PPU College Of Engineering and Technology

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Electrical Engineering Department

Biomedical Engineering and Industrial Automation Engineering Programs

Bachelor Thesis

Graduation Project

Photovoltaic system for energizing an infant incubator

Project Team

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2013

ABSTRACT

Premature infant incubator system is a vital and critical area because it deals with premature infant or illness baby. It is essential to detect any abnormal conditions occur in the premature infant incubator system as soon as possible. Temperature, humidity, and oxygen concentration are the main parameters must be control in the premature infant incubator system.

In this project we designed a feedback control system to control the infant incubator parameters including temperature and humidity by using programmable logic controller (PLC) unit.

Photovoltaic system is used in this project in order to energize an infant incubator by implementing stand-alone type.

ملخص المشروع

الاطفال الخدج الذين يولدون قبل فترة الحمل الطبيعية هؤلاء الاطفال يحتاجون الى عناية خاصة وذلك لعدم اكتمال نموهم ووجود مشاكل لديهم في الرئتين او الكبد او لعدم اكتمال الجهاز العصبي لديهم وهذا يتطلب وجود جو مناسب و مشابه لجو رحم الأم يتضمن حرارة مناسبة ونسبة رطوبة و أكسجين ملائمة وذلك من خلال توفير جهاز طبي يتحكم بكل من الحرارة والأكسجين والرطوبة يدعى حاضنة الاطفال الخدج.

وقد تم في هذا المشروع تصميم جهاز الحاضنة للتحكم في الحراة والرطوبة من خلال استخدام المتحكم (PLC) .

كما تم في هذا المشروع بناء نظام طاقة شمسية لشحن جهاز الحاضنة باستخدام نظام الطاقة الشمسية المعزول (stand-alone) .

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1.1 Introduction

The incubator is considered as an air conditioned room with special specification which we can control it with respect to the condition of baby incubator which case the air flowing to upper area so dismiss the CO2 from the special upper windows.

Incubators are designed to provide an optimal environment for newborn babies with growth problems (premature baby) or with illness problems. The incubator is isolated area environment with no dust, bacteria, and has the ability to control temperature, humidity, and oxygen to remain them in acceptable levels such as (36°C-38°C) for temperature, (70%-75%) for humidity and (25%-60%) for oxygen Concentration.

In this project, Photovoltaic System will be used to energize an infant incubator. Besides being a clean source of energy, Photovoltaic System is a feasible solution in those areas where grid power is not available or reliable.

The system will not be connected to the grid. Solar photovoltaic panels will be used for power generation, while batteries will be used for energy storage and backup. The incubator and the power system will be controlled using Programmable Logic Controllers (PLC). Figure (1.1) shows a Photovoltaic Incubator System.

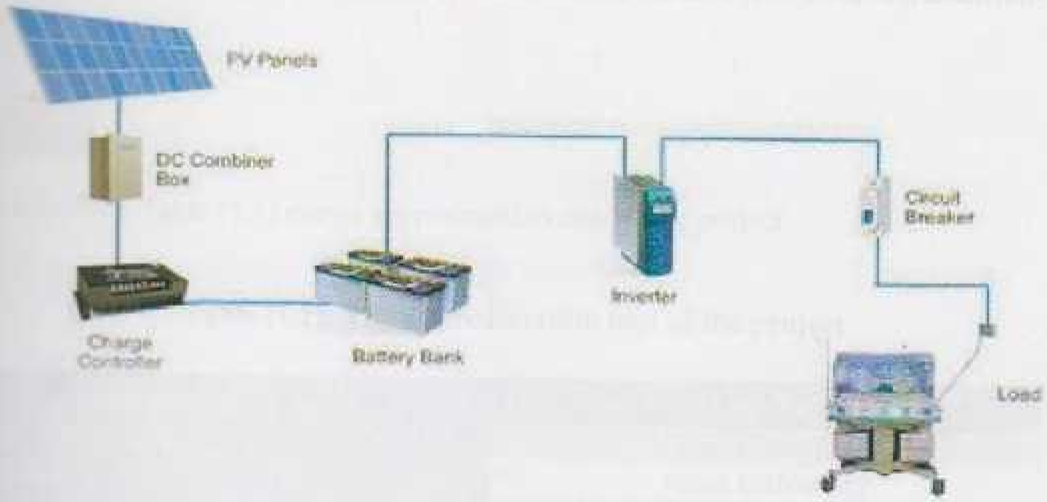


Figure (1.1): Photovoltaic Incubator System

The components used in this project is:

- Photovoltaic panels
- Batteries
- Charge controller
- Inverter
- Incubator

1.2 Objectives

The project aims to build and design photovoltaic system to energize an infant incubator, and use programming logic controller (PLC) to control in the Incubator Parameters.

1.3 Project advantages

Features of the project are summarized as follows:

- Photovoltaic System is a feasible solution in those areas where grid power is not available or reliable.
- Using pure, renewable and clear energy source.
- Preserve the lives of thousands of infants from the risk of interruption electricity.

1.4 Cost

The following Table (1.1) shows approximation cost of the project

Table (1.1): The approximation cost of the project

Components of project	Cost (NIS)
Photovoltaic unit	From University
Batteries	From University
Charge controller	400 NIS
Inverter	800 NIS
Incubator	From Al-Helal hospital
PLC & touch screen	2800 NIS
Wires & connection	300 NIS
TOTAL	**4300 NIS**

1.5 System operations of the project

The following steps summarize the work principle for the project:

- Photovoltaic panels receive sun shine and converts to DC voltage.
- The DC voltage is transfer through charge controller to charge batteries.
- After charging process is completed, the batteries supply dc voltage to the inverter.
- Inverter converts DC voltage to AC voltage to supply the load.
- Control panel used to run and control of an incubator.
- PLC used to control and monitor the workflow of the incubator.

1.6 Project Contents

This project contains six chapters, and these chapters can be summarizing as the following:

- **Chapter one**: This chapter gives a general idea and introduction about the whole project.
- **Chapter two**: this chapter talks about the infant incubator (history, types, block diagram) and includes the control and sensing system.
- **Chapter three**: Talks about Stand-alone photovoltaic system
- **Chapter four**: this chapter talks about system design.
- **Chapter five**: this chapter talks about hardware and software implementation
- **Chapter six**: Talks about Conclusion and recommendations

1.7 Time scheduling

The time planning includes two time schedules ; the first one shows what is done in the first semester as shown in Table (1.2) and the second shows the tasks scheduling for the second semester as shown in Table (1.3).

Table (1.2): First semester time scheduling

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Determine the project																
Collection of data																
Design and analysis																
Selection the component																
Documentation																

Table (1.3): Second semester time scheduling

Weeks	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Buy pieces and install them															
Work of control panel															
Connecting pieces															
Testing the project															

Chapter Two:

Infant Incubator

2.1 Introduction

2.2 History

2.3 Infant Physiological test

2.4 Definition

2.5 How it works

2.6 Types of an Incubator

2.7 The air circulation

2.8 Heat loss

2.9 Control System

2.10 Alarm System

2.11 Sensing System

2.1 Introduction

Premature infants born before the end of a full intra uterine pregnancy, so they have some difficulties in controlling: temperature, humidity level and oxygen concentration, these babies need a special care to maintain a healthy body temperature, regulate oxygen concentration and also humidity level, and by placing an infant in an incubator can control in these parameters.

2.2 History

History of an infant incubator [1] shown in Table (2.1)

Table (2.1) : History of an Infant Incubator

Prior to the eighteenth century	Keeping small babies warm swaddling with multiple layers of clothes, providing body constant with the mother.
1835	Von Ruehl warming tube
1891	First idea to construct an infant incubator
1901	First infant placed in an exhibit incubator in India
1907	A study released on regulating the infant body temperature
1932	First incubator proposed a mechanism for the additional
1933 ↓ Up to day	A report on the improved survival of a new born infant nurtured with humidity has released

2.3 Infant Physiological Test

- The newborn is commonly assessed with the APGAR test; A quick test performed at 1 and 5 minutes after birth to determine the physical condition of the newborn.
- APGAR test evaluates the newborn on 5 simple criteria on scale from "0" to "2":
  - Appearance → Skin Color.
  - Pulse → Heart Rate.
  - Grimace → Reflex Irritability.
  - Activity → Muscle Tone.
  - Respiration → Respiration Rate.
- Each of these categories is scored with 0, 1 or 2 depending on the observed condition of the newborn [2] as shown in Table (2.2).

Table (2.2): APGAR test

Criteria	Meaning	Score 0	Score 1	Score 2
Appearance	Skin Color	Blue all over	Blue at extremities	Normal
Pulse	Hear Rate	Absent	<100	>100
Grimace	Reflex Irritability	No response to stimulation	Grimace, feeble, cry when stimulated	Sneeze, cough, pulls away when stimulated
Activity	Muscle Tone	None	Some flexion	Active movement
Respiration	Respiration Rate	Absent	Weak or irregular	Strong

2.4 Definition

Infant incubator is a very little size house used during the care of such in-risk infants and designed with the intent of producing environmental conditions that suites to each unique infant particular needs[3].

2.5 How It Works

The incubator monitors the baby's skin temperature using a temperature probe which is taped to the baby's skin, Oxygen supplementary can be taken in by an oxygen inlet connection where it is mixed with fresh air through the filter. the humidity can be increased By the use of water paths (passive humidification) or By dripping water on a heating element (active humidification)[2].

2.6 Types of Incubators

There are many different kinds of incubators, depending on how they are constructed, heated and controlled [2]:

1) **Closed Incubator:**
Microclimate is produced within a rigid wall chamber ,it is heated using a fan to create a flow over a metallic heating coil to enter the infant chamber[1] this type includes:

A) **Intensive Care Incubator:**
Must be found at any hospital in the ICU and emergency department. It is the most important type because it provides controlled environment for (T, O_2 and humidity)[4]. Figure (2.1) shows Intensive Care Incubator .

Figure (2.1): Intensive Care Incubator

B) **Transport Incubator:**

Easily movable, safe and can be carried by ambulance because of its small size[2]. Figure (2.2) shows Transport Incubator

Figure (2.2): Transport Incubator

2) Open Incubator:

No wall and no chamber, It is heated using a radiant warmer focused over the mattress area[1], this type includes:

A) **Radiant heater:**

It is designed to provide a quick and effective treatment for newborn who suffer from extreme heat loss, it is not supplied with oxygen source[2]. Figure (2.3) shows a Radiant Heater.

Figure (2.3): Radiant Heater.

2.7 The Air Circulation:

Underneath the baby is an air-blown electric heating system and humidification system which circulates heated humid air at a desired temperature and humidity through the incubator chamber, Additional O_2 may be introduced to the chamber.

- **In closed door incubators the circulation will be around the x-axis as shown in Figure (2.4).**

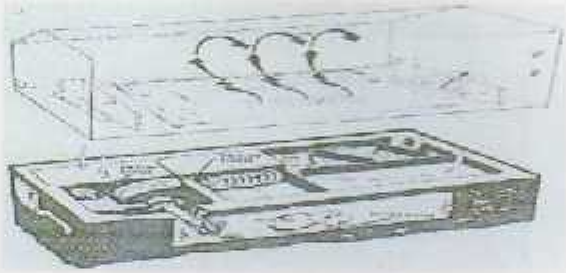


Figure (2.4): circulation around the x-axis

- **In opened door incubators the circulation will be around the y-axis[2] as shown in Figure (2.5)**

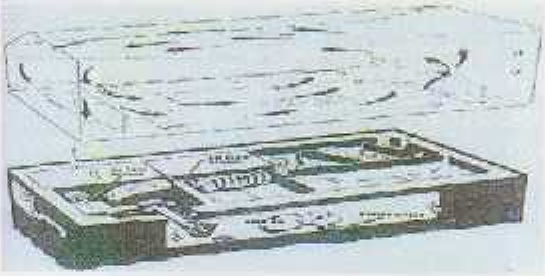


Figure (2.5): circulation around the y-axis

2.8 Heat Loss

- **Heat loss that happens when water evaporates from skin and respiratory tracts. Figure (2.6) shows Evaporation.**

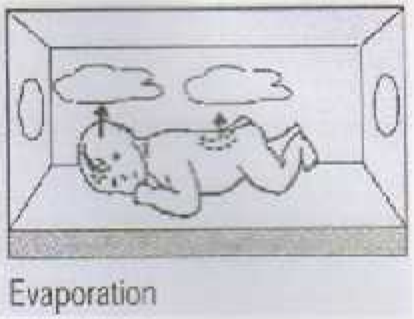


Figure (2.6): Evaporation

- **Heat loss to cooler surrounding. Figure (2.7) shows Conduction**

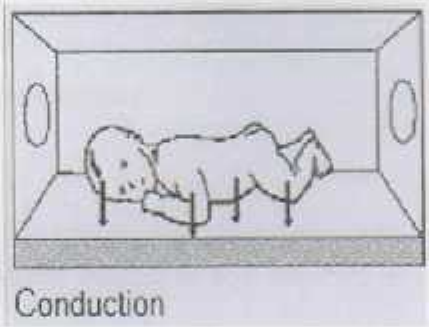


Figure (2.7): Conduction

- **Heat loss to cooler solid objects which are in direct physical contact .Figure (2.8) Shows convection.**

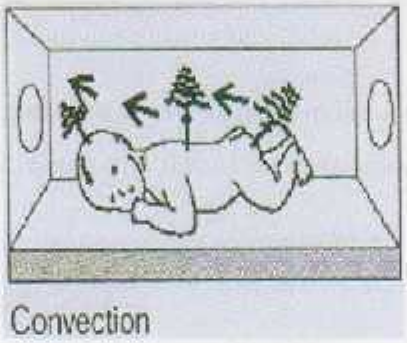


Figure (2.8): Convection

- **Heat loss to cooler solid objects which are not in direct physical contact[2]. Figure (2.9) shows Radiation.**

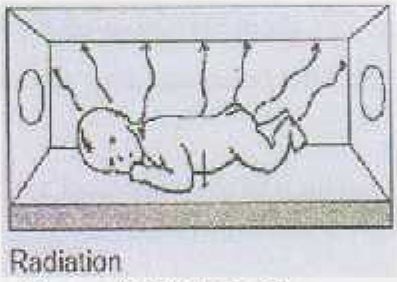


Figure (2.9) Radiation

2.9 Control System

To control the environment inside the hood of the incubator we have two main control circuits:

- Temperature Control.
- Humidity Control [3].

2.9.1 Temperature Control:

In most incubators there are two ways of controlling temperature

- Air temperature mode.
- Skin temperature mode.

In both ways the heaters output will be proportional to the amount of heat required to maintain the desired temperature [5].

2.9.1.1 Air temperature mode:

Incubator temperature is regulated by means of the temperature sensor located in the air path because (the control of temperature is achieved by means of a forced air circulation system)[6].

- The range of temperature measurement is between 5-50°C.
- The range of temperature control in the normal mode is between 20-37°C .
- The graduation unit of a temperature sensor is 0.1°C.
- Maximum setting temperature is increased to 39°C in the over- ride mode [7].
- The temperature is sensed by a probe located below the desk compared with set point.
- The initial set point is preset to 35°C ± 0.1°C, and the incubator will heat up to this temperature until the setting is changed
- An additional sensor can be used to monitor and control the maximum air temperature and at this time an alarm is activated and the heater shut off[3] .Temperature Control Flowchart shown in Figure (2.10)

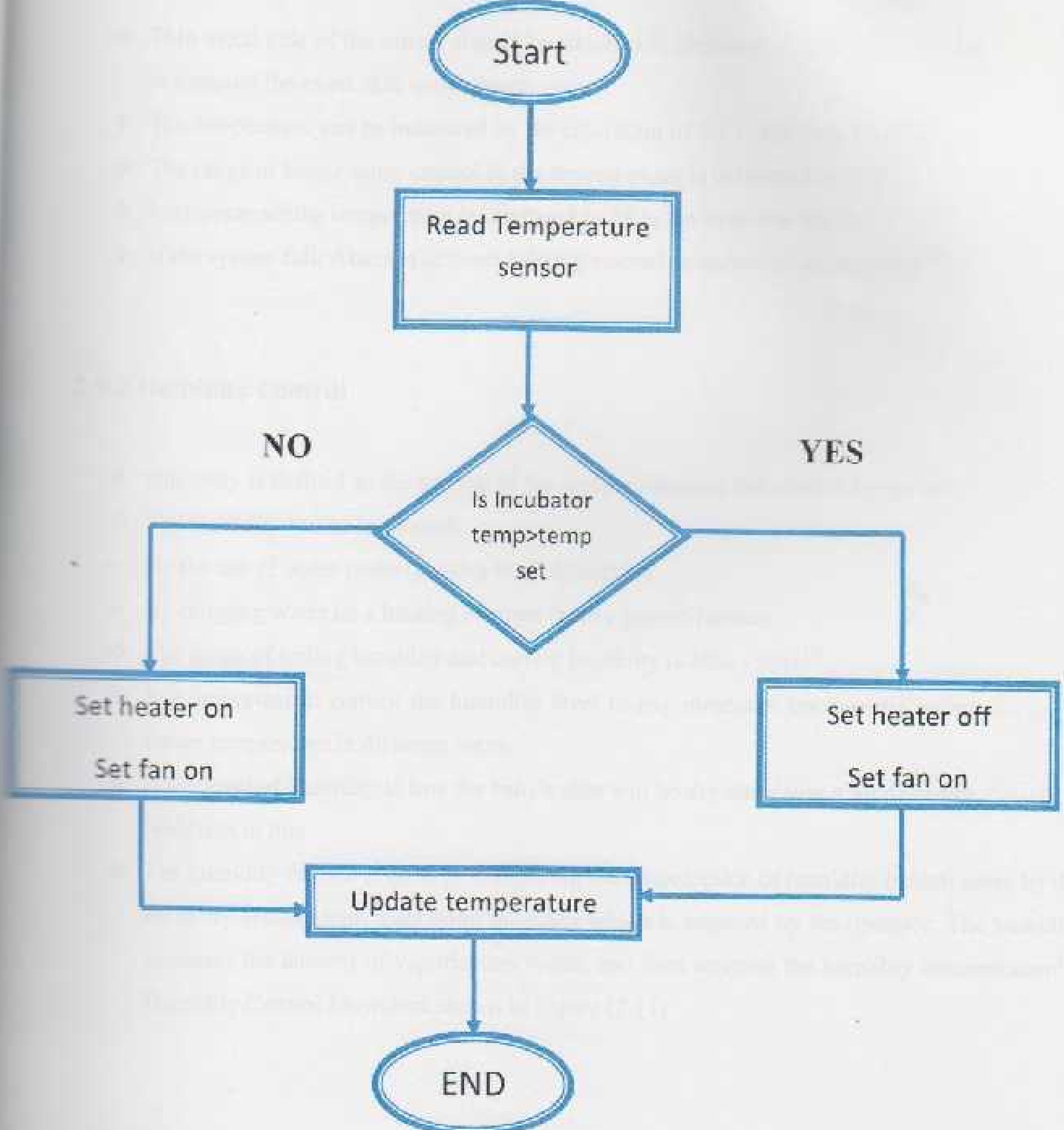


Figure (2.10): Temperature control flowchart

2.9.1.2 Skin temperature mode

- Thin metal side of the sensor should be attached to abdomen of an infant in order to measure the exact skin temperature.
- The temperature can be measured by the resolution of 0.1°C between 22-42°C.
- The range of temperature control in the normal mode is between 34-37°C.
- Maximum setting temperature is increased to 38 in the over-ride mode.
- If the system fail; Alarm is activated during normal operation of an incubator [7].

2.9.2 Humidity Control

- Humidity is defined as the percent of the water molecules that carried by the air.
- The humidity can be increased:
  - By the use of water paths (passive humidification)
  - By dripping water on a heating element (active humidification.
- The range of setting humidity and current humidity is 30% - 90%[7]
- It is important to control the humidity level in any incubator because the infant losses temperature in different ways.
- If the level of humidity is low the baby's skin will be dry and cause a lot of health problems to him
- The humidity control is done by comparing the sensed value of humidity (which sense by the humidity sensor) with a set point humidity which is adjusted by the operator. The humidity increases the amount of vaporization water, and then increase the humidity concentration[4]. Humidity Control Flowchart shown in Figure (2.11)

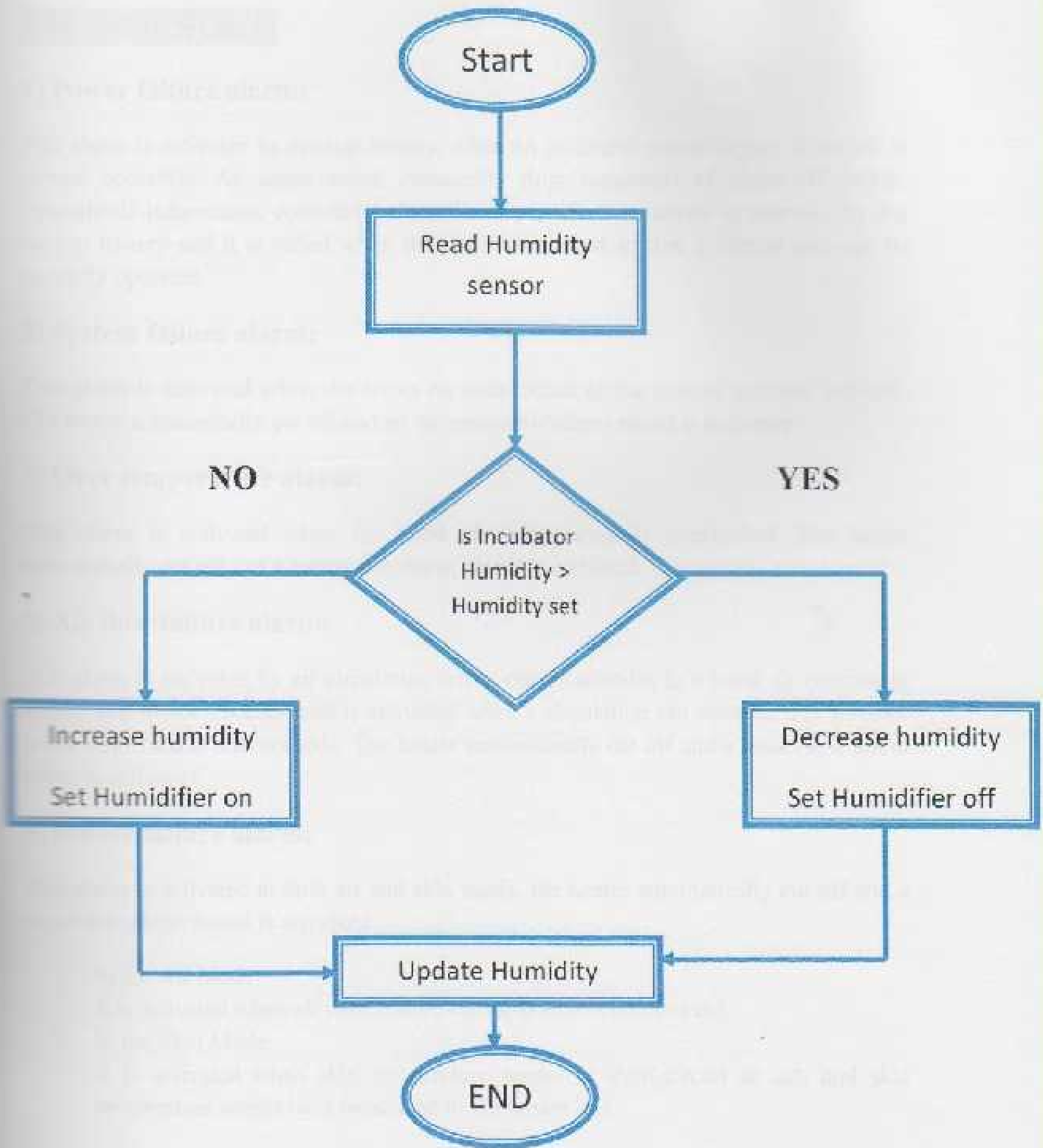


Figure (2.11): Humidity control flowchart

2.10Alarm System

1) Power failure alarm:

This alarm is activated by backup battery, when an incubator power supply is cut off in normal operation. An alarm sound incessantly rings regardless of alarm off switch. Operational information collected before the error occurs is stored in memory by the backup battery and it is called when the error is repaired so that a control part can be normally operated.

2) System failure alarm:

This alarm is activated when the errors on main board of the control part are detected. The heater automatically cut off and an un removable alarm sound is activated.

3) Over temperature alarm:

This alarm is activated when the hood air temperature is overheated. The heater automatically cut off and a removable alarm sound is activated.

4) Air flow failure alarm:

This alarm is activated by air circulation errors due to troubles in a hood air circulation system and motor troubles, and is activated when a circulation fan connected to a motor is not well fixed at a motor axis. The heater automatically cut off and a removable alarm sound is activated.

5) Sensor failure alarm:

This alarm is activated at both air and skin mode. the heater automatically cut off and a removable alarm sound is activated.

- In the Air Mode
  It is activated when air temperature sensor is short-circuit or cut.
- In the Skin Mode
  It is activated when skin temperature sensor is short-circuit or cut, and skin temperature sensor isn't connected to the sensor box.

6) Air temperature alarm

This alarm is activated when the difference between hood temperature and control temperature is higher than 1.5°C or lower than 3 °C during air mode. If an incubator starts at air mode, Air temperature alarm won't activated for about 40 minutes after the temperature is set and 15 minutes after the control temperature is changed.

7) Skin Temperature Alarm:

This alarm is activated when the difference of 1.0°C or higher between skin temperature and skin control temperature appears.

If the Air is lower than 34°C at air mode and if the skin temperature sensor is not attached on the patient skin, the skin temperature alarm is activated as soon as the mood is changed from air to skin[7] .

2.11 Sensing System

A sensor is a device, which responds to an input quantity by generating a functionally related output usually in the form of an electrical signal. The form of an output signal whether it is an AC or a DC signal whether the output is a change in resistance or a change in capacitance, and whether the signal is digital or analog[8].

The sensing system of the incubator consists of temperature and humidity .

2.11.1 Temperature sensor (LM 35)

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (centigrade) temperature .The LM35 thus has an advantage over linear temperature sensors calibrated in Kelvin ,as the user is not required to subtract a large constant voltage from its output to obtain convenient centigrade scaling.

The main features of the LM35 temperature sensor are:

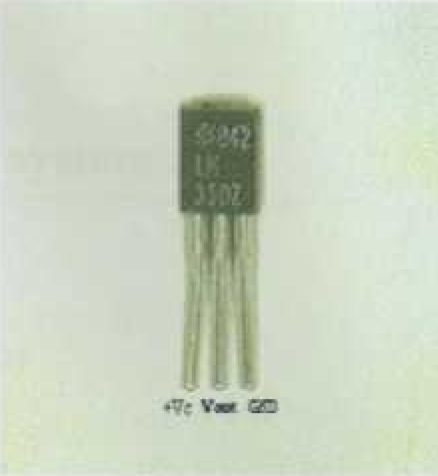


Figure (2.12): LM 35 sensor

- Calibrated directly in ° Celsius (Centigrade)
- Linear +10.0 m V/ °C scale facto
- 0.5 c accuracy guarantee able (at +25 ° C)
- Suitable for remote applications
- Low cost due to wafer- level trimming
- Operates from 4 to 30 volts[9].

  Temperature sensor LM35 shown in figure (2.12)

2.11.2 Humidity sensor (HIH 4030):-

HIH-4030 humidity sensor measures relative humidity (%RH) and delivers it as an analog output voltage. Voltage applied to the supply pins should be within 4-5.8 Volt DC, and optimally at 5 Volt. The sensor will typically only consume about 200µA.
This sensor has three pins as shown in the Figure (2.13)

Features:

- Near linear, analog output
- 4-5.8 Volt DC voltage supply
- All pins broken out to a 0.1" pitch header
- Laser trimmed interchangeability
- Low power design, typical current draw of only 200µA
- Enhanced accuracy
- Fast response time
- Stable, low drift performance

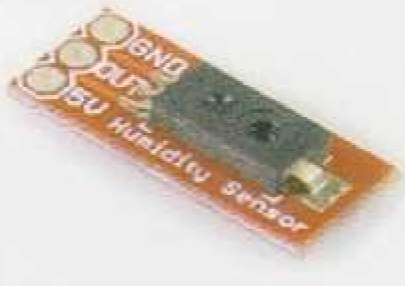


Figure (2.13): HIH 4030

Chapter Three:

Stand-alone photovoltaic system

3.1 Stand-alone photovoltaic system

3.2 Inverter

3.3 Charge controller

3.4 Solar batteries

3.5 Photovoltaic cell

3.1 Stand-alone photovoltaic system

Stand-alone photovoltaic power systems are electrical power systems energized by photovoltaic panels which are independent of the utility grid. These types of systems may use solar panels only or may be used in conjunction with a diesel generator or a wind turbine[10].

This system has two types of stand-alone photovoltaic power systems are direct-coupled system without batteries and stand alone system with batteries.

Stand-alone PV system include four devices are PV panels; charge controller, solar inverter, and batteries. Figure (3.1) shows Stand- alone photovoltaic system

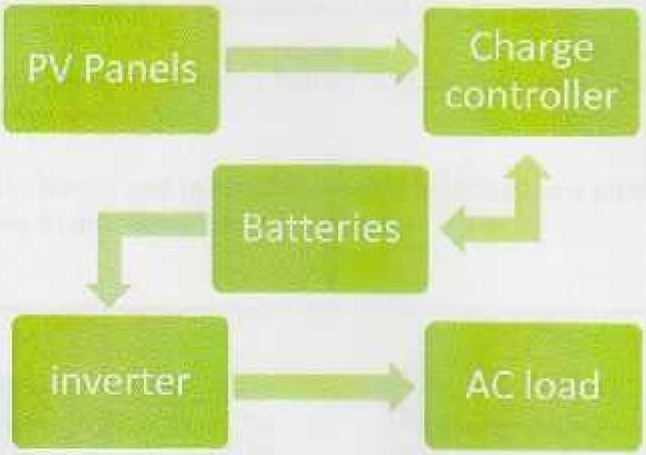


Figure (3.1):Stand-alone photovoltaic system

3.2 Solar Inverter

PV inverter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network.

Solar inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection.

3.2.1 Types of solar inverters

There are three distinct types of solar energy inverters [11], each of which serve a different function and are used for a different type of solar energy system, although each inverter still converts DC into AC:

1. Stand Alone Solar Inverter

- Stand-alone inverters are often used to convert direct current produced by many renewable energy sources like solar panels or small wind turbines, into the alternating current..
- It runs by pulling direct current power from batteries charged by other resources like engine generators, hydro turbines and wind turbines.
- Stand-alone inverters refill the battery coming from an alternating current source whenever possible.
- It is used in homes and in small industrial buildings as a power backup. Figure (3.2) shows Stand Alone Solar Inverter.

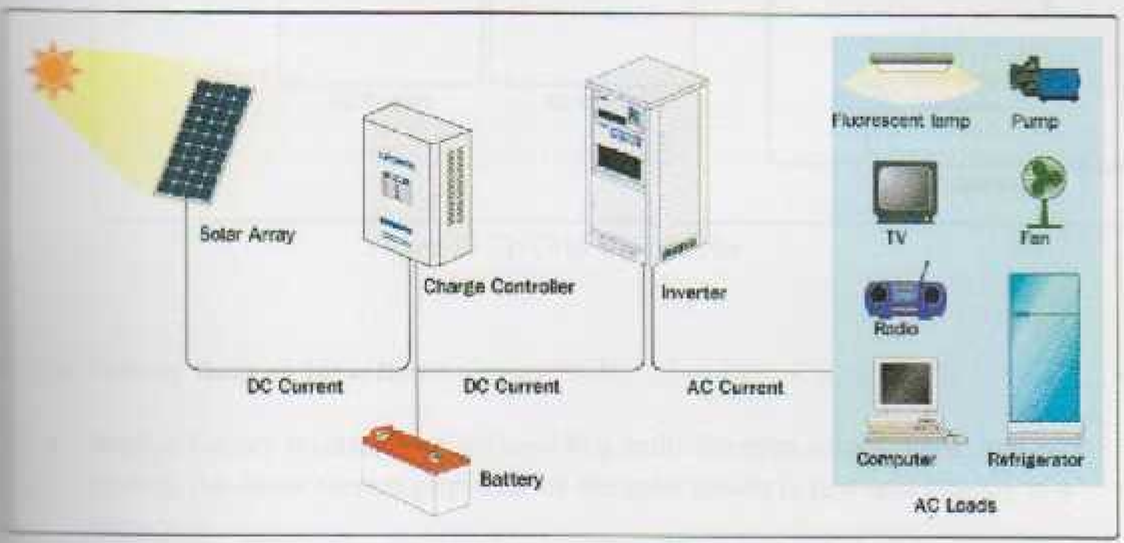


Figure (3.2): Stand Alone Solar Inverter.

2. The Grid Tie Inverters

- Is connected to utility grid and feeds power back into the grid. The system consists of PV panel connected to grid tie inverter .

- The power produced by the PV system can be either supplied to loads or fed back into grid when the PV system output is greater than the load demand.

- When the PV system output is less than the load demand (e.g. at night), energy will be consumed from the utility grid. Figure (3.3) shows Grid Tie Inverter

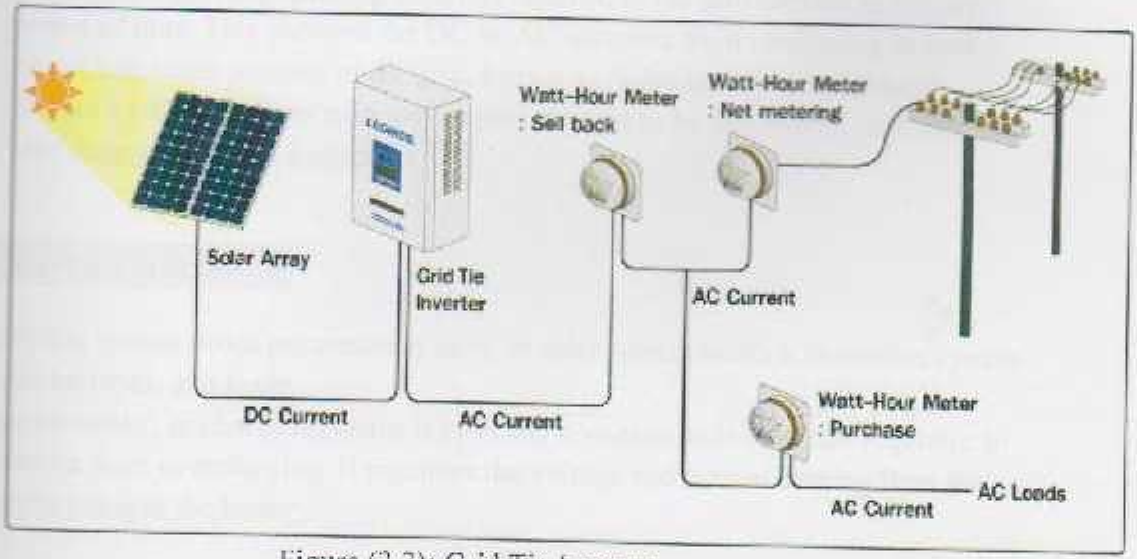


Figure (3.3): Grid Tie Inverter

3. The Battery Backup Inverters

- Backup battery inverters and are used in a multi-function solar system. In this system, the direct current generated by the solar panels is first sent directly to a battery.

- The energy from the batteries is then sent to the inverter and converted to alternating current whenever electricity is required. However, when the batteries are fully charged, any excess direct current electricity that is generated is sent directly to the inverter and is then sent into the local power grid.

- This system combines the other two systems into one self-reliant and possibly money generating solar unit.

3.2.2 Special functions of inverters:

1. **Maximum power point tracking (MPPT)** :
   is a technique that grid-tie inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels,[12] though optical power transmission systems can benefit from similar technology.

2. **Anti-islanding protection:**
   In the event of a power failure on the electric grid, it is required that any independent power-producing inverters attached to the grid turn off in a short period of time. This prevents the DC-to-AC inverters from continuing to feed power into small sections of the grid, known as "islands." Powered islands present a risk to workers who may expect the area to be unpowered, and they may also damage grid-tied equipment [12].

3.3 Charge controller

Any electrical system needs protection system, so solar system needs a protection system for panels, batteries, and loads.
A charge controller, or charge regulator is basically a voltage and/or current regulator to keep batteries from overcharging. It regulates the voltage and current coming from the solar panels going to the battery.

3.3.1 Working principle:

The principle behind a solar charge controller is simple (Figure 3.4). There is a circuit to measure the battery voltage, which operates a switch to divert power away from the battery when it is fully charged. Because solar cells are not damaged by being short or open-circuits, either of these methods can be used to stop power reaching the battery.

A controller which short-circuits the panel is known as a shunt regulator, and that which opens the circuit as a series regulator. Optionally there may also be a switch which automatically disconnects the power from the loads when the battery voltage falls dangerously low. This is known as a low-voltage disconnects function [13].

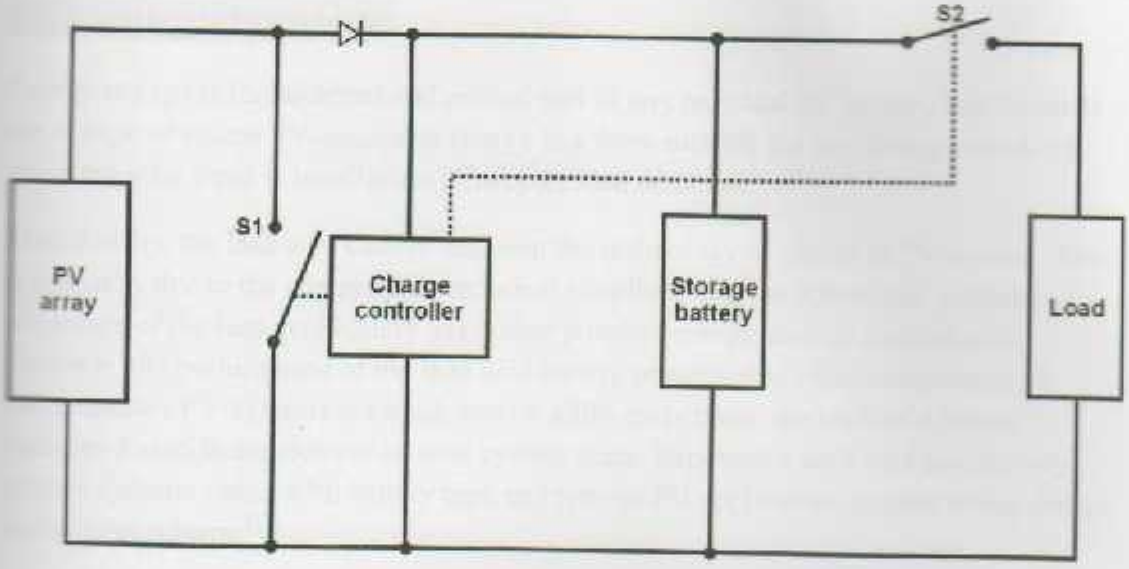


Figure (3.4): Working principle of charge controller.

3.3.2 Basics of charge controller:

1) Regulation set point (VR): This set point is the maximum voltage a controller allows the battery to reach. At this point a controller will either discontinue battery charging or begin to regulate the amount of current delivered to the battery. Proper selection of this set point depends on the specific battery chemistry and operating temperature.

2) Low voltage disconnects (LVD): The set point is voltage at which the load is disconnected from the battery to prevent over discharge. The LVD defines the actual allowable maximum depth-of-discharge and available capacity of the battery. The available capacity must be carefully estimated in the system design and sizing process.

3.4 Lead acid battery:

Energy storage is fundamental and critical part of any practical PV system, and involves the storage of excess PV-generated energy in a form suitable for use during periods of when the solar input is insufficient to support load demands.

Traditionally, the lead acid battery has been the technology of choice in PV-system. This is primarily due to the comparative technical simplicity and the substantial capital cost advantage of the lead acid battery over other possible energy storage technologies. However, the performance of the lead acid battery compared to other components of contemporary PV-systems is varied, and on a life cycle basis, the lead-acid battery becomes a significant element of total system costs. Experience with lead acid battery storage systems varies with battery type and type of PV application, system sizing design and control scheme [12].

Definition the battery:

Is combination of one or more electrochemical cells, used to convert stored chemical energy into electrical energy.

3.4.1 Batteries for solar systems:

There are several different types of battery chemistry including liquid lead-acid, nickel-iron (NiFe), nickel-cadmium (NiCad), alkaline, and gel-cell.

Batteries are either sealed or vented. Simply, there are only two principal types of batteries:

1- Starting batteries

Starting batteries are designed for high cranking power, but not for deep cycling. Used as energy storage, they will not last long in a deep cycle application. Starting batteries use lots of thin plates to maximize the surface area of the battery. This allows very high starting current but lets the plates warp when the battery is cycled. This type of battery is not recommended for the storage of energy in hybrid system. However, they are recommended as starting battery for the back-up generator.

2- Deep cycle batteries

Deep cycle batteries are the type of battery best suited for use with inverters. The physical dimension of the plates is thicker and the active material that holds the charge is denser to increase cycle life.

The deep cycle type of battery is designed to have the majority of their capacity used before being recharged. They are available in many sizes and in either non-sealed or sealed types.

3.4.2 Battery Specification

1- Days of autonomy Rely On:

Autonomy is the number of days a battery storage system will provide the load without being recharged by the photovoltaic solar panels or another source.

Days of autonomy rely on weather conditions, so the number of non-sun and cloudy days of autonomy. The designer can reduce the number of days of autonomy when adding a hybrid alternative as generator or wind turbine. The days of autonomy affect the size and cost of the solar system.

2-Battery Capacity:

The capacity of battery is based on the power needed to operate the loads and how much stored energy will be needed to feed the loads when the weather is cloudy.

Battery capacity is affected by load, rate of discharge, depth of discharge, temperature and age.

3-Rate and depth of discharge:

The rate of discharge affects the battery capacity. If it is discharged quickly the capacity is less, but when the battery is discharged slowly the capacity will be greater.

Depth of discharge (DOD) refers to how much capacity will be withdrawn from the battery. Battery life is affected by the depth of discharge as shown in Figure (3.5).

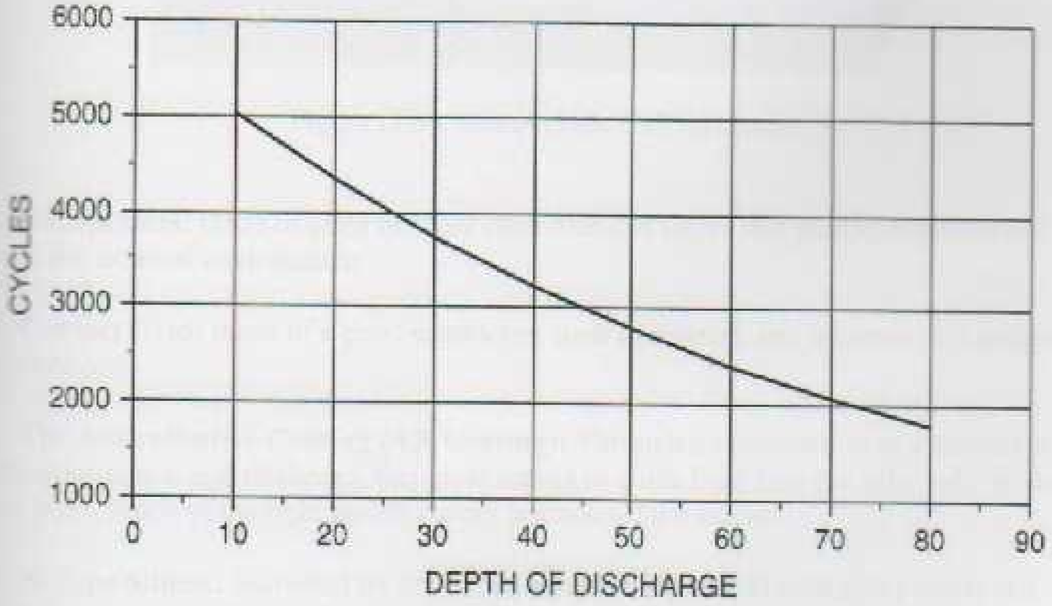


Figure (3.5): Impact of Depth of Discharge on the Number of Cycles [1]

3.5 Photovoltaic Technology

Solar energy technologies, which harness the sun's energy to generate electrical power, are one of the fastest growing sources of renewable energy on the market today. Around the world, engineers and scientists are collaborating to lower the material costs of solar cells, increase their energy conversion efficiency, and create innovative and efficient new products and applications based on photovoltaic (PV) technology.

3.5.1 Photovoltaic Cell Structure:

Figure (3.6): Photovoltaic Cell Structure

A. **Encapsulate:** made of glass or other clear material such clear plastic, seals the cell from the external environment.

B. **Contact Grid:** made of a good conductor, such as a metal, and it serves as a collector of electrons.

C. **The Antireflective Coating (AR Coating):** Through a combination of a favorable refractive index, and thickness, this layer serves to guide light into the solar cell. Without this layer, much of the light would simply bounce off the surface.

D. **N-Type Silicon:** is created by doping (contaminating) the Si with compounds that contain one more valence electrons than Si does, such as with either Phosphorus or Arsenic. Since only four electrons are required to bond with the four adjacent silicon atoms, the fifth valence electron is available for conduction.

E. **P-Type Silicon:** is created by doping with compounds containing one less valence electrons than Si does, such as with Boron. When silicon (four valence electrons) is doped with atoms that have one less valence electrons (three valence electrons), only three electrons are available for bonding with four adjacent silicon atoms, therefore an incomplete bond (hole) exists which can attract an electron from a nearby atom. Filling one hole creates another hole in a different Si atom. This movement of holes is available for conduction.

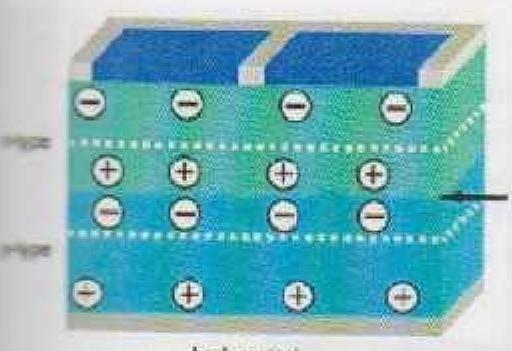
F. **Back Contact:** made out of a metal, covers the entire back surface of the solar cell and acts as a conductor.

3.5.2 P-N junction:

The region in the solar cell where the n-type and p-type Si layers meet is called the p-n junction. As you may have already guessed, the p-type silicon layer contains more positive charges, called holes, and the n-type silicon layer contains more negative charges, or electrons. When p-type and n-type materials are placed in contact with each other (see figure 3.7a), current will flow readily in one direction (forward biased) but not in the other (reverse biased).

An interesting interaction occurs at the p-n junction of a darkened solar cell. Extra valence electrons in the n-type layer move into the p-type layer filling the holes in the p-type layer forming what is called a depletion zone. The depletion zone does not contain any mobile positive or negative charges. Moreover, this zone keeps other charges from the p and n-type layers from moving across it.

So, to recap, a region depleted of carriers is left around the junction, and a small electrical imbalance exists inside the solar cell. This electrical imbalance amounts to about 0.6 to 0.7 volts. So due to the p-n junction, a built in electric field is always present across the solar cell.



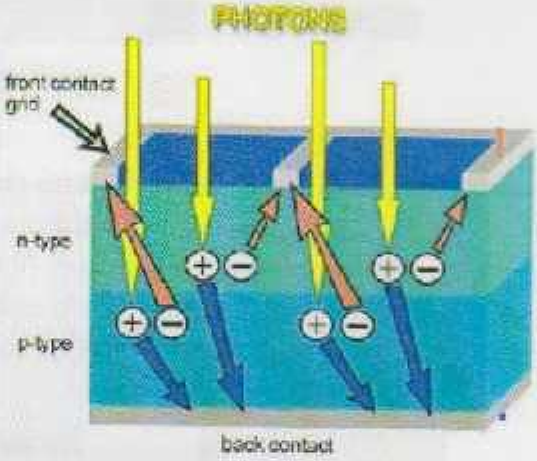


Figure (3.7: a) solar cell p-n junction, b) p-n junction when photons hit the solar cell

When photons hit the solar cell (see Figure 3.7.b), freed electrons (-) attempt to unite with holes on the p-type layer. The p-n junction, a one-way road, only allows the electrons to move in one direction. If we provide an external conductive path, electrons will flow through this path to their original (p-type) side to unite with holes.

3.5.3 Types of photovoltaic cells

1. Monocrystalline cells:

Monocrystalline cells are made from thin slices (wafers) cut from a single crystal of silicon as shown in (figure 3.8), which is produced by immersing a crystal nucleus with a defined orientation into a bath of melt-silicon and very slowing drawing the crystal from the bath. The wafer is doped with impurities to form p-type areas and n-type areas [12]. After that, electrical leads are attached to the wafers, thus forming the Monocrystalline cells. The cell efficiency of Monocrystalline cells is in the range of 15 - 18%.

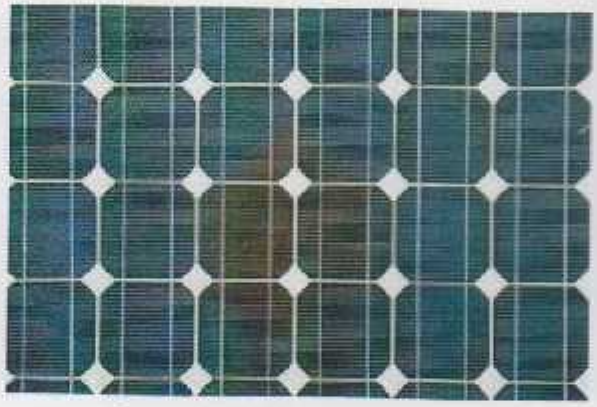


Figure (3.8): Monocrystalline.

2. Polycrystalline cells

Polycrystalline cells are made from thin slices (wafers) cut from a cast silicon block. After doping the wafer with impurities and attaching electrical leads to the wafer, polycrystalline cells are formed as shown in (figure 3.9). Since crystals of various orientations are formed during block casting, the surface of a polycrystalline cell has an appearance of shattered glass [12]. The cell efficiency of polycrystalline cells is in the range of 13 -16%.

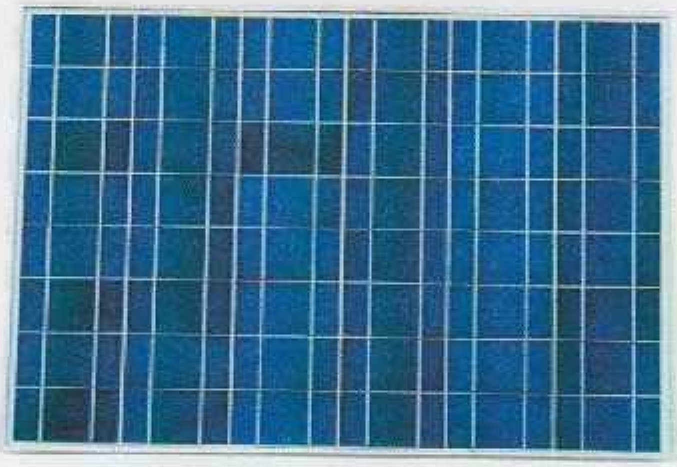


Figure (3.9): Polycrystalline silicon.

3. Amorphous silicon cells

amorphous cells are made by applying a thin layer (film) of active silicon on a solid substrate or flexible backing, typically a thin stainless steel sheet. After doping the wafer with impurities and attaching electrical leads to the wafer, polycrystalline cells are formed as shown in (figure 3.10). The advantages of amorphous silicon cells include lower cost than that of crystalline cells, and can be applied on flexible and light-weight substrate. However, they have the disadvantage of lower efficiency and the problem of light-induced degradation[12]. The module efficiency of amorphous silicon modules is in the range of 5 - 8 %.

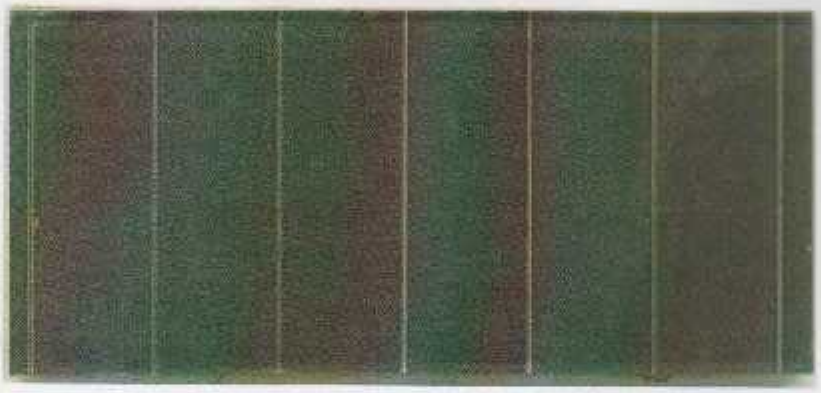


Figure (3.10): Amorphous silicon.

4. Copper indium diselenide cells (CIS cells)

The active semiconductor material of CIS cells is made from copper indium diselenide alloyed with gallium and/or sulphur. The CIS cells do not have the problem of light-induced degradation but they show stability problems in hot and humid environments. The module efficiency of CIS modules is between 7.5 - 9.5%, which is the highest among all thin-film technologies (figure 3.11).

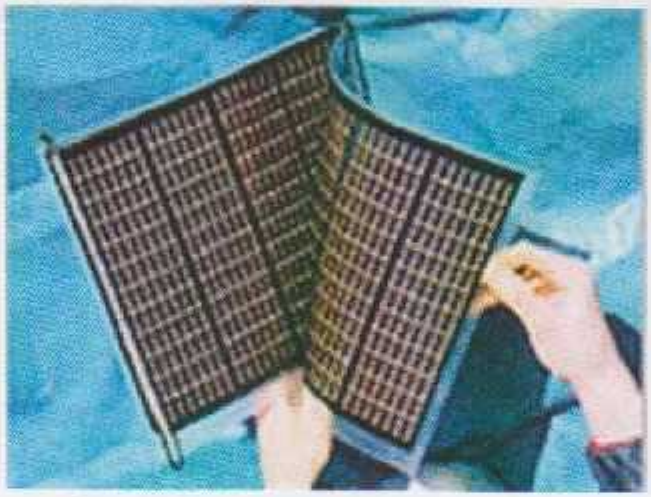


Figure (3.11): Copper indium diselenide

5. Cadmium telluride cells (CdTe cells)

CdTe cells are thin film cells with cadmium telluride as the active semiconductor material (figure 3.12). The cadmium telluride layer acts as the p-type absorber layer and is coated on top of an n-type cadmium sulphide layer. The module efficiency of CdTe modules is between 6-9%

Figure (3.12): Cadmium telluride

3.5.4Equivalent circuit of a solar cell:

PV cells can be modeled as a current source in parallel with a diode. When there is no light present to generate any current [3], the PV cell behaves like a diode [21]. As the intensity of incident light increases, current is generated by the PV cell, as illustrated in figure (3.13).

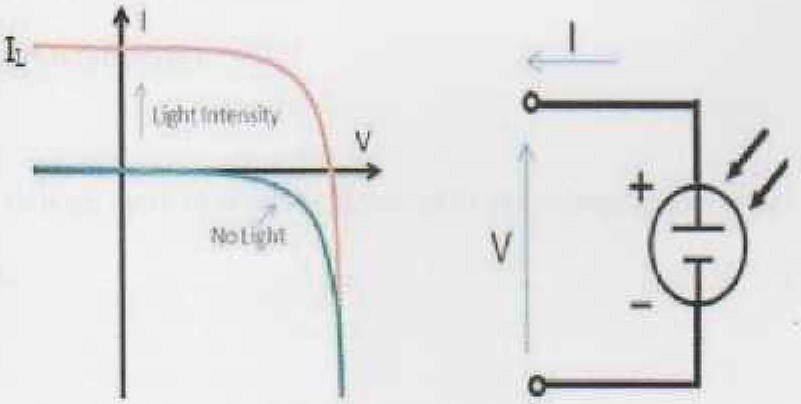


Figure 3.13: I-V Curve of PV Cell and Associated schematic symbol of solar cell

From the equivalent circuit (see Fig 3.14), it is evident that the current produced by the solar cell is equal to that produced by the current source, minus that which flows through the diode, minus that which flows through the shunt resistor :

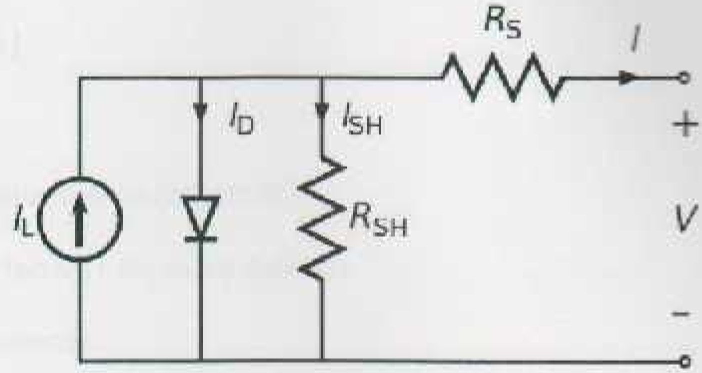


Figure 3.14: Simplified Equivalent Circuit Model for a Photovoltaic Cell

$$I = I_L - I_D - I_{SH} \qquad (3.1)$$

Where:

I: output current (amperes).

I_L: photogene rated current (amperes).

I_D: diode current (amperes).

I_{SH}: shunt current (amperes).

The current through these elements is governed by the voltage across them:

$$V_J = V + I.R_S \qquad (3.2)$$

Where:

V_J: Voltage across both diode and resistor R_{SH} (volt).

V: voltage across the output terminals (volt).

I: output current (amperes).

Rs: series resistance (Ω).

By the diode law, the current diverted through the diode is:

$$I_D = I_0 [e^{[\frac{qVJ}{nKT}]} - 1] \quad (3.3)$$

Where:

I_0: reverse saturation current (amperes).

n: diode ideality factor (1 for an ideal diode).

K: Boltzmann's constant.

T: absolute temperature.

By Ohm's law, the current diverted through the shunt resistor is:

$$I_{SH} = \frac{VJ}{RSH} \quad (3.4)$$

Where:

RSH: shunt resistance (Ω).

Substituting these into the first equation produces the characteristic equation of a solar cell, which relates solar cell parameters to the output current and voltage:

$$I = I_L - I_0 [e^{[\frac{qVJ}{nKT}]} - 1] - \frac{V + I.RS}{RSH} \quad (3.5)$$

3.5.5 The affects of temperature

(Figure 3.15) shows the effects of temperature on the I-V curve of a PV cell. I_{SC} increases slightly with temperature by about 6μA per °C for $1cm^2$ of cell; this is so small that it is normally ignored. However, a more significant effect is the temperature dependence of voltage which decreases with increasing temperature. Typically the voltage will decrease by 2.3mV per °C per cell.

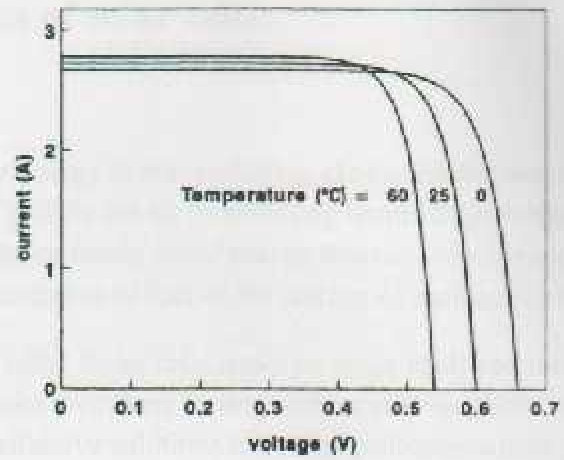


Figure (3.15): Effect of temperature on the I-V c curve of a solar cell.

3.5.6 The affects of irradiance

Solar irradiance is a measure of the sun's energy, under standard conditions the amount of energy reaching the Earth's surface on a clear day is taken to be $1kW/m^2$. The amount of irradiance reduces with the slightest amount of haze and becomes quite small on overcast days. I_{SC} is directly proportional to the irradiance; so that if irradiance halves so does I_{SC}. The voltage variation is very small and usually ignored (see fig 3.16).

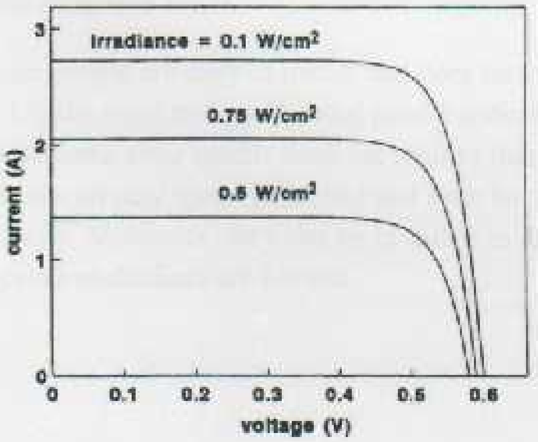


Figure (3.16): The effects of irradiance on the I-V curve of solar cells.

3.5.7 Advantages of solar cells:

1. **No Pollution:** Solar energy is non-polluting, clean, reliable and renewable source of electricity. It does not pollute the air by releasing harmful gases like carbon dioxide, nitrogen oxide and sulphur oxide. Solar energy does not require and fuel and thus avoid the problems of transportation of fuel or the storage of radioactive waste.

2. **Long lasting solar cells:** Solar cells make no noise at all and there are no moving parts in solar cells which make them long lasting and require very little maintenance. Solar energy provides cost effective solutions to energy problems where there is no electricity at all.

3. **Renewable Source:** Solar energy is a renewable source of energy and will continue to produce electricity as long as sun exists. Although solar energy cannot be produce during night and cloudy days but it can be used again and again during day time. Solar energy from sun is consistent and constant power source and can be used to harness power in remote locations.

4. **Low maintenance:** A solar cell generally doesn't require any maintenance and run for long time. More solar panels can be added from time to time when needed. Although, solar panels have initial cost but there are no recurring costs. Initial cost that is incurred once can be recovered in the long run. Apart from this, solar panel does not create any noise and does not release offensive smell.

5. **Easy Installation:** Solar panels are easy to install and does not require any wires, cords or power sources. Unlike wind and geothermal power stations which require them to be tied with drilling machines, solar panels does not require them and can be installed on the rooftops which means no new space is needed and each home or business user can generate their own electricity. Moreover, they can be installed in distributed fashion which means no large scale installations are needed.

3.5.8 Disadvantages of Solar Cells:

1. **Initial Cost:** The initial cost of purchasing and installing solar panels always become the first disadvantage when the subject of comes up. Although subsidy programs, tax initiatives and rebate incentives are given by government to promote the use of solar panels we are still way behind in making full and efficient use of solar energy. As new technologies emerge, the cost of solar panels is likely to decrease and then we can see an increase in the use of solar cells to generate electricity.

2. **Reliability:** Unlike other renewable source which can also be operated during night, solar panels prove to be useless during night which means you have to depend on the local utility grid to draw power in the night. Else you can buy solar batteries to store excess power which you can later utilize in the night.

3. **Variability of available solar Radiation:** Weather can greatly affect the power output of any solar-based energy system. Variations in climate or site conditions require modifications in system design.

4. **Energy storage:** Some PV systems use batteries for storing energy, increasing the size, cost, and complexity of a system.

5. **Inefficiency:** Since not all the light from the sun is absorbed by the solar panels therefore most solar panels have a 40% efficiency rate which means 60% of the sunlight gets wasted and is not harnessed. New emerging technologies however have increased the rate of efficiency of solar panels from 40 to 80% and on the downside have increased the cost of solar panels as well.

Chapter four:

System design

4.1 Introduction

4.2 Programmable logic controller

4.3 Block diagram of the project

4.4 Photovoltaic design

4.1 Introduction

In this chapter we will design the control Unit in the incubator (PLC and touch screen), the block diagram of the project, and photovoltaic system design.

Photovoltaic design includes the size of PV panels, inverter, charge controller, and battery to fit with the size of load.

In this project we will use PLC and user interface (touch screen), with analog control signal; to control of temperature, humidity sensors in incubator.

4.2 Design of control Unit

Designing the control unit basically depends on system requirement such as determine the external interfacing units with the control unit and the methods used to transfer data between the units that connected to the control unit.

4.2.1 Programmable logic controller (PLC)

PLC that used is Delta , with model DVP-20EX , it's contain 8 digital input ,6 digital output , 4 analog input and 2 analog output , choosing this model is based upon containing internal extension module that gives analog inputs and outputs needed for sensors used in project. There are four analog sensors: Air Temperature sensor, Skin Temperature sensor, Humidity sensor, voltage divider for battery.

The function of PLC in project is to take analog command from sensors, process it and gives the appropriate decision based upon program save inside PLC, it deals with orders step by step, every step is 20mv, and the analog signal in PLC is dealt from -10mv to 0 and from 0 to 10mv.

PLC 20EX is connected with relays through digital Output and with sensors through analog input. PLC 20EX connections as shown in Figure (4.1) is:

X0 → X7: digital input.

V0+ → V4- : analog input.

Y0 → Y3: digital output.

AO+ → A1- : analog output.

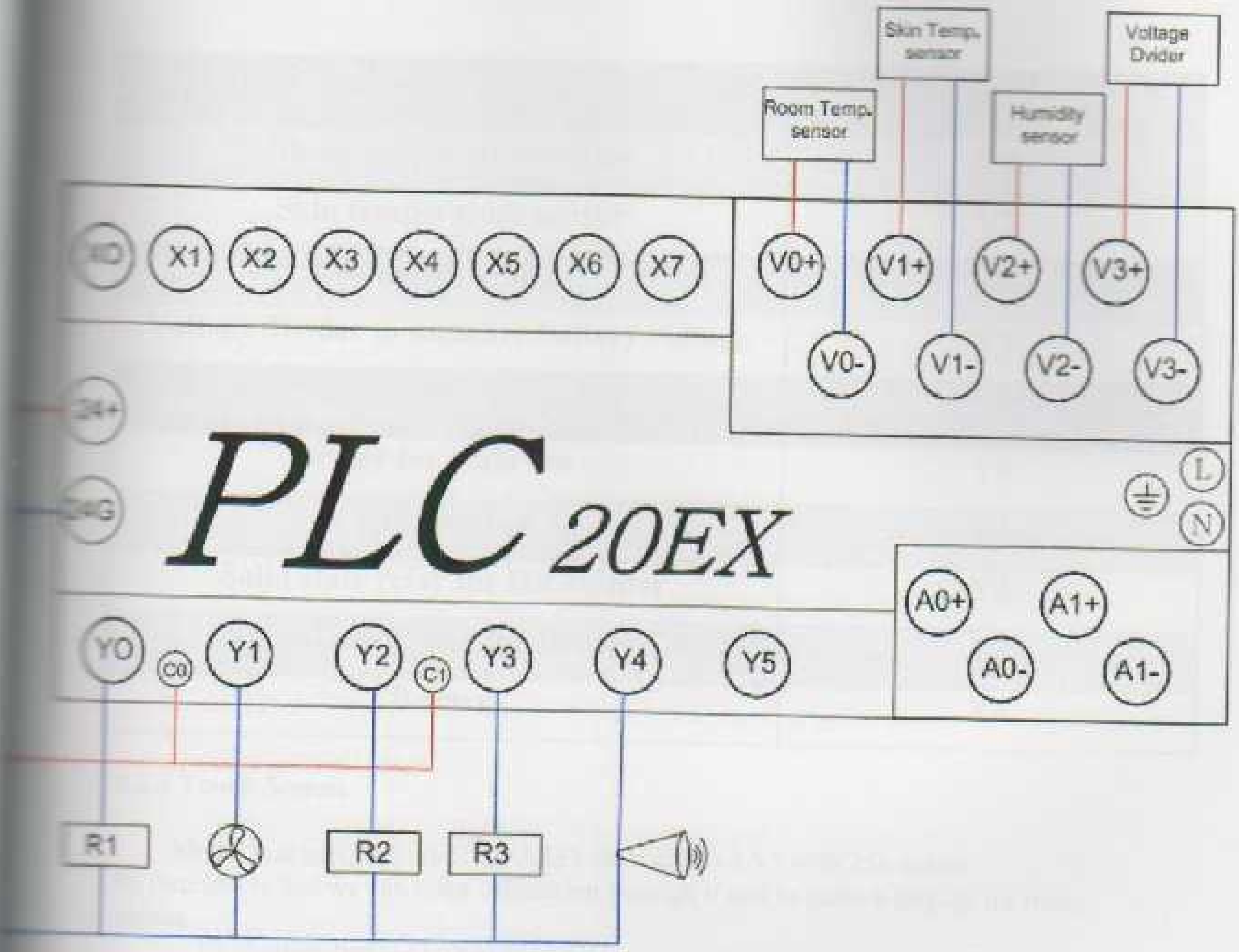


Figure (4.1): PLC 20EX Connections

Table (4.1): input /output allocation table.

Input variable	Address
Room temperature sensor	V0
Skin temperature sensor	V1
Humidity sensor	V2
Voltage divider to measure battery voltage	V3
output variable	**Address**
relay for main fan	Y0
External fan	Y1
Solid state relay for Humidifier	Y2
Solid state relay for Heater	Y3
Buzzer	Y4

4.2.2 Touch Screen

Model that used is delta DOP-AS35, its width is 3.5 " with 256 colors. Its function is that we can enter calibration through it and to make a display for many values.

Calibration that set by touch screen:

- Biomedical calibration
  - switching on and off System as a whole.
  - switching on and off heater
  - switching on and off humidifier
  - switching on and off alarm system
- Display page show:
  1) Air temperature
  2) Skin temperature
  3) Humidity percentage
  4) If an emergency condition happened, show what it is.

4.2.3 Control Unit Diagram

Control unit diagram shown in Figure (4.2) :

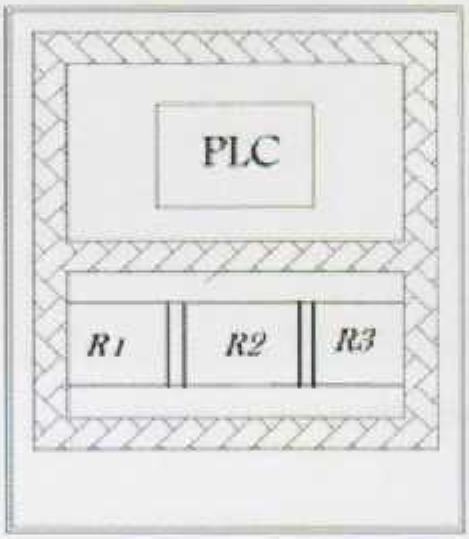


Figure: (4.2) : Control Unit Diagram

Where :

R1, R2: 220 VAC solid state relays for heater and humidifier respectively

R3: power relay 24v used for induction motor

PLC : programmable logic Controller, delta PLC (DVP-20EX).

4.2.4 Amplification circuit

Because the output voltage of LM35 Temperature sensor is between 0 mV and 10 mV and isn't reach the step voltage (20mv) , so to connect this sensor with PLC we need to amplify the output voltage of sensor, this done by using the LM358 Operational Amplifier as a non inverting amplifier with gain 10 to amplify the output voltage that is used for calibration (0.1 Volt for 1 °C). Amplification circuit shown in Figure (4.3)

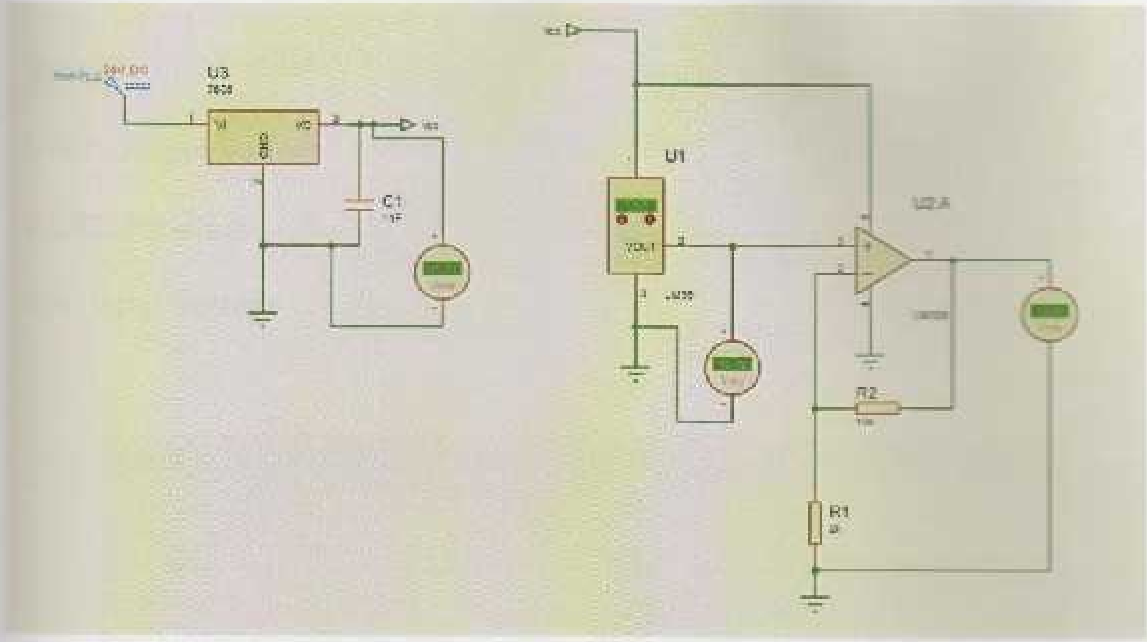


Figure (4.3): Amplification circuit

$$Av = 1 + R2/R1 \quad (4.1)$$
$$= 1 + 18K/2K = 10$$

Where :

Av: Gain (number of amplification)

R1,R2 :resistors

4.2.5 Battery voltage measurement

We can measure battery voltage by using 2 weirs putting on battery electrode.Through voltage divider circuit used to protect PLC analog module. and finally to PLC analog module to Read the voltage of the battery (figure 4.4).

$$Vout = Vin * \frac{R2}{R2+R1} \quad (4.2)$$

$$= 12 * \frac{5K}{5K+1K} = 10V$$

Where :

Vout :output voltage

R1,R2: resistors

Vin :input voltage

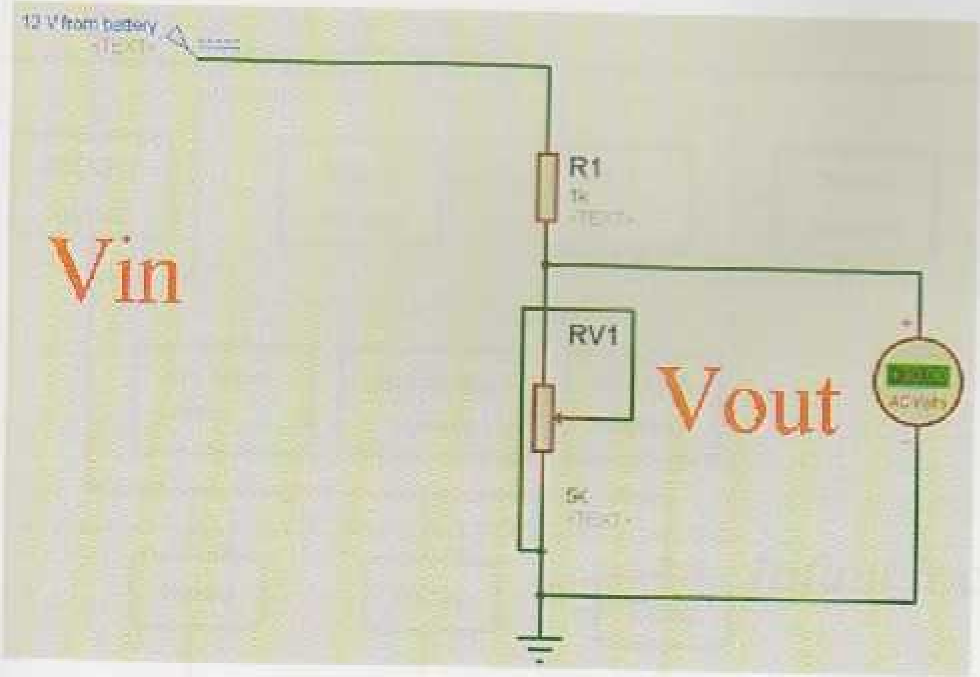


Figure (4.4): Voltage divider circuit

When the battery voltage drops to below 10 Volt, the alarm turn-on.

4.3 Block diagram of the project

Block diagram of the project shown in Figure (4.5)

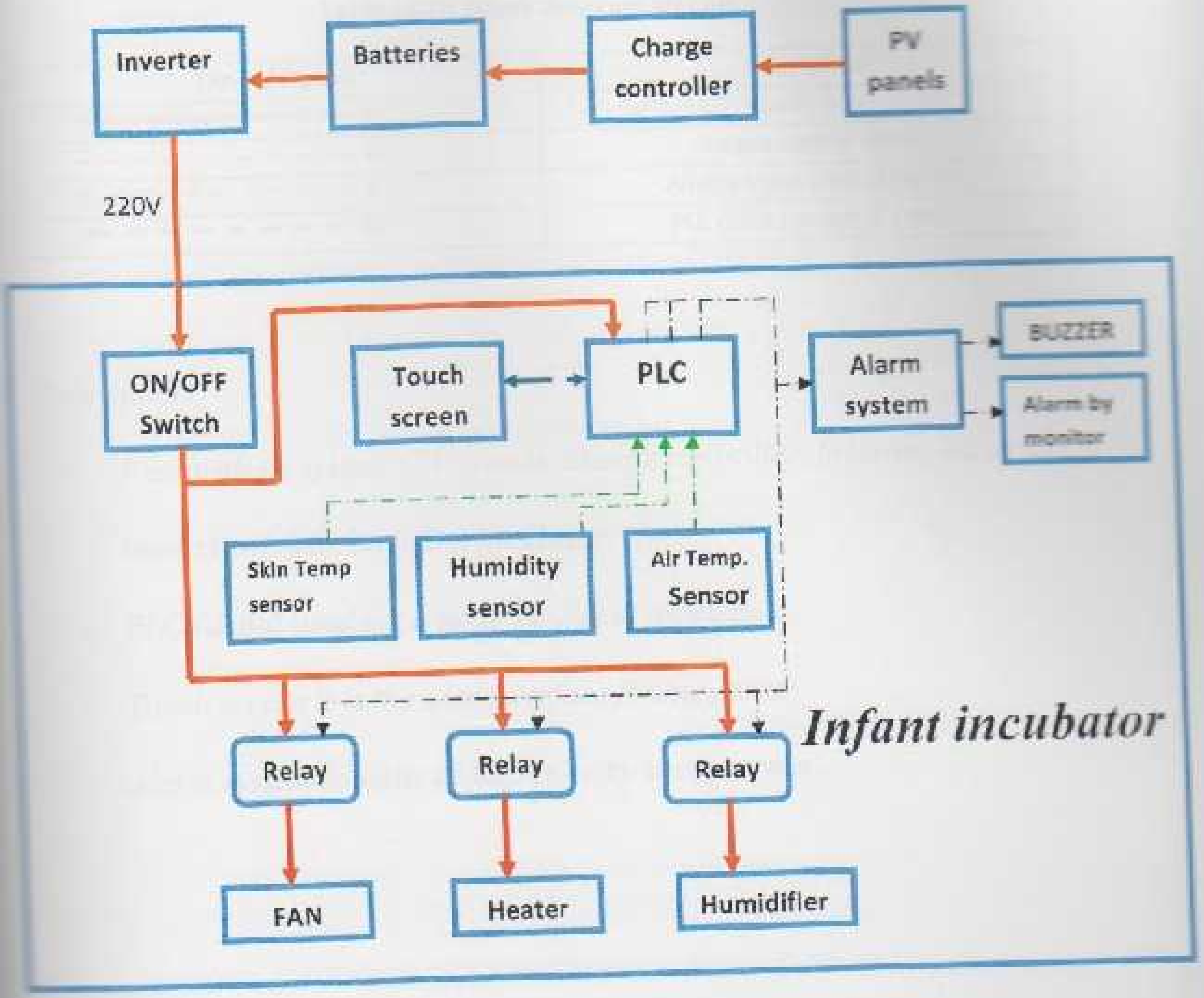


Figure (4.5): Block diagram of the project

Table (4.2) shows block diagram signals

Table (4.2): Block diagram signals

Type of Signals	**Description**
———————→	Power flow
- - - - - - - - - - - ►	Output control signal
- · - · - · - · - · - ►	Analog input control signal
← — — — — — — →	PLC cable (power & data)

Description:

- *Photovoltaic system (PV panels, charge controller ,inverter, batteries) used to energize an infant incubator.*
- *PLC (delta) used for control of I/O of incubator.*
- *Touch screen it is the user interface for incubator.*
- *Alarm system consists of buzzer or by using screen.*

4.4 Photovoltaic design.

4.4.1 Photovoltaic calculation:-

This design for stand-by photovoltaic system, as appropriate for available device and photovoltaic units; so we will design system to work a four hours.

Table (4.3): incubator loads with it wattages

Incubator loads	Power (W)	Hr/(for 4 hour)	Watt-Hr(Wh)
Heater	440 W	1	440
Humidity heater	100 W	1	100
PLC & touch screen	70 W	4	280
Two Fans	30 W	4	120
Maximum Possible Wattage	640	Total daily Watt-Hr/day	940

❖ Wh/ (stand-by system) = $\frac{\text{Load WH}}{\text{battery efficiency} * \text{Wiring efficiency}}$ (4.3)

$= \frac{940}{0.85*0.98}$ =1128.45Wh

Battery bank size base on depth of discharge and autonomy requirements:

Autonomy = 1.7 days

Depth of discharge = 60% deep cycle batteries

Battery bank size in Watt-hours = $\frac{[\text{Wh/ (stand-by system)}]*\text{autonomy}}{\text{Depth of discharge}}$ (4.4)

$= \frac{1128.45*1.7}{.6}$ = 3197 Wh

Batteries capacity in Ampere-hours= $\frac{\text{battery size in Wh}}{\text{system voltage}}$ (4.5)

12 volt dc system will be chosen.

Batteries capacity in Ampere-hours= $\frac{3197\text{ Wh}}{12\text{ V}}$ = 266.4 Ah

$\frac{266.4\text{ Ah}}{2}$ = 133.2 Ah.

We will choose 2 batteries 12V- 140 Ah

Two batteries are connect in parallel

- Wh of solar panels = $\frac{(\text{load Wh})}{(\text{total efficiency})}$ (4.6)

$\eta_{Total} = \eta_{battery} * \eta_{wires} * \eta_{charge\ controller} * \eta_{temp} * \eta_{inverter}$ (4.7)

$\eta_{temp.} = 1 - 0.005 * (\text{Average glass temp.} - 25)$

$= 1 - 0.005(30 - 25) = 0.975$

$\eta_{total} = 0.85 * 0.98 * 0.96 * 0.975 * 0.85 = 0.66$

Wh of solar panels = $\frac{940}{.66}$ =1424Wh

Average perfect sun hours = 6 hours

Power of the solar panels = $\frac{\text{Wh of solar panels}}{\text{Average perfect sun hours}}$ (4.8)

$= \frac{1424\ \text{Wh}}{6\ \text{hours}} = 237$ Watt

We will choose two panels (120 Watts - 12 Volts)

Both of them will connect in parallel.

- Consider inverter efficiency 85% and divide total wattage by 0.85 and approximate inverter wattage to nearest available standard wattage.

Total wattage = 640, Inverter Efficiency = 85%.

Inverter capacity = 640 /0.85 = 753VA. (4.9)

Nearest Available inverter Capacity = 800 VA, 12 V

The fuse of inverter = 800 W / 220V =3.63A

For safe design we will select 5A inverter fuse.

- The rating of charge controller = 120Watt /12V =10 A

For safe design we will select 15 A for charge controller.

4.4.2 Energy saving and Feasibility Study:

This Feasibility Study to design stand-alone photovoltaic system to energize the incubator for 24 hour.

Average energy per day = 5640Wh/day

Total annual consumed energy = P*t =5640W *365 day =2058.6 KWh.

Total cost = E * unit price=2058.6KWh *NIS 0.52/KW = 1070.5 NIS.

Total Cost of stand-alone system* = 12450 NIS.

Payback time = 12450 NIS/1070.5 NIS = 11.6 years.

Table (4.4): The Total Cost of Components that required for infant incubator to work 24 hour.

Components	NIS Cost
Polycrystalline Silicon Solar Panels (200W)	6*900 NIS =5400 NIS
Charge Controller 15A 12 Volt	1 * 380 NIS = 380 NIS
Batteries 12V 200Ah	8 * 750 NIS =6000 NIS
Inverter 1KW	1 * 700 NIS =700 NIS
Total Cost*	12450 NIS

Chapter 5:

Hardware and Software implementation

5.1 Hardware implementation

5.2 Software implementation

5.1 Hardware Implementation

Hardware implementation represents all processes in project except programming plc , it consists build infant incubator with controller PLC , Construct Amplification, Regulator ,voltage divider ,Temperature sensor (LM35) and Humidity sensor (HIH-4030) circuits with an incubator, and connect the photovoltaic system with the incubator.

5.1.1 closed Infant Incubator (Drager)

The incubator used in project is drager closed infant incubator, in this incubator as we said in chapter two Microclimate is produced within a rigid wall chamber, it is heated using a fan to create a flow over a metallic heating coil to enter the infant chamber Figure (5.1) shows infant incubator of the project.

Figure (5.1): Infant Incubator of the project.

5.1.1.1 The electrical components

The electrical components in an incubator are considered the main parts to build the incubator and this component as shown in Figure (5.2) is:

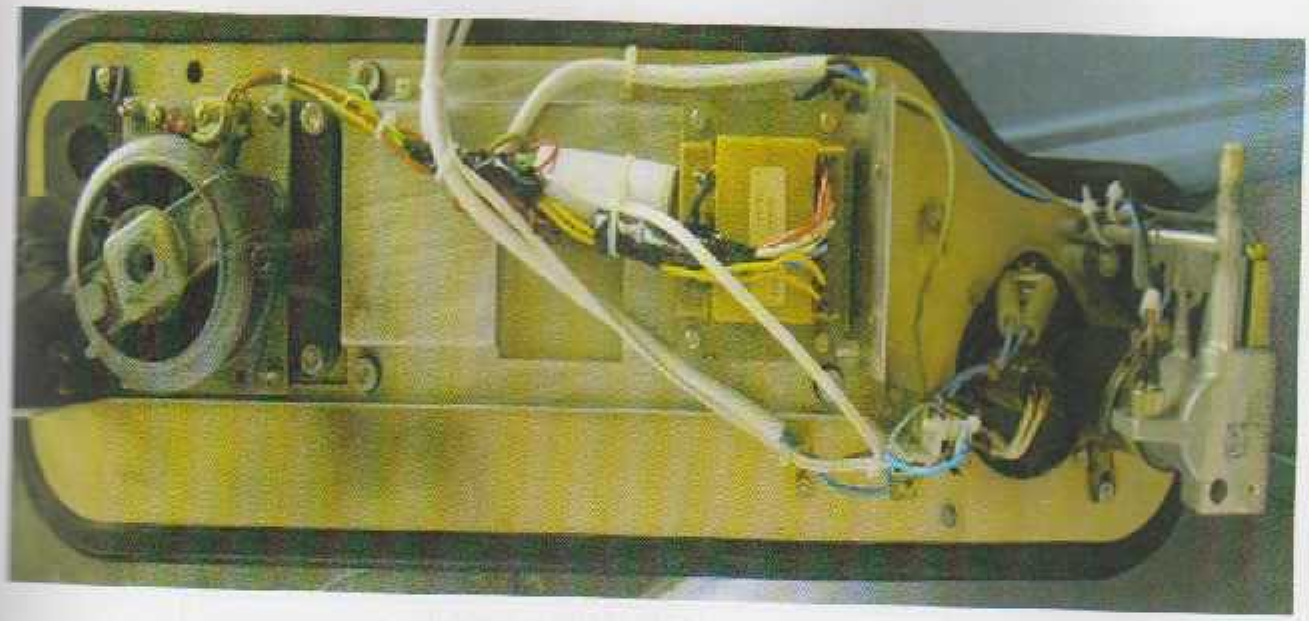


Figure (5.2): electrical components of the incubator

1- Transformer (220V /24V)

This part is used to transform 220 volt to 24 volt to supply the fan.

2- Single phase induction motor "IM"

Single phase induction motor used in project as a main fan, has a fixed Speed is used to circulate the air through the incubator. Figure (5.3) shows a single phase induction motor.

Figure (5.3): single phase induction motor.

Table (5.1) shows the electrical specifications for single phase induction motor

Table (5.1): The electrical specifications for single phase induction motor

PAPST – MOTOREN	
S.P Induction motor model :	902 5020 044
24 V , 50/60 Hz	
Capacitor : 68 μF	
TW 6.-93	

The Equivalent Circuit of single phase induction motor[22] shown in Figure (5.4)

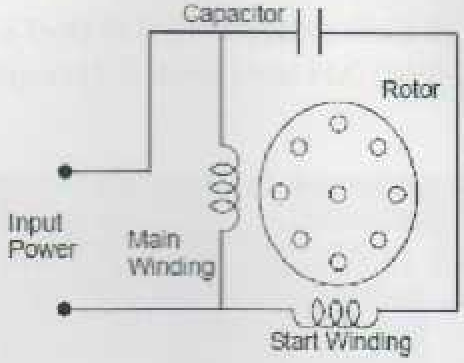


Figure (5.4): Equivalent Circuit of single phase induction motor

The capacitor used to prevents the motor to draw more current during starting.

3- Heater

The main source of the heat. (50 HZ) (220V) (440W) , it is used to heat the air that will inter in the hood of the incubator. The heater output is proportional to the amount of heat required to maintain the desired temperature.

4- Humidifier

In this Incubator the humidifier is considered an electrical component with other heater (100 W) used to heat the water. The main function of this part is to generate the desired humidification inside the hood of incubator.

5.1.2 Delta PLC (DVP-20EX) Connections

The PLC used in project is Delta PLC (DVP-20EX), and it is connected as we explained this in previous chapter .Figure (5.5) shows Delta PLC (DVP-20EX) connections.

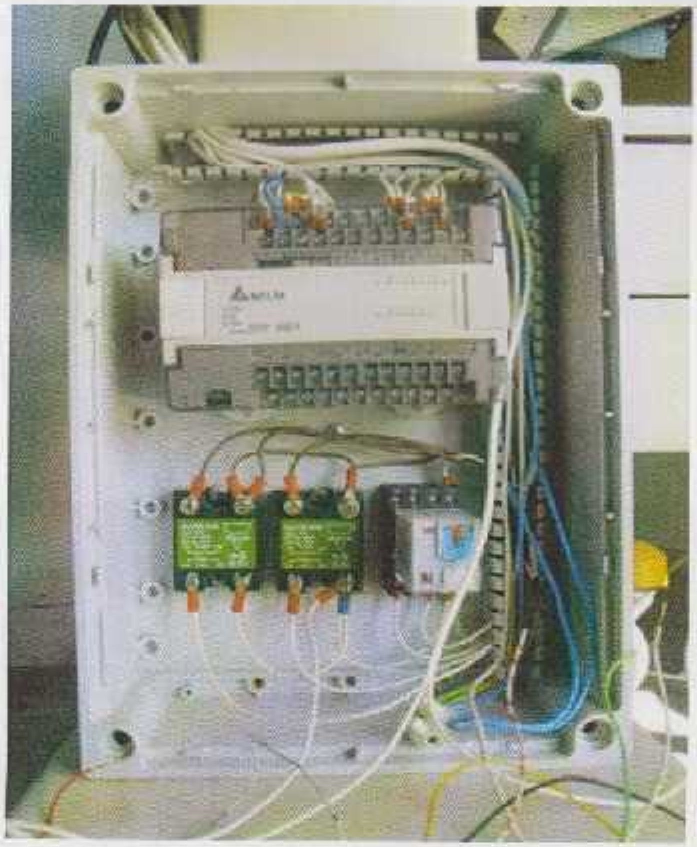


Figure (5.5): Delta PLC (DVP-20EX) connections

5.1.3 Amplification, (7805, 7812) Regulators and Voltage Divider Circuits

1-Amplification circuit

We build this circuit as we designed it in previous chapter to amplify the output voltage of LM35 that is used for calibration(0.1 V for 1 °C). Amplification Circuit shown in Figure (5.6) .

2- (7805,7812) Regulators

This Regulators used to supply the circuits with fixed voltages +5V and +12V. (7805, 7812) Regulators shown in Figure (5.6)

3- Voltage Divider circuit

This circuit Used To protect PLC analog module when it is reading the output voltage from battery.

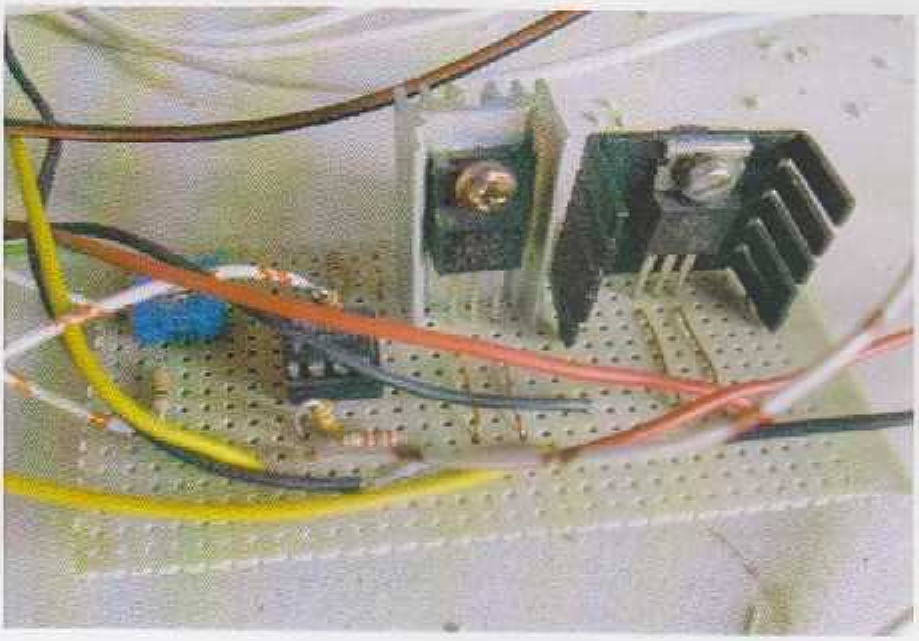


Figure (5.6): Amplification, 7805 7812 regulators and voltage divider Circuits

5.1.4 Circuit of (LM35) and (HIH- 4030) sensors

Circuit of LM35 and HIH 4030 sensors shown in Figure (5.7)

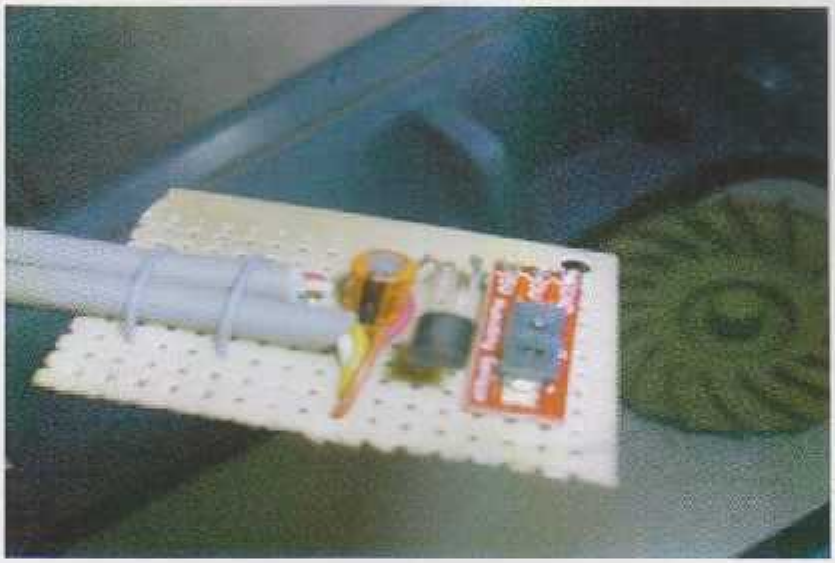


Figure (5.7): Circuit of LM35 and HIH 4030 sensors

5.1.4 Circuit of (LM35) and (HIH- 4030) sensors

Circuit of LM35 and HIH 4030 sensors shown in Figure (5.7)

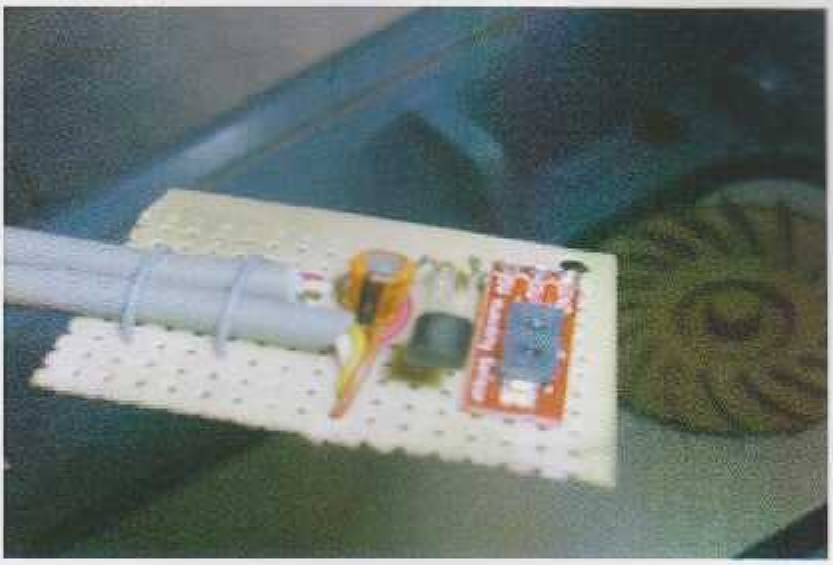


Figure (5.7): Circuit of LM35 and HIH 4030 sensors

5.1.5 Photovoltaic module:

The module used is (PW1250) shown in Figure (5.8)

Figure (5.8): PW1250 module

The electrical specifications of PW1250 shown in Table (5.2) :

Table (5.2): [PW1250] electrical specifications

Electrical ratings		(PW1250) 18V
Typical power	[W]	115
Operating voltage	[V]	25.4
Current at op.voltage	[A]	4.5
Short circuit current	[A]	4.7
Open circuit voltage	[V]	31.9
Minimum power	[V]	110
Maximum syst. Voltage	[V]	600V
Serie fuse		8A

5.2 Software Implementation

Software plays the main role in developing control system. It is used to operate all the work of the system, to control all the work of the system we read the input sensors signal (temperature, humidity) and then we compare them with the setting points, the result of the comparing used to control the actuators.

5.2.1 Touch Screen Programming:

The touch screen from DELTA can be program in special software " screen editor " and design the logo of screen's on the same software .First step in program connect all commend in internal plc relay "Flag's" (M0-M999) And some command will be need some register in PLC and (D0-D999).The beginning window of touch screen shown in the Fig (5.9) .

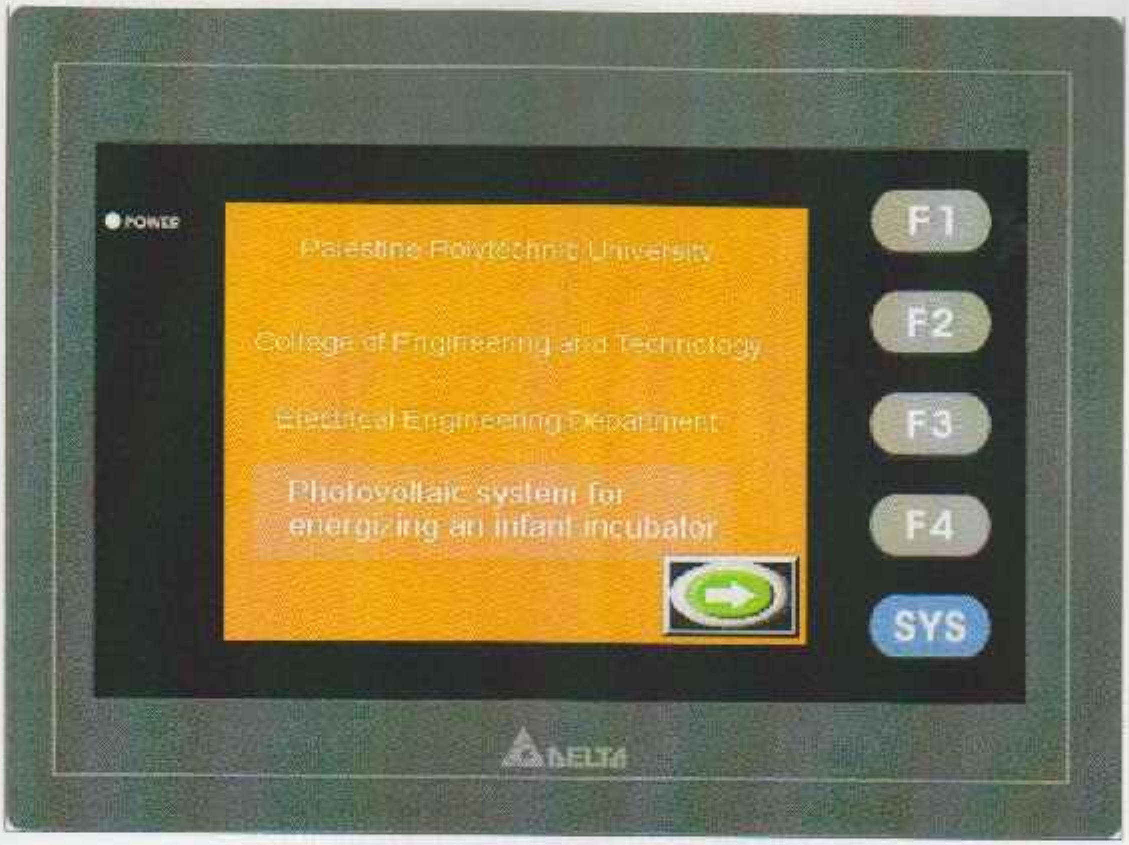


Figure (5.9): The beginning window of touch screen

5.2.2 PLC Programming:

The Delta PLC software called " WPL Soft"
The following program consist of analog input, digital output and connect in touch screen as shown in Figure (5.10).

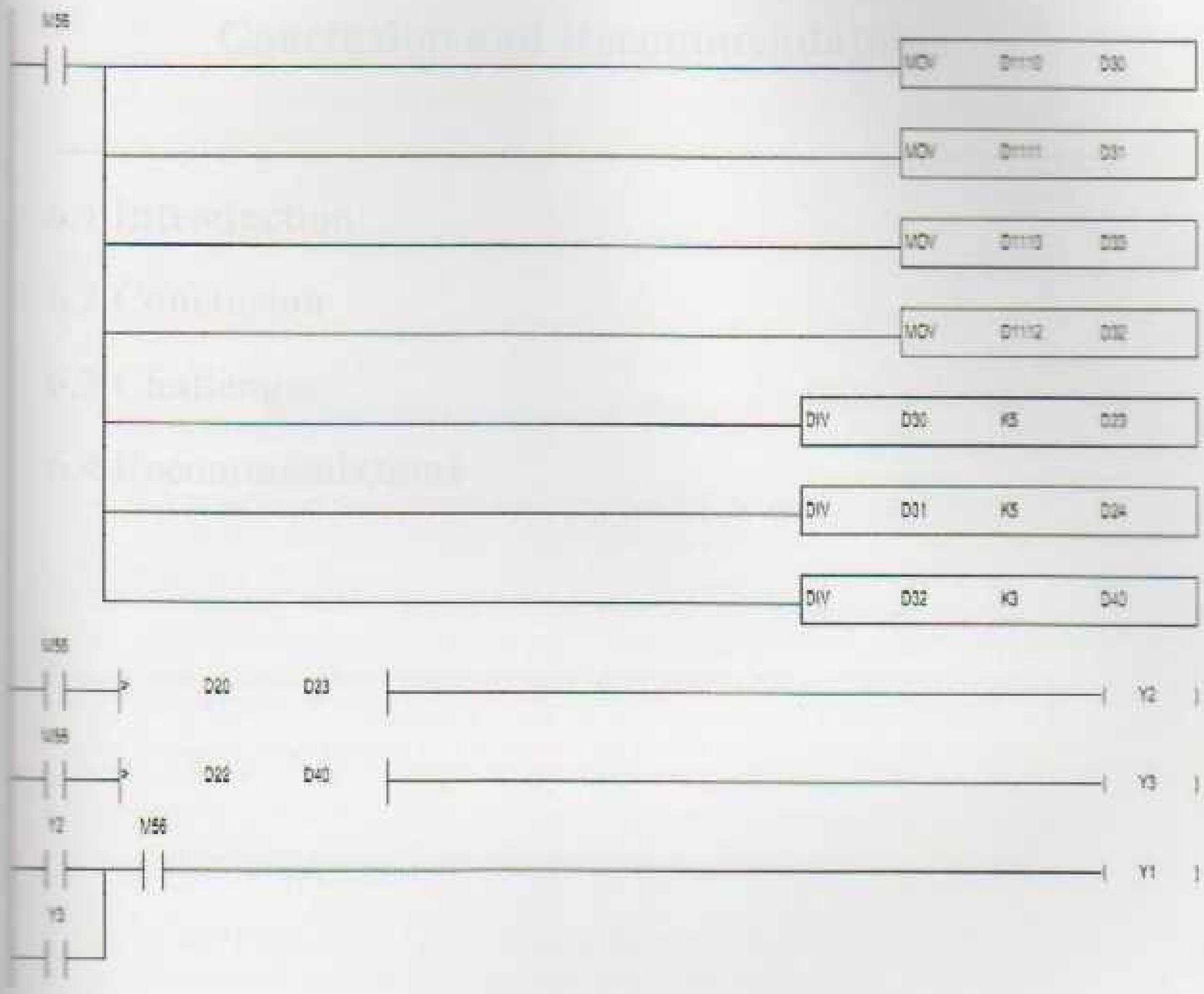


Figure: (5.10): Delta PLC program

Chapter six:

Conclusion and Recommendations

6.1 Introduction

6.2 Conclusion

6.3 Challenges

6.4 Recommendations

6.1 Introduction:

This chapter presents some conclusions that resulted from implementing and testing the project, also it explains in details the goals that were achieved from the project. Finally, it proposes some suggestions and recommendations for developing the system in the future.

6.2 Conclusion

- Three important parameters are found to simulate the control system inside the incubator; these parameters are temperature, humidity, and oxygen Concentration·
- Three different types of sensors are modified and used to sense the three parameters in the chosen incubator these sensors are temperature sensor, humidity sensor and oxygen sensor).
- Photovoltaic Infant Incubator control system is proposed, justified, and implemented. This System depends on computing the voltages and currents outputs sensors [7] and converts it to temperature and humidity level and oxygen concentration and these all can be work by photovoltaic system.
- Despite high cost of the project, but is a feasible solution in those areas where grid power is not available or reliable.
- Using PLC controller give us highly efficient in control of incubator, And observe the workflow of operations by using touch screen.

6.3 Challenges

- The project components are expensive.
- The Oxygen sensor doesn't exist and is very expensive.
- Analog signals Programming using PLC is difficult and takes a much time.

- The work was paused for some time because the components not available and needs a long time to bring.

6.4 Recommendations

After the great efforts during the last year in constructing the model completely and working perfectly, and because of its high importance of project we highly recommend the following:

- Increasing the utilization of electric energy generated from photovoltaic systems in Palestine.
- Manufacturing photovoltaic systems in Palestine.
- Develop the system by making interface to control a group of incubator at the same time, through display data for every incubator on the screen.

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Appendix

Appendix (A):LM35

LM35

LM35 Precision Centigrade Temperature Sensors

TEXAS INSTRUMENTS

Literature Number: SNIS159B

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

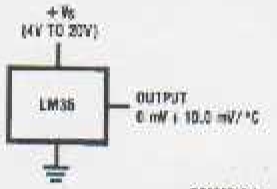
General Description

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

Features

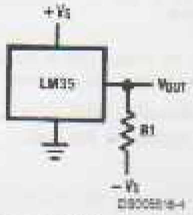
- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 μA current drain
-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

Typical Applications



DS005516-3

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



DS005516-4

Choose $R_1 = -V_S/50\ \mu A$
V_{OUT} = +1,500 mV at +150°C
= +250 mV at +25°C
= −550 mV at −55°C

FIGURE 2. Full-Range Centigrade Temperature Sensor

 DS005516

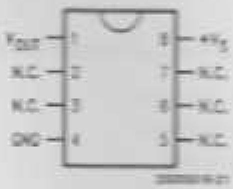
Connection Diagrams

TO-46
Metal Can Package*

*Case is connected to negative pin (GND)

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

SO-8
Small Outline Molded Package



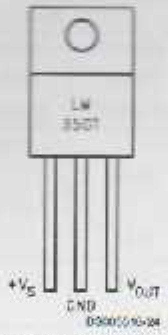
N.C. = No Connection

Top View
Order Number LM35DM
See NS Package Number M08A

TO-92
Plastic Package

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

TO-220
Plastic Package*



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

Order Number LM35DT
See NS Package Number TA03F

Absolute Maximum Ratings (Note 10)

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

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60°C to +180°C
TO-92 Package,	−60°C to +150°C
SO-8 Package,	−65°C to +150°C
TO-220 Package,	−65°C to +150°C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300°C
TO-92 and TO-220 Package, (Soldering, 10 seconds)	260°C
SO Package (Note 12)	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
ESD Susceptibility (Note 11)	2500V
Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)	
LM35, LM35A	−55°C to +150°C
LM35C, LM35CA	−40°C to +110°C
LM35D	0°C to +100°C

Electrical Characteristics

(Notes 1, 6)

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

Electrical Characteristics

(Notes 1, 6)

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

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

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

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

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

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

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

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

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

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

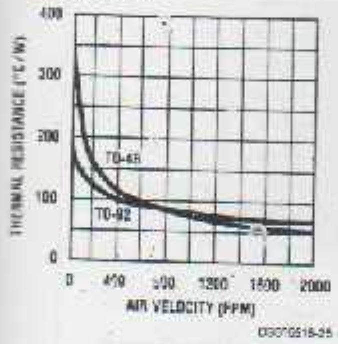
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

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

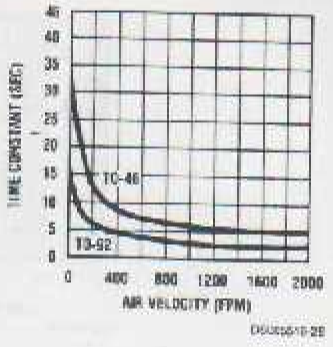
Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Typical Performance Characteristics

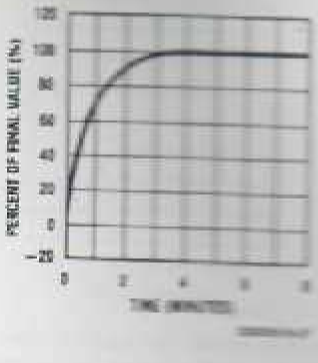
Thermal Resistance Junction to Air



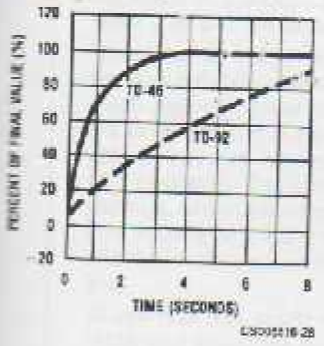
Thermal Time Constant



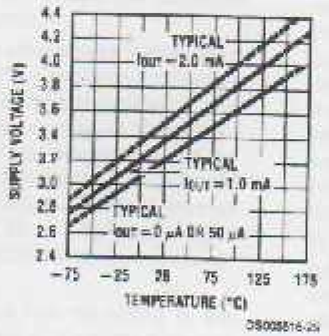
Thermal Response in Still Air



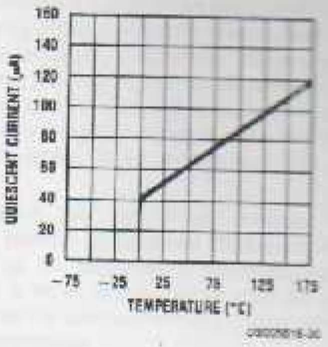
Thermal Response in Stirred Oil Bath



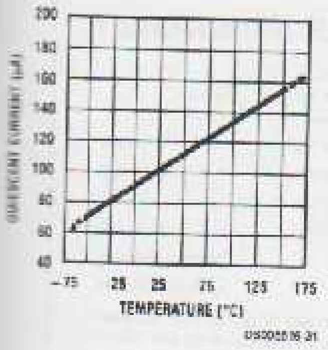
Minimum Supply Voltage vs. Temperature



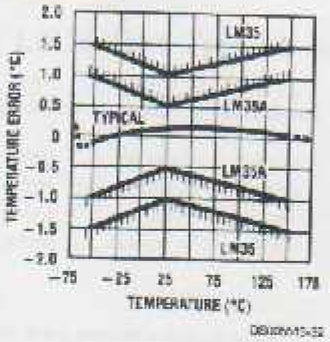
Quiescent Current vs. Temperature (In Circuit of *Figure 1*.)



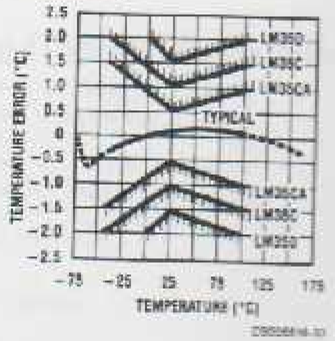
Quiescent Current vs. Temperature (In Circuit of *Figure 2*.)



Accuracy vs. Temperature (Guaranteed)

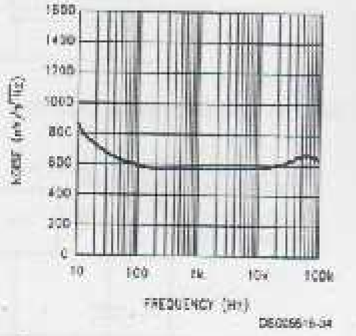


Accuracy vs. Temperature (Guaranteed)

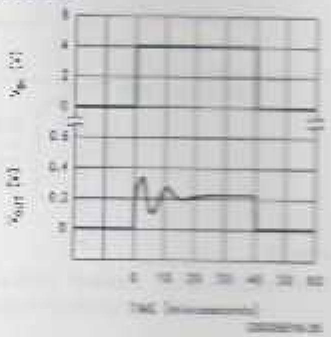


Typical Performance Characteristics (Continued)

Noise Voltage



Start-Up Response



Applications

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

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

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

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

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

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

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

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

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

Typical Applications

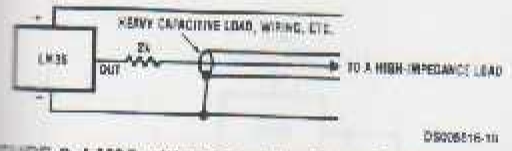


FIGURE 3. LM35 with Decoupling from Capacitive Load

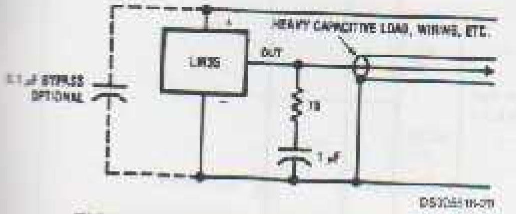


FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

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

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

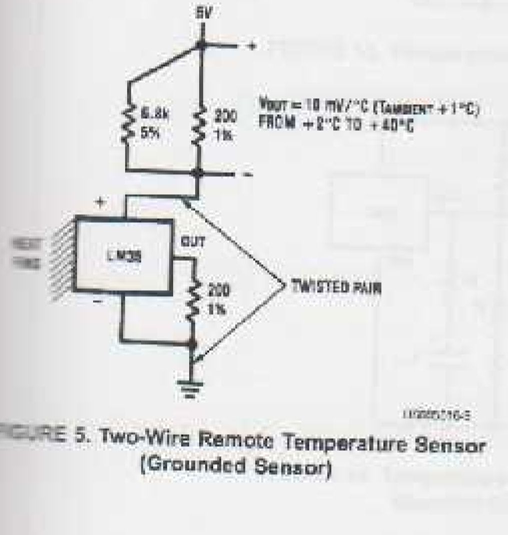


FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)

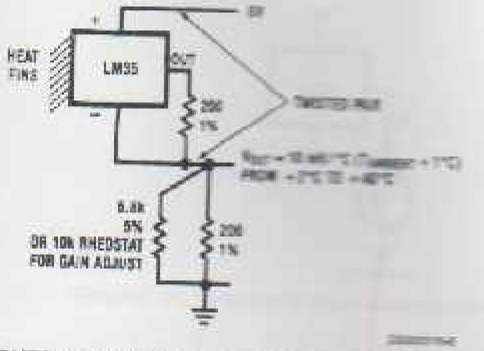


FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

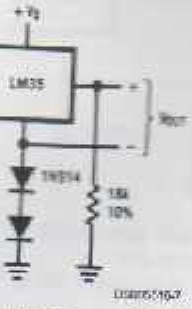


FIGURE 7. Temperature Sensor, Single Supply, −55° to +150°C

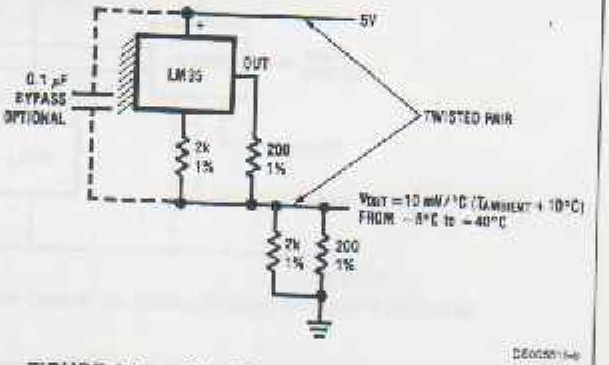


FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

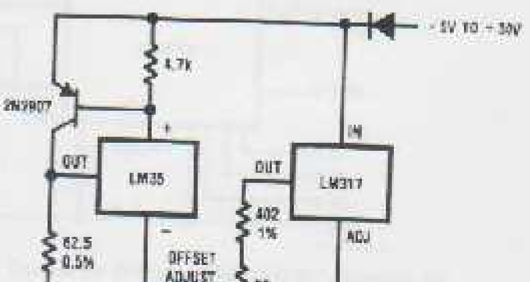


FIGURE 9. 4-To-20 mA Current Source (0°C to +100°C)

Typical Applications (Continued)

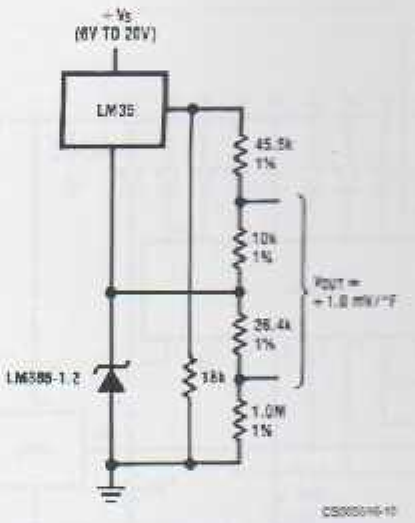


FIGURE 10. Fahrenheit Thermometer

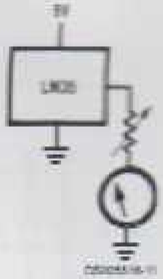


FIGURE 11. Centigrade Thermometer (Analog Meter)

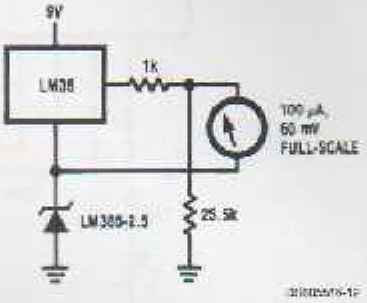


FIGURE 12. Fahrenheit ThermometerExpanded Scale Thermometer
(50° to 80° Fahrenheit, for Example Shown)

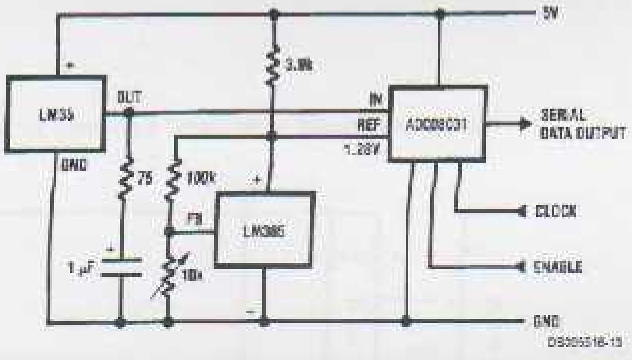


FIGURE 13. Temperature To Digital Converter (Serial Output) (+128°C Full Scale)

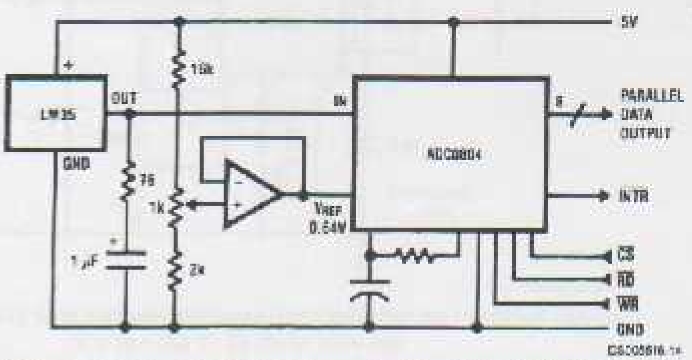
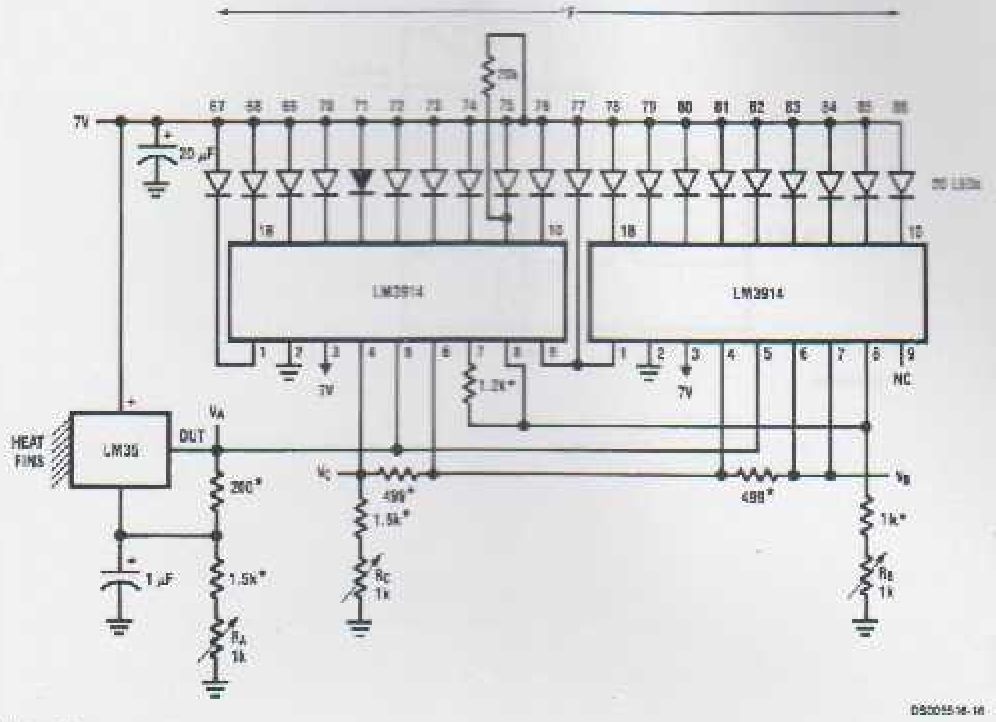


FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE™ Outputs for Standard Data Bus to µP Interface) (128°C Full Scale)

Typical Applications (Continued)



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

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

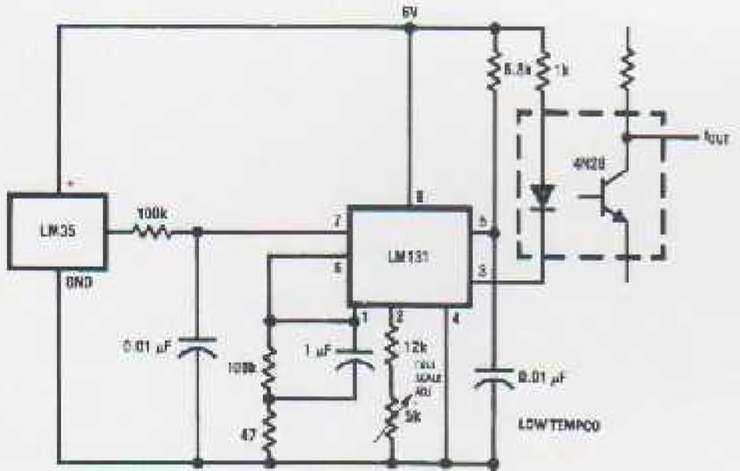
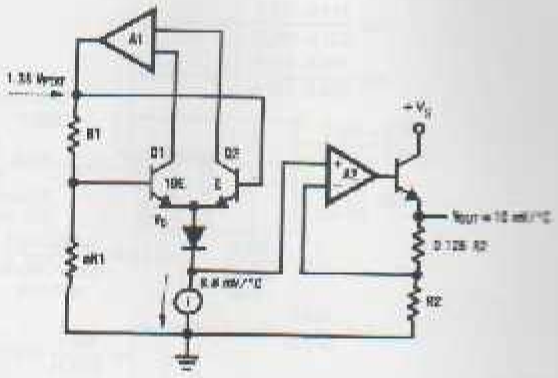
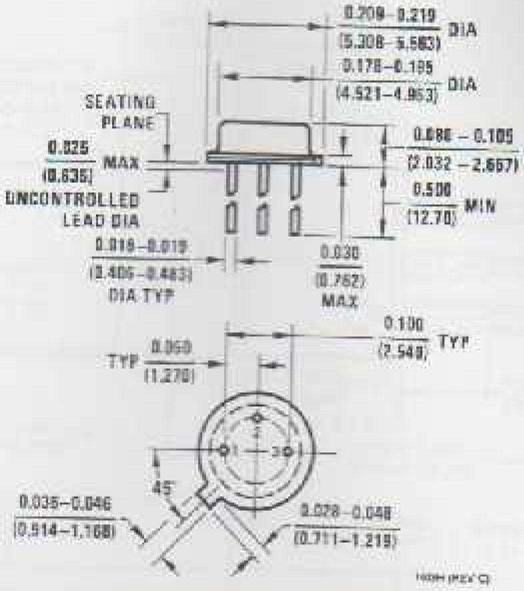


FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output (2°C to +150°C; 20 Hz to 1500 Hz)

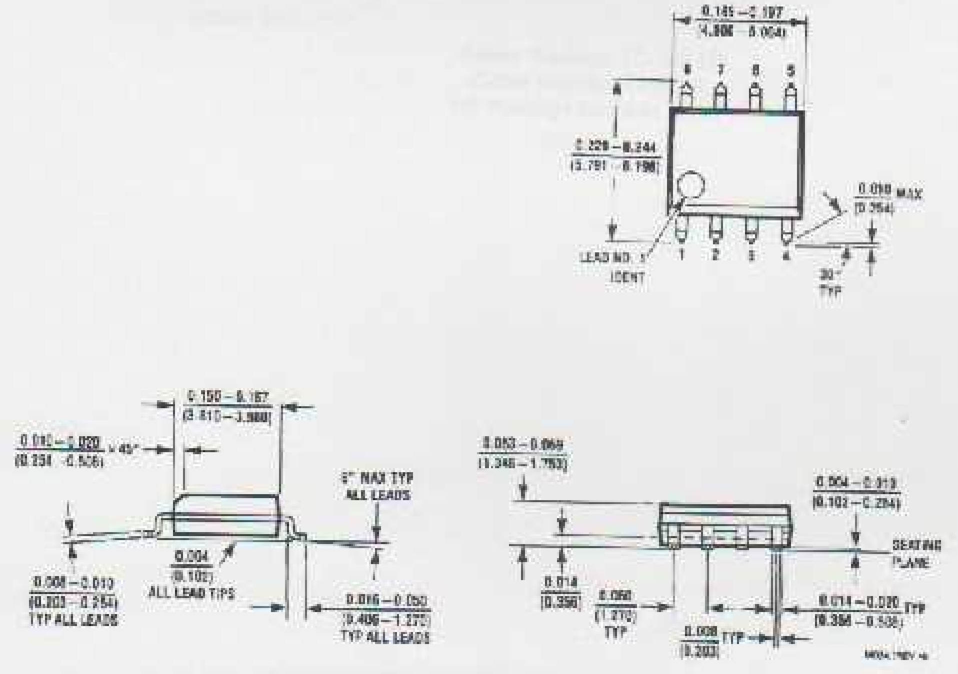
Block Diagram



Physical Dimensions inches (millimeters) unless otherwise noted

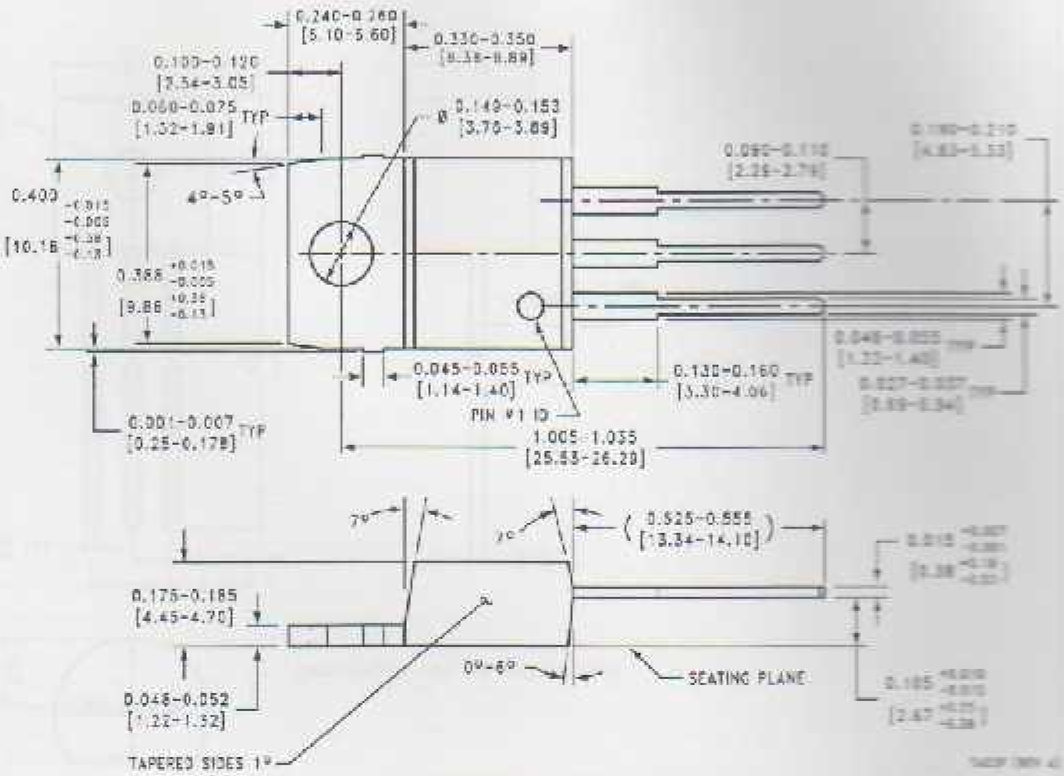


TO-46 Metal Can Package (H)
Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH
NS Package Number H03H



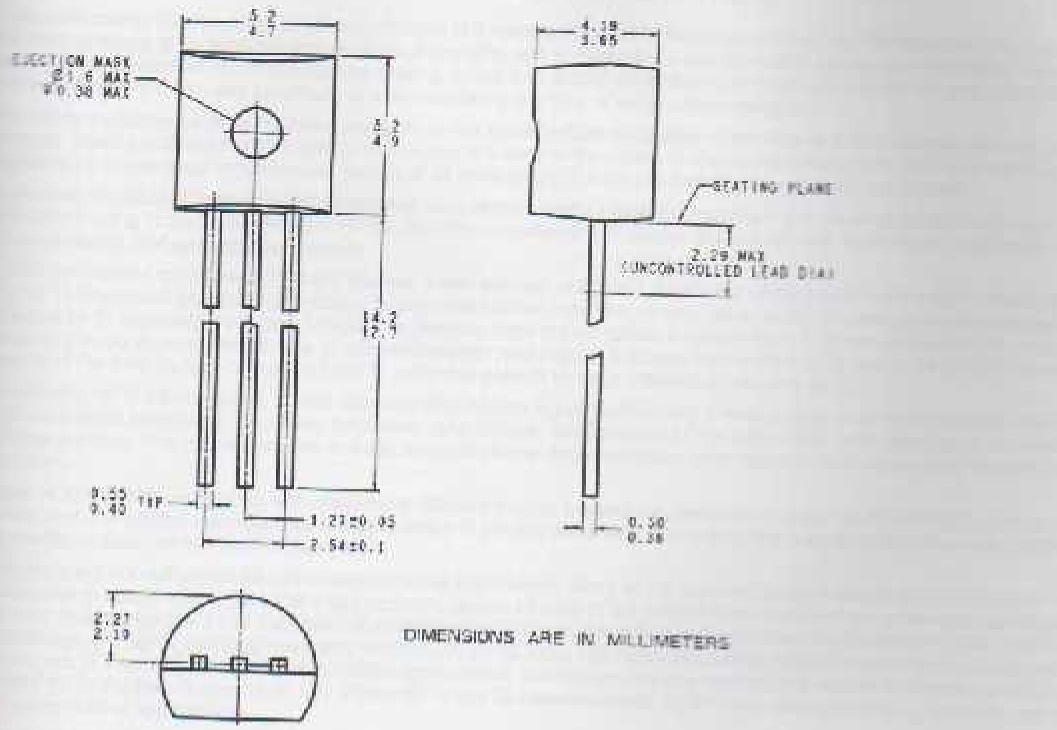
SO-8 Molded Small Outline Package (M)
Order Number LM35DM
NS Package Number M08A

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



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

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



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

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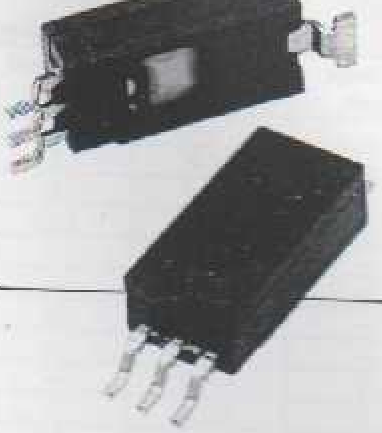
Appendix (B): HIH4030

Honeywell



HIH-4030/31 Series

Humidity Sensors

DESCRIPTION

Honeywell has expanded our HIH Series to include an SMD (Surface Mount Device) product line: the new HIH 4030/4031. The HIH 4030/4031 complements our existing line of non-SMD humidity sensors. SMD packaging on tape and reel allows for use in high volume, automated pick and place manufacturing, eliminating lead misalignment to printed circuit board through-hole.

The HIH-4030/4031 Series Humidity Sensors are designed specifically for high volume OEM (Original Equipment Manufacturer) users.

Direct input to a controller or other device is made possible by this sensor's near linear voltage output. With a typical current draw of only 200 μA, the HIH-4030/4031 Series is often ideally suited for low drain, battery operated systems.

Tight sensor interchangeability reduces or eliminates OEM production calibration costs. Individual sensor calibration data is available.

The HIH-4030/4031 Series delivers instrumentation-quality RH (Relative Humidity) sensing performance in a competitively priced, solderable SMD.

The HIH-4030 is a covered integrated circuit humidity sensor. The HIH-4031 is a covered, condensation-resistant, integrated circuit humidity sensor that is factory-fitted with a hydrophobic filter allowing it to be used in condensing environments including industrial, medical and commercial applications.

The RH sensor uses a laser trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning.

The sensing element's multilayer construction provides excellent resistance to most application hazards such as condensation, dust, dirt, oils and common environmental chemicals.

Sample packs are available. See order guide.

FEATURES

- Tape and reel packaging allows for use in high volume pick and place manufacturing (1,000 units per tape and reel)
- Molded thermoset plastic housing
- Near linear voltage output vs %RH
- Laser trimmed interchangeability
- Low power design
- Enhanced accuracy
- Fast response time
- Stable, low drift performance
- Chemically resistant

POTENTIAL APPLICATIONS

- Refrigeration equipment
- HVAC (Heating, Ventilation and Air Conditioning) equipment
- Medical equipment
- Drying
- Metrology
- Battery-powered systems
- OEM assemblies

HIH-4030/31 Series

TABLE 1. PERFORMANCE SPECIFICATIONS (At 5 Vdc supply and 25 °C [77 °F] unless otherwise noted.)

Parameter	Minimum	Typical	Maximum	Unit	Specific Note
Interchangeability (first order curve)	–	–	–	–	–
0% RH to 59% RH	-5	–	5	% RH	–
60% RH to 100% RH	-8	–	8	% RH	–
Accuracy (best fit straight line)	-3.5	–	+3.5	% RH	1
Hysteresis	–	3	–	% RH	–
Repeatability	–	±0.5	–	% RH	–
Settling time	–	–	70	ms	–
Response time (1/e in slow moving air)	–	5	–	s	–
Stability (at 50% RH in a year)	–	±1.2	–	% RH	2
Stability (at 50% RH in a year)	–	±0.5	–	% RH	3
Voltage supply	4	–	5.8	Vdc	4
Current supply	–	200	500	µA	–
Voltage output (1st order curve fit)	$V_{OUT}=(V_{SUPPLY})(0.0062(\text{sensor RH}) + 0.16)$, typical at 25 °C				
Temperature compensation	True RH = (Sensor RH)/(1.0546 – 0.00216T), T in °C				
Output voltage temp. coefficient at 50% RH, 5 V	–	-4	–	mV/°C	–
Operating temperature	-40[-40]	See Figure 1.	85[185]	°C[°F]	–
Operating humidity (HIH-4030)	0	See Figure 1.	100	% RH	5
Operating humidity (HIH-4031)	0	See Figure 1.	100	% RH	–
Storage temperature	-50[-58]	–	125[257]	°C[°F]	–
Storage humidity	See Figure 2.			% RH	5

Specific Notes:

1. Can only be achieved with the supplied slope and offset. For HIH-4030/31-003 catalog listings only.
2. Includes testing outside of recommended operating zone.
3. Includes testing for recommended operating zone only.
4. Device is calibrated at 5 Vdc and 25 °C.
5. Non-condensing environment. When liquid water falls on the humidity sensor die, output goes to a low rail condition indicating no humidity.

General Notes:

- Sensor is ratiometric to supply voltage.
- Extended exposure to ≥90% RH causes a reversible shift of 3% RH.
- Sensor is light sensitive. For best performance, shield sensor from bright light.

FACTORY CALIBRATION DATA

HIH-4030/31 Sensors may be ordered with a calibration and data printout. See Table 2 and the order guide on the back page.

TABLE 2. EXAMPLE DATA PRINTOUT

[illegible]	HIH-4030-003
[illegible]	92
[illegible]	030996M
[illegible]	337313
Calculated values at 5 V V_{OUT} at 0% RH V_{OUT} at 75.3% RH	 0.958 V 3.268 V
Linear output for 3.5% RH accuracy at 25 °C Zero offset Slope Sensor RH	 0.958 V 30.680 mV/%RH (V_{OUT} - zero offset)/slope (V_{OUT} - 0.958)/0.0307
Ratiometric response for 0% RH to 100% RH V_{OUT}	 V_{SUPPLY} (0.1915 to 0.8130)

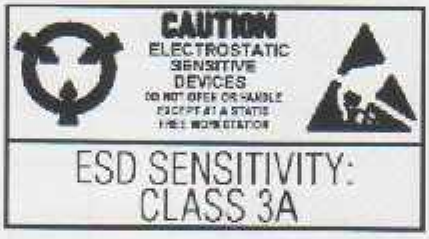


FIGURE 1. OPERATING ENVIRONMENT (Non-condensing environment for HIH-4030 catalog listings only.)

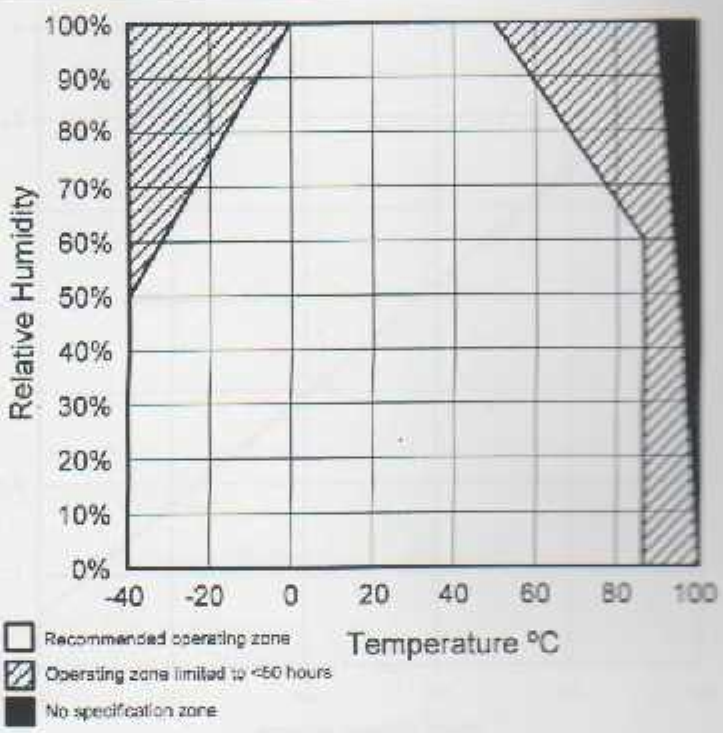


FIGURE 2. STORAGE ENVIRONMENT (Non-condensing environment for HIH-4030 catalog listings only.)

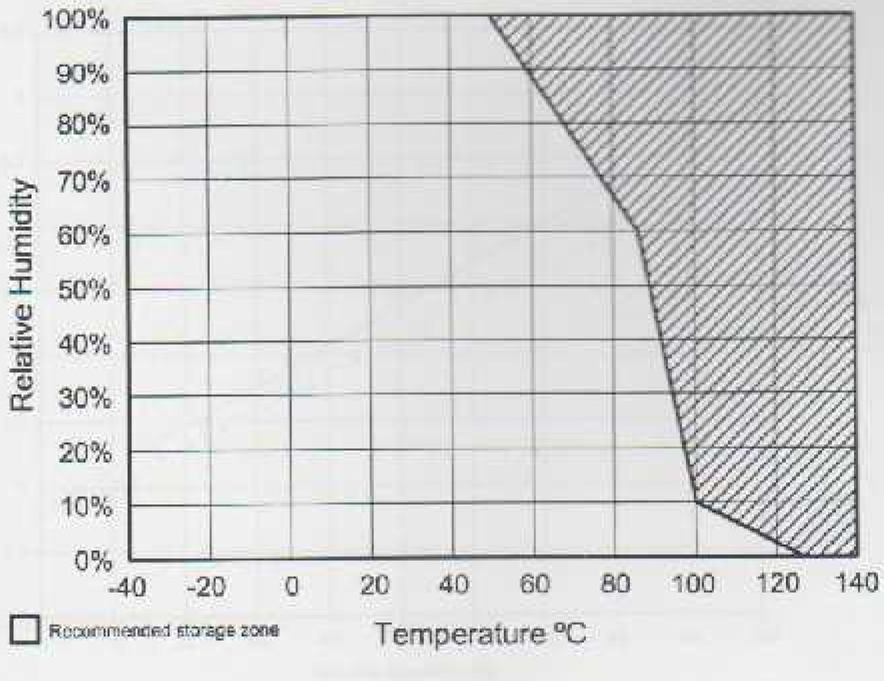


FIGURE 3. TYPICAL OUTPUT VOLTAGE VS RELATIVE HUMIDITY (At 25 °C and 5 V.)

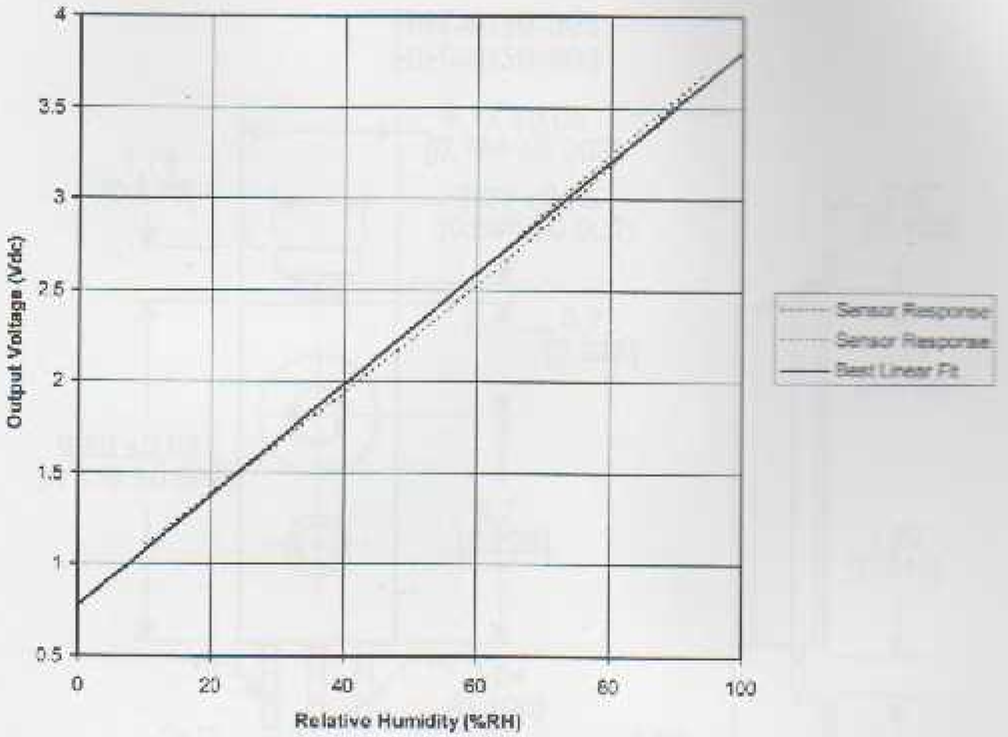


FIGURE 4. TYPICAL OUTPUT VOLTAGE (BFSL) VS RELATIVE HUMIDITY (At 0 °C, 70 °C and 5 V.)

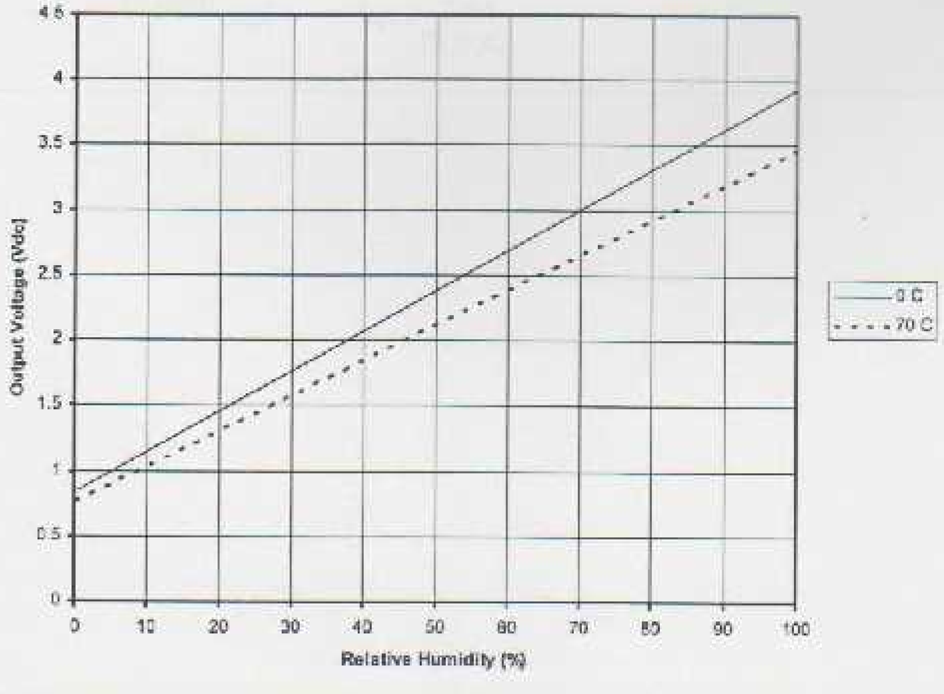


FIGURE 5. HIH-4030 MOUNTING DIMENSIONS (For reference only. mm/[in])

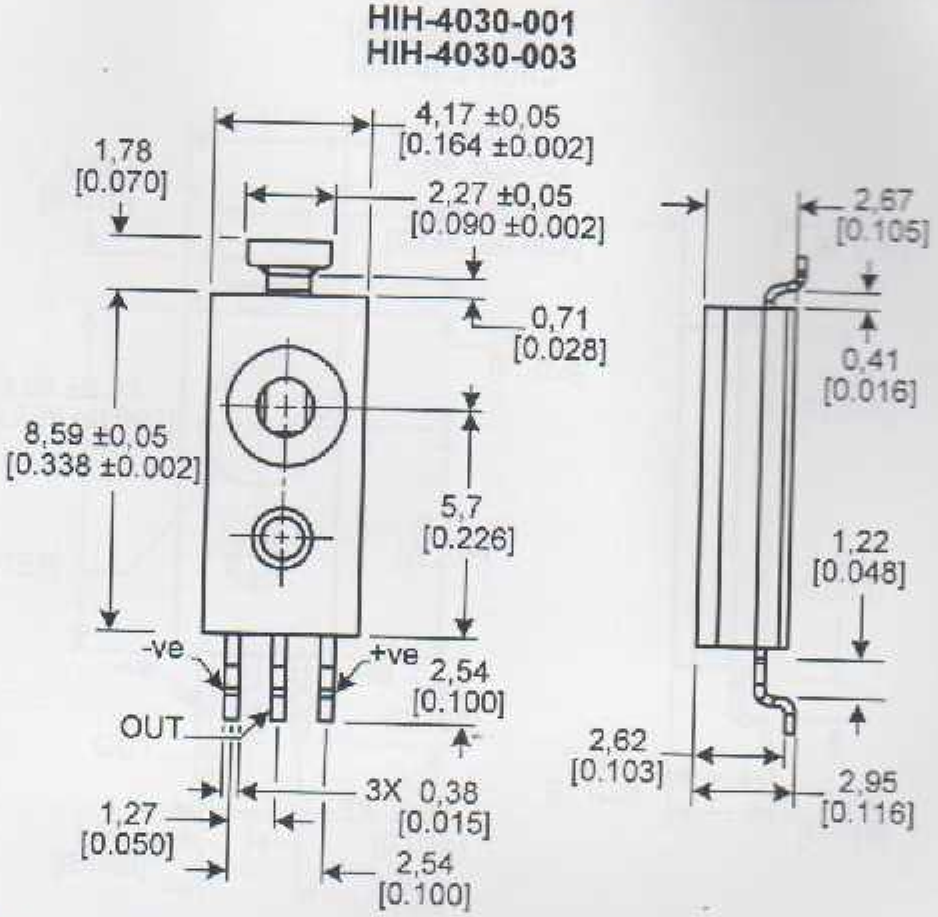


FIGURE 6. HIH-4031 MOUNTING DIMENSIONS (For reference only. mm/[in])

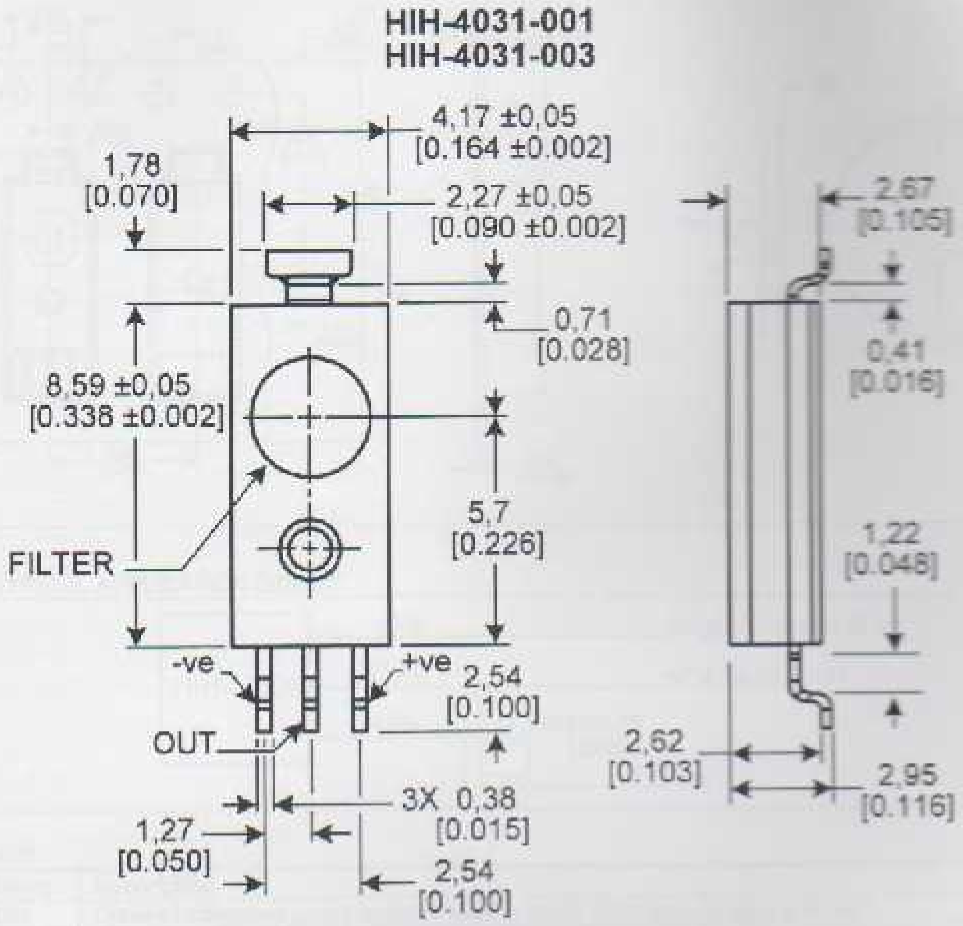


FIGURE 7. HIH-4031 PCB LANDING PATTERN (For reference only. mm/[in])

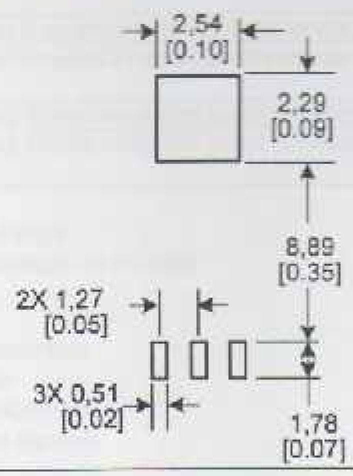


FIGURE 8. TAPE AND REEL DIMENSIONS (For reference only. mm/[in])

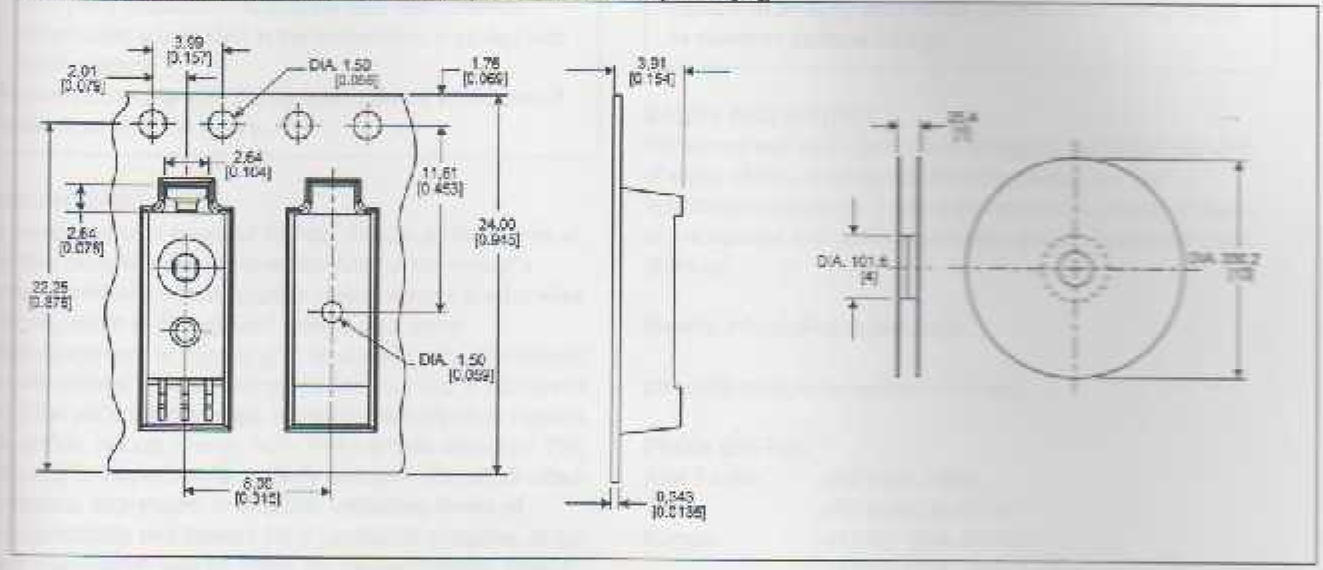
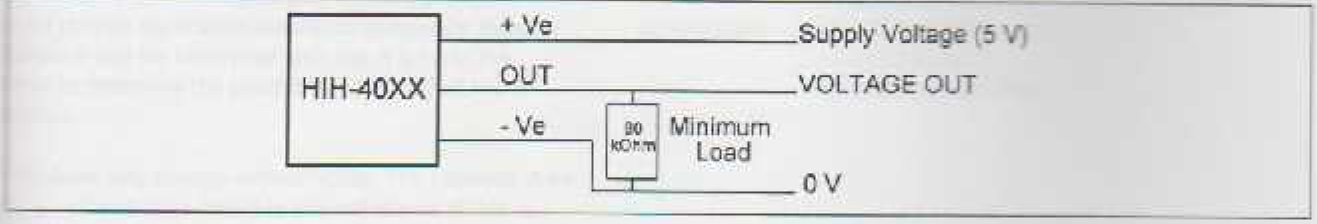


FIGURE 9. TYPICAL APPLICATION CIRCUIT



ORDER GUIDE

Catalog Listing	Description
HIH-4030-001	Covered integrated circuit humidity sensor, SMD, 1000 units on tape and reel
HIH-4030-003	Covered integrated circuit humidity sensor, SMD, calibration and data printout, 1000 units on tape and reel
HIH-4031-001	Covered, filtered integrated circuit humidity sensor, SMD, 1000 units on tape and reel
HIH-4031-003	Covered, filtered integrated circuit humidity sensor, SMD, calibration and data printout, 1000 units on tape and reel
HIH-4030-001S	Sample pack: covered integrated circuit humidity sensor, SMD, five units on tape
HIH-4030-003S	Sample pack: covered integrated circuit humidity sensor, SMD, calibration and data printout, five units on tape
HIH-4031-001S	Sample pack: covered, filtered integrated circuit humidity sensor, SMD, sample pack, five units on tape
HIH-4031-003S	Sample pack: covered, filtered integrated circuit humidity sensor, SMD, calibration and data printout, five units on tape

FURTHER HUMIDITY SENSOR INFORMATION

See the following associated literature is available on the Web:

- Product installation instructions
- Application sheets:
  - Humidity Sensor Performance Characteristics
  - Humidity Sensor Theory and Behavior
  - Humidity Sensor Moisture and Psychrometrics
  - Thermoset Polymer-based Capacitive Sensors

⚠ WARNING

MISUSE OF DOCUMENTATION

- The information presented in this product sheet is for reference only. Do not use this document as a product installation guide.
- Complete installation, operation, and maintenance information is provided in the instructions supplied with each product.

Failure to comply with these instructions could result in death or serious injury.

WARRANTY/REMEDY

Honeywell warrants goods of its manufacture as being free of defective materials and faulty workmanship. Honeywell's standard product warranty applies unless agreed to otherwise by Honeywell in writing; please refer to your order acknowledgement or consult your local sales office for specific warranty details. If warranted goods are returned to Honeywell during the period of coverage, Honeywell will repair or replace, at its option, without charge those items it finds defective. **The foregoing is buyer's sole remedy and is in lieu of all other warranties, expressed or implied, including those of merchantability and fitness for a particular purpose. In no event shall Honeywell be liable for consequential, special, or indirect damages.**

While we provide application assistance personally, through our literature and the Honeywell web site, it is up to the customer to determine the suitability of the product in the application.

Specifications may change without notice. The information we supply is believed to be accurate and reliable as of this printing. However, we assume no responsibility for its use.

⚠ WARNING

PERSONAL INJURY

DO NOT USE these products as safety or emergency stop devices or in any other application where failure of the product could result in personal injury.

Failure to comply with these instructions could result in death or serious injury.

SALES AND SERVICE

Honeywell serves its customers through a worldwide network of sales offices, representatives and distributors. For application assistance, current specifications, pricing or name of the nearest Authorized Distributor, contact your local sales office or:

E-mail: info.sc@honeywell.com

Internet: www.honeywell.com/sensing

Phone and Fax:

Asia Pacific	+65 6355-2828
	+65 6445-3033 Fax
Europe	+44 (0) 1698 481481
	+44 (0) 1698 481676 Fax
Latin America	+1-305-805-8188
	+1-305-883-8257 Fax
USA/Canada	+1-800-537-6945
	+1-815-235-6847
	+1-815-235-6545 Fax

Sensing and Control
Honeywell
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www.honeywell.com/sensing

Honeywell

008001-4-EN IL50 GLO Printed in USA
March 2008

Appendix (C): LM358

LM2904,LM358/LM358A,LM258/LM258A

Dual Operational Amplifier

Features

Description

Internal Block Diagram

FAIRCHILD
SEMICONDUCTOR®

www.fairchildsemi.com

LM2904,LM358/LM358A,LM258/ LM258A

Dual Operational Amplifier

Features

- Internally Frequency Compensated for Unity Gain
- Large DC Voltage Gain: 100dB
- Wide Power Supply Range:
  LM258/LM258A, LM358/LM358A: 3V~32V (or ±1.5V ~ 16V)
  LM2904 : 3V~26V (or ±1.5V ~ 13V)
- Input Common Mode Voltage Range Includes Ground
- Large Output Voltage Swing: 0V DC to Vcc -1.5V DC
- Power Drain Suitable for Battery Operation.

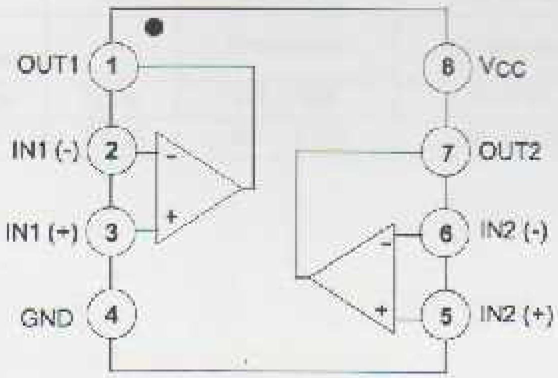
Description

The LM2904,LM358/LM358A, LM258/LM258A consist of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltage. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. Application areas include transducer amplifier, DC gain blocks and all the conventional OP-AMP circuits which now can be easily implemented in single power supply systems.

8-DIP

8-SOP

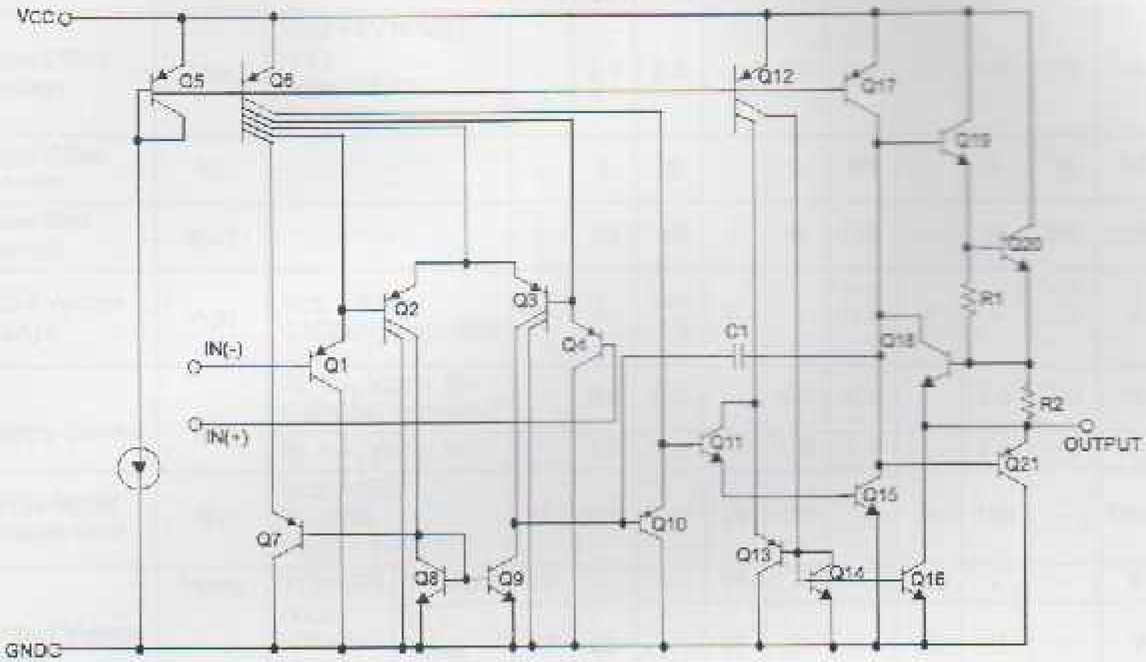
Internal Block Diagram



Rev. 1.0.2

Schematic Diagram

(One section only)



Absolute Maximum Ratings

Parameter	Symbol	LM258/LM258A	LM358/LM358A	LM2904	Unit
Supply Voltage	V_{CC}	±16 or 32	±16 or 32	±13 or 26	V
Differential Input Voltage	$V_{I(DIFF)}$	32	32	26	V
Input Voltage	V_I	-0.3 to +32	-0.3 to +32	-0.3 to +26	V
Output Short Circuit to GND $V_{CC} \leq 15V$, T_A = 25°C(One Amp)	-	Continuous	Continuous	Continuous	-
Operating Temperature Range	T_{OPR}	-25 ~ +85	0 ~ +70	-40 ~ +85	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	-65 ~ +150	-65 ~ +150	°C

Electrical Characteristics

(V_{CC} = 5.0V, V_{EE} = GND, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Conditions	LM258			LM358			LM2904			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V, $V_{O(P)}$ = 1.4V, R_S = 0Ω	-	2.9	5.0	-	2.9	7.0	-	2.9	7.0	mV
Input Offset Current	I_{IO}	-	-	3	30	-	5	50	-	5	50	nA
Input Bias Current	I_{BIAS}	-	-	45	150	-	45	250	-	45	250	nA
Input Voltage Range	$V_{I(R)}$	V_{CC} = 30V (LM2904, V_{CC}=26V)	0	-	V_{CC} -1.5	0	-	V_{CC} -1.5	0	-	V_{CC} -1.5	V
Supply Current	I_{CC}	R_L = ∞, V_{CC} = 30V (LM2904, V_{CC}=26V)	-	0.8	2.0	-	0.8	2.0	-	0.8	2.0	mA
		R_L = ∞, V_{CC} = 5V	-	0.5	1.2	-	0.5	1.2	-	0.5	1.2	mA
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L= 2kΩ, $V_{O(P)}$ = 1V to 11V	50	100	-	25	100	-	25	100	-	V/mV
Output Voltage Swing	$V_{O(H)}$	V_{CC}=30V (V_{CC} =26V for LM2904), R_L = 2kΩ	26	-	-	26	-	-	22	-	-	V
		V_{CC}=30V (V_{CC} =26V for LM2904), R_L= 10kΩ	27	28	-	27	28	-	23	24	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L= 10kΩ	-	5	20	-	5	20	-	5	20	mV
Common-Mode Rejection Ratio	CMRR	-	70	85	-	65	80	-	50	80	-	dB
Power Supply Rejection Ratio	PSRR	-	65	100	-	65	100	-	50	100	-	dB
Channel Separation	CS	f = 1kHz to 20kHz (Note1)	-	120	-	-	120	-	-	120	-	dB
Short Circuit to GND	I_{SC}	-	-	40	60	-	40	60	-	40	60	mA
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V, V_{CC} = 15V, $V_{O(P)}$ = 2V	20	30	-	20	30	-	20	30	-	mA
	I_{SINK}	$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V, V_{CC} = 15V, $V_{O(P)}$ = 2V	10	15	-	10	15	-	10	15	-	mA
		$V_{I(+)}$ = 0V, $V_{I(-)}$ =1V, V_{CC} = 15V, $V_{O(P)}$ = 200mV	12	100	-	12	100	-	-	-	-	µA
Differential Input Voltage	$V_{I(DIFF)}$	-	-	-	V_{CC}	-	-	V_{CC}	-	-	V_{CC}	V

Note:

1. This parameter, although guaranteed, is not 100% tested in production.

Electrical Characteristics (Continued)

(V_{CC}= 5.0V, V_{EE} = GND, unless otherwise specified)
The following specification apply over the range of -25°C ≤ T_A ≤ +85°C for the LM258; and the 0°C ≤ T_A ≤ +70°C for the LM358; and the -40°C ≤ T_A ≤ +85°C for the LM2904

Parameter	Symbol	Conditions	LM258			LM358			LM2904			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω	-	-	7.0	-	-	9.0	-	-	10.0	mV
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	R_S = 0Ω	-	7.0	-	-	7.0	-	-	7.0	-	μV/°C
Input Offset Current	I_{IO}	-	-	-	100	-	-	150	-	45	200	nA
Input Offset Current Drift	$\Delta I_{IO}/\Delta T$	-	-	10	-	-	10	-	-	10	-	pA/°C
Input Bias Current	I_{BIAS}	-	-	40	300	-	40	500	-	40	500	nA
Input Voltage Range	$V_{I(R)}$	V_{CC} = 30V (LM2904 , V_{CC} = 26V)	0	-	Vcc -2.0	0	-	Vcc -2.0	0	-	Vcc -2.0	V
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L =2.0kΩ $V_{O(P)}$ = 1V to 11V	25	-	-	15	-	-	15	-	-	V/mV
Output Voltage Swing	$V_{O(H)}$	V_{CC}=30V (V_{CC} = 26V for LM2904), R_L = 2kΩ	26	-	-	26	-	-	22	-	-	V
		V_{CC}=30V (V_{CC} = 26V for LM2904), R_L=10kΩ	27	28	-	27	28	-	23	24	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L=10kΩ	-	5	20	-	5	20	-	5	20	mV
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V	10	30	-	10	30	-	10	30	-	mA
	I_{SINK}	$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V V_{CC} = 15V, $V_{O(P)}$ = 2V	5	8	-	5	9	-	5	9	-	mA
Differential Input Voltage	$V_{I(DIFF)}$	-	-	-	Vcc	-	-	Vcc	-	-	Vcc	V

Electrical Characteristics (Continued)

(V_{CC} = 5.0V, V_{EE} = GND, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Conditions	LM258A			LM358A			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω	-	1.0	3.0	-	2.0	3.0	mV
Input Offset Current	I_{IO}	-	-	2	15	-	5	30	nA
Input Bias Current	I_{BIAS}	-	-	40	80	-	45	100	nA
Input Voltage Range	$V_{I(R)}$	V_{CC} = 30V	0	-	V_{CC} -1.5	0	-	V_{CC} -1.5	V
Supply Current	I_{CC}	R_L = ∞, V_{CC} = 30V	-	0.8	2.0	-	0.8	2.0	mA
		R_L = ∞, V_{CC} = 5V	-	0.5	1.2	-	0.5	1.2	mA
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L= 2kΩ V_O = 1V to 11V	50	100	-	25	100	-	V/mV
Output Voltage Swing	V_{OH}	V_{CC} = 30V, R_L = 2kΩ	26	-	-	26	-	-	V
		V_{CC} = 30V, R_L =10kΩ	27	28	-	27	28	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L=10kΩ	-	5	20	-	5	20	mV
Common-Mode Rejection Ratio	CMRR	-	70	85	-	65	85	-	dB
Power Supply Rejection Ratio	PSRR	-	65	100	-	65	100	-	dB
Channel Separation	CS	f = 1kHz to 20kHz (Note1)	-	120	-	-	120	-	dB
Short Circuit to GND	I_{SC}	-	-	40	60	-	40	60	mA
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V	20	30	-	20	30	-	mA
	I_{SINK}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V	10	15	-	10	15	-	mA
		V_{in+} = 0V, $V_{in(-)}$ = 1V $V_{O(P)}$ = 200mV	12	100	-	12	100	-	μA
Differential Input Voltage	$V_{I(DIFF)}$	-	-	-	V_{CC}	-	-	V_{CC}	V

Note:

1. This parameter, although guaranteed, is not 100% tested in production.

Electrical Characteristics (Continued)

(V_{CC} = 5.0V, V_{EE} = GND, unless otherwise specified)
The following specification apply over the range of -25°C ≤ T_A ≤ +85°C for the LM258A; and the 0°C ≤ T_A ≤ +70°C for the LM358A

Parameter	Symbol	Conditions		LM258A Min.	LM258A Typ.	LM258A Max.	LM358A Min.	LM358A Typ.	LM358A Max.	Unit
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V, $V_{O(P)}$ = 1.4V, R_S = 0Ω		-	-	4.0	-	-	5.0	mV
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	-		-	7.0	15	-	7.0	20	μV/°C
Input Offset Current	I_{IO}	-		-	-	30	-	-	75	nA
Input Offset Current Drift	$\Delta I_{IO}/\Delta T$	-		-	10	200	-	10	300	pA/°C
Input Bias Current	I_{BIAS}	-		-	40	100	-	40	200	nA
Input Common-Mode Voltage Range	$V_{I(R)}$	V_{CC} = 30V		0	-	Vcc -2.0	0	-	Vcc -2.0	V
Output Voltage Swing	$V_{O(H)}$	V_{CC} = 30V	R_L = 2kΩ	26	-	-	26	-	-	V
			R_L = 10kΩ	27	28	-	27	28	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L=10kΩ		-	5	20	-	5	20	mV
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L=2.0kΩ, $V_{O(P)}$ = 1V to 11V		25	-	-	15	-	-	V/mV
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V, V_{CC} = 15V, $V_{O(P)}$ = 2V		10	30	-	10	30	-	mA
	I_{SINK}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V, V_{CC} = 15V, $V_{O(P)}$ = 2V		5	9	-	5	9	-	mA
Differential Input Voltage	$V_{I(DIFF)}$	-		-	-	V_{CC}	-	-	V_{CC}	V

Typical Performance Characteristics

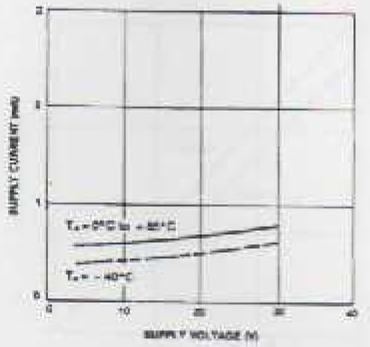


Figure 1. Supply Current vs Supply Voltage

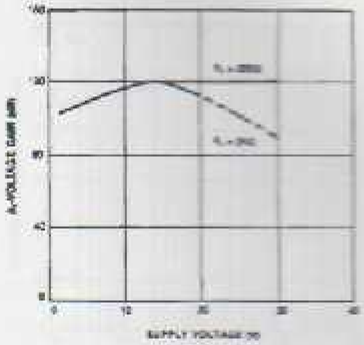


Figure 2. Voltage Gain vs Supply Voltage

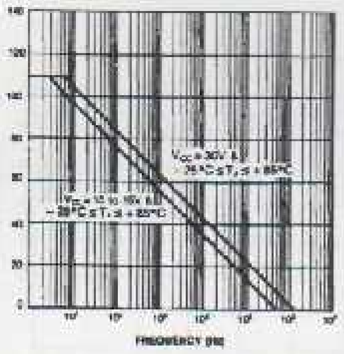


Figure 3. Open Loop Frequency Response

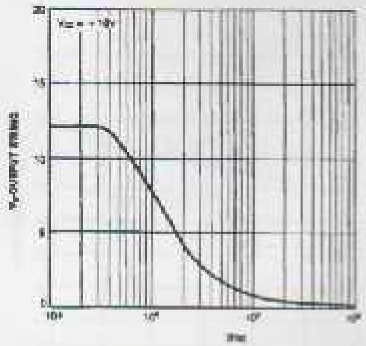


Figure 4. Large Signal Output Swing vs Frequency

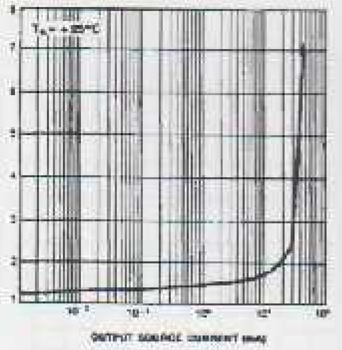


Figure 5. Output Characteristics vs Current Sourcing

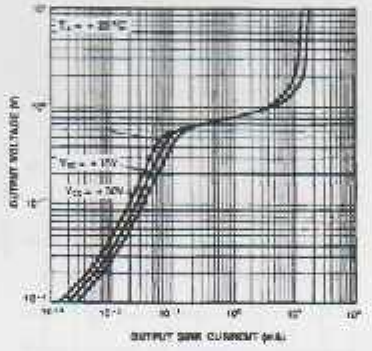


Figure 6. Output Characteristics vs Current Sinking

Typical Performance Characteristics (Continued)

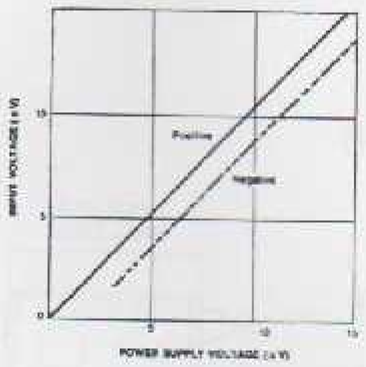


Figure 7. Input Voltage Range vs Supply Voltage

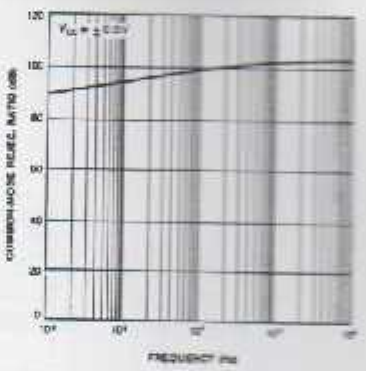


Figure 8. Common-Mode Rejection Ratio

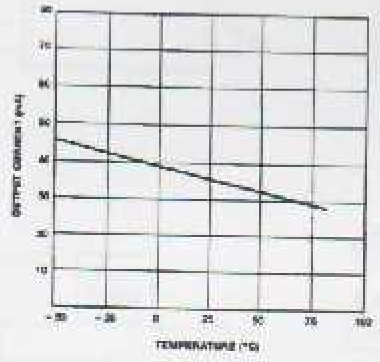


Figure 9. Output Current vs Temperature (Current Limiting)

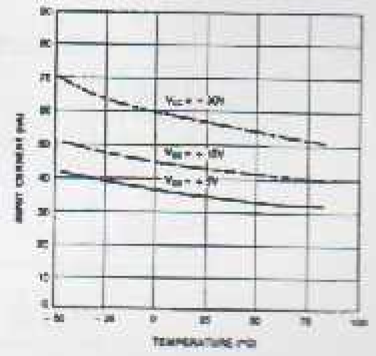


Figure 10. Input Current vs Temperature

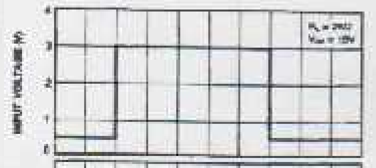


Figure 11. Voltage Follower Pulse Response

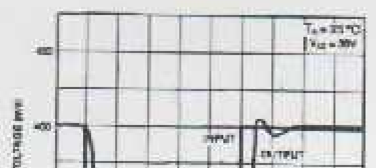


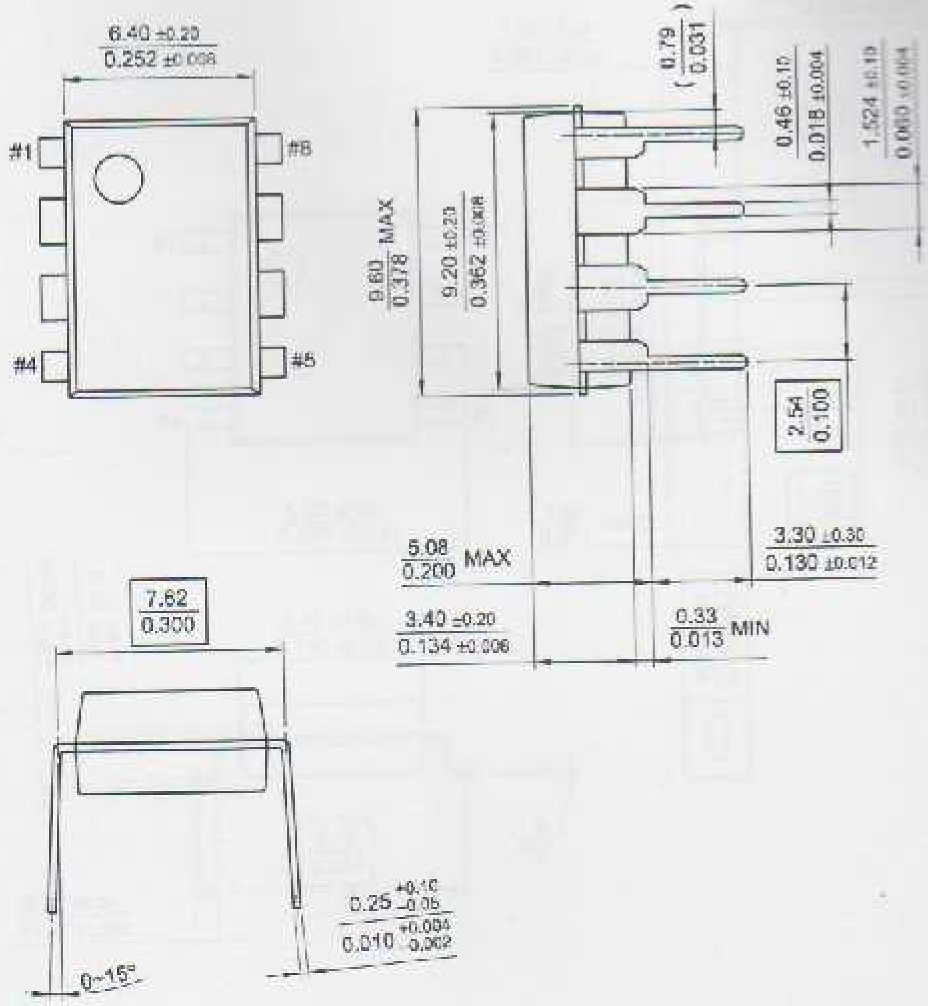
Figure 12. Voltage Follower Pulse Response (Small Signal)

Mechanical Dimensions

Package

Dimensions in millimeters

8-DIP

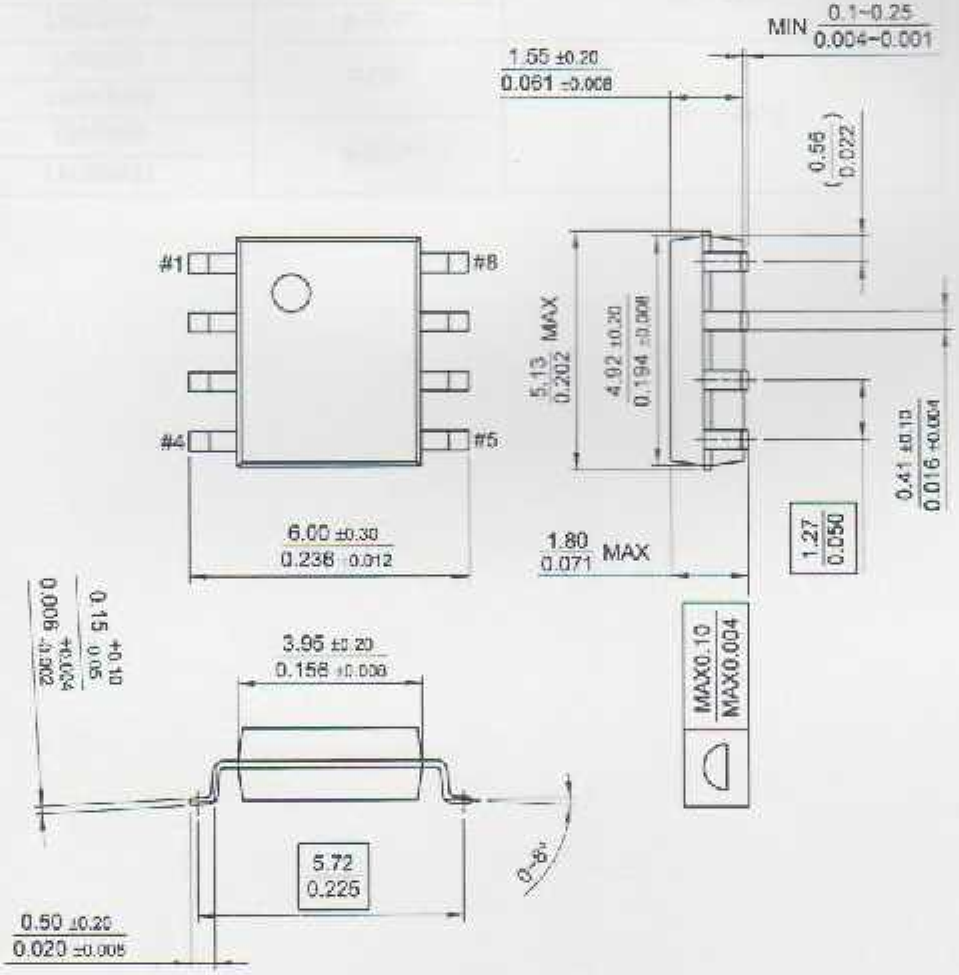


Mechanical Dimensions (Continued)

Package

Dimensions in millimeters

8-SOP



Ordering Information

Product Number	Package	Operating Temperature
LM358N	8-DIP	0 ~ +70°C
LM358AN		
LM358M	8-SOP	
LM358AM		
LM2904N	8-DIP	-40 ~ +85°C
LM2904M	8-SOP	
LM258N	8-DIP	-25 ~ +85°C
LM258AN		
LM258M	8-SOP	
LM258AM		

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1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and (c) whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury of the user.
2. A critical component in any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

8/26/02 0.0m 001
Stock#DSxxxxxxxx

Appendix (D) : LM78XX

LM78XX Series Voltage Regulators

General Description

Features

Voltage Range

Connection Diagrams

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

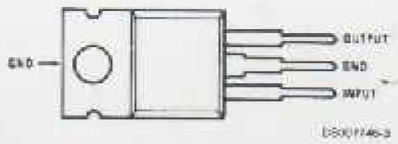
LM7805C	5V
LM7812C	12V
LM7815C	15V

Connection Diagrams

Metal Can Package
TO-3 (K)
Aluminum

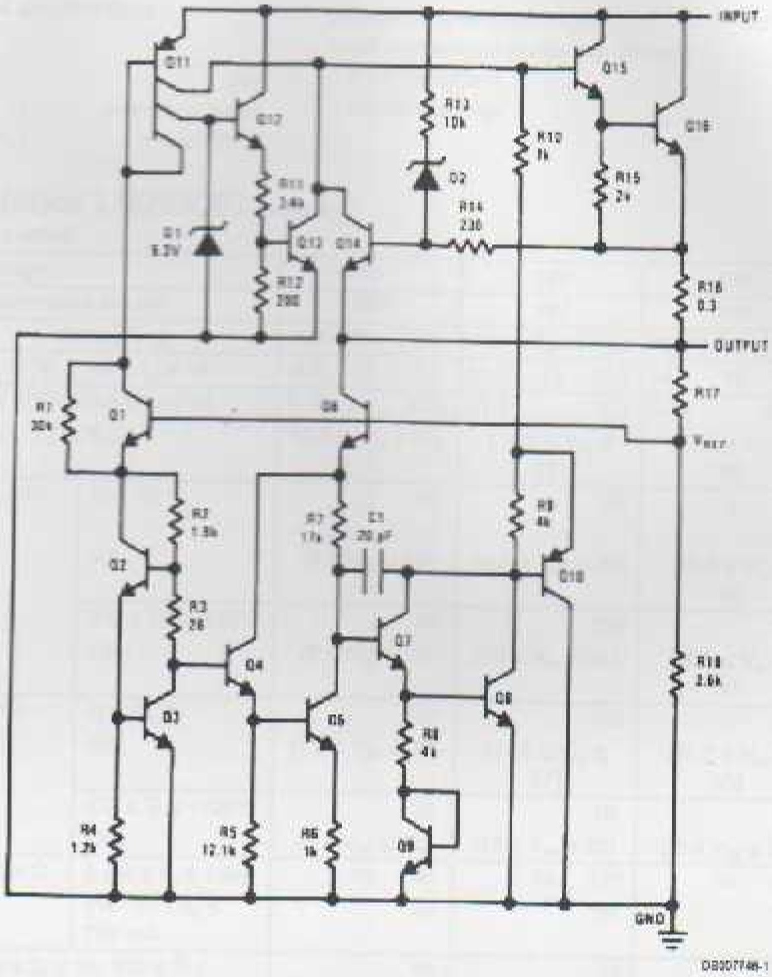
Bottom View
Order Number LM7805CK,
LM7812CK or LM7815CK
See NS Package Number KC02A

Plastic Package
TO-220 (T)



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

Schematic



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 ≤ T_J ≤ 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} ≤ V_{IN} ≤ 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} ≤ V_{IN} ≤ 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} ≤ V_{IN} ≤ 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} ≤ V_{IN} ≤ 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°C ≤ T_J ≤ 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	
	Short-Circuit Current	Tj = 25°C		2.1			1.5			1.2		A
	Peak Output Current	Tj = 25°C		2.4			2.4			2.4		A
	Average TC of V_{OUT}	0°C ≤ Tj ≤ +125°C, I_O = 5 mA		0.6			1.5			1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	Tj = 25°C, I_O ≤ 1A		7.5		14.6			17.7			V

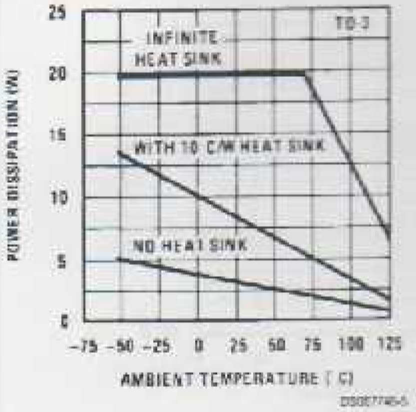
Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

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 ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

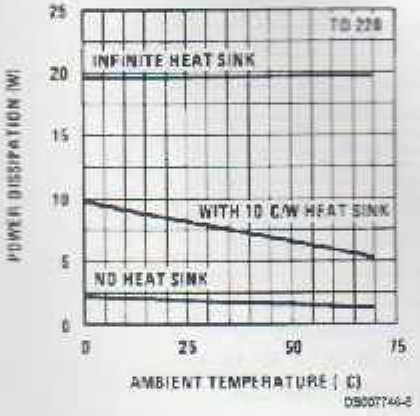
Note 3: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

Typical Performance Characteristics

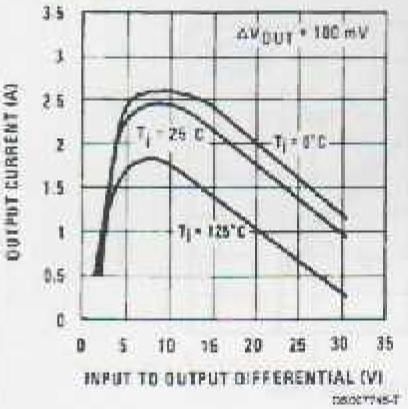
Maximum Average Power Dissipation



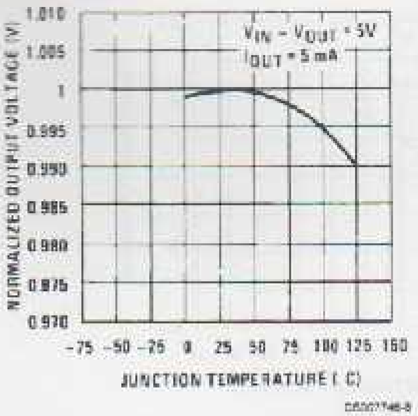
Maximum Average Power Dissipation



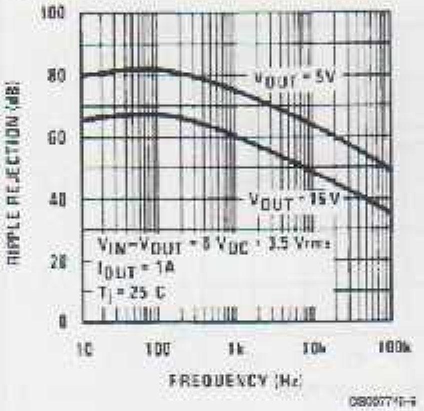
Peak Output Current



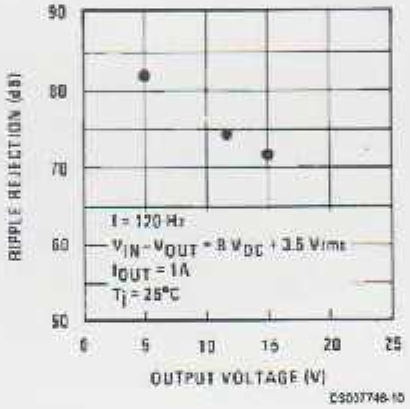
Output Voltage (Normalized to 1V at T_J = 25°C)



Ripple Rejection

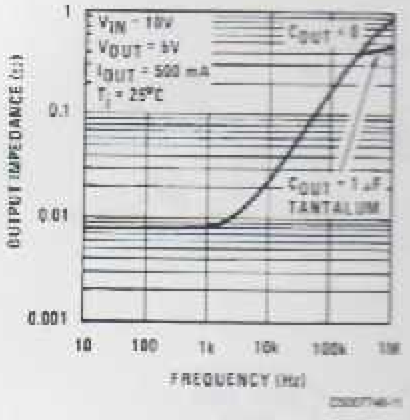


Ripple Rejection

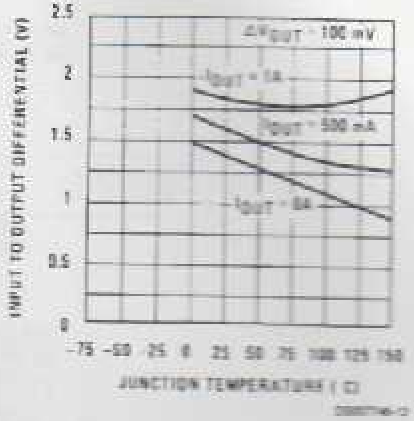


Typical Performance Characteristics (Continued)

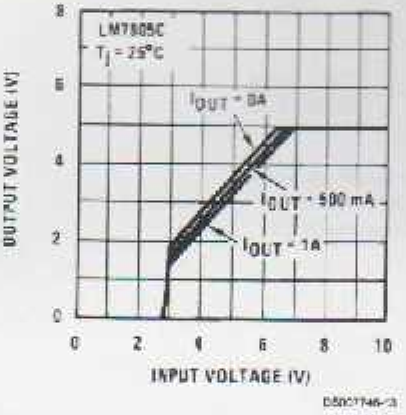
Output Impedance



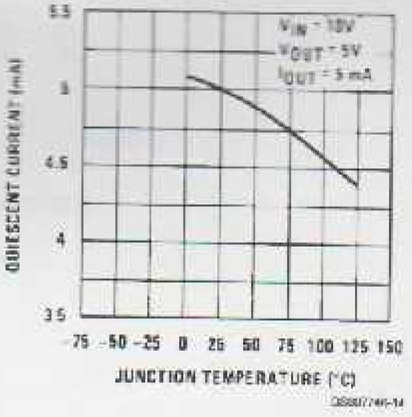
Dropout Voltage



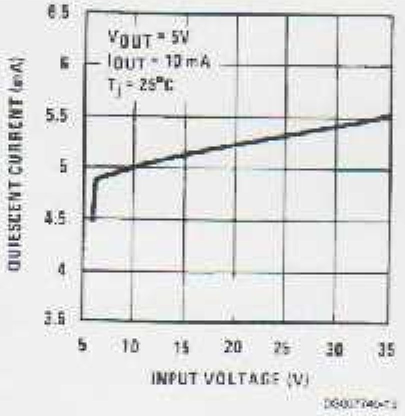
Dropout Characteristics



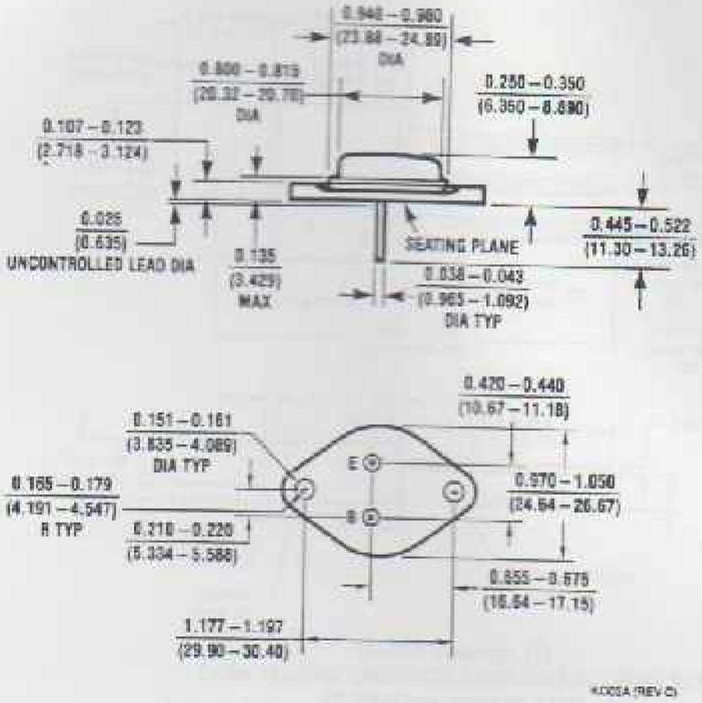
Quiescent Current



Quiescent Current

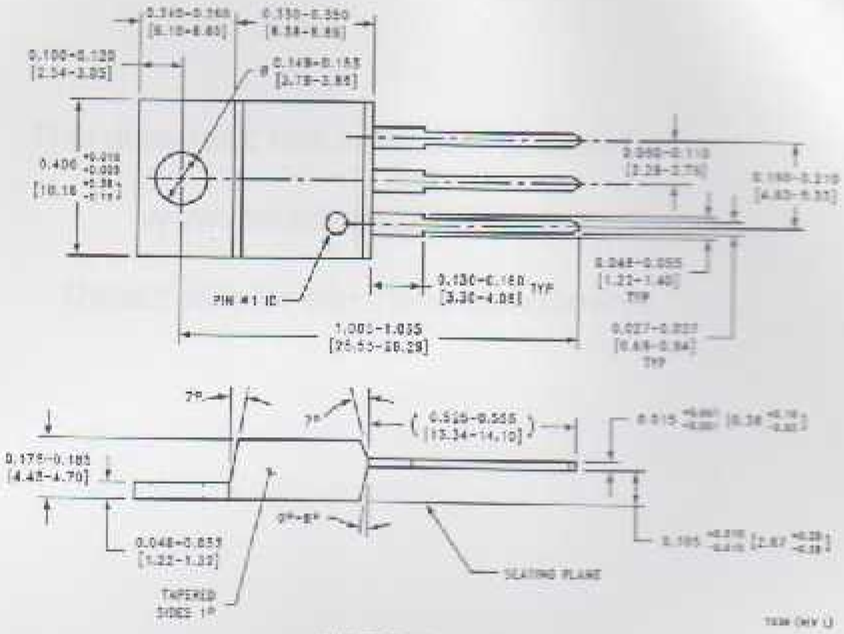


Physical Dimensions inches (millimeters) unless otherwise noted



Aluminum Metal Can Package (KC)
Order Number LM7805CK, LM7812CK or LM7815CK
NS Package Number KC02A

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



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

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