends a Route Reply to R3.



Note: R6 could send multiple replies if it identifies a better route.

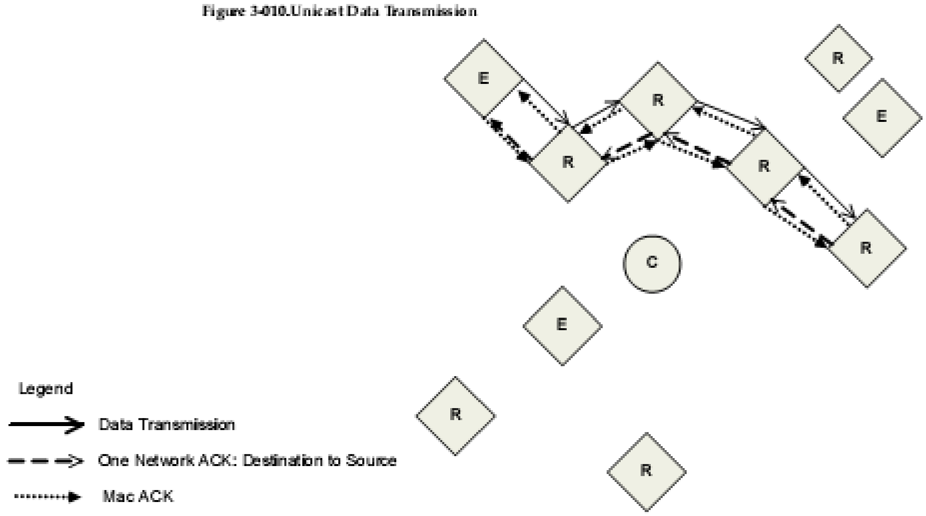
Retries and Acknowledgments

ZigBee includes acknowledgment packets at both the Mac and Application Support (APS) layers. When data is transmitted to remote device, it may traverse multiple hops to reach the destination. As data is transmitted from one node to its neighbor, an acknowledgment packet (Ack) is transmitted in the opposite direction to indicate that the transmission was successfully received. If the Ack is not received, the transmitting device will retransmit the data, up to 4 times. This Ack is called the Mac layer acknowledgment.

In addition, the device that originated the transmission expects to receive an acknowledgment packet (Ack) from the destination device. This Ack will traverse the same path that the data traversed, but in the opposite direction. If the originator fails to receive this Ack, it will retransmit the data, up to 2 times until an Ack is received. This Ack is called the ZigBee APS layer acknowledgment.

Refer to the ZigBee specification for more details.

Figure 3-010.Unicast Data Transmission



High Performance 8-Bit Microcontrollers

Z8 Encore! XP® F0822 Series

Product Specification

PS022517-0508

Introduction

Zilog's Z8 Encore! XP® MCU product family is a line of Zilog microcontrollers based on the 8-bit eZ8 CPU. Z8 Encore! XP® F0822 Series, hereafter referred as Z8 Encore! XP or the 8K Series adds Flash memory to Zilog's extensive line of 8-bit microcontrollers. The Flash in-circuit programming allows faster development time and program changes in the field. The new eZ8 CPU is upward-compatible with the existing Z8® instructions. The rich peripheral set of Z8 Encore! XP makes it suitable for a variety of applications including motor control, security systems, home appliances, personal electronic devices, and sensors.

Features

The features of Z8 Encore! XP MCU product family include:

- 20 MHz eZ8 CPU core
- Up to 8 KB Flash with in-circuit programming capability
- 1 KB Register RAM
- Optional 2- to 5-channel, 10-bit Analog-to-Digital Converter (ADC)
- Full-duplex 9-bit Universal Asynchronous Receiver/Transmitter (UART) with bus transceiver Driver Enable Control
- Inter-Integrated Circuit (I^2C)
- Serial Peripheral Interface (SPI)
- Infrared Data Association (IrDA)-compliant infrared encoder/decoders
- Two 16-bit timers with Capture, Compare, and PWM capability
- Watchdog Timer (WDT) with internal RC oscillator
- 11 to 19 Input/Output pins depending upon package
- Up to 19 interrupts with configurable priority
- On-Chip Debugger (OCD)
- Voltage Brownout (VBO) protection
- Power-On Reset (POR)
- Crystal oscillator with three power settings and RC oscillator option

- 2.7 V to 3.6 V operating voltage with 5 V-tolerant inputs
- 20-pin and 28-pin packages
- 0 °C to +70 °C standard temperature and -40 °C to +105 °C extended temperature operating ranges

Part Selection Guide

Table 1 identifies the basic features and package styles available for each device within the Z8 Encore! XP® F0822 Series product line.

Table 1. Z8 Encore! XP® F0822 Series Part Selection Guide

Part Number	Flash (KB)	RAM (KB)	I/O	16-bit Timers with PWM	ADC Inputs	UARTs with IrDA	I^2C	SPI	Package Pin Counts 20	Package Pin Counts 28
Z8F0822	8	1	19	2	5	1	1	1		X
Z8F0821	8	1	11	2	2	1	1		X	
Z8F0812	8	1	19	2	0	1	1	1		X
Z8F0811	8	1	11	2	0	1	1		X	
Z8F0422	4	1	19	2	5	1	1	1		X
Z8F0421	4	1	11	2	2	1	1		X	
Z8F0412	4	1	19	2	0	1	1	1		X
Z8F0411	4	1	11	2	0	1	1		X	

Block Diagram

Figure 1 displays the block diagram of the architecture of Z8 Encore! XP® F0822 Series devices.

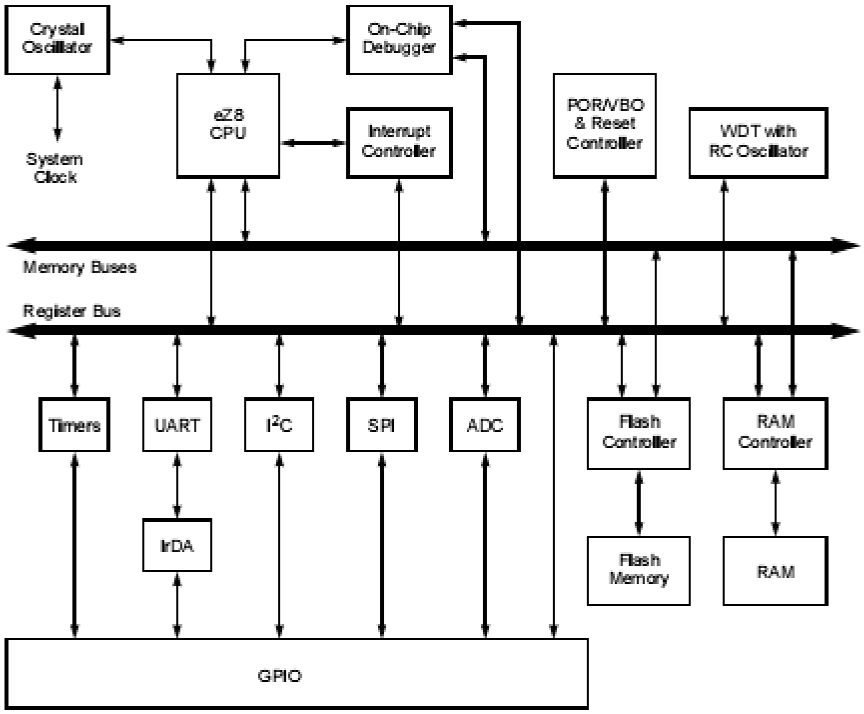


Figure 1. Z8 Encore! XP® F0822 Series Block Diagram

CPU and Peripheral Overview

eZ8 CPU Features

Zilog's latest eZ8 8-bit CPU, meets the continuing demand for faster and more code-efficient microcontrollers. The eZ8 CPU executes a superset of the original Z8® instruction set.

The eZ8 CPU features include:

- Direct register-to-register architecture allows each register to function as an accumulator, improving execution time and decreasing the required Program Memory.
- Software stack allows much greater depth in subroutine calls and interrupts than hardware stacks.
- Compatible with existing Z8® code.
- Expanded internal Register File allows access of up to 4 KB.
- New instructions improve execution efficiency for code developed using higher-level programming languages, including C.
- Pipelined instruction fetch and execution.
- New instructions for improved performance including BIT, BSWAP, BTJ, CPC, LDC, LDCI, LEA, MULT, and SRL.
- New instructions support 12-bit linear addressing of the Register File.
- Up to 10 MIPS operation.
- C-Compiler friendly.
- 2 to 9 clock cycles per instruction.

For more information regarding the eZ8 CPU, refer to *eZ8 CPU Core User Manual (UM0128)* available for download at www.zilog.com.

General Purpose Input/Output

Z8 Encore! XP® F0822 Series features 11 to 19 port pins (Ports A–C) for General Purpose Input/Output (GPIO). The number of GPIO pins available is a function of package. Each pin is individually programmable. Ports A and C supports 5 V-tolerant inputs.

Flash Controller

The Flash Controller programs and erases the Flash memory.

10-Bit Analog-to-Digital Converter

The optional Analog-to-Digital Converter (ADC) converts an analog input signal to a 10-bit binary number. The ADC accepts inputs from 2 to 5 different analog input sources.

UART

The Universal Asynchronous Receiver/Transmitter (UART) is full-duplex and capable of handling asynchronous data transfers. The UART supports 8-bit and 9-bit data modes and selectable parity.

I^{2}C

The Inter-Integrated Circuit (I^{2}C) controller makes the Z8 Encore! XP compatible with the I^{2}C protocol. The I^{2}C Controller consists of two bidirectional bus lines, a serial data (SDA) line, and a serial clock (SCL) line.

Serial Peripheral Interface

The Serial Peripheral Interface (SPI) allows the Z8 Encore! XP to exchange data between other peripheral devices such as EEPROMs, A/D converters, and ISDN devices. The SPI is a full-duplex, synchronous, and character-oriented channel that supports a four-wire interface.

Timers

Two 16-bit reloadable timers are used for timing/counting events or for motor control operations. These timers provide a 16-bit programmable reload counter and operate in One-Shot, Continuous, Gated, Capture, Compare, Capture and Compare, and PWM modes.

Interrupt Controller

Z8 Encore! XP® F0822 Series products support up to 18 interrupts. These interrupts consist of 7 internal peripheral interrupts and 11 GPIO pin interrupt sources. The interrupts have 3 levels of programmable interrupt priority.

Signal and Pin Descriptions

Z8 Encore! XP® F0822 Series products are available in a variety of packages, styles, and pin configurations. This chapter describes the signals and available pin configurations for each of the package styles. For information regarding the physical package specifications, see Packaging on page 233.

Available Packages

Table 2 identifies the package styles available for each device within Z8 Encore! XP F0822 Series product line.

Table 2. Z8 Encore! XP F0822 Series Package Options

Part Number	10-Bit ADC	20-Pin SSOP and PDIP	28-Pin SOIC and PDIP
Z8F0822	Yes		X
Z8F0821	Yes	X	
Z8F0812	No		X
Z8F0811	No	X	
Z8F0422	Yes		X
Z8F0421	Yes	X	
Z8F0412	No		X
Z8F0411	No	X	

Pin Configurations

Figure 2 through Figure 5 display the pin configurations for all of the packages available in Z8 Encore! XP F0822 Series. See Table 4 for a description of the signals.

Note: *The analog input alternate functions (ANAx) are not available on Z8 Encore! XP® F0822 Series devices.*

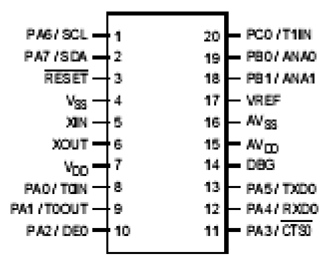


Figure 2. Z8F0821 and Z8F0421 in 20-Pin SSOP and PDIP Packages

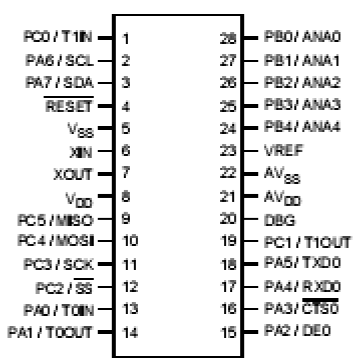


Figure 3. Z8F0822 and Z8F0422 in 28-Pin SOIC and PDIP Packages

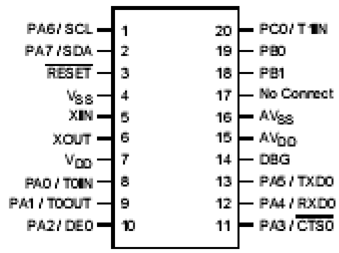


Figure 4. Z8F0811 and Z8F0411 in 20-Pin SSOP and PDIP Packages

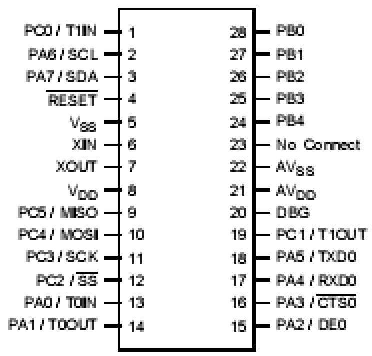


Figure 5. Z8F0812 and Z8F0412 in 28-Pin SOIC and PDIP Packages

Signal Descriptions

Table 3 describes Z8 Encore! XP® F0822 Series signals. See Pin Configurations on page 7 to determine the signals available for the specific package styles

Table 3. Signal Descriptions

Signal Mnemonic	I/O	Description
General-Purpose I/O Ports A-H		
PA[7:0]	I/O	Port C—These pins are used for general-purpose I/O and supports 5 V-tolerant inputs.
PB[4:0]	I/O	Port B—These pins are used for general-purpose I/O.
PC[5:0]	I/O	Port C—These pins are used for general-purpose I/O and support 5 V-tolerant inputs.
I^2C Controller		
SCL	I/O	Serial Clock—This open-drain pin clocks data transfers in accordance with the I^2C standard protocol. This pin is multiplexed with a GPIO pin. When the GPIO pin is configured for alternate function to enable the SCL function, this pin is open-drain.
SDA	I/O	Serial Data—This open-drain pin transfers data between the I^2C and a slave. This pin is multiplexed with a GPIO pin. When the GPIO pin is configured for alternate function to enable the SDA function, this pin is open-drain.

Table 3. Signal Descriptions (Continued)

Signal Mnemonic	I/O	Description
SPI Controller		
$\overline{SS}$	I/O	**Slave Select**—This signal can be an output or an input. If the Z8 Encore! XP® is the SPI Master, this pin can be configured as the Slave Select output. If the Z8 Encore! XP is the SPI Slave, this pin is the input slave select. It is multiplexed with a GPIO pin.
SCK	I/O	**SPI Serial Clock**—The SPI Master supplies this pin. If the Z8 Encore! XP is the SPI Master, this pin is the output. If the Z8 Encore! XP is the SPI Slave, this pin is the input. It is multiplexed with a GPIO pin.
MOSI	I/O	**Master-Out/Slave-In**—This signal is the data output from the SPI Master device and the data input to the SPI Slave device. It is multiplexed with a GPIO pin.
MISO	I/O	**Master-In/Slave-Out**—This pin is the data input to the SPI Master device and the data output from the SPI Slave device. It is multiplexed with a GPIO pin.
UART Controllers		
TXD0	O	**Transmit Data**—This signal is the transmit output from the UART and IrDA. The TXD signals are multiplexed with GPIO pins.
RXD0	I	**Receive Data**—This signal is the receiver input for the UART and IrDA. The RXD signals are multiplexed with GPIO pins.
$\overline{CTS0}$	I	**Clear To Send**—This signal is control inputs for the UART. The $\overline{CTS}$ signals are multiplexed with GPIO pins.
DE0	O	**Driver Enable**—This signal allows automatic control of external RS-485 drivers. This signal is approximately the inverse of the TXE (Transmit Empty) bit in the UART Status 0 Register. The DE signal can be used to ensure the external RS-485 driver is enabled when data is transmitted by the UART.
Timers		
T0OUT / T1OUT	O	**Timer Output 0–1**—These signals are output pins from the timers. The Timer Output signals are multiplexed with GPIO pins.
T0IN / T1IN	I	**Timer Input 0–1**—These signals are used as the Capture, Gating and Counter inputs. The Timer Input signals are multiplexed with GPIO pins.
Analog		
ANA[4:0]	I	**Analog Input**—These signals are inputs to the Analog-to-Digital Converter (ADC). The ADC analog inputs are multiplexed with GPIO pins.
VREF	I	**Analog-to-Digital Converter reference voltage input**—As an output, the VREF signal is not recommended for use as a reference voltage for external devices. If the ADC is configured to use the internal reference voltage generator, this pin should be left unconnected or capacitively coupled to analog ground (AVSS).

Pin Characteristics

Table 4 provides detailed information on the characteristics for each pin available on Z8 Encore! XP® F0822 Series products. Table 4 data is sorted alphabetically by the pin symbol mnemonic.

Table 4. Pin Characteristics

Symbol Mnemonic	Direction	Reset Direction	Active Low or Active High	Tri-State Output	Internal Pull-up or Pull-down	Schmitt-Trigger Input	Open Drain Output
AV_{DD}	N/A	N/A	N/A	N/A	No	No	N/A
AV_{SS}	N/A	N/A	N/A	N/A	No	No	N/A
DBG	I/O	I	N/A	Yes	No	Yes	Yes
PA[7:0]	I/O	I	N/A	Yes	Programmable Pull-up	Yes	Yes, Programmable
PB[4:0]	I/O	I	N/A	Yes	Programmable Pull-up	Yes	Yes, Programmable
PC[5:0]	I/O	I	N/A	Yes	Programmable Pull-up	Yes	Yes, Programmable
RESET	I	I	Low	N/A	Pull-up	Yes	N/A
V_{DD}	N/A	N/A	N/A	N/A	No	No	N/A
VREF	Analog	N/A	N/A	N/A	No	No	N/A
V_{SS}	N/A	N/A	N/A	N/A	No	No	N/A
XIN	I	I	N/A	N/A	No	No	N/A
XOUT	O	O	N/A	No	No	No	No

Address Space

The eZ8 CPU accesses three distinct address spaces:

- The Register File contains addresses for the general-purpose registers and the eZ8 CPU, Peripheral, and GPIO Port Control Registers.
- The Program Memory contains addresses for all memory locations having executable code and/or data.
- The Data Memory contains addresses for all memory locations that hold data only.

These three address spaces are covered briefly in the following sections. For more information on the eZ8 CPU and its address space, refer to *eZ8 CPU Core User Manual (UM0128)* available for download at www.zilog.com.

Register File

The Register File address space in the Z8 Encore! XP® is 4 KB (4096 bytes). It is composed of two sections—Control Registers and General-Purpose Registers. When instructions are executed, registers are read from when defined as sources and written to when defined as destinations. The architecture of the eZ8 CPU allows all general-purpose registers to function as accumulators, address pointers, index registers, stack areas, or scratch pad memory.

The upper 256 bytes of the 1 KB Register File address space is reserved for control of the eZ8 CPU, the on-chip peripherals, and the I/O ports. These registers are located at addresses from `F00H` to `FFFH`. Some of the addresses within the 256-byte Control Register section is reserved (unavailable). Reading from the reserved Register File addresses returns an undefined value. Writing to reserved Register File addresses is not recommended and can produce unpredictable results.

The on-chip RAM always begins at address `000H` in the Register File address space. Z8 Encore! XP F0822 Series contains 1 KB of on-chip RAM. Reading from Register File addresses outside the available RAM addresses (and not within the control register address space) returns an undefined value. Writing to these Register File addresses produces no effect.

Program Memory

The eZ8 CPU supports 64 KB of Program Memory address space. Z8 Encore! XP® F0822 Series contain 4 KB to 8 KB on-chip Flash in the Program Memory address space, depending on the device. Reading from Program Memory addresses outside the available Flash addresses returns `FFH`. Writing to unimplemented Program Memory addresses produces no effect. Table 5 describes the Program Memory Maps for Z8 Encore! XP F0822 Series devices.

Table 5. Z8 Encore! XP® F0822 Series Program Memory Maps

Program Memory Address (Hex)	Function
Z8F082x and Z8F081x Products	
0000-0001	Option Bits
0002-0003	Reset Vector
0004-0005	WDT Interrupt Vector
0006-0007	Illegal Instruction Trap
0008-0037	Interrupt Vectors*
0038-1FFF	Program Memory
Z8F042x and Z8F041x Products	
0000-0001	Option Bits
0002-0003	Reset Vector
0004-0005	WDT Interrupt Vector
0006-0007	Illegal Instruction Trap
0008-0037	Interrupt Vectors*
0038-0FFF	Program Memory

Note: *See Table 24 on page 57 for a list of the interrupt vectors.

Data Memory

Z8 Encore! XP® F0822 Series does not use the eZ8 CPU's 64 KB Data Memory address space.

Information Area

Table 6 describes the Z8 Encore! XP F0822 Series Information Area. This 512 byte Information Area is accessed by setting bit 7 of the Page Select Register to 1. When access is enabled, the Information Area is mapped into the Program Memory and overlays the 512 bytes at addresses `FE00H` to `FFFFH`. When the Information Area access is enabled, all reads from these Program Memory addresses return the Information Area data rather than the Program Memory data. Access to the Information Area is read-only.

Table 6. Information Area Map

Program Memory Address (Hex)	Function
FE00H-FE3FH	Reserved
FE40H-FE53H	**Part Number** 20-character ASCII alphanumeric code Left justified and filled with zeros
FE54H-FFFFH	Reserved

PIC16F627A/628A/648A Data Sheet

Flash-Based, 8-Bit CMOS

Microcontrollers with nanoWatt Technology

PIC16F627A/628A/648A

18-pin Flash-Based, 8-Bit CMOS Microcontrollers with nanoWatt Technology

High-Performance RISC CPU:

- Operating speeds from DC – 20 MHz
- Interrupt capability
- 8-level deep hardware stack
- Direct, Indirect and Relative Addressing modes
- 35 single-word instructions:
  - All instructions single cycle except branches

Special Microcontroller Features:

- Internal and external oscillator options:
  - Precision internal 4 MHz oscillator factory calibrated to ±1%
  - Low-power internal 48 kHz oscillator
  - External Oscillator support for crystals and resonators
- Power-saving Sleep mode
- Programmable weak pull-ups on PORTB
- Multiplexed Master Clear/Input-pin
- Watchdog Timer with independent oscillator for reliable operation
- Low-voltage programming
- In-Circuit Serial Programming™ (via two pins)
- Programmable code protection
- Brown-out Reset
- Power-on Reset
- Power-up Timer and Oscillator Start-up Timer
- Wide operating voltage range (2.0-5.5V)
- Industrial and extended temperature range
- High-Endurance Flash/EEPROM cell:
  - 100,000 write Flash endurance
  - 1,000,000 write EEPROM endurance
  - 40 year data retention

Low-Power Features:

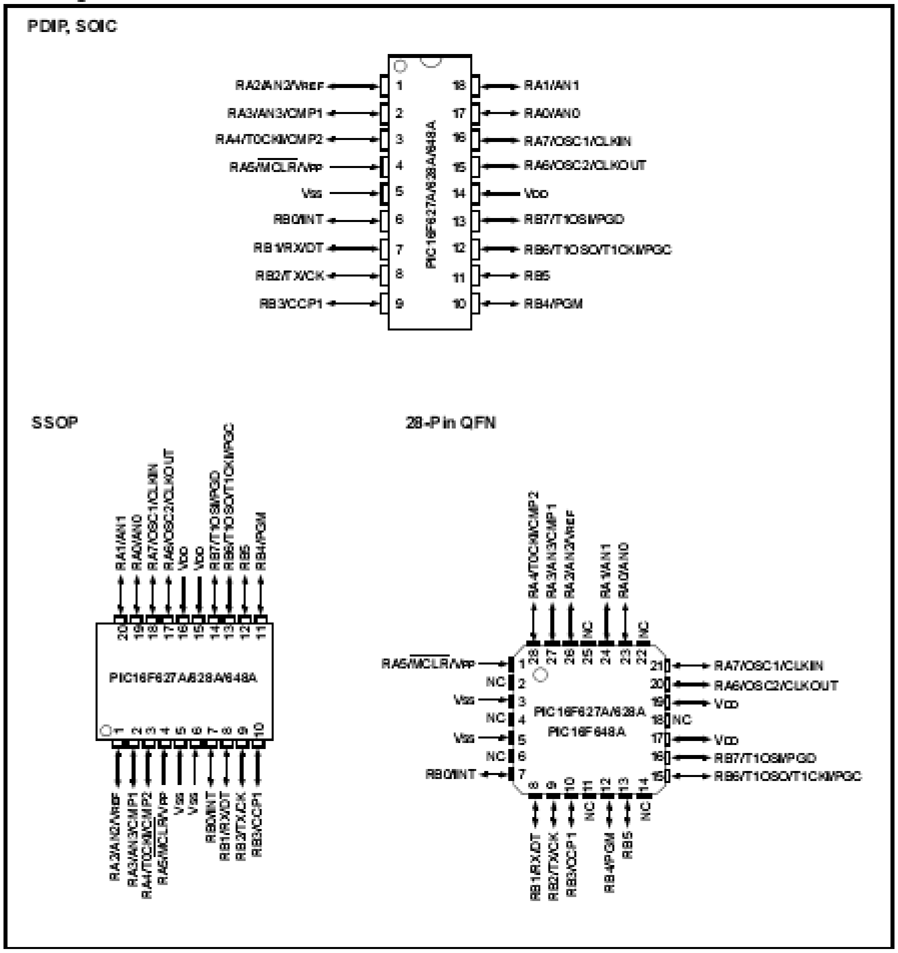
- Standby Current:
  - 100 nA @ 2.0V, typical
- Operating Current:
  - 12 μA @ 32 kHz, 2.0V, typical
  - 120 μA @ 1 MHz, 2.0V, typical
- Watchdog Timer Current:
  - 1 μA @ 2.0V, typical
- Timer1 Oscillator Current:
  - 1.2 μA @ 32 kHz, 2.0V, typical
- Dual-speed Internal Oscillator:
  - Run-time selectable between 4 MHz and 48 kHz
  - 4 μs wake-up from Sleep, 3.0V, typical

Peripheral Features:

- 16 I/O pins with individual direction control
- High current sink/source for direct LED drive
- Analog comparator module with:
  - Two analog comparators
  - Programmable on-chip voltage reference (VREF) module
  - Selectable internal or external reference
  - Comparator outputs are externally accessible
- Timer0: 8-bit timer/counter with 8-bit programmable prescaler
- Timer1: 16-bit timer/counter with external crystal/clock capability
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Capture, Compare, PWM module:
  - 16-bit Capture/Compare
  - 10-bit PWM
- Addressable Universal Synchronous/Asynchronous Receiver/Transmitter USART/SCI

Device	Program Memory	Data Memory		I/O	CCP (PWM)	USART	Comparators	Timers 8/16-bit
	Flash (words)	SRAM (bytes)	EEPROM (bytes)					
PIC16F627A	1024	224	128	16	1	Y	2	2/1
PIC16F628A	2048	224	128	16	1	Y	2	2/1
PIC16F648A	4096	256	256	16	1	Y	2	2/1

Pin Diagrams



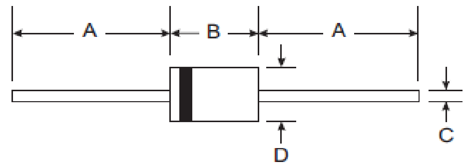
1N4001/L - 1N4007/L

1.0A RECTIFIER

SPICE MODELS: 1N4001 1N4002 1N4003 1N4004 1N4005 1N4006 1N4007

Features

- Diffused Junction
- High Current Capability and Low Forward Voltage Drop
- Surge Overload Rating to 30A Peak
- Low Reverse Leakage Current
- **Lead Free Finish, RoHS Compliant (Note 4)**



Mechanical Data

- Case: DO-41, A-405
- Case Material: Molded Plastic. UL Flammability Classification Rating 94V-0
- Moisture Sensitivity: Level 1 per J-STD-020C
- Terminals: Finish - Bright Tin. Plated Leads Solderable per MIL-STD-202, Method 208
- Polarity: Cathode Band
- Mounting Position: Any
- Ordering Information: See Last Page
- Marking: Type Number
- Weight: DO-41 0.30 grams (approximate)
  A-405 0.20 grams (approximate)

Dim	DO-41 Plastic		A-405	
	Min	Max	Min	Max
A	25.40	—	25.40	—
B	4.06	5.21	4.10	5.20
C	0.71	0.864	0.53	0.64
D	2.00	2.72	2.00	2.70
All Dimensions in mm				

"L" Suffix Designates A-405 Package
No Suffix Designates DO-41 Package

Maximum Ratings and Electrical Characteristics

@ $T_A = 25°C$ unless otherwise specified

Single phase, half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

Characteristic	Symbol	1N 4001/L	1N 4002/L	1N 4003/L	1N 4004/L	1N 4005/L	1N 4006/L	1N 4007/L	Unit
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average Rectified Output Current (Note 1) @ $T_A = 75°C$	I_O	1.0							A
Non-Repetitive Peak Forward Surge Current 8.3ms single half sine-wave superimposed on rated load (JEDEC Method)	I_{FSM}	30							A
Forward Voltage @ $I_F = 1.0A$	V_{FM}	1.0							V
Peak Reverse Current @ $T_A = 25°C$ at Rated DC Blocking Voltage @ $T_A = 100°C$	I_{RM}	5.0 50							µA
Typical Junction Capacitance (Note 2)	C_j	15				8			pF
Typical Thermal Resistance Junction to Ambient	$R_{\theta JA}$	100							K/W
Maximum DC Blocking Voltage Temperature	T_A	+150							°C
Operating and Storage Temperature Range (Note 3)	T_j, T_{STG}	-65 to +175							°C

Notes:
1. Leads maintained at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1. MHz and applied reverse voltage of 4.0V DC.
3. JEDEC Value.
4. RoHS revision 13.2.2003. Glass and High Temperature Solder Exemptions Applied, se e EU Directive Annex Notes 5 and 7.

DIODES INCORPORATED

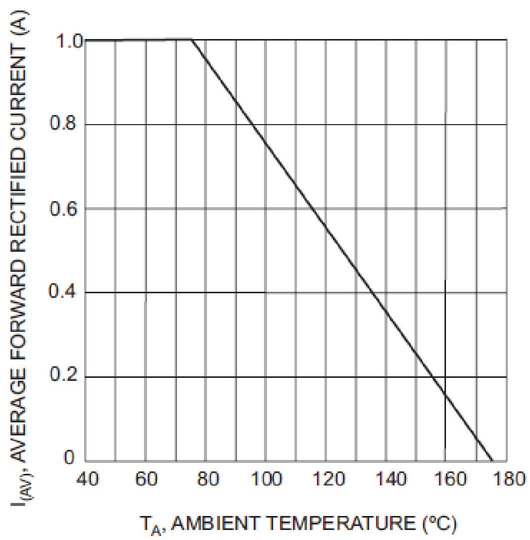


Fig. 1 Forward Current Derating Curve

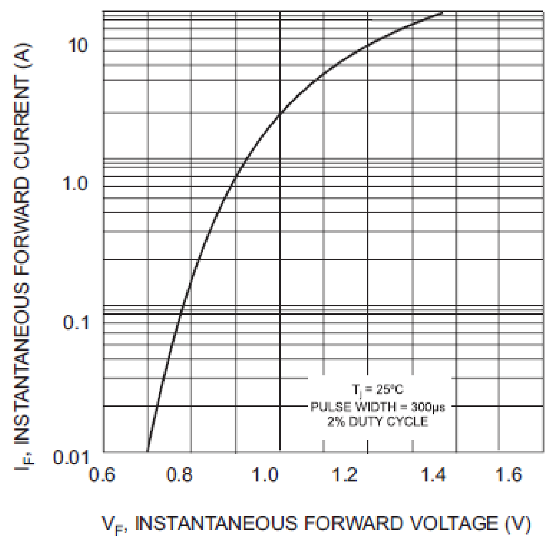


Fig. 2 Typical Forward Characteristics

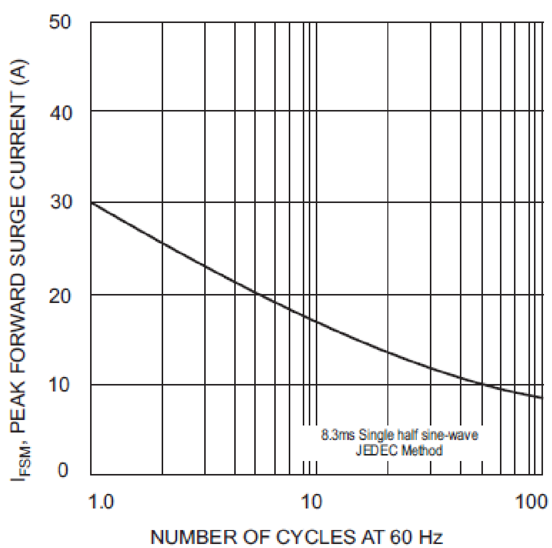


Fig. 3 Max Non-Repetitive Peak Fwd Surge Current

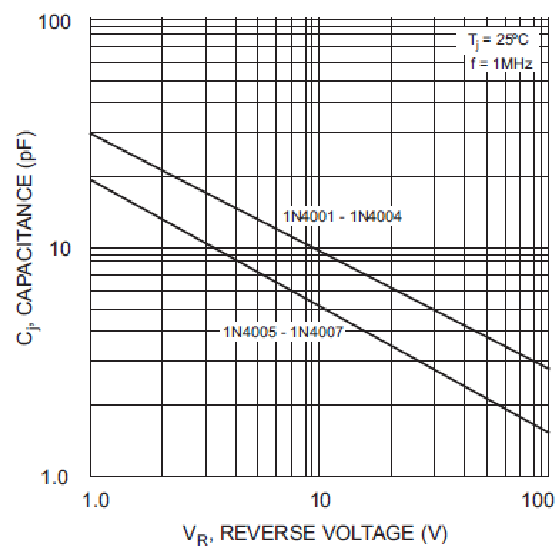
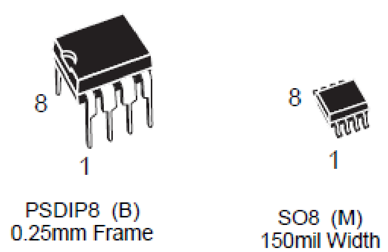


Fig. 4 Typical Junction Capacitance

ST24C04, ST25C04
ST24W04, ST25W04

4 Kbit Serial I²C Bus EEPROM with User-Defined Block Write Protection

- 1 MILLION ERASE/WRITE CYCLES with 40 YEARS DATA RETENTION
- SINGLE SUPPLY VOLTAGE:
  - 3V to 5.5V for ST24x04 versions
  - 2.5V to 5.5V for ST25x04 versions
- HARDWARE WRITE CONTROL VERSIONS: ST24W04 and ST25W04
- PROGRAMMABLE WRITE PROTECTION
- TWO WIRE SERIAL INTERFACE, FULLY I²C BUS COMPATIBLE
- BYTE and MULTIBYTE WRITE (up to 4 BYTES)
- PAGE WRITE (up to 8 BYTES)
- BYTE, RANDOM and SEQUENTIAL READ MODES
- SELF TIMED PROGRAMMING CYCLE
- AUTOMATIC ADDRESS INCREMENTING
- ENHANCED ESD/LATCH UP PERFORMANCES



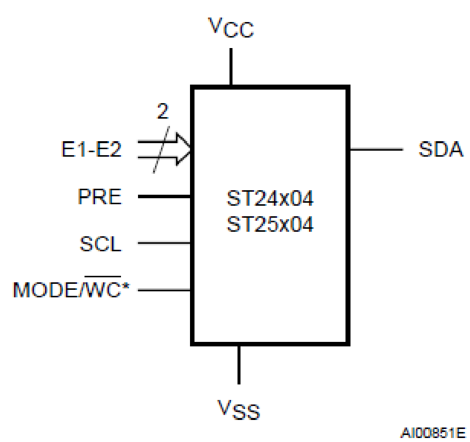
DESCRIPTION

This specification covers a range of 4 Kbits I²C bus EEPROM products, the ST24/25C04 and the ST24/25W04. In the text, products are referred to as ST24/25x04, where "x" is: "C" for Standard version and "W" for hardware Write Control version.

Table 1. Signal Names

PRE	Write Protect Enable
E1-E2	Chip Enable Inputs
SDA	Serial Data Address Input/Output
SCL	Serial Clock
MODE	Multibyte/Page Write Mode (C version)
$\overline{WC}$	Write Control (W version)
V_{CC}	Supply Voltage
V_{SS}	Ground

Figure 1. Logic Diagram



Note: $\overline{WC}$ signal is only available for ST24/25W04 products.

Figure 2A. DIP Pin Connections

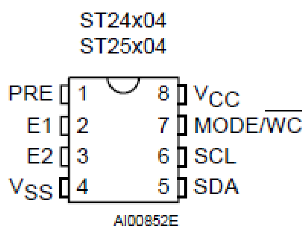


Figure 2B. SO Pin Connections

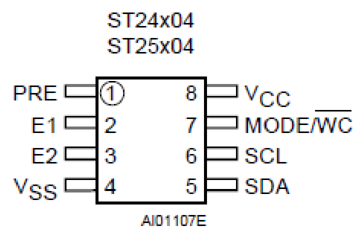


Table 2. Absolute Maximum Ratings (1)

Symbol	Parameter	Value	Unit
T_A	Ambient Operating Temperature	–40 to 125	°C
T_{STG}	Storage Temperature	–65 to 150	°C
T_{LEAD}	Lead Temperature, Soldering (SO8 package) 40 sec (PSDIP8 package) 10 sec	215 260	°C
V_{IO}	Input or Output Voltages	–0.6 to 6.5	V
V_{CC}	Supply Voltage	–0.3 to 6.5	V
V_{ESD}	Electrostatic Discharge Voltage (Human Body model) (2)	4000	V
	Electrostatic Discharge Voltage (Machine model) (3)	500	V

Notes: 1. Except for the rating "Operating Temperature Range", stresses above those listed in the Table "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and operation of the device at these or any other conditions above those indicated in the Operating sections of this specification is not implied. Exposure to Absolute Maximum Rating conditions for extended periods may affect device reliability. Refer also to the STMicroelectronics SURE Program and other relevant quality documents.
2. MIL-STD-883C, 3015.7 (100pF, 1500 Ω).
3. EIAJ IC-121 (Condition C) (200pF, 0 Ω).

DESCRIPTION (cont'd)

The ST24/25x04 are 4 Kbit electrically erasable programmable memories (EEPROM), organized as 2 blocks of 256 x8 bits. They are manufactured in STMicroelectronics's Hi-Endurance Advanced CMOS technology which guarantees an endurance of one million erase/write cycles with a data retention of 40 years.

Both Plastic Dual-in-Line and Plastic Small Outline packages are available.

The memories are compatible with the I^2C standard, two wire serial interface which uses a bi-directional data bus and serial clock. The memories carry a built-in 4 bit, unique device identification code (1010) corresponding to the I^2C bus definition. This is used together with 2 chip enable inputs (E2, E1) so that up to 4 x 4K devices may be attached to the I^2C bus and selected individually. The memories behave as a slave device in the I^2C protocol with all memory operations synchronized by the serial clock. Read and write operations are initiated by a START condition generated by the bus master. The START condition is followed by a stream of 7 bits (identification code 1010), plus one read/write bit and terminated by an acknowledge bit.

Table 3. Device Select Code

	Device Code				Chip Enable		Block Select	$R\overline{W}$
Bit	b7	b6	b5	b4	b3	b2	b1	b0
Device Select	1	0	1	0	E2	E1	A8	$R\overline{W}$

Note: The MSB b7 is sent first.

Table 4. Operating Modes (1)

Mode	$R\overline{W}$ bit	MODE	Bytes	Initial Sequence
Current Address Read	'1'	X	1	START, Device Select, $R\overline{W}$ = '1'
Random Address Read	'0'	X	1	START, Device Select, $R\overline{W}$ = '0', Address,
	'1'			reSTART, Device Select, $R\overline{W}$ = '1'
Sequential Read	'1'	X	1 to 512	Similar to Current or Random Mode
Byte Write	'0'	X	1	START, Device Select, $R\overline{W}$ = '0'
Multibyte Write (2)	'0'	V_{IH}	4	START, Device Select, $R\overline{W}$ = '0'
Page Write	'0'	V_{IL}	8	START, Device Select, $R\overline{W}$ = '0'

Notes: 1. X = V_{IH} or V_{IL}
2. Multibyte Write not available in ST24/25W04 versions.

When writing data to the memory it responds to the 8 bits received by asserting an acknowledge bit during the 9th bit time. When data is read by the bus master, it acknowledges the receipt of the data bytes in the same way. Data transfers are terminated with a STOP condition.

Power On Reset: V_{CC} lock out write protect. In order to prevent data corruption and inadvertent write operations during power up, a Power On Reset (POR) circuit is implemented. Until the V_{CC} voltage has reached the POR threshold value, the internal reset is active, all operations are disabled and the device will not respond to any command. In the same way, when V_{CC} drops down from the operating voltage to below the POR threshold value, all operations are disabled and the device will not respond to any command. A stable V_{CC} must be applied before applying any logic signal.

SIGNAL DESCRIPTIONS

Serial Clock (SCL). The SCL input pin is used to synchronize all data in and out of the memory. A resistor can be connected from the SCL line to V_{CC} to act as a pull up (see Figure 3).

Serial Data (SDA). The SDA pin is bi-directional and is used to transfer data in or out of the memory. It is an open drain output that may be wire-OR'ed with other open drain or open collector signals on the bus. A resistor must be connected from the SDA bus line to V_{CC} to act as pull up (see Figure 3).

Chip Enable (E1 - E2). These chip enable inputs are used to set the 2 least significant bits (b2, b3) of the 7 bit device select code. These inputs may be driven dynamically or tied to V_{CC} or V_{SS} to establish the device select code.

Protect Enable (PRE). The PRE input pin, in addition to the status of the Block Address Pointer bit (b2, location 1FFh as in Figure 7), sets the PRE write protection active.

Mode (MODE). The MODE input is available on pin 7 (see also $\overline{WC}$ feature) and may be driven dynamically. It must be at V_{IL} or V_{IH} for the Byte Write mode, V_{IH} for Multibyte Write mode or V_{IL} for Page Write mode. When unconnected, the MODE input is internally read as V_{IH} (Multibyte Write mode).

Write Control ($\overline{WC}$). An hardware Write Control feature ($\overline{WC}$) is offered only for ST24W04 and ST25W04 versions on pin 7. This feature is usefull to protect the contents of the memory from any erroneous erase/write cycle. The Write Control signal is used to enable ($\overline{WC}$ = V_{IH}) or disable ($\overline{WC}$ = V_{IL}) the internal write protection. When unconnected, the $\overline{WC}$ input is internally read as V_{IL} and the memory area is not write protected.

Table 5. Input Parameters [1] (T_A = 25 °C, f = 100 kHz)

Symbol	Parameter	Test Condition	Min	Max	Unit
C_{IN}	Input Capacitance (SDA)			8	pF
C_{IN}	Input Capacitance (other pins)			6	pF
Z_{WCL}	$\overline{WC}$ Input Impedance (ST24/25W04)	$V_{IN} \leq 0.3\ V_{CC}$	5	20	kΩ
Z_{WCH}	$\overline{WC}$ Input Impedance (ST24/25W04)	$V_{IN} \geq 0.7\ V_{CC}$	500		kΩ
t_{LP}	Low-pass filter input time constant (SDA and SCL)			100	ns

Note: 1. Sampled only, not 100% tested.

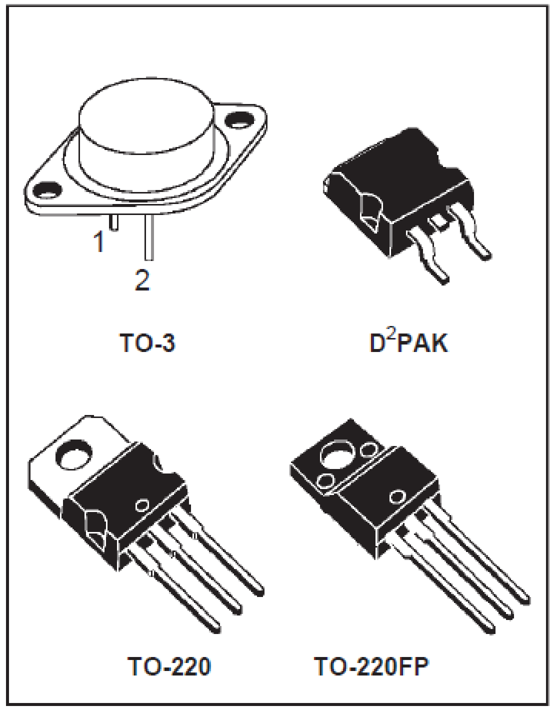
Table 6. DC Characteristics
(T_A = 0 to 70°C, –20 to 85°C or –40 to 85°C; V_{CC} = 3V to 5.5V or 2.5V to 5.5V)

Symbol	Parameter	Test Condition	Min	Max	Unit
I_{LI}	Input Leakage Current	$0V \leq V_{IN} \leq V_{CC}$		±2	µA
I_{LO}	Output Leakage Current	$0V \leq V_{OUT} \leq V_{CC}$ SDA in Hi-Z		±2	µA
I_{CC}	Supply Current (ST24 series)	V_{CC} = 5V, f_C = 100kHz (Rise/Fall time < 10ns)		2	mA
	Supply Current (ST25 series)	V_{CC} = 2.5V, f_C = 100kHz		1	mA
I_{CC1}	Supply Current (Standby) (ST24 series)	$V_{IN} = V_{SS}$ or V_{CC}, V_{CC} = 5V		100	µA
		$V_{IN} = V_{SS}$ or V_{CC}, V_{CC} = 5V, f_C = 100kHz		300	µA
I_{CC2}	Supply Current (Standby) (ST25 series)	$V_{IN} = V_{SS}$ or V_{CC}, V_{CC} = 2.5V		5	µA
		$V_{IN} = V_{SS}$ or V_{CC}, V_{CC} = 2.5V, f_C = 100kHz		50	µA
V_{IL}	Input Low Voltage (SCL, SDA)		–0.3	0.3 V_{CC}	V
V_{IH}	Input High Voltage (SCL, SDA)		0.7 V_{CC}	V_{CC} + 1	V
V_{IL}	Input Low Voltage (E1-E2, PRE, MODE, $\overline{WC}$)		–0.3	0.5	V
V_{IH}	Input High Voltage (E1-E2, PRE, MODE, $\overline{WC}$)		V_{CC} – 0.5	V_{CC} + 1	V
V_{OL}	Output Low Voltage (ST24 series)	I_{OL} = 3mA, V_{CC} = 5V		0.4	V
	Output Low Voltage (ST25 series)	I_{OL} = 2.1mA, V_{CC} = 2.5V		0.4	V

L7800 SERIES

POSITIVE VOLTAGE REGULATORS

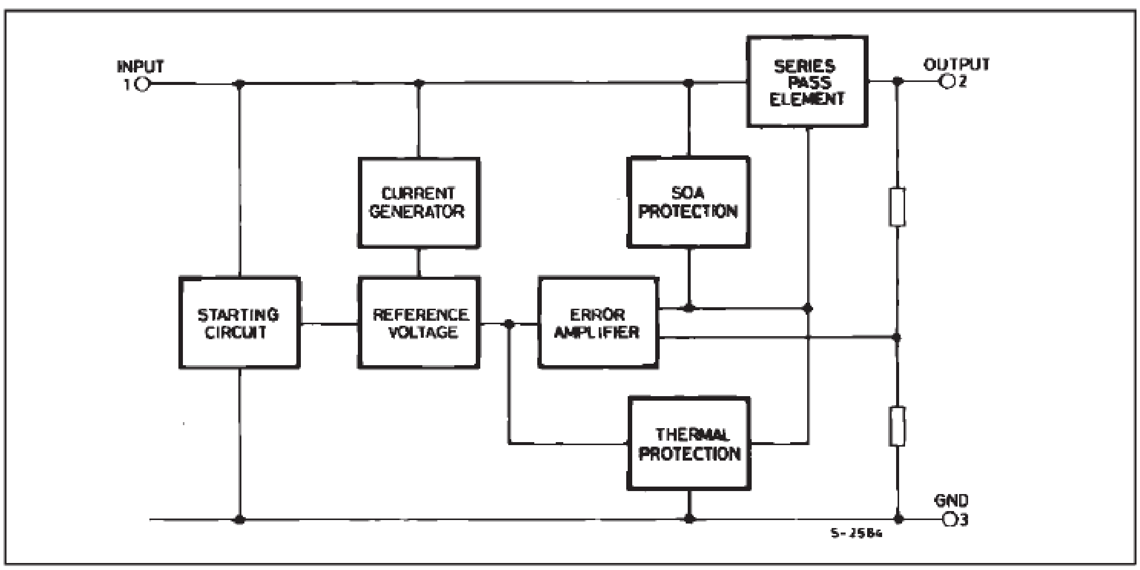
- OUTPUT CURRENT UP TO 1.5 A
- OUTPUT VOLTAGES OF 5; 5.2; 6; 8; 8.5; 9; 12; 15; 18; 24V
- THERMAL OVERLOAD PROTECTION
- SHORT CIRCUIT PROTECTION
- OUTPUT TRANSITION SOA PROTECTION



DESCRIPTION

The L7800 series of three-terminal positive regulators is available in TO-220 TO-220FP TO-3 and D^2PAK packages and several fixed output voltages, making it useful in a wide range of applications.These regulators can provide local on-card regulation, eliminating the distribution problems associated with single point regulation. Each type employs internal current limiting, thermal shut-down and safe area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

BLOCK DIAGRAM



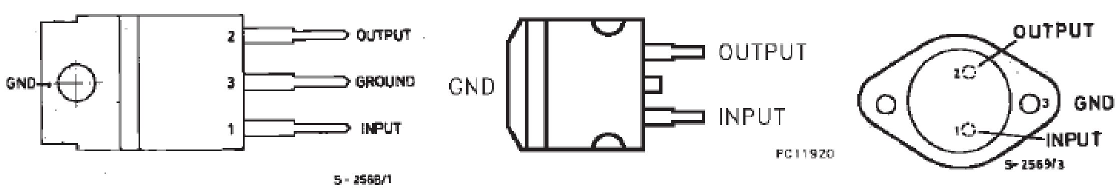
ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_i	DC Input Voltage (for V_O = 5 to 18V) (for V_O = 20, 24V)	35 40	V V
I_o	Output Current	Internally limited	
P_{tot}	Power Dissipation	Internally limited	
T_{op}	Operating Junction Temperature Range (for **L7800**) (for **L7800C**)	-55 to 150 0 to 150	°C °C
T_{stg}	Storage Temperature Range	-65 to 150	°C

THERMAL DATA

Symbol	Parameter		D²PAK	TO-220	TO-220FP	TO-3	Unit
$R_{thj\text{-}case}$	Thermal Resistance Junction-case	Max	3	3	5	4	°C/W
$R_{thj\text{-}amb}$	Thermal Resistance Junction-ambient	Max	62.5	50	60	35	°C/W

CONNECTION DIAGRAM AND ORDERING NUMBERS (top view)

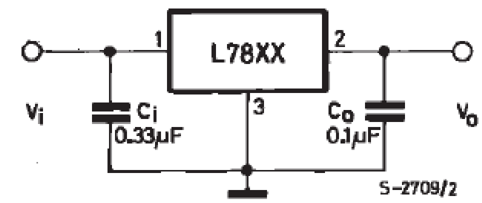


TO-220 & TO-220FP | D²PAK | TO-3

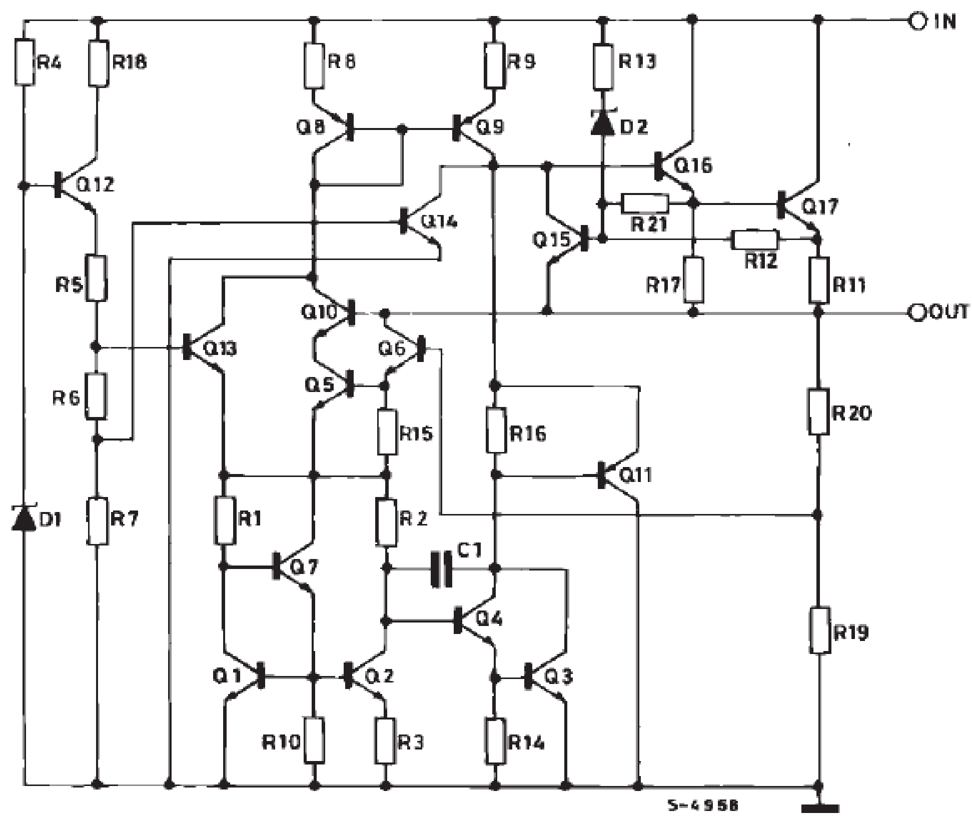
Type	TO-220	D²PAK (*)	TO-220FP	TO-3	Output Voltage
L7805				L7805T	5V
L7805C	L7805CV	L7805CD2T	L7805CP	L7805CT	5V
L7852C	L7852CV	L7852CD2T	L7852CP	L7852CT	5.2V
L7806				L7806T	6V
L7806C	L7806CV	L7806CD2T	L7806CP	L7806CT	6V
L7808				L7808T	8V
L7808C	L7808CV	L7808CD2T	L7808CP	L7808CT	8V
L7885C	L7885CV	L7885CD2T	L7885CP	L7885CT	8.5V
L7809C	L7809CV	L7809CD2T	L7809CP	L7809CT	9V
L7812				L7812T	12V
L7812C	L7812CV	L7812CD2T	L7812CP	L7812CT	12V
L7815				L7815T	15V
L7815C	L7815CV	L7815CD2T	L7815CP	L7815CT	15V
L7818				L7818T	18V
L7818C	L7818CV	L7818CD2T	L7818CP	L7818CT	18V
L7820				L7820T	20V
L7820C	L7820CV	L7820CD2T	L7820CP	L7820CT	20V
L7824				L7824T	24V
L7824C	L7824CV	L7824CD2T	L7824CP	L7824CT	24V

(*) AVAILABLE IN TAPE AND REEL WITH "-TR" SUFFIX

APPLICATION CIRCUIT



SCHEMATIC DIAGRAM



TEST CIRCUITS

Figure 1 : DC Parameter

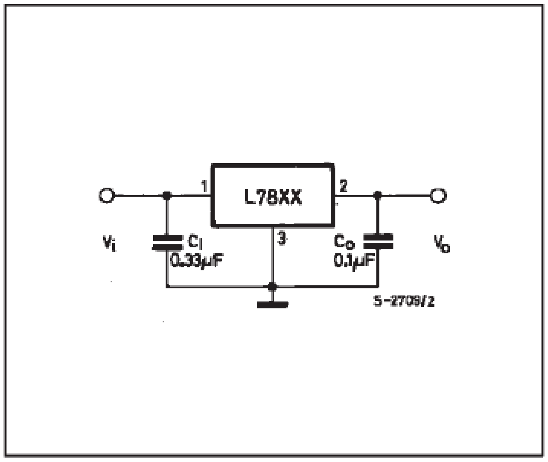


Figure 2 : Load Regulation.

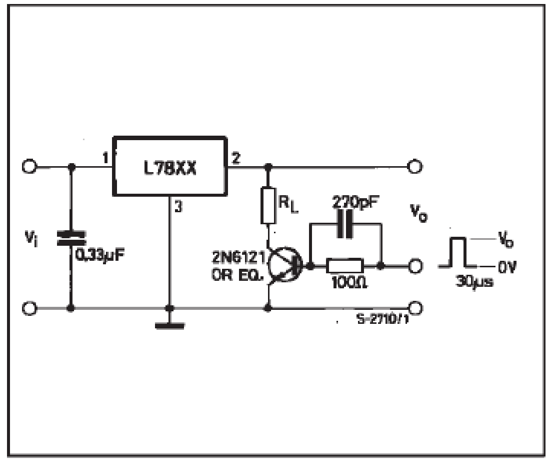
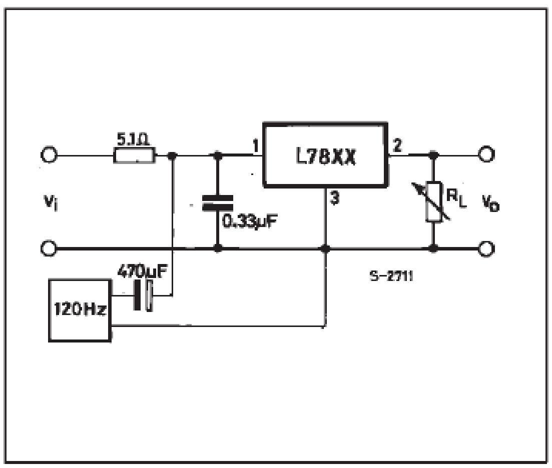


Figure 3 : Ripple Rejection.



ELECTRICAL CHARACTERISTICS FOR L7805 (refer to the test circuits, T_j = -55 to 150 ^oC, V_i = 10V, I_o = 500 mA, C_i = 0.33 µF, C_o = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_o	Output Voltage	T_j = 25 °C	4.8	5	5.2	V
V_o	Output Voltage	I_o = 5 mA to 1 A $P_o \leq$ 15 W V_i = 8 to 20 V	4.65	5	5.35	V
ΔV_o*	Line Regulation	V_i = 7 to 25 V T_j = 25 °C V_i = 8 to 12 V T_j = 25 °C		3 1	50 25	mV mV
ΔV_o*	Load Regulation	I_o = 5 to 1500 mA T_j = 25 °C I_o = 250 to 750 mA T_j = 25 °C			100 25	mV mV
I_d	Quiescent Current	T_j = 25 °C			6	mA
ΔI_d	Quiescent Current Change	I_o = 5 to 1000 mA			0.5	mA
ΔI_d	Quiescent Current Change	V_i = 8 to 25 V			0.8	mA
$\frac{\Delta V_o}{\Delta T}$	Output Voltage Drift	I_o = 5 mA		0.6		mV/°C
eN	Output Noise Voltage	B = 10Hz to 100KHz T_j = 25 °C			40	µV/V_O
SVR	Supply Voltage Rejection	V_i = 8 to 18 V f = 120 Hz	68			dB
V_d	Dropout Voltage	I_o = 1 A T_j = 25 °C		2	2.5	V
R_o	Output Resistance	f = 1 KHz		17		mΩ
I_{sc}	Short Circuit Current	V_i = 35 V T_j = 25 °C		0.75	1.2	A
I_{scp}	Short Circuit Peak Current	T_j = 25 °C	1.3	2.2	3.3	A

PNP 5 GHz wideband transistor BFT92

DESCRIPTION

PNP transistor in a plastic SOT23 envelope.

It is primarily intended for use in RF wideband amplifiers, such as in aerial amplifiers, radar systems, oscilloscopes, spectrum analyzers, etc. The transistor features low intermodulation distortion and high power gain; due to its very high transition frequency, it also has excellent wideband properties and low noise up to high frequencies.

NPN complements are BFR92 and BFR92A.

PINNING

PIN	DESCRIPTION
	Code: W1p
1	base
2	emitter
3	collector

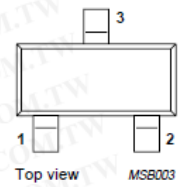


Fig.1 SOT23.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	TYP.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter	–	–20	V
V_{CEO}	collector-emitter voltage	open base	–	–15	V
I_C	DC collector current		–	–25	mA
P_{tot}	total power dissipation	up to T_s = 95 °C; note 1	–	300	mW
f_T	transition frequency	I_C = –14 mA; V_{CE} = –10 V; f = 500 MHz	5	–	GHz
C_{re}	feedback capacitance	I_C = –2 mA; V_{CE} = –10 V; f = 1 MHz	0.7	–	pF
G_{UM}	maximum unilateral power gain	I_C = –14 mA; V_{CE} = –10 V; f = 500 MHz; T_{amb} = 25 °C	18	–	dB
F	noise figure	I_C = –5 mA; V_{CE} = –10 V; f = 500 MHz; T_{amb} = 25 °C	2.5	–	dB
d_{im}	intermodulation distortion	I_C = –14 mA; V_{CE} = –10 V; R_L = 75 Ω; V_o = 150 mV; T_{amb} = 25 °C; $f_{(p+q-r)}$ = 493.25 MHz	–60	–	dB

Note

1. T_s is the temperature at the soldering point of the collector tab.

PNP 5 GHz wideband transistor BFT92

LIMITING VALUES

In accordance with the Absolute Maximum System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter	–	–20	V
V_{CEO}	collector-emitter voltage	open base	–	–15	V
V_{EBO}	emitter-base voltage	open collector	–	–2	V
I_C	DC collector current		–	–25	mA
I_{CM}	peak collector current	f > 1 MHz	–	–35	mA
P_{tot}	total power dissipation	up to T_s = 95 °C; note 1	–	300	mW
T_{stg}	storage temperature		–65	150	°C
T_j	junction temperature		–	175	°C

THERMAL RESISTANCE

SYMBOL	PARAMETER	CONDITIONS	THERMAL RESISTANCE
$R_{th\ j\text{-}s}$	thermal resistance from junction to soldering point	up to T_s = 95 °C; note 1	260 K/W

Note

1. T_s is the temperature at the soldering point of the collector tab.

CHARACTERISTICS

T_j = 25 °C unless otherwise specified.

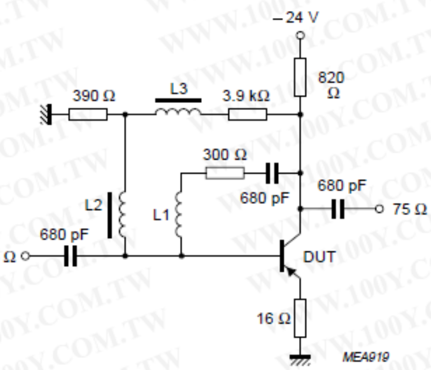
SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
I_{CBO}	collector cut-off current	I_E = 0; V_{CB} = –10 V;	–	–	–50	nA
h_{FE}	DC current gain	I_C = –14 mA; V_{CE} = –10 V	20	50	–	
f_T	transition frequency	I_C = –14 mA; V_{CE} = –10 V; f = 500 MHz	–	5	–	GHz
C_c	collector capacitance	$I_E = i_e$ = 0; V_{CB} = –10 V; f = 1 MHz	–	0.75	–	pF
C_e	emitter capacitance	$I_C = i_c$ = 0; V_{EB} = –0.5 V; f = 1 MHz	–	0.8	–	pF
C_{re}	feedback capacitance	I_C = –2 mA; V_{CE} = –10 V; f = 1 MHz	–	0.7	–	pF
G_{UM}	maximum unilateral power gain (note 1)	I_C = –14 mA; V_{CE} = –10 V; f = 500 MHz; T_{amb} = 25 °C	–	18	–	dB
F	noise figure	I_C = –5 mA; V_{CE} = –10 V; f = 500 MHz; T_{amb} = 25 °C	–	2.5	–	dB
V_o	output voltage	note 2	–	150	–	mV

Notes

1. G_{UM} is the maximum unilateral power gain, assuming S_{12} is zero and

$$G_{UM} = 10 \log \frac{|S_{21}|^2}{\left(1-|S_{11}|^2\right)\left(1-|S_{22}|^2\right)} \text{dB}.$$

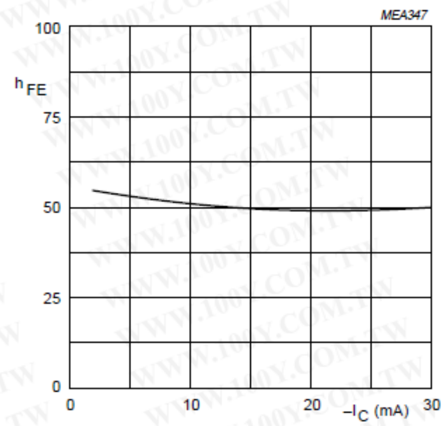
2. d_{im} = –60 dB (DIN 45004B); I_C = –14 mA; V_{CE} = –10 V; R_L = 75 Ω;
   $V_p = V_o$ at d_{im} = –60 dB; f_p = 495.25 MHz;
   $V_q = V_o$ –6 dB; f_q = 503.25 MHz;
   $V_r = V_o$ –6 dB; f_r = 505.25 MHz;
   measured at $f_{(p+q-r)}$ = 493.25 MHz.



L2 = L3 = 5 µH Ferroxcube choke, catalogue number 3122 108 20150.

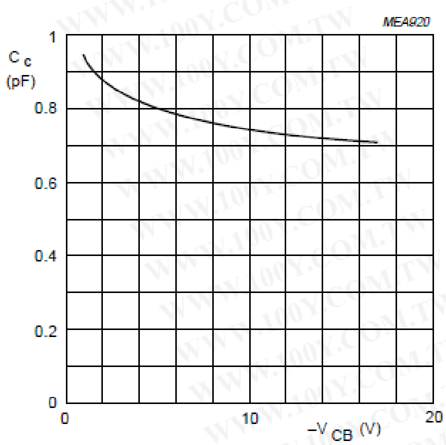
L1 = 4 turns 0.35 mm copper wire; winding pitch 1 mm; internal diameter 4 mm.

Fig.2 Intermodulation distortion test circuit.



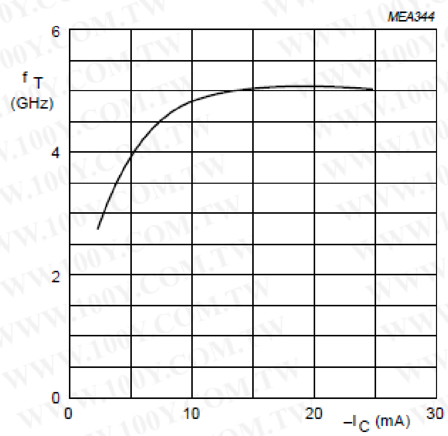
V_{CE} = −10 V; T_j = 25 °C.

Fig.3 DC current gain as a function of collector current.



$I_E = i_e = 0$; f = 1 MHz; T_j = 25 °C.

Fig.4 Collector capacitance as a function of collector-base voltage.



V_{CE} = −10 V; f = 500 MHz; T_j = 25 °C.

Fig.5 Transition frequency as a function of collector current.

FAIRCHILD
SEMICONDUCTOR®

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LM317

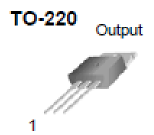
3-Terminal Positive Adjustable Regulator

Features

- Output Current In Excess of 1.5A
- Output Adjustable Between 1.2V and 37V
- Internal Thermal Overload Protection
- Internal Short Circuit Current Limiting
- Output Transistor Safe Operating Area Compensation
- TO-220 Package

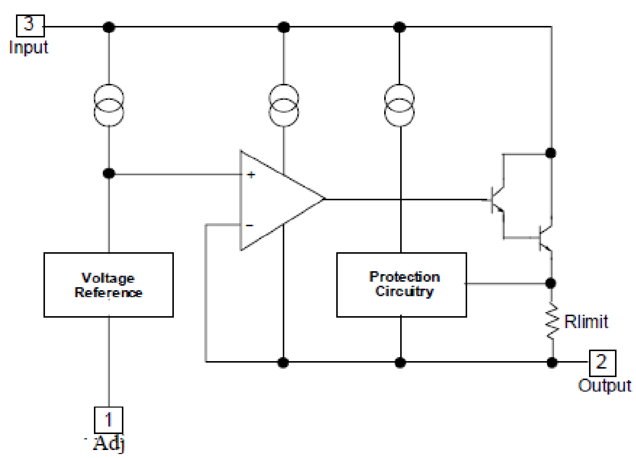
Description

This monolithic integrated circuit is an adjustable 3-terminal positive voltage regulator designed to supply more than 1.5A of load current with an output voltage adjustable over a 1.2 to 37V. It employs internal current limiting, thermal shut-down and safe area compensation.



1. Adj 2. Output 3. Input

Internal Block Diagram



Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input-Output Voltage Differential	$V_I - V_O$	40	V
Lead Temperature	T_{LEAD}	230	°C
Power Dissipation	P_D	Internally limited	W
Operating Junction Temperature Range	T_j	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +125	°C
Temperature Coefficient of Output Voltage	$\Delta V_o / \Delta T$	±0.02	%/°C

Note 1: Absolute Maximum Ratings: are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the Electrical Characteristics tables are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.

Electrical Characteristics

(V_I-V_O = 5V, I_O = 0.5A, 0°C ≤ T_J ≤ +125°C, I_{MAX} = 1.5A, P_{DMAX} = 20W, unless otherwise specified)

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Line Regulation (Note2)	Rline	T_A = +25°C 3V ≤ $V_I - V_O$ ≤ 40V	-	0.01	0.04	%/ V
		3V ≤ $V_I - V_O$ ≤ 40V	-	0.02	0.07	%/ V
Load Regulation (Note2)	Rload	T_A = +25°C, 10mA ≤ I_O ≤ I_{MAX} V_O< 5V V_O ≥ 5V	-	18 0.4	25 0.5	mV%/V_O
		10mA ≤ I_O ≤ I_{MAX} V_O < 5V V_O ≥ 5V	-	40 0.8	70 1.5	mV%/V_O
Adjustable Pin Current	I_{ADJ}	-	-	46	100	μA
Adjustable Pin Current Change	ΔI_{ADJ}	3V ≤ $V_I - V_O$ ≤ 40V 10mA ≤ I_O ≤ I_{MAX} P_D ≤ P_{MAX}	-	2.0	5	μA
Reference Voltage	V_{REF}	3V ≤ $V_{IN} - V_O$ ≤ 40V 10mA ≤ I_O ≤ I_{MAX} P_D ≤ P_{MAX}	1.20	1.25	1.30	V
Temperature Stability	ST_T	-	-	0.7	-	%/V_O
Minimum Load Current to Maintain Regulation	$I_{L(MIN)}$	$V_I - V_O$ = 40V	-	3.5	12	mA
Maximum Output Current	$I_{O(MAX)}$	$V_I - V_O$ ≤ 15V, P_D ≤ P_{MAX} $V_I - V_O$ ≤ 40V, P_D ≤ P_{MAX} T_A=25°C	1.0	2.2 0.3	-	A
RMS Noise, % of V_{OUT}	e_N	T_A= +25°C, 10Hz ≤ f ≤ 10kHz	-	0.003	0.01	%/V_O
Ripple Rejection	RR	V_O = 10V, f = 120Hz without C_{ADJ} C_{ADJ} = 10μF (Note3)	66	60 75	-	dB
Long-Term Stability, T_J = T_{HIGH}	ST	T_A = +25°C for end point measurements, 1000HR	-	0.3	1	%
Thermal Resistance Junction to Case	$R_{\theta JC}$	-	-	5	-	°C/W

Note 2: Load and line regulation are specified at constant junction temperature. Change in V_D due to heating effects must be taken into account separately. Pulse testing with low duty is used. (P_{MAX} = 20W)
Note 3: C_{ADJ}, when used, is connected between the adjustment pin and ground.

Typical Performance Characteristics

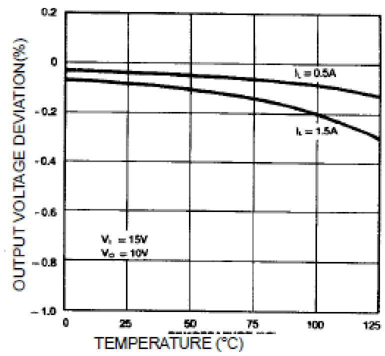


Figure 1. Load Regulation

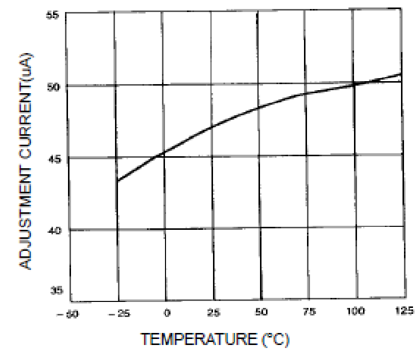


Figure 2. Adjustment Current

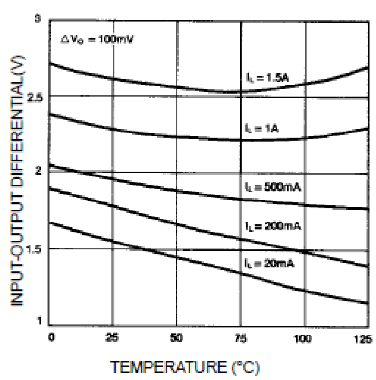


Figure 3. Dropout Voltage

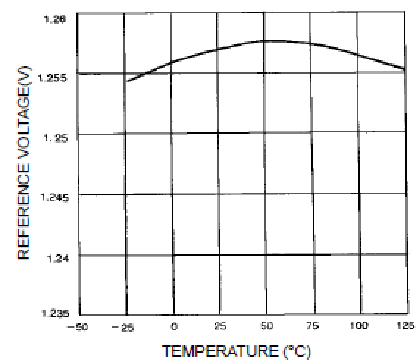
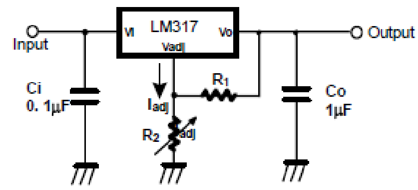


Figure 4. Reference Voltage

Typical Application



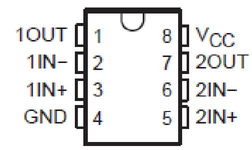
$V_O = 1.25V\ (1 + R_2/R_1) + I_{adj} R_2$

Figure 5. Programmable Regulator

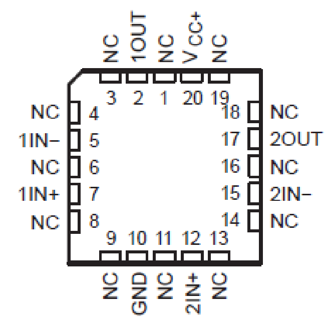
- C_i is required when regulator is located an appreciable distance from power supply filter.
  C_O is not needed for stability, however, it does improve transient response.
  Since I_{ADJ} is controlled to less than 100μA, the error associated with this term is negligible in most applications.

- **Wide Supply Range:**
  - **Single Supply . . . 3 V to 32 V (26 V for LM2904)**
  - **or Dual Supplies . . . ±1.5 V to ±16 V (±13 V for LM2904)**
- **Low Supply-Current Drain, Independent of Supply Voltage . . . 0.7 mA Typ**
- **Common-Mode Input Voltage Range Includes Ground, Allowing Direct Sensing Near Ground**
- **Low Input Bias and Offset Parameters:**
  - **Input Offset Voltage . . . 3 mV Typ**
    A Versions . . . 2 mV Typ
  - **Input Offset Current . . . 2 nA Typ**
  - **Input Bias Current . . . 20 nA Typ**
    A Versions . . . 15 nA Typ
- **Differential Input Voltage Range Equal to Maximum-Rated Supply Voltage . . . 32 V (26 V for LM2904)**
- **Open-Loop Differential Voltage Amplification . . . 100 V/mV Typ**
- **Internal Frequency Compensation**

LM158, LM158A . . . JG PACKAGE
LM258, LM258A . . . D, DGK, OR P PACKAGE
LM358 . . . D, DGK, P, PS, OR PW PACKAGE
LM358A . . . D, DGK, P, OR PW PACKAGE
LM2904 . . . D, DGK, P, PS, OR PW PACKAGE
(TOP VIEW)



LM158, LM158A . . . FK PACKAGE
(TOP VIEW)



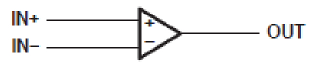
NC – No internal connection

description/ordering information

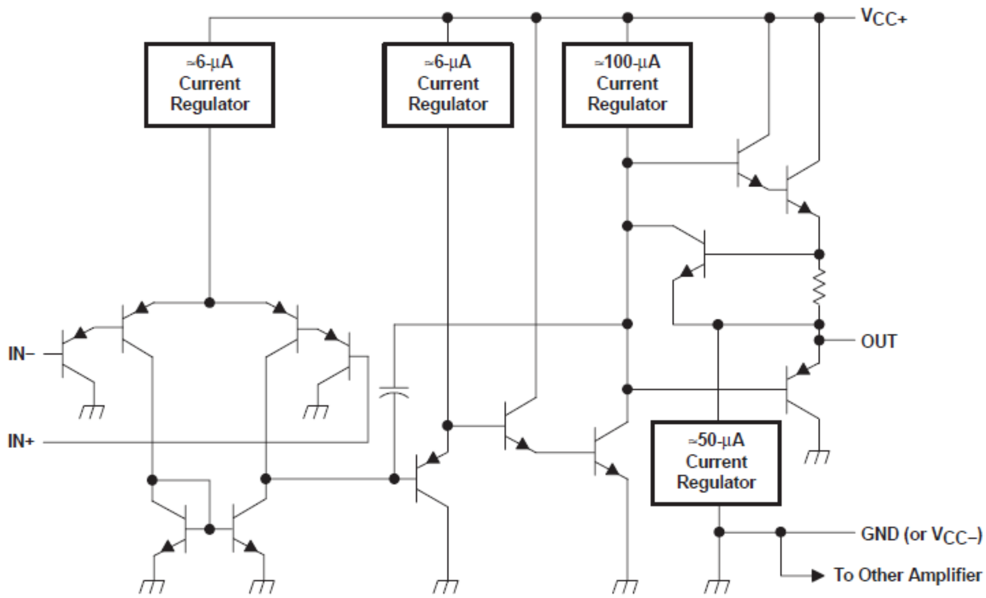
These devices consist of two independent, high-gain, frequency-compensated operational amplifiers designed to operate from a single supply over a wide range of voltages. Operation from split supplies also is possible if the difference between the two supplies is 3 V to 32 V (3 V to 26 V for the LM2904), and V_{CC} is at least 1.5 V more positive than the input common-mode voltage. The low supply-current drain is independent of the magnitude of the supply voltage.

Applications include transducer amplifiers, dc amplification blocks, and all the conventional operational amplifier circuits that now can be implemented more easily in single-supply-voltage systems. For example, these devices can be operated directly from the standard 5-V supply used in digital systems and easily can provide the required interface electronics without additional ±5-V supplies.

symbol (each amplifier)



schematic (each amplifier)



COMPONENT COUNT	
Epi-FET	1
Diodes	2
Resistors	7
Transistors	51
Capacitors	2

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

		LM158, LM158A LM258, LM258A LM358, LM358A LM2904V	LM2904	UNIT
Supply voltage, V_{CC} (see Note 1)		±16 or 32	±13 or 26	V
Differential input voltage, V_{ID} (see Note 2)		±32	±26	V
Input voltage, V_I (either input)		−0.3 to 32	−0.3 to 26	V
Duration of output short circuit (one amplifier) to ground at (or below) 25°C free-air temperature ($V_{CC} \le 15$ V) (see Note 3)		Unlimited	Unlimited	
Package thermal impedance, θ_{JA} (see Notes 4 and 5)	D package	97	97	°C/W
	DGK package	172	172	
	P package	85	85	
	PS package	95	95	
	PW package	149	149	
Package thermal impedance, θ_{JC} (see Notes 6 and 7)	FK package	5.61		°C/W
	JG package	14.5		
Operating free-air temperature range, T_A	LM158, LM158A	−55 to 125		°C
	LM258, LM258A	−25 to 85		
	LM358, LM358A	0 to 70		
	LM2904	−40 to 125	−40 to 125	
Operating virtual junction temperature, T_J		150	150	°C
Case temperature for 60 seconds	FK package	260		°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds	JG package	300	300	°C
Storage temperature range, T_{stg}		−65 to 150	−65 to 150	°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES:
1. All voltage values, except differential voltages and V_{CC} specified for measurement of I_{OS}, are with respect to the network ground terminal.
2. Differential voltages are at IN+ with respect to IN−.
3. Short circuits from outputs to V_{CC} can cause excessive heating and eventual destruction.
4. Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) - T_A)/\theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.
5. The package thermal impedance is calculated in accordance with JESD 51-7.
6. Maximum power dissipation is a function of T_J(max), θ_{JC}, and T_C. The maximum allowable power dissipation at any allowable case temperature is $P_D = (T_J(max) - T_C)/\theta_{JC}$. Operating at the absolute maximum T_J of 150°C can affect reliability.
7. The package thermal impedance is calculated in accordance with MIL-STD-883.

operating conditions, V_{CC} = ±15 V, T_A = 25°C

PARAMETER		TEST CONDITIONS	TYP	UNIT
SR	Slew rate at unity gain	R_L = 1 MΩ, C_L = 30 pF, V_I = ±10 V (see Figure 1)	0.3	V/μs
B_1	Unity-gain bandwidth	R_L = 1 MΩ, C_L = 20 pF (see Figure 1)	0.7	MHz
V_n	Equivalent input noise voltage	R_S = 100 Ω, V_I = 0 V, f = 1 kHz (see Figure 2)	40	nV/$\sqrt{Hz}$

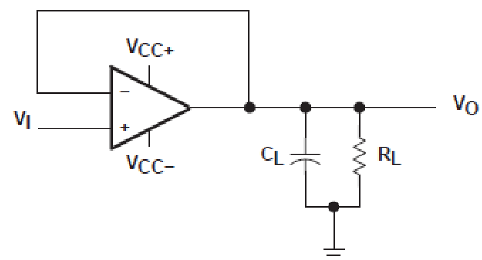


Figure 1. Unity-Gain Amplifier

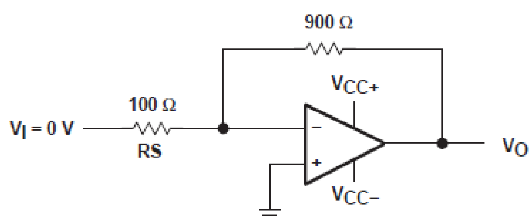
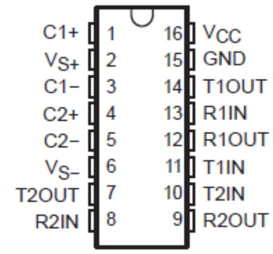


Figure 2. Noise-Test Circuit

- **Meets or Exceeds TIA/EIA-232-F and ITU Recommendation V.28**
- **Operates From a Single 5-V Power Supply With 1.0-μF Charge-Pump Capacitors**
- **Operates Up To 120 kbit/s**
- **Two Drivers and Two Receivers**
- **±30-V Input Levels**
- **Low Supply Current . . . 8 mA Typical**
- **ESD Protection Exceeds JESD 22**
  - **2000-V Human-Body Model (A114-A)**
- **Upgrade With Improved ESD (15-kV HBM) and 0.1-μF Charge-Pump Capacitors is Available With the MAX202**
- **Applications**
  - **TIA/EIA-232-F, Battery-Powered Systems, Terminals, Modems, and Computers**

MAX232 . . . D, DW, N, OR NS PACKAGE
MAX232I . . . D, DW, OR N PACKAGE
(TOP VIEW)



description/ordering information

The MAX232 is a dual driver/receiver that includes a capacitive voltage generator to supply TIA/EIA-232-F voltage levels from a single 5-V supply. Each receiver converts TIA/EIA-232-F inputs to 5-V TTL/CMOS levels. These receivers have a typical threshold of 1.3 V, a typical hysteresis of 0.5 V, and can accept ±30-V inputs. Each driver converts TTL/CMOS input levels into TIA/EIA-232-F levels. The driver, receiver, and voltage-generator functions are available as cells in the Texas Instruments LinASIC™ library.

ORDERING INFORMATION

T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP (N)	Tube of 25	MAX232N	MAX232N
	SOIC (D)	Tube of 40	MAX232D	MAX232
		Reel of 2500	MAX232DR	
	SOIC (DW)	Tube of 40	MAX232DW	MAX232
		Reel of 2000	MAX232DWR	
	SOP (NS)	Reel of 2000	MAX232NSR	MAX232
−40°C to 85°C	PDIP (N)	Tube of 25	MAX232IN	MAX232IN
	SOIC (D)	Tube of 40	MAX232ID	MAX232I
		Reel of 2500	MAX232IDR	
	SOIC (DW)	Tube of 40	MAX232IDW	MAX232I
		Reel of 2000	MAX232IDWR	

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

Function Tables

EACH DRIVER

INPUT TIN	OUTPUT TOUT
L	H
H	L

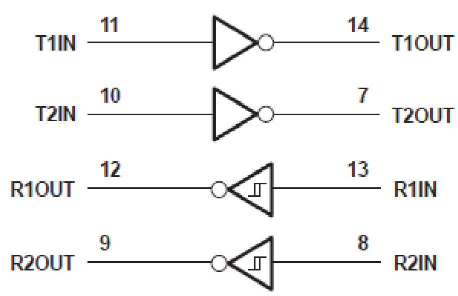
H = high level, L = low level

EACH RECEIVER

INPUT RIN	OUTPUT ROUT
L	H
H	L

H = high level, L = low level

logic diagram (positive logic)



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Input supply voltage range, V_{CC} (see Note 1) . . . . −0.3 V to 6 V
Positive output supply voltage range, V_{S+} . . . . V_{CC} – 0.3 V to 15 V
Negative output supply voltage range, V_{S-} . . . . −0.3 V to −15 V
Input voltage range, V_I: Driver . . . . −0.3 V to V_{CC} + 0.3 V
Receiver . . . . ±30 V
Output voltage range, V_O: T1OUT, T2OUT . . . . V_{S-} – 0.3 V to V_{S+} + 0.3 V
R1OUT, R2OUT . . . . −0.3 V to V_{CC} + 0.3 V
Short-circuit duration: T1OUT, T2OUT . . . . Unlimited
Package thermal impedance, θ_{JA} (see Notes 2 and 3): D package . . . . 73°C/W
DW package . . . . 57°C/W
N package . . . . 67°C/W
NS package . . . . 64°C/W
Operating virtual junction temperature, T_J . . . . 150°C
Storage temperature range, T_{stg} . . . . −65°C to 150°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. All voltages are with respect to network GND.
2. Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) - T_A)/\theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.
3. The package thermal impedance is calculated in accordance with JESD 51-7.

recommended operating conditions

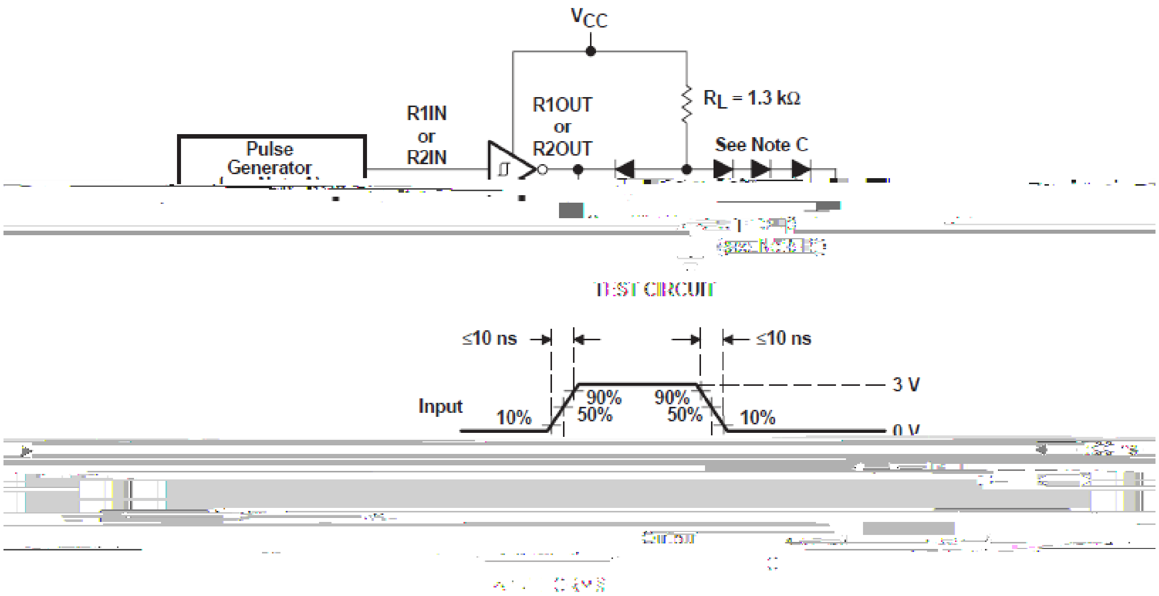
			MIN	NOM	MAX	UNIT
V_{CC}	Supply voltage		4.5	5	5.5	V
V_{IH}	High-level input voltage (T1IN,T2IN)		2			V
V_{IL}	Low-level input voltage (T1IN, T2IN)				0.8	V
R1IN, R2IN	Receiver input voltage				±30	V
T_A	Operating free-air temperature	MAX232	0		70	°C
		MAX232I	−40		85	

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Note 4 and Figure 4)

PARAMETER		TEST CONDITIONS	MIN	TYP‡	MAX	UNIT
I_{CC}	Supply current	V_{CC} = 5.5 V, All outputs open, T_A = 25°C		8	10	mA

‡ All typical values are at V_{CC} = 5 V and T_A = 25°C.
NOTE 4: Test conditions are C1−C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

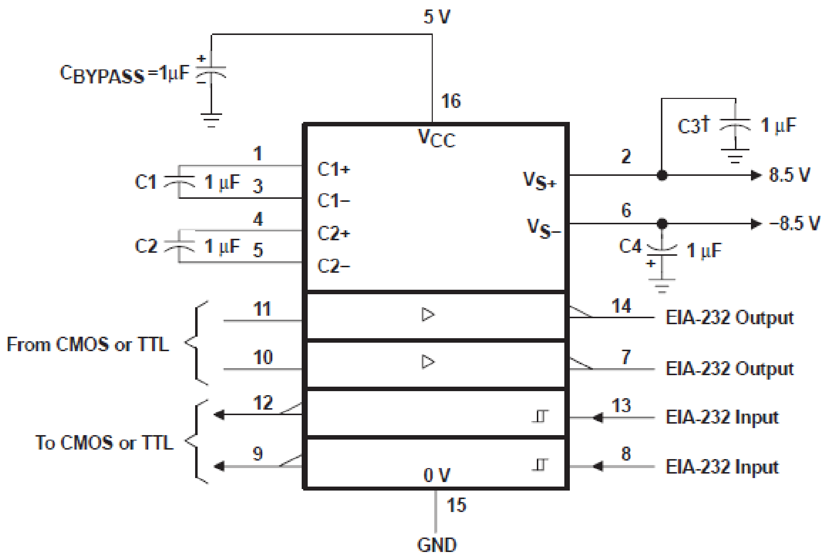
PARAMETER MEASUREMENT INFORMATION



NOTES: A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.
B. C_L includes probe and jig capacitance.
C. All diodes are 1N3064 or equivalent.

Figure 1. Receiver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements

APPLICATION INFORMATION



† C3 can be connected to V_{CC} or GND.

NOTES: A. Resistor values shown are nominal.

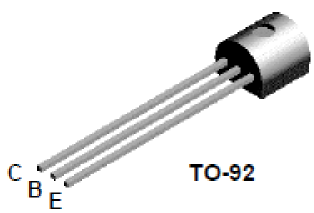
B. Nonpolarized ceramic capacitors are acceptable. If polarized tantalum or electrolytic capacitors are used, they should be connected as shown. In addition to the 1-µF capacitors shown, the MAX202 can operate with 0.1-µF capacitors.

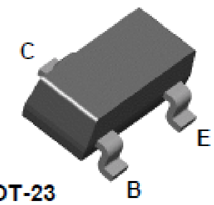
Figure 4. Typical Operating Circuit

FAIRCHILD
SEMICONDUCTOR™

PN100
PN100A

MMBT100
MMBT100A





SOT-23
Mark: NA / NA1

NPN General Purpose Amplifier

This device is designed for general purpose amplifier applications at collector currents to 300 mA. Sourced from Process 10.

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	45	V
V_{CBO}	Collector-Base Voltage	75	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	500	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:
1) These ratings are based on a maximum junction temperature of 150 degrees C.
2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics T_A = 25°C unless otherwise noted

Symbol	Characteristic	Max		Units
		PN100 PN100A	*MMBT100 *MMBT100A	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3		°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	°C/W

*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06."

Electrical Characteristics

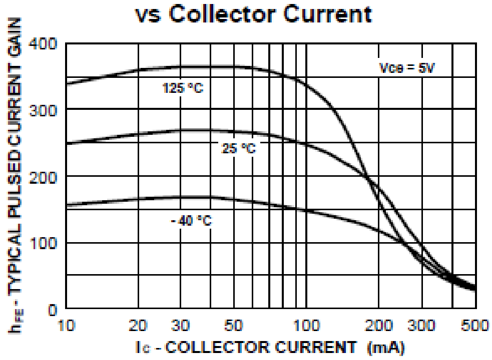
$T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Test Conditions	Min	Max	Units
OFF CHARACTERISTICS					
BV_{CBO}	Collector-Base Breakdown Voltage	$I_C = 10\ \mu A$, $I_B = 0$	75		V
BV_{CEO}	Collector-Emitter Breakdown Voltage*	$I_C = 1\ mA$, $I_E = 0$	45		V
BV_{EBO}	Emitter-Base Breakdown Voltage	$I_E = 10\ \mu A$, $I_C = 0$	6.0		V
I_{CBO}	Collector Cutoff Current	$V_{CB} = 60\ V$		50	nA
I_{CES}	Collector Cutoff Current	$V_{CE} = 40\ V$		50	nA
I_{EBO}	Emitter Cutoff Current	$V_{EB} = 4\ V$		50	nA
ON CHARACTERISTICS					
h_{FE}	DC Current Gain	$I_C = 100\ \mu A$, $V_{CE} = 1.0\ V$ **100**	80		
		100A	240		
		$I_C = 10\ mA$, $V_{CE} = 1.0\ V$ **100**	100	450	
		100A	300	600	
		$I_C = 100\ mA$, $V_{CE} = 1.0\ V$*	100		
		$I_C = 150\ mA$, $V_{CE} = 5.0\ V$* **100**	100	350	
		100A	100		
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	$I_C = 10\ mA$, $I_B = 1.0\ mA$		0.2	V
		$I_C = 200\ mA$, $I_B = 20\ mA$*		0.4	V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	$I_C = 10\ mA$, $I_B = 1.0\ mA$		0.85	V
		$I_C = 200\ mA$, $I_B = 20\ mA$*		1.0	V
SMALL SIGNAL CHARACTERISTICS					
f_T	Current Gain - Bandwidth Product	$V_{CE} = 20\ V$, $I_C = 20\ mA$	250		MHz
C_{obo}	Output Capacitance	$V_{CB} = 5.0\ V$, $f = 1.0\ MHz$		4.5	pF
NF	Noise Figure	$I_C = 100\ \mu A$, $V_{CE} = 5.0\ V$, **100**		5.0	dB
		$R_G = 2.0\ k\Omega$, $f = 1.0\ kHz$ **100A**		4.0	dB

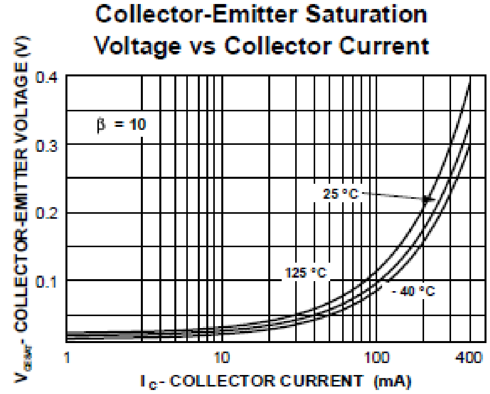
*Pulse Test: Pulse Width $\leq 300\ \mu s$, Duty Cycle $\leq 2.0\%$

Typical Characteristics

Typical Pulsed Current Gain vs Collector Current

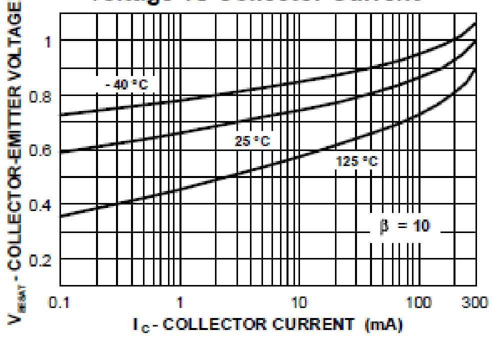


Collector-Emitter Saturation Voltage vs Collector Current

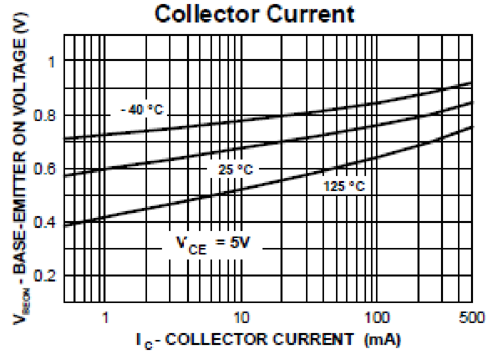


Typical Characteristics (continued)

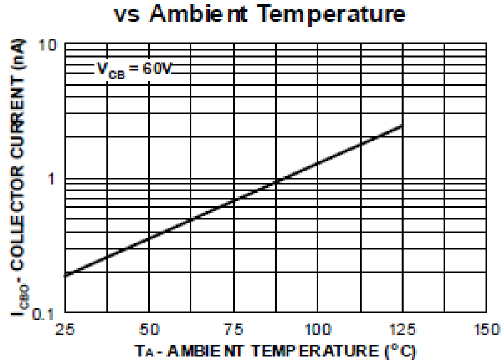
Base-Emitter Saturation Voltage vs Collector Current



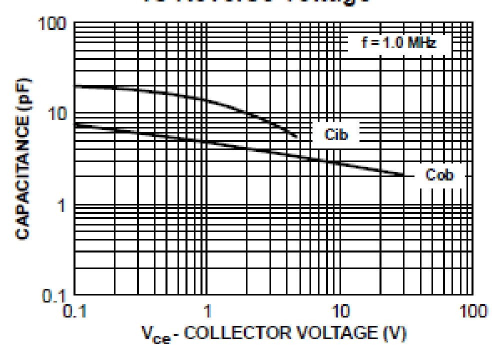
Base-Emitter ON Voltage vs Collector Current



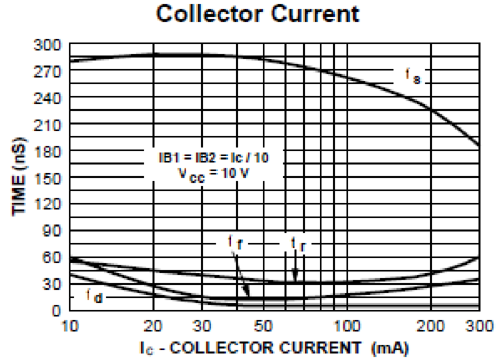
Collector-Cutoff Current vs Ambient Temperature



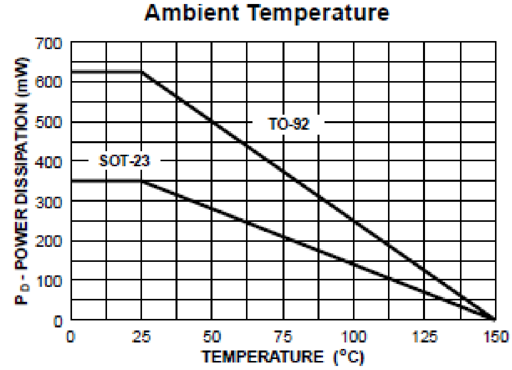
Input and Output Capacitance vs Reverse Voltage



Switching Times vs Collector Current



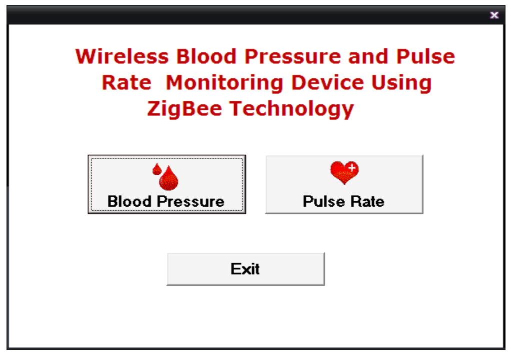
Power Dissipation vs Ambient Temperature



APPENDIX C

User's Manual

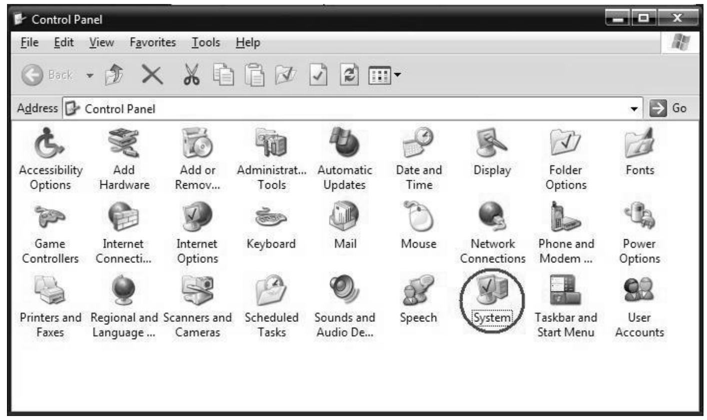
1. Install the accompanied software on the host PC before using this device. The device needed the software to output the results on the PC through the program's GUI display.



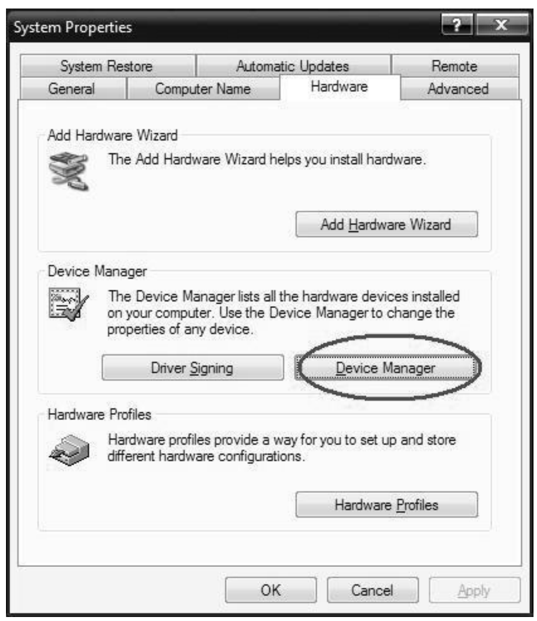
Ensure that the host PC has a serial port to connect the receiver part of the system.

2. Connect the receiver part of the system to the serial port of the host PC. If the computer is using Windows XP check the designated number of the serial port to be used by the program. Please follow the steps below:

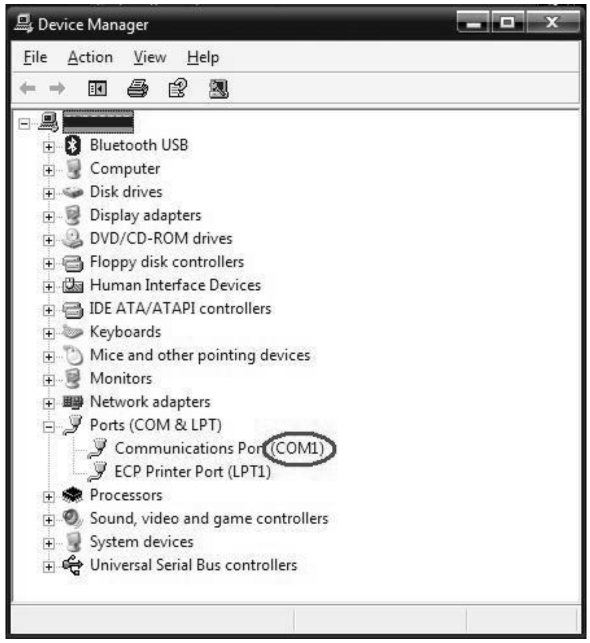
a. Click Start → Control Panel → System



b. Under the System Properties, Click the "Device Manager" Button



c. Expand the "Ports" category by clicking the plus sign beside it and look for the number beside available communication port name, in this case "1" is the available port.



3. For the required voltage of the blood pressure and pulse rate measuring system, it needs an AC source of 220 volts. After plugging the device to a valid power outlet, turn the device on by turning the "ON" switch.

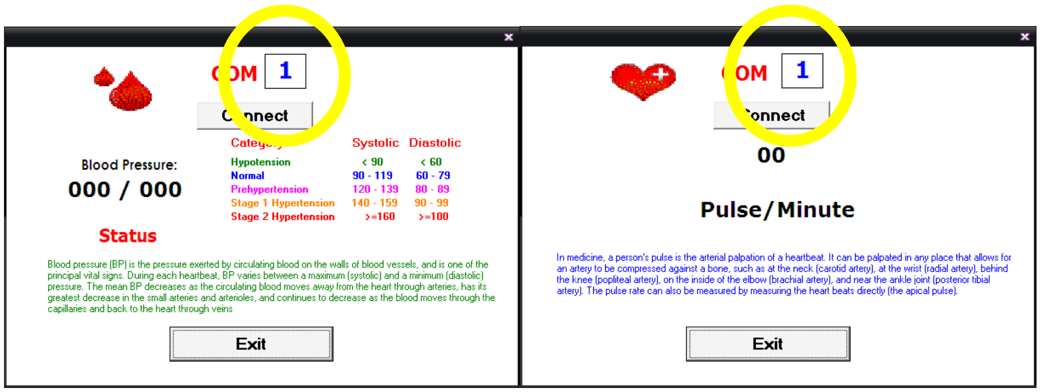
4. Run the accompanied program which is installed earlier in the host PC.

5. Determine what function to be used in the device. To use the blood pressure measuring part, push the "Enable BP" button.

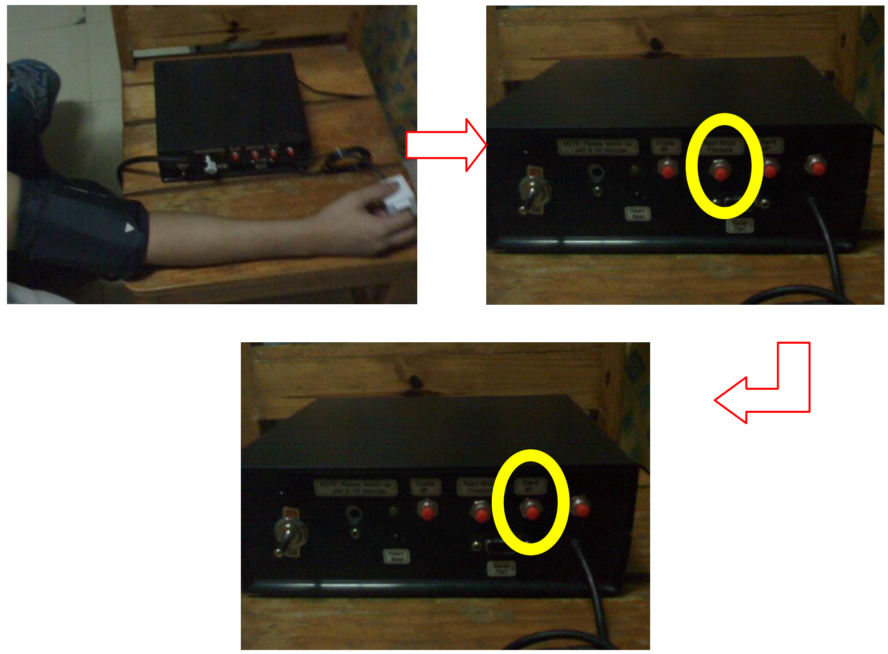
To use the pulse rate measuring part of the device, push the "Pulse Rate" button.

6. In the running program, choose between the pulse rate and the blood pressure measurement.

Click the button to select the function. In the "Port" textbox near the top of the GUI of the program, input the number of the port which is checked earlier from step 2.



If the blood pressure GUI is to be used, carefully place the arm-cuff from the device to the arm of the patient, press the "Read Blood Pressure" in the device to start inflating the arm-cuff and let the device read the blood pressure of the patient. After the arm-cuff has released the air which indicates that the device has finished taking the blood pressure, press the "Send BP" in the device to transfer the measurement to the PC which will be displayed in the software



If the pulse reading system is to be used, place the pointing finger of the person to the pulse reading device. Please note the proper side of the device before placing the finger in the input of the device. Upon using the pulse rate measurement system, an indicator will flash in the GUI program to indicate that the program is reading the pulse rate of the person. A LED indicator is also present in the device to indicate this measurement.