DESIGN AND DEVELOPMENT OF THERMAL CONDUCTIVITY DETECTOR

By

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FINAL PROJECT REPORT

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CERTIFICATION OF APPROVAL

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Approved:

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June 2006

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.

Yurahafzan Binti Yusoff

ABSTRACT

Emerging need for a safe and healthy living nowadays lead to this project of gas detection. The main target of the project is to construct a thermal conductivity gas detector for environment monitoring. A gas detector which can detect potentially hazardous gases released to the environment. If the air composition is different from the normal, the thermal conductivity of gas detector should change to detect and give a warning alarm to the people. A heat sensing circuit is employed here for this purpose, which by comparing the thermal conductivity of a potentially hazardous gas with normal air gives a warning signal. The literature review presents various methods of gas detection used these days. The methodology section gives detail design and development process taken in this project. The result is a practical heat detection circuit that is constructed, tested and calibrated with respect to normal air. It gives an indication of abnormality through bar graph display used in dot mode. Additionally, the project cost has been kept as low as possible.

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LIST OF ABBREVIATIONS

ECD	Electron Capture Detector
FID	Flame Ionizations Detector
FPD	Flame Photometric Detector
GC	Gas Chromatography
IC	Integrated circuit
IR	Infrared
PMT	Photomultiplier Tube
TCD	Thermal Conductivity Detector
TC	Thermal Conductivity
UV	Ultra Violet

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Gas monitoring and detection is one of the most important safety challenges. All facilities involved with the production, refining and distribution of oil, natural gas and petrochemicals need such monitors. They are needed for domestic safety also where natural gas leakages can cause damage to humans and properties.

Measuring the thermal conductivity (TC) of gases was one of the earliest forms of gas detection and it is suitable for low levels of certain binary mixtures (two different gases, one of which can be air). The thermal conductivity characterizes the capability of a material to transfer heat.

TC gas detectors operate by comparing the thermal conductivity of the sample with a reference gas. A heated platinum filament is mounted so that it is exposed to a sample and a reference gas.

If the sample gas has a higher thermal conductivity than the reference gas, heat is lost from the exposed element and its temperature decreases, whilst if the thermal conductivity is lower than the reference, the temperature of the exposed element increases. These temperature changes cause electrical resistance changes, which are measured by means of a bridge circuit.

But there are some limitations in the use of TC detectors where data on the thermal conductivities of gases is normally stated relative to air. Gas concentrations are often measured by TC techniques and when thermal conductivity relative to air is greater than one, hence their presence leads to cooling of the exposed thermistor or filament.

The thermal conductivity gas detector is not as sensitive as some other detectors but it is non-specific to gas type and non-destructive.

1.2 Problem Statement

Environmental pollution is a major issue these days. Some industries due to accidents or irresponsible attitude release hazardous gases to the environment, which result in poor health or even death of citizen.

Natural gas is an energy source that is commonly used in homes for cooking, heating, etc. It is primarily composed of methane which is a highly flammable. Although it only happens rarely, a natural gas leak can sometimes occur inside a home. A natural gas leak increases the risk of fire or explosion, leading to lost of lives.

These gases are sometimes colorless and odorless that can not be easily detected and cause fatal consequences. Gas companies work hard to provide adequate warning in the event of a gas leak. They add a "rotten-egg" smell as warning that can be easily detected by most people. However, people who have a diminished sense of smell may not be able to respond to this safety mechanism. A gas detector in this case can be an important tool to help in order to overcome the problem.

For this reason, the design and development of an environmental changes monitor has been undertaken. This monitoring is based on hot wire or thermal conductivity gas detection technique. This monitor will contribute positively to the pollution monitoring of environment. The aim is to detect the changes in normal environment, which is done after initial calibration of monitor in a normal environment. A good detector, for this purpose, should respond quickly to the environment changes and alert the people.

1.3 Objectives

The main objective of the project is to construct a thermal conductivity gas detector. This detector will sense any hazardous gas released to the environment. If the air composition is crossing the normal limit, this detector should give a warning alarm to the people.

The objectives of this project are as follows:

- To gather the basic background information by extensive literature review.
- To construct low cost part of environment monitoring system.
- To integrate these parts after testing them individually.
- To document of constructional details and results obtained from the project.

1.4 Scope of Study

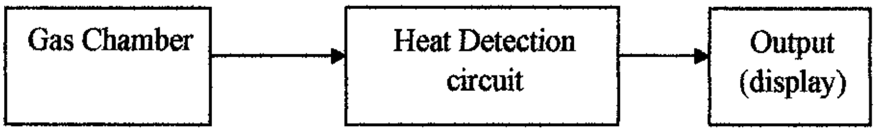

Figure 1.1 Gas detection system.

There are three areas of study involved in the design and development process. These include studies on gas chamber, heat detection system and the display of collected information. The gas chamber is a container which consists of air pump and the detection circuit inside it. It is a closed container having the gas flow rate and internal temperature constant.

The heat sensor circuit is the heart of this system. It will detect the loss of heat due to gas flowing through the circuit and activate the output to give an indication.

The student is required to:

- Design and construct the mechanical parts of the system which consist of gas chamber and the gas injection/pump system.
- Design and construct the heat detection circuit of the system.
- Design and construct the output circuit of the system which includes visual and sound indicator.

CHAPTER 2
LITERATURE REVIEW

A gas detector is an instrument that detects the presence of a certain amount of gas in the environment. It is used to give an early warning signal, perhaps in the form of sound and visual alarm to indicate the leakage of gas at working area. Gas detectors consist of a sensor, control unit, and an alarm.

2.1 Gas Detection Techniques

A number of gas detection techniques are available to measure the concentration of the gases. The selection of a technique depends on the type of gas to be detected. There are many physical properties of gases, which can be used for their detection.

Spectroscopic means of gas detection such as microwave, optical or chromatography are more widely used in the analytical field compared to safety instrumentation. This is due to the relative cost and complexity of the technology employed.

Surface acoustic wave (SAW) technologies may have a part to play in future gas detectors. Certain gas molecules can be absorbed onto the surface of doped semiconductors and the change in material's characteristics can be detected by the optical or acoustical radiation traveling over the treated surface. Molecular absorption onto other materials, such as optical fibers, is another area of academic research that may form the basis of future generations of gas sensors [4].

The following techniques are generally used by combustible gas detectors:

2.1.1 Electro-Catalytic Detector

Electro-catalytic detector uses two identical beads, one active, which oxidizes any combustible gases present, and one glass coated, which is used for reference. The glass coating on the reference bead allows it to respond to changes in temperature, humidity and pressure without responding to combustible gases, which cannot penetrate the glass coating.

The reference bead serves as a "baseline" signal, which can then be compared to the resistance of the active bead to determine the concentration of gas present. As gas oxidizes on the active bead, the bead temperature increases in direct proportion to the concentration of the gas in the atmosphere. This temperature rise increases the resistance of the active bead, and when compared with the reference bead resistance, results in a measurable voltage differential, which is used by the instrument [5].

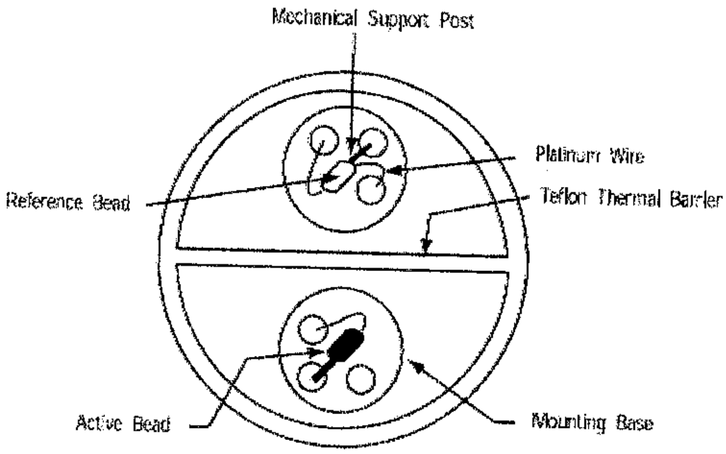

Figure 2.1 Catalytic bead sensors

2.1.2 Infrared Detector

Infrared gas detection is based on the ability of some gases to absorb IR radiation. Devices using this technology have a light source and a light detector and measure the light intensity at two specific wavelengths, one at an absorption (active) wavelength and one outside of the absorption (reference) wavelength. If a volume of gas passes between the source and detector, the amount of light in the active wavelength falling on the detector is reduced, while the amount of light in the reference wavelength remains unchanged. Much like the catalytic detectors, the gas concentration is determined from the relative difference between the two signals [6].

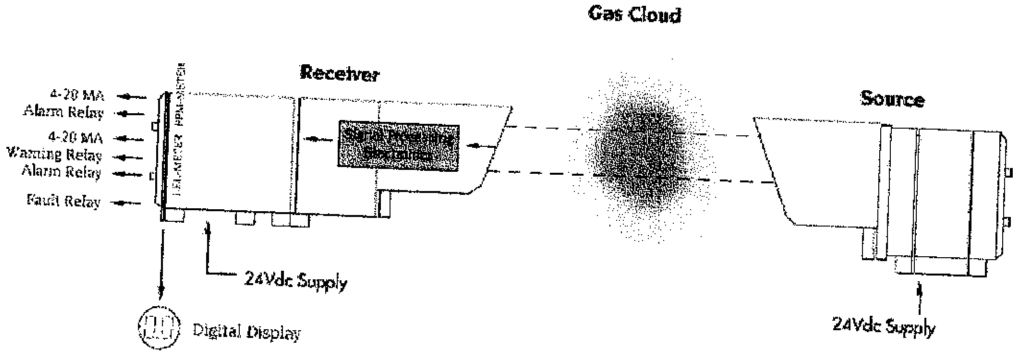

Figure 2.2 Open path IR detector

2.1.3 Semiconductor Temperature Detector

The operating principle is the semiconductor's conductivity altered by the surface interaction occurring between a gas and the gas-sensitive semiconductor. The conductivity is increased by the reducing gases such as hydrocarbons and decreased by the oxidizing gases such as oxygen. Hence, the concentration of the hydrocarbons in the air can be measured with the change in the semiconductor's electrical conductivity [7].

2.1.4 Ultrasonic Detector

This method is ideal for detecting leaks in high pressure gas systems. Any gas that leaks from the high pressure pipeline or the other pressurized gas system produces ultrasonic sound. This is the basic principle for this detector. An acoustic sensor is used to listen to the ultrasonic sound and provide a measure of the leak [8].

2.2 Gas Chromatography

Gas-liquid chromatography (GLC), or simply gas chromatography (GC), is a technique in which the mobile phase is a carrier gas, usually an inert gas like helium or nitrogen. The stationary phase is a thin layer of liquid on an inert solid support. The stationary phase lines the inside of a very long and very thin tube known as a column.

This technique involves a sample being injected and vaporized into the head of the chromatographic column. The sample is transported through the column by the flow of inert, gaseous mobile phase. The gas molecules, depending on their size, are bunched and detected in time domain.

A number of detector types are used in gas chromatography. The most common one is the thermal conductivity detector (TCD), which monitors changes in the thermal conductivity of the effluent. Some of the other types of detectors such as the flame ionization detector (FID), electron capture detector (ECD), flame photometric detector (FPD), photo-ionization detector (PID), and sensitive to the type of gas.

2.2.1 Flame Ionization Detector (FID)

The FID is widely used and it is generally applicable. The effluent from the column is mixed and ignited with a mixture of hydrogen and air. Organic compounds burning in the flame produce ions and electrons which can conduct electricity through the flame. A large electrical potential is applied at the burner tip, and a collector electrode is located above the flame. The current resulting from the pyrolysis of any organic compounds is measured. This current is very small of the orders of pico ampere.

The operating principle of this detector is that the electrical current produces will be directly proportional to the number of ions in the gas. The high temperature hydrogen flame is the source for ionization. The FID is a useful general purpose detector for the analysis of organic compound. It has high sensitivity, large linear response range, and low noise. It is also robust and easy to use, but prohibitively expensive. Figure 2.3 shows the typical diagram of flame ionization detector [9].

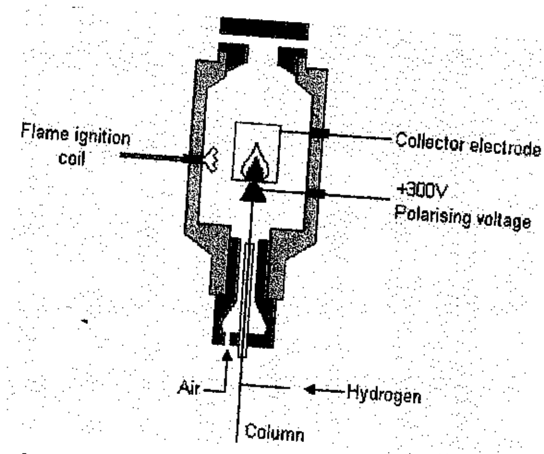

Figure 2.3 Flame Ionization Detector

2.2.2 Photo-ionization Detector (PID)

The sensing technologies include various means of ionizing the gas sample so that its ability to conduct a small electric charge. This current gives an indication of the presence or absence of certain gases. Photo ionization (PID) utilizes an ultra violet (UV) radiation emitting lamp to ionize a wide range of volatile organic substances. The operating principle of this method is similar to that of flame ionization, but the difference is that a UV lamp is used as the source for ionization. The ions produced by this process are collected by electrodes, and hence the current generated is therefore a measure of the analyte concentration. Figure 2.4 shows a typical schematic of Photo Ionization Detector [10]

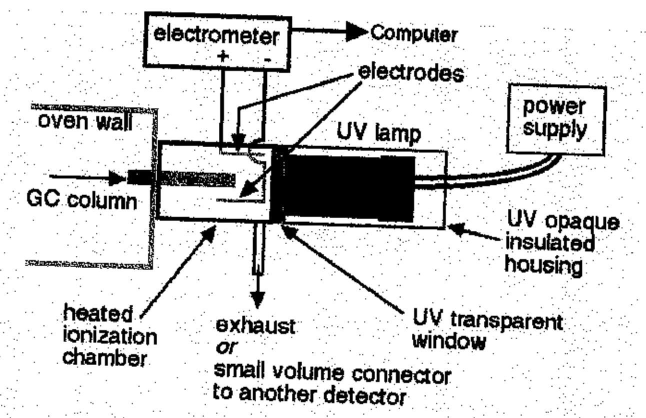

Figure 2.4 Photo Ionization Detector

2.2.3 *Electron Capture Detector (ECD)*

The ECD uses a radioactive Beta emitter (electrons) to ionize the carrier gas and produce a current between a biased pair of electrodes. When organic molecules containing electronegative functional groups, like halogens, phosphorous, and nitro groups pass by the detector, some of the electrons are captured by them and reduce the current between the electrodes. The ECD is as sensitive as the FID but has a limited dynamic range and finds its greatest application in analysis of halogenated compounds. Figure 2.5 shows a typical schematic of ECD [11]

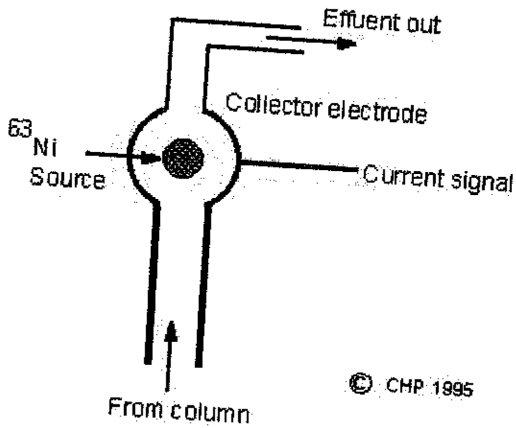

Figure 2.5 Electron Capture Detector

2.2.4 *Flame Photometric Detector (FPD)*

The reason to use more than one kind of detector for gas chromatography is to achieve selective or highly sensitive detection of specific compounds encountered in particular chromatographic analyses. The determination of sulfur or phosphorus containing compounds is the job of the flame photometric detector (FPD). This device uses the chemiluminescent reactions of these compounds in a hydrogen or air flame as a source of analytical information. The light emitting species for sulfur compounds is excited S_2.

In order to selectively detect one or the other family of compounds as it elutes from the GC column, an interference filter is used between the flame and the photomultiplier tube (PMT). The purpose of this filter is to isolate the appropriate emission band. This filter needs to change between chromatographic runs if the other family of compounds is to be detected. This is a major drawback of this technique. Figure below shows a typical schematic of FPD [12].

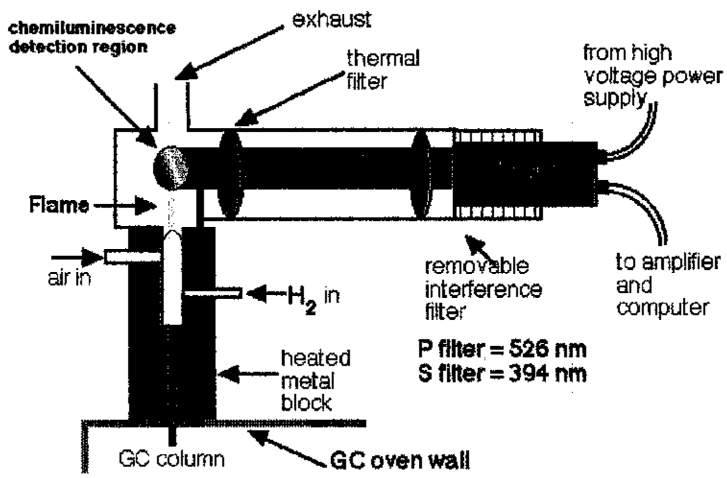

Figure 2.6 Flame Photometric Detector

2.2.5 Thermal conductivity

The principle of differential heat conduction by gases is used as the operating principle of this detector. By comparing the thermal conductivity of a sample gas and the reference gas, the concentration of the sample gas can be found and measured by the heated element's heat dissipation. The off balanced voltage from a resistance bridge is a measure of the gas concentration. The bridge is capable of compensating ambient temperature changes.

Thermal conductivity detectors are in use since before the beginning of gas chromatography. Substitute of TCD's has the same ease of use and stability. They are also employed when the auxiliary or combustion gases required by other detectors are unsafe or impractical. Although they cannot match the sensitivity of ionization detectors, TCD's are the third most widely used detector, surpassed only by flame ionization and bench-top mass-spectrometry detectors.

A TCD usually consists of an electrically-heated wire. The temperature of the sensing element depends on the thermal conductivity of the gas flowing around it. Changes in thermal conductivity, such as when organic molecules displace some of the carrier gas, cause a temperature rise in the element which is sensed as a change in resistance. Though TCD is not as sensitive as some other detectors but it is not specific to the type of gas.

Various configurations of TCDs are used in gas chromatographs. A common one uses an element placed in the sample column and another pair is placed in a reference column. The resistances of the two are then arranged in a bridge circuit as shown in figure 2.7.

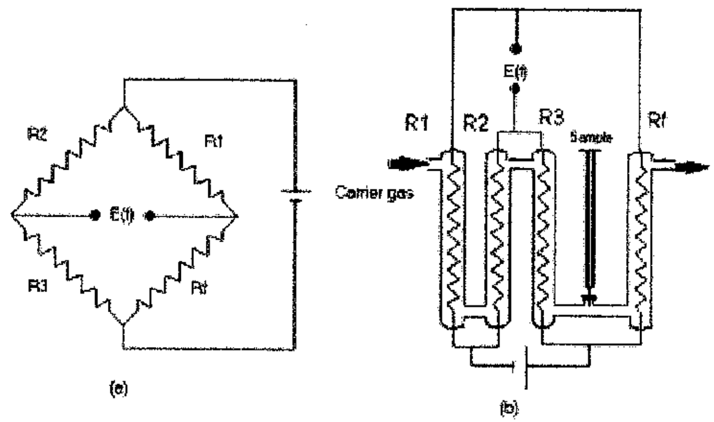

Figure 2.7 Thermal Conductivity detector

Table 2.1 Table of Common GC detectors [13]

Detector	Type	Support gases	Selectivity
Flame ionization (FID)	Mass flow	Hydrogen and air	Most organic compounds
Thermal conductivity (TCD)	Concentration	Reference	Universal
Electron capture (ECD)	Concentration	Make-up	Halides, nitrates, nitriles, peroxides, anhydrides, organometallics
Nitrogen-phosphorus	Mass flow	Hydrogen and air	Nitrogen, phosphorus
Flame photometric (FPD)	Mass flow	Hydrogen and air possibly oxygen	Sulphur, phosphorus, tin, boron, arsenic, germanium, selenium, chromium
Photo-ionization (PID)	Concentration	Make-up	Aliphatics, aromatics, ketones, esters, aldehydes, amines, heterocyclics, organosulphurs, some organometallics
Hall electrolytic conductivity	Mass flow	Hydrogen, oxygen	Halide, nitrogen, nitrosamine, sulphur

CHAPTER 3
METHODOLOGY AND PROJECT WORK

3.1 Procedure Identification

In the design and development of thermal conductivity gas detector, there are three areas of work involved:

1. Design and construction of the electrical parts of the system which include the electrical circuit that functions as sensors.
2. Design and construction of the mechanical parts of the system which included the gas chamber.
3. Design and construction of the indicators which is the sound alarm and bar graph display of the monitoring system.

3.1.1 Wheatstone bridge Circuit

The Wheatstone bridges are widely used for the measurement of resistance, capacitance and inductance. A basic resistive bridge is Wheatstone bridge circuit that contains four resistances, a constant voltage source and a voltmeter. It is used to measure an unknown electrical resistance by balancing two arms of a bridge circuit, one arm of which includes the unknown component. Its operation is similar to the basic potentiometer method except that in potentiometer circuits a sensitive galvanometer is used.

The Wheatstone bridge is used in two ways:

1. To measure the value of an unknown resistor by comparison to standard resistors,
2. To detect small changes in a resistive transducer (e.g. thermistor) as sensor.

In order to determine the resistances of the unknown resistor, the resistance of the other three are adjusted to balance the bridge, the current passing through the galvanometer decreases to zero at the balanced condition.

$$\frac{R_1}{R_2} = \frac{R_3}{R_x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

By selecting the suitable arms for sample and reference, the Wheatstone bridge can amplify small changes in the resistance of sample to give voltage proportional to changes in sample concentration. It is widely used across the industry even today.

3.1.2 Circuit Analysis

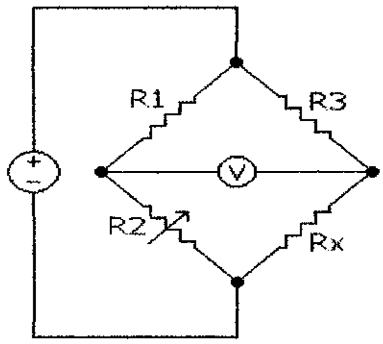

Figure 3.1 Wheatstone Bridge Circuit

Here, R_x is the unknown resistance to be measured; R_1, and R_3 are resistors of known value while resistance of R_2 is adjustable. If the ratio of the two resistances in the known arm (R_2/R_1) is equal to the ratio of the two in the unknown arm (R_x/R_3), the voltage at the detector V will be zero and no current will flow through the detector, R_2 is varied until this condition is reached. The direction of the current indicates whether R_2 is higher or lower than R_x.

Detecting zero current can be done to a high accuracy. Therefore, if R_1, R_2 and R_3 are of high precision, the R_x can be measured quite accurately. Very small changes in Rx disrupt the balance and are readily detected. Alternatively, if R_1, R_2 and R_3 are known, but R_2 is not adjustable, the voltage or current flow through the meter can be used to calculate the value of R_x, by using network analysis theorems.

Equation 3.1 is obtained by balancing both arms of the Wheatstone bridge circuit as shown in figure 3.1:

$$E_1 = E\left(\frac{R_2}{R_1 + R_2}\right)$$

$$E_2 = E\left(\frac{R_x}{R_3 + R_x}\right)$$

$$E_1 - E_2 = E\left(\frac{R_2}{R_1 + R_2}\right) - E\left(\frac{R_x}{R_3 + R_x}\right) = 0$$

$$0 = E\left(\frac{R_2}{R_1 + R_2} - \frac{R_x}{R_3 + R_x}\right)$$

$$0 = E\left[\frac{R_2(R_3 + R_x)}{(R_1 + R_2)} \frac{R_x(R_1 + R_2)}{(R_3 + R_x)}\right]$$

$$0 = E\left[\frac{R_2R_3 + R_2R_x - R_1R_2 - R_2R_x}{R_1R_2 + R_1R_x + R_2R_3 + R_2R_x}\right]$$

$$0 = R_2R_3 + R_2R_x - R_1R_2 - R_2R_x$$

Separating and dividing both sides by R_2R_x:

$$\frac{R_2R_3 + R_2R_x}{R_2R_x} = \frac{R_1R_x + R_2R_x}{R_2R_x}$$

$$\frac{R_2R_3}{R_2R_x} + 1 = \frac{R_1R_x}{R_2R_x} + 1$$

$$\frac{R_3}{Rx} = \frac{R_1}{R_2}$$

Or $\frac{R_x}{R_3} = \frac{R_2}{R_1}$

3.1.3 Thermal Conductivity of Air composition

The Thermal Conductivity Detector is a universal detector. Since thermal conductivity describes the ability of a substance to conduct heat, the heat is absorbed by the gas according to their TC. Heat tends to flow in the direction of the temperature gradient, from regions of higher temperature to region of lower temperature.

Gases have different abilities to conduct heat, so their thermal conductivities are different. The thermal conductivity gas detector responds to the differences in thermal conductivities between the carrier gas and the measured components. Greater the difference between carrier gas and measured gas, the greater the sensitivity of the measurement. To illustrate these differences, the following table shows thermal conductivity values of some gases [14].

Table 3.1 Thermal Conductivity Relative to Air at 100°C

Name	***Factor***
Air	*1.0*
Hydrogen	*6.9*
Methane	*1.4*
Nitrogen	*1.0*
Ethane	*0.75*
Carbon dioxide	*0.7*
Propane	*0.6*
Water vapor	*0.8*

As indicated in the table 1, hydrogen has a greater ability to conduct heat than the others. This means that it will effectively cool the surroundings better than the others.

Gases transfer heat by direct collisions between their molecules, and as would be expected, their thermal conductivity is low compared to most solids. For an ideal gas the heat transfer rate is proportional to the average molecular velocity, the mean free path, and the molar heat capacity of the gas. Heat transfer is always directed from a higher to a lower temperature. Denser substances are usually better conductors; hence metals are excellent conductors

3.2 Design of Visual Alarm System

If an alarm system is connected in place of the galvanometer of a Wheatstone bridge, it can warn both visually and verbally. The alarm system in this case consists of a sensitive operational amplifier whose output is the input signal to the bar/dot display. The bar/dot display used here is a popular LM3915 integrated circuit (IC).

3.2.1 LM 3915 Bar/Dot Display

The LM3915 is a monolithic integrated circuit that senses analog voltage levels and drives up to ten LEDs or LCDs. The pin 9 changes the display from a bar graph to a moving dot display. LED current drive is regulated and programmable, eliminating the need for current limiting resistors. The whole display system can operate from a single supply as low as 3V or as high as 25V.

The LM3915 is easy to use with lowest component count. A 1.2V full-scale meter requires only one resistor in addition to the ten LEDs. One more resistor programs the full-scale anywhere from 1.2V to 12V independent of supply voltage. LED brightness can be easily controlled with a single pot.

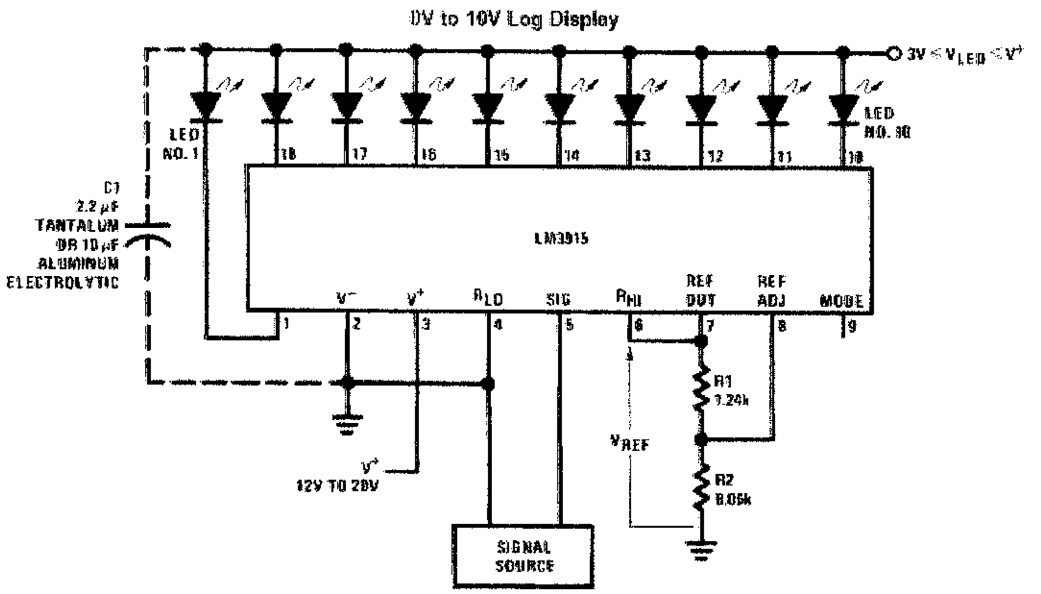

Figure 3.2 Typical Applications of LM3915 bar/dot display [14]

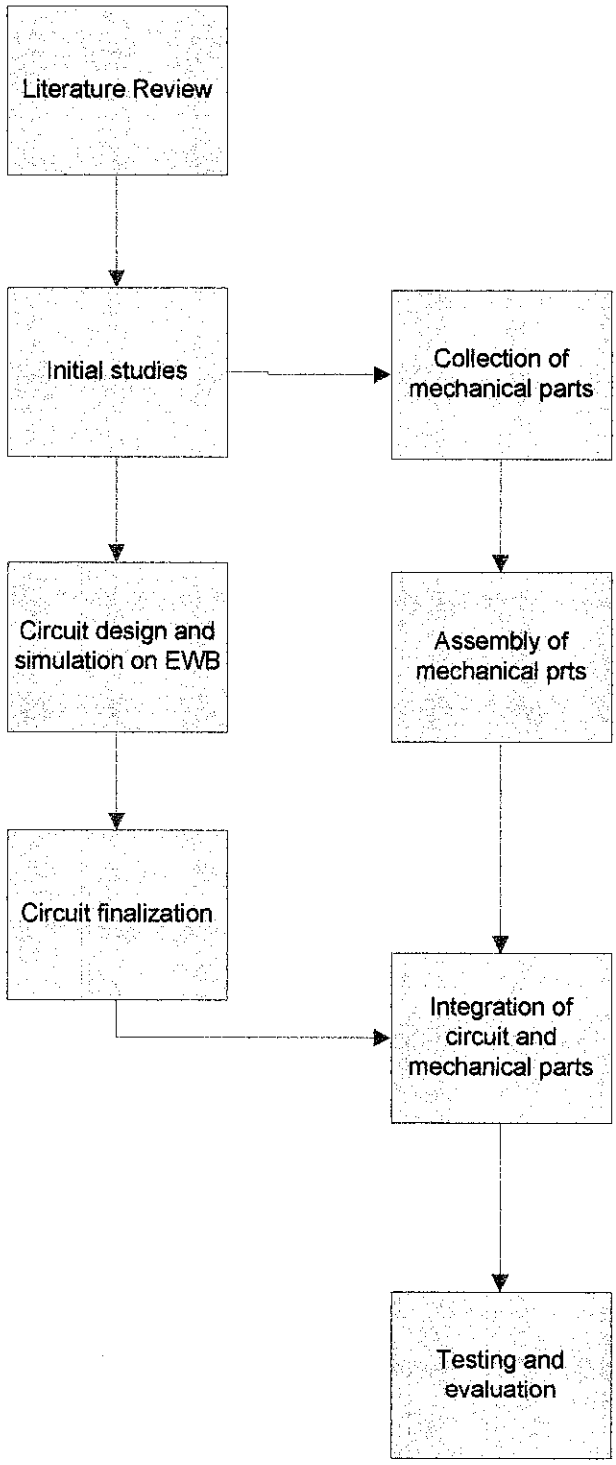

Figure 3.3 Overall Flow Chart of the design process

3.3 Tools Required

3.3.1 Hardware:

In order to construct the Wheatstone bridge based gas sensor circuit circuit, following components are used. Buzzer and bar/dot display IC are used in verbal and visual alarm.

- Potentiometer
- Negative Temperature Coefficient (NTC) Thermistor
- Fixed resistors
- Buzzer
- LED
- Batteries
- Operational amplifiers 741
- Bar/dot display IC LM3915
- Sample gas-butane gas refill

3.3.1.1 Thermistor

A thermistor is a temperature sensitive resistor that exhibits a change in electrical resistance with a change in ambient temperature. The resistance is measured by passing a small, direct current (dc) through it and measuring the voltage drop across it.

The relationship between change in resistance and change in temperature is linear: $\Delta R = k\Delta T$

Where ΔR = change in resistance

ΔT = change in temperature

k = first-order temperature coefficient of resistance

Thermistor can be classified into two types depending on the sign of k. If k is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (PTC) thermistor, *posistor* or *sensistor*.

If k is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (NTC) thermistor. Resistors that are commonly used are designed to have the smallest possible k, so that their resistance remains almost constant over a wide temperature range.

Negative Temperature Coefficient (NTC) thermistor are mostly used in temperature sensing circuitry while Positive Temperature Coefficient (PTC) thermistor are mostly used in electric current control.

3.3.1.2 Sample gas used for testing and evaluation

Figure 3.4 Sample Gas Used for Testing and Evaluation

For circuit testing and evaluation, the sample gas shown in figure above is used. The results obtained are included in results and discussion section.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Balancing Wheatstone bridge Circuit

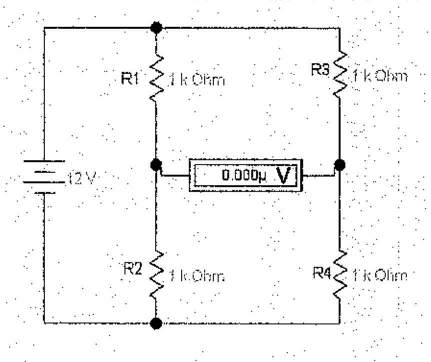

Figure 4.1 Balanced bridge circuit

The Thermal Conductivity Detector (TCD) circuit is usually comprised of a Wheatstone bridge. The Wheatstone bridge shown above is made up of four fixed resistors of equal value. The potentiometer is adjusted so that no potential difference between the two junctions of the bridge circuit. This bridge is therefore balanced with an output of zero volts.

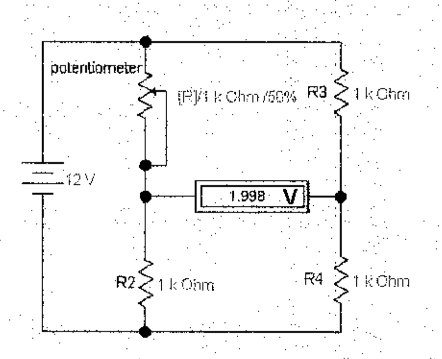

Figure 4.2 Unbalanced bridge circuits

4.2 Heat Detection circuit

The circuit in figure 4.3 shows the comparison between the voltages of two junctions of a Wheatstone bridge along with detector output voltage. The first junction consist of two fixed resistors of the same value, R_1=R_2=1kΩ. The junction acts as the reference junction where the voltage is set to half the supply voltage. This can be referred to the set point of the heat detection.

The other junction consists of a potentiometer and a thermistor that is exposed to sample gas. The potentiometer controls the balance of this junction when it is calibrated to environmental temperature.

Change in temperature varies the resistance of the thermistor, the voltage at that junction changes, changing the potential difference between the two junctions. Thus position of output will change and an appropriate LED at the output will grow. The position of the LED will be proportional to the sensed temperature.

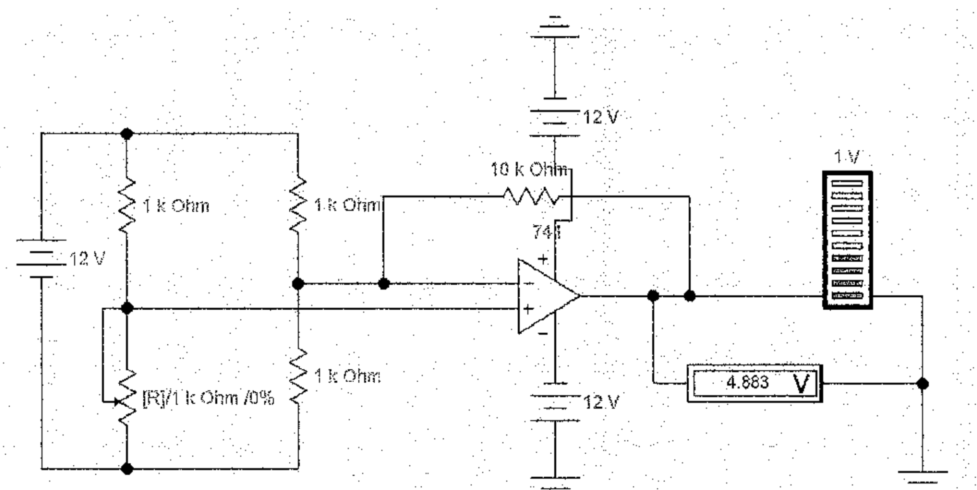

Figure 4.3 Wheatstone bridge circuit with gain = 10

To find gain of the amplifier:

$$A = \frac{R_f}{R_i} = \frac{10k\Omega}{1k\Omega} = 10$$

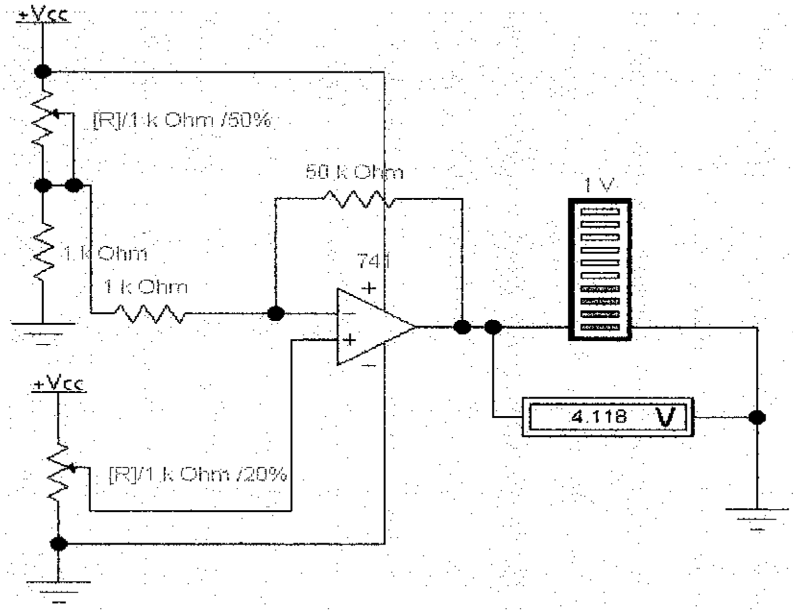

Figure 4.4 Heat Sensing Circuit with Gain=50

Figure 4.4 shows potentiometer and the thermistor is arranged in voltage divider configuration. Operational amplifiers amplify their input voltage either inverting or non-inverting. This allows them to be used with both NTC and PTC sensors to move the output reading to a suitable scale of measurement.

Gain of the amplifier:

$$A = \frac{R_f}{R_i} = \frac{50k\Omega}{1k\Omega} = 50$$

4.3 LM3915 Bar/dot Display

The output of the op amp is directly connected to the bar/dot display. Thus the whole circuit functions as gas detector that will display an abnormal condition when the sample input is other than equilibrium condition. If the concentration of a hazardous gas in air detected abnormal, the LED position will indicate shift from the equilibrium point.

The bar/ dot display responds to the input signal according to the input voltage. Below are the threshold input voltages for LEDs connected to LM3915 up to the input signal of 9V.

Table 4.1 Response of LM3915 Circuit to Input Voltage.

LED (no)	Threshold voltage (V)
1	0.4
2	0.6
3	0.8
4	1.2
5	1.6
6	2.0
7	2.8
8	4.0
9	5.6
10	7.9

Table 4.1 shows the response of LM3915 bar/dot display circuit to input voltage. As shown in the table, the voltage change is not linear. The span of first LED voltage and the last LED voltage is 7.5V. Approximately 7.9V is needed to turn 10^{th} LED and the voltage difference between 10^{th} LED and 9^{th} LED is 2.3V. The result is not satisfactory. A less voltage deviation between each LED is desirable for better sensitivity of the gas sensing.

To improve the response of LM3915 to the sensing circuit, a new circuit configuration is set up as shown in figure 4.5. Output from the heat sensing circuit is applied to pin no.5. The result of the new configuration is shown in table 4.2.

As can be seen from table 4.2, the threshold voltage has been considerable reduced giving a more sensitive response. The LED connected to pin no.5 is taken as the reference and it represent the normal environment. The LED glowing to its left or right represents abnormal conditions. In these conditions, presence of any unusual gas is indicated.

Table 4.2 Linear transition of LM3915 Circuit

LED (no)	Threshold voltage (mV)
1	60
2	80
3	110
4	170
5	240
6	330
7	450
8	640
9	900
10	1.30V

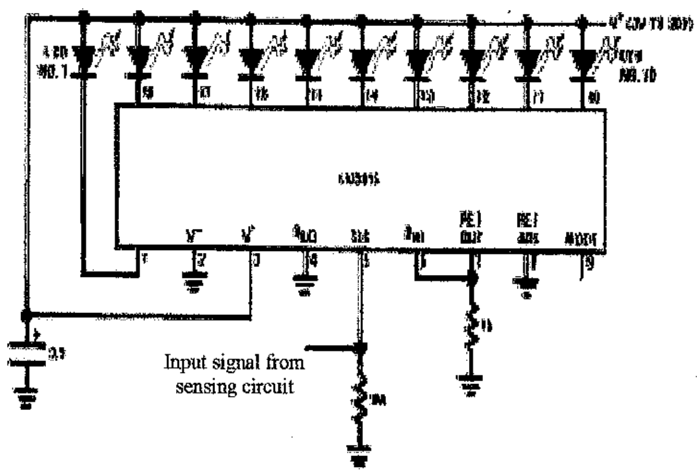

Figure 4.5 Circuit Configuration of Bar/Dot Display for Linear Transition

Figure 4.6 shows the responding bar/dot display when the sensing circuit is exposed to heat higher than ambient temperature. Figure 4.7 shows the bar/dot display at ambient temperature which is the normal environment while figure 4.8 shows the responding bar/dot display when heat sensed is less than ambient temperature.

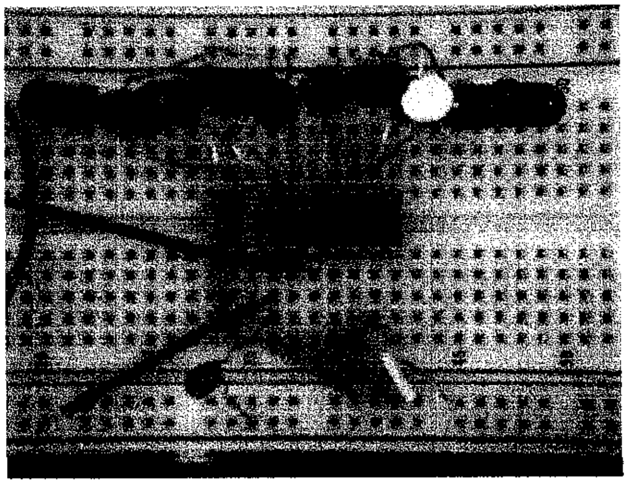

Figure 4.6 Bar/Dot display when heat sensed is more than the normal environment

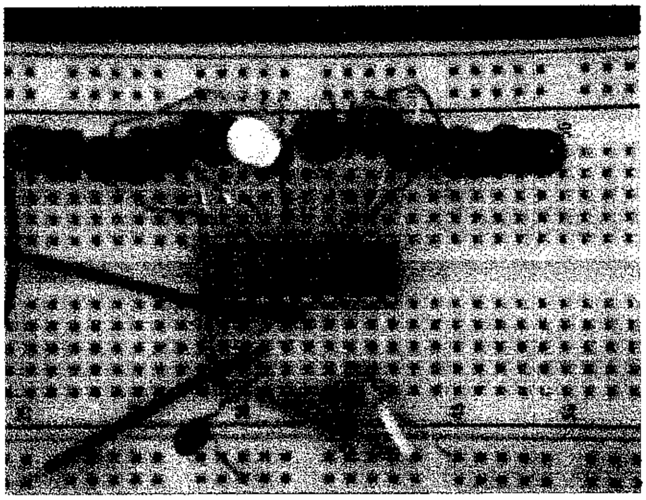

Figure 4.7 Bar/Dot Display at normal environment

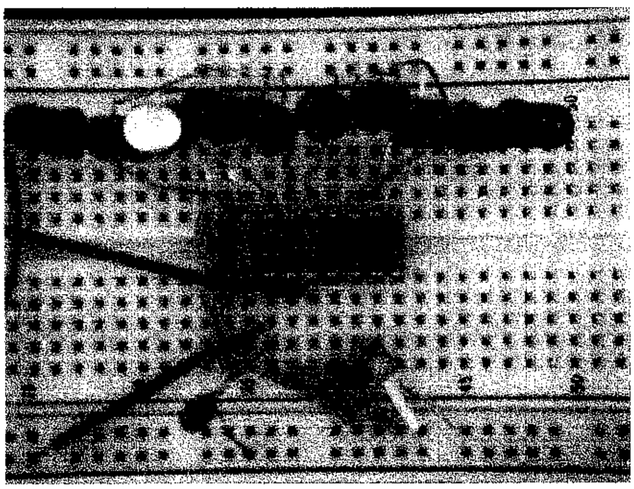

Figure 4.8 Bar/dot display when Heat sensed at less than normal environment

CHAPTER 5
CONCLUSION

5.1 Conclusion

A thermal conductivity gas detector was developed and its developmental phases were described in this report. The importance of this detector is evident from the fact that environmental pollution is increasing day by day. Industries are negligent in their responsibilities. This is causing health problem for the public at large.

In this project, a bar/dot display is responded to a heat sensing circuit. The normal condition is set to give an output of 210mV which will turn on LED no.5. Two possible conditions can be observed: a) LED below no.5 is on if heat sensed is less than normal condition. b) LED above no.5 is on if heat sensed is higher than normal condition. A smooth transition of LEDs is obtained by reducing the span of LED's threshold voltage.

This device described here is simple and cost effective. The heart of the device has shown to be the sensitive temperature sensing circuit builds around a cheap thermistor. Other gas detectors are good but are prohibitively expensive for common people. This detector can be built cheaply and made available to common people.

5.2 Recommendation

For better results, an improved chamber construction and more sensitive thermistor are required. The maintenance of gas flow is very important for accurate measurement. Similarly, maintenance of content temperature of the chamber is crucial. Since thermistor sense the temperature whether it is the fluctuation of chamber temperature due to specific gas or it is due to changes in flow rate. Hence to sense this effect of thermal conductivity of a specific gas only, other temperature affecting factor must be kept constant.

REFERENCE

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[2] GCM Meijer and AW Van Herwaarden, "Thermal Sensors", Institut of Physics Publishing, London, 1994.

[3] R. L. Boylestad and L.neshelsky, "Electronis Devices and Circuit Theory", Prentice Hall, 2002.

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[5] Electro-catalytic Combustible Sensors (page 8)

http://www.gasmonitors.com/PDF/Sensor-Discussion.pdf

[6] Combustible Handbook

http://www.gasmonitors.com/PDF/Sensor-Discussion.pdf

[7] Introduction to Semiconductor Temperature Sensors

http://www.capgo.com/Resources/Temperature/Semiconductor/Semi.html

[8] About Gas Detector

http://www.reedlink.com/ProductInfo~Productid~95720~ProductName~Gas-Detectors.html

[9] Flame Ionization Detector

http://www.chemistry.adelaide.edu.au/external/soc-rel/content/fid.htm

[10] Photo Ionization Detector (PID)

http://www.shsu.edu/~chemistry/PID/PID.html

[11] Electron Capture Detector (ECD)

http://www.chemistry.adelaide.edu.au/external/soc-rel/content/ecd.htm

[12] Flame Photometric GC Detector

http://www.shsu.edu/~chemistry/FPD/FPD.html

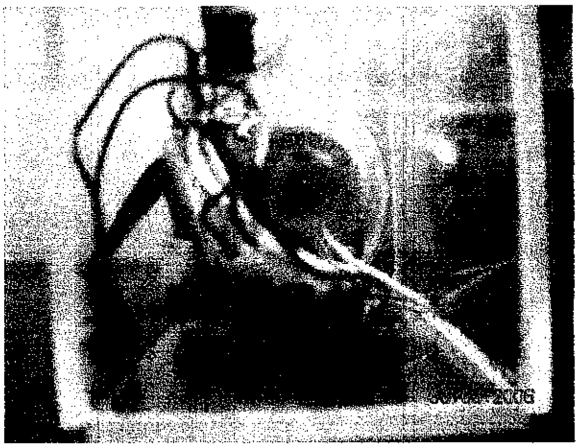
[13] Gas Chromatography

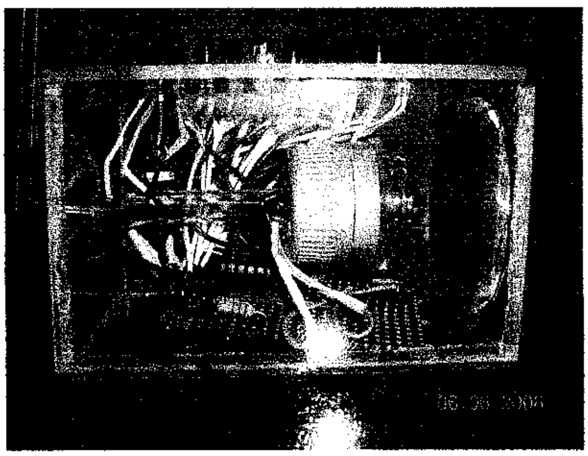
http://www.shu.ac.uk/schools/sci/chem/tutorials/chrom/gaschrm.htm

[14] LM3915 Datasheet by National Semiconductor

APPENDICES

APPENDIX A
IMPLEMENTED HARDWARE





APPENDIX B

UA741 OPERATIONAL AMPLIFIER

GENERAL PURPOSE SINGLE OPERATIONAL AMPLIFIER

- LARGE INPUT VOLTAGE RANGE
- NO LATCH-UP
- HIGH GAIN
- SHORT-CIRCUIT PROTECTION
- NO FREQUENCY COMPENSATION REQUIRED
- SAME PIN CONFIGURATION AS THE UA709

N
DIP8
(Plastic Package)

D
SO8
(Plastic Micropackage)

DESCRIPTION

The UA741 is a high performance monolithic operational amplifier constructed on a single silicon chip. It is intented for a wide range of analog applications.

- Summing amplifier
- Voltage follower
- Integrator
- Active filter
- Function generator

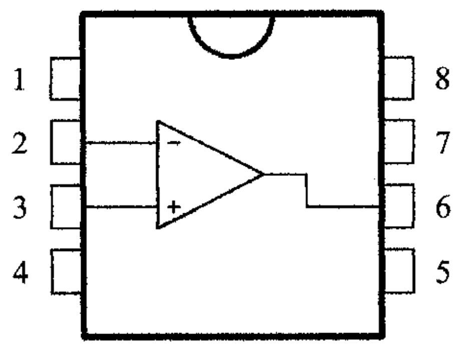
The high gain and wide range of operating voltages provide superior performances in integrator, summing amplifier and general feedback applications. The internal compensation network (6dB/octave) insures stability in closed loop circuits.

ORDER CODES

Part Number	Temperature Range	Package N	Package D
UA741C	0°C, +70°C	•	•
UA741I	-40°C, +105°C	•	•
UA741M	-55°C, +125°C	•	•

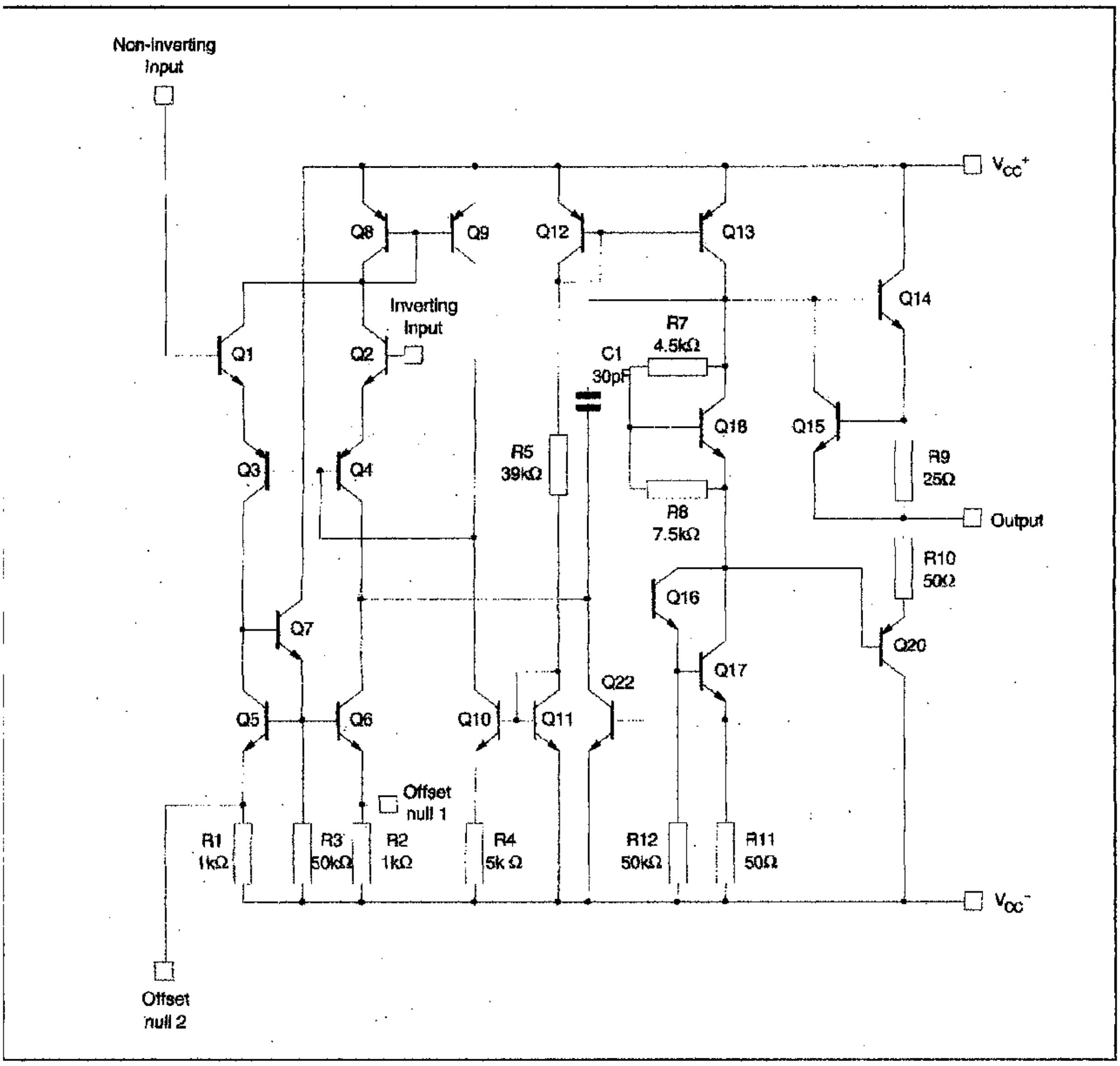
Example : UA741CN

PIN CONNECTIONS (top view)



1 - Offset null 1
2 - Inverting input
3 - Non-inverting input
4 - V_{CC}^-
5 - Offset null 2
6 - Output
7 - V_{CC}^+
8 - N.C.

SCHEMATIC DIAGRAM



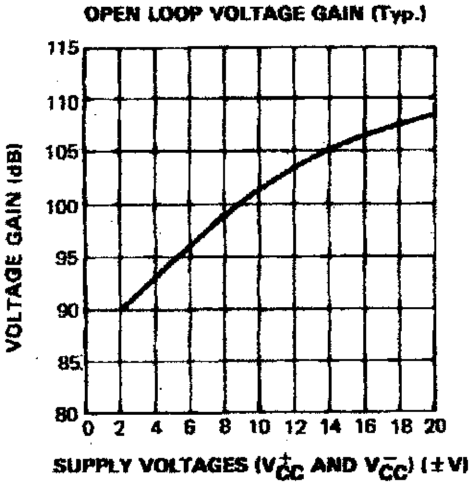
ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	UA741M	UA741I	UA741C	Unit
V_{cc}	Supply Voltage	±22			V
V_{id}	Differential Input Voltage	±30			V
V_i	Input Voltage	±15			V
P_{tot}	Power Dissipation	500			mW
	Output Short-circuit Duration	Infinite			
T_{oper}	Operating Free Air Temperature Range	-55 to +125	-40 to +105	0 to +70	°C
T_{stg}	Storage Temperature Range	-65 to +150	-65 to +150	-65 to +150	°C

ELECTRICAL CHARACTERISTICS

V_{CC} = ±15V , T_{amb} = +25°C (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_{io}	Input Offset Voltage ($R_S \leq 10k\Omega$) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$		1	5 6	mV
I_{io}	Input Offset Current T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$		2	30 70	nA
I_{ib}	Input Bias Current T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$		10	100 200	nA
A_{vd}	Large Signal Voltage Gain * (V_O ±10V, R_L = 2kΩ) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$	50 25	200		V/mV
SVR	Supply Voltage Rejection Ratio ($R_S \leq 10k\Omega$) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$	77 77	90		dB
I_{CC}	Supply Current, no load T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$		1.7	2.8 3.3	mA
V_{icm}	Input Common Mode Voltage Range T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$	±12 ±12			V
CMR	Common-mode Rejection Ratio ($R_S \leq 10k\Omega$) T_{amb} = +25°C $T_{min.} \leq T_{amb} \leq T_{max.}$	70 70	90		dB
I_{OS}	Output Short-circuit Current	10	25	40	mA
$\pm V_{OPP}$	Output Voltage Swing T_{amb} = +25°C R_L = 10kΩ R_L = 2kΩ $T_{min.} \leq T_{amb} \leq T_{max.}$ R_L = 10kΩ R_L = 2kΩ	12 10 12 10	14 13		V
SR	Slew Rate (V_i = ±10V, R_L =2kΩ, C_L= 100pF, T_{amb} = 25°C, unity gain)	0.25	0.5		V/μs
t_r	Rise Time (V_i = ±20mV, R_L = 2kΩ, C_L = 100pF, T_{amb} = 25°C, unity gain)		0.3		μs
K_{OV}	Overshoot (V_i = 20mV, R_L = 2kΩ, CL = 100pF, T_{amb} = 25°C, unity gain)		5		%
R_i	Input Resistance	0.3	2		MΩ
GBP	Gain Bandwidth Product (V_i = 10mV, R_L = 2kΩ, C_L= 100pF, f = 100kHz)	0.7	1		MHz
THD	Total Harmonic Distortion (f = 1kHz, A_V = 20dB, R_L =2kΩ, V_O = $2V_{PP}$, C_L = 100pF, T_{amb} = 25°C)		0.06		%
e_n	Equivalent Input Noise Voltage (f = 1kHz, R_s = 100Ω)		23		$\frac{nV}{\sqrt{Hz}}$
∅m	Phase Margin		50		Degrees



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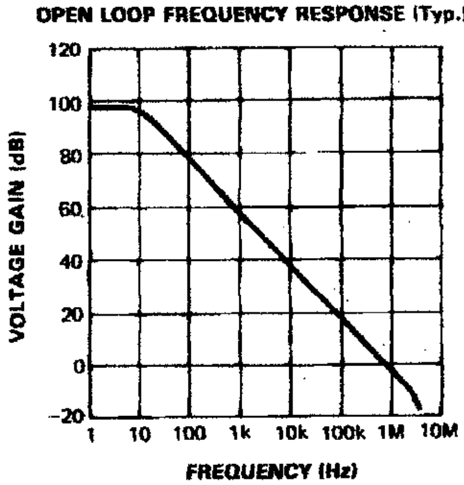

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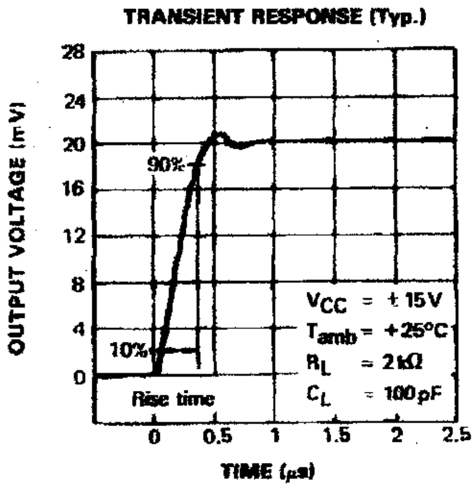

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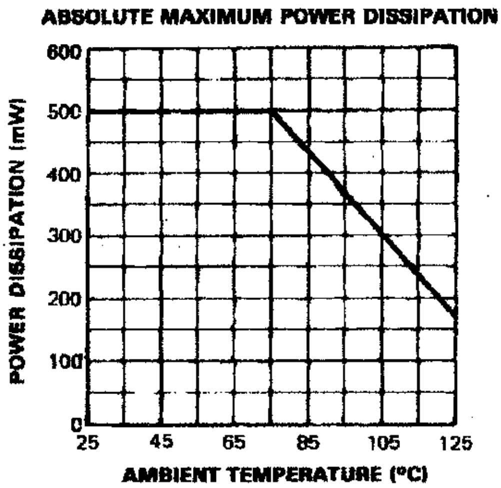

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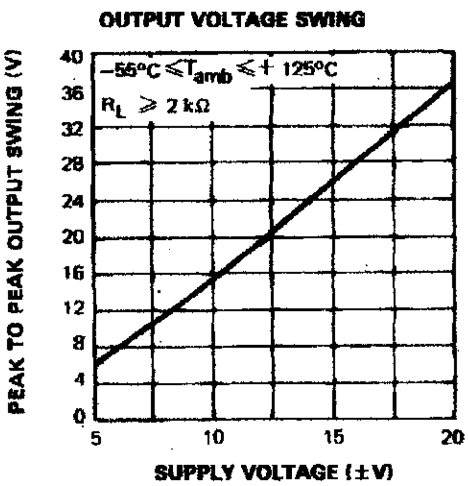

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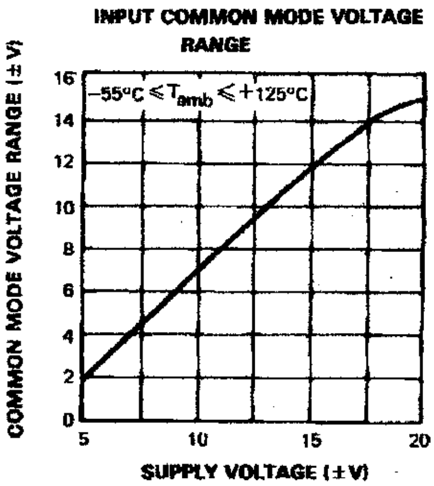

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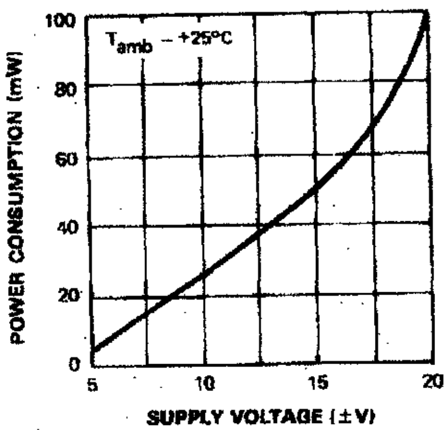
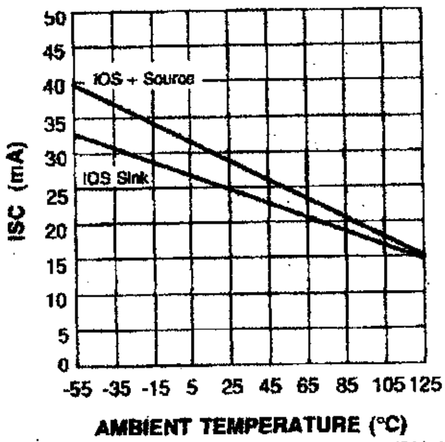
POWER CONSUMPTION



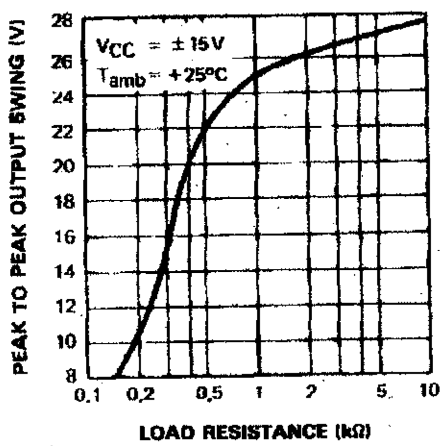
741-10.EPS

OUTPUT CURRENT vs AMBIENT TEMPERATURE



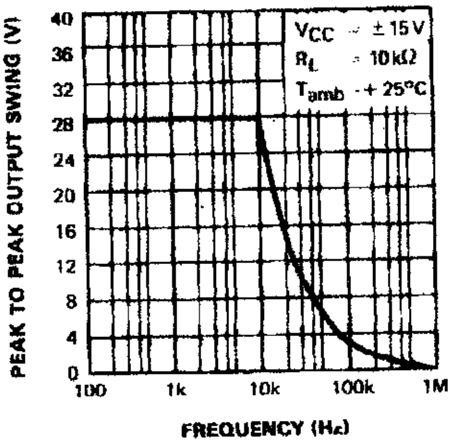
741-11.EPS

OUTPUT VOLTAGE SWING



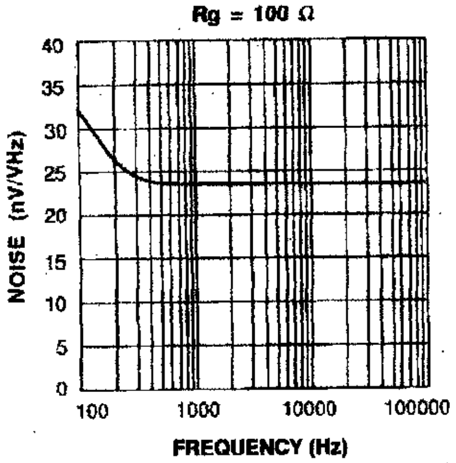
741-12.EPS

OUTPUT VOLTAGE SWING



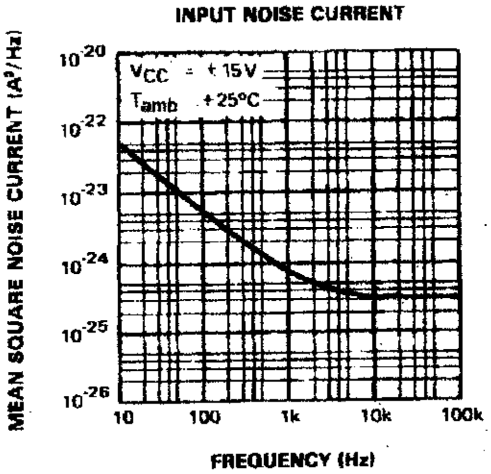
741-13.EPS

EQUIVALENT INPUT NOISE vs FREQUENCY
Rg = 100 Ω



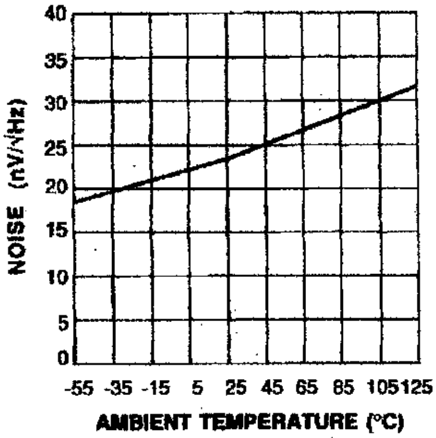
741-14.EPS

INPUT NOISE CURRENT



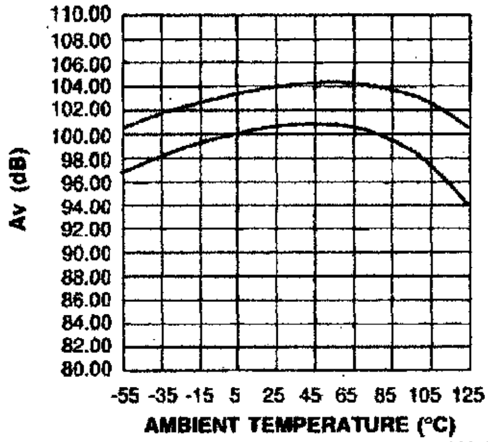
741-15.EPS

EQUIVALENT INPUT NOISE vs AMBIENT TEMPERATURE



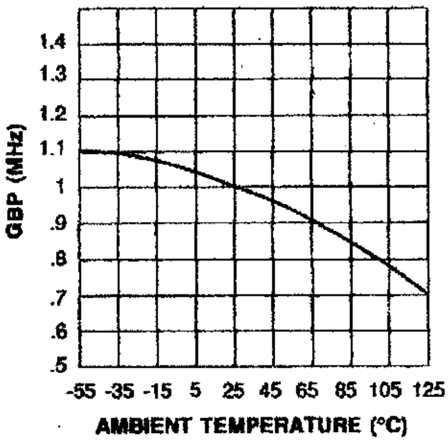
741-16.EPS

LARGE SIGNAL VOLTAGE GAIN vs AMBIENT TEMPERATURE



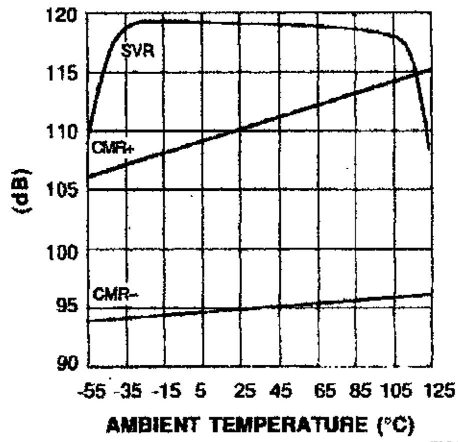
741-17.EPS

GAIN BANDWIDTH PRODUCT vs AMBIENT TEMPERATURE



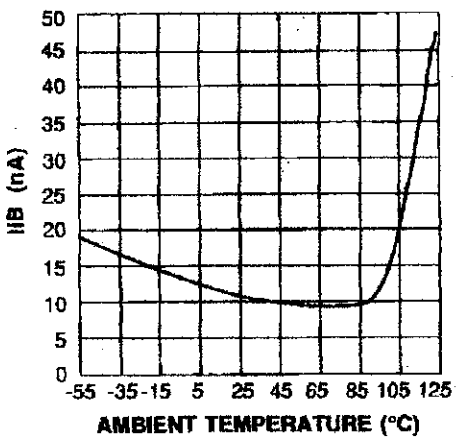
741-18.EPS

POWER SUPPLY & COMMON MODE REJECTION RATIO vs AMBIENT TEMPERATURE



741-19.EPS

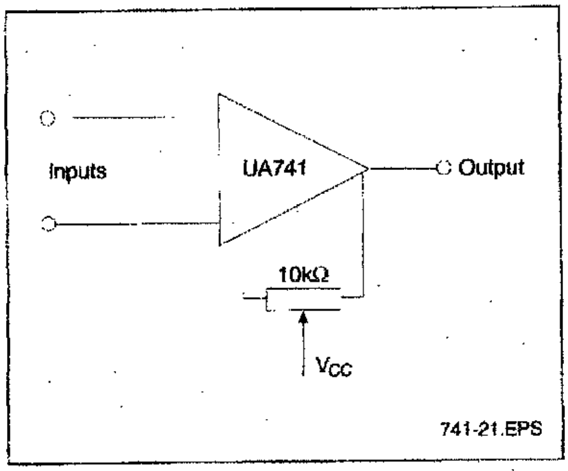
INPUT BIAS CURRENT vs AMBIENT TEMPERATURE



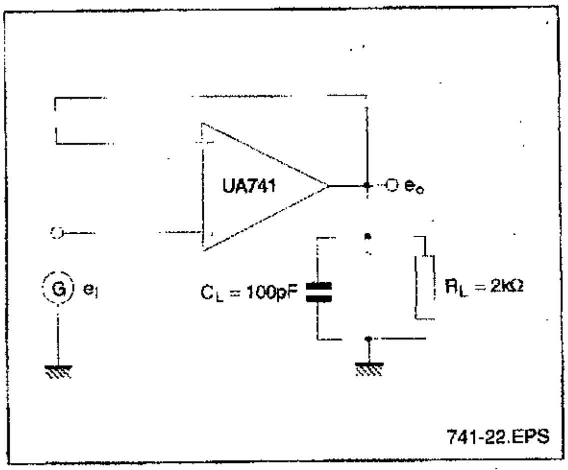
741-20.EPS

MEASUREMENT DIAGRAMS

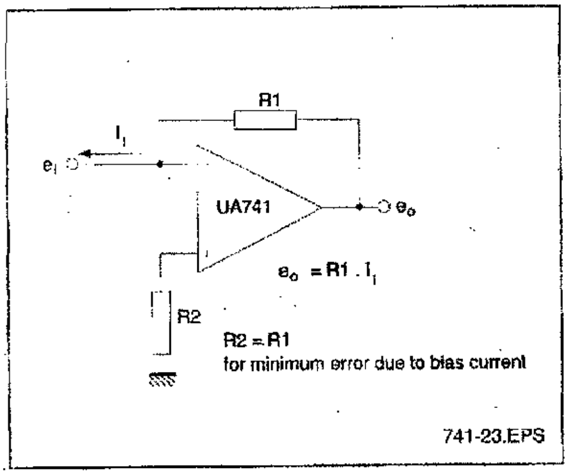
OFFSET VOLTAGE NULL CIRCUIT



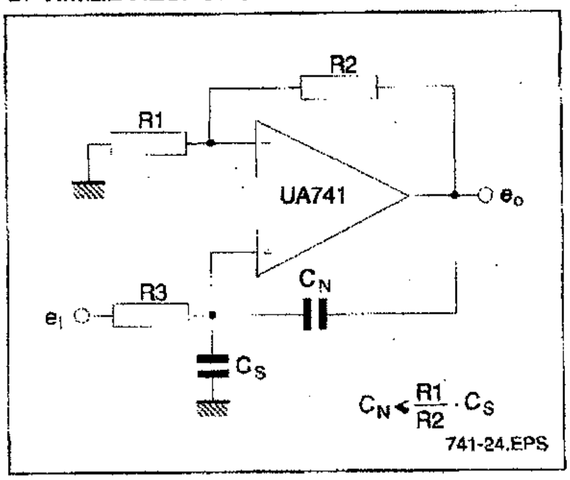
TRANSIENT RESPONSE TEST CIRCUIT



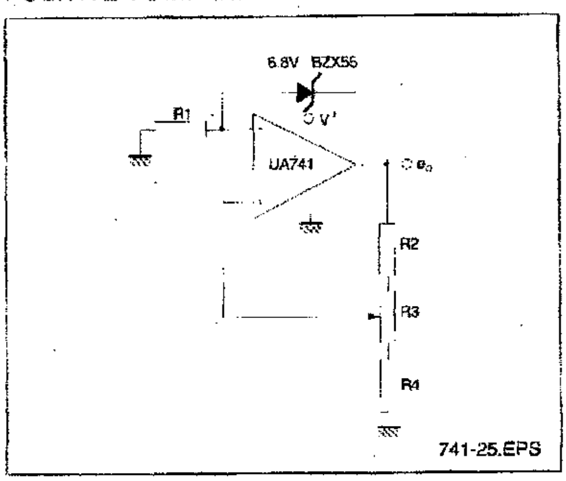
CURRENT TO VOLTAGE CONVERTER



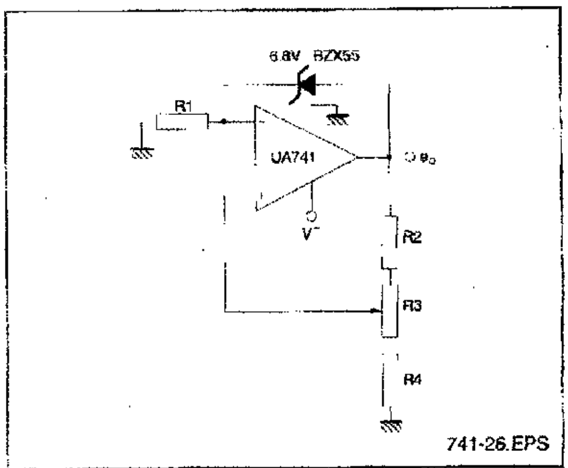
NEUTRALIZING INPUT CAPACITANCE TO OPTIMIZE RESPONSE TIME



POSITIVE VOLTAGE REFERENCE

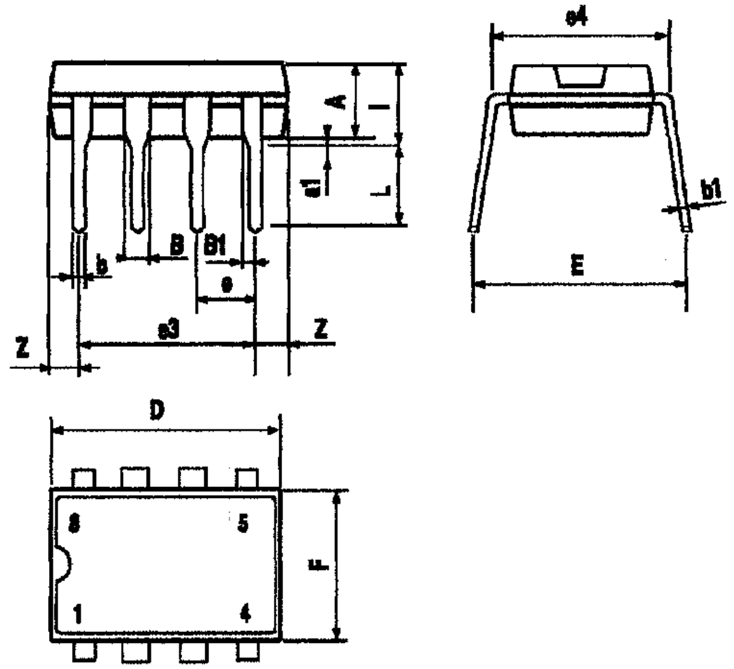


NEGATIVE VOLTAGE REFERENCE



PACKAGE MECHANICAL DATA

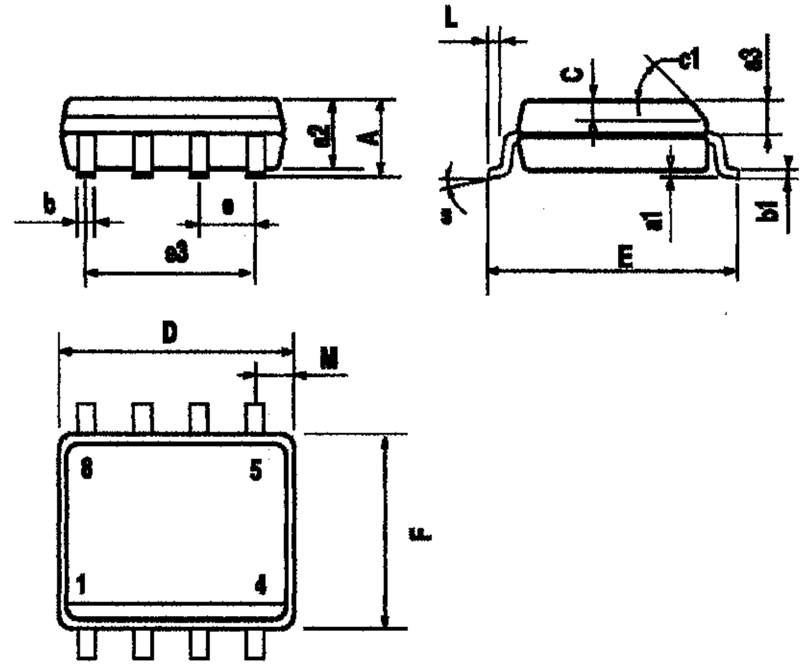
8 PINS - PLASTIC DIP



Dim.	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A		3.32			0.131	
a1	0.51			0.020		
B	1.15		1.65	0.045		0.065
b	0.356		0.55	0.014		0.022
b1	0.204		0.304	0.008		0.012
D			10.92			0.430
E	7.95		9.75	0.313		0.384
e		2.54			0.100	
e3		7.62			0.300	
e4		7.62			0.300	
F			6.6			0260
i			5.08			0.200
L	3.18		3.81	0.125		0.150
Z			1.52			0.060

PACKAGE MECHANICAL DATA

8 PINS - PLASTIC MICROPACKAGE (SO)



Dim.	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.75			0.069
a1	0.1		0.25	0.004		0.010
a2			1.65			0.065
a3	0.65		0.85	0.026		0.033
b	0.35		0.48	0.014		0.019
b1	0.19		0.25	0.007		0.010
C	0.25		0.5	0.010		0.020
c1	45° (typ.)					
D	4.8		5.0	0.189		0.197
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		3.81			0.150	
F	3.8		4.0	0.150		0.157
L	0.4		1.27	0.016		0.050
M			0.6			0.024
S	8° (max.)					

APPENDIX C

NTC THERMISTOR

NTC Thermistors, Long Non-Insulated Leads

FEATURES

- Long and flexible leads for special mounting or assembly requirements
- Small diameter

APPLICATIONS

- Temperature sensing and control

These thermistors have a negative temperature coefficient. The device consists of a chip with two tinned nickel leads.

PACKAGING

The thermistors are packed in cardboard boxes; each box containing 1000 units (10 plastic bags, each containing 100 units).

MARKING

The body of the device is coated with a yellow coloured EPQ lacquer.

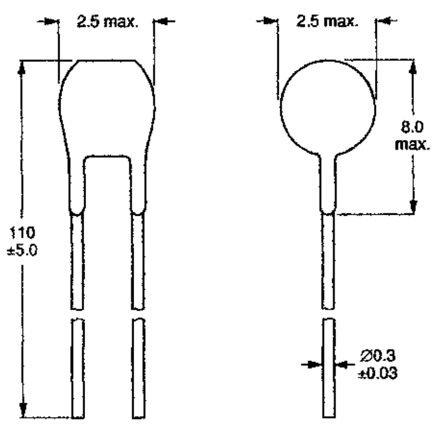
MOUNTING

By soldering in any position

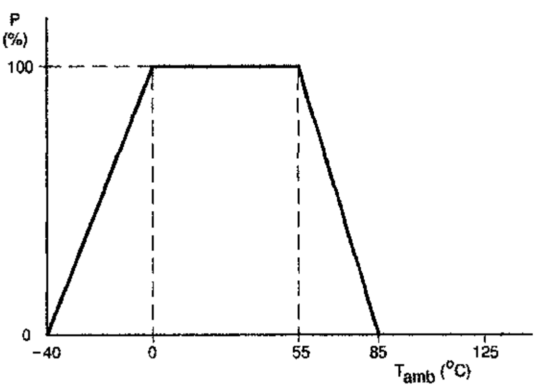
JICK REFERENCE DATA

\RAMETER	VALUE
ɜsistance value at 25 °C	10 kΩ
lerance on R_{25}-value	±5%
$_{5/100}$-value	3993 K
lerance on $B_{25/100}$-value	±1.2%
ited dissipation	100 mW
ssipation factor τ	1.4 mW/K
ɔerating temperature range:	
t zero dissipation	−40 to +125 °C
t maximum dissipation	0 to +55 °C
ass	≈0.16 g

IENSIONS in millimeters



DERATING



Power derating curve.

ISTANCE VALUES AT INTERMEDIATE TEMPERATURES

T_{oper} (°C)	RESISTANCE (Ω)	TC (%/K)	RESISTANCE TOLERANCE (%)
–40	328.4	6.57	±9.5
–35	237.7	-	-
–30	173.9	6.15	±8.7
–25	128.5	-	-
–20	95.89	5.76	±7.9
–15	72.23	-	-
–10	54.89	5.40	±7.2
–5	42.07	-	-
0	32.51	5.08	±6.5
5	25.31	-	-
10	19.86	4.78	±5.9
15	15.69	-	-
20	12.49	4.50	±5.3
25	10.00	4.37	±5.0
30	8.060	4.25	±5.3
35	6.536	-	-
40	5.331	4.02	±5.8
45	4.372	-	-
50	3.606	3.80	±6.3
55	2.989	-	-
60	2.490	3.60	±6.8
65	2.085	-	-
70	1.753	3.42	±7.2
75	1.481	-	-
80	1.256	3.25	±7.6
85	1.070	-	-
90	0.9155	3.09	±8.0
95	0.7861	-	-
100	0.6775	2.94	±8.4
105	0.5860	-	-
110	0.5086	2.80	±8.8
115	0.4429	-	-
120	0.3870	2.67	±9.2
125	0.3392	-	-

APPENDIX D

LM3915 BAR/DOT DISPLAY

National Semiconductor

.M3915
)ot/Bar Display Driver

;eneral Description

1e LM3915 is a monolithic integrated circuit that senses ıalog voltage levels and drives ten LEDs, LCDs or vacuum ıorescent displays, providing a logarithmic 3 dB/step ana- g display. One pin changes the display from a bar graph to moving dot display. LED current drive is regulated and ogrammable, eliminating the need for current limiting re- ;tors. The whole display system can operate from a single ıpply as low as 3V or as high as 25V.

1e IC contains an adjustable voltage reference and an :curate ten-step voltage divider. The high-impedance input ıffer accepts signals down to ground and up to within 1.5V the positive supply. Further, it needs no protection against puts of ±35V. The input buffer drives 10 individual com- ırators referenced to the precision divider. Accuracy is pically better than 1 dB.

1e LM3915's 3 dB/step display is suited for signals with ide dynamic range, such as audio level, power, light inten- ty or vibration. Audio applications include average or peak vel indicators, power meters and RF signal strength eters. Replacing conventional meters with an LED bar 'aph results in a faster responding, more rugged display ith high visibility that retains the ease of interpretation of an ıalog display.

1e LM3915 is extremely easy to apply. A 1.2V full-scale eter requires only one resistor in addition to the ten LEDs. ne more resistor programs the full-scale anywhere from 2V to 12V independent of supply voltage. LED brightness easily controlled with a single pot.

The LM3915 is very versatile. The outputs can drive LCDs, vacuum fluorescents and incandescent bulbs as well as LEDs of any color. Multiple devices can be cascaded for a dot or bar mode display with a range of 60 or 90 dB. LM3915s can also be cascaded with LM3914s for a linear/ log display or with LM3916s for an extended-range VU meter.

Features

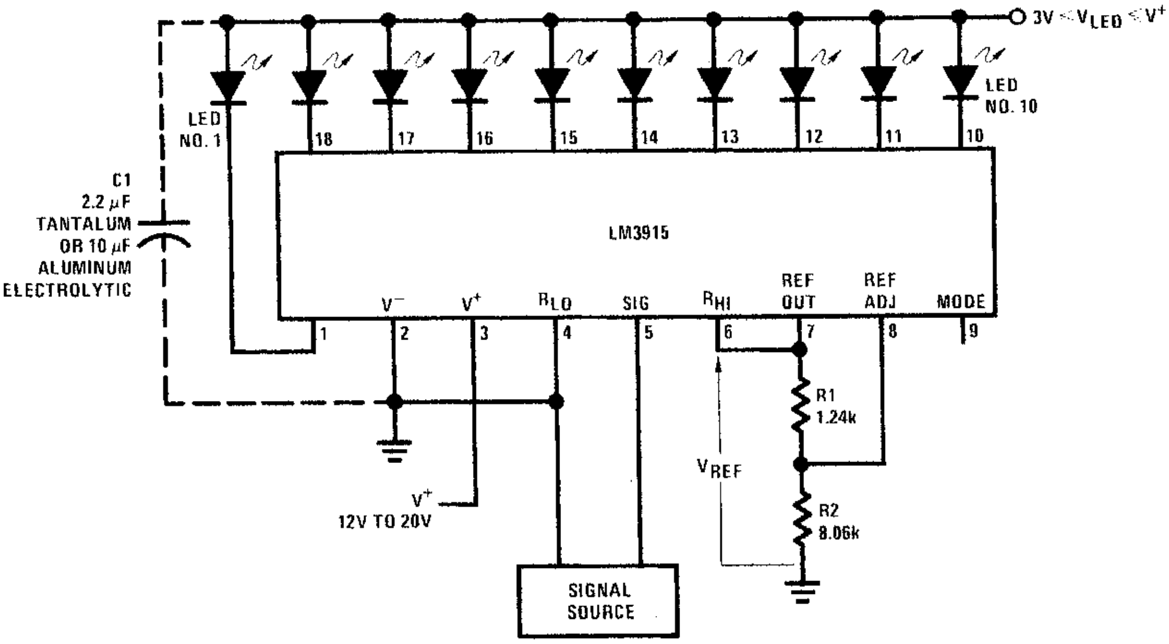
- 3 dB/step, 30 dB range
- Drives LEDs, LCDs, or vacuum fluorescents
- Bar or dot display mode externally selectable by user
- Expandable to displays of 90 dB
- Internal voltage reference from 1.2V to 12V
- Operates with single supply of 3V to 25V
- Inputs operate down to ground
- Output current programmable from 1 mA to 30 mA
- Input withstands ±35V without damage or false outputs
- Outputs are current regulated, open collectors
- Directly drives TTL or CMOS
- The internal 10-step divider is floating and can be referenced to a wide range of voltages

The LM3915 is rated for operation from 0°C to +70°C. The LM3915N-1 is available in an 18-lead molded DIP package.

 DS005104

Typical Applications

0V to 10V Log Display



DS005104-1

Notes: Capacitor C1 is required if leads to the LED supply are 6" or longer.

Circuit as shown is wired for dot mode. For bar mode, connect pin 9 to pin 3. V_{LED} must be kept below 7V or dropping resistor should be used to limit IC power dissipation.

$$V_{REF} = 1.25V\left(1 + \frac{R2}{R1}\right) + R2 \times 80\ \mu A$$

$$I_{LED} = \frac{12.5V}{R1} + \frac{V_{REF}}{2.2\ k\Omega}$$

›lute Maximum Ratings (Note 1)

ıry/Aerospace specified devices are required, ;ontact the National Semiconductor Sales Office/ ıtors for availability and specifications.

)issipation (Note 6)	
ded DIP(N)	1365 mW
Voltage	25V
Voltage on Output Drivers	25V
Input Signal Overvoltage (Note 4)	±35V
Divider Voltage	−100 mV to V^+
Reference Load Current	10 mA
Storage Temperature Range	−55°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C

ꞁrical Characteristics (Notes 2, 4)

Parameter	Conditions (Note 2)	Min	Typ	Max	Units
ꞄATOR					
ıltage, Buffer and First tor	$0V \le V_{RLO} = V_{RHI} \le 12V$, $I_{LED} = 1$ mA		3	10	mV
ıltage, Buffer and Any Other tor	$0V \le V_{RLO} = V_{RHI} \le 12V$, $I_{LED} = 1$ mA		3	15	mV
$_{ED}/\Delta V_{IN}$)	$I_{L(REF)} = 2$ mA, $I_{LED} = 10$ mA	3	8		mA/mV
s Current (at Pin 5)	$0V \le V_{IN} \le (V^+ - 1.5V)$		25	100	nA
nal Overvoltage	No Change in Display	−35		35	V
ɪE-DIVIDER					
:esistance	Total, Pin 6 to 4	16	28	36	kΩ
Accuracy (Input Change Any Two Threshold Points)	(Note 3)	2.0	3.0	4.0	dB
Accuracy at Each Threshold	(Note 3)				
	$V_{IN} = -3, -6$ dB	−0.5		+0.5	dB
	$V_{IN} = -9$ dB	−0.5		+0.65	dB
	$V_{IN} = -12, -15, -18$ dB	−0.5		+1.0	dB
	$V_{IH} = -21, -24, -27$ dB	−0.5		+1.5	dB
ɪE REFERENCE					
oltage	$0.1 \text{ mA} \le I_{L(REF)} \le 4$ mA, $V^+ = V_{LED} = 5V$	1.2	1.28	1.34	V
ɿulation	$3V \le V^+ \le 18V$		0.01	0.03	%/V
gulation	$0.1 \text{ mA} \le I_{L(REF)} \le 4$ mA, $V^+ = V_{LED} = 5V$		0.4	2	%
'oltage Change with ꞁture	$0°C \le T_A \le +70°C$, $I_{L(REF)} = 1$ mA, $V^+ = V_{LED} = 5V$		1		%
in Current			75	120	µA
' DRIVERS					
rent	$V^+ = V_{LED} = 5V$, $I_{L(REF)} = 1$ mA	7	10	13	mA
rent Difference (Between ɜnd Smallest LED Currents)	$V_{LED} = 5V$, $I_{LED} = 2$ mA		0.12	0.4	mA
	$V_{LED} = 5V$, I_{LED} 20 mA		1.2	3	mA
rent Regulation	$2V \le V_{LED} \le 17V$, $I_{LED} = 2$ mA		0.1	0.25	mA
	$I_{LED} = 20$ mA		1	3	mA
Voltage	$I_{LED(ON)} = 20$ mA, @ $V_{LED} = 5V$, $\Delta I_{LED} = 2$ mA			1.5	V
ın Voltage	$I_{LED} = 2.0$ mA, $I_{L(REF)} = 0.4$ mA		0.15	0.4	V
.eakage, Each Collector	(Bar Mode) (Note 5)		0.1	10	µA
.eakage 0–18	(Dot Mode) (Note 5)		0.1	10	µA
		60	150	450	µA
' CURRENT					
Supply Current ›uts Off)	$V^+ = +5V$, $I_{L(REF)} = 0.2$ mA		2.4	4.2	mA
	$V^+ = +20V$, $I_{L(REF)} = 1.0$ mA		6.1	9.2	mA

Electrical Characteristics (Notes 2, 4) (Continued)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. Electrical Characteristics state DC and AC electrical specifications under particular test conditions which guarantee specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not guaranteed for parameters where no limit is given, however, the typical value is a good indication of device performance.

Note 2: Unless otherwise stated, all specifications apply with the following conditions:

$3\ V_{DC} \leq V^+ \leq 20\ V_{DC}$ $-0.015V \leq V_{RLO} \leq 12\ V_{DC}$ $T_A = 25°C$, $I_{L(REF)} = 0.2$ mA, pin 9 connected to pin 3 (bar mode).

$3\ V_{DC} \leq V_{LED} \leq V^+$ $V_{REF}, V_{RHI}, V_{RLO} \leq (V^+ - 1.5V)$ For higher power dissipations, pulse testing is used.

$-0.015V \leq V_{RHI} \leq 12\ V_{DC}$ $0V \leq V_{IN} \leq V^+ - 1.5V$

Note 3: Accuracy is measured referred to 0 dB = + 10.000 V_{DC} at pin 5, with + 10.000 V_{DC} at pin 6, and 0.000 V_{DC} at pin 4. At lower full scale voltages, buffer and comparator offset voltage may add significant error. See table for threshold voltages.

Note 4: Pin 5 input current must be limited to ±3 mA. The addition of a 39k resistor in series with pin 5 allows ±100V signals without damage.

Note 5: Bar mode results when pin 9 is within 20 mV of V^+. Dot mode results when pin 9 is pulled at least 200 mV below V^+. LED #10 (pin 10 output current) is disabled if pin 9 is pulled 0.9V or more below V_{LED}.

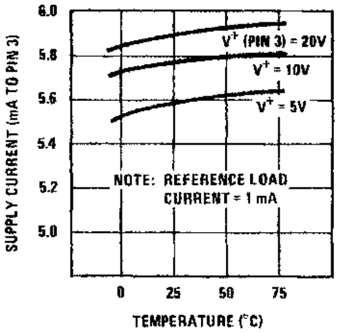
Note 6: The maximum junction temperature of the LM3915 is 100°C. Devices must be derated for operation at elevated temperatures. Junction to ambient thermal resistance is 55°C/W for the molded DIP (N package).

Threshold Voltage (Note 3)

Output	dB	Min	Typ	Max	Output	dB	Min	Typ	Max
1	−27	0.422	0.447	0.531	6	−12	2.372	2.512	2.819
2	−24	0.596	0.631	0.750	7	−9	3.350	3.548	3.825
3	−21	0.841	0.891	1.059	8	−6	4.732	5.012	5.309
4	−18	1.189	1.259	1.413	9	−3	6.683	7.079	7.498
5	−15	1.679	1.778	1.995	10	0	9.985	10	10.015

Typical Performance Characteristics

Supply Current vs Temperature



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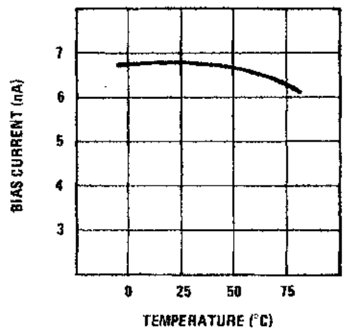
Operating Input Bias Current vs Temperature



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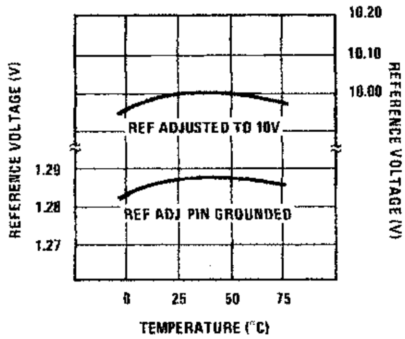
Reference Voltage vs Temperature



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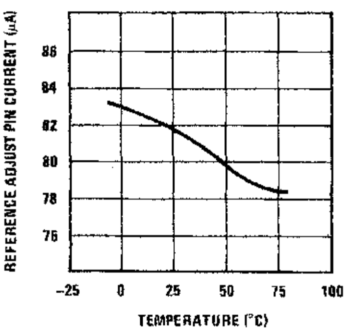
Reference Adjust Pin Current vs Temperature



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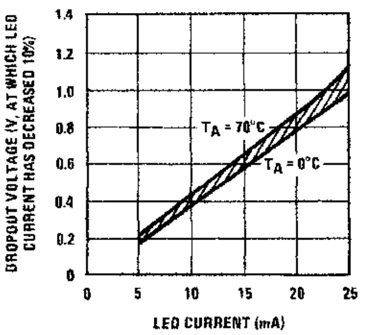
LED Current-Regulation Dropout



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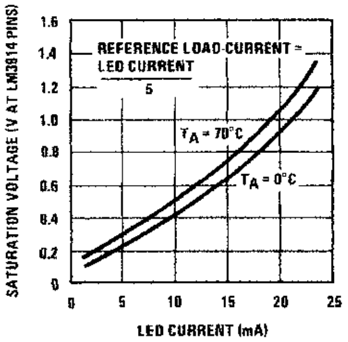
LED Driver Saturation Voltage



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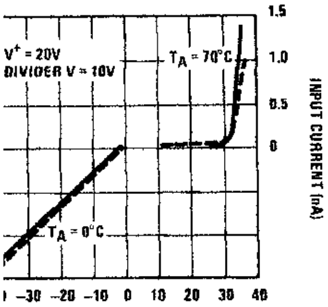
:al Performance Characteristics (Continued)

urrent Beyond
Range (Pin 5)



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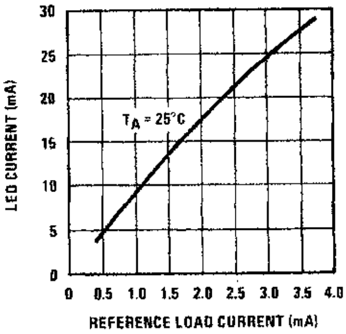
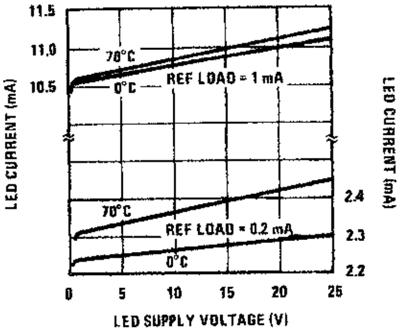
LED Current vs
Reference Loading



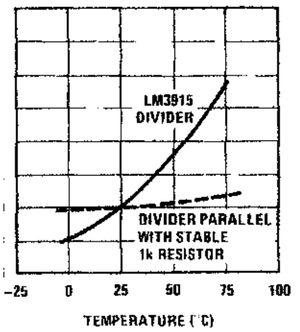
DS005104-41

LED Driver Current
Regulation



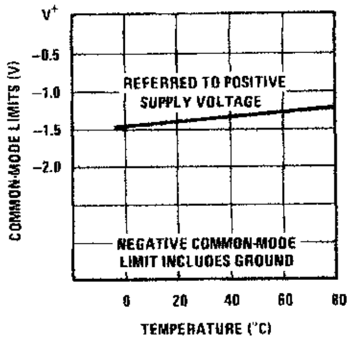
DS005104-42

ivider Resistance
perature



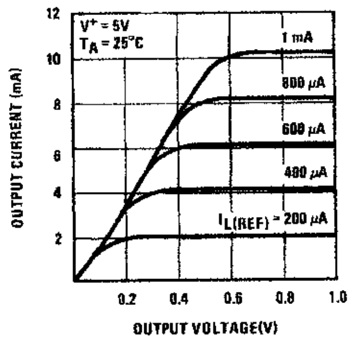
DS005104-43

Common-Mode Limits



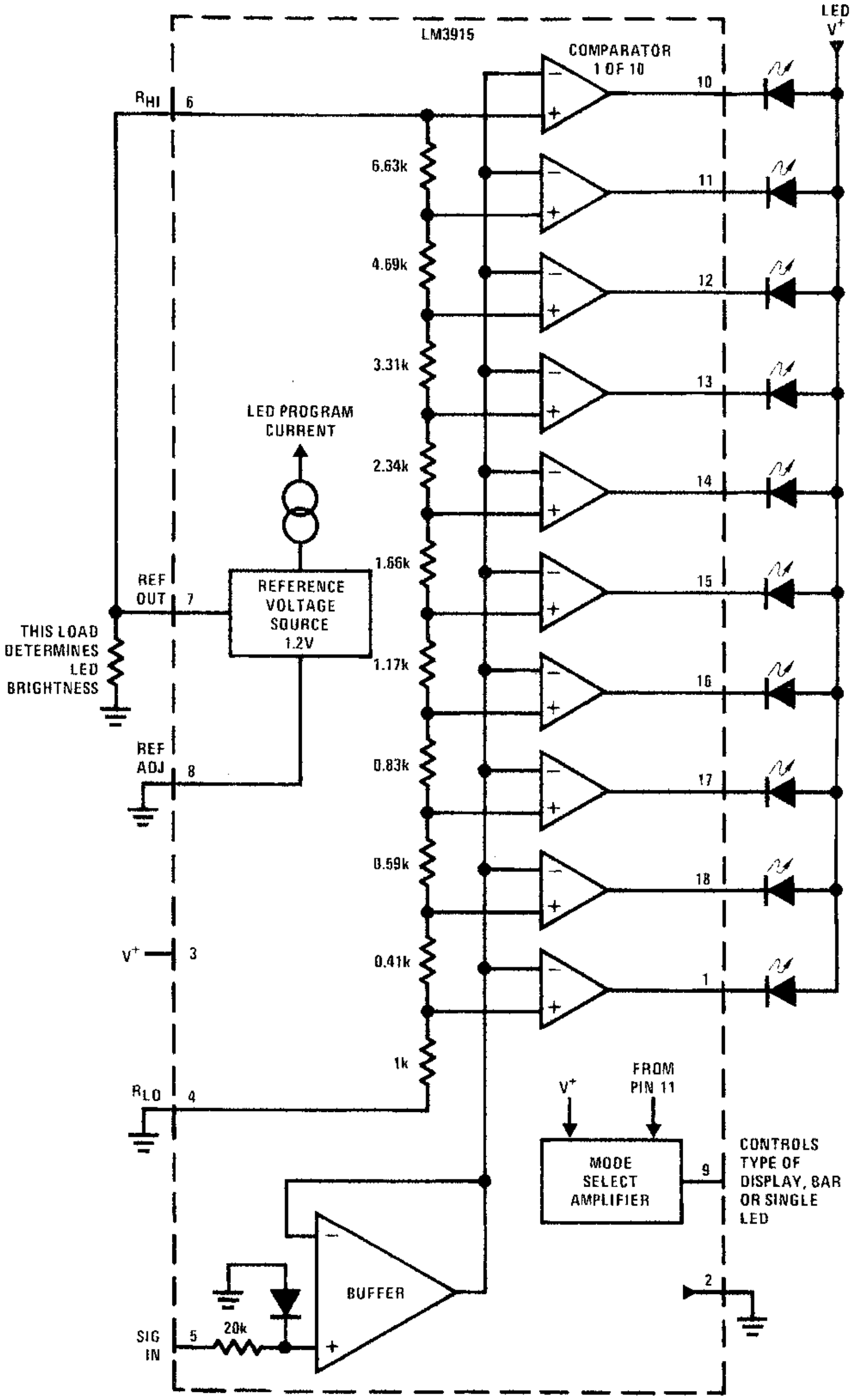
DS005104-44

Output Characteristics



DS005104-45

Block Diagram (Showing Simplest Application)



DS005104-4

tional Description

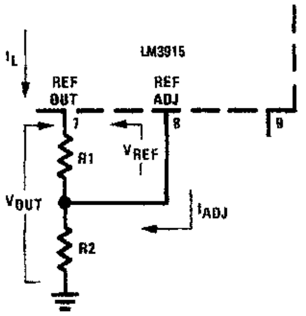
ɔlified LM3915 block diagram is included to give the idea of the circuit's operation. A high input imped- 'fer operates with signals from ground to 12V, and is ɟ against reverse and overvoltage signals. The sig- en applied to a series of 10 comparators; each of biased to a different comparison level by the resistor

ɩample illustrated, the resistor string is connected to ɾal 1.25V reference voltage. In this case, for each t the input signal increases, a comparator will switch ıer indicating LED. This resistor divider can be con- ɔetween any 2 voltages, providing that they are at iV below V^+ and no lower than V^-.

AL VOLTAGE REFERENCE

ırence is designed to be adjustable and develops a 1.25V between the REF OUT (pin 7) and REF ADJ ɜrminals. The reference voltage is impressed across · resistor R1 and, since the voltage is constant, a t current I_1 then flows through the output set resistor g an output voltage of:

$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2$$



DS005104-5

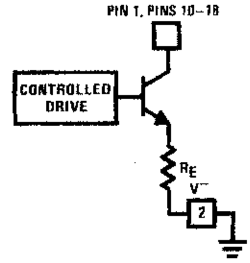
ıe 120 µA current (max) from the adjust terminal nts an error term, the reference was designed to ɘ changes of this current with V^+ and load changes. 'ect operation, reference load current should be be- ⁾0 µA and 5 mA. Load capacitance should be less ⁾5 µF.

:NT PROGRAMMING

'e not completely illustrated by the block diagram is) brightness control. The current drawn out of the ɔe voltage pin (pin 7) determines LED current. Ap- ıtely 10 times this current will be drawn through each LED, and this current will be relatively constant de- ɹpply voltage and temperature changes. Current ɔy the internal 10-resistor divider, as well as by the l current and voltage-setting divider should be in- n calculating LED drive current. The ability to modu- Ɔ brightness with time, or in proportion to input volt- l other signals can lead to a number of novel displays ; of indicating input overvoltages, alarms, etc.

:3915 outputs are current-limited NPN transistors as ɔelow. An internal feedback loop regulates the tran- rive. Output current is held at about 10 times the ɔe load current, independent of output voltage and ;ing variables, as long as the transistor is not satu-

LM3915 Output Circuit



DS005104-6

Outputs may be run in saturation with no adverse effects, making it possible to directly drive logic. The effective saturation resistance of the output transistors, equal to R_E plus the transistors' collector resistance, is about 50Ω. It's also possible to drive LEDs from rectified AC with no filtering. To avoid oscillations, the LED supply should be bypassed with a 2.2 µF tantalum or 10 µF aluminum electrolytic capacitor.

MODE PIN USE

Pin 9, the Mode Select input, permits chaining of multiple LM3915s, and controls bar or dot mode operation. The following tabulation shows the basic ways of using this input. Other more complex uses will be illustrated in the applications.

Bar Graph Display: Wire Mode Select (pin 9) *directly* to pin 3 (V^+ pin).

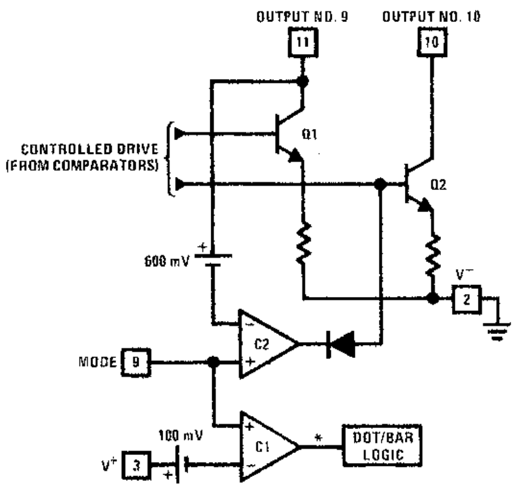
Dot Display, Single LM3915 Driver: Leave the Mode Select pin open circuit.

Dot Display, 20 or More LEDs: Connect pin 9 of the *first* driver in the series (i.e., the one with the lowest input voltage comparison points) to pin 1 of the next higher LM3915 driver. Continue connecting pin 9 of lower input drivers to pin 1 of higher input drivers for 30 or more LED displays. The last LM3915 driver in the chain will have pin 9 left open. All previous drivers should have a 20k resistor in parallel with LED #9 (pin 11 to V_{LED}).

Mode Pin Functional Description

This pin actually performs two functions. Refer to the simplified block diagram below.

Block Diagram of Mode Pin Function



DS005104-7

*High for bar

Mode Pin Functional Description

(Continued)

DOT OR BAR MODE SELECTION

The voltage at pin 9 is sensed by comparator C1, nominally referenced to (V^+ − 100 mV). The chip is in bar mode when pin 9 is above this level; otherwise it's in dot mode. The comparator is designed so that pin 9 can be left open circuit for dot mode.

Taking into account comparator gain and variation in the 100 mV reference level, pin 9 should be no more than 20 mV below V^+ for bar mode and more than 200 mV below V^+ (or open circuit) for dot mode. In most applications, pin 9 is either open (dot mode) or tied to V^+ (bar mode). In bar mode, pin 9 should be connected directly to pin 3. Large currents drawn from the power supply (LED current, for example) should not share this path so that large IR drops are avoided.

DOT MODE CARRY

In order for the display to make sense when multiple LM3915s are cascaded in dot mode, special circuitry has been included to shut off LED #10 of the first device when LED #1 of the second device comes on. The connection for cascading in dot mode has already been described and is depicted below.

As long as the input signal voltage is below the threshold of the second LM3915, LED #11 is off. Pin 9 of LM3915 #1 thus sees effectively an open circuit so the chip is in dot mode. As soon as the input voltage reaches the threshold of LED #11, pin 9 of LM3915 #1 is pulled an LED drop (1.5V or more) below V_{LED}. This condition is sensed by comparator C2, referenced 600 mV below V_{LED}. This forces the output of C2 low, which shuts off output transistor Q2, extinguishing LED #10.

V_{LED} is sensed via the 20k resistor connected to pin 11. The very small current (less than 100 µA) that is diverted from LED #9 does not noticeably affect its intensity.

An auxiliary current source at pin 1 keeps at least 100 µA flowing through LED #11 even if the input voltage rises high enough to extinguish the LED. This ensures that pin 9 of LM3915 #1 is held low enough to force LED #10 off when *any* higher LED is illuminated. While 100 µA does not normally produce significant LED illumination, it may be noticeable when using high-efficiency LEDs in a dark environment. If this is bothersome, the simple cure is to shunt LED #11 with a 10k resistor. The 1V IR drop is more than the 900 mV worst case required to hold off LED #10 yet small enough that LED #11 does not conduct significantly.

OTHER DEVICE CHARACTERISTICS

The LM3915 is relatively low-powered itself, and since any number of LEDs can be powered from about 3V, it is a very efficient display driver. Typical standby supply current (all LEDs OFF) is 1.6 mA. However, any reference loading adds 4 times that current drain to the V^+ (pin 3) supply input. For example, an LM3916 with a 1 mA reference pin load (1.3k) would supply almost 10 mA to every LED while drawing only 10 mA from its V^+ pin supply. At full-scale, the IC is typically drawing less than 10% of the current supplied to the display.

The display driver does not have built-in hysteresis so that the display does not jump instantly from one LED to the next. Under rapidly changing signal conditions, this cuts down high frequency noise and often an annoying flicker. An "overlap" is built in so that at no time are all segments completely off in the dot mode. Generally 1 LED fades in while the other fades out over a mV or more of range. The change may be much more rapid between LED #10 of one device and LED #1 of a *second* device "chained" to the first.

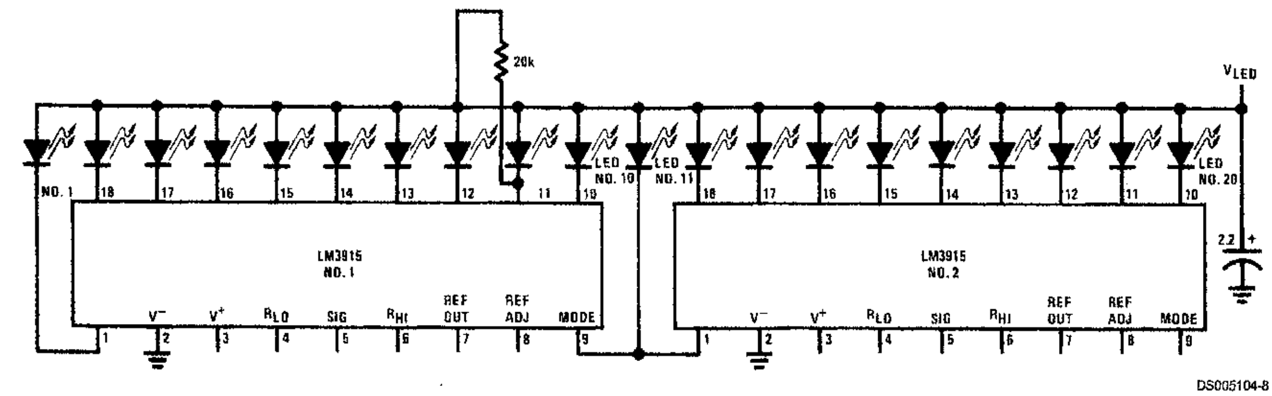
Application Hints

The most difficult problem occurs when large LED currents are being drawn, especially in bar graph mode. These currents flowing out of the ground pin cause voltage drops in external wiring, and thus errors and oscillations. Bringing the return wires from signal sources, reference ground and bottom of the resistor string to a single point very near pin 2 is the best solution.

Long wires from V_{LED} to LED anode common can cause oscillations. Depending on the severity of the problem 0.05 µF to 2.2 µF decoupling capacitors from LED anode common to pin 2 will damp the circuit. If LED anode line wiring is inaccessible, often similar decoupling from pin 1 to pin 2 will be sufficient.

If LED turn ON seems slow (bar mode) or several LEDs light (dot mode), oscillation or excessive noise is usually the problem. In cases where proper wiring and bypassing fail to stop oscillations, V^+ voltage at pin 3 is usually below suggested limits. Expanded scale meter applications may have one or both ends of the internal voltage divider terminated at relatively high value resistors. These high-impedance ends should be bypassed to pin 2 with at least a 0.001 µF capacitor, or up to 0.1 µF in noisy environments.

Cascading LM3915s in Dot Mode



DS005104-8

ication Hints (Continued)

issipation, especially in bar mode should be given ation. For example, with a 5V supply and all LEDs med to 20 mA the driver will dissipate over 600 mW. ıse a 7.5Ω resistor in series with the LED supply will ɔe heating in half. The negative end of the resistor ıe bypassed with a 2.2 µF solid tantalum capacitor to

ı RECTIFIER CIRCUITS

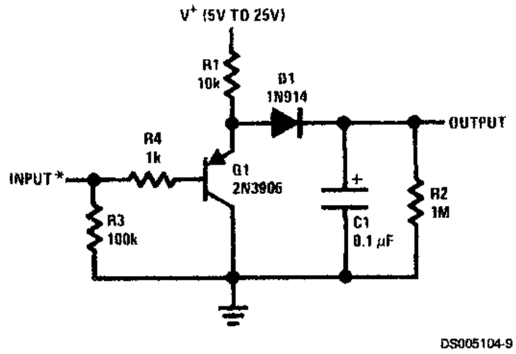
plest way to display an AC signal using the LM3915 ɔly it right to pin 5 unrectified. Since the LED illumi- ›presents the instantaneous value of the AC wave- .e can readily discern both peak and average values signals in this manner. The LM3915 will respond to half-cycles only but will not be damaged by signals ł5V (or up to ±100V if a 39k resistor is in series with t). It's recommended to use dot mode and to run the : 30 mA for high enough average intensity.

erage or peak detection requires rectification. If an ı is set up with 10V full scale across its voltage the turn-on point for the first LED is only 450 mV. A ɜilicon diode rectifier won't work well at the low end the 600 mV diode threshold. The half-wave peak · in *Figure 1* uses a PNP emitter-follower in front of e. Now, the transistor's base-emitter voltage cancels diode offset, within about 100 mV. This approach is satisfactory when a single LM3915 is used for a 30 lay.

circuits using two or more LM3915s for a dynamic f 60 dB or greater require more accurate detection. In cision half-wave rectifier of *Figure 2* the effective ffset is reduced by a factor equal to the open-loop the op amp. Filter capacitor C2 charges through R3 charges through R2 and R3, so that appropriate n of these values results in either a peak or an › detector. The circuit has a gain equal to R2/R1.

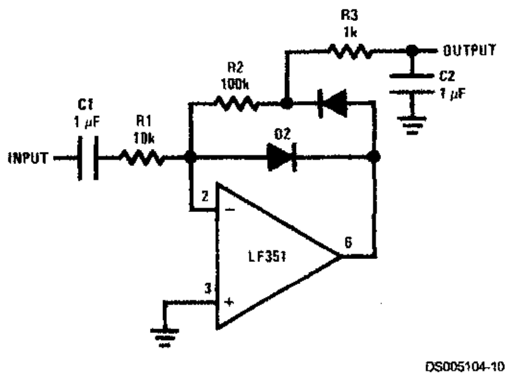
t to capacitively couple the input. Audio sources tly have a small DC offset that can cause significant the low end of the log display. Op amps that slew such as the LF351, LF353, or LF356, are needed to ı respond to sudden transients. It may be necessary ɔut the op amp DC offset voltage to accurately cover 3 range. Best results are obtained if the circuit is ɟ for the correct output when a low-level AC signal to 20 mV) is applied, rather than adjusting for zero vith zero input.

cision full-wave averaging use the circuit in *Figure 3.* % resistors for R1 through R4, gain for positive and negative signal differs by only 0.5 dB worst case. Substituting 5% resistors increases this to 2 dB worst case. (A 2 dB gain difference means that the display may have a ±1 dB error when the input is a nonsymmetrical transient). The averaging time constant is R5–C2. A simple modification results in the precision full-wave detector of *Figure 4*. Since the filter capacitor is not buffered, this circuit can drive only high impedance loads such as the input of an LM3915.



*DC Couple

FIGURE 1. Half-Wave Peak Detector

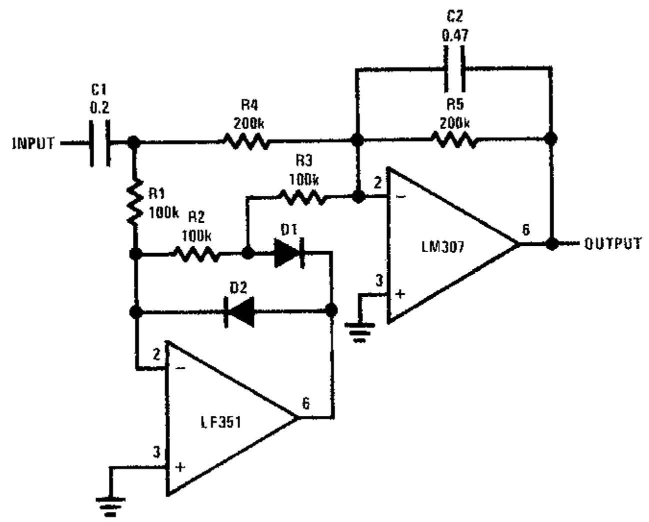


D1, D2: 1N914 or 1N4148

	Average	Peak
R2	1k	100k
R3	100k	1k

R1 = R2 for $A_V = 1$
R1 = R2/R10 for $A_V = 10$
C1 = 10/R1

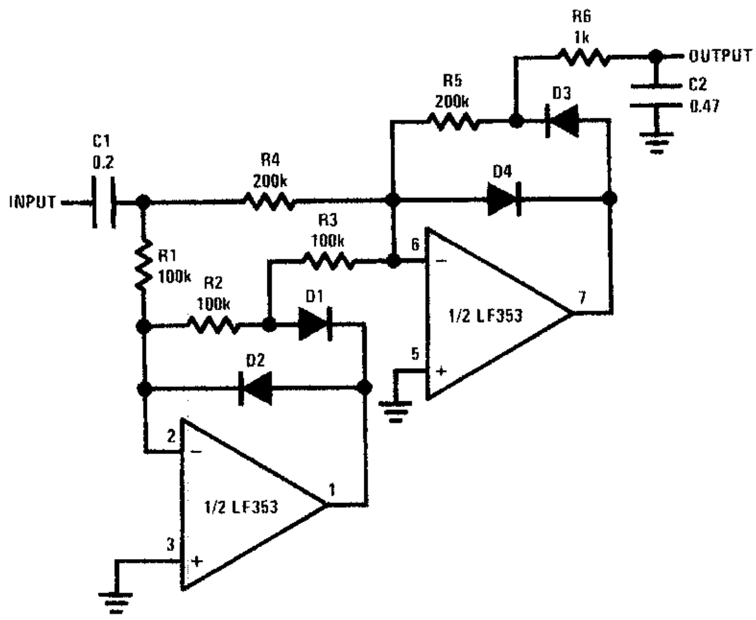
FIGURE 2. Precision Half-Wave Rectifier



DS005104-11

D1, D2: 1N914 or 1N4148

FIGURE 3. Precision Full-Wave Average Detector



DS005104-12

D1, D2, D3, D4: 1N914 or 1N4148

FIGURE 4. Precision Full-Wave Peak Detector

CASCADING THE LM3915

To display signals of 60 dB or 90 dB dynamic range, multiple LM3915s can be easily cascaded. Alternatively, it is possible to cascade an LM3915 with LM3914s for a log/linear display or with an LM3916 to get an extended range VU meter.

A simple, low cost approach to cascading two LM3915s is to set the reference voltages of the two chips 30 dB apart as in *Figure 5*. Potentiometer R1 is used to adjust the full scale voltage of LM3915 #1 to 316 mV nominally while the second IC's reference is set at 10V by R4. The drawback of this method is that the threshold of LED #1 is only 14 mV and, since the LM3915 can have an offset voltage as high as 10 mV, large errors can occur. This technique is not recommended for 60 dB displays requiring good accuracy at the first few display thresholds.

A better approach shown in *Figure 6* is to keep the reference at 10V for both LM3915s and amplify the input signal to the lower LM3915 by 30 dB. Since two 1% resistors can set the amplifier gain within ±0.2 dB, a gain trim is unnecessary. However, an op amp offset voltage of 5 mV will shift the first LED threshold as much as 4 dB, so that an offset trim may be required. Note that a single adjustment can null out offset in both the precision rectifier and the 30 dB gain stage. Alternatively, instead of amplifying, input signals of sufficient amplitude can be fed directly to the lower LM3915 and *attenuated* by 30 dB to drive the second LM3915.

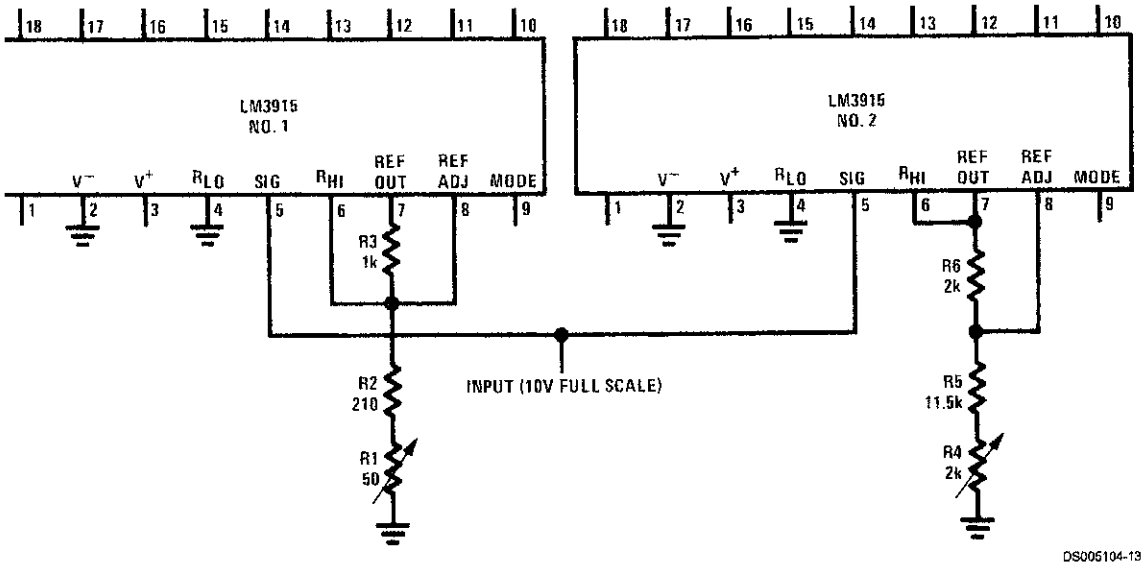


FIGURE 5. Low Cost Circuit for 60 dB Display

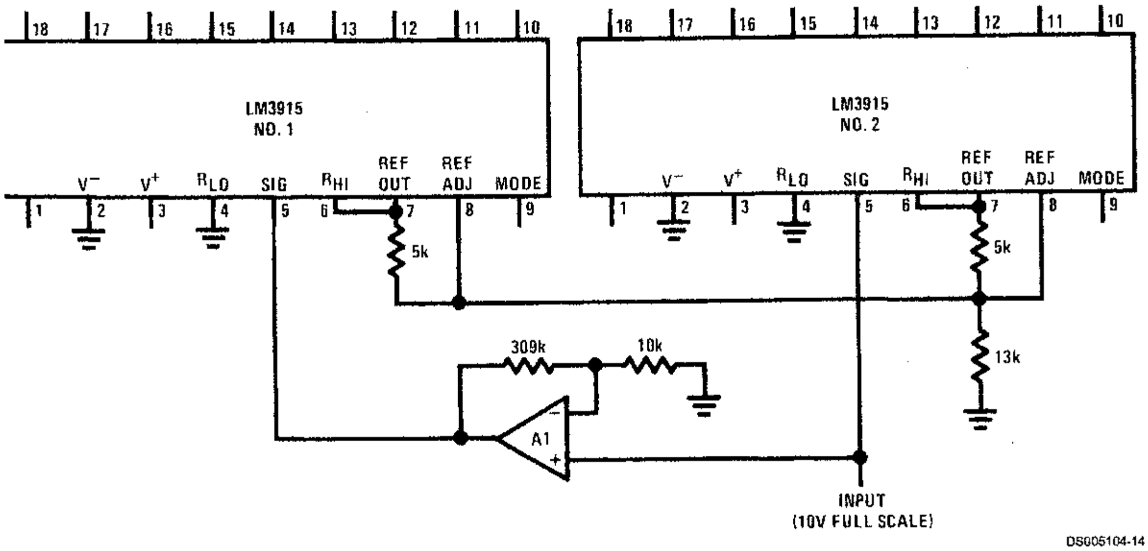


FIGURE 6. Improved Circuit for 60 dB Display

ınd this approach to get a 90 dB display, another of amplification must be placed in the signal path ɔf the lowest LM3915. Extreme care is required as the LM3915 displays input signals down to 0.5 mV! Sev- 'set nulls may be required. High currents should not he same path as the low level signal. Also power line ʒhould be kept away from signal lines.

ıN REFERENCE VOLTAGE
ED CURRENT PROGRAMMING

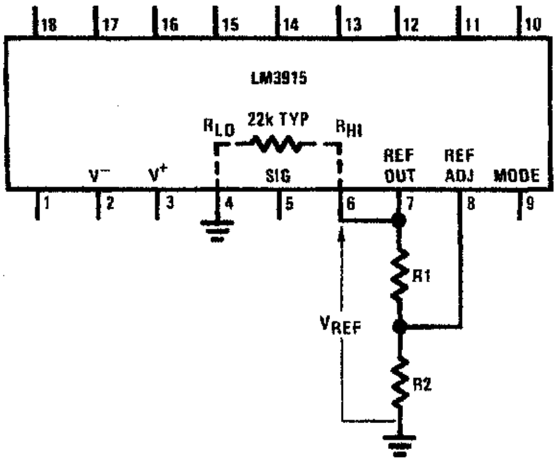
E LM3915

ıuations in *Figure 7* illustrate how to choose resistor to set reference voltage for the simple case where no tensity adjustment is required. A LED current of 10 mA nA generally produces adequate illumination. Having ll-scale across the internal voltage divider gives best cy by keeping signal level high relative to the offset ɜ of the internal comparators. However, this causes 450 µA to flow from pin 7 into the divider which means that the LED current will be at least 5 mA. R1 will typically be between 1 kΩ and 2 kΩ. To trim the reference voltage, vary R2.

The circuit in *Figure 8* shows how to add a LED intensity control which can vary LED current from 9 mA to 28 mA. The reference adjustment has some effect on LED intensity but the reverse is not true.

MULTIPLE LM3915s

Figure 9 shows how to obtain a common reference trim and intensity control for two LM3915s. The two ICs may be connected in cascade for a 60 dB display or may be handling separate channels for stereo. This technique can be extended for larger numbers of LM3915s by varying the values of R1, R2 and R3 in inverse proportion to the number of devices tied in. The ICs' internal references track within 100 mV so that worst case error from chip to chip is only 0.1 dB for V_{REF} = 10V.



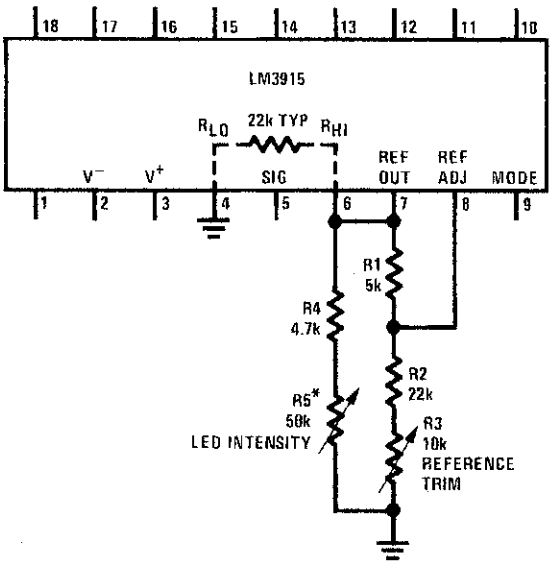
DS005104-15

Adjust R2 to vary V_{REF}

$$\text{Pick R1} = \frac{12.5V}{I_{LED} - V_{REF}/2.2\,k\Omega}$$

$$\text{Pick R2} = \frac{(V_{REF} - 1.25V)}{(1.25V/R1) + 0.08\,mA}$$

FIGURE 7. Design Equations for Fixed LED Intensity



DS005104-16

*9 mA < I_{LED} < 28 mA @ V_{REF} = 10V

FIGURE 8. Varying LED Intensity

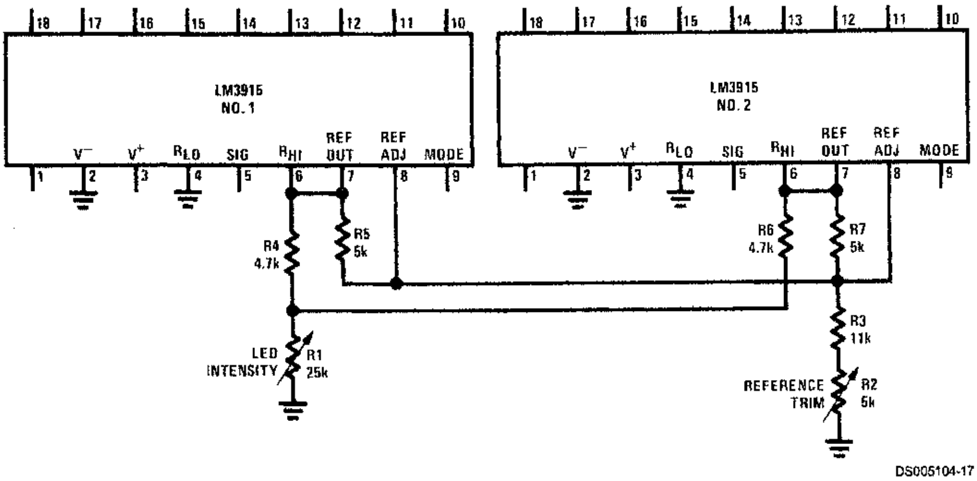


FIGURE 9. Independent Adjustment of Reference Voltage and LED Intensity for Multiple LM3915s

ıeme in *Figure 10* is useful when the reference and ensity must be adjusted independently over a wide The R_{HI} voltage can be adjusted from 1.2V to 10V effect on LED current. Since the internal divider here ıt load down the reference, minimum LED current is ıwer. At the minimum recommended reference load ʌ, LED current is about 0.8 mA. The resistor values ȷive a LED current range from 1.5 mA to 20 mA.

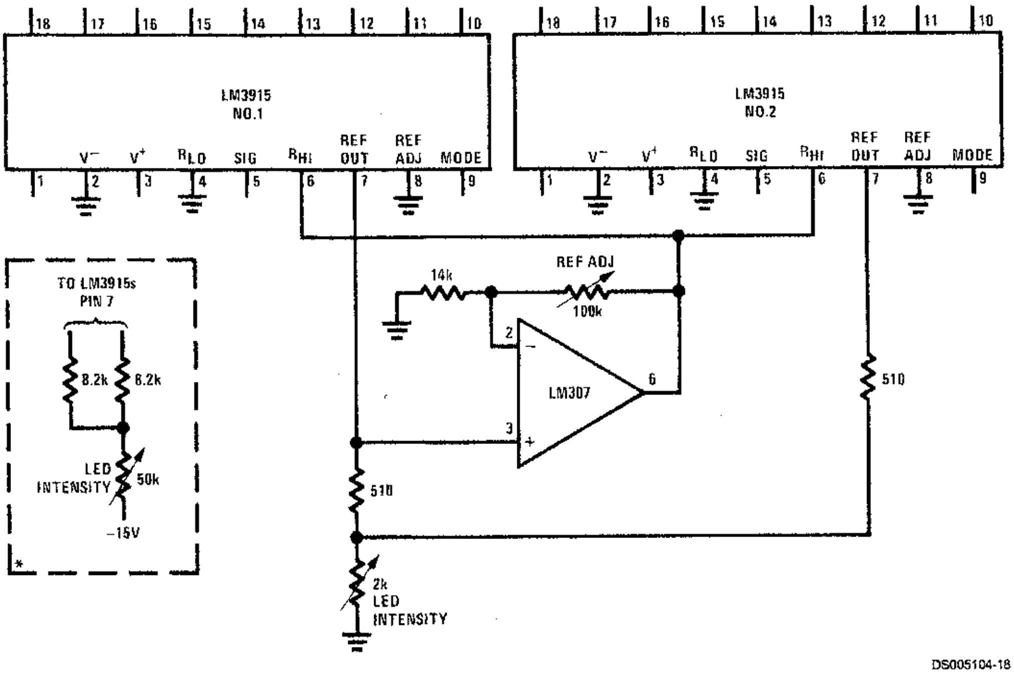
ɔw end of the intensity adjustment, the voltage drop the 510Ω current-sharing resistors is so small that ɔhip variation in reference voltage may yield a visible ı in LED intensity. The optional approach shown of ːing the bottom end of the intensity control pot to a ɘ supply overcomes this problem by allowing a larger drop across the (larger) current-sharing resistors.

Other Applications

For increased resolution, it's possible to obtain a display with a smooth transition between LEDs. This is accomplished by varying the reference level at pin 6 by 3 dBp-p as shown in *Figure 11*. The signal can be a triangle, sawtooth or sine wave from 60 Hz to 1 kHz. The display can be run in either dot or bar mode.

When an exponentially decaying RC discharge waveform is applied to pin 5, the LM3915's outputs will switch at equal intervals. This makes a simple timer or sequencer. Each time interval is equal to RC/3. The output may be used to drive logic, opto-couplers, relays or PNP transistors, for example.

Typical Applications



*Optional circuit for improved intensity matching at low currents.
See text.

FIGURE 10. Wide-Range Adjustment of Reference Voltage and LED Intensity for Multiple LM3915s

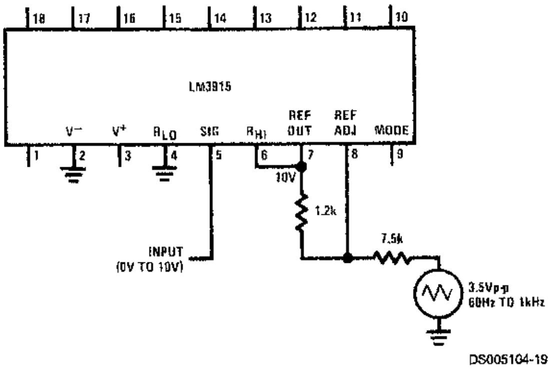
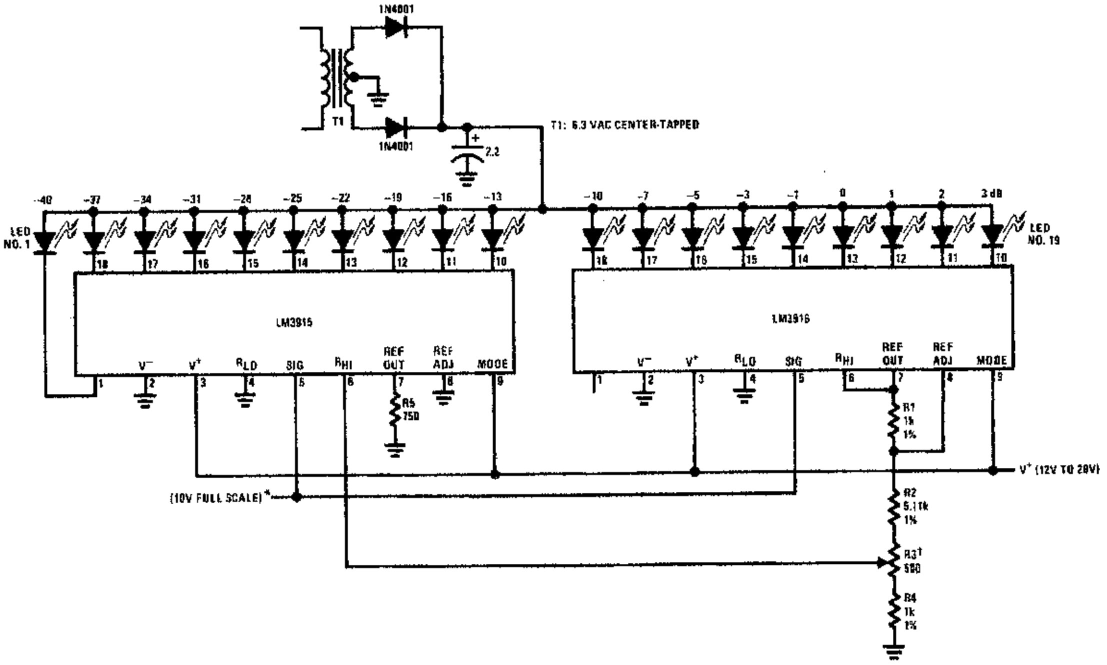


FIGURE 11. 0V to 10V Log Display with Smooth Transitions

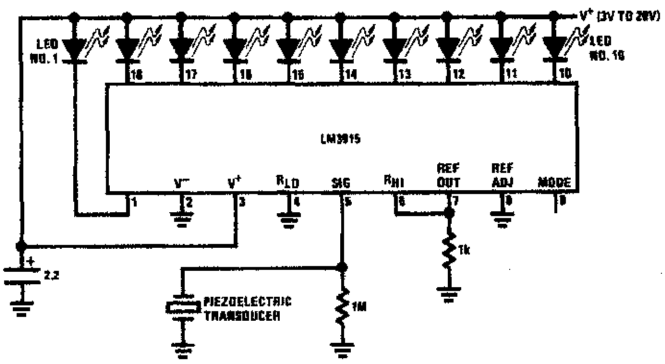
Extended Range VU Meter



DS005104-20

ication shows that the LED supply requires minimal filtering.
lication Hints for optional Peak or Average Detector.
3 for 3 dB difference between LED #11 and LED #12.

Vibration Meter

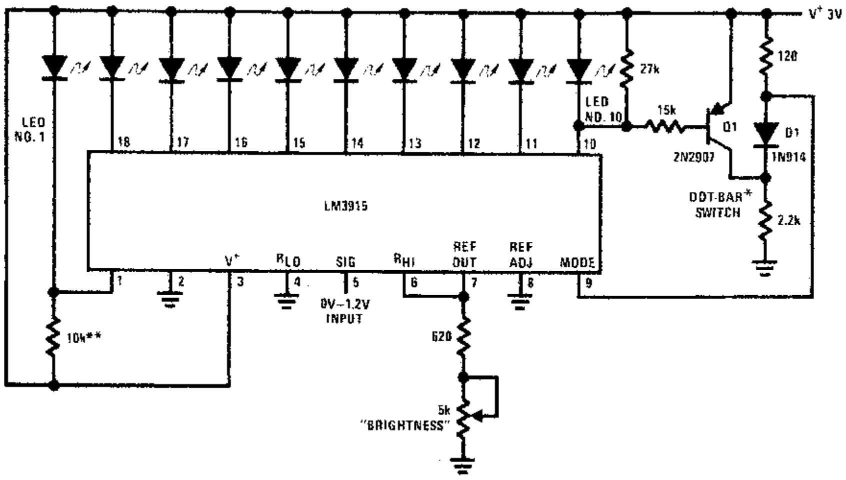


DS005104-21

LED	Threshold
1	60 mV
2	80 mV
3	110 mV
4	160 mV
5	220 mV
6	320 mV
7	440 mV
8	630 mV
9	890 mV
10	1.25V

Typical Applications (Continued)

Indicator and Alarm, Full-Scale Changes Display from Dot to Bar

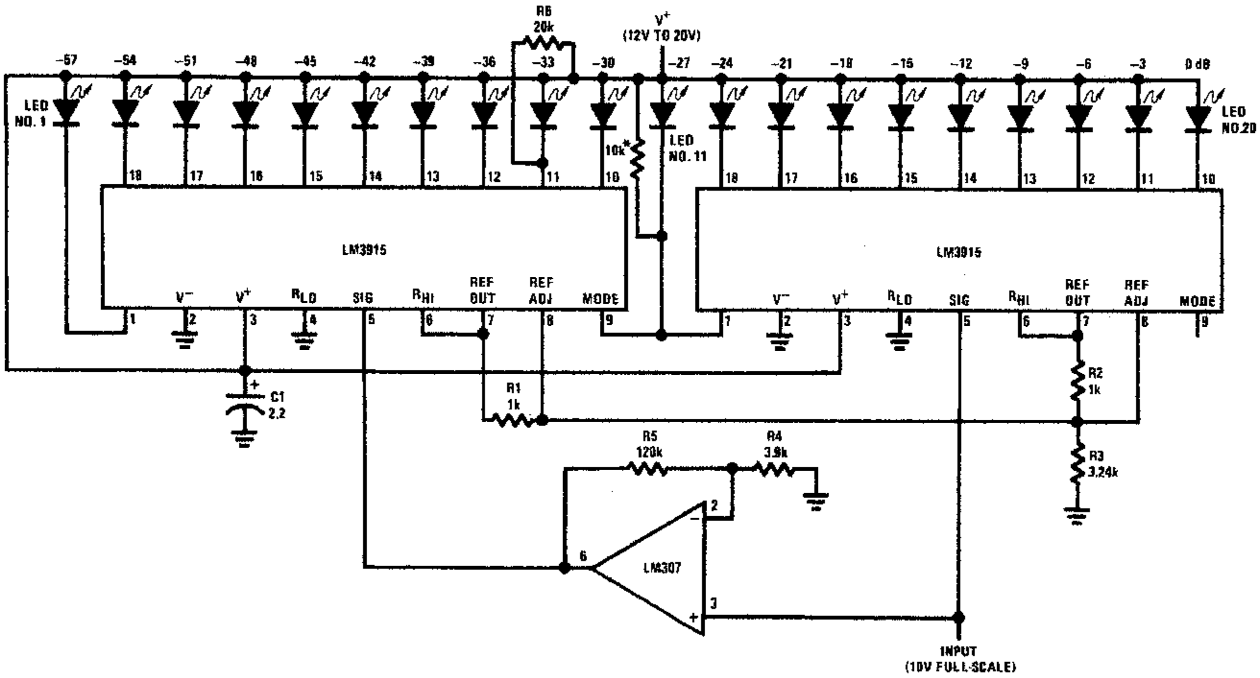


DS005104-22

*The input to the dot bar switch may be taken from cathodes of other LEDs. Display will change to bar as soon as the LED so selected begins to light.

**Optional. Shunts 100 µA auxiliary sink current away from LED #1.

60 dB Dot Mode Display

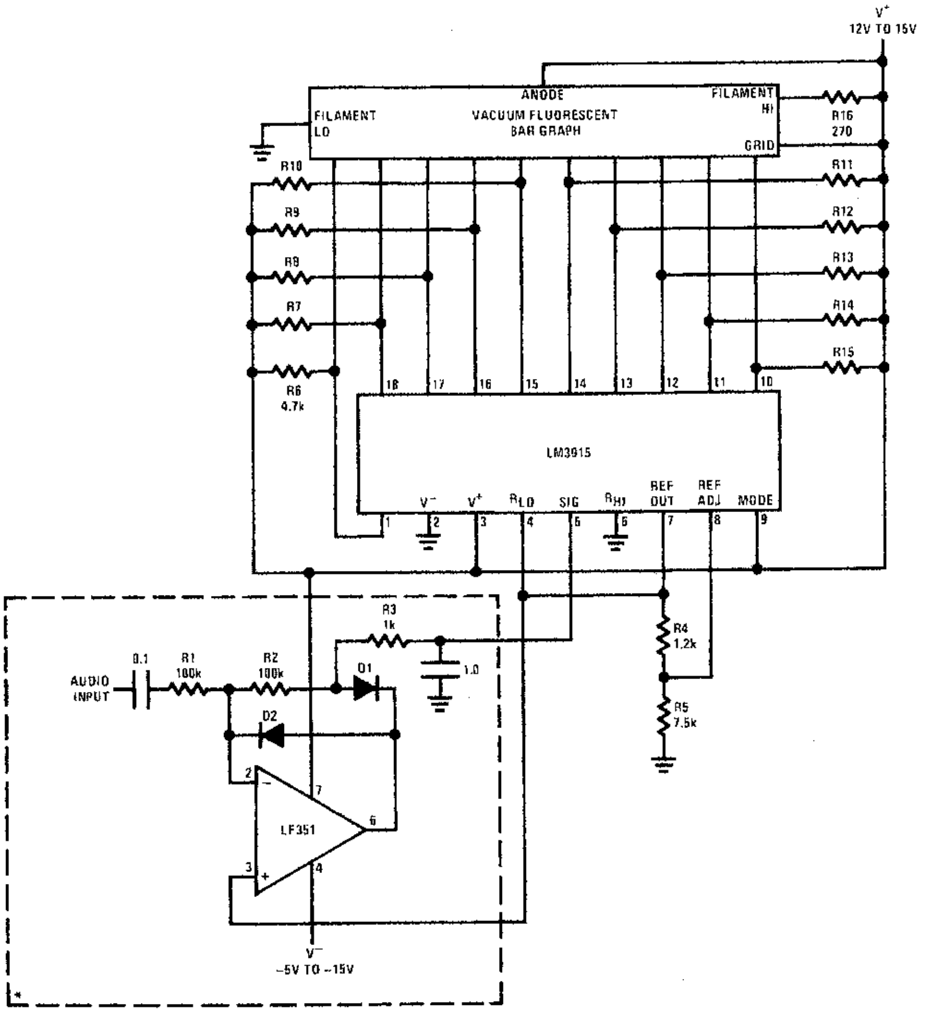


DS005104-23

**Optional. Shunts 100 µA auxiliary sink current away from LED #11.

:al Applications (Continued)

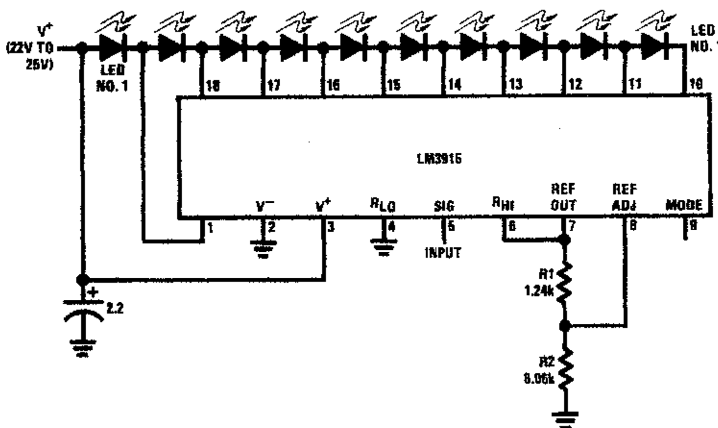
Driving Vacuum Fluorescent Display



DS005104-24

.15: 10k ±10%
N914 or 1N4148
e peak detector.
cation Hints.

Low Current Bar Mode Display

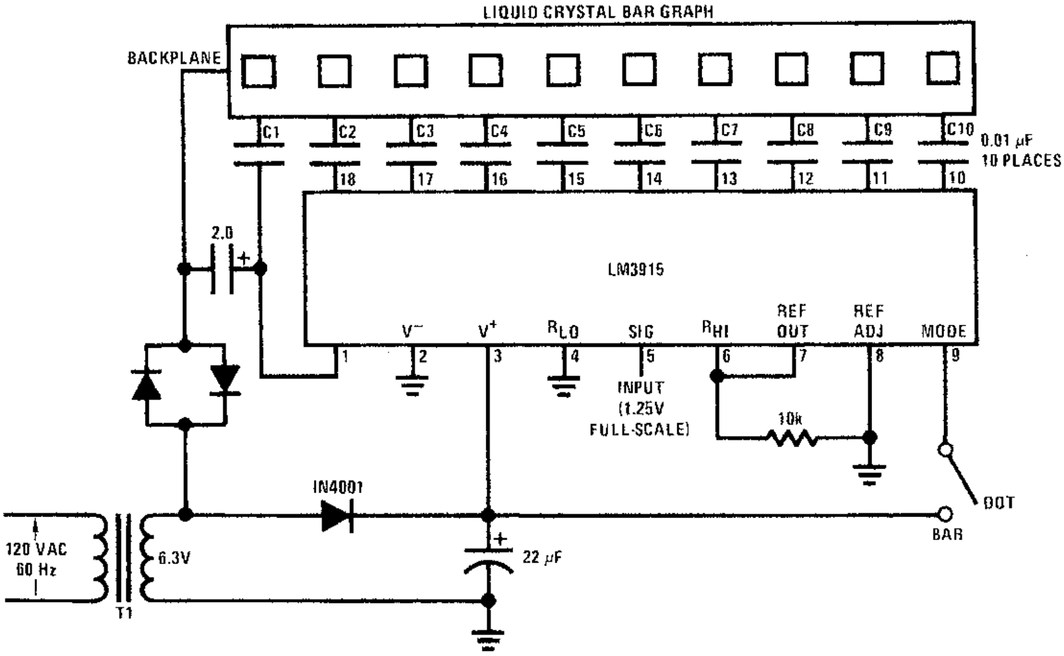


DS005104-25

ırrent drain is only 15 mA with ten LEDs illuminated.

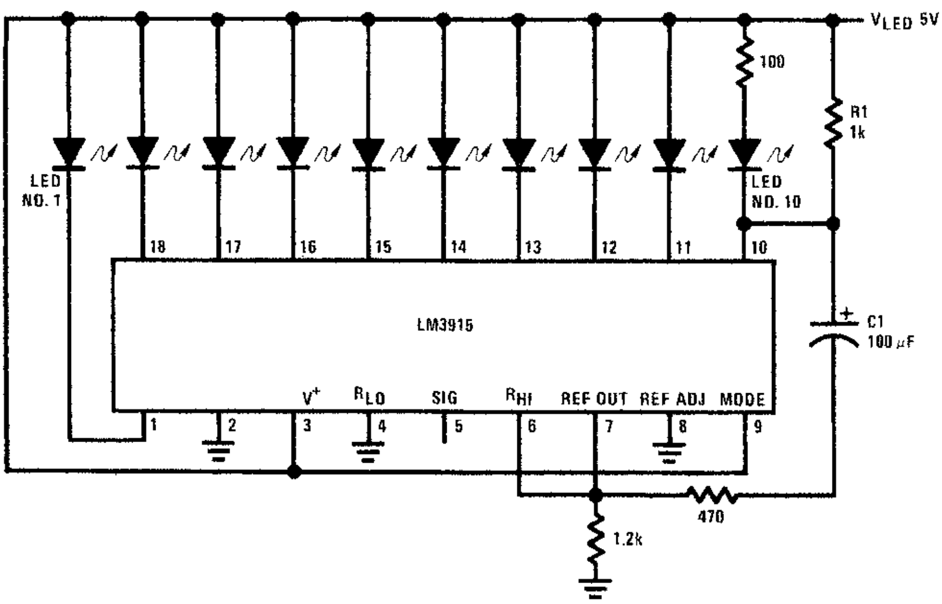
Typical Applications (Continued)

Driving Liquid Crystal Display



DS005104-26

Bar Display with Alarm Flasher

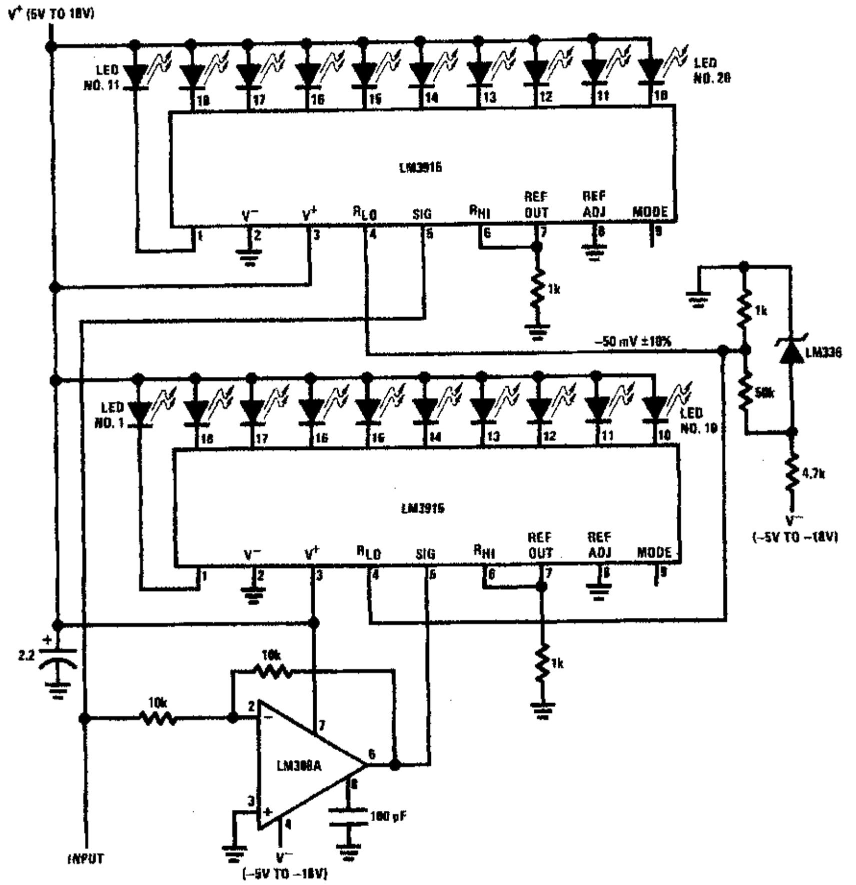


DS005104-27

Full-scale causes the full bar display to flash. If the junction of R1 and C1 is connected to a different LED cathode, the display will flash when that LED lights, and at any higher input signal.

cal Applications (Continued)

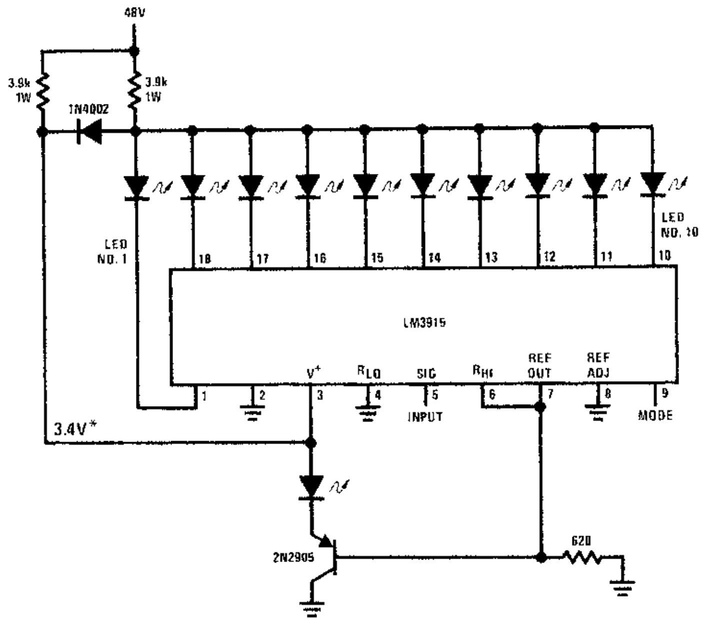
Precision Null Meter



DS005104-28

ıic response allows coarse and fine adjustments without changing scale.
ɪn ranges from 10 mV at V_{IN} = 0 mV to 500 mV at V_{IN} = ±1.25V.

Operating with a High Voltage Supply (Dot Mode Only)

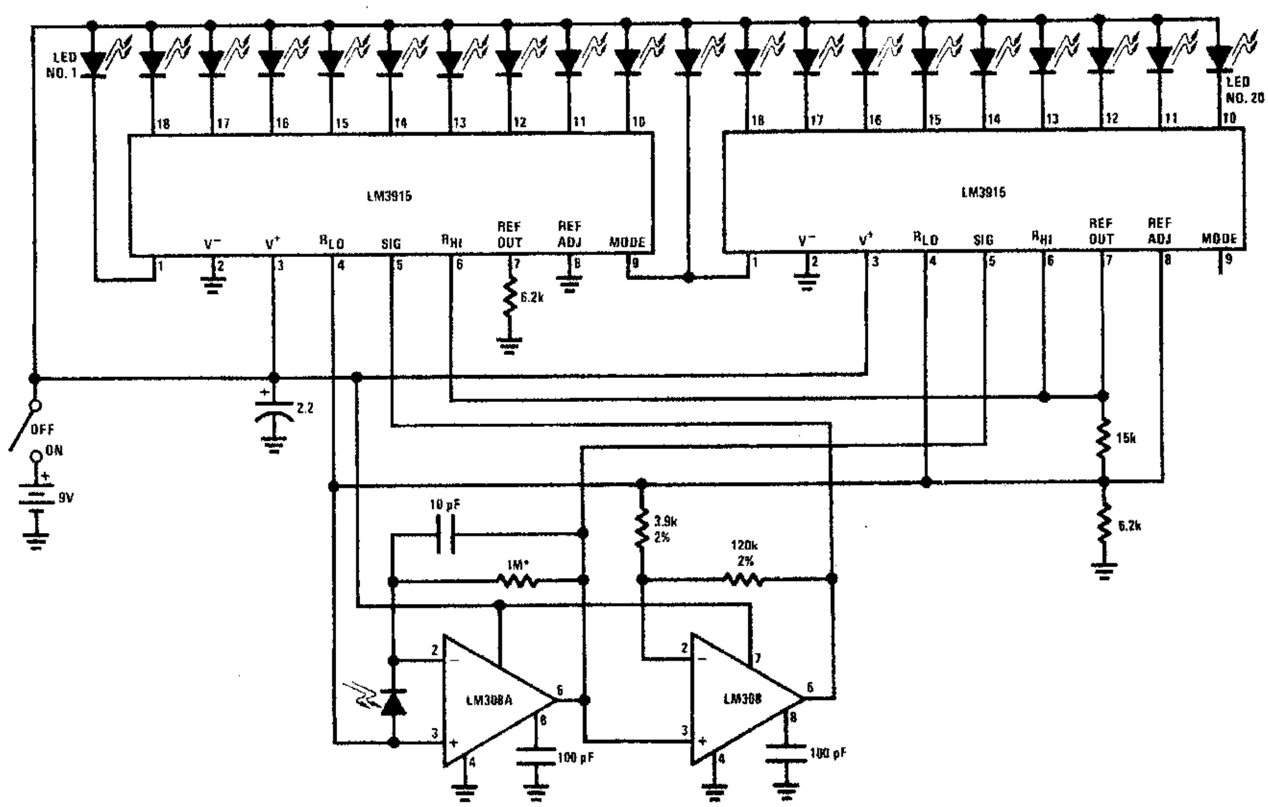


DS005104-29

The LED currents are approximately 10 mA, and the LM3915 outputs operate in saturation for minimum dissipation.

*This point is partially regulated and decreases in voltage with temperature. Voltage requirements of the LM3915 also decrease with temperature.

Light Meter

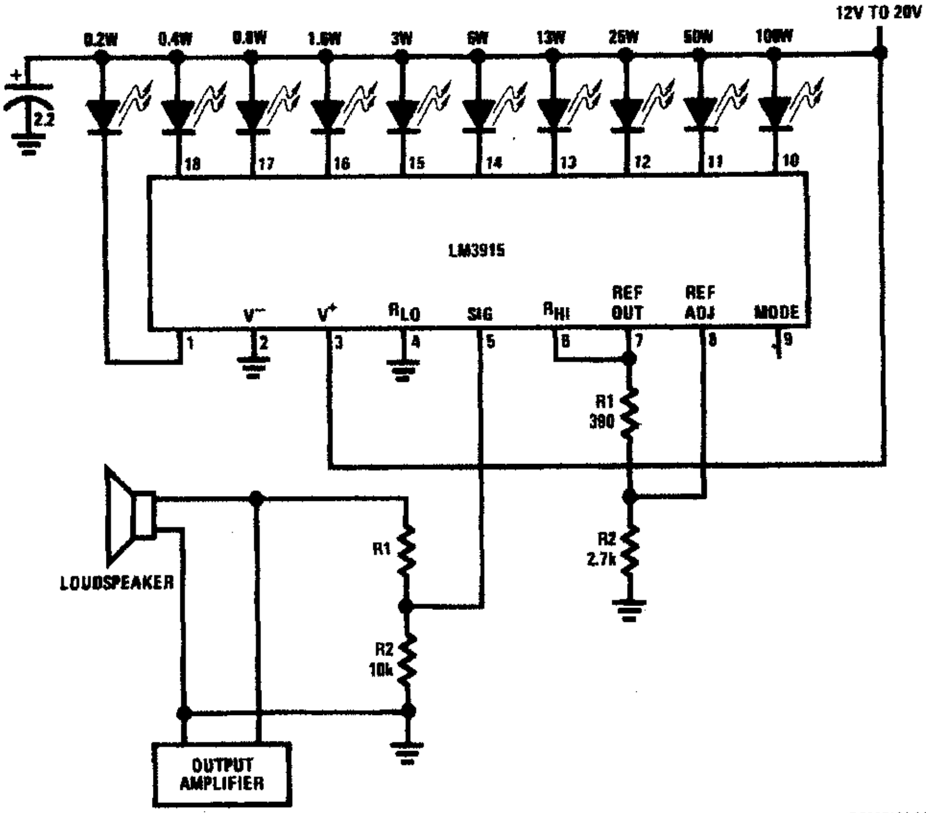


DS005104-30

*Resistor value selects exposure
1/2 f/stop resolution
Ten f/stop range (1000:1)
Typical supply current is 8 mA.

cal Applications (Continued)

Audio Power Meter



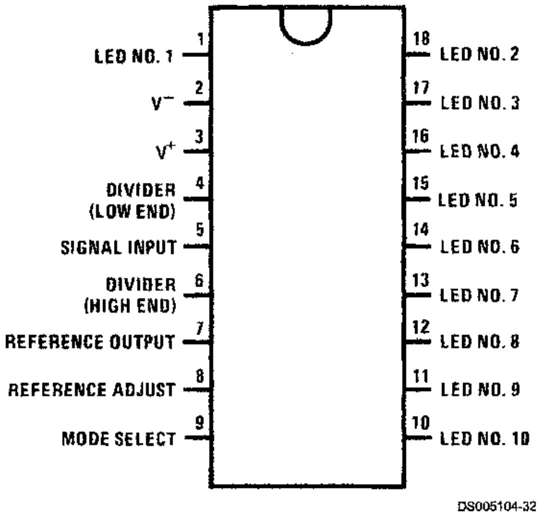
DS005104-31

Load Impedance	R1
4Ω	10k
8Ω	18k
16Ω	30k

See Application Hints for optional Peak or Average Detector

Connection Diagram

Dual-in-Line Package



Top View
Order Number LM3915N-1
See NS Package Number NA18A
Order Number LM3915N *
See NS Package Number N18A
***Discontinued, Life Time Buy date 12/20/99**

Definition of Terms

Absolute Accuracy: The difference between the observed threshold voltage and the ideal threshold voltage for each comparator. Specified and tested with 10V across the internal voltage divider so that resistor ratio matching error predominates over comparator offset voltage.

Adjust Pin Current: Current flowing out of the reference adjust pin when the reference amplifier is in the linear region.

Comparator Gain: The ratio of the change in output current (I_{LED}) to the change in input voltage (V_{IN}) required to produce it for a comparator in the linear region.

Dropout Voltage: The voltage measured at the current source outputs required to make the output current fall by 10%.

Input Bias Current: Current flowing out of the signal input when the input buffer is in the linear region.

LED Current Regulation: The change in output current over the specified range of LED supply voltage (V_{LED}) as measured at the current source outputs. As the forward voltage of an LED does not change significantly with a small change in forward current, this is equivalent to changing the voltage at the LED anodes by the same amount.

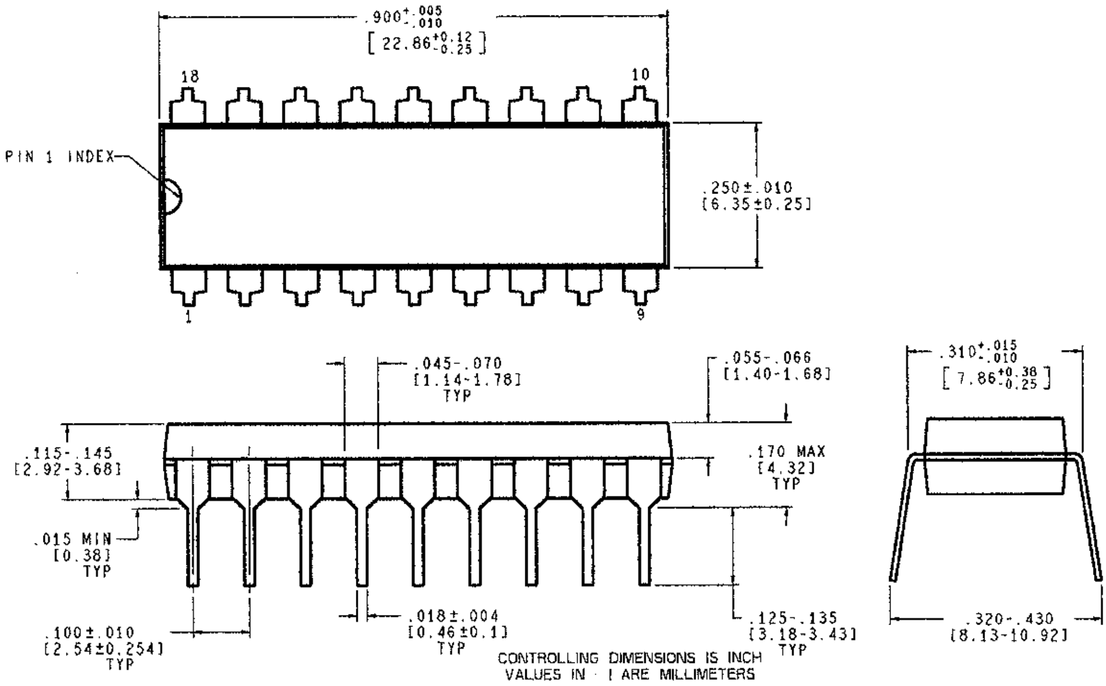
Line Regulation: The average change in reference output voltage (V_{REF}) over the specified range of supply voltage (V^+).

Load Regulation: The change in reference output voltage over the specified range of load current ($I_{L(REF)}$).

Offset Voltage: The differential input voltage which must be applied to each comparator to bias the output in the linear region. Most significant error when the voltage across the internal voltage divider is small. Specified and tested with pin 6 voltage (V_{RHI}) equal to pin 4 voltage (V_{RLO}).

Relative Accuracy: The difference between any two adjacent threshold points. Specified and tested with 10V across the internal voltage divider so that resistor ratio matching error predominates over comparator offset voltage.

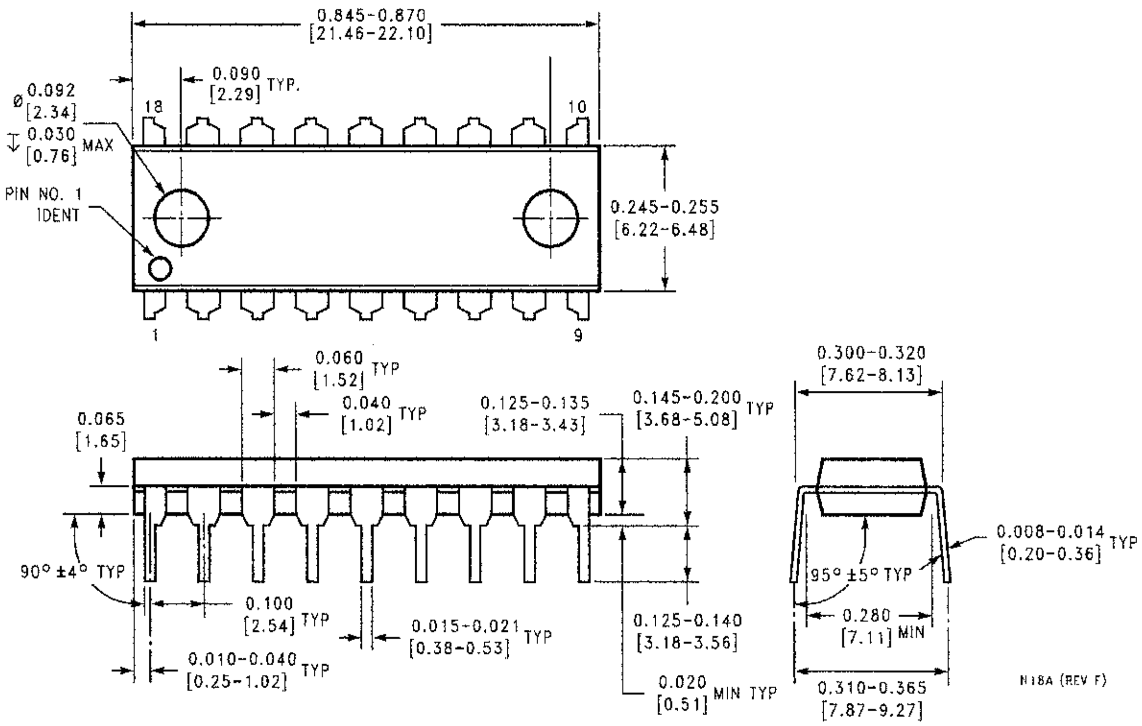
;ical Dimensions inches (millimeters) unless otherwise noted



Jnless otherwise specified.
dard Lead Finish:
nicroinches /5.08 micrometer minimum
tin 37/63 or 15/85 on alloy 42 or equivalent or copper
rence JEDEC registration MS-001, Variation AC, dated May 1993.

Molded Dual-In-Line Package (N)
Order Number LM3915N-1
NS Package Number NA18A

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



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