CERTIFICATION OF APPROVAL

Automatic Electronic Control of the Level of LPG in air in a Confined Space

by

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ARBAEYAH BT ISMAIL

ABSTRACT

Documentation of the automatic electronic control of the level of LPG in air in a confined space can be viewed in this project. Humans are increasingly becoming dependent on petrochemical products for their daily life. Ignition of these combustible products can have catastrophic effect especially in a confined space where there exist limited amount of air. Therefore, a sensor is needed to monitor the level of gases in homes and also in industry to avoid all possibilities of the accidents.

The aim of this project is to design an automatic electronic control of the level of flammable gases in a closed chamber as one of the solution in curbing the concentration of these gasses from increasing in air and reaching its lower explosive limit (LEL). Literature review was done in order to select the suitable sensor and the appropriate circuit. Some lab work was also conducted to verify all the findings and simulate the circuit designed.

After simulation, the circuit was designed and tested on breadboard. Graphs of voltage changes versus time and when exposed to gas was plotted. From detailed analysis using the spreadsheet provided, it was demonstrated that the sensor is very sensitive and its response time is less than a minutes. The circuit is demonstrated to be working once the sensor is to be working once the sensor is exposed to the gas by actuating a venting fan. A prototype sensor circuit is finally designed and tested.

ACKNOWLEDGEMENT

The author would like to take this opportunity to express appreciation to those who had assisted in making author's final year project a success.

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Electrical and Electronic Engineering

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INTRODUCTION

1.1 Background of Study

Liquefied Petroleum Gas (LPG) is the generic name for commercial propane and commercial butane [1]. These are hydrocarbon products produced by the oil and gas industries. Commercial Propane predominantly consists of hydrocarbons containing three carbon atoms, mainly propane (C_3H_8). They have a special property of becoming liquid at atmospheric temperature if moderately compressed and reverting to gases when the pressure is sufficiently reduced. There is an advantage in using this property to transport and store these products in the liquid state, where they are roughly 250 times as dense as they are when in the gaseous state.

This flammable gas is generally used for lighting, space heating, control heating in a confined space, air conditioning system, hot water supply, refrigeration and also cooking at home. In addition, it is also used in the manufacturing plants or factories to for instance maintain the temperature at certain level by heating and also as heat supply to maintain pressure in the vessels of the plants.

The capability of all these gasses to create flame or burn once it is exposed to a spark in an oxygen atmosphere is a very dangerous hazard. The awareness of this danger has raised concerns on ways or alternatives to avoid accidents caused by flammable gases.

1.2 Problem Statement

LPG and Methane are flammable gasses and have caused some home accidents because people lack awareness of the dangers possessed by these gases once they reach certain critical limits known as lower explosive limit (LEL). From a survey made in September 2002, it is found that currently there are home accidents caused by LPG gas tank explosion [2]. This hazardous gas is flammable and might cause fire once a spark or fire exist in the surrounding.

As a reminder or safety precaution, for user attention or to normalized the flammable gas level automatically once it reaches the dangerous limit, design of a gas detector is needed to monitor these levels electronically. Therefore, this project will focus on using a hydrocarbon sensor and designing an appropriate electronic circuit to detect LPG and methane as well as to control and keep the levels of these gases below the LEL in a confined environment.

1.3 Objectives of Study

- To acquire a reliable gas sensor to be applied in the design
- To design a suitable sensor circuit and ensure that it is capable of reacting to presence of 20% of the LEL of LPG set by the designer.
- To incorporate a ventilation fan to be automatically activated to normalized back the level of LPG in air in a confined space or area.
- To design a prototype sensor devices.

CHAPTER 2

LITERATURE REVIEW

2.1 Enclosure Fire Growth

Generally, fire development in an enclosure is commonly divided into stages. If we are able to control the fire at an early stage, accidents can be avoided. Referring to Figure 1, it is clearly viewed that the stages are:

1. Ignition: Process that produce exothermic reaction by an increase in temperature above the ambient.
2. Growth: Depend on the type of combustion, fuel, interaction with surroundings and access to oxygen.
3. Flashover: Transition state from growth to fully developed fire
4. Fully developed fire: Energy release in the enclosure is at its greatest and often limited by the availability of oxygen.
5. Decay

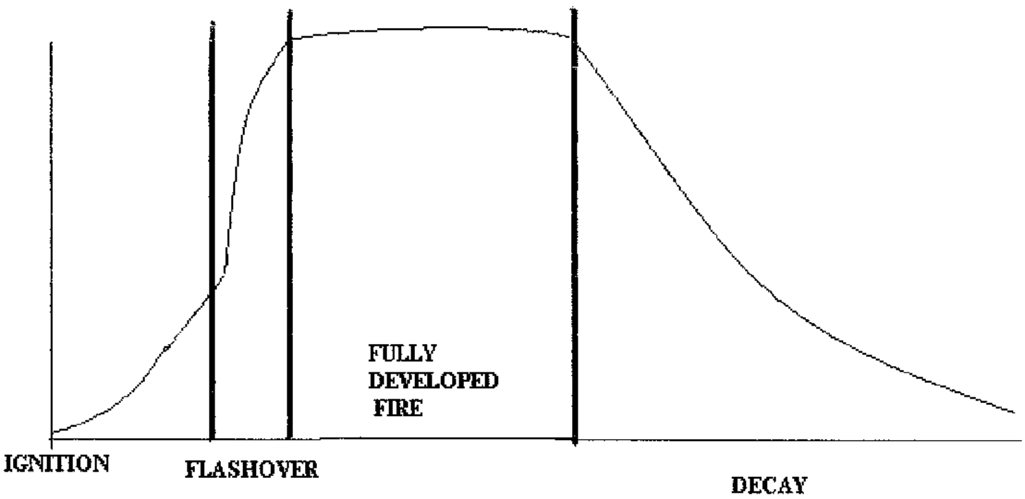


Figure1: Level of stages of fire in a closed enclosure condition

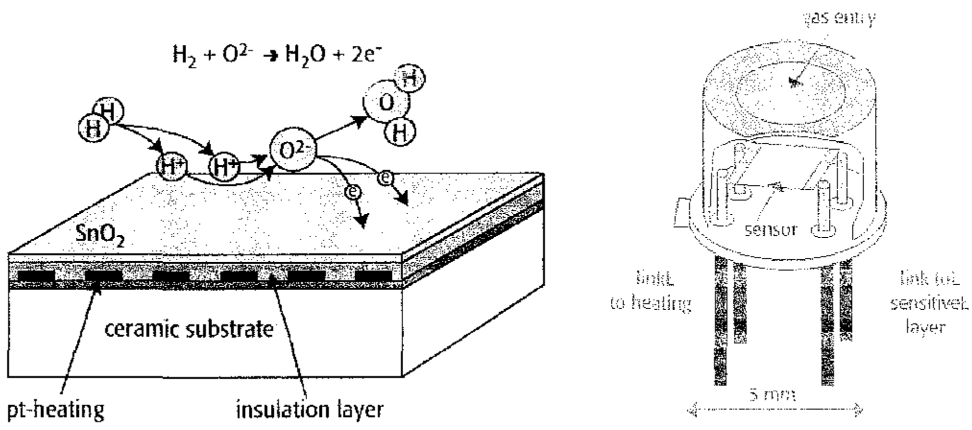
Enclosure fire is much more dangerous than the open fire as there are remaining gas that cannot be burn because of the lack of oxygen in the space. Once there is an opportunity to spread to the outside area, a high pressure of gas and flame could be seen and it is called thermal feedback where high flame came out of a compartment opening such as windows etc.

Therefore, it is important for the fire to be avoided. With the sensor that will trigger alarm or open the venting fan, the level of gas in an enclosure space is controlled from reaching the dangerous level.

2.2 Gas sensors

From researches made through the internet, some relevant materials were found regarding gas sensors. Generally, there are a few types of gas sensors available in the market and after doing some literature survey, below are information and comments made by some researchers on the gas sensor types.

Heinz Petig [3] explains that the detection of gasses by the semiconductor gas detectors based on tin dioxide (SnO_2) are not only cheap but also resilient. The gas contained in the surrounding air chemically combines on the sensor surface, causing the gas molecule to lose some of the electrical charge. This in turn increases the conductivity of the semiconductor. In other words, the conductivity of the sensor element increases in proportion to the gas concentration. Figure 2(a) shows the mechanism mentioned above. As an example, the hydrogen gas in the air and oxygen molecules will combine with each other and produce water and also electron that will be absorb by the tin oxide layer. The higher level of the hydrogen, it means that more electrons will be absorb and the higher the resistance and at certain limit will activate the relay that will activate the alarm or the venting fan. Figure 2(b) shows the design of the sensor. Basically, the top part of the sensor or the cover is made of plastic that allow gas penetration. The size is very small and have four legs where 2 of them are supplying current for heating element and the other two are to energize the sensor.



(a) (b)

Figure2: Showing how the sensor sense the gas

Zhenan Tang [4] has similar concepts of the sensor as he explain that tin dioxide Taguchi gas sensor based on thick film technology was demonstrated to be sensitive to selected gas such as H_2, NH_4, CO etc. The resistance of the SnO_2 film decrease due to the removal of chemisorbed oxygen by the gas. This type of gas sensor operates at high temperature (typically at 450^0).

Generally, the semiconductor sensor of any type will have similar connections. Figure 3 shows the general connection of sensor with the power supply.

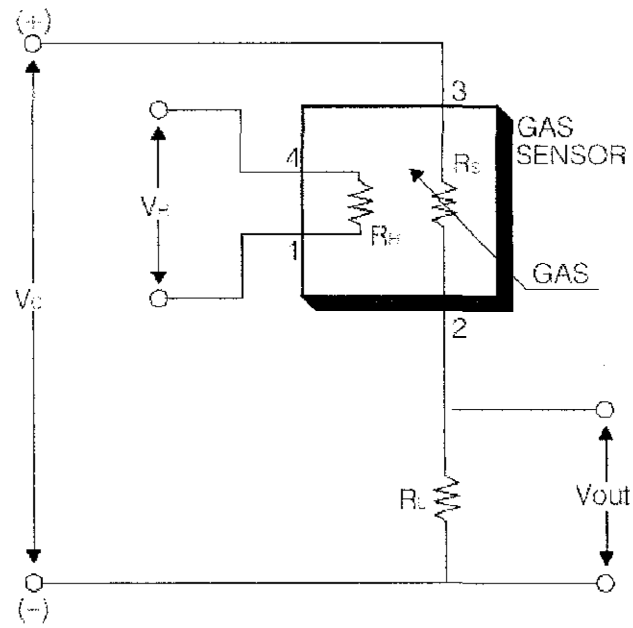


Figure 3: Cross sectional drawing of the gas sensor

V_H is the heater voltage that needs to be supplied to heat up the sensor to enable it to trap electrons and increase its resistivity. V_C is the supply voltage for the circuit and connected to the sensor resistor that varies with respect to the amount of electron trapped in the sensor. As more hydrocarbon was exposed to it, the resistance will decrease as more electrons will be free to move around the circuit instead of being trap on the sensor. The V_{OUT} is the point where it is connected to the circuit that need to be constructed to activate the venting fan and ensure the safety of user.

Another type of sensor is the metal oxide semiconductor (MOS) sensor that measures the change in conductivity from a heated oxidation reaction (hydrocarbon) on a metal oxide surface which will give a nonlinear and unstable reading over time and temperature input. However, this sensor requires frequent calibration to avoid any false alarm [5].

From research made, it is proven that most gases have a unique infrared absorption line and provides conclusive identification and measurement of the target gas with little interference from other gases. Since the sensor elements do not touch the gas, they are not poisoned by contact with the environment [5]. This type of infra-red sensor applies photonic crystal and surface plasmon interaction. It uses micro-bridge structure to enable power efficient heating of device and increase the sensitivity to gas concentration and level. This has proven that the infrared sensor is much better than the MOS. However, in term of its price, it has higher price compared to the semiconductors and MOS.

For the semiconductor sensor, it had been found that there are two applicable sensors, that is, the Taguchi Figaro sensor model TGS 2610 and Han Wei sensor model MQ-6.

The Taguchi Figaro Gas sensor model TGS2610 is suitable for flammable gas , detection and specifically LPG detection. The type is D1 that have low power consumption. This sensor has two elements in it that is the heater elements that are place at the reverse side of the chip. It is packed in a metal can with small holes on top to capture the hydrocarbon gasses into the sensor. This sensor cost USD 7 per sensor.

Its sensitivity characteristic is explained in detail by referring to Figure 4 below.

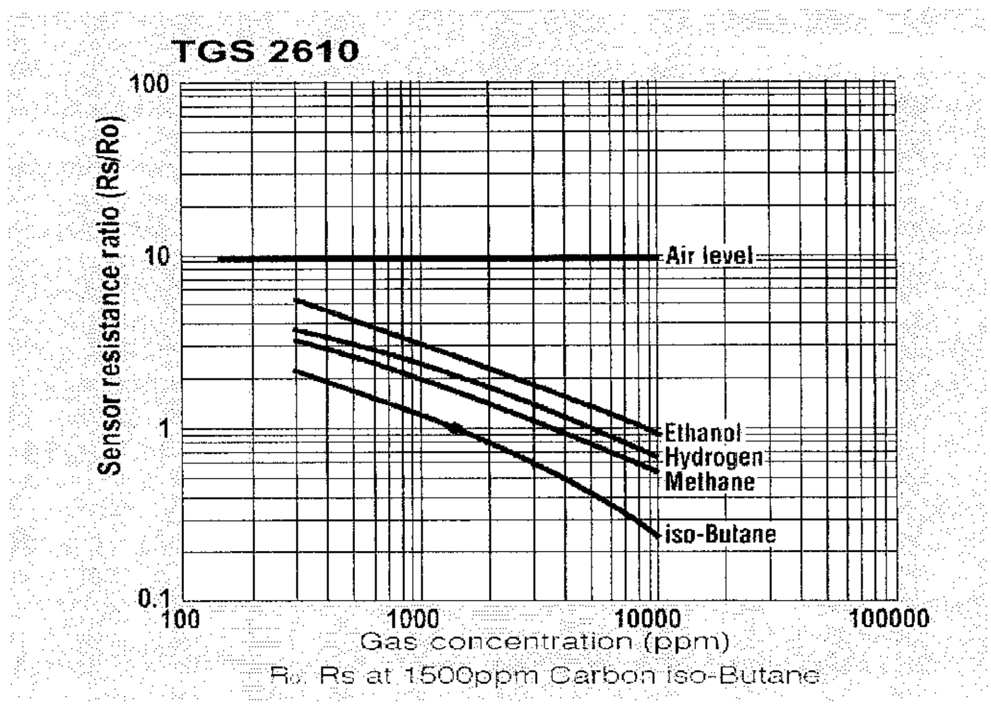


Figure 4: The characteristic of TGS2610

The sensor resistor, R_S is normalized according to the sensor resistance at specific condition, R_O. The y- axis shows the ratio of the sensor and specific resistance. This R_S has a range between 1 up to 5 V varying depending on the amount of electron attached on the sensor. This sensor will be applied to the circuit by taking all the considerations on its characteristics.

2.3 MQ-6

Among the choices, the Han Wei sensor model MQ-6 has been chosen[1]. This sensor is made of micro AL_2O_3 ceramic tube, Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater. This sensor has a high sensitivity in LPG, isobutene and propane. The advantage of this sensor is that it has a very small sensitivity to alcohol and smoke. This ensures that only the real LPG will be sensed and probability of having a faulty error can be minimized. It has a very fast response that is approximately 5 seconds.

In term of its physical construction, this sensor has a gas sensing layer made of SnO_2 while its electrode is made of Au. Its heater coil is made of the nickel-chromium alloy and its tubular ceramic is made of Al_2O_3. This sensor is very small and approximately 2 cm diameter.

Figure 5 shows the cross sectional drawing of the MQ 6 sensor .The enveloped MQ-6 have 6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current. Leg A and B is for fetching signal where its resistance will change according to gas concentration in air while the heater is for heating the sensor to ensure it is capable to trap oxygen on its surface at certain temperature. Once connected to the circuit, this sensor will need the adjustment of the load resistance as the sensor output is different depending on the humidity condition and also the sensitivity depends on the environment of its placement.

[1] The data sheet is available in Appendix 1

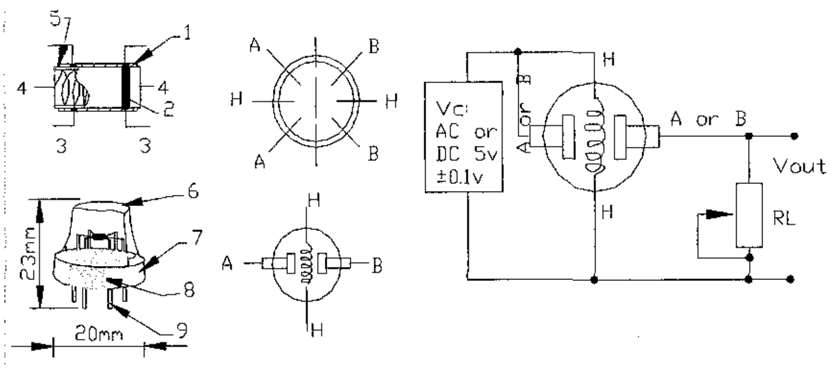


Figure 5: Cross sectional drawing of MQ 6

Labels in Figure 5 show the structure and basic configuration of the sensor:

1- Gas sensing layer made of tin dioxide

2- Electrode

3- Electrode line

4- Heater coil

5- Tubular ceramic

6- Anti explosion network made of stainless steel gauze

7- Clamp ring made of copper plating with nickel

8- Resin base made of bakelite

9- Tube Pin for connections made of copper plating nickel

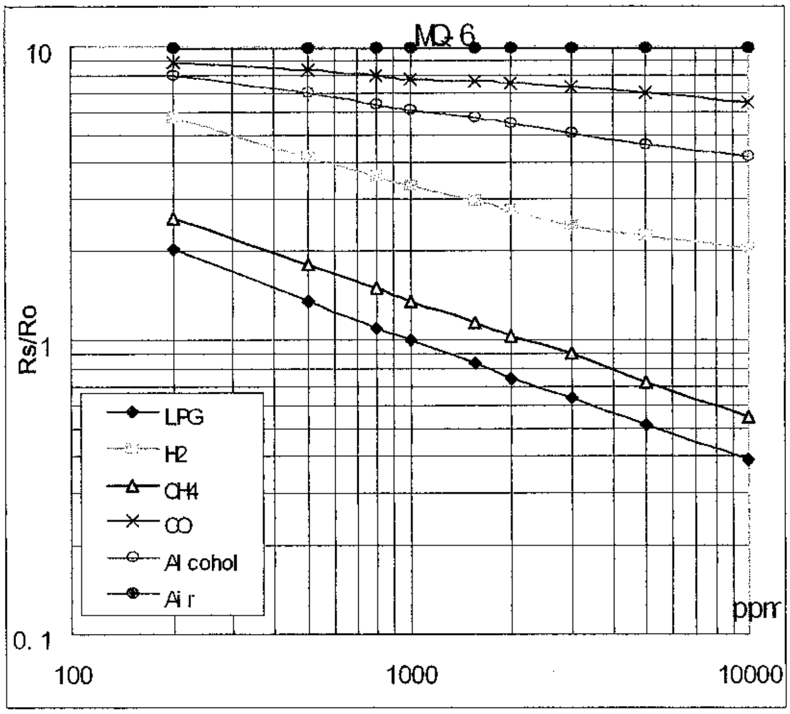


Figure 6: The characteristic of MQ-6

Figure 6 shows the characteristic curve of the MQ 6 made from observation and analysis, MQ-6 sensitivity characteristic of several types of gasses in a normal temperature and humidity.

As the amount of gas increases, the resistance will decrease and allow more current to pass through. It reaches its lowest resistance at a maximum of 10,000 ppm. We can see that the most influencing type of gas for this sensor is the LPG and propane. The other gasses will have a higher resistance and its decrement is very small compared to the two gasses mentioned earlier. This sensor is made in Taiwan and its cost is USD 2 per sensor.

2.4 Circuit designs

A few circuit designs were explored during the research and each of them differ depending on the component parts used.

2.4.1 Using SCR as a triggering element

One of the circuits uses the SCR as a triggering switch and need to be reset once the alarm and venting fan has been triggered.

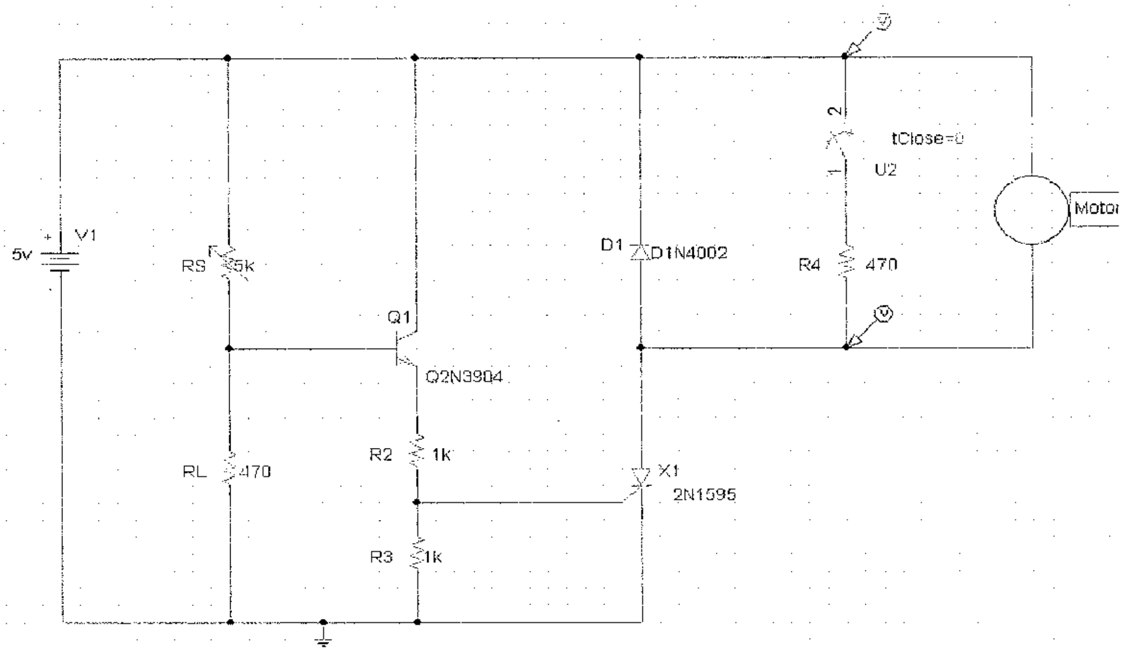


Figure 7: Using SCR to trigger the motor

Referring to Figure 7, R_S at normal condition has a high resistance as the electrons in the circuit were bonded with the oxygen and hydrogen in the air on the sensor. Therefore, a small current is only allowed in the circuit. In order to activate the circuit, a certain amount of voltage must appear on the R_L-R_S junction to trigger the SCR and activate the fan motor to switch on the fan. As more hydrocarbon accumulated in the air , it will block the absorption of electrons in the air and therefore more electrons are free to move in the circuit and the resistance R_S goes lower and enough voltage appear on the R_L-R_S junction to trigger the SCR which drives the motor. R_4 is used to self latch the alarm. It is wired across the motor so that SCR triggering leg do not fall to '0' as the motor self-interrupts. Q_1 is a buffer between R_2 and SCR. This circuit however will need people to turn the fan motor OFF manually by using the switch, U2 once the level is predicted to be normalized.

2.4.2 Using 555 Timer as a triggering element

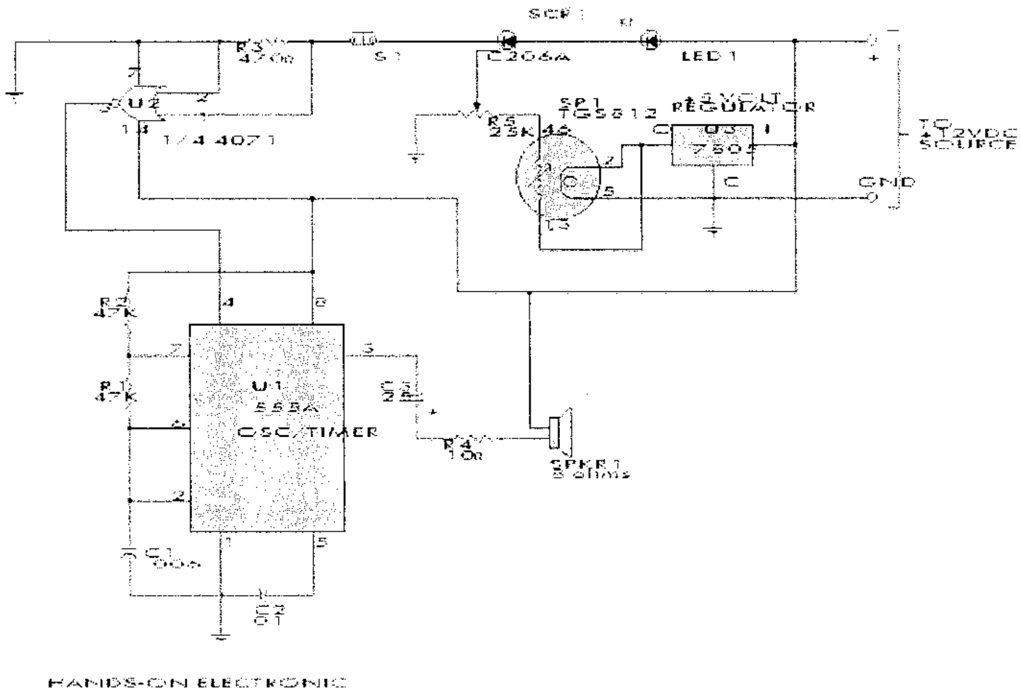


Figure 8: Using the timer to trigger the motor

Figure 8 shows the circuit diagram of a gas sensor that will trigger an alarm once the level of gas increased [6]. The gas-sensitive semiconductor (acting like a variable resistor in the presence of toxic gas) decreases in electrical resistance when gaseous toxins are absorbed from the sensor surface. A 25,000 ohm potentiometer (R5) connected to the sensor serves as a load, voltage-dividing network, and sensitivity control and has its center tap connected to the gate of SCR1. When toxic fumes come in contact with the sensor, decreasing its electrical resistance, current flows through the load (potentiometer R5). The voltage developed across the wiper of R5, which is connected to the gate of SCR1, triggers the SCR into conduction. With SCR1 now conducting, pin 1-volt supply for the semiconductor elements of the

TGS812 in spite of the suggested 10 volts, thus reducing the standby current. A 7805 regulator is used to meet the 5-volt requirement for the heater and semiconductor elements.

2.4.3 Using operational amplifier as the triggering element

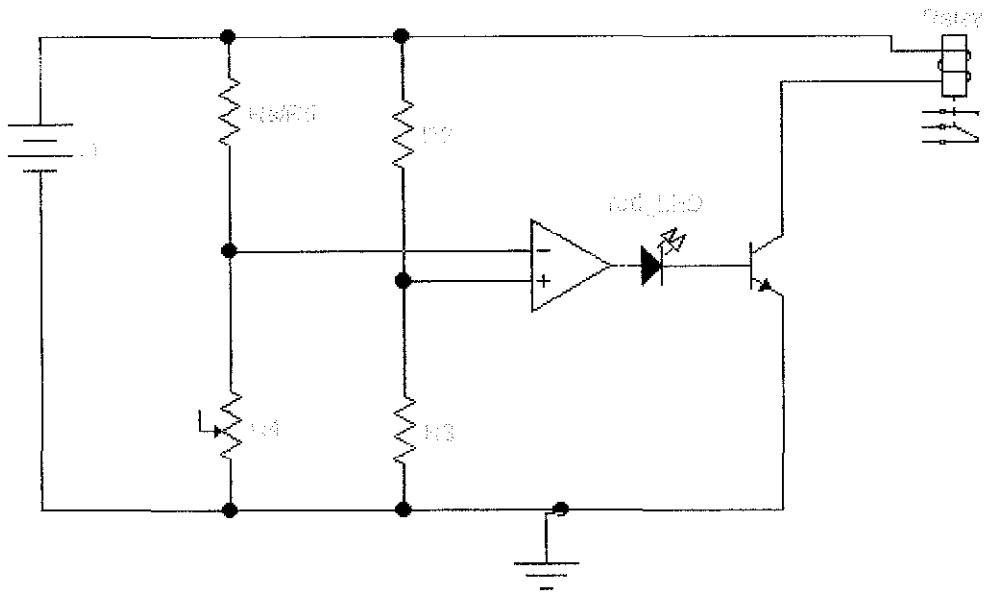


Figure 9: Operational amplifier as the triggering element

Referring to Figure 9, both the operational amplifier inverting input and non inverting input are connected to a voltage divider supply. As a comparator, this op-amp will determine when an input voltage exceeds a certain level. The negative voltage is used to set the fixed reference voltage or limit to switch on the op-amp. The positive or non-inverting input will receive input voltage. Once this input exceeds the reference voltage, the output goes to its maximum positive voltage. For the voltage to turn from maximum negative voltage back to maximum positive voltage, the input voltage to the non inverting input must fall below V_{LTP}(voltage at lower triggering point). To ensure the hysterisis is minimized, the most essential part is to place a feedback for the sensor to solve and make adjustments accordingly depending on the research done.

CHAPTER 3

METHODOLOGY

In order to make this project successful, a plan has been developed that covers all methods applied throughout this period of completing this project. The flow chart of the plan is indicated in Figure 9.

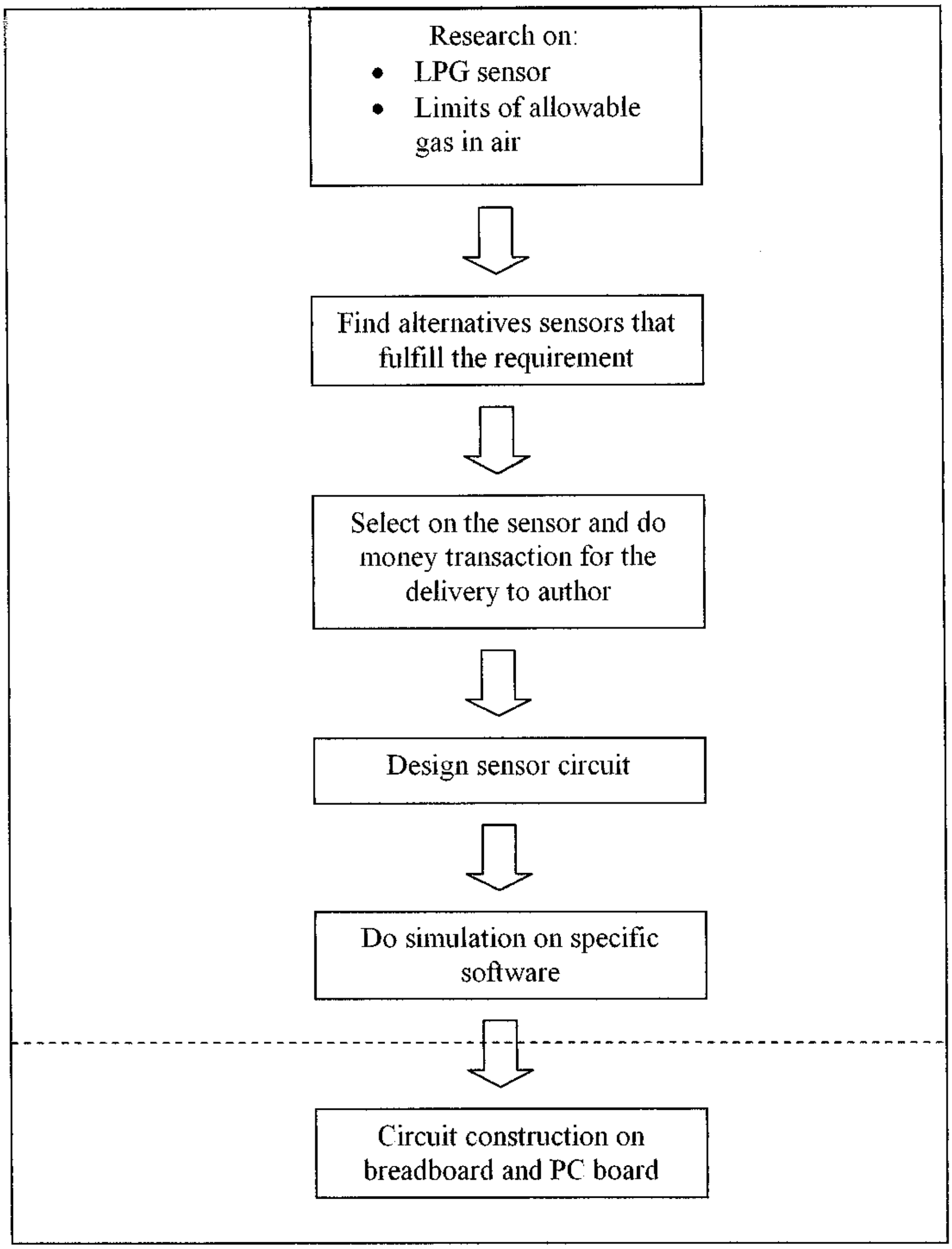


Figure 10: Plan for project completion

3.1 Research

First of all some research regarding the sensors, specifically hydrocarbon sensors and its applications is carried out. These researches had been done during the first 4 weeks of the first semester. All sort of sources are used such as books in the library, on electronic devices, journals and surfing the internet. Besides trying to understand the basic concepts of the sensor and its function, specifications on various sensors related to the project is also collected as a reference from the vendors.

Meanwhile, survey is done on the prices and availability of all the components needed such as relay, silicon diodes, potentiometer, capacitors and the gas sensor that will be use for circuit construction. Surveys are made at the hardware shops nearby, in this country and further contacts has been made to the vendors and suppliers of the sensors overseas.

Besides components, price of specific percentage of gas supply that need to be ordered from MOX need to be known to estimate the expenditure of this project. Simultaneously, a connection circuit for combining the sensor circuit and the relay to activate the automatic control is to be designed with the correct value of the components.

Next, a research on some available sensors in the market had been done to get a general idea of the expected design of the sensor circuit. This research was done online and also through some books at the library. Comparison was carried out by analyzing the sensitivity and response of the sensors once the gas was detected at certain level. Besides the gas sensor circuits, other circuits designs were also observed and some modifications made to suit the project objectives.

3.2 Sensor Selection

Once all essential research has been done, there was need to select a single type of sensor to be used in the project. Furthermore, a testing gas supply is also need to be prepared for future applications. Once the specific sensor had been chosen, an arrangement for purchasing the sensor was done. Emails were sent to the manufacturer to ask for the price together with its delivery charge. It is agreed that the amount that need to be paid is RM218.50, which is the delivering fee while the sensors were given for free as samples. Once the deal was done, money was banked in to the manufacturer's account in the Bank of China in Taiwan before the sensor was delivered by air. Money transaction and delivery of the sensor took approximately 14 days.

3.3 Sensor Testing

In order to verify the data in the data sheet and monitor the sensor performance, a test was conducted solely on the sensor itself. Figure 10 is a schematic diagram of the sensor circuit indicating the sensor, heater and load resistance, R_L. The procedures below are followed in doing the testing of the sensor:

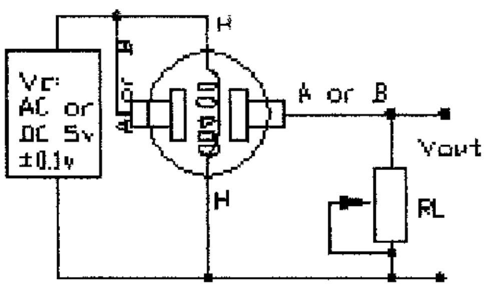


Figure 11: Circuit connection for sensor testing

i. The sensor is connected to the power supply as in Figure 11.
ii. The sensor is heated not less than 24 hours.

iii. Using the Data Studio, the probe is connected to the negative side of the sensor resistor, R_S and heater leg to measure V_{OUT} as labeled in Figure 10 and monitor the voltage value at the output
iv. Using the Data Studio, observe the value of voltage at normal surrounding air across the load resistor.
v. Using a lighter, expose some gas at a distance of approximately 0.5 meter from the sensor.[2]
vi. Using the Data Studio again, observe the voltage during exposure of gas.
vii. Using timer, note the time for the voltage to normalized back to normal voltage.

3.4 Circuit Construction

3.4.1 Design

The next step is to design a circuit that interfaces the sensor with the fan motor. Taking examples from findings in the internet and also reference books, a simple circuit has been constructed. Later after simulations was done, changes were made from using SCR as a triggering element to using Operational Amplifier to trigger the fan motor using relay. Once the breadboard testing was done according to the design, the design was review and another power supply was added in the relay circuit. For proving purposes, simulations of the design circuit using software were done before testing the circuit on board.

3.4.2 Implementation on bread board

Once the circuit was successfully simulated, it was implemented on the breadboard to verify that the theoretical value used in the simulation is applicable in real design. The breadboard is considered as a basic board for basic design. Once implementation on breadboard was done, alterations

[2] This is to avoid probability of destroying the sensor as it is very sensitive. Exposure at a very short distance might destroy its sensitivity.

needed to be made on the simulation and design was carried out. Up until the final design, the bread board implementation circuit and the designing process is alternately repeated.

3.4.3 Implementation on PCB board

The implementation on PCB was done once the final design was shown to be successfully working on the bread board. It is more complex to use the PCB as soldering and connection on the board need to be done extra carefully due to the sensitive and small size of the PCB. Some intermediate component such as heat sinks and IC legs need to be used to avoid components from being destroyed because of the heat experienced during the soldering process.

3.5 Software used

3.5.1 Design

The software that the designer has been using to construct the circuit is the Electrical Workbench (EWB) that **simulates** circuit performance. It is much more user friendly compared to the PSpice used previously. This software allows us to choose components needed and change its specification according to our requirement.

Basically, this sensor has some shortcuts to help user to insert important component that have already been separated according to its usage. Figure 12 indicates the working space for constructing circuit in the EWB work station.

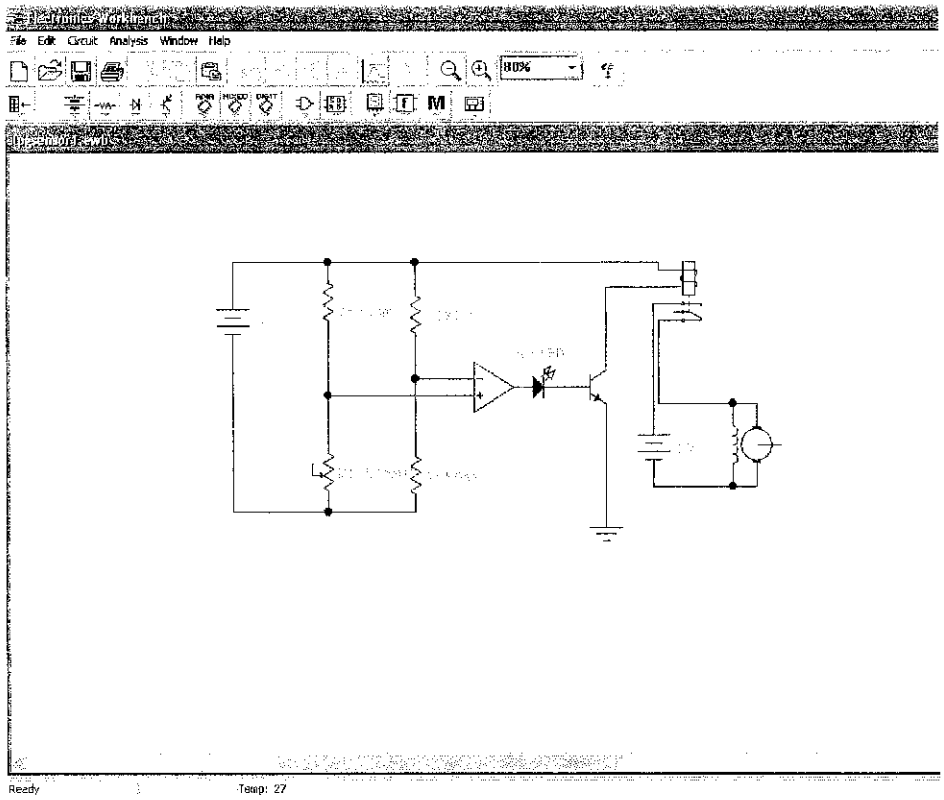


Figure 12: Electrical Work Bench

The icons on the top part of the EWB represent the electronic components available for use in the simulation. These parts include:

- *Source part* - Describes the types of sources available EWB, including battery, AC voltage source, Vcc source and FM source.
- *Basic Parts* - Describes the basic components available in EWB, including resistor, capacitor, relay, switch and transformer.
- *Diode Parts* - Describes the types of diodes available in EWB, including diac, triac, LED and Zener diode.
- *Transistor Parts* - Describes the transistor-associated parts in EWB, including NPN transistor, P-channel JFET, N-channel GaAsFet and 3-terminal enhanced P-MOSFET.
- *Analog IC Parts* - Describes the operational amplifiers available in EWB, including 5-terminal op-amp, 9-terminal op-amp, comparator and phase-locked loop.
- *Mixed IC Parts* - Describes the analog-to-digital converter, digital-to-analog converter, mono-stable and 555 timer.

- *Indicator parts* - Describes the indicators available in EWB including voltmeter, ammeter, probe, bulb, buzzer, 7-segment display and bar graph.
- *Instruments* - Describes the different instruments available in EWB, including digital multimeter, function generator, oscilloscope, logic analyzer and word generator.

In order to construct a circuit, the mouse is used to click on the parts needed according to classifications mentioned above and dragged to the blank space available. Once all components have been selected, they are rearranged according to the design required. The components are interconnected together by clicking on each component and joint it next. Once all components have been interconnected, the switch on the top right side of the EWB workspace is clicked on to simulate the circuit.

To view the value of voltage or current, a multimeter can be placed anywhere in the circuit to monitor the changes. This multimeter can act as a voltmeter, ammeter, and ohmmeter and also for measuring decibels.

3.5.2 Verification of value changes of the sensor using PASCO 750

To verify the data gathered during manual testing, PASCO 750 together with Data Studio, version 1.7, was used. Figure 13 shows the general over view of the PASCO once a new experiment is to be created. By just plugging the sensor into the interface, the necessary setup in Data Studio is performed and data can immediately be collected. This software is capable of measuring data at a high frequency and detail and continuous data can be gathered. By connecting the sensor to the 5V supply and using a probe, the voltage changes can be monitored and the graph plotted from the moment the heating process started up to when exposed to gas.

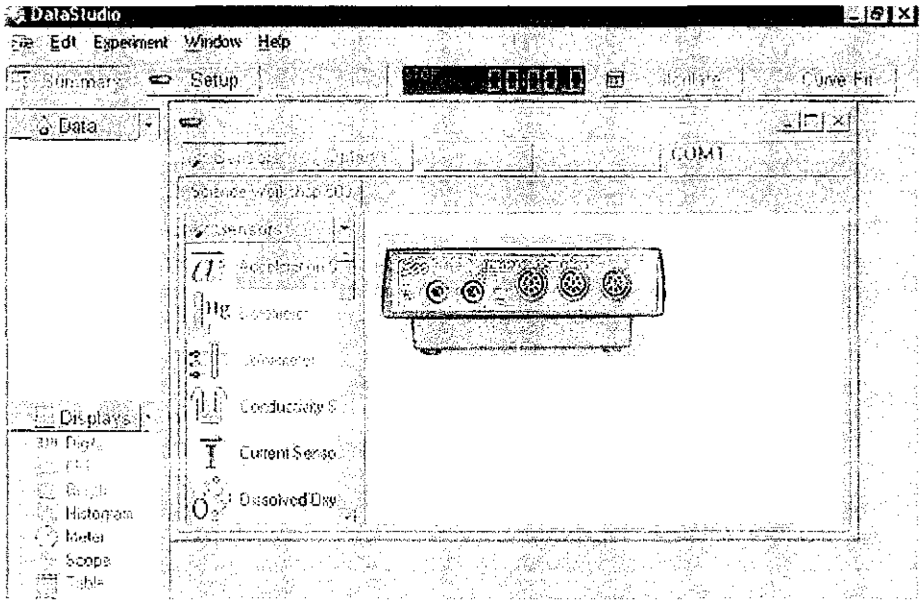


Figure 13: PASCO general view

In order to use the software, there are some steps that need to be followed:

i. A Science Workshop sensor is connected to any channel on the interface by inserting the connector to the interface box.

ii. The Data Studio is then opened and the "Create Experiment" icon is clicked.

iii. In the sensor list, the sensor is double clicked to associate the sensor with the interface channel in the setup window. Three experiments can be done simultaneously as there are 3 probes available that can be connected to any devices at the same time. In Data Studio, the sensor icon is located in the appropriate channel on the interface picture in the Setup Window.

iv. PASCO 750 contains a built in function generator for creating up to eight type of waveform (sine, square, triangle, saw-tooth, ramp up, ramp down, positive ramp up , positive ramp down and DC voltages) when the interface is used with the Data Studio. Relevant signal is chosen when needed by the sensor. It can be chosen by double clicking the source shortcut available under the sensor shortcut. After choosing the type of power supply needed, the value required is fixed according to specifications and the minimum time set for data to be taken. This timing can either be in frequency value (Hz) or in seconds (s).

v. In the Display list, any of the display of interest can be opened by double clicking the icons. (E.g.: Channel A to monitor its oscilloscope pattern where the user just clicks on Channel A at the at the top left side under the data setting and drag it to the scope on the bottom left side of the page. Once this was done, the oscilloscopes will automatically be displayed for observation)

vi. The Start button is clicked to collect the data on the main toolbar. Result: Data appear in real-time in the display

vii. The Stop button is clicked at the main toolbar to stop collecting the data.

As the sensor need to be heated not less than 24 hours before it can perform its gas sensing perfectly, a more than 24 hours data need to be collected before transferring to other software for data analysis. This software will store the data for observation and plotted the output graph simultaneously.[3]

[3] Refer Appendix 5

CHAPTER 4

RESULTS AND DISCUSSION

4.1 The gas to be sensed

Gasses are odorless and colorless materials that exist in the air that is important for life as it is needed for breathing and other usage. For instance, hydrocarbon gas, specifically the Liquefied Petroleum Gas (LPG), is very important and is widely used for cooking at homes. However, it can be dangerous when the amount of this gas in a confined space reaches a certain level in air because of its flammable characteristics when exposed to a small spark or fire. Furthermore, because it is odorless, it is difficult to detect in the surrounding environment. Therefore, there is a need for a sensor that is capable of monitoring the level of flammable gases in air and giving information for necessary action.

Gas sensitivity security circuits therefore can be used to automatically activate alarms or trigger a ventilation fan when the monitored gas goes above the pre- set level. This type of circuit can be use to ensure safety at home and in industrial plant. For this purpose, the semiconductor gas sensor made of SnO_2 is chosen to sense the liquefied pressure gas (LPG) in air and is described next.

4.2 Sensor Selection and Specifications.

From the two choices mentioned during the theoretical part earlier, the Han Wei sensor model MQ-6 was selected for the project work. This sensor has been chosen because of the following reasons. First of all, the supplier has been willing to give 5 samples of the sensor for study purposes and agreed to deliver it as soon as possible. This Han Wei manufacturing company is located in Taiwan while the Figaro is manufactured in United Kingdom.

Therefore as the Han Wei manufacturing location is near to this country, it is easier to be delivered.

Besides, its performance is much more promising and a faulty signal can be minimized as it is capable to differentiate between alcohol, smoke and LPG gas. This is very essential as in daily life all these gases exist in the environment and false alarm can occur if the sensor failed to differentiate between the alcohol or other type of gases and LPG. Furthermore, comparing the prices of the two sensors, it is cheaper to use the Han Wei sensor as it only costs USD 2 per piece and the shipping costs USD 50, while the Figaro sensor that is manufactured in United Kingdom costs USD 5 per piece and the shipping cost is much higher.

In terms of its size, MQ-6 is much smaller but more sensitive compared to the Taguchi Figaro sensor. Figure 14 shows the cross-sectional drawing of the MQ-6.

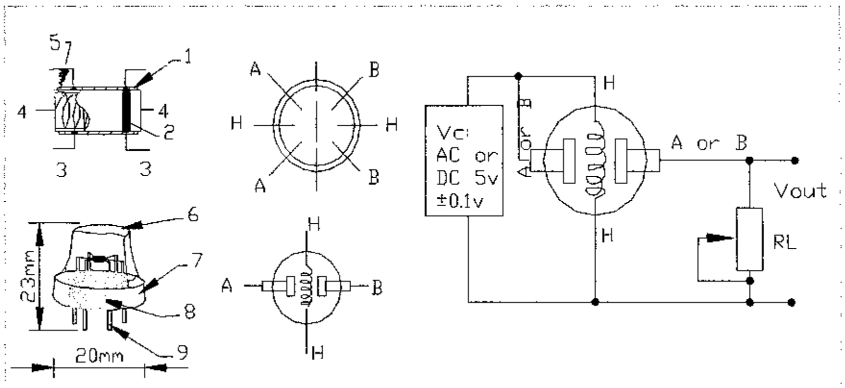


Figure 14: The Cross sectional drawing of MQ-6

The figure clearly shows that the sensor is very small with a diameter of only 2 cm and needs very small power consumption. This sensor basically has 3 main parts. The first part is its anti explosion network made of stainless steel gauze (6 in Figure 14) that is capable of trapping the surrounding gasses and prevent occurrence of explosion. The second part is the nickel chromium alloy heater that allows the electron of the gas to be trapped and attached to its surface. The last part is the gas sensing layer that changes the resistance of the sensor as the amount of LPG in air increases or reduces. This layer is made of SnO_2.

This sensor operates by the following principles. During normal conditions, the sensor will attract electrons from the surrounded air to be bonded with the one in the circuit. As it is steadily bonded, this sensor will have a very high resistance and low current will pass through it. However, during a high level of LPG in ambient air, the sensor surface will be covered with the LP gas and more electrons will be free in the circuit. Therefore, more current will pass and at certain limit will activate the fan circuit to ventilate the room. The heater attached with this sensor is to ensure that the sensor is heated to the optimum operating temperature for the electrons to be bonded with the oxygen in the air. For more detail on this sensor, please refer to Appendix 1

The load resistance connected in parallel with the sensor is used to control the amount of allowable LPG in the air and at the same time limit the amount of current to pass through to activate the circuit. From Figure 14, it was seen that the load resistance uses a potentiometer. Actually, it is included to enable the user to change the value of the resistance according to the change occurring in the environment and at the same time make the sensor more flexible for use in various surroundings.

4.2 Sensor Characteristic Verification

From testing done using PASCO, the data gathered are in Figure 15 which is a plot of the graph for the voltage value for the first hour testing while was heated.

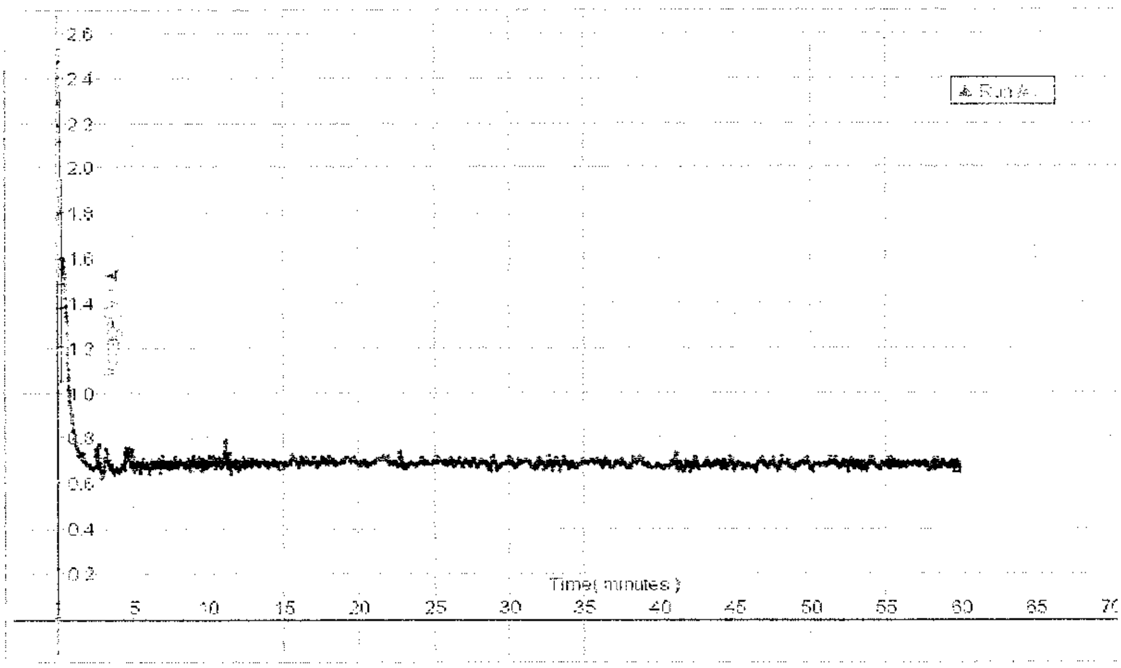


Figure 15: Graph plotted for the first one hour testing (preheat process)

As can be seen, the voltage varies largely during start up of the heating process. After approximately 5 minutes, it starts to stabilize back and fluctuates slowly along the way. During this first hour, the value of stable voltage is still quite low as the sensor is not yet ready as it is not yet preheated for 24 hours. The voltage value at this hour is around 0.6 V to 0.7 V.

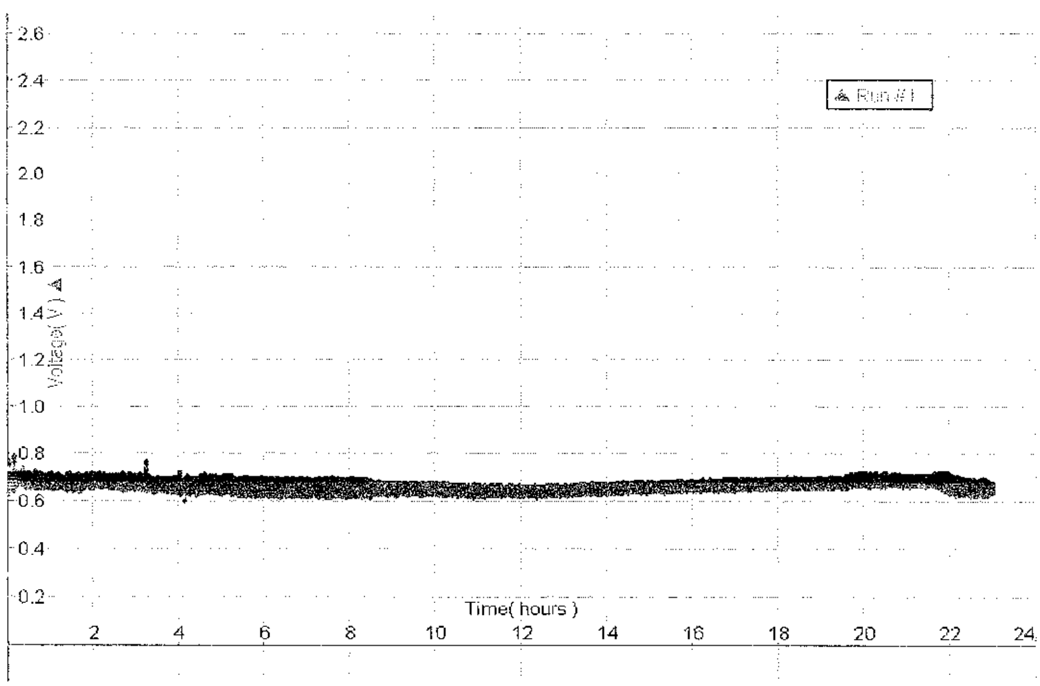


Figure 16: Graph plotted after 24 hours preheated

Figure 16 shows the graph plotted after 24 hours of preheat process was done. As we can see from this graph, it has stabilized itself between 0.6 to 0.8V.This means that the sensor had stabilized itself and heated itself completely.

Figure 17 show the graph plotted once the sensor was exposed to the LPG gas. The time taken for the voltage to go back to its original value is observed.

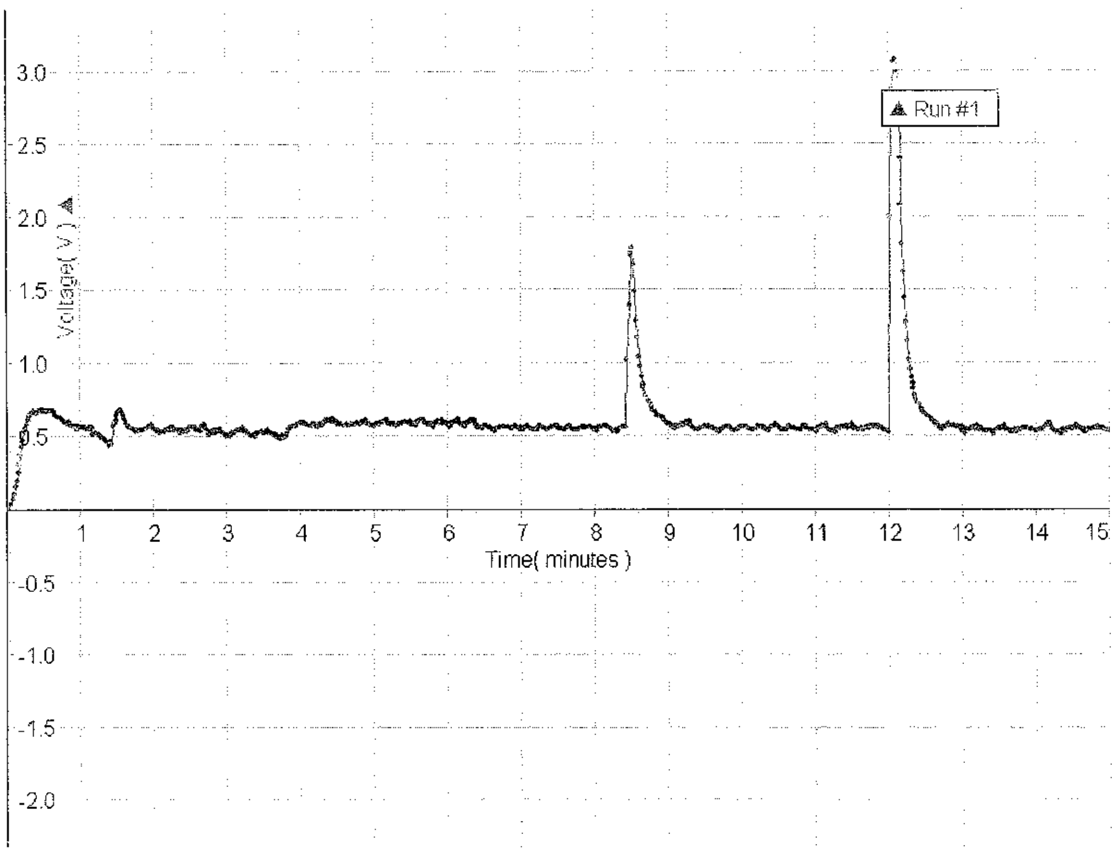


Figure 17: Graph plotted when exposed to LPG gas.

From the graph it is observed that the voltage increased to 1.75 and 3.0 V once exposed to the gas and it takes approximately 30 seconds before it stabilized back to its normal value of 0.6 to 0.7 V.

4.3 Sensor Circuit

The sensor circuit combines the sensor internal resistance with the activation circuit. The R_S at normal condition have a high resistance as the electrons in the circuit were bonded with the oxygen and hydrogen in the air on the sensor. Therefore, only a small current flows in the circuit.

As the requirement for this design is to have an automatic ON – OFF of the fan once the level of gas increases and decreases, respectively, this means that there is no need of any memory devices such as SCR or timer in the circuit. Figure 18 is showing the circuit diagram of the system designed.

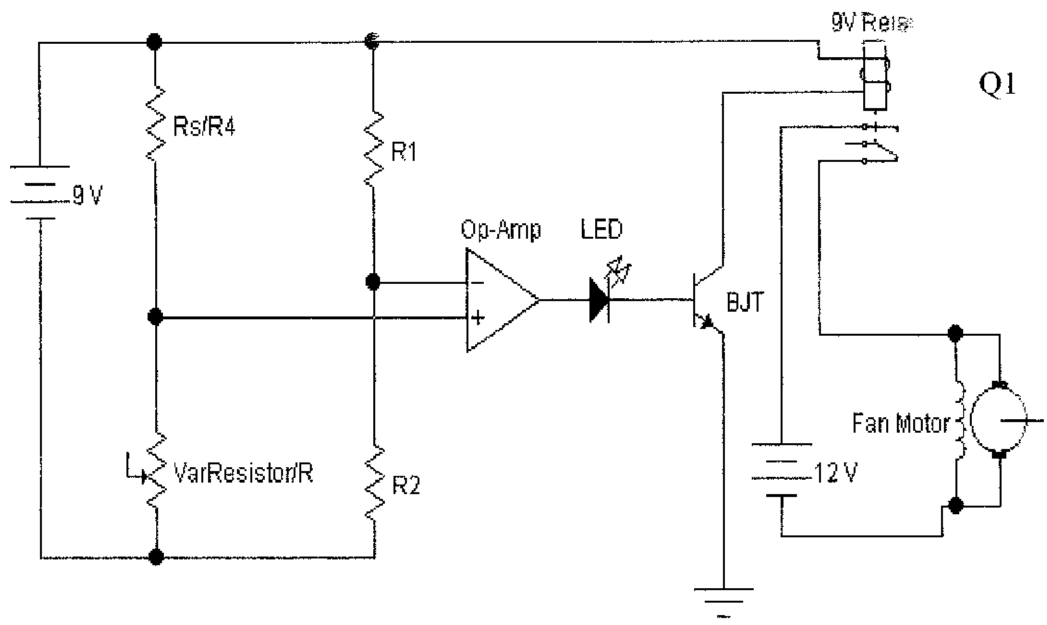


Figure 18: Circuit diagram of the system

This circuit applies the wheat-stone bridge with the op-amp which is used to detect when the bridge is balanced. One leg of the bridge is connected to the sensor resistor, R_S whose resistance decreases as the level of gas increases. The potentiometer (variable resistor), R_2 is set at a value equal to the resistance of the sensor at the critical level of gas. During normal condition, the transistor (BJT) will be off as the bridge is unbalanced. Once the sensor resistance drops as the amount of LPG gas increases in air up to the resistance value of the potentiometer it will give a high value that will allow the V_{CE} to pass through the transistor. Once the circuit is thus completed the relay magnet Q1, will activate the fan and it will be switched 'ON'. When the level of the gas drops back to normal conditions, the op-amp comparator will give a low value and the base of the BJT will not allow current to pass through the collector to emitter and the circuit will not be completed and the fan will be OFF automatically.

This system allows the sensor to detect certain level of gas and switch on the fan to neutralize the air in the closed chamber and switch itself off automatically once the level of the gas drops to the normal condition[4]. As this circuit does not have memory, there is no need of any reset button to put the fan back to normal conditions.

4.4 Calculations and Discussion

Some calculations were made to determine the theoretical value of the sensor resistance given in the data sheet and compare this with the actual values obtained. This was done before implementing the circuit on the bread board. As the circuit supply uses a 9V battery, a voltage regulator is needed to step down the voltage to 5V for the sensor heater and resistor. Before testing the whole circuit, the sensor performance was tested. As stated in the datasheet, the sensing resistance in air of MQ 6 is at the range of 40 to 400kΩ . To verify the theory, a calculation had been made as follows:

$$
\begin{aligned}
V_C &= V_S + V_L \\
&= IR_S + V_L \\
&= V_L R_S + V_L
\end{aligned}
$$

[4] Simulation has been done and the results is shown in Appendix 6(a) and 6(b).

Therefore,

$$R_S = R_L \frac{(V_C - V_L)}{V_L}$$
$$= R_L\left(\frac{V_C}{V_L} - 1\right)$$

Where R_S - Sensor resistance

R_L - Load resistance

V_L - Voltage at the load resistance

V_C - Voltage supply or input voltage

From lab testing done, the value of

$$V_L = 0.6V$$
$$R_S = 147k\Omega$$

The R_s value is proven to be in the range specified in the data sheet. In assuring that the operational amplifier is activated at certain percentage of LPG level in air, reference is made to the datasheet [5]that states the normal ratio of response time as

$$\frac{R \text{ in air}}{\text{Rin typical gas}} \geq 5$$

Taking the value of R_S in air = 147kΩ , R_S in typical gas should not be more than 29.3kΩ.

For the operational amplifier value of the V_{REF}, calculating the voltage needed to activate the operational amplifier such that R_S is lower than 29.3 is calculated as follows:

[5] Refer datasheet in Appendix 1

$$\frac{R_{load}}{R_{sensor} + R_{load}} \times 5V = \frac{R_2}{R_1 + R_2} \times 9V$$

Taking R_s in gas as 10kΩ and the variable resistance as 9.6kΩ with a voltage supply of 5V, we need to balance the value of voltage gained with another voltage at the other leg of the operational amplifier to apply the comparator role of it.

Taking one of the resistors as 10kΩ, the other resistor should be

$$\frac{9.6}{19.6} \times 5V \equiv \frac{R}{[10 + R]} \times 9$$

Therefore,

$$R = 3.9k\Omega$$

Once all the value of resistors needed had been determined, the circuit is constructed according to all the values selected.

A 9V relay is used according to the voltage supplied to the circuit. However, connected together with the fan at the relay is another power supply just to allow the fan to turn on as the fan specification is 12 V dc supply. Once the winding of the relay is energized, the circuit will be completed and the fan will be ventilating the confined space.

Through some testing done up to this point, the fan will be on for quite some time as the sensor will drop its resistance rapidly and will recover its resistance back in approximately a minute . So we can predict that the fan will be on approximately a minute before the operational amplifier became unstable again and cut the complete circuit.

Putting all the values in place, the simulation result can be viewed as shown in Figure 18 and 19. From the simulation data, analysis is carried out and the design verified.

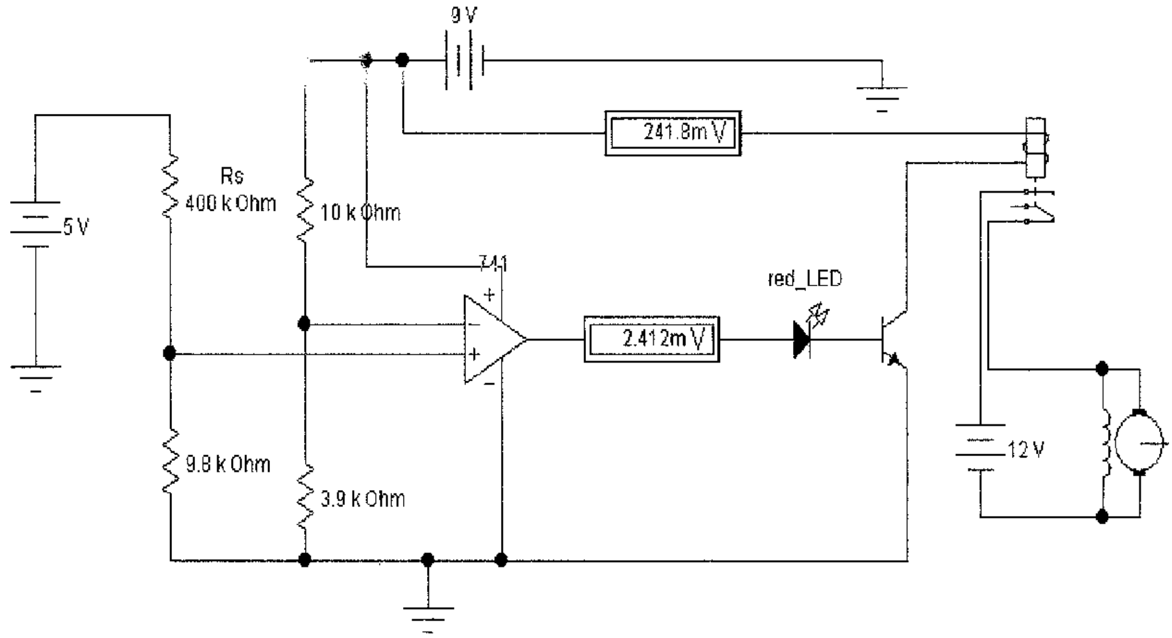


Figure 19: Simulation done in condition of normal surrounding air

In Figure 19, the value of the sensor resistance is to be 400kΩ which is the value of the resistor at surrounding air. As can be seen, the BJT is not activated as the value of V_B is lower than 0.7V. Therefore, the relay will not be activated and the motor will not be on to turn the fan.

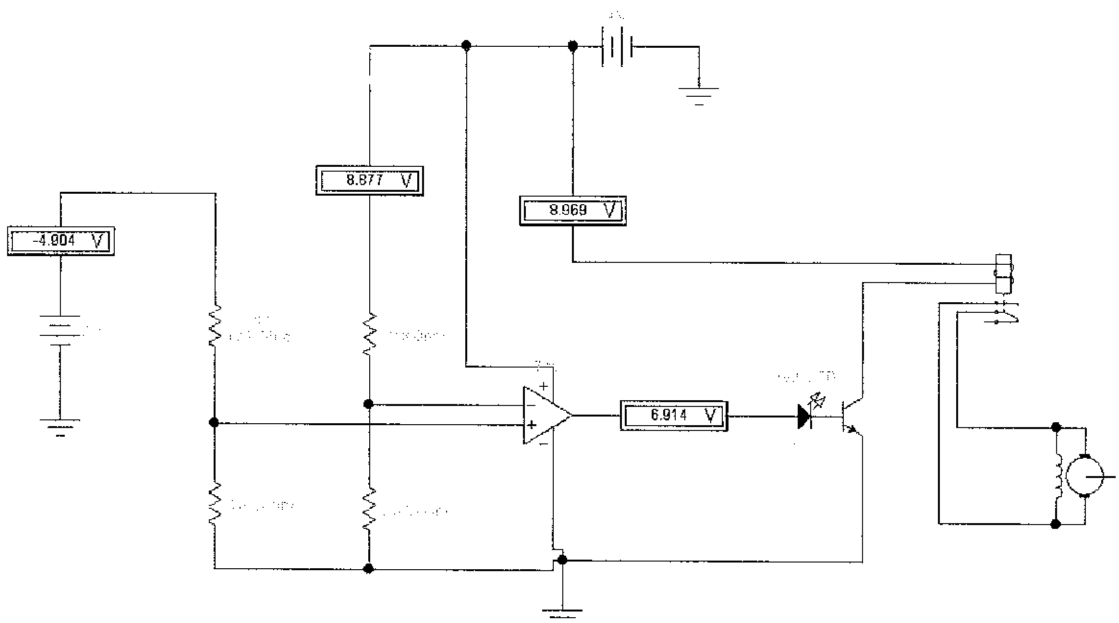


Figure 20: Simulation done in condition of exposure to LPG

From Figure 20, the R_S value is 10kΩ as it is the value of resistor once exposed to the LPG. The BJT has now allowed supply to pass through and the relay had been activated and turn on the fan motor. The value of the output of the operational amplifier is observed to be 6.914V and the relay circuit is closed. This is proven by observing the voltage value across the relay circuit that is approximately 9V.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, this project on Electronic control of the level of LPG in air has been successfully achieved based on the methods specified, researches done and also progresses made throughout the 2 semesters. Theories on the sensor had been verified through some lab testing and the simulations done had ensured the success of this system. A prototype of the detector was designed and tested and found to functions according to the results and discussions done earlier. Besides that, it was a beneficial opportunity to have a hands on experience on applying all knowledge learnt previously in terms of theoretical concepts and also management skills. At the same time the exposure given and effort done is hopefully will give a fruitful outcomes at the end of this semester.

5.2 Recommendation

For improving this design, few recommendations are proposed:

1. It is recommended that this project be extended for using AC power supply instead of DC so that the battery will not need to be changed continuously from time to time. In this way, the circuit can be connected directly to the power supply at homes as it can be used at a static place at homes and also factories

2. This project can be further improved by using the micro-controller that is capable of setting the triggering value digitally instead of calculations needed to be done manually.

3. The design will be better and less power consuming if new sensors that need not to be heated are found. This will save time and ensure that the sensor works perfectly once supplied with specific voltage.

4. If the budget allocation is increased, the testing can be extended using the actual ppm of gas concentration to have a better accuracy in the result.

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APPENDIXES

TECHNICAL DATA MQ-6 GAS SENSOR

FEATURES

* High sensitivity to LPG, iso-butane, propane
* Small sensitivity to alcohol, smoke.
* Fast response . * Stable and long life * Simple drive circuit

APPLICATION

They are used in gas leakage detecting equipments in family and industry, are suitable for detecting of LPG, iso-butane, propane, LNG, avoid the noise of alcohol and cooking fumes and cigarette smoke.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	Technical condition	Remarks
Vc	Circuit voltage	5V±0.1	AC OR DC
V_H	Heating voltage	5V±0.1	ACOR DC
P_L	Load resistance	20KΩ	
R_H	Heater resistance	33Ω ±5%	Room Tem
P_H	Heating consumption	less than 750mw	

B. Environment condition

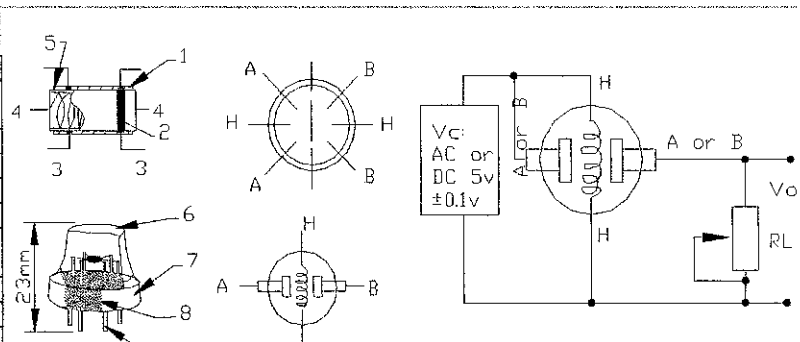
Symbol	Parameter name	Technical condition	Remarks
Tao	Using Tem	-10℃-50℃	
Tas	Storage Tem	-20℃-70℃	
R_H	Related humidity	less than 95%Rh	
O_2	Oxygen concentration	21%(standard condition)Oxygen concentration can affect sensitivity	minimum value is over 2%

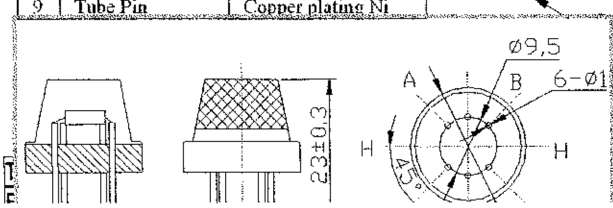
C. Sensitivity characteristic

Symbol	Parameter name	Technical parameter	Remarks
Rs	Sensing Resistance	10KΩ - 60KΩ (1000ppm LPG)	Detecting concentration scope: 200-10000ppm LPG , iso-butane, propane, LNG
α (1000ppm/ 4000ppm LPG)	Concentration slope rate	≤0.6	
Standard detecting condition	Temp: 20℃±2℃ Vc:5V±0.1 Humidity: 65%±5% Vh: 5V±0.1		
Preheat time	Over 24 hour		

D. Strucyure and configuration, basic measuring circuit

	Parts	Materials
1	Gas sensing layer	SnO_2
2	Electrode	Au
3	Electrode line	Pt
4	Heater coil	Ni-Cr alloy
5	Tubular ceramic	Al_2O_3
6	Anti-explosion network	Stainless steel gauze (SUS316 100-mesh)
7	Clamp ring	Copper plating Ni
8	Resin base	Bakelite
9	Tube Pin	Copper plating Ni





Structure and configuration of MQ-6 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro AL_2O_3 ceramic tube, Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-6 have 6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current.

Electric parameter measurement circuit is shown as Fig.2

E. Sensitivity characteristic curve

Fig.2

Fig.2 sensitivity characteristics of the MQ-6

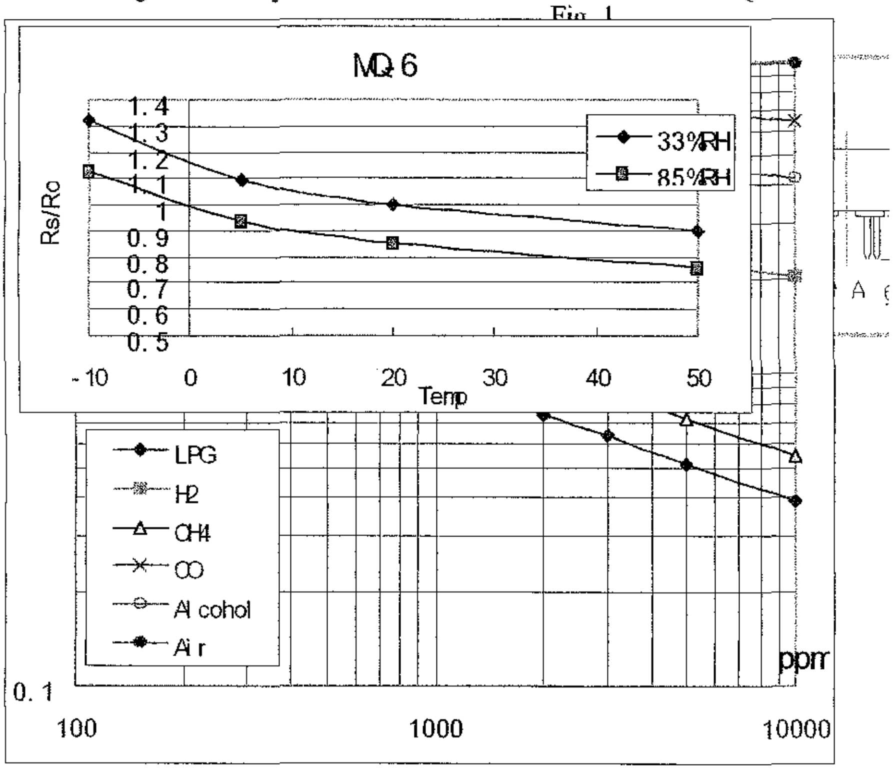


Fig.3 is shows the typical sensitivity characteristics of the MQ-6 for several gases.
in their: Temp: 20℃、
Humidity: 65%、
O_2 concentration 21%
RL=20kΩ
Ro: sensor resistance at 1000ppm LPG in the clean air.
Rs:sensor resistance at various concentrations of gases.

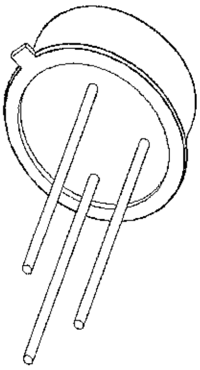
SENSITVITY ADJUSTMENT

Resistance value of MQ-6 is difference to various kinds and various concentration gases. So, When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 1000ppm of LPG concentration in air and use value of Load resistance (R_L) about 20KΩ (10KΩ to 47KΩ).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

Fig.4 is shows the typical dependence the MQ-6 on temperature and humidi
Ro: sensor resistance at 1000ppm of LPG ir at 33%RH and 20 degree.
Rs: sensor resistance at 1000ppm of LPG ir at different temperatures and humiditi

DATA SHEET



2N2222; 2N2222A

NPN switching transistors

Product specification
Supersedes data of September 1994
File under Discrete Semiconductors, SC04

1997 May 29

Philips
Semiconductors

PHILIPS

NPN switching transistors 2N2222; 2N2222A

FEATURES

- High current (max. 800 mA)
- Low voltage (max. 40 V).

APPLICATIONS

- Linear amplification and switching.

DESCRIPTION

NPN switching transistor in a TO-18 metal package.
PNP complement: 2N2907A.

PINNING

PIN	DESCRIPTION
1	emitter
2	base
3	collector, connected to case

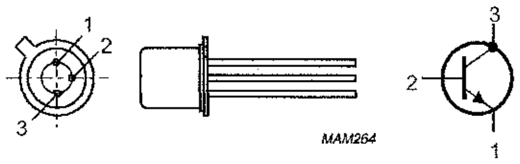


Fig.1 Simplified outline (TO-18) and symbol.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	2N2222		–	60	V
	2N2222A		–	75	V
V_{CEO}	collector-emitter voltage	open base			
	2N2222		–	30	V
	2N2222A		–	40	V
I_C	collector current (DC)		–	800	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	500	mW
h_{FE}	DC current gain	I_C = 10 mA; V_{CE} = 10 V	75	–	
f_T	transition frequency	I_C = 20 mA; V_{CE} = 20 V; f = 100 MHz			
	2N2222		250	–	MHz
	2N2222A		300	–	MHz
t_{off}	turn-off time	I_{Con} = 150 mA; I_{Bon} = 15 mA; I_{Boff} = −15 mA	–	250	ns

NPN switching transistors 2N2222; 2N2222A

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	2N2222		–	60	V
	2N2222A		–	75	V
V_{CEO}	collector-emitter voltage	open base			
	2N2222		–	30	V
	2N2222A		–	40	V
V_{EBO}	emitter-base voltage	open collector			
	2N2222		–	5	V
	2N2222A		–	6	V
I_C	collector current (DC)		–	800	mA
I_{CM}	peak collector current		–	800	mA
I_{BM}	peak base current		–	200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	500	mW
		$T_{case} \leq 25$ °C	–	1.2	W
T_{stg}	storage temperature		−65	+150	°C
T_j	junction temperature		–	200	°C
T_{amb}	operating ambient temperature		−65	+150	°C

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	in free air	350	K/W
$R_{th\ j\text{-}c}$	thermal resistance from junction to case		146	K/W

NPN switching transistors — 2N2222; 2N2222A

CHARACTERISTICS

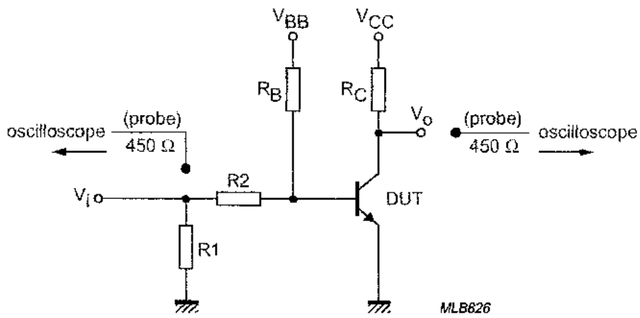
T_j = 25 °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
I_{CBO}	collector cut-off current				
	2N2222	$I_E = 0$; V_{CB} = 50 V	–	10	nA
		$I_E = 0$; V_{CB} = 50 V; T_{amb} = 150 °C	–	10	μA
I_{CBO}	collector cut-off current				
	2N2222A	$I_E = 0$; V_{CB} = 60 V	–	10	nA
		$I_E = 0$; V_{CB} = 60 V; T_{amb} = 150 °C	–	10	μA
I_{EBO}	emitter cut-off current	$I_C = 0$; V_{EB} = 3 V	–	10	nA
h_{FE}	DC current gain	I_C = 0.1 mA; V_{CE} = 10 V	35	–	
		I_C = 1 mA; V_{CE} = 10 V	50	–	
		I_C = 10 mA; V_{CE} = 10 V	75	–	
		I_C = 150 mA; V_{CE} = 1 V; note 1	50	–	
		I_C = 150 mA; V_{CE} = 10 V; note 1	100	300	
h_{FE}	DC current gain	I_C = 10 mA; V_{CE} = 10 V; T_{amb} = –55 °C			
	2N2222A		35	–	
h_{FE}	DC current gain	I_C = 500 mA; V_{CE} = 10 V; note 1			
	2N2222		30	–	
	2N2222A		40	–	
V_{CEsat}	collector-emitter saturation voltage				
	2N2222	I_C = 150 mA; I_B = 15 mA; note 1	–	400	mV
		I_C = 500 mA; I_B = 50 mA; note 1	–	1.6	V
V_{CEsat}	collector-emitter saturation voltage				
	2N2222A	I_C = 150 mA; I_B = 15 mA; note 1	–	300	mV
		I_C = 500 mA; I_B = 50 mA; note 1	–	1	V
V_{BEsat}	base-emitter saturation voltage				
	2N2222	I_C = 150 mA; I_B = 15 mA; note 1	–	1.3	V
		I_C = 500 mA; I_B = 50 mA; note 1	–	2.6	V
V_{BEsat}	base-emitter saturation voltage				
	2N2222A	I_C = 150 mA; I_B = 15 mA; note 1	0.6	1.2	V
		I_C = 500 mA; I_B = 50 mA; note 1	–	2	V
C_c	collector capacitance	$I_E = i_e = 0$; V_{CB} = 10 V; f = 1 MHz	–	8	pF
C_e	emitter capacitance	$I_C = i_c = 0$; V_{EB} = 500 mV; f = 1 MHz			
	2N2222A		–	25	pF
f_T	transition frequency	I_C = 20 mA; V_{CE} = 20 V; f = 100 MHz			
	2N2222		250	–	MHz
	2N2222A		300	–	MHz
F	noise figure	I_C = 200 μA; V_{CE} = 5 V; R_S = 2 kΩ; f = 1 kHz; B = 200 Hz			
	2N2222A		–	4	dB

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
Switching times (between 10% and 90% levels); see Fig.2					
t_{on}	turn-on time	I_{Con} = 150 mA; I_{Bon} = 15 mA; I_{Boff} = −15 mA	–	35	ns
t_d	delay time		–	10	ns
t_r	rise time		–	25	ns
t_{off}	turn-off time		–	250	ns
t_s	storage time		–	200	ns
t_f	fall time		–	60	ns

Note

1. Pulse test: $t_p \leq 300$ µs; $\delta \leq 0.02$.

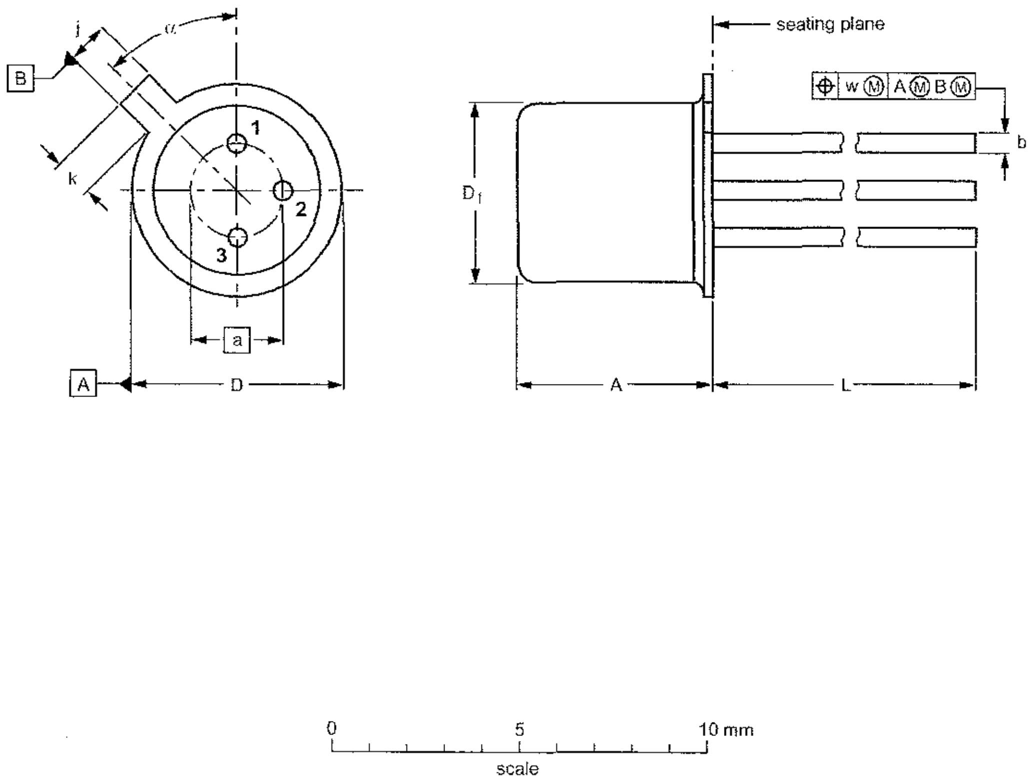


V_i = 9.5 V; T = 500 µs; t_p = 10 µs; $t_r = t_f \leq 3$ ns.
R1 = 68 Ω; R2 = 325 Ω; R_B = 325 Ω; R_C = 160 Ω.
V_{BB} = −3.5 V; V_{CC} = 29.5 V.
Oscilloscope input impedance Z_i = 50 Ω.

Fig.2 Test circuit for switching times.

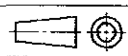
PACKAGE OUTLINE

Metal-can cylindrical single-ended package; 3 leads **SOT18/13**



DIMENSIONS (millimetre dimensions are derived from the original inch dimensions)

UNIT	A	a	b	D	D_1	j	k	L	w	α
mm	5.31 4.74	2.54	0.47 0.41	5.45 5.30	4.70 4.55	1.03 0.94	1.1 0.9	15.0 12.7	0.40	45°

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT18/13	B11/C7 type 3	TO-18				97-04-18

NPN switching transistors | 2N2222; 2N2222A

DEFINITIONS

Data sheet status	
Objective specification	This data sheet contains target or goal specifications for product development.
Preliminary specification	This data sheet contains preliminary data; supplementary data may be published later.
Product specification	This data sheet contains final product specifications.
Limiting values	
Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.	
Application information	
Where application information is given, it is advisory and does not form part of the specification.	

LIFE SUPPORT APPLICATIONS

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November 1994

LM741 Operational Amplifier

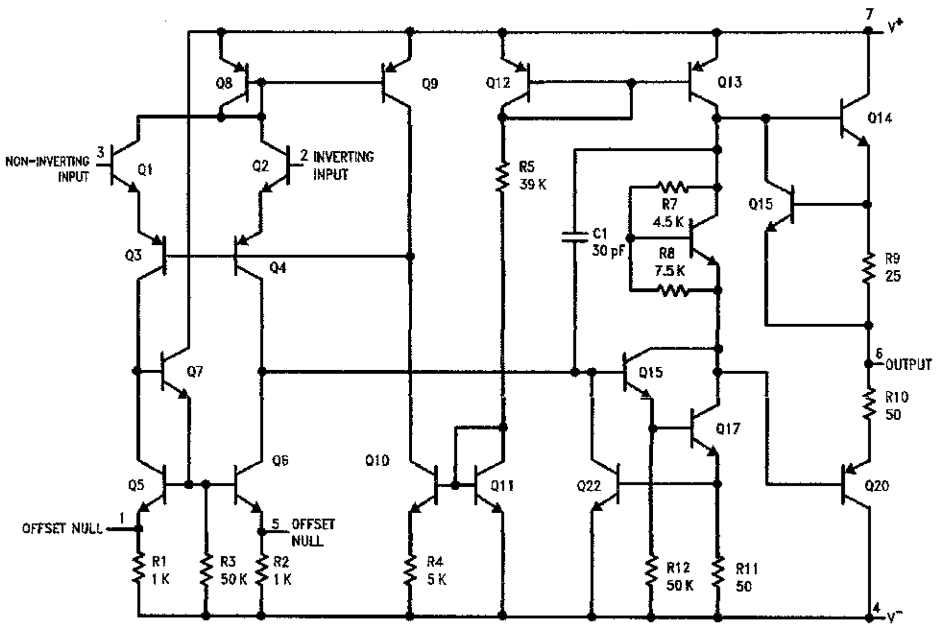
General Description

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

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

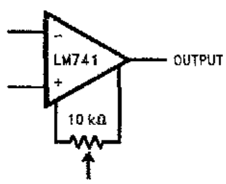
The LM741C/LM741E are identical to the LM741/LM741A except that the LM741C/LM741E have their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Schematic Diagram



TL/H/9341–1

Offset Nulling Circuit



TL/H/9341–7

RRD-B30M115/Printed in U. S. A.

Absolute Maximum Ratings

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

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

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

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

Electrical Characteristics (Note 3)

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

Electrical Characteristics (Note 3) (Continued)

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

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

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

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

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

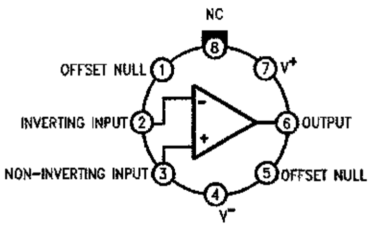
Note 4: Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

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

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

Connection Diagrams

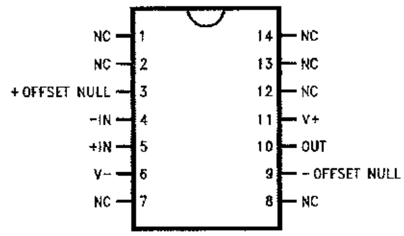
Metal Can Package



TL/H/9341-2

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

Ceramic Dual-In-Line Package

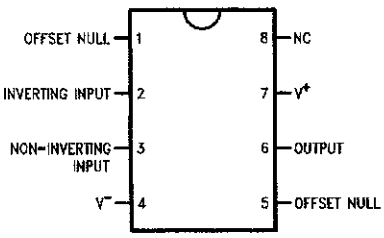


TL/H/9341-5

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

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

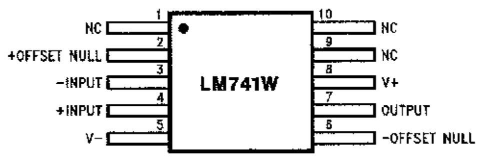
Dual-In-Line or S.O. Package



TL/H/9341-3

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

Ceramic Flatpak

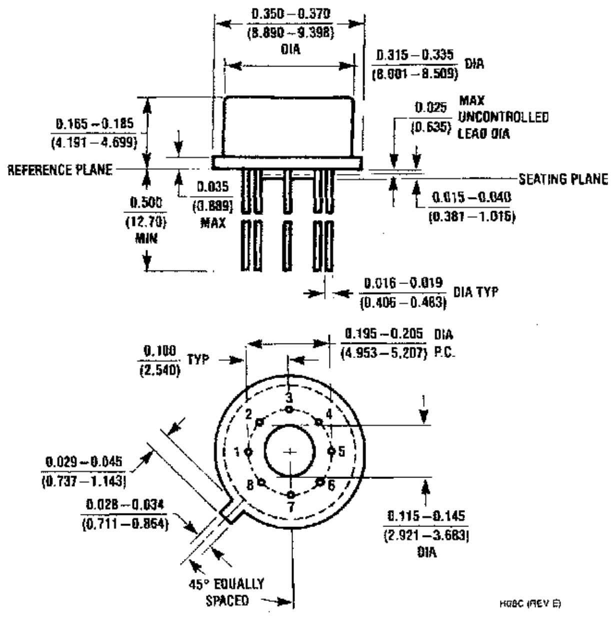


TL/H/9341-6

Order Number LM741W/883
See NS Package Number W10A

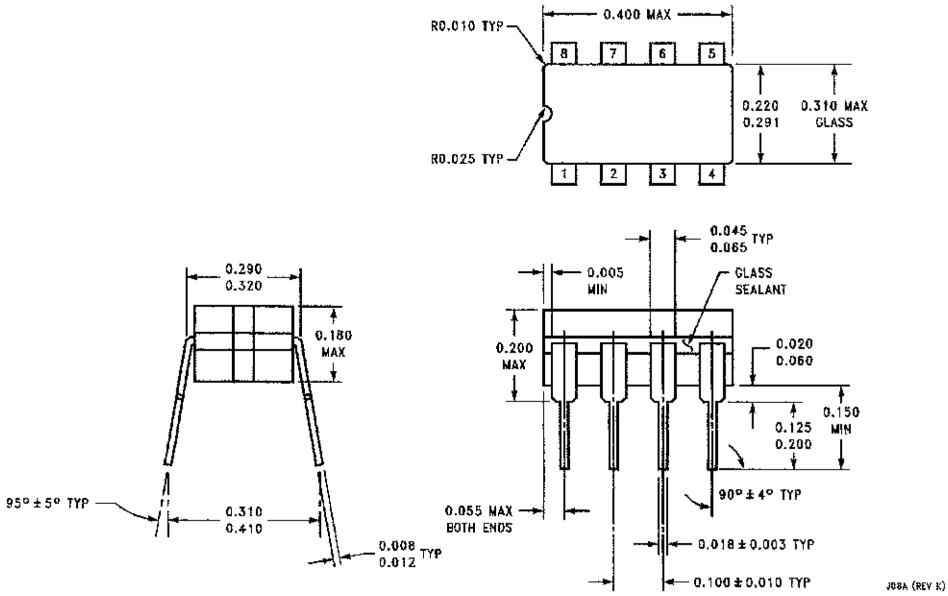
*LM741H is available per JM38510/10101

Physical Dimensions inches (millimeters)

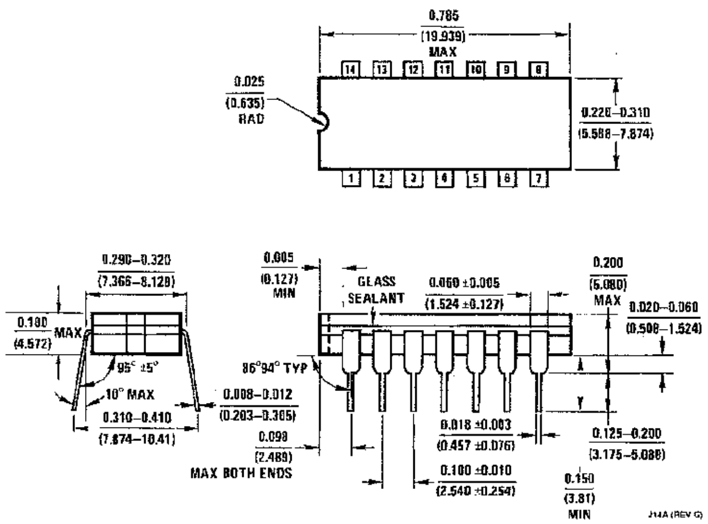


Metal Can Package (H)
Order Number LM741H, LM741H/883, LM741AH/883, LM741CH or LM741EH
NS Package Number H08C

Physical Dimensions inches (millimeters) (Continued)

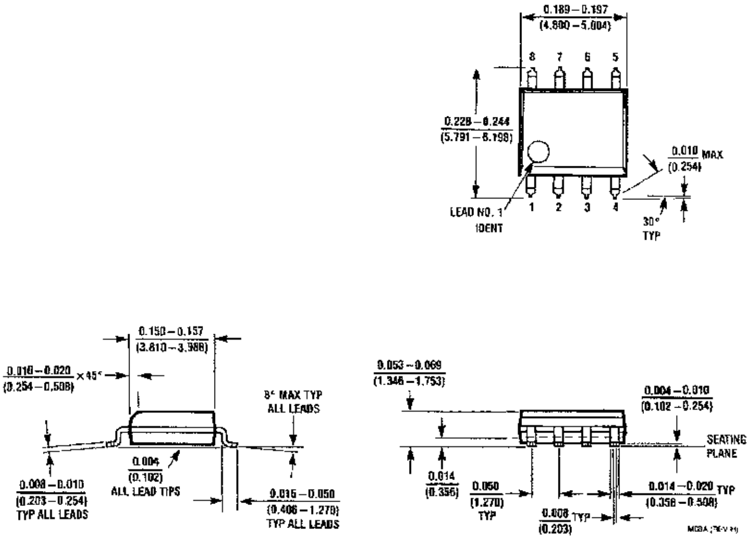


Ceramic Dual-In-Line Package (J)
Order Number LM741CJ or LM741J/883
NS Package Number J08A

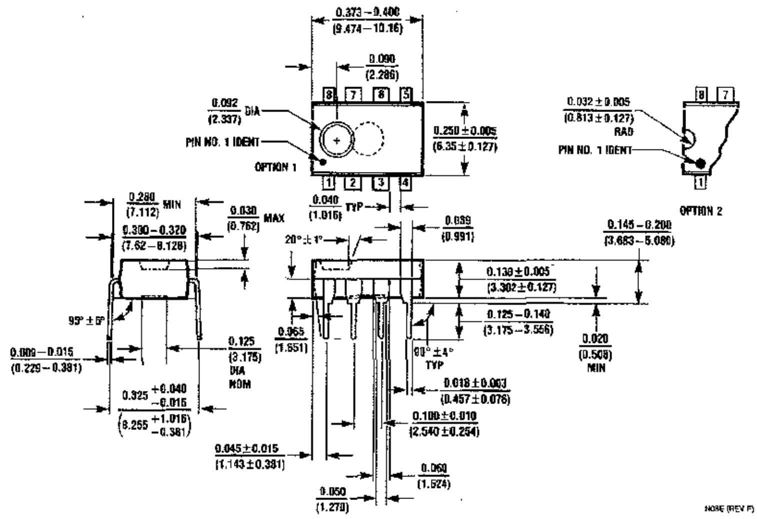


Ceramic Dual-In-Line Package (J)
Order Number LM741J-14/883 or LM741AJ-14/883
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)

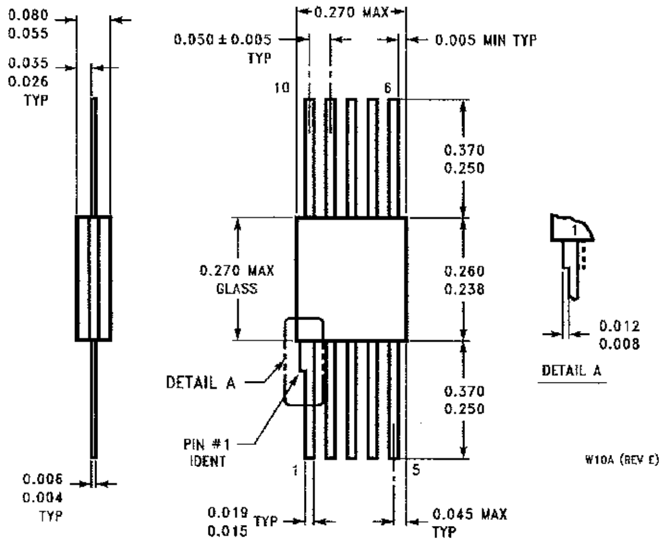


Small Outline Package (M)
Order Number LM741CM
NS Package Number M08A



Dual-In-Line Package (N)
Order Number LM741CN or LM741EN
NS Package Number N08E

Physical Dimensions inches (millimeters) (Continued)



10-Lead Ceramic Flatpak (W)
Order Number LM741W/883
NS Package Number W10A

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National Semiconductor

July 1999

LM341/LM78MXX Series 3-Terminal Positive Voltage Regulators

General Description

The LM341 and LM78MXX series of three-terminal positive voltage regulators employ built-in current limiting, thermal shutdown, and safe-operating area protection which makes them virtually immune to damage from output overloads.

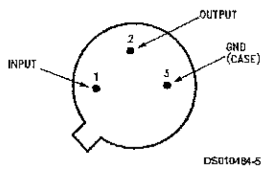
With adequate heatsinking, they can deliver in excess of 0.5A output current. Typical applications would include local (on-card) regulators which can eliminate the noise and degraded performance associated with single-point regulation.

Features

- Output current in excess of 0.5A
- No external components
- Internal thermal overload protection
- Internal short circuit current-limiting
- Output transistor safe-area compensation
- Available in TO-220, TO-39, and TO-252 D-PAK packages
- Output voltages of 5V, 12V, and 15V

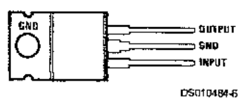
Connection Diagrams

TO-39 Metal Can Package (H)



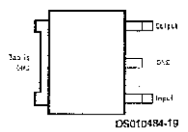
Bottom View
Order Number LM78M05CH, LM78M12CH or LM78M15CH
See NS Package Number H03A

TO-220 Power Package (T)



Top View
Order Number LM341T-5.0, LM341T-12, LM341T-15, LM78M05CT, LM78M12CT or LM78M15CT
See NS Package Number T03B

TO-252



Top View
Order Number LM78M05CDT
See NS Package Number TD03B

 DS010484

Absolute Maximum Ratings (Note 1)

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

Lead Temperature (Soldering, 10 seconds)	
TO-39 Package (H)	300°C
TO-220 Package (T)	260°C
Storage Temperature Range	−65°C to +150°C
Operating Junction Temperature Range	−40°C to +125°C
Power Dissipation (Note 2)	Internally Limited
Input Voltage	
$5V \le V_O \le 15V$	35V
ESD Susceptibility	TBD

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, and limits in **boldface type** apply over the −40°C to +125°C operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods.

LM341-5.0, LM78M05C

Unless otherwise specified: $V_{IN} = 10V$, $C_{IN} = 0.33\ \mu F$, $C_O = 0.1\ \mu F$

Symbol	Parameter	Conditions		Min	Typ	Max	Units
V_O	Output Voltage	$I_L = 500$ mA		4.8	5.0	5.2	V
		$5\ mA \le I_L \le 500\ mA$ $P_D \le 7.5W$, $7.5V \le V_{IN} \le 20V$		**4.75**	**5.0**	**5.25**	
$V_{R\ LINE}$	Line Regulation	$7.2V \le V_{IN} \le 25V$	$I_L = 100$ mA			50	mV
			$I_L = 500$ mA			100	
$V_{R\ LOAD}$	Load Regulation	$5\ mA \le I_L \le 500\ mA$				100	
I_Q	Quiescent Current	$I_L = 500$ mA			4	10.0	mA
ΔI_Q	Quiescent Current Change	$5\ mA \le I_L \le 500\ mA$				0.5	
		$7.5V \le V_{IN} \le 25V$, $I_L = 500$ mA				1.0	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz			40		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	f = 120 Hz, $I_L = 500$ mA			78		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	$I_L = 500$ mA		7.2			V
ΔV_O	Long Term Stability	$I_L = 500$ mA				**20**	mV/khrs

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the −40°C to +125°C operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. (Continued)

LM341-12, LM78M12C

Unless otherwise specified: V_{IN} = 19V, C_{IN} = 0.33 µF, C_O = 0.1 µF

Symbol	Parameter	Conditions		Min	Typ	Max	Units
V_O	Output Voltage	I_L = 500 mA		11.5	12	12.5	V
		5 mA ≤ I_L ≤ 500 mA P_D ≤ 7.5W, 14.8V ≤ V_{IN} ≤ 27V		**11.4**	**12**	**12.6**	
$V_{R\ LINE}$	Line Regulation	14.5V ≤ V_{IN} ≤ 30V	I_L = 100 mA			120	mV
			I_L = 500 mA			240	
$V_{R\ LOAD}$	Load Regulation	5 mA ≤ I_L ≤ 500 mA				240	
I_Q	Quiescent Current	I_L = 500 mA			4	10.0	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_L ≤ 500 mA				0.5	
		14.8V ≤ V_{IN} ≤ 30V, I_L = 500 mA				1.0	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz			75		µV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	f = 120 Hz, I_L = 500 mA			71		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	I_L = 500 mA		14.5			V
ΔV_O	Long Term Stability	I_L = 500 mA				**48**	mV/khrs

LM341-15, LM78M15C

Unless otherwise specified: V_{IN} = 23V, C_{IN} = 0.33 µF, C_O = 0.1 µF

Symbol	Parameter	Conditions		Min	Typ	Max	Units
V_O	Output Voltage	I_L = 500 mA		14.4	15	15.6	V
		5 mA ≤ I_L ≤ 500 mA P_D ≤ 7.5W, 18V ≤ V_{IN} ≤ 30V		**14.25**	**15**	**15.75**	
$V_{R\ LINE}$	Line Regulation	17.6V ≤ V_{IN} ≤ 30V	I_L = 100 mA			150	mV
			I_L = 500 mA			300	
$V_{R\ LOAD}$	Load Regulation	5 mA ≤ I_L ≤ 500 mA				300	
I_Q	Quiescent Current	I_L = 500 mA			4	10.0	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_L ≤ 500 mA				0.5	
		18V ≤ V_{IN} ≤ 30V, I_L = 500 mA				1.0	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz			90		µV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	f = 120 Hz, I_L = 500 mA			69		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	I_L = 500 mA		17.6			V
ΔV_O	Long Term Stability	I_L = 500 mA				**60**	mV/khrs

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

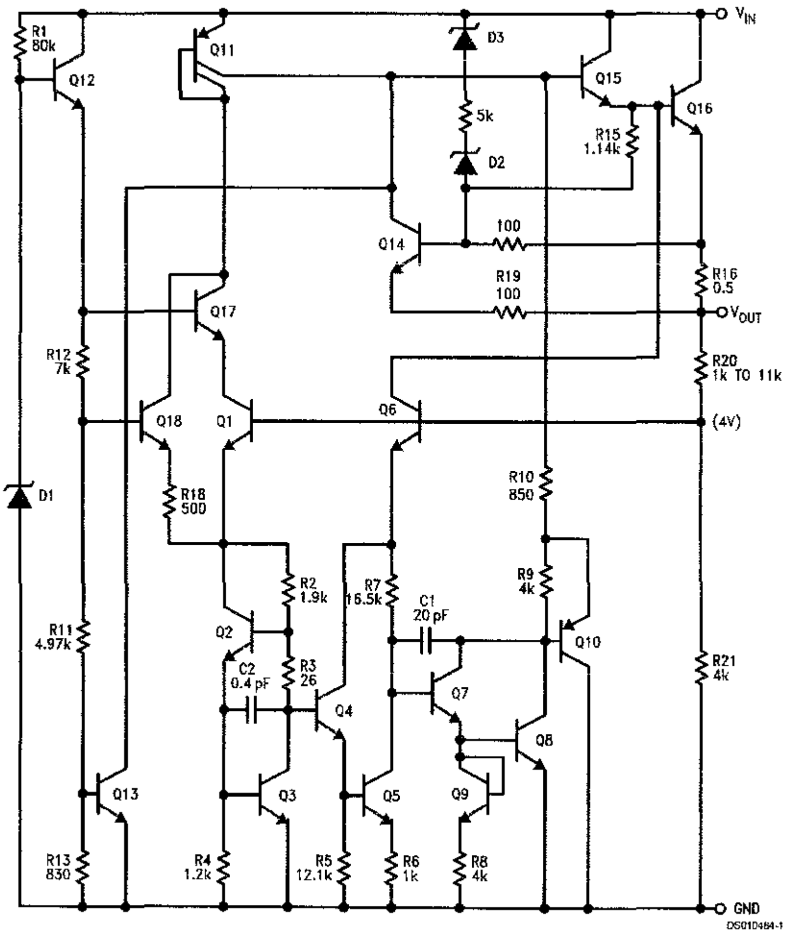
Note 2: The typical thermal resistance of the three package types is:

T (TO-220) package: $\theta_{(JA)}$ = 60 °C/W, $\theta_{(JC)}$ = 5 °C/W

H (TO-39) package: $\theta_{(JA)}$ = 120 °C/W, $\theta_{(JC)}$ = 18 °C/W

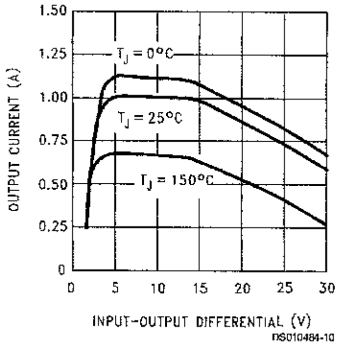
DT (TO-252) package: $\theta_{(JA)}$ = 92 °C/W, $\theta_{(JC)}$ = 10 °C/W

Schematic Diagram

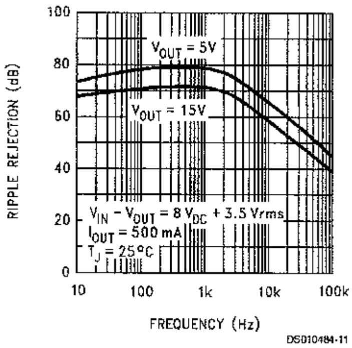


Typical Performance Characteristics

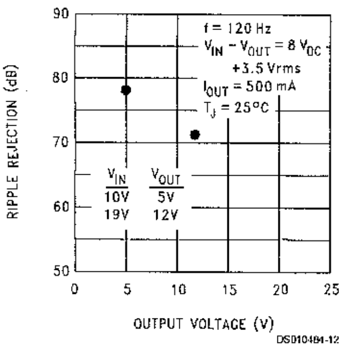
Peak Output Current



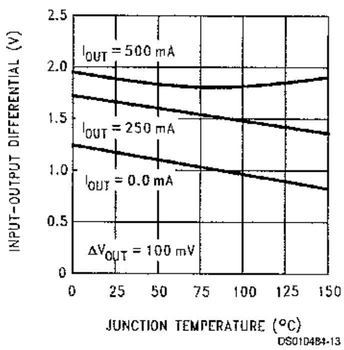
Ripple Rejection



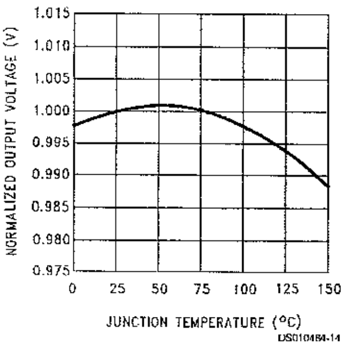
Ripple Rejection



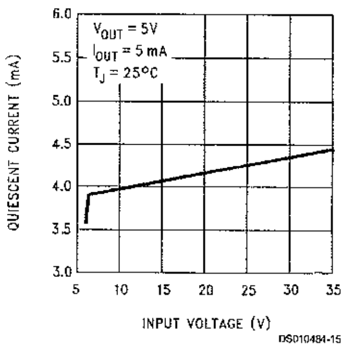
Dropout Voltage



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

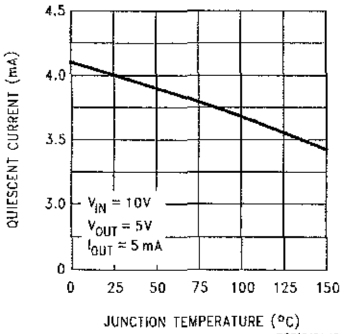


Quiescent Current

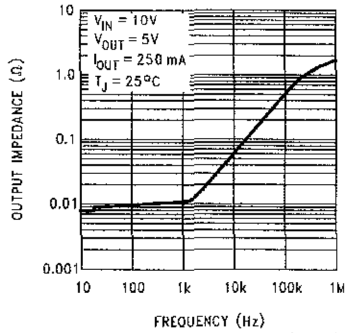


Typical Performance Characteristics (Continued)

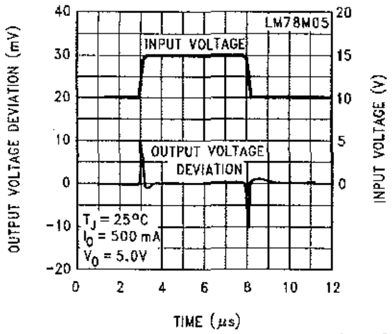
Quiescent Current



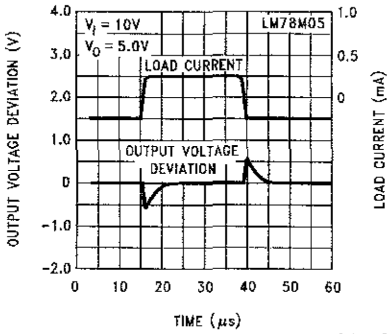
Output Impedance



Line Transient Response



Load Transient Response



Design Considerations

The LM78MXX/LM341XX fixed voltage regulator series has built-in thermal overload protection which prevents the device from being damaged due to excessive junction temperature.

The regulators also contain internal short-circuit protection which limits the maximum output current, and safe-area protection for the pass transistor which reduces the short-circuit current as the voltage across the pass transistor is increased.

Although the internal power dissipation is automatically limited, the maximum junction temperature of the device must be kept below +125°C in order to meet data sheet specifications. An adequate heatsink should be provided to assure this limit is not exceeded under worst-case operating conditions (maximum input voltage and load current) if reliable performance is to be obtained).

1.0 Heatsink Considerations

When an integrated circuit operates with appreciable current, its junction temperature is elevated. It is important to quantify its thermal limits in order to achieve acceptable performance and reliability. This limit is determined by summing the individual parts consisting of a series of temperature rises from the semiconductor junction to the operating environment. A one-dimension steady-state model of conduction heat transfer is demonstrated in The heat generated at the device junction flows through the die to the die attach pad, through the lead frame to the surrounding case material, to the printed circuit board, and eventually to the ambient environment. Below is a list of variables that may affect the thermal resistance and in turn the need for a heatsink.

$R^{\theta JC}$(Component Variables)	$R^{\theta CA}$(Application Variables)
Leadframe Size & Material	Mounting Pad Size, Material, & Location
No. of Conduction Pins	Placement of Mounting Pad
Die Size	PCB Size & Material
Die Attach Material	Traces Length & Width
Molding Compound Size and Material	Adjacent Heat Sources
	Volume of Air
	Air Flow
	Ambient Temperature
	Shape of Mounting Pad

Design Considerations (Continued)

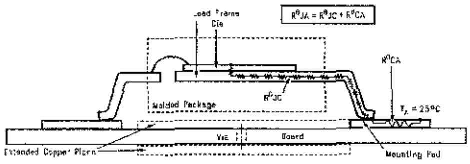


FIGURE 1. Cross-sectional view of Integrated Circuit Mounted on a printed circuit board. Note that the case temperature is measured at the point where the leads contact with the mounting pad surface

The LM78MXX/LM341XX regulators have internal thermal shutdown to protect the device from over-heating. Under all possible operating conditions, the junction temperature of the LM78MXX/LM341XX must be within the range of 0˚C to 125˚C. A heatsink may be required depending on the maximum power dissipation and maximum ambient temperature of the application. To determine if a heatsink is needed, the power dissipated by the regulator, P_D, must be calculated:

$I_{IN} = I_L + I_G$

$P_D = (V_{IN}-V_{OUT})\, I_L + V_{IN} I_G$

shows the voltages and currents which are present in the circuit.

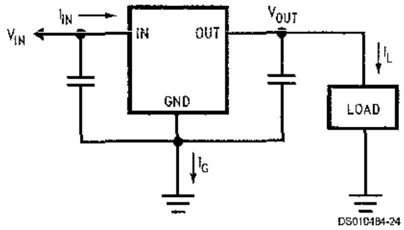


FIGURE 2. Power Dissipation Diagram

The next parameter which must be calculated is the maximum allowable temperature rise, T_R(max):

$\theta_{JA} = TR\ (max)/P_D$

If the maximum allowable value for θ_{JA}˚C/w is found to be ≥60˚C/W for TO-220 package or ≥92˚C/W for TO-252 package, no heatsink is needed since the package alone will dissipate enough heat to satisfy these requirements. If the calculated value for θ_{JA} fall below these limits, a heatsink is required.

As a design aid, *Table 1* shows the value of the θ_{JA} of TO-252 for different heatsink area. The copper patterns that we used to measure these θ_{JA} are shown at the end of the Application Note Section. reflects the same test results as what are in the *Table 1*

shows the maximum allowable power dissipation vs. ambient temperature for theTO-252 device. shows the maximum allowable power dissipation vs. copper area (in^2) for the TO-252 device. Please see AN1028 for power enhancement techniques to be used with TO-252 package.

TABLE 1. θ_{JA} Different Heatsink Area

Layout	Copper Area		Thermal Resistance
	Top Sice (in^2)*	Bottom Side (in^2)	(θ_{JA}, ˚C/W) TO-252
1	0.0123	0	103
2	0.066	0	87
3	0.3	0	60
4	0.53	0	54
5	0.76	0	52
6	1	0	47
7	0	0.2	84
8	0	0.4	70
9	0	0.6	63
10	0	0.8	57
11	0	1	57
12	0.066	0.066	89
13	0.175	0.175	72
14	0.284	0.284	61
15	0.392	0.392	55
16	0.5	0.5	53

*Tab of device attached to topside copper

Design Considerations (Continued)

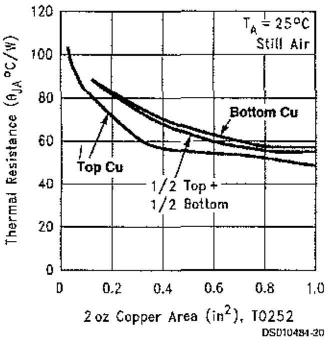


FIGURE 3. θ_{JA} **vs. 2oz Copper Area for TO-252**

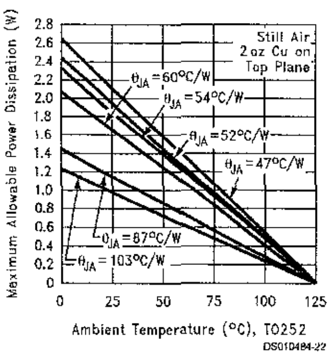


FIGURE 4. Maximum Allowable Power Dissipation vs. Ambient Temperature for TO-252

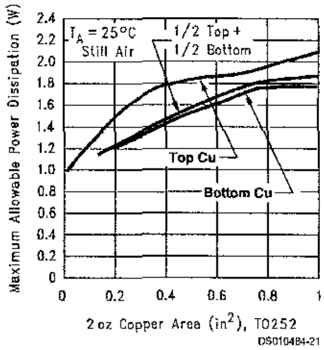
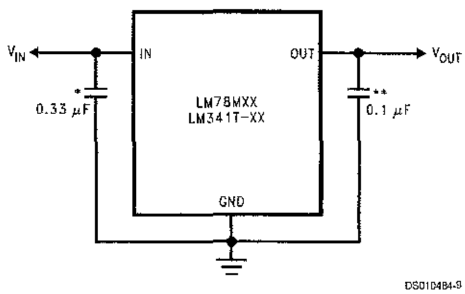


FIGURE 5. Maximum Allowable Power Dissipation vs. 2oz. Copper Area for TO-252

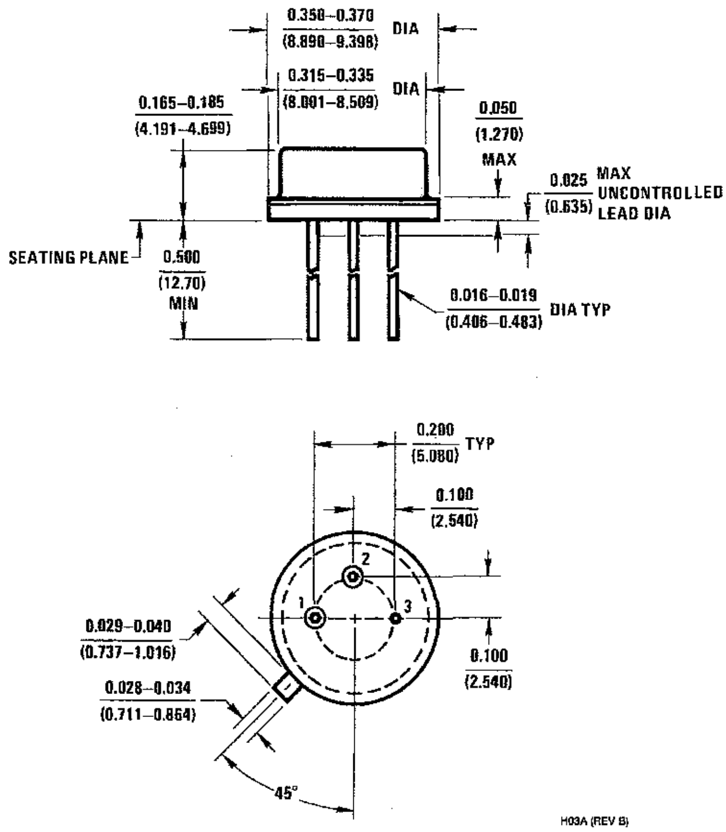
Typical Application



*Required if regulator input is more than 4 inches from input filter capacitor (or if no input filter capacitor is used).

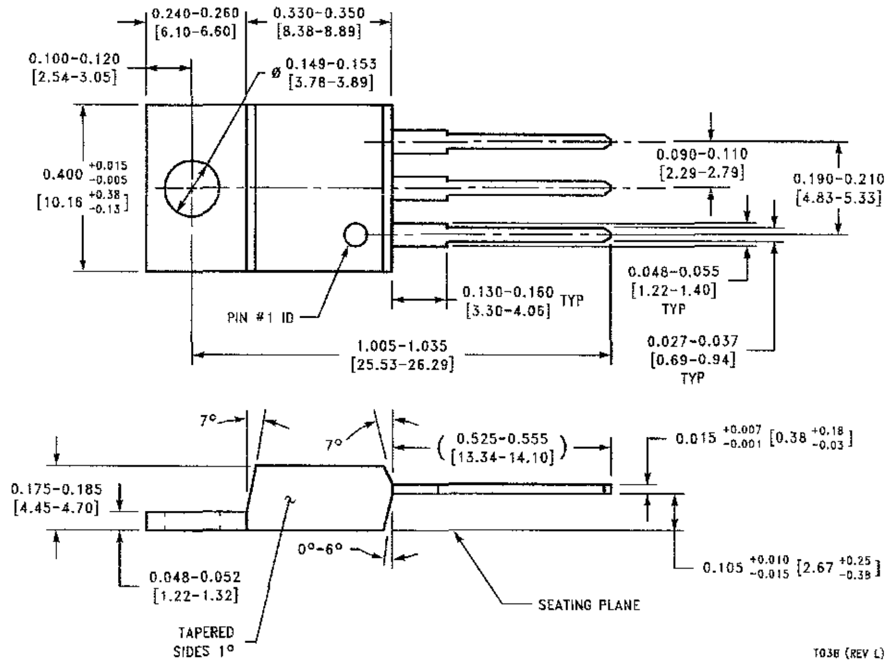
**Optional for improved transient response.

Physical Dimensions inches (millimeters) unless otherwise noted



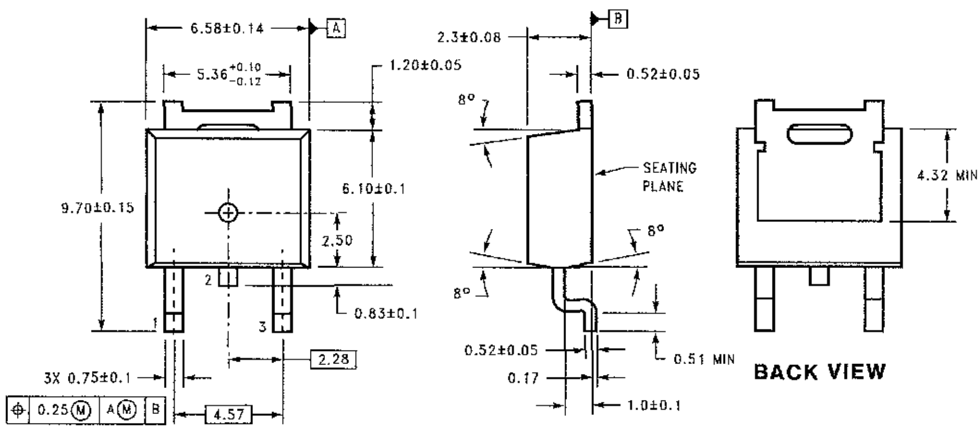
TO-39 Metal Can Package (H)
Order Number LM78M05CH, LM78M12CH or LM78M15CH
NS Package Number H03A

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



TO-220 Power Package (T)
Order Number LM341T-5.0, LM341T-12, LM341T-15, LM78M05CT, LM78M12CT or LM78M15CT
NS Package Number T03B

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



DIMENSIONS ARE IN MILLIMETERS

TO-252
Order Number LM78M05CDT
NS Package Number TD03B

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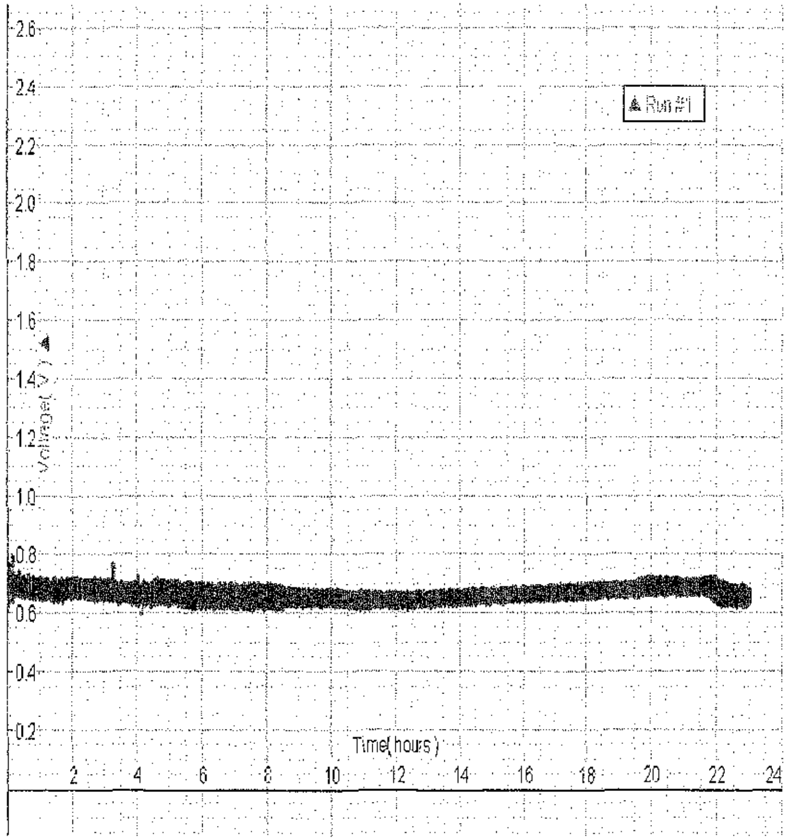
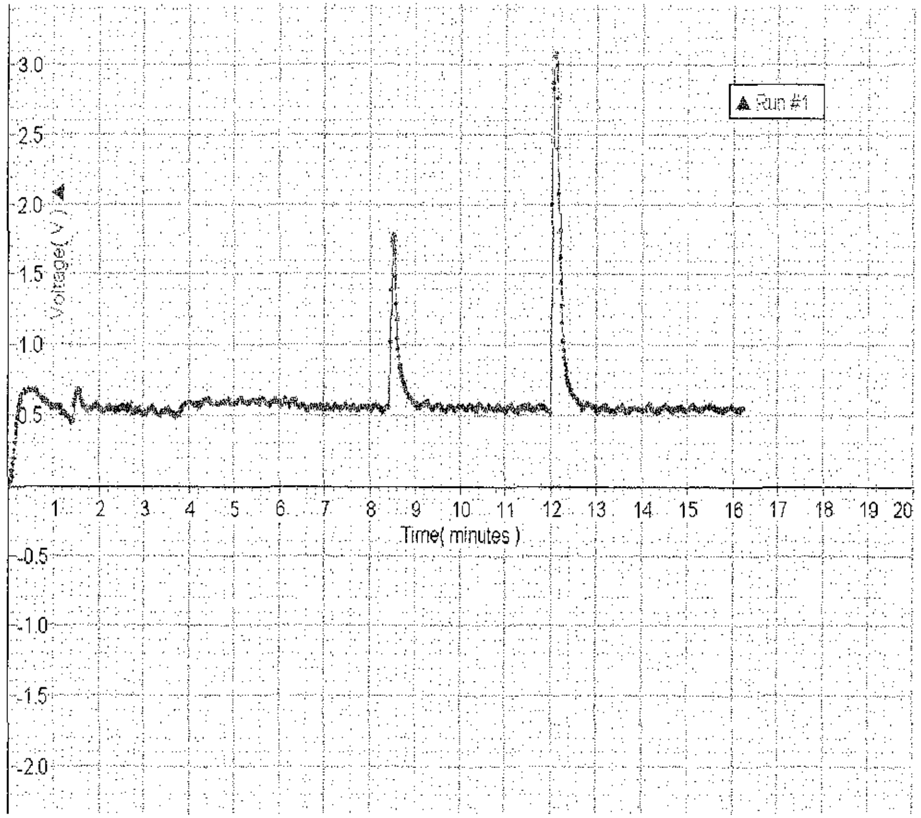
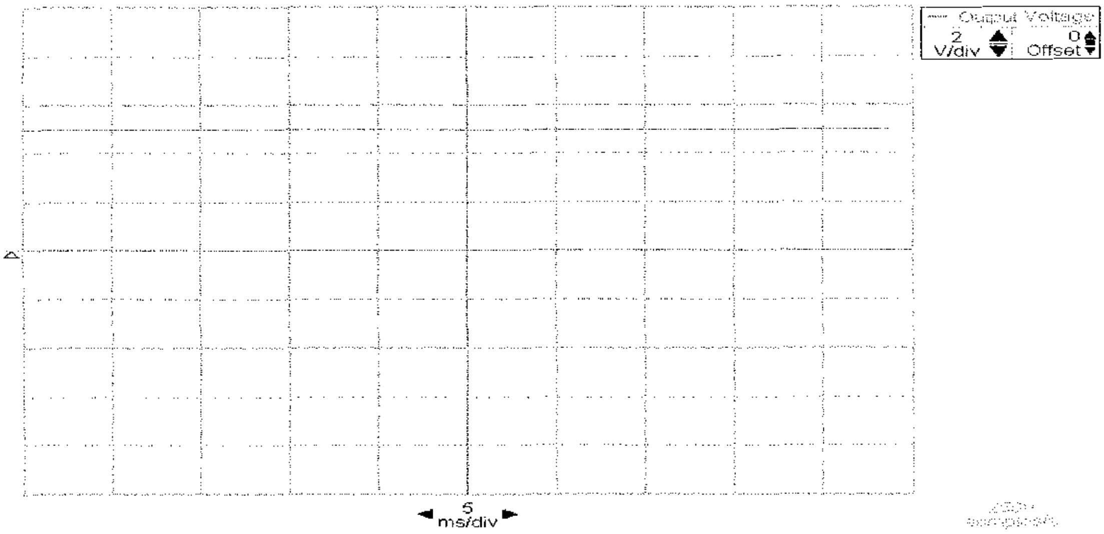
APPENDIX 5(A)

Voltage, ChA Run #1	
Time (minutes)	Voltage (V)
1381.3333	0.659
1381.3500	0.655
1381.3667	0.654
1381.3833	0.648
1381.4000	0.651
1381.4167	0.642
1381.4333	0.631
1381.4500	0.637
1381.4667	0.640
1381.4833	0.638
1381.5000	0.637
1381.5167	0.644
1381.5333	0.652
1381.5500	0.654
1381.5667	0.660
1381.5833	0.652
1381.6000	0.662
1381.6167	0.665
1381.6333	0.665
1381.6500	0.657
1381.6667	0.663
Minimum	-0.009
Maximum	2.528

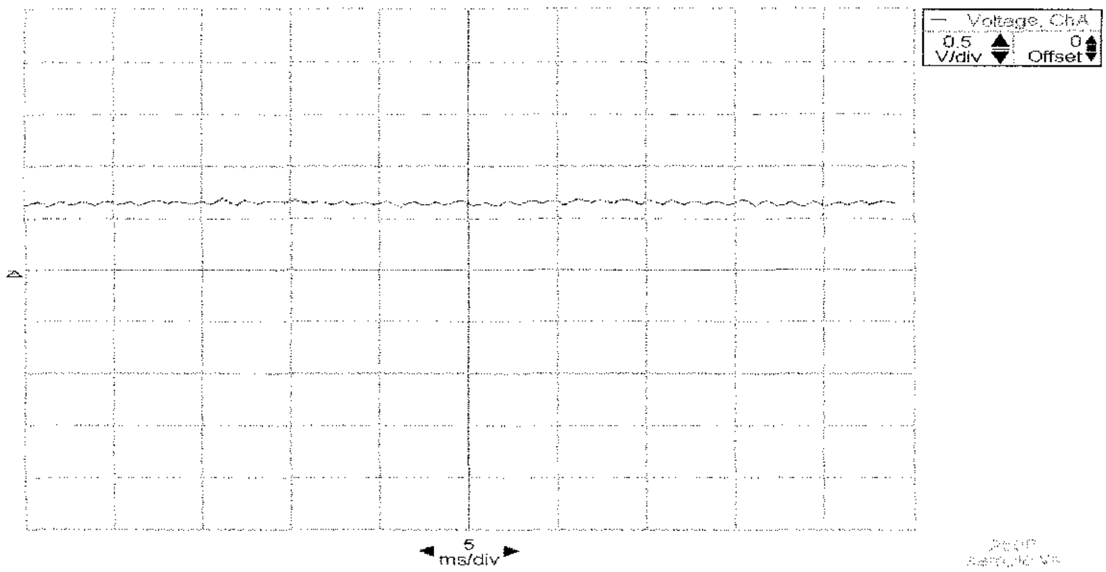

Run #1
Voltage(V)
Time(hours)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
2
4
6
8
10
12
14
16
18
20
22
24


Run #1
Voltage(V)
Time(minutes)
3.0
2.5
2.0
1.5
1.0
0.5
-0.5
-1.0
-1.5
-2.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

APPENDIX 5(B)

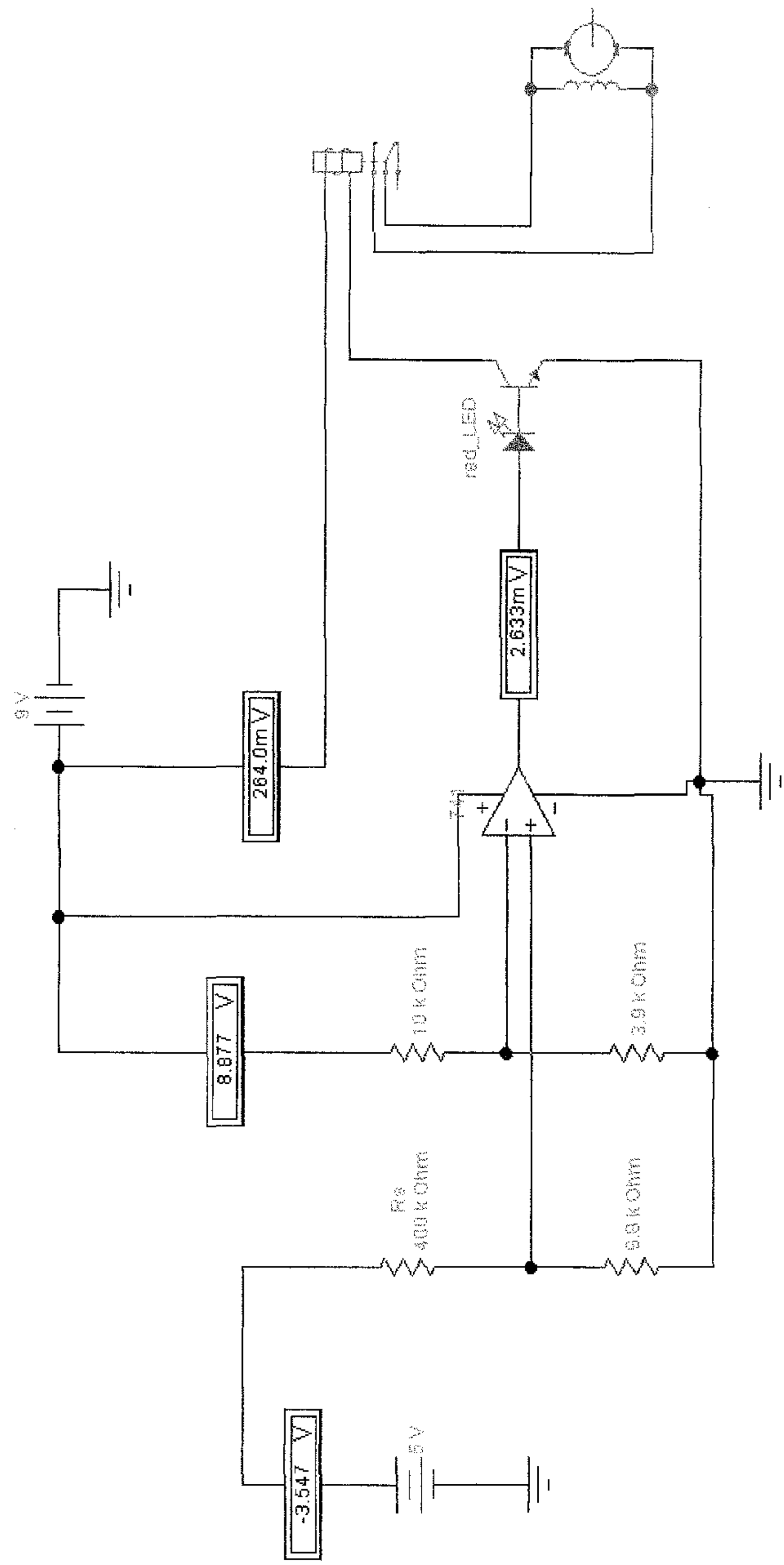


Scope input value monitored

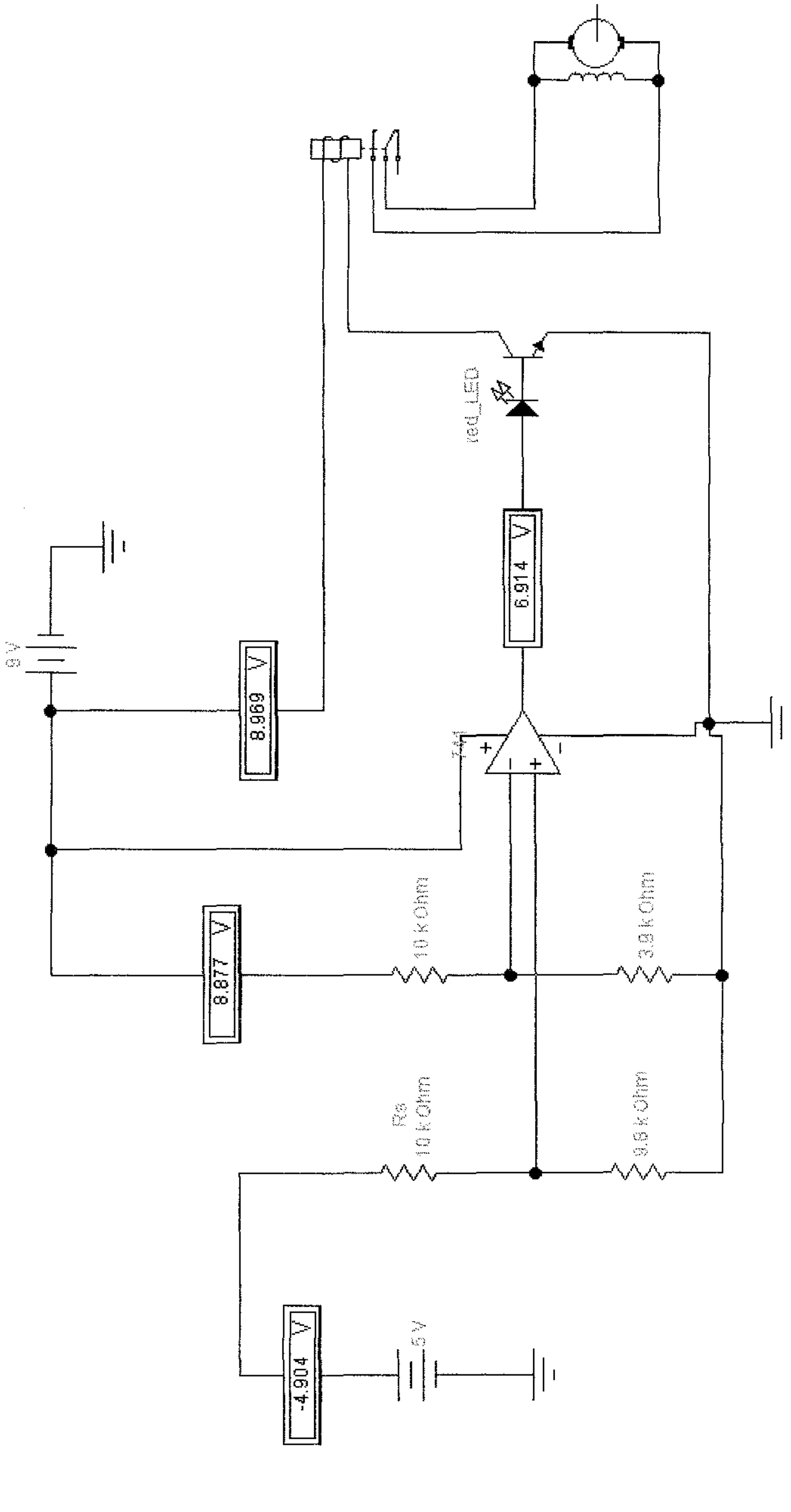


Scope output monitored

APPENDIX 6(



APPENDIX 6(l



9V
8.969 V
6.914 V
red_LED
741
8.877 V
10 k Ohm
3.9 k Ohm
Rs
10 k Ohm
9.6 k Ohm
-4.904 V
5 V