EMBEDDED BASED REMOTE MONITORING AND CONTROLLING SYSTEM

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EMBEDDED BASED REMOTE MONITORING AND CONTROLLING SYSTEM

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Electronics)

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"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Electronics)"

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ABSTRACT

Remote monitoring and controlling system is a system that capable of measuring several ecological parameters in distance away room and capable setting the condition into desire environment through wireless communication system from central room. Depending on its application needs, various technologies as well as improvements have been designed, developed and implemented. In this case, a Zigbee based wireless communication approach is considered to monitor and control various parameters in remote location. This wireless technology offers an effective and noise-free communication between the central and remote room arrangement. Several sensors are equipped in each remote location to measure environmental parameters and these measurements are sent to the central office for storage and analysis purpose. In addition, the central office capable of instruct several command to remote location for output control execution. These features offer an efficient way to maintain condition in the room and allow user to obtain caution on occurrence of any abnormal conditions like parameters exceeding human comfort zone.

ABSTRAK

Sistem memantau dan mengawal secara jarak jauh adalah suatu sistem yang mampu mengukur beberapa elemen ekologi di bilik jarak jauh dan mampu menetapkan keadaan persekitaran melalui sistem komunikasi tanpa wayar dari pusat kawalan. Bergantung kepada keperluan aplikasinya, pelbagai teknologi serta pembaikan telah dirancang, dibangunkan dan dilaksanakan. Dalam hal ini, pendekatan komunikasi tanpa wayar berasaskan teknologi Zigbee diambil kira untuk memantau dan mengendalikan pelbagai elemen di lokasi jarak jauh. Teknologi tanpa wayar ini menawarkan komunikasi antara bilik jarak jauh dan pusat kawalan yang berkesan dan bebas gangguan. Setiap lokasi jarak jauh dilengkapi beberapa pengesan untuk mengukur elemen persekitaran dan ukuran tersebut dihantar ke pusat kawalan untuk tujuan simpanan dan analisis. Beberapa arahan mampu dikeluarkan dari pusat kawalan untuk mengawal peralatan di lokasi jarak jauh. Ciri-ciri ini menawarkan cara yang cekap untuk menjaga keadaan di dalam bilik dan membolehkan pengguna menerima amaran bila berlaku keadaan tidak normal seperti elemen ekologi melebihi zon keselesaan manusia.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless sensor networks have come to the forefront of the scientific community recently. Depending on its application needs, various technologies have been applied in design and development of wireless sensor network for remote monitoring. The technology is typically being used in various fields including meteorological system to solve unpredictable climate condition. In this case, several factors are involved including ambient temperature, relative humidity, and light brightness intensity. For this reason, a simple but an efficient professional meteorological system is required to monitor and control the environmental condition remotely. Lately, remote monitoring and controlling system has become a promising field of future technology which is entering a new era with the development of wireless sensing devices. In the beginning it is limited to supervisory control and data acquisition only, but these days remote monitoring and controlling refers to the measurement from a network operation centre and the ability to change any operation of certain devices from the room.

In similar manner, embedded system have gain enormous amount of processing power and functionality over recent years. Many of the formerly external components can now be integrated into a single system-on-chip. Embedded system is a combination of a microchip and software to perform a specific task, embedded into a manufactured product. This tendency has resulted in a dramatic reduction in the size and cost of embedded systems. Embedded system is an essential element of many innovations where it is designed to increase the reliability and performance of the product. The perfect combination of wireless and embedded system has been used by designer engineers to design various type of wireless monitoring and controlling system. This technology allows the remote location to report information of measurement to the system designer or operator. One of the advantages of this technology is it allows automatic monitoring, alerting and necessary record-keeping parameter for safe and efficient operations.

A distributed control strategy is the most desirable and reliable setup for monitoring environmental measurement. In addition, supervisory in real-time would preserve the quality for the process because of existence wireless link between the remote interface computer and the measurement sensor network. Furthermore, output control device provide eminence feature along the system. Thus, the aim of this project is to develop an embedded based monitoring and controlling system based on Zigbee technology. The system capable monitoring environment parameter at remote location and provide a communication link between the device and user for controlling purpose. The environment parameter specifically temperature, light intensity and humidity are displayed through computer using GUI application. The system provides mutual interoperability between various electronic and power devices as well as interactive interface for people to control the system operation.

1.2 Project Objectives

The main objective of this project is to develop a system that capable of monitoring and controlling various parameters in remote location and place the location into desire environment by using Zigbee-based wireless communication line. The environmental parameter specifically temperature, light intensity and humidity are displayed through personal computer at central operation network.

1.3 Project Scope

In order to achieve the objectives of the project, the scope of the project are summarized as follow:

- Develop microcontroller sub-system at remote location in star topology network
- Design and construct temperature, humidity and light intensity sensors circuit to measure environment parameter.
- Develop output module circuit to activate AC appliance and set environment into desire condition.
- Develop a serial asynchronous communication system between master module and personal computer for user-friendly environment.
- Develop and configure wireless communication link between two operational arrangement using Zigbee devices.
- Develop the firmware for graphical user interface for acquiring input data process and command control execution output device.

1.4 Thesis Outline

The thesis consists of six chapters. Each chapter discuss the development and operation of Embedded Based Remote Monitoring and Controlling System (ERING). Below are the elaborations of every chapter in the thesis.

Chapter 1 describes an overall review of the project. Aspect that included is objectives, project background and scopes as well as thesis organization.

Chapter 2 discusses the literature review of the project. The development of monitoring system, controlling system and wireless communication will be discussed in this chapter.

Chapter 3 presents the architecture and operation of the system. Block diagram for each module involved are discussed.

Chapter 4 discusses the details of hardware design of each module. The connections of hardware are shown in circuit schematic diagram.

Chapter 5 indicates the software development for each module network. The discussion is based on modular approach where a flow chart diagram is used for simple approach explanation.

Chapter 6 present various testing and result of each module operation aspect. The entire integrated modules operation is also discussed in this session.

Chapter 7 concludes the outcome of the project. The recommendation on this project is included in this chapter for future works to enhance system performance.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the research and finding that have been made regarding this project field. The discussion starts from the development of monitoring system, controlling system and wireless communication as well as its function to acquiring data input and sending output command. All the related research papers and journals that provide thought and concept concerning this project ground also is explained into a simple means.

2.2 Project Literature Review

Transceiver is a device that has both the transmitter and receiver circuits are integrated and share common or single housing. Technically, transceivers must combine a large number of transmitter and receiver circuit operations. Similar devices include transponders, transverses, and repeater. In this project, an Xbee RF module as shown in

Figure 2.1 is used as a transceiver. XBee OEM RF modules are IEEE 802.15.4 compliant solution that meets the unique needs of low cost and low power wireless sensor networks. Features of this module are easy to use, require 3.3 volt power, and provide reliable delivery of critical data between devices [1].

Zigbee is a new wireless technology that now can be seeing widely used to deploy a sensor network. This technology has put such a compromising enhancement into the sensor network in various fields. The infrastructure comprised of sensing, computing and communications elements allows the administrator to observe and react in the direction of events and phenomena shifting in a specified environment [2]. Typical applications include, but are not limited to, data collection, monitoring, surveillance and medical telemetry. The major applications of Zigbee focus on sensor and automatic control, such as military application, industrial control, smart buildings and environment monitoring. Agriculture automation is also an applicable field recommended by Zigbee alliance.

ZigBee is a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs). ZigBee builds upon the 802.15.4 standard to define application profiles that can be shared among different manufacturers. IEEE 802.15.4 is a standard defined by the IEEE [3]. It allows the technology to be widely deployed in wireless control and monitoring applications. The low power-usage allows longer life with smaller batteries and the mesh networking provides high reliability and larger range. ZigBee operates in the industrial, scientific and medical (ISM) radio bands. The technology is intended to be simpler and less expensive than other WPAN such as Bluetooth [3].

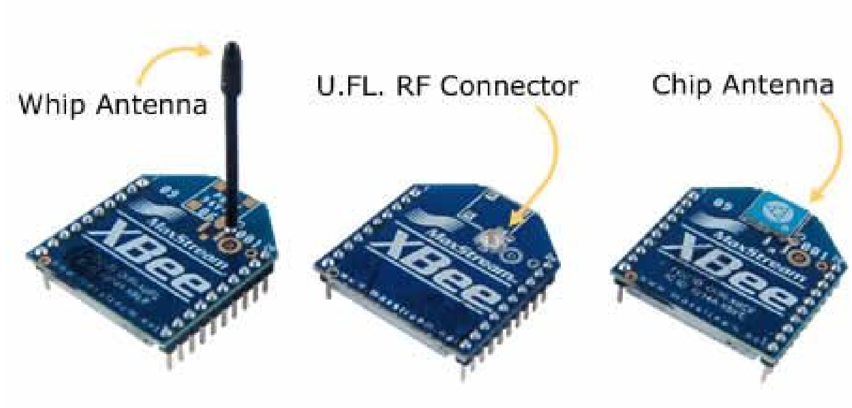

Figure 2.1: Example of Zigbee Devices

A wireless network is an infrastructure for communication “through the air” in which no cables are needed to connect from one point to another. Wireless communication is generally considered to be a branch of telecommunications. Wireless operations permits services, such as long range communications, that are impossible or impractical to implement with the use of wires and it can be implement via radio frequency communication, microwave communication or infrared (IR) short-range communication. Applications may involve point-to-point communication, point-to-multipoint communication, broadcasting, cellular networks and other wireless networks [4].

According of [2], the frameworks of Zigbee operating arrangement can be classified as high-tech network. As shown in Figure 2.2, each node can sense, compute and communicate each other. They can either receive message or transmits message (full-duplex), and can transmit messages to a gateway via self-configuration and multi-hop routing. The gateway can use many ways to communicate with remote network, such as Internet, satellite, mobile communication network and in this system we use pc interfacing. More than one gateway may be used for large-scale application. Because of its limited communication areas the node must use multi-hop routing to access the nodes out of communication areas and in this case, it will compromise two nodes. One of them will act as the central server where the Zigbee will directly connect to the personal computer.

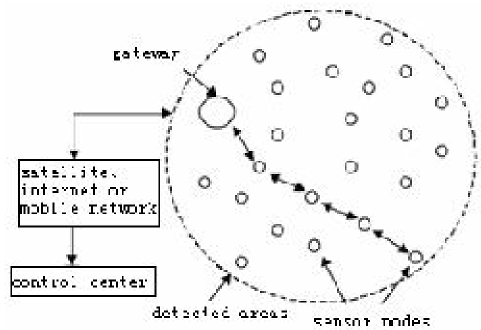

Figure 2.2: Typical Zigbee Framework of Wireless Sensor Network

Furthermore, [2] describes that in every greenhouse in this system comprises a gateway and some wireless nodes. Gateways and nodes are all embedded with a CC2420 RF transceiver (ZigBee compliant) produced by Chipcon company. Data can be transmitted by transceiver between gateways and nodes, and finally the data from all greenhouses are collected to be transmitted to a server. The wireless sensor network nodes use battery power and their power capabilities are limited due to its small size of node. The transmission rate of the network is low and it needs enough power to work steadily for a long time. Therefore low-power design is significant.

In this modern age, communication had becomes an essential element in various arrangement and coordination system. In order to form a communication lines, humans currently using diverse way to join and connect each gateway. Referring [5], one of the examples is by using mobile phone and PC. Mobile phone can serve as powerful tool for world-wide wireless communication. A system is developed to remotely monitor process through spoken commands using mobile. Sound spectrum features are extracted from spoken words. For recognition of various words used in the command learning Vector Quantization Neural Network is required. The accuracy of spoken commands is about 98%. A text message is generated and sent to control system mobile in form of SMS. On receipt of SMS, control system mobile informs micro-controller based card, which performs specified task. The system alerts user in case of occurrence of any abnormal conditions like power failure, loss of control, etc [5].

It is observed that many mobile users especially older generation find it inconvenient to use mobile keypad for text entry as it involves continuous pressing of many keys for alphabets and is time consuming. In order to relieve the users from this burden, spoken words are used to send commands for control. The Block Diagram of the scheme is shown in figure 2.3. The microphone is connected to MIC interface of sound section on motherboard of Pentium IV based PC. User mobile is connected through cable using USB port. In this approach, predetermined phrases of words are selected for various commands. The Mel cepstrum features are extracted from the spoken words for recognition. Mel cepstrum exploits auditory principles as well as discriminating property of the cepstrum and is proven to be one of the most successful feature representations in speech related recognition tasks [5].

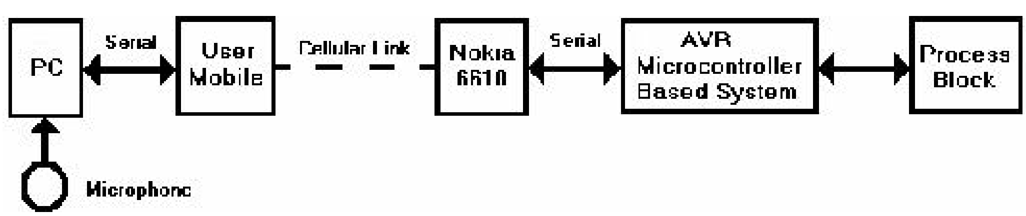

Figure 2.3: Block Diagram of The Command Control System

In addition, communication lines also can be formed using personal computer (PC) interfacing. In [6] described the application of the wireless devices for the purpose of temperature data collection and storage using digital computer. PC interfacing offer several attractive features like acknowledgement about execution of command from system, ease of implementation and cost-effective approach. In Figure 2.4, block diagram of the data collection process in the system is shown. The PC system connected to Zigbee based coordinator board through serial communication using RS-232 cable. Meanwhile, the sensor network connected to microprocessor before it sends data to Zigbee before it transmit to another one. This system will help to minimize the need for wire connections, cost, power consumption and manpower to promote stable environment in order to produce good quality products [6].

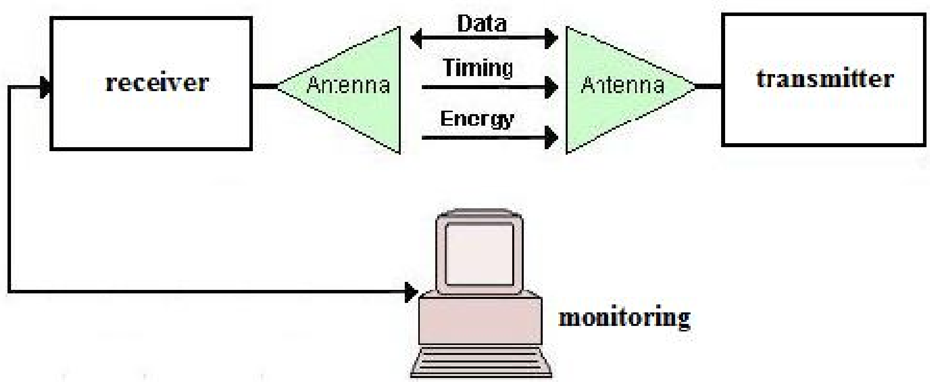

Figure 2.4: Block Diagram of Data Collection Process

In telecommunication and computer science, serial communication is the process of sending data one bit at one time, sequentially, over a communication channel or computer bus. There are two basic types of serial communications, synchronous and asynchronous. With synchronous communications, the two devices initially synchronize themselves to each other, and then continually send characters to stay in synchronous. Asynchronous means "no synchronization", and thus does not require sending and receiving idle characters [7]. In [8] describe about the Universal Serial Bus (USB) that has been developed to overcome disadvantages of previously available communication interfaces; it is a fast, bi-directional, isochronous, low-cost, dynamically attachable serial interface that is consistent with the requirements of the PC platform now and future. The USB is versatile enough for a wide range of peripheral devices, including input devices such as mice, keyboards, disks, printers, audio and video devices. It is also used for data acquisition devices, control and monitoring systems, multimedia devices, and even security ones [8].

Figure 2.5 shows diagram of simple wireless application using Zigbee and PC interfacing method for its communication between human and hardware. This system is the non-contact and non-line-of-sight that can be read several meters away thus reduces the need for manual scanning and easy in data transportation. This system use two Zigbee transceivers which are for transmitter and receiver. The transmitter will emits a signal and periodically send the data from the memory of a microcontroller. This microcontroller will perform the calculation and send it to the output of Universal Asynchronous Receive/Transmit (UART) in the receiver's input. These two transceivers communicate with each other where the data from the transmitter is sent to the receiver. The display will indicate the remote unit identification as well as the environment measurement by using the UART port of the receiver, the data will be sent to the computer com port via Universal Serial Bus (USB).

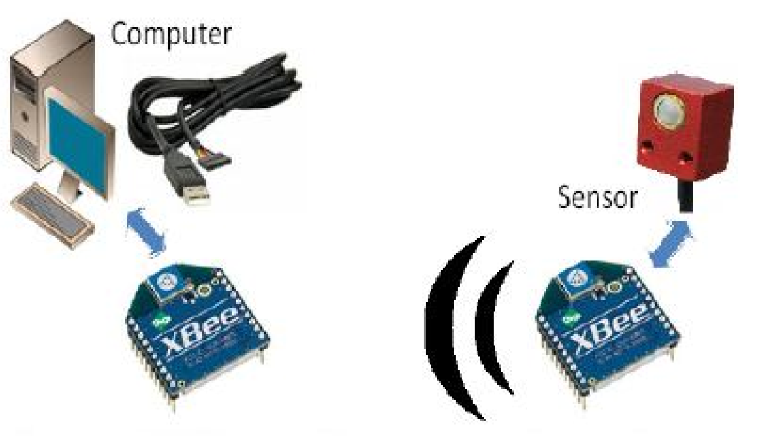

Figure 2.5: Diagram of Simple Wireless Application Using Zigbee

For acquiring data input and sending output command part, [9] discussed on how to design an embedded based for automatic room light detection and control to monitor specific environment parameter and implement the controller circuit. The controller circuit consists of circuits for power supply, microcontroller and sensor. The microcontroller is loaded with program using programmer board to read data from the sensor, calculated it accordingly and send the signal to the UART port. Monitoring unit starts with a scan for presence of transmitted data. If data is available, the data is received and examined to ensure error free transmission and reception. Then the data is disassembled and examined or matching encoder/decoder addresses. If the addresses matched, the data is received from the correspondence remote unit. The data is decoded, manipulated and displayed on the PC. [9]

Triac are widely used in AC power control applications. In [10] and [11], the triac circuit are able to switch high voltages and high levels of current, and over both parts of an AC waveform. This makes triac circuits ideal for use in a variety of applications where power switching is needed. One particular use of triac circuits is in light dimmers for domestic lighting, and they are also used in many other power control situations including motor control. In this project, the triac circuit create DC controlled Solid State Relay is deployed to activate 240V AC equipment instantaneously if the room condition exceed the normal condition. The output is like a normally open contact (NO) of a relay and has to be in series with the loads. This circuit is called opt coupler circuit and for the beginning the load are lamp and fan.

2.3 Principle of Temperature

Temperature, a measure of the quantity of heat in an object and environment, usually as measured on a thermometer, meter data-logger and sensor. The principle by which instruments measures temperature is simple - sensor is placed in the sample, a potential is applied across the sensor and the current or resistance is measured and converted into temperature [12]. Generally, the potential is very low when thermostat being use as the sensing elements to prevent self heating. There are several unit measures of temperature. Each can be converted from one form to another. Equation (2.1) to Equation (2.4) are the temperature conversion equation.

$$\text{Kelvin: } °K = °C + 273.15 \tag{2.1}$$

$$\text{Centigrade: } °C = (°F - 32) \times 5/9 \tag{2.2}$$

$$\text{Fahrenheit: } °F = (9/5 \times °C) + 32 \tag{2.3}$$

$$\text{Rankin: } °R = °F + 459.67 \tag{2.4}$$

2.4 Principle of Humidity

Relative humidity, temperature measurement and monitoring are very useful for the purpose of analysis [13]. The variation in relative humidity at a particular place may be caused by factors, such as power failure, equipment failure and human discomfort climate. Humidity is the amount of water vapors in the air. Humidity may also be expressed as specific humidity. Relative humidity is an important metric used in forecasting weather. Humidity indicates the probability of precipitation, dew, or fog. High humidity makes people feel hotter outside in the summer because it reduces the effectiveness of sweating to cool the body by reducing the evaporation of perspiration from the skin [13]. The amount of water vapor in the air at any given time is usually less than that required to saturate the air. The relative humidity is the percent of saturation humidity, generally calculated in relation to saturated vapor density. Equation (2.5) shows the relative humidity formula.

$$Relative\ Humidity = \frac{actual\ vapor\ density}{saturation\ vapor\ density} x100\%$$

(2.5)

The most common units for vapour density are gm/m^3. Referring Equation (2.6), if the actual vapour density is 10 g/m^3 at 20°C compared to the saturation vapour density at that temperature of 17.3 g/m^3, then the relative humidity is:

$$R.H. = \frac{10g/m^3}{17.3g/m^3} x100\% = 57.8\%$$

(2.6)

2.5 Principle of Light Intensity

Some scientists express the "brightness" of light in terms of "intensity." The brighter the light, the more intense it is. The word "intensity" can be used to for both the light and the heat of the sun. Heat is usually most intense when light is most intense. We should specify a standard source in order to define the light intensity in a clearer way. A standard source is anybody which radiates energy, although not all the energy is considered lighting energy (the one we perceive through the sense of sight) but part of that lighting energy is converted into heat and non visible radiations. Thus, part of that energy which is emitted by a source, is not a visible energy. The lighting radiations come from the warming of a given material by which energy radiates [9].

In recent years the energy crisis has become one problem which the whole world must confront. Home power consumption makes up the largest part of energy consumption in the world. In particular, the power consumption of lamps in a typical home is a factor which can't be ignored. The typical user needs different light intensities in different places. Sometimes the light intensity from outside is sufficient for the user, and thus we don't need to turn on any light. But sometimes the user leaves but forgets to turn off the light. These factors cause energy waste. Therefore some power management of light control in a home is necessary in order to save energy [9].

CHAPTER 3

SYSTEM ARCHITECTURE OF ERING

3.1 Introduction

This chapter discusses the system architecture of Embedded Based Remote Monitoring and Controlling System (ERING) in simple approach. As shown in Figure 3.1, a simple concept is used in this system where temperature, humidity and light intensity of two different remote locations can be monitored and controlled in a central room. Temperature, humidity and light intensity sensors are implemented in each remote room. All the sensors sense current condition environment in remote room and display it on PC at the central room. If the condition exceed human comfort zone, user can send a command to activate any electrical devices at remote rooms from the PC. Each system network in remote room has a microcontroller to manipulate the command and activate the solid state relay circuit to switch on AC appliances. The data transmissions are handled by Zigbee transceiver to allow the full-duplex communication between remote location and central rooms.

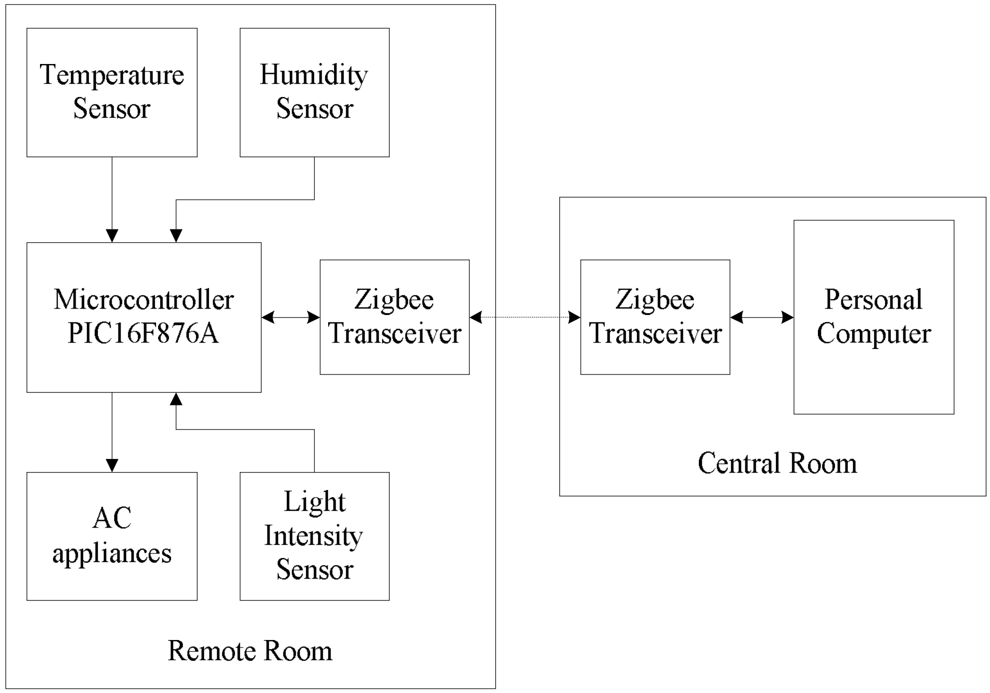

Figure 3.1: Full System Block Diagram

3.2 Microcontroller System Board Module

In this project, microcontroller PIC16F876A is chosen to implement in the embedded system because of its multi-tasking capabilities, processing data and the ability to control the functionality of other device. CMOS FLASH-based 8-bit microcontroller is a powerful microcontroller but yet is easy to program. The block diagram for microcontroller system is shown in Figure 3.3. It consists of clock circuit, power supply and reset circuit. Power supply module is needed to supply approximately constant 5V to the system while reset circuit used as primary interrupt to reset microcontroller process. On the other hand, clock circuit is used to provide 20 MHz pulses for the system to operate.

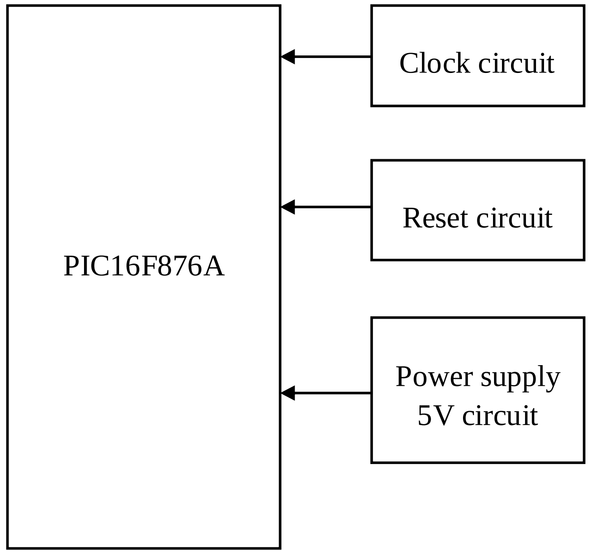

Figure 3.2: Block Diagram of Microcontroller Board Module

3.3 Sensor Modules

To design reliable control system for monitoring and controlling system, suitable sensor modules are required. Presently, there are many new developments in electronics sensors that are applicable in designing monitoring system. Humidity, temperature and light intensity sensors are the most common sensors used in monitoring system. Figure 3.3 shows a simple block diagram of the sensor modules interface with microcontroller at the remote room network.

In this project, HSM-20G is chosen to be implemented as humidity sensor. It is a device consisting of a special plastic material whose electrical characteristic change according to the amount of humidity in the air. In other words, this sensor senses the amount of vapour water in air and converts the relative humidity into standard voltage output.

Temperature sensor on the other hand, is an integrated circuit sensor that can be used to measure temperature. In this system, the module of LM35 converts the measurement into standard analogue output voltage which is proportional the temperature in degree Celsius (◦C).

In similar manner, TSL250R is an optical sensor device to measure the light intensity of the environment. This device is chosen because it has improved amplifier offset-voltage stability and low power consumption. Output voltage is directly proportional to the light intensity or irradiance in micro-watt per centimetres square ($\mu W/cm^2$) on the photodiode.

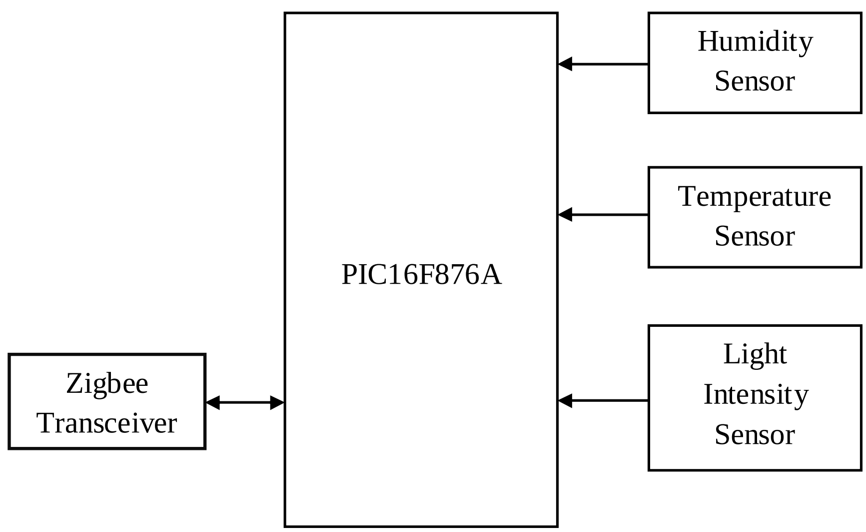

Figure 3.3: Block Diagram of Sensors Module

3.4 Zigbee Transceiver Module

The data transmission between remote location and central room is handled by using Zigbee 802.15.4 devices. It is a transceiver device which both the transmitter and receiver circuits are integrated and share a single housing. Figure 3.5 and 3.6 shows a simple block diagram of the Xbee RF modules at central and remote room network. Two Xbee RF modules, UART to USB converter and PC are required to develop the module. In this project, UART to USB Converter developed by Cytron is used because of its operating voltage is 3.3V.

As shown in Figure 3.4, the Xbee device at central room network is connected to the PC through UART to USB converter. Figure 3.5 shows that the interfacing block diagrams between microcontroller and Xbee device at remote room network. Voltage divider circuit is required at communication line between PIC16F876A and Xbee device to regulate signals from microcontroller to Xbee device so that it does not exceed its limit. It is necessary to make sure the input signal to the Xbee device pin is in a range from 3.28 V to 3.33V to avoid any malfunction of the device.

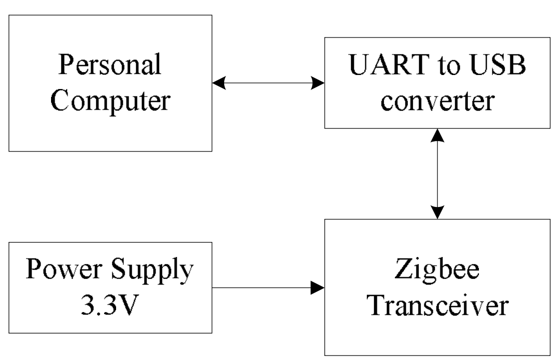

Figure 3.4: Block Diagram of Xbee Module at Central Room Network

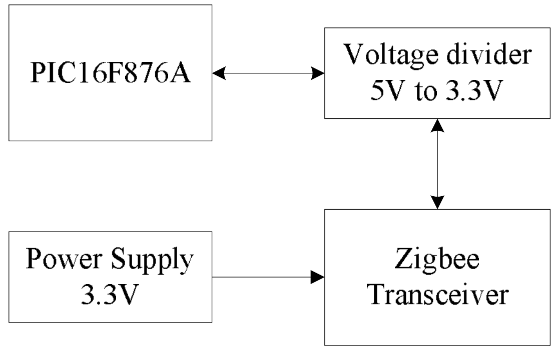

Figure 3.5: Block Diagram of Xbee Module at Remote Room Network

3.5 Serial Communication Module

In the PIC16F876A, pin RB6 is a data transmit (TX) pin and pin RB7 is a data receive (RX) pin. It has two modes of operation, synchronous (using a separate clock signal) and asynchronous (no clock connection). In this project, asynchronous mode is been used where the data are transmitted in 8-bit words and receiver sampled the input at the same rate as the transmitted data. Thus, a standard baud rate at 9600 baud is considered in order to allow data transmission between those two devices. Full duplex technique can be applied in the design as both Tx and Rx use different line communication. Figure 3.6 and 3.7 shows simple block diagrams of serial communication at central and remote room node.

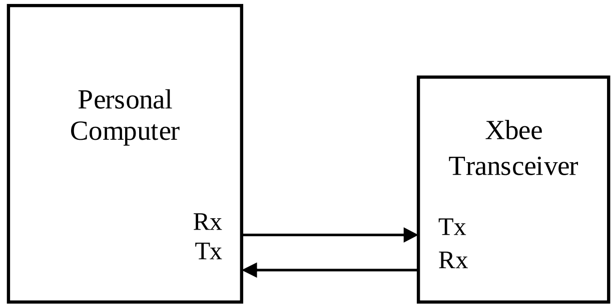

Figure 3.6: Block Diagram of Serial Communication at Central Room Node

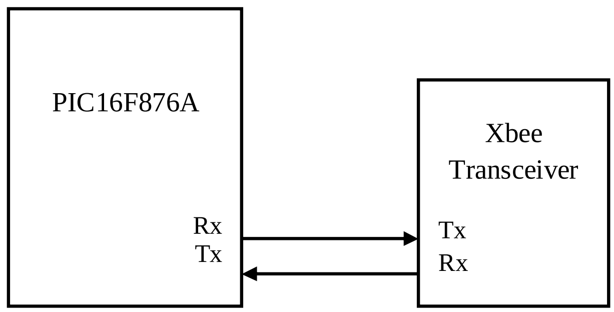

Figure 3.7: Block Diagram of Serial Communication at Remote Room Node

3.6 Solid State Relay Circuit Module

In this project, a solid state relay circuit is implemented to switch on the AC appliances at remote location. The circuit contain TRIAC or Triode for Alternating Current which is an electronic component that able to activate 240V AC equipment instantaneously. The TRIAC controls and conducts current flow during both alternations of an ac cycle, instead of only one. This results in a bidirectional electronic switch which can conduct current in either direction when it is triggered (turned on) and thus doesn't have any polarity. In addition, solid-state relay devices have no moving parts to wear out and provide no bounce-contact if the circuit accidentally went through a vibration scenario. Figure 3.8 shows a simple block diagram of solid state relay circuit at the remote room network.

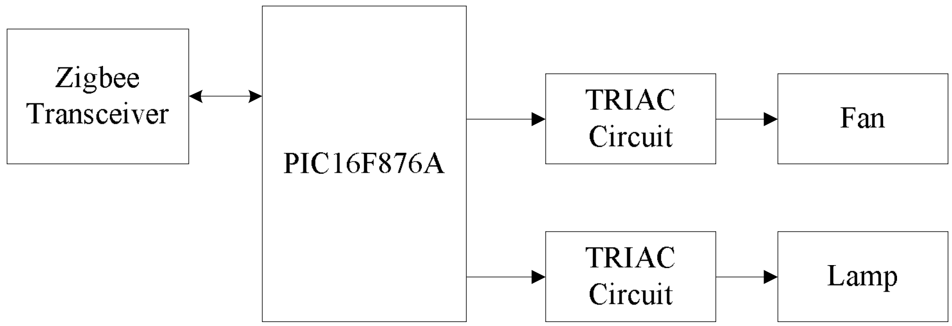

Figure 3.8: Block Diagram of Solid State Relay Circuit Module

CHAPTER 4

HARDWARE DESIGN

4.1 Introduction

In general, this chapter discusses hardware design of the ERING. It contains circuit schematic information of microcontroller module, sensors module, Zigbee transceiver module, serial communication module and solid state relay circuit module for AC appliances. The circuit schematic also illustrate connection of each component and device in more comprehend way then a block diagram figure.

4.2 Microcontroller Module

PIC16F876A is chosen to be implemented in this project due to its unique as it uses flash memory as its program code memory. Thus it can be programmed all over again without using ultra-violet to erase its program memory. It is one of the 8-bit micro-controller produced by Microchip Technology.

The microcontroller is a core in the remote room as it controls the system operation. Figure 4.1 is a schematic diagram of the PIC16F876A module. In order for the microcontroller to function properly, it requires 5V power supply circuit, reset circuit and clock circuit. The power supply module requires the use of voltage regulator to regulate the supply voltage. Therefore, regulator LM7805 is used in order to generate 5V output and provide voltage input for the microcontroller. The regulator also provides stable 5 volt supply to other devices in the system such as sensors and ICs. Several capacitors are required at the regulator to diminish voltage ripples.

External oscillator circuitry is also required in this microcontroller module to generate clock for microcontroller to execute instruction command with high speed capability. Consequently, High Speed Crystal (HS) with value 20MHz is chosen to establish the oscillation where it is connected in between OSC1 and OSC2 pins as shown in figure 4.1. Two capacitors with quite small farad value are required at the crystal to filter glitches of the oscillation signal. Meanwhile, any mechanical switch can be used to function as RESET switch for the microcontroller. It is connected to MCLR (master clear) pin of the microcontroller to enable microcontroller to be "reset" by switching the switch on.

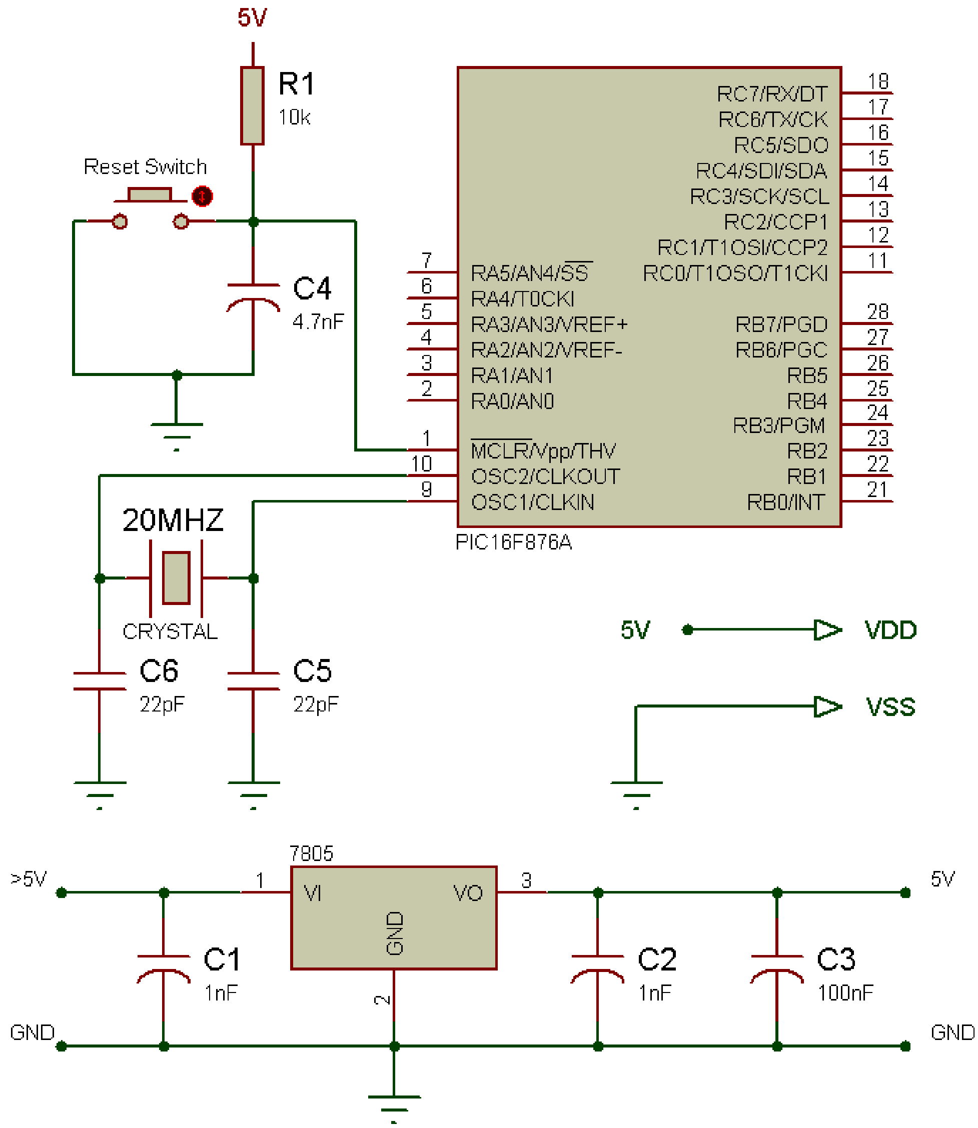

Figure 4.1: PIC16F876A Circuit Schematic Module

4.3 Sensors Module

There are three type of sensors used in the system which are connected to the PIC16F876A at remote room. They are temperature sensor, humidity sensor and light intensity sensor. As shown in Figure 4.2, simple circuit connection of each sensor is depicted in the figure.

Due to its simplicity and high tolerance, LM35 is used as temperature sensor. LM35 does not require any external calibration or trimming to provide typical accuracies of temperature measurement. In this project, the sensor senses current temperature in Celsius at remote room. Then the analogue information is sent to microcontroller through analogue input pin of Port A where the converting process is performed.

On the other hand, TSL250 is a light-to-voltage optical sensor. Its output voltages are directly proportional to the light intensity sense on the integral photodiode lens of the sensor. In this case, the sensor will be implemented in each remote room to sense the brightness in of the room. The measurement unit for this light sensor is μw/cm2. As mention earlier, the analogue signal sensed by light sensor is sent to microcontroller to manipulate it into digital signal.

HSM-20G is the most widely used humidity sensor. It consists of special plastic material whose electrical characteristics change according to the amount of humidity in the air. Basically, the sensor senses the amount of water vapour in air which is relative humidity and converts it to standard voltage output. External circuit is considered to be implemented with the sensor to ensure the relationship between humidity and voltage output after the conversion is linear.

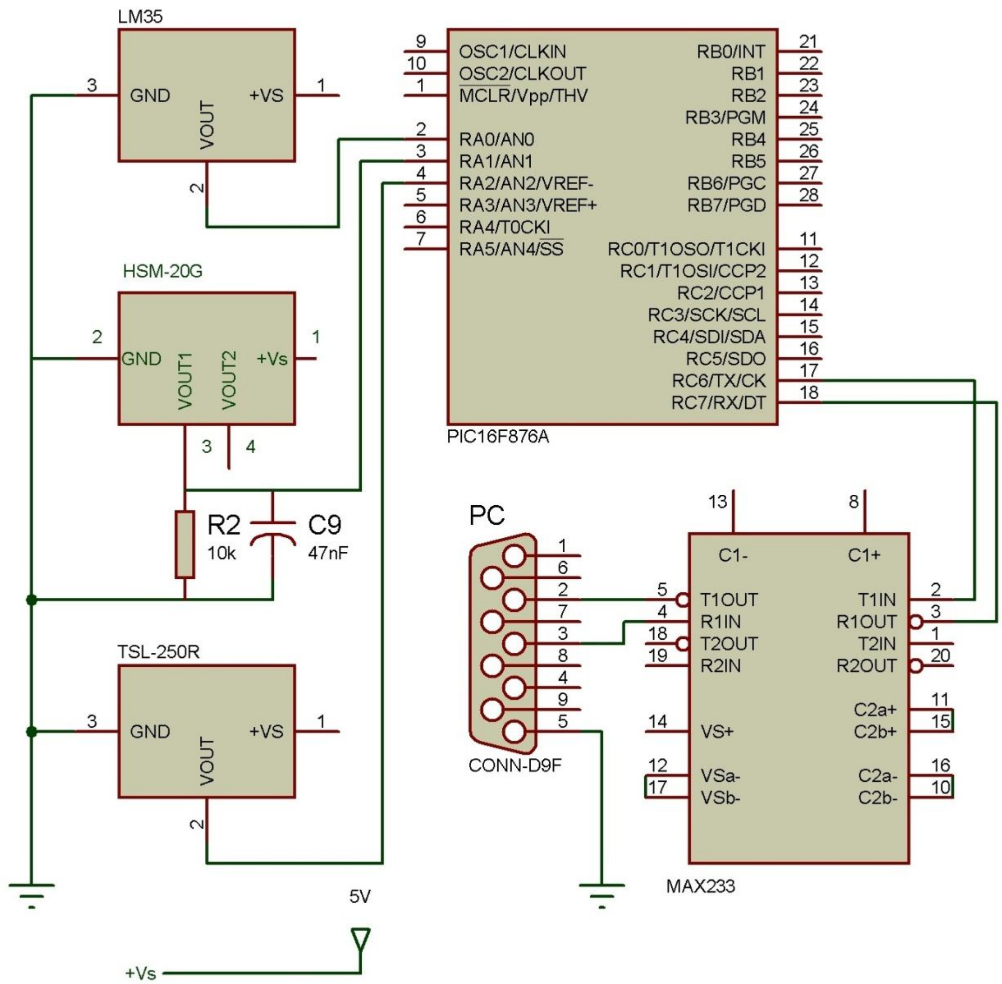

Figure 4.2: Circuit Schematic of Sensors Module

4.4 Zigbee Transceiver Module

In order to transmit signals through radio wave, 2 transceiver are used at both ends of the remote room and central room network. In view of the fact that the system operate in two way communication, Xbee OEM RF device is chosen to be implemented in this project because of its unique feature which has both the transmitter and receiver circuits integrated in single housing. Figure 4.3 and 4.4 shows circuit connection of the transceiver at remote room and central room respectively.

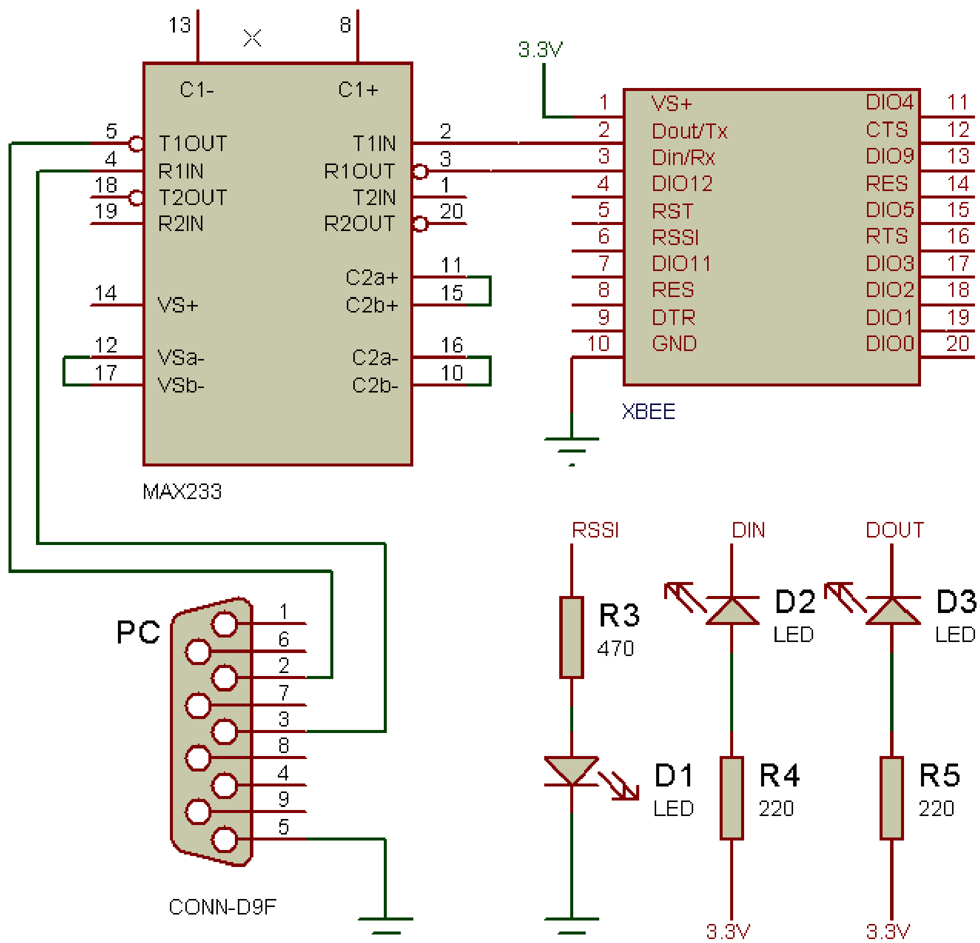

Figure 4.3: Circuit Schematic of Xbee at Central Room

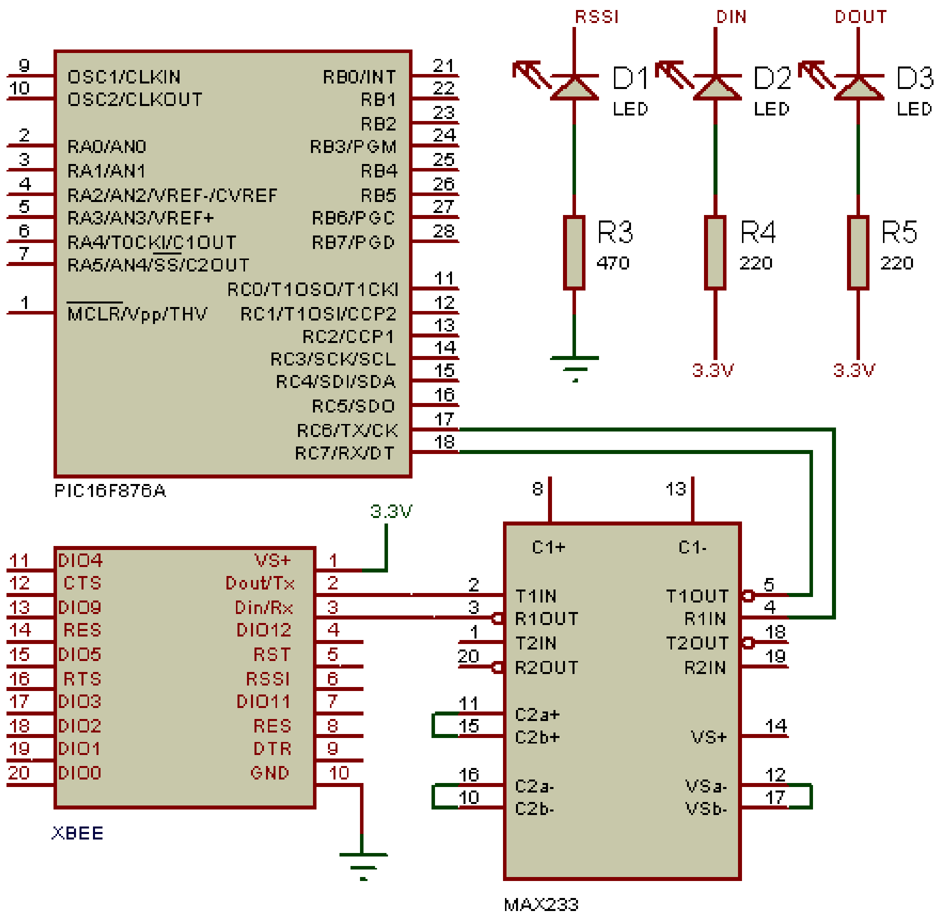

Figure 4.4: Circuit Schematic of Xbee at Remote Room

Unlike most electrical devices, Xbee operates at 3.3V to ensure the transceiver work efficiently. Thus, regulator LM1117 is chosen to provide the 3.3V power supply. The LM1117 is a series of low dropout voltage regulators with a dropout of 1.2V at 800mA of load current. It has the same pin-out as National Semiconductor's industry standard LM317. The input dc voltage feed to LM1117 must not exceed 12V. The simple circuit connection is shown in Figure 4.5.

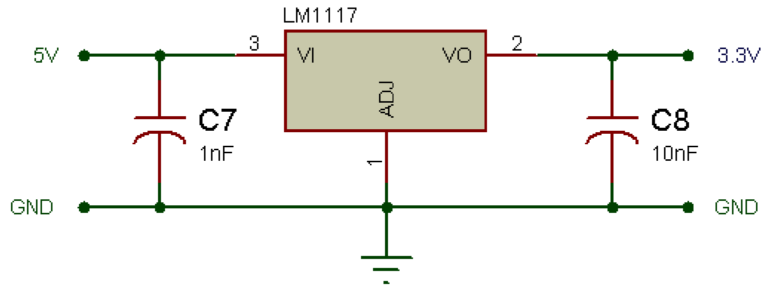

Figure 4.5: Circuit Schematic Power Supply 3.3V

4.5 Solid State Relay Circuit

Figure 4.6 shows a DC controlled Solid State Relay which can activate 240V AC equipment instantaneously. The output is like a normally open contact (NO) of a relay and has to be in series with the load (fan or lamp). The circuit provides random (anywhere in half-cycle) fast turn-on (<10 us) of AC loads. When pin RB7 is activated, a small control current will trigger opto-coupler (MOC3041) and subsequently trigger TRIAC (BTA08) to conduct.

Generally, semiconductor relays use opto-coupler for isolating the main side electronics from low voltage side. As a result, large currents can be controlled by handles small current to turn on the TRIAC. TRIAC is an almost ideal component for controlling AC power loads with a high duty cycle. Using a TRIAC eliminates completely the contact sticking, bounce and wear associated with conventional electromechanically relays.

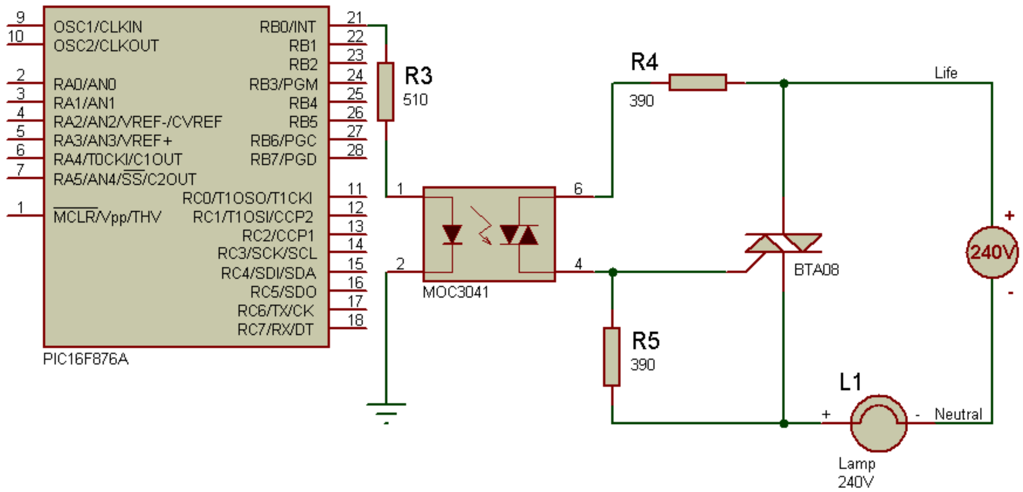

Figure 4.6: Solid State Relay Circuit

CHAPTER 5

SOFTWARE DEVELOPMENT

5.1 Introduction

This chapter describes the important software that have noteworthy role on overall system performance and explain the software development of each module network. The software development is complicated processes which acquire extensive research, development, testing, modification and improvement. In order to develop an efficient high performance software for microcontroller system, it requires scrutinize planning and execution. Basically, there are five software that been used in the overall project. Two of them contribute massively to the system performance are the Custom Computer Services (CCS) C Compiler and Microsoft Visual Studio 2008. Others are Melabs Programmer, XCTU software and Proteus 7 Professional. CCS C compiler used as the platform to write C programming code, compile it to hex code and finally load it to PIC microcontroller using Melabs Programmer. Microsoft Visual 2008 is used as platform to develop the end user system Graphical User Interfaces (GUI) and Proteus 7 Professional is used to run simulation of the project circuit and designing the circuit as discussed in Chapter 4. Finally, the X-CTU software is used as a tool for Xbee configuration and data reliability checking at the end user PC.

5.2 Remote Room Network

Once the system is powered up, environmental parameter at remote room location are sensed by temperature sensor (LM35), light sensor (TSL250R) and humidity sensor (HSM-20G) respectively. The values are sent to microcontroller for manipulation purpose. Temperature and light intensity values are in analogue form are converted to digital form by using internal Analog-to-Digital converter (ADC). Generally PIC Microcontrollers offer 10 Bit of A/D Conversion. This means that when the PIC measure an incoming voltage, it compare that voltage to a reference voltage, and give the comparison represented as a 10-bit number (0-1023). Then, the measurements are sent to Xbee transceiver through UART. The Xbee device sent those values wirelessly to another Xbee at central room and displays it through PC. At the same time, microcontroller at remote room constantly scans for any incoming signal from central room through UART. This signal most likely are used for activate several electrical appliances that issued by user from central office. Figure 5.1 and 5.2 shows each flow chart for the program receive and transmit at remote room network.

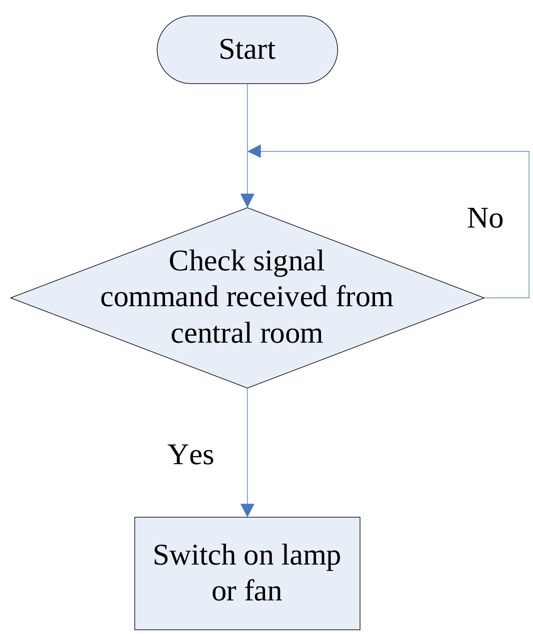

Figure 5.1: Flow Chart Program Receive at Remote Room

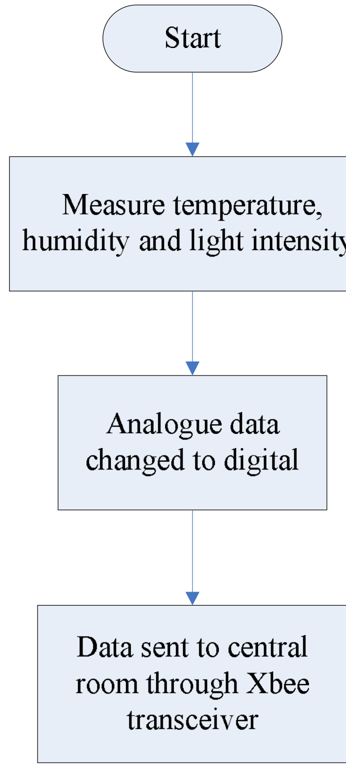

Figure 5.2: Flow Chart Program Transmit at Remote Room

5.3 Central Room Network

In central room, data are received by the Xbee transceiver from remote room. Then the Xbee at central network examines the received transmission data by comparing upper and lower 32 bits of the 64 bit destination address to distinguish between two remote rooms. Personal Area Network (PAN) ID for each Xbee is crucially important to ensure data broadcasting of the network is highly secured and noise-free. Once the address is identified, the parameters of measurements are displayed on the PC. At the same time, the system provide additional feature where the user can send command to remote room to activate any electrical appliances or set certain parameters so that it will not exceed human comfort zone. Figure 5.3 and Figure 5.4 shows each flow chart for the program system receive and transmit at central room network.

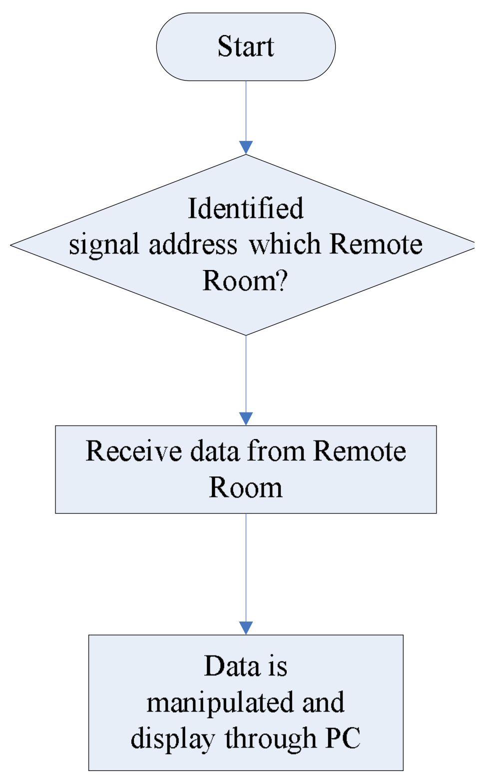

Figure 5.3: Flow Chart Program Receive at Central Room

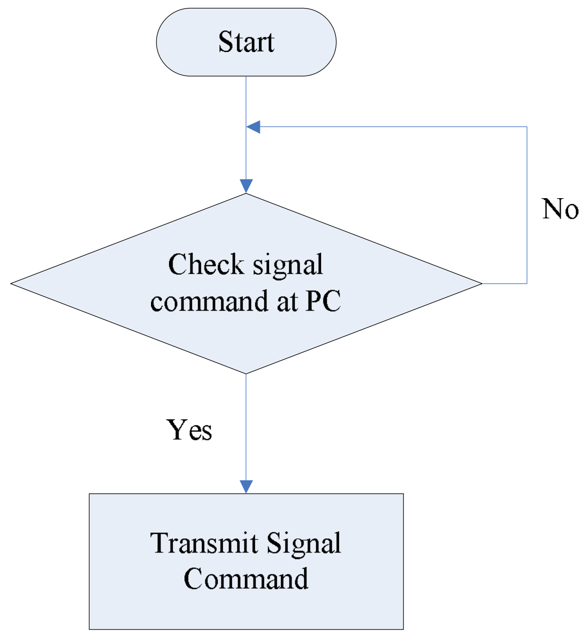

Figure 5.4: Flow Chart Program Transmit at Central Room

CHAPTER 6

TESTING AND EVALUATING RESULT

6.1 Introduction

This chapter emphasizes on the testing approach and result for each module. Testing each module is important to make sure the module function properly before the module is integrated to form ERING. In addition, testing module is very useful for troubleshooting if the system does not perform as desired. In general, there are six modules involved

- Microcontroller System testing
- Serial Communication module testing
- Sensors module testing
- Xbee OEM RF module testing
- Solid State Relay Circuit

6.2 Microcontroller System Board Module Testing

Microcontroller system board module test is designed as shown in figure 6.1. A simple program as shown in figure 6.2 is assembled and downloaded into the PIC16F876A. When the program is executed, a simple output pattern of LED which is connected at pin Port B produce a glowing pattern to verify the functionality of the microcontroller system board module.

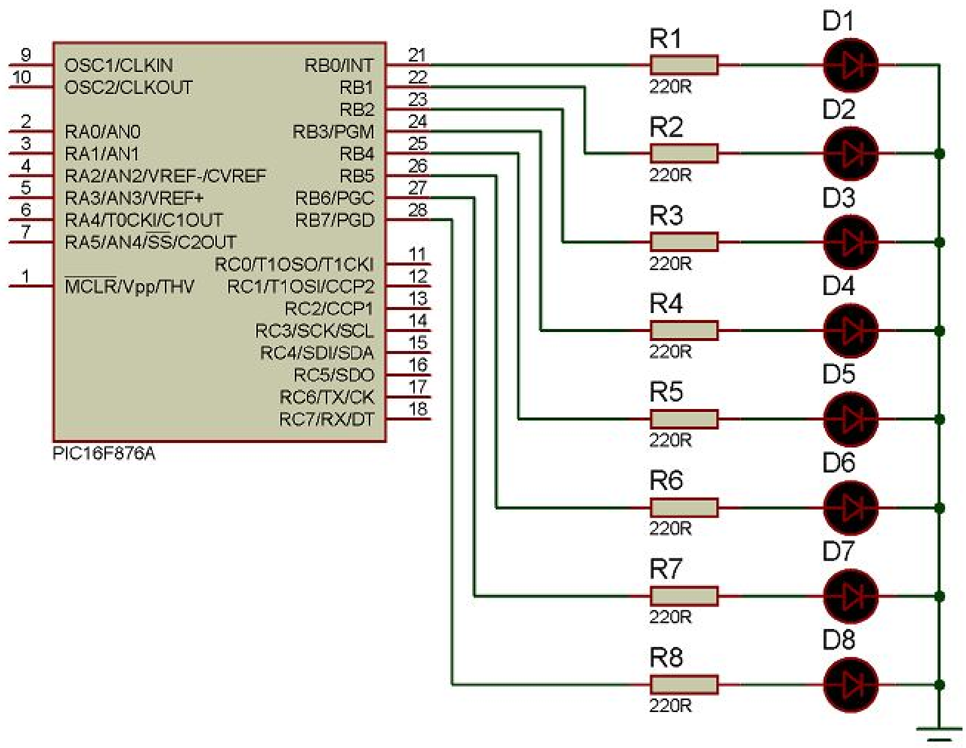

Figure 6.1: Circuit Schematic for Microcontroller Module Testing

```
#INCLUDE <16F876A.h>
#FUSES XT,NOWDT,NOPROTECT
#USE DELAY( CLOCK=20000000 )

void main(){
TRISB=0x00;       //set port b as output port
do{
PORTB = 0x00;     //send output low at port b
delay_ms(2000);   //delay 2 seconds
PORTB = 0xFF;     //send output high at port b
delay_ms(20000);  //delay 2 seconds
}
while(1);        //continuously looping
}
```

Figure 6.2: Microcontroller Module Testing Program

6.3 Serial Communication Module Testing

In order to test the functionality of serial communication, the circuit is shown in Figure 6.3 is constructed. Then a simple program is written to send data to PC. This is shown in Figure 6.4. When the program is executed, an upward count of integer is transmitted continuously through the serial communication. This is verified by the output display on The PC as shown in Figure 6.5.

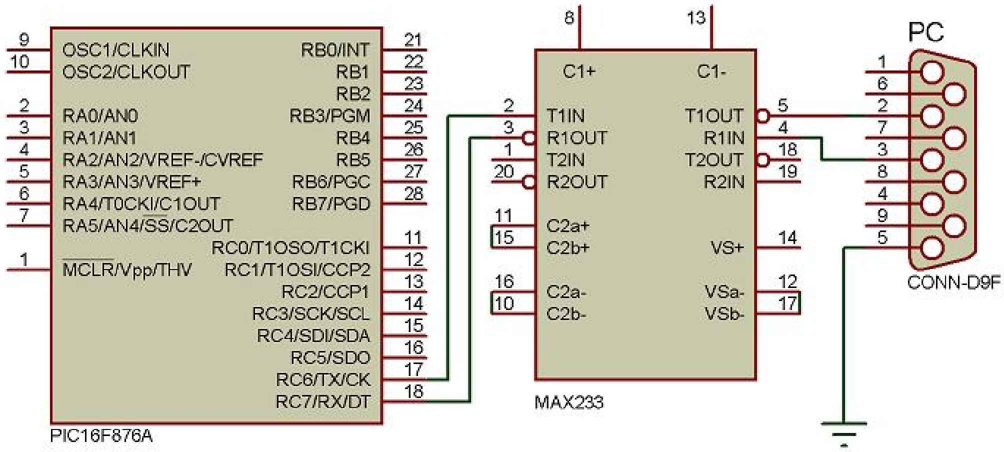

Figure 6.3: Circuit Schematic for Serial Communication Testing

```
#include <16F876.h>
#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=20000000)
#use rs232 (baud=57600,rcv=PIN_C7, xmit=PIN_C6)

int count;

void main()
{
while(1)
delay_ms(1000);  //1 Sec Delay
count ++;              //Upward Count
if (count>60)
count=0;

printf("\n\rCount Value: %d",count); //Send data to PC
}
}
```

Figure 6.4: Serial Communication Testing Program

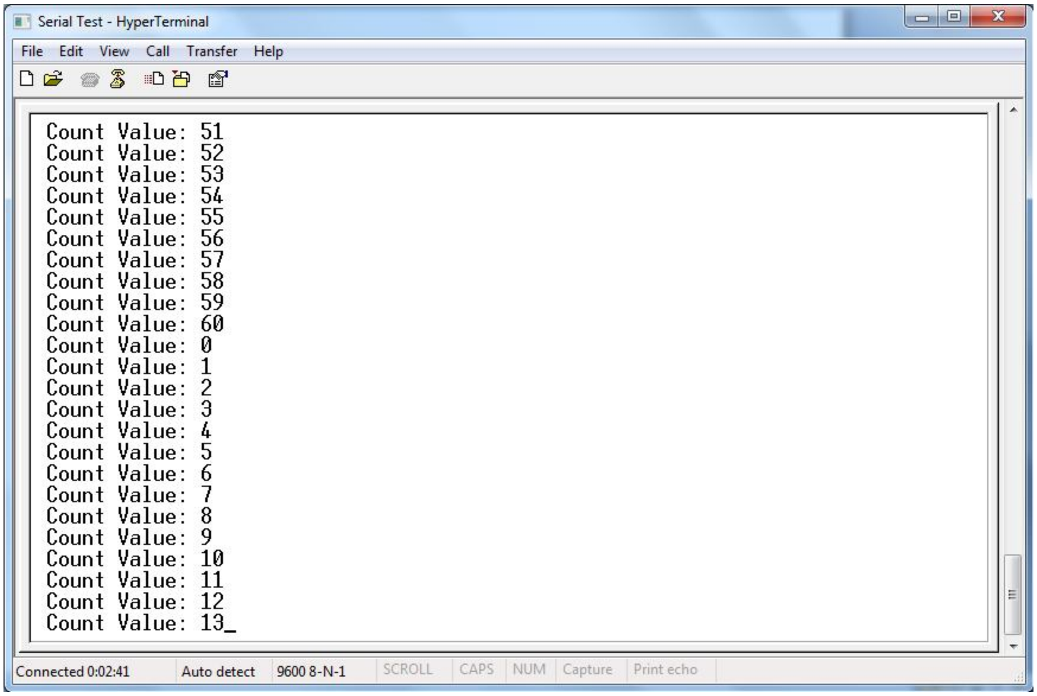

Figure 6.5: Serial Communication Testing Result

6.4 Sensors Module Testing

The hardware connection for temperature, humidity and light intensity sensor are shown in Figure 4.2. A simple program is written as shown in Figure 6.6 to test each sensor module. When the program is executed, the measurement of each sensor is transmitted to PC over serial communication line and data are displayed using HyperTerminal software. The testing is conducted repeatedly to ensure system reliability. The displayed data as shown in figure 6.7 concludes that the sensors are fully functioning and ready to be used to measure the environment condition in both remote rooms.

```
float value1;
float value2;
float value3;
float temp;
float humid;
float volt;
float light;

void main()
{
//Initialize and Configure ADC
setup_adc_ports( ALL_ANALOG );      //setup analog port
setup_adc(ADC_CLOCK_INTERNAL );     //adc clock

while(1)
{
delay_ms(2000);             //1 Sec Delay
////// TEMPERATURE SENSOR /////
set_adc_channel( 0 );       // Select adc channel
delay_ms(1000);             //1 Sec Delay
value1 = read_adc();         //Read ADC Value
volt = (value1 / 1023) * 5; //Convert Value into Volts
temp = volt * 100;          //Convert Volts into Temperature
printf("       Temperature: %.1f\n\r ",temp);
printf("\n\r");
///// HUMIDTY SENSOR //////
set_adc_channel(1);
delay_ms(1000);             //1 Sec Delay
value2 = read_adc();         //Read ADC Value
volt = (value2 / 1023) * 5; //Convert Value into Volts
humid = volt * 30;          //Convert Volts into Humidity
printf("       Humidity: %.1f\n\r ",humid);
printf("\n\r");
////// LIGHT SENSOR /////
set_adc_channel( 2 );       // Select adc channel
delay_ms(1000);             //1 Sec Delay
light = read_adc();         //Read ADC Value
value3 = light / 15;
printf("       Light Intensity: %.1f\n\r ",light);
printf("\n\r");
delay_ms(1000);             //1 Sec Delay
}
}
```

Figure 6.6: Sensors Module Testing Program

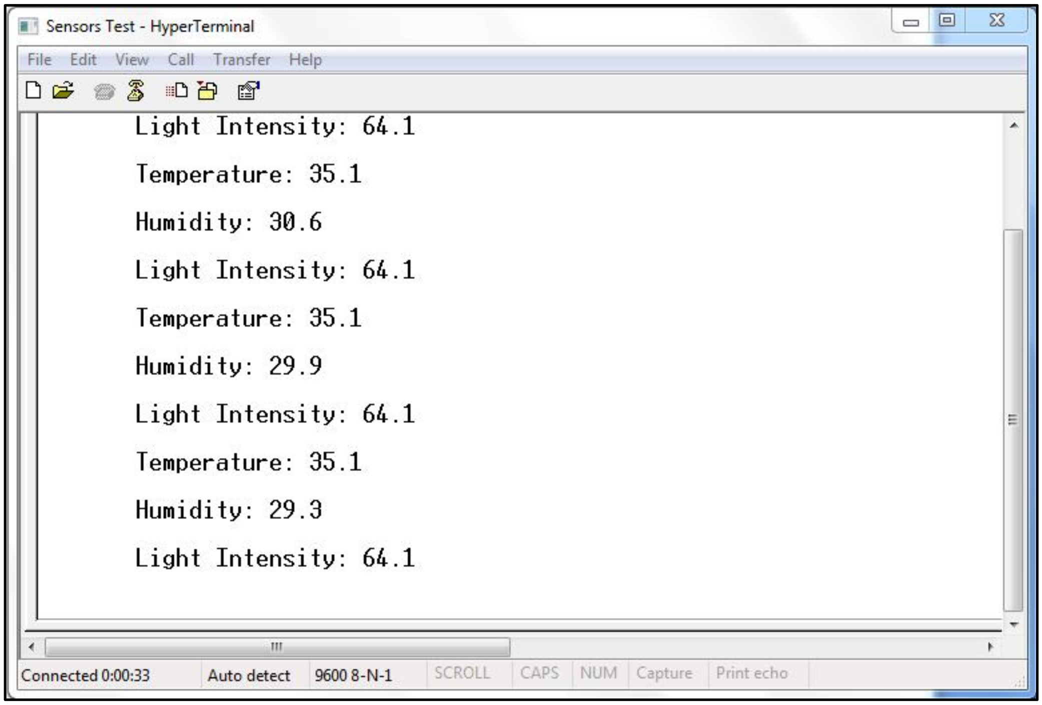

Figure 6.7: Sensors Module Testing Result

6.5 Xbee OEM RF module testing

Two Xbee modules and a PC are required in this testing module. The diagram in Figure 4.3 and Figure 4.4 explains the connection of the two Xbee modules respectively. Loop-back test is carried out between those two Xbee where a packet of data is transmitted and received continuously. As shown in Figure 6.8, the repeated glowing at pin Rx and Tx for each Xbee verified the test.

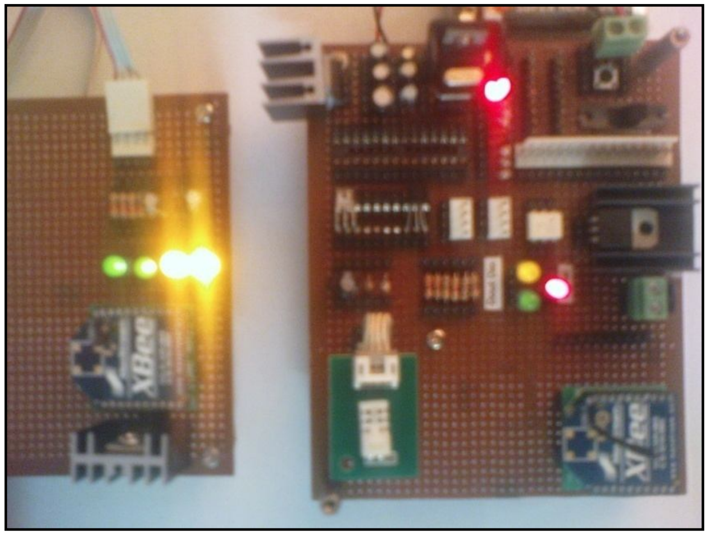

Figure 6.8: Xbee Module Testing Result

6.6 AC Fan and Lamp Testing

The set up of the experiment is shown in figure 4.12. When MOC3041 received 5V source, 510Ω resistor limits the current into the opto-coupler (MOC3041) and causes the LED to illuminate inside the chip. Line voltage flows through the 390 resistor and pass through the zero-crossing circuit in the opto-coupler. When the zero –crossing detects a zero-crosssing voltage and the LED is illuminated, the gate on the TRIAC in the opto-isolator (MOC3041) is triggered with the same phase as the phase of the line voltage. This line phase current is then used as the gate trigger to the TRIAC (BTA08). This causes the line current to flow through the triac and activate the load. The load can be any AC appliances which are low wattage such as lamp and fan.

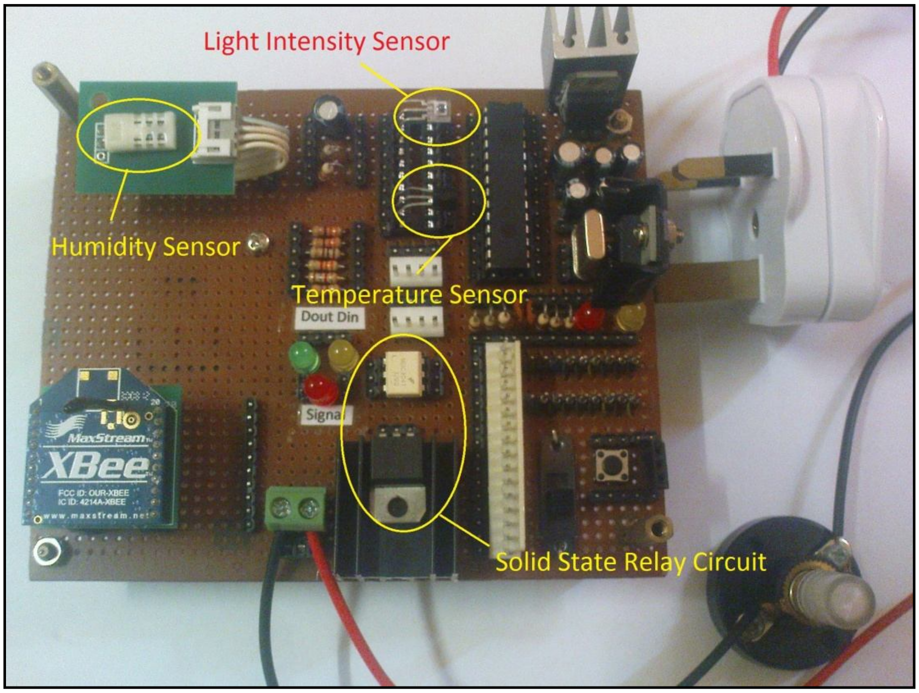

Figure 6.9: Remote Room 1 Circuit Board

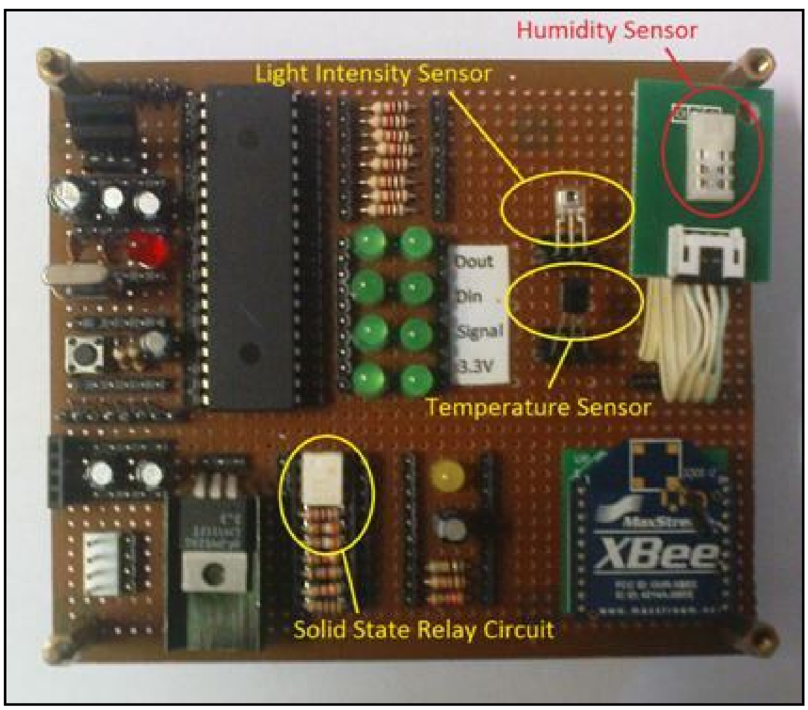

Figure 6.10: Remote Room 2 Circuit Board

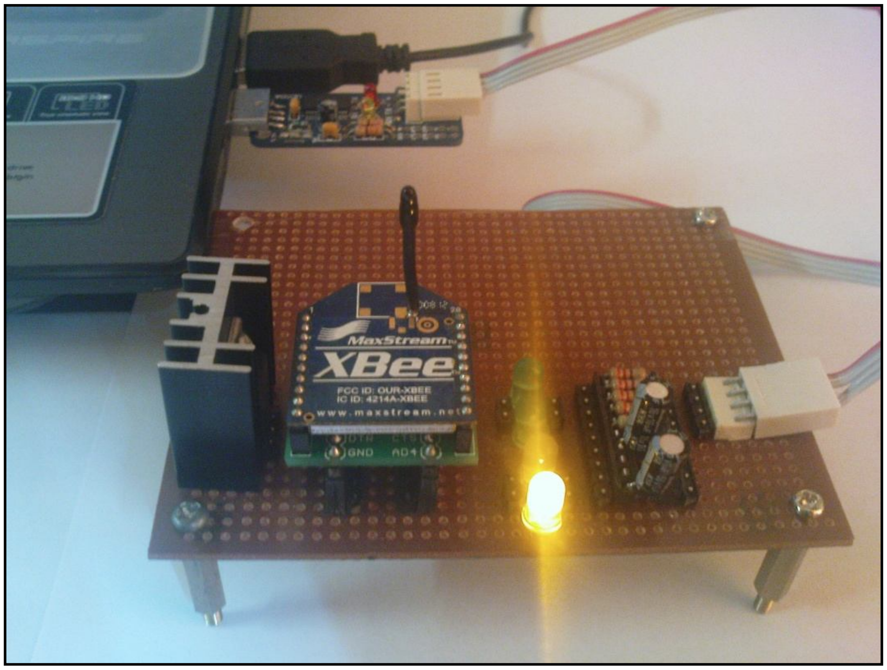

Figure 6.11: Central Room Circuit Board

CHAPTER 7

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

This project described the development of multi-remote in-door parametric monitoring and controlling system using off-the-shelf components for low-cost design. Testing of the wireless parametric monitoring system for in-door use has proven its capabilities to capture the temperature, humidity and light intensity measurements at two different locations and transmit the measurement to a central monitoring station. The system also capable of controls the condition in each remote room if the condition exceeding human comfort zone. Data transmission between multiple remote units and the central room system is achieved without error and noticeable delay. In short, a simple multiple remote monitoring and controlling system has been successfully developed. This system can be used to monitor and control the favourable weather condition in home, laboratory and high-risk plant area.

7.2 Recommendation

During the development of this project, several shortcoming of the project was noted. There are some recommendations and future work on this project which are:

- Implementation of wind sensor, barometric pressure sensor, gas sensor, solar radiation sensor in this project can enhance the function and application of the new system.

- Develop a system capable of monitoring and controlling several remote locations as well as develop larger star topology network.

- Final output of the system is presented using GUI for computer. However, more functional task can be applied to the GUI for data utilization such as alarm system, where the computer can alerts the user if the environmental parameter exceeding human comfort zone.

- For wider coverage, it is suggested that the Xbee Pro module should replace Xbee module as the Xbee provide coverage only 100m compared to Xbee Pro is 1.6 km.

- Redesign the solid state relay circuit to switch on ac appliances which are higher wattage such as heater and air-conditioner.

7.3 Costing and Commercialization

The ERING consists of two remote locations board and a central room board. The overall cost of the whole project is RM350 with each remote room board module cost approximately RM140 and one central room board module cost RM70. This cost is considerable as the system offers capability to monitor and control environment condition remotely. The simple system is quiet easy to operate and provide an efficient professional meteorological system to satisfy the needs of customers in terms of functionality. Therefore the system proves that it has high commercialization potential and value in existing market.

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Program for Remote Room 1

```
#include <16F876A.h>
#DEVICE ADC=10
#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=20000000)
#use rs232
(baud=9600,rcv=PIN_C7,xmit=PIN_C6,PARITY=N,ERRORS)
#include <stdlib.h>

float value1;
float value2;
float temp;
float humid;
float volt;
float light;

#define led_0  PIN_B0
#define led_1  PIN_B1


void main()
{
//Initialize and Configure ADC
setup_adc_ports( ALL_ANALOG );      //setup analog port
setup_adc(ADC_CLOCK_INTERNAL );     //adc clock

while(1)
{

printf("\n\r");
printf("\n\r");
printf(" ****************************************\n\r");
printf(" *                                      *\n\r");
```

```
printf(" *  PSMII 2010/2011                         *\n\r");
printf(" *  Embedded Based Remote Monitoring        *\n\r");
printf(" *  & Controlling System  (ERING)           *\n\r");
printf(" *                                          *\n\r");
printf(" *  ABDUL MUIZ BIN ROOMAI NOR               *\n\r");
printf(" *  EN. NIK MOHD KAMIL BIN NIK YUSSOF       *\n\r");
printf(" *                                          *\n\r");
printf(" ****************************************\n\r");
printf("\n\r");
printf("\n ROOM 1\r");
printf("\n\r");
delay_ms(1000);

///// HUMIDTY SENSOR //////
set_adc_channel(0);
delay_ms(1000);
value1 = read_adc();
volt = value1 * 32.60267;
humid = volt - 30.3601;
printf("       Humidity : %.1f\n\r ",humid);
printf("\n\r");

////// TEMPERATURE SENSOR /////
set_adc_channel(1);
delay_ms(1000);
value2 = read_adc();
volt = (value2 / 1023) * 5;
temp = volt * 100;
printf("       Temperature : %.1f\n\r ",temp);
printf("\n\r");

////// LIGHT SENSOR /////
set_adc_channel( 2 );
delay_ms(1000);
```

```
volt = read_adc();
light = volt /10;
printf("       Light Intensity : %.1f\n\r ",light);
printf("\n\r");
delay_ms(2000);



    if (temp>31)
   {
       output_high(led_0);
   }
    else if (temp<30)
   {
       output_low(led_0);
   }
   if (light<50)
   {
     output_high(led_1);
   }
   else if (light>75)
   {
     output_low(led_1);
   }
   delay_ms(100);
   }
}
```

Program for Remote Room 2

```
#include <18F4550.h>
#DEVICE ADC=10
#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=20000000)
#use rs232
(baud=9600,rcv=PIN_C7,xmit=PIN_C6,PARITY=N,ERRORS)
#include <stdlib.h>

float value1;
float value2;
float temp;
float humid;
float volt;
float light;

#define led_0  PIN_B0
#define led_1  PIN_B1


void main()
{
//Initialize and Configure ADC
setup_adc_ports( ALL_ANALOG );      //setup analog port
setup_adc(ADC_CLOCK_INTERNAL );     //adc clock

while(1)
{

printf("\n\r");
printf("\n\r");
printf(" ****************************************\n\r");
printf(" *                                      *\n\r");
```

```
printf(" *  PSMII 2010/2011                         *\n\r");
printf(" *  Embedded Based Remote Monitoring        *\n\r");
printf(" *  & Controlling System  (ERING)           *\n\r");
printf(" *                                          *\n\r");
printf(" *  ABDUL MUIZ BIN ROOMAI NOR               *\n\r");
printf(" *  EN. NIK MOHD KAMIL BIN NIK YUSSOF       *\n\r");
printf(" *                                          *\n\r");
printf(" ****************************************\n\r");
printf("\n\r");
printf("\n ROOM 2\r");
printf("\n\r");
delay_ms(1000);

///// HUMIDTY SENSOR //////
set_adc_channel(0);
delay_ms(1000);
value1 = read_adc();
volt = value1 * 32.60267;
humid = volt - 30.3601;
printf("       Humidity : %.1f\n\r ",humid);
printf("\n\r");

////// TEMPERATURE SENSOR /////
set_adc_channel(1);
delay_ms(1000);
value2 = read_adc();
volt = (value2 / 1023) * 5;
temp = volt * 100;
printf("       Temperature : %.1f\n\r ",temp);
printf("\n\r");

////// LIGHT SENSOR /////
set_adc_channel( 2 );
delay_ms(1000);
```

```
volt = read_adc();
light = volt /10;
printf("       Light Intensity : %.1f\n\r ",light);
printf("\n\r");
delay_ms(2000);



    if (temp>31)
   {
       output_high(led_0);
   }
    else if (temp<30)
   {
       output_low(led_0);
   }
   if (light<50)
   {
     output_high(led_1);
   }
   else if (light>75)
   {
     output_low(led_1);
   }
   delay_ms(100);
   }
}
```

APPENDIX A

Program for Embedded Based Remote Monitoring and Controlling System

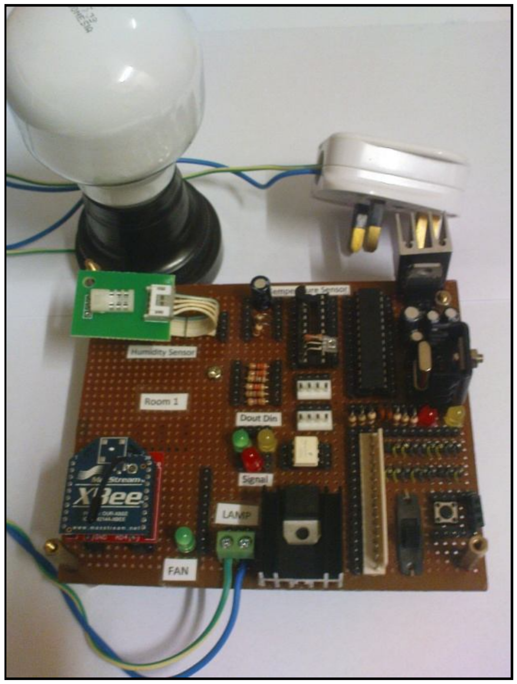


Figure B.1: Remote Room 1 Board

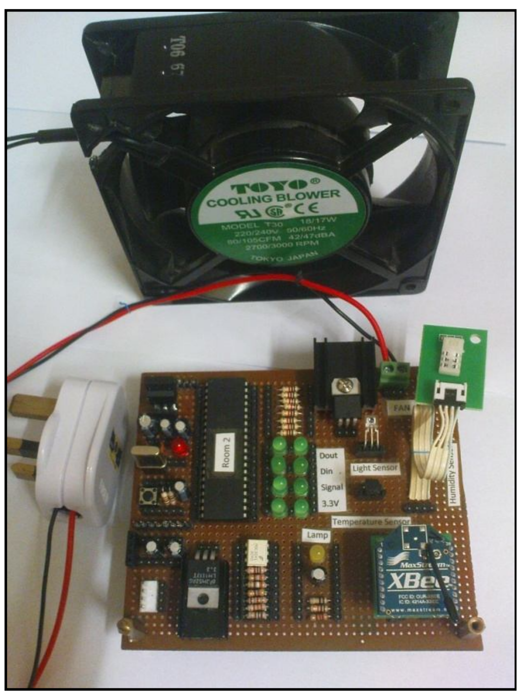


Figure B.2: Remote Room 2 Board

Figure B.3: Central Room Board

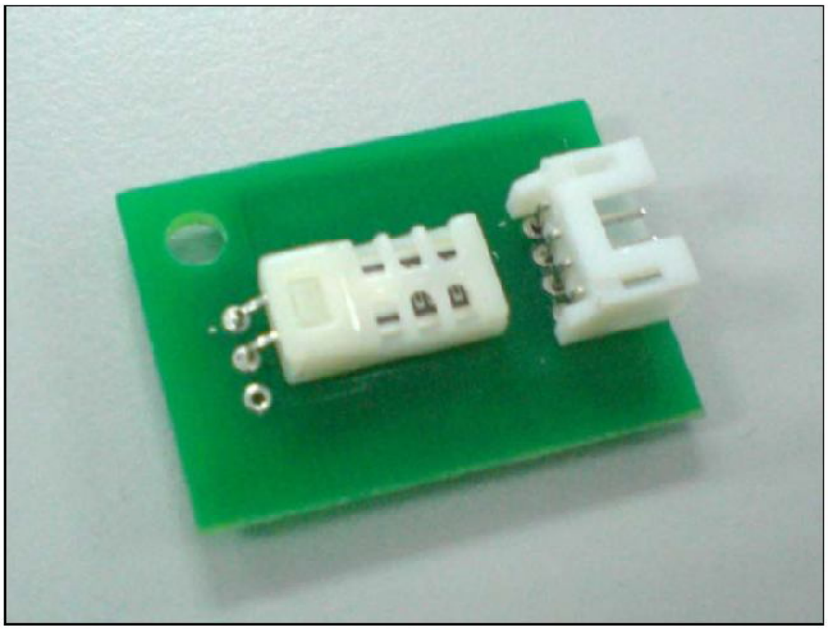
APPENDIX B

Hardware

APPENDIX C

Datasheets

SN-HMD
Humidity Sensor



User's Manual

V1.2

April 2009

Index

1. INTRODUCTION AND OVERVIEW

Humidity sensor is a device consisting of a special plastic material whose electrical characteristics change according to the amount of humidity in the air. Basically it is a sensor that senses the amount of water vapor in air. The module of HSM-20G is essential for those applications where the relative humidity can be converted to standard voltage output. The applications include:

- Humidifiers & dehumidifiers
- Air-conditioner
- Humidity data loggers
- Automotive climate control
- Other applications

The product features include:

- Voltage analog output for both humidity and temperature.
- Small size makes it easy to conceal
- Compatible with all types of microcontrollers
- High sensitivity to humidity in the air

2. PRODUCT SPECIFICATION

2.1 The specifications of humidity sensor

No.	Specification	Humidity Sensor
1.	Input voltage range	DC 5.0±0.2 V
2.	Output voltage range	DC 1.0—3.0 V
3.	Measurement Accuracy	±5% RH
4.	Operating Current (Maximum)	2mA
5.	Storage RH Range	0 to 99% RH
6.	Operating RH Range	20 to 95% (100% RH intermittent)
7.	Transient Condensation	< 3%RH
8.	Temperature Range: - Storage - Operating	 20℃ to 70℃ 0℃ to 50℃
9.	Hysteresis (RH @ 25℃)	MAX 2%RH
10.	Long Term Stability (typical drift per year)	±1.5%
11.	Linearity	Linearity
12.	Time Response (63% step change)	1 min
13.	Dimensions (L*W)	30mm*22mm

Table 2.1

2.2 Pin Definitions and Ratings

Pin	Name	Function
-	GND	Connects to Ground
H	Humudity Output	Voltage analog output.
+	Vcc	Connects to Vcc (+5V)
T	Temperature Output	Voltage analog output.

Note: Please refer Getting Started for the pin connection

Table 2.2

3. PRODUCT LAYOUT

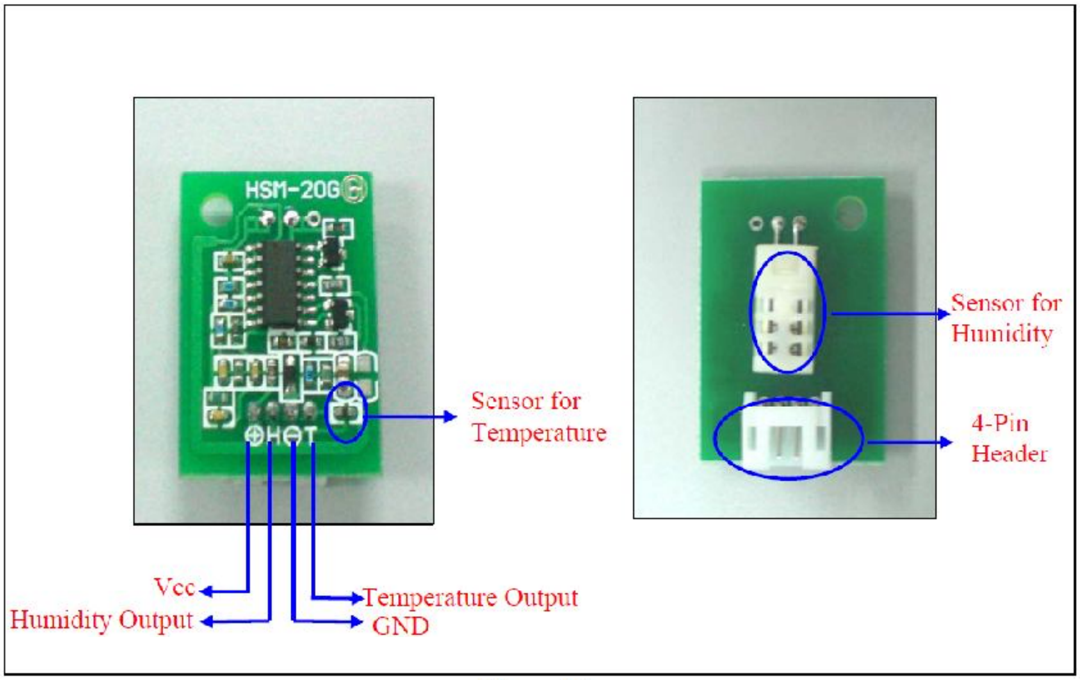


Figure 3.1

Label	Description
Vcc	The power supply to the sensor.
Humidity Output	The analog output of Humidity for the sensor.
GND	The Ground of the sensor.
Temperature Output	The analog output of Temperature for the sensor.
Sensor for Temperature Sensor for Humidity	The sensor to sense the temperature. The sensor to sense the humidity.
4-Pin Header	The connector to the cable which connect to testing/microcontroller circuit.

Table 3.1

4. GETTING STARTED

4.1 Connecting and Testing

To use the Humidity Sensor, users have to build a connector cable to connect the sensor to the PCB circuit. Connect the 4-pin header to your circuit so that the (-) pin connects to ground, the (+) pin connects to Vcc, H pin and T pin connects to your microcontroller's I/O pin. The microcontroller's I/O pin needs to be set to ADC mode. The circuit in Figure 4.1 shows the example circuit for humidity sensor. The relationship between output voltage and temperature shows in Figure 4.2. Please take note that when the temperature is higher than 45℃, the output voltage becomes unstable.

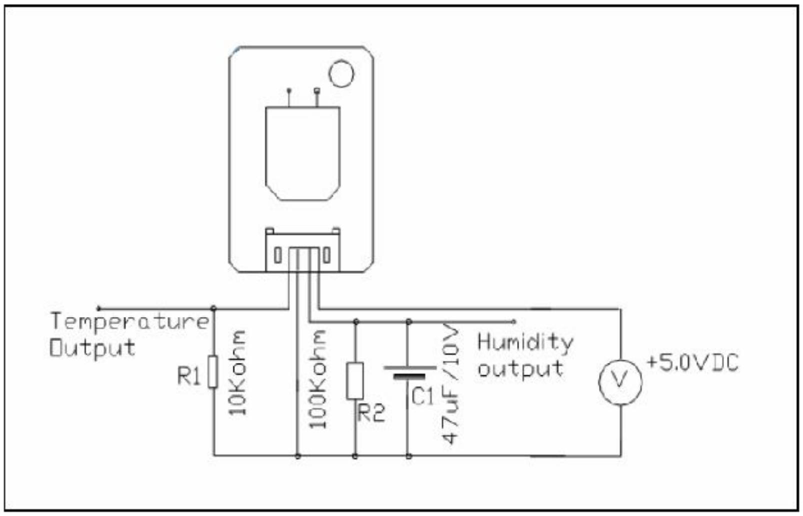


Figure 4.1

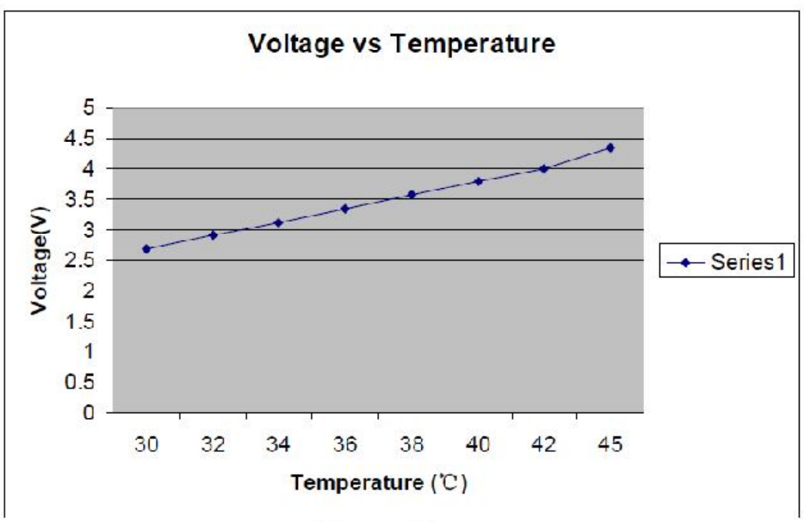


Figure 4.2

Figure 4.3 shows the relationship between output voltage and humidity while Table 4.1 shows the standard characteristics of the humidity sensor.

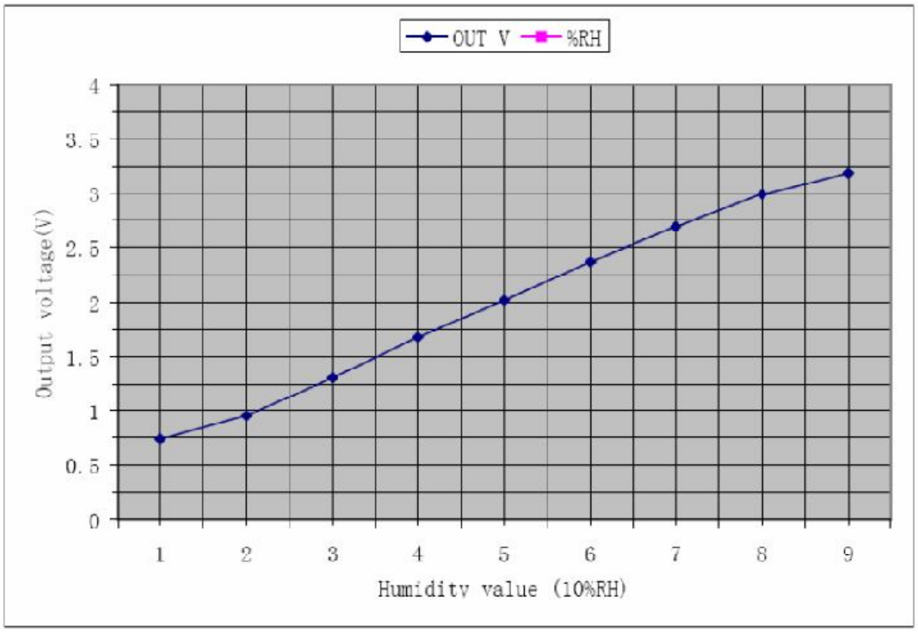


Figure 4.2

%RH	10	20	30	40	50	60	70	80	90
OutpotV	0.74	0.95	1.31	1.68	2.02	2.37	2.69	2.99	3.19

Table 4.1

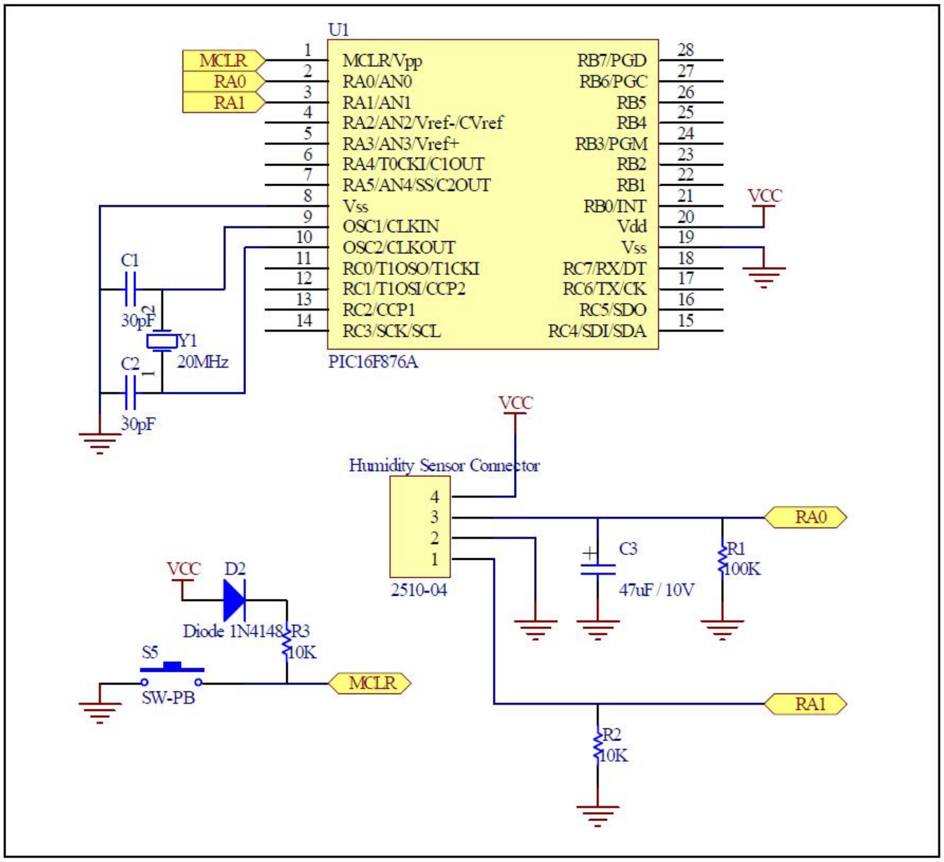


Figure 4.4

Figure 4.4 shows the connection of humidity sensor to PIC microcontroller, which is PIC16F876A. The voltage supply (VCC) of the circuit is 5V. The voltage analog output of humidity (H) is connected to RA0 (AN0) while the voltage analog output of temperature (T) is connected to RA1 (AN1). However, user is free to choose any type of microcontroller, just have to make sure that both of the voltage analog outputs of humidity sensor are connected to the ADC (Analog Digital Convector) pin of that particular microcontroller. For more details of example application, please refer Cytron product, PR15 which can be found in the web site: www.cytron.com.my .

5. WARRANTY

- Product warranty is valid for 6 months.
- Warranty only applies to manufacturing defect.
- Damage caused by miss-use is not covered under warranty.
- Warranty does not cover freight cost for both ways.

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National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ˚ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼˚C at room temperature and ±¾˚C over a full −55 to +150˚C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1˚C in still air. The LM35 is rated to operate over a −55˚ to +150˚C temperature range, while the LM35C is rated for a −40˚ to +110˚C range (−10˚ with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08˚C in still air
- Nonlinearity only ±¼˚C typical
- Low impedance output, 0.1 Ω for 1 mA load

Typical Applications

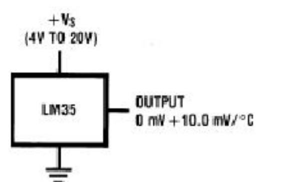
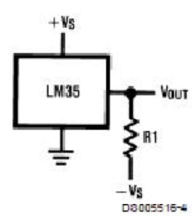


FIGURE 1. Basic Centigrade Temperature Sensor (+2˚C to +150˚C)



Choose $R_1 = -V_S/50\ \mu A$

V_{OUT} = +1,500 mV at +150˚C

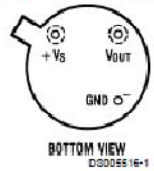
= +250 mV at +25˚C

= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

Connection Diagrams

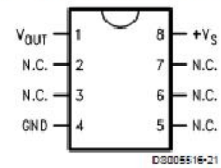
TO-46
Metal Can Package*



*Case is connected to negative pin (GND)

Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH
See NS Package Number H03H

SO-8
Small Outline Molded Package



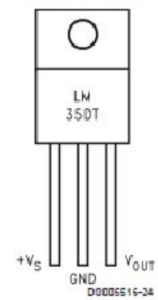
N.C. = No Connection

Top View
Order Number LM35DM
See NS Package Number M08A

TO-92
Plastic Package

Order Number LM35CZ, LM35CAZ or LM35DZ
See NS Package Number Z03A

TO-220
Plastic Package*



*Tab is connected to the negative pin (GND).
Note: The LM35DT pinout is different than the discontinued LM35DP.

Order Number LM35DT
See NS Package Number TA03F

Absolute Maximum Ratings (Note 10)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60°C to +180°C
TO-92 Package,	−60°C to +150°C
SO-8 Package,	−65°C to +150°C
TO-220 Package,	−65°C to +150°C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300°C
TO-92 and TO-220 Package, (Soldering, 10 seconds)	260°C
SO Package (Note 12)	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
ESD Susceptibility (Note 11)	2500V

Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)

LM35, LM35A	−55°C to +150°C
LM35C, LM35CA	−40°C to +110°C
LM35D	0°C to +100°C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35A Typical	LM35A Tested Limit (Note 4)	LM35A Design Limit (Note 5)	LM35CA Typical	LM35CA Tested Limit (Note 4)	LM35CA Design Limit (Note 5)	Units (Max.)
Accuracy (Note 7)	T_A=+25°C	±0.2	±0.5		±0.2	±0.5		°C
	T_A=−10°C	±0.3			±0.3		±1.0	°C
	$T_A=T_{MAX}$	±0.4	±1.0		±0.4	±1.0		°C
	$T_A=T_{MIN}$	±0.4	±1.0		±0.4		±1.5	°C
Nonlinearity (Note 8)	$T_{MIN}\le T_A\le T_{MAX}$	±0.18		±0.35	±0.15		±0.3	°C
Sensor Gain (Average Slope)	$T_{MIN}\le T_A\le T_{MAX}$	+10.0	+9.9, +10.1		+10.0		+9.9, +10.1	mV/°C
Load Regulation (Note 3) $0\le I_L\le 1$ mA	T_A=+25°C	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN}\le T_A\le T_{MAX}$	±0.5		±3.0	±0.5		±3.0	mV/mA
Line Regulation (Note 3)	T_A=+25°C	±0.01	±0.05		±0.01	±0.05		mV/V
	$4V\le V_S\le 30V$	±0.02		±0.1	±0.02		±0.1	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25°C	56	67		56	67		μA
	V_S=+5V	105		131	91		114	μA
	V_S=+30V, +25°C	56.2	68		56.2	68		μA
	V_S=+30V	105.5		133	91.5		116	μA
Change of Quiescent Current (Note 3)	$4V\le V_S\le 30V$, +25°C	0.2	1.0		0.2	1.0		μA
	$4V\le V_S\le 30V$	0.5		2.0	0.5		2.0	μA
Temperature Coefficient of Quiescent Current		+0.39		+0.5	+0.39		+0.5	μA/°C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35 Typical	LM35 Tested Limit (Note 4)	LM35 Design Limit (Note 5)	LM35C, LM35D Typical	LM35C, LM35D Tested Limit (Note 4)	LM35C, LM35D Design Limit (Note 5)	Units (Max.)
Accuracy, LM35, LM35C (Note 7)	T_A=+25°C	±0.4	±1.0		±0.4	±1.0		°C
	T_A=−10°C	±0.5			±0.5		±1.5	°C
	$T_A=T_{MAX}$	±0.8	±1.5		±0.8		±1.5	°C
	$T_A=T_{MIN}$	±0.8		±1.5	±0.8		±2.0	°C
Accuracy, LM35D (Note 7)	T_A=+25°C				±0.6	±1.5		°C
	$T_A=T_{MAX}$				±0.9		±2.0	°C
	$T_A=T_{MIN}$				±0.9		±2.0	°C
Nonlinearity (Note 8)	$T_{MIN}\le T_A\le T_{MAX}$	±0.3		±0.5	±0.2		±0.5	°C
Sensor Gain (Average Slope)	$T_{MIN}\le T_A\le T_{MAX}$	+10.0	+9.8, +10.2		+10.0		+9.8, +10.2	mV/°C
Load Regulation (Note 3) $0\le I_L\le 1$ mA	T_A=+25°C	±0.4	±2.0		±0.4	±2.0		mV/mA
	$T_{MIN}\le T_A\le T_{MAX}$	±0.5		±5.0	±0.5		±5.0	mV/mA
Line Regulation (Note 3)	T_A=+25°C	±0.01	±0.1		±0.01	±0.1		mV/V
	$4V\le V_S\le 30V$	±0.02		±0.2	±0.02		±0.2	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25°C	56	80		56	80		µA
	V_S=+5V	105		158	91		138	µA
	V_S=+30V, +25°C	56.2	82		56.2	82		µA
	V_S=+30V	105.5		161	91.5		141	µA
Change of Quiescent Current (Note 3)	$4V\le V_S\le 30V$, +25°C	0.2	2.0		0.2	2.0		µA
	$4V\le V_S\le 30V$	0.5		3.0	0.5		3.0	µA
Temperature Coefficient of Quiescent Current		+0.39		+0.7	+0.39		+0.7	µA/°C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

Note 1: Unless otherwise noted, these specifications apply: $-55°C\le T_J\le +150°C$ for the LM35 and LM35A; $-40°\le T_J\le +110°C$ for the LM35C and LM35CA; and $0°\le T_J\le +100°C$ for the LM35D. V_S=+5Vdc and I_{LOAD}=50 µA, in the circuit of *Figure 2*. These specifications also apply from +2°C to T_{MAX} in the circuit of *Figure 1*. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400°C/W, junction to ambient, and 24°C/W junction to case. Thermal resistance of the TO-92 package is 180°C/W junction to ambient. Thermal resistance of the small outline molded package is 220°C/W junction to ambient. Thermal resistance of the TO-220 package is 90°C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested Limits are guaranteed and 100% tested in production.

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10mv/°C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in °C).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of *Figure 1*.

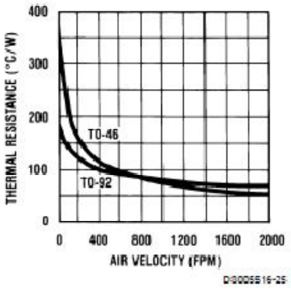
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

Note 11: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

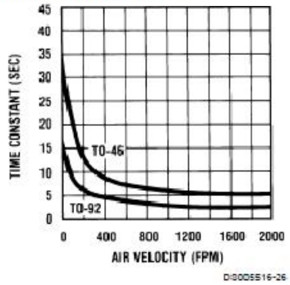
Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Typical Performance Characteristics

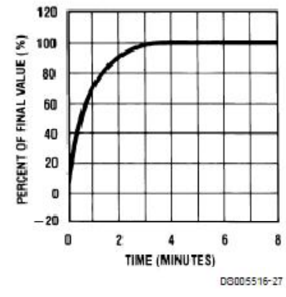
Thermal Resistance Junction to Air



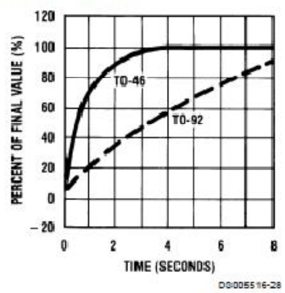
Thermal Time Constant



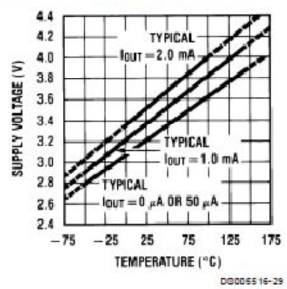
Thermal Response in Still Air



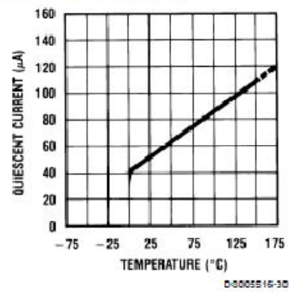
Thermal Response in Stirred Oil Bath



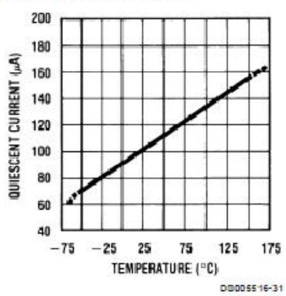
Minimum Supply Voltage vs. Temperature



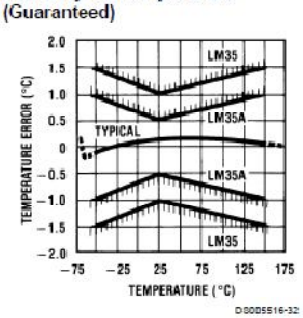
Quiescent Current vs. Temperature (In Circuit of *Figure 1*.)



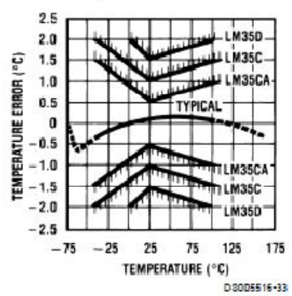
Quiescent Current vs. Temperature (In Circuit of *Figure 2*.)



Accuracy vs. Temperature (Guaranteed)

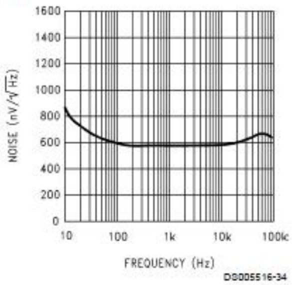


Accuracy vs. Temperature (Guaranteed)

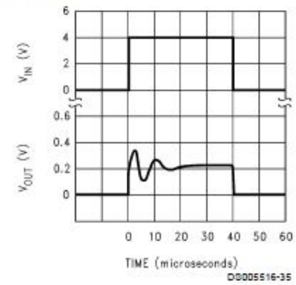


Typical Performance Characteristics (Continued)

Noise Voltage



Start-Up Response



Applications

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01°C of the surface temperature.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is expecially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature.

To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die's temperature will not be affected by the air temperature.

The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V− terminal of the circuit will be grounded to that metal. Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections.

These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

Temperature Rise of LM35 Due To Self-heating (Thermal Resistance, θ_{JA})

	TO-46, no heat sink	TO-46*, small heat fin	TO-92, no heat sink	TO-92**, small heat fin	SO-8 no heat sink	SO-8** small heat fin	TO-220 no heat sink
Still air	400°C/W	100°C/W	180°C/W	140°C/W	220°C/W	110°C/W	90°C/W
Moving air	100°C/W	40°C/W	90°C/W	70°C/W	105°C/W	90°C/W	26°C/W
Still oil	100°C/W	40°C/W	90°C/W	70°C/W			
Stirred oil	50°C/W	30°C/W	45°C/W	40°C/W			
(Clamped to metal, Infinite heat sink)	(24°C/W)				(55°C/W)		

*Wakefield type 201, or 1" disc of 0.020" sheet brass, soldered to case, or similar.

**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Applications

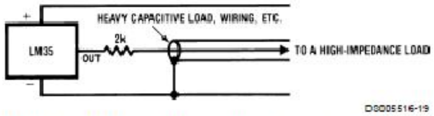


FIGURE 3. LM35 with Decoupling from Capacitive Load

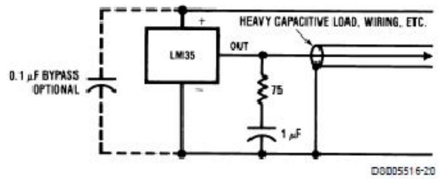


FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

Like most micropower circuits, the LM35 has a limited ability to drive heavy capacitive loads. The LM35 by itself is able to drive 50 pf without special precautions. If heavier loads are anticipated, it is easy to isolate or decouple the load with a resistor; see *Figure 3*. Or you can improve the tolerance of capacitance with a series R-C damper from output to ground; see *Figure 4*.

When the LM35 is applied with a 200Ω load resistor as shown in *Figure 5*, *Figure 6* or *Figure 8* it is relatively immune to wiring capacitance because the capacitance forms a by-pass from ground to input, not on the output. However, as with any linear circuit connected to wires in a hostile environment, its performance can be affected adversely by intense electromagnetic sources such as relays, radio transmitters, motors with arcing brushes, SCR transients, etc, as its wiring can act as a receiving antenna and its internal junctions can act as rectifiers. For best results in such cases, a bypass capacitor from V_{IN} to ground and a series R-C damper such as 75Ω in series with 0.2 or 1 µF from output to ground are often useful. These are shown in *Figure 13*, *Figure 14*, and *Figure 16*.

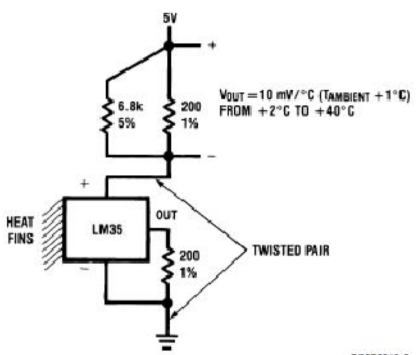


FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)

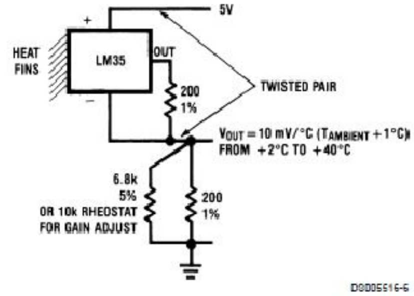


FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

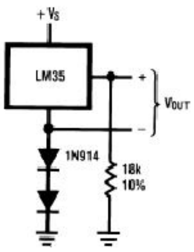


FIGURE 7. Temperature Sensor, Single Supply, −55° to +150°C

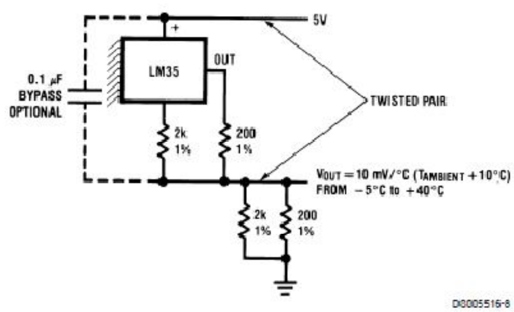


FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

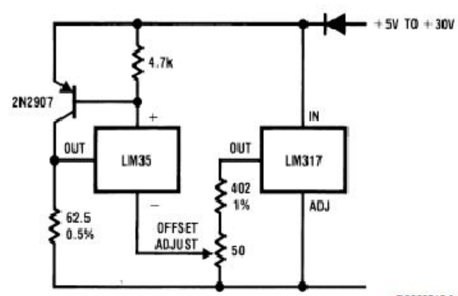


FIGURE 9. 4-To-20 mA Current Source (0°C to +100°C)

Typical Applications (Continued)

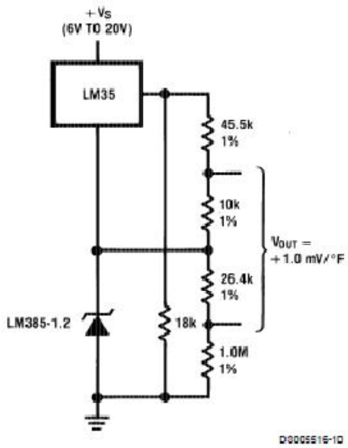


FIGURE 10. Fahrenheit Thermometer

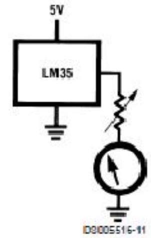


FIGURE 11. Centigrade Thermometer (Analog Meter)

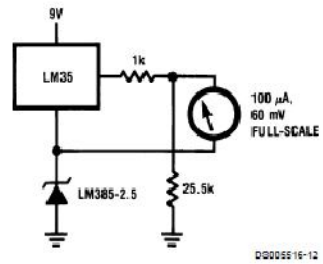


FIGURE 12. Fahrenheit ThermometerExpanded Scale Thermometer
(50° to 80° Fahrenheit, for Example Shown)

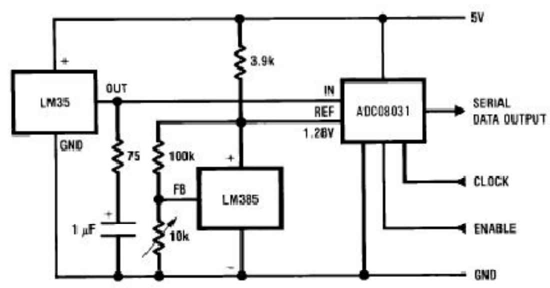


FIGURE 13. Temperature To Digital Converter (Serial Output) (+128°C Full Scale)

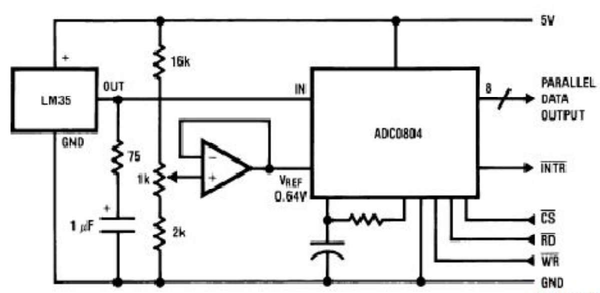
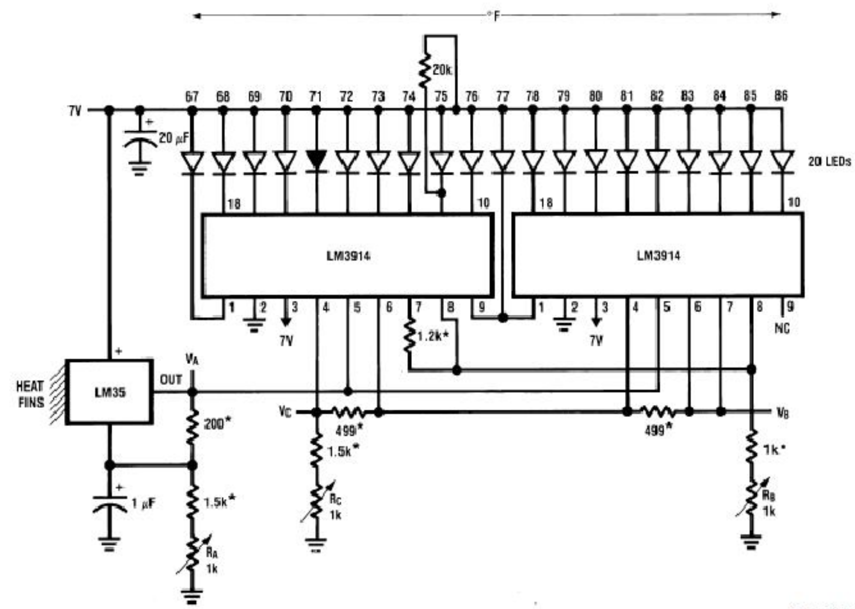


FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE™ Outputs for Standard Data Bus to µP Interface) (128°C Full Scale)

Typical Applications (Continued)



*=1% or 2% film resistor
Trim R_B for V_B=3.075V
Trim R_C for V_C=1.955V
Trim R_A for V_A=0.075V + 100mV/°C x $T_{ambient}$
Example, V_A=2.275V at 22°C

FIGURE 15. Bar-Graph Temperature Display (Dot Mode)

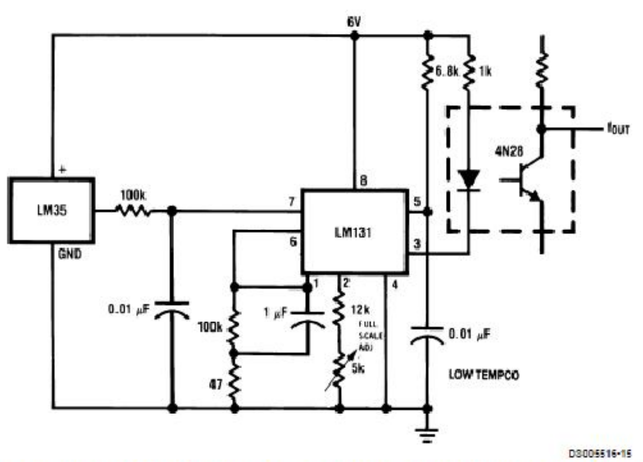
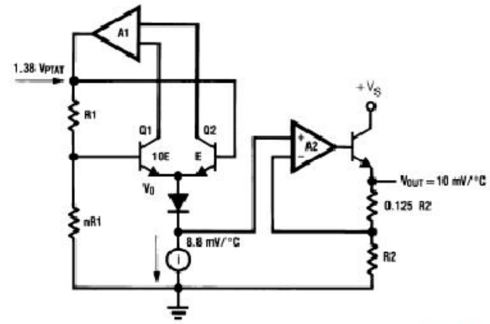


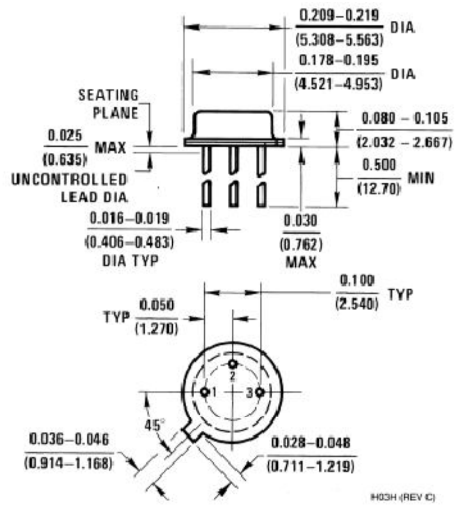
FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output
(2°C to +150°C; 20 Hz to 1500 Hz)

Block Diagram

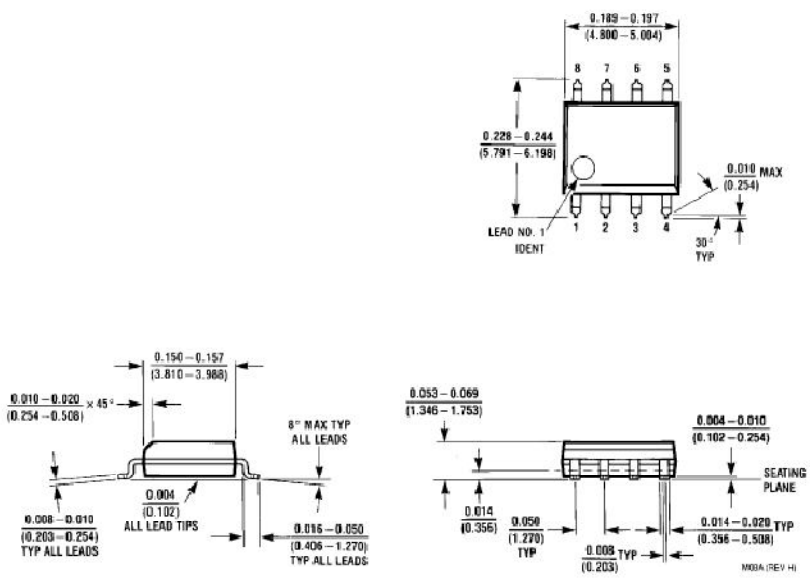


DS005516-23

Physical Dimensions inches (millimeters) unless otherwise noted

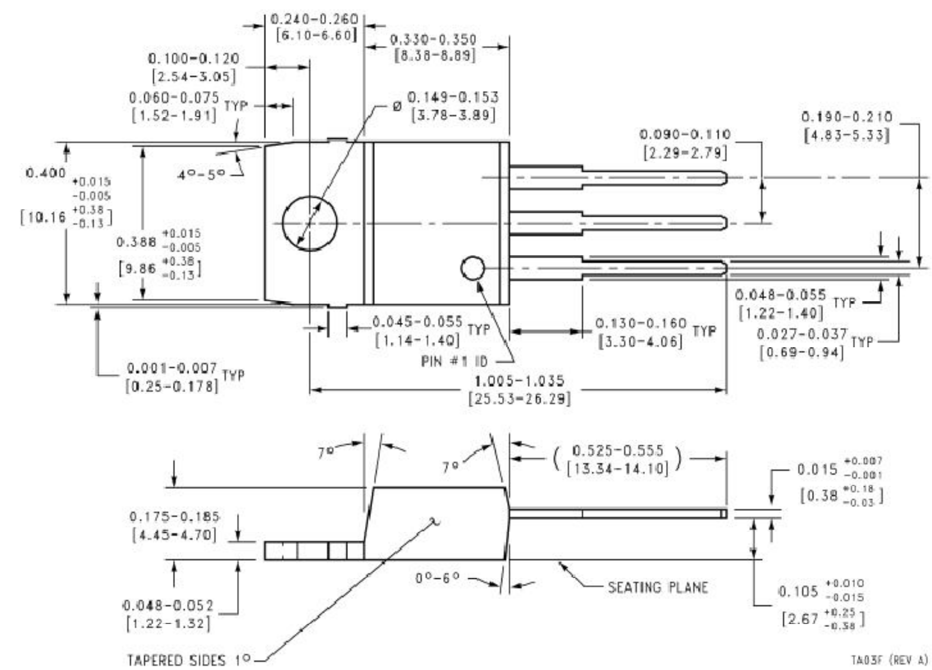


TO-46 Metal Can Package (H)
Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH
NS Package Number H03H



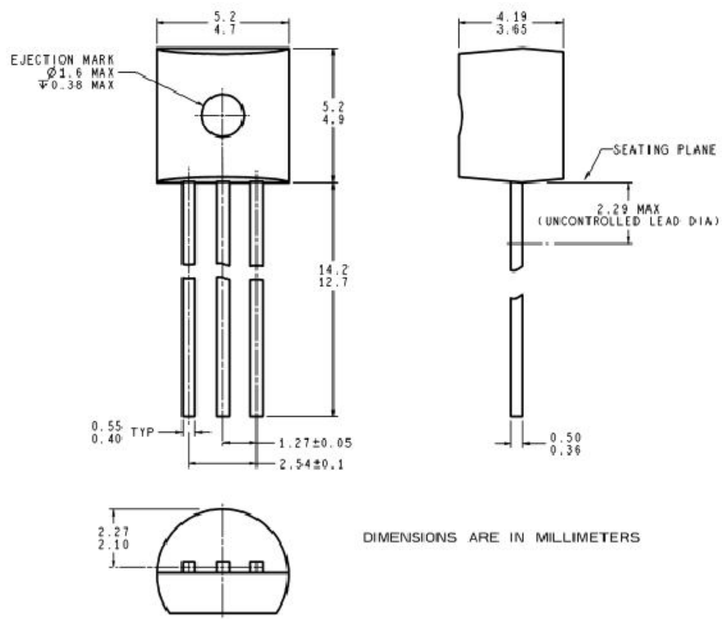
SO-8 Molded Small Outline Package (M)
Order Number LM35DM
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Power Package TO-220 (T)
Order Number LM35DT
NS Package Number TA03F

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



TO-92 Plastic Package (Z)
Order Number LM35CZ, LM35CAZ or LM35DZ
NS Package Number Z03A

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TSL250, TSL251, TSL252
LIGHT-TO-VOLTAGE OPTICAL SENSORS

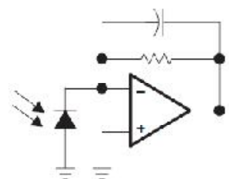
SOES004C – AUGUST 1991 – REVISED NOVEMBER 1995

- **Monolithic Silicon IC Containing Photodiode, Operational Amplifier, and Feedback Components**
- **Converts Light Intensity to Output Voltage**
- **High Irradiance Responsivity Typically 80 mV/(µW/cm^2) at λ_p = 880 nm (TSL250)**
- **Compact 3-Leaded Clear Plastic Package**
- **Low Dark (Offset) Voltage . . . 10 mV Max at 25°C, V_{DD} = 5 V**
- **Single-Supply Operation**
- **Wide Supply-Voltage Range . . . 3 V to 9 V**
- **Low Supply Current . . . 800 µA Typical at V_{DD} = 5 V**
- **Advanced LinCMOS™ Technology**

description

The TSL250, TSL251, and TSL252 are light-to-voltage optical sensors, each combining a photodiode and a transimpedance amplifier (feedback resistor = 16 MΩ, 8 MΩ, and 2 MΩ respectively) on a single monolithic IC. The output voltage is directly proportional to the light intensity (irradiance) on the photodiode. These devices utilize Texas Instruments silicon-gate LinCMOS™ technology, which provides improved amplifier offset-voltage stability and low power consumption.

functional block diagram



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

Supply voltage, V_{DD} (see Note 1) . . . . 10 V
Output current, I_O . . . . ±10 mA
Duration of short-circuit current at (or below) 25°C (see Note 2) . . . . 5 s
Operating free-air temperature range, T_A . . . . −25°C to 85°C
Storage temperature range, T_{stg} . . . . −25°C to 85°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . 240°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 GND.
2. Output may be shorted to supply.

recommended operating conditions

	MIN	NOM	MAX	UNIT
Supply voltage, V_{DD}	3	5	9	V
Operating free-air temperature, T_A	0		70	°C

electrical characteristics at V_{DD} = 5 V, T_A = 25°C, λp = 880 nm, R_L = 10 kΩ (unless otherwise noted) (see Note 3)

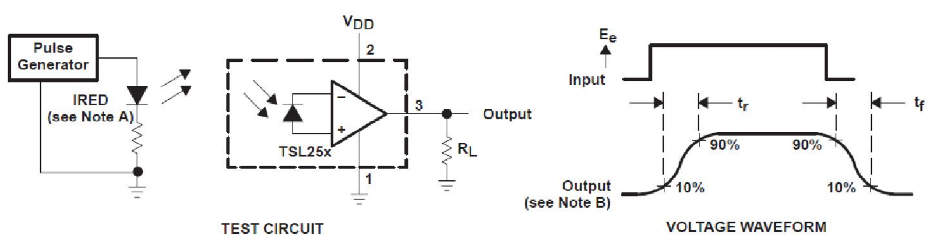
PARAMETER		TEST CONDITIONS	TSL250			TSL251			TSL252			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
V_D	Dark voltage	E_e = 0		3	10		3	10		3	10	mV
V_{OM}	Maximum output voltage swing	E_e = 2 mW/cm^2	3.1	3.5		3.1	3.5		3.1	3.5		V
V_O	Output voltage	E_e = 25 µW/cm^2	1	2	3							V
		E_e = 45 µW/cm^2				1	2	3				
		E_e = 285 µW/cm^2							1	2	3	
α_{VO}	Temperature coefficient of output voltage (V_O)	E_e = 25 µW/cm^2, T_A = 0°C to 70°C		±1								mV/°C
		E_e = 45 µW/cm^2, T_A = 0°C to 70°C					±1					
		E_e = 285 µW/cm^2, T_A = 0°C to 70°C								±1		
N_e	Irradiance responsivity	See Note 4		80			45			7		mV/(µW/cm^2)
I_{DD}	Supply current	E_e = 25 µW/cm^2		900	1600							µA
		E_e = 45 µW/cm^2					900	1600				
		E_e = 285 µW/cm^2								900	1600	

NOTES: 3. The input irradiance E_e is supplied by a GaAlAs infrared-emitting diode with λ_p = 880 nm.
4. Irradiance responsivity is characterized over the range V_O = 0.05 to 3 V.

operating characteristics at T_A = 25°C (see Figure 1)

PARAMETER		TEST CONDITIONS	TSL250			TSL251			TSL252			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
t_r	Output pulse rise time	V_{DD} = 5 V, λ_p = 880 nm		360			90			7		µs
t_f	Output pulse fall time	V_{DD} = 5 V, λ_p = 880 nm		360			90			7		µs
V_n	Output noise voltage	V_{DD} = 5 V, f = 20 Hz		0.6			0.5			0.4		µV/√Hz

PARAMETER MEASUREMENT INFORMATION



NOTES: A. The input irradiance is supplied by a pulsed GaAlAs infrared-emitting diode with the following characteristics: λ_p = 880 nm, t_r < 1 µs, t_f < 1 µs.
B. The output waveform is monitored on an oscilloscope with the following characteristics: t_r < 100 ns, Z_i ≥ 1 MHz, C_i ≤ 20 pF.

Figure 1. Switching Times

TYPICAL CHARACTERISTICS

OUTPUT VOLTAGE
vs
IRRADIANCE

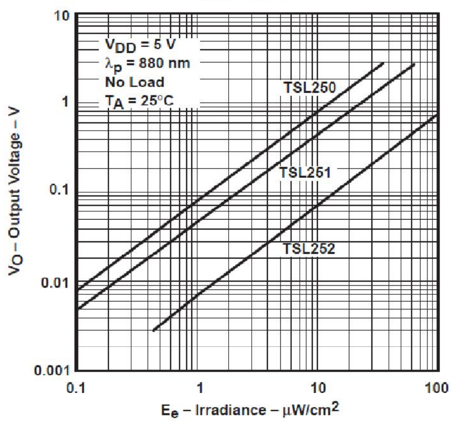


Figure 2

PHOTODIODE SPECTRAL RESPONSIVITY

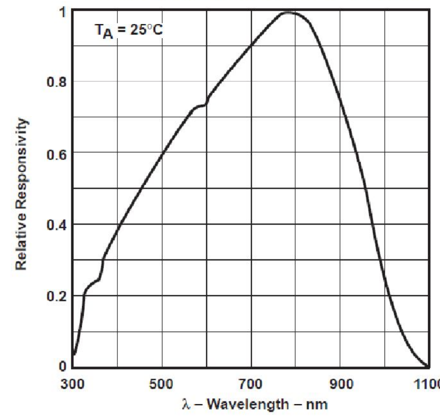


Figure 3

MAXIMUM OUTPUT VOLTAGE
vs
SUPPLY VOLTAGE

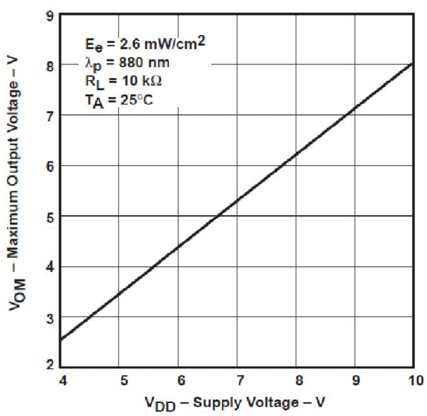


Figure 4

SUPPLY CURRENT
vs
OUTPUT VOLTAGE

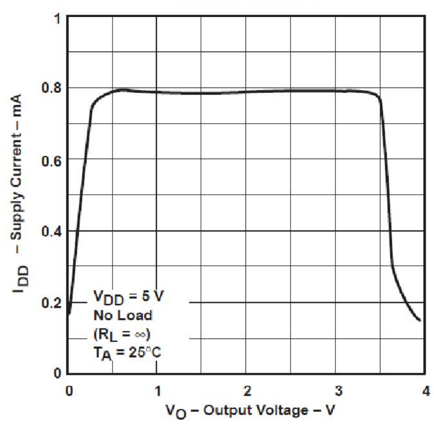


Figure 5

TYPICAL CHARACTERISTICS

NORMALIZED OUTPUT VOLTAGE
vs
ANGULAR DISPLACEMENT

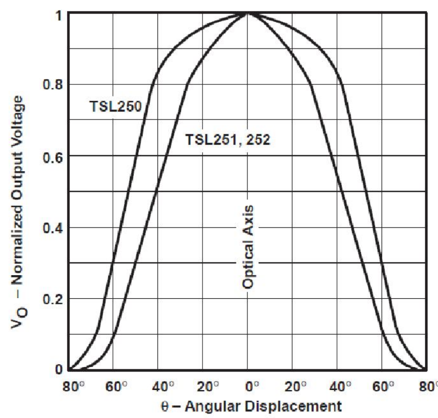
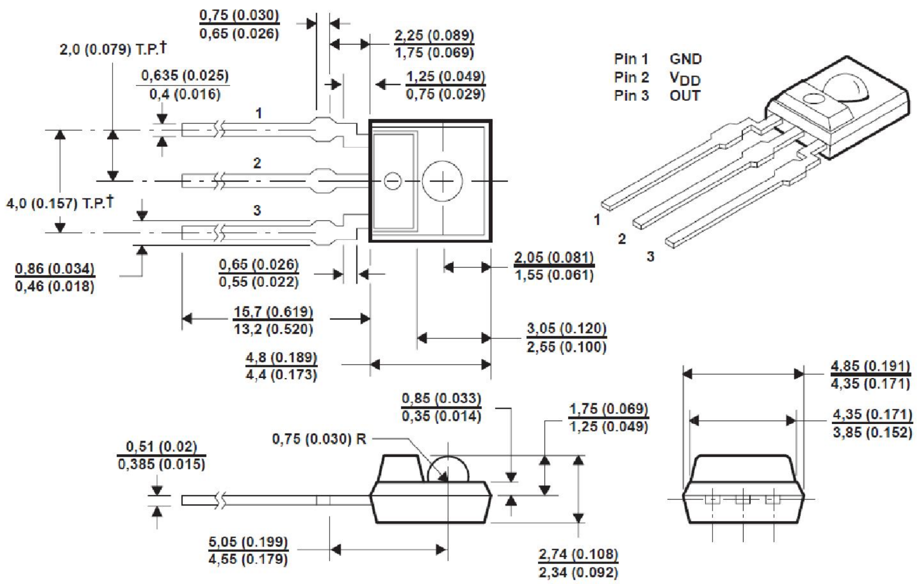


Figure 6

APPLICATION INFORMATION

The photodiode/amplifier chip is packaged in a clear plastic three-leaded package. The integrated photodiode active area is typically 1,0 mm^2 (0.0016 in^2) for TSL250, 0,5 mm^2 (0.00078 in^2) for the TSL251, and 0,26 mm^2 (0.0004 in^2) for the TSL252.



† True position when unit is installed.

NOTES: A. All linear dimensions are in millimeters (inches).
B. This drawing is subject to change without notice.

Figure 7. Mechanical Data

IMPORTANT NOTICE