MICROCONTROLLER BASED FAULT DETECTION SCHEME FOR THREE PHASE INDUCTION MOTOR

A PROJECT REPORT

Submitted by

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in

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Under the guidance of

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BONAFIDE CERTIFICATE

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(INTERNAL EXAMINER) **(EXTERNAL EXAMINER)**

DEDICATED TO

OUR BELOVED PARENTS

&

FRIENDS

ACKNOWLEDGEMENT

ACKNOWLEDGEMENT

The satisfaction that accompanies the successful completion of any task would be incomplete without the mention of the people whose constant guidance and encouragement crowns all effort with success.

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ABSTRACT

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Electrical motors, in particular Induction motors are the lifeline of most of the industries. They are exposed to variety of environment and operating conditions. These leads to development of incipient faults, which has its direct consequence in the company's production. Hence it is necessary to monitor all the parameters of the motor to prevent fatigue failure. The protection scheme required for the safety operation of the motor is being implemented in this project.

The electrical parameters such as voltage, current and the mechanical parameters such as speed, temperature are continuously monitored. The sensed parameters are fed to microcontroller. The microcontroller is programmed suitably so that it continuously monitors the parameters and detects the fault if any. Based on the severity of the fault the trip circuit is actuated. The sensed parameters and details regarding the faults are displayed using the LCD display. The controller is also interfaced to PC.

This system identifies the fault at incipient stage and hence it is an epitome for the saying "Prevention is better than cure". Thus preventive maintenance can be implemented in an organized manner.

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LIST OF SYMBOLS

I_R - R phase current in ampere.

I_Y - Y phase current in ampere.

I_B - B phase current in ampere.

I_{R0} - Zero sequence component of R phase.

I_{Y0} - Zero sequence component of Y phase.

I_{B0} - Zero sequence component of B phase.

I_{R1} - Positive sequence component of R phase.

I_{Y1} - Positive sequence component of Y phase.

I_{B1} - Positive sequence component of B phase.

I_{R2} - Negative sequence component of R phase.

I_{Y2} - Negative sequence component of Y phase.

I_{B2} - Negative sequence component of B phase.

α - $1\angle 120°$.

θ_z - Phase angle of zero sequence component.

θ_n - Phase angle of negative sequence component.

θ - Phase angle between negative and zero sequence component.

V_1 - Equivalent DC voltage of R phase voltage.

V_2 - Equivalent DC voltage of Y phase voltage.

V_3 - Equivalent DC voltage of B phase voltage.

I_1 - Equivalent DC voltage of R phase current.

I_2 - Equivalent DC voltage of Y phase current.

I_3 - Equivalent DC voltage of B phase current.

T - Equivalent DC voltage of temperature.

N - Pulse proportional to the speed.

FR - Fault ratio in percentage (negative sequence/positive sequence).

INTRODUCTION

1.INTRODUCTION

Now-a-days AC motors in particular Induction motor finds a great application in most of the industries. It contributes 90% of all process done in industries. For the trouble free operation the induction motor should be operated effectively without failure.

1.1 CAUSES FOR FAILURE

Electrical motors in particular Induction motors are the lifeline of most of the industries. They are exposed to variety of environment and operating conditions. These leads to development of incipient faults.

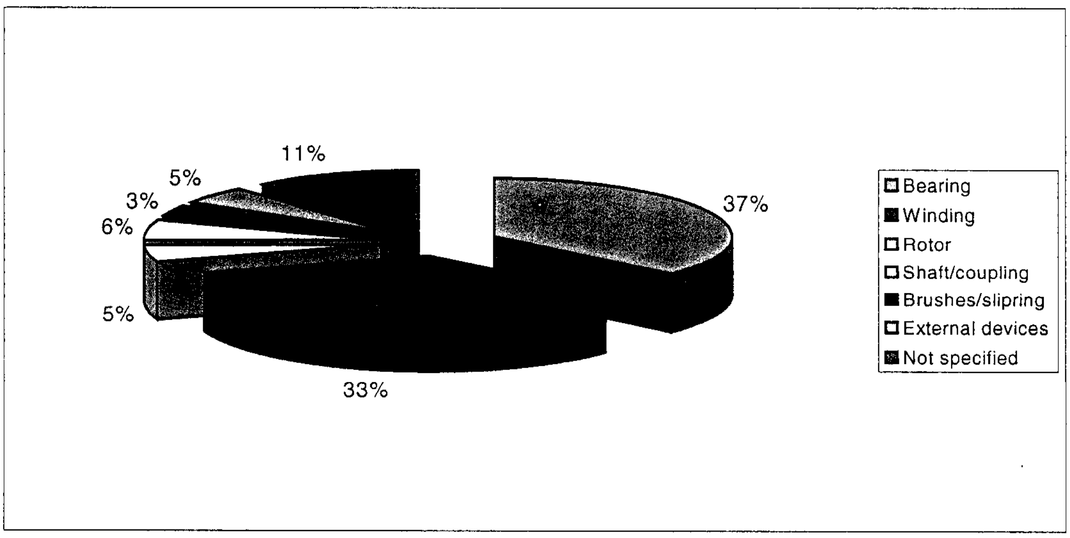


FIGURE 1.1 FAULT STATISTICS

The possible faults that occur in induction motor are insulation failure, bearing failure, rotor fault, shaft coupling, brushes and due to external devices. Insulation failure and bearing failure are the faults that occur frequently in induction motor.

The main reasons for insulation failure are due to unbalanced terminal voltage, wide variation in supply voltage compared to the permissible limits given by the manufacturers and insufficient cooling.

When the line voltages applied to the motor is not the same unbalanced current will flow in the stator winding. The presence of a small amount of unbalance in the line voltage in the motor terminal will cause a large unbalance in the line currents and leads to over heating and damage to the winding.

A few reasons behind bearing failure is due to unbalance, misalignment, mechanical looseness, bad belt drives, defective sleeve bearings and vibration due to eccentricity.

Another important reason for motor breakdown is due to over temperature. The increase in temperature depends upon the ambient temperature and the losses in the machine. Any unbalance or fluctuation in the motor parameters may change the motor operation and change the operating temperature.

1.2 NECCESSITY OF FAULT DETECTION SYSTEM

In the modern scenario processes are getting more and more automated and the trend is to have a control through continuous monitoring.

The top priority factor for any industries is to have high plant availability, with minimum downtime both during normal as well as during maintenance shutdowns.

In an ordinary system if a fault occurs, it is time consuming for identifying the nature of fault, location of fault and rectification of the fault thereby leading to significant production losses.

So, an intelligent system is needed for precisely identifying the faults, displaying the nature of faults and the location of faults. It is also essential that the system should deal with preventive maintenance and continuous real time monitoring of the motor parameters.

METHODOLOGY

2.METHODOLOGY

2.1 SYMMETRICAL COMPONENTS

A balanced system is one in which the three phase voltages and currents throughout the system are completely balanced, i.e., they have equal magnitudes in each phase and are progressively displaced in time phase by 120°. In a balanced system, analysis can proceed on a single-phase basis. The knowledge of voltage and current in one phase is sufficient to completely determine voltages and currents in the other two phases. Real and reactive powers are simply three times the corresponding per phase values.

But an unbalanced system operation can result in an otherwise balanced system due to unsymmetrical fault. These faults are, in fact, of more common occurrence than the symmetrical fault. System operation may also become unbalanced when loads are unbalanced as in the presence of large single-phase loads. Analysis under unbalanced conditions has to be carried out on a three-phase basis. Alternatively, a more convenient method of analyzing unbalanced operation is through symmetrical components where the three-phase voltages and currents, which may be unbalanced, are transformed into three sets of unbalanced voltages and currents called symmetrical components.

The symmetrical components are classified into three as,

- Positive sequence
- Negative sequence
- Zero sequence

Positive sequence

As shown in the figure, the positive sequence is the set of three balanced phasors (voltages / currents) I_R, I_Y, I_B is characterized by equal magnitude with phase differences of 120° and having a phase sequence (RYB) same as that of power supply.

$$I_{R1}=I_R \; ; \; I_{Y1}=\alpha^2 I_{R1} \; ; \; I_{B1}=\alpha I_{R1}$$

where the complex number operator is defined as $\alpha=e^{-j120^\circ}$

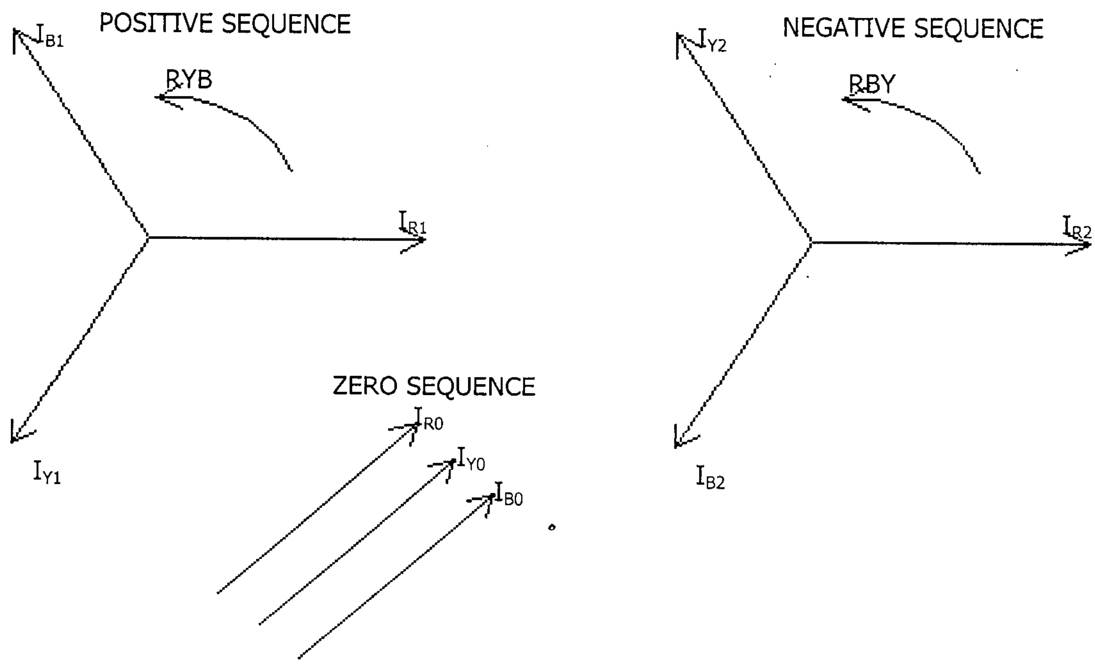


FIGURE 2.1 SEQUENCE DIAGRAM

Negative sequence

Similarly in negative sequence components, the three phasors (voltages / currents) are of same magnitude but having a phase sequence opposite to that of the supply.

$I_{R1}=I_R$; $I_{Y1}=\alpha I_{R1}$; $I_{B1}=\alpha^2 I_{R1}$

Zero sequence

In case of zero sequence components, the three voltage vectors are of same magnitude but are in phase with supply.

$I_{R0}=I_{Y0}=I_{B0}$

Consider now a set of three current (phasors) I_R, I_Y, I_B which in general may be unbalanced. According to Fortesque's theorem the three phasors can be expressed as sum of positive, negative and zero sequence phasors defined above. Thus

$I_R = I_{R1}+I_{R2}+I_{R0}$; (2.1)

$I_Y=I_{Y1}+I_{Y2}+I_{Y0}$; (2.2)

$I_B=I_{B1}+I_{B2}+I_{B0}$; (2.3)

Hence the three phasor sequences (positive, negative and zero) are called as the symmetrical components of the original phasor set I_R, I_Y, I_B. Let us now express the above equations in terms of reference phasors I_{R1}, I_{R2} and I_{R0}.Thus

$I_R = I_{R1}+I_{R2}+I_{R0}$; (2.4)

$I_Y=\alpha^2 I_{R1}+\alpha I_{R2}+I_{R0}$; (2.5)

$I_B=\alpha I_{R1}+\alpha^2 I_{R2}+I_{R0}$; (2.6)

These equations can be expressed in the matrix form as,

$$\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ \alpha^2 & \alpha & 1 \\ \alpha & \alpha^2 & 1 \end{bmatrix} \begin{bmatrix} I_{R1} \\ I_{R2} \\ I_{R0} \end{bmatrix} \qquad (2.7)$$

(Or)

Ip = A*Is, where

$$Ip = \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \text{vector of original phasors.}$$

$$Is = \begin{bmatrix} I_{R1} \\ I_{R2} \\ I_{R0} \end{bmatrix} = \text{vectors of symmetrical components.}$$

$$A = \begin{bmatrix} 1 & 1 & 1 \\ \alpha^2 & \alpha & 1 \\ \alpha & \alpha^2 & 1 \end{bmatrix} \qquad (2.8)$$

We can write the equation Ip = A*Is as Is = A^{-1}Ip.Computing A^{-1} using the above equations results as,

$$A^{-1} = (1/3)*\begin{bmatrix} 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \\ 1 & 1 & 1 \end{bmatrix} \qquad (2.9)$$

In expanded form we can express Is as,

$$I_{R1} = (1/3)*(I_R+\alpha I_Y+\alpha^2 I_B) \quad (2.10)$$

$$I_{R2} = (1/3)*(I_R+\alpha^2 I_Y+\alpha I_B) \quad (2.11)$$

$$I_{R0} = (1/3)*(I_R+I_Y+I_B) \quad (2.12)$$

2.2 FAULT ANALYSIS

The fault detection technique of this scheme is based on the symmetrical component, which is explained earlier. To determine the scheme a three phase winding study motor is chosen as test motor. The test motor is wound for 4 pole, lap winding as shown in FIGURE 2.3. The winding faults are simulated in the motor by externally short-circuiting the windings and the corresponding parameters of the motor are noted. We analyzed the fault as stated below.

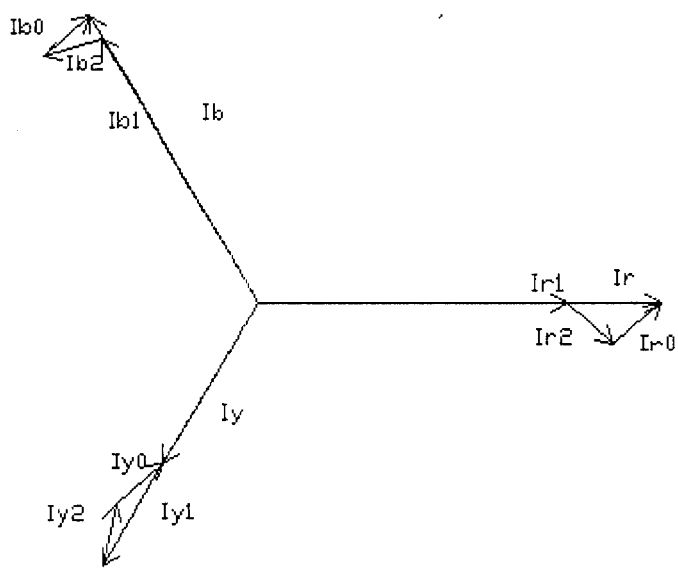


FIGURE 2.2 PHASOR DIAGRAM

In phasor diagram shown in FIGURE 2.2 the angle between the negative sequence vector and the zero axis indicates the occurrence of fault. Similarly the angle between the negative sequence vector and zero sequence vector indicates the severity of the fault. It can be computed from the formulated expressions given below.

R-phase

I Quadrant $\theta = (180-\theta_{n-}\theta_z)$

II Quadrant $\theta = \theta_n - \theta_z$

III Quadrant $\theta = \theta_n - \theta_z$

IV Quadrant $\theta = (180-\theta_{n-}\theta_z)$

Y-phase

I Quadrant $\theta = (180-\theta_z)+ \theta_n$

II Quadrant $\theta = (180-\theta_n)+ \theta_z$

III Quadrant $\theta = (180-\theta_n)+ \theta_z$

IV Quadrant $\theta = (180-\theta_z)+\theta_n$

B-phase

I Quadrant $\theta = (180-\theta z)+\theta_n$

II Quadrant $\theta = (180-\theta_n)+ \theta_z$

III Quadrant $\theta = (180-\theta_n)- \theta_z$

IV Quadrant $\theta = (180-\theta_z)+\theta_n$

If fault occurs in R phase vector of the negative sequence component exists between 90°and 270° through clockwise direction with respect to R-phase.

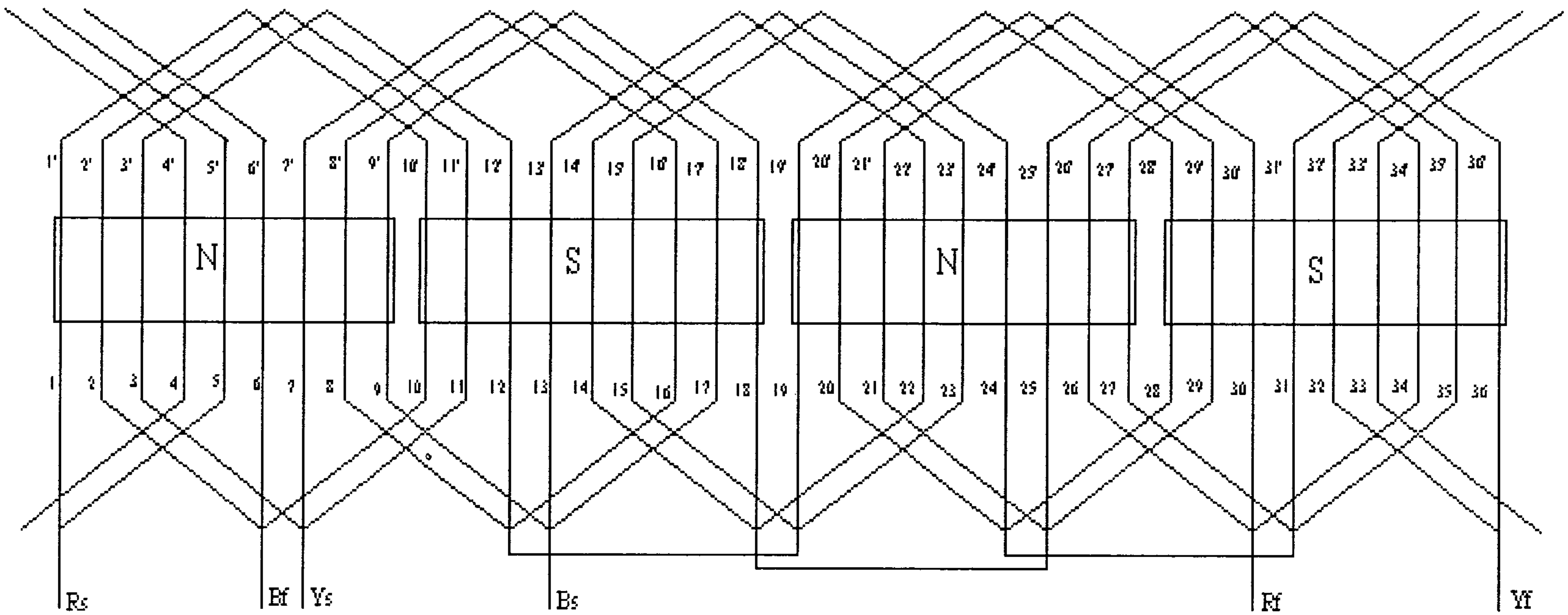


FIGURE 2.3 WINDING DIAGRAM

If fault occurs in Y phase the vector of negative sequence component exists between 90° and 270° through clockwise direction with respect to Y-phase.

Similarly, in case of B phase the vector of negative sequence component exists between 90° and 270° through clockwise with respect to B- phase.

For example, the fault is created by short-circuiting two coil sides (1-1'& 2-2') in R-phase in North Pole and the current in all the phases are observed.

I_R-1.225 A; I_Y-0.68 A; I_B-0.64 A

For these current values the corresponding positive, negative and zero sequences are calculated using the equation 2.10,2.11,2.12 .

$I_{R0} = I_{Y0} = I_{B0} = 0.188 \angle -3.4$;

$I_{R1} = 0.848 \angle 0$; $I_{R2} = 0.189 \angle 3.428$

$I_{Y1} = 0.848 \angle -120$; $I_{Y2} = 0.189 \angle 123.42$

$I_{B1} = 0.848 \angle 120$; $I_{B2} = 0.189 \angle -116.42$

It is seen that in the above the angle of negative sequence vector of R-phase is between 90° and 270° and the unbalance is in R-phase. Thus by using this methodology unbalanced phase can be found.

Similarly by using the same procedure the unbalance in the voltage can also be found. The faults such as single phasing, open circuit, low voltage, over voltage and over temperature is also considered in our project.

If any one of the phase voltage becomes zero it causes single voltage occurs at the motor terminal, which is the vector addition of other two phase voltage. This condition is termed as single phasing. In case of induction motor one of the phase voltage is not zero but it is a low value compared to other phases. By continuously monitoring the voltages in all the three phases and checking the above conditions, single phasing fault can be detected.

Open circuit occurs under normal voltage condition ,when the current in any one or two phase is zero. By continuously monitoring the current in all the three phases open circuit fault can be detected.

Low voltage and over voltage are detected by checking the voltage values are within the limits. In our project the low voltage limit is fixed as 200V and the over voltage limit is fixed as 255V.

Over temperature will cause damages to the insulation of the winding. So we have also incorporated temperature detector in our project. Temperature of the motor is continuously monitored and checked with in limit. For different class of insulation there exists corresponding temperature limits. They are shown in table 2.1. We have set the limits for class F type and the temperature limit is above 155°C.

TABLE 2.1 TEMPERATURE RANGE FOR INSULATION

CLASS	TEMPERATURE
Y	90°C
A	105°C
E	120°C
B	130°C
F	155°C
H	180°C
C	Above 180°C

TABLE 2.2 DISPLAY FORMAT

FORMAT	DESCRIPTION
TRIP 1	Single Phasing trip
TRIP 2	Open Circuit trip
TRIP 3	Voltage unbalance
TRIP 4	Low voltage
TRIP 5	Over voltage
TRIP 6	Winding fault
TRIP 7	Over temperature

These faults are detected by the microcontroller and displayed in the LCD. In order to reduce the usage of program memory the fault display logic is incorporated. It is shown in table 2.2.On the occurrence of the faults the corresponding format is displayed in the LCD. The flowchart for our methodology is shown in FIGURE 2.4.

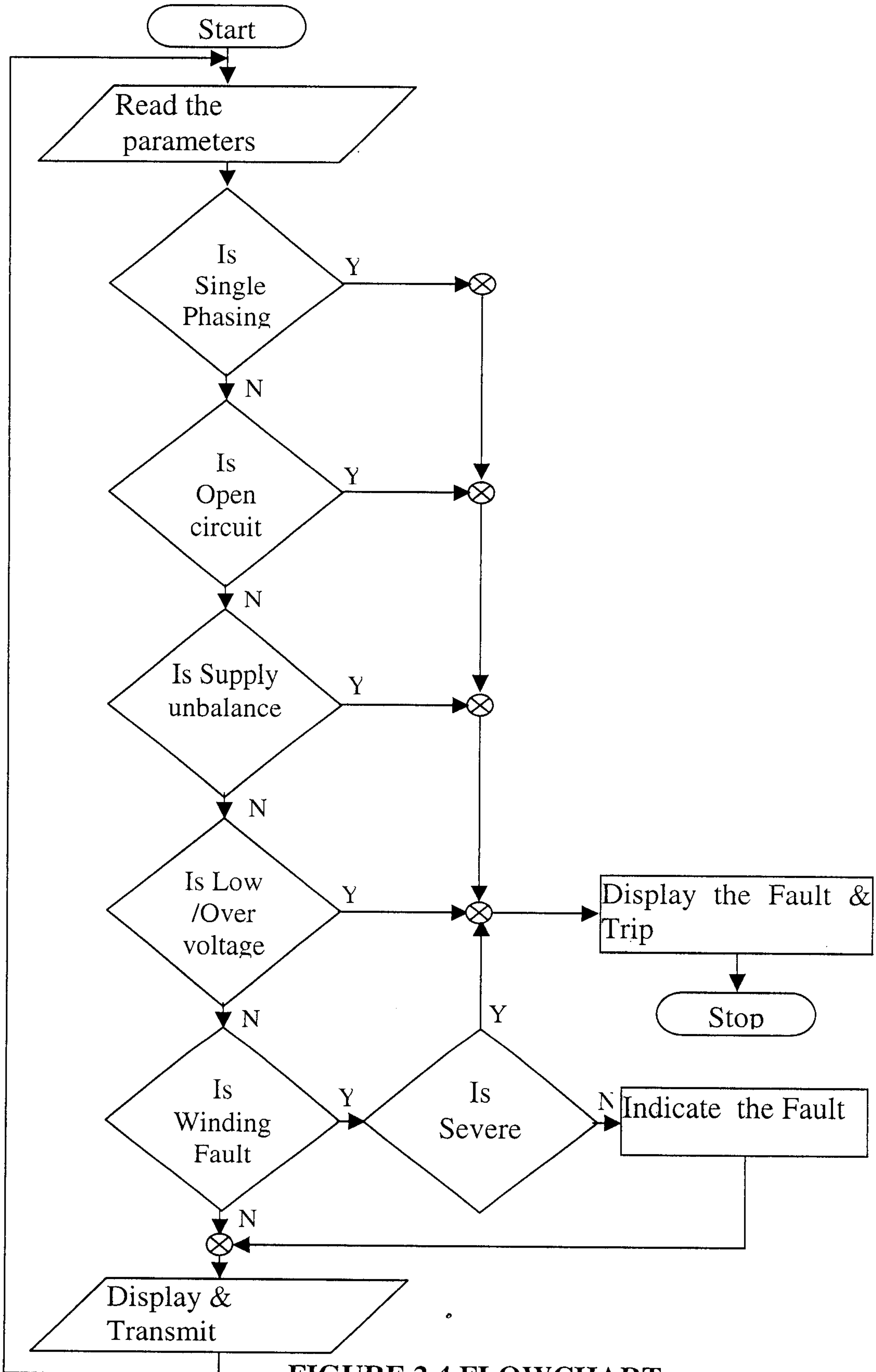


FIGURE 2.4 FLOWCHART

2.3 BLOCK DIAGRAM

The block diagram of our project is as shown in FIGURE 2.5

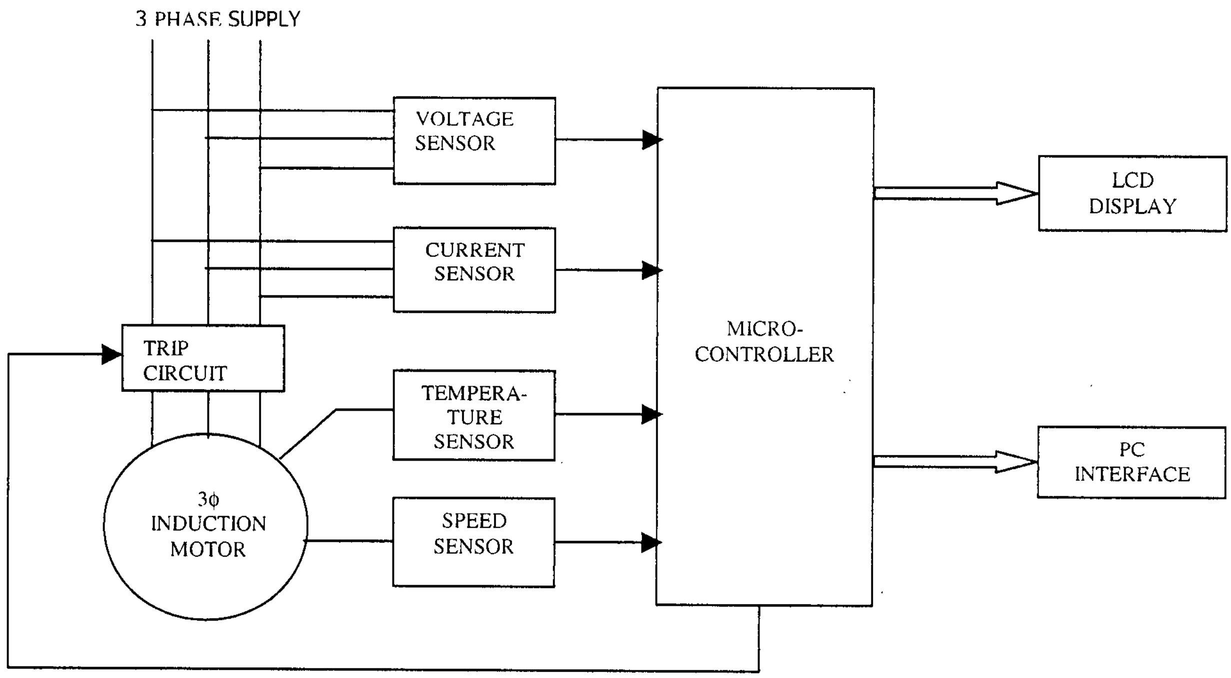


FIGURE 2.5 BLOCK DIAGRAM

The main criteria involved in this project is calculation of phase voltage, phase current, temperature, speed and displaying the values in the LCD display continuously, if faults occurs it also displays the type of fault and trips the motor.

Both the microcontroller and the LCD use +5 volt power supply. Also the op amp used here requires a dual power supply. This requires +12 volts and –12 volts. Suitable voltage regulators are used for this purpose. Thus the power supply unit is designed.

The electrical parameters such as voltage and current are sensed using potential transformer and current transformer respectively. The voltage, which is to be sensed, is first stepped down using PT. This stepped down voltage is then given to an inverting amplifier, which acts as precision rectifier. Thus the AC voltage is converted to an equivalent DC voltage. This is then fed to an inverting amplifier, which converts the negative output to positive output. Thus the output of inverting amplifier is an equivalent DC voltage of AC voltage.

The output of CT is converted into AC voltage by connecting a shunt resistor across the CT. The working of current circuit is similar to that of voltage circuit.

The mechanical parameter speed is sensed using proximity sensor. The time taken for one revolution is obtained from the proximity sensor and from that the RPM of the motor is calculated. Temperature of the motor is measured using thermistor. Thermistor circuit consists of a wheatstone bridge, which calculates small change in the resistance as the temperature varies. The output of the bridge is fed to differential amplifier to amplify the difference voltage between a fixed voltage and the bridge output. The output is again amplified using an inverting amplifier. Thus the temperature is sensed.

These parameters are then fed into the PIC microcontroller. The analog values are converted into digital values by the in-built A/D converter of 10-bit resolution.

The program is developed using C language. It is then compiled using Hitech C. Then the assembly code is converted to machine language using MPLAB.

The microcontroller monitors the parameters continuously. The parameters are displayed and if fault occurs the type of fault is also displayed in the LCD. The microcontroller is also interfaced using RS232 with the computer for data acquisition. The trip circuit is actuated during the occurrence of fault. The trip circuit consists of relay and contactor.

HARDWARE DESCRIPTION

3.HARDWARE DESCRIPTION

3.1 DESIGN OF POWER SUPPLY CIRCUITRY

Power supply unit

As we all know any invention of latest technology cannot be activated without the source of power. So in this fast moving world we deliberately need a proper power source, which will be apt for a particular requirement. All the electronic components starting from diode to Intel IC's only work with a DC supply ranging from ± 5 V to ± 12V.

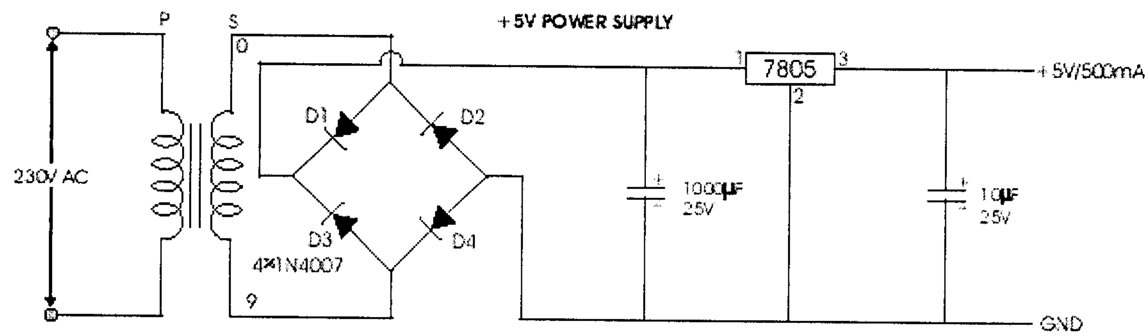


FIGURE 3.1 +5V POWER SUPPLY

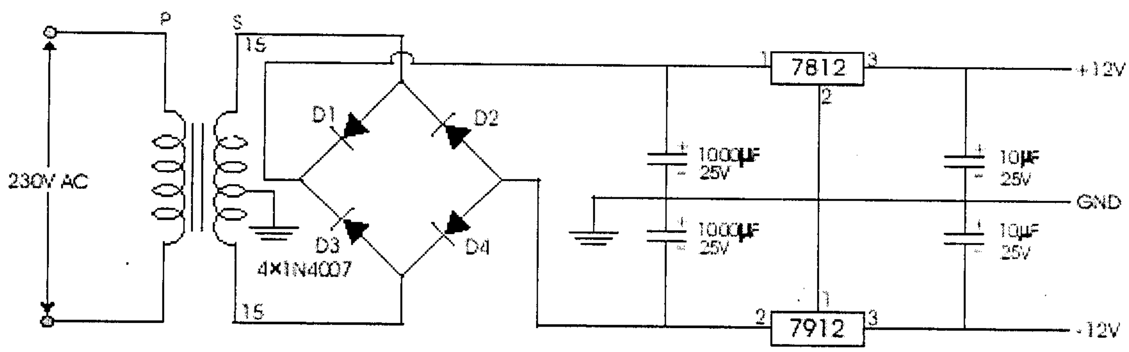


FIGURE 3.2 12V POWER SUPPLY

We are utilizing for the same, the cheapest and commonly available energy source of 230V-50 Hz and stepping down, rectifying, filtering and regulating the voltage. 12V power supply is shown in the FIGURE 3.1 and 5V power supply is shown as in the FIGURE 3.2.This will be dealt briefly in the forth-coming sections.

Step down transformer

When AC is applied to the primary winding of the power transformer it can be stepped down depending on the value of DC needed. In our circuit the transformers of 230V/15-0-15V and 230V/0-9V are used to perform the step down operation. The current rating of the transformer used in our project is 1.5A. Apart from stepping down AC voltages, it gives isolation between the power source and electronic circuitries.

Rectifier unit

In the power supply unit, rectification is normally achieved using a solid-state diode. Diode has the property that will let the electron flow easily in one direction at proper biasing condition. As AC is applied to the diode, electrons only flow when the anode is positive and cathode is negative. Reversing the polarity of voltage will not permit electron flow.

A commonly used circuit for supplying large amounts of DC power is the bridge rectifier. In bridge rectifier, four diodes (1N4007) are used to achieve full wave rectification. Two diodes will conduct during the positive cycle and the other two will conduct during the negative half cycle. The DC voltage appearing across the output terminals of the bridge rectifier will be somewhat less than 90% of the applied RMS value.

In this circuit due to positive half cycle D1 & D4 will conduct to give 10.8V pulsating DC. The DC output has a ripple frequency of 100Hz. Since each alteration produces a resulting output pulse, frequency = 2*50 Hz. The output obtained is not a pure DC and therefore filtration has to be done.

Filtering unit

Filter circuits usually consist of a capacitor, which smoothens the pulsating DC. This capacitor is also called as a decoupling capacitor or a bypassing capacitor, is used not only to 'short' the ripple with frequency of 120Hz to ground but also to leave the frequency of the DC to appear at the output.

1000μf/25V = for the reduction of ripples from the pulsating.

10μf/25V = for maintaining the stability of the voltage at the load side.

Voltage regulators

The voltage regulators play an important role in any power supply unit. The primary purpose of a regulator is to aid the rectifier and filter circuit in providing a constant DC voltage to the device. Power supplies without regulators have an inherent problem of changing DC voltage values due to variations in the load or due to fluctuations in the AC line voltage.

With a regulator connected to the DC output, the voltage can be maintained within a close tolerant region of the desired output. IC7805 is used in the project for providing +5V DC supply. IC7812 and 7912 is used in this project for providing +12V and –12V DC supply.

Specifications

Conducting drop across the diodes = 2*0.7 = 1.4V.

At the secondary side of the transformer,

Applied voltage = 15V

Without capacitor

Vavg = (15-1.4) V = 13.6V pulsating DC

Frequency =100Hz

With capacitor

V = Vavg*1.11 (form factor)

V = 15.06 V.

Frequency = 0Hz

With 7812 voltage regulator

V0 = +12V

With 7912 voltage regulator

V0 = -12V

At the secondary side of the transformer,

Applied voltage = 9V

Without capacitor

Vavg = (9-1.4) V = 7.6V pulsating DC

Frequency =100Hz

With capacitor

V = Vavg*1.11 (form factor)

V = 8.83 V.

Frequency = 0Hz

With 7805 voltage regulator:

V0 = +5V

3.2 VOLTAGE MEASUREMENT

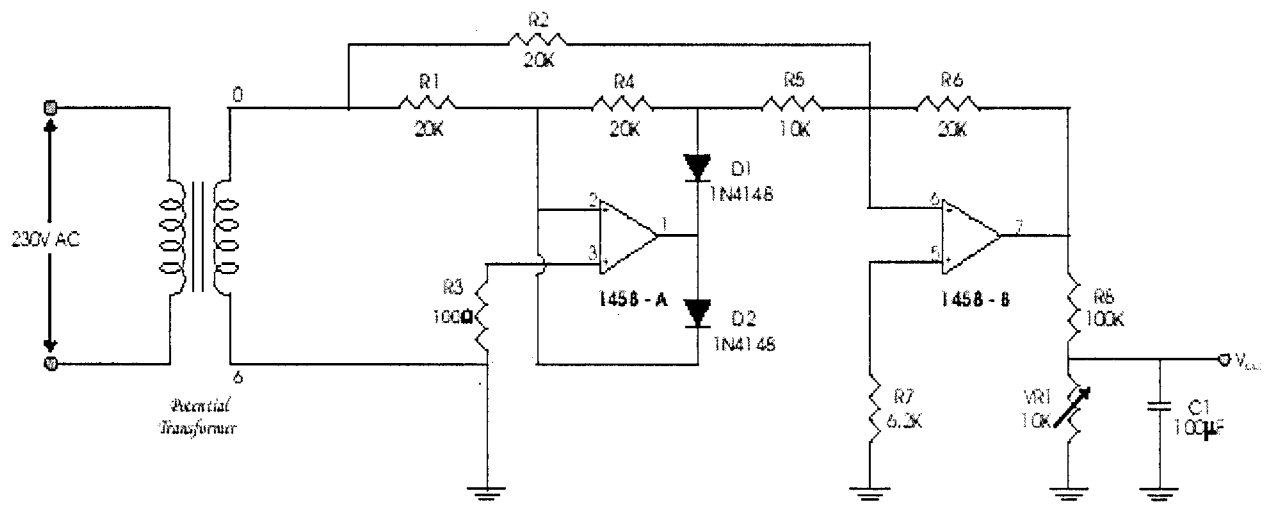


FIGURE 3.3 VOLTAGE MEASUREMENT CIRCUIT

The voltage measurement circuit of this project is shown as in the FIGURE 3.3.In case of voltage measurement, three PT's are connected across three phases supply, which is to be monitored. The PT is rated at 230V/6V.The AC output voltage of the PT is rectified, filtered and converted into pure DC by using precision rectifier.

In the precision rectifier circuit, A is an inverting rectifier. The output from A is added to the original input signal in B (summing mixer). Negative alterations of Ein results in no output at E1 due to the rectification. Ein feeds B through a 20K ohms resistor and E1 feeds B through a 10K ohms resistor.

The net effect of this scaling is that, for equal amplitudes of Ein and E1.E1 will produce twice as much current flow into the summing point. This fact is used as an advantage here, as the negative alteration of E1 produces twice the input current of precisely half the amplitude, which E1 alone would generate due to the subtraction of Ein. It is the equivalent of having E1 feed through a 20K ohms input resistor and having Ein non-existing during this half cycle and it results in a positive going output at B.

3.3 CURRENT MEASUREMENT

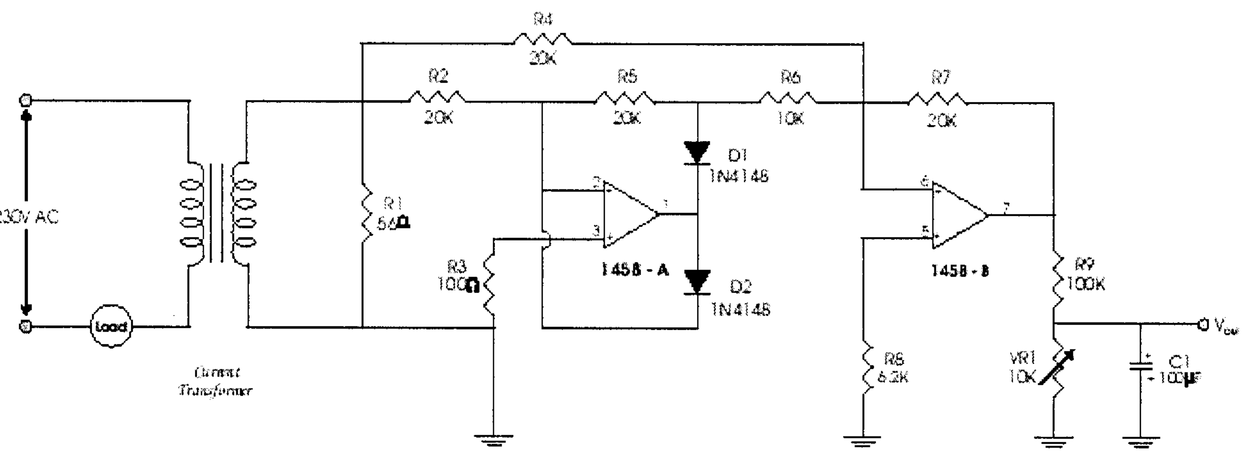


FIGURE 3.4 CURRENT MEASUREMENT CIRCUIT

The current measuring circuit of this project is shown as in the FIGURE 3.4.The CT's are connected in series with the motor under test. The CT is rated at 5A/150mA. The shunt resistor of value 56 ohm is connected across the CT. Hence we have ac voltage proportional to the current flowing through the primary of the CT given as the input to the rectifier unit and by a similar procedure as seen in the previous case, we get pure DC at the output stage.

3.4 TEMPERATURE MEASUREMENT

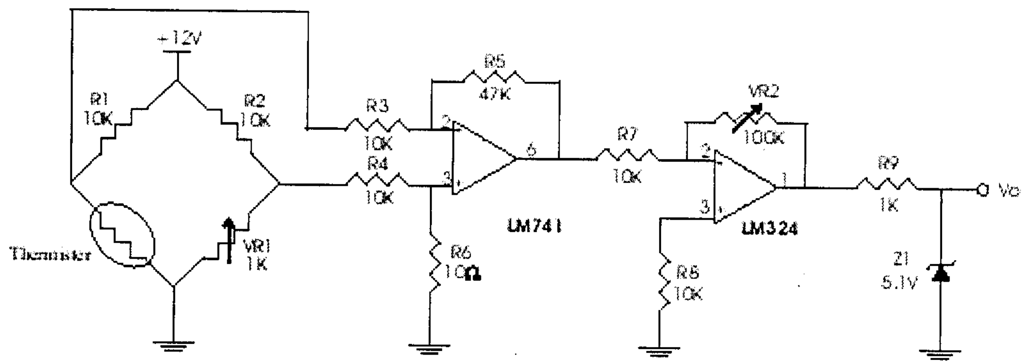


FIGURE 3.5 TEMPERATURE MEASUREMENT CIRCUIT

The temperature sensing circuit of this project is shown as in the FIGURE 3.5.In our project temperature is measured using thermistor. Thermistor is a semiconductor device that behaves as resistor with high negative temperature coefficient of resistance.

The thermistor circuit used consists of Wheatstone bridge, Differential amplifier and an Inverting amplifier. The bridge is used for measurement of small resistive changes that occur in passive resistive transducers like thermistor. It consists of four resistive arms with a source of EMF and a meter, which acts as a detector. The detector is usually a current sensitive galvanometer. Measurement may be carried out either by balancing the bridge or by determining the magnitude of unbalance.

The output of the Wheatstone bridge is given to the differential amplifier, which amplifies the difference between two signals. The input to the inverting terminal of the differential amplifier is a fixed voltage and the input to the non-inverting terminal is obtained from the thermistor. When the thermistor is heated, the voltage across the non-inverting terminal varies. The differential amplifier amplifies the difference between these signals. The output of the differential amplifier is given to the amplifier stage. This amplifier again amplifies the differential signal. This signal is proportional to the temperature, which is to be measured.

3.5 SPEED MEASUREMENT

The speed sensing circuit of our project is shown as in the FIGURE 3.6. We are using proximity sensor. This type is most commonly used. The main advantage of using this is simple in construction, less maintenance, easy to calibrate and inexpensive. A magnetic pickup sensor is placed near the strip, which is fixed on the rotor whose speed is to be measured.

When the rotor rotates, an EMF is induced in the pick-up coil due to change in reluctance of air gap between pick-up and strip. The output will be in pulses and the time difference between the pulses are calculated, from this speed can be calculated

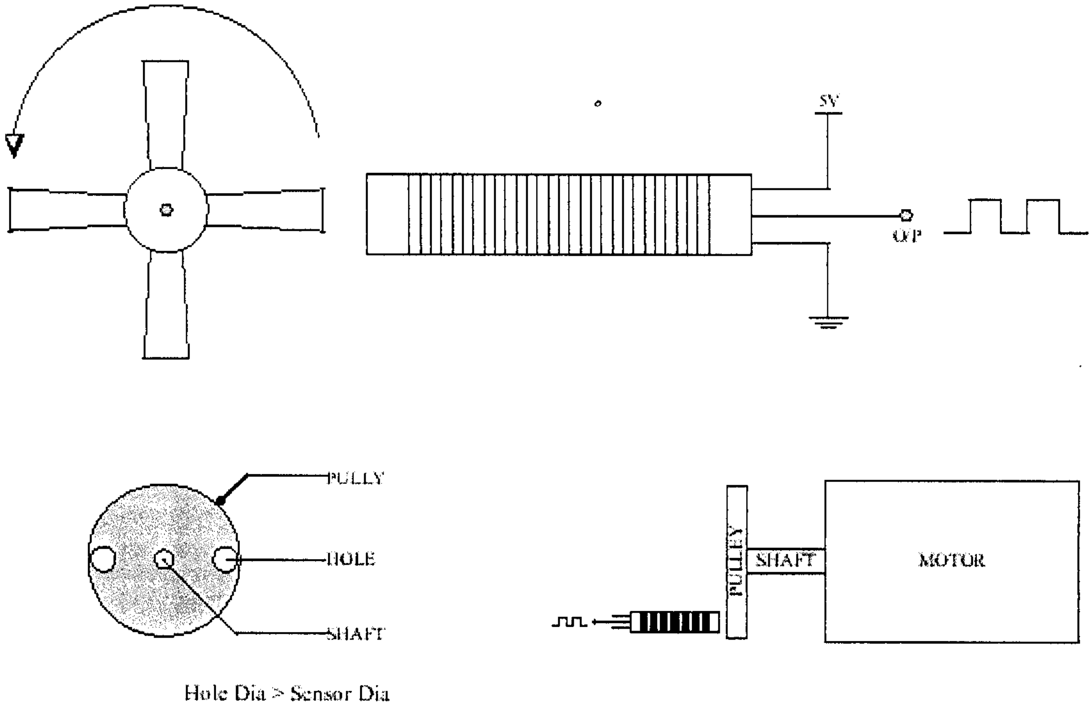


FIGURE 3.6 SPEED MEASUREMENT

3.6 PIC INTERFACE

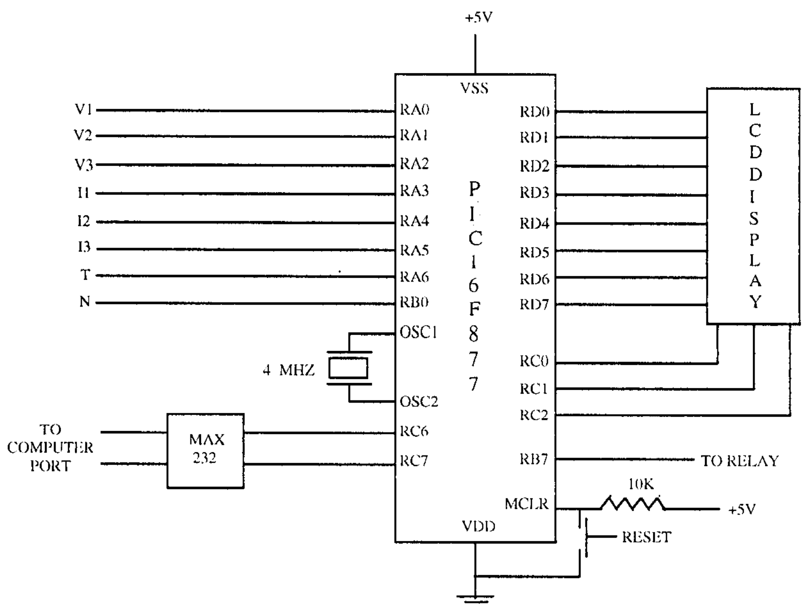


FIGURE 3.7 PIC INTERFACE DIAGRAM

The PIC interface diagram of the project is shown in FIGURE 3.7. The motor parameters are interfaced to the PIC via the port. The port assignment tabular column is shown in TABLE 3.1.

TABLE 3.1 PORT ASSIGNMENT

PIN	ASSIGNMENT
RA0	R phase voltage (V_1)
RA1	R phase current (I_1)
RA2	Y phase voltage (V_2)
RA3	Y phase current (I_2)
RA4	B phase voltage (V_3)
RA5	B phase current (I_3)
RA6	Temperature (T)
RB0	Speed(N)
RB7	Relay control
RC0-RC2	LCD control bit
RC6,RC7	PC Interface
RD0-RD7	LCD Data bit

The sensed signals are digitalized using the in-built A/D converter in the PIC microcontroller. The digital value is used by the PIC for the fault detection. Then the digital value is converted into equivalent numeric value, and it is displayed in the LCD. These data's are also interfaced to PC. The PIC also controls the relay circuit.

3.7 LCD DISPLAY

In this project the sensed values of voltage, current, temperature and speed are shown on LCD. If fault occurs in the motor the type of fault is also displayed on the LCD.

A LCD consists of two glass panels, with the liquid crystal material sandwitched between them. The inner surfaces 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 oriented angle.

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 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.

3.8 RS232 INTERFACE

The most common communication interface for short distance is RS-232. RS-232 defines a serial communication for one device to one computer communication port, with speeds up to 19,200 baud. Typically 7 or 8 bits (on/off) signal is transmitted to represent a character or digit. The 9-pin connector is used.

Max-232

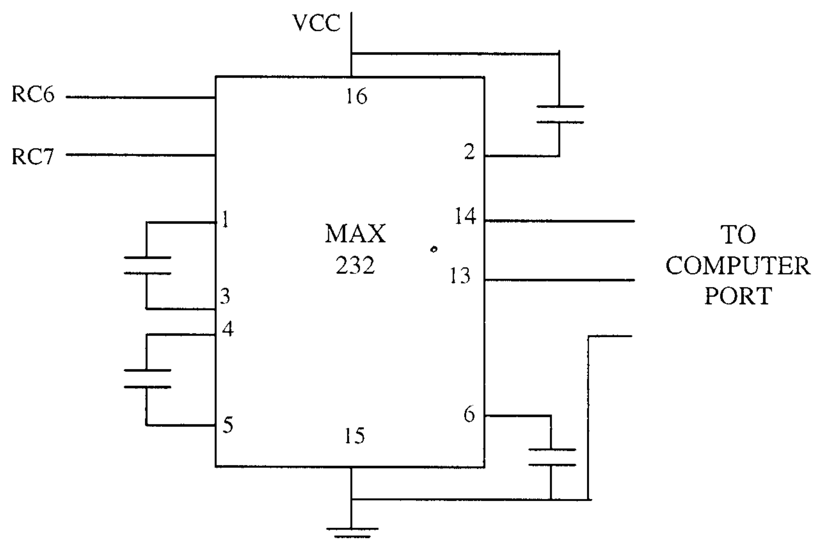


FIGURE 3.8SYSTEM INTERFACE IC

The IC diagram of MAX 232 is shown in the FIGURE 3.8. Each of the two transmitters is a CMOS inverter powered by +10V internally generated supply. The input is TTL and CMOS compatible with a logic threshold of about 26% of Vcc. If an unused transmitter section can be left unconnected as the internal 400KΩ pull up resistor connected between the transistor input and Vcc will pull the input high forming the unused transistor output low.

The open circuit output voltage swing is guaranteed to meet the RS232 specification +5V outputswing under the worst of both transmitter driving the 3KΩ minimum load impedance, the Vcc input at 4.5V and maximum allowable ambient temperature typical voltage with 5KΩ and Vcc= +0.9V.

The slew rate at output is limited to less than 30V / μs and the powered done Vcc = 0V. The outputs are short circuit protected and can be short circuited to ground indefinitely.

Receiver section

The two receivers fully conform to RS232 specifications. Their input impedance is between 3KΩ either with or without 5V power applied and their switching threshold is within the +3V of RS232 specification. To ensure compatibility with either RS232 IIP or TTI/CMOS input. The MAX232 receivers have VIL of 0.8V and VIH of 2.4V the receivers have 0.5V of hysterisis to improve noise rejection. The TTL/CMOS compatible output of receiver will be low whenever the RS232 input is greater than 2.4V. The receiver output will be high when input is floating or driven between +0.8V and –30V.

Electrical specification of MAX232

Vcc = 6V

V+ = 12V

V- = 12V

Input voltage

T1in, T2in = -0.3 to (Vcc+ 0.3V)

R1in, R2in = +30V or –30V

Output voltage

T1out,T2out = ((V+)+0.3V) to ((V-)+0.3V)

R1out, R2out = -0.3V to (Vcc+0.3V)

Power dissipation = 375 mW

Output resistance = 300Ω

3.9 CONTROL CIRCUIT

The control circuit mainly includes two components. They are,

a) Relay circuit.

b) Contactor circuit.

ELECTROMECHANICAL RELAY

Relays are electromagnetic switches, which provide contact between two mechanical elements. Relays have a coil, which works on 12V dc power supply and provides DPST action as an output. In general, relays provide potential free contacts which can be used for universal functions like DC, AC voltage switching and to control bigger electrical switchgears. The relay circuit used in this project is shown in FIGURE 3.9.

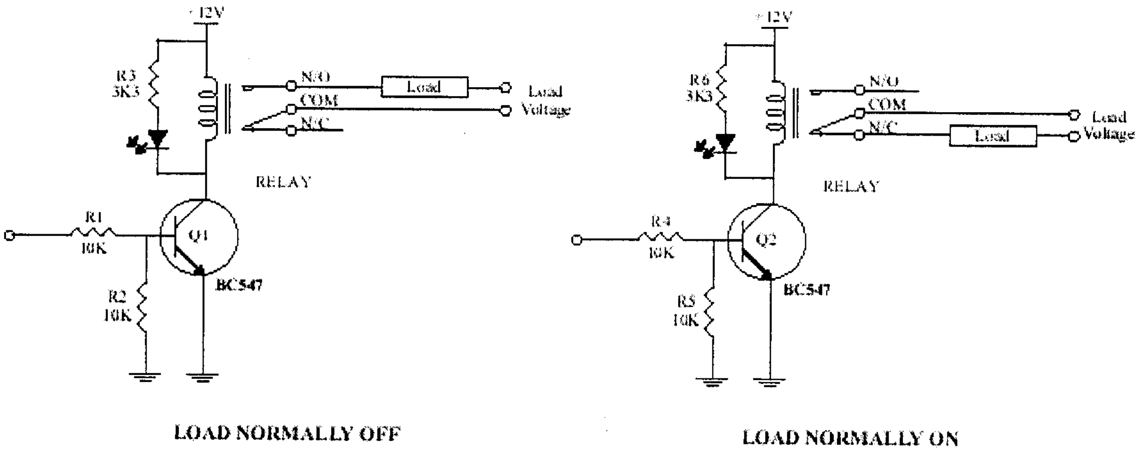


FIGURE 3.9 RELAY CIRCUIT

CONTACTOR CIRCUIT

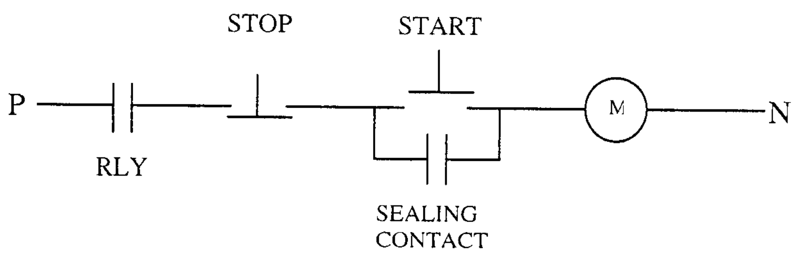


FIGURE 3.10 CONTACTOR CIRCUIT

The contactor circuit used in this project is shown in FIGURE 3.10. When the supply is switched ON, at normal condition microcontroller sends high signal to the relay circuit. Thereby relay's NO contact closes. When start push button shown in the circuit is pressed, main contactor coil (M) is energized; hence main and sealing contacts are closed. As the three-phase supply is fed to the motor, motor starts running. If any fault occurs, the signal from the microcontroller turns low leading to opening of contacts in the relay circuit and the motor stops running.

MICROCONTROLLER

4. MICROCONTROLLER

Microcontroller is a semiconductor device, which has many, built in features to support any application. Microcontroller differs from microprocessor in many features. Microprocessor has many operational codes for moving data from external memory to the CPU. But microcontroller has fewer codes. Microprocessors have one or two bit handling instructions. But microcontroller has many. Microcontroller has got many built in features. Microcontroller works faster than microprocessor because of rapid movement of bit within the chip. Microcontroller can function has a computer with the addition of no external parts. This project uses PIC microcontroller .PIC stands for Peripheral Interface Controller. There are many features and packages. The different series are 16,17,18,19,etc. This project uses PIC 16F877 microcontroller.

4.1 SPECIAL FEATURES

- Improved architecture-Harvard architecture
- Built-in three timers
- In built A/D converters
- Separate program and data memory
- High frequency operation
- Flexible programming
- Instruction pipelining
- 5 I/O programmable ports
- Easy interfacing facilities

Architecture

PIC microcontroller based devices have following architectural features to attain the high performance.

- Harvard architecture
- Long word instructions
- Single word instructions
- Single cycle instructions
- Instruction pipelining
- Reduced instruction set
- Register file architecture
- Orthogonal (symmetric) instructions

Harvard Architecture

Harvard architecture has the program memory and data memory has separate memories and they are accessed from separate buses. This improves bandwidth over traditional Van Neumann architecture in which program and data are fetched from the same memory using the same bus. These separated buses allow one instruction to execute while the next instruction is fetched.

Instruction Pipeline

The instruction pipeline is a 2-stage pipeline, which overlaps the fetch and execution of instructions.

Reduced instruction set

When an instruction set is well designed and highly orthogonal (symmetric), fewer instructions are required to perform all needed tasks. With fewer instructions, the whole set can be more rapidly learned.

Central Processing Unit

The CPU is responsible for using the information in the program memory to control the operation of the device. Many of these instructions operate on data memory. It is responsible for fetching the correct instruction for execution, decoding that instruction and then executing the instruction. The CPU sometimes works in conjunction with the ALU to complete the execution of arithmetic and logical operations. The CPU controls the program memory address bus, the data memory address bus, and accesses to the stack.

Arithmetic and Logic Unit

PIC microcontroller contain an 8-bit ALU and an 8-bit working register. The ALU is a general-purpose arithmetic and logic unit. It performs arithmetic and Boolean functions between the data in the working register and any register file. The ALU is 8-bit wide and is capable of addition, subtraction, shift and logical operations. Depending on the instruction executed, the ALU may affect the values of the carry, digit carry and zero bits in the status register.

The status register contains the arithmetic status of the ALU, the RESET status and the bank selects bits for data memory.

4.2 MEMORY ORGANIZATION

Memory organization has two blocks

1. Program memory
2. Data memory

Each block has its own bus, so that access to each block can occur during the same oscillator cycle. The data memory can further be broken down into General purpose RAM and the Special Function Register (SFRs).

Program memory organization

Mid-range MCU devices have a 13-bit program counter capable of addressing an 8K x 14 program memory space. The width of the program memory bus is 14 bits. Since all instructions are a single word, a device with an 8K x 14 program memory has a space for 8K of instructions. This makes it much easer to determine if a device as sufficient program memory for a desired application.

Program counter

The program counter (PC) specifies the address of the instruction to fetch for execution. The PC is 13 bits wide. The low byte is called the PCL register. This register is readable and writable. The high byte is called the PCH register. This register contains the PC<12:8> bits and is not directly readable or writable

Reset Vector

On any device, a reset forces the Program Counter to address 0h.

Interrupt Vector

When an interrupt is acknowledged the PC is forced to address 0004h.

Stack

Stack contains the return address from this branch in program execution.

Program memory paging

Some devices have program memory sizes greater than 2K words, but the CALL and GOTO instructions only have an 11-bit address range.

Data memory organization

Data memory is made up of the Special Function Register (SFRs) area, and the General purpose Register (GPR) area. The SFRs control the operation of the device, while GPRs are general areas for data storage and scratch pad operation. The GPR area is banked to allow greater than 96 bytes of general RAM to be addressed.

General Purpose Registers

GPRs are not initialized by a power on reset and are unchanged on all other resets. The register file can be accessed either directly, or using the File Select Register FSR, indirectly.

Special Function Registers

The CPU and peripheral Modules use the SFRs for controlling the desired operation of the device. These register are implemented as static RAM. The SFRs can be classified into two sets, those associated with the 'core' function and those related to the peripheral functions.

Banking

The data memory is partitioned into 4 banks. Each bank contains general-purpose registers and the special function registers. Switching between these banks requires the RP0 and RP1 bits in the STATUS register to be configured for the desired bank when using direct addressing. The IRP bit in the STATUS register is used for indirect addressing.

TABLE 4.1 BANK SELECTION

ACCESSED BANK	DIRECT (RP1:RP0)	INDIRECT (IRP)
0	00	0
1	01	0
2	10	1
3	11	1

4.3 A/D CONVERTERS

The analog-to-digital converter has up to eight analog inputs. The A/D allows conversion of an analog input signal to a corresponding 8-bit digital number. The output of the sample and hold is the input into the converter, which generates the result via successive approximation. The analog reference voltage is software selectable to either the device's positive supply voltage (V_{dd}) or the voltage level on the V_{ref} pin. The A/D converter has an unique feature of being able to operate while the device is in SLEEP mode.

The A/D module has three registers. These registers are

A/D result register (ADRES)

A/D control register0 (ADCON0)

A/D control register1 (ADCON1)

The ADCON0 register controls the operation of the A/D module. The ADCON1 register configures the functions of the port pins. The I/O pins can be configured as analog inputs (one I/O can also be a voltage reference) or as digital I/O.

When the A/D conversion is complete, the result is loaded into the ADRES register, the GO/DONE bit is cleared, and the A/D interrupt flag bit, ADIF is set. After the A/D module has been configured as desired, the selected channel must be acquired before the conversion is started. The analog input channel must have their corresponding TRIS bits selected as an input. After this acquisition time has elapsed the A/D conversion can be started.

The following steps should be followed for doing an A/D conversion,

1. Configure the A/D module
    - Configure the analog pins/voltage reference /and digital I/O (ADCON1)
    - Select A/D input channel (ADCON0)
    - Select A/D conversion clock (ADCON0)
    - Turn on A/D module (ADCON0)
2. Configure A/D interrupt (if desired)
    - Clear the ADIF bit.
    - Set the ADIE bit.
    - Set the GIE bit.
3. Wait the required acquisition time
4. Start conversion
    - Set the GO/DONE bit (ADCON0)
5. Wait for A/D conversion to complete, by either

- Polling for the GO/DONE bit to be cleared
- Waiting for the A/D interrupt

6. Read A/D result register (ADRES), clear the ADIF bit, if required
7. For next conversion, goto step 1 or step2 as required. The A/D conversion time per bit is defined as Tad. A minimum wait of 2 Tad is required before the next acquisition starts.

4.4 TIMERS

Timer 1

Timer1 module is a 16bit timer and counter consisting of 2 8-bit registers which are readable and writable. It increments from 0000H to FFFFH and rolls over to 0000H.

It can be operated in one of the following three modes

- As a Synchronous timer
- As a synchronous counter
- As a asynchronous counter

The operating mode is selected by clock selection bit TMR1CS and the synchronization bit (T1SYNC). In timer mode, it increments for every instruction cycle and in counter mode it increments on every rising edge of the external clock input. It can be turned on and off using the TMR1ON control bit.

Timer Mode

Selected by clearing TMR1CS bit, the input clock to timer is Fosc/4. The synchronize control bit has no effect since internal clock is always synchronized.

Synchronous Counter Mode

Counter mode is selected by setting TMR1CS bit. The timer increments on every rising edge of clock input on the T1OS1 pin when oscillator enable bit is set, or when T1OSCEN bit is cleared. If T1SYNC bit is cleared, then the external clock input is synchronized with internal phase clocks.

Asynchronous Counter Mode

This type of mode is achieved setting the T1SYNC to high which asynchronizes the external clock input. The timer continues to run during SLEEP mode, which can be used to implement real type clock.

Timer2

Timer2 is an 8-bit timer with prescaler, a postscaler and period register. The overflow time is the same as a 16-bit timer. The TMR2 register is readable and writable and is cleared on all device resets. It increments from 00H on reset increment cycle. The match output of TMR2 goes to 2 sources.

- Timer2 postscaler

- SSP clock input

When postscaler overflows, TMR2 is also routed to synchronous serial port (SSP) module.

Timer0

It has the following features

- 8-bit timer/counter
- Readable and writable
- Clock source selectable to be internal or external
- Interrupt on overflow from FFH to 00H
- Edge select for external clock

Timer mode is selected by clearing TOCS bit. Counter bit is selected by setting the TOCS bit. In counter mode, TIMER0 will increment either on every rising or falling edge. The TMR0 interrupt is generated when the TMR0 register overflows from FFH to 00H. The response of the timer to the clock pulse can be made as positive edge triggered or negative edge triggered

SOFTWARE DESCRIPTION

5. SOFTWARE DESCRIPTION

5.1 ALGORITHM FOR PIC PROGRAMMING

The PIC 16F877 microcontroller used in the project is programmed using HiTech C. The program is converted into machine language using MPLAB software. The algorithm and flowchart for this project are as follows:

Step 1 : Start the program.

Step 2 : Assign the ports in the microcontroller as input/output depending upon the requirement.

Step 3 : Initialize the ADCON registers.

Step 4 : Enable the global interrupt and peripheral interrupt.

Step 5 : The voltage measured in each of the 3 phase is multiplied by suitable value to obtain the original value.

Step 7 : Similar procedure is repeated for current and temperature.

Step 8 : Pulses are counted and the speed is calculated.

Step 9 : The values of voltage, current, temperature and speed is given to the LCD display.

Step 10: The measured values are checked for faults, if any.

Step 11: Details about the fault are also passed to the LCD display.

Step 12: The values of voltage, current, temperature, speed and the details regarding the fault is given to the PC.

Step 13: If the severity of the fault is more, the fault has to be cleared to reset the program.

Step 14: Else step 6 to step 12 is repeated continuously.

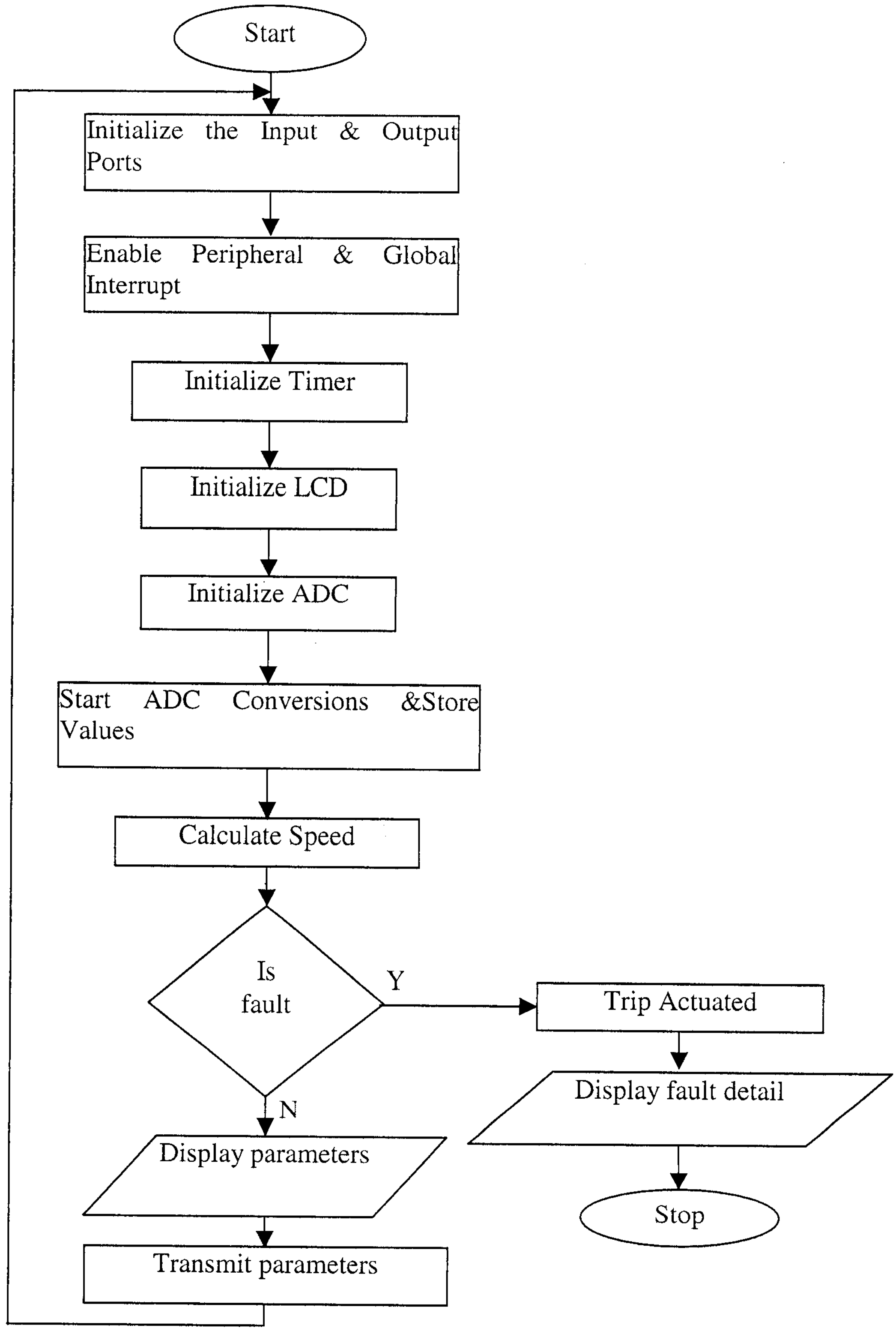


FIGURE 5.1 FLOWCHART FOR PIC PROGRAMMING

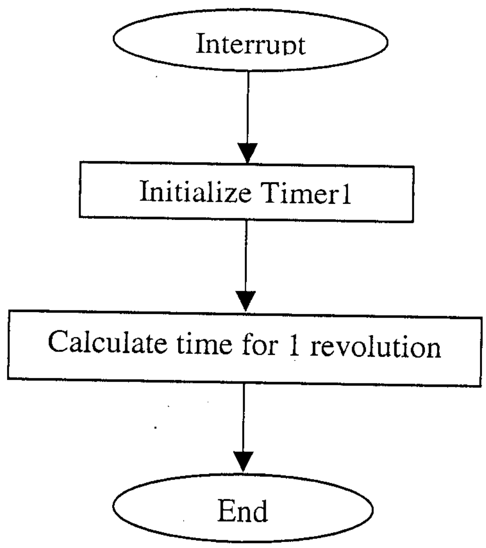


FIGURE 5.2 FLOWCHART FOR INTERRUPT SUBROUTINE

5.2 ALGORITHM FOR VB CODING

The VB coding is written in order to display the voltage, current, temperature, speed and status of the motor. The data from the Max 232 IC are continuously send to the PC at a presettable baud rate. These data's are set with a start bit. Now these data's are received in the COM PORT1 of the CPU. These data's should be first read and displayed on the system. The algorithm and flow chart (FIGURE 5.3) for VB coding is shown. The VB form for displaying the motor parameters is shown in FIGURE 5.4.

Step 1: Start the program.

Step 2: Initialize the variables to collect the data.

Step 3: Determine the characters after the start bit.

Step 4: Place the voltage, current, temperature, speed and status of the motor on appropriate text box continuously.

Step 5: Status of the motor is stored in the system if fault occurs.

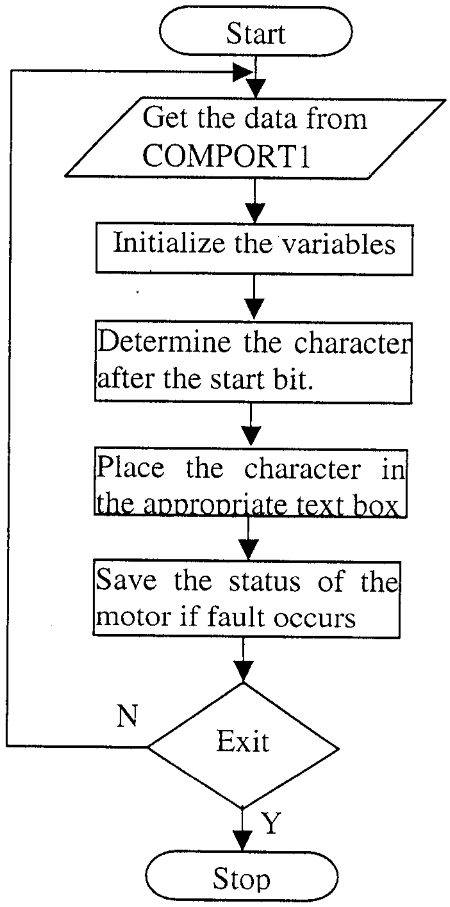


FIGURE 5.3 FLOWCHART FOR VB CODING

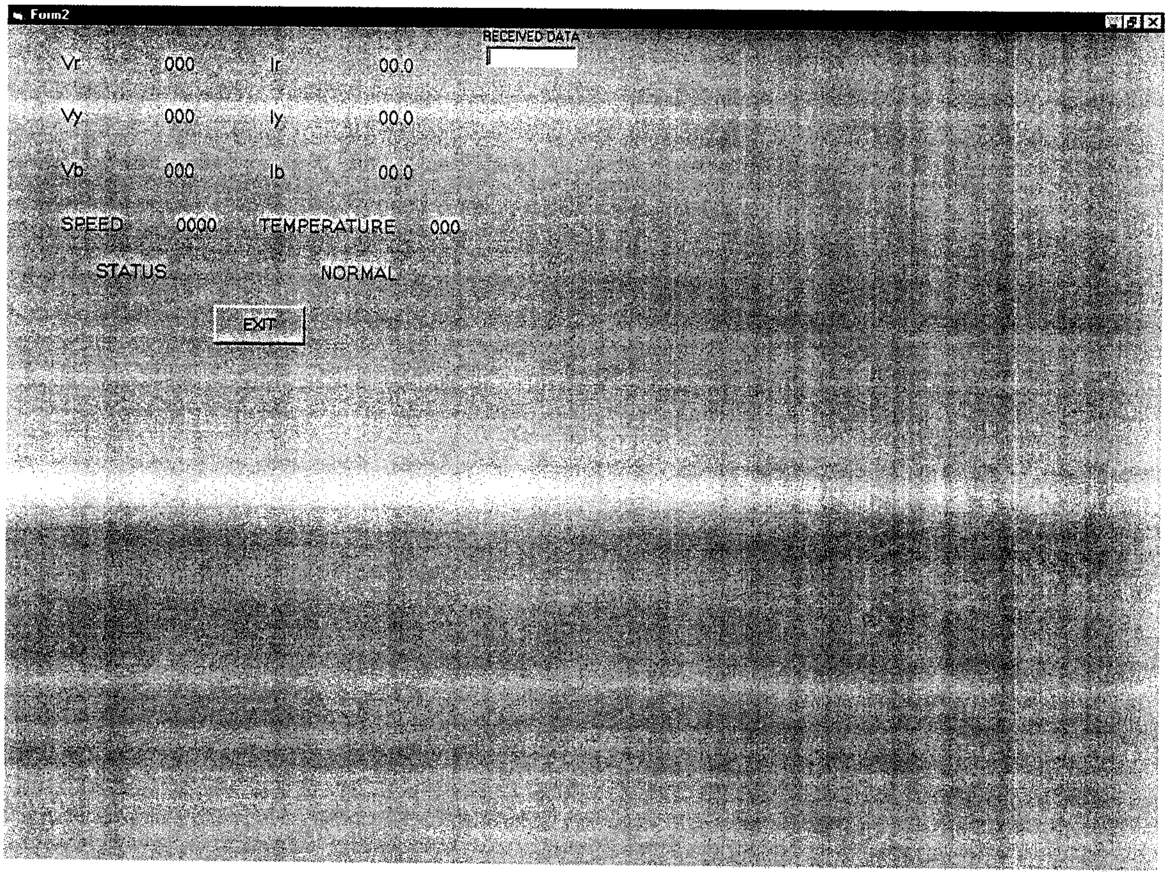


FIGURE 5.4 VISUAL BASIC FORM

RESULTS & DISCUSSION

6.RESULTS AND DISCUSSION

We conducted the experiment on the three phase induction motor. The winding connection of the motor is as shown in FIGURE 2.3. The readings are obtained under normal condition and also by externally creating faults in the motor. The table 6.1 shows the readings obtained manually by connecting the analog meters and by connecting the project.

TABLE 6.1 EXPERIMENTAL RESULTS

CONDITION	MANUAL READING				PROJECT READING			
	I_R	I_Y	I_B	FR	I_R	I_Y	I_B	FR
	Ampere	ampere	ampere	%	ampere	ampere	ampere	%
Normal	0.8	0.51	0.59	13.5	0.8	0.5	0.6	13
1coil shorted	0.94	0.55	0.64	16.5	0.9	0.6	0.6	17
2coils shorted	1.225	0.68	0.64	22.3	1.2	0.7	0.6	22

From the tabular column it is clear that readings obtained by connecting the project is similar to the manual reading. The proposed system detected the fault and displayed the phase along with FR, if FR is greater than 15. This system actuated the trip circuit if FR is greater than 20.

CONCLUSION & FUTURE SCOPE

7.CONCLUSION AND FUTURE SCOPE

The microcontroller based online fault detection scheme has been implemented for three phase induction motor based on monitoring the negative sequence current. This project also monitors the values of line voltage, speed and temperature continuously. This project is tested for different fault conditions. The experimental results for the winding fault are presented. The proposed system also capable of detecting the other faults such as single phasing, open circuit, voltage unbalance, low/over voltage, over temperature. Since the faults are detected at their earlier stages, the maintenance can be in an organized manner.

The further work that can be implemented to our project includes,

- The fault detection scheme can be carried out based on monitoring the negative sequence impedance.
- This system is incorporated with 4MHz crystal with operating speed of 1μs per instruction cycle. If any increase in the operating speed is required, 20MHz crystal can be made use of with operating speed of 200ns per instruction cycle.
- This scheme can also be extended to other types of electrical motors.

APPENDICES

```
// PIC PROGRAM
#include<stdio.h>
#include<conio.h>
#include<math.h>
#include<pic1687x.h>
#include "lcd.h"

#define rly RB7

void sqr(long m,long n);
void mul(int j,int k,int m,int n);
void seq(int j,int k,int l,int m,int n,int p);
void phsft(unsigned int j,unsigned int k,unsigned int l);
display_trip(unsigned char);
delay();


bank1 unsigned int i1,i2,i3,v1,v2,v3,d1,d2,n,pulse_sec;
bank1 unsigned char sec=0,count,flag=0;
bank2 unsigned char tx_array[40];
int u1,u2,a1,a2,a3,a4,a5,a6,b1,b2,b3,b4,b5,b6;
bit e,f,scr,disp_f,ad_flag=0,st_f=0,pulse_f;
unsigned char k,trip,d,t;
unsigned long h;

void main()
 {
  ADCON1=0X80;
  TRISC=0XF0;
  TRISD=0;
  TRISB=0x01;
  T1CON=0X30;
  rly=1;
  OPTION=0X07;
  GIE=1;
  INTE=1;
  PEIE=1;
  TMR1H=TMR1L=0;
  T0IE=1;
  lcd_init();
```

```
clear_lcd();
TXSTA=0X24;
SPBRG=25;
SPEN=1;
display_string("FAULT MONITORING");
while(1)
 {
  if(ad_flag)
   {
    ad_flag=0;
    ADCON0=0x81;
    delay();
    ADGO=1;
    while(ADGO);
    v1=(ADRESH*256)+ADRESL;

    ADCON0=0x89;
    delay();
    ADGO=1;
    while(ADGO);
    v2=(ADRESH*256)+ADRESL;

    ADCON0=0x91;
    delay();
    ADGO=1;
    while(ADGO);
    v3=(ADRESH*256)+ADRESL;

    ADCON0=0x99;
    delay();
    ADGO=1;
    while(ADGO);
    i1=(ADRESH*256)+ADRESL;

    ADCON0=0xa1;
    delay();
    ADGO=1;
    while(ADGO);
    i2=(ADRESH*256)+ADRESL;
```

```
    ADCON0=0xa9;
    delay();
    ADGO=1;
    while(ADGO);
    i3=(ADRESH*256)+ADRESL;

    ADCON0=0xb1;
    delay();
    ADGO=1;
    while(ADGO);
    t=((ADRESH*256)+ADRESL)/4.01;

    check();
    transmit_values();
   }

  if(scr==0 && disp_f)
   {
    disp_f=0;
    display_scr1();
   }
  else if(scr && disp_f)
   {
    disp_f=0;
    display_scr2();
   }
  }
 }


check()
 {
 //SINGLE PHASING DETECTION
  k=0;
  if(v1<600)
   k++;
  if(v2<600)
   k++;
  if(v3<600)
   k++;
```

```
if(k>=2)
 {
  trip = 4;
  rly=0;
  clear_lcd();
  display_voltage();
  display_trip(trip);
  GIE=0;
  transmit_values();
  while(1);
 }
else if(k>0)
 {
  trip = 1;
  rly=0;
  clear_lcd();
  display_voltage();
  display_trip(trip);
  GIE=0;
  transmit_values();
  while(1);
 }

//OPEN CIRCUIT DETECTION
k=0;
if(i1<=7)
 k++;
if(i2<=7)
 k++;
if(i3<=7)
 k++;
if(k==3)
 goto skip;
else if((k<=2) && (k>=1))
 {
  trip = 2;
  rly=0;
  clear_lcd();
  display_current();
  display_trip(trip);
```

```
  GIE=0;
  transmit_values();
  while(1);
  }

//SUPPLY VOLTAGE UNBALANCE DETECTION
 skip:;
 phsft(v1,v2,v3);
 seq(a1,a2,a3,a4,a5,a6);
 sqr(u1,u2);
 d1=sqrt(h);
 seq(a1,a2,a5,a6,a3,a4);
 sqr(u1,u2);
 d2=sqrt(h);
 d=((d2*100)/d1);
 if(d>4)
  {
   trip=3;
   rly=0;
   clear_lcd();
   display_voltage();
   display_trip(trip);
   GIE=0;
   transmit_values();
   while(1);
  }

//LOW VOLTAGE DETECTION
 if((v1<800)&&(v2<800)&&(v3<800))
  {
  trip=4;
  rly=0;
  clear_lcd();
  display_voltage();
  display_trip(trip);
  GIE=0;
  transmit_values();
  while(1);
  }
```

```
//OVER VOLTAGE DETECTION
 if((v1>=1022)&&(v2>=1022)&&(v3>=1022))
  {
   trip=5;
   rly=0;
   clear_lcd();
   display_voltage();
   display_trip(trip);
   GIE=0;
   transmit_values();
   while(1);
  }

//CURRENT UNBALANCE DETECTION
 if(k==3)
  goto bypass;
 e=0;
 f=0;
 k=0;
 phsft(i1,i2,i3);
 seq(a1,a2,a3,a4,a5,a6);
 sqr(u1,u2);
 d1=sqrt(h);
 seq(a1,a2,a5,a6,a3,a4);
 sqr(u1,u2);
 d2=sqrt(h);
 d=((d2*100)/d1);
 if(d>15)
  {
   display_trip6();
   seq(a1,a2,a5,a6,a3,a4);
   b1=u1;
   b2=u2;
   seq(a3,a4,a1,a2,a5,a6);
   b3=u1/2;
   b4=u2/2;
   seq(a5,a6,a3,a4,a1,a2);
   b5=u1/2;
   b6=u2/2;
   u1=(b4*100)/b3;
```

```
u2=(b6*100)/b5;
if((b1>=0&&b2>=0)||(b1>=0&&b2<=0))
 e=1;
if(b3<=0&&b4>=0)
 if(u1>-57)
  f=1;
if(b3>=0&&b4<=0)
 if(u1<-57)
  f=1;
if(b3<=0&&b4<=0)
 f=1;
if(b5>=0&&b6>=0)
 if(u2>57)
  k=1;
if(b5<=0&&b6<=0)
 if(u2<57)
  k=1;
if(b5<=0&&b6>=0)
 k=1;
if(e==1&&f==1)
 {
  if(i1>i2)
    display_string("R Y");
  else
    display_string("Y R");
 }
else if(f==1&&k==1)
 {
  if(i2>i3)
    display_string("Y B");
  else
    display_string("B Y");
 }
else if(e==1&&k==1)
 {
  if(i1>i3)
    display_string("R B");
  else
    display_string("B R");
 }
```

```
    else if(e==1)
     display('R');
    else if(f==1)
     display('Y');
    else if(k==1)
     display('B');
    if(d>20)
     {
      trip=6;
      rly=0;
      display_trip(trip);
      GIE=0;
      transmit_values();
      while(1);
     }
   }
bypass:;
  if(t>185)
   {
    trip=7;
    rly=0;
    clear_lcd();
    display_scr2();
    display_trip(trip);
    GIE=0;
    transmit_values();
    while(1);
   }
 }

void phsft(unsigned int j,unsigned int k,unsigned int l)
 {
  mul(j,0,8,0);
  a1=u1;
  a2=u2;
  mul(k,0,-4,-7);
  a3=u1;
  a4=u2;
  mul(l,0,-4,7);
  a5=u1;
```

```
 a6=u2;
 }

void seq(int j,int k,int l,int m,int n,int p)
 {
 mul(j,k,8,0);
 j=u1;
 k=u2;
 mul(l,m,-4,7);
 j=j+u1;
 k=k+u2;
 mul(n,p,-4,-7);
 j=j+u1;
 k=k+u2;
 u1=j;
 u2=k;
 }

void mul(int j,int k,int m,int n)
 {
 u1=(j*m-k*n)/8;
 u2=(j*n+k*m)/8;
 }

void sqr(long m,long n)
 {
 h=m*m+n*n;
 }

void interrupt isr()
 {
 if(INTF)
  {
  INTF=0;
  pulse_f=1;
  if(!st_f)
   {
   st_f=1;
   TMR1H=TMR1L=0;
   TMR1ON=1;
```

```
display_voltage()
 {
  unsigned char temp=0;
  unsigned char volt1;

  display('V');
  display(' ');
  volt1=v1/4.01;
  display((volt1/100)+0x30);
  temp=volt1%100;
  display((temp/10)+0x30);
  display((temp%10)+0x30);
  display(' ');

  volt1=v2/4.01;
  display((volt1/100)+0x30);
  temp=volt1%100;
  display((temp/10)+0x30);
  display((temp%10)+0x30);
  display(' ');

  volt1=v3/4.01;
  display((volt1/100)+0x30);
  temp=volt1%100;
  display((temp/10)+0x30);
  display((temp%10)+0x30);
 }

display_current()
 {
  unsigned char temp=0;
  unsigned char volt1;

  display('I');
  display(' ');
  volt1=i1/6.82;
  display((volt1/100)+0x30);
  temp=volt1%100;
  display((temp/10)+0x30);
  display('.');
```

```
      }
     else if(st_f)
      {
       TMR1ON=0;
       pulse_sec=(TMR1H*256)+TMR1L;
       n=7500000/pulse_sec;
       st_f=0;
      }
    }
  if(T0IF)
   {
    T0IF=0;
    count++;
    if(count==15)
     {
      count=0;
      ad_flag=1;
      sec++;
      if(!pulse_f)
       n=0;
      else
       pulse_f=0;
     }
    if(sec==3)
     {
      scr=scr^1;
      sec=0;
      disp_f=1;
     }
   }
 }

display_scr1()
 {
  clear_lcd();
  display_voltage();
  cursor_loc(0xc0);
  display_current();
 }
```

```
 display((temp%10)+0x30);
 display(' ');

 volt1=i2/6.82;
 display((volt1/100)+0x30);
 temp=volt1%100;
 display((temp/10)+0x30);
 display('.');
 display((temp%10)+0x30);
 display(' ');

 volt1=i3/6.82;
 display((volt1/100)+0x30);
 temp=volt1%100;
 display((temp/10)+0x30);
 display('.');
 display((temp%10)+0x30);
}

display_scr2()
{
 unsigned char temp=0;
 unsigned int itemp=0;

 clear_lcd();
 display('N');
 display(' ');
 display((n/1000)+0x30);
 itemp=n%1000;
 display((itemp/100)+0x30);
 temp=itemp%100;
 display((temp/10)+0x30);
 display((temp%10)+0x30);
 display(' ');

 display('T');
 display(' ');
 display((t/100)+0x30);
 temp=t%100;
 display((temp/10)+0x30);
```

```
  display((temp%10)+0x30);

  cursor_loc(0xc0);
  display('P');
  display(' ');
  display((pulse_sec/10000)+0x30);
  itemp=pulse_sec%10000;
  display((itemp/1000)+0x30);
  itemp=itemp%1000;
  display((itemp/100)+0x30);
  temp=itemp%100;
  display((temp/10)+0x30);
  display((temp%10)+0x30);
  display(' ');
 }

display_trip(unsigned char dat1)
 {
  cursor_loc(0xc0);
  display_string("TRIP:");
  display(dat1+0x30);
 }

display_trip6()
 {
  clear_lcd();
  display_string("FR ");
  display((d/10)+0x30);
  display((d%10)+0x30);
  display(' ');
 }

delay()
 {
  unsigned char i=0;
  for(i=0;i<100;i++);
 }

transmit_values()
 {
```

```
unsigned char volt1=0,temp=0,i=0;

tx_array[0]=('{');
tx_array[1]=(' ');
volt1=v1/4.01;
tx_array[2]=((volt1/100)+0x30);
temp=volt1%100;
tx_array[3]=((temp/10)+0x30);
tx_array[4]=((temp%10)+0x30);
tx_array[5]=(' ');

volt1=v2/4.01;
tx_array[6]=((volt1/100)+0x30);
temp=volt1%100;
tx_array[7]=((temp/10)+0x30);
tx_array[8]=((temp%10)+0x30);
tx_array[9]=(' ');

volt1=v3/4.01;
tx_array[10]=((volt1/100)+0x30);
temp=volt1%100;
tx_array[11]=((temp/10)+0x30);
tx_array[12]=((temp%10)+0x30);
tx_array[13]=(' ');

volt1=i1/6.82;
tx_array[14]=((volt1/100)+0x30);
temp=volt1%100;
tx_array[15]=((temp/10)+0x30);
tx_array[16]=('.');
tx_array[17]=((temp%10)+0x30);
tx_array[18]=(' ');

volt1=i2/6.82;
tx_array[19]=((volt1/100)+0x30);
temp=volt1%100;
tx_array[20]=((temp/10)+0x30);
tx_array[21]=('.');
tx_array[22]=((temp%10)+0x30);
tx_array[23]=(' ');
```

```
volt1=i3/6.82;
tx_array[24]=((volt1/100)+0x30);
temp=volt1%100;
tx_array[25]=((temp/10)+0x30);
tx_array[26]=('.');
tx_array[27]=((temp%10)+0x30);
tx_array[28]=(' ');

tx_array[29]=((n/1000)+0x30);
temp=n%1000;
tx_array[30]=((temp/100)+0x30);
temp=n%100;
tx_array[31]=((temp/10)+0x30);
tx_array[32]=((temp%10)+0x30);
tx_array[33]=(' ');

tx_array[34]=((t/100)+0x30);
temp=t%100;
tx_array[35]=((temp/10)+0x30);
tx_array[36]=((temp%10)+0x30);
tx_array[37]=(' ');

tx_array[38]=(trip+0x30);
tx_array[39]=(' ');

for(i=0;i<=39;i++)
 {
  TXREG=tx_array[i];
  while(!TRMT);
  TRMT=0;
 }
}
```

```
' VISUAL BASIC CODING
Dim dat As String
Dim value As String

Private Sub Command1_Click()
End
End Sub

Private Sub Form_Load()
MSComm1.CommPort = 1
MSComm1.Settings = "9600,N,8,1"
MSComm1.PortOpen = True
End Sub

Private Sub Text1_Change()
Form1.Show
If (Len(Form1.Text1.Text) >= 31) Then
   dat = Text1.Text
   Text1.Text = ""
    If (Mid$(dat, 1, 1) = "{") Then
    Form1.Label2.Caption = Mid$(dat, 2, 3)
    Form1.Label4.Caption = Mid$(dat, 5, 3)
    Form1.Label6.Caption = Mid$(dat, 8, 3)
    Form1.Label8.Caption = Mid$(dat, 11, 4)
    Form1.Label10.Caption = Mid$(dat, 15, 4)
    Form1.Label12.Caption = Mid$(dat, 19, 4)
    Form1.Label14.Caption = Mid$(dat, 23, 4)
    Form1.Label16.Caption = Mid$(dat, 27, 3)
    value = Mid$(dat, 30, 1)
    If value = "0" Then
       Form1.Label17.Caption = "NORMAL"
    ElseIf value = "1" Then
       Form1.Label17.Caption = "SINGLE PHASING"
    ElseIf value = "2" Then
      Form1.Label17.Caption = "OPEN CIRCUIT"
    ElseIf value = "3" Then
       Form1.Label17.Caption = "SUPPLY UNBALANCE"
    ElseIf value = "4" Then
       Form1.Label17.Caption = "LOW VOLTAGE"
    ElseIf value = "5" Then
```

```
      Form1.Label17.Caption = "HIGH VOLTAGE"
    ElseIf value = "6" Then
      Form1.Label17.Caption = "WINDING FAULT"
    ElseIf value = "7" Then
      Form1.Label17.Caption = "OVER TEMPERATURE"
    End If
   End If
End If
End Sub

Private Sub Timer1_Timer()
If value > "0" Then
  Open CommonDialog1.FileName For Append As #1
  Print #1, "date=" & Date
  Print #1, "time=" & Time
  Print #1, "Vr = " + Form1.Label2.Caption
  Print #1, "Vy = " + Form1.Label4.Caption
  Print #1, "Vb = " + Form1.Label6.Caption
  Print #1, "Ir = " + Form1.Label8.Caption
  Print #1, "Iy = " + Form1.Label10.Caption
  Print #1, "Ib = " + Form1.Label12.Caption
  Print #1, "SPEED = " + Form1.Label14.Caption
  Print #1, "TEMPERATURE = " + Form1.Label16.Caption
  Print #1, "FAULT : " + Form1.Label17.Caption
  Print #1, "---------------------------"
  Close #1
End If
End Sub

Private Sub Timer2_Timer()
 Form1.Text1.Text = Form1.Text1.Text + MSComm1.Input
End Sub
```

MICROCHIP

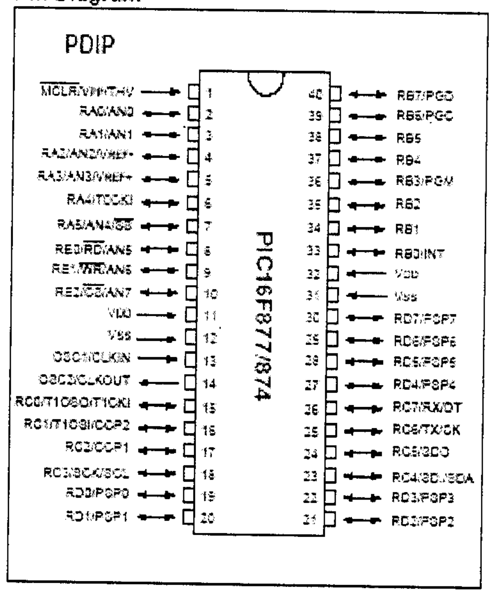
PIC16F87X

28/40-pin 8-Bit CMOS EEPROM/Flash Microcontrollers

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
- ★ Pinout compatible to the PIC16C73/74/76/77
- Interrupt capability (up to 14 internal/external interrupt 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 EPROM/EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ via two pins
- ★ Only single 5V source needed for programming
- ★ In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.5V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial and Industrial temperature ranges
- Low-power consumption:
  - < 2 mA typical @ 5V, 4 MHz
  - 20 µA typical @ 3V, 32 kHz
  - < 1 µA typical standby current

Pin Diagram

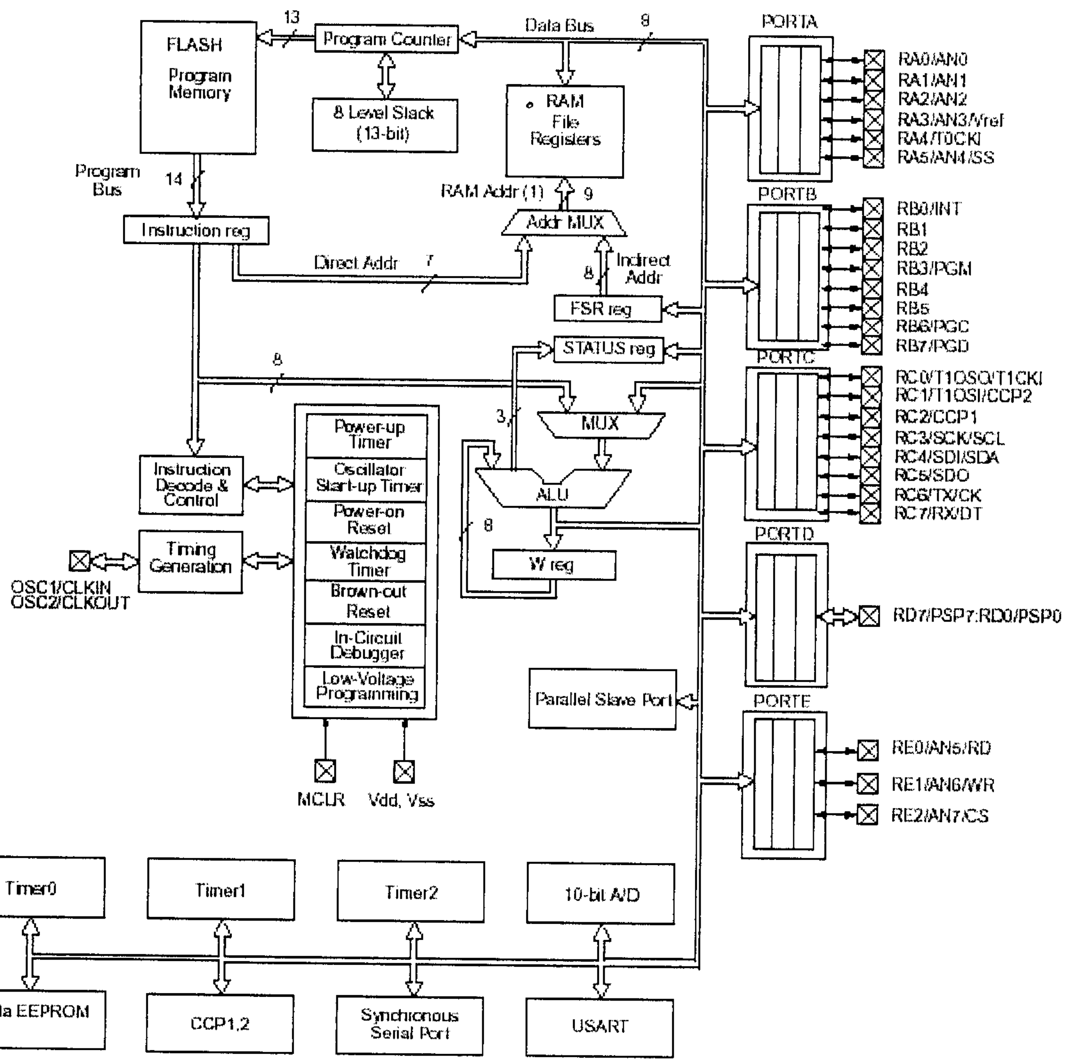


Peripheral Features:

- 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 register, 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 I²C™ (Master/Slave)
- ★ Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

PIC16F877 BLOCK DIAGRAM

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.

PIC16F877/876 REGISTER FILE MAP

Bank 0	File Address	Bank 1	File Address	Bank 2	File Address	Bank 3	File Address
Indirect addr.(*)	00h	Indirect addr.(*)	80h	Indirect addr.(*)	100h	Indirect addr.(*)	180h
TMR0	01h	OPTION_REG	81h	TMR0	101h	OPTION_REG	181h
PCL	02h	PCL	82h	PCL	102h	PCL	182h
STATUS	03h	STATUS	83h	STATUS	103h	STATUS	183h
FSR	04h	FSR	84h	FSR	104h	FSR	184h
PORTA	05h	TRISA	85h		105h		185h
PORTB	06h	TRISB	86h	PORTB	106h	TRISB	186h
PORTC	07h	TRISC	87h		107h		187h
PORTD (1)	08h	TRISD (1)	88h		108h		188h
PORTE (1)	09h	TRISE (1)	89h		109h		189h
PCLATH	0Ah	PCLATH	8Ah	PCLATH	10Ah	PCLATH	18Ah
INTCON	0Bh	INTCON	8Bh	INTCON	10Bh	INTCON	18Bh
PIR1	0Ch	PIE1	8Ch	EEDATA	10Ch	EECON1	18Ch
PIR2	0Dh	PIE2	8Dh	EEADR	10Dh	EECON2	18Dh
TMR1L	0Eh	PCON	8Eh	EEDATH	10Eh	Reserved(2)	18Eh
TMR1H	0Fh		8Fh	EEADRH	10Fh	Reserved(2)	18Fh
T1CON	10h		90h	General Purpose Register 16 Bytes	110h	General Purpose Register 16 Bytes	190h
TMR2	11h	SSPCON2	91h		111h		191h
T2CON	12h	PR2	92h		112h		192h
SSPBUF	13h	SSPADD	93h		113h		193h
SSPCON	14h	SSPSTAT	94h		114h		194h
CCPR1L	15h		95h		115h		195h
CCPR1H	16h		96h		116h		196h
CCP1CON	17h		97h		117h		197h
RCSTA	18h	TXSTA	98h		118h		198h
TXREG	19h	SPBRG	99h		119h		199h
RCREG	1Ah		9Ah		11Ah		19Ah
CCPR2L	1Bh		9Bh		11Bh		19Bh
CCPR2H	1Ch		9Ch		11Ch		19Ch
CCP2CON	1Dh		9Dh		11Dh		19Dh
ADRESH	1Eh	ADRESL	9Eh		11Eh		19Eh
ADCON0	1Fh	ADCON1	9Fh		11Fh		19Fh
General Purpose Register 96 Bytes	20h–7Fh	General Purpose Register 80 Bytes	A0h–EFh	General Purpose Register 80 Bytes	120h–16Fh	General Purpose Register 80 Bytes	1A0h–1EFh
		accesses 70h-7Fh	F0h–FFh	accesses 70h-7Fh	170h–17Fh	accesses 70h - 7Fh	1F0h–1FFh

Shaded: Unimplemented data memory locations, read as '0'.

* Not a physical register.

Note 1: These registers are not implemented on 28-pin devices.

2: These registers are reserved, maintain these registers clear.

2.2.2.3 INTCON REGISTER

The INTCON Register is a readable and writable register which contains various enable and flag bits for the TMR0 register overflow, RB Port change and External RB0/INT pin interrupts.

Note: Interrupt flag bits get set when an interrupt condition occurs regardless of the state of its corresponding enable bit or the global enable bit, GIE (INTCON<7>). User software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

FIGURE 2-7: INTCON REGISTER (ADDRESS 0Bh, 8Bh, 10Bh, 18Bh)

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-x
GIE	PEIE	T0IE	INTE	RBIE	T0IF	INTF	RBIF
bit7							bit0

R= Readable bit
W= Writable bit
U= Unimplemented bit, read as '0'
- n= Value at POR reset

bit 7: **GIE**: Global Interrupt Enable bit
1 = Enables all un-masked interrupts
0 = Disables all interrupts

bit 6: **PEIE**: Peripheral Interrupt Enable bit
1 = Enables all un-masked peripheral interrupts
0 = Disables all peripheral interrupts

bit 5: **T0IE**: TMR0 Overflow Interrupt Enable bit
1 = Enables the TMR0 interrupt
0 = Disables the TMR0 interrupt

bit 4: **INTE**: RB0/INT External Interrupt Enable bit
1 = Enables the RB0/INT external interrupt
0 = Disables the RB0/INT external interrupt

bit 3: **RBIE**: RB Port Change Interrupt Enable bit
1 = Enables the RB port change interrupt
0 = Disables the RB port change interrupt

bit 2: **T0IF**: TMR0 Overflow Interrupt Flag bit
1 = TMR0 register has overflowed (must be cleared in software)
0 = TMR0 register did not overflow

bit 1: **INTF**: RB0/INT External Interrupt Flag bit
1 = The RB0/INT external interrupt occurred (must be cleared in software)
0 = The RB0/INT external interrupt did not occur

bit 0: **RBIF**: RB Port Change Interrupt Flag bit
1 = At least one of the RB7:RB4 pins changed state (must be cleared in software)
0 = None of the RB7:RB4 pins have changed state

TIMER0 MODULE

REGISTERS ASSOCIATED WITH TIMER0

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other resets
01h,101h	TMR0	Timer0 module's register								xxxx xxxx	uuuu uuuu
0Bh,8Bh, 10Bh,18Bh	INTCON	GIE	PEIE	T0IE	INTE	RBIE	T0IF	INTF	RBIF	0000 000x	0000 000u
81h,181h	OPTION_REG	RBPU	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0	1111 1111	1111 1111
85h	TRISA	—	—	PORTA Data Direction Register						--11 1111	--11 1111

Legend: x = unknown, u = unchanged, - = unimplemented locations read as '0'. Shaded cells are not used by Timer0.

10.0 UNIVERSAL SYNCHRONOUS ASYNCHRONOUS RECEIVER TRANSMITTER (USART)

The Universal Synchronous Asynchronous Receiver Transmitter (USART) module is one of the two serial I/O modules. (USART is also known as a Serial Communications Interface or SCI). The USART can be configured as a full duplex asynchronous system that can communicate with peripheral devices such as CRT terminals and personal computers, or it can be configured as a half duplex synchronous system that can communicate with peripheral devices such as A/D or D/A integrated circuits, Serial EEPROMs etc.

The USART can be configured in the following modes:

- Asynchronous (full duplex)
- Synchronous - Master (half duplex)
- Synchronous - Slave (half duplex)

Bit SPEN (RCSTA<7>), and bits TRISC<7:6>, have to be set in order to configure pins RC6/TX/CK and RC7/RX/DT as the Universal Synchronous Asynchronous Receiver Transmitter.

The USART module also has a multi-processor communication capability using 9-bit address detection.

FIGURE 10-1: TXSTA: TRANSMIT STATUS AND CONTROL REGISTER (ADDRESS 98h)

R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0	R-1	R/W-0
CSRC	TX9	TXEN	SYNC	—	BRGH	TRMT	TX9D
bit7							bit0

R = Readable bit
W = Writable bit
U = Unimplemented bit, read as '0'
- n =Value at POR reset

bit 7: **CSRC**: Clock Source Select bit
Asynchronous mode
Don't care
Synchronous mode
1 = Master mode (Clock generated internally from BRG)
0 = Slave mode (Clock from external source)

bit 6: **TX9**: 9-bit Transmit Enable bit
1 = Selects 9-bit transmission
0 = Selects 8-bit transmission

bit 5: **TXEN**: Transmit Enable bit
1 = Transmit enabled
0 = Transmit disabled
Note: SREN/CREN overrides TXEN in SYNC mode.

bit 4: **SYNC**: USART Mode Select bit
1 = Synchronous mode
0 = Asynchronous mode

bit 3: **Unimplemented**: Read as '0'

bit 2: **BRGH**: High Baud Rate Select bit
Asynchronous mode
1 = High speed
0 = Low speed
Synchronous mode
Unused in this mode

bit 1: **TRMT**: Transmit Shift Register Status bit
1 = TSR empty
0 = TSR full

bit 0: **TX9D**: 9th bit of transmit data. Can be parity bit.

10.1 USART Baud Rate Generator (BRG)

The BRG supports both the Asynchronous and Synchronous modes of the USART. It is a dedicated 8-bit baud rate generator. The SPBRG register controls the period of a free running 8-bit timer. In asynchronous mode bit BRGH (TXSTA<2>) also controls the baud rate. In synchronous mode bit BRGH is ignored. Table 10-1 shows the formula for computation of the baud rate for different USART modes which only apply in master mode (internal clock).

Given the desired baud rate and Fosc, the nearest integer value for the SPBRG register can be calculated using the formula in Table 10-1. From this, the error in baud rate can be determined.

Example 10-1 shows the calculation of the baud rate error for the following conditions:

FOSC = 16 MHz
Desired Baud Rate = 9600
BRGH = 0
SYNC = 0

EXAMPLE 10-1: CALCULATING BAUD RATE ERROR

Desired Baud rate = Fosc / (64 (X + 1))

$$9600 = 16000000 / (64 (X + 1))$$

$$X = \lfloor 25.042 \rfloor = 25$$

Calculated Baud Rate = 16000000 / (64 (25 + 1))

$$= 9615$$

$$\text{Error} = \frac{(\text{Calculated Baud Rate} - \text{Desired Baud Rate})}{\text{Desired Baud Rate}}$$

$$= (9615 - 9600) / 9600$$

$$= 0.16\%$$

It may be advantageous to use the high baud rate (BRGH = 1) even for slower baud clocks. This is because the FOSC/(16(X + 1)) equation can reduce the baud rate error in some cases.

Writing a new value to the SPBRG register, causes the BRG timer to be reset (or cleared), this ensures the BRG does not wait for a timer overflow before outputting the new baud rate.

10.1.1 SAMPLING

The data on the RC7/RX/DT pin is sampled three times by a majority detect circuit to determine if a high or a low level is present at the RX pin.

TABLE 10-1 BAUD RATE FORMULA

SYNC	BRGH = 0 (Low Speed)	BRGH = 1 (High Speed)
0	(Asynchronous) Baud Rate = FOSC/(64(X+1))	Baud Rate= FOSC/(16(X+1))
1	(Synchronous) Baud Rate = FOSC/(4(X+1))	NA

X = value in SPBRG (0 to 255)

TABLE 10-2 REGISTERS ASSOCIATED WITH BAUD RATE GENERATOR

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other resets
98h	TXSTA	CSRC	TX9	TXEN	SYNC	—	BRGH	TRMT	TX9D	0000 -010	0000 -010
18h	RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	0000 000x	0000 000x
99h	SPBRG	Baud Rate Generator Register								0000 0000	0000 0000

Legend: x = unknown, - = unimplemented read as '0'. Shaded cells are not used by the BRG.

11.0 ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE

The analog-to-digital (A/D) converter module has five inputs for the 28-pin devices, and eight for the other devices.

The analog input charges a sample and hold capacitor. The output of the sample and hold capacitor is the input into the converter. The converter then generates a digital result of this analog level via successive approximation. This A/D conversion, of the analog input signal, results in a corresponding 10-bit digital number.

The A/D converter has a unique feature of being able to operate while the device is in SLEEP mode. To operate in sleep, the A/D clock must be derived from the A/D's internal RC oscillator.

The A/D module has four registers. These registers are:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register0 (ADCON0)
- A/D Control Register1 (ADCON1)

The ADCON0 register, shown in Figure 11-1, controls the operation of the A/D module. The ADCON1 register, shown in Figure 11-2, configures the functions of the port pins. The port pins can be configured as analog inputs (RA3 can also be the voltage reference) or as digital I/O.

FIGURE 11-1: ADCON0 REGISTER (ADDRESS: 1Fh)

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
ADCS1	ADCS0	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	—	ADON
bit7							bit0

R = Readable bit
W = Writable bit
U = Unimplemented bit, read as '0'
- n = Value at POR reset

bit 7-6: **ADCS1:ADCS0**: A/D Conversion Clock Select bits
00 = Fosc/2
01 = Fosc/8
10 = Fosc/32
11 = FRC (clock derived from an RC oscillation)

bit 5-3: **CHS2:CHS0**: Analog Channel Select bits
000 = channel 0, (RA0/AN0)
001 = channel 1, (RA1/AN1)
010 = channel 2, (RA2/AN2)
011 = channel 3, (RA3/AN3)
100 = channel 4, (RA5/AN4)
101 = channel 5, (RE0/AN5)(1)
110 = channel 6, (RE1/AN6)(1)
111 = channel 7, (RE2/AN7)(1)

bit 2: **GO/$\overline{\text{DONE}}$**: A/D Conversion Status bit
If ADON = 1
1 = A/D conversion in progress (setting this bit starts the A/D conversion)
0 = A/D conversion not in progress (This bit is automatically cleared by hardware when the A/D conversion is complete)

bit 1: **Unimplemented**: Read as '0'

bit 0: **ADON**: A/D On bit
1 = A/D converter module is operating
0 = A/D converter module is shutoff and consumes no operating current

Note 1: These channels are not available on the 28-pin devices.

TABLE 13-2 PIC16CXXX INSTRUCTION SET

Mnemonic, Operands		Description	Cycles	14-Bit Opcode MSb			LSb	Status Affected	Notes
BYTE-ORIENTED FILE REGISTER OPERATIONS									
ADDWF	f, d	Add W and f	1	00	0111	dfff	ffff	C,DC,Z	1,2
ANDWF	f, d	AND W with f	1	00	0101	dfff	ffff	Z	1,2
CLRF	f	Clear f	1	00	0001	1fff	ffff	Z	2
CLRW	-	Clear W	1	00	0001	0xxx	xxxx	Z	
COMF	f, d	Complement f	1	00	1001	dfff	ffff	Z	1,2
DECF	f, d	Decrement f	1	00	0011	dfff	ffff	Z	1,2
DECFSZ	f, d	Decrement f, Skip if 0	1(2)	00	1011	dfff	ffff		1,2,3
INCF	f, d	Increment f	1	00	1010	dfff	ffff	Z	1,2
INCFSZ	f, d	Increment f, Skip if 0	1(2)	00	1111	dfff	ffff		1,2,3
IORWF	f, d	Inclusive OR W with f	1	00	0100	dfff	ffff	Z	1,2
MOVF	f, d	Move f	1	00	1000	dfff	ffff	Z	1,2
MOVWF	f	Move W to f	1	00	0000	1fff	ffff		
NOP	-	No Operation	1	00	0000	0xx0	0000		
RLF	f, d	Rotate Left f through Carry	1	00	1101	dfff	ffff	C	1,2
RRF	f, d	Rotate Right f through Carry	1	00	1100	dfff	ffff	C	1,2
SUBWF	f, d	Subtract W from f	1	00	0010	dfff	ffff	C,DC,Z	1,2
SWAPF	f, d	Swap nibbles in f	1	00	1110	dfff	ffff		1,2
XORWF	f, d	Exclusive OR W with f	1	00	0110	dfff	ffff	Z	1,2
BIT-ORIENTED FILE REGISTER OPERATIONS									
BCF	f, b	Bit Clear f	1	01	00bb	bfff	ffff		1,2
BSF	f, b	Bit Set f	1	01	01bb	bfff	ffff		1,2
BTFSC	f, b	Bit Test f, Skip if Clear	1 (2)	01	10bb	bfff	ffff		3
BTFSS	f, b	Bit Test f, Skip if Set	1 (2)	01	11bb	bfff	ffff		3
LITERAL AND CONTROL OPERATIONS									
ADDLW	k	Add literal and W	1	11	111x	kkkk	kkkk	C,DC,Z	
ANDLW	k	AND literal with W	1	11	1001	kkkk	kkkk	Z	
CALL	k	Call subroutine	2	10	0kkk	kkkk	kkkk		
CLRWDT	-	Clear Watchdog Timer	1	00	0000	0110	0100	$\overline{TO}$,$\overline{PD}$	
GOTO	k	Go to address	2	10	1kkk	kkkk	kkkk		
IORLW	k	Inclusive OR literal with W	1	11	1000	kkkk	kkkk	Z	
MOVLW	k	Move literal to W	1	11	00xx	kkkk	kkkk		
RETFIE	-	Return from interrupt	2	00	0000	0000	1001		
RETLW	k	Return with literal in W	2	11	01xx	kkkk	kkkk		
RETURN	-	Return from Subroutine	2	00	0000	0000	1000		
SLEEP	-	Go into standby mode	1	00	0000	0110	0011	$\overline{TO}$,$\overline{PD}$	
SUBLW	k	Subtract W from literal	1	11	110x	kkkk	kkkk	C,DC,Z	
XORLW	k	Exclusive OR literal with W	1	11	1010	kkkk	kkkk	Z	

Note 1: When an I/O register is modified as a function of itself (e.g., `MOVF PORTB, 1`), the value used will be that value present on the pins themselves. For example, if the data latch is '1' for a pin configured as input and is driven low by an external device, the data will be written back with a '0'.

2: If this instruction is executed on the TMR0 register (and, where applicable, d = 1), the prescaler will be cleared if assigned to the Timer0 Module.

3: If Program Counter (PC) is modified or a conditional test is true, the instruction requires two cycles. The second cycle is executed as a NOP.

ON Semiconductor™

Internally Compensated, High Performance Dual Operational Amplifiers

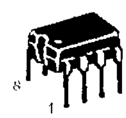
MC1458, C

DUAL OPERATIONAL AMPLIFIERS
(DUAL MC1741)

SEMICONDUCTOR TECHNICAL DATA

The MC1458, C was designed for use as a summing amplifier, integrator, or amplifier with operating characteristics as a function of the external feedback components.

- No Frequency Compensation Required
- Short Circuit Protection
- Wide Common Mode and Differential Voltage Ranges
- Low Power Consumption
- No Latch–Up



P1 SUFFIX
PLASTIC PACKAGE
CASE 626

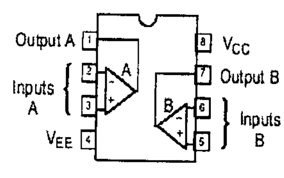
D SUFFIX
PLASTIC PACKAGE
CASE 751
(SO–8)

MAXIMUM RATINGS (T_A = +25°C, unless otherwise noted.)

Rating	Symbol	Value	Unit
Power Supply Voltage	V_{CC} V_{EE}	+18 −18	Vdc
Input Differential Voltage	V_{ID}	±30	V
Input Common Mode Voltage (Note 1)	V_{ICM}	±15	V
Output Short Circuit Duration (Note 2)	t_{SC}	Continuous	
Operating Ambient Temperature Range	T_A	0 to +70	°C
Storage Temperature Range	T_{stg}	−55 to +125	°C
Junction Temperature	T_J	150	°C

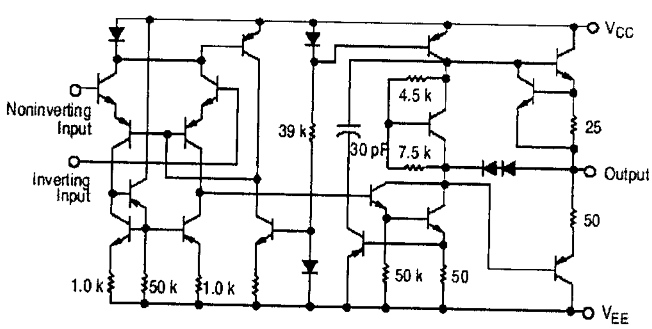
NOTES: 1. For supply voltages less than ±15 V, the absolute maximum input voltage is equal to the supply voltage.
2. Supply voltage equal to or less than 15 V.

PIN CONNECTIONS



(Top View)

Representative Schematic Diagram



ORDERING INFORMATION

Device	Operating Temperature Range	Package
MC1458CD, D	T_A = 0° to +70°C	SO–8
MC1458CP1, P1		Plastic DIP

ELECTRICAL CHARACTERISTICS (V_{CC} = +15 V, V_{EE} = −15 V, T_A = 25°C, unless otherwise noted. (Note 3))

Characteristic	Symbol	MC1458 Min	MC1458 Typ	MC1458 Max	MC1458C Min	MC1458C Typ	MC1458C Max	Unit
Input Offset Voltage (R_S ≤ 10 k)	V_{IO}	–	2.0	6.0	–	2.0	1.0	mV
Input Offset Current	I_{IO}	–	20	200	–	20	300	nA
Input Bias Current	I_{IB}	–	80	500	–	80	700	nA
Input Resistance	r_i	0.3	2.0	–	–	2.0	–	MΩ
Input Capacitance	C_i	–	1.4	–	–	1.4	–	pF
Offset Voltage Adjustment Range	V_{IOR}	–	±15	–	–	±15	–	mV
Common Mode Input Voltage Range	V_{ICR}	±12	±13	–	±11	±13	–	V
Large Signal Voltage Gain (V_O = ±10 V, R_L = 2.0 k) (V_O = ±10 V, R_L = 10 k)	A_{VOL}	 20 –	 200 –	 – –	 – 20	 – 200	 – –	V/mV
Output Resistance	r_o	–	75	–	–	75	–	Ω
Common Mode Rejection (R_S ≤ 10 k)	CMR	70	90	–	60	90	–	dB
Supply Voltage Rejection (R_S ≤ 10 k)	PSR	–	30	150	–	30	–	µV/V
Output Voltage Swing (R_S ≤ 10 k) (R_S ≤ 2.0 k)	V_O	 ±12 ±10	 ±14 ±13	 – –	 ±11 ±9.0	 ±14 ±13	 – –	V
Output Short Circuit Current	I_{SC}	–	20	–	–	20	–	mA
Supply Currents (Both Amplifiers)	I_D	–	2.3	5.6	–	2.3	8.0	mA
Power Consumption	P_C	–	70	170	–	70	240	mW
Transient Response (Unity Gain) (V_I = 20 mV, R_L ≥ 2.0 kΩ, C_L ≤ 100 pF) Rise Time (V_I = 20 mV, R_L ≥ 2.0 kΩ, C_L ≤ 100 pF) Overshoot (V_I = 10 V, R_L ≥ 2.0 kΩ, C_L ≤ 100 pF) Slew Rate	 t_{TLH} os SR	 – – –	 0.3 15 0.5	 – – –	 – – –	 0.3 15 0.5	 – – –	 µs % V/µs

ELECTRICAL CHARACTERISTICS (V_{CC} = +15 V, V_{EE} = −15 V, T_A = T_{high} to T_{low}, unless otherwise noted. (Note 3))*

Characteristic	Symbol	MC1458 Min	MC1458 Typ	MC1458 Max	MC1458C Min	MC1458C Typ	MC1458C Max	Unit
Input Offset Voltage (R_S ≤ 10 kΩ)	V_{IO}	–	–	7.5	–	–	12	mV
Input Offset Current (T_A = 0° to +70°C)	I_{IO}	–	–	300	–	–	400	nA
Input Bias Current (T_A = 0° to +70°C)	I_{IB}	–	–	800	–	–	1000	nA
Output Voltage Swing (R_s ≤ 10 k) (R_s ≤ 2 k)	V_O	 ±12 ±10	 ±14 ±13	 – –	 – ±9.0	 – ±13	 – –	V
Large Signal Voltage Gain (V_O = ±10 V, R_L = 2 k) (V_O = ±10 V, R_L = 10 k)	A_{VOL}	 15 –	 – –	 – –	 – 15	 – –	 – –	V/mV

*T_{low} = 0°C for MC1458, C T_{high} = +70°C for MC1458, C

NOTE: 3. Input pins of an unused amplifier must be grounded for split supply operation or biased at least 3.0 V above V_{EE} for single supply operation.

National Semiconductor

May 2000

LM78XX
Series Voltage Regulators

General Description

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.

Features

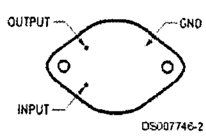
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

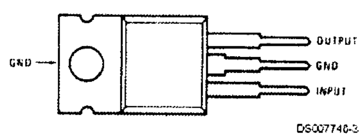
Connection Diagrams

Metal Can Package
TO-3 (K)
Aluminum



Bottom View
Order Number LM7805CK,
LM7812CK or LM7815CK
See NS Package Number KC02A

Plastic Package
TO-220 (T)



Top View
Order Number LM7805CT,
LM7812CT or LM7815CT
See NS Package Number T03B

 DS007746

Absolute Maximum Ratings (Note 3)

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

Input Voltage	
(V_O = 5V, 12V and 15V)	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range (T_A)	0°C to +70°C
Maximum Junction Temperature	
(K Package)	150°C
(T Package)	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package K	300°C
TO-220 Package T	230°C

Electrical Characteristics LM78XXC (Note 2)

$0°C \le T_J \le 125°C$ unless otherwise noted.

Output Voltage				5V			12V			15V			Units
Input Voltage (unless otherwise noted)				10V			19V			23V			
Symbol	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	Tj = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		$V_{MIN} \le V_{IN} \le V_{MAX}$			(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)		V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}		(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			50			120			150	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 1A	Tj = 25°C			50			120			150	mV
			ΔV_{IN}		(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			25			60			75	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)		V
ΔV_O	Load Regulation	Tj = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ Tj ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	Tj = 25°C			8			8			8	mA
			0°C ≤ Tj ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		Tj = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$			(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 500 mA, 0°C ≤ Tj ≤ +125°C				1.0			1.0			1.0	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$			(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
V_N	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, Tj = 25°C or	62	80		55	72		54	70		dB
			I_O ≤ 500 mA 0°C ≤ Tj ≤ +125°C	62			55			54			dB
		$V_{MIN} \le V_{IN} \le V_{MAX}$			(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)		V
R_O	Dropout Voltage	Tj = 25°C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ

Electrical Characteristics LM78XXC (Note 2) (Continued)

$0^{\circ}C \leq T_J \leq 125^{\circ}C$ unless otherwise noted.

Output Voltage			5V			12V			15V			Units
Input Voltage (unless otherwise noted)			10V			19V			23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
	Short-Circuit Current	$T_j = 25^{\circ}C$		2.1			1.5			1.2		A
	Peak Output Current	$T_j = 25^{\circ}C$		2.4			2.4			2.4		A
	Average TC of V_{OUT}	$0^{\circ}C \leq T_j \leq +125^{\circ}C$, $I_O = 5$ mA		0.6			1.5			1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	$T_j = 25^{\circ}C$, $I_O \leq 1A$		7.5		14.6			17.7			V

Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

Note 2: All characteristics are measured with capacitor across the input of 0.22 µF, and a capacitor across the output of 0.1µF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_w \leq 10$ ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 3: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

Order this document by MC7900/D

MOTOROLA

MC7900 Series

Three-Terminal Negative Voltage Regulators

THREE–TERMINAL NEGATIVE FIXED VOLTAGE REGULATORS

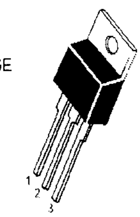
The MC7900 series of fixed output negative voltage regulators are intended as complements to the popular MC7800 series devices. These negative regulators are available in the same seven–voltage options as the MC7800 devices. In addition, one extra voltage option commonly employed in MECL systems is also available in the negative MC7900 series.

Available in fixed output voltage options from –5.0 V to –24 V, these regulators employ current limiting, thermal shutdown, and safe–area compensation – making them remarkably rugged under most operating conditions. With adequate heatsinking they can deliver output currents in excess of 1.0 A.

- No External Components Required
- Internal Thermal Overload Protection
- Internal Short Circuit Current Limiting
- Output Transistor Safe–Area Compensation
- Available in 2% Voltage Tolerance (See Ordering Information)

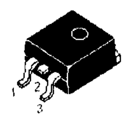
T SUFFIX
PLASTIC PACKAGE
CASE 221A

Heatsink surface connected to Pin 2.



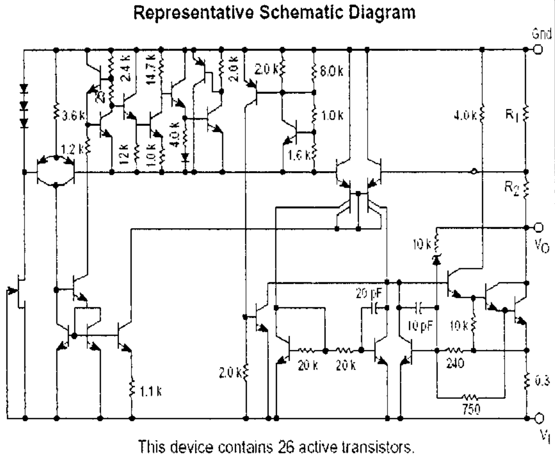
Pin 1. Ground
2. Input
3. Output

D2T SUFFIX
PLASTIC PACKAGE
CASE 936
(D^2PAK)



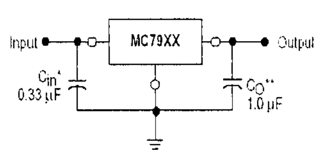
Heatsink surface (shown as terminal 4 in case outline drawing) is connected to Pin 2

Representative Schematic Diagram



This device contains 26 active transistors.

STANDARD APPLICATION



A common ground is required between the input and the output voltages. The input voltage must remain typically 2.0 V above more negative even during the high point of the input ripple voltage.

XX, These two digits of the type number indicate nominal voltage.
* C_{in} is required if regulator is located an appreciable distance from power supply filter.
** C_O improve stability and transient response.

ORDERING INFORMATION

Device	Output Voltage Tolerance	Operating Temperature Range	Package
MC79XXACD2T	2%	T_J = 0° to +125°C	Surface Mount
MC79XXCD2T	4%		
MC79XXACT	2%		Insertion Mount
MC79XXCT	4%		
MC79XXBD2T	4%	T_J = –40° to +125°C	Surface Mount
MC79XXBT			Insertion Mount

XX indicates nominal voltage.

DEVICE TYPE/NOMINAL OUTPUT VOLTAGE

MC7905	5.0 V	MC7912	12 V
MC7905.2	5.2 V	MC7915	15 V
MC7906	6.0 V	MC7918	18 V
MC7908	8.0 V	MC7924	24 V

 Rev 6

MC7912C

ELECTRICAL CHARACTERISTICS (V_I = −19 V, I_O = 500 mA, 0°C < T_J < +125°C, unless otherwise noted.)

Characteristics	Symbol	Min	Typ	Max	Unit
Output Voltage (T_J = +25°C)	V_O	−11.5	−12	−12.5	Vdc
Line Regulation (Note 1) (T_J = +25°C, I_O = 100 mA) −14.5 Vdc ≥ V_I ≥ −30 Vdc −16 Vdc ≥ V_I ≥ −22 Vdc (T_J = +25°C, I_O = 500 mA) −14.5 Vdc ≥ V_I ≥ −30 Vdc −16 Vdc ≥ V_I ≥ −22 Vdc	Reg_{line}	 – – – –	 13 6.0 55 24	 120 60 240 120	mV
Load Regulation, T_J = +25°C (Note 1) 5.0 mA ≤ I_O ≤ 1.5 A 250 mA ≤ I_O ≤ 750 mA	Reg_{load}	 – –	 46 17	 240 120	mV
Output Voltage −14.5 Vdc ≥ V_I ≥ −27 Vdc, 5.0 mA ≤ I_O ≤ 1.0 A, P ≤ 15 W	V_O	 −11.4	 –	 −12.6	Vdc
Input Bias Current (T_J = +25°C)	I_{IB}	–	4.4	8.0	mA
Input Bias Current Change −14.5 Vdc ≥ V_I ≥ −30 Vdc 5.0 mA ≤ I_O ≤ 1.5 A	ΔI_{IB}	 – –	 – –	 1.0 0.5	mA
Output Noise Voltage (T_A = +25°C, 10 Hz ≤ f ≤ 100 kHz)	V_n	–	75	–	µV
Ripple Rejection (I_O = 20 mA, f = 120 Hz)	RR	–	61	–	dB
Dropout Voltage I_O = 1.0 A, T_J = +25°C	V_I–V_O	 –	 2.0	 –	Vdc
Average Temperature Coefficient of Output Voltage I_O = 5.0 mA, 0°C ≤ T_J ≤ +125°C	$\Delta V_O/\Delta T$	 –	 −1.0	 –	mV/°C

MC7912AC

ELECTRICAL CHARACTERISTICS (V_I = −19 V, I_O = 500 mA, 0°C < T_J < +125°C, unless otherwise noted.)

Characteristics	Symbol	Min	Typ	Max	Unit
Output Voltage (T_J = +25°C)	V_O	−11.75	−12	−12.25	Vdc
Line Regulation (Note 1) −16 Vdc ≥ V_I ≥ −22 Vdc; I_O = 1.0 A, T_J = +25°C −16 Vdc ≥ V_I ≥ −22 Vdc; I_O = 1.0 A −14.8 Vdc ≥ V_I ≥ −30 Vdc; I_O = 500 mA −14.5 Vdc ≥ V_I ≥ −27 Vdc; I_O = 1.0 A, T_J = +25°C	Reg_{line}	 – – – –	 6.0 24 24 13	 60 120 120 120	mV
Load Regulation (Note 1) 5.0 mA ≤ I_O ≤ 1.5 A, T_J = +25°C 250 mA ≤ I_O ≤ 750 mA 5.0 mA ≤ I_O ≤ 1.0 A	Reg_{load}	 – – –	 46 17 35	 150 75 150	mV
Output Voltage −14.8 Vdc ≥ V_I ≥ −27 Vdc, 5.0 mA ≤ I_O ≤ 1.0 A, P ≤ 15 W	V_O	 −11.5	 –	 −12.5	Vdc
Input Bias Current	I_{IB}	–	4.4	8.0	mA
Input Bias Current Change −15 Vdc ≥ V_I ≥ −30 Vdc 5.0 mA ≤ I_O ≤ 1.0 A 5.0 mA ≤ I_O ≤ 1.5 A, T_J = +25°C	ΔI_{IB}	 – – –	 – – –	 0.8 0.5 0.5	mA
Output Noise Voltage (T_A = +25°C, 10 Hz ≤ f ≤ 100 kHz)	V_n	–	75	–	µV
Ripple Rejection (I_O = 20 mA, f = 120 Hz)	RR	–	61	–	dB
Dropout Voltage I_O = 1.0 A, T_J = +25°C	V_I–V_O	 –	 2.0	 –	Vdc
Average Temperature Coefficient of Output Voltage I_O = 5.0 A, 0°C ≤ T_J ≤ +125°C	$\Delta V_O/\Delta T$	 –	 −1.0	 –	mV/°C

NOTE: 1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

National Semiconductor

November 1994

LM741 Operational Amplifier

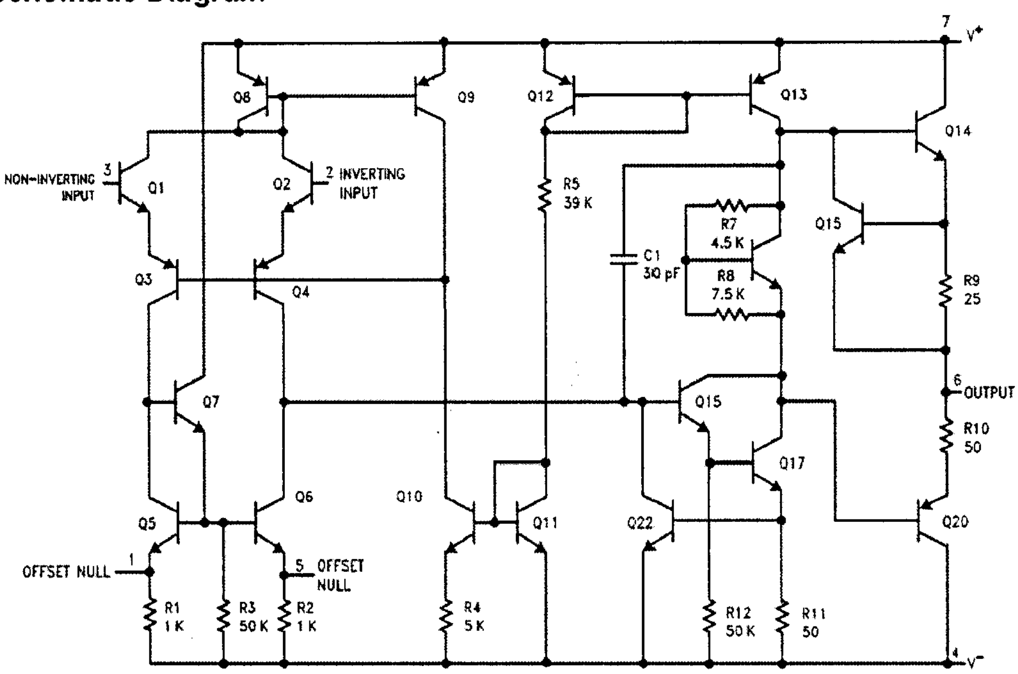
General Description

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

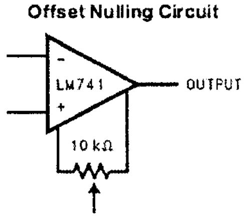
The LM741C/LM741E are identical to the LM741/LM741A except that the LM741C/LM741E have their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Schematic Diagram



TL/H/9341–1

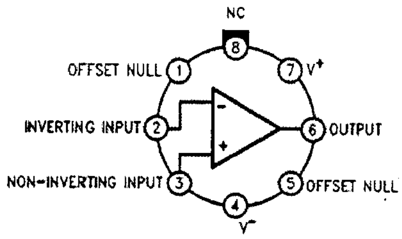
Offset Nulling Circuit



TL/H/9341–7

Connection Diagrams

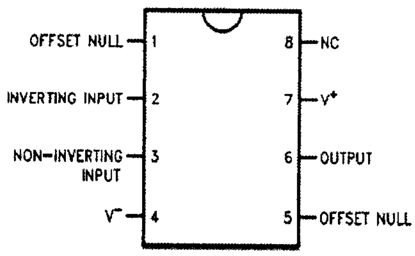
Metal Can Package



TL/H/9341-2

Order Number LM741H, LM741H/883*, LM741AH/883 or LM741CH
See NS Package Number H08C

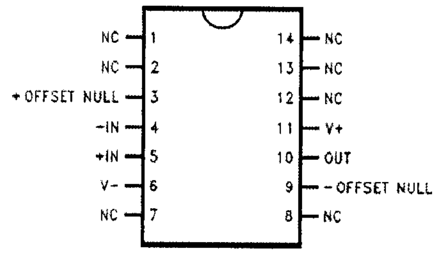
Dual-In-Line or S.O. Package



TL/H/9341-3

Order Number LM741J, LM741J/883, LM741CM, LM741CN or LM741EN
See NS Package Number J08A, M08A or N08E

Ceramic Dual-In-Line Package

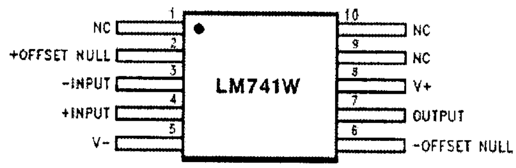


TL/H/9341-5

Order Number LM741J-14/883*, LM741AJ-14/883**
See NS Package Number J14A

*also available per JM38510/10101
**also available per JM38510/10102

Ceramic Flatpak



TL/H/9341-6

Order Number LM741W/883
See NS Package Number W10A

*LM741H is available per JM38510/10101

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.
(Note 5)

	LM741A	LM741E	LM741	LM741C
Supply Voltage	±22V	±22V	±22V	±18V
Power Dissipation (Note 1)	500 mW	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V	±30V
Input Voltage (Note 2)	±15V	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	0°C to +70°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	100°C	150°C	100°C
Soldering Information				
N-Package (10 seconds)	260°C	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C	300°C
M-Package				
Vapor Phase (60 seconds)	215°C	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C	215°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

	LM741A	LM741E	LM741	LM741C
ESD Tolerance (Note 6)	400V	400V	400V	400V

Electrical Characteristics (Note 3)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25°C$										
	$R_S \leq 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \leq 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 50\Omega$			4.0							mV
	$R_S \leq 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/°C
Input Offset Voltage Adjustment Range	$T_A = 25°C, V_S = \pm 20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25°C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	$T_A = 25°C$		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	$T_A = 25°C, V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm 20V$	0.5									MΩ
Input Voltage Range	$T_A = 25°C$							±12	±13		V
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				±12	±13					V
Large Signal Voltage Gain	$T_A = 25°C, R_L \geq 2\ k\Omega$										
	$V_S = \pm 20V, V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V, V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $R_L \geq 2\ k\Omega$,										
	$V_S = \pm 20V, V_O = \pm 15V$	32									V/mV
	$V_S = \pm 15V, V_O = \pm 10V$				25			15			V/mV
	$V_S = \pm 5V, V_O = \pm 2V$	10									V/mV

Electrical Characteristics (Note 3) (Continued)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage Swing	$V_S = \pm 20V$										
	$R_L \geq 10\ k\Omega$	±16									V
	$R_L \geq 2\ k\Omega$	±15									V
	$V_S = \pm 15V$										
	$R_L \geq 10\ k\Omega$				±12	±14		±12	±14		V
	$R_L \geq 2\ k\Omega$				±10	±13		±10	±13		V
Output Short Circuit Current	$T_A = 25°C$	10	25	35		25			25		mA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 10\ k\Omega$, $V_{CM} = \pm 12V$				70	90		70	90		dB
	$R_S \leq 50\Omega$, $V_{CM} = \pm 12V$	80	95								dB
Supply Voltage Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
	$V_S = \pm 20V$ to $V_S = \pm 5V$										
	$R_S \leq 50\Omega$	86	96								dB
	$R_S \leq 10\ k\Omega$				77	96		77	96		dB
Transient Response	$T_A = 25°C$, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		µs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 4)	$T_A = 25°C$	0.437	1.5								MHz
Slew Rate	$T_A = 25°C$, Unity Gain	0.3	0.7			0.5			0.5		V/µs
Supply Current	$T_A = 25°C$					1.7	2.8		1.7	2.8	mA
Power Consumption	$T_A = 25°C$										
	$V_S = \pm 20V$		80	150							mW
	$V_S = \pm 15V$					50	85		50	85	mW
LM741A	$V_S = \pm 20V$										
	$T_A = T_{AMIN}$			165							mW
	$T_A = T_{AMAX}$			135							mW
LM741E	$V_S = \pm 20V$										
	$T_A = T_{AMIN}$			150							mW
	$T_A = T_{AMAX}$			150							mW
LM741	$V_S = \pm 15V$										
	$T_A = T_{AMIN}$					60	100				mW
	$T_A = T_{AMAX}$					45	75				mW

Note 1: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_{jC} (Junction to Case)	N/A	N/A	25°C/W	N/A

Note 2: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 3: Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55°C \leq T_A \leq +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \leq T_A \leq +70°C$.

Note 4: Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

Note 5: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 6: Human body model, 1.5 kΩ in series with 100 pF.

+5V RS-232 Transceivers with 0.1µF External Capacitors

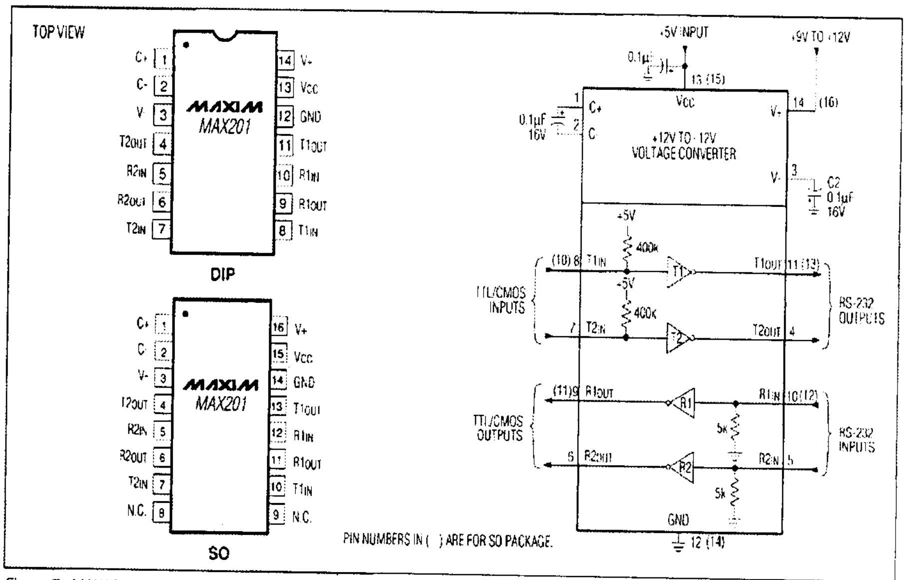


Figure 7. MAX201 Pin Configurations and Typical Operating Circuit

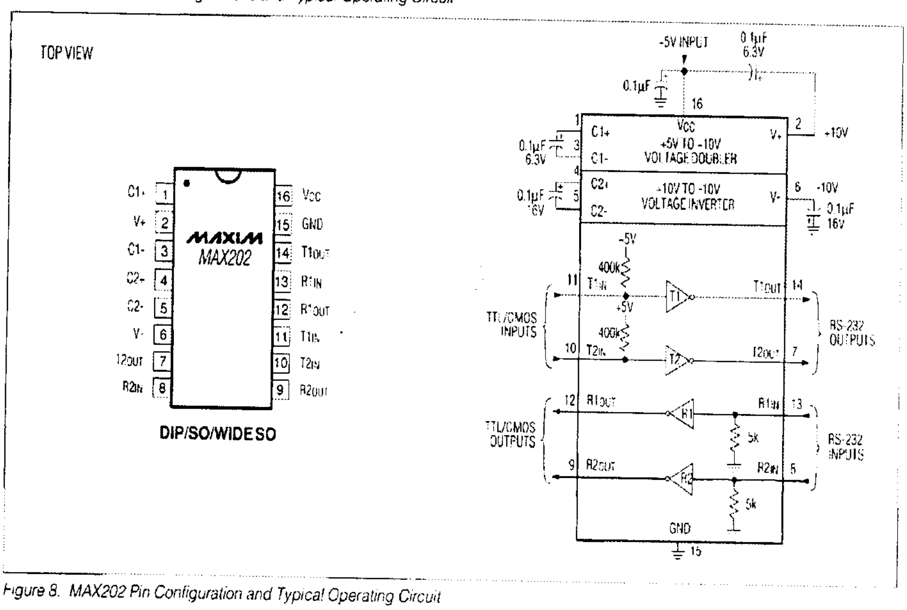


Figure 8. MAX202 Pin Configuration and Typical Operating Circuit

+5V RS-232 Transceivers with 0.1μF External Capacitors

ABSOLUTE MAXIMUM RATINGS

V_{CC} .... -0.3V to +6V
V+ .... (V_{CC} - 0.3V) to +14V
V- .... +0.3V to -14V
Input Voltages
  T_{IN} .... -0.3V to (V_{CC} + 0.3V)
  R_{IN} .... ±30V
Output Voltages
  T_{OUT} .... (V+ + 0.3V) to (V- - 0.3V)
  R_{OUT} .... -0.3V to (V_{CC} + 0.3V)
Short-Circuit Duration
  T_{OUT} .... Continuous
Continuous Power Dissipation (T_A = +70°C)
  14-Pin Plastic DIP (derate 10.00mW/°C above +70°C) .800mW
  16-Pin Plastic DIP (derate 10.53mW/°C above +70°C) 842mW
  16-Pin SO (derate 8.70mW/°C above +70°C) 696mW
  16-Pin Wide SO (derate 9.52mW/°C above +70°C) .. 762mW
  16-Pin CERDIP (derate 10.00mW/°C above +70°C) .. 800mW
  20-Pin Plastic DIP (derate 11.11mW/°C above +70°C) 889mW
  20-Pin Wide SO (derate 10.00mW/°C above +70°C) .. 800mW
  20-Pin CERDIP (derate 11.11mW/°C above +70°C) .. 889mW
  24-Pin Narrow Plastic DIP (derate 13.33mW/°C above +70°C) 1067mW
  24-Pin Wide Plastic DIP (derate 9.09mW/°C above+70°C) 727mW
  24-Pin Wide SO (derate 11.76mW/°C above +70°C) .. 941mW
  24-Pin SSOP (derate 8.00mW/°C above +70°C) 640mW
  24-Pin CERDIP (derate 12.50mW/°C above +70°C) . 1000mW
  28-Pin Wide SO (derate 12.50mW/°C above +70°C) . 1000mW
  28-Pin SSOP (derate 9.52mW/°C above +70°C) 762mW
Operating Temperature Ranges:
  MAX2_ _C_ _ .... 0°C to +70°C
  MAX2_ _E_ _ .... -40°C to +85°C
  MAX2_ _M_ _ .... -55°C to +125°C
Storage Temperature Range .... -65°C to +160°C
Lead Temperature (soldering, 10sec) .... +300°C

Stresses beyond those listed under 'Absolute Maximum Ratings' may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(MAX202/204/206/208/211/213 V_{CC} = 5V ±10%, MAX200/203/205/207 V_{CC} = 5V ±5%, C1-C4 = 0.1μF, MAX201/MAX209 V_{CC} = 5V ±10%, V+ = 9.0V to 13.2V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

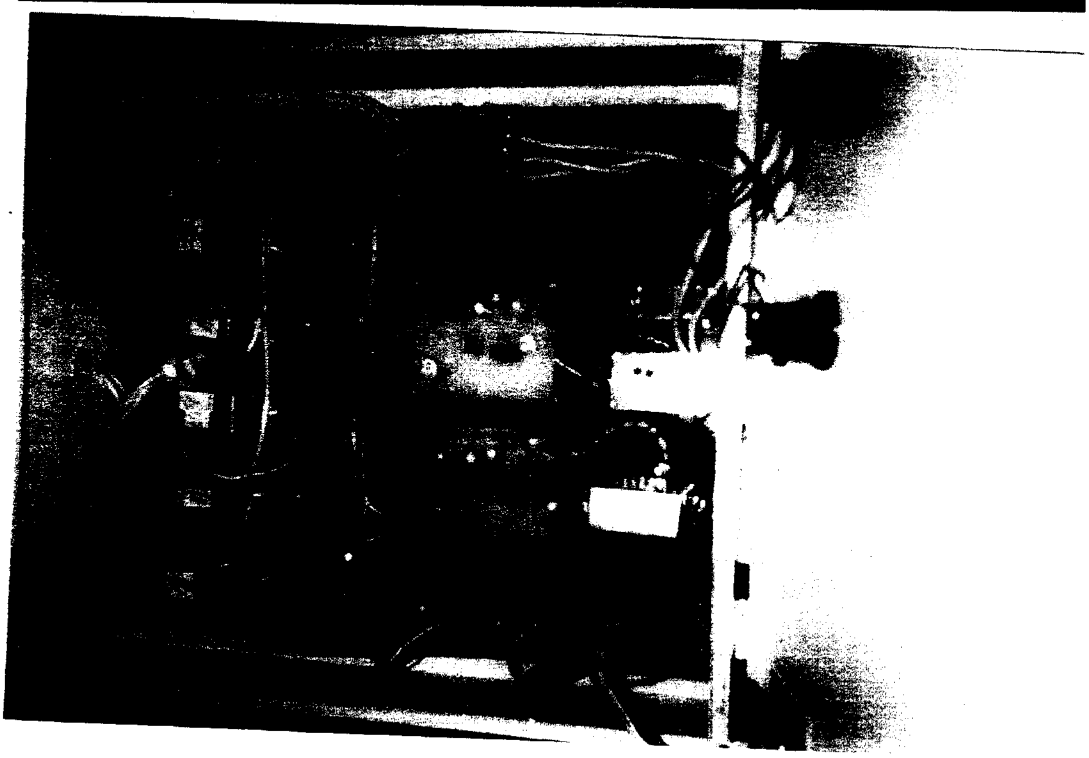
PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Output Voltage Swing	All transmitter outputs loaded with 3kΩ to ground		±5	±8		V
V_{CC} Power-Supply Current	No load, T_A = +25°C	MAX202, MAX203		8	15	mA
		MAX200, MAX204-MAX208, MAX211, MAX213		11	20	
		MAX201, MAX209		0.4	1	
V+ Power-Supply Current	No load	MAX201		5	10	mA
		MAX209		7	15	
Shutdown Supply Current	Figure 1, T_A = +25°C	MAX200, MAX205, MAX206, MAX211		1	10	μA
		MAX213		15	50	
Input Logic Threshold Low	T_{IN}, $\overline{EN}$, SHDN, EN, $\overline{SHDN}$				0.8	V
Input Logic Threshold High	T_{IN}		2.0			V
	$\overline{EN}$, SHDN, EN, $\overline{SHDN}$		2.4			
Logic Pull-Up Current	T_{IN} = 0V			15	200	μA
RS-232 Input Voltage Operating Range			-30		+30	V
Receiver Input Threshold Low	V_{CC} = 5V, T_A = +25°C	Active mode	0.8	1.2		V
		Shutdown mode, MAX213, R4, R5	0.6	1.5		
Receiver Input Threshold High	V_{CC} = 5V, T_A = +25°C	Active mode		1.7	2.4	V
		Shutdown mode, MAX213, R4, R5		1.5	2.4	
RS-232 Input Hysteresis	V_{CC} = 5V, no hysteresis in shutdown		0.2	0.5	1.0	V
RS-232 Input Resistance	V_{CC} = 5V, T_A = +25°C		3	5	7	kΩ

ELECTRICAL CHARACTERISTICS (continued)

(MAX202/204/206/208/211/213 V_{CC} = 5V ±10%, MAX200/203/205/207 V_{CC} = 5V ±5%, C1-C4 = 0.1μF, MAX201/MAX209 V_{CC} = 5V ±10%, V+ = 9.0V to 13.2V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
TTL/CMOS Output Voltage Low	I_{OUT} = 3.2mA (MAX201, MAX202, MAX203), I_{OUT} = 1.6mA (all others)				0.4	V
TTL/CMOS Output Voltage High	I_{OUT} = 1.0mA		3.5			V
TTL/CMOS Output Leakage Current	$\overline{EN}$ = V_{CC}, EN = 0V, 0V ≤ R_{OUT} ≤ V_{CC}			0.05	±10	μA
Output Enable Time (Figure 2)	MAX205, MAX206, MAX209, MAX211, MAX213			600		ns
Output Disable Time (Figure 2)	MAX205, MAX206, MAX209, MAX211, MAX213			200		ns
Receiver Propagation Delay	MAX213	$\overline{SHDN}$ = 0V, R4, R5		4	40	μs
		$\overline{SHDN}$ = V_{CC}		0.5	10	
	MAX200-MAX211			0.5	10	
Transmitter Output Resistance	V_{CC} = V+ = V- = 0V, V_{OUT} = ±2V		300			Ω
Transition Region Slew Rate	C_L = 50pF to 2500pF, R_L = 3kΩ to 7kΩ, V_{CC} = 5V, T_A = +25°C measured from +3V to -3V or -3V to +3V	MAX200, MAX202-MAX211, MAX213	3	5.5	30	V/μs
		MAX201		4	30	
RS-232 Output Short-Circuit Current				±10	±60	mA
Maximum Data Rate	R_L = 3kΩ to 7kΩ, C_L = 50pF to 1000pF, one transmitter		120			kbps

HARDWARE SETUP



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REFERENCES

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