DISTRIBUTED EMBEDDED NON-LINEAR TEMPERATURE CONTROLLER

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Submitted By

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PROJECT REPORT

2002 – 2003

Under the guidance of

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In partial fulfillment of the requirements for the award of the degree of

Bachelor of Engineering in Mechatronics Engineering

By Bharathiar University

Department of Mechatronics Engineering

Kumaraguru College of Technology

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Project Report 2002 – 2003
CERTIFICATE

This is to certify that the report entitled

DISTRIBUTED EMBEDDED LON-LINEAR TEMPERATURE CONTROLLER

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13/3/2003

Guide

Head of the Department

The certificate was examined by us in the Project Work Viva-Voce Examination held on 21-MARCH-2003 and his University Registration Number is _____

Internal Examiner

External Examiner

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Synopsis

Temperature controllers are widely used in most of the industries today, starting from plastic setting to foundries, high precision controlled environments like annealing chambers. The control of these heaters has been initially by discrete electronic components for P/PI/PID control scheme, followed by non – linear era of the micro–processors and controllers. But in the modern era of total automation, there is a need to integrate all these temperature controllers in a nut shell to make it easier for the integration.

In this process the previous step was to establish an intelligent component capable of interacting with a network master. However this proved to be tedious having multiple lines running to the server, loading it a lot in multiplexing and performing the task of data acquisition and control.

The principle aim of the project is to propose a standard of communication that would suit the industrial environment, also to establish a distributed network with individual intelligent components for each process. These Intelligent devices would help in interacting with the network and would be connected in a common bus like structure reducing the number of cables running to the main system or the master.

Apart from this the trials to establish a master – slave relationship, a technique to drive the system into self sustained network of controllers were given a trial. A proposed plan to establish a command verb that would make the system's non – linear response into a programmable one was given a test run. But due to the noise restrictions of the transmission and memory restriction of the controller used, the idea has not been implemented, but added to the future expansion possibilities.

The features of the system includes data logging (one at a time basis), visual reading of data, power saving schemes of operation and network expansion up to 255 devices per control branch.

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1. Introduction

1.1 Modern Industries

In a period just a decade ago the industries were mechanically controlled with only motors as the electrical components. After this for a short span of period there were discrete circuits of electronic & electrical component working together with little ease. Now in the present day the industries are moving towards automation in faster pace. People started preferring small, compact, less power consuming yet the most flexible and reliable systems to work for them.

This trend calls for new devices and equipments that are smart enough to understand and operate depending upon the programmer and/or operator needs. Every device needs to be interlinked with the main network computer for easy data processing and maintaining the time schedule of operations. Such requirements have also been arising in industries that use furnaces and other means of heat control.

More reports and operation of such controllers and their reliability, flexibility etc. has been written to pages, proven in laboratories and implemented in most of the famous industries. Still there have been small problems like individual personal computer requirement for each of the system. One more problem in the implementation was the computers rigidity about its environment.

Now it is the high time to decide on two facts and aim at the two targets in same shot, namely,

1. Network that would not require individual computers
2. Intelligent controllers and communicator that is rugged in construction to suit the industrial environment.

1.2 The Project

The project aims in building a system that would satisfy the primary goals. The other objectives of the project are to establish a protocol that would be very suitable for the industries to implement with error free and maintenance free operation. The principle disadvantage of the electronic controls lie in the disturbances created by the noise by various coupling means like capacitive (in the circuit itself), Electro Magnetic

Interference (noise factors in the industrial environment), and power injected noises (due to high speed switching of power circuits and current fluctuation in large scale).

But the project aims to establish a flexible system, that would not suffer any of these draw backs and would maintain its accuracy to the proposed level in any of the worst said situations.

1.3 The Intelligent Technology

The project utilizes one the recent and fast technology namely the micro – controllers to work with. Micro controller (μC) is a single chip micro computer with all the requirements of small programmers built-in inside the chip. The main features inside them include:

- ✓ A core micro processor that includes
  - o Arithmetic and Logic Unit (ALU)
  - o Memory Addressing Unit (MAU)
  - o Special Access Control units (SAC)
  - o Control Unit
  - o Interrupt Managers
- ✓ In built Program memory (usually ROM)
- ✓ In built User memory (usually RAM)
- ✓ Timers / Counters
- ✓ Analog to Digital Converters (ADC)
- ✓ Special features like
  - o Watch Dog Timers
  - o Sleep mode
  - o Serial Port (USART)
  - o Parallel Ports
- ✓ Expansion sin compromise with ports
  - o External memory
  - o Input / output devices like keyboard and display

1.4 The Interface

There exist communication interfaces that are pre – defined and widely used in the industries. The project utilizes two of them namely RS232 (to interface with a personal computer) and the RS485 (to interface within the network of controllers). There are also converters used in the project that would convert the signals of RS232 to RS485 and vice versa. Care is taken to select a converter that would not compromise the speed but that would work with only one power supply and with least other restrictions.

1.5 The Program

Much care has been taken in writing the program with special utilities that would ease the operator to visualize the conditions of the system easily. The features include the collecting the samples of data and logging it to a file, visualizing graph (bar chart or line graph) about the temperature of a system.

To have a better visualization and good feel to use system, the program has been developed in Visual BASIC that is a good GUI (Graphical User Interface) package developed for windows platform. It supports multiple windows switching which would be very useful in this project to have a better command over the multiple inter faces with various systems. The programs work on time sharing basis and not on threading, which would be more flexible but complicated to control the ports.

1.6 The Minimum Requirements

The minimum requirements of the implementation would be:

1. A personal computer that would support Windows 9X/ME/2000 or NT
2. A serial port which is not used by mouse or any other device like modem
3. The RS485 daisy chain cable and its terminators with number of nodes as one greater than the number of control cards in the system.

2. Literature Survey

2.1 About Industrial Controller

Controllers are intelligent devices that are meant for directing the industrial components to behave in certain way so that the operator gets the output in his planned way. They may be discrete electronic circuits, micro processors, micro controllers, PLC's or other form of electronics equipments working in P, PI, PID, linear, non-linear or memory planned mode.

2.1.1 Types

The controllers can be widely classified as:

1. electronic Controller
    a. analog Controller
        i. linear Controller
            - P Controller
            - I Controller
            - D Controller
            - PI Controller
            - PD Controller
            - PID Controller
        ii. non-linear Controller
    b. digital Controller
        i. stand by Controller
        ii. networked Controller
    c. fuzzy Controller
    d. physical variable controlled devices
2. Non- electronic Controller
    a. Pneumatic Controller
    b. Hydraulic Controller
    c. CAM operated Controller
    d. Lever and spring chains Controller
    e. Physical variable controlled devices

Of these electronics controllers are regarded as the most reliable and flexible as they can be programmed to work in any style or pattern required. This demands a little skill and experience, yet they are easily attainable.

In certain places like high load operations, mechanical controls are most preferred. Certain devices like thermostat work both in mechanical and electronics basis. The primary objective of controllers is to attain the output what is desired irrespective of the adverse or unexpected input modifications.

2.1.2 Electronic Controllers

There are varieties of controllers in the electronics category. The controllers are implemented in various applications which demand the characteristics of the particular type. The brief explanation about each of them is as follows:

1. **P controllers**:

   This is an analog controller whose output is defined as *proportional* to input signal(s). The output is defined as the function of input without the previous history and is given by the equation

   $$P(y) = a_p x + b_p$$

   Where a_p = amplification

   b_p = origin shift value

   And both a_p and b_p are unrestricted. The application of this type includes the clipping, clamping and amplifier controls.

2. **I controllers**:

   This is an analog controller whose output is defined as *Integral* of input signal(s) with respect to time. The output is defined as the function of input with the previous history and is given by the equation

   $$I(y) = a_i \int x.\, dt + b_i$$

   Where a_i = amplification

   b_i = origin shift value

   And both a_i and b_i are unrestricted. The application of this control is in filter design and ramp output generation.

3. **D controllers**:

This is an analog controller whose output is defined as Differential of input signal(s) with respect to time. The output is defined as the function of input with the changes and is given by the equation

$$D(y) = a_d \, dx. / dt + b_d$$

Where a_d = amplification

b_d = origin shift value

And both a_d and b_d are unrestricted. The application of this control is in spikes output generation.

4. **PI controllers**:

This is a combinational analog controller whose output is defined as *function of Proportional and Integral values of input* signal(s) with respect to time. The output is defined as the function of input along with the history and is given by the equation

$$F(y) = f(P(x), I(x))$$

The relation may be linear or other type of functions depending upon the requirements.

5. **PD controllers**:

This is a combinational analog controller whose output is defined as *function of Proportional and Differential values of input* signal(s) with respect to time. The output is defined as the function of input along the changes in it and is given by the equation

$$F(y) = f(P(x), D(x))$$

The relation may be linear or other type of functions depending upon the requirements.

6. **PID controllers**:

This is a combinational analog controller whose output is defined as *function of Proportional, Integral and Differential values of input* signal(s) with

respect to time. The output is defined as the function of input, its history and the changes in it and is given by the equation

$$F(y) = f(P(x), I(x), D(x))$$

The relation may be linear or other type of functions depending upon the requirements.

7. **Non – linear controllers**:

These have the non-linearity in them. The output is defined as the multiple functions that would be chosen based on the input state. There is no restriction for number of equations, their condition, continuity, etc. and they are most non-standard form of controllers. This proves to be their flexibility as customized controllers. An example of this type of output implementation would be like:

$$F(y) = \begin{cases} 0 & \text{for } x<0 \\ 10x + 2, & \text{for } x<1 \\ 12 & \text{otherwise} \end{cases}$$

8. **Digital controllers**:

These are more advantageous features like flexible error free operation. They are also advantageous by the fact that they are easy for modification and implement the soft wired schemes like in PLC's. Also the use of computers is very easy and interface is fast and does not contain any sampling and quantizing errors.

They can act individually. Yet for the flexibility and data communication the controllers can be made to work in a network that would share data and certain common functions, features and other resources.

There are pre-defined protocols that specify the communication rules, data format, error correction features, type of wires to use, the maximum data rate, cable length, type and topology of network to be established, the mode of data transfer, the sequence of data, parity and other handshaking signals, type of connectors to use, the connectors in transmission and reception style, etc.

2.2 About Heaters

Heaters are nowadays considered to be the most widely seen application of electricity. They can be seen any where starting from kitchen toaster to water heaters, industrial heaters ranging from oil heaters to boilers, etc. The users of this device constitute about 30 – 40% of power users. And the place where they lose the power is wastage of energy in reheating the hot substance and certain times heating beyond the requirement without noticing. It is wise if we gain this by just turning OFF and ON the device whenever required but with least concern about it.

But it is not advisable to put a thermometer and a person in action. The industry is in need of some device that would save the energy wasted by the heaters. Most of the heaters are electrically controlled coils of NiChrome or other alloys. They can be easily controlled by controlling the input voltage to them or the current applied to them. The solution yesterday was to use a thermistor. Once a value of temperature is set in it, the value remains same. Wide degree of calibration is necessary to vary the values and run time modification is nearly impossible.

2.2.1 Frequency Heaters

These are the heaters used in industry where the heating is to a lower temperature or requires fast heating. The principle of heating is by eddy currents. Eddy current is the current generated in any core of the inductor due to induction. The core is simply a huge short circuited conductor with negligible resistance. Hence a small induced voltage would generate a very high current and heating would be at a very high rate. These are used as crucible heaters and more appropriate application is in heat treatment process where the core is replaced by the component to be hardened. After heating the component is cooled gradually or abruptly based on the hardening requirement.

2.2.2 Coil Heaters

These are the most commonly seen heaters in most of the domestic and small heating equipments. It contains a NiChrome coil acting as the heating element. NiChrome is an alloy of nickel and Chromium. Similar alloys have been finding enough application based on their features. The advantage of this heater is that they are voltage or current controlled. These two parameters are easy to control rather than the frequency which needs a good synchronized control and more devices.

2.3 About Temperature sensors

Most electronic sensors used in engineering fall into one of the two classes: resistive or thermoelectric type. Resistive devices may be either metallic or semiconductor, and require some form of bridge circuit for signal conditioning since they are modulating transducers. Thermo electric sensors or thermo couples are self generating, but their very low output means that an amplifier is always needed in practice. The thermal expansion of solids can also be used as a temperature transducer, for example to control thermostat opening in water-cooled IC engines.

2.3.1 Metallic RTD's

These transducers are similar in appearance to wire wound resistors and often take the form of a non-inductively wound coil of a suitable metallic wire such as platinum, copper, nickel or their alloys. The variation of resistance R with temperature T for most metallic materials can be represented by an equation of the form:

$R = R_o (1 + a_1T + a_2T^2 + a_3T^3 + \ldots + a_nT^n)$, where R_o is the resistance at the temperature $T = 0$.

2.3.2 Thermistors

Thermistors are small semi conducting transducers, usually manufactured in the shape of beads, disc, and rods. They are made by combining two or more metal oxides. If oxides of cobalt, copper, iron, magnesium, manganese, nickel, tin, titanium, vanadium or zinc are used, the resulting semiconductor is said to have a negative temperature co-efficient (NTC) of resistance. That is the resistance falls with the rise in temperature. Thermistors are markedly nonlinear (unlike metallic RTDs). The resistance temperature relation is usually in the form:

$R = R_o e^{\beta(1/T - 1/T_0)}$, where R_o is the nominal resistance at the temperature T_0 and β is a constant which is characteristic of thermistor material (in the order of 4000).

2.3.2 Thermocouples

Thermocouple is a self generating transducer comprising of two or more junction between dissimilar metals. It is necessary to maintain one of the junction at refernce temperature i.e. 0°C, melting ice temperature, the other end in the temperature to be measured (hot junction). But this is not practically possible for any measurement hence

the other way of using is to put a compensation network that would take care of the temperature shift. The thermocouple works on the Peltier's effect, which states the flow of emf from the hot junction to cold junction of dissimilar metals. The major advantage is the new junctions at any point but at the same temperature would not disturb the normal operation and a general condition of $T \rightarrow 0 = T \rightarrow T_{ref} + T_{ref} \rightarrow 0$ for output milli volts and for any unit of T within the measurable range of the thermo couples.

2.3.2.1 Types of Thermocouples

Type	Names of Materials	Range (°C)
B	Platinum30% Rhodium (+) Vs. Platinum 6% Rhodium (-)	0 to 1500
E	Chromel (+) Vs. Constantan (-) (Cr-Ni Vs. Cu-Ni)	-200 to 850
J	Iron (+) Vs. Constantan (-) (Fe Vs. Cu-Ni)	-200 to 850
K	*Chromel (+) Vs. Alumel (-) (Ni-Cr Vs Ni-Al)*	*-200 to 1100*
N	Nicrosil (+) Vs. Nisil (-) (Ni-Cr-Si Vs. Ni-Si-Mg)	-270 to 1300
R	Platinum 13% Rhodium (+) Vs. Platinum (-)	0 to 1500
S	Platinum 10% Rhodium (+) Vs. Platinum (-)	0 to 1500
T	Copper (+) Vs Constantan (-) (Cu Vs. Cu-Ni)	-250 to 400

2.3.2.2 Accuracy & Advantages of thermocouple

Type	Range (°C)	Accuracy (±°C)	Advantages
B	0 – 100 1100 – 1550	3 4	Best life expectancy at high temperatures
E	0 – 400	3	Resistant to oxidizing atmospheres
J	0 – 300 300 – 850	3 1	Low cost general purpose
K	0 – 400 400 – 1100	3 1	General purpose, good in oxidizing environment
R, S	0 – 1100 1100 – 1400 1400 – 1500	1 2 3	High temperature Corrosion resistant
T	0 – 100 100 – 400	1 1%	High resistance to corrosion by water

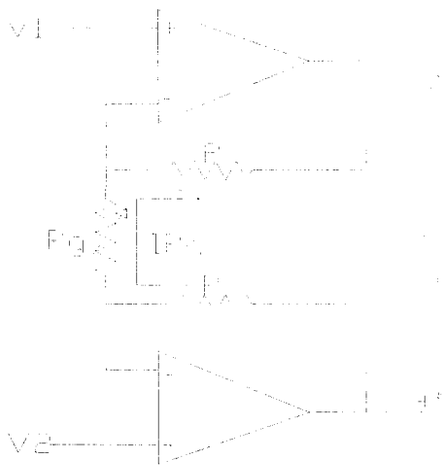
2.4 About Instrumentation Amplifier

Instrumentation amplifier is a common type of application of opamp. It is a dedicated differential amplifier with extremely high input impedance. Its gain can be precisely set by a single external resistor. The high common mode rejection makes the amplifier very useful in recovering small signals buried in large common mode offsets and noises. The major advantage of this type of amplifier is as follows:

1. The common mode signals are totally rejected.
2. The input resistance for common mode signals is infinite.
3. The differential inputs need not be grounded (as required by the thermocouple).
4. The gain can be tuned to any value as desired.

2.4.1 Input stage

The input stage consists of two carefully matched opamp's. These opamp's are configured as voltage a follower that produces the instrumentation amplifiers very high input impedance. The outputs of the opamp's are connected to string of resistors.



Since both opamp terminals are at same potential the voltage across the resistor R_g is given by

$$V_{Rg} = V_2 - V_1 = I_{RG} R_G$$

$$I_{RG} = (V_2 - V_1) / R_G$$

This current must flow through all the resistors as opamp never accepts any current in input terminals. So the output voltage must be,

$$V_O = I_{RG} (2R + R_G)$$

$$V_O = (V_2 - V_1) (2R + R_G) / R_G$$

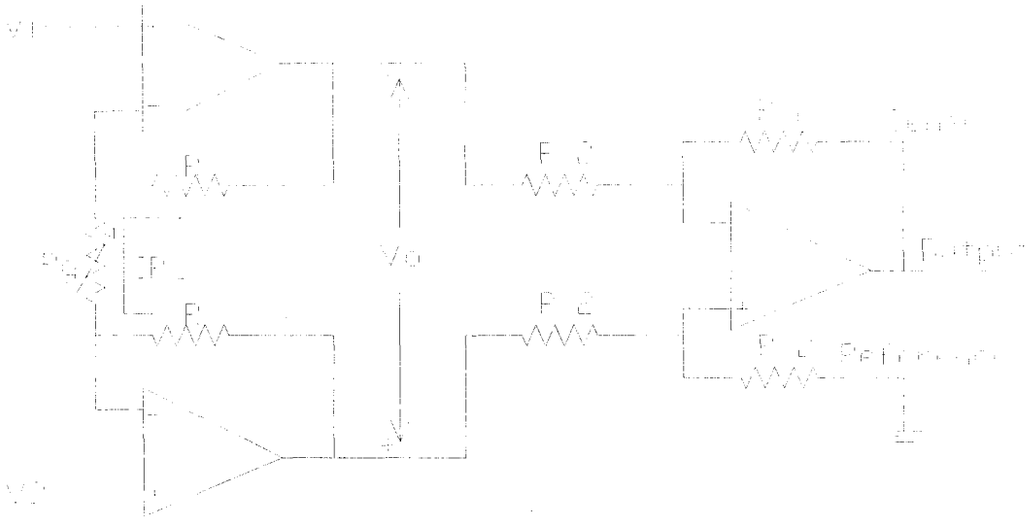
$$V_O = (V_2 - V_1) (2R / R_G + 1),$$

which shows that Increase in R_g would reduce the gain and vice versa.

2.4.2 Output stage

The output stage is simply a differential feedback amplifier. The output is difference of inputs multiplied by the ratio of resistance in each of the respective strings.

2.4.3 Final Circuit



The total output of the circuit is the difference between the inputs amplified by the fact of (2R/Rg +1). The input side never gets loaded, i.e. the input circuit need not supply any current or the demand will be very low. This makes the instrumentation amplifier the best suited for the thermocouple application.

Any common noise pickup by the thermocouple wires will be taken care off by the differential amplifier, whose CMRR (common mode rejection ratio) is theoretically infinite and practically of the order of 10^8.

2.5 About RS232

2.5.1 Introduction

All IBM PC and compatible computers are typically equipped with two serial ports and one parallel port. Although these two types of ports are used for communicating with external devices, they work in different ways.

A parallel port sends and receives data eight bits at a time over 8 separate wires. This allows data to be transferred very quickly; however, the cable required is more bulky because of the number of individual wires it must contain. Parallel ports are typically used to connect a PC to a printer and are rarely used for much else. A serial port sends and receives data one bit at a time over one wire. While it takes eight times as long to transfer each byte of data this way, only a few wires are required. In fact, two-way (full duplex) communications is possible with only three separate wires - one to send, one to receive, and a common signal ground wire.

2.5.2 Bi-Directional Communications

The serial port on your PC is a full-duplex device meaning that it can send and receive data at the same time. In order to be able to do this, it uses separate lines for transmitting and receiving data. Some types of serial devices support only one-way communications and therefore use only two wires in the cable - the transmit line and the signal ground.

2.5.3 Communicating by Bits

Once the start bit has been sent, the transmitter sends the actual data bits. There may either be 5, 6, 7, or 8 data bits, depending on the number selected. Both receiver and the transmitter must agree on the number of data bits, as well as the baud rate. Almost all devices transmit data using either 7 or 8 data bits.

Notice that when only 7 data bits are employed, ASCII values greater than 127 cannot be sent. Likewise, using 5 bits limits the highest possible value to 31. After the data has been transmitted, a stop bit is sent. A stop bit has a value of 1 - or a mark state - and it can be detected correctly even if the previous data bit also had a value of 1. This is accomplished by the stop bit's duration. Stop bits can be 1, 1.5, or 2 bit periods in length.

The RS-232C standard describes a communication method where information is sent bit by bit on a physical channel. The information must be broken up in data words. The length of a data word is variable. On PC's a length between 5 and 8 bits can be selected. This length is the net to information length of each word. For proper transfer additional bits are added for synchronisation and error checking purposes. It is important, that the transmitter and receiver use the same number of bits. Otherwise, the data word may be misinterpreted, or not recognized at all.

With synchronous communication, a clock or trigger signal must be present which indicates the beginning of each transfer. The absence of a clock signal makes an asynchronous communication channel cheaper to operate. Fewer lines are necessary in the cable. A disadvantage is that the receiver can start at the wrong moment receiving the information. Resynchronization is then needed which costs time. All data received in the resynchronization period is lost. Another disadvantage is that extra bits are needed in the data stream to indicate the start and end of useful information. These extra bits take up bandwidth.

Data bits are sent with a predefined frequency, the baud rate. Both the transmitter and receiver must be programmed to use the same bit frequency. After the first bit is received, the receiver calculates at which moments the other data bits will be received. It will check the line voltage levels at those moments.

The line voltage level can have two states. The on state is also known as **marking**, the off state as **spacing**. No other line states are possible. When the line is idle, it is kept in the marking state.

Start bit – RS-232C defines an asynchronous type of communication. This means, that sending of a data word can start on each moment. If starting at each moment is possible, this can pose some problems for the receiver to know that is the first bit to receive. To overcome this problem, each data word is started with an attention bit. This attention bit, also known as the start bit, is always identified by the space line level. Because the line is in marking state when idle, the start bit is easily recognized by the receiver.

Data bits – Directly following the start bit, the data bits are sent. A bit value 1 causes the line to go in marking state; the bit value 0 is represented by a space. The least significant bit is always the first bit sent.

Parity bit – For error detecting purposes, it is possible to add an extra bit to the data word automatically. The transmitter calculates the value of the bit depending on the information sent. The receiver performs the same calculation and checks if the actual parity bit value corresponds to the calculated value.

Stop bits – Suppose that the receiver has missed the start bit because of noise on the transmission line. It started on the first following data bit with a space value. This causes garbled date to reach the receiver. A mechanism must be present to resynchronize the communication. To do this, framing is introduced. Framing means, that all the data bits and parity bit are contained in a frame of start and stop bits. The period of time lying between the start and stop bit is a constant defined by the baud rate and number of data and parity bits. The start bit has always space value, the stop bit always marking value. If the receiver detects a value other than marking when the stop bit should be present on the line, it knows that there is a synchronization failure. This causes a framing error condition in the receiving UART. The device then tries to resynchronize on new incoming bits.

For re-synchronizing, the receiver scans the incoming data for valid start and stop bit pairs. This works, as long as there is enough variation in the bit patterns of the data words. If data value zero is sent repeatedly, resynchronization is not possible for example.

The stop bit identifying the end of a data frame can have different lengths. Actually, it is not a real bit but a minimum period of time the line must be idle (marking state) at the end of each word. On PC's this period can have three lengths: the time equal to 1, 1.5 or 2 bits. 1.5 bits is only used with data words of 5 bits length and 2 only for longer words. A stop bit length of 1 bit is possible for all data word sizes.

2.5.4 The Parity Bit

Besides the synchronization provided by the use of start and stop bits, an additional bit called a parity bit may optionally be transmitted along with the data. A parity bit affords a small amount of error checking, to help detect data corruption that might occur during transmission. The choices for are: even parity, odd parity, mark parity, space parity or none at all. When even or odd parity is being used, the number of marks (logical '1' bits) in each data byte are counted, and a single bit is transmitted following the data bits to indicate whether the number of 1 bits just sent is even or odd.

For example, when even parity is chosen, the parity bit is transmitted with a value of 0 if the number of preceding marks is an even number. For the binary value of 0110 0011 the parity bit would be 0. If even parity was in effect and the binary number 1101 0110 was sent, then the parity bit would be 1. Odd parity is just the opposite, and the parity bit is 0 when the number of mark bits in the preceding word is an odd number. Parity error checking is very rudimentary. While it will tell if there is a single bit error in the character, it doesn't show which bit was received in error. Also, if an even number of bits is in error then the parity bit would not reflect any error at all.

Mark parity means that the parity bit is always set to the mark signal condition and likewise space parity always sends the parity bit in the space signal condition. Since these two parity options serve no useful purpose whatsoever, they are almost never used.

2.5.5 RS-232C

RS-232 stands for Recommend Standard number 232 and C is the latest revision of the standard. The serial ports on most computers use a subset of the RS-232C standard. The full RS-232C standard specifies a 25-pin "D" connector of which 22 pins are used. Most of these pins are not needed for normal PC communications, and indeed, most new PCs are equipped with male D type connectors having only 9 pins.

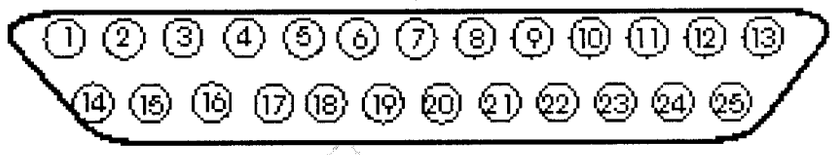
2.5.6 DCE and DTE Devices

DTE stands for Data Terminal Equipment, and DCE stands for Data Communications Equipment. These terms are used to indicate the pin-out for the connectors on a device and the direction of the signals on the pins. Your computer is a DTE device, while most other devices are usually DCE devices.

The RS-232 standard states that DTE devices use a 25-pin male connector, and DCE devices use a 25-pin female connector. DTE device to a DCE using a straight pin-for-pin connection can be used. However, to connect two like devices, instead a null modem cable must be used. Null-modem cables interchange the connections between transmit and receive lines in the cable, and are discussed later in this chapter.

2.5.7 Pin connections

The listing below shows the connections and signal directions for both 25 and 9-pin connectors:

25 Pin Connector on a DTE device (PC connection)	
Male RS232 DB25	
Pin #	Direction of signal:
1	Protective Ground
2	Transmitted Data (TD) Outgoing Data (from a DTE to a DCE)
3	Received Data (RD) Incoming Data (from a DCE to a DTE)
4	Request To Send (RTS) Outgoing flow control signal controlled by DTE
5	Clear To Send (CTS) Incoming flow control signal controlled by DCE
6	Data Set Ready (DSR) Incoming handshaking signal controlled by DCE
7	Signal Ground Common reference voltage
8	Carrier Detect (CD) Incoming signal from a modem
20	Data Terminal Ready (DTR) Outgoing handshaking signal controlled by DTE
22	Ring Indicator (RI) Incoming signal from a modem

9 Pin Connector on a DTE device (PC connection)	
Male RS232 DB9	
Pin #	**Direction of signal:**
1	Carrier Detect (CD) (from DCE) Incoming signal from a modem
2	Received Data (RD) Incoming Data from a DCE
3	Transmitted Data (TD) Outgoing Data to a DCE
4	Data Terminal Ready (DTR) Outgoing handshaking signal
5	Signal Ground Common reference voltage
6	Data Set Ready (DSR) Incoming handshaking signal
7	Request To Send (RTS) Outgoing flow control signal
8	Clear To Send (CTS) Incoming flow control signal
9	Ring Indicator (RI) (from DCE) Incoming signal from a modem

The **TD (transmit data)** wire is the one through which data from a DTE device is transmitted to a DCE device. This name can be deceiving, because this wire is used by a DCE device to receive its data. The TD line is kept in a mark condition by the DTE device when it is idle.

The **RD (receive data)** wire is the one on which data is received by a DTE device, and the DCE device keeps this line in a mark condition when idle.

RTS stands for **Request To Send**. This line and the CTS line are used when "hardware flow control" is enabled in both the DTE and DCE devices. The DTE device puts this line in a mark condition to tell the remote device that it is ready and able to receive data. If the DTE device is not able to receive data (typically because its receive buffer is almost full), it will put this line in the space condition as a signal to the DCE to stop sending data. When the DTE device is ready to receive more data (i.e. after data has been removed from it's receive buffer), it will place this line back in the mark condition.

The complement of the RTS wire is **CTS**, which stands for **Clear To Send**. The DCE device puts this line in a mark condition to tell the DTE device that it is ready to receive the data. Likewise, if the DCE device is unable to receive data, it will place this line in the space condition. Together, these two lines make up what is called RTS/CTS or "hardware" flow control. The Software Wedge supports this type of flow control, as well as Xon/XOff or "software" flow control. Software flow control uses special control characters transmitted from one device to another to tell the other device to stop or start sending data. With software flow control the RTS and CTS lines are not used.

DTR stands for **Data Terminal Ready**. Its intended function is very similar to the RTS line. DSR (Data Set Ready) is the companion to DTR in the same way that CTS is to RTS. Some serial devices use DTR and DSR as signals to simply confirm that a device is connected and is turned on. The Software Wedge sets DTR to the mark state when the serial port is opened and leaves it in that state until the port is closed. The DTR and DSR lines were originally designed to provide an alternate method of hardware handshaking. It would be pointless to use both RTS/CTS and DTR/DSR for flow control signals at the same time. Because of this, DTR and DSR are rarely used for flow control.

CD stands for **Carrier Detect**. Carrier Detect is used by a modem to signal that it has a made a connection with another modem, or has detected a carrier tone.

The last remaining line is **RI** or **Ring Indicator**. A modem toggles the state of this line when an incoming call rings your phone.

The Carrier Detect (CD) and the Ring Indicator (RI) lines are only available in connections to a modem. Because most modems transmit status information to a PC when either a carrier signal is detected (i.e. when a connection is made to another modem) or when the line is ringing, these two lines are rarely used.

2.5.8 9 to 25 Pin Adapters

The following table shows the connections inside a standard 9 pin to 25 pin adapter.

9-Pin Connector	25 Pin Connector
Pin 1 DCD	Pin 8 DCD
Pin 2 RD	Pin 3 RD
Pin 3 TD	Pin 2 TD
Pin 4 DTR	Pin 20 DTR
Pin 5 GND	Pin 7 GND
Pin 6 DSR	Pin 6 DSR
Pin 7 RTS	Pin 4 RTS
Pin 8 CTS	Pin 5 CTS
Pin 9 RI	Pin 22 RI

2.5.9 Baud vs. Bits per Second

The baud unit is named after Jean Maurice Emile Baudot, who was an officer in the French Telegraph Service. He is credited with devising the first uniform-length 5-bit code for characters of the alphabet in the late 19th century. What baud really refers to is modulation rate or the number of times per second that a line changes state. This is not always the same as bits per second (BPS). If two serial devices are connected together using direct cables then baud and BPS are in fact the same. Thus, if line is at 19200 BPS, then the line is also changing states 19200 times per second. But when considering modems, this isn't the case.

Because modems transfer signals over a telephone line, the baud rate is actually limited to a maximum of 2400 baud. This is a physical restriction of the lines provided by the phone company. The increased data throughput achieved with 9600 or higher baud

modems is accomplished by using sophisticated phase modulation, and data compression techniques.

2.5.10 Cables, Null Modems, and Gender Changers

In a perfect world, all serial ports on every computer would be DTE devices with 25-pin male "D" connectors. All other devices to would be DCE devices with 25-pin female connectors. This would allow using a cable in which each pin on one end of the cable is connected to the same pin on the other end. Unfortunately, we don't live in a perfect world. Serial ports use both 9 and 25 pins; many devices can be configured as either DTE or DCE, and - as in the case of many data collection devices - may use completely non standard or proprietary pin-outs. Because of this lack of standardization, special cables called null modem cables, gender changers and custom made cables are often required.

2.5.11 Cables Lengths

The RS-232C standard imposes a cable length limit of 50 feet. This starndard can usually be ignored, since a cable can be as long as 10000 feet at baud rates up to 19200 if a high quality, well shielded cable is used. The external environment has a large effect on lengths for unshielded cables. In electrically noisy environments, even very short cables can pick up stray signals. The following chart offers some reasonable guidelines for 24 gauge wire under typical conditions.

Baud Rate	Shielded Cable Length	Unshielded Cable Length
110	5000	1000
300	4000	1000
1200	3000	500
2400	2000	500
4800	500	250
9600	250	100

The cable length can be extended by using additional devices like optical isolators and signal boosters. Optical isolators use LEDs and Photo Diodes to isolate each line in a serial cable including the signal ground. Any electrical noise affects all lines in the optically isolated cable equally - including the signal ground line. This causes the voltages on the signal lines relative to the signal ground line to reflect the true voltage of the signal and thus canceling out the effect of any noise signals.

2.5.12 Null Modem Cables and Null Modem Adaptors

If two DTE devices (or two DCE devices) are connected using a straight RS232 cable, then the transmit line on each device will be connected to the transmit line on the other device and the receive lines will likewise be connected to each other. A Null Modem cable or Null Modem adapter simply inter connects receive and transmit lines so that transmit on one end is connected to receive on the other end and vice versa. In addition to transmit and receive, DTR & DSR, as well as RTS & CTS are also crossed in a Null modem connection.

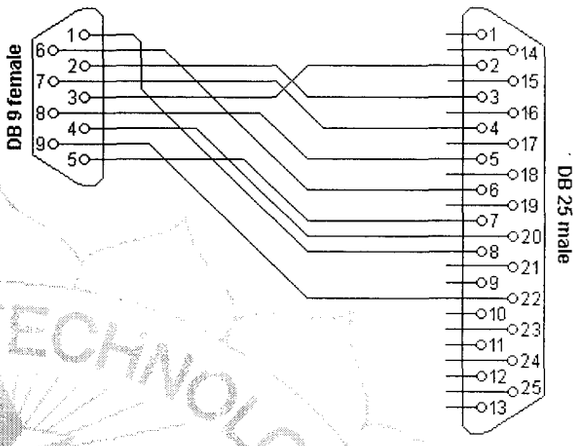
2.5.13 Synchronous and Asynchronous Communications

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 sync. Even when data is not really being sent, a constant flow of bits allows each device to know where the other is at any given time. That is, each character that is sent is either actual data or an idle character. Synchronous communications allows faster data transfer rates than asynchronous methods, because additional bits to mark the beginning and end of each data byte are not required. The serial ports on IBM-style PCs are asynchronous devices and therefore only support asynchronous serial communications.

Asynchronous means "no synchronization", and thus does not require sending and receiving idle characters. However, the beginning and end of each byte of data must be identified by start and stop bits. The start bit indicate when the data byte is about to begin and the stop bit signals when it ends. The requirement to send these additional two bits cause asynchronous communications to be slightly slower than synchronous however it has the advantage that the processor does not have to deal with the additional idle characters. An asynchronous line that is idle is identified with a value of 1, (also called a mark state). By using this value to indicate that no data is currently being sent, the devices are able to distinguish between an idle state and a disconnected line. When a character is about to be transmitted, a start bit is sent. A start bit has a value of 0, (also called a space state). Thus, when the line switches from a value of 1 to a value of 0, the receiver is alerted that a data character is about to come down the line.

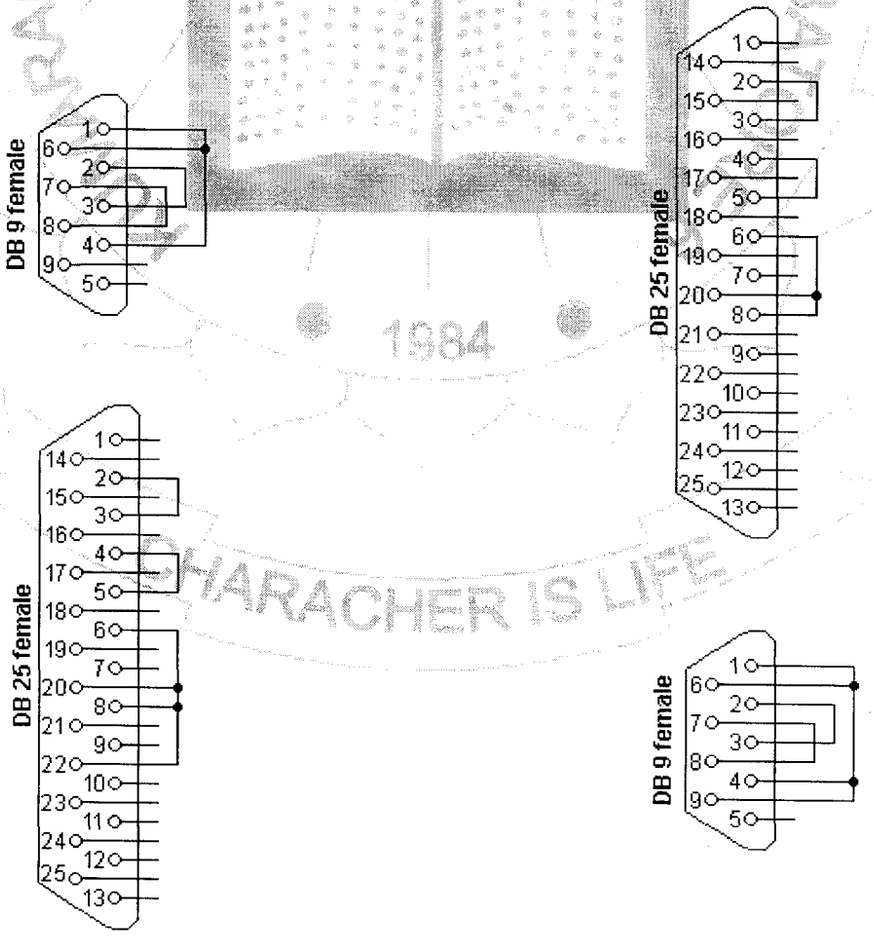
2.5.14 DB9 to DB25 converter

The original pin layout for RS232 was developed for a 25 pins sub D connector. Since the IBM-AT, 9 pins connectors are commonly used. In mixed applications, a 9 to 25 pins converter can be used to connect connectors of different sizes.



2.5.15 RS232 loop back test plug

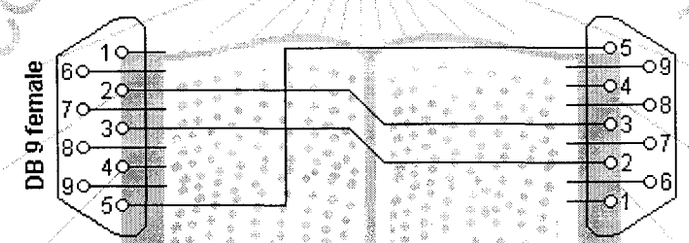
The following connectors can be used to test a serial port on your computer. The data and handshake lines have been linked. In this way all data will be sent back immediately. The PC controls its own handshaking. The first one (upper two connectors) can be used to check the function of the serial port with standard terminal software. The second version (lower two connectors) can be used to test the full functionality of the serial port with Norton Diagnostics or Check It.



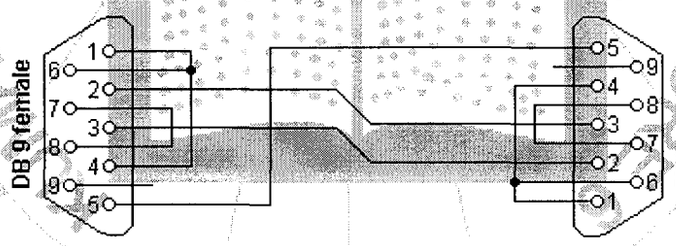
2.5.16 RS232 null modem cables

The easiest way to connect two PC's is using a null modem cable. The only problem is the large variety of null-modem cables available. For simple connections, a three line cable connecting the signal ground and receive and transmit lines is sufficient. Depending of the software used, some sort of handshaking may however be necessary. For a Windows 95/98 Direct Cable Connection, the null modem cable with loop back handshaking is a good choice. Null modem cables with handshaking can be defined in numerous ways, with loop back handshaking to each PC, or complete handshaking between the two systems. The most common cable types are shown here.

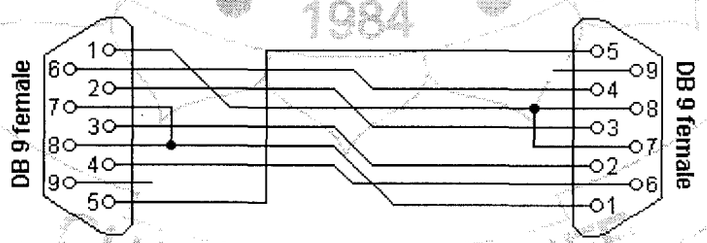
Simple null modem without handshaking



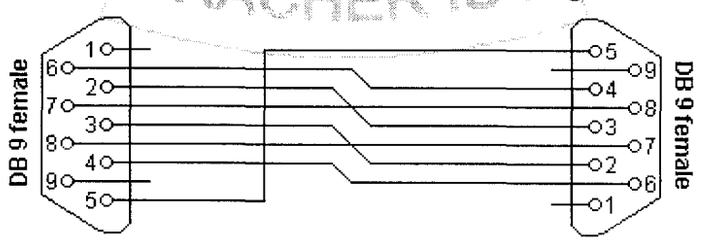
Null modem with loop back handshaking



Null modem with partial handshaking



Null modem with full handshaking



2.6 About RS485

2.6.1 Introduction

The interface popularly known as RS-485 is an electrical specification for multipoint systems that use balanced lines. RS-485 is similar to RS-422, but RS-422 allows just one driver with multiple receivers whereas RS-485 supports multiple drivers and receivers. The specification document (TIA/ EIA-485-A) defines the electrical characteristics of the line and its drivers and receivers. There are brief suggestions relating to terminations and wiring, but there's no discussion of connector pin outs or software protocols (as there is for RS-232).

An RS-485 network can have up to 32 unit loads, with one unit load equivalent to an input impedance of 12k. By using high-impedance receivers, there can be 256 nodes. An RS-485 link can extend as far as 4000feets and can transfer data at up to 10 Mbps, but not both at the same time. At 90 kbps, the maximum cable length is 4000feets, at 1 Mbps it drops to 400feets, and at 10 Mbps it drops to 50feets. For more nodes or long distances, repeaters can be that regenerate the signals and begin a new RS-485 line.

Although the RS-485 standard says nothing about protocols, most RS-485 links use the familiar asynchronous protocols supported by the UARTs in PCs and other computers. A transmitted word consists of a start bit followed by data bits, an optional parity bit, and a stop bit.

Two ways to add RS-485 to a PC are on an expansion card and by attaching an RS-485 converter to an existing port. Converters for RS-232 are widely available and Inside Out Networks has developed a USB–to–RS-485 converter. On microcontrollers, an RS-485 transceiver can be connected to any asynchronous serial port.

Many network circuits also require a port bit to control each transceiver's driver-enable input. Ports designed for RS-232 communications can use the RTS output. If that's not available, any spare output bit will do. Most serial-eommunications tools, including Visual Basic's MSComm, support RS-485 communications with RTS controlled in software. The COMM-DRV serial port drivers from WCSC have automatic

RTS control built-in. The main reason why RS-485 links can extend so far is their use of balanced, or differential, signals. Two wires (usually a twisted pair) carry the

signal voltage and its inverse. The receiver detects the difference between the two. Because most noise that couples into the wires is common to both wires, it cancels out. In contrast, interfaces like RS-232 use unbalanced, or single-ended, signals. The receiver detects the voltage difference between a signal voltage and a common ground.

The ground wire tends to be noisy because it carries the return currents for all of the signals in the interface, along with whatever other noise has entered the wire from other sources. And noise on the ground wire can cause the receiver to misread transmitted logic levels. The datasheets for interface chips label the non inverted RS-485 line as line A and the inverted line as line B.

An RS-485 receiver must see a voltage difference of just 200 mV between A and B. If A is at least 200 mV greater than B, the receiver's output is logic high. If B is at least 200 mV greater than A, the output is a logic low. For differences less than 200 mV, the output is undefined. At the driver, the voltage difference must be at least 1.5 V, so the interface tolerates a fair amount of non-common mode noise and attenuation.

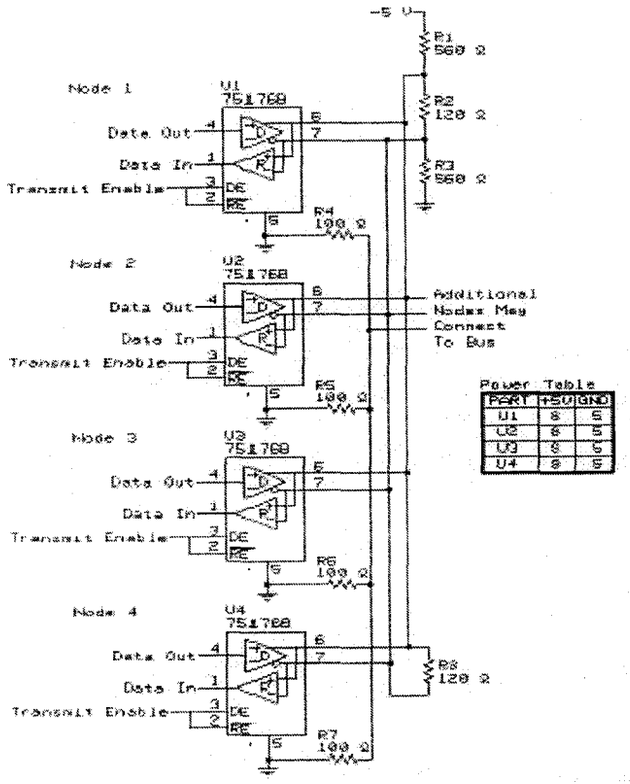
RS-485 is designed to be wired in a daisy-chain or bus topology. Any stubs that connect a node to the line should be as short as possible. Most links use twisted pairs because of their ability to cancel magnetically and electromagnetically coupled noise.

2.6.2 General-Purpose Link

Each node has a Texas Instruments SN75176B transceiver that interfaces between RS-485 and TTL logic levels. The chip has a two-wire RS-485 interface, a TTL driver input and receiver output, and TTL enable inputs for the driver and receiver. Similar chips include Linear Technology's LTC485, Maxim's MAX485, and National Semiconductor's DS3695. The circuit has two 120-W terminating resistors connected in parallel, at or just beyond the final node at each end of the link. One end of the link also has two 560-W biasing resistors.

The terminations reduce voltage reflections that can cause the receiver to misread logic levels. The receiver sees reflected voltages as output switches, and the line settles from its initial current to its final current. The termination eliminates reflections by making the initial and final currents equal. The initial current is a function of the line's characteristic impedance, which is the input impedance of an infinite open line.

The value varies with the wires' diameters, the spacing between them, and the insulation type. For digital signals (which consist mainly of frequencies greater than 100 kHz), the characteristic impedance is mostly resistive; the inductive and capacitive components are small.



A typical value for 24-AWG twisted pair is 120 W. The final current is a function of the line termination, the receivers' input impedance, and the line's series impedance. In a typical RS-485 line without a termination, the initial current is greater than the final current because the characteristic impedance is less than the receivers' combined input impedance. On a line without a termination, the first reflection occurs when the initial current reaches the receiver. The receiver's input can absorb only a fraction of the current.

The rest reflects back to the driver. As the current reverses direction, its magnetic field collapses and induces a voltage on the line. As a result, the receiver initially sees a greater voltage than what was transmitted. When the reflected voltage reaches the driver, which has lower impedance than the line, the driver absorbs some of the reflection and bounces the rest back to the receiver.

This reflection is of opposite polarity to the first reflection and causes the receiver to see a reduced voltage. The reflections bounce back and forth like this for a few rounds before they die out and the line settles to its final current. If the line terminates with a resistor equal to the line's characteristic impedance, there are no reflections. When the initial current reaches the termination, it sees exactly what it was expecting—a load equal to the line's characteristic impedance. The entire transmitted voltage drops across the load. In a network with two parallel terminations, the drivers drive two lines with each

ending at a termination. The biasing resistors hold the line in a known state when no drivers are enabled.

Most RS-485 transceivers have internal biasing circuits, but adding a termination defeats their ability to bias the line. A typical internal circuit is a 100-kW pull up from line A to V+, and a 100-kW pull down from line B to ground. With no termination and when no drivers are enabled, the biasing resistors hold line A more positive than line B. When two 120-W terminations are added, the difference between A and B shrinks to a few milli volts, much less than the required 200 mV. The solution is to add smaller resistors in parallel with the internal biasing so that a greater proportion of the series voltage drops across the termination.

The size of the biasing resistors is a tradeoff. For a greater voltage difference and higher noise immunity on an idle line, use smaller values. For lower power consumption and a greater differential voltage on a driven line, use larger values. When the receiver is disabled, the receiver's output is high impedance. If the output doesn't connect to a input with an internal pull up, adding a pull up here ensures that the node doesn't see false start bits when its receiver is disabled.

To comply with the specification, all of the nodes must share a common ground connection. This ground may be isolated from earth ground. The ground wire provides a path for the current that result from small imbalances in the balanced line. If the A and B outputs balance exactly with equal, opposite currents, the two currents in the ground wire cancel each other out and the wire carries no current at all.

In real life, components don't balance perfectly; one driver will be a little stronger and one receiver will have slightly larger input impedance. Without a common ground, the circuit may work, but the energy from the imbalance has to go somewhere and may dissipate as electromagnetic radiation.

The RS-485 specification recommends connecting a 100-W resistor of at least 0.5 W in series between each node's signal ground and the network's ground wires. This way, if the ground potentials of two nodes vary, the resistors limit the current in the ground wire.

2.6.3 Simplified Low-Power Link

Adding terminations increases a link's power consumption. With two parallel 120-W terminations and a differential output of 1.5 V, the current through the combined terminations is 25 mA (disregarding the effects of biasing, attenuation, etc.). Without terminations, the load is the parallel combination of the receivers' input impedances and varies with the number of receivers. The maximum 32-unit loads have a combined parallel impedance of 375 W to ground or V+.

For some shorter and slower links, power can be saved and components by not using terminating and biasing components. This option is feasible if the line is electrically short, which means it behaves as a lumped, rather than distributed, system. On a short line, the reflections die out long before the receiver is ready to read the signal. A general guideline is that a line is short if the rise time of its signals is greater than four times the signals' one way delay. The one-way delay is the amount of time needed for a signal to travel from the driver to the receiver.

It's a function of the line's physical length and the speed of signals in the line. In copper wire, a typical speed is two-thirds the speed of light, which works out to 8" per nano second. Cable manufacturers often specify a value for products likely to be used in network wiring. The rise time is specified in the driver's datasheet. The slowest chip is Maxim's MAX3080, with a minimum rise time of 667 ns.

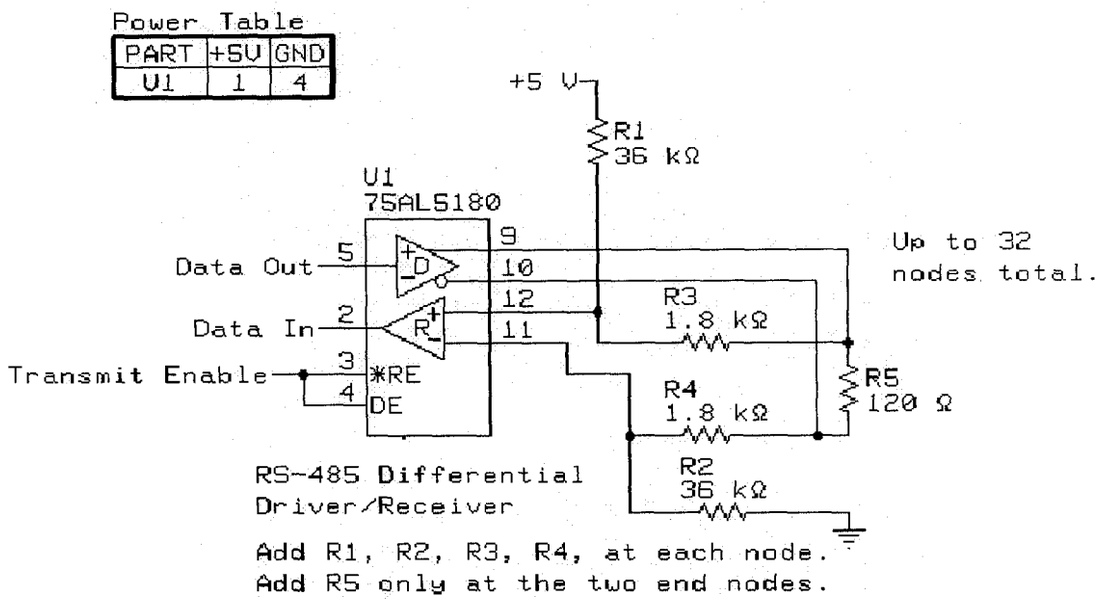
With cables of up to 100², the rise time is greater than four times the one-way delay (4 × 150 ns), so the line behaves as a short line and doesn't need terminating or biasing. Another advantage is that the internal biasing pulls idle lines to nearly V+ and ground, greater noise immunity is obtained. The downside to using this chip is that the slow rise time means that it's rated for use only at 115,200 bps or less.

2.6.4 Short-Circuit Protection

The previous circuits ensured that the line was in a predictable state when idle or open. Instead of a single pair of biasing resistors for the entire line, the circuit has four biasing resistors at each node. The circuit uses Texas Instruments 75ALS180B transceivers, which have full-duplex RS-485 inputs and outputs. The separate transmit and receive pairs enable the receiver to have its own series biasing resistors. The two RS-485 lines connect just beyond the biasing circuits. If the signal lines short together, the

1.8-kW series resistors in combination with the 36-kW biasing resistors hold input A more positive than B.

The node can't communicate with the network if the line is open or shorted, but at least it remains in an idle state (with no false start bits) until the problem is fixed. Another way to accomplish the same thing is to use transceivers with built-in fail-safe protection for open and short circuits. Chips that have this feature take varying approaches. Linear Technologies' LTC1482 has a carrier-detect function that brings the receiver's output high when the differential input voltage is too small to be a valid logic level.

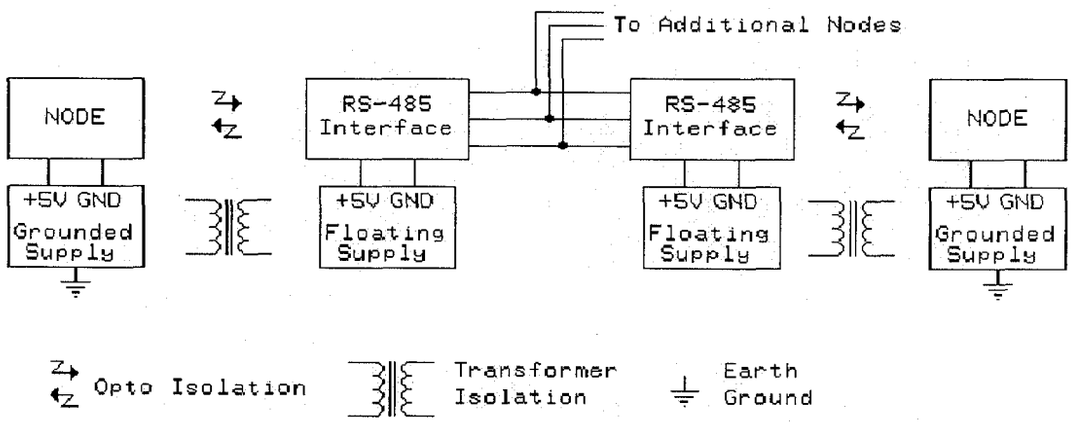


The chip has a carrier detect output that indicates when the line is in an invalid state. National Semiconductor's DS36276 has internal circuits that bring the receiver's output high if the line is shorted or open. Maxim's MAX3080–89 series provide short circuit biasing by redefining the threshold for logic 0. Instead of specifying all differential inputs of less than 200 mV as undefined, these chips define a differential voltage of –50 mV or greater as a logic 0. Voltages equal to or more negative than –200 mV remain defined as logic 1s. The only undefined region is from –50 to –200 mV. With these definitions, a shorted line (which results in a differential input of 0 V) is a logic 0, which results in a high output at the receiver.

2.6.5 Isolated Link

The entire RS-485 network has to share a ground, but the network can be galvanically isolated from other circuits the network connects to as well as from earth ground. All RS-485 components must be able to operate with common-mode voltages between –7 V and +12 V. Some components have higher ratings. The common mode voltage at the receiver equals half the sum of the two signal voltages, referenced to the receiver's signal ground.

The voltage varies with the differential signal voltages, the difference in ground potentials between the driver and receiver, and noise on the line. Where the ground connection is long, isolating the ground can ensure that the components don't exceed their ratings. Isolation also protects the circuits the network connects to if the network circuits are damaged by high voltage. Complete isolation requires isolating the power supplies and the network's signals. The power supplies typically use transformer isolation, whereas the signals use opto isolators.



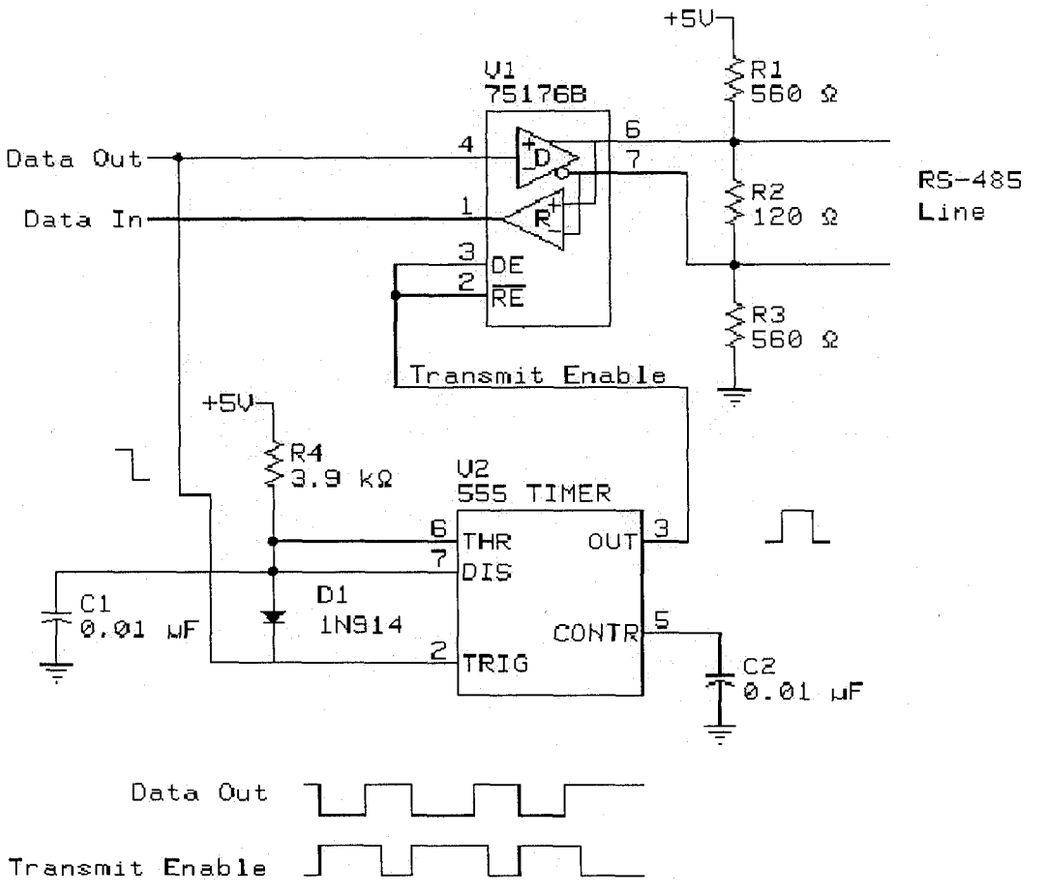
A one-chip way to achieve isolation is to use Maxim's MAX1480, which contains its own transformer-isolated supply and opto isolated signal path.

2.6.6 Auto-Switching Link

One of challenges in designing an RS-485 link is controlling the driver enable lines. Because all of the nodes share a data path, only one driver can be enabled at a time. Before transmitting, a driver must be sure that the previous driver has been disabled. Many RS-485 networks use a command response protocol; one node sends commands and the node being addressed returns a response. The UART in the node being addressed

detects the final stop bit in the middle of the bit width, or slightly sooner or later if the sender's clock doesn't match exactly.

A very fast node may be ready to send a reply within a few microseconds after detecting the stop bit. To prevent the need for a delay before responding, the sending node's driver should be disabled as soon as possible after the leading edge of its final stop bit. In most systems, the transmitting driver is enabled on the leading edge of the start bit and remains enabled for the entire transmission. It is disabled as soon as possible after the final stop bit. In the delays between transmissions, biasing holds the line in an idle state. There are various ways that the transmitting node can determine when a transmission has finished and it is safe to disable the driver. The node may read back what it sent, or it may use a hardware or software timer to estimate the time needed to transmit.



With this circuit, the program code doesn't have to toggle a signal to enable and disable the driver, and a transmitting driver doesn't need to allow extra time to be sure that the previous driver has been disabled. Unlike other methods of automatic control,

there are no jumpers to set for a particular bit rate. Instead of keeping the transmitter enabled for the entire transmission, the circuit enables the driver on the leading edge of the start bit or any logic low at the driver's input.

It also disables the driver ~40 μs after the leading edge of the stop bit or any logic high at the driver's input. When the driver is disabled, biasing resistors ensure the receiver's output is logic high. The delay is generated by a 555 timer configured as a mono stable (one shot). The enable inputs of the driver and receiver are tied together so the receiver is disabled when the driver transmits.

The timer's output controls the transceiver's enable inputs. A falling edge at Data Out indicates a start bit and triggers the timer. The timer's output goes high, enabling the driver and bringing line B more positive than line A. Diode feedback to the Trigger input holds the timer's output high for as long as Trigger remains low. When Data Out goes high, the RS-485 line switches, bringing line A more positive than line B. The same logic high also causes the timer to begin timing out.

About 40 μs after the rising edge, the timer's output goes low, disabling the driver. The delay ensures that the driver's RS-485 output switches without delay, while the driver is enabled. When the driver is disabled, the biasing components continue to hold A more positive than B. Similarly, any falling edges in the transmitted data enable the driver and any rising edges disable the driver after the delay.

On the final stop bit, the driver is disabled no later than 40 μs after the stop bit's leading edge. At rates of 9600 bps or less, the bit width is greater than 100 μs, which means the driver is disabled at around the middle of the bit width. At faster bit rates, the driver will still be disabled no more than 40 μs after the stop bit's leading edge. For networks needing very fast response time at faster bit rates, decrease R4 for a shorter delay.

A downside is that the final voltage for logic zeros is the biasing voltage, which is usually less than the differential voltage when the driver is enabled. But because the biasing voltage needs to be great enough to prevent errors from noise on an idle line, it should do the job for active logic states as well.

2.7 About Displays

2.7.1 Liquid crystal display (LCD)

LCD also are used as numerical indicators, especially in digital watches where their much smaller current needs than LED displays (microamperes compared with milli amperes) prolong battery life. Liquid crystals are organic (carbon) compounds, which exhibit both solid and liquid properties.

A 'cell' with transparent metallic conductors, called electrodes, on opposite daces, containing a liquid crystal, and on which light falls, goes 'dark' when a voltage is applied across the electrodes. The effect is due to molecular rearrangement within the liquid crystal.

There is a pattern of the conducting electrodes on a seven-segment LCD decimal display for producing the numbers 0 to 9. Only the liquid crystal under those electrodes to which the voltage is applied goes 'dark'.

The display has a silvered background which reflects back incident light and it is against this continuously visible background (except in darkness when it has to be illuminated) that the numbers shown up as dark segments. An LED display is lit only when required. LCD requires an AC supply to drive them using special circuitry. They are more expensive than LED displays.

2.7.2 Filament display

This was one of the first seven-segment displays and is commonly used in petrol pumps. Like a domestic electric filament lamp, the segments consist of short-coiled lengths of tungsten wire, which get white hot and emit light when current passes through them. However, by operating at lower temperatures (e.g.. 1500^0C) their working life up to 100 000 hours. Each segment needs about 15mA at 5V.

2.7.3 Gas discharge display (GDD)

Each segment of a GDD consists of a glass tube containing mainly neon gas at low pressure, which produces a bright orange glow when a current is passed through it. Although about 170V is required to start the display, the current taken by a segment may only be about 200μA.

2.7.4 Fluorescent vacuum display

Blue-green light is produced when electrons, emitted from an electrically heated filament and controlled by the voltage on a wire mesh (the grid), strike a fluorescent screen in an evacuated glass tube. This type of display is used for some calculators.

LED, filament, gas discharge and fluorescent display generate their own light, i.e., are 'active' display and are most easily seen if the surrounding (ambient) light level is low. LCD is 'passive' display, viewed best in bright light since they are seen by reflected ambient light.

2.7.4 Light –Emitting Diode (LED)

The cathode lead is nearer the 'flat' at the base of the LED and some, but by no means all, manufacturers make it shorter than the anode lead.

2.7.4.1 Working

An LED consists of a junction diode made from the semi-conducting compound gallium arsenide phosphide. It emits light when light when forward biased, the colour depending on the composition and impurity content of the compound. At present red, yellow and green LED's are available. When a p-n junction diode is forward biased, electrons move across the junction from the n-type side to the p-type side where they recombine with holes near the junction.

The same occurs with holes going across the junction from the p-type side. Every recombination results in the release of a certain amount of energy, causing, in most semiconductors, a temperature rise. In gallium arsenide phosphide some of the energy is emitted as light, which gets out of the LED because the junction is formed very close to the surface of the material. An LED does not light when reverse biased and if the bias is 5V or more it may be damaged.

2.7.4.2 External resistor

Unless LED is of the 'constant-current type (incorporating an integrated circuit regulator use on a 2 to 18 V DC or AC supply), it must have an external resistor R connected in series to limit the forward current which, typically, may be 10 mA (0.01 A).

Taking the voltage drop (V_f) across a conducting LED to be about 1.7V, R can be calculated approximately from R = (supply voltage – 1.7) / 0.01 A. For example, on a 5 V supply, R = 3.3/0.01 = 330 Ω.

2.7.4.3 Uses

LED's are used as indicator lamps, particularly in digital electronic circuits to show whether the output is 'high' or 'low'. One way of using an LED is to test for a 'high' output (9V in this case) and for a 'low' output (0V). In the first case the output acts as the 'source' of the LED current and in the second it has to be able to accept or 'sink' the current. If the output is unable to supply the current required by the LED, the circuit of can be employed. Here the output supplies the small base current to the transistor, which then drives the LED.

2.7.4.4 Decimal Display

Many electronic calculators, clocks, each registers and measuring instruments have seven-segment red or green LED displays as numerical indicators. Each segment is an LED and depending on which segments are energized, the display lights up the numbers 0 to 9. Such displays are usually designed to work on a 5 V supply.

Each segment needs a separate current-limiting resistor and all the cathodes (or anodes) are joined together to form a common connection. The advantages of LED are small size, reliability, long small current requirement and high operating speed.

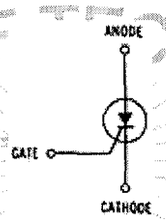
2.7.4.5 Opto-switch (opto isolator)

This consists of an LED combined with a phototransistor in the same package. It allows the transfer of signals (on-off digital or continuously varying analogue) from one circuit to another that cannot be connected electrically to the first because, for example, it works at a different voltage. Light (or infrared) from the LED falls on the phototransistor which is shielded from outside light. The insulation between the two is typically 2kV. Slotted opto-switches like the one shown are used for the detection of liquid levels and as event counters to indicate for instance, when the end of a tape has passed through the slot.

2.8 About SCR

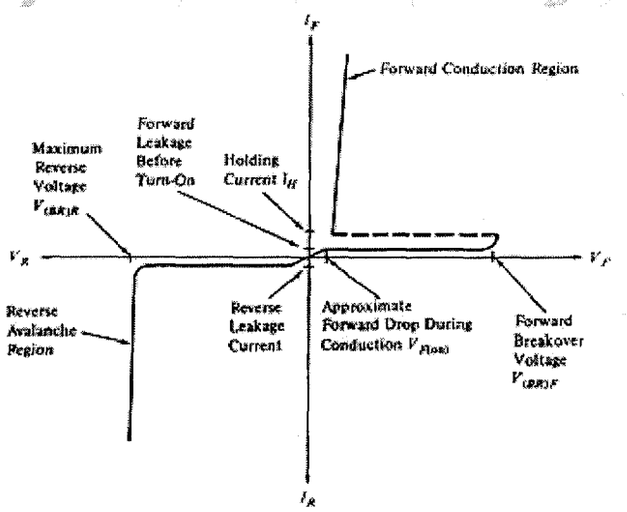
2.8.1 Introduction

The Silicon Controlled Rectifier (SCR) is simply a conventional rectifier controlled by a gate signal. The main circuit is a rectifier, however the application of a forward voltage is not enough for conduction. A gate signal controls the rectifier conduction. *The schematic representation is:*



2.8.2 VI Characteristic

The rectifier circuit (anode-cathode) has a low forward resistance and a high reverse resistance. It is controlled from an off state (high resistance) to the on state (low resistance) by a signal applied to the third terminal, the gate. Once it is turned on it remains on even after removal of the gate signal, as long as a minimum current, the holding current, Ih, is maintained in the main or rectifier circuit. To turn off an SCR the anode-cathode current must be reduced to less than the holding current, Ih. *The characteristic curve is as shown below.*



V–I characteristics of the SCR with gate open.

The reverse characteristics are the same as the rectifier or diode, having a break over voltage with its attending avalanche current; and a leakage current for voltages less than the break over voltage. However, in the forward direction with open gate, the SCR remains essentially in an off condition (notice though that there is a small forward leakage) up until the forward break over voltage is reached. At that point the curve snaps back to a typical forward rectifier characteristic. The application of a small forward gate voltage switches the SCR onto its standard diode forward characteristic for voltages less than the forward break over voltage.

Obviously, the SCR can also be switched by exceeding the forward break over voltage, however this is usually considered a design limitation and switching is normally controlled with a gate voltage. One serious limitation of the SCR is the rate of rise of voltage with respect to time, dV/dt. A large rate of rise of circuit voltage can trigger an SCR into conduction. This is a circuit design concern. Most SCR applications are in power switching, phase control, chopper, and inverter circuits.

2.8.3 Considerations

Major considerations when ordering a SCR are:

(a) Peak forward and reverse breakdown voltages

(b) Maximum forward current

(c) Gate trigger voltage and current

(d) Minimum holding current,Ih

(e) Power dissipation

(f) Maximum dV/dt

2.9 About PCB

2.9.1 Introduction

A printed circuit is a wiring arrangement that is fabricated by means of foil runs on the circuit board. Printed circuits can be mass produced inexpensively and efficiently. Printed circuits allow extreme miniaturization and high reliability. Most electronic

devices today are built using Printed –Circuit technology, although high power circuits still use point to point wiring methods.

Printed circuits are fabricated by first drawing and etching pattern. This pattern is then photograph and reproduced on clear plastic sheet. The plastic sheet is placed over a copper coated glass epoxy or phenolic board, and then the assembly under goes a photochemical process. And the resulting copper coated board consists of the printed tracks which interconnects the components as per the schematic design.

2.9.2 Advantages of PCB

- ✓ Size of the circuit is greatly reduced.
- ✓ Assembly of the components is very easier.
- ✓ Production time is greatly reduced.
- ✓ Trouble shooting is very easier and faster.
- ✓ It reduces the failure rate of the components due to rigid assembly.
- ✓ Since the component assembly is very easier using unskilled labors reduces the production costs.
- ✓ PCB's allow integration of small value of capacitance, resistance and inductors to be formed with the tracks itself. So, external components with lower values can be reduced significantly.
- ✓ Using PCB's although reduces the sizes of the product; it also increases the aesthetic appearance of it.
- ✓ PCB's also serve as support for other assemblies in rare cases.

2.9.3 Types of PCB

1. Single side board
2. Double side board
3. Multilayer Board

2.9.4 Do's and Don'ts

- ❖ The room should be well ventilated an exhaust fan should be installed in the room where a continuous work of PCB production goes on.
- ❖ Unnecessary contact with the solvents should be avoided.

- ❖ No operation should be carried out near open flames or in the presence of excessive heat.
- ❖ Containers for resist, developer, dye, thinner and rinse should be of glass, stainless steel of enamelware. Plastic should not be used while handling these chemicals.
- ❖ The containers and tanks should be kept covered when not in use.
- ❖ Water should not come in contact with these chemicals before use.
- ❖ The room should be lightened with a low-wattage yellow colored lamp for preparation of the board before exposure and for developing after exposure.

2.9.5 Tips to Simplify PCB Manufacturing

To begin with, collect the following items.

1. ***PCB Sheet:*** - Paper base is cheaper and should be enough for most of the projects.
2. ***Hand-drill and bit:*** - Small type in the workbench with a 0.8mm bit should do. Be careful in handling. Don't try to 'press' the hole with the drill-bit to drill it.
3. ***Quick-Set Etch Resistant Paint:*** - The French polish is equally good and they set quickly than the others. Enamel paints take much longer to get dry.
4. ***Painting Brush:*** - Water-color type, Go for something pointed, to draw narrow lines.
5. ***Etching Solution:*** - Ferric chloride (FeCl3) available in 500g packing can be used. Very pure quality is not required.
6. ***Dish:*** - Take an enameled dish, flat at the bottom and wide enough to accept the work piece. Avoid aluminium, steel etc. since warming on a heater may be required, plastic is out of question.

2.10 About Visual Basic 6.0

2.10.1 Introduction

Visual Basic as a language is considered HIGH Level. Almost all commands are English. MIDDLE level languages like C++, using sometimes cryptic commands and syntax, allow you to create very powerful and often faster Windows programs. There is a workaround to this, see below. LOW level languages basically are Assembly. Some severe masochists go beyond Assembly to write HEX and BINARY programs. Microsoft Visual Basic 6.0 is the quickest and easiest way to create powerful applications for

Microsoft windows operating system. Visual Basic provides one with a complete set of tools to simplify rapid application development.

The "VISUAL" part refers to the method use to create Graphical User Interface (GUI). The Visual Basic programming system allows creating robust and useful application that fully makes use of Graphical User Interface. Rather than writing numerous lines of code to describe the appearance and location of interface elements, one can simply drag and drop rebuilt objects into place on the screen.

The "BASIC" part refers to the basic language, a language of more programmers than any other language in the history of computing. Visual Basic evolved from original basic Language and now contains several hundred statements, function and keywords, many of which relate directly to the window GUI

2.10.2 Visual Basic 6.0 Controls

Control Name	Description
Pointer	Selection of components in design phase of design of form/window
Text Box	To accept input from user and to show outputs
Label	To display the data to the user
Frame	To group various objects, acts as a container object
Command button	To get the commands from the user
Check box	To get the Yes/No options about individual control
Option button	To choose the one option from a group of available lists
Timer	To initiate a work after fixed interval of time
Drive list	To show the list of disk drives available
Directory list	To show the list of directories available
File list	To show the list of files
MSComm	Microsoft communication control to support port operations
SSTab	Tabbed dialog boxes to reduce the form size
Slider	To select a value within the maximum and minimum values
Toolbar	To display a tool bar containing custom buttons
Status bar	To display the status about any operation or action
Line	To draw a line between two XY co-ordinates
Rich text box	To display text in selective formatted

3. Existing System Study

3.1 Assumptions

The study is aimed in analyzing the efficiency, effectiveness and the automation level of the systems currently implemented in control of heaters and other thermally active devices like annealing chambers. The study was based on the data gathered from industries. The questionnaire was answered by all cadres of people, with various depths of experience and technology. The study is based on the assumptions:

1. The people will answer the questionnaire in his full attention, with no hesitation to answer.
2. The questionnaire is designed to analyze the technical knowledge of the person answering and his will towards the improvements of the firm.
3. The number of peoples studied was theoretically assumed to be of moderate to high sufficiency and would give an optimal statistical mean, for solution attained.
4. The people answered has a good idea about the temperature control schemes, it effectiveness (either theoretically or practically) and the drawback or hurdles in attaining the results.
5. the solution in the case of loop back solution (head – on – tail solution) is taken as the just before loop solution, not entering in to the iterations. This would reduce the time for analysis.

3.2 Limitations

Since the study has certain assumptions as specified in the previous section, there are chances of getting a wrong result partially or totally. The purpose of the study and the project may be proved false or the results may become a 'head on tail solution'. Also the solution may be proved totally fatal and the implementation may become impossible due certain non-technical reasons. The results of wrong assumptions may lead to false opinions. The statistical data is presented in this report for the reader to analyse.

3.3 Statistical Data

The following tables show the preferences of various cadre of users. All the data may not prove useful yet the idea is to present the entire status of the data collected.

Designation →	Manager	Supervisor	Fore man	Lay man
Number of respondents	15	25	60	50
Idea about the electronic controller	Theoretically proven record	Practically Okay, not all time	No idea about the present rend	Not known
Consideration about cost	Most	Likely most	Not likely	No idea
Consideration about Quality	Most	Most	Likely most	Likely Most
Time for next change	Within a year	-	-	-
Experience (mean for all respondents)	15	10	5	12
Satisfaction level of the present system	Good as it yields to expectation	Good, but not so neat and tidy	Tough to operate	Not so much good
Brand loyal	Yes	Yes	Some times	No
About the automation	Best to implement	Reduces need for inspection	Reduces morale of employees	Not good, job may be lost
Accuracy criteria	That will not yield bad	5 – 10%	15 – 20%	May be up to 50 degrees

3.4 Support for changes

- The managers expect the change in the existing system, but do not prefer the costlier version.
- The supervisors prefer the changes only if it proves to be taking less maintenance and requires only less intervention for result analysis.
- Both the supervisor and the lay men only worry about the flexibility, but oppose the automation fearing the unemployment or under employment possibilities.

3.5 Existing Practices and accuracy

3.5.1 Prevailing Systems & accuracy

Hot wire pyrometer: Accuracy lies in calibration and operators experience

Chart pyrometer: Accuracy largely depends on the operator

Thermistors: Accuracy depends upon calibration and impurities deposited on the device

Thermocouple: largely on the circuit implemented

3.5.2 Data logging and analysis

Manual modes of data logging are done at most of the places. The sampling rate and the results obtained are not much of importance and the people least worry about the data collected and its accuracy and mostly hate the monotonous work.

The data analysis is done visually just noting the defects or abrupt changes in the values. The need for graphs and online analysis is almost nil at these industries.

3.5.3 The losses and gains

Accuracy	Reason	Consequences
-	Manual logging	Less investment ; Skill needed is low Easy to work with ; Ease of substitution
-	Manual analysis	Less investment ; Skill is not needed much Time consuming works are reduced;
-	Devices of poor quality	Cheaper and ready availability
-	Poor calibration	Costlier procedures ; Facilities not accessible
-	Less experience	Cheaper labor
-	Physically unfit employment	Cheap source of labor Does not demand much on accidents
+	Machine logging	Accurate data ; increased power consumption Better outlook on the job ; needs more investment
+	Calibrated devices	Accurate results in planned time intervals Not readily available, but customized

4. Proposed System & Implementation

4.1 Introduction

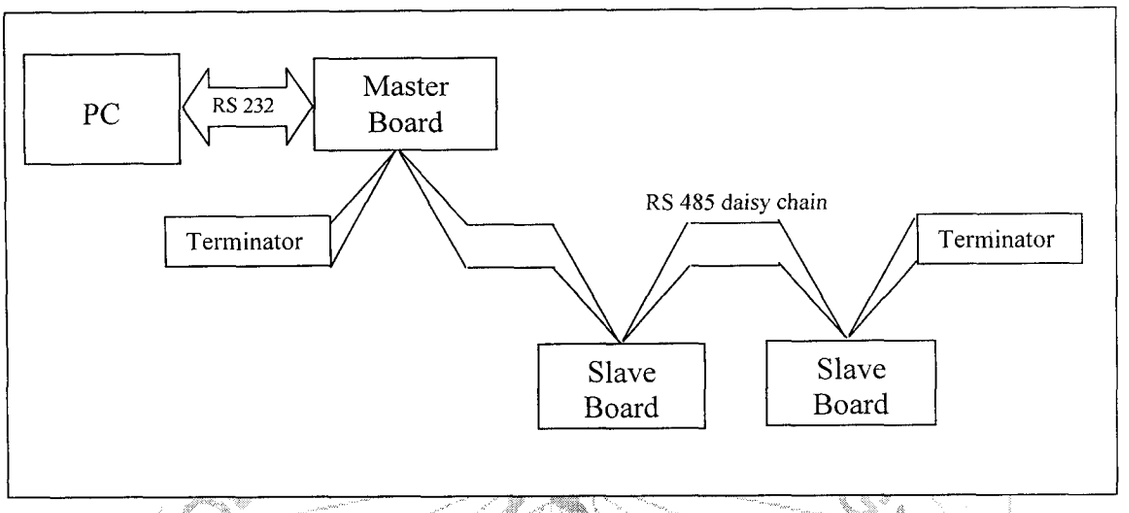
The proposed system uses a network of micro controllers stringed by the RS485 network in daisy chain configuration. This helps in achieving the two main objectives of the project namely, network establishment and a controller that would suit industrial environment. The planned features of the system include:

- Modifiable power output circuit.
- Extensions up to 255 devices per arm.
- Master slave establishment.
- Multiple ways of programming, etc.

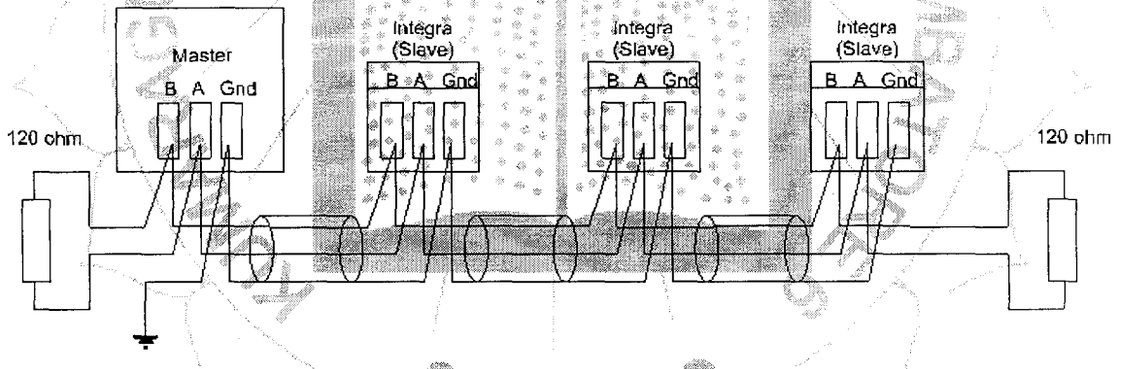
4.2 Technical specification (proposed)

- Master CPU – PIC16F877
- Slave CPU – PIC16F876
- Instrumentation Amplifier – (Custom) LM324
- Power Supply
  - 5V DC, 1Amp (Max) (for control part)
  - 12V DC, 1 Amp (Max) (for isolation circuits)
- Power Circuit – 230V, 5Amp
- Output Waves
  - Mod Sine
  - Fractional Mod Sine
- Output Control Schemes
  - On/Off control
  - Firing Angle Control
- Communication Standard:
  - Master to PC – RS 232
  - Master to Slave – RS 485
- Display – LCD 16 characters X 1 Row
- Key Board – 6 Key – Custom Board
- Thermo Couple → Chromel – Alumel (Type K)
- Cold Junction Compensation - by thermistor (10 K at 25°C)

4.3 The Network and Topology

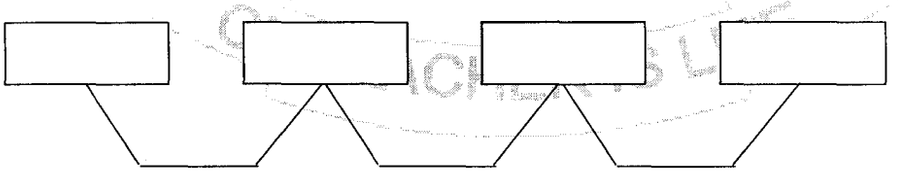


The diagram shows how the network will be established in the industry. The slaves can be at any place within a distance of 4000 feet (approximately) from its adjacent connections. Also they can be either active or inactive, controlling the furnace or acting as other control device. The schematic of the RS 485 interface looks like:

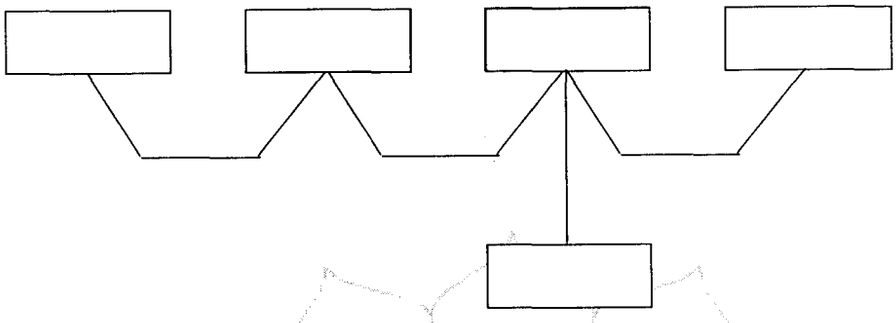


The correct and wrong forms of the daisy chain are as follows:

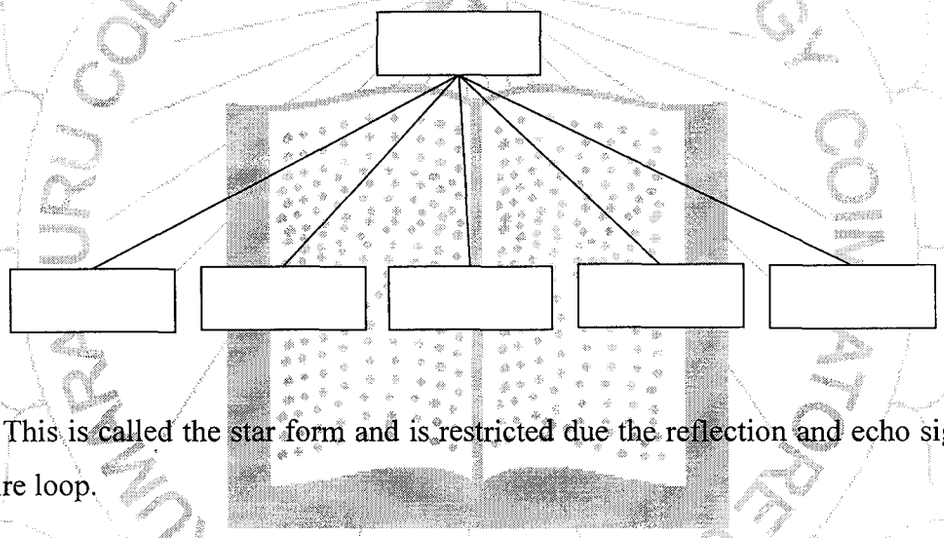
This is the correct daisy chain as no terminal has more than 2 connections. This ensures that a "Daisy Chain or "straight line" configuration is used.



The wrong ways are as illustrated in the following diagrams.



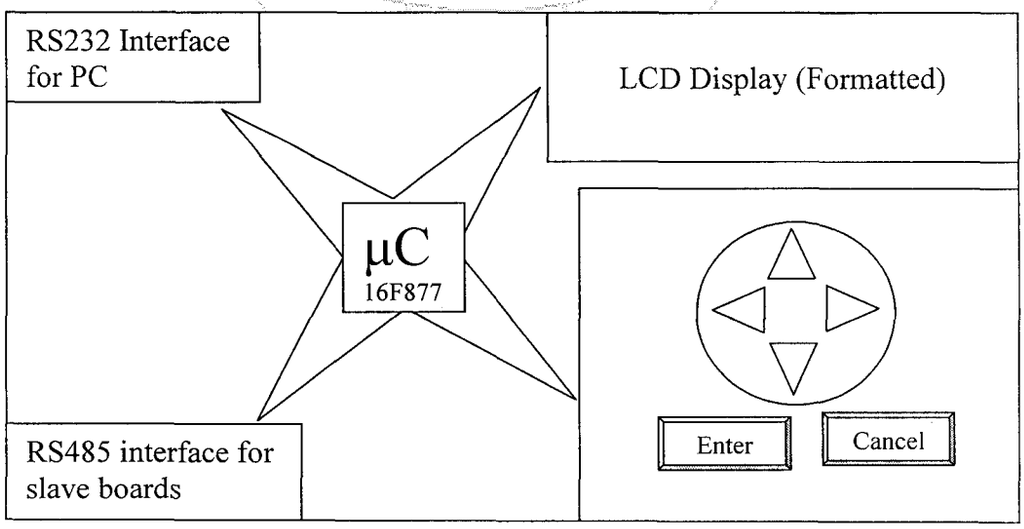
This is called the stub form and is restricted due the reflection in the arm connecting to it.



This is called the star form and is restricted due the reflection and echo signals in the entire loop.

4.4 Master Board

4.4.1 Block Diagram



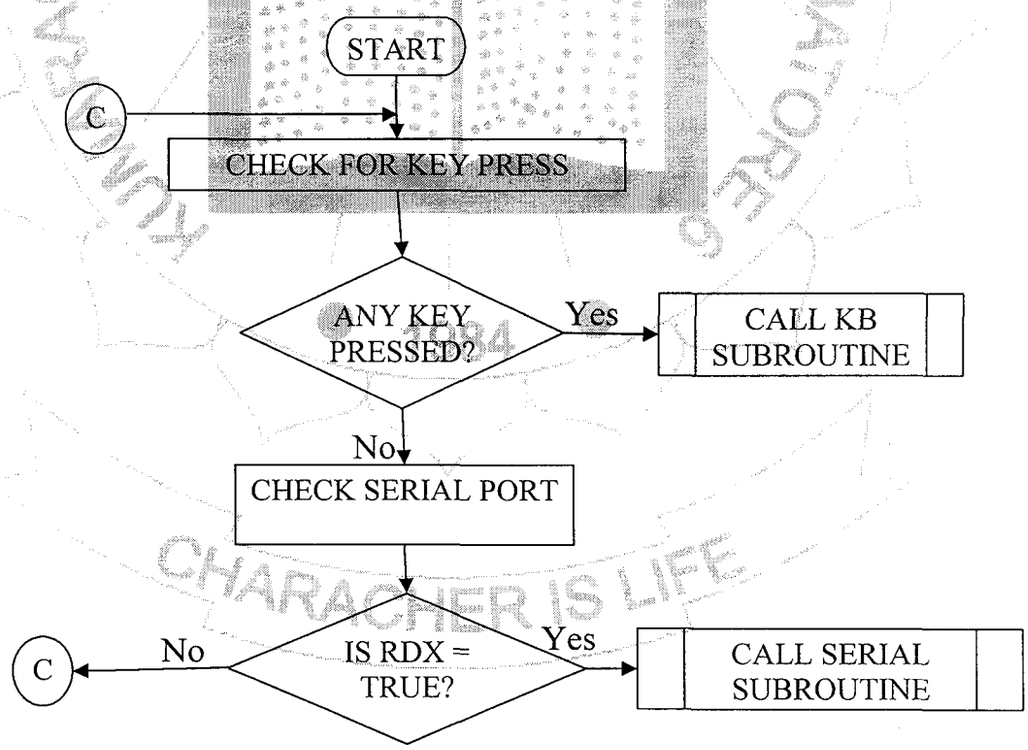
As shown in the figure master board consists of all the user interfaces necessary either by direct means or by computer. This acts just as a linkage between the user and various slaves that lack the user interface. No slave is connected with program keys or the display to reduce the overall implementation cost and the software and hardware burden of the slaves.

4.4.2 Components

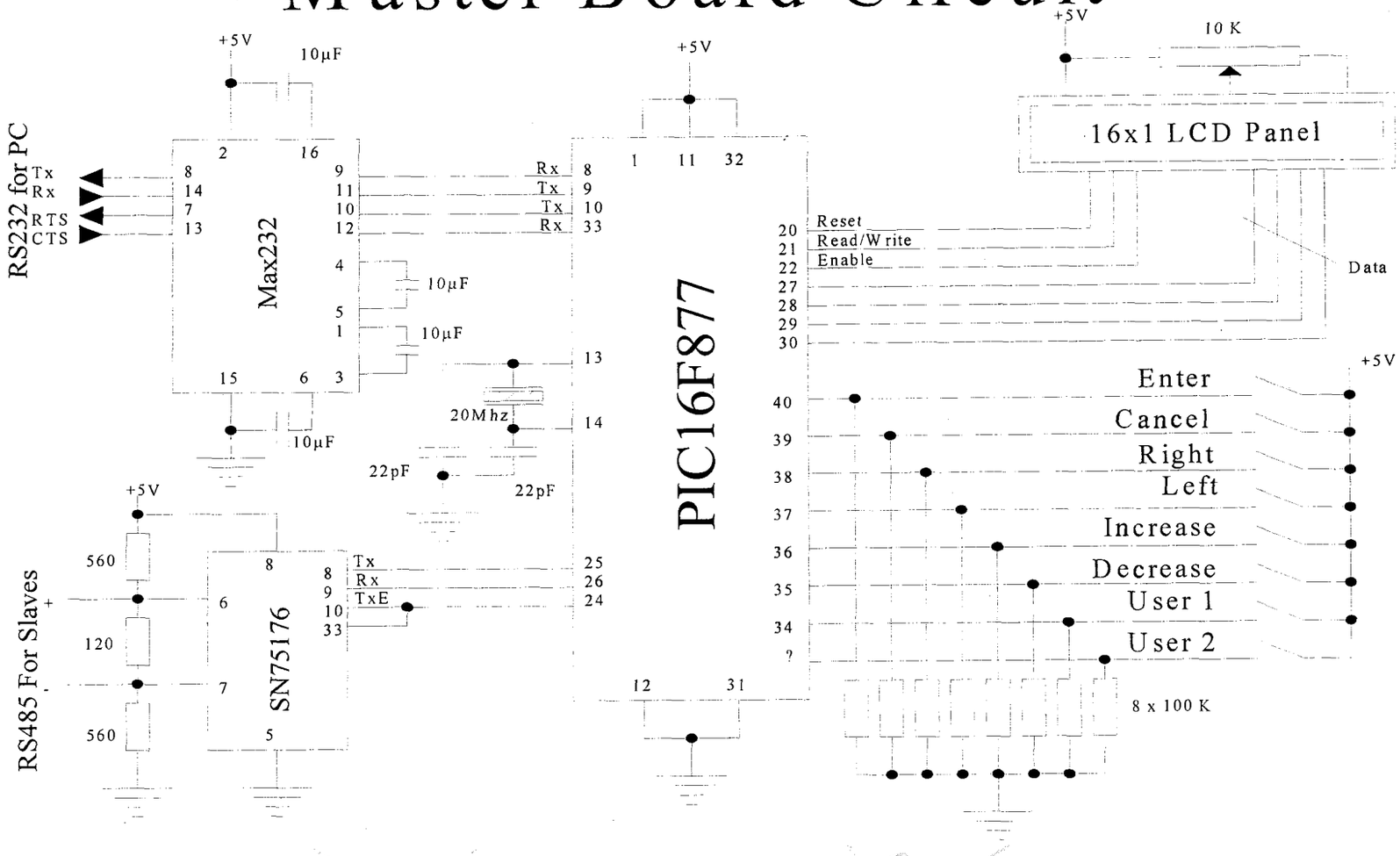
The components in the master board are:

1. PIC 16F877 – acting as the master CPU
2. 16x1 LCD panel
3. MAX 232 – acting as RS232 to TTL and TTL to RS232 converter
4. MAX 485 / SN 75176 – acting as the RS485 to TTL and TTL to RS485 converter
5. Six key keyboard (with two expansion keys).

4.4.3 Flow Chart

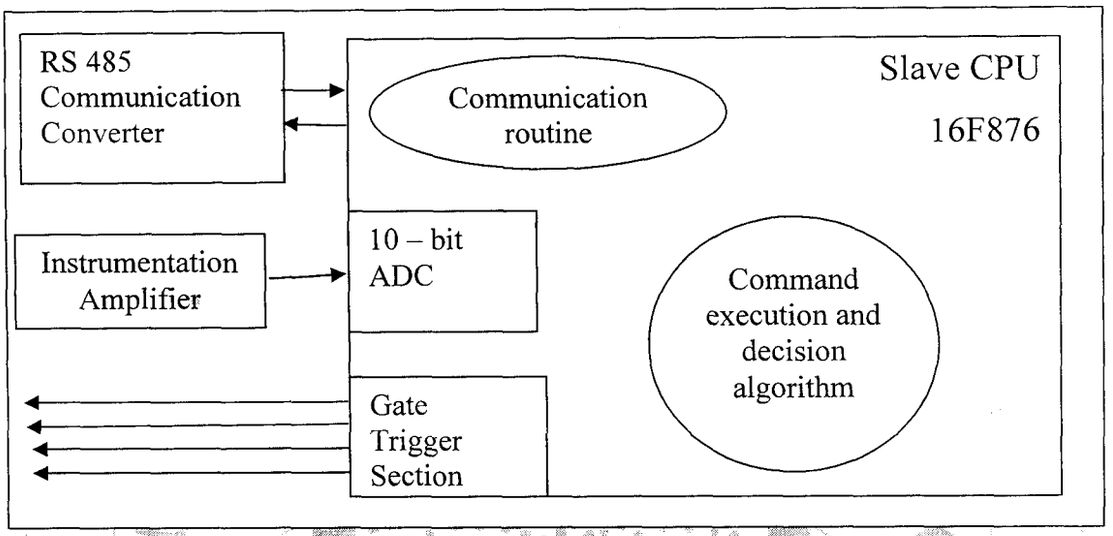


Master Board Circuit



4.5 Slave Board

4.5.1 Block Diagram

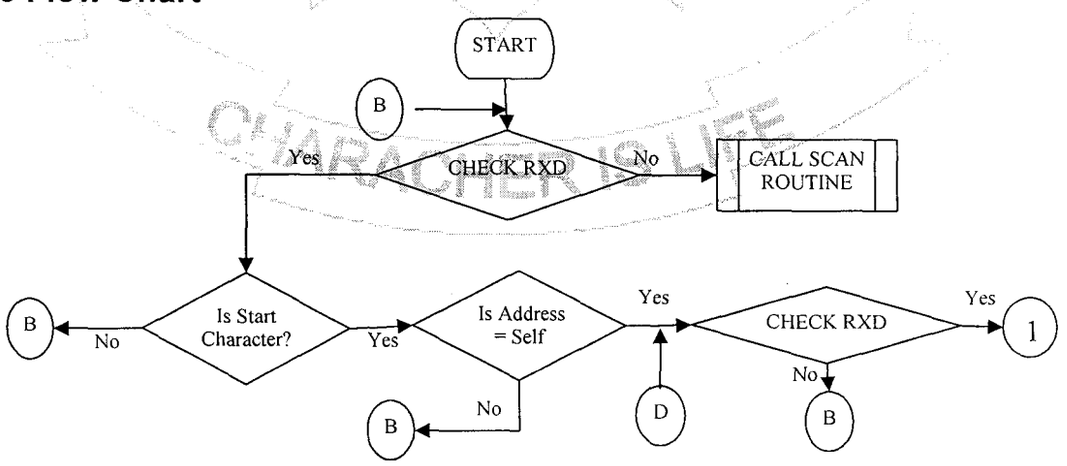


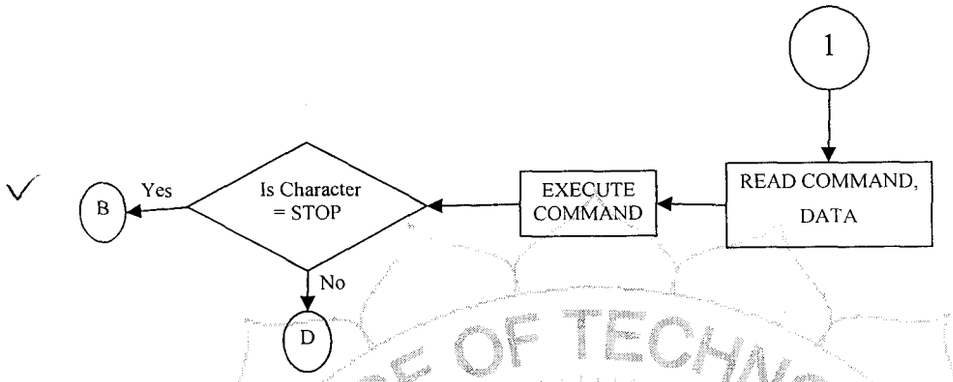
4.5.2 Components

The components in the master board are:

1. PIC 16F876 – acting as the slave CPU
2. instrumentation amplifier
3. cold junction compensation network
4. MAX 485 / SN 75176 – acting as the RS485 to TTL and TTL to RS485 converter
5. Address select and mode select keys (with two expansion keys).

4.5.3 Flow Chart





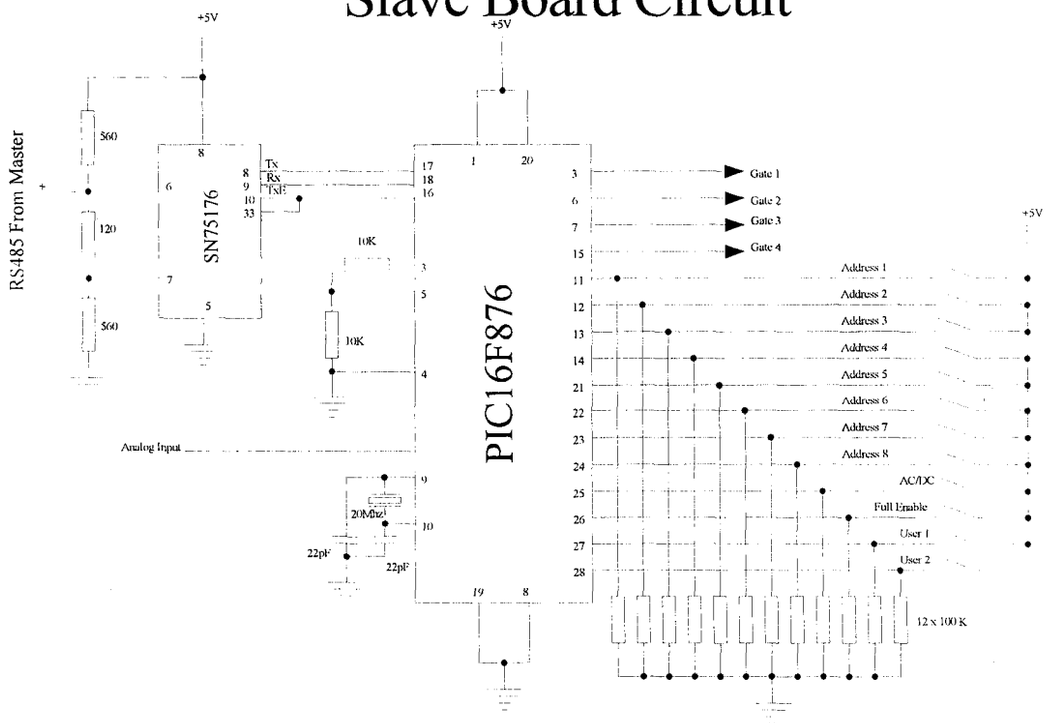
4.5.4 Notable Features

Important features to be noted in the slave board assembly include:

1. Isolated power supply for the instrumentation amplifier and other circuits.
2. Elevated ground inside the instrumentation amplifier
3. Individual isolated battery supply for the opto – isolators.

4.5.5 Circuit Diagram

Slave Board Circuit



✓4.6 Power Supply Board

4.6.1 Introduction

Since all electronic circuits work only with low D.C. voltage, there is a need for power supply unit to provide the appropriate voltage supply. This unit consists of transformer, rectifier, filter and regulator. A.C. voltage typically 230V rms is connected to a transformer which steps that AC voltage down to the level to the desired AC voltage. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a DC voltage. This resulting DC voltage usually has some ripple or AC voltage variations. A regulator circuit can use this DC input to provide DC voltage that not only has much less ripple voltage but also remains the same DC value even the DC voltage varies some what, or the load connected to the output DC voltages changes.

✓4.6.2 Components

The power supply unit supplies the operating DC voltage to the entire project parts and it consists of

4.6.2.1 Transformer

A transformer is a static (or stationary) piece of which electric power in one circuit is transformed into electric power of the same frequency in the other circuit. It can raise or lower the voltage in a circuit but with a corresponding decrease or increase in current. It works with the principle of mutual induction. In our project we are using step down transformer for providing a necessary supply for the electronic circuits. In this project 15-0-15 center tapped transformer is being used.

4.6.2.2 Rectifier

The DC level obtained from a sinusoidal input can be improved 100% using a process called full-wave rectification. It uses 4 diodes in a bridge configuration. From the basic bridge configuration we see that two diodes (say D2 & D3) are conducting while the other two diodes (D1 & D4) are in

"off" state during the period t =0 to T/2. Accordingly for he negative of the input the conducting diodes are D1 & D4. Thus the polarity across the load is the same.

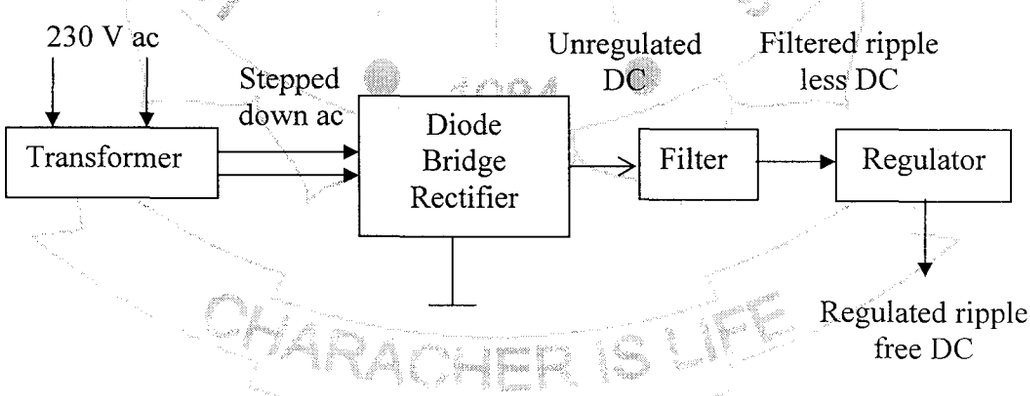
4.6.2.3 Filter

The filter circuit used here is the capacitor filter circuit where a capacitor is connected at the rectifier output, and a DC is obtained across it. The filtered waveform is essentially a DC voltage with negligible ripples, which is ultimately fed to the load.

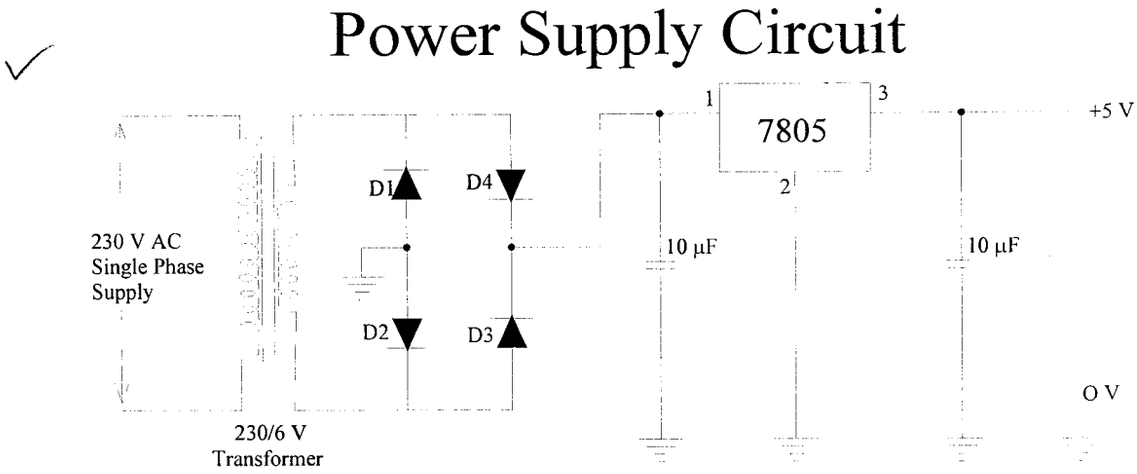
4.6.2.4 Regulator

The output voltage from the capacitor is more filtered and finally regulated. The voltage regulator is a device, which maintains the output voltage constant irrespective of the change in supply variations, load variation and temperature changes. Here we use two fixed voltage regulators namely LM 7812, LM 7805 and LM7912. The IC 7812 is a +12V regulator IC 7912 is a -12V regulator and IC 7805 is a +5V regulator.

4.6.3 Block Diagram



4.6.4 Circuit Diagram



4.7 Instrumentation Amplifier

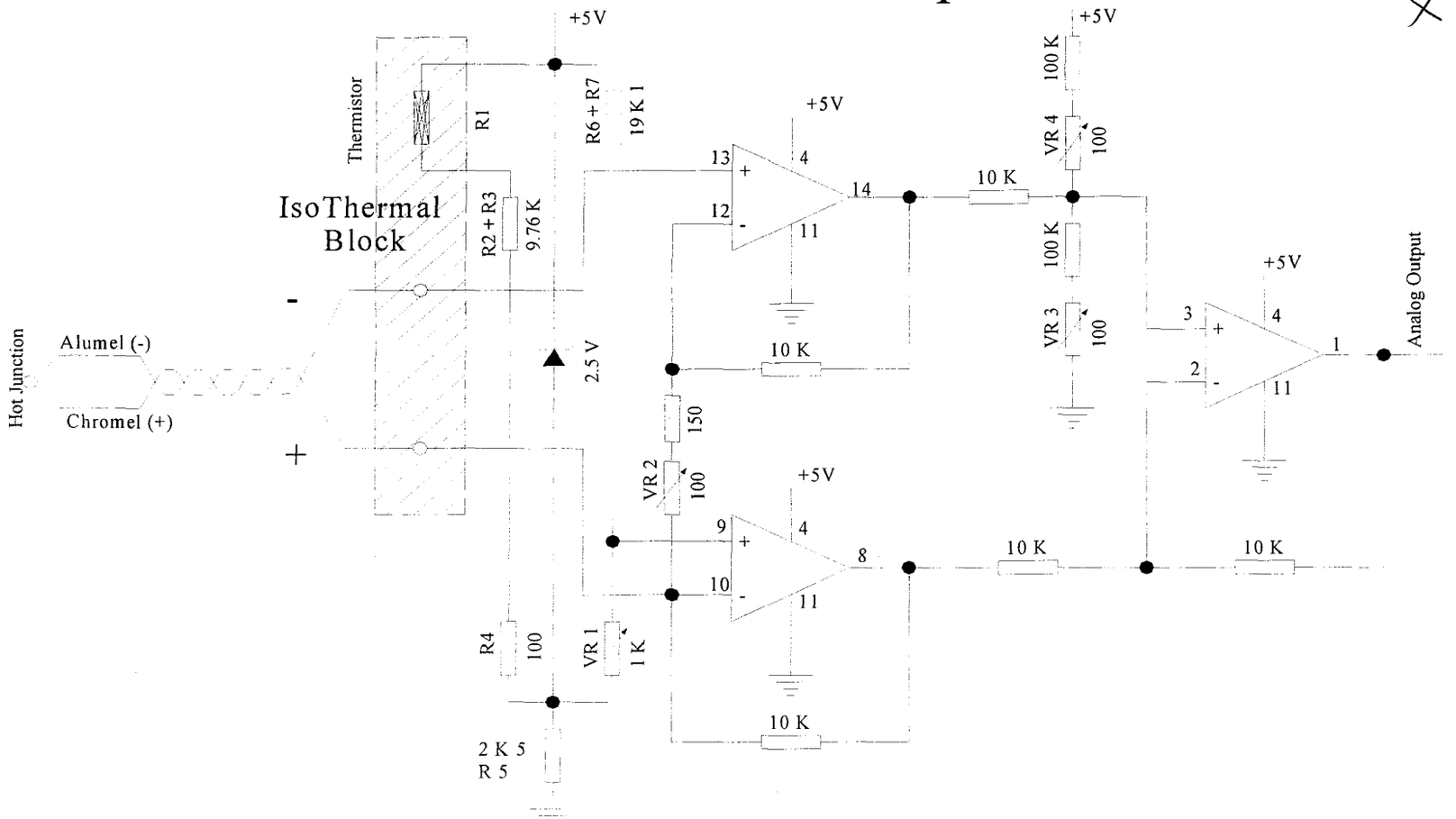
4.7.1 Introduction

This is the most crucial part of the circuit which decides the accuracy of the total system. The circuit is designed to take care of the cold junction compensation. Quad Opamp in LM324 IC is used for the purpose.

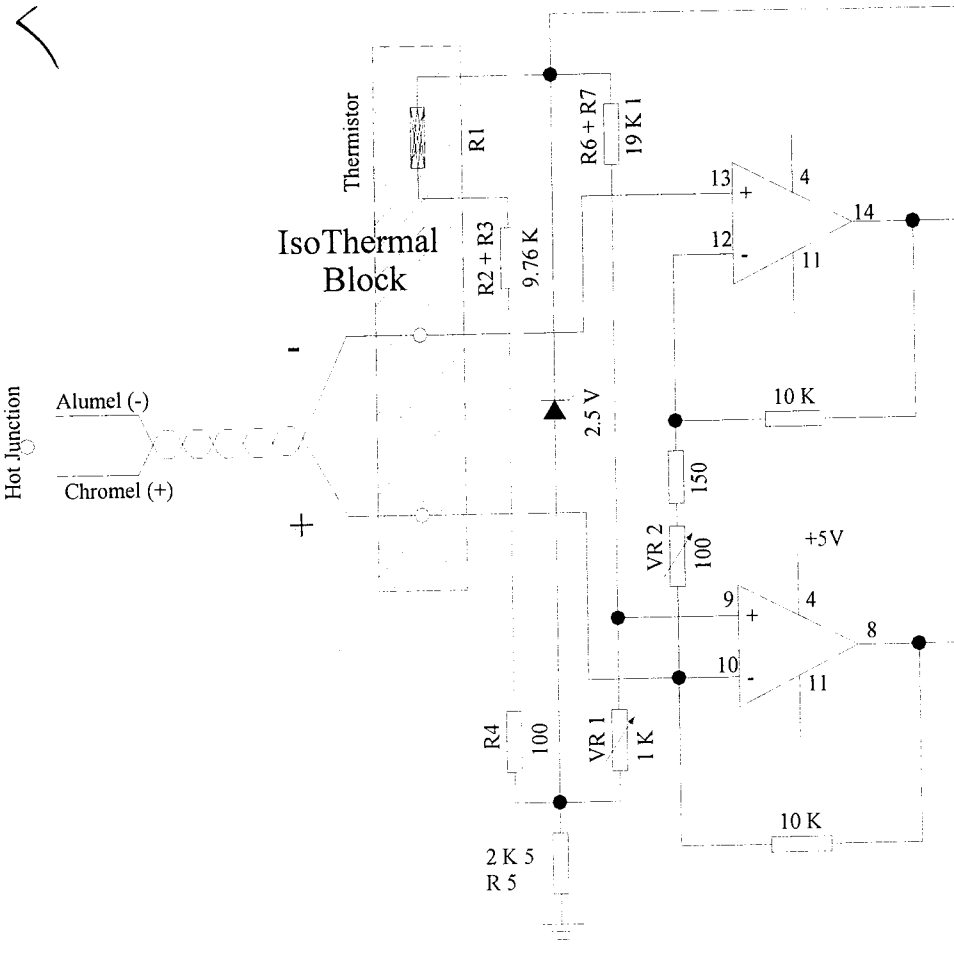
4.7.2 The older and newer versions

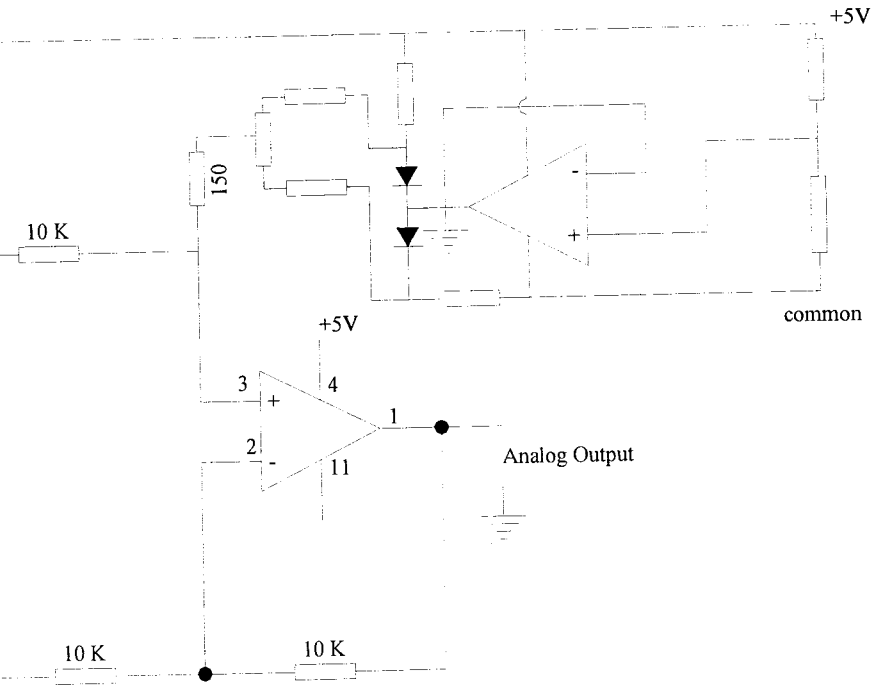
The older version of the amplifier was made as three amp device. But due to the imbalance created in the input supply, the outputs were drifting too much off the values beyond the non-linear control limit. To compensate for this a dual supply was constructed using the fourth opamp, with floating ground to satisfy the dual supply need of the other three amplifiers. Thus the newer version constitutes four amplifiers in it.

4.7.3 The Three Amplifier Circuit



4.7.4 The Four Amplifier Circuit




+5V
150
10 K
-
+
common
+5V
3
+
4
1
2
-
11
Analog Output
10 K
10 K

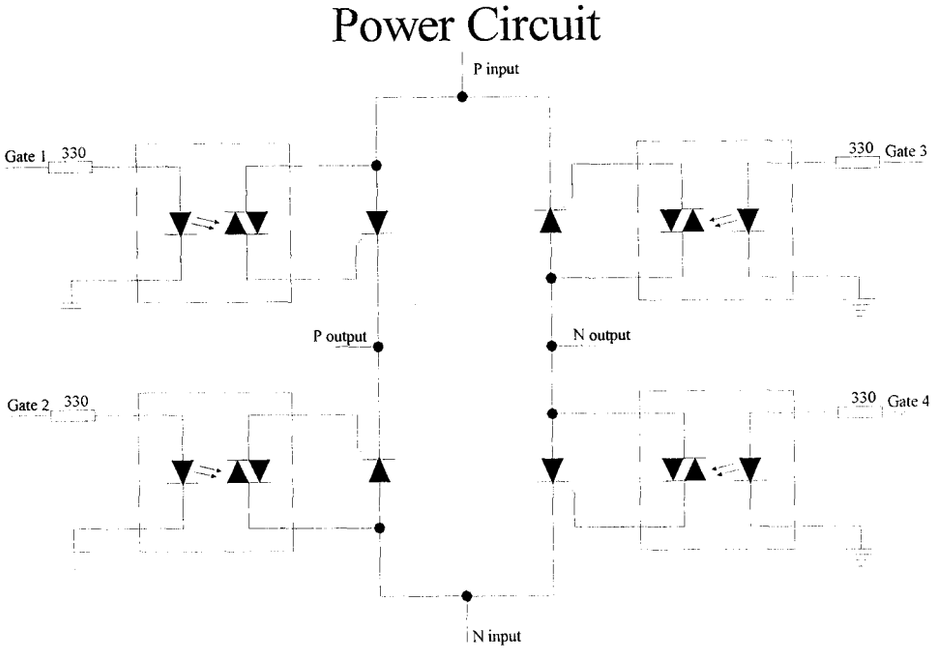
4.8 Power Circuit Board

4.4.1 Components

The components in the power circuit are:

1. SCR
2. Opto-isolators MCT2E

4.4.2 Circuit Diagram



The output module can be modified if required to get AC output.

4.9 The User Interface

4.9.1 Introduction

The user of the system is allowed to interface the slaves with PC by a serial port. For this purpose a PC interface section is given. The front end tool is VB which works with the user and the system in the name of TMS (Temperature Monitoring System). Registry is used

for storing the variables as the user modifies the settings. The system also uses a graphical tool to display the output in graphical format.

4.9.2 Features

If required the values in the system is logged in a file. The file can be viewed as required. The time for scanning and the colors of graph are modifiable, as per the demands. The software is made little hack proof by pass word authentication. The details of the program and its function are as follows:

- Main screen which acts as a Multi Document Interface form for all other forms
- Also it acts the route for serial port access
- Login form authenticates the user to work in the TMS environment
- Graph form to set the graphical display options
- Monitor form to view the temperature online as graph
- Read form to read a single value
- Set form to write a limit value to the devices
- Setting form to adjust the system setting
- Log form to write all the data into a file
- The same command can help in viewing the previously stored files

The output can be seen in various units like Celsius, Fahrenheit and Kelvin
The values of address can be seen as hexadecimal or as normal decimal I values.
The program, output screens are given in the appendix.

5. Observation & Inferences

5.1 Observation

The proposed system was given to most of the industries where the data collection was done. The result of the implementation is resulted below:

Property	Good	Fair	Bad
Compatibility with existing system	10	5	10
Reliable output	12	13	-
Satisfaction in Accuracy	10	5	10
Output Presentation	5	12	8
Noise level & other disturbances	22	-	3
Cost (cheaper → good)	3	10	12
Cost Effectiveness	3	5	17
Technical skill requirement (more → bad)	3	5	17
Technology implemented (New → good)	2	10	13
Idea about purchase (good→yes, may be→fair, bad→No)	1	10	14
Total ranking of the product (>7→good, >4→fair)	2	20	3

* Note: Only the supervisor cadre people were accessing the project and the chances of quantitative part being wrong is note worthy. Also the financial report about the product may not be as good as a financial manager's report.

5.2 Inferences

The data inferred were with the assumptions that the means used for the analysis will give the best possible effective results. With this assumption the things that were inferred from the project and its implementation were:

1. The are willing to support a product only if it can replace the existing system with
    a. Least modification
    b. Reduced investment
    c. Accuracy and quality of the product is improved

d. The system implementation does not effect the regular work
e. The installation and uninstalling process are very simpler
f. Continuous support is available for servicing

2. Also suggestions to improve the communication and PC interface were given. They include:
   a. The delay loop should be optimized.
   b. The data logging must be done in a database.
   c. The recovery of data must be faster, and other manipulations ca be implemented.
   d. Filter criteria for the data recovery and data access must be written and implemented
   e. The cable length can be increased and small repeaters can be installed to suit the industries.
   f. Possibility of wire less communication must be analyzed.
   g. The master board must be given facilities to view graph and other pictures.
   h. The computer program must be made smaller (the size o be reduced).
   i. Non – standard parts of the project must be eliminated and replaced by standard components for easy replacement.
   j. The interface must be tested in all platforms and if possible must be made in some DOS based program.
   k. The speed of execution must be improved by threading or other schemes.

3. The inferences made about the presentation were:
   a. The report must be made more quantitative in the results basis.
   b. A manual that would guide installation, usage of product by the technical support person must be prepared and distributed with the product.
   c. The software must be made more secure by adding hardware lock or other features to avoid hacking.
   d. The password must be made non – available to others.

6. Conclusion

The proposed system will prove to be useful only of the company is willing to implement a solution that will be in a position to meet the standards like 1-5% accuracy, non-linear controls, data logging, security and medium cost automation. The cost of the system at present is high due to initial design failures and initial cost on design (PCB design, Code development, etc.). These factors will not be there in the mass or bulk production and the cost can be brought down to about 60% .

The software can be made custom made or a facility to customize can be added. Due technical in-feasibility the implementation of PC interface through the master board was not possible. For this the master CPU must be changed. Also for the implementation to be completely successful, the RS 485 configuration must be with shields, terminators and with galvanic isolation. This will help in actual distance implementation and speed achievement.

Though the project has not reached its goal to the full extent, the idea of learning the scheme and developing the prototype has proven successful to the expected extent.

The programs used are presented in full bare form for the reader to analyse and can be used for optimization.

Chapter – 7

Future Enhancements

7. Future Enhancement

The system has a lot of scope for future improvements. These include:

- The CPU can be replaced for faster and good response.
- Quantizing errors in the CPU can be reduced by implementation a16 – bit processor or by adding a floating point arithmetic unit (FPU).
- These may increase cost a little, but may be ignored for the facilities.
- The system interface can be redesigned to be operated by any skilled or unskilled person.
- The security level and the access facilities can be made with multi level access.
- The software can be made to work in a LAN network or remote servers.
- The interface can be made to work globally with the internet and other facilities.
- It is possible to eliminate the noise disturbances, then an encoded form of wireless communication can be implemented.

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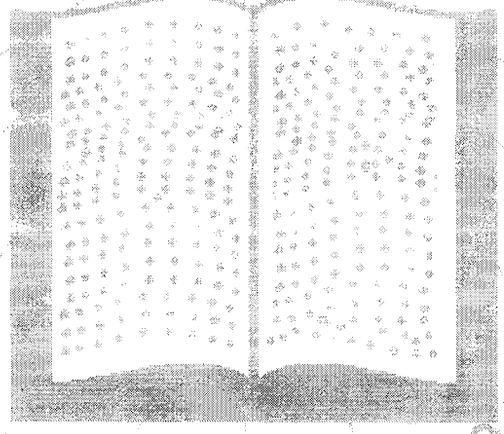
7. "Networks for Monitoring and Control Using an RS-485 interface", by Jan Axelson in the MICROCOMPUTER JOURNAL, the July/August issue, published in 1995, pages 27 – 40.



Appendix

Appendix A

A.1 78LM12

A.I.1 Introduction

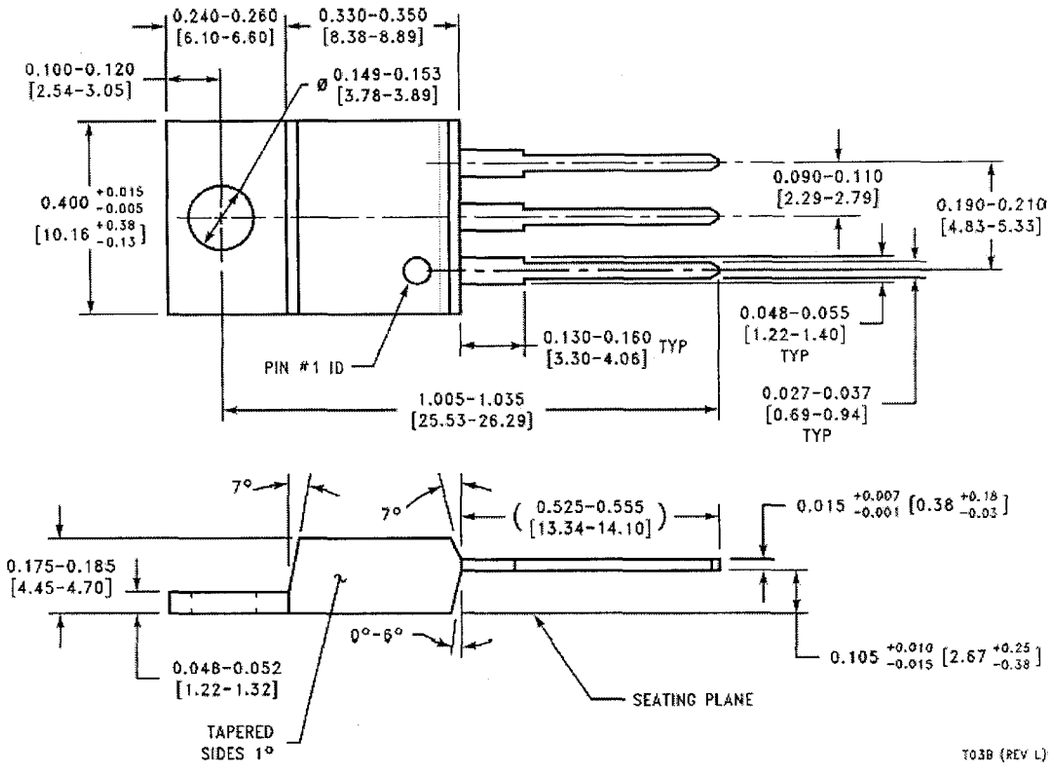
The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating. Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply. For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

A.1.2 Features

- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

A.1.3 Physical Dimensions (in mm)

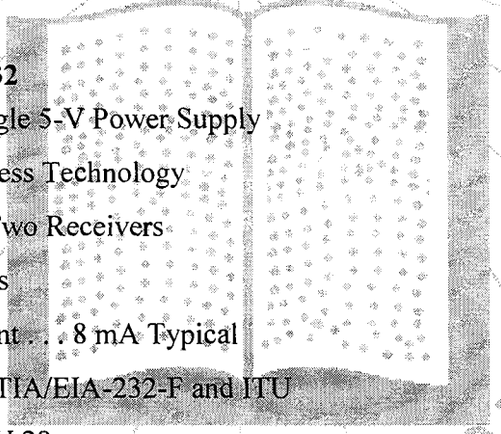


TO-220 Package (T)
Order Number LM7805CT, LM7812CT or LM7815CT
NS Package Number T03B

A.2 Max 232

A.2.1 General Description

The MAX232 device is a dual driver/receiver that includes a capacitive voltage generator to supply EIA-232 voltage levels from a single 5-V supply. Each receiver converts EIA-232 inputs to 5-V TTL/CMOS levels. These receivers have a typical threshold of 1.3 V and a typical hysteresis of 0.5 V, and can accept ±30-V inputs. Each driver converts TTL/CMOS input levels into EIA-232 levels. The driver, receiver, and voltage-generator functions are available as cells in the Texas Instruments Lin ASIC library. The MAX232 is characterized for operation from 0°C to 70°C. The MAX232I is characterized for operation from –40°C to 85°C.



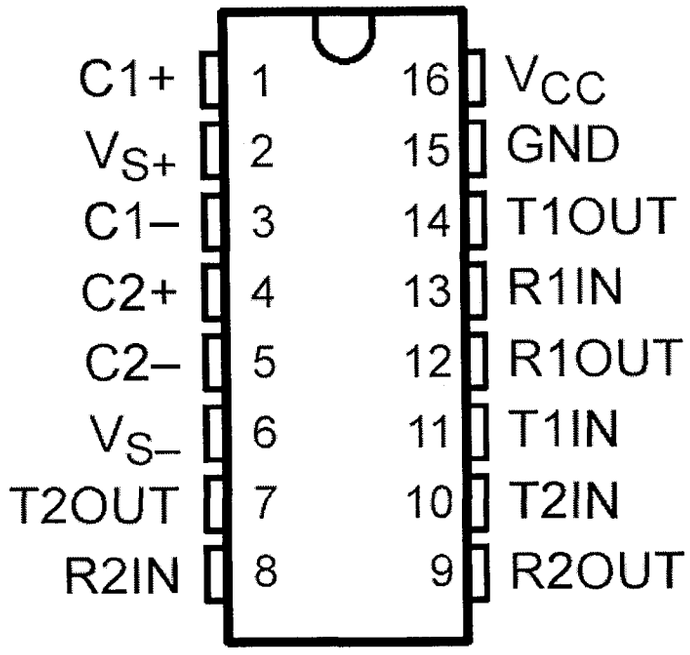
A.2.2 Features of Max 232

- Operates With Single 5-V Power Supply
- LinBiCMOS. Process Technology
- Two Drivers and Two Receivers
- ±30-V Input Levels
- Low Supply Current . . . 8 mA Typical
- Meets or Exceeds TIA/EIA-232-F and ITU
- Recommendation V.28
- Designed to be Interchangeable With
- Maxim MAX232
- ESD Protection Exceeds JESD 22 - 2000-V Human-Body Model (A114-A)

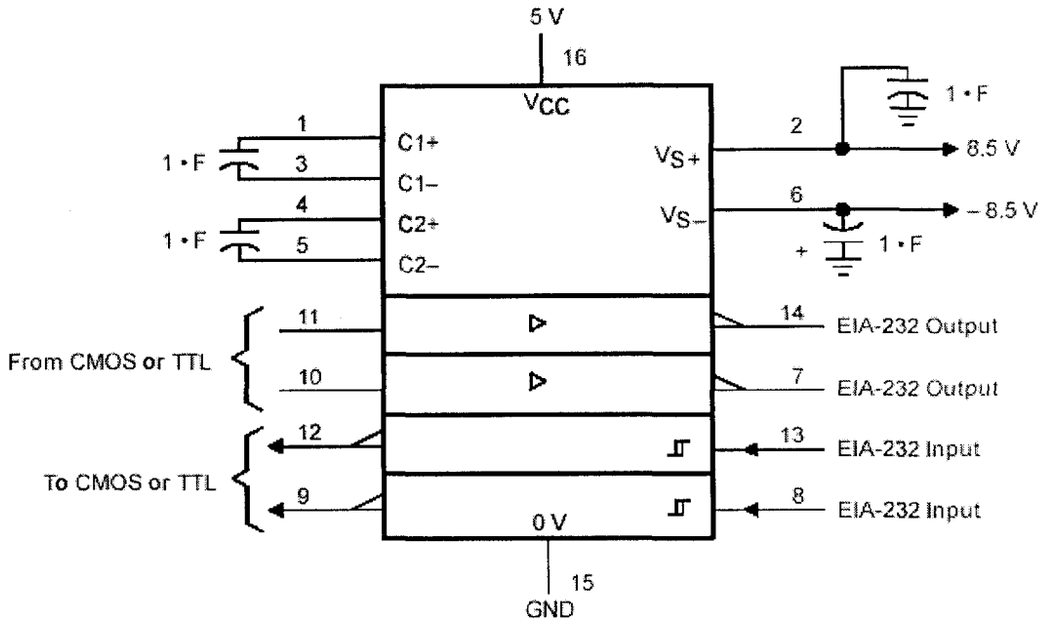
A.2.3 Applications

- TIA/EIA-232-F
- Battery-Powered Systems
- Terminals
- Modems
- Computers

A.2.4 Pin Details



A.2.5 Application Notes



A.3 Max 485

A.3.1 General Description

The MAX481, MAX483, MAX485, MAX487–MAX491, and MAX1487 are low-power transceivers for RS-485 and RS-422 communication. Each part contains one driver and one receiver. The MAX483, MAX487, MAX488, and MAX489 feature reduced slew-rate drivers that minimize EMI and reduce reflections caused by improperly terminated cables, thus allowing error-free data transmission up to 250kbps. The driver slew rates of the MAX481, MAX485, MAX490, MAX491, and MAX1487 are not limited, allowing them to transmit up to 2.5Mbps. These transceivers draw between 120µA and 500µA of supply current when unloaded or fully loaded with disabled drivers. Additionally, the MAX481, MAX483, and MAX487 have a low-current shutdown mode in which they consume only 0.1µA. All parts operate from a single 5V supply. Drivers are short-circuit current limited and are protected against excessive power dissipation by thermal shutdown circuitry that places the driver outputs into a high-impedance state. The receiver input has a fail-safe feature that guarantees a logic-high output if the input is open circuit. The MAX487 and MAX1487 feature quarter-unit-load receiver input impedance, allowing up to 128 MAX487/ MAX1487 transceivers on the bus. Full-duplex communications are obtained using the MAX488–MAX491, while the MAX481, MAX483, MAX485, MAX487, and MAX1487 are designed for half-duplex applications.

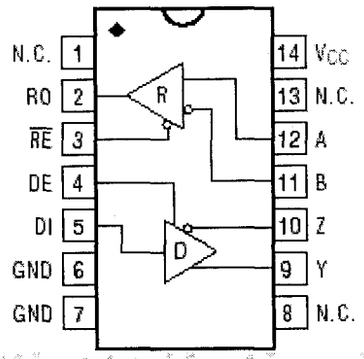
A.3.2 Features

- Smallest 8-Pin SO
- Slew-Rate Limited for Error-Free Data Transmission (MAX483/487/488/489)
- 0.1µALow-Current Shutdown Mode (MAX481/483/487)
- Low Quiescent Current:
    - 120µA (MAX483/487/488/489)
    - 230µA (MAX1487)
    - 300µA (MAX481/485/490/491)
- -7V to +12V Common-Mode Input Voltage Range
- Three-State Outputs
- 30ns Propagation Delays, 5ns Skew (MAX481/485/490/491/1487)
- Full-Duplex and Half-Duplex Versions Available
- Operate from a Single 5V Supply
- Allows up to 128 Transceivers on the Bus (MAX487/MAX1487)
- Current-Limiting and Thermal Shutdown for Driver Overload Protection

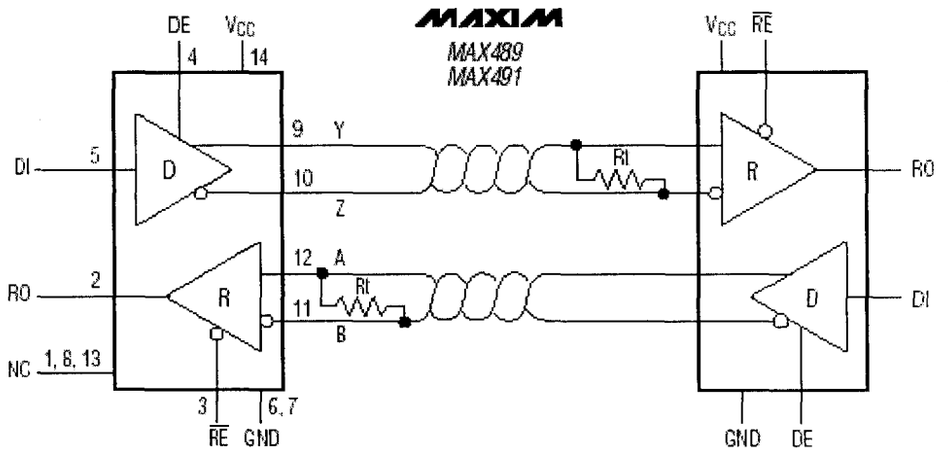
A.3.3 Applications

1. Low-Power RS-485 Transceivers
2. Low-Power RS-422 Transceivers
3. Level Translators
4. Transceivers for EMI-Sensitive Applications
5. Industrial-Control Local Area Networks

A.3.4 Pin Diagram



A.3.5 Application Notes



A.4 LM324

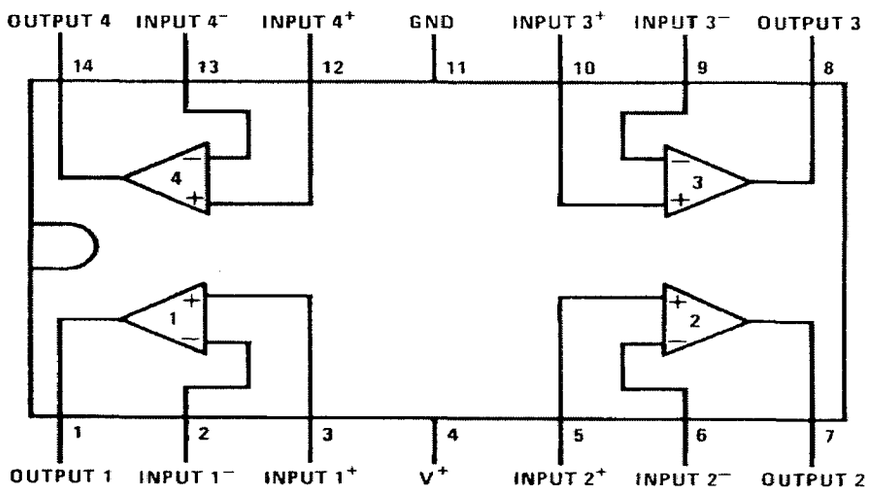
A.4.1 General Description

The LM124 series consists of four independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM124 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

A.4.2 Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage
- The unity gain cross frequency is temperature compensated
- The input bias current is also temperature compensated

A.4.3 Pin Details



A.4.4 Advantages

- Eliminates need for dual supplies
- Four internally compensated op amps in a single package
- Allows directly sensing near GND and VOUT also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

A.4.5 Features

- ✓ Internally frequency compensated for unity gain
- ✓ Large DC voltage gain 100 dB
- ✓ Wide bandwidth (unity gain) 1 MHz (temperature compensated)
- ✓ Wide power supply range:
  - Single supply 3V to 32V
  - Dual supplies ±1.5V to ±16V
- ✓ Very low supply current drain (700 μA)—essentially independent of supply voltage
- ✓ Low input biasing current 45 nA (temperature compensated)
- ✓ Low input offset voltage 2 mV and offset current: 5 nA
- ✓ Input common-mode voltage range includes ground
- ✓ Differential input voltage range equal to the power supply voltage
- ✓ Large output voltage swing 0V to V+ - 1.5V

A.4.6 Application Notes

The LM124 series are op amps which operate with only a single power supply voltage, have true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0 VDC. These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At 25°C amplifier operation is possible down to a minimum supply voltage of 2.3 VDC.

The pin outs of the package have been designed to simplify PC board layouts. Inverting inputs are adjacent to outputs for all of the amplifiers and the outputs have also been placed at the corners of the package (pins 1, 7, 8, and 14). Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited

current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Large differential input voltages can be easily accommodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than V+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than -0.3 VDC (at 25°C). An input clamp diode with a resistor to the IC input terminal can be used.

To reduce the power supply drain, the amplifiers have a class A output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifier to both source and sinks large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor should be used, from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion. Where the load is directly coupled, as in dc applications, there is no crossover distortion.

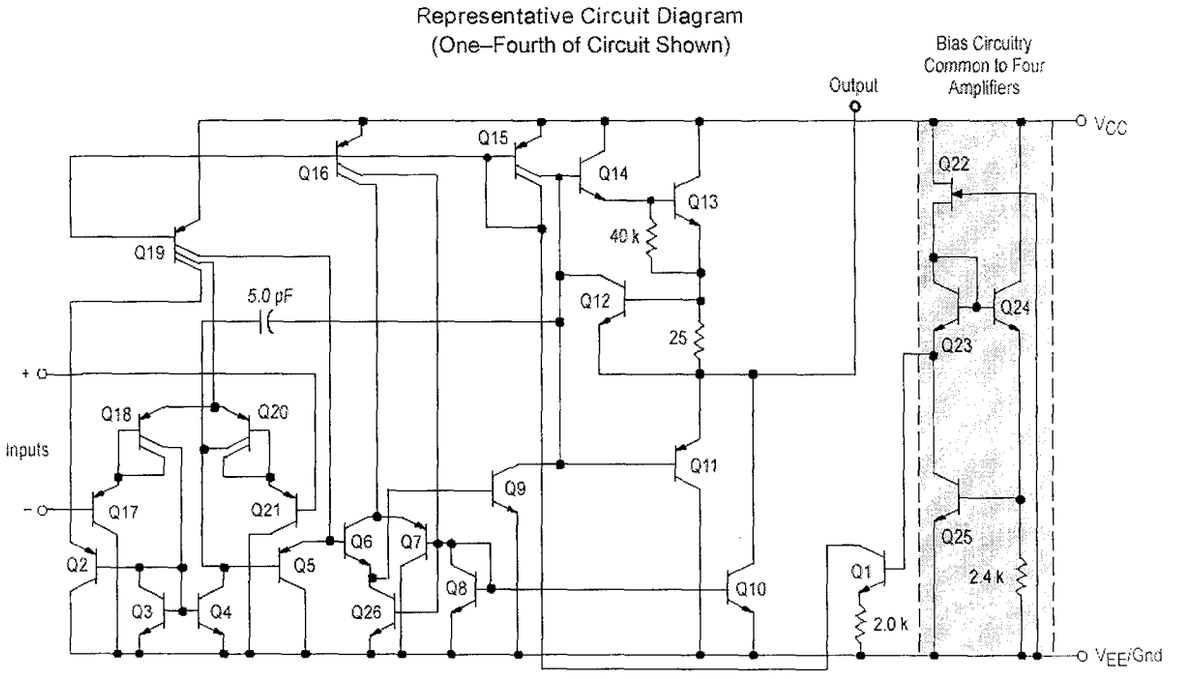
Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accommodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

The bias network of the LM124 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of from 3 VDC to 30 VDC. Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive junction temperatures.

Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels, if not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers. The larger value of output source current which is available at 25°C provides a larger output current capability at elevated temperatures than a standard IC op amp.

The circuits presented in the section on typical applications emphasize operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of V+/2) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground. In most cases, input biasing is not required and input voltages which range to ground can easily be accommodated.

A.4.7 Internal Architecture



A.5 PIC 16F877 and 16F876

A.5.1 Microcontroller Core Features:

- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input
- DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
- Up to 368 x 8 bytes of Data Memory (RAM)
- Up to 256 x 8 bytes of EEPROM data memory
- Pin out compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and
- Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low-power, high-speed CMOS FLASH/EEPROM technology
- Fully static design
- In-Circuit Serial Programmingä (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source Current: 25 mA

- Commercial and Industrial temperature ranges
- Low-power consumption:
    - < 2 mA typical @ 5V, 4 MHz
    - 20 mA typical @ 3V, 32 kHz
    - < 1 mA typical standby current

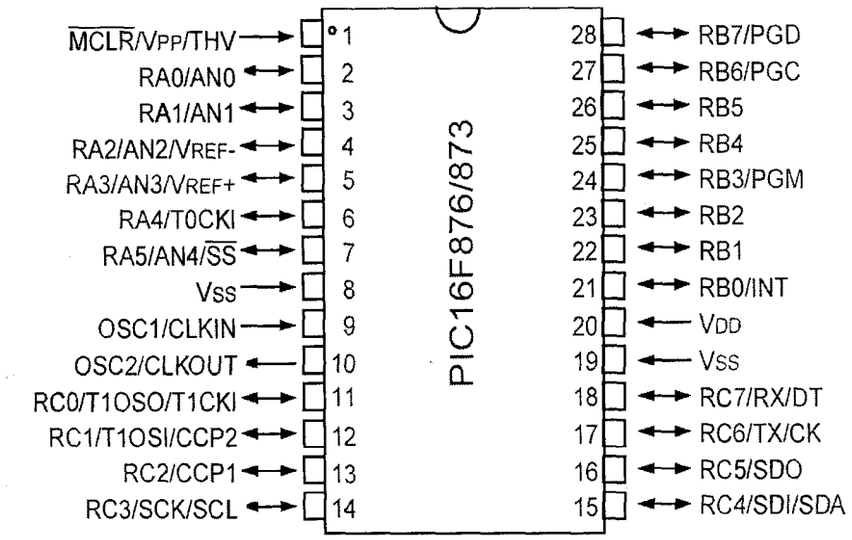
A.5.2 Peripheral Features

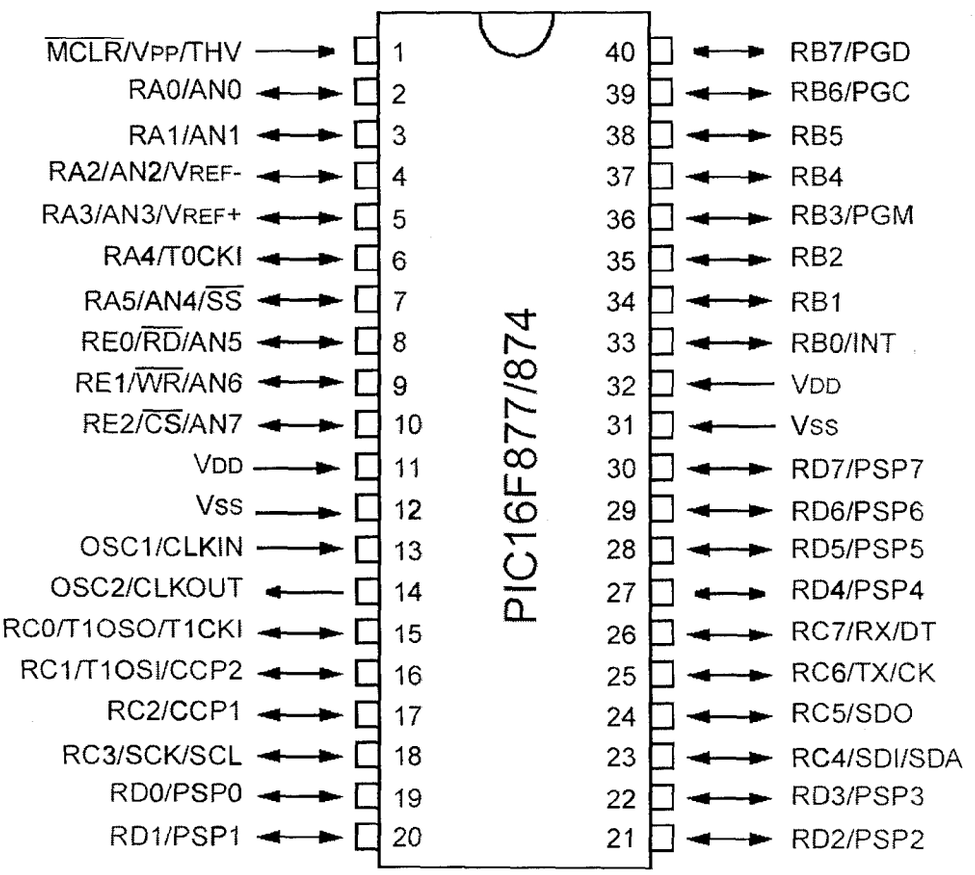
- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period bregister, prescaler and postscaler
- Two Capture, Compare, PWM modules
- Capture is 16-bit, max. resolution is 12.5 ns
- Compare is 16-bit, max. resolution is 200 ns
- PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI (Master Mode) and I^2C (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external (active low) RD, WR and CS control (40/44-pin only).
- Brown-out detection circuitry for Brown-out Reset (BOR)

A.5.3 Device Overview

The PIC16F876/873 devices come in 28-pin packages and the PIC16F877/874 devices come in 40- pin packages. The 28-pin devices do not have a Parallel Slave Port implemented.

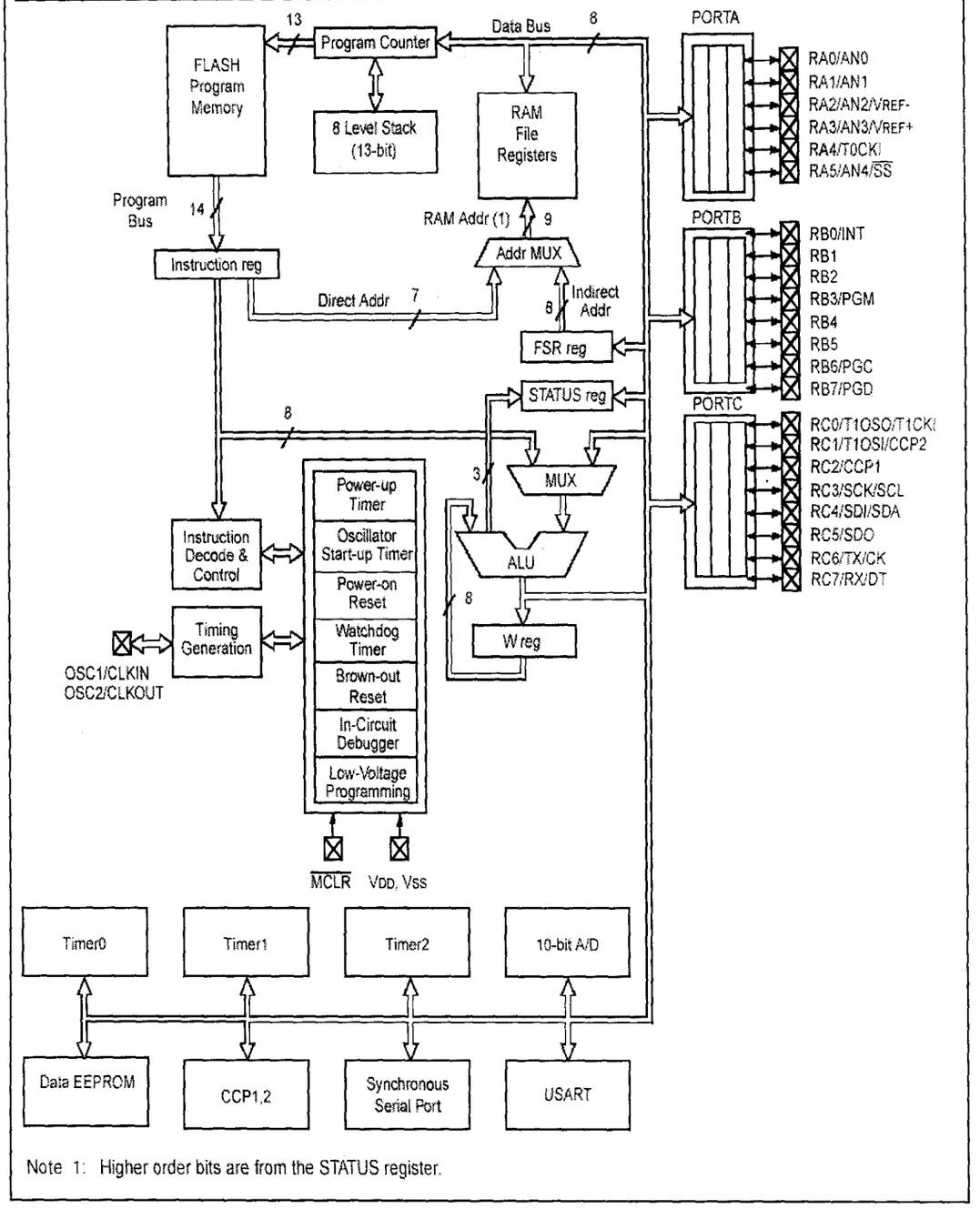
A.5.4 Pin Diagram





A.5.5 16F876 – Internal Architecture

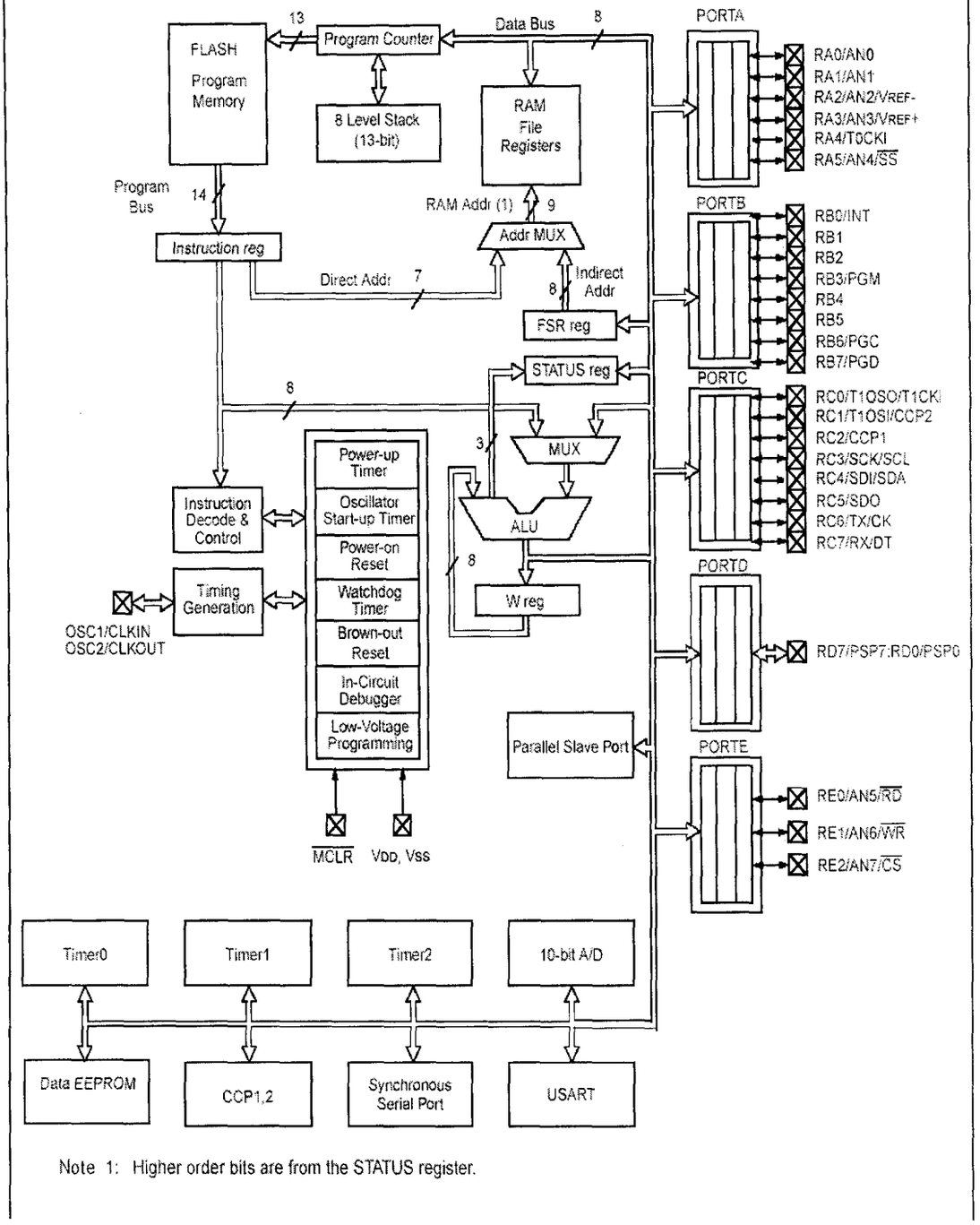
Device	Program FLASH	Data Memory	Data EEPROM
PIC16F873	4K	192 Bytes	128 Bytes
PIC16F876	8K	368 Bytes	256 Bytes



Note 1: Higher order bits are from the STATUS register.

A.5.6 16F877 – Internal Architecture

Device	Program FLASH	Data Memory	Data EEPROM
PIC16F874	4K	192 Bytes	128 Bytes
PIC16F877	8K	368 Bytes	256 Bytes



Note 1: Higher order bits are from the STATUS register.

A.5.7 16F876/877 – Instructions

ADDLW Add Literal and W
Syntax: [label] ADDLW k
Operands: 0 <= k <=255
Operation: (W) + k → (W)
Status Affected: C, DC, Z
Description: The content of the W register are added to the eight bit literal k and the result is placed in the W register.

ADDWF Add W and f
Syntax: [label] ADDWF f, d
Operands: 0 <=f <=127 & d [0, 1]
Operation: (W) + (f) → (destination)
Status Affected: C, DC, Z
Description: Add the content of the W register with register f. If d is 0, the result is stored in the W register. If d is 1, the result is stored back in register f.

ANDLW AND Literal with W
Syntax: [label] ANDLW k
Operands: 0 <=k <=255
Operation: (W) AND (k) → (W)
Status Affected: Z
Description: The contents of W register are AND-ed with the eight bit literal k. The result is placed in the W register.

ANDWF AND W with f
Syntax: [label] ANDWF f, d
Operands: 0 <=f <=127 & d [0, 1]
Operation: (W) AND (f) → (destination)
Status Affected: Z
Description: AND the W registers with register f. If d is 0, the result is stored in the W register. If d is 1, the result is stored back in register f.

BCF Bit Clear f
Syntax: [label] BCF f, b
Operands: 0 <=f <=127 & 0 <=b <=7
Operation: 0 → (f<b>)
Status Affected: None
Description: Bit b in register f is cleared.

BSF Bit Set f
Syntax: [label] BSF f, b
Operands: 0 <=f <=127 & 0 <=b <=7
Operation: 1 → (f<b>)
Status Affected: None
Description: Bit b in register f is set.

BTFSS Bit Test f, Skip if Set
Syntax: [label] BTFSS f, b
Operands: 0 <=f <=127 & 0 <=b < 7
Operation: skip if (f<b>) = 1
Status Affected: None
Description: If bit b in register f is 0, the next instruction is executed. If bit b is 1, then the next instruction is discarded and a NOP is executed instead making this a 2TCY instruction.

BTFSC Bit Test, Skip if Clear
Syntax: [label] BTFSC f, b
Operands: 0 <=f <=127 & 0 <=b <=7
Operation: skip if (f<b>) = 0
Status Affected: None
Description: If bit b in register f is 1, the next instruction is executed. If bit b, in register f, is 0, the next instruction is discarded, and a NOP is executed instead, making this a 2TCY instruction.

CALL Call Subroutine
Syntax: [label] CALL k
Operands: 0 <=k <=2047
Operation: (PC) +1→TOS, k →PC<10:0>, (PCLATH<4:3>) →PC<12:11>
Status Affected: None
Description: Call Subroutine. First, return address (PC+1) is pushed onto the stack. The eleven bit immediate address is loaded into PC bits <10:0>. The upper bits of the PC are loaded from PCLATH. CALL is a two cycle instruction.

CLRF Clear f
Syntax: [label] CLRF f
Operands: 0 <=f <=127
Operation: 00h → (f) & 1 → Z

Status Affected: Z
Description: The contents of register f are cleared and the Z bit is set.

CLRW Clear W
Syntax: [label] CLRW
Operands: None
Operation: 00h → (W) & 1 → Z
Status Affected: Z
Description: W register is cleared. Zero bit (Z) is set.

CLRWDT Clear Watchdog Timer
Syntax: [label] CLRWDT
Operands: None
Operation: 00h → WDT
0 → WDT pre-scaler & 1 → TO
1 → PD
Status Affected: TO, PD
Description: CLRWDT instruction resets the Watchdog Timer. It also resets the pre-scaler of the WDT. Status bits TO and PD are set.

COMF Complement f
Syntax: [label] COMF f, d
Operands: 0 <=f <=127 d [0,1]
Operation: (f) → (destination)
Status Affected: Z
Description: The contents of register f are complemented. If d is 0, the result is stored in W. If d is 1, the result is stored back in register f.

DECF Decrement f
Syntax: [label] DECF f, d
Operands: 0 <=f <=127 & d [0,1]
Operation: (f) - 1 → (destination)
Status Affected: Z
Description: Decrement register f. If d is 0, the result is stored in the W register. If d is 1, the result is stored back in register f.

DECFSZ Decrement f, Skip if 0
Syntax: [label] DECFSZ f,d
Operands: 0 <=f <=127 & d □[0,1]
Operation: (f) - 1 → (destination); skip if result = 0
Status Affected: None
Description: The contents of register f are decremented. If d is 0, the result is placed in the W register. If d is 1, the result is placed back in register f. If the result is 1, the next instruction is executed. If the result is 0, then a NOP is executed instead making it a 2TCY instruction.

GOTO Unconditional Branch
Syntax: [label] GOTO k
Operands: 0 <=k <=2047
Operation: k → PC<10:0>
PCLATH<4:3> → PC<12:11>
Status Affected: None
Description: GOTO is an unconditional branch. The eleven bit immediate value is loaded into PC bits <10:0>. The upper bits of PC are loaded from PCLATH<4:3>. GOTO is a two cycle instruction.

INCF Increment f
Syntax: [label] INCF f, d
Operands: 0 <=f <=127 & d □ [0, 1]
Operation: (f) + 1 → (destination)
Status Affected: Z
Description: The contents of register f are incremented. If d is 0, the result is placed in the W register. If d is 1, the result is placed back in register f.

INCFSZ Increment f, Skip if 0
Syntax: [label] INCFSZ f, d
Operands: 0 <=f <=127 & d □ [0, 1]
Operation: (f) + 1→ (destination), skip if result = 0
Status Affected: None
Description: The contents of register f are incremented. If d is 0, the result is placed in the W register. If d is 1, the result is placed back in register f. If the result is 1, the next instruction is executed. If the result is 0, a NOP is executed instead making it a 2TCY instruction.

IORLW Inclusive OR Literal with W
Syntax: [label] IORLW k
Operands: 0 <=k <=255
Operation: (W) OR k→ (W)
Status Affected: Z
Description: The contents of the W register are OR-ed with the eight bit literal k. The result is placed in the W register.

IORWF Inclusive OR W with f
Syntax: [label] IORWF f, d
Operands: 0 <=f <=127 & d [0, 1]
Operation: (W) OR (f) → (destination)
Status Affected: Z
Description: Inclusive OR the W register with register f. If d is 0 the result is placed in the W register. If d is 1 the result is placed back in register f.

MOVF Move f
Syntax: [label] MOVF f, d
Operands: 0 <=f <=127 & d [0, 1]
Operation: (f) → (destination)
Status Affected: Z
Description: The contents of register f are moved to a destination dependant upon the status of d. If d = 0, destination is W register. If d = 1, the destination is file register f itself. d = 1 is useful to test a file register since status flag Z is affected.

MOVLW Move Literal to W
Syntax: [label] MOVLW k
Operands: 0 <=k <=255
Operation: k →(W)
Status Affected: None
Description: The eight bit literal k is loaded into W register. The don't cares will assemble as 0s.

MOVWF Move W to f
Syntax: [label] MOVWF f
Operands: 0 <=f <=127
Operation: (W)→ (f)
Status Affected: None
Description: Move data from W register to register f.

NOP No Operation
Syntax: [label] NOP
Operands: None
Operation: No operation
Status Affected: None
Description: No operation.

RETFIE Return from Interrupt
Syntax: [label] RETFIE
Operands: None
Operation: TOS → PC & 1 → GIE
Status Affected: None

RETLW Return with Literal in W
Syntax: [label] RETLW k
Operands: 0 <=k <=255
Operation: k → (W); TOS →PC
Status Affected: None
Description: The W register is loaded with the eight bit literal k. The program counter is loaded from the top of the stack (the return address). This is a two cycle instruction.

RETURN Return from Subroutine
Syntax: [label] RETURN
Operands: None
Operation: TOS →PC
Status Affected: None
Description: Return from subroutine. The stack is POP-ed and the top of the stack (TOS) is loaded into the program counter. This is a two cycle instruction.

RLF Rotate Left f through Carry
Syntax: [label] RLF f, d
Operands: 0 <=f <=127 & d [0, 1]
Operation: See description below
Status Affected: C
Description: The contents of register f are rotated one bit to the left through the Carry Flag. If d is 0, the result is placed in the W register. If d is 1, the result is stored back in register f.

RRF Rotate Right f through Carry
Syntax: [label] RRF f, d
Operands: 0 <=f <=127 & d [0, 1]

Operation: See description below
Status Affected: C
Description: The contents of register f are rotated one bit to the right through the Carry Flag. If d is 0, the result is placed in the W register. If d is 1, the result is placed back in register f.

SLEEP
Syntax: [label] SLEEP
Operands: None
Operation: 00h →WDT, 0 →WDT pre-scaler, 1 →TO, 0 → PD
Status Affected: TO, PD
Description: The power-down status bit, PD is cleared. Time-out status bit, TO is set. Watchdog Timer and its pre-scaler are cleared. The processor is put into SLEEP mode with the oscillator stopped. Register f
C Register f C

SUBLW Subtract W from Literal
Syntax: [label] SUBLW k
Operands: 0 <=k <=255
Operation: k - (W) →(W)
Status Affected: C, DC, Z
Description: The W register is subtracted (2s complement method) from the eight bit literal k. The result is placed in the W register.

SUBWF Subtract W from f
Syntax: [label] SUBWF f, d
Operands: 0 <=f <=127 & d [0,1]
Operation: (f) - (W) →(destination)
Status Affected: C, DC, Z
Description: Subtract (2s complement method) W register from register f. If d is 0, the result is stored in the W register. If d is 1, the result is stored back in register f.

SWAPF Swap Nibbles in f
Syntax: [label] SWAPF f, d
Operands: 0 <=f <=127 & d [0, 1]
Operation: (f<3:0>) → (destination<7:4>), (f<7:4>) → (destination <3:0>)
Status Affected: None
Description: The upper and lower nibbles of register f are exchanged. If d is 0, the result is placed in W register. If d is 1, the result is placed in register f.

XORLW Exclusive OR Literal with W
Syntax: [label] XORLW k
Operands: 0 <=k <=255
Operation: (W) XOR k → W)
Status Affected: Z
Description: The contents of the W register are XOR-ed with the eight bit literal k. The result is placed in the W register.

XORWF Exclusive OR W with f
Syntax: [label] XORWF f, d
Operands: 0 <=f <=127 & d [0,1]
Operation: (W) XOR (f) → destination)
Status Affected: Z
Description: Exclusive OR the contents of the W register with register f. If d is 0, the result is stored in the W register. If d is 1, the result is stored back in register f.

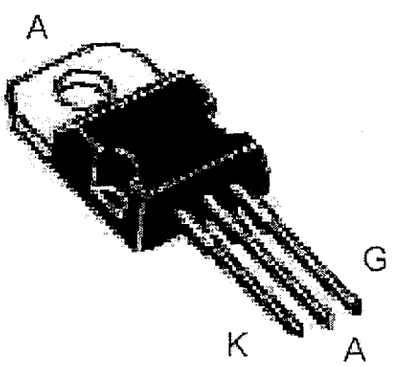
A.6 TYN 612

A.6.1 Specification

TYN612

V_{rms}	600V
I_{rms}	12 A
I_{gt}	15 mA
I_h	30 mA
dV/dt	200 V/us
dI/dt	100 A/us
package	TO220

A.6.2 Pin Details



TO220

Appendix – B

Thermocouple Output Data

B.1 Thermocouple

B.1.1 Introduction

Thermocouples are temperature sensors suitable for use with any make of instrument designed or programmed for use with the same type of thermocouple. Thermocouples are based on the principle that when two dissimilar metals are joined a predictable voltage will be generated that relates to the difference in temperature between the measuring junction and the reference junction (connection to the measuring device

The selection of the optimum thermocouple type (metals used in their construction) is based on application temperature, atmosphere, and required length of service, accuracy and cost. When a replacement thermocouple is required, it is of the utmost importance that the type of thermocouple type used in the replacement matches that of the measuring instrument. Different thermocouple types have very different voltage output curves. It is also required that thermocouple or thermocouple extension wire, of the proper type, be used all the way from the sensing element to the measuring element. Large errors can develop if this practice is not followed.

B.1.2 Considerations

Wire Size of Thermocouple: Selecting the wire size used in the thermocouple sensor depends upon the application. Generally, when longer life is required for the higher temperatures, the larger size wires should be chosen. When sensitivity is the prime concern, the smaller sizes should be used.

Length of Thermocouple Probe: Since the effect of conduction of heat from the hot end of the thermocouple must be minimized, the thermocouple probe must have sufficient length. Unless there is sufficient immersion, readings will be low. It is suggested the thermocouple be immersed for a minimum distance equivalent to four times the outside diameter of a protection tube or well.

Location of Thermocouple: Thermocouples should always be in a position to have a definite temperature relationship to the work load. Usually, the thermocouple should be located between the work load and the heat source and be located approximately 1/3 the distance from the work load to the heat source.

B.1.3 Important Terms

Cold Junction or Reference Junction: - The junction that is generally at the measuring device that is held at a relatively constant temperature.

Cold Junction Compensation - Measures the ambient temperature at the connection of the thermocouple wire to the measuring device. This allows for accurate computation of the temperature at the hot junction by the measuring device.

Dual Element - Two thermocouple elements housed within one thermocouple hardware assembly.

Extension Wire - Wires which connect the thermocouple itself to a reference junction, i.e. controller, receiver, recorder, etc. Extension wire must be of the same type as the thermocouple. Special plugs and jacks made of the same alloys as the thermocouple should be used if a quick disconnect is required for the application.

Grounded Junction - The internal conductors of this thermocouple are welded directly to the surrounding sheath material, forming a completely sealed integral junction.

Ungrounded Junction - Although the internal thermocouple conductors are welded together they are electrically insulated from the external sheath material and are not connected to the sheath in any way. Ungrounded junction thermocouples are ideal for use in conductive solutions or wherever circuit isolation is required. Ungrounded junctions are required where the measuring instrumentation does not provide channel to channel isolation.

Exposed Junction - The thermocouple junction or measuring point is exposed without any protection assembly or tube. Exposed junction thermocouples due to their design, offer the user the fastest response time.

Hot Junction: - The measuring junction.

Immersion Length: - The portion of the thermocouple which is subject to the temperature which is being measured.

Measuring Junction: - The junction in a thermocouple which actually measures the temperature of the object. (Often referred to as the Hot Junction)

Protection Tube - A tube like assembly in which the thermocouple is installed in order to protect the element from harsh environments.

RTD - Abbreviation for Resistance Temperature Detector. It is a sensor which operates on the principle that the resistance increases with an increase in temperature at a specific rate. They are commonly manufactured using a platinum resistance element, characterized by more accuracy and more linearity in response than most thermocouples and generally much more costly and slow responding.

Thermocouple - A temperature sensor based on the principle that a voltage is produced when two dissimilar metals. The junction produces a voltage in proportion to the difference in temperature between the measuring junction and the reference junction.

Thermo well - A threaded or flanged closed end tube which is mounted directly to the process or vessel, designed to protect the thermocouple from the process surroundings.

Thermopile – a group of homo/heterogeneous thermocouple to produce accurate results in output (more than milli volts).

C.1 Output Voltage of K – type Thermo couple

C.1.1 Celsius vs. Milli Volts

°C	0	1	2	3	4	5	6	7	8	9	°C
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	20
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	30
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	40
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	50
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	60
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	70
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	80
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	90
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	100
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	110
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	120
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	130
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	140
150	6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500	150
160	6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901	160
170	6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300	170
180	7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699	180
190	7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099	190
200	8.138	8.178	8.218	8.258	8.298	8.338	8.378	8.418	8.458	8.499	200
210	8.539	8.579	8.619	8.659	8.699	8.739	8.779	8.819	8.860	8.900	210
220	8.940	8.980	9.020	9.061	9.101	9.141	9.181	9.222	9.262	9.302	220
230	9.343	9.383	9.423	9.464	9.504	9.545	9.585	9.626	9.666	9.707	230
240	9.747	9.788	9.828	9.869	9.909	9.950	9.991	10.031	10.072	10.113	240
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	250
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	260
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	270
280	11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753	280
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	290
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	300
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	310
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	320
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	330
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	340
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	350
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	360
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	370
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	380
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	390
400	16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778	400
410	16.820	16.862	16.904	16.947	16.989	17.031	17.074	17.116	17.158	17.201	410
420	17.243	17.285	17.328	17.370	17.413	17.455	17.497	17.540	17.582	17.624	420
430	17.667	17.709	17.752	17.794	17.837	17.879	17.921	17.964	18.006	18.049	430
°C	0	1	2	3	4	5	6	7	8	9	°C

440	18.091	18.134	18.176	18.218	18.261	18.303	18.346	18.388	18.431	18.473	**440**
450	18.516	18.558	18.601	18.643	18.686	18.728	18.771	18.813	18.856	18.898	**450**
460	18.941	18.983	19.026	19.068	19.111	19.154	19.196	19.239	19.281	19.324	**460**
470	19.366	19.409	19.451	19.494	19.537	19.579	19.622	19.664	19.707	19.750	**470**
480	19.792	19.835	19.877	19.920	19.962	20.005	20.048	20.090	20.133	20.175	**480**
490	20.218	20.261	20.303	20.346	20.389	20.431	20.474	20.516	20.559	20.602	**490**
500	20.644	20.687	20.730	20.772	20.815	20.857	20.900	20.943	20.985	21.028	**500**
510	21.071	21.113	21.156	21.199	21.241	21.284	21.326	21.369	21.412	21.454	**510**
520	21.497	21.540	21.582	21.625	21.668	21.710	21.753	21.796	21.838	21.881	**520**
530	21.924	21.966	22.009	22.052	22.094	22.137	22.179	22.222	22.265	22.307	**530**
540	22.350	22.393	22.435	22.478	22.521	22.563	22.606	22.649	22.691	22.734	**540**
550	22.776	22.819	22.862	22.904	22.947	22.990	23.032	23.075	23.117	23.160	**550**
560	23.203	23.245	23.288	23.331	23.373	23.416	23.458	23.501	23.544	23.586	**560**
570	23.629	23.671	23.714	23.757	23.799	23.842	23.884	23.927	23.970	24.012	**570**
580	24.055	24.097	24.140	24.182	24.225	24.267	24.310	24.353	24.395	24.438	**580**
590	24.480	24.523	24.565	24.608	24.650	24.693	24.735	24.778	24.820	24.863	**590**
600	24.905	24.948	24.990	25.033	25.075	25.118	25.160	25.203	25.245	25.288	**600**
610	25.330	25.373	25.415	25.458	25.500	25.543	25.585	25.627	25.670	25.712	**610**
620	25.755	25.797	25.840	25.882	25.924	25.967	26.009	26.052	26.094	26.136	**620**
630	26.179	26.221	26.263	26.306	26.348	26.390	26.433	26.475	26.517	26.560	**630**
640	26.602	26.644	26.687	26.729	26.771	26.814	26.856	26.898	26.940	26.983	**640**
650	27.025	27.067	27.109	27.152	27.194	27.236	27.278	27.320	27.363	27.405	**650**
660	27.447	27.489	27.531	27.574	27.616	27.658	27.700	27.742	27.784	27.826	**660**
670	27.869	27.911	27.953	27.995	28.037	28.079	28.121	28.163	28.205	28.247	**670**
680	28.289	28.332	28.374	28.416	28.458	28.500	28.542	28.584	28.626	28.668	**680**
690	28.710	28.752	28.794	28.835	28.877	28.919	28.961	29.003	29.045	29.087	**690**
700	29.129	29.171	29.213	29.255	29.297	29.338	29.380	29.422	29.464	29.506	**700**
710	29.548	29.589	29.631	29.673	29.715	29.757	29.798	29.840	29.882	29.924	**710**
720	29.965	30.007	30.049	30.090	30.132	30.174	30.216	30.257	30.299	30.341	**720**
730	30.382	30.424	30.466	30.507	30.549	30.590	30.632	30.674	30.715	30.757	**730**
740	30.798	30.840	30.881	30.923	30.964	31.006	31.047	31.089	31.130	31.172	**740**
750	31.213	31.255	31.296	31.338	31.379	31.421	31.462	31.504	31.545	31.586	**750**
760	31.628	31.669	31.710	31.752	31.793	31.834	31.876	31.917	31.958	32.000	**760**
770	32.041	32.082	32.124	32.165	32.206	32.247	32.289	32.330	32.371	32.412	**770**
780	32.453	32.495	32.536	32.577	32.618	32.659	32.700	32.742	32.783	32.824	**780**
790	32.865	32.906	32.947	32.988	33.029	33.070	33.111	33.152	33.193	33.234	**790**
800	33.275	33.316	33.357	33.398	33.439	33.480	33.521	33.562	33.603	33.644	**800**
810	33.685	33.726	33.767	33.808	33.848	33.889	33.930	33.971	34.012	34.053	**810**
820	34.093	34.134	34.175	34.216	34.257	34.297	34.338	34.379	34.420	34.460	**820**
830	34.501	34.542	34.582	34.623	34.664	34.704	34.745	34.786	34.826	34.867	**830**
840	34.908	34.948	34.989	35.029	35.070	35.110	35.151	35.192	35.232	35.273	**840**
850	35.313	35.354	35.394	35.435	35.475	35.516	35.556	35.596	35.637	35.677	**850**
860	35.718	35.758	35.798	35.839	35.879	35.920	35.960	36.000	36.041	36.081	**860**
870	36.121	36.162	36.202	36.242	36.282	36.323	36.363	36.403	36.443	36.484	**870**
880	36.524	36.564	36.604	36.644	36.685	36.725	36.765	36.805	36.845	36.885	**880**
890	36.925	36.965	37.006	37.046	37.086	37.126	37.166	37.206	37.246	37.286	**890**
900	37.326	37.366	37.406	37.446	37.486	37.526	37.566	37.606	37.646	37.686	**900**
910	37.725	37.765	37.805	37.845	37.885	37.925	37.965	38.005	38.044	38.084	**910**
920	38.124	38.164	38.204	38.243	38.283	38.323	38.363	38.402	38.442	38.482	**920**
930	38.522	38.561	38.601	38.641	38.680	38.720	38.760	38.799	38.839	38.878	**930**
940	38.918	38.958	38.997	39.037	39.076	39.116	39.155	39.195	39.235	39.274	**940**
950	39.314	39.353	39.393	39.432	39.471	39.511	39.550	39.590	39.629	39.669	**950**
960	39.708	39.747	39.787	39.826	39.866	39.905	39.944	39.984	40.023	40.062	**960**
970	40.101	40.141	40.180	40.219	40.259	40.298	40.337	40.376	40.415	40.455	**970**
°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**°C**

980	40.494	40.533	40.572	40.611	40.651	40.690	40.729	40.768	40.807	40.846	**980**
990	40.885	40.924	40.963	41.002	41.042	41.081	41.120	41.159	41.198	41.237	**990**
1000	41.276	41.315	41.354	41.393	41.431	41.470	41.509	41.548	41.587	41.626	**1000**
1010	41.665	41.704	41.743	41.781	41.820	41.859	41.898	41.937	41.976	42.014	**1010**
1020	42.053	42.092	42.131	42.169	42.208	42.247	42.286	42.324	42.363	42.402	**1020**
1030	42.440	42.479	42.518	42.556	42.595	42.633	42.672	42.711	42.749	42.788	**1030**
1040	42.826	42.865	42.903	42.942	42.980	43.019	43.057	43.096	43.134	43.173	**1040**
1050	43.211	43.250	43.288	43.327	43.365	43.403	43.442	43.480	43.518	43.557	**1050**
1060	43.595	43.633	43.672	43.710	43.748	43.787	43.825	43.863	43.901	43.940	**1060**
1070	43.978	44.016	44.054	44.092	44.130	44.169	44.207	44.245	44.283	44.321	**1070**
1080	44.359	44.397	44.435	44.473	44.512	44.550	44.588	44.626	44.664	44.702	**1080**
1090	44.740	44.778	44.816	44.853	44.891	44.929	44.967	45.005	45.043	45.081	**1090**
1100	45.119	45.157	45.194	45.232	45.270	45.308	45.346	45.383	45.421	45.459	**1100**
1110	45.497	45.534	45.572	45.610	45.647	45.685	45.723	45.760	45.798	45.836	**1110**
1120	45.873	45.911	45.948	45.986	46.024	46.061	46.099	46.136	46.174	46.211	**1120**
1130	46.249	46.286	46.324	46.361	46.398	46.436	46.473	46.511	46.548	46.585	**1130**
1140	46.623	46.660	46.697	46.735	46.772	46.809	46.847	46.884	46.921	46.958	**1140**
1150	46.995	47.033	47.070	47.107	47.144	47.181	47.218	47.256	47.293	47.330	**1150**
1160	47.367	47.404	47.441	47.478	47.515	47.552	47.589	47.626	47.663	47.700	**1160**
1170	47.737	47.774	47.811	47.848	47.884	47.921	47.958	47.995	48.032	48.069	**1170**
1180	48.105	48.142	48.179	48.216	48.252	48.289	48.326	48.363	48.399	48.436	**1180**
1190	48.473	48.509	48.546	48.582	48.619	48.656	48.692	48.729	48.765	48.802	**1190**
1200	48.838	48.875	48.911	48.948	48.984	49.021	49.057	49.093	49.130	49.166	**1200**
1210	49.202	49.239	49.275	49.311	49.348	49.384	49.420	49.456	49.493	49.529	**1210**
1220	49.565	49.601	49.637	49.674	49.710	49.746	49.782	49.818	49.854	49.890	**1220**
1230	49.926	49.962	49.998	50.034	50.070	50.106	50.142	50.178	50.214	50.250	**1230**
1240	50.286	50.322	50.358	50.393	50.429	50.465	50.501	50.537	50.572	50.608	**1240**
1250	50.644	50.680	50.715	50.751	50.787	50.822	50.858	50.894	50.929	50.965	**1250**
1260	51.000	51.036	51.071	51.107	51.142	51.178	51.213	51.249	51.284	51.320	**1260**
1270	51.355	51.391	51.426	51.461	51.497	51.532	51.567	51.603	51.638	51.673	**1270**
1280	51.708	51.744	51.779	51.814	51.849	51.885	51.920	51.955	51.990	52.025	**1280**
1290	52.060	52.095	52.130	52.165	52.200	52.235	52.270	52.305	52.340	52.375	**1290**
1300	52.410	52.445	52.480	52.515	52.550	52.585	52.620	52.654	52.689	52.724	**1300**
1310	52.759	52.794	52.828	52.863	52.898	52.932	52.967	53.002	53.037	53.071	**1310**
1320	53.106	53.140	53.175	53.210	53.244	53.279	53.313	53.348	53.382	53.417	**1320**
1330	53.451	53.486	53.520	53.555	53.589	53.623	53.658	53.692	53.727	53.761	**1330**
1340	53.795	53.830	53.864	53.898	53.932	53.967	54.001	54.035	54.069	54.104	**1340**
1350	54.138	54.172	54.206	54.240	54.274	54.308	54.343	54.377	54.411	54.445	**1350**
1360	54.479	54.513	54.547	54.581	54.615	54.649	54.683	54.717	54.751	54.785	**1360**
1370	54.819	54.852	54.886								**1370**

C.1.2 Fahrenheit vs. Milli Volts

°F	0	1	2	3	4	5	6	7	8	9	°F
-450	-6.456	-6.456	-6.457	-6.457	-6.458						-450
-440	-6.446	-6.448	-6.449	-6.450	-6.451	-6.452	-6.453	-6.454	-6.454	-6.455	-440
-430	-6.431	-6.433	-6.435	-6.436	-6.438	-6.440	-6.441	-6.443	-6.444	-6.445	-430
-420	-6.409	-6.411	-6.414	-6.416	-6.419	-6.421	-6.423	-6.425	-6.427	-6.429	-420
-410	-6.380	-6.383	-6.386	-6.389	-6.392	-6.395	-6.398	-6.401	-6.404	-6.406	-410
-400	-6.344	-6.348	-6.352	-6.355	-6.359	-6.363	-6.366	-6.370	-6.373	-6.377	-400
-390	-6.301	-6.306	-6.310	-6.315	-6.319	-6.323	-6.328	-6.332	-6.336	-6.340	-390
-380	-6.251	-6.257	-6.262	-6.267	-6.272	-6.277	-6.282	-6.287	-6.292	-6.296	-380
-370	-6.195	-6.201	-6.207	-6.213	-6.218	-6.224	-6.230	-6.235	-6.241	-6.246	-370
-360	-6.133	-6.139	-6.146	-6.152	-6.158	-6.165	-6.171	-6.177	-6.183	-6.189	-360
-350	-6.064	-6.071	-6.078	-6.085	-6.092	-6.099	-6.106	-6.113	-6.119	-6.126	-350
-340	-5.989	-5.997	-6.004	-6.012	-6.020	-6.027	-6.035	-6.042	-6.049	-6.057	-340
-330	-5.908	-5.917	-5.925	-5.933	-5.941	-5.949	-5.957	-5.965	-5.973	-5.981	-330
-320	-5.822	-5.831	-5.840	-5.848	-5.857	-5.866	-5.874	-5.883	-5.891	-5.900	-320
-310	-5.730	-5.739	-5.749	-5.758	-5.767	-5.776	-5.786	-5.795	-5.804	-5.813	-310
-300	-5.632	-5.642	-5.652	-5.662	-5.672	-5.682	-5.691	-5.701	-5.711	-5.720	-300
-290	-5.529	-5.540	-5.550	-5.561	-5.571	-5.581	-5.592	-5.602	-5.612	-5.622	-290
-280	-5.421	-5.432	-5.443	-5.454	-5.465	-5.476	-5.487	-5.497	-5.508	-5.519	-280
-270	-5.308	-5.320	-5.331	-5.343	-5.354	-5.365	-5.377	-5.388	-5.399	-5.410	-270
-260	-5.190	-5.202	-5.214	-5.226	-5.238	-5.250	-5.261	-5.273	-5.285	-5.296	-260
-250	-5.067	-5.079	-5.092	-5.104	-5.117	-5.129	-5.141	-5.153	-5.166	-5.178	-250
-240	-4.939	-4.952	-4.965	-4.978	-4.991	-5.003	-5.016	-5.029	-5.042	-5.054	-240
-230	-4.806	-4.820	-4.833	-4.847	-4.860	-4.873	-4.886	-4.900	-4.913	-4.926	-230
-220	-4.669	-4.683	-4.697	-4.711	-4.724	-4.738	-4.752	-4.766	-4.779	-4.793	-220
-210	-4.527	-4.542	-4.556	-4.570	-4.584	-4.599	-4.613	-4.627	-4.641	-4.655	-210
-200	-4.381	-4.396	-4.411	-4.425	-4.440	-4.455	-4.469	-4.484	-4.498	-4.513	-200
-190	-4.231	-4.246	-4.261	-4.276	-4.291	-4.306	-4.321	-4.336	-4.351	-4.366	-190
-180	-4.076	-4.091	-4.107	-4.123	-4.138	-4.154	-4.169	-4.185	-4.200	-4.215	-180
-170	-3.917	-3.933	-3.949	-3.965	-3.981	-3.997	-4.013	-4.029	-4.044	-4.060	-170
-160	-3.754	-3.771	-3.787	-3.803	-3.820	-3.836	-3.852	-3.869	-3.885	-3.901	-160
-150	-3.587	-3.604	-3.621	-3.638	-3.655	-3.671	-3.688	-3.705	-3.721	-3.738	-150
-140	-3.417	-3.434	-3.451	-3.468	-3.486	-3.503	-3.520	-3.537	-3.554	-3.571	-140
-130	-3.243	-3.260	-3.278	-3.295	-3.313	-3.330	-3.348	-3.365	-3.382	-3.400	-130
-120	-3.065	-3.083	-3.101	-3.119	-3.136	-3.154	-3.172	-3.190	-3.207	-3.225	-120
-110	-2.884	-2.902	-2.920	-2.938	-2.957	-2.975	-2.993	-3.011	-3.029	-3.047	-110
-100	-2.699	-2.718	-2.736	-2.755	-2.773	-2.792	-2.810	-2.829	-2.847	-2.865	-100
-90	-2.511	-2.530	-2.549	-2.568	-2.587	-2.605	-2.624	-2.643	-2.662	-2.680	-90
-80	-2.320	-2.339	-2.359	-2.378	-2.397	-2.416	-2.435	-2.454	-2.473	-2.492	-80
-70	-2.126	-2.146	-2.165	-2.185	-2.204	-2.223	-2.243	-2.262	-2.282	-2.301	-70
-60	-1.929	-1.949	-1.969	-1.988	-2.008	-2.028	-2.048	-2.067	-2.087	-2.106	-60
-50	-1.729	-1.749	-1.770	-1.790	-1.810	-1.830	-1.850	-1.869	-1.889	-1.909	-50
-40	-1.527	-1.547	-1.568	-1.588	-1.608	-1.628	-1.649	-1.669	-1.689	-1.709	-40
-30	-1.322	-1.343	-1.363	-1.384	-1.404	-1.425	-1.445	-1.466	-1.486	-1.507	-30
-20	-1.114	-1.135	-1.156	-1.177	-1.198	-1.218	-1.239	-1.260	-1.281	-1.301	-20
-10	-0.905	-0.926	-0.947	-0.968	-0.989	-1.010	-1.031	-1.052	-1.073	-1.094	-10
0	-0.692	-0.714	-0.735	-0.756	-0.778	-0.799	-0.820	-0.841	-0.862	-0.883	0
0	-0.692	-0.671	-0.650	-0.628	-0.607	-0.586	-0.564	-0.543	-0.521	-0.500	0
10	-0.478	-0.457	-0.435	-0.413	-0.392	-0.370	-0.349	-0.327	-0.305	-0.284	10
20	-0.262	-0.240	-0.218	-0.197	-0.175	-0.153	-0.131	-0.109	-0.088	-0.066	20
30	-0.044	-0.022	0.000	0.022	0.044	0.066	0.088	0.110	0.132	0.154	30

°F	0	1	2	3	4	5	6	7	8	9	°F
40	0.176	0.198	0.220	0.242	0.264	0.286	0.308	0.330	0.353	0.375	40
50	0.397	0.419	0.441	0.463	0.486	0.508	0.530	0.552	0.575	0.597	50
60	0.619	0.642	0.664	0.686	0.709	0.731	0.753	0.776	0.798	0.821	60
70	0.843	0.865	0.888	0.910	0.933	0.955	0.978	1.000	1.023	1.045	70
80	1.068	1.090	1.113	1.136	1.158	1.181	1.203	1.226	1.249	1.271	80
90	1.294	1.316	1.339	1.362	1.384	1.407	1.430	1.453	1.475	1.498	90
100	1.521	1.543	1.566	1.589	1.612	1.635	1.657	1.680	1.703	1.726	100
110	1.749	1.771	1.794	1.817	1.840	1.863	1.886	1.909	1.931	1.954	110
120	1.977	2.000	2.023	2.046	2.069	2.092	2.115	2.138	2.161	2.184	120
130	2.207	2.230	2.253	2.276	2.298	2.321	2.344	2.367	2.390	2.413	130
140	2.436	2.459	2.483	2.506	2.529	2.552	2.575	2.598	2.621	2.644	140
150	2.667	2.690	2.713	2.736	2.759	2.782	2.805	2.828	2.851	2.874	150
160	2.897	2.920	2.944	2.967	2.990	3.013	3.036	3.059	3.082	3.105	160
170	3.128	3.151	3.174	3.197	3.220	3.244	3.267	3.290	3.313	3.336	170
180	3.359	3.382	3.405	3.428	3.451	3.474	3.497	3.520	3.544	3.567	180
190	3.590	3.613	3.636	3.659	3.682	3.705	3.728	3.751	3.774	3.797	190
200	3.820	3.843	3.866	3.889	3.912	3.935	3.958	3.981	4.004	4.027	200
210	4.050	4.073	4.096	4.119	4.142	4.165	4.188	4.211	4.234	4.257	210
220	4.280	4.303	4.326	4.349	4.372	4.395	4.417	4.440	4.463	4.486	220
230	4.509	4.532	4.555	4.578	4.601	4.623	4.646	4.669	4.692	4.715	230
240	4.738	4.760	4.783	4.806	4.829	4.852	4.874	4.897	4.920	4.943	240
250	4.965	4.988	5.011	5.034	5.056	5.079	5.102	5.124	5.147	5.170	250
260	5.192	5.215	5.238	5.260	5.283	5.306	5.328	5.351	5.374	5.396	260
270	5.419	5.441	5.464	5.487	5.509	5.532	5.554	5.577	5.599	5.622	270
280	5.644	5.667	5.690	5.712	5.735	5.757	5.779	5.802	5.824	5.847	280
290	5.869	5.892	5.914	5.937	5.959	5.982	6.004	6.026	6.049	6.071	290
300	6.094	6.116	6.138	6.161	6.183	6.205	6.228	6.250	6.272	6.295	300
310	6.317	6.339	6.362	6.384	6.406	6.429	6.451	6.473	6.496	6.518	310
320	6.540	6.562	6.585	6.607	6.629	6.652	6.674	6.696	6.718	6.741	320
330	6.763	6.785	6.807	6.829	6.852	6.874	6.896	6.918	6.941	6.963	330
340	6.985	7.007	7.029	7.052	7.074	7.096	7.118	7.140	7.163	7.185	340
350	7.207	7.229	7.251	7.273	7.296	7.318	7.340	7.362	7.384	7.407	350
360	7.429	7.451	7.473	7.495	7.517	7.540	7.562	7.584	7.606	7.628	360
370	7.650	7.673	7.695	7.717	7.739	7.761	7.783	7.806	7.828	7.850	370
380	7.872	7.894	7.917	7.939	7.961	7.983	8.005	8.027	8.050	8.072	380
390	8.094	8.116	8.138	8.161	8.183	8.205	8.227	8.250	8.272	8.294	390
400	8.316	8.338	8.361	8.383	8.405	8.427	8.450	8.472	8.494	8.516	400
410	8.539	8.561	8.583	8.605	8.628	8.650	8.672	8.694	8.717	8.739	410
420	8.761	8.784	8.806	8.828	8.851	8.873	8.895	8.918	8.940	8.962	420
430	8.985	9.007	9.029	9.052	9.074	9.096	9.119	9.141	9.163	9.186	430
440	9.208	9.231	9.253	9.275	9.298	9.320	9.343	9.365	9.388	9.410	440
450	9.432	9.455	9.477	9.500	9.522	9.545	9.567	9.590	9.612	9.635	450
460	9.657	9.680	9.702	9.725	9.747	9.770	9.792	9.815	9.837	9.860	460
470	9.882	9.905	9.927	9.950	9.973	9.995	10.018	10.040	10.063	10.086	470
480	10.108	10.131	10.153	10.176	10.199	10.221	10.244	10.267	10.289	10.312	480
490	10.334	10.357	10.380	10.402	10.425	10.448	10.471	10.493	10.516	10.539	490
500	10.561	10.584	10.607	10.629	10.652	10.675	10.698	10.720	10.743	10.766	500
510	10.789	10.811	10.834	10.857	10.880	10.903	10.925	10.948	10.971	10.994	510
520	11.017	11.039	11.062	11.085	11.108	11.131	11.154	11.176	11.199	11.222	520
530	11.245	11.268	11.291	11.313	11.336	11.359	11.382	11.405	11.428	11.451	530
540	11.474	11.497	11.519	11.542	11.565	11.588	11.611	11.634	11.657	11.680	540
550	11.703	11.726	11.749	11.772	11.795	11.818	11.841	11.864	11.887	11.910	550

°F	0	1	2	3	4	5	6	7	8	9	°F
560	11.933	11.956	11.978	12.001	12.024	12.047	12.070	12.093	12.116	12.140	560
570	12.163	12.186	12.209	12.232	12.255	12.278	12.301	12.324	12.347	12.370	570
580	12.393	12.416	12.439	12.462	12.485	12.508	12.531	12.554	12.577	12.600	580
590	12.624	12.647	12.670	12.693	12.716	12.739	12.762	12.785	12.808	12.831	590
600	12.855	12.878	12.901	12.924	12.947	12.970	12.993	13.016	13.040	13.063	600
610	13.086	13.109	13.132	13.155	13.179	13.202	13.225	13.248	13.271	13.294	610
620	13.318	13.341	13.364	13.387	13.410	13.433	13.457	13.480	13.503	13.526	620
630	13.549	13.573	13.596	13.619	13.642	13.665	13.689	13.712	13.735	13.758	630
640	13.782	13.805	13.828	13.851	13.874	13.898	13.921	13.944	13.967	13.991	640
650	14.014	14.037	14.060	14.084	14.107	14.130	14.154	14.177	14.200	14.223	650
660	14.247	14.270	14.293	14.316	14.340	14.363	14.386	14.410	14.433	14.456	660
670	14.479	14.503	14.526	14.549	14.573	14.596	14.619	14.643	14.666	14.689	670
680	14.713	14.736	14.759	14.783	14.806	14.829	14.853	14.876	14.899	14.923	680
690	14.946	14.969	14.993	15.016	15.039	15.063	15.086	15.109	15.133	15.156	690
700	15.179	15.203	15.226	15.250	15.273	15.296	15.320	15.343	15.366	15.390	700
710	15.413	15.437	15.460	15.483	15.507	15.530	15.554	15.577	15.600	15.624	710
720	15.647	15.671	15.694	15.717	15.741	15.764	15.788	15.811	15.834	15.858	720
730	15.881	15.905	15.928	15.952	15.975	15.998	16.022	16.045	16.069	16.092	730
740	16.116	16.139	16.163	16.186	16.209	16.233	16.256	16.280	16.303	16.327	740
750	16.350	16.374	16.397	16.421	16.444	16.468	16.491	16.515	16.538	16.561	750
760	16.585	16.608	16.632	16.655	16.679	16.702	16.726	16.749	16.773	16.796	760
770	16.820	16.843	16.867	16.890	16.914	16.937	16.961	16.984	17.008	17.031	770
780	17.055	17.078	17.102	17.125	17.149	17.173	17.196	17.220	17.243	17.267	780
790	17.290	17.314	17.337	17.361	17.384	17.408	17.431	17.455	17.478	17.502	790
800	17.526	17.549	17.573	17.596	17.620	17.643	17.667	17.690	17.714	17.738	800
810	17.761	17.785	17.808	17.832	17.855	17.879	17.902	17.926	17.950	17.973	810
820	17.997	18.020	18.044	18.068	18.091	18.115	18.138	18.162	18.185	18.209	820
830	18.233	18.256	18.280	18.303	18.327	18.351	18.374	18.398	18.421	18.445	830
840	18.469	18.492	18.516	18.539	18.563	18.587	18.610	18.634	18.657	18.681	840
850	18.705	18.728	18.752	18.776	18.799	18.823	18.846	18.870	18.894	18.917	850
860	18.941	18.965	18.988	19.012	19.035	19.059	19.083	19.106	19.130	19.154	860
870	19.177	19.201	19.224	19.248	19.272	19.295	19.319	19.343	19.366	19.390	870
880	19.414	19.437	19.461	19.485	19.508	19.532	19.556	19.579	19.603	19.626	880
890	19.650	19.674	19.697	19.721	19.745	19.768	19.792	19.816	19.839	19.863	890
900	19.887	19.910	19.934	19.958	19.981	20.005	20.029	20.052	20.076	20.100	900
910	20.123	20.147	20.171	20.194	20.218	20.242	20.265	20.289	20.313	20.336	910
920	20.360	20.384	20.407	20.431	20.455	20.479	20.502	20.526	20.550	20.573	920
930	20.597	20.621	20.644	20.668	20.692	20.715	20.739	20.763	20.786	20.810	930
940	20.834	20.857	20.881	20.905	20.929	20.952	20.976	21.000	21.023	21.047	940
950	21.071	21.094	21.118	21.142	21.165	21.189	21.213	21.236	21.260	21.284	950
960	21.308	21.331	21.355	21.379	21.402	21.426	21.450	21.473	21.497	21.521	960
970	21.544	21.568	21.592	21.616	21.639	21.663	21.687	21.710	21.734	21.758	970
980	21.781	21.805	21.829	21.852	21.876	21.900	21.924	21.947	21.971	21.995	980
990	22.018	22.042	22.066	22.089	22.113	22.137	22.160	22.184	22.208	22.232	990
1000	22.255	22.279	22.303	22.326	22.350	22.374	22.397	22.421	22.445	22.468	1000
1010	22.492	22.516	22.540	22.563	22.587	22.611	22.634	22.658	22.682	22.705	1010
1020	22.729	22.753	22.776	22.800	22.824	22.847	22.871	22.895	22.919	22.942	1020
1030	22.966	22.990	23.013	23.037	23.061	23.084	23.108	23.132	23.155	23.179	1030
1040	23.203	23.226	23.250	23.274	23.297	23.321	23.345	23.368	23.392	23.416	1040
1050	23.439	23.463	23.487	23.510	23.534	23.558	23.581	23.605	23.629	23.652	1050
1060	23.676	23.700	23.723	23.747	23.771	23.794	23.818	23.842	23.865	23.889	1060
1070	23.913	23.936	23.960	23.984	24.007	24.031	24.055	24.078	24.102	24.126	1070

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1080	24.149	24.173	24.197	24.220	24.244	24.267	24.291	24.315	24.338	24.362	1080
1090	24.386	24.409	24.433	24.457	24.480	24.504	24.527	24.551	24.575	24.598	1090
1100	24.622	24.646	24.669	24.693	24.717	24.740	24.764	24.787	24.811	24.835	1100
1110	24.858	24.882	24.905	24.929	24.953	24.976	25.000	25.024	25.047	25.071	1110
1120	25.094	25.118	25.142	25.165	25.189	25.212	25.236	25.260	25.283	25.307	1120
1130	25.330	25.354	25.377	25.401	25.425	25.448	25.472	25.495	25.519	25.543	1130
1140	25.566	25.590	25.613	25.637	25.660	25.684	25.708	25.731	25.755	25.778	1140
1150	25.802	25.825	25.849	25.873	25.896	25.920	25.943	25.967	25.990	26.014	1150
1160	26.037	26.061	26.084	26.108	26.132	26.155	26.179	26.202	26.226	26.249	1160
1170	26.273	26.296	26.320	26.343	26.367	26.390	26.414	26.437	26.461	26.484	1170
1180	26.508	26.532	26.555	26.579	26.602	26.626	26.649	26.673	26.696	26.720	1180
1190	26.743	26.767	26.790	26.814	26.837	26.861	26.884	26.907	26.931	26.954	1190
1200	26.978	27.001	27.025	27.048	27.072	27.095	27.119	27.142	27.166	27.189	1200
1210	27.213	27.236	27.260	27.283	27.306	27.330	27.353	27.377	27.400	27.424	1210
1220	27.447	27.471	27.494	27.517	27.541	27.564	27.588	27.611	27.635	27.658	1220
1230	27.681	27.705	27.728	27.752	27.775	27.798	27.822	27.845	27.869	27.892	1230
1240	27.915	27.939	27.962	27.986	28.009	28.032	28.056	28.079	28.103	28.126	1240
1250	28.149	28.173	28.196	28.219	28.243	28.266	28.289	28.313	28.336	28.360	1250
1260	28.383	28.406	28.430	28.453	28.476	28.500	28.523	28.546	28.570	28.593	1260
1270	28.616	28.640	28.663	28.686	28.710	28.733	28.756	28.780	28.803	28.826	1270
1280	28.849	28.873	28.896	28.919	28.943	28.966	28.989	29.013	29.036	29.059	1280
1290	29.082	29.106	29.129	29.152	29.176	29.199	29.222	29.245	29.269	29.292	1290
1300	29.315	29.338	29.362	29.385	29.408	29.431	29.455	29.478	29.501	29.524	1300
1310	29.548	29.571	29.594	29.617	29.640	29.664	29.687	29.710	29.733	29.757	1310
1320	29.780	29.803	29.826	29.849	29.873	29.896	29.919	29.942	29.965	29.989	1320
1330	30.012	30.035	30.058	30.081	30.104	30.128	30.151	30.174	30.197	30.220	1330
1340	30.243	30.267	30.290	30.313	30.336	30.359	30.382	30.405	30.429	30.452	1340
1350	30.475	30.498	30.521	30.544	30.567	30.590	30.613	30.637	30.660	30.683	1350
1360	30.706	30.729	30.752	30.775	30.798	30.821	30.844	30.868	30.891	30.914	1360
1370	30.937	30.960	30.983	31.006	31.029	31.052	31.075	31.098	31.121	31.144	1370
1380	31.167	31.190	31.213	31.236	31.260	31.283	31.306	31.329	31.352	31.375	1380
1390	31.398	31.421	31.444	31.467	31.490	31.513	31.536	31.559	31.582	31.605	1390
1400	31.628	31.651	31.674	31.697	31.720	31.743	31.766	31.789	31.812	31.834	1400
1410	31.857	31.880	31.903	31.926	31.949	31.972	31.995	32.018	32.041	32.064	1410
1420	32.087	32.110	32.133	32.156	32.179	32.202	32.224	32.247	32.270	32.293	1420
1430	32.316	32.339	32.362	32.385	32.408	32.431	32.453	32.476	32.499	32.522	1430
1440	32.545	32.568	32.591	32.614	32.636	32.659	32.682	32.705	32.728	32.751	1440
1450	32.774	32.796	32.819	32.842	32.865	32.888	32.911	32.933	32.956	32.979	1450
1460	33.002	33.025	33.047	33.070	33.093	33.116	33.139	33.161	33.184	33.207	1460
1470	33.230	33.253	33.275	33.298	33.321	33.344	33.366	33.389	33.412	33.435	1470
1480	33.458	33.480	33.503	33.526	33.548	33.571	33.594	33.617	33.639	33.662	1480
1490	33.685	33.708	33.730	33.753	33.776	33.798	33.821	33.844	33.867	33.889	1490
1500	33.912	33.935	33.957	33.980	34.003	34.025	34.048	34.071	34.093	34.116	1500
1510	34.139	34.161	34.184	34.207	34.229	34.252	34.275	34.297	34.320	34.343	1510
1520	34.365	34.388	34.410	34.433	34.456	34.478	34.501	34.524	34.546	34.569	1520
1530	34.591	34.614	34.637	34.659	34.682	34.704	34.727	34.750	34.772	34.795	1530
1540	34.817	34.840	34.862	34.885	34.908	34.930	34.953	34.975	34.998	35.020	1540
1550	35.043	35.065	35.088	35.110	35.133	35.156	35.178	35.201	35.223	35.246	1550
1560	35.268	35.291	35.313	35.336	35.358	35.381	35.403	35.426	35.448	35.471	1560
1570	35.493	35.516	35.538	35.560	35.583	35.605	35.628	35.650	35.673	35.695	1570
1580	35.718	35.740	35.763	35.785	35.807	35.830	35.852	35.875	35.897	35.920	1580
1590	35.942	35.964	35.987	36.009	36.032	36.054	36.076	36.099	36.121	36.144	1590

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1600	36.166	36.188	36.211	36.233	36.256	36.278	36.300	36.323	36.345	36.367	1600
1610	36.390	36.412	36.434	36.457	36.479	36.501	36.524	36.546	36.568	36.591	1610
1620	36.613	36.635	36.658	36.680	36.702	36.725	36.747	36.769	36.792	36.814	1620
1630	36.836	36.859	36.881	36.903	36.925	36.948	36.970	36.992	37.014	37.037	1630
1640	37.059	37.081	37.104	37.126	37.148	37.170	37.193	37.215	37.237	37.259	1640
1650	37.281	37.304	37.326	37.348	37.370	37.393	37.415	37.437	37.459	37.481	1650
1660	37.504	37.526	37.548	37.570	37.592	37.615	37.637	37.659	37.681	37.703	1660
1670	37.725	37.748	37.770	37.792	37.814	37.836	37.858	37.881	37.903	37.925	1670
1680	37.947	37.969	37.991	38.013	38.036	38.058	38.080	38.102	38.124	38.146	1680
1690	38.168	38.190	38.212	38.235	38.257	38.279	38.301	38.323	38.345	38.367	1690
1700	38.389	38.411	38.433	38.455	38.477	38.499	38.522	38.544	38.566	38.588	1700
1710	38.610	38.632	38.654	38.676	38.698	38.720	38.742	38.764	38.786	38.808	1710
1720	38.830	38.852	38.874	38.896	38.918	38.940	38.962	38.984	39.006	39.028	1720
1730	39.050	39.072	39.094	39.116	39.138	39.160	39.182	39.204	39.226	39.248	1730
1740	39.270	39.292	39.314	39.335	39.357	39.379	39.401	39.423	39.445	39.467	1740
1750	39.489	39.511	39.533	39.555	39.577	39.599	39.620	39.642	39.664	39.686	1750
1760	39.708	39.730	39.752	39.774	39.796	39.817	39.839	39.861	39.883	39.905	1760
1770	39.927	39.949	39.970	39.992	40.014	40.036	40.058	40.080	40.101	40.123	1770
1780	40.145	40.167	40.189	40.211	40.232	40.254	40.276	40.298	40.320	40.341	1780
1790	40.363	40.385	40.407	40.429	40.450	40.472	40.494	40.516	40.537	40.559	1790
1800	40.581	40.603	40.624	40.646	40.668	40.690	40.711	40.733	40.755	40.777	1800
1810	40.798	40.820	40.842	40.864	40.885	40.907	40.929	40.950	40.972	40.994	1810
1820	41.015	41.037	41.059	41.081	41.102	41.124	41.146	41.167	41.189	41.211	1820
1830	41.232	41.254	41.276	41.297	41.319	41.341	41.362	41.384	41.405	41.427	1830
1840	41.449	41.470	41.492	41.514	41.535	41.557	41.578	41.600	41.622	41.643	1840
1850	41.665	41.686	41.708	41.730	41.751	41.773	41.794	41.816	41.838	41.859	1850
1860	41.881	41.902	41.924	41.945	41.967	41.988	42.010	42.032	42.053	42.075	1860
1870	42.096	42.118	42.139	42.161	42.182	42.204	42.225	42.247	42.268	42.290	1870
1880	42.311	42.333	42.354	42.376	42.397	42.419	42.440	42.462	42.483	42.505	1880
1890	42.526	42.548	42.569	42.591	42.612	42.633	42.655	42.676	42.698	42.719	1890
1900	42.741	42.762	42.783	42.805	42.826	42.848	42.869	42.891	42.912	42.933	1900
1910	42.955	42.976	42.998	43.019	43.040	43.062	43.083	43.104	43.126	43.147	1910
1920	43.169	43.190	43.211	43.233	43.254	43.275	43.297	43.318	43.339	43.361	1920
1930	43.382	43.403	43.425	43.446	43.467	43.489	43.510	43.531	43.552	43.574	1930
1940	43.595	43.616	43.638	43.659	43.680	43.701	43.723	43.744	43.765	43.787	1940
1950	43.808	43.829	43.850	43.872	43.893	43.914	43.935	43.957	43.978	43.999	1950
1960	44.020	44.041	44.063	44.084	44.105	44.126	44.147	44.169	44.190	44.211	1960
1970	44.232	44.253	44.275	44.296	44.317	44.338	44.359	44.380	44.402	44.423	1970
1980	44.444	44.465	44.486	44.507	44.528	44.550	44.571	44.592	44.613	44.634	1980
1990	44.655	44.676	44.697	44.719	44.740	44.761	44.782	44.803	44.824	44.845	1990
2000	44.866	44.887	44.908	44.929	44.950	44.971	44.992	45.014	45.035	45.056	2000
2010	45.077	45.098	45.119	45.140	45.161	45.182	45.203	45.224	45.245	45.266	2010
2020	45.287	45.308	45.329	45.350	45.371	45.392	45.413	45.434	45.455	45.476	2020
2030	45.497	45.518	45.539	45.560	45.580	45.601	45.622	45.643	45.664	45.685	2030
2040	45.706	45.727	45.748	45.769	45.790	45.811	45.832	45.852	45.873	45.894	2040
2050	45.915	45.936	45.957	45.978	45.999	46.019	46.040	46.061	46.082	46.103	2050
2060	46.124	46.145	46.165	46.186	46.207	46.228	46.249	46.269	46.290	46.311	2060
2070	46.332	46.353	46.374	46.394	46.415	46.436	46.457	46.477	46.498	46.519	2070
2080	46.540	46.560	46.581	46.602	46.623	46.643	46.664	46.685	46.706	46.726	2080
2090	46.747	46.768	46.789	46.809	46.830	46.851	46.871	46.892	46.913	46.933	2090
2100	46.954	46.975	46.995	47.016	47.037	47.057	47.078	47.099	47.119	47.140	2100
2110	47.161	47.181	47.202	47.223	47.243	47.264	47.284	47.305	47.326	47.346	2110

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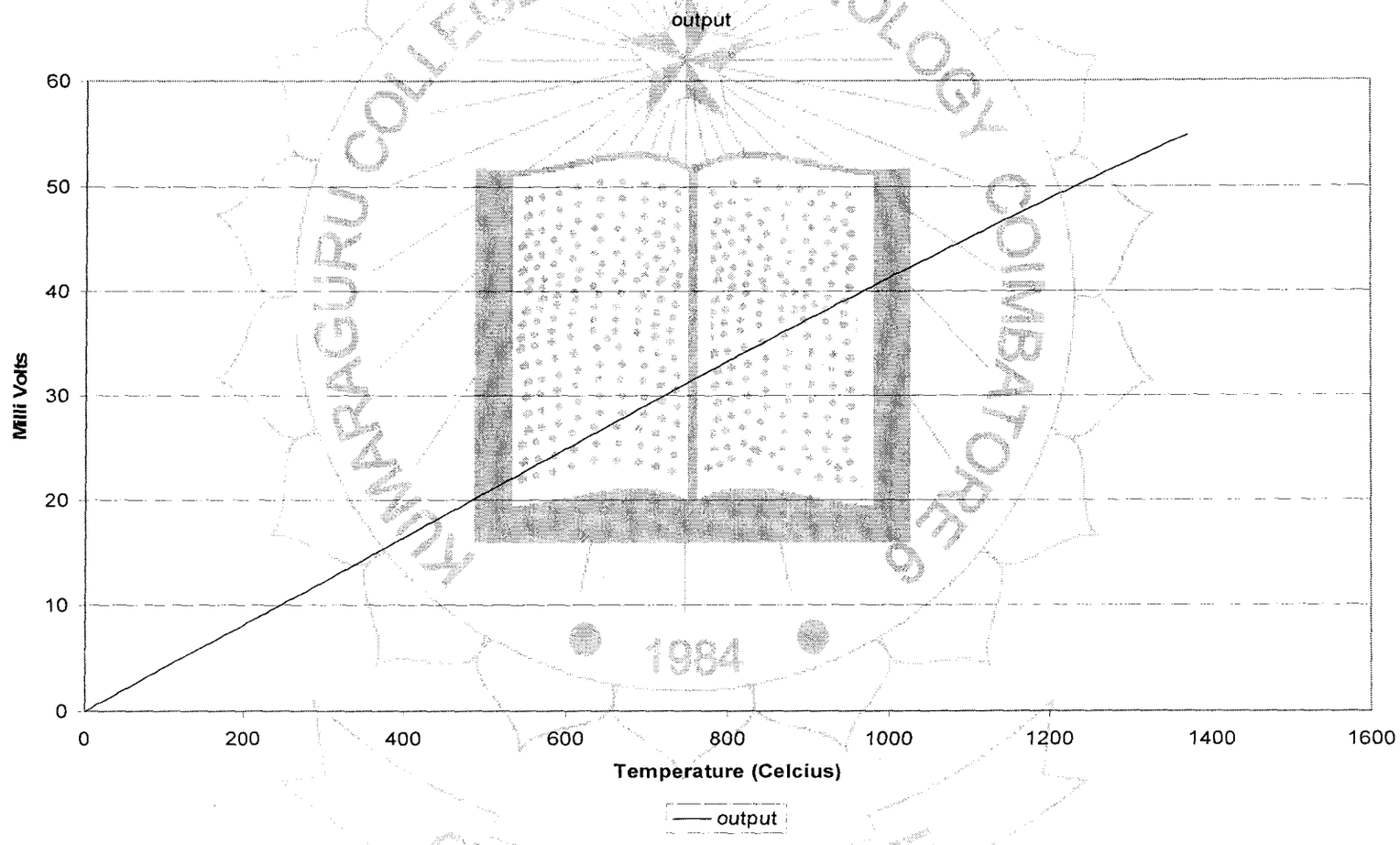
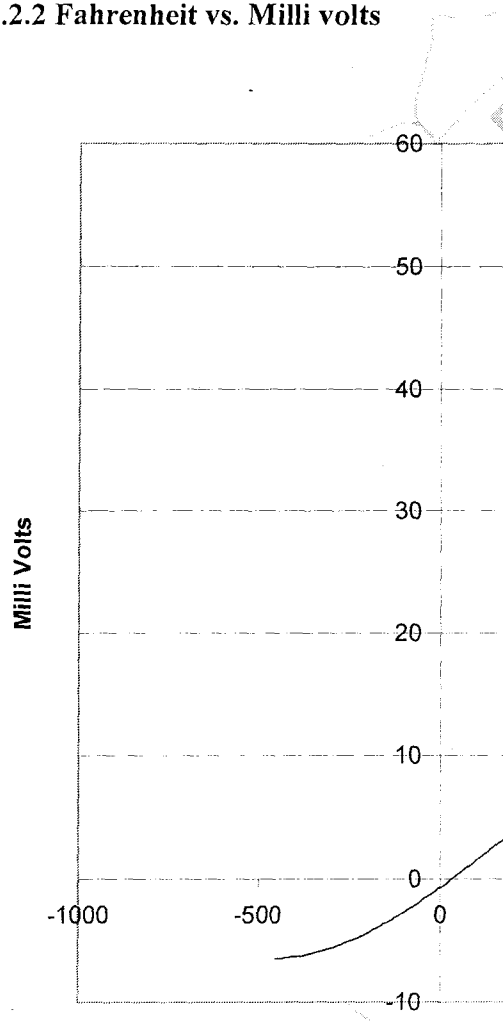
2120	47.367	47.387	47.408	47.429	47.449	47.470	47.490	47.511	47.531	47.552	2120
2130	47.573	47.593	47.614	47.634	47.655	47.675	47.696	47.716	47.737	47.757	2130
2140	47.778	47.798	47.819	47.839	47.860	47.880	47.901	47.921	47.942	47.962	2140
2150	47.983	48.003	48.024	48.044	48.065	48.085	48.105	48.126	48.146	48.167	2150
2160	48.187	48.208	48.228	48.248	48.269	48.289	48.310	48.330	48.350	48.371	2160
2170	48.391	48.411	48.432	48.452	48.473	48.493	48.513	48.534	48.554	48.574	2170
2180	48.595	48.615	48.635	48.656	48.676	48.696	48.717	48.737	48.757	48.777	2180
2190	48.798	48.818	48.838	48.859	48.879	48.899	48.919	48.940	48.960	48.980	2190
2200	49.000	49.021	49.041	49.061	49.081	49.101	49.122	49.142	49.162	49.182	2200
2210	49.202	49.223	49.243	49.263	49.283	49.303	49.323	49.344	49.364	49.384	2210
2220	49.404	49.424	49.444	49.465	49.485	49.505	49.525	49.545	49.565	49.585	2220
2230	49.605	49.625	49.645	49.666	49.686	49.706	49.726	49.746	49.766	49.786	2230
2240	49.806	49.826	49.846	49.866	49.886	49.906	49.926	49.946	49.966	49.986	2240
2250	50.006	50.026	50.046	50.066	50.086	50.106	50.126	50.146	50.166	50.186	2250
2260	50.206	50.226	50.246	50.266	50.286	50.306	50.326	50.346	50.366	50.385	2260
2270	50.405	50.425	50.445	50.465	50.485	50.505	50.525	50.545	50.564	50.584	2270
2280	50.604	50.624	50.644	50.664	50.684	50.703	50.723	50.743	50.763	50.783	2280
2290	50.802	50.822	50.842	50.862	50.882	50.901	50.921	50.941	50.961	50.981	2290
2300	51.000	51.020	51.040	51.060	51.079	51.099	51.119	51.139	51.158	51.178	2300
2310	51.198	51.217	51.237	51.257	51.276	51.296	51.316	51.336	51.355	51.375	2310
2320	51.395	51.414	51.434	51.453	51.473	51.493	51.512	51.532	51.552	51.571	2320
2330	51.591	51.611	51.630	51.650	51.669	51.689	51.708	51.728	51.748	51.767	2330
2340	51.787	51.806	51.826	51.845	51.865	51.885	51.904	51.924	51.943	51.963	2340
2350	51.982	52.002	52.021	52.041	52.060	52.080	52.099	52.119	52.138	52.158	2350
2360	52.177	52.197	52.216	52.235	52.255	52.274	52.294	52.313	52.333	52.352	2360
2370	52.371	52.391	52.410	52.430	52.449	52.468	52.488	52.507	52.527	52.546	2370
2380	52.565	52.585	52.604	52.623	52.643	52.662	52.681	52.701	52.720	52.739	2380
2390	52.759	52.778	52.797	52.817	52.836	52.855	52.875	52.894	52.913	52.932	2390
2400	52.952	52.971	52.990	53.010	53.029	53.048	53.067	53.087	53.106	53.125	2400
2410	53.144	53.163	53.183	53.202	53.221	53.240	53.260	53.279	53.298	53.317	2410
2420	53.336	53.355	53.375	53.394	53.413	53.432	53.451	53.470	53.490	53.509	2420
2430	53.528	53.547	53.566	53.585	53.604	53.623	53.643	53.662	53.681	53.700	2430
2440	53.719	53.738	53.757	53.776	53.795	53.814	53.833	53.852	53.871	53.890	2440
2450	53.910	53.929	53.948	53.967	53.986	54.005	54.024	54.043	54.062	54.081	2450
2460	54.100	54.119	54.138	54.157	54.176	54.195	54.214	54.233	54.252	54.271	2460
2470	54.289	54.308	54.327	54.346	54.365	54.384	54.403	54.422	54.441	54.460	2470
2480	54.479	54.498	54.517	54.536	54.554	54.573	54.592	54.611	54.630	54.649	2480
2490	54.668	54.687	54.705	54.724	54.743	54.762	54.781	54.800	54.819	54.837	2490
2500	54.85										2500

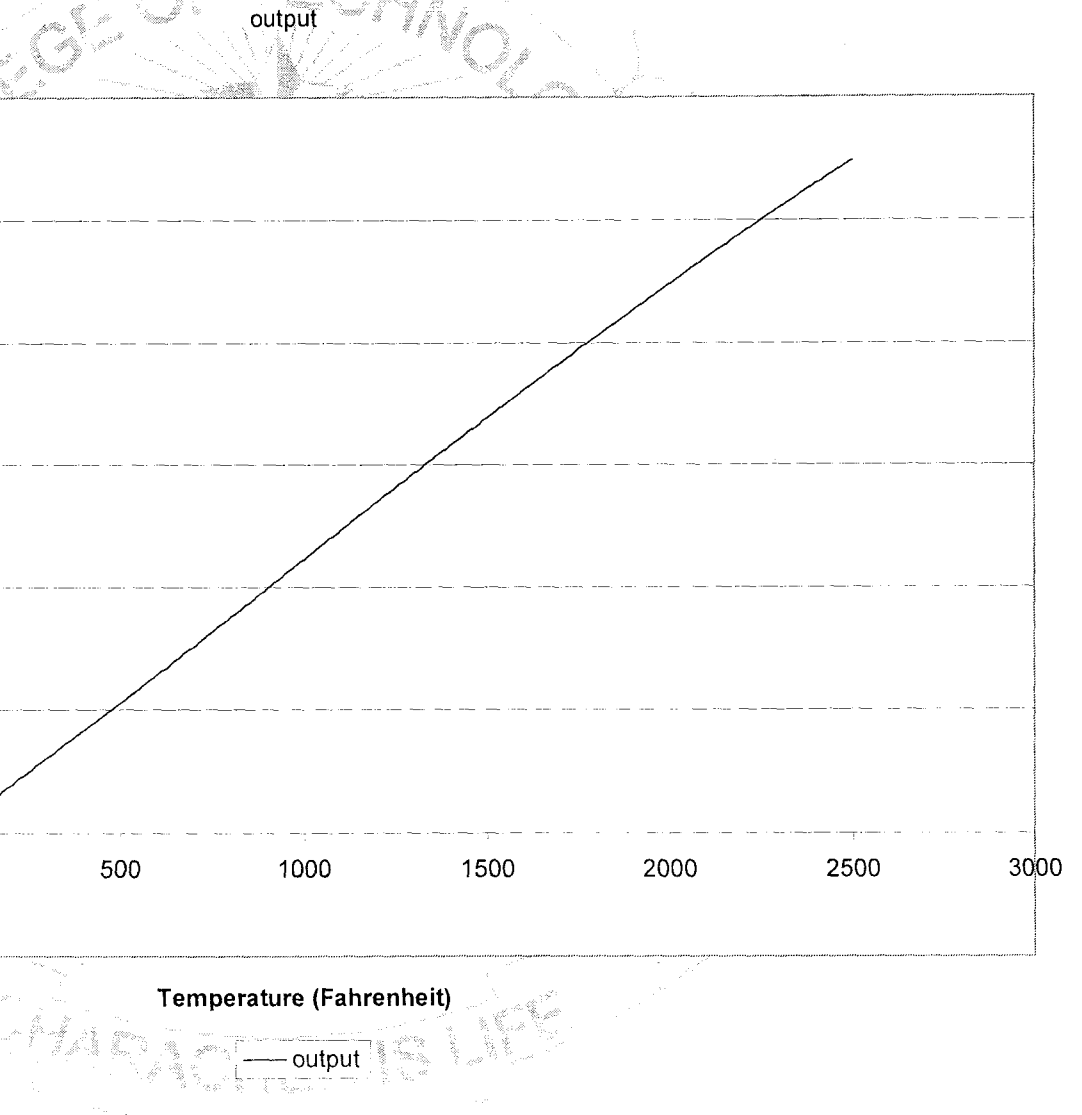
C.2 Output Voltage Graph of K – type Thermo couple

C.2.1 Celsius vs. Milli volts



C.2.2 Fahrenheit vs. Milli volts




output
500
1000
1500
2000
2500
3000
Temperature (Fahrenheit)
output

D.1 Communication Standards

D.1.1 Introduction

Line drivers and receivers are commonly used to exchange data between two or more points (nodes) on a network. Reliable data communications can be difficult in the presence of induced noise, ground level differences, impedance mismatches, failure to effectively bias for idle line conditions, and other hazards associated with installation of a network. The connection between two or more elements (drivers and receivers) should be considered a transmission line if the rise and/or fall time is less than half the time for the signal to travel from the transmitter to the receiver.

Standards have been developed to insure compatibility between units provided by different manufacturers, and to allow for reasonable success in transferring data over specified distances and/or data rates. The Electronics Industry Association (EIA) has produced standards for RS485, RS422, RS232, and RS423 that deal with data communications. Suggestions are often made to deal with practical problems that might be encountered in a typical network. EIA standards where previously marked with the prefix "RS" to indicate recommended standard; however, the standards are now generally indicated as "EIA" standards to identify the standards organization. While the standards bring uniformity to data communications, many areas are not specifically covered and remain as "gray areas" for the user to discover (usually during installation) on his own.

D.1.1.1 Single Ended Data Transmission

Electronic data communications between elements will generally fall into two broad categories: single-ended and differential. RS232 (single-ended) was introduced in 1962, and despite rumors for its early demise, has remained widely used through the industry. The specification allows for data transmission from one transmitter to one receiver at relatively slow data rates (up to 20K bits/second) and short distances (up to 50Ft. @ the maximum data rate).

Independent channels are established for two-way (full-duplex) communications. The RS232 signals are represented by voltage levels with respect to a system common (power / logic ground). The "idle" state (MARK) has the signal level negative with respect to common, and the "active" state (SPACE) has the signal level positive with

respect to common. RS232 has numerous handshaking lines (primarily used with modems), and also specifies a communications protocol. In general if not connected to a modem the handshaking lines can present a lot of problems, if not disabled in software or accounted for in the hardware (loop-back or pulled-up). RTS (Request to send) does have some utility in certain applications. RS423 is another single ended specification with enhanced operation over RS232; however, it has not been widely used in the industry.

D.1.1.2 Differential Data Transmission

When communicating at high data rates, or over long distances in real world environments, single-ended methods are often inadequate. Differential data transmission (balanced differential signal) offers superior performance in most applications. Differential signals can help nullify the effects of ground shifts and induced noise signals that can appear as common mode voltages on a network.

RS422 (differential) was designed for greater distances and higher Baud rates than RS232. In its simplest form, a pair of converters from RS232 to RS422 (and back again) can be used to form an "RS232 extension cord." Data rates of up to 100K bits / second and distances up to 4000 Ft. can be accommodated with RS422. RS422 is also specified for multi-drop (party-line) applications where only one driver is connected to, and transmits on, a "bus" of up to 10 receivers. While a multi-drop "type" application has many desirable advantages, RS422 devices cannot be used to construct a truly multi-point network. A true multi-point network consists of multiple drivers and receivers connected on a single bus, where any node can transmit or receive data.

"Quasi" multi-drop networks (4-wire) are often constructed using RS422 devices. These networks are often used in a half-duplex mode, where a single master in a system sends a command to one of several "slave" devices on a network. Typically one device (node) is addressed by the host computer and a response is received from that device. Systems of this type (4-wire, half-duplex) are often constructed to avoid "data collision" (bus contention) problems on a multi-drop network (more about solving this problem on a two-wire network in a moment).

RS485 meets the requirements for a truly multi-point communications network, and the standard specifies up to 32 drivers and 32 receivers on a single (2-wire) bus. With the introduction of "automatic" repeaters and high-impedance drivers / receivers this

"limitation" can be extended to hundreds (or even thousands) of nodes on a network. RS485 extends the common mode range for both drivers and receivers in the "tri-state" mode and with power off. Also, RS485 drivers are able to withstand "data collisions" (bus contention) problems and bus fault conditions.

To solve the "data collision" problem often present in multi-drop networks hardware units (converters, repeaters, micro-processor controls) can be constructed to remain in a receive mode until they are ready to transmit data. Single master systems (many other communications schemes are available) offer a straight forward and simple means of avoiding "data collisions" in a typical 2-wire, half-duplex, multi-drop system. The master initiates a communications request to a "slave node" by addressing that unit. The hardware detects the start-bit of the transmission and automatically enables (on the fly) the RS485 transmitter. Once a character is sent the hardware reverts back into a receive mode in about 1-2 microseconds (at least with R.E. Smith converters, repeaters, and remote I/O boards).

Any number of characters can be sent, and the transmitter will automatically re-trigger with each new character (or in many cases a "bit-oriented" timing scheme is used in conjunction with network biasing for fully automatic operation, including any Baud rate and/or any communications specification, eg. 9600,N,8,1). Once a "slave" unit is addressed it is able to respond immediately because of the fast transmitter turn-off time of the automatic device. It is NOT necessary to introduce long delays in a network to avoid "data collisions." Because delays are NOT required, networks can be constructed, that will utilize the data communications bandwidth with up to 100% through put.

D.1.2 Comparison Chart

SPECIFICATIONS	RS232	RS423	RS422	RS485
Mode of Operation	Single-ended	Single-ended	Differential	Differential
Number of Drivers and Receivers on One Line	1 driver 1 receiver	1 driver 10 receiver	1 driver 10 receiver	32 driver (only one active at a time) 32 receiver
Maximum Cable Length	50 FT.	4000 FT.	4000 FT.	4000 FT.
Maximum Data Rate (40ft. - 4000ft. for RS422/RS485)	20kb/s	100kb/s	10Mb/s-100Kb/s	10Mb/s-100Kb/s
Maximum Driver Output Voltage	+/-25V	+/-6V	-0.25V to +6V	-7V to +12V
Driver Output Signal Level (Loaded Min.)	+/-5V to +/-15V	+/-3.6V	+/-2.0V	+/-1.5V
Driver Output Signal Level (Unloaded Max)	+/-25V	+/-6V	+/-6V	+/-6V
Driver Load Impedance (Ohms)	3k to 7k	>=450	100	54
Max. Driver Current in High Z State (Power On)	N/A	N/A	N/A	+/-100uA
Max. Driver Current in High Z State (Power Off)	+/-6mA @ +/-2v	+/-100uA	+/-100uA	+/-100uA
Slew Rate (Max.)	30V/uS	Adjustable	N/A	N/A
Receiver Input Voltage Range	+/-15V	+/-12V	-10V to +10V	-7V to +12V
Receiver Input Sensitivity	+/-3V	+/-200mV	+/-200mV	+/-200mV
Receiver Input Resistance (Ohms), (1 Standard Load for RS485)	3k to 7k	4k min.	4k min.	>=12k

D.1.3 RS485

D.1.3.1 General Description

(2-wire, half-duplex, differential, multi-drop (32 nodes), communications standard for distances up to 4000ft.)

D.1.3.2 Standard specifications

The RS485 standard addresses the problem of data transmission, where a balanced (differential) transmission line is used in a multi-drop (party line) configuration (or point-to-point if only two devices are on the network). Up to 32-nodes (drivers and receivers) are allowed on one multi-drop, bi-directional network. Data rates of up to 10M bps are supported over short distances (40ft.). At the four-thousand foot distance limit, data rates of up to 100K bps are allowable. RS485 specifies a 2-wire, half-duplex communications bus. Because there are differences between RS485 and RS422 (minor in many instances, except for loading [12K vs. 4K) many people refer to 4-wire RS485. While RS485 is a 2-wire standard, it does offer 32 nodes on a network, on the other hand RS422 (a 4-wire standard) only specifies up to 10 nodes. Therefore, while not technically correct, it does make some sense to refer to a 4-wire RS485 network that would extend the number of nodes on a 4-wire network to 32 standard loads.

The RS485 standard only specifies electrical characteristics of the driver and the receiver; it does not specify or recommend any protocol. Because matters of protocol are left to the user, it is often difficult (if not impossible) to connect RS485 devices from different manufacturers on the same network.

The RS485 standard allows the user to configure inexpensive local networks and multi – drop communications links using twisted pair wire. A typical RS485 network can operate properly in the presence of reasonable ground differential voltages, withstand driver contentious situations, provide reliable communications in electrically noisy environments (good common mode rejection using twisted pair cable, shielding provides additional protection), and support thirty-two or more (many IC manufacturers have 1/2, 1/4, 1/8 unit load devices) drivers and receivers on the line.

Twisted pair wire with a characteristic impedance of 120 ohms is recommended with 120 ohm termination at each end of the communications line. The common-mode

voltage range is -7V to +12V. A driver in the high impedance (off) state is able to remain in this state over the common mode range, whether power is applied or not. The receiver is able to respond to differential signal levels of 200mV over the common mode range. The receiver load impedance is 12K ohms (or higher) and transmitter "leakage" current is ±100μA (or less) in either the powered or un–powered state. Unloaded driver output differential voltage can be as high as ±6V. Loaded driver voltage (32 nodes on the network and termination) should typically exceed ±1.5V.

D.1.4 RS422

D.1.4.1 General Description

(4-wire, full-duplex, differential, multi-drop (10 nodes), communications standard)

D.1.4.2 Standard specifications

While RS422 is comparable to RS485, it is limited to unidirectional data traffic, and is terminated only on the end of the line opposite the transmitter. One transmitter and 10 receivers are allowed on a network, with a distance limit of 3600ft. RS422 was on the market prior to RS485; however, due to loading limitations, one of the best uses of RS422 is probably in point-to-point communications, such as RS232 extension cords. By converting from single-ended RS232 to differential RS422 and then, converting back from RS422 to RS232 at the other end of the line, distance and noise immunity can be greatly improved.

D.1.5 RS232

D.1.5.1 General Description

(3-wire, full-duplex, single-ended, 50ft cable limit)

D.1.5.2 Standard specifications

Communication as defined in the RS-232C standard is an asynchronous serial communication method. The word serial means, that the information is sent one bit at a time. Asynchronous tells us that the information is not sent in predefined time slots. Data transfer can start at any given time and it is the task of the receiver to detect when a message starts end ends. Asynchronous communication has some advantages and disadvantages which are both discussed in the next paragraph.

RS232 was developed in the 1960s, and among other things, specified an electrical standard, a protocol standard, handshaking, and connector pin-out. In general, many current applications for RS232 use only the electrical standard (3-wires, TDX, RXD, and Common) and connector pin-out. While handshaking is still with us, it is usually best to disable it in software (if possible) and/or "loop-back" the pairs of signals (RTS to CTS, DTR to DSR, etc.) While RS232 was rumored o be on the "way out" with the advent of many of the new communications standards, it is still alive and well today. While the standard only supports low data rates and short line length (50ft.) it is still widely used and, very useful in many applications. With an external converters (RS232<=>RS485) many of the limitations of RS232 can be improved, to take advantage of, the superior properties of differential communications (2-wire or 4-wire).

D.1.5.3 Physical Parameters

The RS232 standard describes a communication method capable of communicating in different environments. This has had its impact on the maximum allowable voltages etc. on the pins. In the original definition, the technical possibilities of that time were taken into account. The maximum baud rate defined for example is 20 kbps. With current devices like the 16550A UART, maximum speeds of 1.5 Mbps are allowed.

D.1.5.4 Voltages

The signal level of the RS232 pins can have two states. A high bit, or marking state is identified by a **negative** voltage and a low bit or space state uses a **positive** value. This might be a bit confusing, because in normal circumstances, high logical values are defined by high voltages also. The maximum voltage swing the computer can generate on its port can have influence on the maximum cable length and communication speed that is allowed. Also, if the voltage difference is small, data distortion will occur sooner.

For example, Toshiba laptop mark's voltage is -9.3 V, compared to -11.5 V on desktop computer. The laptop has difficulties to communicate with Mitsubishi PLC's in industrial environments with high noise levels where the desktop computer has no data errors at all using the same cable. Thus, even far beyond the minimum voltage levels, 2 volts extra can make a huge difference in communication quality.

Level	Transmitter capable (V)	Receiver capable (V)
Logical 0 space state	+5 ... +15	+3 ... +25
Logical 1 mark state	-5 ... -15	-3 ... -25
Undefined	-	-3 ... +3

Despite the high voltages present, it is not possible to destroy the serial port by short circuiting. Only applying external voltages with high currents may eventually burn out the driver chips. Still then, the UART won't be damaged in most cases.

D.1.5.5 Electrical Characteristics

The following criteria apply to the electrical characteristics of each of the above lines:

1) The magnitude of an open circuit voltage shall not exceed 25V.

2) The driver shall be able to sustain a short to any other wire in the cable without damage to itself or to the other equipment, and the short circuit current shall not exceed 0.5 ampere.

3) Signals shall be considered in the MARK (logic 1) state when the voltage is more negative than -3V with respect to the Signal Ground. Signals shall be considered in the SPACE (logic 0) state when the voltage is more positive that 3V with respect to the Signal Ground. The range between -3V and 3V is defined as the transition region, within which the signal state is not defined.

4) The load impedance shall have a DC resistance of less than 7000 ohms when measured with an applied voltage of from 3V to 25V but more than 3000 ohms when measured with a voltage of less than 25V.

5) When the terminator load resistance meets the requirements of Rule 4 above, and the terminator open circuit voltage is 0V, the magnitude of the potential of that circuit with respect to Signal Ground will be in the 5V to 15V range.

6) The driver shall assert a voltage between -5V and -15V relative to the signal ground to represent a MARK signal condition. The driver shall assert a voltage

between 5V and 15V relative to the Signal Ground to represent a SPACE signal condition. Note that this rule in conjunction with Rule 3 above allows for 2V of noise margin. Note also that in practice, -12V and 12V are typically used.

7) The driver shall change the output voltage at a rate not exceeding 30 volts per microsecond, but the time required for the signal to pass through the -3V to +3V transition region shall not exceed 1 millisecond, or 4 percent of a bit time, whichever is smaller.

8) The shunt capacitance of the terminator shall not exceed 2500 Pico farads, including the capacitance of the cable. Note that when using standard cable with 40 to 50 Pico farads per foot capacitance, this limits the cable length to no more than 50 feet. Lower capacitance cable allows longer runs.

9) The impedance of the driver circuit under power-off conditions shall be greater than 300 ohms.

D.1.5.6 Definition of the Most Common Terms

1. CG – Chassis Ground

This circuit (also called Frame Ground) is a mechanism to insure that the chassis of the two devices are at the same potential, to prevent electrical shock to the operator. Note that this circuit is not used as the reference for any of the other voltages. This circuit is optional. If it is used, care should be taken to not set up ground loops.

2. TD – Transmit Data

This circuit is the path whereby serial data is sent from the DTE to the DCE. This circuit must be present if data is to travel in that direction at any time.

3. RD – Receive Data

This circuit is the path whereby serial data is sent from the DCE to the DTE. This circuit must be present if data is to travel in that direction at any time.

4. RTS – Request To Send

This circuit is the signal that indicates that the DTE wishes to send data to the DCE (note that no such line is available for the opposite direction, hence the DTE must always be ready to accept data). In normal operation, the RTS line will be OFF (logic 1 / MARK). Once the DTE has data to send and has determined that the channel is not busy, it will set RTS to ON (logic 0 / SPACE), and await an ON condition on CTS from the DCE, at which time it may then begin sending. Once the DTE is through sending, it will reset RTS to OFF (logic 1 / MARK). On a full-duplex or simplex channel, this signal may be set to ON once at initialization and left in that state. Note that some DCEs must have an incoming RTS in order to transmit (although this is not strictly according to the standard). In this case, this signal must either be brought across from the DTE, or provided by a wraparound (e.g. from DSR) locally at the DCE end of the cable.

5. CTS – Clear To Send

This circuit is the signal that indicates that the DCE is ready to accept data from the DTE. In normal operation, the CTS line will be in the OFF state. When the DTE asserts RTS, the DCE will do whatever is necessary to allow data to be sent (e.g. a modem would raise carrier, and wait until it stabilized). At this time, the DCE would set CTS to the ON state, which would then allow the DTE to send data. When the RTS from the DTE returns to the OFF state, the DCE releases the channel (e.g. a modem would drop carrier), and then set CTS back to the OFF state. Note that a typical DTE must have incoming CTS before it can transmit. This signal must either be brought over from the DCE, or provided by a wraparound (e.g. from DTR) locally at the DTE end of the cable.

6. DSR – Data Set Ready

This circuit is the signal that informs the DTE that the DCE is alive and well. It is normally set to the ON state by the DCE upon power-up and left there. Note that a typical DTE must have an incoming DSR in order to function normally. This line must either be brought over from the DCE, or provided by a wraparound (e.g. from DTR) locally at the DTE end of the cable. On the DCE end of the interface, this signal is almost always present, and may be wrapped back around (to DTR and/or RTS) to satisfy required signals whose normal function is not required.

7. SG – Signal Ground

This circuit is the ground to which all other voltages are relative. It must be present in any RS-232 interface.

8. DCD – Data Carrier Detect

This circuit is the signal whereby the DCE informs the DTE that it has an incoming carrier. It may be used by the DTE to determine if the channel is idle, so that the DTE can request it with RTS. Note that some DTEs must have an incoming DCD before they will operate. In this case, this signal must either be brought over from the DCE, or provided locally by a wraparound (e.g. from DTR) locally at the DTE end of the cable.

15. TC – Transmit Clock

This circuit provides the clock for the transmitter section of a synchronous DTE. It may or may not be running at the same rate as the receiver clock. This circuit must be present on synchronous interfaces.

17. RC – Receiver Clock

This circuit provides the clock for the receiver section of a synchronous DTE. It may of may not be running at the same rate as the transmitter clock. Note that both TC and RC are sourced by the DCE. This circuit must be present on synchronous interfaces.

20. DTR – Data Terminal Ready

This circuit provides the signal that informs the DCE that the DTE is alive and well. It is normally set to the ON state by the DTE at power-up and left there. Note that a typical DCE must have an incoming DTR before it will function normally. This signal must either be brought over from the DTE, or provided by a wraparound (e.g. from DSR) locally at the DCE end of the cable. On the DTE side of the interface, this signal is almost always present, and may be wrapped back around to other circuits (e.g. DSR, CTS and/or DCD) to satisfy required hand-shaking signals if their normal function is not required.

In an *asynchronous* channel, both ends provide their own internal timing, which (as long as they are within 5% of each other) is sufficient for them to agree when the bits occur within a single character. In this case, no timing information need be sent over the interface between the two devices. In a *synchronous* channel, however, both ends must

agree when the bits occur over possibly thousands of characters. In this case, both devices must use the same clocks. The transmitter and receiver may be running at different rates.

BOTH clocks are provided by the DCE. When one has a synchronous terminal tied into a synchronous port on a computer via two synchronous modems and the terminal is transmitting, the terminal's modem supplies the Transmit Clock, which is brought directly out to the terminal at its end, and encodes the clock with the data, sends it to the computer's modem, which recovers the clock and brings it out as the Receive Clock to the computer. When the computer is transmitting, the same thing happens in the other direction. Hence, whichever modem is transmitting must supply the clock for that direction, but on each end, the DCE device supplies both clocks to the DTE device. All of the above applies to interfacing a DTE device to a DCE device.

In order to interface two DTE devices, it is usually sufficient to provide a 'flipped' cable, in which the pairs (TD, RD), (RTS, CTS) and (DTR, DSR) have been flipped. Hence, the TD of one DTE is connected to the RD of the other DTE, and vice versa. It may be necessary to wrap several of the hand-shaking lines back around from the DTR on each end in order to have both ends work. In a similar manner, two DCE devices can be interfaced to each other.

An RS-232 *break-out box* is particularly useful in solving interfacing problems. This is a device which is inserted between the DTE and DCE. Firstly, it allows to monitor the state of the various hand-shaking lines (light on = signal ON / logic 0), and watch the serial data flicker on TD and/or RD. Secondly, it allows to break the connection on one or more of the lines (with dip-switches), and make any kind of cross-connections and/or wraparounds (with jumper wires).

Using this, it is fairly easy to determine which line(s) are not functioning as required and quickly build a prototype cable that will serve to interface the two devices. At this point, the break-out box can be removed and a real cable built that performs the same function.

D.1.6 Converters

Converters in general can be used to change the electrical characteristic of one communications standard into another, to take advantage of the best properties of the

alternate standard selected. For example, an Automatic RS232<=>RS485 converter, could be connected to a computer's RS232, full-duplex port, and transform it into an RS485 half-duplex, multi-drop network at distances up to 4000ft.

Converters in most instances, pass data through the interface without changing the timing and/or protocol. While the conversion is "transparent" the software must be able to communicate with the expanded network features.

An "Automatic Converter" (RS232<=>RS485) will turn on the RS485 transmitter when data is detected on the RS232 port, and revert back into the receive mode after a character has been sent. This avoids timing problems (and software changes) that are difficult to deal with in typical systems. When full-duplex is converted into half-duplex only one device at a time can transmit data. Automatic Converters take care of the timing problems and allow fast communications without software intervention.

D.1.7 Bias (failsafe)

When there is no data activity on an RS485 network (or in many instances RS422 networks, other than point-to-point), the communications lines are "floating" and, thus susceptible to external noise or interference. Receivers on a network (RS485 or RS422) have built in hysteresis (200mV differential required to insure known state). To insure that a receiver stays in an inactive state, when no data signal is present, bias is generally added to a network at one or more locations.

D.1.8 Multi port Repeaters

Once an RS485 network exceeds about 32 nodes on a network, serious consideration should be given to using galvanic isolation. Even though some IC manufacturers offer light loading devices that can accommodate 256 or even 400 nodes on one RS485 network. One reason is that, large networks accumulate distributed electrical noise which can make communications unreliable. In general it is very important not to run communications wires in the same trough or conduit or in parallel with AC power cables. Maintain as much distance as possible and cross any power cable at a right angle.

While shielding is not specified for RS485 systems, it can help in many instances. By "isolating" sections of a large network, the accumulated noise on one isolated leg is not so likely to cause a data error that will propagate to another leg of the network. Galvanic isolation will break a large problem into several small, but manageable ones. Galvanic isolation can also help eliminate "ground loops."

Another potential problem with large networks without isolation is that severe damage can occur to your entire system, if a high voltage source is connected (accidentally or otherwise) to your communications lines. Your entire network could be damaged. With galvanic isolation the damage is generally limited to only one leg of the network, except in extreme cases of very high voltage (induced by lightening for example).

While it goes against conventional wisdom, and can potentially cause a problem with circulating currents by grounding a shielded cable at both ends, this method is very effective at keeping induced lightening noise away from the communications lines. In the alternative, ground one end of the shield and connect the other end to ground through a bi-directional transient protector (from a few volts to a few hundred volts depending on the situation).

In general RS485 is designed for multi-drop, "daisy-chain" operation over a single twisted pair cable with a nominal characteristic impedance of 120 Ohms. This cable is usually 24AWG. Category-5 cable will generally work well in most instances even though its characteristic impedance is 100 Ohms. "Tap points" or "T" connections should be short to eliminate reflections.

It is possible to connect several RS485 circuits in parallel if the distances are below about 200 feet per leg @ 9600bps. At greater distances and higher data rates, the cable impedances add up and load the network. In addition there is no good way to add terminations resistors at the ends of a "star" network. The combination of the cable impedances and/or termination resistors will load the network and can make communications unreliable.

D.1.8 Galvanic Isolation

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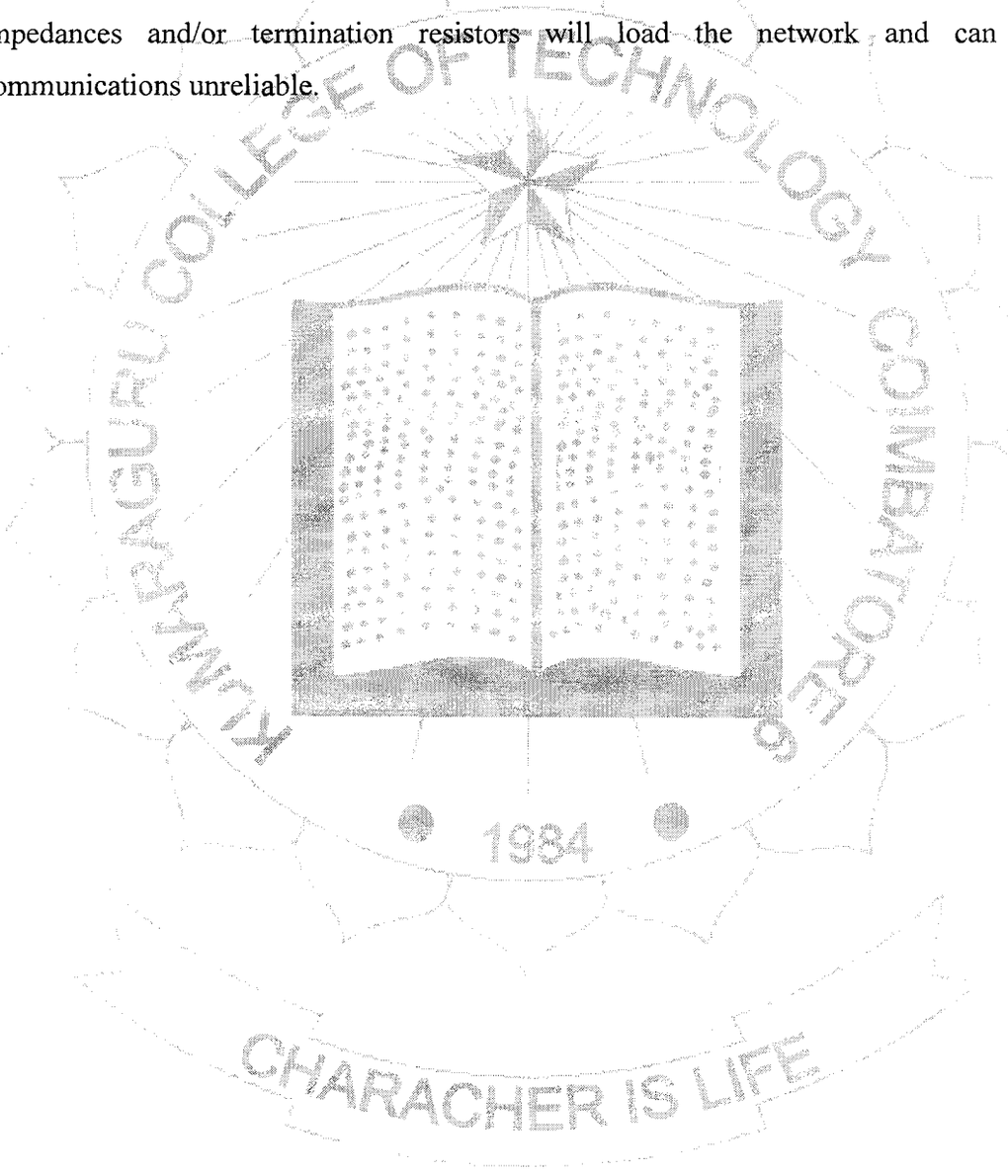


E.1 LCD Display

E.1.1 Introduction

Liquid crystal displays (LCDs) have materials, which combine the properties of both liquids and crystals. Rather than having a melting point, they have a temperature range within which the molecules are almost as mobile as they would be in a liquid, but are grouped together in an ordered form similar to a crystal.

An LCD consists of two glass panels, with the liquid crystal material sand witched in between them. The inner surface of the glass plates are coated with transparent electrodes which define the character, symbols or patterns to be displayed polymeric layers are present in between the electrodes and the liquid crystal, which makes the liquid crystal molecules to maintain a defined orientation angle.

One each polarisers are pasted outside the two glass panels. These polarisers would rotate the light rays passing through them to a definite angle, in a particular direction When the LCD is in the off state, light rays are rotated by the two polarisers and the liquid crystal, such that the light rays come out of the LCD without any orientation, and hence the LCD appears transparent.

When sufficient voltage is applied to the electrodes, the liquid crystal molecules would be aligned in a specific direction. The light rays passing through the LCD would be rotated by the polarisers, which would result in activating / highlighting the desired characters. The LCD's are lightweight with only a few millimeters thickness. Since the LCD's consume less power, they are compatible with low power electronic circuits, and can be powered for long durations.

The LCD's does not generate light and so light is needed to read the display. By using backlighting, reading is possible in the dark. The LCD's have long life and a wide operating temperature range. Changing the display size or the layout size is relatively simple which makes the LCD's more customers friendly.

The LCDs used exclusively in watches, calculators and measuring instruments are the simple seven-segment displays, having a limited amount of numeric data. The recent

advances in technology have resulted in better legibility, more information displaying capability and a wider temperature range. These have resulted in the LCDs being extensively used in telecommunications and entertainment electronics. The LCDs have even started replacing the cathode ray tubes (CRTs) used for the display of text and graphics, and also in small TV applications.

E.1.2 Power Supply

The power supply should be of +5V, with maximum allowable transients of 10mv. To achieve a better / suitable contrast for the display, the voltage (VL) at pin 3 should be adjusted properly.

A module should not be inserted or removed from a live circuit. The ground terminal of the power supply must be isolated properly so that no voltage is induced in it. The module should be isolated from the other circuits, so that stray voltages are not induced, which could cause a flickering display.

E.1.3 Hardware

Develop a uniquely decoded 'E' strobe pulse, active high, to accompany each module transaction. Address or control lines can be assigned to drive the RS and R/W inputs.

Utilize the Host's extended timing mode, if available, when transacting with the module. Use instructions, which prolong the Read and Write or other appropriate data strobes, so as to realize the interface timing requirements.

If a parallel port is used to drive the RS, R/W and 'E' control lines, setting the 'E' bit simultaneously with RS and R/W would violate the module's set up time. A separate instruction should be used to achieve proper interfacing timing requirements.

E.1.4 Mounting

- Cover the display surface with a transparent protective plate, to protect the polarizer.
- Don't touch the display surface with bare hands or any hard materials. This will stain the display area and degrade the insulation between terminals.

- Do not use organic solvents to clean the display panel as these may adversely affect tape or with absorbant cotton and petroleum benzene.
- The processing or even a slight deformation of the claws of the metal frame will have effect on the connection of the output signal and cause an abnormal display.
- Do not damage or modify the pattern wiring, or drill attachment holes in the PCB. When assembling the module into equipment, the space between the module and the fitting plate should have enough height, to avoid causing stress to the module surface.
- Make sure that there is enough space behind the module, to dissipate the heat generated by the ICs while functioning for longer durations.
- When an electrically powered screwdriver is used to install the module, ground it properly.
- While cleaning by a vacuum cleaner, do not bring the sucking mouth near the module. Static electricity of the electrically powered driver or the vacuum cleaner may destroy the module.

E.1.5 Environmental Precautions

Operate the LCD module under the relative condition of 40°C and 50% relative humidity. Lower temperature can cause retardation of the blinking speed of the display, while higher temperature makes the overall display discolor.

When the temperature gets to be within the normal limits, the display will be normal. Polarization degradation, bubble generation or polarizer peel-off may occur with high temperature and humidity.

Contact with water or oil over a long period of time may cause deformation or colour fading of the display. Condensation on the terminals can cause electro-chemical reaction disrupting the terminal circuit.

E.1.6 Trouble Shooting

E.1.6.1 Introduction

When the power supply is given to the module, with the pin 3 (VL) connected to ground, all the pixels of a character gets activated in the following manner:

✓ All the characters of a single line display, as in CDM 16108.

- ✓ The first eight characters of a single line display, operated in the two-line display mode, as in CDM 16116.
- ✓ The first line of characters of a two-line display as in CDM 16216 and 40216. The first and third line of characters of a four-line display operated in the two-line display mode, as in CDM 20416.

If the above mentioned does not occur, the module should be initialized by software. Make sure that the control signals 'E', R/W and RS are according to the interface timing requirements.

E.1.6.2 Improper Character Display

- ❖ When the characters to be displayed are missing between, the data read/write is too fast. A slower interfacing frequency would rectify the problem.
- ❖ When uncertainty is there in the start of the first characters other than the specified ones are rewritten, check the initialization and the software routine.
- ❖ In a multi-line display, if the display of characters in the subsequent lines doesn't take place properly, check the DD RAM addresses set for the corresponding display lines.
- ❖ When it is unable to display data, even though it is present in the DD RAM, either the display on/off flag is in the off state or the display shift function is not set properly. When the display shift is done simultaneous with the data write operation, the data may not be visible on the display.
- ❖ If a character not found in the font table is displayed, or a character is missing, the CG ROM is faulty and the controller IC has to be changed
- ❖ If particular pixels of the characters are missing, or not getting activated properly, there could be an assembling problem in the module.

E.1.7 Crystalonics Display

E.1.7.1. Introduction

Crystalonics dot –matrix (alphanumeric) liquid crystal displays are available in TN, STN types, with or without backlight. The use of C-MOS LCD controller and driver ICs result in low power consumption. These modules can be interfaced with a 4-bit or 8-bit microprocessor /Micro controller.

- The built-in controller IC has the following features:
- Correspond to high speed MPU interface (2MHz)
- 80 x 8 bit display RAM (80 Characters max)
- 9,920-bit character generator ROM for a total of 240 character fonts. 208 character fonts (5 x 8 dots) 32 character fonts (5 x 10 dots)
- 64 x 8 bit character generator RAM 8 character generator RAM 8 character fonts (5 x 8 dots) 4 characters fonts (5 x 10 dots)
- Programmable duty cycles
- 1/8 – for one line of 5 x 8 dots with cursor
- 1/11 – for one line of 5 x 10 dots with cursor
- 1/16 – for one line of 5 x 8 dots with cursor
- Wide range of instruction functions display clear, cursor home, display on/off, cursor on/off, display character blink, cursor shift, display shift.
- Automatic reset circuit that initializes the controller / driver ICs after power on.

E.1.7.2 Functional Description of the Controller IC

E.1.7.2.1 Registers

The controller IC has two 8 bit registers, an instruction register (IR) and a data register (DR). The IR stores the instruction codes and address information for display data RAM (DD RAM) and character generator RAM (CG RAM). The IR can be written, but not read by the MPU.

The DR temporally stores data to be written to /read from the DD RAM or CG RAM. The data written to DR by the MPU is automatically written to the DD RAM or CG RAM as an internal operation.

When an address code is written to IR, the data is automatically transferred from the DD RAM or CG RAM to the DR.

Data transfer between the MPU is then completed when the MPU reads the DR. likewise, for the next MPU read of the DR, data in DD RAM or CG RAM at the address is sent to the DR automatically.

Similarly, for the MPU write of the DR, the next DD RAM or CG RAM address is selected for the write operation. The register selection table is as shown below:

RS	R/W	Operation
0	0	IR write as an internal operation
0	1	Read busy flag (DB7) and address counter (DB0 to DB6)
1	0	DR write as an internal operation (DR to DDRAM or CG RAM)
1	1	DR read as an internal operation (DD RAM or CG RAM to DR)

E.1.7.2.2 Busy flag

When the busy flag is1, the controller is in the internal operation mode, and the next instruction will not be accepted. When RS = 0 and R/W = 1, the busy flag is output to DB7. The next instruction must be written after ensuring that the busy flag is 0.

E.1.7.2.3 Address Counter

The address counter allocates the address for the DD RAM and CG RAM read/write operation when the instruction code for DD RAM address or CG RAM address setting is input to IR, the address code is transferred from IR to the address counter. After writing/reading the display data to/from the DD RAM or CG RAM, the address counters increments/decrements by one the address, as an internal operation. The data of the address counter is output to DB0 to DB6 while R/W = 1 and RS = 0.

E.1.7.2.4 Display Data Ram (DDRAM)

The characters to be displayed are written into the display data RAM (DD RAM), in the form of 8 bit character codes present in the character font table. The extended capacity of the DD RAM is 80 x 8 bits i.e. 80 characters.

E.1.7.2.5 Character Generator Rom (CGROM)

The character generator ROM generates 5 x 8 dot 5 x 10 dot character patterns form 8 bit character codes. It generates 208, 5 x 8 dot character patterns and 32, 5 x 10 dot character patterns.

E.1.7.2.6 Character Generator Ram (CGRAM)

In the character generator RAM, the user can rewrite character patterns by program. For 5 x 8 dots, eight character patterns can be written, and for 5 x 10 dots, four character patterns can be written.

E.1.8 Interfacing the Microprocessor / Controller:

The module, interfaced to the system, can be treated as RAM input/output, expanded or parallel I/O. Since there is no conventional chip select signal, developing a strobe signal for the enable signal (E) and applying appropriate signals to the register select (RS) and read/write (R/W) signals are important.

The module is selected by gating a decoded module – address with the host – processor's read/write strobe. The resultant signal, applied to the LCDs enable (E) input, clocks in the data. The 'E' signal must be a positive going digital strobe, which is active while data and control information are stable and true. The falling edge of the enable signal enables the data / instruction register of the controller. All module timings are referenced to specific edges of the 'E' signal. The 'E' signal is applied only when a specific module transaction is desired.

The read and write strobes of the host, which provides the 'E' signals, should not be linked to the module's R/W line. An address bit which sets up earlier in the host's machine cycle can be used as R/W. When the host processor is so fast that the strobes are too narrow to serve as the 'E' pulse

- Prolong these pulses by using the hosts 'Ready' input
- Prolong the host by adding wait states
- Decrease the Hosts Crystal frequency.

In spite of doing the above mentioned, if the problem continues, latch both the data and control information and then activate the 'E' signal. When the controller is performing an internal operation he busy flag (BF) will set and will not accept any instruction. The user should check the busy flag or should provide a delay of approximately 2ms after each instruction. The module presents no difficulties while interfacing slower MPUs.

The liquid crystal display module can be interfaced, either to 4-bit or 8-bit MPUs. For 4-bit data interface, the bus lines DB4 to DB7 are used for data transfer, while DB0 to DB3 lines are disabled. The data transfer is complete when the 4-bit data has been transferred twice. The busy flag must be checked after the 4-bit data has been transferred twice. Two more 4-bit operations then transfer the busy flag and address counter data. For 8-bit data interface, all eight-bus lines (DB0 to DB7) are used.

F.1 Questionnaire

Date : _____

Name : _____

Company Name : _____

Present Designation : ( ) Manager ( ) Supervisor ( ) Foreman ( ) Layman

Experience : ( ) 0 – 5 yr ( ) 5- 10 yr ( ) more than 10 yrs

Technical Qualification: ( ) Graduate ( ) Post Graduate ( ) Diploma ( ) others _____

Additional Qualification: _____

Types of controllers known:

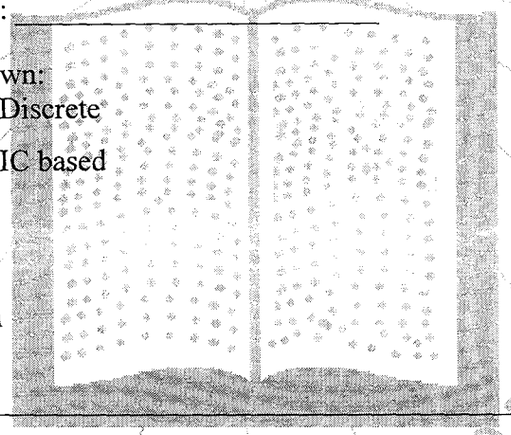
[ ]. Electronic – Discrete

[ ]. Electronic – IC based

[ ]. PLC based

[ ]. PC based

[ ]. DAQ system



System presently used: _____

Reasons for selection: _____

Positive facts about it: _____

Drawback or shortcomings: _____

Flexibility Needed: _____

Accuracy Preferred: _____

Proposed usage: _____ Hours per day: _____

Idea about maintenance: _____

Approximate hours per month on maintenance: _____

Planned time for next update: _____

Priority of cost: _____ Brand: _____ Quality: _____

Service: _____

G.1 Visual Basic Coding

G.1.1 Main form - frmMain

```
Option Explicit

Private Sub MDIForm_Load()
Me.WindowState = 2
mnuCelcius.Checked = True
mnuHexa.Checked = True
GBGC = 12632256
GFGC = 16711680
thick = 1
End Sub

Private Sub mnuCelcius_Click()
mnuCelcius.Checked = True
mnuFahren.Checked = False
mnuKelvin.Checked = False
End Sub

Private Sub mnuDecimal_Click()
mnuDecimal.Checked = True
mnuHexa.Checked = False
End Sub

Private Sub mnuExit_Click()
Dim reply
reply = MsgBox("Are you Sure to Exit?", vbYesNo + vbQuestion, "Confirmation")
If reply = vbNo Then Exit Sub
SaveSetting "TMS", "Comm", "PortID", MSComm1.CommPort
SaveSetting "TMS", "Comm", "Settings", MSComm1.Settings
If MSComm1.PortOpen Then MSComm1.PortOpen = False
End Sub

Private Sub mnuFahren_Click()
mnuCelcius.Checked = False
mnuFahren.Checked = True
mnuKelvin.Checked = False
End Sub

Private Sub mnuFileView_Click()
mnuLog_Click
End Sub

Private Sub mnuHexa_Click()
mnuDecimal.Checked = False
mnuHexa.Checked = True
```

```
End Sub

Private Sub mnuIcons_Click()
mnuIcons.Checked = Not mnuIcons.Checked
Toolbar.Visible = mnuIcons.Checked
End Sub

Private Sub mnuKelvin_Click()
mnuCelcius.Checked = False
mnuFahren.Checked = False
mnuKelvin.Checked = True
End Sub

Private Sub mnuLog_Click()
Dim ss As frmLog
Set ss = New frmLog
ss.Show
End Sub

Private Sub mnuLogin_Click()
frmLogin.Show
End Sub

Private Sub mnuMonitor_Click()
Dim vv As frmMonitor
Set vv = New frmMonitor
vv.Show
End Sub

Private Sub mnuPlot_Click()
Dim v As frmMonitor
Set v = New frmMonitor
v.Show
End Sub

Private Sub mnuSet_Click()
Dim kk As frmSet
Set kk = New frmSet
kk.Show
End Sub

Private Sub mnuSettings_Click()
frmSetting.Scale
End Sub

Private Sub mnuView_Click()
Dim jj As frmRead
Set jj = New frmRead
jj.Show
End Sub
```

```
Private Sub Toolbar_ButtonClick(ByVal Button As MSComctlLib.Button)
Select Case Button
Case Is = "&Login"
   mnuLogin_Click
Case Is = "E&xit"
   mnuExit_Click
Case Is = "&ViewLog"
   mnuFileView_Click
Case Is = "&Log"
   mnuLog_Click
Case Is = "&Graph"
   mnuPlot_Click
Case Is = "Settings"
   mnuSettings_Click
Case Is = "&Set"
   mnuSet_Click
Case Is = "&View"
   mnuView_Click
Case Is = "&Monitor"
   mnuMonitor_Click
End Select
End Sub
```

G.1.2 Login form - frmLogin

```
Option Explicit
Dim i As Variant

Private Sub cmdCancel_Click()
   Unload Me
End Sub

Private Sub cmdOk_Click()
   If txtPassword = GetSetting("TMS", "Authentication", "Password", "monitor") Then
      With frmMain
      .mnuLogin.Enabled = False
      .mnuLog.Enabled = True
      .mnuMonitor.Enabled = True
      .mnuPlot.Enabled = True
      .mnuSet.Enabled = True
      .mnuView.Enabled = True
      .mnuFileView.Enabled = True
      .mnuSettings.Enabled = True
      .mnuView.Enabled = True
      .MSComm1.CommPort = GetSetting("TMS", "Comm\PortID", "PortID", 1)
      .MSComm1.Settings = GetSetting("TMS", "Comm\Settings", "Settings",
"9600,n,8,1")
      .MSComm1.PortOpen = True
         With .Toolbar
            .Buttons(1).Enabled = False
            For i = 2 To 13
```

```
            .Buttons(i).Enabled = True
            Next i
          End With
        End With
        Unload Me
    Else
        MsgBox "Invalid Password, try again!", , "Login"
        txtPassword.SetFocus
        SendKeys "{Home}+{End}"
    End If
End Sub
```

G.1.3 Read form - frmRead

```
Private Sub cmdClear_Click()
txtTemp = ""
udAddress.Value = 0
Call udAddress_Change
End Sub

Private Sub cmdExit_Click()
Unload Me
End Sub

Private Sub cmdRead_Click()
With frmMain.MSComm1
    .RTSEnable = True
    .Input = Chr(96) + Chr(Val(txtAddress)) + "R" + Chr(255)
    For delay = 1 To 1000000: Next delay
    .RTSEnable = False
    For delay = 1 To 1000000: Next delay
    temp = .Output
    If Len(temp) < 4 Then Exit Sub
    If Asc(Mid(temp, 2, 1)) <> Val(txtAddress) Then Exit Sub
    If frmMain.mnuHexa.Checked = True Then txtTemp = Asc(Mid(temp, 3, 1)) / 255 *
100
    If frmMain.mnuDecimal.Checked = True Then txtTemp = Asc(Mid(temp, 3, 1)) / 255
* 100
End With
End Sub

Private Sub udAddress_Change()
If frmMain.mnuHexa.Checked = True Then txtAddress = Hex(udAddress.Value)
If frmMain.mnuDecimal.Checked = True Then txtAddress = udAddress.Value
End Sub
```

G.1.4 Set form - frmSet

```
Private Sub cmdClear_Click()
txtTemp.Text = ""
txtAddress.Text = ""
```

```
udAddress.Value = 0
udTemp.Value = 0
End Sub

Private Sub cmdExit_Click()
Unload Me
End Sub

Private Sub cmdSend_Click()
With frmMain.MSComm1
   .RTSEnable = True
   .Input = Chr(96) + Chr(Val(txtAddress)) + "S" + Chr(Val(txtTemp) * 255 / 1000) +
Chr(255)
   For delay = 1 To 1000000: Next delay
   .RTSEnable = False
End With
End Sub

Private Sub Option1_Click(Index As Integer)
udAddress.Increment = Val(Option1(Index).Caption)
udTemp.Increment = Val(Option1(Index).Caption)
End Sub

Private Sub udAddress_Change()
If frmMain.mnuHexa.Checked = True Then txtAddress.Text = Hex(udAddress.Value)
If frmMain.mnuDecimal.Checked = True Then txtAddress.Text = udAddress.Value
End Sub

Private Sub udTemp_Change()
If frmMain.mnuCelcius.Checked = True Then
If frmMain.mnuHexa.Checked = True Then txtTemp.Text = Hex(udTemp.Value)
If frmMain.mnuDecimal.Checked = True Then txtTemp.Text = udTemp.Value
End If
If frmMain.mnuKelvin.Checked = True Then
If frmMain.mnuHexa.Checked = True Then txtTemp.Text = Hex(udTemp.Value + 273)
If frmMain.mnuDecimal.Checked = True Then txtTemp.Text = udTemp.Value + 273
End If
If frmMain.mnuFahren.Checked = True Then
If frmMain.mnuHexa.Checked = True Then txtTemp.Text = Hex(udTemp.Value * 1.8 +
32)
If frmMain.mnuDecimal.Checked = True Then txtTemp.Text = udTemp.Value * 1.8 + 32
End If
End Sub
```

G.1.5 Monitoring form - frmMonitor

```
Dim Values(20), recvd As Double
Dim i, j, Limit As Integer

Private Sub cmdExit_Click()
Unload Me
```

```
End Sub

Private Sub cmdGraph_Click()
frmGraph.Show
End Sub

Private Sub cmdMonitor_Click()
If cmdMonitor.Caption = "Monitor" Then cmdMonitor.Caption = "Stop"
If cmdMonitor.Caption = "Stop" Then cmdMonitor.Caption = "Monitor"
Timer1.Enabled = Not Timer1.Enabled
End Sub

Private Sub Form_Load()
Limit = -1
recv = False
L3V = True
L4V = False
Call Initiate
End Sub

Private Sub Slider1_Click()
Timer1.Interval = 1000 * Slider1.Value
Slider1.ToolTipText = Timer1.Interval & "milli seconds"
End Sub

Private Sub Timer1_Timer()
With frmMain.MSComm1
   .RTSEnable = True
   .Input = Chr(96) + Chr(Val(Text1)) + "R" + Chr(255)
   For delay = 1 To 1000000: Next delay
   .RTSEnable = False
   For delay = 1 To 1000000: Next delay
   temp = .Output
   If Len(temp) < 4 Then Exit Sub
   If Asc(Mid(temp, 2, 1)) <> Val(txtAddress) Then Exit Sub
   recvd = Asc(Mid(temp, 3, 1)) / 255 * 100
End With
If Limit < 20 Then
   Limit = Limit + 1
   Values(Limit) = recvd
Else
   For i = 0 To 19
      Values(i) = Values(i + 1)
   Next i
   Values(20) = recvd
End If
For i = 0 To Limit - 1
'change y2 for line3
Line3(i).Visible = L3V
Line3(i).Y2 = 4 * Values(i)
'change y1 & y2 for line4
```

```
Line4(i).Y1 = 4 * Values(i)
Line4(i).Y2 = 4 * Values(i + 1)
Line4(i).Visible = L4V
Next i
Line3(Limit).Y2 = 4 * Values(Limit)
Line3(Limit).Visible = L3V
Call Initiate
End Sub

Private Sub UpDown1_Change()
Text1.Text = UpDown1.Value
End Sub

Public Sub Initiate()
For i = 0 To 20
   Line3(i).BorderWidth = thick
   Line4(i).BorderWidth = thick
   Line3(i).BorderColor = GFGC
   Line4(i).BorderColor = GFGC
Next i
Frame1.BackColor = GBGC
End SubtxtTemp.Text = ""
```

G.1.6 Loging form – frmLog

```
Dim file As Integer

Private Sub cmdLog_Click()
cmdStop.Enabled = True
cmdExit.Enabled = False
cmdLog.Enabled = False
Timer1.Enabled = True
End Sub

Private Sub cmdSelect_Click()
If Right$(File1.Path, 1) <> "\" Then
   txtFile.Text = File1.Path + "\" + File1.List(File1.ListIndex)
Else
   txtFile.Text = File1.Path + File1.List(File1.ListIndex)
End If
End Sub

Private Sub cmdStop_Click()
cmdStop.Enabled = False
cmdExit.Enabled = True
cmdLog.Enabled = True
Timer1.Enabled = False
Close All
End Sub

Private Sub cmdView_Click()
```

```
If Trim(txtFile) = "" Then GoTo Xit
file = FreeFile
rtb.LoadFile Trim(txtFile)
Open txtFile For Input As kk
SSTab1.Tab = 1
'Dim ss As String
'   While EOF(kk) = False
'   Line Input #1, ss
'   rtb.Text = rtb.Text + ss
'   Wend
'Close kk
Exit Sub
Xit:
MsgBox "Select File then press view button", vbCritical + vbOKOnly, "Error"
End Sub

Private Sub Dir1_Change()
File1.Path = Dir1.Path
End Sub

Private Sub Drive1_Change()
Dir1.Path = Drive1.Drive
End Sub

Private Sub Slider1_Change()
Slider1.ToolTipText = Str(Slider1.Value / 1000) & "Seconds"
Timer1.Interval = Slider1.Value * 1000
End Sub

Private Sub Timer1_Timer()
Dim address, data, temp As Variant
With frmMain.MSComm1
   .RTSEnable = True
   .Input = Chr(96) + Chr(Val(txtAddress)) + "R" + Chr(255)
   For delay = 1 To 1000000: Next delay
   .RTSEnable = False
   For delay = 1 To 1000000: Next delay
   temp = .Output
   If Len(temp) < 4 Then Exit Sub
   address = Asc(Mid(temp, 2, 1))
   data = Asc(Mid(temp, 3, 1))
   Print #file, address, data
End With
End Sub

Private Sub UpDown1_Change()
txtAddress = UpDown1.Value
End Sub
```

G.1.7 Graph Settings form - frmGraph

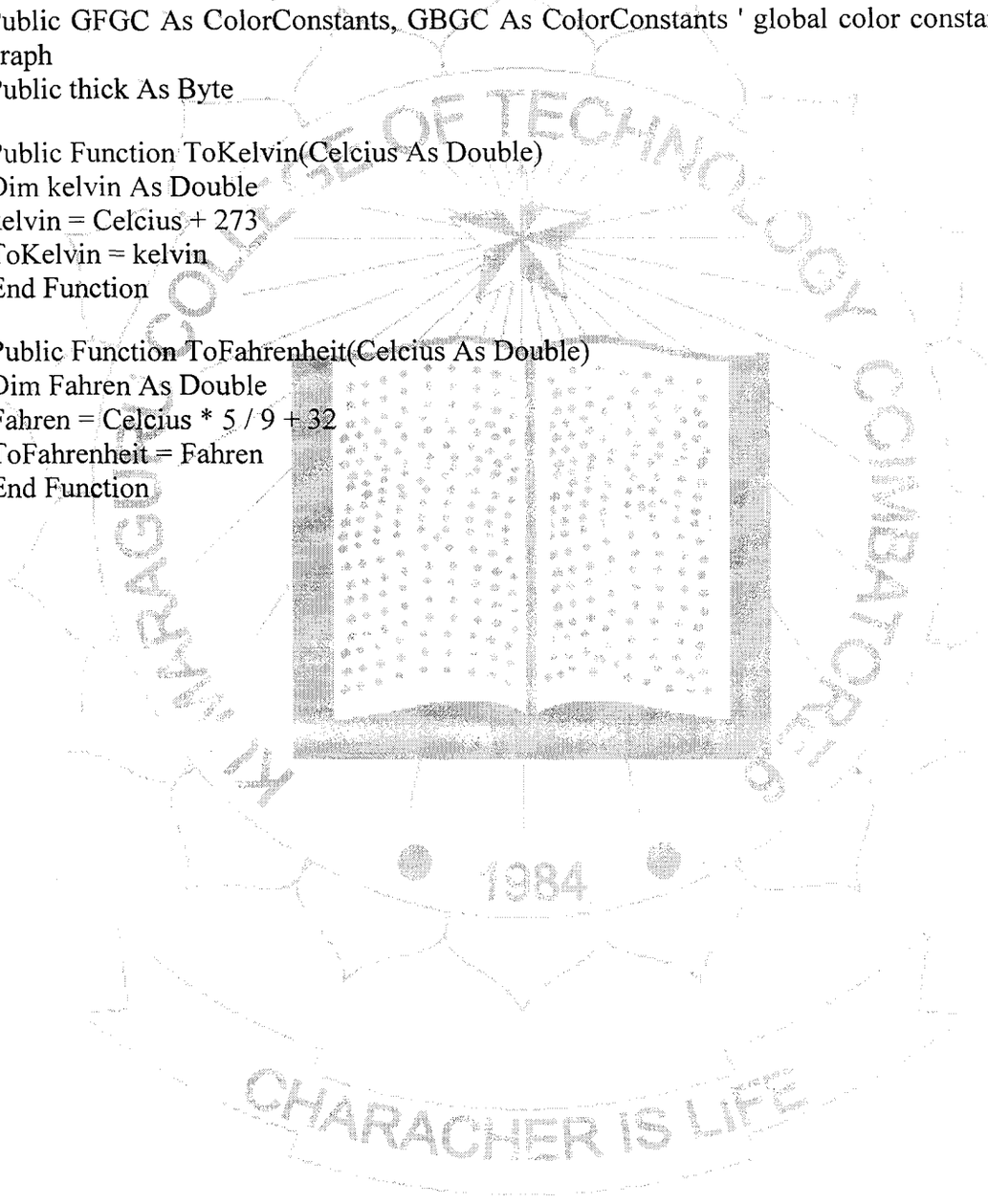
```
Option Explicit
Dim FGColor, BGColor As ColorConstants

Private Sub CancelButton_Click()
Unload Me
End Sub

Private Sub cmdDefault_Click()
Optplot(0).Value = True
txtBG = 12632256
BGColor = 12632256
Label1(1).ForeColor = 12632256
'GBGC = 12632256
txtFG = 16711680
FGColor = 16711680
Label1(0).ForeColor = 16711680
'GFGC = 16711680
Slider1.Value = 1
'thick = 1
End Sub

Private Sub Command1_Click()
cdlg.ShowColor
txtFG = cdlg.Color
FGColor = cdlg.Color
Label1(0).ForeColor = cdlg.Color
End Sub

Private Sub Command2_Click()
cdlg.ShowColor
txtBG = cdlg.Color
BGColor = cdlg.Color
Label1(1).ForeColor = cdlg.Color
End Sub

Private Sub OKButton_Click()
GBGC = BGColor
GFGC = FGColor
thick = Slider1.Value
L3V = Optplot(0).Value
L4V = Optplot(1).Value
If Optplot(2).Value Then L3V = L4V = True
Unload Me
End Sub

Private Sub Slider1_Change()
Slider1.ToolTipText = "Line Thickness = " & Slider1.Value
End Sub
```

```
Private Sub Slider1_Scroll()
Call Slider1_Change
End Sub

Private Sub txtBG_Change()
Label1(1).ForeColor = Val(txtBG)
End Sub

Private Sub txtFG_Change()
Label1(0).ForeColor = Val(txtFG)
End Sub
```

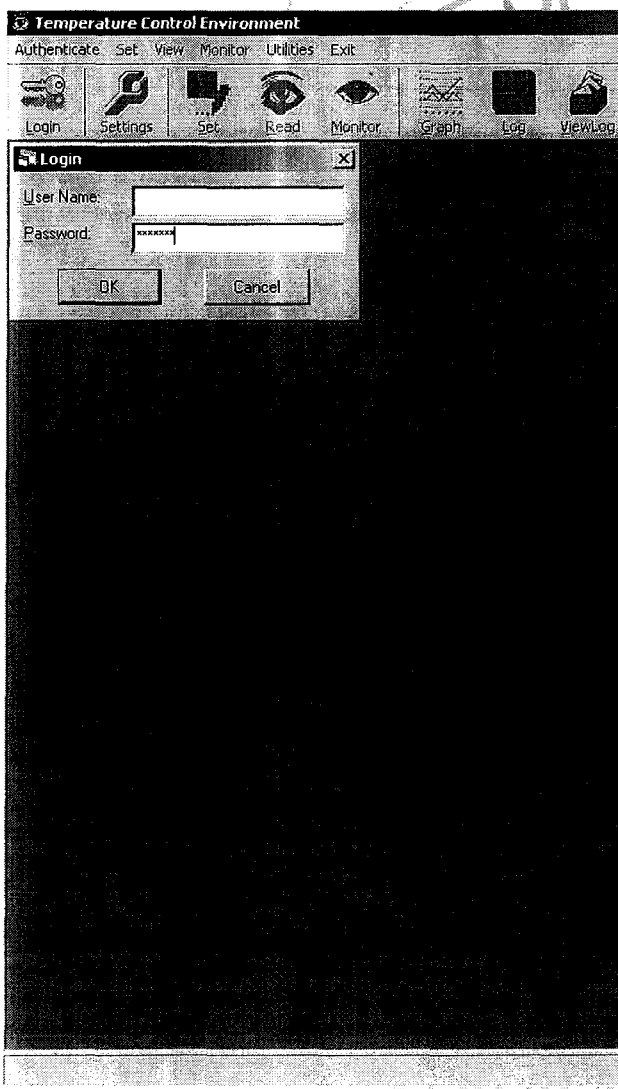
G.1.8 Settings form - frmSettings

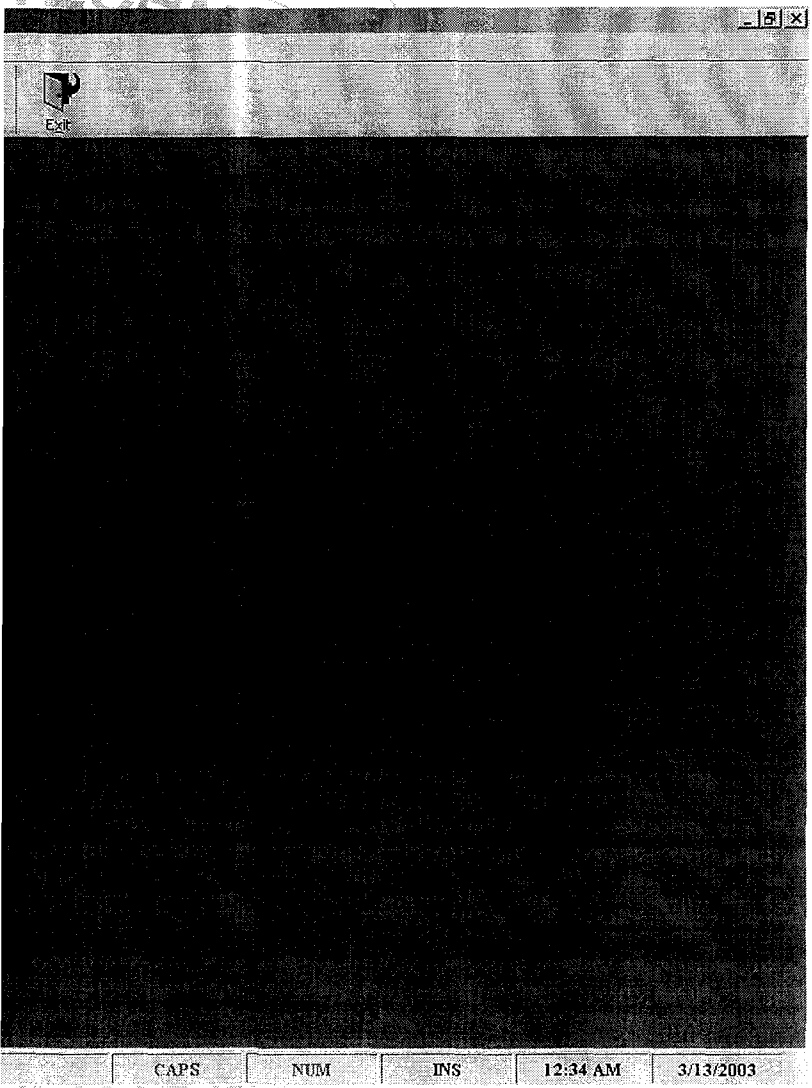
```
Option Explicit
Dim selport As Integer

Private Sub cmdDefault_Click()
Dim kk As Variant
kk = MsgBox("Are you sure to load default values?" + vbCr + "Press Yes to replace password" + vbCrLf + "No to load other values only", vbYesNoCancel + vbQuestion, "Confirm")
If kk = vbCancel Then Exit Sub
If kk = vbYes Then
   SaveSetting "TMS", "Authentication", "password", "monitor"
SaveSetting "TMS", "Comm\PortID", "PortID", 1
SaveSetting "TMS", "Comm\Settings", "Settings", "9600,n,8,1"
End Sub

Private Sub cmdFile_Click()
CommonDialog1.ShowOpen
MsgBox CommonDialog1.FileName
End Sub

Private Sub cmdGraph_Click()
Dim ss As frmGraph
Set ss = New frmGraph
ss.Show
End Sub

Private Sub cmdOk_Click()
frmMain.MSComm1.CommPort = selport
SaveSetting "TMS", "Comm\portID", "PortID", frmMain.MSComm1.CommPort
If Text3 <> Text2 And Text1 <> GetSetting("TMS", "Authentication", "Password", "monitor") Then
   MsgBox "Invalid attempt to change password", vbOKOnly + vbCritical
   Exit Sub
Else
SaveSetting "TMS", "Authentication", "password", Text3
```

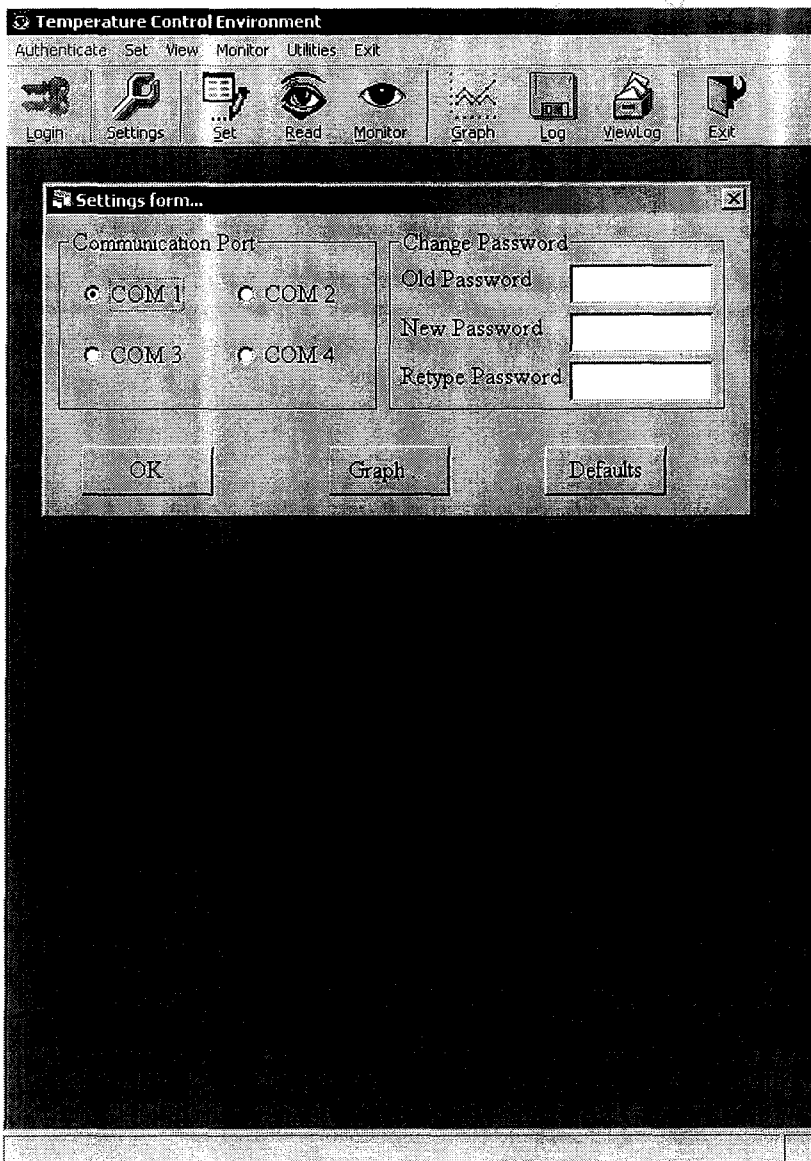
```
End If
End Sub

Private Sub OptPort_Click(Index As Integer)
selport = Index
End Sub

Public L3V As Boolean, L4V As Boolean
Public GFGC As ColorConstants, GBGC As ColorConstants ' global color constants for graph
Public thick As Byte

Public Function ToKelvin(Celcius As Double)
Dim kelvin As Double
kelvin = Celcius + 273
ToKelvin = kelvin
End Function

Public Function ToFahrenheit(Celcius As Double)
Dim Fahren As Double
Fahren = Celcius * 5 / 9 + 32
ToFahrenheit = Fahren
End Function
```

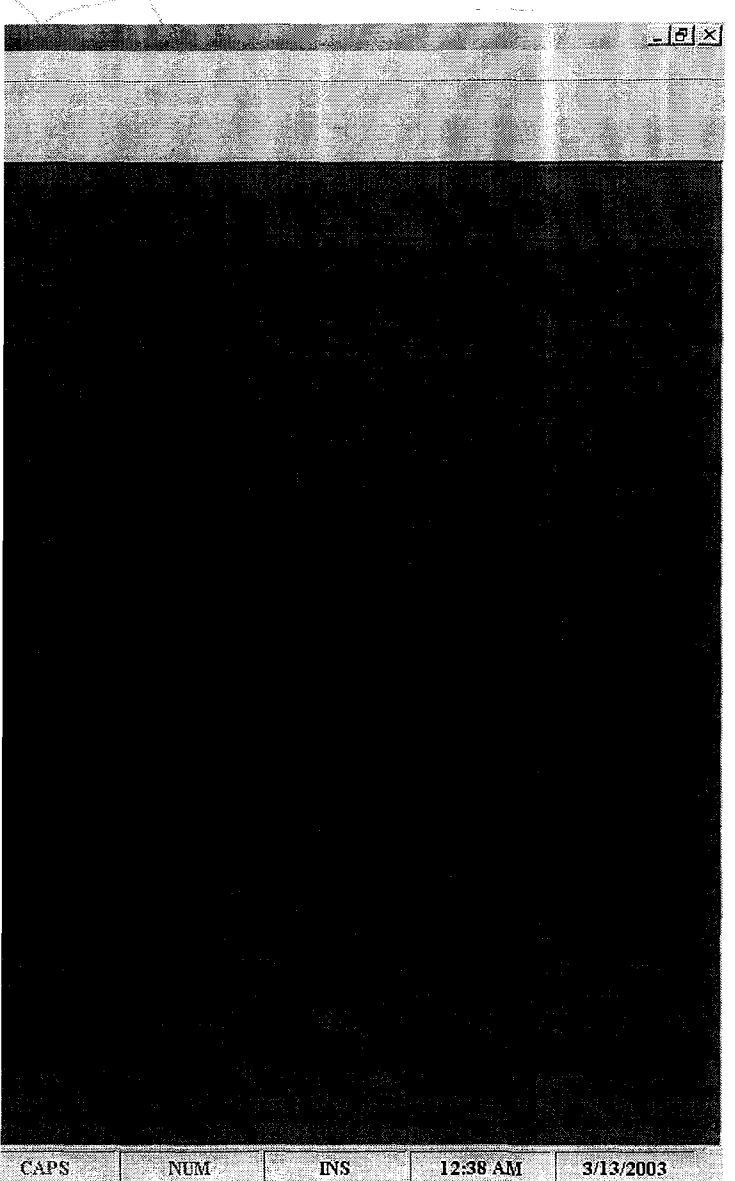


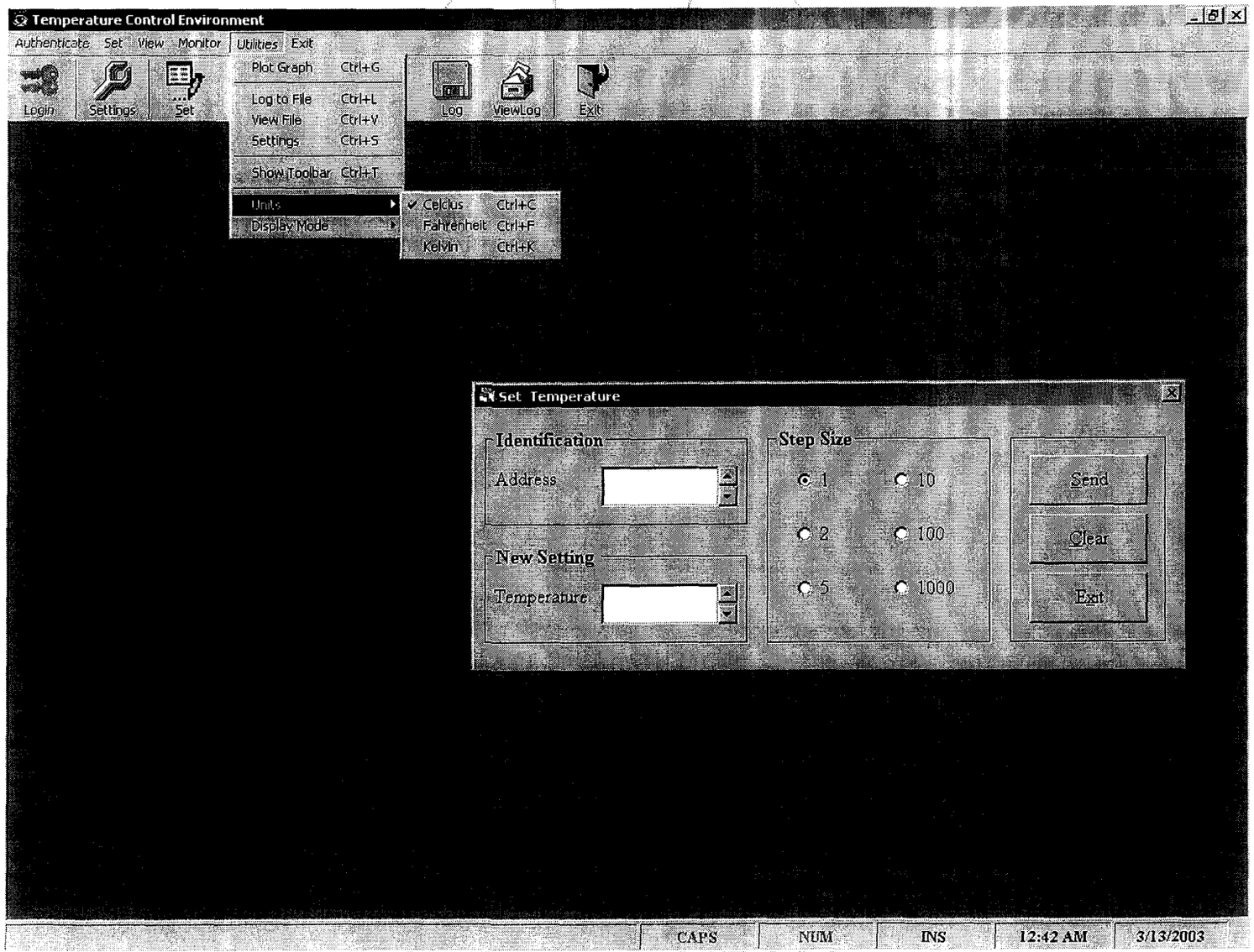
G.2 Visual Basic Output Screens

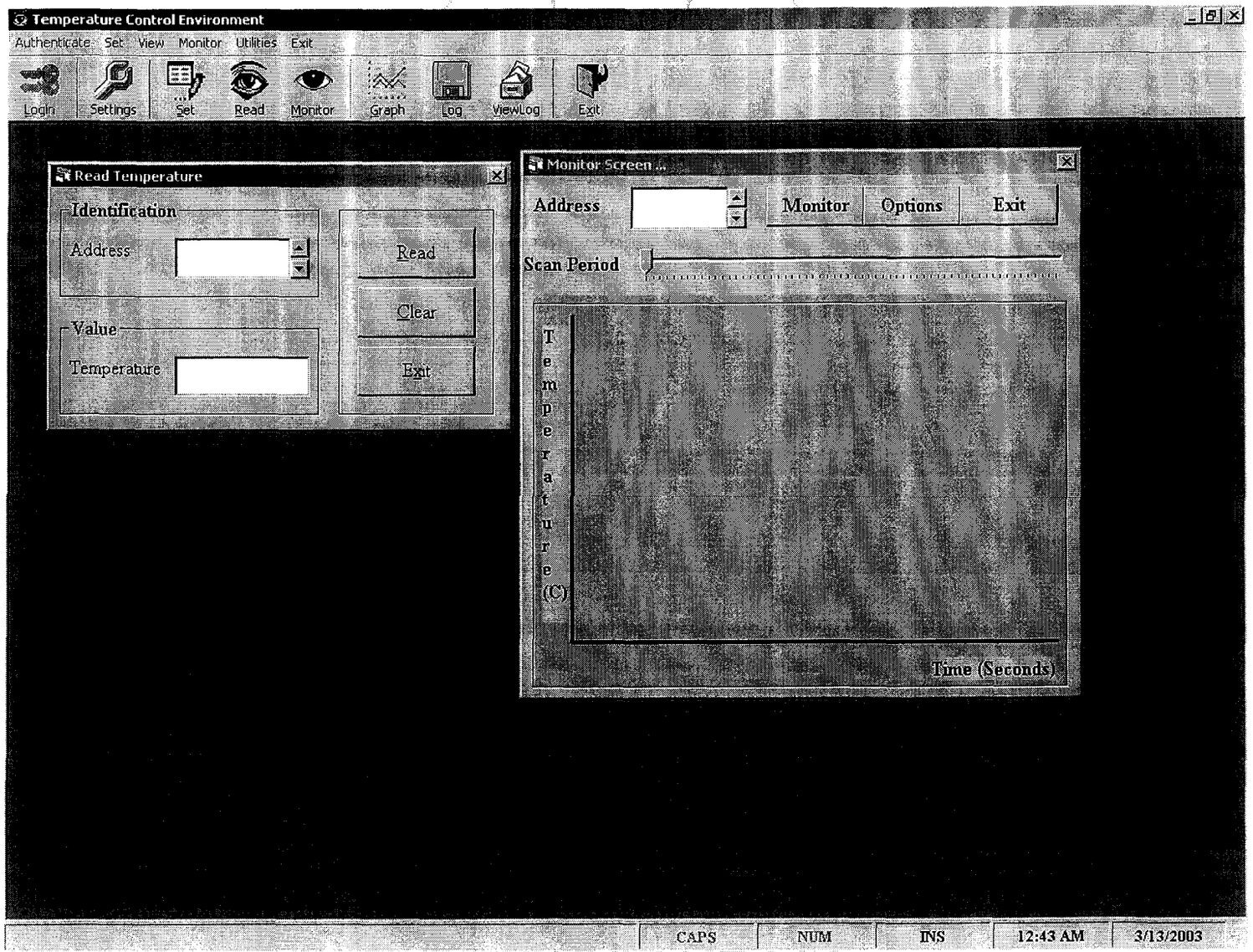


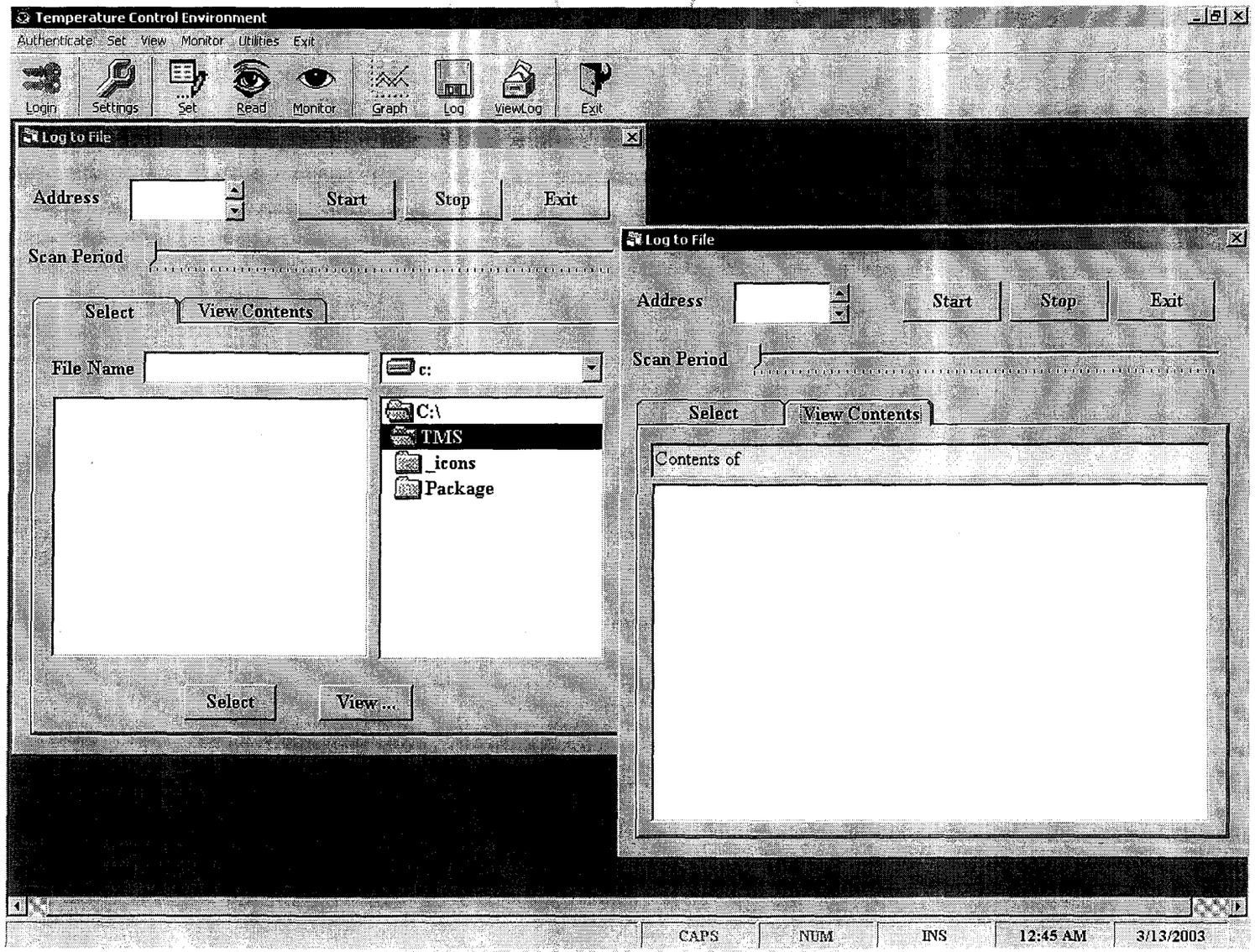

Exit
CAPS
NUM
INS
12:34 AM
3/13/2003


Temperature Control Environment
Authenticate Set View Monitor Utilities Exit
Login
Settings
Set
Read
Monitor
Graph
Log
ViewLog
Exit
Settings form...
Communication Port
COM 1
COM 2
COM 3
COM 4
Change Password
Old Password
New Password
Retype Password
OK
Graph
Defaults


CAPS
NUM
INS
12:38 AM
3/13/2003


Temperature Control Environment
Authenticate
Set
View
Monitor
Utilities
Exit
Plot Graph Ctrl+G
Log to File Ctrl+L
View File Ctrl+V
Settings Ctrl+S
Show Toolbar Ctrl+T
Units
Display Mode
Celcius Ctrl+C
Fahrenheit Ctrl+F
Kelvin Ctrl+K
Login
Settings
Set
Log
ViewLog
Exit
Set Temperature
Identification
Address
New Setting
Temperature
Step Size
1
10
2
100
5
1000
Send
Clear
Exit
CAPS
NUM
INS
12:42 AM
3/13/2003


Temperature Control Environment
Authenticate Set View Monitor Utilities Exit
Login
Settings
Set
Read
Monitor
Graph
Log
ViewLog
Exit
Read Temperature
Identification
Address
Value
Temperature
Read
Clear
Exit
Monitor Screen ...
Address
Monitor
Options
Exit
Scan Period
Temperature (C)
Time (Seconds)
CAPS
NUM
INS
12:43 AM
3/13/2003


Temperature Control Environment
Authenticate Set View Monitor Utilities Exit
Login
Settings
Set
Read
Monitor
Graph
Log
ViewLog
Exit
Log to File
Address
Start
Stop
Exit
Scan Period
Select
View Contents
File Name
c:
C:\
TMS
_icons
Package
Select
View...
Log to File
Address
Start
Stop
Exit
Scan Period
Select
View Contents
Contents of
CAPS
NUM
INS
12:45 AM
3/13/2003

Appendix H

F.1 Master Program

```
#include      <pic.h>
#include      <conio.h>
#include     <stdio.h>
#include      <delay.c>

unsigned char tabl[] = {0X20, 0X20, 0X20, 0X20, 0X20, 0X20, 0X20, 0X20, 0X20,
0X20, 0X20, 0X20, 0X20, 0X20, 0X20, 0X20};

unsigned char car,temp,num,data;
char tab_temp[]={0,0,0,0};
unsigned char start_byte, stop_byte, addr_byte, cpu_serial, value, temp_value,
temp_temp_value, set_value, temp_set_value;
int delay;
bit flag, start_bit, addr_bit, stop_bit, data_process_bit, cmd_read, cmd_get, cmd_data,
put, get;

unsigned char input;

void lcd_init();
void out (unsigned char);
void gren();
void nop(void);
void display(void);
unsigned char getbyte(void);
void putbyte(unsigned char byte);
void isr_putbyte(unsigned char byte);
unsigned char isr_getbyte(void);

main()
{
        lcd_init();
        start_byte = 0x60; stop_byte = 0xFF; addr_byte = 0x00;
        start_bit = 1;
        addr_bit = 0;
        data_process_bit = 0;
        cmd_read = 1;
        cmd_get = 1;
        cmd_data = 0;
        stop_bit = 0;
        TRISB = 0x00;
        TRISC = 0x80;
        RB1 = 0;
        RCSTA=0x90;
        TXSTA=0x26;
        SPBRG=129;
        INTCON = 0xC0;
```

```
SPEN=1;
TXEN=1;
RCIE=1;
TXIF=0;
temp_temp_value = 255;
temp_set_value = 255;
gren();
while(1)
{
        if ( set_value != temp_set_value )
        {
                flag = 0;
                out(car=0x80);
                flag = 1;
                out(car='D');
                flag = 1;
                out(car='e');
                flag = 1;
                out(car='v');
                flag = 1;
                out(car='i');
                flag = 1;
                out(car='c');
                flag = 1;
                out(car='e');
                flag = 1;
                out(car=' ');
              sprintf (tabl,"%03d",addr_byte);
                flag = 1;
                out(car=tabl[0]);
                flag = 1;
                out(car=tabl[1]);
                flag = 1;
                out(car=tabl[2]);
                flag = 1;
                out(car=':');
                flag = 1;
                out(car=' ');
                flag = 1;
             sprintf (tabl,"%04d",set_value);
                out(car=tabl[0]);
                flag = 1;
                out(car=tabl[1]);
                flag = 1;
                out(car=tabl[2]);
                flag = 1;
                out(car=tabl[3]);
                temp_set_value = set_value;
        }
        if ( temp_value != temp_temp_value )
```

```
{
        flag = 0;
        out(car=0x80);
        flag = 1;
        out(car='D');
        flag = 1;
        out(car='e');
        flag = 1;
        out(car='v');
        flag = 1;
        out(car='i');
        flag = 1;
        out(car='c');
        flag = 1;
        out(car='e');
        flag = 1;
        out(car=' ');
      sprintf (tabl,"%03d",addr_byte);
        flag = 1;
        out(car=tabl[0]);
        flag = 1;
        out(car=tabl[1]);
        flag = 1;
        out(car=tabl[2]);
        flag = 0;
        out(car=0xC0);
        flag = 1;
        out(car='T');
        flag = 1;
        out(car='e');
        flag = 1;
        out(car='m');
        flag = 1;
        out(car='p');
        flag = 1;
        out(car=' ');
        flag = 1;
        out(car=' ');
        flag = 1;
        out(car=' ');
        flag = 1;
        out(car=' ');
        flag = 1;
        out(car=' ');
        flag = 1;
        out(car=' ');
        flag = 1;
        out(car=' ');
        flag = 1;
        out(car=':');
        flag = 1;
        out(car=' ');
```

```
                    sprintf (tabl,"%04d",temp_value);
                        flag = 1;
                        out(car=tabl[0]);
                        flag = 1;
                        out(car=tabl[1]);
                        flag = 1;
                        out(car=tabl[2]);
                        flag = 1;
                        out(car=tabl[3]);
                        temp_temp_value = temp_value;
                }
        }
}

void interrupt isr( void )
{
        data = getbyte();
        if ( data == start_byte && start_bit )
        {
                start_bit = 0;
                addr_bit = 1;
                data_process_bit = 0;
                stop_bit = 0;
        }
        else if( addr_bit )
        {
                addr_byte = data;
                start_bit = 0;
                addr_bit = 0;
                data_process_bit = 1;
                stop_bit = 0;
                cmd_data = 0;
        }
        else if( data_process_bit )
        {
                if ( cmd_data )
                {
                        if ( put )
                        {
                                set_value = data;
                        }
                        else
                        {
                                temp_value = data;
                        }
                        cmd_data = 0;
                        data_process_bit = 0;
                        stop_bit = 1;
                }
                else if ( data == 'S' && cmd_read )
```

```
                {
                        cmd_data = 1;
                        data_process_bit = 1;
                        stop_bit = 1;
                        put = 1;
                }
                else if ( data == 'T' && cmd_get )
                {
                        cmd_data = 1;
                        data_process_bit = 1;
                        stop_bit = 0;
                        put = 0;
                }

        }
        else if( data == stop_byte && stop_bit )
        {
                cmd_data = 0;
                start_bit = 1;
                addr_bit = 0;
                data_process_bit = 0;
                stop_bit = 0;
        }
}

unsigned char getbyte(void)
{
        while(!RCIF)
        {
        }
        return RCREG;
}

unsigned char isr_getbyte(void)
{
        while(!RCIF)
        {
        }
        return RCREG;
}

void putbyte(unsigned char byte)
{
        while (!TXIF)
        {
        }
        TXREG=byte;
}

void isr_putbyte(unsigned char byte)
{
```

```
        while (!TXIF)
        {
        }
        TXREG=byte;
}

void lcd_init()
{
 while (delay<5000)
        delay++;
 delay=0;
 out(car=0x30);
 while(delay<1000)
 delay++;
 delay=0;
 out(car=0X30);
 while (delay<100)
        delay++;
 delay=0;
 out(car=0x30);
 nop();
 out(car=0x21);
 nop();
 out(car=0x0C);
 nop();
 out(car=0x06);
 nop();
 out(car=0x01);
 nop();
 // out(car=0x02);
 }

 void out (unsigned char)
 {
 PORTD=0;
 TRISD=0XF1;
 RD1=0;
 RD2=1;
 nop();
 RD3=1;
 nop();
 while(RD7);
 PORTD=0;
 TRISD=0X01;
 temp=car&0xf0;
 PORTD=temp;
 if(flag)
        RD1=1;
 nop();
 RD3=1;
```

```
nop();
RD3=0;
temp=car;
temp=temp<<4;
temp=temp&0xf0;
PORTD=temp;
if(flag)
        RD1=1;
nop();
RD3=1;
nop();
RD3=0;
RD2=0;
flag=0;
return;
}

void gren()
{
//INTF=1;
tabl[0]=' ';
tabl[1]='G';
tabl[2]='R';
tabl[3]='E';
tabl[4]='N';
tabl[5]='T';
tabl[6]='E';
tabl[7]='L';
//tabl[8]=' ';
tabl[8]=' ';
tabl[9]='T';
tabl[10]='E';
tabl[11]='C';
tabl[12]='H';
tabl[13]=' ';
tabl[14]=' ';
tabl[15]=' ';
display();
}

void nop(void)
{
#asm
NOP
NOP
NOP
#endasm
return;
}
```

```
void display(void)
{
flag=0;
out(car=0x80);
num=0;
while(num<8)
        {
        flag=1;
        out (car=tabl[num]);
        num++;
        }
flag=0;
out(car=0xC0);
while(num<16)
        {
        flag=1;
        out (car=tabl[num]);
        num++;
        }
flag=0;
return;
}
```

F.2 Slave Program

```
#include      <pic.h>
#include      <conio.h>
#include     <stdio.h>
#include      <delay.c>

unsigned char tabl[] = {0X20, 0X20, 0X20, 0X20, 0X20, 0X20, 0X20, 0X20, 0X20,
0X20, 0X20, 0X20, 0X20, 0X20, 0X20, 0X20};

unsigned char car,temp,num,data;
char tab_temp[]={0,0,0,0};
unsigned char start_byte,stop_byte,addr_byte,cpu_serial;
int delay,get_temp,set_temp,value;
bit flag, start_bit, addr_bit, stop_bit, data_process_bit, cmd_read, cmd_get, cmd_data;
unsigned char input;

void lcd_init();
void out (unsigned char);
void gren();
void nop(void);
void display(void);
unsigned char getbyte(void);
void putbyte(unsigned char byte);
void isr_putbyte(unsigned char byte);
unsigned char isr_getbyte(void);
int adc_read(unsigned char channel);
int isr_adc_read(unsigned char channel);
```

```
main()
{
        lcd_init();
        start_byte = 0x60; stop_byte = 0xFF; addr_byte = 0x10;

        start_bit = 1;
        addr_bit = 0;
        data_process_bit = 0;
        cmd_read = 1;
        cmd_get = 1;
        cmd_data = 0;
        stop_bit = 0;

        TRISB = 0x00;
        RB1 = 0;
        RCSTA=0x90;
        TXSTA=0x26;
        SPBRG=129;
        INTCON = 0xC0;
        SPEN=1;
        TXEN=1;
        RCIE=1;
        TXIF=0;
        putbyte('V');
        while(1)
        {
         value=adc_read(2);
         sprintf (tabl,"%4d",value);
         display();
         if (value < set_temp)
                {
                RB1 = 1;
                }
         else
                {
                RB1 = 0;
                }
        }
}

void interrupt isr( void )
{
        data = getbyte();
        isr_putbyte( data );
        if ( data == start_byte && start_bit )
        {
                start_bit = 0;
                addr_bit = 1;
                data_process_bit = 0;
                stop_bit = 0;
```

```
}
else if( data == addr_byte && addr_bit )
{
        start_bit = 0;
        addr_bit = 0;
        data_process_bit = 1;
        stop_bit = 0;
}
else if( data_process_bit )
{
        if ( cmd_data )
        {
                cmd_read = 1;
                cmd_get = 1;
                cmd_data = 0;
                set_temp = data;
//              sprintf (tab_temp,"%4d",set_temp);
                isr_putbyte('S');
                isr_putbyte('=');
                isr_putbyte(data);
                /*isr_putbyte(tab_temp[0]);
                isr_putbyte(tab_temp[1]);
                isr_putbyte(tab_temp[2]);
                isr_putbyte(tab_temp[3]);*/
                data_process_bit = 0;
                stop_bit = 1;
        }
        else if ( data == 'R' && cmd_read )
        {
                cmd_data = 0;
                get_temp = value;
//              sprintf (tab_temp,"%4d",value);
                isr_putbyte('T');
                isr_putbyte('=');
                isr_putbyte(value);
                /*isr_putbyte(tab_temp[0]);
                isr_putbyte(tab_temp[1]);
                isr_putbyte(tab_temp[2]);
                isr_putbyte(tab_temp[3]);*/
                data_process_bit = 0;
                stop_bit = 1;
        }
        else if ( data == 'S' && cmd_get )
        {
                cmd_read = 0;
                cmd_get = 0;
                cmd_data = 1;
                data_process_bit = 1;
                stop_bit = 0;
        }
```

```
        }
        else if( data == stop_byte && stop_bit )
        {
                start_bit = 1;
                addr_bit = 0;
                data_process_bit = 0;
                stop_bit = 0;
                        cmd_read = 1;
                        cmd_get = 1;
                        cmd_data = 0;
        }

}

unsigned char getbyte(void)
{
        while(!RCIF)
        {
        }
        return RCREG;
}

unsigned char isr_getbyte(void)
{
        while(!RCIF)
        {
        }
        return RCREG;
}

void putbyte(unsigned char byte)
{
        while (!TXIF)
        {
        }
        TXREG=byte;
}

void isr_putbyte(unsigned char byte)
{
        while (!TXIF)
        {
        }
        TXREG=byte;
}

int adc_read(unsigned char channel)
{
 unsigned char del;
 int result;
```

```
 ADCON0=(channel<<3)+0x81;
 for (del=100;del--;);
 ADGO=1;
 while (ADGO);
 *(((unsigned char*)&result)+1)=ADRESH;
 *(((unsigned char*)&result))=ADRESL;
 return(result);
 }

int isr_adc_read(unsigned char channel)
{
 unsigned char del;
 int result;
 ADCON0=(channel<<3)+0x81;
 for (del=100;del--;);
 ADGO=1;
 while (ADGO);
 *(((unsigned char*)&result)+1)=ADRESH;
 *(((unsigned char*)&result))=ADRESL;
 return(result);
 }

void lcd_init()
{
 while (delay<5000)
        delay++;
 delay=0;
 out(car=0x30);
 while(delay<1000)
 delay++;
 delay=0;
 out(car=0X30);
 while (delay<100)
        delay++;
 delay=0;
 out(car=0x30);
 nop();
 out(car=0x21);
 nop();
 out(car=0x0C);
 nop();
 out(car=0x06);
 nop();
 out(car=0x01);
 nop();
 // out(car=0x02);
 }

void out (unsigned char)
{
```

```
PORTD=0;
TRISD=0XF1;
RD1=0;
RD2=1;
nop();
RD3=1;
nop();
while(RD7);
PORTD=0;
TRISD=0X01;
temp=car&0xf0;
PORTD=temp;
if(flag)
        RD1=1;
nop();
RD3=1;
nop();
RD3=0;
temp=car;
temp=temp<<4;
temp=temp&0xf0;
PORTD=temp;
if(flag)
        RD1=1;
nop();
RD3=1;
nop();
RD3=0;
RD2=0;
flag=0;
return;
}

void gren()
{
//INTF=1;
tabl[0]=' ';
tabl[1]='G';
tabl[2]='R';
tabl[3]='E';
tabl[4]='N';
tabl[5]='T';
tabl[6]='E';
tabl[7]='L';
//tabl[8]=' ';
tabl[8]=' ';
tabl[9]='T';
tabl[10]='E';
tabl[11]='C';
tabl[12]='H';
```

```
tabl[13]=' ';
tabl[14]=' ';
tabl[15]=' ';
display();
}

void nop(void)
{
#asm
NOP
NOP
NOP
#endasm
return;
}

void display(void)
{
flag=0;
out(car=0x80);
num=0;
while(num<8)
        {
        flag=1;
        out (car=tabl[num]);
        num++;
        }
flag=0;
out(car=0xC0);
while(num<16)
        {
        flag=1;
        out (car=tabl[num]);
        num++;
        }
flag=0;
return;
}
```