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JUDUL: **WIRELESS TEMPERATURE MONITORING AND CONTROL**

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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 (Control and Instrumentation)"

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Date : 24/11/2009

WIRELESS TEMPERATURE MONITORING AND CONTROL

MOHD FARIS BIN AB. ABAS

A project report submitted in partial fulfilment of the
requirements for the award of the Bachelor Degree of Electrical Engineering (Control and Instrumentations)

Faculty of Electrical & Electronics Engineering
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NOVEMBER 2009

DECLARATION

I declare that this project report "*Wireless Temperature Monitoring and Control*" is the result of my own research except for works that have been cited in the reference. The project report has not been accepted any degree and not concurrently submitted in candidature of any other degree.

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Dedicated to :

My family, friends, lecturer

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ABSTRACT

The goal of this project is to design a wireless temperature measurement and control using a Motorola 68HC11 microcontroller. The system is composed of to 2 main boards which is transmitting board and receiving board. The device performs the measurement of temperature by using sensor and transmit the measurement via wireless. The measured temperature will be displayed at Graphical User Interface (GUI) by connecting receiver board to the computer. The set point of the temperature will be compared with the measured temperature and when the set point is lower or higher, it will triggered the heater or cooler element. The temperature will be measured and displayed continuously.

ABSTRAK

Tujuan projek ini adalah untuk mereka bentuk sistem tanpa wayar yang mengukur dan mengawal suhu menggunakan MC68HC11 *microcontroller*. Sistem ini menpunyai 2 papan utama iaitu papan penghantaran dan papan penerima. Alat ini akan mengukur suhu menggunakan pengesan suhu dan suhu yang telah di kesan akan di hantar melalui papan penerima yang menggunakan sistem tanpa wayar. Suhu yang telah diukur akan di pamer pada GUI melalui papan penerima yang telah disambung kepada komputer. Nilai tetap suhu akan dibandingkan dengan nilai suhu yang diukur dan apabila nilai suhu yang diukur kurang atau melebihi nilai suhu tetap, sistem pemanasan ataupun sistem penyejukan akan dipasang secara automatik. Nilai suhu akan di ukur dan di pamer sepanjang masa.

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LIST OF ABBREVIATIONS

ADC	Analog-to-Digital Converter
GUI	Graphical User Interface
VB	Visual Basic
SCI	Serial Communication Interface
ISM	Industrial, Science & Medical
VLSI	Single Very Large Integration
SP	Stack Pointer
PC	Program Counter
BASIC	Beginner's All purpose Symbolic Instruction Code
OOP	Object Oriented Software Architecture
CPU	Central Processing Unit
ROM	Read Only Memory
RAM	Random Access Memory
PCB	Printed Circuit Board
UART	Universal Asynchronous Receiver Transmitter
CCF	Conversion Complete Flag
TC	Transmit Complete
RDRF	Receive Data Register Full

CHAPTER 1

INTRODUCTION

1.1 Background

This project is based on wireless system monitoring and controlling to measure process variables like temperature, pressure, flow and level. A microcontroller is used to control the sensor to measure the variables and also to interface with the computer. Wireless module is used as a part of communication process to replace hard wire communication. This project is develop using Motorola MC68HC11 as the controller and ZigBee wireless module as communicator between sensor and computer.

This project is specifically measure the temperature and control the changes of the measured temperature. Input from the temperature sensor is in analog form. These data will be converted to digital form by using Analog-to-Digital converter (ADC) which is integrated in the microcontroller. The ZigBee module is used to transmit and receive the data.

These data will be log into computer by using Visual Basic (VB) program which offer user to develop their own Graphical User Interface (GUI) based on their own project. Comparison of data will be made based on the set point that is defined by user and if the comparison data is not the same as the set point, microcontroller will triggered signal to inform user.

1.2 Problem Statement

As researched has been done, there are lots of microcontroller used as part of the measuring system. But there are some microcontroller that does not have features like MC68HC11 and also ZigBee module which are specially design for the sensor networks.

1.2.1 Existing Controller, Wireless Module And Software

This project can used various type of microcontroller and also wireless module to communicate with each other. For software part, software like VB, LabView, MATLAB that is related to engineering can be used. However there are some problem which is :

i. Microcontroller

There are many types of new microcontroller with an advanced features but they did not have the build in ADC which are integrated in the MC68HC11. There will be some problem occur if we used external ADC to communicate with microcontroller.

ii. Wireless module

The basic requirement for wireless module is that they must be able to transmit data for long range and the power consumption is low. The frequency used is also considered to make sure no collision between different data. Most of the wireless module used low range frequency and does not have longer range data transmitting.

iii. Software

LabView is not all user friendly because we need to download separately from manufacturer's website the control toolkit and to integrate between MATLAB and microcontroller is not an easy part. These two software does not provide easy, and user friendly interface.

1.2.2 Problem Solving

Based on the problems stated above, I have come out with several solution in order to start the project. The solution is :

i. MC68HC11 provide up to 8-bit ADC and Serial Communication Interface (SCI). It used low power consumption and operating voltage is only 5V DC.

ii. ZigBee offers longer range of data transmitting and operate at ISM (Industrial, Scientific & Medical) 2.4 GHz frequency band and support the needs for low cost, low power wireless sensor network.

iii. Visual Basic (VB) is common for its simple interface and user friendly window. We can build from simple to advanced GUI based on our system and it is easy to interface the GUI with the microcontroller.

1.3 Objectives

There are two objectives that need to be achieve which is :

i. To design a wireless temperature monitoring and control system.
ii. To develop a simple user interface window using Visual Basic (VB).

1.4 Scopes

Several scopes are outlined based on this project :

i. Continuous temperature monitoring.
ii. Comparison with the set point.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explain the hardware and software used in this research. It will divided in two section which is hardware design section and software design section.

2.2 Hardware Design

2.2.1 Microcontroller

Microcontroller is defined as a computer implemented on a single very large integration (VLSI) chip[1]. The microcontroller used in this project is Motorola MC68HC11. This model offers various subsystems such as ADC, interrupts, timer and etc. The assembly language is simple because the processor uses the Von Neumann architecture. Various free software and references available at the internet. It is one of the popular and most often used in robotics and automotive system[2]. There are a lot of features in this microcontroller which includes :

i. Power Saving STOP and WAIT Modes
ii. 8 Kbytes ROM
iii. 512 Bytes of On-Chip EEPROM
iv. 256 Bytes of On-Chip RAM (All Saved During Standby)

v. 16-Bit Timer System

- 3 Input Capture Channels
- 5 Output Compare Channels

vi. 8-Bit Pulse Accumulator

vii. Real-Time Interrupt Circuit

viii. Computer Operating Properly (COP) Watchdog System

ix. Synchronous Serial Peripheral Interface (SPI)

x. Asynchronous Nonreturn to Zero (NRZ) Serial Communications Interface (SCI)

xi. 8-Channel, 8-Bit Analog-to-Digital (A/D) Converter

xii. 38 General-Purpose Input/Output (I/O) Pins

- 5 Bidirectional I/O Pins
- 11 Input-Only Pins and 12 Output-Only Pins

MC68HC11 is a 48 pin microcontroller and all the pin assignment is shown in Figure 2.1.

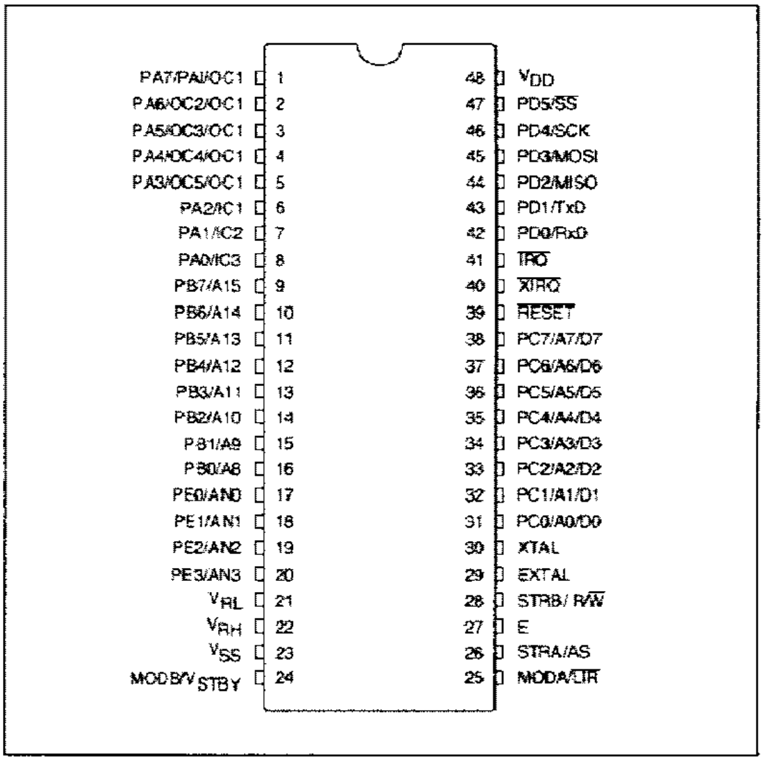


Figure 2.1 : MC68HC11 pin assignment

A microprocessor does its work by moving data from memory into its internal registers, processing on it, and then copying it back into memory. These registers are like variables that the processor uses to do its computations. There are two different types of registers which is accumulators and index registers.

Accumulators are used to perform most arithmetic operations, such as addition, subtraction, performing logical and bit operations (AND, OR, Invert). The result of those operations is written back into register. It is for this reason that the name accumulator is appropriate for these register types, they accumulate the results of on-going computations.

Index register consists the address of data to be reached. The illustration of the programming model is shown in Figure 2.2.

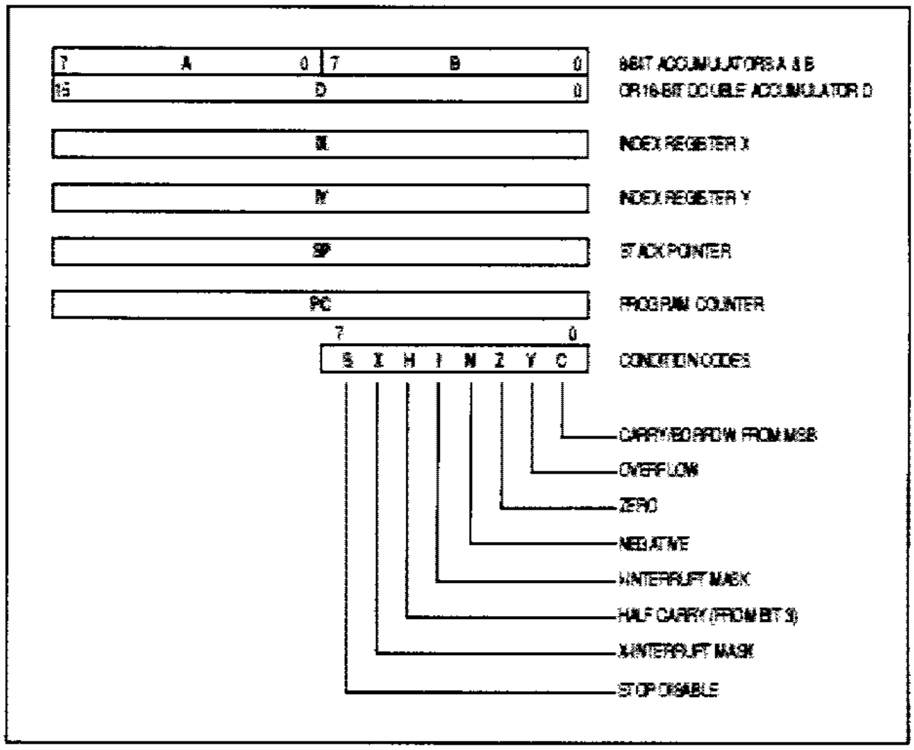


Figure 2.2 : MC68HC11 programming model

The 68HC11 has two accumulators, labeled A and B. Each accumulator is 8-bit registers and they hold one byte of data.

The general-purpose index registers are the X and Y registers. These are 16-bit registers and commonly used to address data in memory.

The Stack Pointer (SP) register store the location of the program stack. The stack is used for temporary storage of data, and to store the return address before a subroutine is called.

The Program Counter (PC) is used to keep track of the current instruction being executed. The PC is automatically incremented as the microprocessor proceeds through the instruction stream.

2.2.2 Wireless Module

ZigBee or XBee wireless modules is design to meet IEEE 802.15.4 standards and support the unique needs of low cost and low power wireless sensor network. To power up the module, its only need 2.4 – 3.4 V which is low voltage level. This module provide reliable delivery of data between devices. The modules operate within the ISM 2.4 GHz frequency band and are pin-to-pin compatible with each other[3]. The module is shown in Figure 2.3.

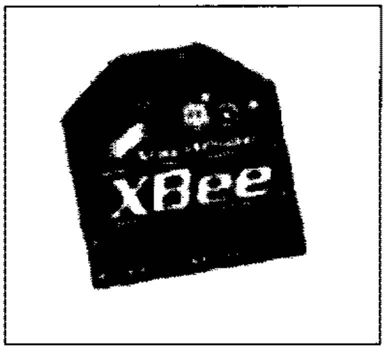


Figure 2.3 : ZigBee module

Some features of this modules include :-

1. High performance, Low cost :
   - Indoor/Urban range up to 30m.
   - Outdoor line-of-sight up to 100m.
   - Transmit power is 1 mW (0 dBm).
   - Receiver sensitivity is -92 dBm.
2. Low power module :
   - Transmit current : 45 mA @ 3.3 V.
   - Receive current : 50 mA @ 3.3 V.
   - Power-down current : < 10 μA.

Several advantages of the modules is :

1. Low duty cycle – provides long battery life.
2. Low latency.
3. Support for multiple network topologies.
4. Collision avoidance.
5. Link quality avoidance.
6. Clear channel assessment.

There are two types of Zigbee modules which is ZigBee and ZigBee PRO. The modules used in this research is ZigBee because the transmission of data is for short distance measurement only. The pin assignment is shown in Figure 2.4.

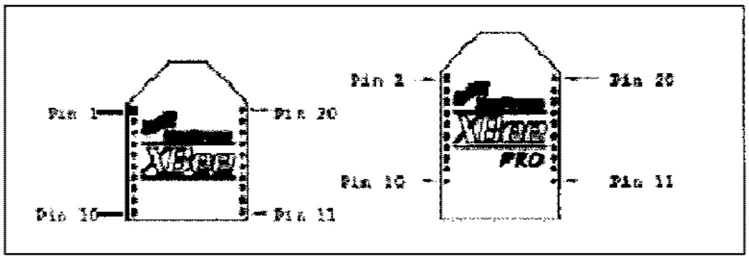


Figure 2.4 : ZigBee and ZigBee PRO pin assignment

The function for each pin is shown in Table 2.1 :

Table 2.1 : Pin function for ZigBee Module

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

2.2.3 Temperature Sensor

A sensor is a device that measures physical quantity and converts it into a signal which can be read by an observer or instrument[4]. The most simple and effective temperature sensor is LM35 sensor series. 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 ±1⁄4°C at room temperature and ±3⁄4°C over a full −55 to +150°C temperature range[5].

The features for this temperature sensor are :

i. Calibrated directly in ° Celsius (Centigrade)
ii. Linear + 10.0 mV/°C scale factor
iii. 0.5°C accuracy guarantee able (at +25°C)
iv. Rated for full −55° to +150°C range
v. Suitable for remote applications
vi. Low cost due to wafer-level trimming
vii. Operates from 4 to 30 volts
viii. Less than 60 μA current drain
ix. Low self-heating, 0.08°C in still air
x. Nonlinearity only ±1⁄4°C typical
xi. Low impedance output, 0.1 W for 1 mA load

The temperature sensor used in this project is LM35-DZ which is in plastic package and the description for this sensor is shown in Figure 2.5.

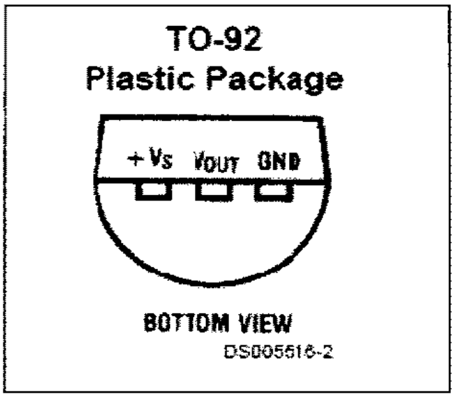


Figure 2.5 : LM35-DZ pin assignment

2.2.4 Serial Communication Interface

In a microcontroller, there are subsystems which called Serial Communication Interface (SCI) and these subsystem is used to communicate between microcontroller and computer. Voltage output from microcontroller is 5 V and voltage output from computer port is different. Therefore a line driver is needed to interface between those two voltage level. The most common line drivers is RS-232, RS-422 and RS-423. The simplest line driver and easy to integrate is RS-232.

To communicate between these two voltage level, a connector called DB-9 which has 9-pins and an IC called MAX233 are used. In RS-232, bit 1 is represent by -3 V to -25 V while bit 0 is +3 V to +25 V, making -3 to +3 undefined. For this reason, MAX233 is used to connect any RS-232 to a microcontroller as a voltage converters.

The pin configuration and typical connection to operate the voltage converter is shown in Figure 2.6.

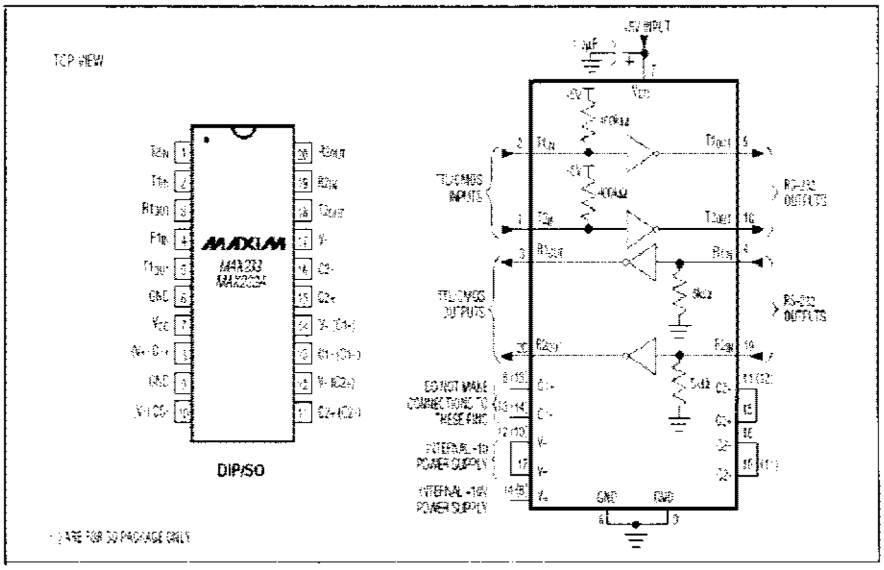


Figure 2.6 : Pin Configuration and Typical Operating Circuit for MAX233

2.3 Software

2.3.1 Visual Basic

The Beginner's All purpose Symbolic Instruction Code (BASIC) was designed as a language to teach people how to program by Professors Kemeny and Kurtz at Dartmouth College back in 1963. It was so successful that soon a lot of companies were using BASIC as their programming language of choice. In fact, BASIC was the very first PC language because Bill Gates and Paul Allen wrote a BASIC interpreter for the MITS Altair 8800, the computer most people accept as the first PC, in machine language.

Visual Basic, however, was created by Microsoft in 1991. The main reason for the first version of Visual Basic was to make it a lot faster and easier to write programs for the new, graphical Windows operating system. Before VB, Windows programs had to be written in C++. They were expensive and difficult to write and usually had a lot of bugs in them. VB changed all that.

There have been nine versions of Visual Basic up to the current version. The first six versions were all called Visual Basic. But in 2002, Microsoft introduced Visual Basic .NET 1.0, a completely redesigned and rewritten version that was a key part of a whole computer software revolution at Microsoft. The first six versions were all "backward compatible" which means that later versions of VB could handle programs written with an earlier version. Because the .NET architecture was such a radical change, any programs written in Visual Basic 6 or earlier had to be rewritten before they could be used with .NET. It was a controversial move at the time, but VB.NET has now proven to be a great programming advance.

One of the biggest changes in VB.NET was the use of a object oriented software architecture (OOP). VB6 was mostly OOP, but VB.NET is totally OOP. The rules of object orientation are recognized as a superior design. Visual Basic had to change or it would have become obsolete[6].

The interface window for Visual Basic is shown in Figure 2.7.

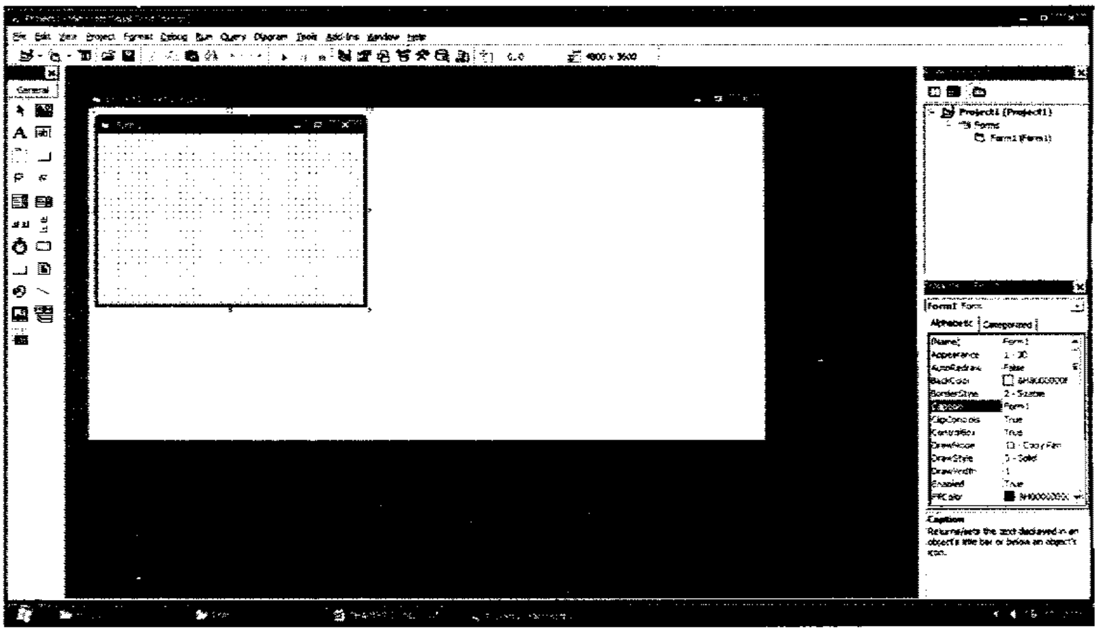


Figure 2.7 : Visual Basic interface window

The windows are easy to understand. The design toolbar is located at the left side on the windows and it consists components which user can select and drag it to form window.

In these form window, user can design its own interface window. It can be expand and edit depends on how user design it. The properties toolbar for each function is located at the bottom right of the window. Each components can be change its properties based on user design specification.

Each components need to be program first in code editor window. Double click the form window and code editor window will appear. The project can be save by clicking the save button under file function.

2.3.2 MC68HC11 Simulator Program

The Motorola 68HC11 microcontroller is a popular microcontroller used in many applications. With the THRSim11 program user can modify, assemble, simulate and debug the codes for the 68HC11 on user windows PC. The simulator simulates the Central Processing Unit (CPU), Read Only Memory (ROM), Random Access Memory (RAM), and all memory mapped Input/Output ports. It also simulates the on board peripherals such as :

i. Timer (including pulse accumulator).
ii. Analog to digital converter.
iii. Parallel ports (including handshake).
iv. Serial port.
v. I/O pins (including analog and interrupt pins).

While debugging the graphical user interface makes it possible to view and control every register (CPU registers and I/O registers), memory location (data, program, and stack) and pin of the simulated microcontroller. It is possible to stop the simulation at any combination of events.

A number of (simulated) external components can be connected to the pins of the simulated 68HC11 while debugging. For example :

i. LED's,
ii. Switches,
iii. Analog sliders (variable voltage potential).
iv. Serial transmitter and receiver.

The interface window for the simulator is shown in Figure 2.8.

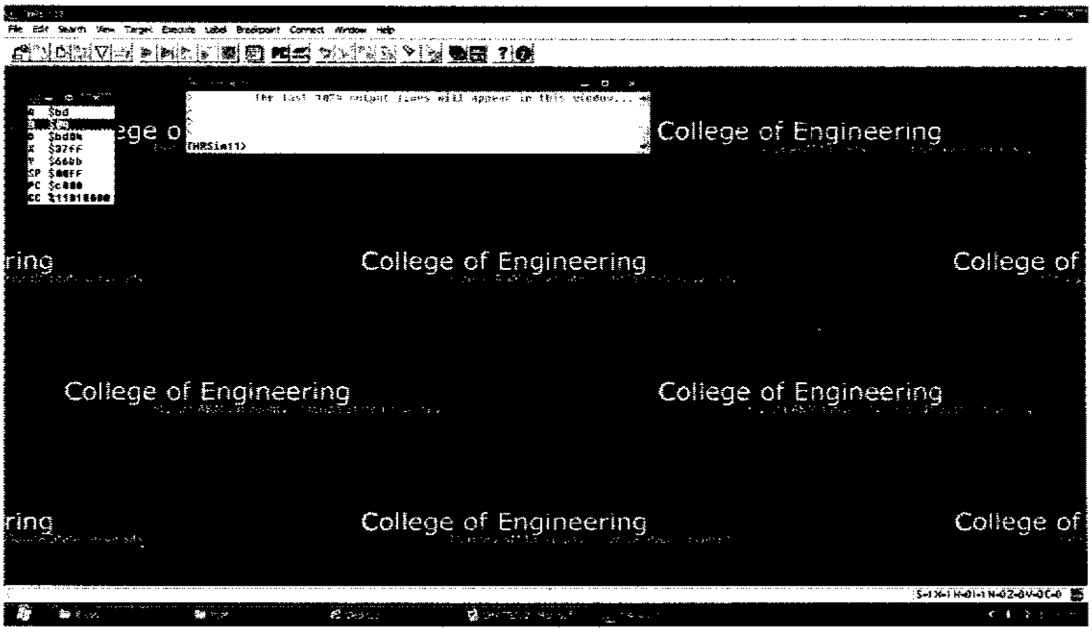


Figure 2.8 : MC68HC11 simulator interface window

There are a lot of function in this window. User can list the code, download the code to board and monitor the register when the program is running.

It is also have simple simulator that has been design such as running LED, traffic light, 7 segment display and much more. These simulator need to be connect with the program that user has defined.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section is divided into four sections. Each sections is explain in details. The sections are :

i. System design.
ii. Hardware block diagram.
iii. Software flowchart.
iv. System description.

3.2 System Design

Project is starting from search for project specification. Which components should be used, type of controller, designing circuit were take into details. All these specification should be considered before this project start.

Next thing to do is to find all sources of components review. From the datasheet of each components until the tutorial about the software were find to make sure all the necessary information is take into account.

Figure 3.1 will show the details about this project flow.

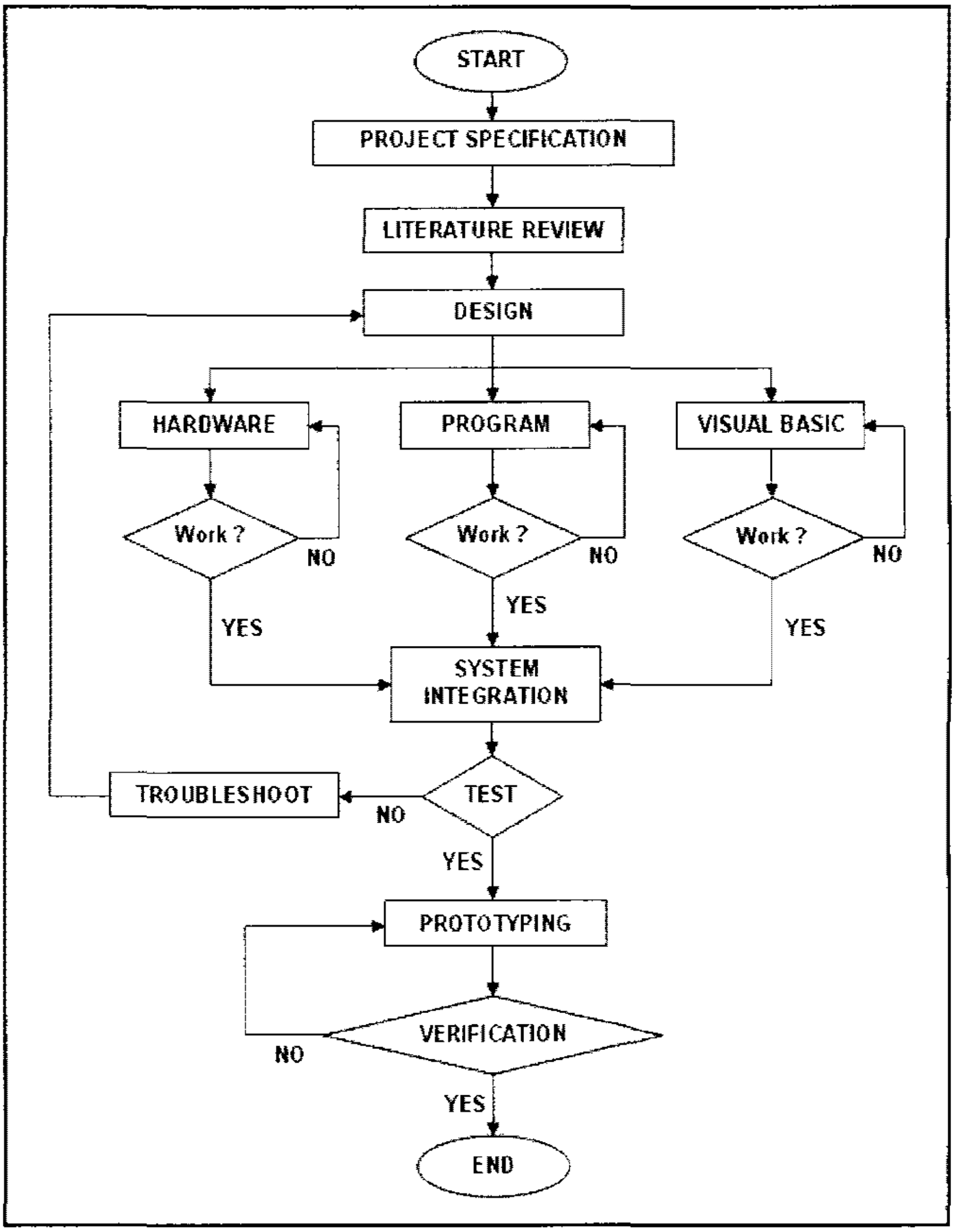


Figure 3.1 : Project flowchart

The first step in system design is hardware integration. All the components is listed first. The interface circuit is design and develop for this purpose. All the connection between the parts must be correct to avoid any wrong connection that will lead to error while integrate the hardware. The schematic circuit is then printed onto the Printed Circuit Board (PCB). After all the components is connected, the circuit need to bet tested before any program is burn into the controller. The parts that need to be tested is power supply, sensor circuit, wireless circuit and also serial communication circuit.

The software development involved in this research is to write coding for microcontroller process the input given. The developed codes is tested before it is placed into microcontroller. After the program tested is running, the software part for this project is done.

Another part in software development is the User Interface of this project. This GUI will display the measured temperature at that time and will respond to any change in temperature within the set point.

Verification testing is carried out to ensure the system functions properly. The error occur is troubleshoot before the system ready to be applied.

After all problems fixed, the prototyping of the project need to be build before it can be presented.

3.3 Hardware Block Diagram

This section is divided into two parts which is transmitting part and receiving part. Both parts will be discussed separately in this section.

3.3.1 Transmitting Part

In the transmitter part, it consists of 3 components which is temperature sensor, microcontroller and transmitter. The connection between these components is shown in Figure 3.2.

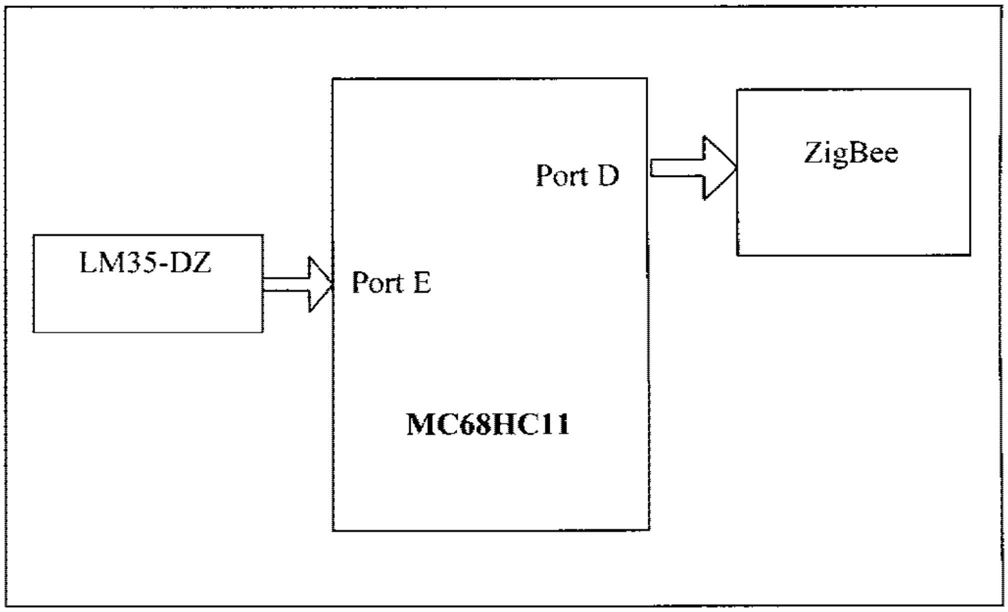


Figure 3.2 : Transmitter block diagram

Temperature sensor used in this project is LM35-DZ. This sensor offers linearity because the output voltage from it is directly proportional to Centigrade ( ). The relationship for this sensor is shown in Figure 3.3.

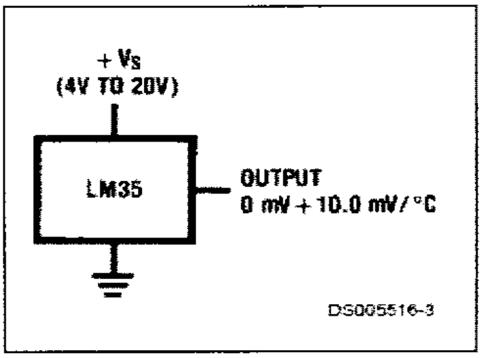


Figure 3.3 : Relationship of output voltage of sensor

As seen above, the output voltage for the sensor is equal to 10 mV for 1 . The range for this sensor in basic configuration is 0 until 100 . Sensor is connected at Port E of MC68HC11 which will act as 8-bit Analog-to-Digital Converter (ADC). The ADC must be initialize first before the conversion can be done. The conversion result can be read at ADR1 to ADR4 register.

After the conversion complete, the data from the register is sent to Port D of MC68HC11. Port D act as Serial Communication Interface (SCI) port to allow data to be send to the transmitter.

ZigBee transmitter is used to transmit the data through wireless communication. The type of data is 8-bit data with 1 start bit and 1 stop bit. To enable the transmission, the baud rate of SCI port and transmitter must be set at same rate.

There are also other parts that need to be installed before the circuit able to function. The parts are power supply circuit, reset circuit and clock circuit. The diagram for those parts is shown in Figure 3.4, Figure 3.5 and Figure 3.6.

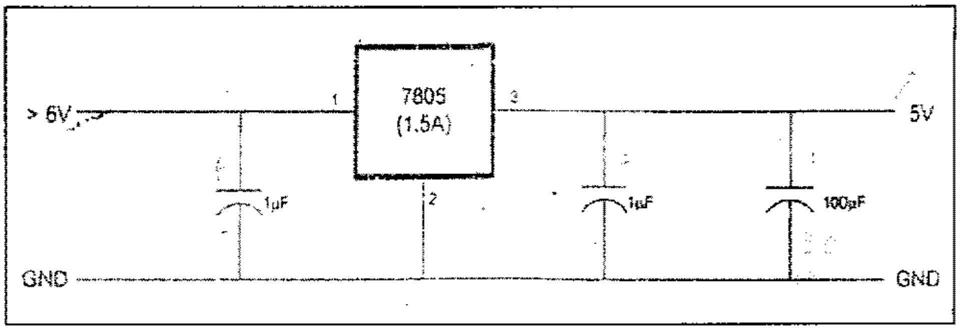


Figure 3.4 : Power supply module

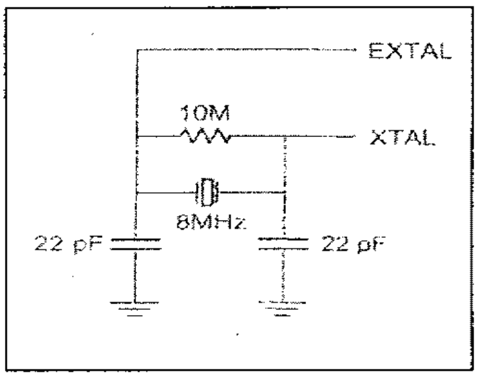


Figure 3.5 : Clock circuit

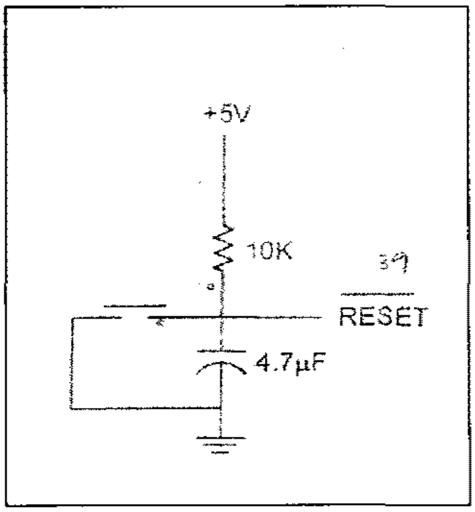


Figure 3.6 : Reset circuit

3.3.2 Receiving Part

In the receiver part, it consists 5 parts which are the receiver, microcontroller, RS-232 interface, heating and cooling element. The connection between these parts is shown in Figure 3.7.

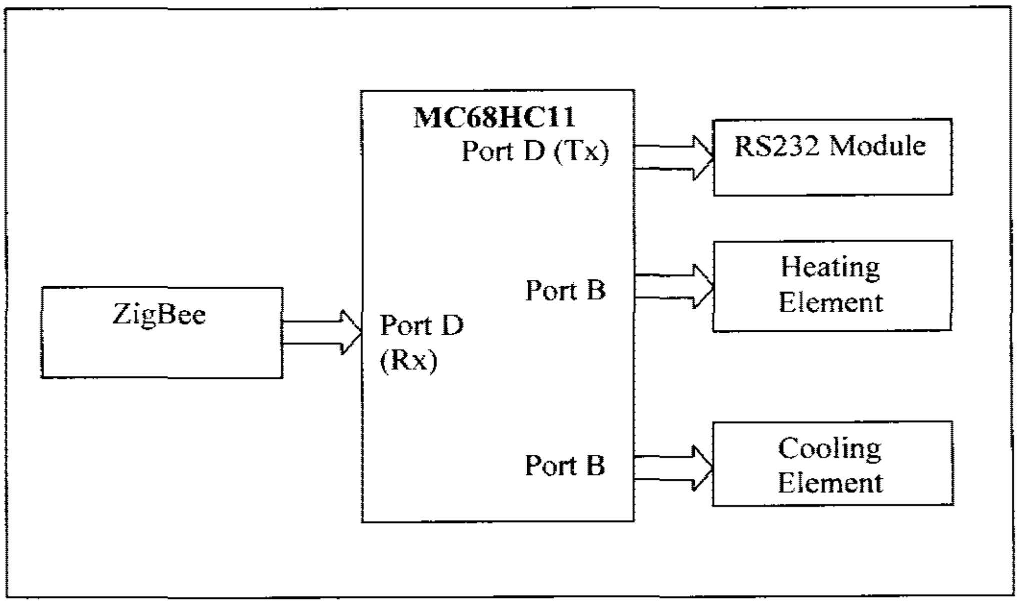


Figure 3.7 : Receiver block diagram

Figure 3.7 show all the components for the receiver part of the circuit. The data from the transmitter will be receive at the receiver. This data will be send to microcontroller register which is SCDR register through port D of microcontroller.

These data is sent out via port D to the RS232 module which include MAX233 as the line driver and DB-9 connector. These connector is connected to the computer to provide input for Visual Basic program. Line driver is used because the voltage level for output of microcontroller is not compatible with computer voltage level. So, a line driver is used to convert these voltage level.

The data in SCDR register will be load into the accumulator of microcontroller and these data is compared with the set point of temperature. If the data is exceed or lower that the set point, heating or cooling element is triggered and response to temperature changes until it locates between the range decided.

The measuring process is continuously running until RESET button is push for both module. The measured temperature will be display in GUI window continuously. Apart from that, the baud rate setting must be the same for all related components. Fail to setting the same baud rate will result in fail to receive or transmit data.

3.4 Software Flowchart

In this section, 3 flowchart is described which are transmitting flowchart, receiving flowchart and VB flowchart. Both transmitting and receiving flowcharts is based on MC68HC11 programming respectively.

3.4.1 Transmitting Flowchart

For transmitter flowchart, it consists of data measurement from temperature sensor and the conversion process done by the ADC. The converted data is then transmitted to the universal asynchronous receiver transmitter (UART) pin that is connected to ZigBee module.

The ADC and SCI register must be initialized to enable access of its register. The register that include in this process is OPTION register to enable the ADC and to select the clock cycle. In this case, internal clock cycle is used. ADCTL register is set to determine the conversion complete flag (CCF) and bits to control the multiplexer and the channel scanning.

The product of conversion is stored into ADR1 to ADR4 registers. ADC must be delay first up to 100 μs to stabilize the ADC. CCF is high if the conversion is complete and will remains low if the conversion is not complete.

The ADC initialization code are shown below.

```
REG         EQU   $1000
OPTION      EQU   $39
LDX         REG
BSET        OPTION,X    $80
BCLR        OPTION,X    $40
BSR         DELAY100
```

Figure 3.8 outline the flowchart of the program in transmitter circuit.

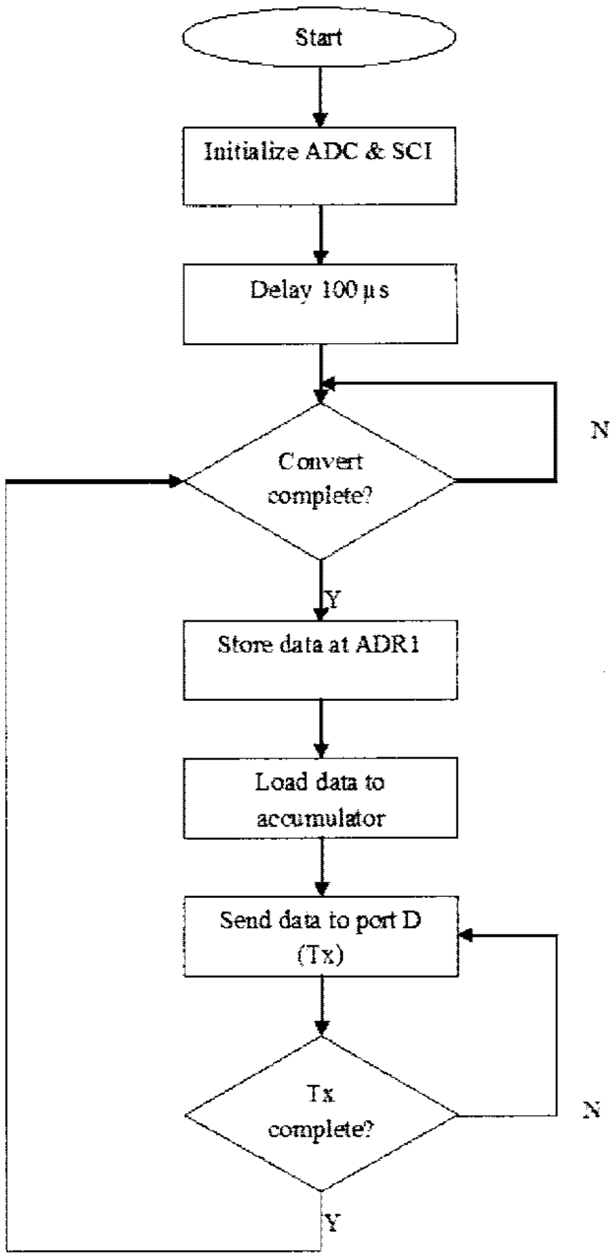


Figure 3.8 : Transmitting flowchart

The UART pin must be initialized as well. Port D of MC68HC11 is used for transmit and receive data. The program to initialize the SCI register is shown below.

```
REG     EQU     $1000
SCCR1   EQU     $2C
SCCR2   EQU     $2D
BAUD    EQU     $2B
        LDX     REG
        CLRA
        STAA    SCCR1,X
        LDAA    #$0C
        STAA    SCCR2,X
        LDAA    #$30
        STAA    BAUD,X
```

The process to transmit data is begin by recall the data in ADR1 register. These data is then loaded into the accumulator. After that, the data is transmitted via port D of MC68HC11 through the ZigBee transmitter. SCSR register act as controller of the serial communication operation and providing the status of operation.

The Transmit Complete (TC) flag turn HIGH if the transmission is completed and remains LOW if vice versa.

3.4.2 Receiving Flowchart

In this flowchart, it consists the receive data from the transmitter, transmit the data to computer and compare it with set point.

It starts from initialize the SCI register and also load the register for port B. Port B do not need to initialize because it can only be used as the output port.

The initialization of SCI register is just the same at transmitter program. The data is received via UART pin at port D. These data is be stored at the SCDR register. To make sure the receiving process is complete or not, Receive Data Register Full (RDRF) flag will be scan. If the flag is HIGH, the receiving process is complete but if the flag is LOW, that means the receiving is not complete yet.

From the SCDR register, it is transmitted to the UART pin of port D. The port is connected to computer and the data is receive by computer through VB program.

Then, the data in SCDR register is loaded into accumulator. From the accumulator, the comparison process is executed to compare the data with set point. If the data is lower than the set point, it will triggered the signal and send it to the heater which is connected to port B pin. If the data is higher than the set point, it will triggered the signal to turn on the cooler which is connected to port B pin.

The flowchart for receiving program is shown in Figure 3.9.

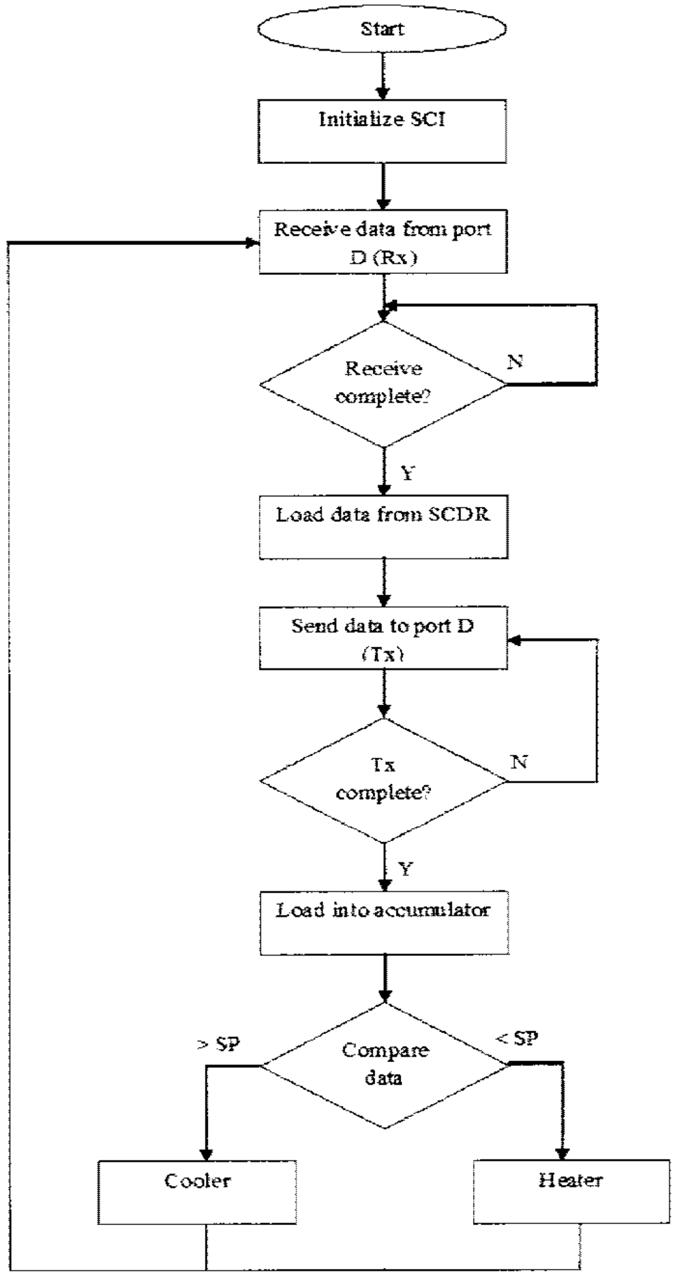


Figure 3.9 : Receiving flowchart

3.4.3 Visual Basic Flowchart

Figure 3.10 is the flowchart for VB GUI interface.

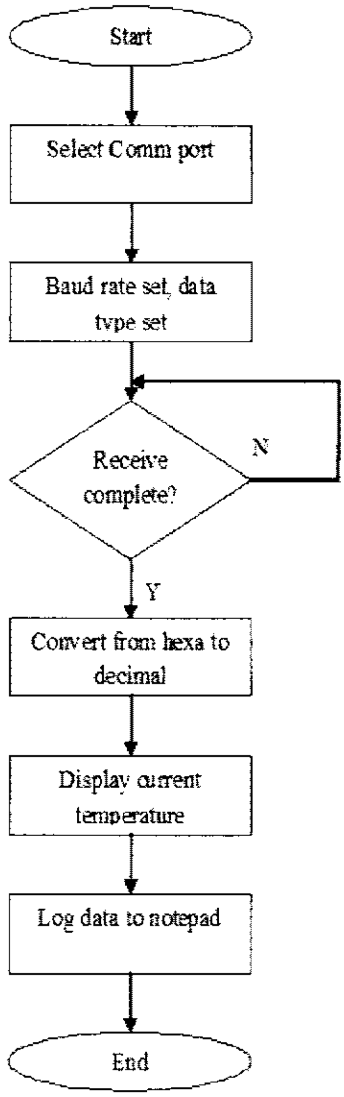


Figure 3.10 : Visual Basic flowchart

From the flowchart above, the GUI will start after we select the *com port* for the interface. If the selected *com port* is right, its indicated that we have select the correct *com port* and it will connect the circuit with the GUI.

To set the *com port* and the baud rate for the GUI, the setting is in the VB code which is listed below :

```
Private Sub Form_Load()
    MSComm1.Settings="1200,N,8,1"
    MSComm1.CommPort=1
    MSComm1.InputLen=1
    MSComm1.PortOpen=True
    MSComm1.Rthreshold =1
End Sub
```

For this setting, the program select 1200 as the baud rate and 8-bit data with 1 start bit and 1 stop bit.

The baud rate and data type will be automatically select if the *com port* is connected. After that, the program will begin to collect the data from the receiver circuit.

These data is in hexadimal form. We need to convert this form into decimal form which user can understand. The calculation is automatic from the program.

After conversion is complete, the interface will display the current receive temperature. After certain time, if there is a maximum or minimum recorded temperature, the interface will display it.

We can log these data into the notepad as our reference. The interface window will exit if we click the exit button. The GUI form is shown in Figure 3.11.

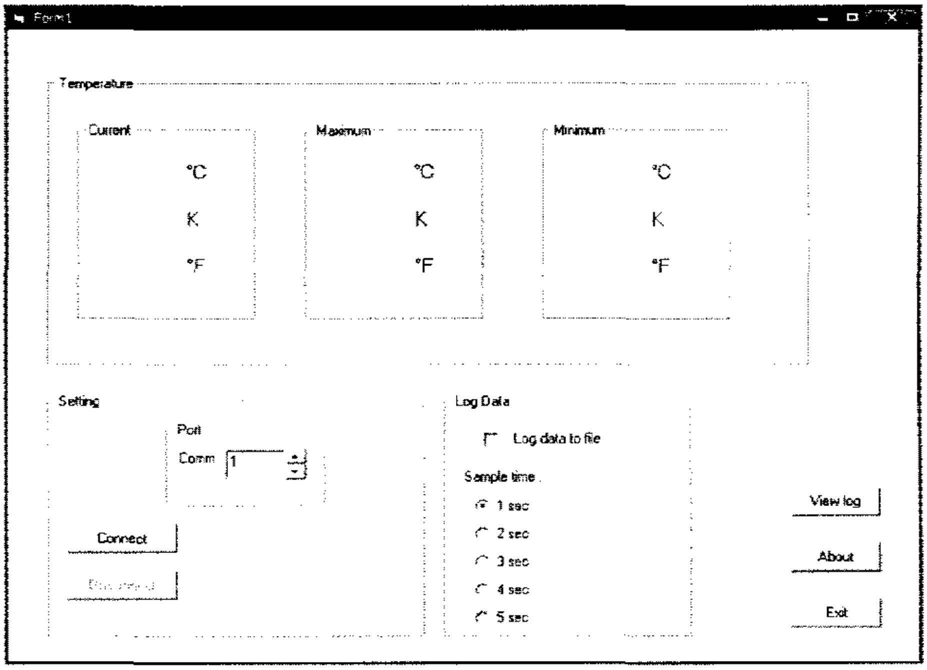


Figure 3.11 : Graphical User Interface (GUI) window

3.5 System Description

This section will discussed about the whole process that happen in the project. System will start after power supply is turn on. Then, all the components will receive the supply voltage. Circuit is ready to operate.

Sensor will begin to measure the current temperature. The analog measurement temperature will be converted into digital form. These digital form is stored in the register and will be called back to transmit the data through ZigBee transmitter.

The transmitter will send the data wirelessly and acknowledgement flag will go high if the transmission is complete. At the receiver ZigBee, these data will received and acknowledgement flag will go high once the receiving is complete.

The data will be stored into the register and these data will be send through serial port to the computer. The measured temperature will be display at the GUI that has been made.

Comparison data will be made and it will triggered either cooler or heater if the value is exceed or lower than set point. The flowchart of the whole system is shown in Figure 3.12.

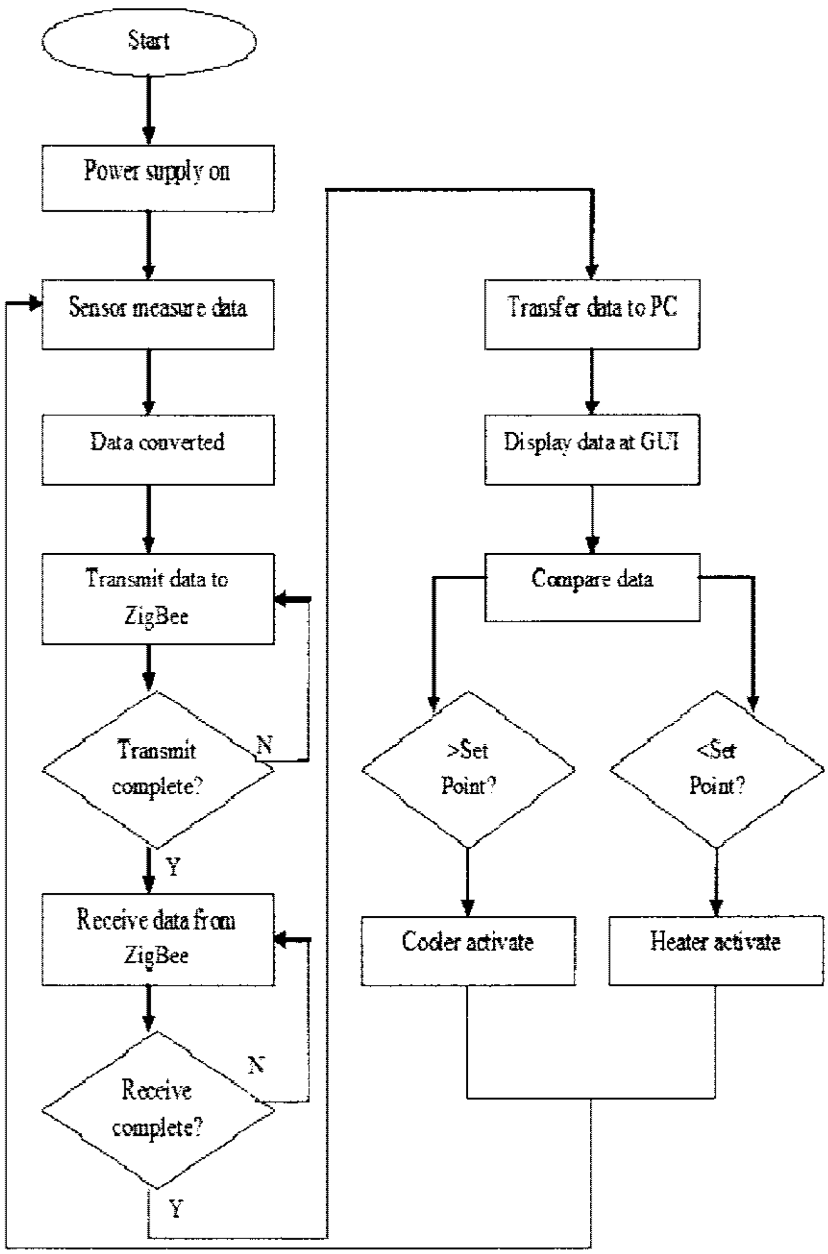


Figure 3.12 : Overall system flowchart

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

In this section there is description for overall project result from hardware design until developing GUI. This section will be divided to 3 part which is hardware, software and system functionality.

4.2 Hardware Design

In this section, hardware test and functionality is described. The parts to described is sensor functionality, power supply functionality and ZigBee functionality. The board for the hardware is shown in Figure 4.1.

Figure 4.1 : Circuit of the project

4.2.1 Sensor

The output voltage from the sensor will be point out to multimeter to display the result.

The output voltage from the sensor must not exceed 1 V since the output voltage only draw 10 mV for 1 °C. Figure 4.2 show the output voltage from sensor.

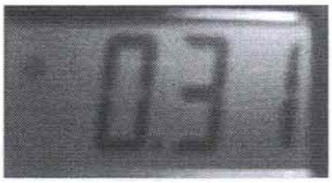


Figure 4.2 : Output voltage from sensor

Based on the figure above, the output voltage from the sensor is 0.31 V. If the output voltage is equal to 10 mV for 1 °C, 0.31 V is equal to 30 °C.

4.2.2 Power Supply

MC68HC11 need a supply of 5 VDC to function. A voltage regulator is used to provide 5V supply to microcontroller. The output from the voltage regulator is shown in Figure 4.3.

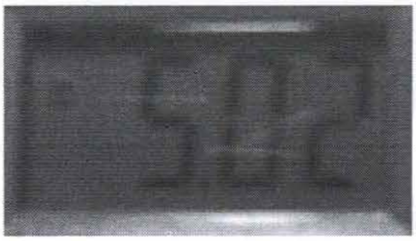


Figure 4.3 : Output Voltage from Voltage Regulator

From Figure 4.3, the output voltage from the voltage regulator is 5.02 V. This is acceptable since there are too many disturbances that will effect the value.

4.3 Software

In this section, the result from the software development is presented. Both VB and MC68HC11 software must be tested first before we can run the program.

4.3.1 Visual Basic

To test the functionality for the VB, we must connect the RS232 connector to the *com port* of the computer. The GUI window will be open and if the selection of *com port* is right, the system will connect. The sample result is shown in Figure 4.4.

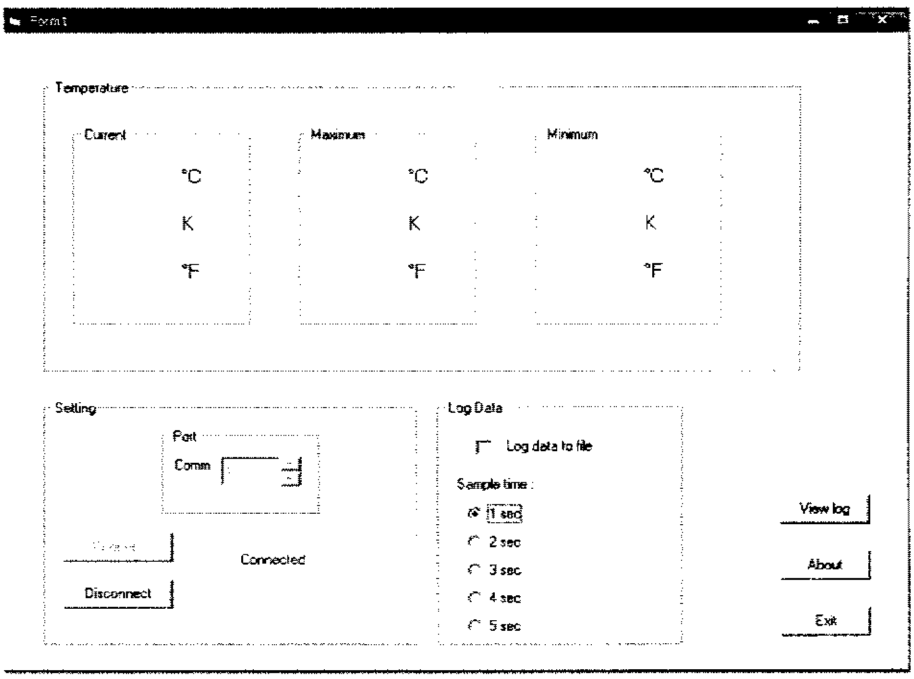


Figure 4.4 : GUI window for "Connect" button

The GUI will display "connected" if the right *com port* of the computer is selected. After the *com port* is connected, system will running and the measured temperature will be displayed continuously.

The measured temperature can be save via log function. Select the sample time and the measured temperature will be save in notepad.

Maximum and minimum temperature will be displayed while system is running based on the measured temperature.

Another sample of GUI is shown where it will display the measured temperature. Figure 4.5 shown the sample.

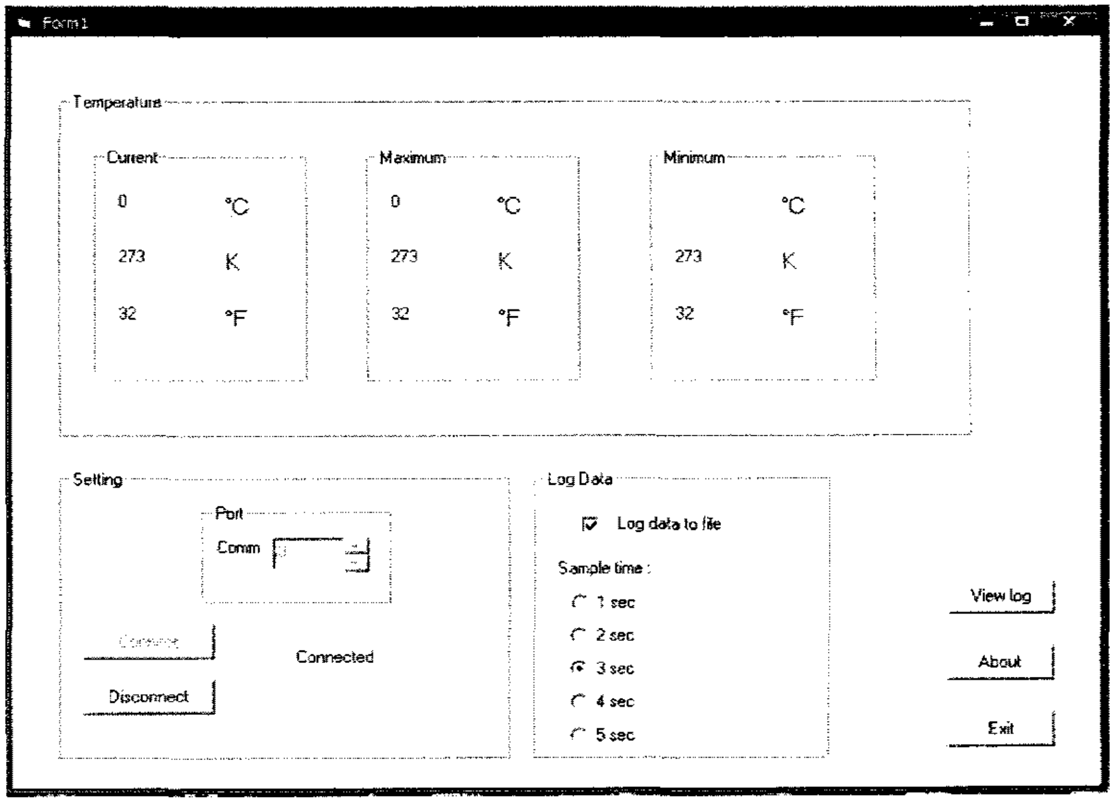
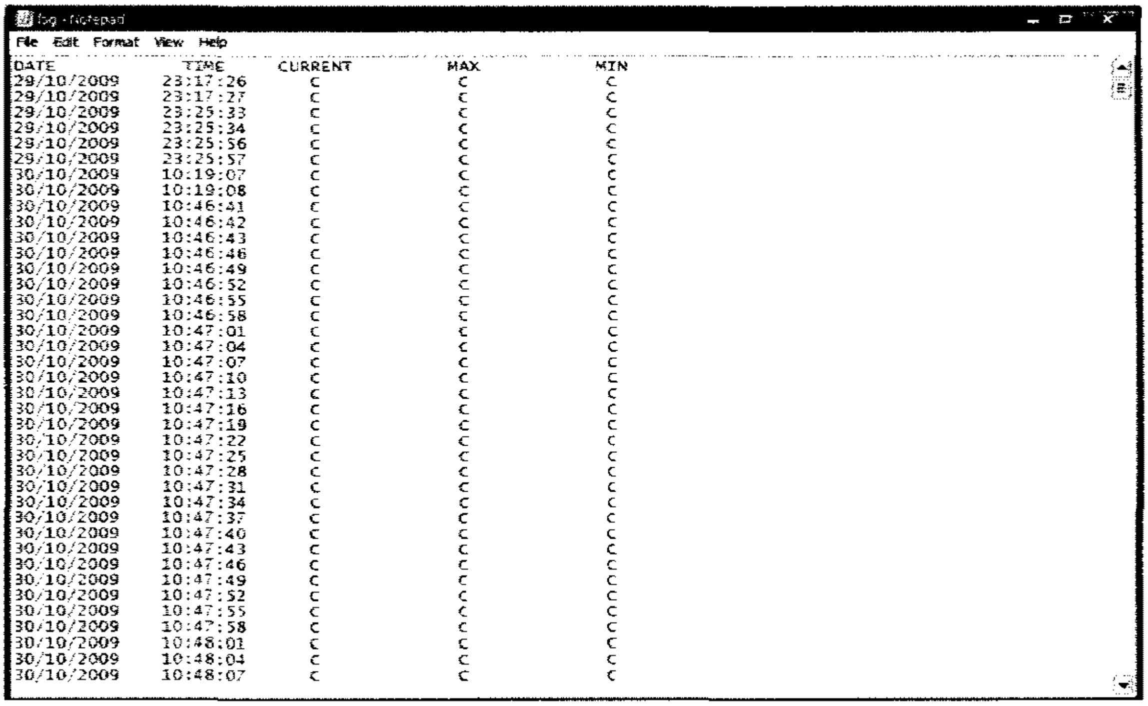


Figure 4.5 : GUI window for displayed temperature

The displayed temperature can be log into a file that will log the temperature. The log interval time can be select from one seconds to five seconds. It will also display date and time.

Figure 4.6 show the log window.


log - Notepad

File Edit Format View Help

DATE	TIME	CURRENT	MAX	MIN
29/10/2009	23:17:26	C	C	C
29/10/2009	23:17:27	C	C	C
29/10/2009	23:25:33	C	C	C
29/10/2009	23:25:34	C	C	C
29/10/2009	23:25:56	C	C	C
29/10/2009	23:25:57	C	C	C
30/10/2009	10:19:07	C	C	C
30/10/2009	10:19:08	C	C	C
30/10/2009	10:46:41	C	C	C
30/10/2009	10:46:42	C	C	C
30/10/2009	10:46:43	C	C	C
30/10/2009	10:46:46	C	C	C
30/10/2009	10:46:49	C	C	C
30/10/2009	10:46:52	C	C	C
30/10/2009	10:46:55	C	C	C
30/10/2009	10:46:58	C	C	C
30/10/2009	10:47:01	C	C	C
30/10/2009	10:47:04	C	C	C
30/10/2009	10:47:07	C	C	C
30/10/2009	10:47:10	C	C	C
30/10/2009	10:47:13	C	C	C
30/10/2009	10:47:16	C	C	C
30/10/2009	10:47:19	C	C	C
30/10/2009	10:47:22	C	C	C
30/10/2009	10:47:25	C	C	C
30/10/2009	10:47:28	C	C	C
30/10/2009	10:47:31	C	C	C
30/10/2009	10:47:34	C	C	C
30/10/2009	10:47:37	C	C	C
30/10/2009	10:47:40	C	C	C
30/10/2009	10:47:43	C	C	C
30/10/2009	10:47:46	C	C	C
30/10/2009	10:47:49	C	C	C
30/10/2009	10:47:52	C	C	C
30/10/2009	10:47:55	C	C	C
30/10/2009	10:47:58	C	C	C
30/10/2009	10:48:01	C	C	C
30/10/2009	10:48:04	C	C	C
30/10/2009	10:48:07	C	C	C

Figure 4.6 : Log window

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This thesis has discussed the development of wireless temperature monitoring and controlling to display continuous temperature measurement and to control any change in temperature measurement.

This project has been able to achieve some of its objectives. Then, conclusion will be made to state out the strength and weakness of the project. Lastly, planning for future work will be discussed.

5.2 Assessment Of Design

While developing this project, several difficulties and problems were countered. This project required knowledge to program the microcontroller and to interface the circuit with the computer. Several problems are faced during the project development. They are :

- Sensor output.

  Output voltage from the sensor did not match the required value. The connection is checked several times.
- Connection between circuit and computer.

  Need to try several times to connect circuit with computer. The selection of *com port* from computer is crucial.
- Microcontroller software.

  A lot of time is took in developing the software. Need better understanding to develop the software.
- Development of the circuit.

  Took a lot of time to develop the circuit. Since there is 2 board to build, a lot of research has to be made to make sure the connection between components is right.

5.3 Strength And Weakness

This project offers simple and easy to use for measurement of data that will be display at the GUI. To construct the project, one must have a better knowledge to program the software. Most of the microcontrollers need to add external ADC. Since MC68HC11 has an internal ADC, the development of the circuit become a little bit easy.

Microsoft Visual Basic offers a simple windows to develop the GUI window that will be interface with the circuit. User need to define the components used in the window before interface it with circuit.

The weakness of this project is the microcontroller technology is way too old to used. There are a lot of new microcontroller with advanced features and technology. The software implementation also a lot easy to develop. Same goes to Visual Basic. The version used for this project is Microsoft Visual Basic 6.0 but the latest version has been updated with more features.

5.4 Suggestion For Future Work

Since this project offers only one sensor to measure temperature, we can upgrade this project to better performance. Some of the suggestion for future work is :-

i. Instead of using only one sensor, we can add more sensor up until microcontroller can support.
ii. It can be used to make a network of clusters consisting of sensors in real time control applications.
iii. Compatible with different network protocols.
iv. A memory database can be build by using on chip memory as well as remotely connected PC through wireless link.

5.5 Costing and Commercialization

The cost for this project is on hardware component and the software used is provided and license free. The total cost for hardware is shown in Table 5.1.

Table 5.1 : Component list and cost

No	Components	Quantity	Cost (RM)
1	Strip Board	1	1.00
2	Header	10	5.00
3	Heat Sink	2	1.00
4	LEDs	2	0.20
5	Reset Switch	2	0.20
6	Wire Wrap	1 roll	4.00
7	DB9 (female)	1	2.00
8	MAX 233	2	5.00
9	MC68HC11A1P	2	80.00

10	LM35DZ	1	8.00
11	ZigBee module	2	300.00
12	5V Fan	2	5.00
13	3-pin Connector	2	4.00
14	IC Base 48 pin	2	0.40
15	IC Base 20 pin	1	0.20
16	Regulator 7805	2	4.00
17	Crystal 8MHz	2	2.00
18	Capacitor 100μF	2	0.50
19	Capacitor 1.0 μF	4	0.50
20	Capacitor 4.7 μF	2	0.70
21	Ceramic Capacitor 22pF	4	0.80
23	Resistor 10MΩ	2	0.20
24	Resistor 10kΩ	2	0.20
25	Resistor 220Ω	2	0.20
Total Cost (RM)			424.60

5.6 Conclusion

As a conclusion, the measurement of the temperature is done and this temperature can be controlled via microcontroller programming. Continuous temperature is display at GUI window. The temperature can be recorded via notepad application.

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[17] http://www.faqs.org/faqs/microcontroller-faq/68hc11/

[18] http://www.rasmicro.com/

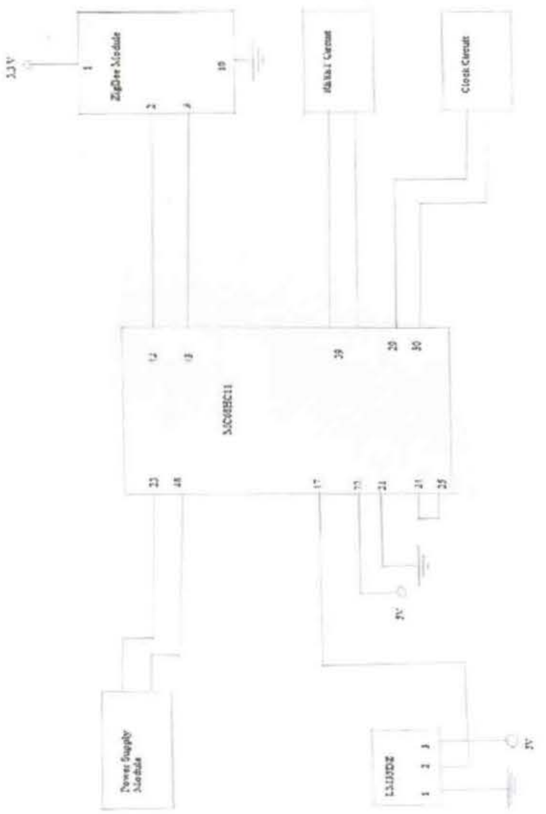
[19] http://www.embeddedrelated.com/groups/hc11/show/7298.php

[20] http://www.compwisdom.com/topics/Motorola-68HC11

Appendix A

Circuit schematic

Transmitter Circuit



Receiver Circuit

Appendix B

Source code

Source code for transmitter circuit

```
                ORG     $B600
REG             EQU     $1000
OPTION          EQU     $39
ADCTL EQU       $30
ADR1            EQU     $31
SCCR1  EQU      $2C
SCCR2  EQU      $2D
SCSR            EQU     $2E
SCDR            EQU     $2F
BAUD            EQU     $2B
START           LDAA    #%10011000      ;enable ADC
                STAA    OPTION
                LDAA    #%00110000      ;00110000 = 9600 BAUD
                STAA    BAUD
                CLR     SCCR1
                LDAA    #$0C
                STAA    SCCR2           ;RECEIVER & TRANS. ENABLED
                CLR     SPCR
LOOP            LDAA #1                 ; Channel 1
                STAA    ADCTL           ; start conversion
                LDX     #$2000          ; delay time
next_delay      DEX
                CPX     #0
                BNE     next_delay

                LDAA    ADR1            ; read ADC value
                STAA    PORTB
                LDAB    SCSR            ; read first Status
                STAA    SCDR            ; save in TX Register
                BRA     LOOP
```

Source code for receiver circuit

```
        ORG    $B600
REG     EQU    $1000
SCCR1   EQU    $2C
SCCR2   EQU    $2D
SCSR    EQU    $2E
SCDR    EQU    $2F
BAUD    EQU    $2B
        LDX    REG
        CLRA
        STAA   SCCR1,X
        LDAA   #$0C
        STAA   SCCR2,X
        LDAA   #$30
        STAA   BAUD,X
LAGI    LDAA   SCSR,X
LOOP1   BRCLR  SCSR,X $20      LOOP1
        LDAA   SCDR,X
        STAA   SCDR,X
        JSR    DELAY1
LOOP2   BRCLR  SCSR,X $80      LOOP2
        STAA   SCDR,X
        JSR    DELAY1
LOOP3   BRCLR  SCSR,X $80      LOOP3
        STAA   SCDR,X
        JSR    DELAY1
        BRA    LAGI
DELAY1 LDAA   #$FF
ULANG1 DECA
        CMPA   #$0
        BRA   ULANG1
        RTS
```

Source code for VB GUI

```
Dim ScrByt As String
Dim Max, Min, current1, current2, max1, max2, min1, min2 As Integer

Private Sub Command1_Click()
On Error GoTo Err
If MSComm1.PortOpen = True Then
MSComm1.PortOpen = False
Else
MSComm1.CommPort = VScroll1.Value
MSComm1.RThreshold = 2
MSComm1.InputLen = 2
MSComm1.InputMode = comInputModeText
MSComm1.PortOpen = True
Command1.Enabled = False
Command2.Enabled = True
Text1.Enabled = False
Label11.Caption = "Connected"
VScroll1.Enabled = False
logging.Enabled = True
End If
Exit Sub
Err:
MsgBox "Please choose another port" & PortNumb, vbCritical, "Comm port error"
End Sub

Private Sub Command2_Click()
logging.Value = False
logging.Enabled = False
VScroll1.Enabled = True
Command2.Enabled = False
Command1.Enabled = True
```

```
Text1.Enabled = True

Label11.Caption = "Disconnected"
MSComm1.PortOpen = False
End Sub

Private Sub Command3_Click()
Shell "Notepad.exe" & VbApp.Path & "\log.txt", vbNormalNoFocus
End Sub

Private Sub Command4_Click()
MsgBox "Copyright Reserved 2009, Universiti Malaysia Pahang" & About, vbInformation, "Editor Information"
End Sub

Private Sub Command5_Click()
End
End Sub

Private Sub Form_Load()
logging.Enabled = False
Timer1.Enabled = False
Option1.Value = True
MSComm1.Settings = "9600,N,8,1"
MSComm1.CommPort = 1
VScroll1.Value = 1
Command2.Enabled = False
End Sub

Private Sub logging_Click()
If logging.Value = 1 Then
Timer1.Enabled = True
Else
```

```
Timer1.Enabled = False
End If
End Sub

Private Sub MSComm1_OnComm()
If MSComm1.CommEvent = 2 Then
SerByt = MSComm1.Input
Label1.Caption = Hex(Asc(Mid$(SerByt, 1, 1)))

If Max < Label1.Caption Then Max = Label1.Caption
If Min > Label1.Caption Then Min = Label7.Caption

'Current
current1 = Label1.Caption + 273
Label2.Caption = currentt1
current2 = Label1.Caption * (9 / 5) + 32
Label3.Caption = current2

'Maximum
Label4.Caption = Max
max1 = Max + 273
Label5.Caption = max1
max2 = Max * (9 / 5) + 32
Label6.Caption = max2

'Minimum
Label7.Caption = Min
min1 = Min + 273
Label8.Caption = min1
min2 = Min * (9 / 5) + 32
Label9.Caption = min2
End If
End Sub
```

```
Private Sub Option1_Click()

Timer1.Interval = 1000

End Sub


Private Sub Option2_Click()

Timer1.Interval = 2000

End Sub


Private Sub Option3_Click()

Timer1.Interval = 3000

End Sub


Private Sub Option4_Click()

Timer1.Interval = 4000

End Sub


Private Sub Option5_Click()

Timer1.Interval = 5000

End Sub


Private Sub Timer1_Timer()

Open App.Path & "\log.txt" For Append As #1

Print #1, Format$(Date$, "DD/MM/YYYY"), Time$, Label1.Caption; "°C", Label4.Caption; "°C",
Label7.Caption; "°C"

Close #1

End Sub


Private Sub VScroll1_Change()

Text1.Text = CStr(VScroll1.Value)

End Sub
```

Appendix C

Datasheet for LM35DZ, MC68HC11, ZigBee and MAX233

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

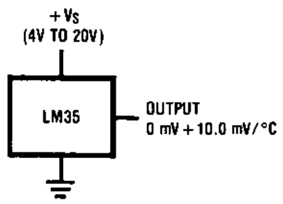
General Description

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

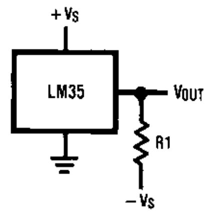
- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 μA current drain
- 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



DS005516-3

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



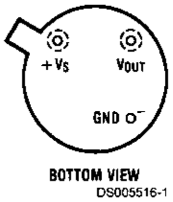
DS005516-4

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

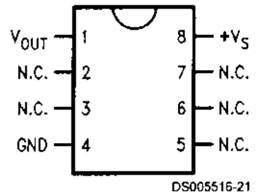
TO-46
Metal Can Package*



*Case is connected to negative pin (GND)

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

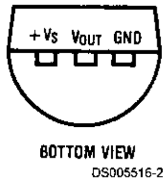
SO-8
Small Outline Molded Package



N.C. = No Connection

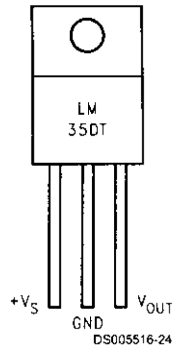
Top View
Order Number LM35DM
See NS Package Number M08A

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

Order this document
by MC68HC11A8TS/D

MC68HC11A8
MC68HC11A1
MC68HC11A0

Technical Summary
8-Bit Microcontrollers

1 Introduction

The MC68HC11A8, MC68HC11A1, and MC68HC11A0 high-performance microcontroller units (MCUs) are based on the M68HC11 Family. These high speed, low power consumption chips have multiplexed buses and a fully static design. The chips can operate at frequencies from 3 MHz to dc. The three MCUs are created from the same masks; the only differences are the value stored in the CONFIG register, and whether or not the ROM or EEPROM is tested and guaranteed.

For detailed information about specific characteristics of these MCUs, refer to the *M68HC11 Reference Manual* (M68HC11RM/AD).

1.1 Features

- M68HC11 CPU
- Power Saving STOP and WAIT Modes
- 8 Kbytes ROM
- 512 Bytes of On-Chip EEPROM
- 256 Bytes of On-Chip RAM (All Saved During Standby)
- 16-Bit Timer System
  - — 3 Input Capture Channels
  - — 5 Output Compare Channels
- 8-Bit Pulse Accumulator
- Real-Time Interrupt Circuit
- Computer Operating Properly (COP) Watchdog System
- Synchronous Serial Peripheral Interface (SPI)
- Asynchronous Nonreturn to Zero (NRZ) Serial Communications Interface (SCI)
- 8-Channel, 8-Bit Analog-to-Digital (A/D) Converter
- 38 General-Purpose Input/Output (I/O) Pins
  - — 15 Bidirectional I/O Pins
  - — 11 Input-Only Pins and 12 Output-Only Pins (Eight Output-Only Pins in 48-Pin Package)
- Available in 48-Pin Dual In-Line Package (DIP) or 52-Pin Plastic Leaded Chip Carrier (PLCC)

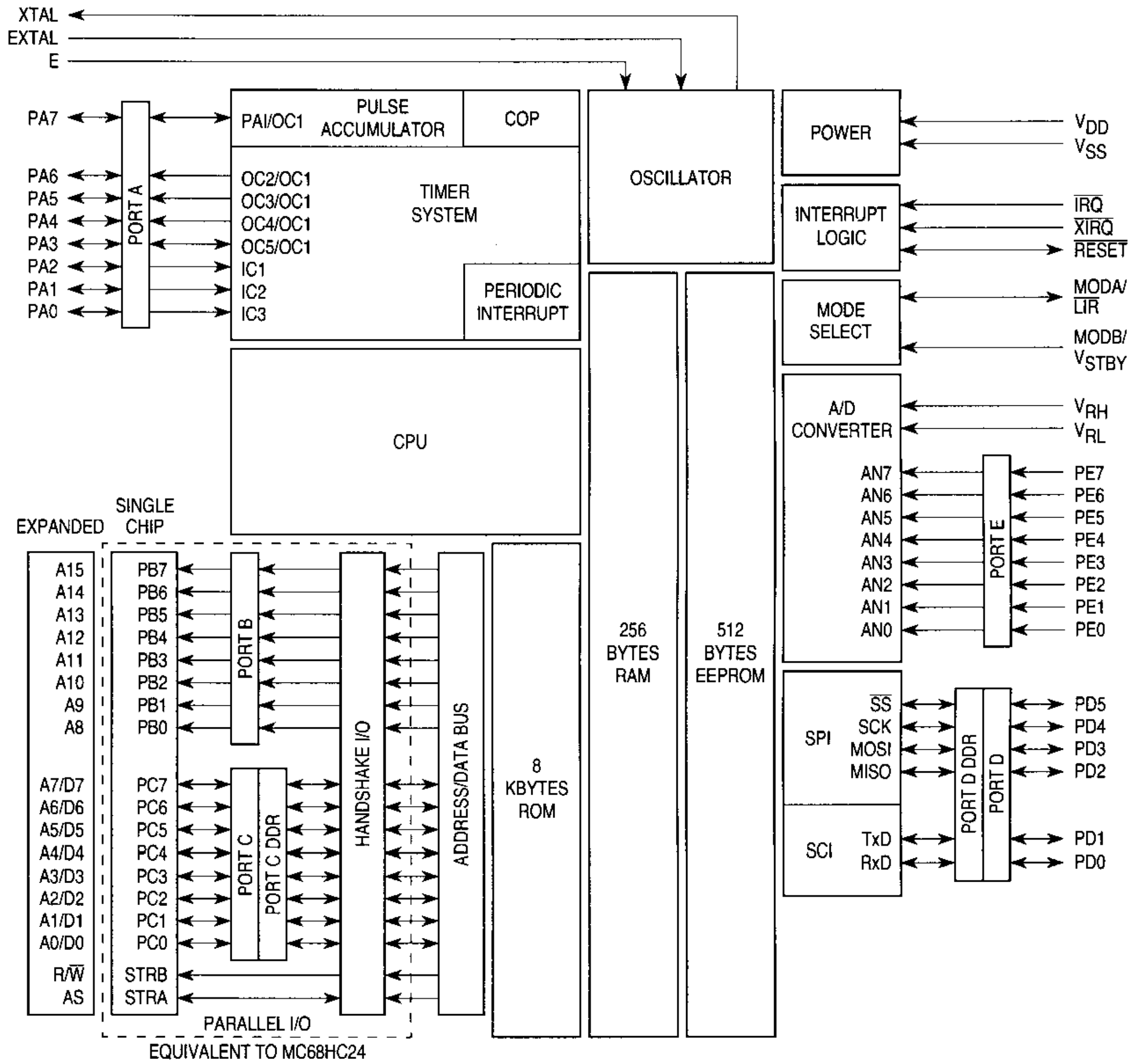


Figure 1 MC68HC11A8 Block Diagram

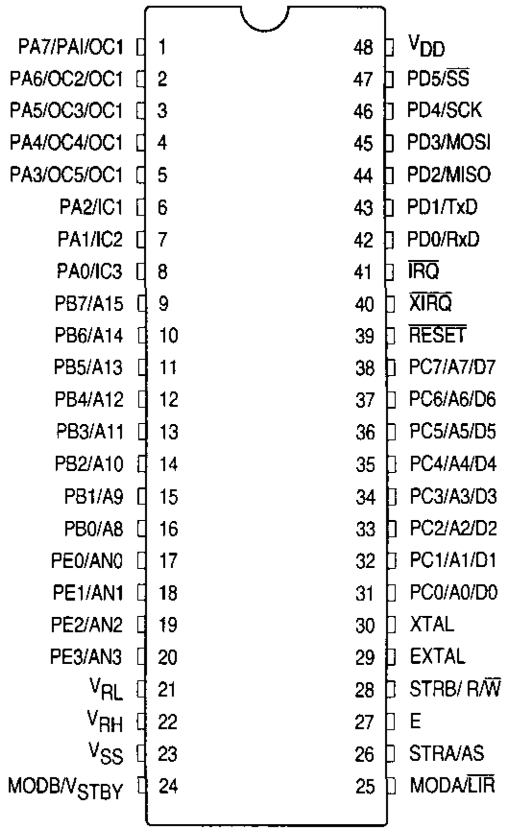


Figure 3 48-Pin DIP Pin Assignments

2 Operating Modes and Memory Maps

In single-chip operating mode, the MC68HC11A8 is a monolithic microcontroller without external address or data buses.

In expanded multiplexed operating mode, the MCU can access a 64 Kbyte address space. The space includes the same on-chip memory addresses used for single-chip mode plus external peripheral and memory devices. The expansion bus is made up of ports B and C and control signals AS and R/$\overline{W}$. The address, R/$\overline{W}$, and AS signals are active and valid for all bus cycles including accesses to internal memory locations. The following figure illustrates a recommended method of demultiplexing low-order addresses from data at port C.

1. XBee/XBee-PRO OEM RF Modules

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

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

1.1. Key Features

Long Range Data Integrity

XBee

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

XBee-PRO

- Indoor/Urban: up to 300' (100 m)
- Outdoor line-of-sight: up to 1 mile (1500 m)
- Transmit Power: 100 mW (20 dBm) EIRP
- Receiver Sensitivity: -100 dBm

RF Data Rate: 250,000 bps

Advanced Networking & Security

Retries and Acknowledgements

DSSS (Direct Sequence Spread Spectrum)

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

Source/Destination Addressing

Unicast & Broadcast Communications

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

Coordinator/End Device operations

Low Power

XBee

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

XBee-PRO

- TX Current: 215 mA (@3.3 V)
- RX Current: 55 mA (@3.3 V)
- Power-down Current: < 10 µA

ADC and I/O line support

Analog-to-digital conversion, Digital I/O

I/O Line Passing

Easy-to-Use

No configuration necessary for out-of box RF communications

Free X-CTU Software (Testing and configuration software)

AT and API Command Modes for configuring module parameters

Extensive command set

Small form factor

Free & Unlimited RF-XPert Support

1.1.1. Worldwide Acceptance

FCC Approval (USA) Refer to Appendix A [p57] for FCC Requirements. Systems that contain XBee/XBee-PRO RF Modules inherit MaxStream Certifications.

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

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

XBee/XBee-PRO RF Modules are optimized for use in the **United States**, **Canada**, **Australia, Israel and Europe**. Contact MaxStream for complete list of government agency approvals.

1.2. Specifications

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

Specification	XBee	XBee-PRO
Performance		
Indoor/Urban Range	up to 100 ft. (30 m)	Up to 300' (100 m)
Outdoor RF line-of-sight Range	up to 300 ft. (100 m)	Up to 1 mile (1500 m)
Transmit Power Output (software selectable)	1mW (0 dBm)	60 mW (18 dBm) conducted, 100 mW (20 dBm) EIRP*
RF Data Rate	250,000 bps	250,000 bps
Serial Interface Data Rate (software selectable)	1200 - 115200 bps (non-standard baud rates also supported)	1200 - 115200 bps (non-standard baud rates also supported)
Receiver Sensitivity	-92 dBm (1% packet error rate)	-100 dBm (1% packet error rate)
Power Requirements		
Supply Voltage	2.8 – 3.4 V	2.8 – 3.4 V
Transmit Current (typical)	45mA (@ 3.3 V)	If PL=0 (10dBm): 137mA(@3.3V), 139mA(@3.0V) PL=1 (12dBm): 155mA (@3.3V), 153mA(@3.0V) PL=2 (14dBm): 170mA (@3.3V), 171mA(@3.0V) PL=3 (16dBm): 188mA (@3.3V), 195mA(@3.0V) PL=4 (18dBm): 215mA (@3.3V), 227mA(@3.0V)
Idle / Receive Current (typical)	50mA (@ 3.3 V)	55mA (@ 3.3 V)
Power-down Current	< 10 µA	< 10 µA
General		
Operating Frequency	ISM 2.4 GHz	ISM 2.4 GHz
Dimensions	0.960" x 1.087" (2.438cm x 2.761cm)	0.960" x 1.297" (2.438cm x 3.294cm)
Operating Temperature	-40 to 85° C (industrial)	-40 to 85° C (industrial)
Antenna Options	Integrated Whip, Chip or U.FL Connector	Integrated Whip, Chip or U.FL Connector
Networking & Security		
Supported Network Topologies	Point-to-point, Point-to-multipoint & Peer-to-peer	
Number of Channels (software selectable)	16 Direct Sequence Channels	12 Direct Sequence Channels
Addressing Options	PAN ID, Channel and Addresses	PAN ID, Channel and Addresses
Agency Approvals		
United States (FCC Part 15.247)	OUR-XBEE	OUR-XBEEPRO
Industry Canada (IC)	4214A XBEE	4214A XBEEPRO
Europe (CE)	ETSI	ETSI (Max. 10 dBm transmit power output)*
Japan	n/a	005NYCA0378 (Max. 10 dBm transmit power output)**

* When operating in Europe: XBee-PRO RF Modules must be configured to operate at a maximum transmit power output level of 10 dBm. The power output level is set using the PL command. The PL parameter must equal "0" (10 dBm).

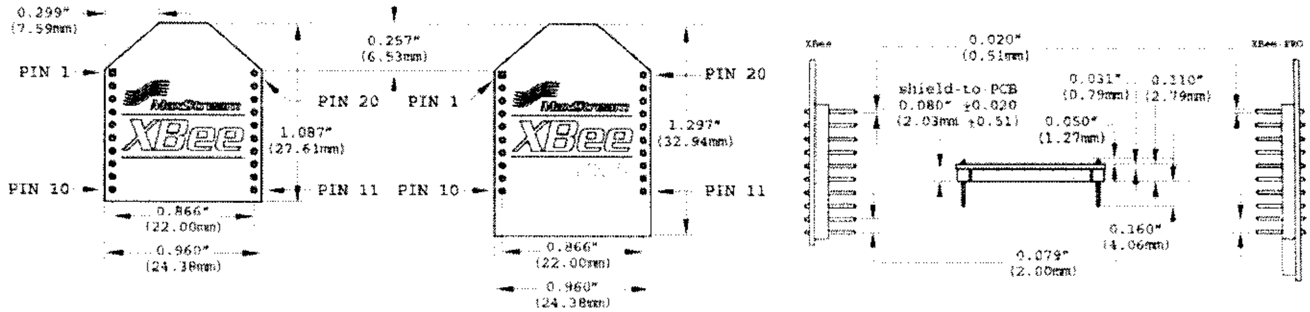
Additionally, European regulations stipulate an EIRP power maximum of 12.86 dBm (19 mW) for the XBee-PRO and 12.11 dBm for the XBee when integrating high-gain antennas.

** When operating in Japan: Transmit power output is limited to 10 dBm. A special part number is required when ordering modules approved for use in Japan. Contact MaxStream for more information [call 1-801-765-9885 or send e-mails to sales@maxstream.net].

Antenna Options: The ranges specified are typical when using the integrated Whip (1.5 dBi) and Dipole (2.1 dBi) antennas. The Chip antenna option provides advantages in its form factor; however, it typically yields shorter range than the Whip and Dipole antenna options when transmitting outdoors. For more information, refer to the "XBee Antenna" application note located on MaxStream's web site (http://www.maxstream.net/support/knowledgebase/article.php?kb=153).

1.3. Mechanical Drawings

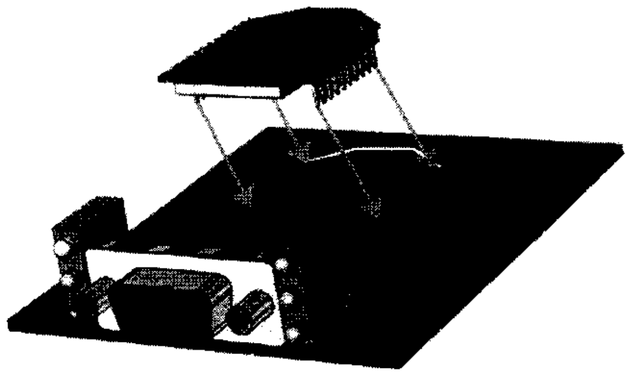
Figure 1-01. Mechanical drawings of the XBee/XBee-PRO OEM RF Modules (antenna options not shown)
The XBee and XBee-PRO RF Modules are pin-for-pin compatible.



1.4. Mounting Considerations

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

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



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

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

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

1.5. Pin Signals

Figure 1-03. XBee/XBee-PRO RF Module Pin Numbers
(top sides shown - shields on bottom)

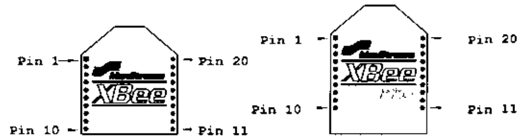


Table 1-02. Pin Assignments for the XBee and XBee-PRO Modules
(Low-asserted signals are distinguished with a horizontal line above signal name.)

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

* Function is not supported at the time of this release

Design Notes:

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

2. RF Module Operation

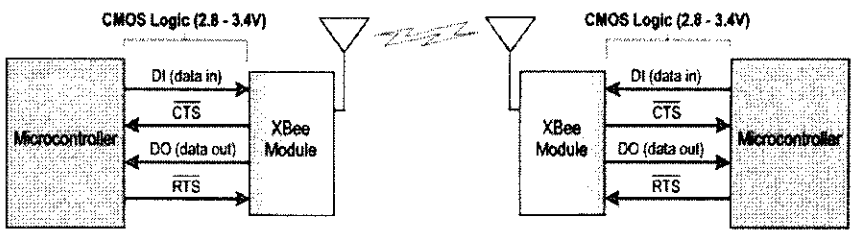
2.1. Serial Communications

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

2.1.1. UART Data Flow

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

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

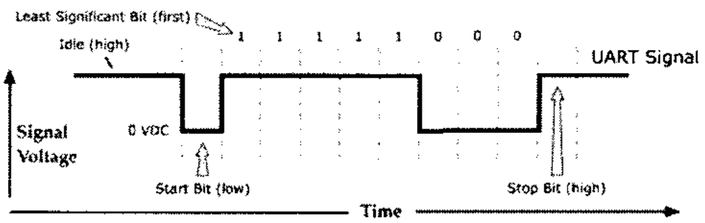


Serial Data

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

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

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



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

+5V-Powered, Multichannel RS-232 Drivers/Receivers

ABSOLUTE MAXIMUM RATINGS—MAX220/222/232A/233A/242/243

Supply Voltage (V_{CC}) ....-0.3V to +6V
Input Voltages
T_{IN} ....-0.3V to (V_{CC} - 0.3V)
R_{IN} (Except MAX220) ....±30V
R_{IN} (MAX220) ....±25V
T_{OUT} (Except MAX220) (Note 1) ....±15V
T_{OUT} (MAX220) ....±13.2V
Output Voltages
T_{OUT} ....±15V
R_{OUT} ....-0.3V to (V_{CC} + 0.3V)
Driver/Receiver Output Short Circuited to GND.........Continuous
Continuous Power Dissipation (T_A = +70°C)
16-Pin Plastic DIP (derate 10.53mW/°C above +70°C)....842mW
18-Pin Plastic DIP (derate 11.11mW/°C above +70°C)....889mW
20-Pin Plastic DIP (derate 8.00mW/°C above +70°C) ..440mW
16-Pin Narrow SO (derate 8.70mW/°C above +70°C) ...696mW
16-Pin Wide SO (derate 9.52mW/°C above +70°C)......762mW
18-Pin Wide SO (derate 9.52mW/°C above +70°C)......762mW
20-Pin Wide SO (derate 10.00mW/°C above +70°C)....800mW
20-Pin SSOP (derate 8.00mW/°C above +70°C) 640mW
16-Pin CERDIP (derate 10.00mW/°C above +70°C).....800mW
18-Pin CERDIP (derate 10.53mW/°C above +70°C).....842mW
Operating Temperature Ranges
MAX2_ _AC_ _, MAX2_ _C_ _ ....0°C to +70°C
MAX2_ _AE_ _, MAX2_ _E_ _ ....-40°C to +85°C
MAX2_ _AM_ _, MAX2_ _M_ _ ....-55°C to +125°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10s) ....+300°C

Note 1: Input voltage measured with T_{OUT} in high-impedance state, $\overline{SHDN}$ or V_{CC} = 0V.
Note 2: For the MAX220, V+ and V- can have a maximum magnitude of 7V, but their absolute difference cannot exceed 13V.

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 in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243

(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
RS-232 TRANSMITTERS					
Output Voltage Swing	All transmitter outputs loaded with 3kΩ to GND	±5	±8		V
Input Logic Threshold Low			1.4	0.8	V
Input Logic Threshold High	All devices except MAX220	2	1.4		V
	MAX220: V_{CC} = 5.0V	2.4			
Logic Pull-Up/Input Current	All except MAX220, normal operation		5	40	µA
	$\overline{SHDN}$ = 0V, MAX222/242, shutdown, MAX220		±0.01	±1	
Output Leakage Current	V_{CC} = 5.5V, $\overline{SHDN}$ = 0V, V_{OUT} = ±15V, MAX222/242		±0.01	±10	µA
	V_{CC} = $\overline{SHDN}$ = 0V, V_{OUT} = ±15V		±0.01	±10	
Data Rate			200	116	kbps
Transmitter Output Resistance	V_{CC} = V+ = V- = 0V, V_{OUT} = ±2V	300	10M		Ω
Output Short-Circuit Current	V_{OUT} = 0V	±7	±22		mA
RS-232 RECEIVERS					
RS-232 Input Voltage Operating Range				±30	V
RS-232 Input Threshold Low	V_{CC} = 5V; All except MAX243 $R2_{IN}$	0.8	1.3		V
	V_{CC} = 5V; MAX243 $R2_{IN}$ (Note 2)	-3			
RS-232 Input Threshold High	V_{CC} = 5V; All except MAX243 $R2_{IN}$		1.8	2.4	V
	V_{CC} = 5V; MAX243 $R2_{IN}$ (Note 2)		-0.5	-0.1	
RS-232 Input Hysteresis	All except MAX243, V_{CC} = 5V, no hysteresis in shdn.	0.2	0.5	1	V
	MAX243		1		
RS-232 Input Resistance		3	5	7	kΩ
TTL/CMOS Output Voltage Low	I_{OUT} = 3.2mA		0.2	0.4	V
TTL/CMOS Output Voltage High	I_{OUT} = -1.0mA	3.5	V_{CC} - 0.2		V
TTL/CMOS Output Short-Circuit Current	Sourcing V_{OUT} = GND	-2	-10		mA
	Shrinking V_{OUT} = V_{CC}	10	30		

ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243 (continued)

(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
TTL/CMOS Output Leakage Current	$\overline{SHDN}$ = V_{CC} or $\overline{EN}$ = V_{CC} ($\overline{SHDN}$ = 0V for MAX222), 0V ≤ V_{OUT} ≤ V_{CC}			±0.05	±10	µA
$\overline{EN}$ Input Threshold Low	MAX242			1.4	0.8	V
$\overline{EN}$ Input Threshold High	MAX242		2.0	1.4		V
Operating Supply Voltage			4.5		5.5	V
V_{CC} Supply Current ($\overline{SHDN}$ = V_{CC}), Figures 5, 6, 11, 19	No load	MAX220		0.5	2	mA
		MAX222/232A/233A/242/243		4	10	
	3kΩ load both inputs	MAX220		12		
		MAX222/232A/233A/242/243		15		
Shutdown Supply Current	MAX222/242	T_A = +25°C		0.1	10	µA
		T_A = 0°C to +70°C		2	50	
		T_A = -40°C to +85°C		2	50	
		T_A = -55°C to +125°C		35	100	
$\overline{SHDN}$ Input Leakage Current	MAX222/242				±1	µA
$\overline{SHDN}$ Threshold Low	MAX222/242			1.4	0.8	V
$\overline{SHDN}$ Threshold High	MAX222/242		2.0	1.4		V
Transition Slew Rate	C_L = 50pF to 2500pF, R_L = 3kΩ to 7kΩ, V_{CC} = 5V, T_A = +25°C, measured from +3V to -3V or -3V to +3V	MAX222/232A/233A/242/243	6	12	30	V/µs
		MAX220	1.5	3	30	
Transmitter Propagation Delay TLL to RS-232 (Normal Operation), Figure 1	t_{PHLT}	MAX222/232A/233A/242/243		1.3	3.5	µs
		MAX220		4	10	
	t_{PLHT}	MAX222/232A/233A/242/243		1.5	3.5	
		MAX220		5	10	
Receiver Propagation Delay RS-232 to TLL (Normal Operation), Figure 2	t_{PHLR}	MAX222/232A/233A/242/243		0.5	1	µs
		MAX220		0.6	3	
	t_{PLHR}	MAX222/232A/233A/242/243		0.6	1	
		MAX220		0.8	3	
Receiver Propagation Delay RS-232 to TLL (Shutdown), Figure 2	t_{PHLS}	MAX242		0.5	10	µs
	t_{PLHS}	MAX242		2.5	10	
Receiver-Output Enable Time, Figure 3	t_{ER}	MAX242		125	500	ns
Receiver-Output Disable Time, Figure 3	t_{DR}	MAX242		160	500	ns
Transmitter-Output Enable Time ($\overline{SHDN}$ Goes High), Figure 4	t_{ET}	MAX222/242, 0.1µF caps (includes charge-pump start-up)		250		µs
Transmitter-Output Disable Time ($\overline{SHDN}$ Goes Low), Figure 4	t_{DT}	MAX222/242, 0.1µF caps		600		ns
Transmitter + to - Propagation Delay Difference (Normal Operation)	t_{PHLT} - t_{PLHT}	MAX222/232A/233A/242/243		300		ns
		MAX220		2000		
Receiver + to - Propagation Delay Difference (Normal Operation)	t_{PHLR} - t_{PLHR}	MAX222/232A/233A/242/243		100		ns
		MAX220		225		

Note 3: MAX243 $R2_{OUT}$ is guaranteed to be low when $R2_{IN}$ is ≥ 0V or is floating.

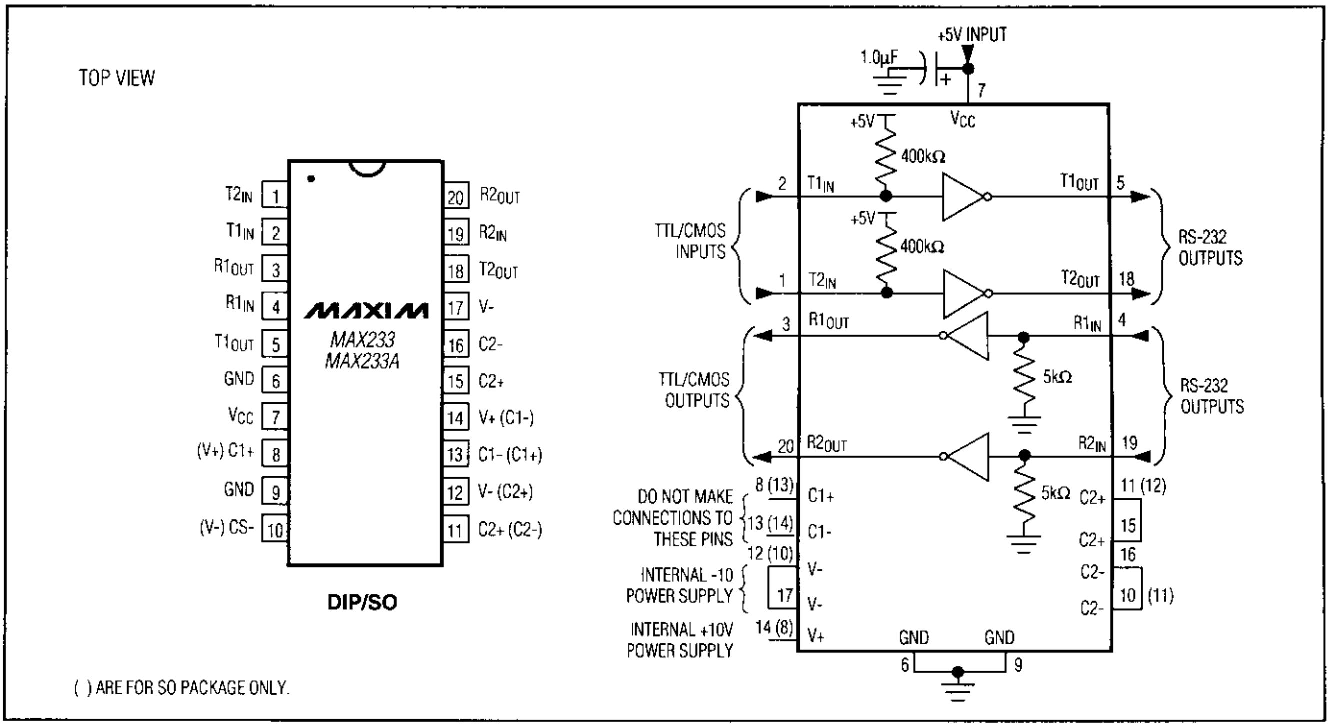


Figure 11. MAX233/MAX233A Pin Configuration and Typical Operating Circuit

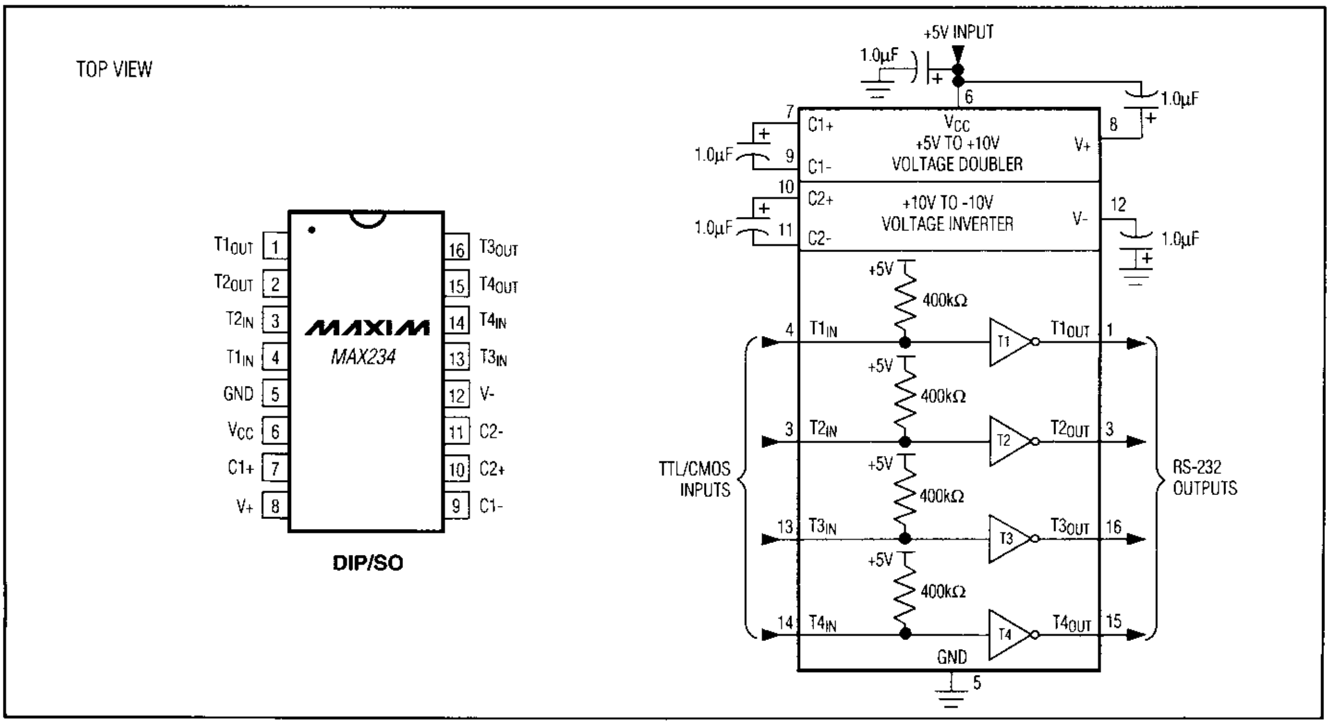


Figure 12. MAX234 Pin Configuration and Typical Operating Circuit