Palestine Polytechnic University

College of Engineering & Technology
Electrical & Computer Engineering Department
Biomedical Engineering

Graduation Project

Acid Base Conductivity Meter For Biomedical Solution

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Hebron – Palestine

June, 2004

Graduation Project Certification Evaluation

Palestine Polytechnic University
(PPU)

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According to the project supervisor and according to the agreement of the testing committee members, this project is submitted to the Department of Electrical and Computer Engineering at faculty of engineering and technology in partial fulfillment of the requirement of (B.A) degree.

Department Head Signature

Name:___________________________

Supervisor Signature

Name:_________________

June 2004

Dedication

- **To the souls of all the martyrs...to their, that has put our steps on the track.**

- **To our parents who spent nights and days doing their best to give us the best and**

- **To all our friends.**

- **To all those we dedicate our work with our best regards.**

Acknowledgements

To our great supervisor, who offered his best for this project to see light through his instructions and advices, Mr. Abdallah Arman with all his kindness we thank him.

We would also like to thank evrey person who offered anything to success this work.

Abstract

Acid Base Conductivity Meter
For Biomedical Solution

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Hebron-Palestine
June 2004

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Acid Base Conductivity Meter For Biomedical Solution

Following the importance of pH in many fields especially in medicine, chemistry, and many other fields. The pH measurement is considered as one of the most popular lab.measurements. pH measurement of the blood is done by a device called blood gas analyser which is special for blood only. So we realized the necessity of this project as a measurement of the pH for any solution in general. Thus we design

this project as a computerized device and easy to use. And the most thing effect the pH measurement is the temperature then we will measure it through this device.

Briefly we will explain the way that how this device works. We have two sensors the first is the temperature sensor and the second is the pH sensor. Small electrical signal measure with mV is entered through a temperature sensor, and another small electrical signal measure with mV is entered through a pH sensor (this signal is produced through series of chemical reactions that generate the voltage), these two electrical signals enter into amplifier to amplify it, then into analog to digital converter (ADC) in order to be dialed with the computer and which through matlab program that stores the results of the pH and temperature and then appear on the computer screen.

تمهيد

جهاز قياس درجة الحموضة للمحاليل الطبية: -

نظرا لأهمية درجة الحموضة في عدة مجالات من أهمها مجال الطب والكيمياء وغيرها من المجالات الأخرى، حيث أن جهاز قياس درجة الحموضة يعد من اشهر أجهزة القياس المخبرية،ومن خلال دراستنا لكيفية قياس درجة الحموضة في المستشفيات وجدنا أنها تتم من خلال جهاز(Blood Gas Analyzer**) مخصص فقط لدرجة الحموضة للدم فقط. لذلك ارتأينا إلى أن نضع هذا المشروع بين أيديكم والذي هو عبارة عن جهاز لقياس درجة الحموضة لاي محلول بشكل عام، ودرجة الحرارة وذلك لأهمية درجة الحرارة حيث تؤثر بشكل رئيسي على درجة الحموضة وقد تم حوسبة هذا الجهاز (باستخدام برنامج الماتلاب) وهو سهل الاستعمال.**

هنا وبإيجاز شديد سنشرح كيفية عمل الجهاز، حيث يتم إدخال إشارتين كهربائيتين صغيرتين جدا تقدر بالمللي فولت من خلال مجسين الأول مجس لدرجة الحرارة والثاني مجس لدرجة الحموضة (حيث يتم الحصول هذه الإشارة من خلال تفاعلات كيميائية تولد هذه الفولتية) إلى مكبر لتكبير الإشارة ومن ثم إلى محول تماثلي/ رقمي لكي يتم التعامل معها في الكمبيوتر ومن خلال برنامج مخزن في الماتلاب يتم حساب قيمة درجة الحرارة ودرجة الحموضة ثم يظهرها على الشاشة.

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Chapter One
Introduction

Chapter one

Introduction:

It is obviously that biomedical engineering technology has a great impotence in the healthcare field. Which makes our life easier and more comfortable, this is because it offers to us what we need to make it easy and to the human life the reason of being alive as much as possible by development and construct of anew different equipment and tools that service this goals.

There is much type of these tools or device with different specification and different usage. In this project we will have one of these equipments that have magnificent importance in the health care field; this device is acid base conductivity meter for biomedical solution.

In this project we will construct an electronic system that measures the ph and temperature by using the computer and special sensors.

The following is a brief description of the subjects that are covered in each chapter:

Chapter two: describes the ph definition, molar concept, the ph meter, temperature effect and calibration of the electrode.

Chapter three talks about the important of the ph in many fields. In human body, in chemical industry and others.

Chapter four: will introduce the necessary implementation and the schematic diagram for the design.

Chapter five: talk about the hardware and software of the project.

Chapter six: it is include the conclusion and future work.

Chapter Two
pH Definition

- **ph Definition.**
- **Molar concept.**
- **Methods to compute the pH.**
- **Basic Instrumentation Theory.**
- **Temperature Effect.**

Chapter Two

2.1 pH Definition: -

pH is a unit of measure, which describes the degree of acidity or alkalinity of a solution. It is measured on a scale of 0 to 14. The term pH is derived from "p", the mathematical symbol of the negative logarithm, and "H", the chemical symbol of Hydrogen. The formal definition of pH is the negative logarithm of the Hydrogen ion activity.

$$pH = -log\ [H+]$$

Where log is a base-10 logarithm and $[H^+]$ is the concentration of hydrogen ions in moles per liter of solution.

Thus pH provides the needed quantitative information by expressing the degree of activity of an acid or base in terms of hydrogen ion activity. Acid and bases have both free hydrogen and hydroxyl ions. Since the relationship between hydrogen ions and hydroxyl ions in a given solution is constant for a given set of conditions, either one can be determined by knowing the other. If the ratio of the hydrogen ion is greater than that of the hydroxyl ion the solution is acidic, and has a pH value below 7. If the ratio of the hydroxyl ion is greater than that of the hydrogen ion the solution is basic, and has a pH value above 7. If the ratio of the hydroxyl ion is equal to that of the hydrogen ion the solution is neutral, and has a pH value of 7.

We can see the pH Meter scale as the following: -

The pH scale

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

← Acid strength increases neutral Base strength increases →

The "strength" of an acid or base increases with distance from pH=7

2.2 Molar concept

Molecules that are dissolved in water may separate (dissociate or ionize) into charged fragments or ions. Often one of these fragments is a hydrogen ion (H^+). The pH of a solution is a measure of the concentration of hydrogen ions (written as $[H^+]$ where, [ ] Means "concentration of") in that solution. pH is also a measure of the alkalinity or acidity of a solution.

Water ionizes when a hydrogen atom that is covalently bound to the oxygen atom of the water molecule leaves its electron behind, breaking apart the water molecule. We can express the ionization of water in the following equation.

$$H_2O \longrightarrow H^+ + OH^-$$

In any given volume of pure water, or in any solution, a small but constant number of water molecules are ionized. In pure water, the number of H^+ ions exactly equals the number of OH^- ions, since one cannot be formed without the other being formed. In pure water, $[H^+] = 1 \text{ X } 10^{-7}$M and $[OH^-] = 1 \text{ X } 10^{-7}$M (where M = molar concentration or moles/liter). The product of the molar concentrations of the two ions, $[H^+][OH^-]$, in pure water is always equal to $1 \text{ X } 10^{-14}$. So for pure water;

$$[H^+][OH^-] = 1 \text{ X } 10^{-14}$$

Or

$$[1 \times 10^{-7}][1 \times 10^{-7}] = 1 \times 10^{-14}$$

Numbers such as these can be expressed as logarithms (base 10). A logarithm is the power to which a number, in this case 10, must be raised to give the desired number. Thus the log of 1×10^{-7} is **-7**, since this is the power to which 10 must be raised to give the number 0.0000001. pH is defined as the negative logarithm of the $[H^+]$ in a solution. The negative logarithm is used when working with pH so that the numbers, and the pH scale, are positive.

Note**:** $-\log (1 \times 10^{-7}) = +7$, or simply, **7**.

The relationship between the pH and pOH of a solution is such that the sum of the negative log of $[H^+]$ and the negative log of $[OH^-]$ is always equal to -log of 1×10^{-14} (to find the product of two numbers written in logarithmic form, add the logarithms). Since the "p" in pH stands for "negative logarithm of," we can write this relationship as:

$$p\,[H^+] + p\,[OH^-] = -\log (1 \times 10^{-14})$$

Or

$$pH + pOH = 14$$

It is important to realize that in any solution, the product of $[H^+]$ and $[OH^-]$ is constant (always 1×10^{-14}). Therefore, if you know the pH you can calculate the pOH (pOH = 14 - pH), and if you know the pOH you can calculate the pH (pH = 14 - pOH). The sum of the negative logarithms of $[H^+]$ and $[OH^-]$ is always 14 and the product of the ion concentrations, $[H^+][OH^-]$, is always 1×10^{-14}.

2.3 Methods to compute the pH:

There are two methods for measure pH of solutions that are:

2.3.1 Indicators:

Weak organic acids and bases whose colors differ from the colors of there conjugate acids or bases. Indication of pH can be obtained using pH papers or indicators, which change color as the pH level varies. These indicators have limitations on their accuracy, and can be difficult to interpret correctly in colored or murky samples.

2.3.2 pH meter:

- An electronic device that measures pH directly.
- pH meters are used in most professional lab settings today.

More accurate pH measurements are obtained with a pH meter. A pH measurement system consists of three parts: a pH measuring electrode, a reference electrode, and a high input impedance meter. The pH electrode can be thought of as a battery, with a voltage that varies with the pH of the measured solution. The pH measuring electrode is a hydrogen ion sensitive glass bulb, with a mill volt output that varies with the changes in the relative hydrogen ion concentration inside and outside of the bulb. The reference electrode output does not vary with the activity of the hydrogen ion. The pH electrode has very high internal resistance, making the voltage change with pH difficult to measure. The input impedance of the pH meter and leakage resistances is therefore important factors. The pH meter is basically a high impedance amplifier that accurately measures the minute electrode voltages and displays the results directly in pH units on either an analog or digital display.

2.4 Basic Instrumentation Theory

The basic phenomenon upon which the pH meter operates is the development of an electrical potential (voltage) by a chemical reaction in an electrochemical cell. Such a cell consists of two dissimilar half-cells, different in materials or concentration, separated by a semipermeable membrane. This allows for the contact of the two solutions but does not allow mixing and hence direct reaction of the substances in the two half-cells. The voltage is measured across the two electrodes in the half-cells as shown in figure (2-1).

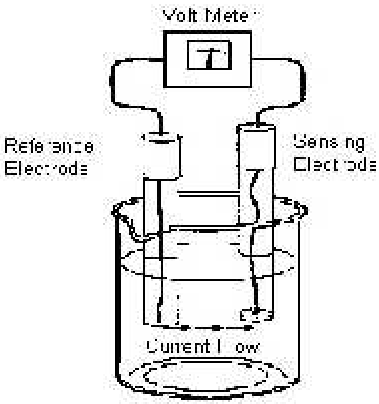


Figure 2-1: Electrode Principle

The system consists of a pH sensor, pH Half Cell, whose voltage varies proportionately to the hydrogen ion activity of the solution, and a reference electrode, Reference Half Cell, which provides a stable and constant reference voltage.

The pH electrode consists of a thin membrane of Hydrogen sensitive glass blown on the end of an inert glass tube. Because this is a special type of glass and very thin, the bulb is very fragile and great care must be exercised in handling it, this tube is filled with an electrolyte, and the signal is carried through Ag/AgCL wire. This is a pH half Cell.

A similar system, but without using a Hydrogen sensitive glass, is used as a reference. A small filter (diaphragm) connects this tube to the external liquid. This system is called a Reference Half Cell

It is very common to find pH meters, which are fitted with only a single combination electrode. As the name implies, a combination electrode is a combination of the glass electrode and the reference electrode into a single probe. The probe is constructed with the reference surrounding the glass electrode. The primary advantage to using a combination electrode is the ability to measure the pH of a smaller volume of sample or a sample in a container with a restricted opening. The main disadvantages to using a combination electrode are the more limited selection of internal elements (most have only a silver-silver chloride internal reference) and the higher cost. The combination electrode on your pH meter may have a plastic shield around the glass bulb to protect it from damage as shown in the figure (2-2).

Figure 2-2: Glass Bulb

The voltage (electrical potential) developed across the two electrodes can be measured by a voltmeter and can be related to the pH of the solution. However, because of the high electrical resistance across the glass membrane, which produces only a very small current with which to measure the voltage, a rather sophisticated voltmeter must be used. The meter measures the difference between the pH Half Cell and the Reference Half Cell in mill volts DC. This mill volt reading is read by the unit and displayed as either mV or pH units.

Fortunately, the voltage change of a pH electrode varies linearly with pH units. At room temperature, a change of 1 pH unit causes a voltage change of about 60 mV (0.060 volts). At zero degrees centigrade, 1 pH unit change causes a 54 mV change. At one hundred degrees centigrade, a 1 pH unit change causes a 70 mV change. Thus, a properly designed pH meter will have a temperature dial which varies the sensitivity of the meter to match the voltage from the electrodes see figure (2-3).

Figure 2-3: pH Meter

2.4.1 Procedures to Measure pH:

First, there is a pH probe, which produces a voltage that can be directly related to the pH of the solution in which we place the probe.

Secondly, there is an electronic circuit within the pH meter cabinet that receives the voltage from the probe and then presents it to the meter scale.

Thirdly, this voltage developed at the probe will cause the meter pointer to move. The value of the number at which the pointer stops or displayed at screen of voltmeter if it digital voltmeter is the pH of the solution.

2.4.2 Electrode Care

Electrodes are very fragile and require careful handling and constant maintenance as shown in the figure below.

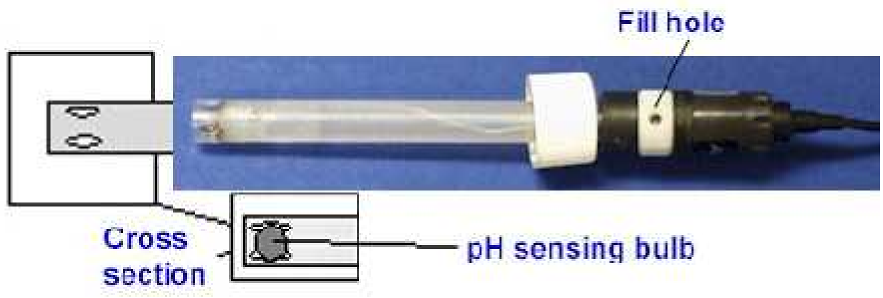


Fig. 2-4: pH Electrode

To ensure the longevity of the life of the electrodes Please follow all directions below:

1) The fill hole must be open when taking measurements and when it is stored in a buffer.
2) To obtain accurate readings, the electrode need only be immersed far enough to cover both the glass pH-sensing bulb and reference junction.
3) Handle the electrode carefully to avoid crushing the very fragile pH-sensing bulb. This bulb is made of a thin glass membrane and breaks very easily.
4) Always rinse the electrode with distilled water between samples. Avoid prolonged measurements in strong alkaline solutions (above pH 9).

5) Due to the high impedance (resistance) of the pH glass membrane, the electrode cable should not be moved or touched while measurements are being made; otherwise, unstable readings may result.
6) Between measurements immerse the electrode in a buffer solution (pH 4 or 7). Keep the fill hole open to avoid contamination of the electrolyte from the buffer solution.

2.4.3 Buffer Solutions

Buffers are solutions that have constant pH values and the ability to resist changes in that pH level. They are used to calibrate the pH measurement system (electrode and meter). There can be small differences between the output of one electrode and another, as well as changes in the output of electrodes over time. Therefore, the system must be periodically calibrated. Buffers are available with a wide range of pH values, and they come in both premixed liquid form or as convenient dry powder capsules. Most pH meters require calibration at several specific pH values. One calibration is usually performed near the isopotential point (the signal produced by an electrode at pH 7 is 0 mV at 25°C), and a second is typically performed at either pH 4 or pH 10. It is best to select a buffer as close as possible to the actual pH value of the sample to be measured.

The list of buffers below outlines those that are recognized by various regulatory bodies: -

- ✓ pH 1.68 at 25 ^{o}C
- ✓ pH 4.01 at 25 ^{o}C
- ✓ pH 6.86 at 25 ^{o}C
- ✓ pH 7.00 at 25 ^{o}C
- ✓ pH 9.18 at 25 ^{o}C

- ✓ pH 10.01 at 25 °C

Buffers are also available as primary buffers (those that are made with direct trace ability to the components that make up the buffer) and secondary buffers.

pH buffers are also dependent on temperature. Many pH meters contain all the pH-temperature profiles for the buffers stated above, so you don't need to adjust anything yourself. However, if you are not using any of these standard buffers, then your pH meter may incorrectly adjust your calibration!

2.4.4 General pH Calibration Procedures

The standard procedure is to select two buffers that bracket the expected sample pH. More buffers can be used for greater accuracy over a wider pH range. For best accuracy, use buffers that are no more than 3 pH units apart.

Consult your pH meter manual for specific details on operating your meter.

1. Remove the electrode from its storage solution and rinse it with distilled water. Dab the electrode with tissue paper to remove excess water (do not rub!) and place the electrode into the first buffer (usually pH 7). Wait for a stable reading.
2. Calibrate the meter to read the temperature corrected value of the first buffer (i.e. you need to know the temperature).
3. Rinse the electrode as before and place in the second buffer. Wait for a stable reading.
4. Calibrate the meter to read the temperature corrected value of the second buffer.

5. Rinse the electrode as before. Place the electrode in your sample and wait for a stable reading.
6. Record the pH and temperature of your sample.

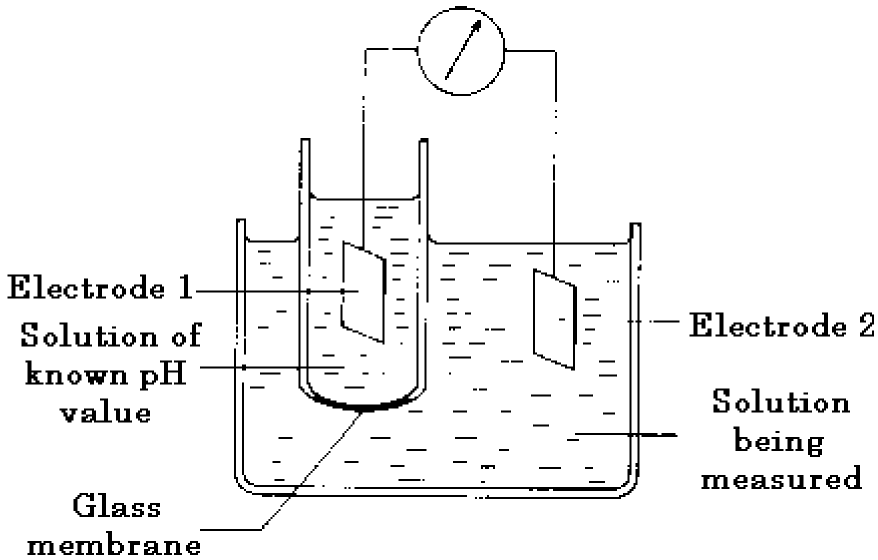


Fig. 2-٥: General pH Calibration

2.5 Temperature Effect:

The pH electrode is temperature dependent, and may be compensated for in the pH meter circuitry. The circuitry of the pH meter utilizes the Nernst equation, which is a general mathematical description of electrode behavior.

$$E = E_o + \frac{2.303RT}{NF} \log AH^+$$

Where:

- E = the total potential (in mV) developed between the sensing and reference electrodes.
- E^0 = is a constant which is characteristic of the particular ISE/reference pair.
- (It is the sum of all the liquid junction potentials in the electrochemical cell)

- 2.303 = the conversion factor from natural to base10 logarithm.
- R = the Gas Constant (8.314 joules/degree/mole).
- T = the Absolute Temperature.
- n = the charge on the ion (with sign).
- F = the Faraday Constant (96,500 coulombs).
- Log (A) = the logarithm of the activity of the measured ion.

Your pH meter uses the above equation to calculate pH values, however we need to find out several variables first:

- The potential (E) is measured by the electrodes.
- The standard potential (E_o) is determined by calibration in a neutral solution (pH7).
- Temperature is very important and is measured using a temperature sensor. If there is no temperature sensor connected to the meter, it must be entered into the meter.
- The slope of the equation must also be determined by calibration in at least two solutions of known concentration.

$$+ \frac{2.303RT}{nF} \log AH+$$

The slope equals the part of the Nernst equation.

Temperature is a key variable in pH measurement, affecting not only the slope of the electrode, but sample and buffer pH values, plus the potential of the electrode internals (causing electrode drift). Temperature must always be reported with the pH value - a pH reading of 5.4 means nothing unless we know what temperature it was taken at! So the temperature is a very important factor in pH measurements and here's why. The voltage output of a probe was about 60 mill volts per pH unit at 25°C (room temperature).

Table 2-1: Probe output for each pH unit

0°C	54 mill volts
25°C	60 mill volts
50°C	64 mill volts
75°C	68 mill volts
100°C	70 mill volts

In looking at this table we realize that our pH meter must be able to move one pH unit with 54-mill volts input or 70 mill volts or any value in between. Most meters can do this. Which we can set the proper sensitivity of the meter to correspond to the temperature of the sample solution.

The following table shows the pH values related to volt:

Table 2-2: pH values related to volt.

Sample	pH value	T= 0ºC	T=25ºC	T=50ºC	T=75ºC	T=100ºC
		mV	mV	mV	mV	mv
	0	378	٤٢٠	٤٤٨	٤٧٦	٤٩٠
	1	٣٢٤	٣٦٠	٣٨٤	٤٠٨	٤٢٠
Stomach acid	2	٢٧٠	٣٠٠	٣٢٠	٣٤٠	٣٥٠
Cola drinks	3	٢١٦	٢٤٠	٢٥٦	٢٧٢	٢٨٠
Tomatoes	4	١٦٢	١٨٠	١٩٢	٢٠٤	٢١٠
Coffee	5	١٠٨	١٢٠	١٢٨	١٣٦	١٤٠
	6	٥٤	٦٠	٦٤	٦٨	٧٠
Pure water	7	٠	٠	٠	٠	٠
Sea water	8	-٥٤	-٦٠	-٦٤	-٦٨	-٧٠
	9	-١٠٨	-١٢٠	-١٢٨	-١٣٦	-١٤٠
Detergent	10	-١٦٢	-١٨٠	-١٩٢	-٢٠٤	-٢١٠
Ammonia	11	-٢١٦	-٢٤٠	-٢٥٦	-٢٧٢	-٢٨٠
Photo developer	12	-٢٧٠	-٣٠٠	-٣٢٠	-٣٤٠	-٣٥٠
	13	-٣٢٤	-٣٦٠	-٣٨٤	-٤٠٨	-٤٢٠
Oven cleaners	14	-٣٧٨	-٤٢٠	-٤٤٨	-٤٧٦	-٤٩٠

Chapter Three
pH Importance

- **pH Importance.**
- **The ph Equation and Health.**
- **Body pH affects everything.**
- **pH Controls the Things you can’t live without.**
- **Mineral Assimilation**

Chapter Three

3.1 pH Importance: -

The pH or acidity of a solution is important throughout all phases of chemistry and biochemistry.

3.1.1 in the human body: -

If the pH of the blood in your body were lowered one unit, you would die. Living things grow and survive in a particular pH environment and when the pH is not correct their growth and survival are threatened. For example, wheat, corn and other foodstuffs grow best in soil of a particular pH. To get the greatest yield, the farmer must condition his soil to achieve the proper pH. This explains, in part, why the yield per acre has increased in recent years since soil science has shown the farmer how to provide optimum conditions for best growth.

3.1.2 In the Chemical Industry: -

The efficient production of nylon, as well as other modern fibers depends on rigid pH control.

3.1.3 In Biochemistry: -

The pH of our blood is normally controlled to within a few tenths of a pH unit by our body chemistry. If our blood pH changes as much as half a pH unit, serious illness will result. Proper skin pH is essential for a healthy complexion. The pH of one's stomach directly affects the digestive process.

3.1.4 In Agronomy: -

The pH of the soil regulates the availability of nutrients for plant growth, as well as the activity of soil bacteria. In alkaline soils (pH 8 and above) the amount of nitrogen, phosphorus, iron and other nutrients in solution become so low that special treatment is necessary to insure proper growth.

3.1.5 In Food Science: -

The efficient production of food products depends upon careful pH control. The proper curd size, uniformity, and structure of cottage cheese are directly related to the pH at cutting time. Yeast can ferment and leaven dough only within certain pH limits. Jelly will not gel properly unless the pH is in the 3.5 regions.

3.1.6 In the Pulp and Paper Industry: -

pH control is essential to the proper operation of bleaching plants and wet-end processes. Also, in order to conform to environmental protection regulations, the pH of wastewater from these plants must be controlled.

3.1.7 in Chemical Research and Engineering: -

Accurate pH measurement is necessary to the study of many chemical processes. The researcher needs to know the pH at which a chemical reaction proceeds at its fastest in order. To understand the reaction. The engineer uses the information to develop practical commercial processes.

3.1.8 in Environmental Research and Pollution Control: -

The pH of a river or lake is important in maintaining a proper ecological balance. The pH of the water directly affects the physiological functions and nutrient utilization by plant and animal life. Extremes in pH can reduce a lake to a lifeless, smelly bog.

3.2 The ph Equation and Health: -

According to the research total healing of chronic illness takes place only when and if the blood is restored to a normal, slightly alkaline pH.

The magnitude of meaning behind this research is of incredible importance to someone who is fighting a disease, overcoming an illness, or just desiring to feel better.

3.3 Body pH affects everything: -

Human blood stays in a very narrow pH range right around 7.3. Below or above this range means symptoms and disease.

When pH goes off, microorganisms in the blood can change shape, mutate, become pathogenic, and thrive.

When pH goes off, ENZYMES that are constructive can become destructive.

More and more research is showing that low oxygen delivery to cells is a major factor in most if not all-degenerative conditions.

When pH is off and our bodies are running more acidic, our cells are getting less oxygen. Cancer thrives under an acid tissue pH/oxygen deficient environment. Is it any wonder today that cancer rates are up. To recall how important oxygen is to your life, just stop breathing for a minute. Get the idea? Each cell in your body can breathe fully or not. Which it is depends upon having an optimum pH balance

3.4 pH Controls the Things you can't live without: -

- **Brain: -** needs fuel to run, and the fuel it uses is glucose. But unlike other cells, your brain can't store glucose. It depends on the second to second supply from the bloodstream - a bloodstream that is affected by pH, which controls the efficiency of INSULIN, which allows sugar to enter into cells, which in turn controls blood sugar levels.

- **Heart: -**As the pH of the blood goes more acid, fatty acids, which are normally, electro-magnetically charged on the negative side switch to positive and automatically are attracted to and begin to stick to the walls of arteries which are electro-magnetically charged on the negative side. It should start to make sense that a society which over-emphasizes food that could push blood to be more acid will have a high rate of heart disease. And so it goes.

- **Enzymes: -** Which are parts of that biochemical process? There are hundreds if not thousands of enzyme processes, which take place in the body. Many are so specific that they are like complex square pegs that need to "fit" into specific square holes in order to carry out their duty. If blood pH is off balance even a little, some important pegs are not "fitting" their respective slots. Enzyme function and thus life itself begins to suffer.

3.5 Mineral Assimilation: -

Affected by pH. Minerals have different pH levels at which they can be assimilated into the body. Minerals on the lower end of the atomic scale can be assimilated in a wider pH range, and minerals higher up on the scale require a narrower and narrower pH range in order to be assimilated by the body. For example…

Sodium and magnesium have wide pH assimilation ranges.

It narrows somewhat for calcium and potassium.

Narrows more for manganese and iron.

More for zinc and copper.

More for iodine Too

Iodine, which is high up on the atomic scale, requires near perfect pH for its assimilation into the body.

Iodine you may know is one of the most important minerals for proper functioning of the *Thyroid*. But, the thyroid doesn't get access to iodine unless the body pH is near perfect.

With a society in a largely pH unbalanced state, one would suspect a lot of thyroid problems. Malfunctioning thyroids have been connected to arthritis, heart attacks, diabetes, cancer, depression, overweight, fatigue and more. Are you starting to see the basic metabolic picture evolving here?

Due primarily to agricultural soil depletion and over-acidic food consumption, mineral deficiency is a large problem facing most people today. And mineral deficiency relates to the quantity of life energy or, more specifically, electricity, in our bodies.

Body mineral content and balances control the quantity of electricity in our bodies.

The speed at which the electricity flows is controlled by the body's pH balance.

3.5.1 pH Balance and the Mineral Connection: -

There are complex biochemical processes taking place in the body constantly in an attempt to keep blood pH as near perfect as possible. These are known as the pH buffering systems. These buffering systems need a good balance of minerals to work effectively. If we are getting inadequate mineral intake from the food we eat, we are going to start having problems with our pH balancing systems.

And if our pH is unbalanced, what is the result? Well, by now you should start having a good idea. Pick your disease, choose your unbalance. Cancer, arthritis, diabetes, heart disease, chronic fatigue, allergies, obesity, just name it. If you don't feel good, one of the basic things that stand between you and perfect health is your body's pH. Your basic metabolic body balance.

3.5.2 Minerals: -

Minerals are as important as, if not more important than, vitamins. Minerals are co-enzymes, which help vitamins function. In the absence of minerals, vitamins can't do their job. Many minerals are referred to as trace minerals, which might make it, seem as though they are of little importance, but nothing could be further from the truth. Minerals and their deficiencies have been implicated in a wide range of off-balance health conditions. Here are some examples:

Supplementing a diet with sufficient chromium and vanadium can help prevent diabetes and has been seen to reverse diabetes in those already diabetic, as vanadium is reportedly able to replace insulin in some cases.

Copper deficiency is implicated in aneurysms (brain, aortic, etc.); too much copper is an irritant to the brain.

Magnesium is quite possibly the most important mineral for the reduction of coronary heart disease. (The latest "cutting edge" research shows that heart disease is really a function of heart muscle acidosis.)

Boron helps keep calcium in the bones, helps women preserve and make estrogen, and helps men keep testosterone. Boron affects alertness. Boron can help eliminate arthritis.

Potassium and magnesium (along with organic sodium) are some of the most important minerals for rebalancing the electrical properties of the cell, for eliminating excess acidity, and for helping to balance calcium. People get irrational when potassium levels are low.

Magnesium helps conduct electrical messages between all the neurons of the body.

Zinc is involved in over 200 brain enzyme interactions; drinking zinc mixed with distilled water can stop anorexia nervosa in a day. Zinc deficiency symptoms include loss of taste and smell, Zinc deficiency in children results in moodiness, depression, irritability, photo phobia (light sensitivity), antagonism, temper tantrums & learning problems. Zinc is needed to balance cadmium.

Cigarette smoke is rich in cadmium (the blue color in the smoke). Cadmium is the most neurotoxin substance known to human beings. A low zinc/high cadmium ratio is implicated in learning disabilities

This information shows just a teeny fraction of how minerals and mineral imbalances can affect your health. Much of this information is buried in professional journals, there for the taking. It appears that due to politics and the influence and strength that the medical/drug industrial complex has over the suppression of information, these things stay buried.

Your Disease is in Perfect Harmony with Your Body: -

From what you've learned so far, you should begin to understand the truth of this statement. When your body's mineral balances are off, your health is off. When your body's pH and basic metabolic processes are off, it sets up the internal environment that becomes a new playground for the opportunistic "bugs" - bacteria, viruses, fungi, etc.

Earlier we talked of the colloids of life in your blood. How they form and what they evolve into is a function of pH - the terrain of the blood. What else is a constituent of the blood? How about the mineral balances we've been speaking about. Research has shown that the microbes of the blood can evolve into different forms when exposed to and combined with elements like heavy metals. For example, patients with high levels of mercury in their mouths often exhibit specific pleomorphic microbes in their blood.

Is it possible that something like high levels of copper; are more than just an irritant to the brain? Might they set up the internal environment in the body whereby the colloids of life form into specific "bugs" that with some level of microbial consciousness are actually behind aggressive, violent or psychotic behavior? Some researchers would say that is exactly correct. And in so saying, your blood becomes much more than what you think it is.

Chapter Four
Project Design

- **Project Design.**
- **Amplifier.**
- **Temperature Sensors.**
- **ADC0804.**
- **Computer interface.**
- **MATLAB 6.5.**

Chapter four

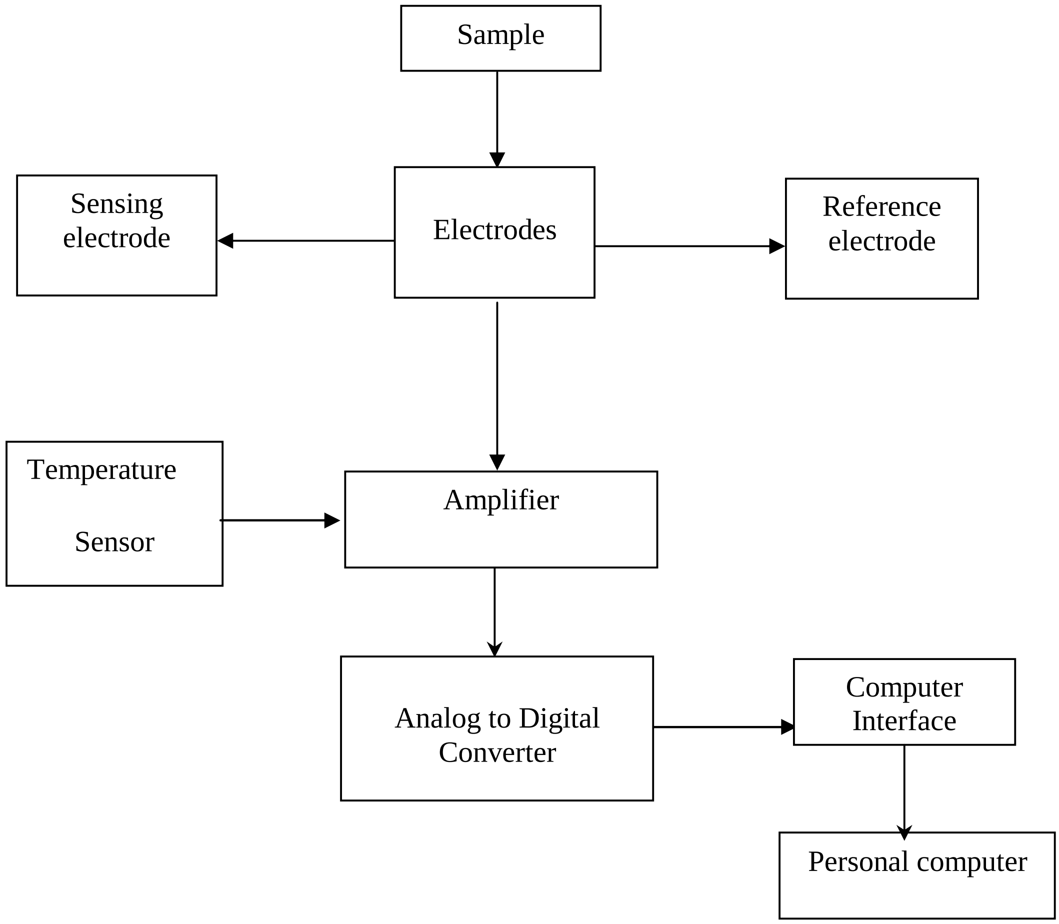
4.1 Project Design

4.1.1 Project objectives: -

- To have an experience in measurement of pH
- To have an experience in measurement of temperature.
- To know the construction, performance of pH meter
- To use the personal computer to show data.

.4.1.2 Block Diagram: -

The block diagram that follows is provided to give the reader the general idea about our project and basic understanding of pH meter system:



4.1.3 Sample: -

This is the solution that we want to measure pH (measure of acidity or alkalinity) for this solution:

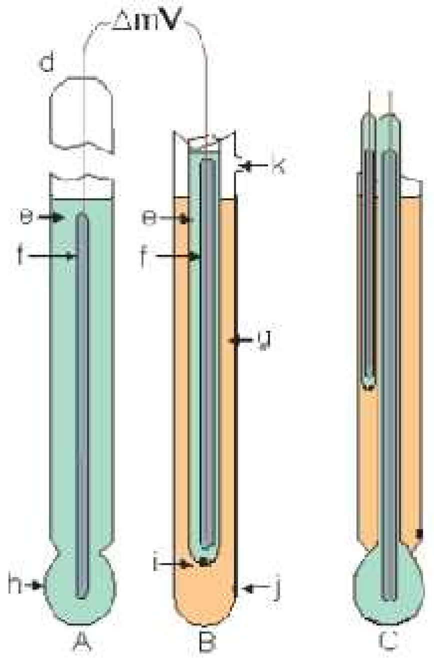
Table 4-1: pH value of some common products

Product	**pH**
Blood	7.35
Pure water	7.0
Coffee	5.0

4.1.4 Electrodes: -

pH electrode is a device for measuring the concentration of hydrogen ions and hence the degree of acidity of a solution since pH is defined as the negative logarithm of the hydrogen ion concentration. In other words the pH electrode, an electrode whose output voltage changes as the pH (hydrogen ion concentration) changes.

The majority of pH electrodes available are combination electrodes. That is, they combine the reference and pH sensing elements into a single electrode. Separate pH and reference electrodes can still be used, but this tends to be for highest precision, research measurements. Naturally, combination pH electrodes are much more practical to use.



Key:

A - pH sensor

B - reference half-cell

C - combination pH electrode (A + B)

d - seal

e - internal filling solution

f - internal reference electrode

g - external filling solution

h - pH-sensitive glass membrane

I - internal liquid junction

j - external liquid junction

k - fill hole

Figure 4-2: Electrode Components.

4.1.4.1 Reference electrode: -

A reference electrode is an electrode whose voltage output stays constant**.**

How does a reference electrode work?

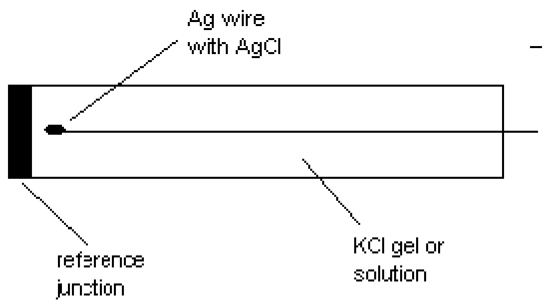


Figure 4-3: Reference Electrode.

A porous reference junction separates the filling solution in the electrode from the solution whose pH is to be measured.

The filling solution's constant chloride ion concentration generates a mill voltage at a pure silver wire with silver chloride on it**.**

The silver wire passes the signal from the solution being measured to the electrode's cable or connector.

4.1.4.2 Sensing electrode: -

Sensing electrode is an electrode that sensitive just to hydrogen ions [H^+].

How does the sensing electrode work?

Special composition glass senses H+ and a mill voltage is generated (59.2 mV per pH unit at 25C.)

A filling solution picks up the signal from the special pH glass

A pure silver wire dipped in silver chloride passes the signal from the solution whose pH is being measured to the electrode's cable or connector.

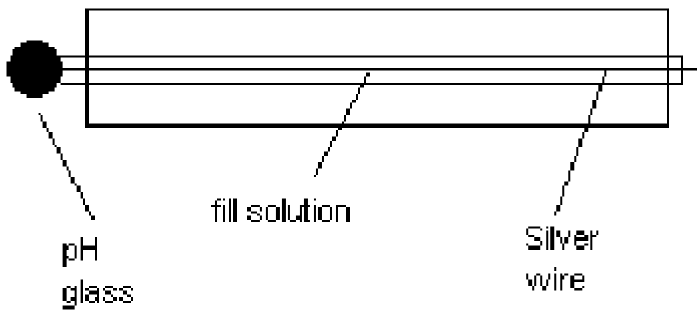


Figure 4-4: Sensing Electrode

4.1.4.3 Combination Electrode: -

A combination electrode consists of a pH electrode and a reference electrode built into a single body or housing. Therefore a combination electrode works like the pH and reference electrodes combined.

The question now how does a combination electrode work?

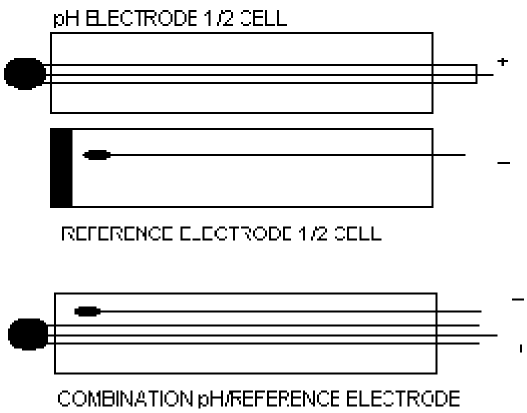


Figure 4-5: The Combination Electrode.

4.2 Amplifier: -

The TL084 JFET-input operational amplifier family is designed to offer a wider selection than any previously developed operational amplifier family. Each of these JFET-input operational amplifiers incorporates well-matched, high-voltage JFET and bipolar transistors in a monolithic integrated circuit. The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient. Offset adjustment and external compensation options are available within the TL084 family.

The C-suffix devices are characterized for operation from 0°C to 70°C. The I-suffix devices are characterized for operation from -40°C to 85°C. The Q-suffix devices are characterized for operation from -40°C to 125°C. The M-suffix devices are characterized for operation over the full military temperature range of -55°C to 125°C.

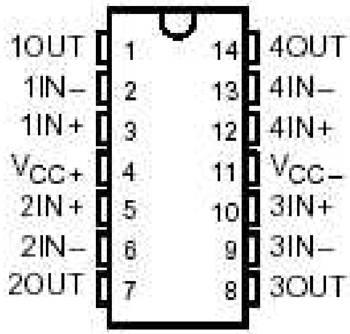


Figure 4-6: TL084.

4 .3 Temperature Sensors: -

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±1.4°C at room temperature and ±3.4°C over a full -55 to +150°C temperature range.

The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a -55° to +150°C temperature range, while the LM35C is rated for a --40° to +110°C range (-10° with improved accuracy).

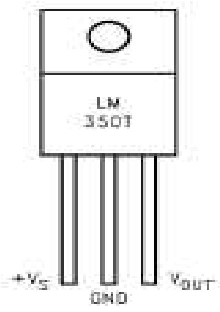


Fig.4-7: LM35DT

4.4ADC0804: -

The ADC0804 is CMOS 8-bit successive approximation A/D converters that use a differential potentiometer ladder-similar to the 256R products. These converters are designed to allow operation with the NSC800 and INS8080A derivative control bus with TRI-STATE output latches directly driving the data bus. These A/Ds appear like memory locations or I/O ports to the microprocessor and no interfacing logic is needed.

Differential analog voltage inputs allow increasing the common-mode rejection and offsetting the analog zero input voltage value. In addition, the voltage reference input can be adjusted to allow encoding any smaller analog voltage span to the full 8 bits of resolution.

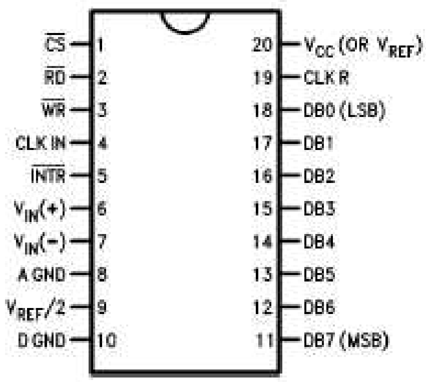


Figure 4-8: ADC 0804

4.5 Computer interface

4.5.1 A Parallel Ports: -

The Parallel Port is the most commonly used port for interfacing home made projects. This port will allow the input of up to 9 bits or the output of 12 bits at any one given time, thus requiring minimal external circuitry to implement many simpler tasks. The port is composed of 4 control lines, 5 status lines and 8 data lines. It's found commonly on the back of the PC as a D-Type 25 Pin female connector. There may also be a D-Type 25 pin male connector. This will be a serial RS-232 port and thus, is a totally incompatible port.

4.5.2 Parallel Port Basics: -

The Parallel Port is the most commonly used port for interfacing home made projects. This port will allow the input of up to 9 bits or the output of 12 bits at any one given time, thus requiring minimal external circuitry to implement many simpler tasks. The port is composed of 4 control lines, 5 status lines and 8 data lines. It's found commonly on the back of your PC as a D-Type 25 Pin female connector. There may also be a D-Type 25 pin male connector. This will be a serial RS-232 port and thus, is a totally incompatible port.

When a PC sends data to a printer or other device using a parallel port, it sends 8 bits of data (1 byte) at a time. These 8 bits are transmitted parallel to each other; as opposed to the same eight bits being transmitted serially (all in a single row) through a serial port. The standard parallel port is capable of sending 50 to 100 kilobytes of data per second.

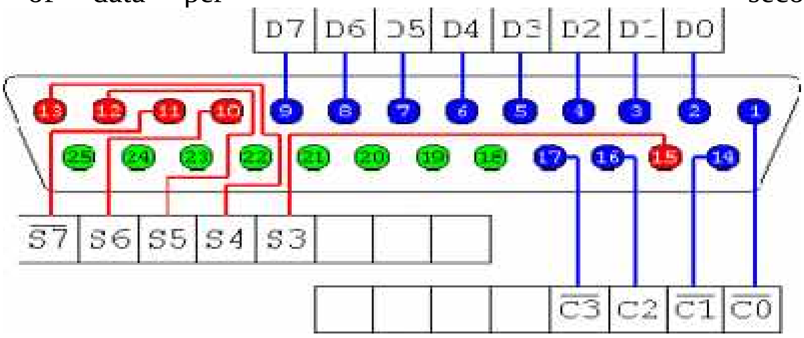


Fig.4-9: Parallel Port

- Whenever a new print job is ready, the computer drops the charge on Pin 16 to initialize the printer.
- Pin 17 is used by the computer to remotely take the printer offline. This is accomplished by sending a charge to the printer and maintaining it as long as you want the printer offline.
- Pins 18-25 are grounds and are used as a reference signal for the low (below 0.5 volts) charge.

4.6 MATLAB 6.5: -

MATLAB is an integrated technical computing environment that combines numeric computation, advanced graphics and visualization, and a high-level programming language. It is used in a variety of application areas including signal and image processing, control system design, financial engineering, and medical research.

Chapter Five
Hardware & Software

- **Hardware designs.**
- **Software.**

Chapter Five

5.1 hardware designs: -

The acid-base conductivity meter for medical solutions design using the following parts:

1. Design of amplifier circuit (TL084).
2. Design of 8-bit analog to digital converter (ADC0804).
3. Design of temperature sensor.
4. Design of Power supply.

5.1.1 Amplifier: -

We use the amplifier (TL084) to amplify the signals, which are generating from temperature sensor, and pH sensor. We connect the amplifier as non-inverting amplifier (i.e. the inputs are connected to pins 3,12. and the outputs are connected to pins 1,14).

In our application we want the voltage at output amplifier around ±5V maximum, so we need to amplify the signal 10 times.

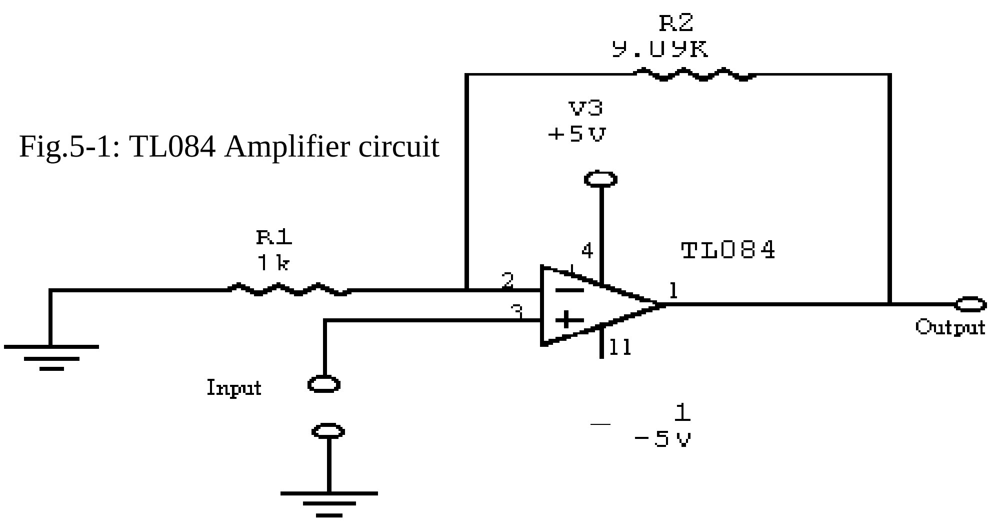


Fig.5-1: TL084 Amplifier circuit

5.1.2 Temperature Sensor: -

We use the LM35 Temperature sensor, which is used to sense and convert the temperature degree to the electric voltage. The value of this voltage is very small so we must connect this sensor with the amplifier to raise the electric voltage to the level of the ADC voltage.

The figure 5-2 shows the connection between the temperature sensors LM35 with the amplifier TL084.

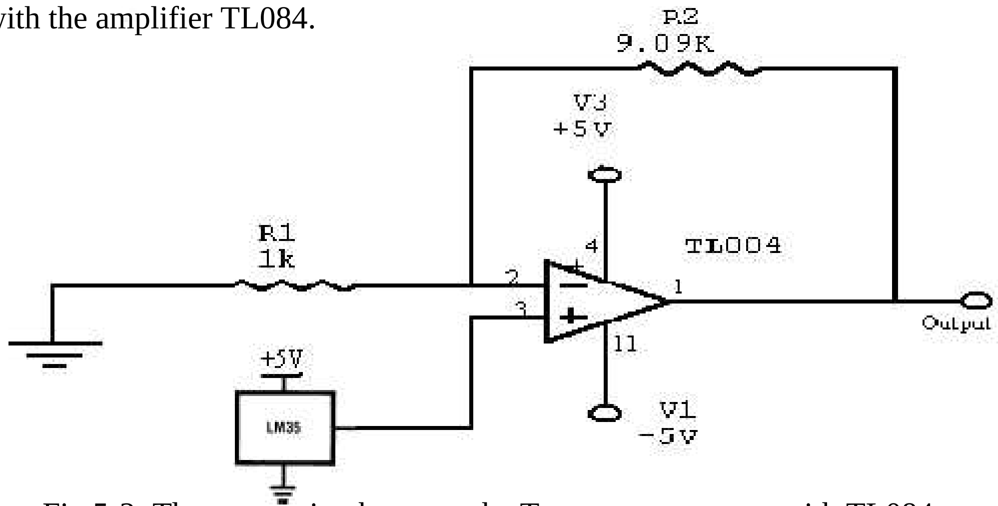


Fig.5-2: The connection between the Temperature sensor with TL084

5.1.3 Analog to Digital Converter: -

We use the ADC0804 to convert the analog signals (Temp. and pH) into digital data to connect the ADC with the computer.

Self-Clocking

The clock for the A/D can be derived from the CPU clock or an external RC can be added to provide self-clocking. TheCLK IN (pin 4) makes use of an Schmitt trigger as shown in Figure 5-3.

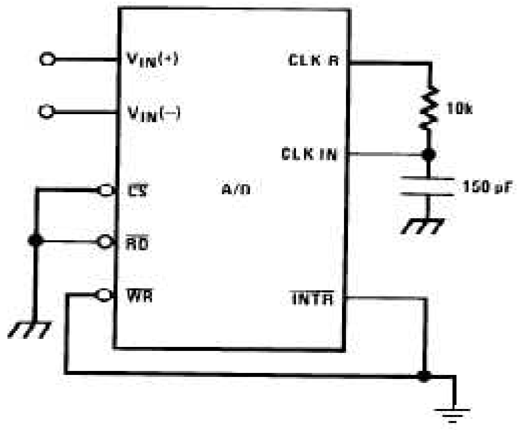


Fig. 5-3: Self-Clocking in Free-Running Mode

Handling ±5V Analog Inputs

For the pH electrode we need to handle a negative input in addition of positive inputs, the following figure (5-4) shows how to handle these inputs.

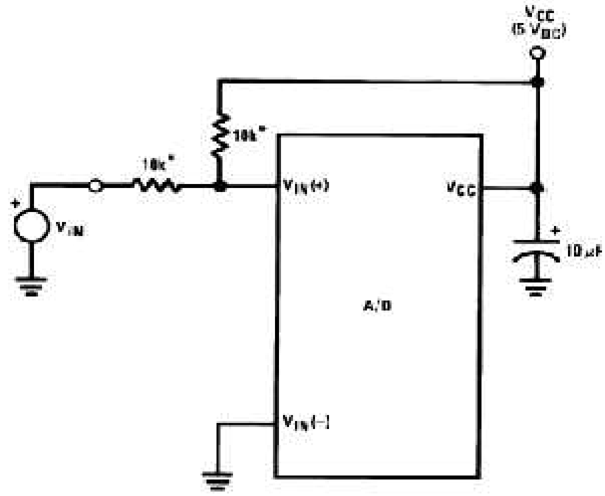


Fig.5-4: Handling ±5V Analog Inputs

5.1.4 pH electrode:

We use the HI1230B pH electrode. It is a combination general-purpose electrode, which is sensitive to the hydrogen concentration in the solution, and gives a voltage output (mV), which is treated and converted to give a pH value.

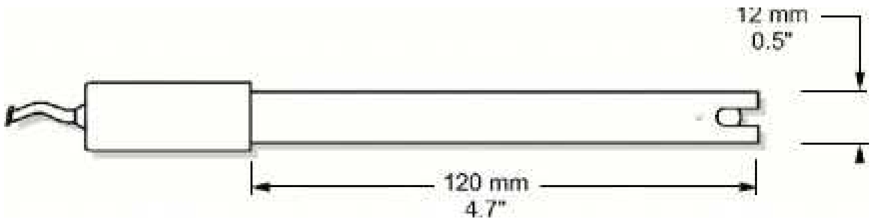


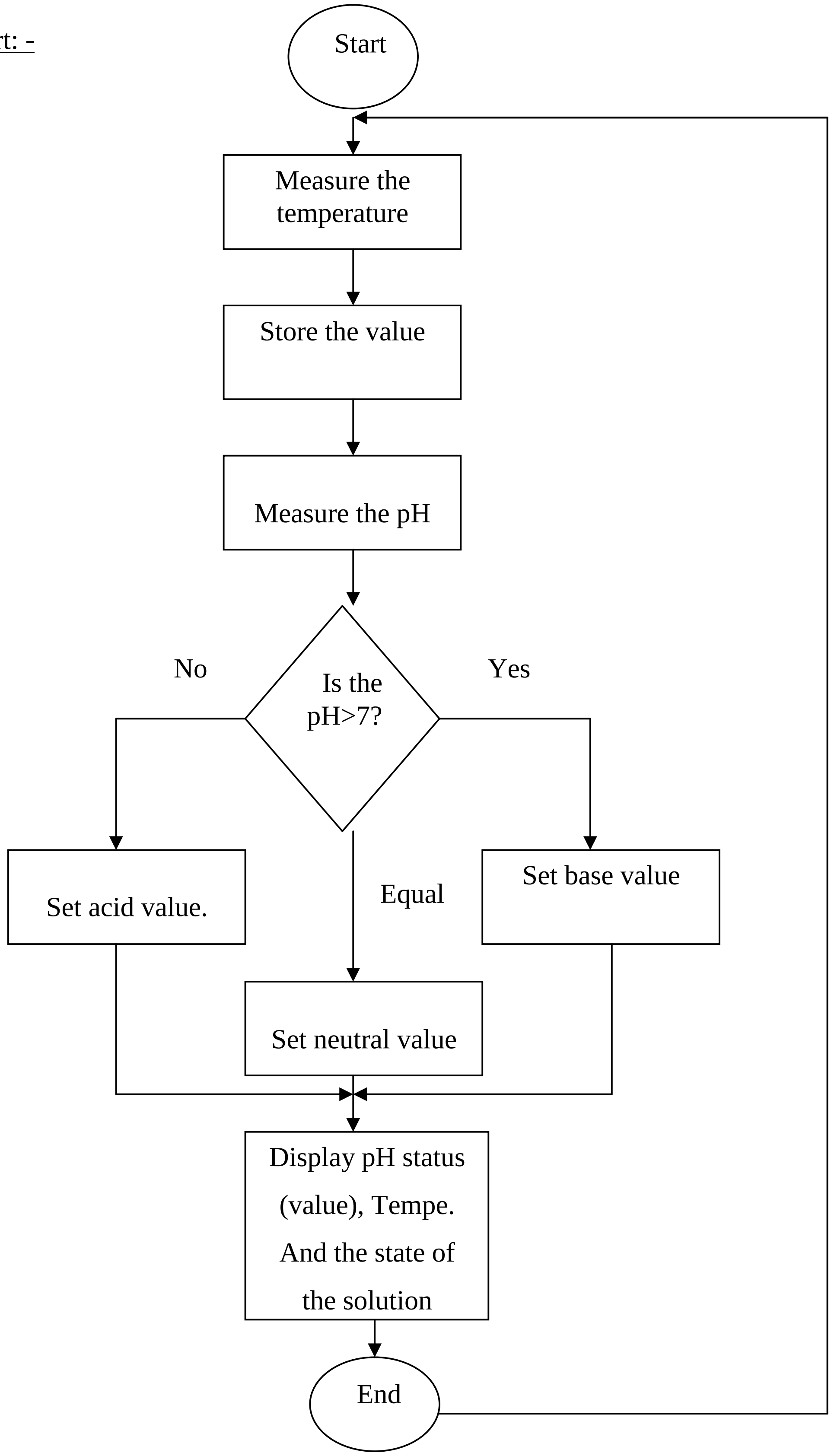
Fig.5-5: HI1230B pH electrode

5.2 Software: -

We use the matlab program to find the Ph value and temperature and we will explain how the program works:

- In the first the is two sensors and each one give very small voltage value and this two values dependent on each others
- And then through the program the two values are read from the parallel port.
- And then use the equation to find the two values.
- Finally the data will appear on the computer screen.

The Flow Chart: -



Chapter Six
Conclusion

Chapter six

Conclusion: -

- PH meter is very sensitive because of we detail with a very small signal by mv range so you must be use it be careful.

- PH is very important measure not for blood only but it is also important for urine, water, food, milk, chemical area, etc…

- Especially in medicine pH gives us big important in diseases diagnosis by pH test.

- pH is dependent on temperature.

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Appendix (A)

Schematics

Appendix (B)

Main Program

Appendix (C)

Data Sheets

References

1- John G Webster, The measurement Instrumentation, and Sensor, CSC Press LLC, Florida, USA. 1999.
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10- http://www.lce.org/equipment/phmeter/phoper.html.
11- http://www.ph-measurement.co.uk/glossary.html.
12- http://www.luminet.net/~wenonah/hydro/ph.html.
13- http://www.bgsu.edu/department/chem/faculty/endres/ch407/ch407_elect.html.
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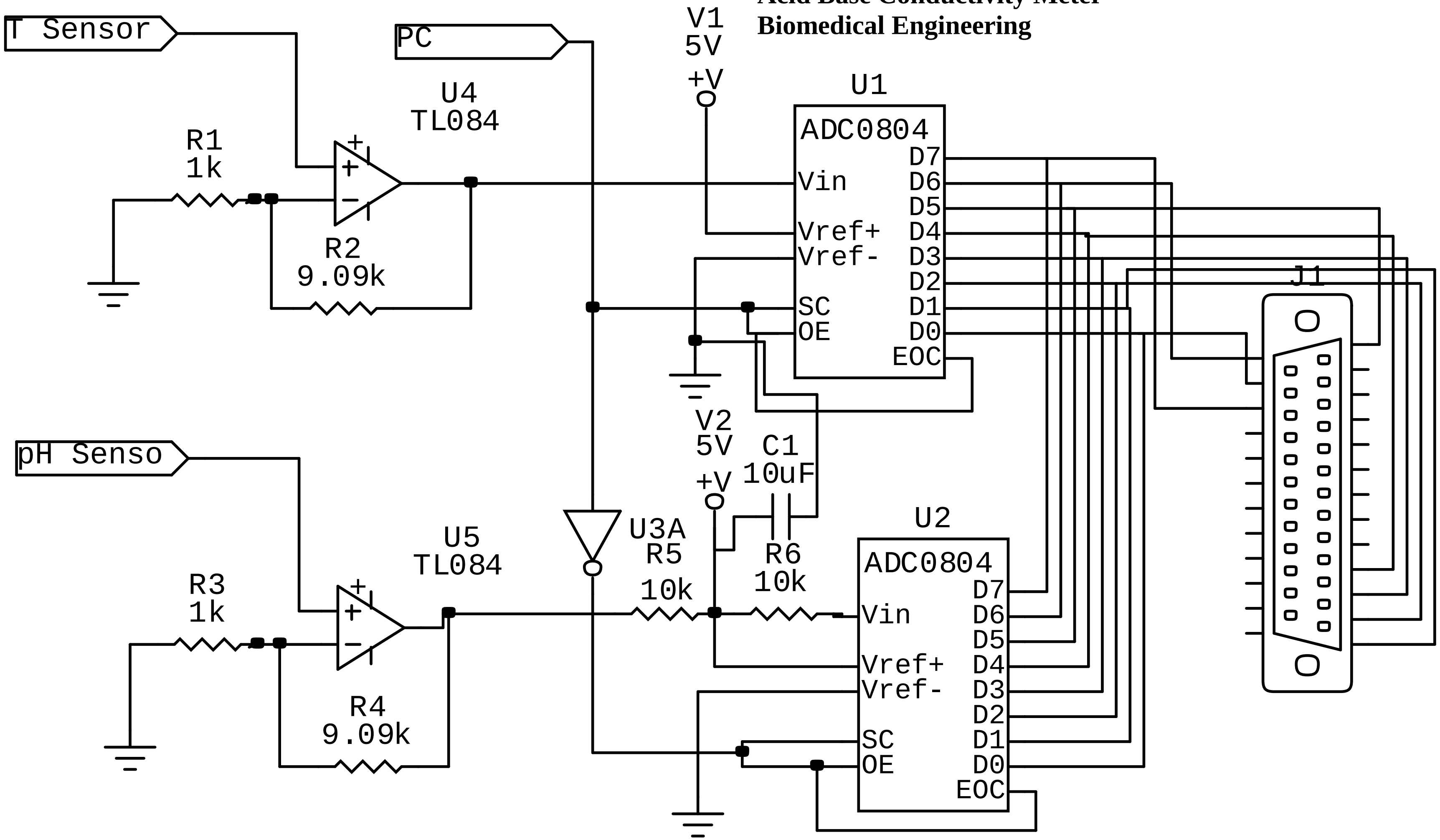
Schematic of Project

Mohammad Yousef Al-Hajajrah.
Mohanad Ghazi Helal
Acid Base Conductivity Meter
Biomedical Engineering



PRELIMINARY EXAMINATION

Remove the instrument from the packing materialand examine it carefully to make surethat no damage has occurred during shipping.If noticeable damage is found, notifyyour Dealer.

Each pH meter is supplied complete with:

- **HI1230B** Combination pH Electrode
- **HI7669/2W** Temperature Probe
- 1.5V AA size Alkaline Batteries (4 pcs)
- pH4, pH7 buffer and cleaning solutions(20 mL each)
- 12VDC power adapter
- Rugged Carrying Case.

The kit versions HI96240 and HI96250 include also:

- **HI92000** Windows® compatible software
- **HI920011** PC connection cable
- **HI3230B** platinum, gel, plastic bodyORP electrode (HI96250KIT only)

Note: Save all packing material until you aresure that the instrument functions correctly.

All defective items must be returnedin the original packaging togetherwith the supplied accessories.

TEMPERATURE EFFECT ON pH

The pH reading is directly effected by temperature.In order for the meter to measurethe pH accurately, temperature must be takenin consideration.

A perfect equilibrium between the pH electrodeand the sample is reached in approximately 15 minutes.To use the meter’s Automatic TemperatureCompensation feature, submerge the temperature probe into the sample as close to the electrode as possible and wait for 1-2 minutes. If you know the temperature of the sample to be tested you can manually compensate for it.

PH calipration:

For greatest accuracy, it is recommended that the instrument is calibrated frequently.For a faster operation, it is possible to standardize the electrode at pH 7.01 only (one point calibration), but it is always good practice to calibrate at least 2 points.The standard calibration program of the meter,however, is prepared for 3 (maximum) buffers.There is a choice of 5 memorized standard buffers:

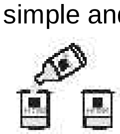
1st buffer (offset) pH **6.86** or **7.01**

2nd buffer (1st slope) pH **4.01**

3rd buffer (2nd slope) pH **9.18** or **10.01**

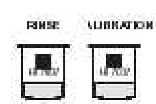
The calibration sequence values of the 2nd and 3rd buffers can be reversed.Due to electrode conditioning time the electrode must be kept immersed in the sample for a few seconds to stabilize. The user will be guided step by step with easy indications on the display during the pH calibration. This will make the calibration a simple and errorfree procedure.

INITIAL PREPARATION



Pour small quantities of:

- pH7.01 (**HI7007**/**HI8007**) or pH 6.86 (**HI7006**/**HI8006**)
- pH4.01 (**HI7004**/**HI8004**) or
- pH 10.01 (**HI7010**/**HI8010**) or pH 9.18 (**HI7009**/**HI8009**) solution into individual beakers.



If possible, use plastic beakers to minimize any EMC interferences. For accurate calibration use two beakers for each buffer solution, the first one for rinsing the electrode, the second one for calibration. By doing this, contamination between the buffers is minimized.To get accurate readings, use pH 7.01 (or pH 6.86) and pH 4.01 if you are going to

measure acid samples, or pH 7.01 and pH 10.01 (or pH 9.18) for alkaline measurements.
A 3-point calibration can also be performed (pH 7.01, 4.01 and 10.01).

pH VALUES AT VARIOUS TEMPERATURE

Temperature has an effect on pH. The calibration buffer solutions are effected by temperature changes to a lesser degree than normal solutions.
During calibration the meter will automatically calibrate to the pH value corresponding to the measured temperature (if used in conjunction with the **HI7669/2W** temperature probe) or to the manually set temperature.

TEMP		pH VALUES				
°C	°F	4.01	6.86	7.01	9.18	10.01
0	32	4.01	6.98	7.13	9.46	10.32
5	41	4.00	6.95	7.10	9.39	10.24
10	50	4.00	6.92	7.07	9.33	10.18
15	59	4.00	6.90	7.04	9.27	10.12
20	68	4.00	6.88	7.03	9.22	10.06
25	77	4.01	6.86	7.01	9.18	10.01
30	86	4.02	6.85	7.00	9.14	9.96
35	95	4.03	6.84	6.99	9.10	9.92
40	104	4.04	6.84	6.98	9.07	9.88
45	113	4.05	6.83	6.98	9.04	9.85
50	122	4.06	6.83	6.98	9.01	9.82
55	131	4.07	6.84	6.98	8.99	9.79
60	140	4.09	6.84	6.98	8.97	9.77
65	149	4.11	6.85	6.99	8.95	9.76
70	158	4.12	6.85	6.99	8.93	9.75

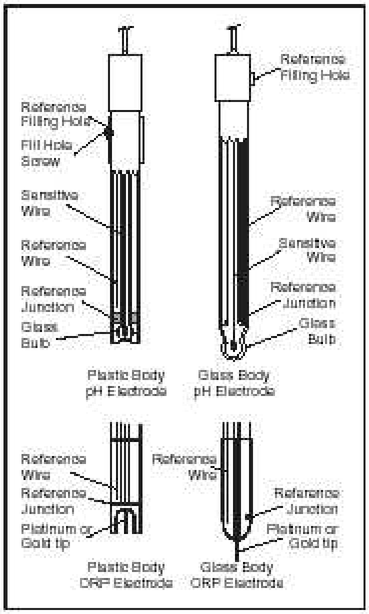
For instance, if the buffer's temperature is 25°C, the display will show pH `4.01` or `7.01` or `10.01`.
If the buffer's temperature is 20°C, the display will show pH `4.00`/`7.03`/`10.06`.
If the buffer's temperature is 50°C, the display will show pH `4.06`/`6.98`/`9.82`.

TEMPERATURE AND mV CALIBRATION

Each meter has been factory calibrated for the temperature and mV and is ready for measurements.
The temperature probes and ORP electrodes are interchangeable and no temperature or mV calibration is needed when the temperature probe or the ORP electrode is replaced.
If, for any reason, the temperature or the mV

measurements are out of accuracy, the temperature or the mV re-calibration should be carried out.
For an accurate recalibration, contact your nearest Hanna Service Center.

ELECTRODE CONDITIONING AND MAINTENANCE



PREPARATION

Remove the protective cap.
DO NOT BE ALARMED IF ANY SALT DEPOSITS ARE PRESENT.
This is normal with electrodes and they will disappear when rinsed with water.
During transport tiny bubbles of air may have formed inside the glass bulb. The electrode cannot function properly under these conditions. These bubbles can be removed by "shaking down" the electrode as you would do with a glass thermometer.
If the bulb and/or junction are dry, soak the electrode in **HI70300 or HI 80300** Storage Solution for at least one hour.

For refillable electrodes:

If the filling solution (electrolyte) is more than 1 cm (½") below the fill hole, add **HI 7082 or HI 8082 3,5M KCl Electrolyte Solution** for double junction or **HI 7071 or HI8071 3,5M KCl+AgCl Electrolyte Solution** for single junction electrodes.
For a faster response, loosen the fill hole screw during measurements.

For AmpHel® electrodes:

If the electrode does not respond to pH

changes, the battery is run down and the electrode should be replaced.

MEASUREMENT

Rinse the electrode tip with distilled water. Immerse the tip (4 cm /1½") in the sample and stir gently for at least 30 seconds. For a faster response and to avoid cross contamination of the samples, rinse the electrode tip with a few drops of the solution to be tested, before taking measurements.

STORAGE

To minimize clogging and assure a quick response time, the glass bulb and the junction should be kept moist and not allowed to dry out.

Replace the solution in the protective cap with a few drops of **HI70300 or HI 80300 Storage Solution** or, in its absence, **Filling Solution** (**HI7071 or HI8071** for single junction or **HI 7082 or HI8082** for double junction electrodes). Follow the Preparation Procedure above before taking measurements.

Note: NEVER STORE THE ELECTRODE IN DISTILLED WATER OR DRY.

PERIODIC MAINTENANCE

Inspect the electrode and the cable. The cable used for the connection to the meter must be intact and there must be no points of broken insulation on the cable or cracks on the electrode stem or bulb. Connectors must be perfectly clean and dry.

If any scratches or cracks are present, replace the electrode.

Rinse off any salt deposits with water.

For refillable electrodes:

Refill the reference chamber with fresh electrolyte (**HI 7071 or HI 8071** for single junction or **HI7082 or HI 8082** for double junction electrodes). Allow the electrode to stand upright for 1 hour.

Follow the Storage Procedure above.

CLEANING PROCEDURE

General Soak in Hanna **HI7061 or HI8061 General Cleaning Solution** for approximately 1 hour.

Removal of films, dirt or deposits on the membrane/junction:

- *Protein* Soak in Hanna **HI7073 or HI8073 Protein Cleaning Solution** for 15 minutes.
- *Inorganic* Soak in Hanna **HI 7074 or HI 8074 Inorganic Cleaning Solution** for 15 minutes.
- *Oil/grease* Rinse with Hanna **HI7077 or HI 8077 Oil and Fat Cleaning Solution**.

IMPORTANT: After performing any of the cleaning procedures rinse the electrode thoroughly with distilled water, refill the reference chamber with fresh electrolyte, (not necessary for GEL filled electrodes) and soak the electrode in **HI70300 or HI 80300 Storage Solution** for at least 1 hour before taking measurements.

TROUBLESHOOTING

Evaluate your electrode performance based on the following.

• **Noise** (Readings fluctuate up and down) could be due to:

- Clogged/Dirty Junction: Refer to the Cleaning Procedure above.

- Loss of shielding due to low electrolyte level (in refillable electrodes only): refill with fresh **HI7071 or HI 8071** for single junction or **HI 7082 or HI8082** for double junction electrodes.

• **Dry Membrane/Junction:** Soak in **Storage Solution HI70300 or HI80300** for at least 1 hour.

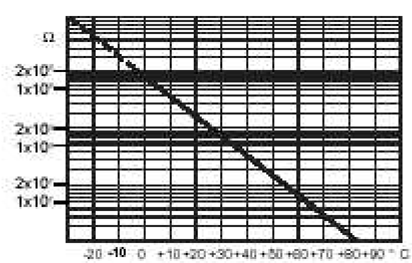
• **Drifting:** Soak the electrode tip in warm Hanna Solution **HI7082 or HI 8082** for one hour and rinse tip with distilled water. Refill with fresh **HI7071 or HI8071** for single junction electrodes and **HI 7082 or HI8082** for double junction electrodes.

• **Low Slope:** Refer to the cleaning procedure above.

• **No Slope:** Check the electrode for cracks in glass stem or bulb and replace the electrode.

• **Slow Response/Excessive Drift:** Soak the tip in Hanna Solution **HI7061 or HI8061** for 30 minutes, rinse thoroughly in distilled water and then follow the Cleaning Procedure above.

TEMPERATURE-RESISTANCE CORRELATION FOR HANNA PH SENSITIVE GLASS



The resistance of glass electrodes partially depends on the temperature. The lower the temperature, the higher the resistance. It takes longer time for the reading to stabilize if the resistance is higher. In addition, the response time will suffer to a greater degree at temperatures below 10°C.

Since the resistance of the pH electrode is in the range of 200 Mohm, the current across the membrane is in the pico Ampere range. Large currents can disturb the calibration of the electrode for many hours.

For these reasons **high humidity environments,**

short circuits and static discharges
are detrimental for a stable pH reading.
The pH electrode's life also depends on the temperature. If constantly used at high temperatures, the electrode life is drastically reduced.

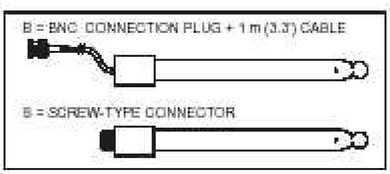
Typical Electrode Life	
Ambient Temperature	1- 3 years
90 °C	Less than 4 months
120°C	Less than 1 month

High concentrations of sodium ions interfere with readings in alkaline solutions; the pH at which the interference starts to be significant depends upon the composition of the glass. This interference is the alkaline error and causes the pH readings to be underestimated. Hanna's glass formulations have the indicated characteristics.

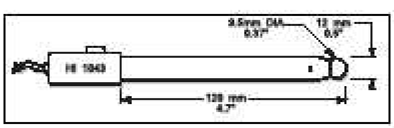
Alkaline Error

Sodium Ion Correction for the Glass at 20-25°C		
Concentration	pH	Error
0.1 Mol L^{-1} Na^+	13.00	0.10
	13.50	0.14
	14.00	0.20
1.0 Mol L^{-1} Na^+	12.50	0.10
	13.00	0.18
	13.50	0.29
	14.00	0.40

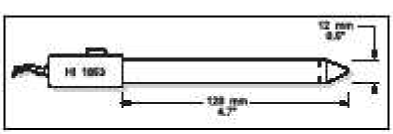
pH ELECTRODES



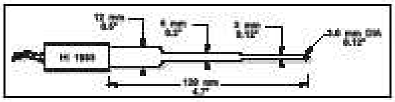
HI1043B / HI1040S
Glass-body, double junction, refillable, combination **pH** electrode. Use: strong acid/alkali.



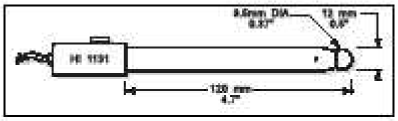
HI1053B / HI1050S
Glass-body, triple ceramic, conic shape, refillable, combination **pH** electrode. Use: emulsions.



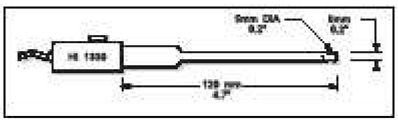
HI1083B
Glass-body, micro, Viscolene, nonrefillable, combination **pH** electrode. Use: biotechnology,micro titration.



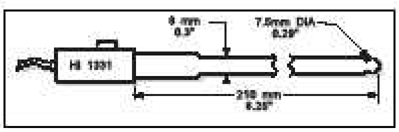
HI1131B / HI1111S
Glass-body, single junction, refillable, combination **pH** electrode. Use: general purpose.



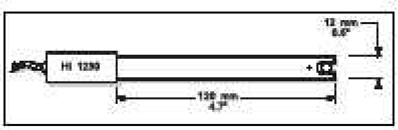
HI1330B / HI1310S
Glass-body, semimicro, single junction, refillable, combination **pH** electrode. Use: laboratory.



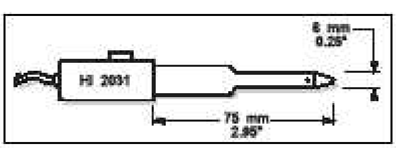
HI1331B / HI1311S
Glass-body, semimicro, single junction, refillable, combination **pH** electrode. Use: flasks.



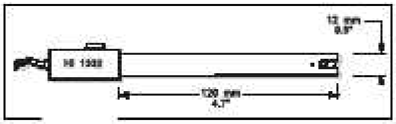
HI1230B / HI1210S
Plastic-body (Ultem®), double junction, gelfilled, combination **pH** electrode. Use: general purpose.



HI2031B / HI2020S
Glass-body, semimicro, conic, refillable, combination **pH** electrode. Use: semisolid products.

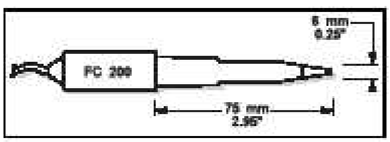


HI1332B / HI1312S
Plastic-body (Ultem®), double junction, refillable, combination **pH** electrode. Use: general purpose.

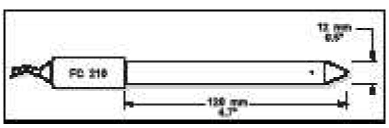


FC100B
Plastic-body (Kynar®), double junction, refillable, combination **pH** electrode. Use: general purpose for food industry.

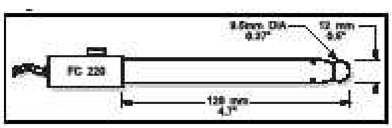
FC200B / FC200S
Plastic-body (Kynar®), single junction, conic, Viscolene, refillable, combination **pH** electrode. Use: meat & cheese.



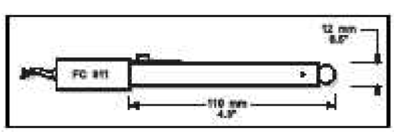
FC210B
Glass-body, double junction, conic, Viscolene, combination **pH** electrode. Use: milk, yogurt.



FC220B
Glass-body, single junction, refillable, combination **pH** electrode. Use: food & wine processing.



FC911B
Plastic-body (Kynar®), double junction, refillable with built-in amplifier, combination **pH** electrode. Use: very high humidity.



HI1413B / HI1410S
Glass-body, single junction, flat tip, Viscolene, combination **pH** electrode. Use: surface measurement.

Extension cables for screw-type electrodes only (screw to BNC connector)

HI7855/1 Extension cable 1m (3.3’) long
HI7855/3 Extension cable 3m (9.9’) long
HI7855/5 Extension cable 5m (16.5’) long
HI7855/10 Extension cable 10m (33’) long
HI7855/15 Extension cable 15m (49.5’) long
1

National Semiconductor

November 1999

ADC0801/ADC0802/ADC0803/ADC0804/ADC0805 8-Bit µP Compatible A/D Converters

General Description

The ADC0801, ADC0802, ADC0803, ADC0804 and ADC0805 are CMOS 8-bit successive approximation A/D converters that use a differential potentiometric ladder — similar to the 256R products. These converters are designed to allow operation with the NSC800 and INS8080A derivative control bus with TRI-STATE output latches directly driving the data bus. These A/Ds appear like memory locations or I/O ports to the microprocessor and no interfacing logic is needed.

Differential analog voltage inputs allow increasing the common-mode rejection and offsetting the analog zero input voltage value. In addition, the voltage reference input can be adjusted to allow encoding any smaller analog voltage span to the full 8 bits of resolution.

Features

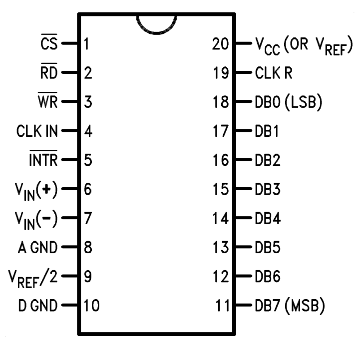
- Compatible with 8080 µP derivatives — no interfacing logic needed - access time - 135 ns
- Easy interface to all microprocessors, or operates “stand alone”
- Differential analog voltage inputs
- Logic inputs and outputs meet both MOS and TTL voltage level specifications
- Works with 2.5V (LM336) voltage reference
- On-chip clock generator
- 0V to 5V analog input voltage range with single 5V supply
- No zero adjust required
- 0.3" standard width 20-pin DIP package
- 20-pin molded chip carrier or small outline package
- Operates ratiometrically or with 5 V_{DC}, 2.5 V_{DC}, or analog span adjusted voltage reference

Key Specifications

- Resolution: 8 bits
- Total error: ±¼ LSB, ±½ LSB and ±1 LSB
- Conversion time: 100 µs

Connection Diagram

ADC080X
Dual-In-Line and Small Outline (SO) Packages



DS005671-30

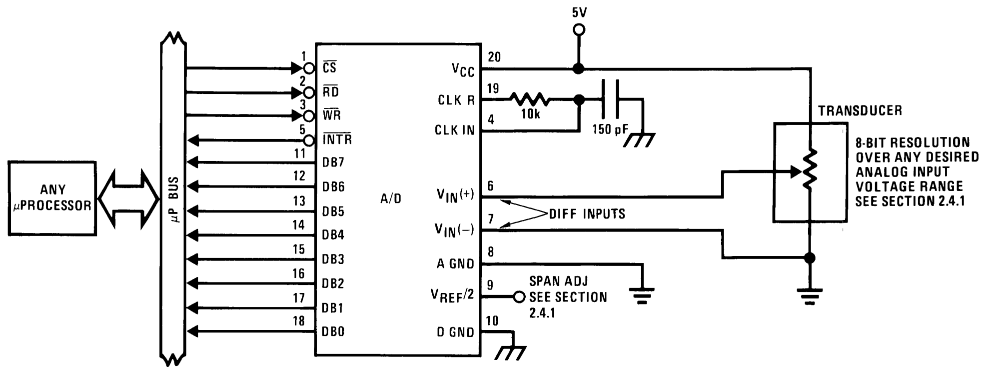
See Ordering Information

Ordering Information

TEMP RANGE		0˚C TO 70˚C	0˚C TO 70˚C	−40˚C TO +85˚C
ERROR	±¼ Bit Adjusted			ADC0801LCN
	±½ Bit Unadjusted	ADC0802LCWM		ADC0802LCN
	±½ Bit Adjusted			ADC0803LCN
	±1Bit Unadjusted	ADC0804LCWM	ADC0804LCN	ADC0805LCN/ADC0804LCJ
PACKAGE OUTLINE		M20B — Small Outline	N20A — Molded DIP	

Z-80® is a registered trademark of Zilog Corp.

Typical Applications



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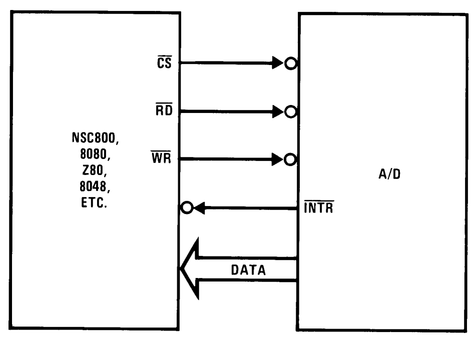
8080 Interface



DS005671-31

Error Specification (Includes Full-Scale, Zero Error, and Non-Linearity)			
Part Number	**Full-Scale Adjusted**	**V_{REF}/2=2.500 V_{DC} (No Adjustments)**	**V_{REF}/2=No Connection (No Adjustments)**
ADC0801	±¼ LSB		
ADC0802		±½ LSB	
ADC0803	±½ LSB		
ADC0804		±1 LSB	
ADC0805			±1 LSB

Absolute Maximum Ratings (Notes 1, 2)

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

Supply Voltage (V_{CC}) (Note 3)	6.5V
Voltage	
Logic Control Inputs	−0.3V to +18V
At Other Input and Outputs	−0.3V to (V_{CC}+0.3V)
Lead Temp. (Soldering, 10 seconds)	
Dual-In-Line Package (plastic)	260˚C
Dual-In-Line Package (ceramic)	300˚C
Surface Mount Package	
Vapor Phase (60 seconds)	215˚C
Infrared (15 seconds)	220˚C
Storage Temperature Range	−65˚C to +150˚C
Package Dissipation at T_A=25˚C	875 mW
ESD Susceptibility (Note 10)	800V

Operating Ratings (Notes 1, 2)

Temperature Range	$T_{MIN} \le T_A \le T_{MAX}$
ADC0804LCJ	$-40˚C \le T_A \le +85˚C$
ADC0801/02/03/05LCN	$-40˚C \le T_A \le +85˚C$
ADC0804LCN	$0˚C \le T_A \le +70˚C$
ADC0802/04LCWM	$0˚C \le T_A \le +70˚C$
Range of V_{CC}	4.5 V_{DC} to 6.3 V_{DC}

Electrical Characteristics

The following specifications apply for V_{CC}=5 V_{DC}, $T_{MIN} \le T_A \le T_{MAX}$ and f_{CLK}=640 kHz unless otherwise specified.

Parameter	Conditions	Min	Typ	Max	Units
ADC0801: Total Adjusted Error (Note 8)	With Full-Scale Adj. (See Section 2.5.2)			±¼	LSB
ADC0802: Total Unadjusted Error (Note 8)	V_{REF}/2=2.500 V_{DC}			±½	LSB
ADC0803: Total Adjusted Error (Note 8)	With Full-Scale Adj. (See Section 2.5.2)			±½	LSB
ADC0804: Total Unadjusted Error (Note 8)	V_{REF}/2=2.500 V_{DC}			±1	LSB
ADC0805: Total Unadjusted Error (Note 8)	V_{REF}/2-No Connection			±1	LSB
V_{REF}/2 Input Resistance (Pin 9)	ADC0801/02/03/05 ADC0804 (Note 9)	2.5 0.75	8.0 1.1		kΩ kΩ
Analog Input Voltage Range	(Note 4) V(+) or V(−)	Gnd–0.05		V_{CC}+0.05	V_{DC}
DC Common-Mode Error	Over Analog Input Voltage Range		±1/16	±⅛	LSB
Power Supply Sensitivity	V_{CC}=5 V_{DC} ±10% Over Allowed V_{IN}(+) and V_{IN}(−) Voltage Range (Note 4)		±1/16	±⅛	LSB

AC Electrical Characteristics

The following specifications apply for V_{CC}=5 V_{DC} and $T_{MIN} \le T_A \le T_{MAX}$ unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
T_C	Conversion Time	f_{CLK}=640 kHz (Note 6)	103		114	µs
T_C	Conversion Time	(Notes 5, 6)	66		73	1/f_{CLK}
f_{CLK}	Clock Frequency Clock Duty Cycle	V_{CC}=5V, (Note 5)	100 40	640	1460 60	kHz %
CR	Conversion Rate in Free-Running Mode	$\overline{INTR}$ tied to $\overline{WR}$ with $\overline{CS}$ =0 V_{DC}, f_{CLK}=640 kHz	8770		9708	conv/s
$t_{W(\overline{WR})L}$	Width of $\overline{WR}$ Input (Start Pulse Width)	$\overline{CS}$ =0 V_{DC} (Note 7)	100			ns
t_{ACC}	Access Time (Delay from Falling Edge of $\overline{RD}$ to Output Data Valid)	C_L=100 pF		135	200	ns
t_{1H}, t_{0H}	TRI-STATE Control (Delay from Rising Edge of $\overline{RD}$ to Hi-Z State)	C_L=10 pF, R_L=10k (See TRI-STATE Test Circuits)		125	200	ns
t_{WI}, t_{RI}	Delay from Falling Edge of $\overline{WR}$ or $\overline{RD}$ to Reset of $\overline{INTR}$			300	450	ns
C_{IN}	Input Capacitance of Logic Control Inputs			5	7.5	pF

AC Electrical Characteristics (Continued)

The following specifications apply for V_{CC}=5 V_{DC} and T_{MIN}≤T_A≤T_{MAX} unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
C_{OUT}	TRI-STATE Output Capacitance (Data Buffers)			5	7.5	pF
CONTROL INPUTS [Note: CLK IN (Pin 4) is the input of a Schmitt trigger circuit and is therefore specified separately]						
V_{IN} (1)	Logical “1” Input Voltage (Except Pin 4 CLK IN)	V_{CC}=5.25 V_{DC}	2.0		15	V_{DC}
V_{IN} (0)	Logical “0” Input Voltage (Except Pin 4 CLK IN)	V_{CC}=4.75 V_{DC}			0.8	V_{DC}
I_{IN} (1)	Logical “1” Input Current (All Inputs)	V_{IN}=5 V_{DC}		0.005	1	µA_{DC}
I_{IN} (0)	Logical “0” Input Current (All Inputs)	V_{IN}=0 V_{DC}	−1	−0.005		µA_{DC}
CLOCK IN AND CLOCK R						
V_T+	CLK IN (Pin 4) Positive Going Threshold Voltage		2.7	3.1	3.5	V_{DC}
V_T−	CLK IN (Pin 4) Negative Going Threshold Voltage		1.5	1.8	2.1	V_{DC}
V_H	CLK IN (Pin 4) Hysteresis (V_T+)−(V_T−)		0.6	1.3	2.0	V_{DC}
V_{OUT} (0)	Logical “0” CLK R Output Voltage	I_O=360 µA V_{CC}=4.75 V_{DC}			0.4	V_{DC}
V_{OUT} (1)	Logical “1” CLK R Output Voltage	I_O=−360 µA V_{CC}=4.75 V_{DC}	2.4			V_{DC}
DATA OUTPUTS AND $\overline{INTR}$						
V_{OUT} (0)	Logical “0” Output Voltage Data Outputs $\overline{INTR}$ Output	 I_{OUT}=1.6 mA, V_{CC}=4.75 V_{DC} I_{OUT}=1.0 mA, V_{CC}=4.75 V_{DC}			 0.4 0.4	 V_{DC} V_{DC}
V_{OUT} (1)	Logical “1” Output Voltage	I_O=−360 µA, V_{CC}=4.75 V_{DC}	2.4			V_{DC}
V_{OUT} (1)	Logical “1” Output Voltage	I_O=−10 µA, V_{CC}=4.75 V_{DC}	4.5			V_{DC}
I_{OUT}	TRI-STATE Disabled Output Leakage (All Data Buffers)	V_{OUT}=0 V_{DC} V_{OUT}=5 V_{DC}	−3		 3	µA_{DC} µA_{DC}
I_{SOURCE}		V_{OUT} Short to Gnd, T_A=25˚C	4.5	6		mA_{DC}
I_{SINK}		V_{OUT} Short to V_{CC}, T_A=25˚C	9.0	16		mA_{DC}
POWER SUPPLY						
I_{CC}	Supply Current (Includes Ladder Current)	f_{CLK}=640 kHz, V_{REF}/2=NC, T_A=25˚C and $\overline{CS}$ =5V				
	ADC0801/02/03/04LCJ/05			1.1	1.8	mA
	ADC0804LCN/LCWM			1.9	2.5	mA

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

Note 2: All voltages are measured with respect to Gnd, unless otherwise specified. The separate A Gnd point should always be wired to the D Gnd.

Note 3: A zener diode exists, internally, from V_{CC} to Gnd and has a typical breakdown voltage of 7 V_{DC}.

Note 4: For V_{IN}(−)≥ V_{IN}(+) the digital output code will be 0000 0000. Two on-chip diodes are tied to each analog input (see block diagram) which will forward conduct for analog input voltages one diode drop below ground or one diode drop greater than the V_{CC} supply. Be careful, during testing at low V_{CC} levels (4.5V), as high level analog inputs (5V) can cause this input diode to conduct–especially at elevated temperatures, and cause errors for analog inputs near full-scale. The spec allows 50 mV forward bias of either diode. This means that as long as the analog V_{IN} does not exceed the supply voltage by more than 50 mV, the output code will be correct. To achieve an absolute 0 V_{DC} to 5 V_{DC} input voltage range will therefore require a minimum supply voltage of 4.950 V_{DC} over temperature variations, initial tolerance and loading.

Note 5: Accuracy is guaranteed at f_{CLK} = 640 kHz. At higher clock frequencies accuracy can degrade. For lower clock frequencies, the duty cycle limits can be extended so long as the minimum clock high time interval or minimum clock low time interval is no less than 275 ns.

Note 6: With an asynchronous start pulse, up to 8 clock periods may be required before the internal clock phases are proper to start the conversion process. The start request is internally latched, see *Figure 4* and section 2.0.

AC Electrical Characteristics (Continued)

Note 7: The $\overline{CS}$ input is assumed to bracket the $\overline{WR}$ strobe input and therefore timing is dependent on the $\overline{WR}$ pulse width. An arbitrarily wide pulse width will hold the converter in a reset mode and the start of conversion is initiated by the low to high transition of the $\overline{WR}$ pulse (see timing diagrams).

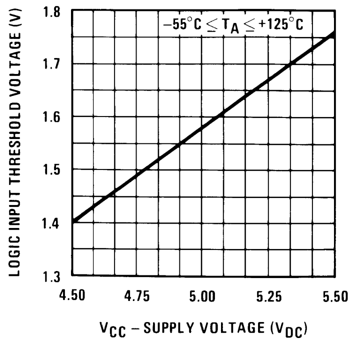
Note 8: None of these A/Ds requires a zero adjust (see section 2.5.1). To obtain zero code at other analog input voltages see section 2.5 and *Figure 7.*

Note 9: The $V_{REF}/2$ pin is the center point of a two-resistor divider connected from V_{CC} to ground. In all versions of the ADC0801, ADC0802, ADC0803, and ADC0805, and in the ADC0804LCJ, each resistor is typically 16 kΩ. In all versions of the ADC0804 except the ADC0804LCJ, each resistor is typically 2.2 kΩ.

Note 10: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

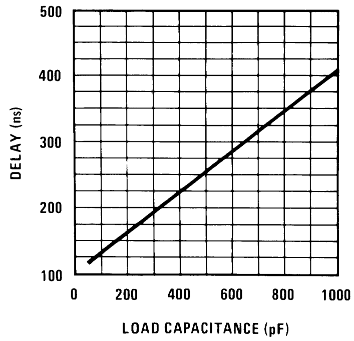
Typical Performance Characteristics

Logic Input Threshold Voltage vs. Supply Voltage



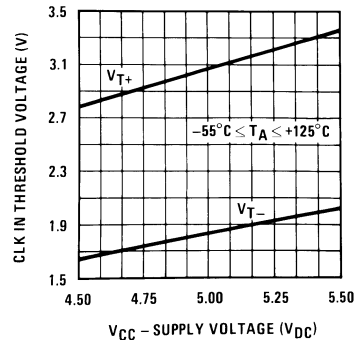
DS005671-38

Delay From Falling Edge of RD to Output Data Valid vs. Load Capacitance



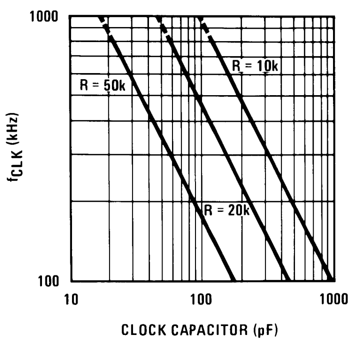
DS005671-39

CLK IN Schmitt Trip Levels vs. Supply Voltage



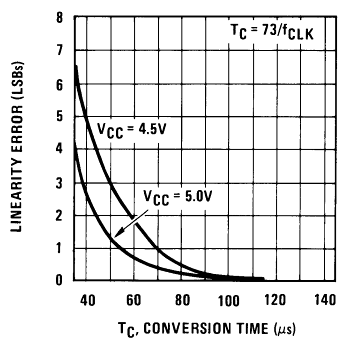
DS005671-40

f_{CLK} vs. Clock Capacitor



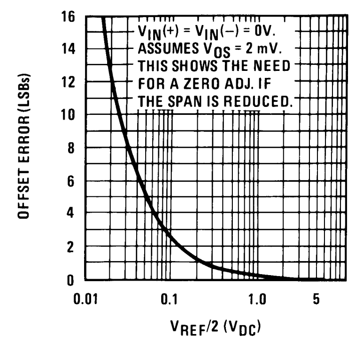
DS005671-41

Full-Scale Error vs Conversion Time



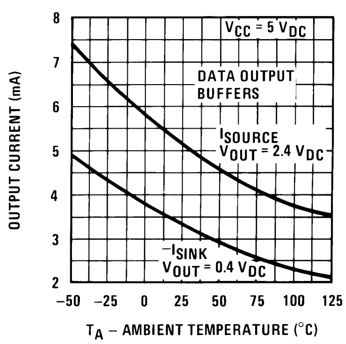
DS005671-42

Effect of Unadjusted Offset Error vs. $V_{REF}/2$ Voltage



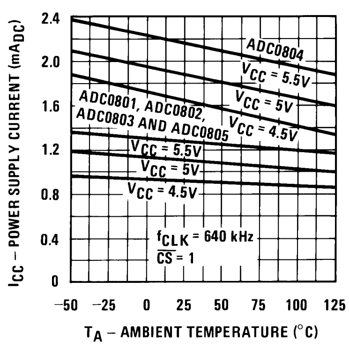
DS005671-43

Output Current vs Temperature



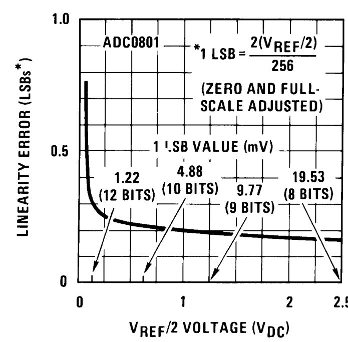
DS005671-44

Power Supply Current vs Temperature (Note 9)



DS005671-45

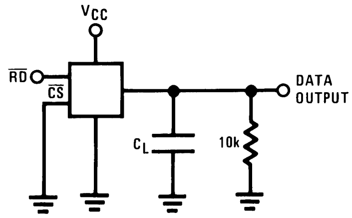
Linearity Error at Low $V_{REF}/2$ Voltages



DS005671-46

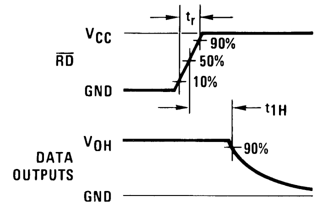
TRI-STATE Test Circuits and Waveforms

t_{1H}



DS005671-47

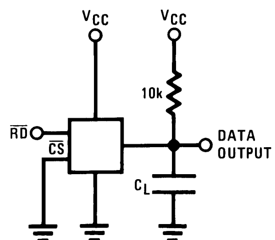
t_{1H}, C_L=10 pF



DS005671-48

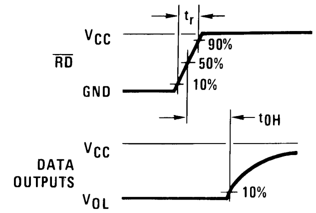
t_r=20 ns

t_{0H}



DS005671-49

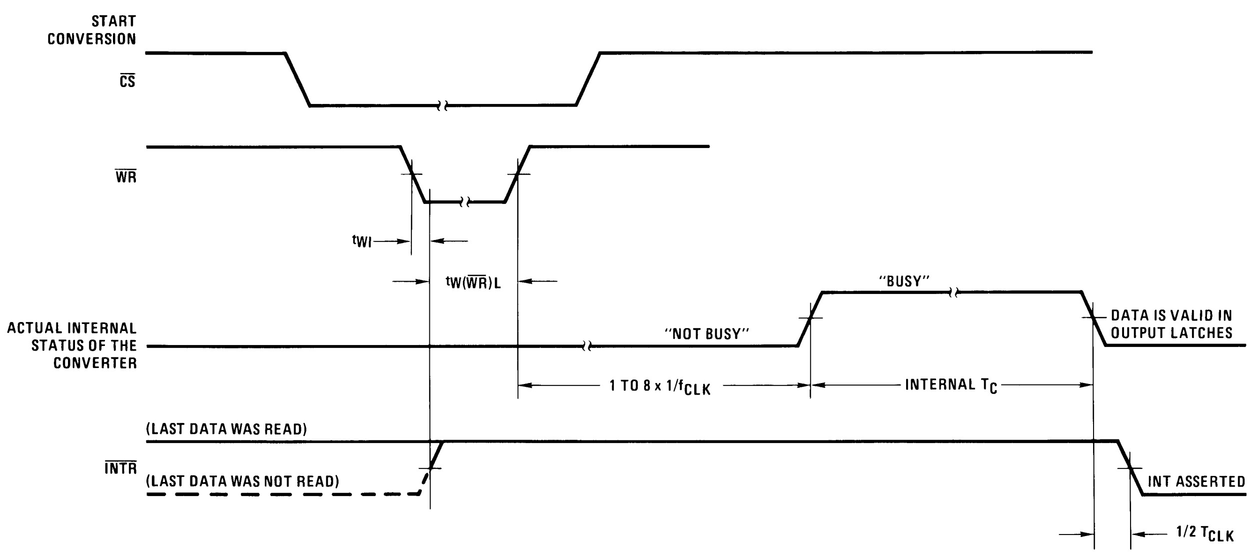
t_{0H}, C_L=10 pF



DS005671-50

t_r=20 ns

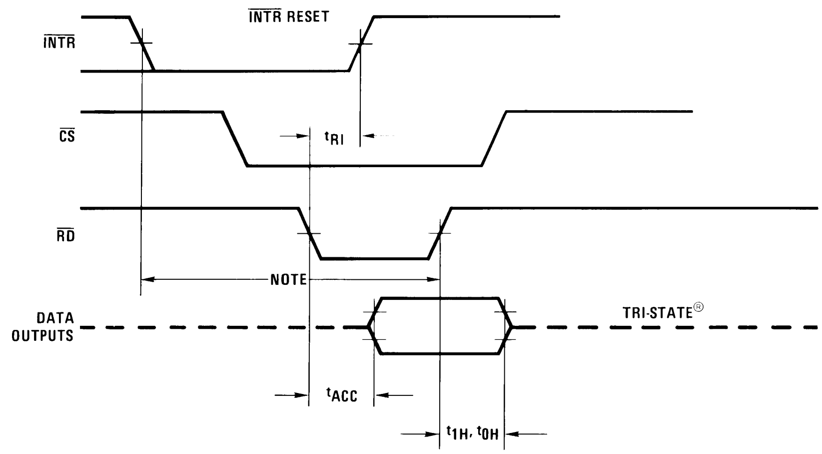
Timing Diagrams (All timing is measured from the 50% voltage points)



DS005671-51

Timing Diagrams (All timing is measured from the 50% voltage points) (Continued)

Output Enable and Reset with $\overline{\text{INTR}}$

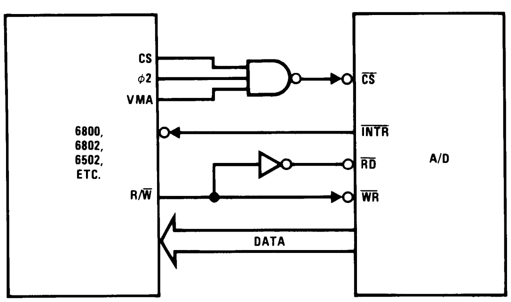


DS005671-52

Note: Read strobe must occur 8 clock periods ($8/f_{CLK}$) after assertion of interrupt to guarantee reset of $\overline{\text{INTR}}$.

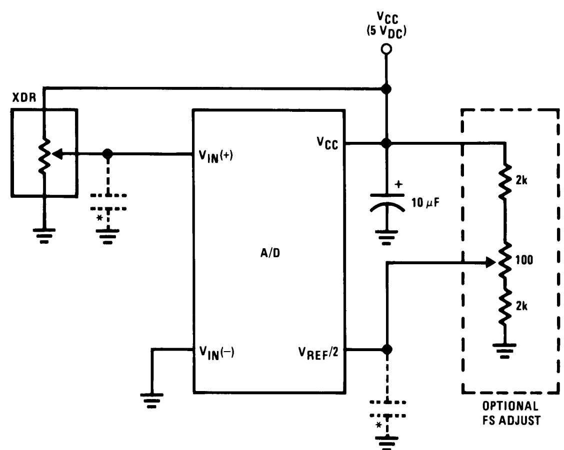
Typical Applications

6800 Interface



DS005671-53

Ratiometeric with Full-Scale Adjust

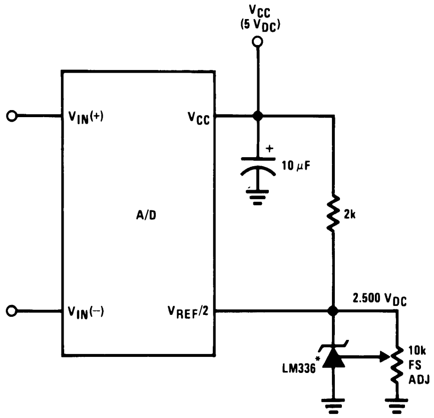


DS005671-54

Note: before using caps at V_{IN} or $V_{REF}/2$,
see section 2.3.2 Input Bypass Capacitors.

Typical Applications (Continued)

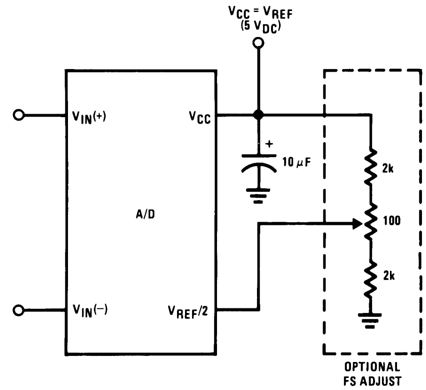
Absolute with a 2.500V Reference



DS005671-55

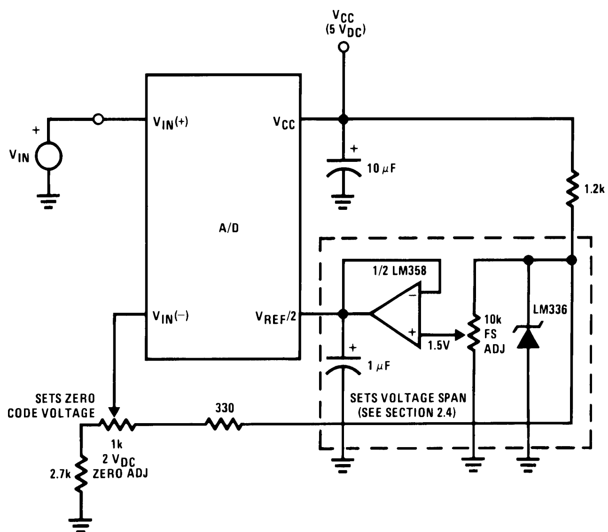
*For low power, see also LM385–2.5

Absolute with a 5V Reference



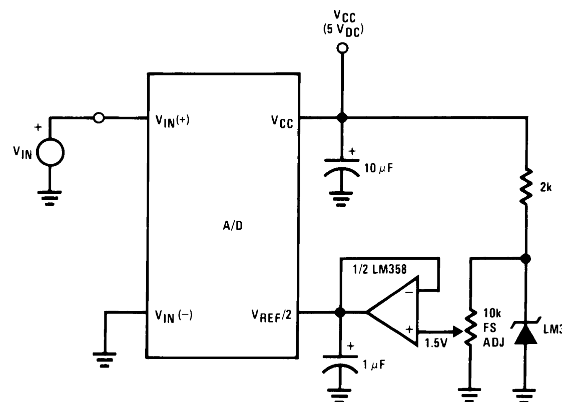
DS005671-56

Zero-Shift and Span Adjust: 2V ≤ V_{IN} ≤ 5V



DS005671-57

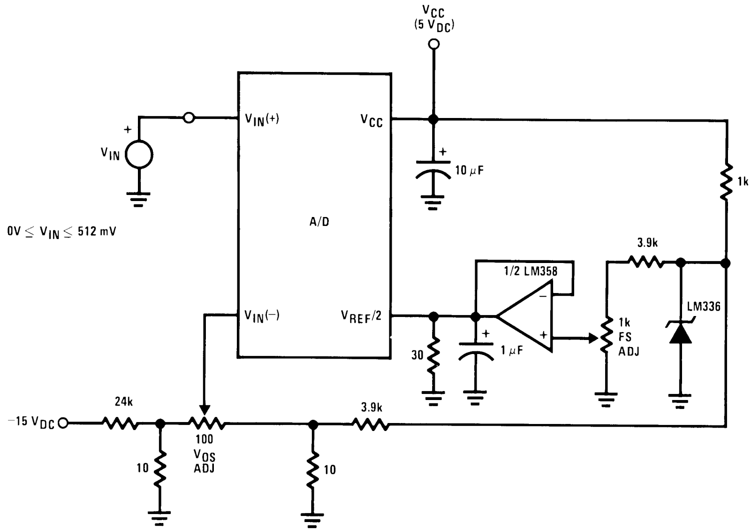
Span Adjust: 0V ≤ V_{IN} ≤ 3V



DS005671-58

Typical Applications (Continued)

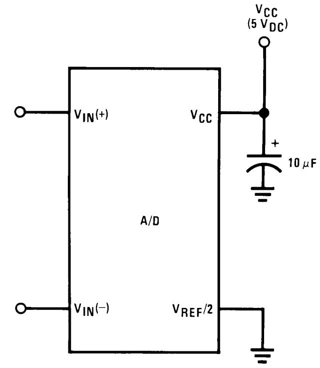
Directly Converting a Low-Level Signal



DS005671-59

$V_{REF}/2$=256 mV

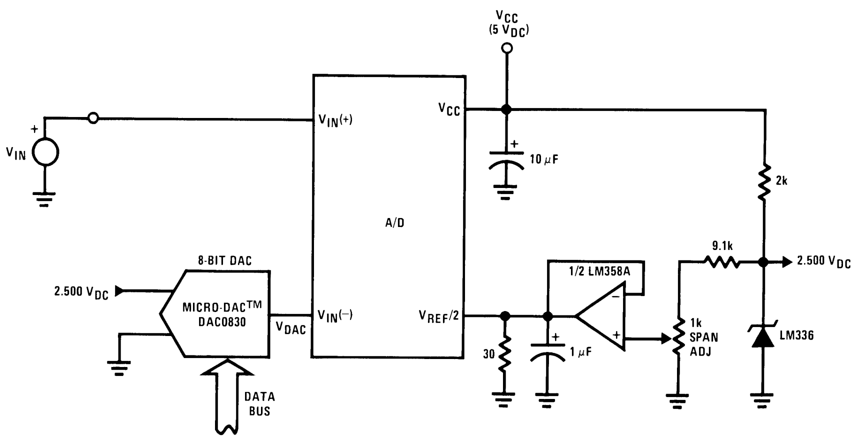
A µP Interfaced Comparator



DS005671-60

For:
$V_{IN}(+)>V_{IN}(-)$
Output=FF_{HEX}
For:
$V_{IN}(+)<V_{IN}(-)$
Output=00_{HEX}

1 mV Resolution with µP Controlled Range

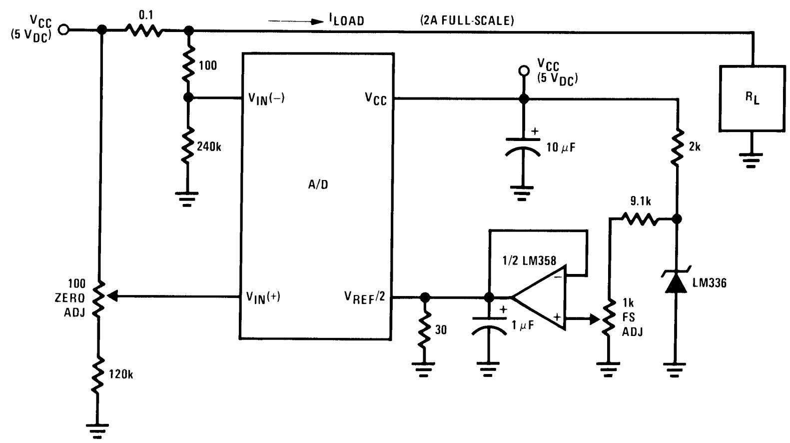


DS005671-61

$V_{REF}/2$=128 mV
1 LSB=1 mV
$V_{DAC} \leq V_{IN} \leq (V_{DAC}+256\ mV)$
$0 \leq V_{DAC} < 2.5V$

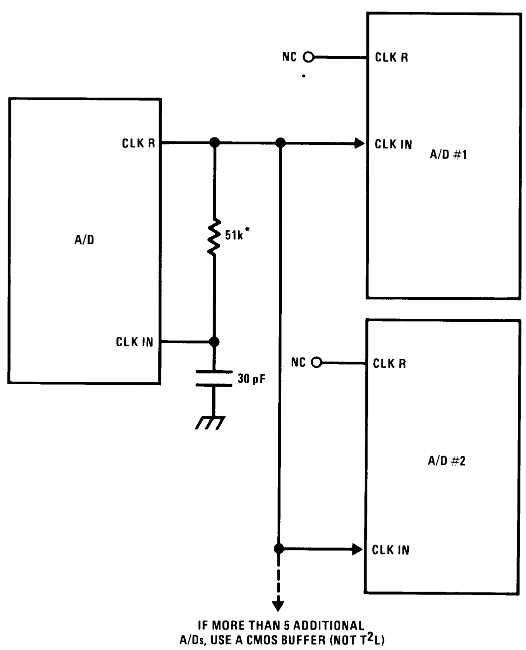
Typical Applications (Continued)

Digitizing a Current Flow



DS005671-62

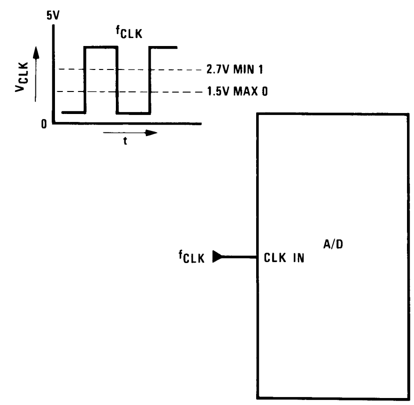
Self-Clocking Multiple A/Ds



DS005671-63

* Use a large R value
to reduce loading
at CLK R output.

External Clocking

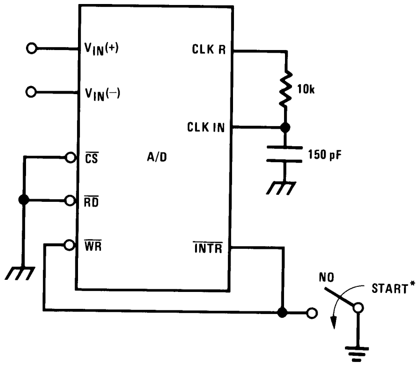


DS005671-64

100 kHz≤f_{CLK}≤1460 kHz

Typical Applications (Continued)

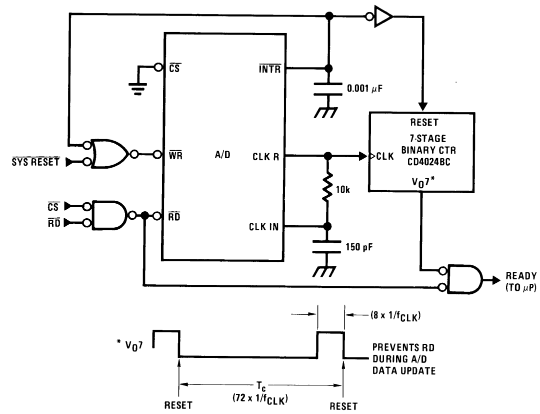
Self-Clocking in Free-Running Mode



DS005671-65

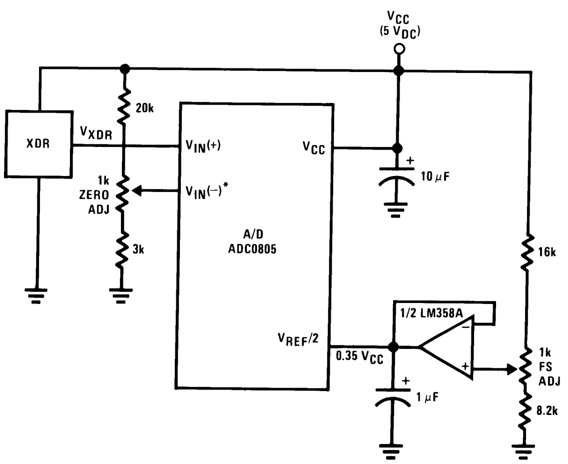
*After power-up, a momentary grounding of the $\overline{WR}$ input is needed to guarantee operation.

µP Interface for Free-Running A/D



DS005671-66

Operating with "Automotive" Ratiometric Transducers

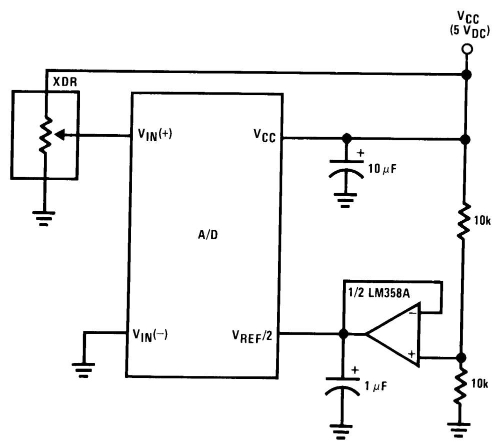


DS005671-67

$^*V_{IN}(-)=0.15\ V_{CC}$

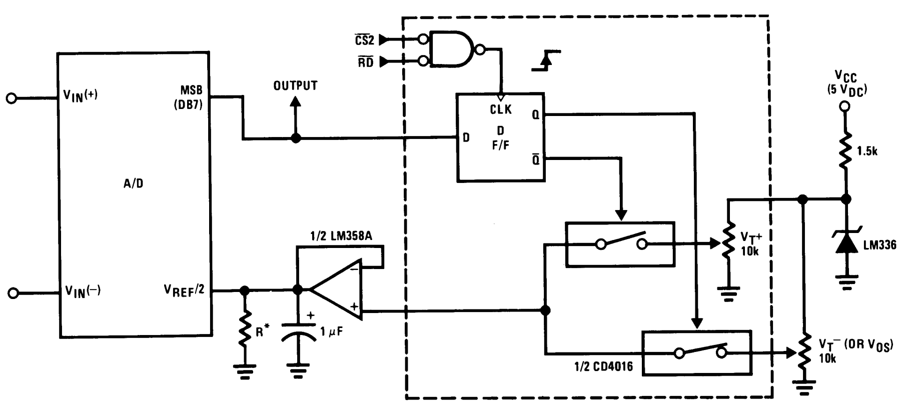
15% of $V_{CC} \leq V_{XDR} \leq 85\%$ of V_{CC}

Ratiometric with $V_{REF}/2$ Forced



DS005671-68

µP Compatible Differential-Input Comparator with Pre-Set V_{OS} (with or without Hysteresis)



DS005671-69

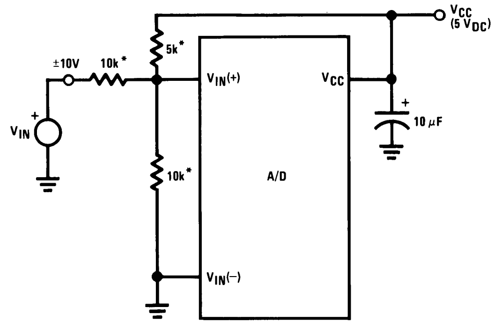
*See *Figure 5* to select R value

DB7="1" for $V_{IN}(+) > V_{IN}(-)+(V_{REF}/2)$

Omit circuitry within the dotted area if hysteresis is not needed

Typical Applications (Continued)

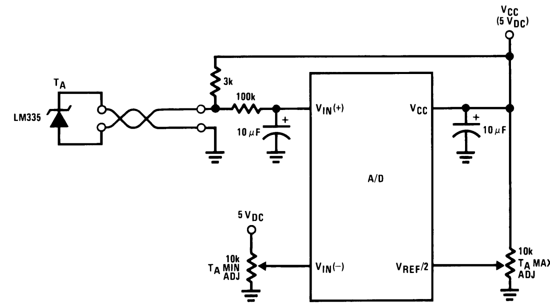
Handling ±10V Analog Inputs



DS005671-70

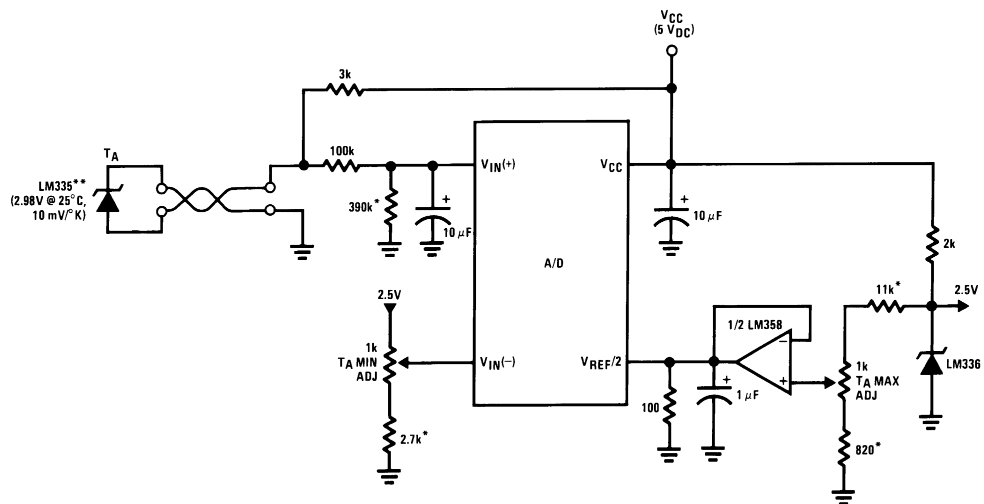
*Beckman Instruments #694-3-R10K resistor array

Low-Cost, µP Interfaced, Temperature-to-Digital Converter



DS005671-71

µP Interfaced Temperature-to-Digital Converter



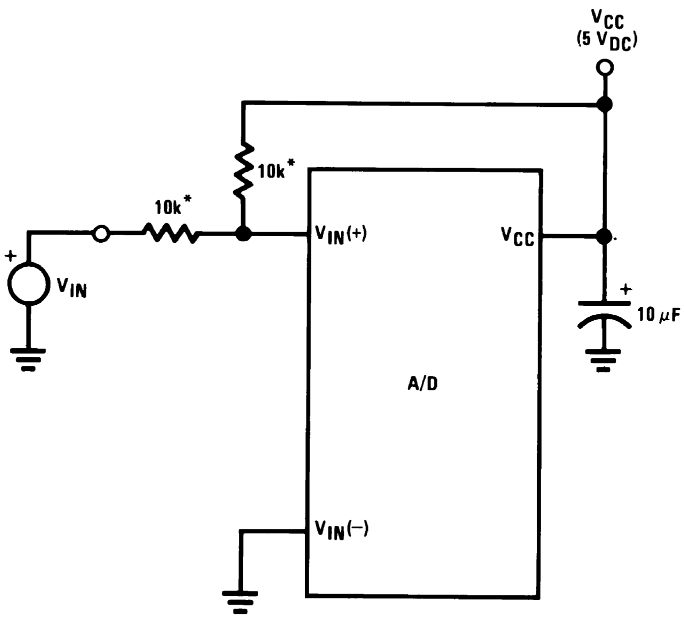
DS005671-72

*Circuit values shown are for 0˚C≤T_A≤+128˚C

***Can calibrate each sensor to allow easy replacement, then A/D can be calibrated with a pre-set input voltage.

Typical Applications (Continued)

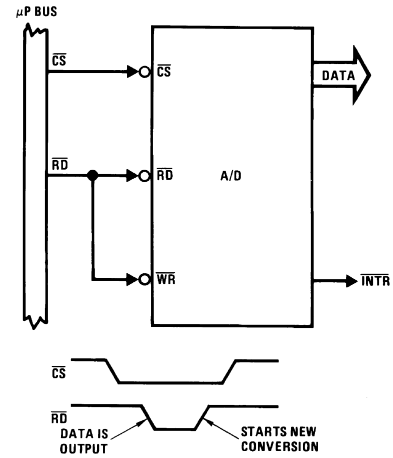
Handling ±5V Analog Inputs



DS005671-33

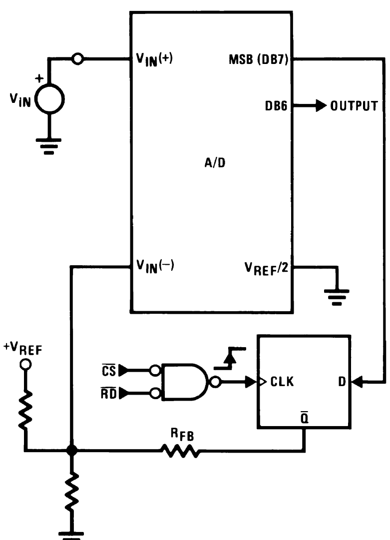
*Beckman Instruments #694-3-R10K resistor array

Read-Only Interface



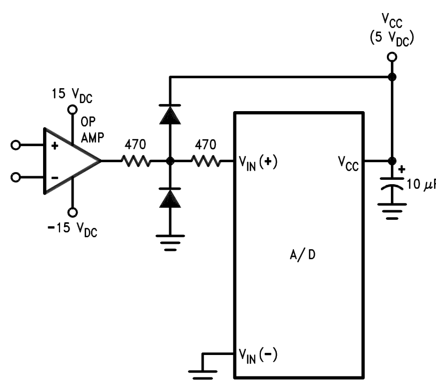
DS005671-34

µP Interfaced Comparator with Hysteresis



DS005671-35

Protecting the Input

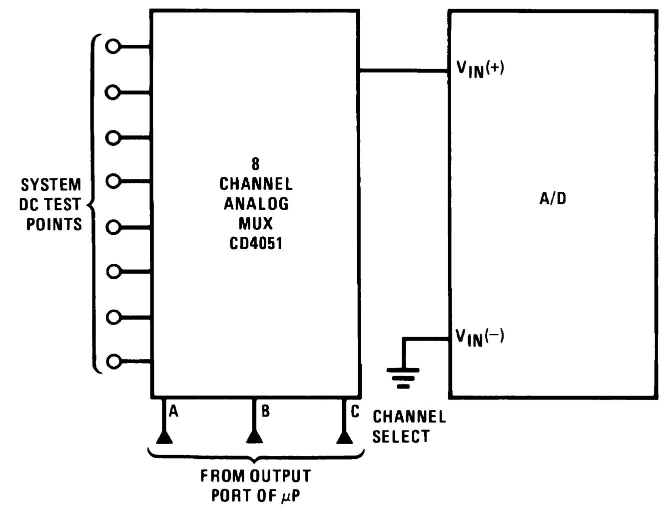


DS005671-9

Diodes are 1N914

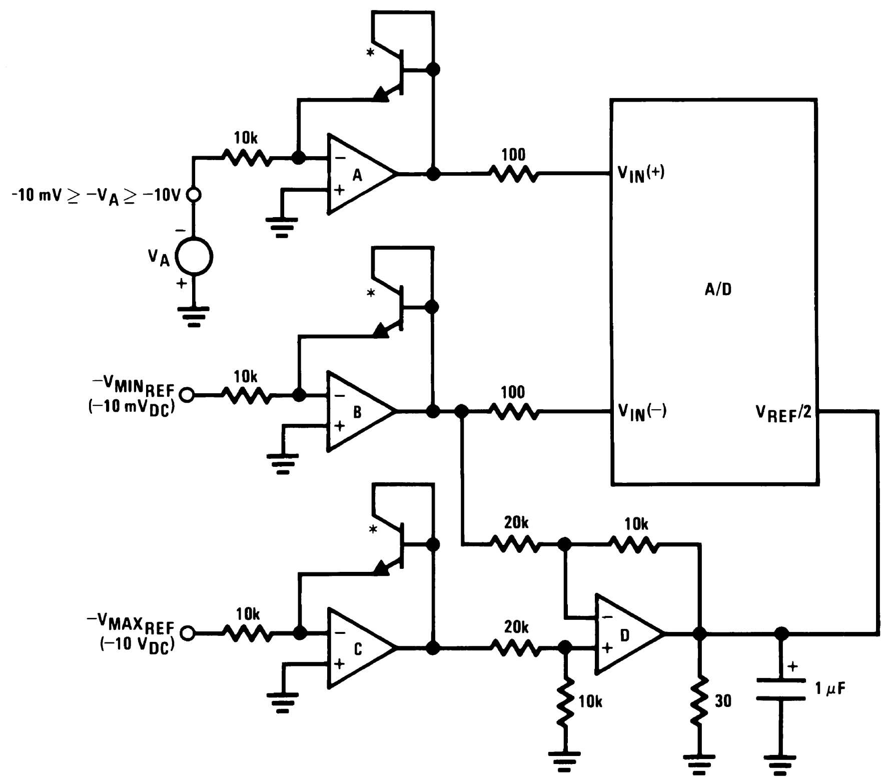
Typical Applications (Continued)

Analog Self-Test for a System



DS005671-36

A Low-Cost, 3-Decade Logarithmic Converter

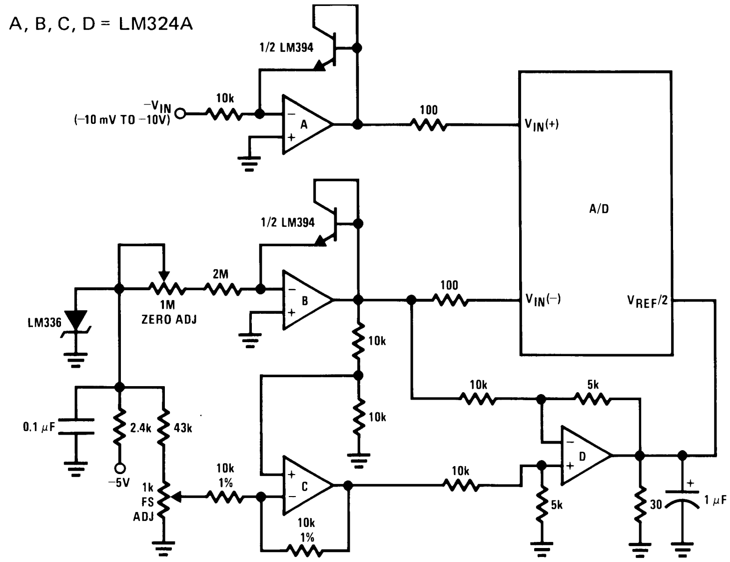


DS005671-37

*LM389 transistors
A, B, C, D = LM324A quad op amp

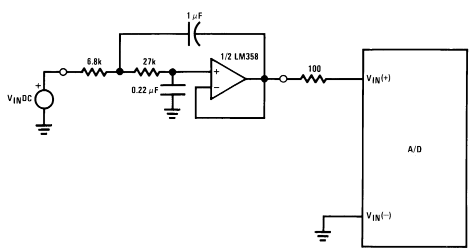
Typical Applications (Continued)

3-Decade Logarithmic A/D Converter



DS005671-73

Noise Filtering the Analog Input



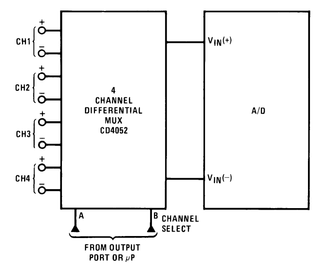
DS005671-74

f_C=20 Hz

Uses Chebyshev implementation for steeper roll-off unity-gain, 2nd order, low-pass filter

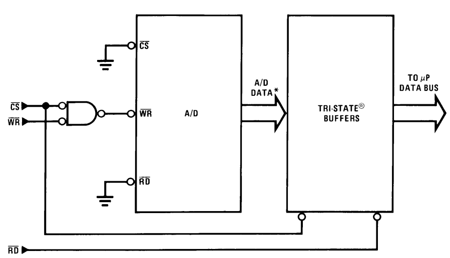
Adding a separate filter for each channel increases system response time if an analog multiplexer is used

Multiplexing Differential Inputs



DS005671-75

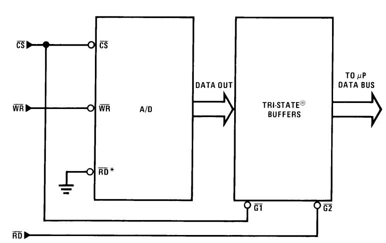
Output Buffers with A/D Data Enabled



DS005671-76

*A/D output data is updated 1 CLK period prior to assertion of $\overline{\text{INTR}}$

Increasing Bus Drive and/or Reducing Time on Bus

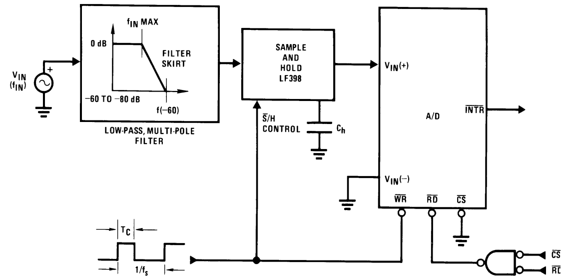


DS005671-77

*Allows output data to set-up at falling edge of $\overline{\text{CS}}$

Typical Applications (Continued)

Sampling an AC Input Signal

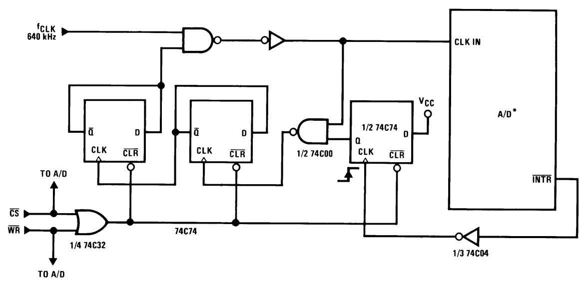


DS005671-78

Note 11: Oversample whenever possible [keep fs > 2f(−60)] to eliminate input frequency folding (aliasing) and to allow for the skirt response of the filter.

Note 12: Consider the amplitude errors which are introduced within the passband of the filter.

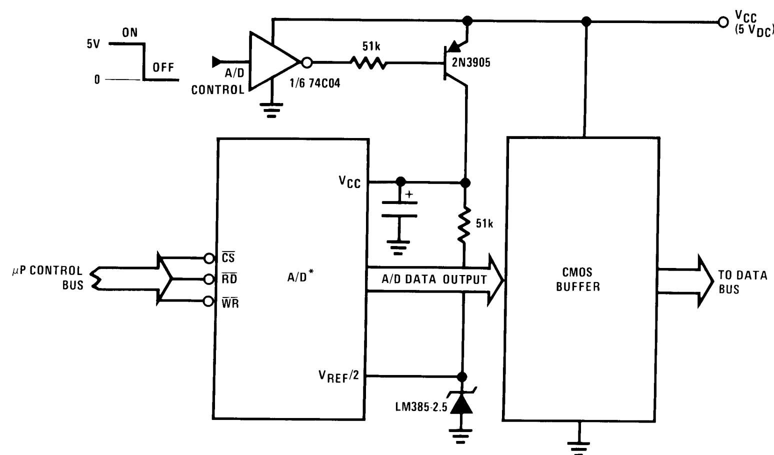
70% Power Savings by Clock Gating



DS005671-79

(Complete shutdown takes ≈ 30 seconds.)

Power Savings by A/D and V_{REF} Shutdown



DS005671-80

*Use ADC0801, 02, 03 or 05 for lowest power consumption.

Note: Logic inputs can be driven to V_{CC} with A/D supply at zero volts.

Buffer prevents data bus from overdriving output of A/D when in shutdown mode.

Functional Description

1.0 UNDERSTANDING A/D ERROR SPECS

A perfect A/D transfer characteristic (staircase waveform) is shown in *Figure 1*. The horizontal scale is analog input voltage and the particular points labeled are in steps of 1 LSB (19.53 mV with 2.5V tied to the $V_{REF}/2$ pin). The digital output codes that correspond to these inputs are shown as D−1, D, and D+1. For the perfect A/D, not only will center-value (A−1, A, A+1, ...) analog inputs produce the correct output digital codes, but also each riser (the transitions between adjacent output codes) will be located ±½ LSB away from each center-value. As shown, the risers are ideal and have no width. Correct digital output codes will be provided for a range of analog input voltages that extend

Functional Description (Continued)

±½ LSB from the ideal center-values. Each tread (the range of analog input voltage that provides the same digital output code) is therefore 1 LSB wide.

Figure 2 shows a worst case error plot for the ADC0801. All center-valued inputs are guaranteed to produce the correct output codes and the adjacent risers are guaranteed to be no closer to the center-value points than ±¼ LSB. In other words, if we apply an analog input equal to the center-value ±¼ LSB, *we guarantee* that the A/D will produce the correct digital code. The maximum range of the position of the code transition is indicated by the horizontal arrow and it is guaranteed to be no more than ½ LSB.

The error curve of *Figure 3* shows a worst case error plot for the ADC0802. Here we guarantee that if we apply an analog input equal to the LSB analog voltage center-value the A/D will produce the correct digital code.

Next to each transfer function is shown the corresponding error plot. Many people may be more familiar with error plots than transfer functions. The analog input voltage to the A/D is provided by either a linear ramp or by the discrete output steps of a high resolution DAC. Notice that the error is continuously displayed and includes the quantization uncertainty of the A/D. For example the error at point 1 of *Figure 1* is +½ LSB because the digital code appeared ½ LSB in advance of the center-value of the tread. The error plots always have a constant negative slope and the abrupt upside steps are always 1 LSB in magnitude.

Transfer Function **Error Plot**

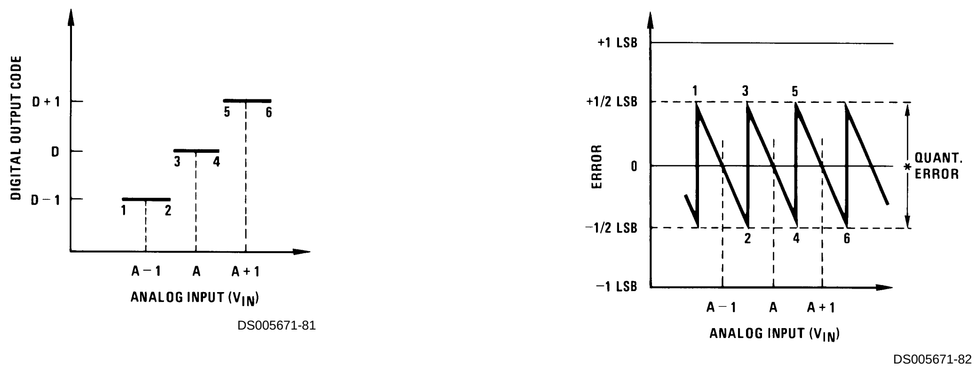


FIGURE 1. Clarifying the Error Specs of an A/D Converter Accuracy=±0 LSB: A Perfect A/D

Transfer Function **Error Plot**

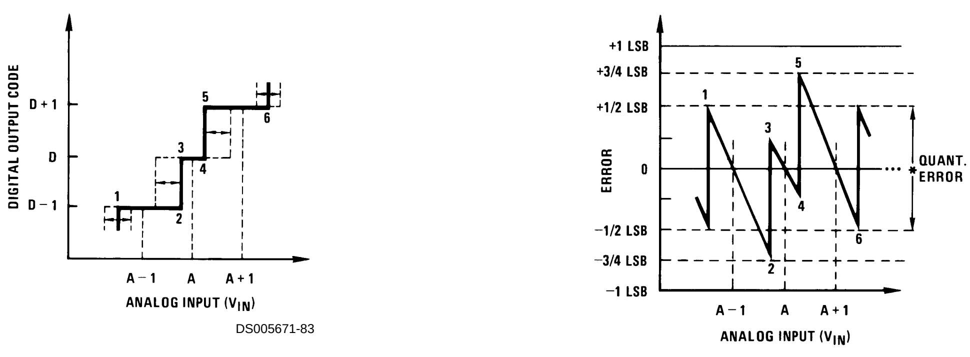
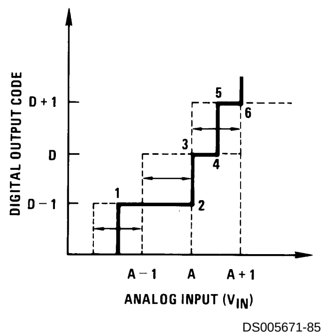


FIGURE 2. Clarifying the Error Specs of an A/D Converter Accuracy=±¼ LSB

Functional Description (Continued)

Transfer Function



Error Plot

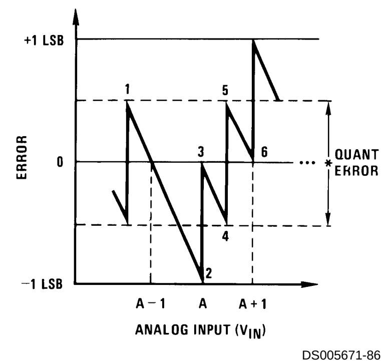


FIGURE 3. Clarifying the Error Specs of an A/D Converter Accuracy=±½ LSB

2.0 FUNCTIONAL DESCRIPTION

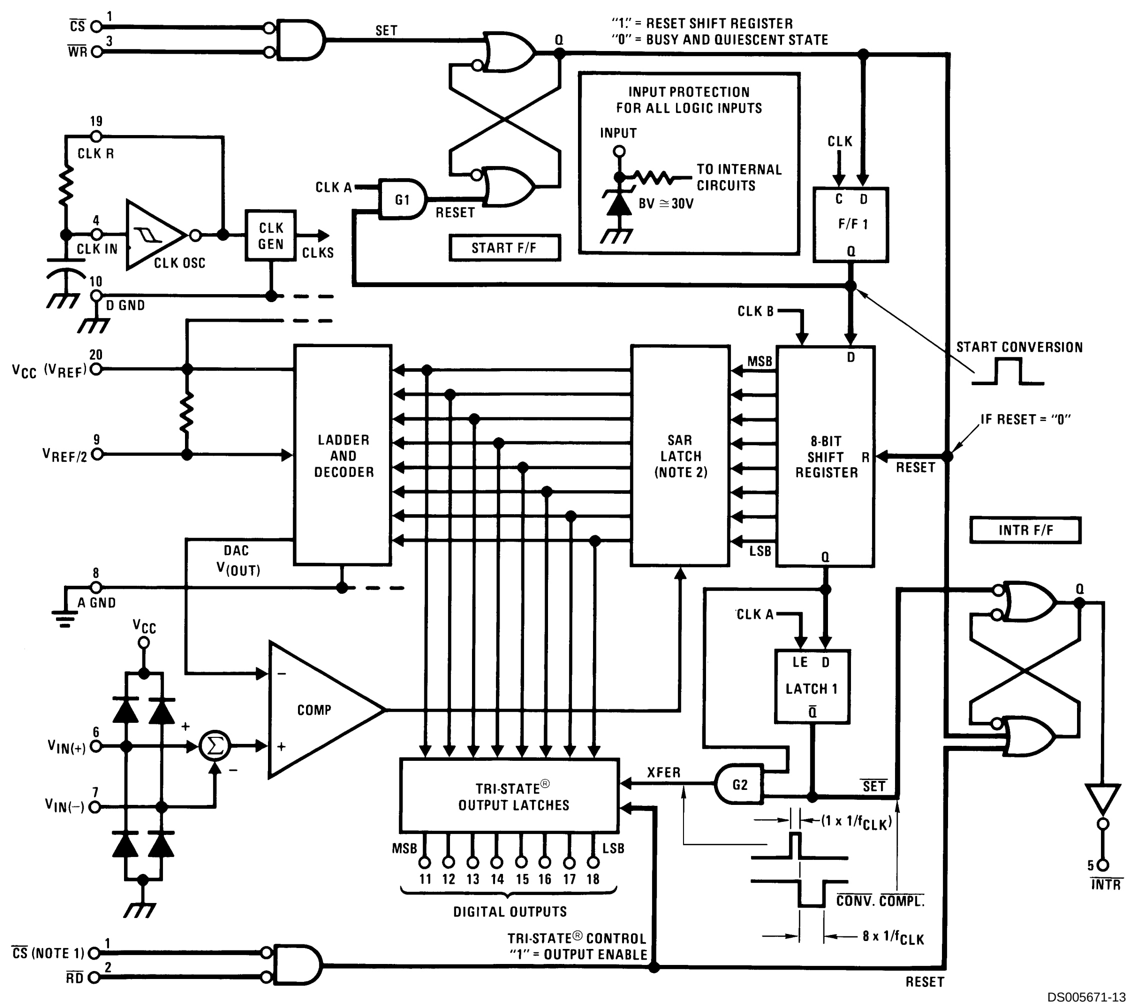
The ADC0801 series contains a circuit equivalent of the 256R network. Analog switches are sequenced by successive approximation logic to match the analog difference input voltage [$V_{IN}(+) - V_{IN}(-)$] to a corresponding tap on the R network. The most significant bit is tested first and after 8 comparisons (64 clock cycles) a digital 8-bit binary code (1111 1111 = full-scale) is transferred to an output latch and then an interrupt is asserted ($\overline{INTR}$ makes a high-to-low transition). A conversion in process can be interrupted by issuing a second start command. The device may be operated in the free-running mode by connecting $\overline{INTR}$ to the $\overline{WR}$ input with $\overline{CS}$ =0. To ensure start-up under all possible conditions, an external $\overline{WR}$ pulse is required during the first power-up cycle.

On the high-to-low transition of the $\overline{WR}$ input the internal SAR latches and the shift register stages are reset. As long as the $\overline{CS}$ input and $\overline{WR}$ input remain low, the A/D will remain in a reset state. *Conversion will start from 1 to 8 clock periods after at least one of these inputs makes a low-to-high transition*.

A functional diagram of the A/D converter is shown in *Figure 4*. All of the package pinouts are shown and the major logic control paths are drawn in heavier weight lines.

The converter is started by having $\overline{CS}$ and $\overline{WR}$ simultaneously low. This sets the start flip-flop (F/F) and the resulting "1" level resets the 8-bit shift register, resets the Interrupt (INTR) F/F and inputs a "1" to the D flop, F/F1, which is at the input end of the 8-bit shift register. Internal clock signals then transfer this "1" to the Q output of F/F1. The AND gate, G1, combines this "1" output with a clock signal to provide a reset signal to the start F/F. If the set signal is no longer present (either $\overline{WR}$ or $\overline{CS}$ is a "1") the start F/F is reset and the 8-bit shift register then can have the "1" clocked in, which starts the conversion process. If the set signal were to still be present, this reset pulse would have no effect (both outputs of the start F/F would momentarily be at a "1" level) and the 8-bit shift register would continue to be held in the reset mode. This logic therefore allows for wide $\overline{CS}$ and $\overline{WR}$ signals and the converter will start after at least one of these signals returns high and the internal clocks again provide a reset signal for the start F/F.

Functional Description (Continued)



Note 13: $\overline{CS}$ shown twice for clarity.

Note 14: SAR = Successive Approximation Register.

FIGURE 4. Block Diagram

After the "1" is clocked through the 8-bit shift register (which completes the SAR search) it appears as the input to the D-type latch, LATCH 1. As soon as this "1" is output from the shift register, the AND gate, G2, causes the new digital word to transfer to the TRI-STATE output latches. When LATCH 1 is subsequently enabled, the Q output makes a high-to-low transition which causes the INTR F/F to set. An inverting buffer then supplies the $\overline{INTR}$ input signal.

Note that this $\overline{SET}$ control of the INTR F/F remains low for 8 of the external clock periods (as the internal clocks run at ⅛ of the frequency of the external clock). If the data output is continuously enabled ($\overline{CS}$ and $\overline{RD}$ both held low), the $\overline{INTR}$ output will still signal the end of conversion (by a high-to-low transition), because the $\overline{SET}$ input can control the Q output of the INTR F/F even though the RESET input is constantly at a "1" level in this operating mode. This $\overline{INTR}$ output will therefore stay low for the duration of the $\overline{SET}$ signal, which is 8 periods of the external clock frequency (assuming the A/D is not started during this interval).

When operating in the free-running or continuous conversion mode ($\overline{INTR}$ pin tied to $\overline{WR}$ and $\overline{CS}$ wired low—see also section 2.8), the START F/F is SET by the high-to-low transition of the $\overline{INTR}$ signal. This resets the SHIFT REGISTER which causes the input to the D-type latch, LATCH 1, to go low. As the latch enable input is still present, the $\overline{Q}$ output will go high, which then allows the INTR F/F to be RESET. This reduces the width of the resulting $\overline{INTR}$ output pulse to only a few propagation delays (approximately 300 ns).

When data is to be read, the combination of both $\overline{CS}$ and $\overline{RD}$ being low will cause the INTR F/F to be reset and the TRI-STATE output latches will be enabled to provide the 8-bit digital outputs.

2.1 Digital Control Inputs

The digital control inputs ($\overline{CS}$, $\overline{RD}$, and $\overline{WR}$) meet standard T^2L logic voltage levels. These signals have been renamed when compared to the standard A/D Start and Output Enable labels. In addition, these inputs are active low to allow an easy interface to microprocessor control busses. For non-microprocessor based applications, the $\overline{CS}$ input (pin 1) can be grounded and the standard A/D Start function is obtained by an active low pulse applied at the $\overline{WR}$ input (pin 3) and the Output Enable function is caused by an active low pulse at the $\overline{RD}$ input (pin 2).

Functional Description (Continued)

2.2 Analog Differential Voltage Inputs and Common-Mode Rejection

This A/D has additional applications flexibility due to the analog differential voltage input. The $V_{IN}(-)$ input (pin 7) can be used to automatically subtract a fixed voltage value from the input reading (tare correction). This is also useful in 4 mA–20 mA current loop conversion. In addition, common-mode noise can be reduced by use of the differential input.

The time interval between sampling $V_{IN}(+)$ and $V_{IN}(-)$ is 4-½ clock periods. The maximum error voltage due to this slight time difference between the input voltage samples is given by:

$$\Delta V_e(MAX) = (V_P)(2\pi f_{cm})\left(\frac{4.5}{f_{CLK}}\right)$$

where:

ΔV_e is the error voltage due to sampling delay

V_P is the peak value of the common-mode voltage

f_{cm} is the common-mode frequency

As an example, to keep this error to ¼ LSB (~5 mV) when operating with a 60 Hz common-mode frequency, f_{cm}, and using a 640 kHz A/D clock, f_{CLK}, would allow a peak value of the common-mode voltage, V_P, which is given by:

$$V_P = \frac{[\Delta V_{e(MAX)}(f_{CLK})]}{(2\pi f_{cm})(4.5)}$$

or

$$V_P = \frac{(5 \times 10^{-3})(640 \times 10^3)}{(6.28)(60)(4.5)}$$

which gives

$V_P \simeq 1.9V$.

The allowed range of analog input voltages usually places more severe restrictions on input common-mode noise levels.

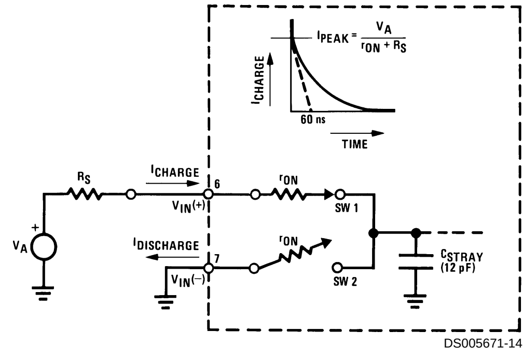
An analog input voltage with a reduced span and a relatively large zero offset can be handled easily by making use of the differential input (see section 2.4 Reference Voltage).

2.3 Analog Inputs

2.3 1 Input Current

Normal Mode

Due to the internal switching action, displacement currents will flow at the analog inputs. This is due to on-chip stray capacitance to ground as shown in *Figure 5*.



r_{ON} of SW 1 and SW 2 ≃ 5 kΩ

$r = r_{ON}\ C_{STRAY}$ ≃ 5 kΩ x 12 pF = 60 ns

FIGURE 5. Analog Input Impedance

The voltage on this capacitance is switched and will result in currents entering the $V_{IN}(+)$ input pin and leaving the $V_{IN}(-)$ input which will depend on the analog differential input voltage levels. These current transients occur at the leading edge of the internal clocks. They rapidly decay and *do not cause errors* as the on-chip comparator is strobed at the end of the clock period.

Fault Mode

If the voltage source applied to the $V_{IN}(+)$ or $V_{IN}(-)$ pin exceeds the allowed operating range of V_{CC}+50 mV, large input currents can flow through a parasitic diode to the V_{CC} pin. If these currents can exceed the 1 mA max allowed spec, an external diode (1N914) should be added to bypass this current to the V_{CC} pin (with the current bypassed with this diode, the voltage at the $V_{IN}(+)$ pin can exceed the V_{CC} voltage by the forward voltage of this diode).

2.3.2 Input Bypass Capacitors

Bypass capacitors at the inputs will average these charges and cause a DC current to flow through the output resistances of the analog signal sources. This charge pumping action is worse for continuous conversions with the $V_{IN}(+)$ input voltage at full-scale. For continuous conversions with a 640 kHz clock frequency with the $V_{IN}(+)$ input at 5V, this DC current is at a maximum of approximately 5 µA. Therefore, *bypass capacitors should not be used at the analog inputs or the V_{REF}/2 pin* for high resistance sources (> 1 kΩ). If input bypass capacitors are necessary for noise filtering and high source resistance is desirable to minimize capacitor size, the detrimental effects of the voltage drop across this input resistance, which is due to the average value of the input current, can be eliminated with a full-scale adjustment while the given source resistor and input bypass capacitor are both in place. This is possible because the average value of the input current is a precise linear function of the differential input voltage.

2.3.3 Input Source Resistance

Large values of source resistance where an input bypass capacitor is not used, *will not cause errors* as the input currents settle out prior to the comparison time. If a low pass filter is required in the system, use a low valued series resistor (≤ 1 kΩ) for a passive RC section or add an op amp RC active low pass filter. For low source resistance applications, (≤ 1 kΩ), a 0.1 µF bypass capacitor at the inputs will prevent noise pickup due to series lead inductance of a long

Functional Description (Continued)

wire. A 100Ω series resistor can be used to isolate this capacitor — both the R and C are placed outside the feedback loop — from the output of an op amp, if used.

2.3.4 Noise

The leads to the analog inputs (pins 6 and 7) should be kept as short as possible to minimize input noise coupling. Both noise and undesired digital clock coupling to these inputs can cause system errors. The source resistance for these inputs should, in general, be kept below 5 kΩ. Larger values of source resistance can cause undesired system noise pickup. Input bypass capacitors, placed from the analog inputs to ground, will eliminate system noise pickup but can create analog scale errors as these capacitors will average the transient input switching currents of the A/D (see section 2.3.1.). This scale error depends on both a large source resistance and the use of an input bypass capacitor. This error can be eliminated by doing a full-scale adjustment of the A/D (adjust $V_{REF}/2$ for a proper full-scale reading — see section 2.5.2 on Full-Scale Adjustment) with the source resistance and input bypass capacitor in place.

2.4 Reference Voltage

2.4.1 Span Adjust

For maximum applications flexibility, these A/Ds have been designed to accommodate a 5 V_{DC}, 2.5 V_{DC} or an adjusted voltage reference. This has been achieved in the design of the IC as shown in *Figure 6*.

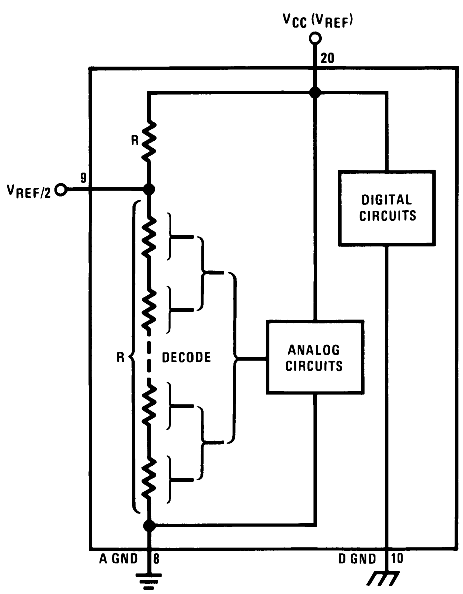


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FIGURE 6. The $V_{REFERENCE}$ Design on the IC

Notice that the reference voltage for the IC is either ½ of the voltage applied to the V_{CC} supply pin, or is equal to the voltage that is externally forced at the $V_{REF}/2$ pin. This allows for a ratiometric voltage reference using the V_{CC} supply, a 5 V_{DC} reference voltage can be used for the V_{CC} supply or a voltage less than 2.5 V_{DC} can be applied to the $V_{REF}/2$ input for increased application flexibility. The internal gain to the $V_{REF}/2$ input is 2, making the full-scale differential input voltage twice the voltage at pin 9.

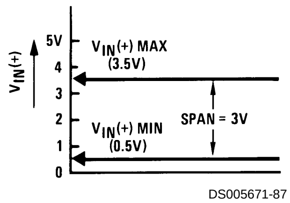
An example of the use of an adjusted reference voltage is to accommodate a reduced span — or dynamic voltage range of the analog input voltage. If the analog input voltage were to range from 0.5 V_{DC} to 3.5 V_{DC}, instead of 0V to 5 V_{DC}, the span would be 3V as shown in *Figure 7*. With 0.5 V_{DC} applied to the $V_{IN}(-)$ pin to absorb the offset, the reference voltage can be made equal to ½ of the 3V span or 1.5 V_{DC}. The A/D now will encode the $V_{IN}(+)$ signal from 0.5V to 3.5 V with the 0.5V input corresponding to zero and the 3.5 V_{DC} input corresponding to full-scale. The full 8 bits of resolution are therefore applied over this reduced analog input voltage range.

2.4.2 Reference Accuracy Requirements

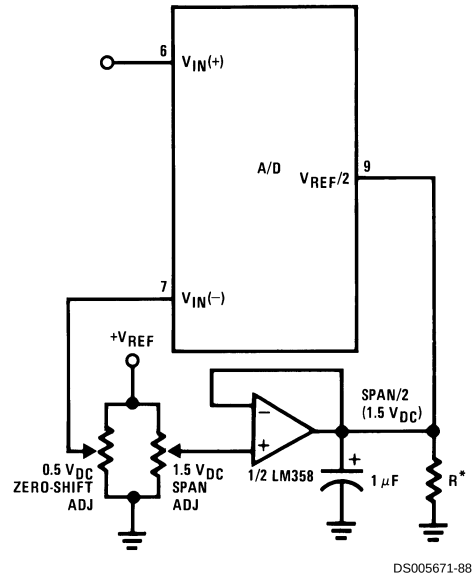
The converter can be operated in a ratiometric mode or an absolute mode. In ratiometric converter applications, the magnitude of the reference voltage is a factor in both the output of the source transducer and the output of the A/D converter and therefore cancels out in the final digital output code. The ADC0805 is specified particularly for use in ratiometric applications with no adjustments required. In absolute conversion applications, both the initial value and the temperature stability of the reference voltage are important factors in the accuracy of the A/D converter. For $V_{REF}/2$ voltages of 2.4 V_{DC} nominal value, initial errors of ±10 mV_{DC} will cause conversion errors of ±1 LSB due to the gain of 2 of the $V_{REF}/2$ input. In reduced span applications, the initial value and the stability of the $V_{REF}/2$ input voltage become even more important. For example, if the span is reduced to 2.5V, the analog input LSB voltage value is correspondingly reduced from 20 mV (5V span) to 10 mV and 1 LSB at the $V_{REF}/2$ input becomes 5 mV. As can be seen, this reduces the allowed initial tolerance of the reference voltage and requires correspondingly less absolute change with temperature variations. Note that spans smaller than 2.5V place even tighter requirements on the initial accuracy and stability of the reference source.

In general, the magnitude of the reference voltage will require an initial adjustment. Errors due to an improper value of reference voltage appear as full-scale errors in the A/D transfer function. IC voltage regulators may be used for references if the ambient temperature changes are not excessive. The LM336B 2.5V IC reference diode (from National Semiconductor) has a temperature stability of 1.8 mV typ (6 mV max) over 0˚C≤T_A≤+70˚C. Other temperature range parts are also available.

Functional Description (Continued)



a) Analog Input Signal Example



*Add if $V_{REF}/2 \leq 1$ V_{DC} with LM358 to draw 3 mA to ground.

b) Accommodating an Analog Input from 0.5V (Digital Out = 00_{HEX}) to 3.5V (Digital Out=FF_{HEX})

FIGURE 7. Adapting the A/D Analog Input Voltages to Match an Arbitrary Input Signal Range

2.5 Errors and Reference Voltage Adjustments

2.5.1 Zero Error

The zero of the A/D does not require adjustment. If the minimum analog input voltage value, $V_{IN(MIN)}$, is not ground, a zero offset can be done. The converter can be made to output 0000 0000 digital code for this minimum input voltage by biasing the A/D $V_{IN}(-)$ input at this $V_{IN(MIN)}$ value (see Applications section). This utilizes the differential mode operation of the A/D.

The zero error of the A/D converter relates to the location of the first riser of the transfer function and can be measured by grounding the V_{IN} (−) input and applying a small magnitude positive voltage to the V_{IN} (+) input. Zero error is the difference between the actual DC input voltage that is necessary to just cause an output digital code transition from 0000 0000 to 0000 0001 and the ideal ½ LSB value (½ LSB = 9.8 mV for $V_{REF}/2$=2.500 V_{DC}).

2.5.2 Full-Scale

The full-scale adjustment can be made by applying a differential input voltage that is 1½ LSB less than the desired analog full-scale voltage range and then adjusting the magnitude of the $V_{REF}/2$ input (pin 9 or the V_{CC} supply if pin 9 is not used) for a digital output code that is just changing from 1111 1110 to 1111 1111.

2.5.3 Adjusting for an Arbitrary Analog Input Voltage Range

If the analog zero voltage of the A/D is shifted away from ground (for example, to accommodate an analog input signal that does not go to ground) this new zero reference should be properly adjusted first. A $V_{IN}(+)$ voltage that equals this desired zero reference plus ½ LSB (where the LSB is calculated for the desired analog span, 1 LSB=analog span/256) is applied to pin 6 and the zero reference voltage at pin 7 should then be adjusted to just obtain the 00_{HEX} to 01_{HEX} code transition.

The full-scale adjustment should then be made (with the proper $V_{IN}(-)$ voltage applied) by forcing a voltage to the $V_{IN}(+)$ input which is given by:

$$V_{IN}(+)\text{ fs adj} = V_{MAX} - 1.5\left[\frac{(V_{MAX} - V_{MIN})}{256}\right]$$

where:

V_{MAX}=The high end of the analog input range

and

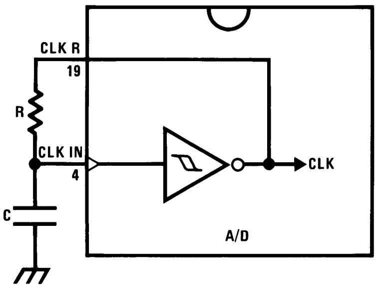
V_{MIN}=the low end (the offset zero) of the analog range. (Both are ground referenced.)

The $V_{REF}/2$ (or V_{CC}) voltage is then adjusted to provide a code change from FE_{HEX} to FF_{HEX}. This completes the adjustment procedure.

2.6 Clocking Option

The clock for the A/D can be derived from the CPU clock or an external RC can be added to provide self-clocking. The CLK IN (pin 4) makes use of a Schmitt trigger as shown in *Figure 8*.

Functional Description (Continued)



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$$f_{CLK} \cong \frac{1}{1.1\ RC}$$

$$R \cong 10\ k\Omega$$

FIGURE 8. Self-Clocking the A/D

Heavy capacitive or DC loading of the clock R pin should be avoided as this will disturb normal converter operation. Loads less than 50 pF, such as driving up to 7 A/D converter clock inputs from a single clock R pin of 1 converter, are allowed. For larger clock line loading, a CMOS or low power TTL buffer or PNP input logic should be used to minimize the loading on the clock R pin (do not use a standard TTL buffer).

2.7 Restart During a Conversion

If the A/D is restarted ($\overline{CS}$ and $\overline{WR}$ go low and return high) during a conversion, the converter is reset and a new conversion is started. The output data latch is not updated if the conversion in process is not allowed to be completed, therefore the data of the previous conversion remains in this latch. The $\overline{INTR}$ output simply remains at the "1" level.

2.8 Continuous Conversions

For operation in the free-running mode an initializing pulse should be used, following power-up, to ensure circuit operation. In this application, the $\overline{CS}$ input is grounded and the $\overline{WR}$ input is tied to the $\overline{INTR}$ output. This $\overline{WR}$ and $\overline{INTR}$ node should be momentarily forced to logic low following a power-up cycle to guarantee operation.

2.9 Driving the Data Bus

This MOS A/D, like MOS microprocessors and memories, will require a bus driver when the total capacitance of the data bus gets large. Other circuitry, which is tied to the data bus, will add to the total capacitive loading, even in TRI-STATE (high impedance mode). Backplane bussing also greatly adds to the stray capacitance of the data bus.

There are some alternatives available to the designer to handle this problem. Basically, the capacitive loading of the data bus slows down the response time, even though DC specifications are still met. For systems operating with a relatively slow CPU clock frequency, more time is available in which to establish proper logic levels on the bus and therefore higher capacitive loads can be driven (see typical characteristics curves).

At higher CPU clock frequencies time can be extended for I/O reads (and/or writes) by inserting wait states (8080) or using clock extending circuits (6800).

Finally, if time is short and capacitive loading is high, external bus drivers must be used. These can be TRI-STATE buffers (low power Schottky such as the DM74LS240 series is recommended) or special higher drive current products which are designed as bus drivers. High current bipolar bus drivers with PNP inputs are recommended.

2.10 Power Supplies

Noise spikes on the V_{CC} supply line can cause conversion errors as the comparator will respond to this noise. A low inductance tantalum filter capacitor should be used close to the converter V_{CC} pin and values of 1 µF or greater are recommended. If an unregulated voltage is available in the system, a separate LM340LAZ-5.0, TO-92, 5V voltage regulator for the converter (and other analog circuitry) will greatly reduce digital noise on the V_{CC} supply.

2.11 Wiring and Hook-Up Precautions

Standard digital wire wrap sockets are not satisfactory for breadboarding this A/D converter. Sockets on PC boards can be used and all logic signal wires and leads should be grouped and kept as far away as possible from the analog signal leads. Exposed leads to the analog inputs can cause undesired digital noise and hum pickup, therefore shielded leads may be necessary in many applications.

A single point analog ground that is separate from the logic ground points should be used. The power supply bypass capacitor and the self-clocking capacitor (if used) should both be returned to digital ground. Any $V_{REF}/2$ bypass capacitors, analog input filter capacitors, or input signal shielding should be returned to the analog ground point. A test for proper grounding is to measure the zero error of the A/D converter. Zero errors in excess of ¼ LSB can usually be traced to improper board layout and wiring (see section 2.5.1 for measuring the zero error).

3.0 TESTING THE A/D CONVERTER

There are many degrees of complexity associated with testing an A/D converter. One of the simplest tests is to apply a known analog input voltage to the converter and use LEDs to display the resulting digital output code as shown in *Figure 9*.

For ease of testing, the $V_{REF}/2$ (pin 9) should be supplied with 2.560 V_{DC} and a V_{CC} supply voltage of 5.12 V_{DC} should be used. This provides an LSB value of 20 mV.

If a full-scale adjustment is to be made, an analog input voltage of 5.090 V_{DC} (5.120–1½ LSB) should be applied to the $V_{IN}(+)$ pin with the $V_{IN}(-)$ pin grounded. The value of the $V_{REF}/2$ input voltage should then be adjusted until the digital output code is just changing from 1111 1110 to 1111 1111. This value of $V_{REF}/2$ should then be used for all the tests.

The digital output LED display can be decoded by dividing the 8 bits into 2 hex characters, the 4 most significant (MS) and the 4 least significant (LS). *Table 1* shows the fractional binary equivalent of these two 4-bit groups. By adding the voltages obtained from the "VMS" and "VLS" columns in *Table 1*, the nominal value of the digital display (when $V_{REF}/2$ = 2.560V) can be determined. For example, for an output LED display of 1011 0110 or B6 (in hex), the voltage values from the table are 3.520 + 0.120 or 3.640 V_{DC}. These voltage values represent the center-values of a perfect A/D converter. The effects of quantization error have to be accounted for in the interpretation of the test results.

Functional Description (Continued)

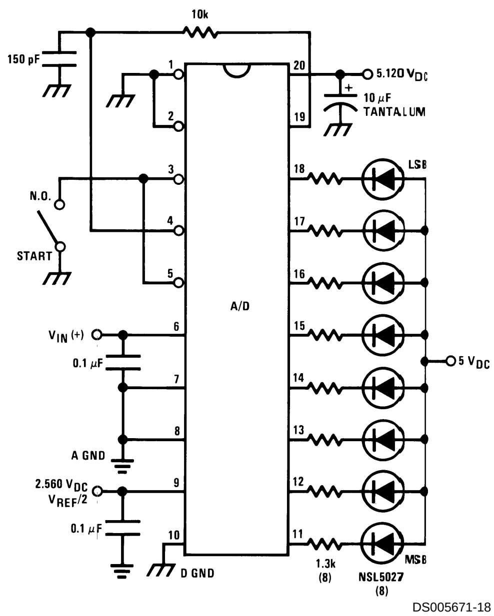


FIGURE 9. Basic A/D Tester

For a higher speed test system, or to obtain plotted data, a digital-to-analog converter is needed for the test set-up. An accurate 10-bit DAC can serve as the precision voltage source for the A/D. Errors of the A/D under test can be expressed as either analog voltages or differences in 2 digital words.

A basic A/D tester that uses a DAC and provides the error as an analog output voltage is shown in *Figure 8*. The 2 op amps can be eliminated if a lab DVM with a numerical subtraction feature is available to read the difference voltage, "A–C", directly. The analog input voltage can be supplied by a low frequency ramp generator and an X-Y plotter can be used to provide analog error (Y axis) versus analog input (X axis).

For operation with a microprocessor or a computer-based test system, it is more convenient to present the errors digitally. This can be done with the circuit of *Figure 11*, where the output code transitions can be detected as the 10-bit DAC is incremented. This provides ¼ LSB steps for the 8-bit A/D under test. If the results of this test are automatically plotted with the analog input on the X axis and the error (in LSB's) as the Y axis, a useful transfer function of the A/D under test results. For acceptance testing, the plot is not necessary and the testing speed can be increased by establishing internal limits on the allowed error for each code.

4.0 MICROPROCESSOR INTERFACING

To dicuss the interface with 8080A and 6800 microprocessors, a common sample subroutine structure is used. The microprocessor starts the A/D, reads and stores the results of 16 successive conversions, then returns to the user's program. The 16 data bytes are stored in 16 successive memory locations. All Data and Addresses will be given in hexadecimal form. Software and hardware details are provided separately for each type of microprocessor.

4.1 Interfacing 8080 Microprocessor Derivatives (8048, 8085)

This converter has been designed to directly interface with derivatives of the 8080 microprocessor. The A/D can be mapped into memory space (using standard memory address decoding for $\overline{CS}$ and the $\overline{MEMR}$ and $\overline{MEMW}$ strobes) or it can be controlled as an I/O device by using the $\overline{I/O\ R}$ and $\overline{I/O\ W}$ strobes and decoding the address bits A0 → A7 (or address bits A8 → A15 as they will contain the same 8-bit address information) to obtain the $\overline{CS}$ input. Using the I/O space provides 256 additional addresses and may allow a simpler 8-bit address decoder but the data can only be input to the accumulator. To make use of the additional memory reference instructions, the A/D should be mapped into memory space. An example of an A/D in I/O space is shown in *Figure 12*.

Functional Description (Continued)

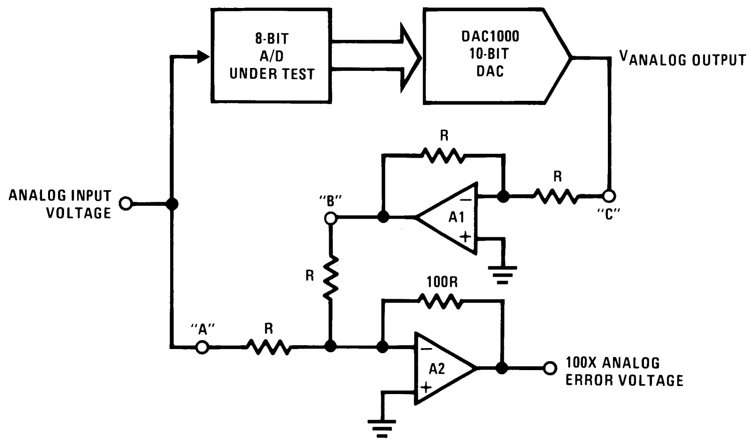


FIGURE 10. A/D Tester with Analog Error Output

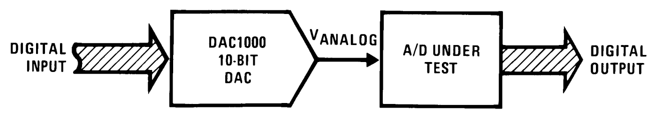


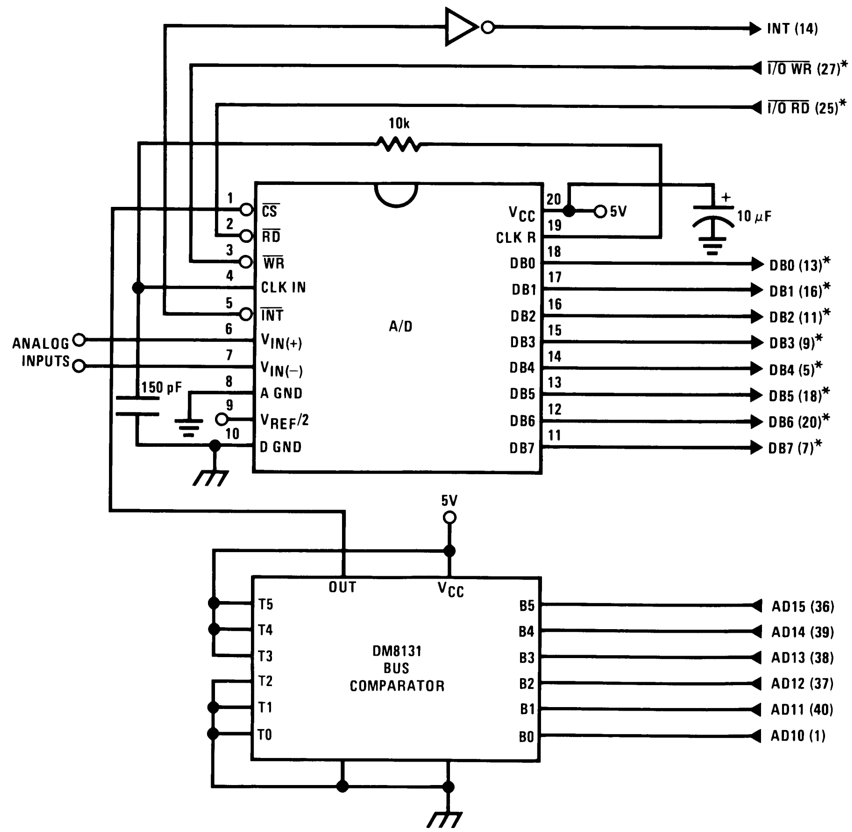
FIGURE 11. Basic "Digital" A/D Tester

TABLE 1. DECODING THE DIGITAL OUTPUT LEDs

HEX	BINARY				FRACTIONAL BINARY VALUE FOR		OUTPUT VOLTAGE CENTER VALUES WITH $V_{REF}/2=2.560\ V_{DC}$	
					MS GROUP	LS GROUP	VMS GROUP (Note 15)	VLS GROUP (Note 15)
F	1	1	1	1	15/16	15/256	4.800	0.300
E	1	1	1	0	7/8	7/128	4.480	0.280
D	1	1	0	1	13/16	13/256	4.160	0.260
C	1	1	0	0	3/4	3/64	3.840	0.240
B	1	0	1	1	11/16	11/256	3.520	0.220
A	1	0	1	0	5/8	5/128	3.200	0.200
9	1	0	0	1	9/16	9/256	2.880	0.180
8	1	0	0	0	1/2	1/32	2.560	0.160
7	0	1	1	1	7/16	7/256	2.240	0.140
6	0	1	1	0	3/8	3/128	1.920	0.120
5	0	1	0	1	5/16	2/256	1.600	0.100
4	0	1	0	0	1/4	1/64	1.280	0.080
3	0	0	1	1	3/16	3/256	0.960	0.060
2	0	0	1	0	1/8	1/128	0.640	0.040
1	0	0	0	1	1/16	1/256	0.320	0.020
0	0	0	0	0			0	0

Note 15: Display Output=VMS Group + VLS Group

Functional Description (Continued)



Note 16: *Pin numbers for the DP8228 system controller, others are INS8080A.

Note 17: Pin 23 of the INS8228 must be tied to +12V through a 1 kΩ resistor to generate the RST 7 instruction when an interrupt is acknowledged as required by the accompanying sample program.

FIGURE 12. ADC0801_INS8080A CPU Interface

Functional Description (Continued)

SAMPLE PROGRAM FOR *Figure 12* ADC0801–INS8080A CPU INTERFACE

```
0038    C3 00 03    RST 7:             JMP    LD DATA
  •        •          •
  •        •          •
0100    21 00 02    START:             LXI H 0200H      ; HL pair will point to
                                                        ; data storage locations
0103    31 00 04    RETURN:            LXI SP 0400H     ; Initialize stack pointer (Note 1)
0106    7D                             MOV A, L         ; Test # of bytes entered
0107    FE 0F                          CPI 0F H         ; If # = 16. JMP to
0109    CA 13 01                       JZ CONT          ; user program
010C    D3 E0                          OUT E0 H         ; Start A/D
010E    FB                             EI               ; Enable interrupt
010F    00          LOOP:              NOP              ; Loop until end of
0110    C3 0F 01                       JMP LOOP         ; conversion
0113       •        CONT:                 •
  •        •          •                   •
  •        •        (User program to      •
  •        •        process data)         •
  •        •          •                   •
  •        •          •                   •
0300    DB E0       LD DATA:           IN E0 H          ; Load data into accumulator
0302    77                             MOV M, A         ; Store data
0303    23                             INX H            ; Increment storage pointer
0304    C3 03 01                       JMP RETURN
```

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Note 18: The stack pointer must be dimensioned because a RST 7 instruction pushes the PC onto the stack.

Note 19: All address used were arbitrarily chosen.

The standard control bus signals of the 8080 $\overline{CS}$, $\overline{RD}$ and $\overline{WR}$) can be directly wired to the digital control inputs of the A/D and the bus timing requirements are met to allow both starting the converter and outputting the data onto the data bus. A bus driver should be used for larger microprocessor systems where the data bus leaves the PC board and/or must drive capacitive loads larger than 100 pF.

4.1.1 Sample 8080A CPU Interfacing Circuitry and Program

The following sample program and associated hardware shown in *Figure 12* may be used to input data from the converter to the INS8080A CPU chip set (comprised of the INS8080A microprocessor, the INS8228 system controller and the INS8224 clock generator). For simplicity, the A/D is controlled as an I/O device, specifically an 8-bit bi-directional port located at an arbitrarily chosen port address, E0. The TRI-STATE output capability of the A/D eliminates the need for a peripheral interface device, however address decoding is still required to generate the appropriate $\overline{CS}$ for the converter.

It is important to note that in systems where the A/D converter is 1-of-8 or less I/O mapped devices, no address decoding circuitry is necessary. Each of the 8 address bits (A0 to A7) can be directly used as $\overline{CS}$ inputs — one for each I/O device.

4.1.2 INS8048 Interface

The INS8048 interface technique with the ADC0801 series (see *Figure 13*) is simpler than the 8080A CPU interface. There are 24 I/O lines and three test input lines in the 8048. With these extra I/O lines available, one of the I/O lines (bit 0 of port 1) is used as the chip select signal to the A/D, thus eliminating the use of an external address decoder. Bus control signals $\overline{RD}$, $\overline{WR}$ and $\overline{INT}$ of the 8048 are tied directly to the A/D. The 16 converted data words are stored at on-chip RAM locations from 20 to 2F (Hex). The $\overline{RD}$ and $\overline{WR}$ signals are generated by reading from and writing into a dummy address, respectively. A sample interface program is shown below.

Functional Description (Continued)

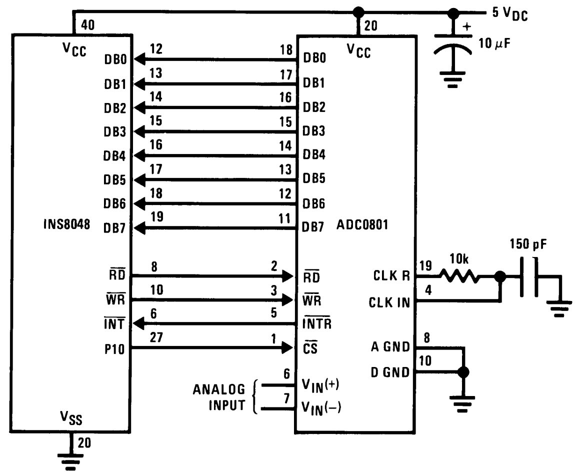

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FIGURE 13. INS8048 Interface

SAMPLE PROGRAM FOR ***Figure 13*** **INS8048 INTERFACE**

```
04 10                   JMP     10H          : Program starts at addr 10
                        ORG     3H
04 50                   JMP     50H          ; Interrupt jump vector
                        ORG     10H          ; Main program
99 FE                   ANL     P1, #0FEH    ; Chip select
81                      MOVX    A, @R1       ; Read in the 1st data
                                             ; to reset the intr
89 01     START:        ORL     P1, #1       ; Set port pin high
B8 20                   MOV     R0, #20H     ; Data address
B9 FF                   MOV     R1, #0FFH    ; Dummy address
BA 10                   MOV     R2, #10H     ; Counter for 16 bytes
23 FF     AGAIN:        MOV     A, #0FFH     ; Set ACC for intr loop
99 FE                   ANL     P1, #0FEH    ; Send CS (bit 0 of P1)
91                      MOVX    @R1, A       ; Send WR out
05                      EN      I            ; Enable interrupt
96 21     LOOP:         JNZ     LOOP         ; Wait for interrupt
EA 1B                   DJNZ    R2, AGAIN    ; If 16 bytes are read
00                      NOP                  ; go to user's program
00                      NOP
                        ORG     50H
81        INDATA:       MOVX    A, @R1       ; Input data, CS still low
A0                      MOV     @R0, A       ; Store in memory
18                      INC     R0           ; Increment storage counter
89 01                   ORL     P1, #1       ; Reset CS signal
27                      CLR     A            ; Clear ACC to get out of
93                      RETR                 ; the interrupt loop
```

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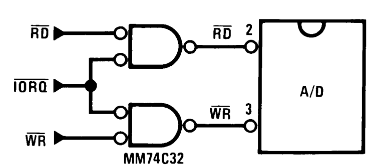
4.2 Interfacing the Z-80

The Z-80 control bus is slightly different from that of the 8080. General $\overline{RD}$ and $\overline{WR}$ strobes are provided and separate memory request, $\overline{MREQ}$, and I/O request, $\overline{IORQ}$, signals are used which have to be combined with the generalized strobes to provide the equivalent 8080 signals. An advantage of operating the A/D in I/O space with the Z-80 is that the CPU will automatically insert one wait state (the $\overline{RD}$ and $\overline{WR}$ strobes are extended one clock period) to allow more time for the I/O devices to respond. Logic to map the A/D in I/O space is shown in *Figure 14*.



DS005671-23

FIGURE 14. Mapping the A/D as an I/O Device for Use with the Z-80 CPU

Additional I/O advantages exist as software DMA routines are available and use can be made of the output data transfer which exists on the upper 8 address lines (A8 to

Functional Description (Continued)

A15) during I/O input instructions. For example, MUX channel selection for the A/D can be accomplished with this operating mode.

4.3 Interfacing 6800 Microprocessor Derivatives (6502, etc.)

The control bus for the 6800 microprocessor derivatives does not use the $\overline{\text{RD}}$ and $\overline{\text{WR}}$ strobe signals. Instead it employs a single R/$\overline{\text{W}}$ line and additional timing, if needed, can be derived fom the ϕ2 clock. All I/O devices are memory mapped in the 6800 system, and a special signal, VMA, indicates that the current address is valid. *Figure 15* shows an interface schematic where the A/D is memory mapped in the 6800 system. For simplicity, the $\overline{\text{CS}}$ decoding is shown using ½ DM8092. Note that in many 6800 systems, an already decoded $\overline{4/5}$ line is brought out to the common bus at pin 21. This can be tied directly to the $\overline{\text{CS}}$ pin of the A/D, provided that no other devices are addressed at HX ADDR: 4XXX or 5XXX.

The following subroutine performs essentially the same function as in the case of the 8080A interface and it can be called from anywhere in the user's program.

In *Figure 16* the ADC0801 series is interfaced to the M6800 microprocessor through (the arbitrarily chosen) Port B of the MC6820 or MC6821 Peripheral Interface Adapter, (PIA). Here the $\overline{\text{CS}}$ pin of the A/D is grounded since the PIA is already memory mapped in the M6800 system and no $\overline{\text{CS}}$ decoding is necessary. Also notice that the A/D output data lines are connected to the microprocessor bus under program control through the PIA and therefore the A/D $\overline{\text{RD}}$ pin can be grounded.

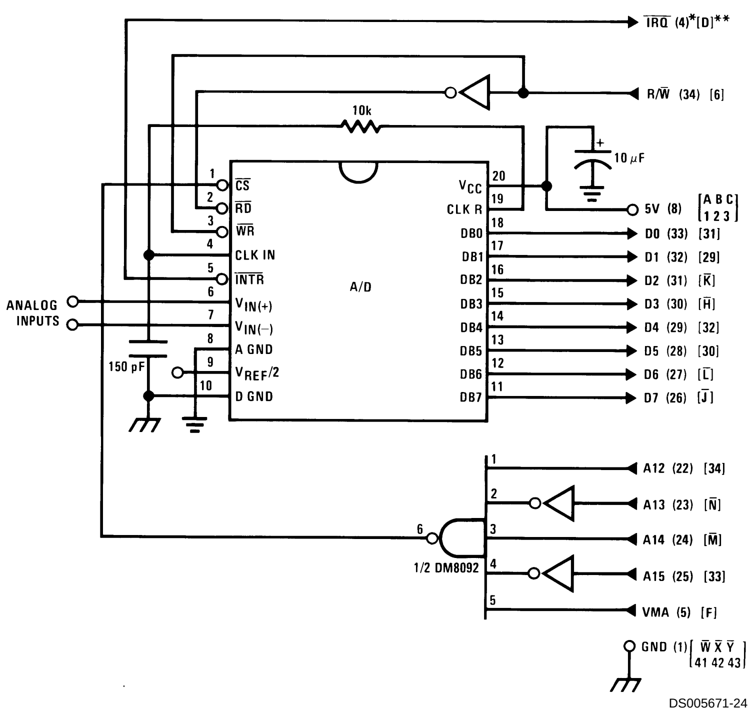
A sample interface program equivalent to the previous one is shown below *Figure 16*. The PIA Data and Control Registers of Port B are located at HEX addresses 8006 and 8007, respectively.

5.0 GENERAL APPLICATIONS

The following applications show some interesting uses for the A/D. The fact that one particular microprocessor is used is not meant to be restrictive. Each of these application circuits would have its counterpart using any microprocessor that is desired.

5.1 Multiple ADC0801 Series to MC6800 CPU Interface

To transfer analog data from several channels to a single microprocessor system, a multiple converter scheme presents several advantages over the conventional multiplexer single-converter approach. With the ADC0801 series, the differential inputs allow individual span adjustment for each channel. Furthermore, all analog input channels are sensed simultaneously, which essentially divides the microprocessor's total system servicing time by the number of channels, since all conversions occur simultaneously. This scheme is shown in *Figure 17*.



Note 20: Numbers in parentheses refer to MC6800 CPU pin out.

Note 21: Number or letters in brackets refer to standard M6800 system common bus code.

FIGURE 15. ADC0801-MC6800 CPU Interface

Functional Description (Continued)

SAMPLE PROGRAM FOR *Figure 15* ADC0801-MC6800 CPU INTERFACE

```
0010   DF 36      DATAIN   STX    TEMP2     ; Save contents of X
0012   CE 00 2C            LDX    #$002C    ; Upon IRQ low CPU
0015   FF FF F8            STX    $FFF8     ; jumps to 002C
0018   B7 50 00            STAA   $5000     ; Start ADC0801
001B   0E                  CLI
001C   3E         CONVRT   WAI              ; Wait for interrupt
001D   DE 34               LDX    TEMP1
001F   8C 02 0F            CPX    #$020F    ; Is final data stored?
0022   27 14               BEQ    ENDP
0024   B7 50 00            STAA   $5000     ; Restarts ADC0801
0027   08                  INX
0028   DF 34               STX    TEMP1
002A   20 F0               BRA    CONVRT
002C   DE 34      INTRPT   LDX    TEMP1
002E   B6 50 00            LDAA   $5000     ; Read data
0031   A7 00               STAA   X         ; Store it at X
0033   3B                  RTI
0034   02 00      TEMP1    FDB    $0200     ; Starting address for
                                            ; data storage
0036   00 00      TEMP2    FDB    $0000
0038   CE 02 00   ENDP     LDX    #$0200    ; Reinitialize TEMP1
003B   DF 34               STX    TEMP1
003D   DE 36               LDX    TEMP2
003F   39                  RTS              ; Return from subroutine
                                            ; To user's program
```

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Note 22: In order for the microprocessor to service subroutines and interrupts, the stack pointer must be dimensioned in the user's program.

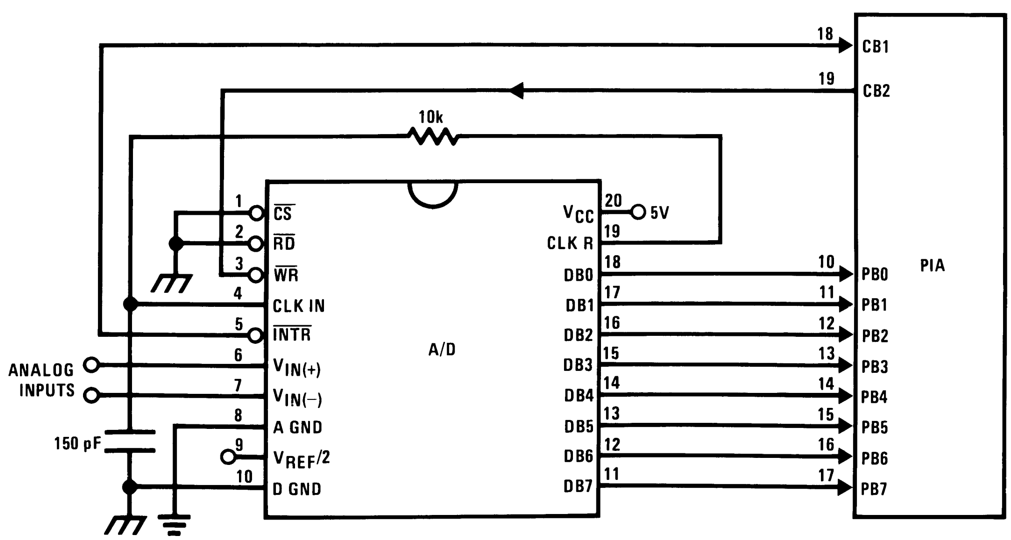

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FIGURE 16. ADC0801–MC6820 PIA Interface

Functional Description (Continued)

SAMPLE PROGRAM FOR ***Figure 16*** **ADC0801–MC6820 PIA INTERFACE**

```
0010   CE 00 38   DATAIN   LDX    #$0038    ; Upon IRQ low CPU
0013   FF FF F8            STX    $FFF8     ; jumps to 0038
0016   B6 80 06            LDAA   PIAORB    ; Clear possible IRQ flags
0019   4F                  CLRA
001A   B7 80 07            STAA   PIACRB
001D   B7 80 06            STAA   PIAORB    ; Set Port B as input
0020   0E                  CLI
0021   C6 34               LDAB   #$34
0023   86 3D               LDAA   #$3D
0025   F7 80 07   CONVRT   STAB   PIACRB    ; Starts ADC0801
0028   B7 80 07            STAA   PIACRB
002B   3E                  WAI              ; Wait for interrupt
002C   DE 40               LDX    TEMP1
002E   8C 02 0F            CPX    #$020F    ; Is final data stored?
0031   27 0F               BEQ    ENDP
0033   08                  INX
0034   DF 40               STX    TEMP1
0036   20 ED               BRA    CONVRT
0038   DE 40      INTRPT   LDX    TEMP1
003A   B6 80 06            LDAA   PIAORB    ; Read data in
003D   A7 00               STAA   X         ; Store it at X
003F   3B                  RTI
0040   02 00      TEMP1    FDB    $0200     ; Starting address for
                                            ; data storage
0042   CE 02 00   ENDP     LDX    #$0200    ; Reinitialize TEMP1
0045   DF 40               STX    TEMP1
0047   39                  RTS              ; Return from subroutine
                  PIAORB   EQU    $8006     ; To user's program
                  PIACRB   EQU    $8007
```

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The following schematic and sample subroutine (DATA IN) may be used to interface (up to) 8 ADC0801's directly to the MC6800 CPU. This scheme can easily be extended to allow the interface of more converters. In this configuration the converters are (arbitrarily) located at HEX address 5000 in the MC6800 memory space. To save components, the clock signal is derived from just one RC pair on the first converter. This output drives the other A/Ds.

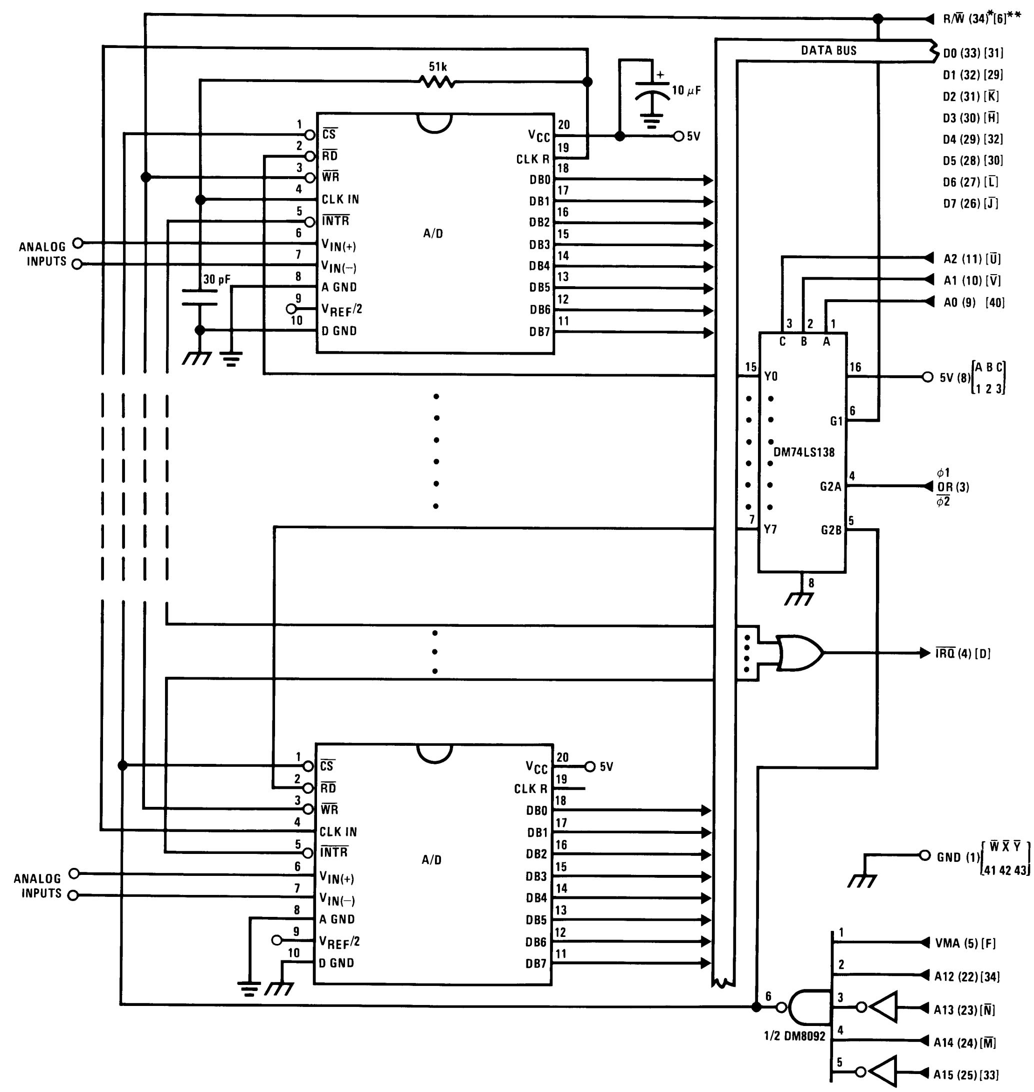
All the converters are started simultaneously with a STORE instruction at HEX address 5000. Note that any other HEX address of the form 5XXX will be decoded by the circuit, pulling all the $\overline{CS}$ inputs low. This can easily be avoided by using a more definitive address decoding scheme. All the interrupts are ORed together to insure that all A/Ds have completed their conversion before the microprocessor is interrupted.

The subroutine, DATA IN, may be called from anywhere in the user's program. Once called, this routine initializes the CPU, starts all the converters simultaneously and waits for the interrupt signal. Upon receiving the interrupt, it reads the converters (from HEX addresses 5000 through 5007) and stores the data successively at (arbitrarily chosen) HEX addresses 0200 to 0207, before returning to the user's program. All CPU registers then recover the original data they had before servicing DATA IN.

5.2 Auto-Zeroed Differential Transducer Amplifier and A/D Converter

The differential inputs of the ADC0801 series eliminate the need to perform a differential to single ended conversion for a differential transducer. Thus, one op amp can be eliminated since the differential to single ended conversion is provided by the differential input of the ADC0801 series. In general, a transducer preamp is required to take advantage of the full A/D converter input dynamic range.

Functional Description (Continued)



Note 23: Numbers in parentheses refer to MC6800 CPU pin out.

Note 24: Numbers of letters in brackets refer to standard M6800 system common bus code.

FIGURE 17. Interfacing Multiple A/Ds in an MC6800 System

Functional Description (Continued)

SAMPLE PROGRAM FOR *Figure 17* INTERFACING MULTIPLE A/D's IN AN MC6800 SYSTEM

ADDRESS	HEX CODE		MNEMONICS		COMMENTS
0010	DF 44	DATAIN	STX	TEMP	; Save Contents of X
0012	CE 00 2A		LDX	#$002A	; Upon $\overline{IRQ}$ LOW CPU
0015	FF FF F8		STX	$FFF8	; Jumps to 002A
0018	B7 50 00		STAA	$5000	; Starts all A/D's
001B	0E		CLI		
001C	3E		WAI		; Wait for interrupt
001D	CE 50 00		LDX	#$5000	
0020	DF 40		STX	INDEX1	; Reset both INDEX
0022	CE 02 00		LDX	#$0200	; 1 and 2 to starting
0025	DF 42		STX	INDEX2	; addresses
0027	DE 44		LDX	TEMP	
0029	39		RTS		; Return from subroutine
002A	DE 40	INTRPT	LDX	INDEX1	; INDEX1 → X
002C	A6 00		LDAA	X	; Read data in from A/D at X
002E	08		INX		; Increment X by one
002F	DF 40		STX	INDEX1	; X → INDEX1
0031	DE 42		LDX	INDEX2	; INDEX2 → X

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SAMPLE PROGRAM FOR *Figure 17* INTERFACING MULTIPLE A/D's IN AN MC6800 SYSTEM

ADDRESS	HEX CODE		MNEMONICS		COMMENTS
0033	A7 00		STAA	X	; Store data at X
0035	8C 02 07		CPX	#$0207	; Have all A/D's been read?
0038	27 05		BEQ	RETURN	; Yes: branch to RETURN
003A	08		INX		; No: increment X by one
003B	DF 42		STX	INDEX2	; X → INDEX2
003D	20 EB		BRA	INTRPT	; Branch to 002A
003F	3B	RETURN	RTI		
0040	50 00	INDEX1	FDB	$5000	; Starting address for A/D
0042	02 00	INDEX2	FDB	$0200	; Starting address for data storage
0044	00 00	TEMP	FDB	$0000	

DS005671-A4

Note 25: In order for the microprocessor to service subroutines and interrupts, the stack pointer must be dimensioned in the user's program.

For amplification of DC input signals, a major system error is the input offset voltage of the amplifiers used for the preamp. *Figure 18* is a gain of 100 differential preamp whose offset voltage errors will be cancelled by a zeroing subroutine which is performed by the INS8080A microprocessor system. The total allowable input offset voltage error for this preamp is only 50 µV for ¼ LSB error. This would obviously require very precise amplifiers. The expression for the differential output voltage of the preamp is:

$$V_O = \underbrace{[V_{IN}(+) - V_{IN}(-)]}_{\text{SIGNAL}} \underbrace{\left[1 + \frac{2R2}{R1}\right]}_{\text{GAIN}} +$$

$$\underbrace{(V_{OS_2} - V_{OS_1} - V_{OS_3} \pm I_X R_X)}_{\text{DC ERROR TERM}} \underbrace{\left(1 + \frac{2R2}{R1}\right)}_{\text{GAIN}}$$

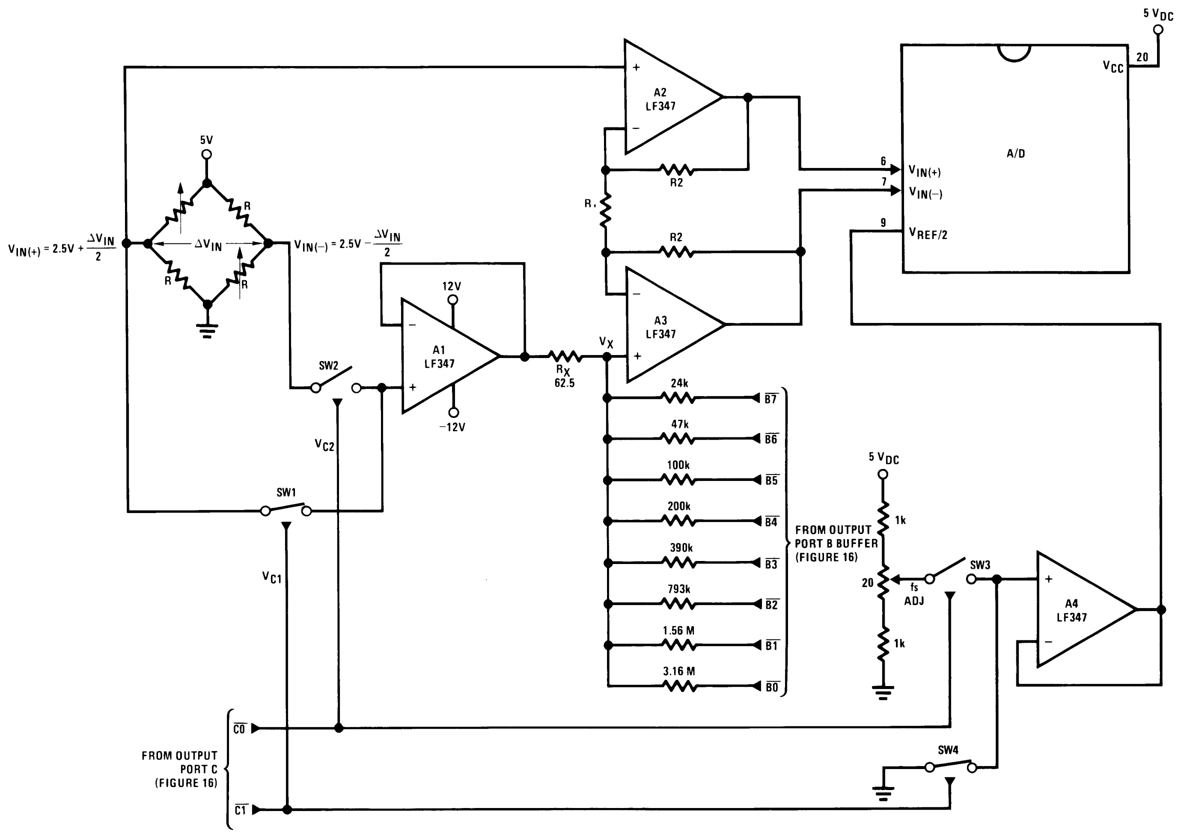
where I_X is the current through resistor R_X. All of the offset error terms can be cancelled by making $\pm I_X R_X = V_{OS1} + V_{OS3} - V_{OS2}$. This is the principle of this auto-zeroing scheme.

The INS8080A uses the 3 I/O ports of an INS8255 Programable Peripheral Interface (PPI) to control the auto zeroing and input data from the ADC0801 as shown in *Figure 19*. The PPI is programmed for basic I/O operation (mode 0) with Port A being an input port and Ports B and C being output ports. Two bits of Port C are used to alternately open or close the 2 switches at the input of the preamp. Switch SW1 is closed to force the preamp's differential input to be zero during the zeroing subroutine and then opened and SW2 is then closed for conversion of the actual differential input signal. Using 2 switches in this manner eliminates concern for the ON resistance of the switches as they must conduct only the input bias current of the input amplifiers.

Output Port B is used as a successive approximation register by the 8080 and the binary scaled resistors in series with each output bit create a D/A converter. During the zeroing subroutine, the voltage at V_x increases or decreases as required to make the differential output voltage equal to zero. This is accomplished by ensuring that the voltage at the output of A1 is approximately 2.5V so that a logic "1" (5V) on

Functional Description (Continued)

any output of Port B will source current into node V_X thus raising the voltage at V_X and making the output differential more negative. Conversely, a logic “0” (0V) will pull current out of node V_X and decrease the voltage, causing the differential output to become more positive. For the resistor values shown, V_X can move ±12 mV with a resolution of 50 µV, which will null the offset error term to ¼ LSB of full-scale for the ADC0801. It is important that the voltage levels that drive the auto-zero resistors be constant. Also, for symmetry, a logic swing of 0V to 5V is convenient. To achieve this, a CMOS buffer is used for the logic output signals of Port B and this CMOS package is powered with a stable 5V source. Buffer amplifier A1 is necessary so that it can source or sink the D/A output current.



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Note 26: R2 = 49.5 R1

Note 27: Switches are LMC13334 CMOS analog switches.

Note 28: The 9 resistors used in the auto-zero section can be ±5% tolerance.

FIGURE 18. Gain of 100 Differential Transducer Preamp

Functional Description (Continued)

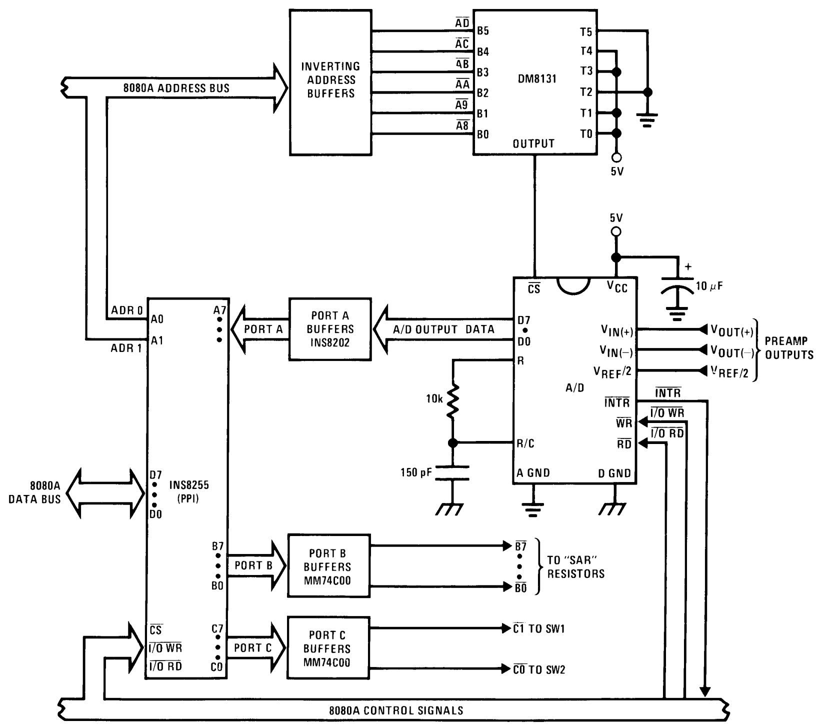

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FIGURE 19. Microprocessor Interface Circuitry for Differential Preamp

A flow chart for the zeroing subroutine is shown in *Figure 20*. It must be noted that the ADC0801 series will output an all zero code when it converts a negative input [$V_{IN}(-) \geq V_{IN}(+)$]. Also, a logic inversion exists as all of the I/O ports are buffered with inverting gates.

Basically, if the data read is zero, the differential output voltage is negative, so a bit in Port B is cleared to pull V_X more negative which will make the output more positive for the next conversion. If the data read is not zero, the output voltage is positive so a bit in Port B is set to make V_X more positive and the output more negative. This continues for 8 approximations and the differential output eventually converges to within 5 mV of zero.

The actual program is given in *Figure 21.* All addresses used are compatible with the BLC 80/10 microcomputer system. In particular:

Port A and the ADC0801 are at port address E4

Port B is at port address E5

Port C is at port address E6

PPI control word port is at port address E7

Program Counter automatically goes to ADDR:3C3D upon acknowledgement of an interrupt from the ADC0801

5.3 Multiple A/D Converters in a Z-80 Interrupt Driven Mode

In data acquisition systems where more than one A/D converter (or other peripheral device) will be interrupting program execution of a microprocessor, there is obviously a need for the CPU to determine which device requires servicing. *Figure 22* and the accompanying software is a method of determining which of 7 ADC0801 converters has completed a conversion ($\overline{\text{INTR}}$ asserted) and is requesting an interrupt. This circuit allows starting the A/D converters in any sequence, but will input and store valid data from the converters with a priority sequence of A/D 1 being read first, A/D 2 second, etc., through A/D 7 which would have the lowest priority for data being read. Only the converters whose INT is asserted will be read.

The key to decoding circuitry is the DM74LS373, 8-bit D type flip-flop. When the Z-80 acknowledges the interrupt, the program is vectored to a data input Z-80 subroutine. This subroutine will read a peripheral status word from the DM74LS373 which contains the logic state of the $\overline{\text{INTR}}$ outputs of all the converters. Each converter which initiates an interrupt will place a logic "0" in a unique bit position in the status word and the subroutine will determine the identity of the converter and execute a data read. An identifier word (which indicates which A/D the data came from) is stored in the next sequential memory location above the location of the data so the program can keep track of the identity of the data entered.

Functional Description (Continued)

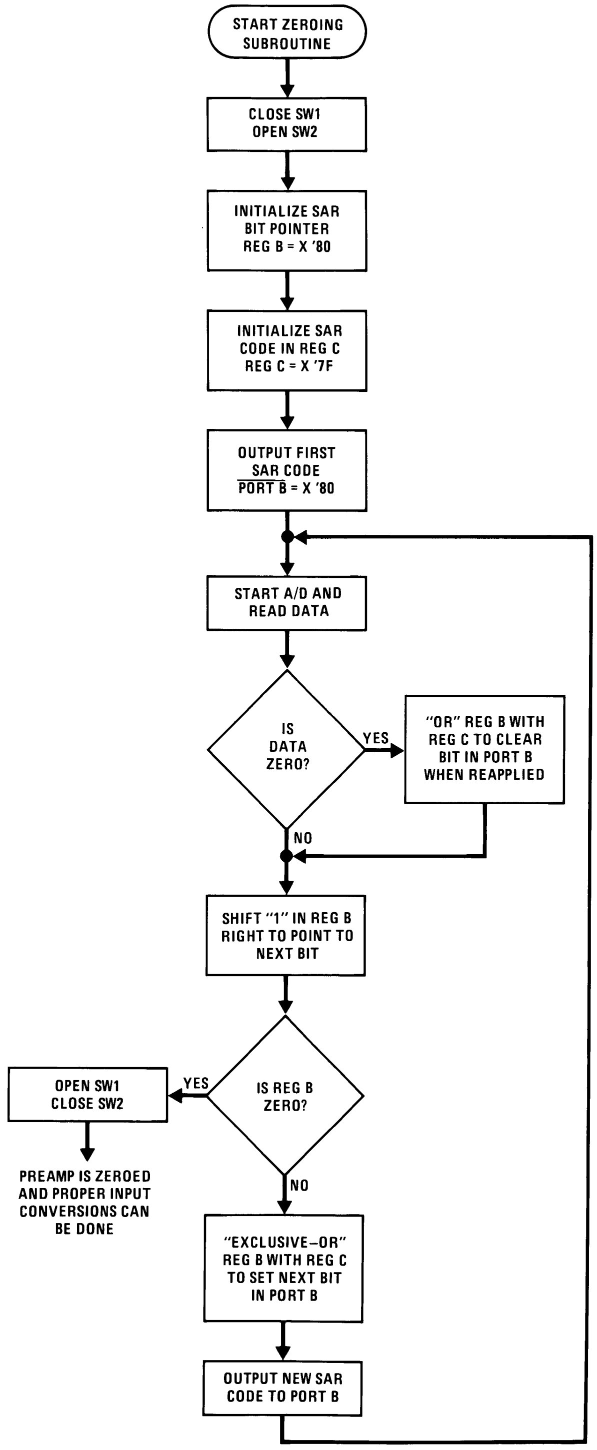


FIGURE 20. Flow Chart for Auto-Zero Routine

Functional Description (Continued)

```
3D00  3E90    MVI 90
3D02  D3E7    Out Control Port                             ; Program PPI
3D04  2601    MVI H 01              Auto-Zero Subroutine
3D06  7C      MOV A,H
3D07  D3E6    OUT C                                        ; Close SW1 open SW2
3D09  0680    MVI B 80                                     ; Initialize SAR bit pointer
3D0B  3E7F    MVI A 7F                                     ; Initialize SAR code
3D0D  4F      MOV C,A               Return
3D0E  D3E5    OUT B                                        ; Port B = SAR code
3D10  31AA3D  LXI SP 3DAA           Start                  ; Dimension stack pointer
3D13  D3E4    OUT A                                        ; Start A/D
3D15  FB      IE
3D16  00      NOP                   Loop                   ; Loop until INT asserted
3D17  C3163D  JMP Loop
3D1A  7A      MOV A,D               Auto-Zero
3D1B  C600    ADI 00
3D1D  CA2D3D  JZ Set C                                     ; Test A/D output data for zero
3D20  78      MOV A,B               Shift B
3D21  F600    ORI 00                                       ; Clear carry
3D23  1F      RAR                                          ; Shift "1" in B right one place
3D24  FE00    CPI 00                                       ; Is B zero? If yes last
3D26  CA373D  JZ Done                                      ; approximation has been made
3D29  47      MOV B,A
3D2A  C3333D  JMP New C
3D2D  79      MOV A,C               Set C
3D2E  B0      ORA B                                        ; Set bit in C that is in same
3D2F  4F      MOV C,A                                      ; position as "1" in B
3D30  C3203D  JMP Shift B
3D33  A9      XRA C                 New C                  ; Clear bit in C that is in
3D34  C30D3D  JMP Return                                   ; same position as "1" in B
3D37  47      MOV B,A               Done                   ; then output new SAR code.
3D38  7C      MOV A,H                                      ; Open SW1, close SW2 then
3D39  EE03    XRI 03                                       ; proceed with program. Preamp
3D3B  D3E6    OUT C                                        ; is now zeroed.
3D3D          •                     Normal
              •
              •
              Program for processing
              proper data values
3C3D  DBE4    IN A                  Read A/D Subroutine    ; Read A/D data
3C3F  EEFF    XRI FF                                       ; Invert data
3C41  57      MOV D,A
3C42  78      MOV A,B                                      ; Is B Reg = 0? If not stay
3C43  E6FF    ANI FF                                       ; in auto zero subroutine
3C45  C21A3D  JNZ Auto-Zero
3C48  C33D3D  JMP Normal
```

DS005671-A5

Note 29: All numerical values are hexadecimal representations.

FIGURE 21. Software for Auto-Zeroed Differential A/D

5.3 Multiple A/D Converters in a Z-80 Interrupt Driven Mode (Continued)

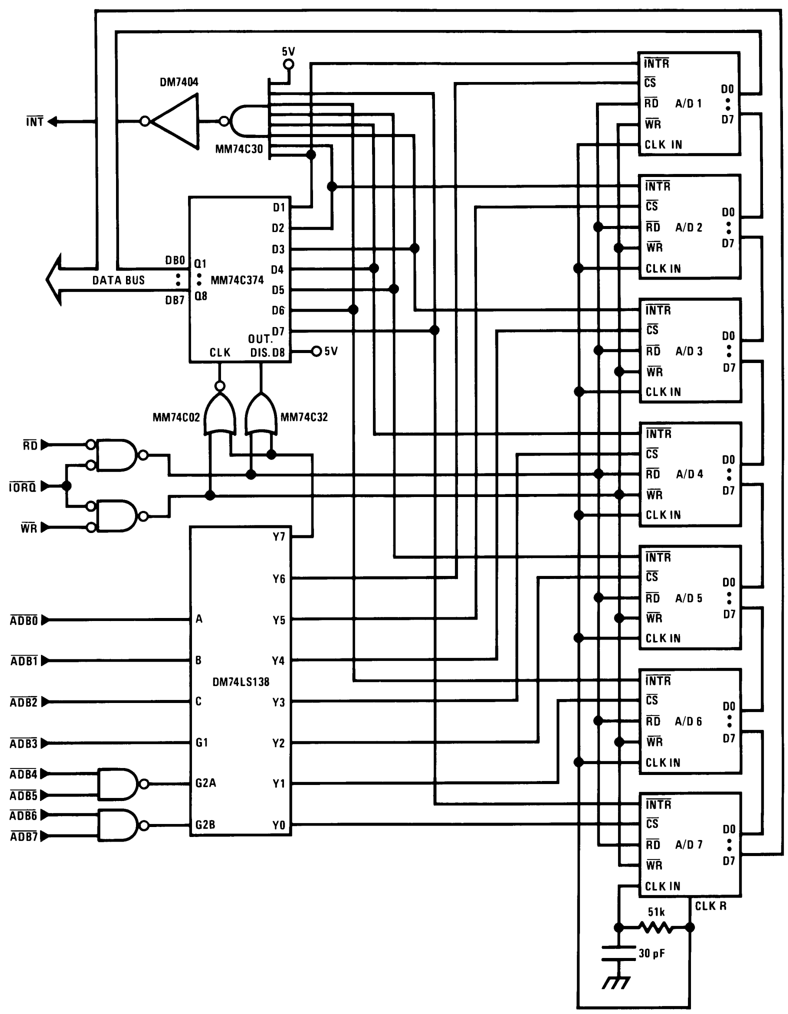
The following notes apply:

- It is assumed that the CPU automatically performs a RST 7 instruction when a valid interrupt is acknowledged (CPU is in interrupt mode 1). Hence, the subroutine starting address of X0038.
- The address bus from the Z-80 and the data bus to the Z-80 are assumed to be inverted by bus drivers.
- A/D data and identifying words will be stored in sequential memory locations starting at the arbitrarily chosen address X 3E00.
- The stack pointer must be dimensioned in the main program as the RST 7 instruction automatically pushes the PC onto the stack and the subroutine uses an additional 6 stack addresses.
- The peripherals of concern are mapped into I/O space with the following port assignments:

Functional Description (Continued)

HEX PORT ADDRESS	PERIPHERAL
00	MM74C374 8-bit flip-flop
01	A/D 1
02	A/D 2
03	A/D 3
04	A/D 4
05	A/D 5
06	A/D 6
07	A/D 7

This port address also serves as the A/D identifying word in the program.



DS005671-29

FIGURE 22. Multiple A/Ds with Z-80 Type Microprocessor

Functional Description (Continued)

INTERRUPT SERVICING SUBROUTINE

LOC	OBJ CODE		SOURCE STATEMENT	COMMENT
0038	E5		PUSH HL	; Save contents of all registers affected by
0039	C5		PUSH BC	; this subroutine.
003A	F5		PUSH AF	; Assumed INT mode 1 earlier set.
003B	21 00 3E		LD (HL),X3E00	; Initialize memory pointer where data will be stored.
003E	0E 01		LD C, X01	; C register will be port ADDR of A/D converters.
0040	D300		OUT X00, A	; Load peripheral status word into 8-bit latch.
0042	DB00		IN A, X00	; Load status word into accumulator.
0044	47		LD B,A	; Save the status word.
0045	79	TEST	LD A,C	; Test to see if the status of all A/D's have
0046	FE 08		CP, X08	; been checked. If so, exit subroutine
0048	CA 60 00		JPZ, DONE	
004B	78		LD A,B	; Test a single bit in status word by looking for
004C	1F		RRA	; a "1" to be rotated into the CARRY (an $\overline{\text{INT}}$
004D	47		LD B,A	; is loaded as a "1"). If CARRY is set then load
004E	DA 5500		JPC, LOAD	; contents of A/D at port ADDR in C register.
0051	0C	NEXT	INC C	; If CARRY is not set, increment C register to point
0052	C3 4500		JP,TEST	; to next A/D, then test next bit in status word.
0055	ED 78	LOAD	IN A, (C)	; Read data from interrupting A/D and invert
0057	EE FF		XOR FF	; the data.
0059	77		LD (HL),A	; Store the data
005A	2C		INC L	
005B	71		LD (HL),C	; Store A/D identifier (A/D port ADDR).
005C	2C		INC L	
005D	C3 51 00		JP,NEXT	; Test next bit in status word.
0060	F1	DONE	POP AF	; Re-establish all registers as they were
0061	C1		POP BC	; before the interrupt.
0062	E1		POP HL	
0063	C9		RET	; Return to original program

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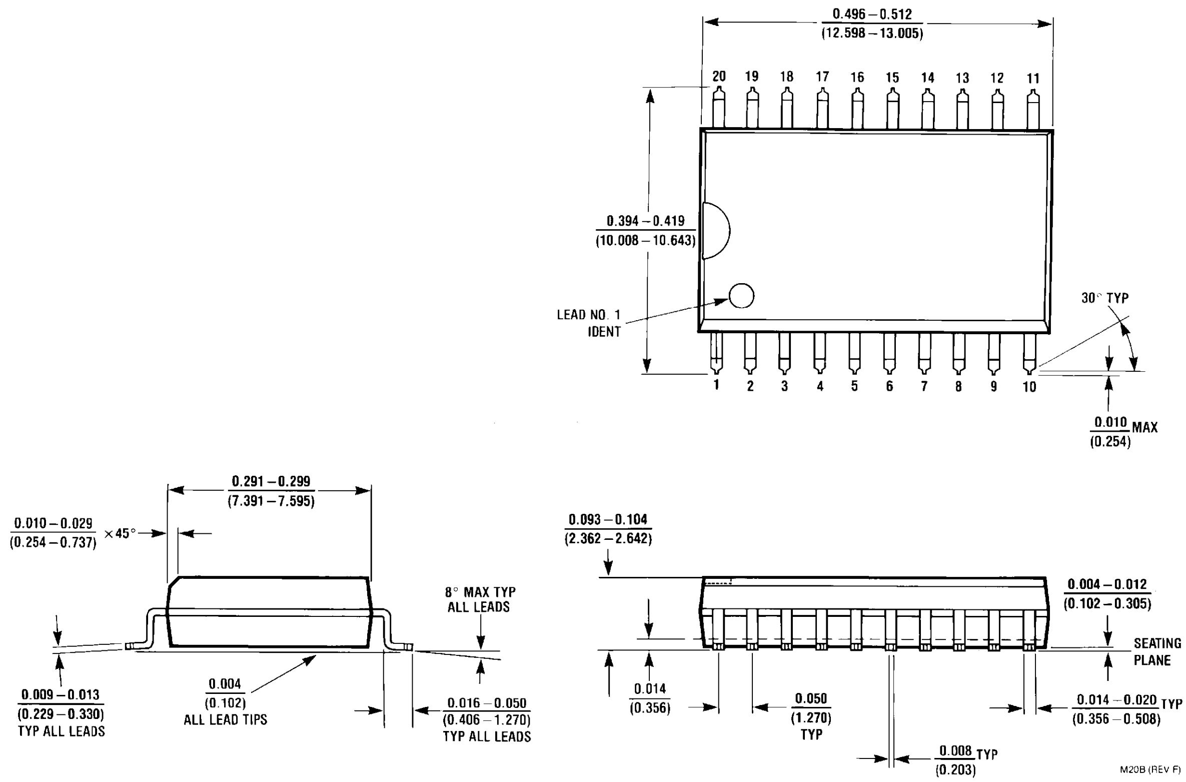
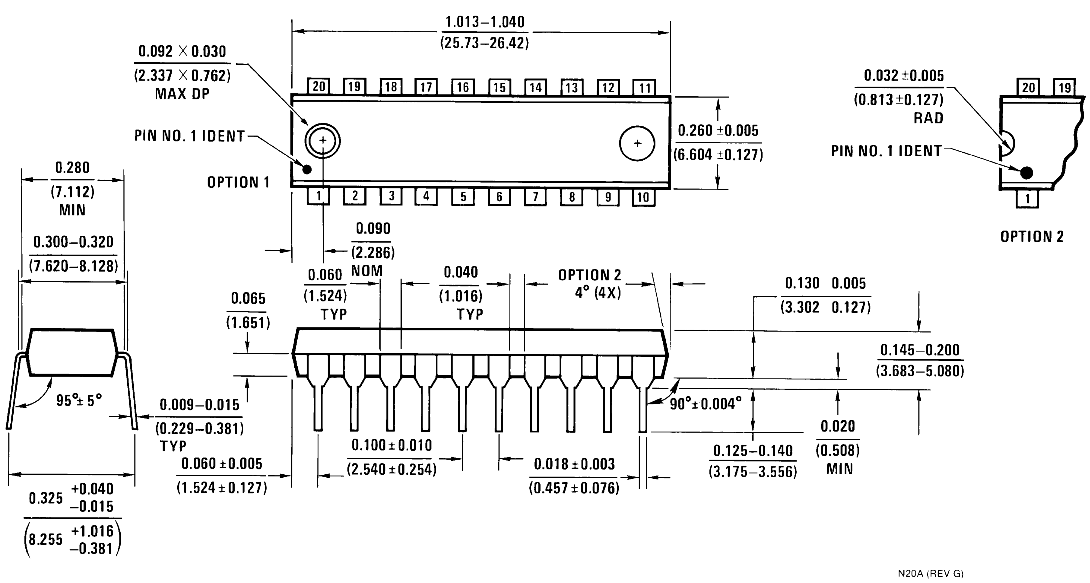
Physical Dimensions inches (millimeters) unless otherwise noted



SO Package (M)
Order Number ADC0802LCWM or ADC0804LCWM
NS Package Number M20B



Molded Dual-In-Line Package (N)
Order Number ADC0801LCN, ADC0802LCN,
ADC0803LCN, ADC0804LCN or ADC0805LCN
NS Package Number N20A

Notes

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National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

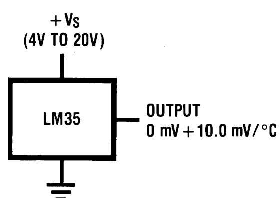
General Description

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

Features

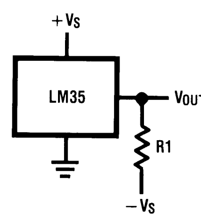
- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
-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

Typical Applications



DS005516-3

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



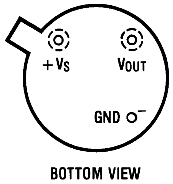
DS005516-4

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

FIGURE 2. Full-Range Centigrade Temperature Sensor

Connection Diagrams

TO-46
Metal Can Package*

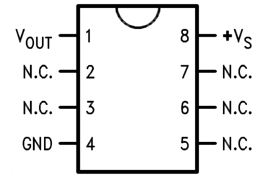


DS005516-1

*Case is connected to negative pin (GND)

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

SO-8
Small Outline Molded Package

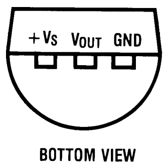


DS005516-21

N.C. = No Connection

Top View
Order Number LM35DM
See NS Package Number M08A

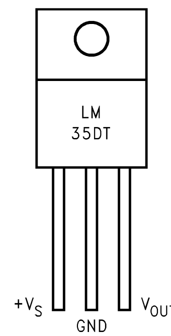
TO-92
Plastic Package



DS005516-2

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

TO-220
Plastic Package*



DS005516-24

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

Order Number LM35DT
See NS Package Number TA03F

Absolute Maximum Ratings (Note 10)

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

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

Electrical Characteristics

(Notes 1, 6)

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

Electrical Characteristics

(Notes 1, 6)

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

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

Note 2: Thermal resistance of the TO-46 package is 400˚C/W, junction to ambient, and 24˚C/W junction to case. Thermal resistance of the TO-92 package is 180˚C/W junction to ambient. Thermal resistance of the small outline molded package is 220˚C/W junction to ambient. Thermal resistance of the TO-220 package is 90˚C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

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

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

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

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

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

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

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

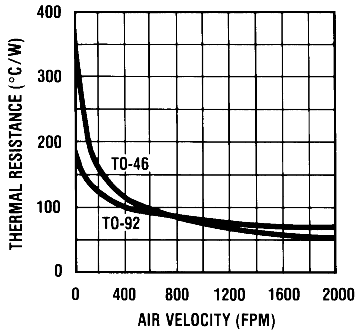
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

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

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

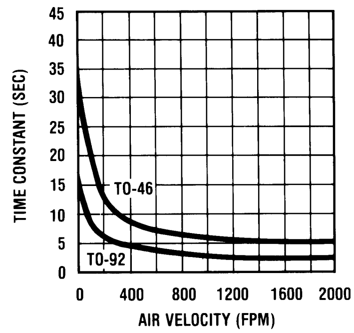
Typical Performance Characteristics

Thermal Resistance Junction to Air



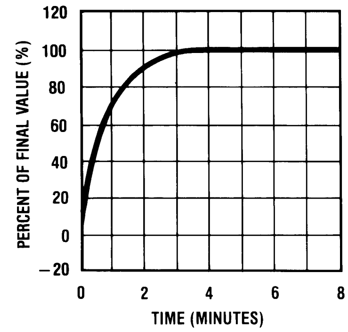
DS005516-25

Thermal Time Constant



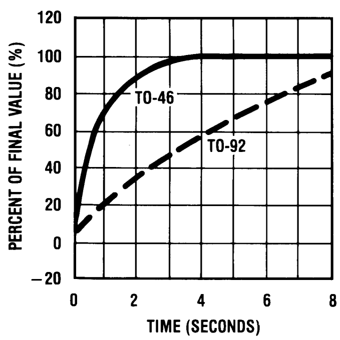
DS005516-26

Thermal Response in Still Air



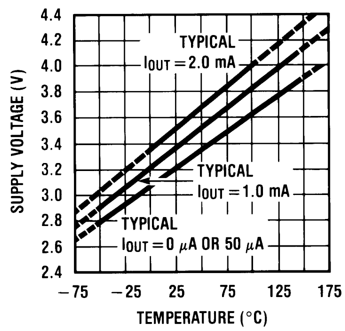
DS005516-27

Thermal Response in Stirred Oil Bath



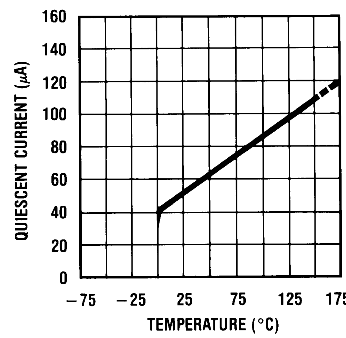
DS005516-28

Minimum Supply Voltage vs. Temperature



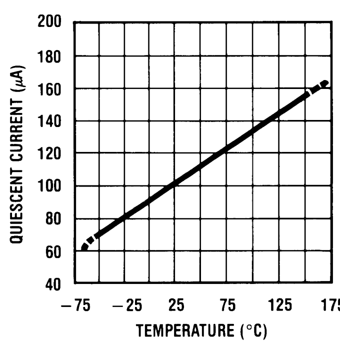
DS005516-29

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



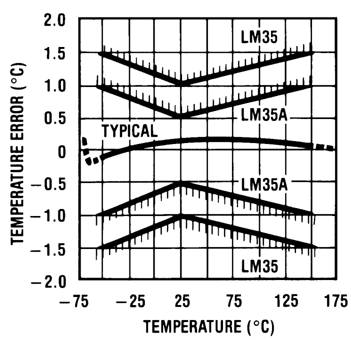
DS005516-30

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



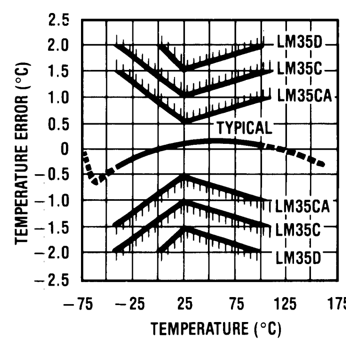
DS005516-31

Accuracy vs. Temperature (Guaranteed)



DS005516-32

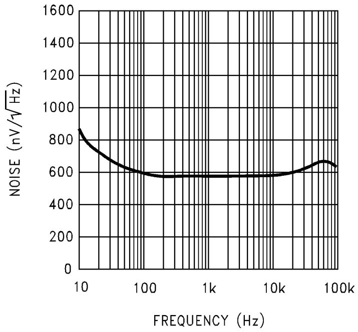
Accuracy vs. Temperature (Guaranteed)



DS005516-33

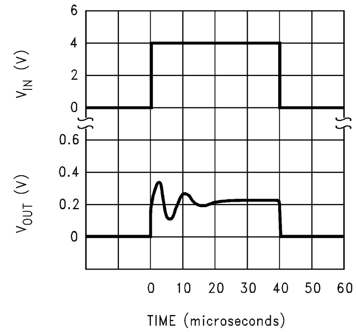
Typical Performance Characteristics (Continued)

Noise Voltage



DS005516-34

Start-Up Response



DS005516-35

Applications

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

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

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

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

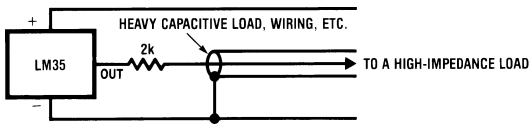
These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

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

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

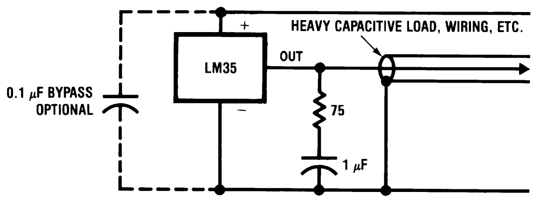
*Wakefield type 201, or 1" disc of 0.020" sheet brass, soldered to case, or similar.
**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Applications



DS005516-19

FIGURE 3. LM35 with Decoupling from Capacitive Load



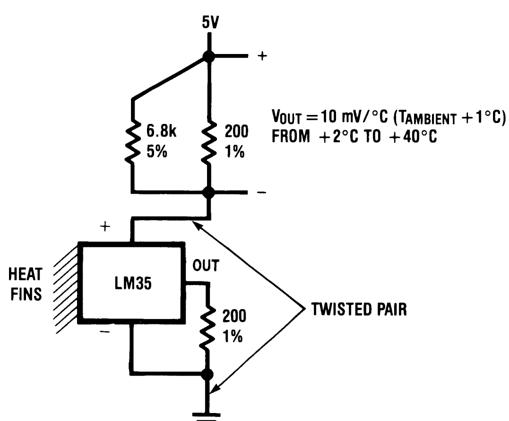
DS005516-20

FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

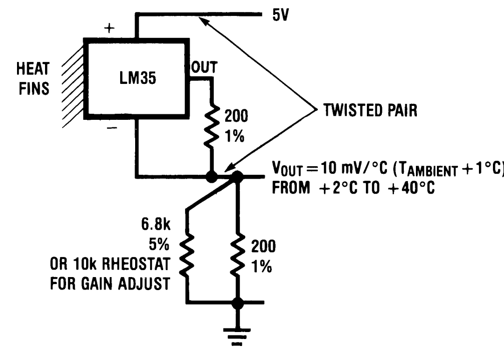
Like most micropower circuits, the LM35 has a limited ability to drive heavy capacitive loads. The LM35 by itself is able to drive 50 pf without special precautions. If heavier loads are anticipated, it is easy to isolate or decouple the load with a resistor; see *Figure 3*. Or you can improve the tolerance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

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



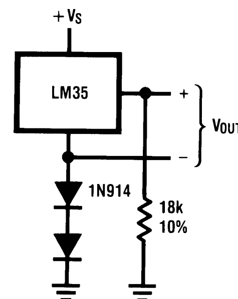
DS005516-5

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



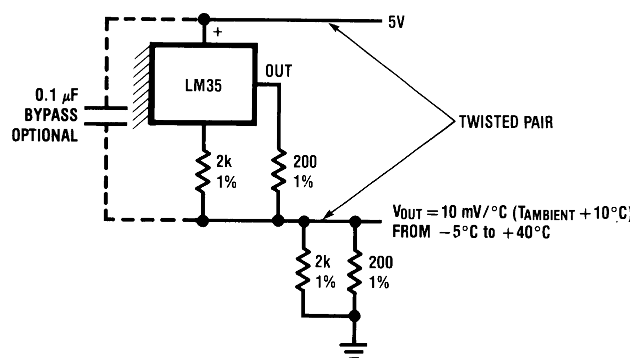
DS005516-6

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



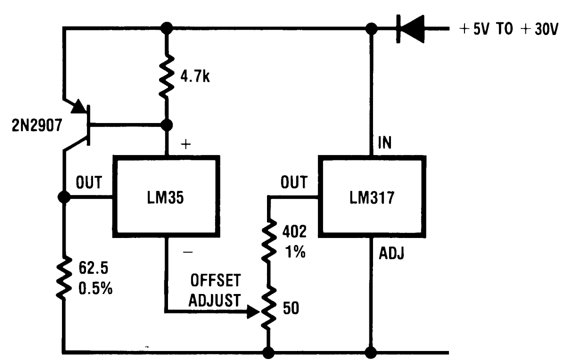
DS005516-7

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



DS005516-8

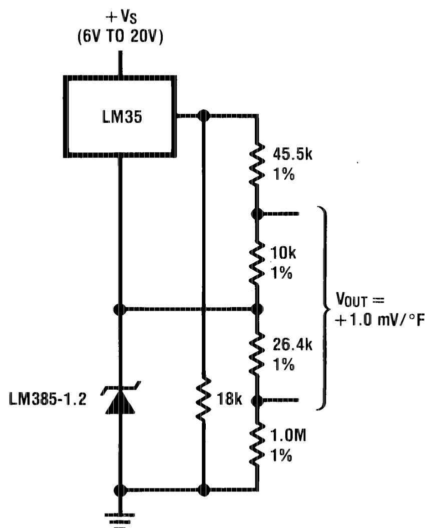
FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)



DS005516-9

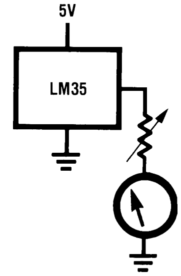
FIGURE 9. 4-To-20 mA Current Source (0˚C to +100˚C)

Typical Applications (Continued)



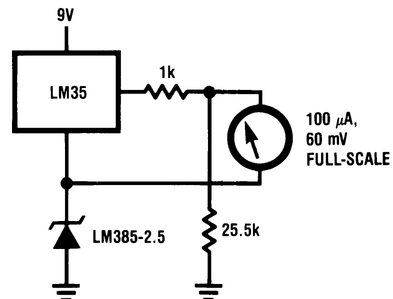
DS005516-10

FIGURE 10. Fahrenheit Thermometer



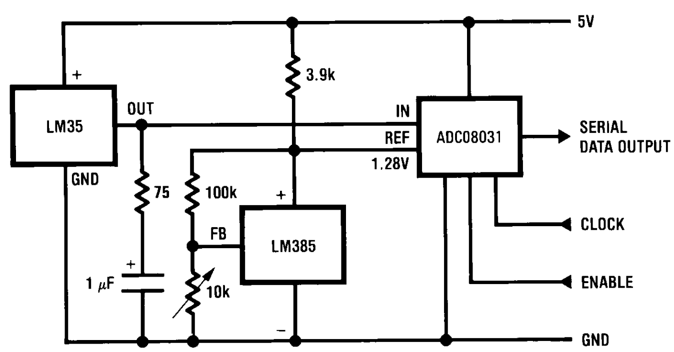
DS005516-11

FIGURE 11. Centigrade Thermometer (Analog Meter)



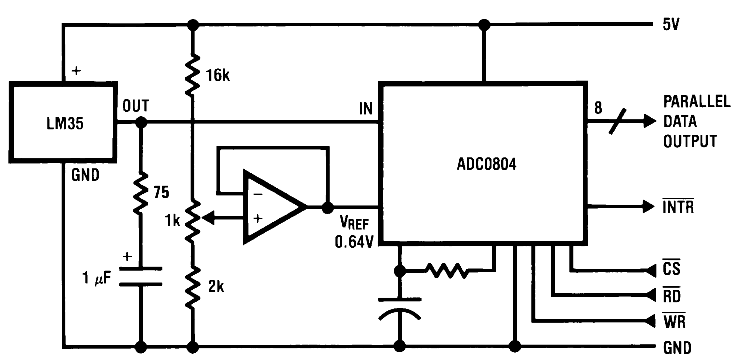
DS005516-12

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



DS005516-13

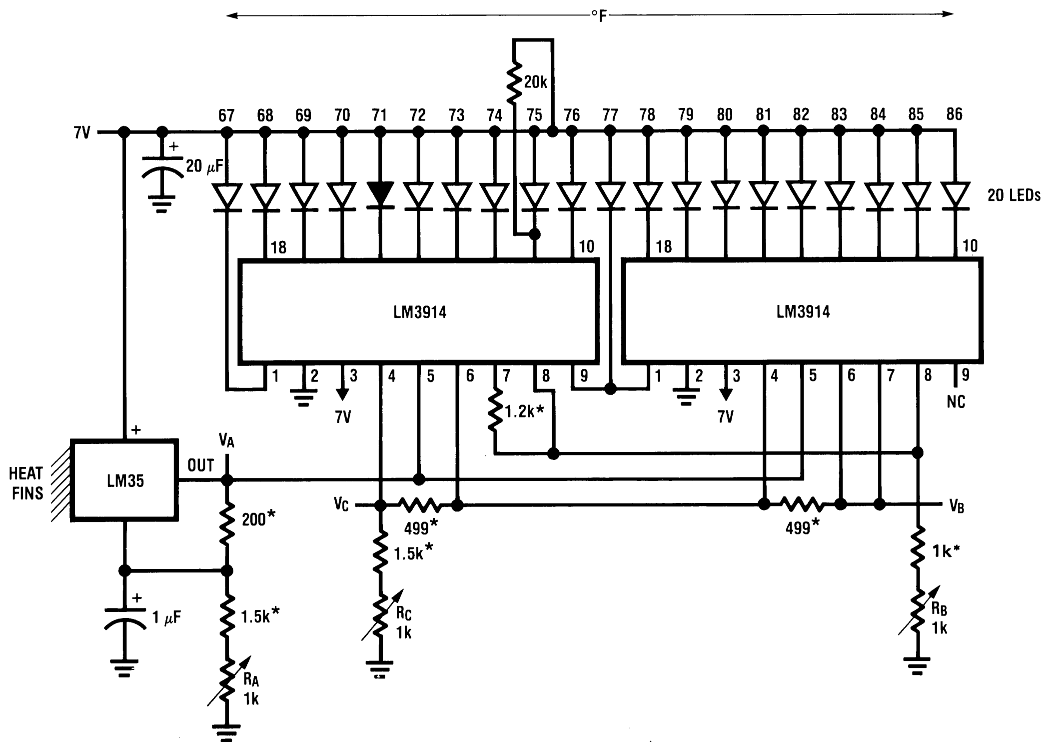
FIGURE 13. Temperature To Digital Converter (Serial Output) (+128˚C Full Scale)



DS005516-14

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

Typical Applications (Continued)



*=1% or 2% film resistor
Trim R_B for V_B=3.075V
Trim R_C for V_C=1.955V
Trim R_A for V_A=0.075V + 100mV/˚C x $T_{ambient}$
Example, V_A=2.275V at 22˚C

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

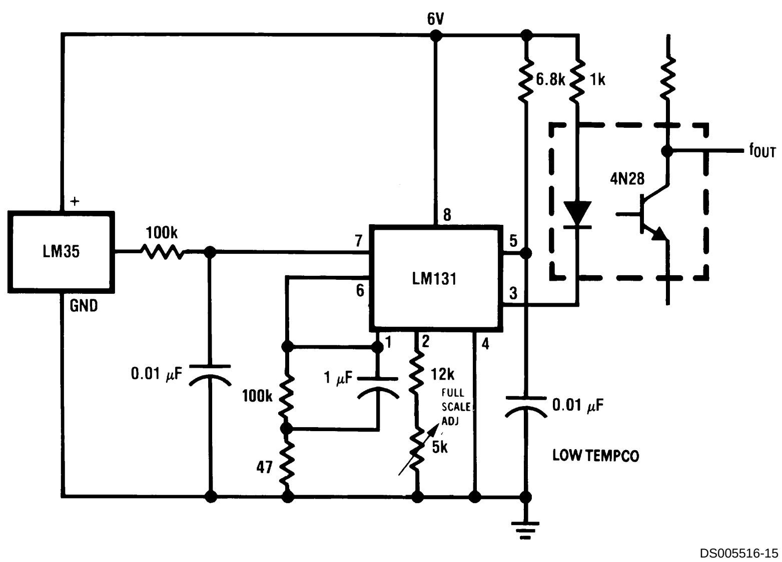
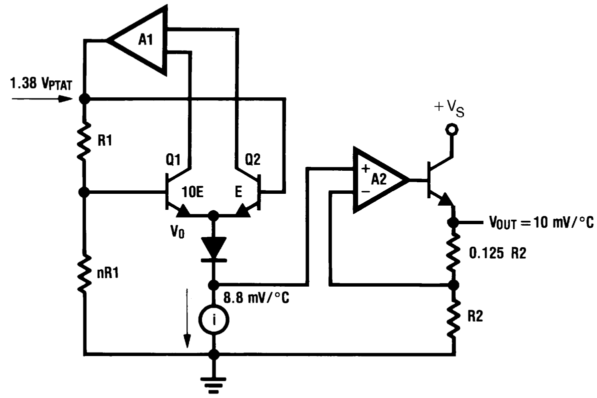


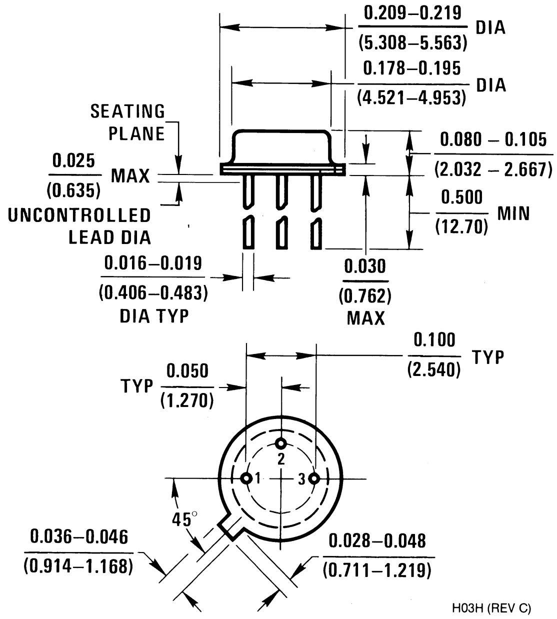
FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output (2˚C to +150˚C; 20 Hz to 1500 Hz)

Block Diagram

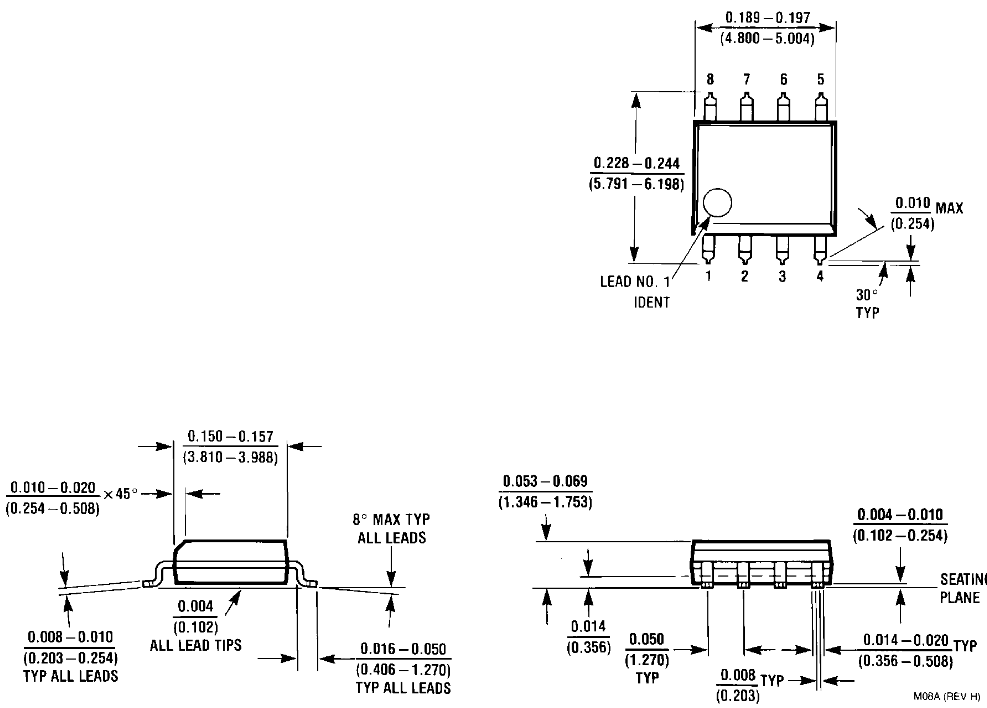


DS005516-23

Physical Dimensions inches (millimeters) unless otherwise noted

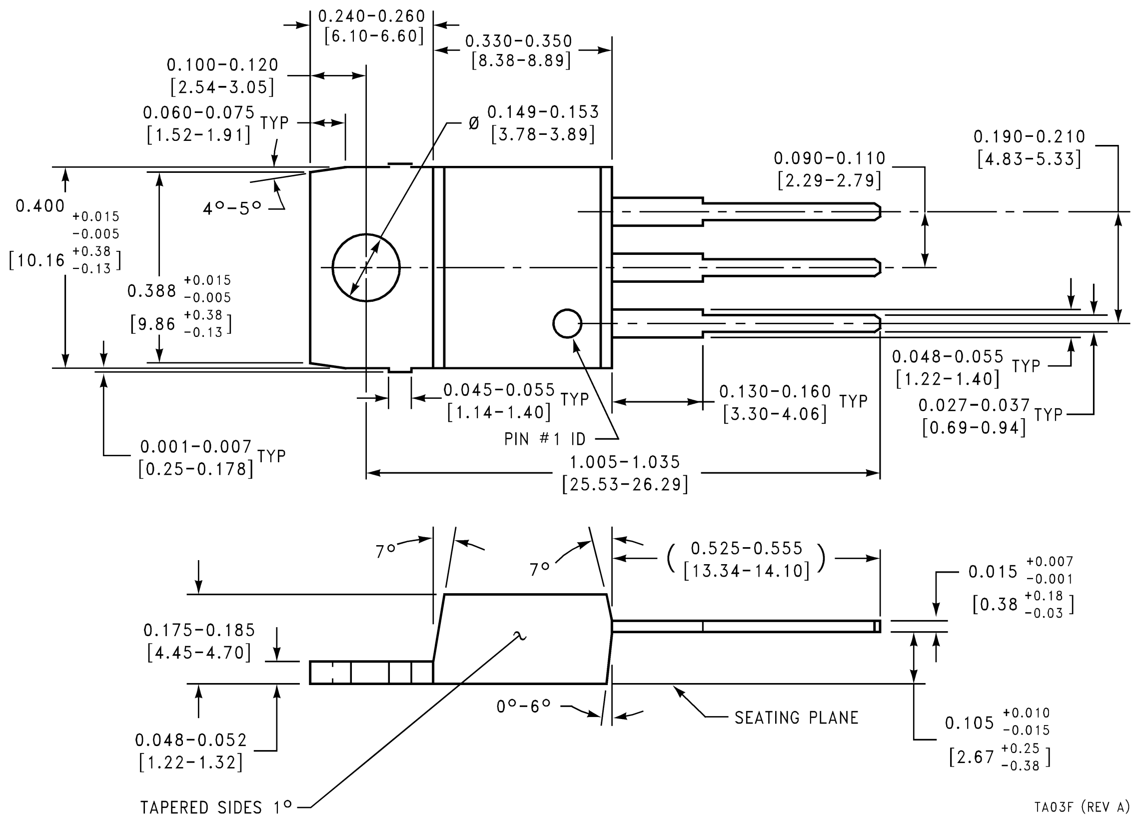


TO-46 Metal Can Package (H)
Order Number LM35H, LM35AH, LM35CH, LM35CAH, or LM35DH
NS Package Number H03H



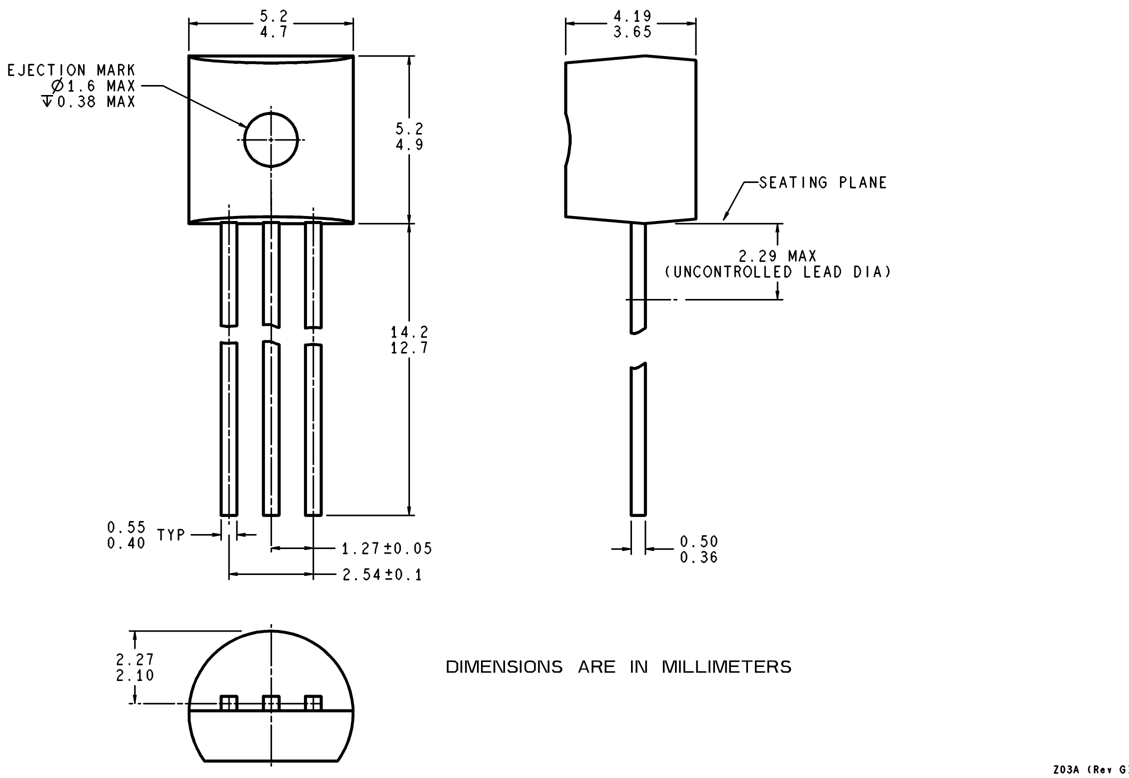
SO-8 Molded Small Outline Package (M)
Order Number LM35DM
NS Package Number M08A

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



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

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



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

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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TL081, TL081A, TL081B, TL082, TL082A, TL082B
TL082Y, TL084, TL084A, TL084B, TL084Y
JFET-INPUT OPERATIONAL AMPLIFIERS

SLOS081E – FEBRUARY 1977 – REVISED FEBRUARY 1999

- **Low Power Consumption**
- **Wide Common-Mode and Differential Voltage Ranges**
- **Low Input Bias and Offset Currents**
- **Output Short-Circuit Protection**
- **Low Total Harmonic Distortion . . . 0.003% Typ**
- **High Input Impedance . . . JFET-Input Stage**
- **Latch-Up-Free Operation**
- **High Slew Rate . . . 13 V/μs Typ**
- **Common-Mode Input Voltage Range Includes V_{CC+}**

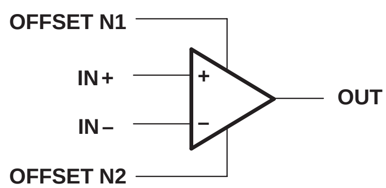
description

The TL08x JFET-input operational amplifier family is designed to offer a wider selection than any previously developed operational amplifier family. Each of these JFET-input operational amplifiers incorporates well-matched, high-voltage JFET and bipolar transistors in a monolithic integrated circuit. The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient. Offset adjustment and external compensation options are available within the TL08x family.

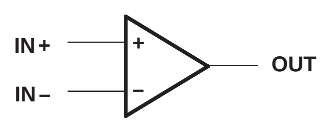
The C-suffix devices are characterized for operation from 0°C to 70°C. The I-suffix devices are characterized for operation from –40°C to 85°C. The Q-suffix devices are characterized for operation from –40°C to 125°C. The M-suffix devices are characterized for operation over the full military temperature range of –55°C to 125°C.

symbols

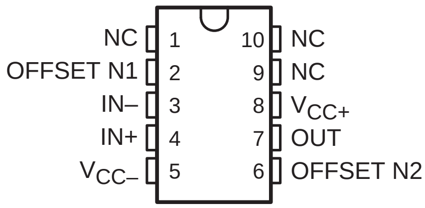
TL081



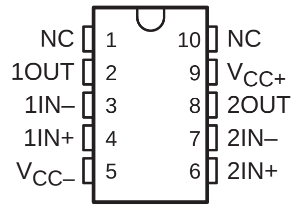
TL082 (EACH AMPLIFIER)
TL084 (EACH AMPLIFIER)



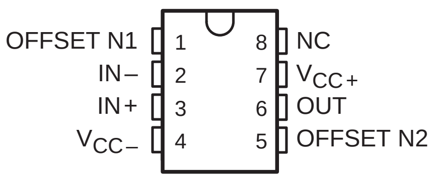
TL081M
U PACKAGE
(TOP VIEW)



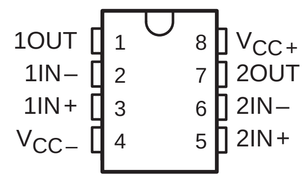
TL082M
U PACKAGE
(TOP VIEW)



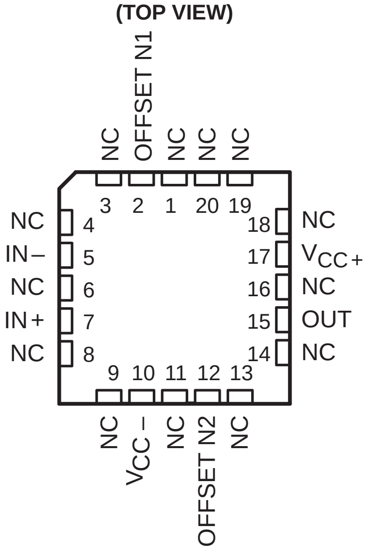
TL081, TL081A, TL081B
D, JG, P, OR PW PACKAGE
(TOP VIEW)



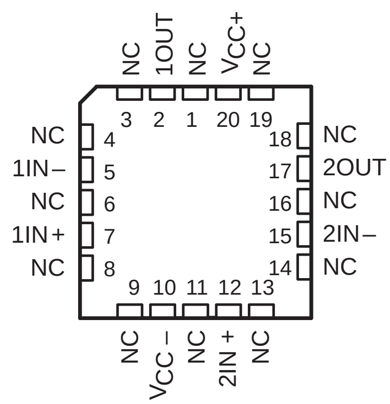
TL082, TL082A, TL082B
D, JG, P, OR PW PACKAGE
(TOP VIEW)



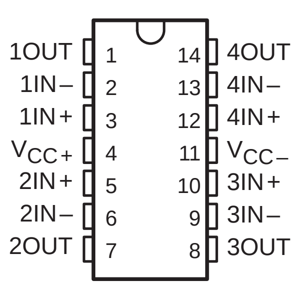
TL081M . . . FK PACKAGE
(TOP VIEW)



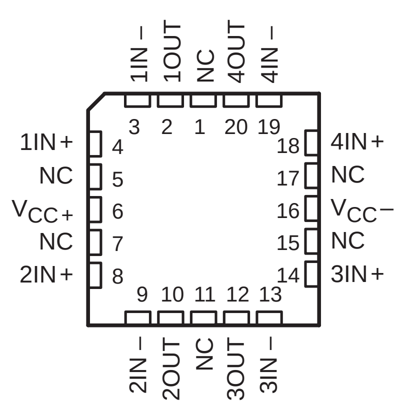
TL082M . . . FK PACKAGE
(TOP VIEW)



TL084, TL084A, TL084B
D, J, N, PW, OR W PACKAGE
(TOP VIEW)



TL084M . . . FK PACKAGE
(TOP VIEW)



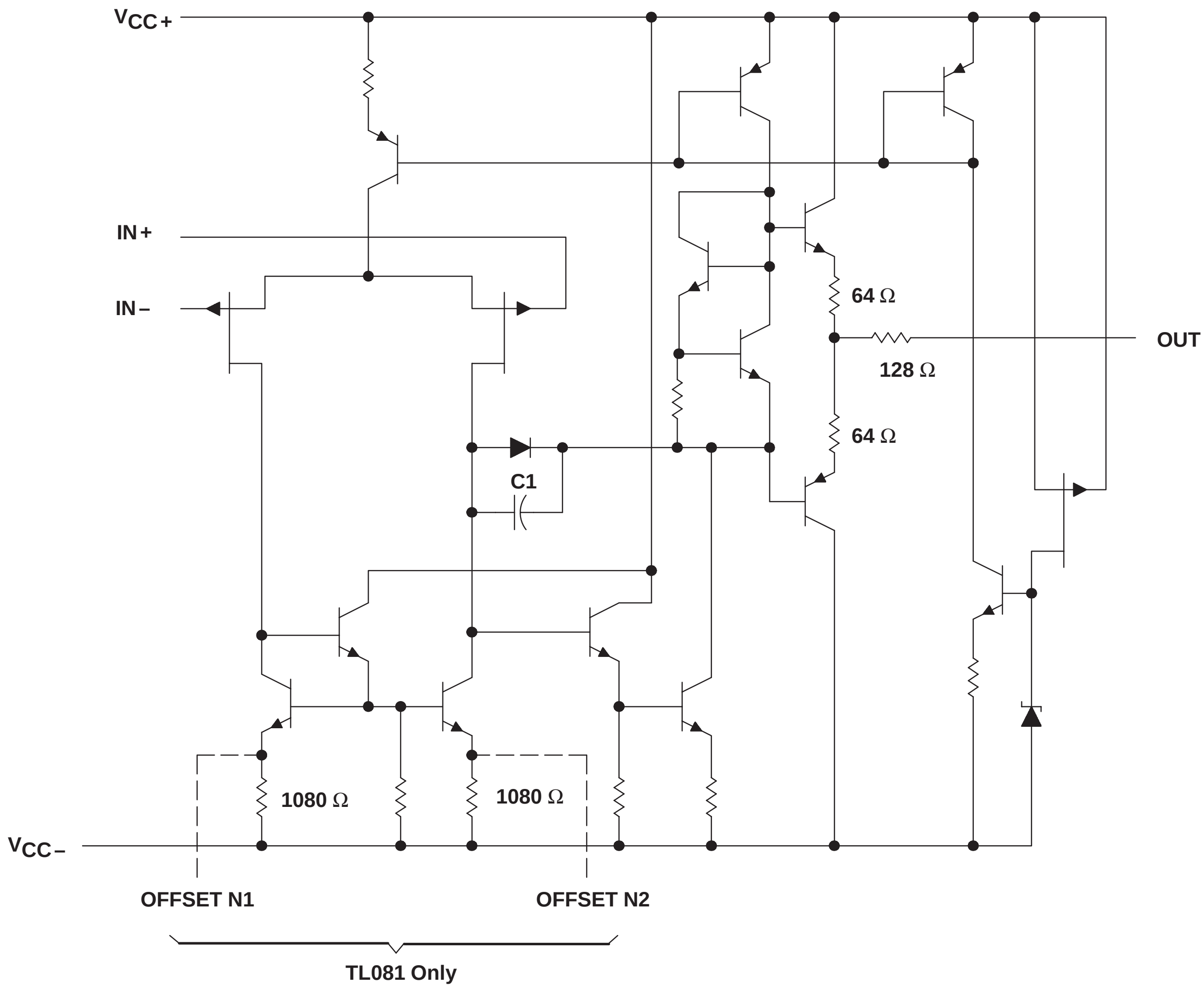
NC – No internal connection

AVAILABLE OPTIONS

T_A	V_{IO}max AT 25°C	PACKAGED DEVICES										CHIP FORM (Y)
		SMALL OUTLINE (D008)	SMALL OUTLINE (D014)	CHIP CARRIER (FK)	CERAMIC DIP (J)	CERAMIC DIP (JG)	PLASTIC DIP (N)	PLASTIC DIP (P)	TSSOP (PW)	FLAT PACK (U)	FLAT PACK (W)	
0°C to 70°C	15 mV 6 mV 3 mV	TL081CD TL081ACD TL081BCD	—	—	—	—	—	TL081CP TL081ACP TL081BCP	TL081CPW	—	—	—
	15 mV 6 mV 3 mV	TL082CD TL082ACD TL082BCD	—	—	—	—	—	TL082CP TL082ACP TL082BCP	TL082CPW	—	—	TL082Y
	15 mV 6 mV 3 mV	—	TL084CD TL084ACD TL084BCD	—	—	—	TL084CN TL084ACN TL084BCN	—	TL084CPW	—	—	TL084Y
−40°C to 85°C	6 mV 6 mV 6 mV	TL081ID TL082ID TL084ID	TL084ID	—	—	—	TL084IN	TL081IP TL082IP	—	—	—	—
−40°C to 125°C	9 mV	—	TL084QD	—	—	—	—	—	—	—	—	—
−55°C to 125°C	6 mV 6 mV 9 mV	—	—	TL081MFK TL082MFK TL084MFK	TL084MJ	TL081MJG TL082MJG	—	—	—	TL081MU TL082MU	TL084MW	—

The D package is available taped and reeled. Add R suffix to the device type (e.g., TL081CDR).

schematic (each amplifier)

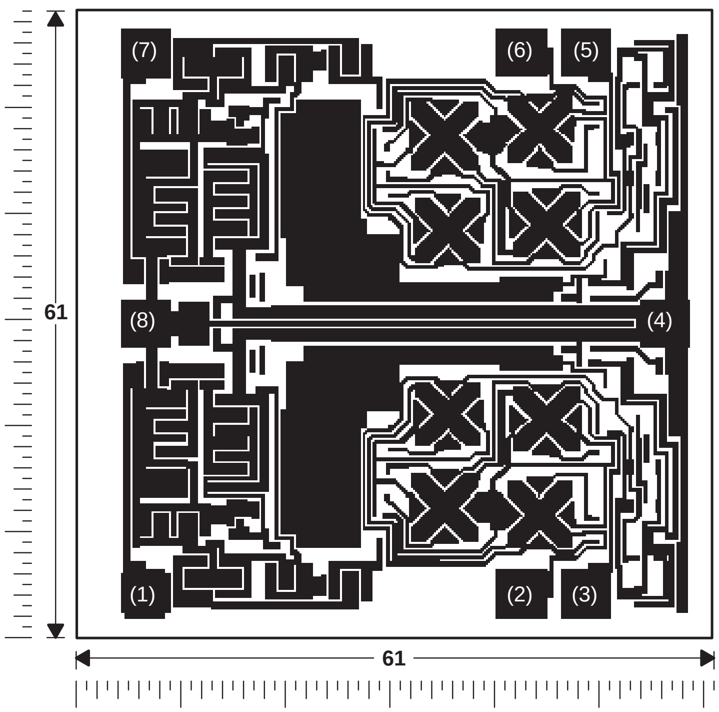


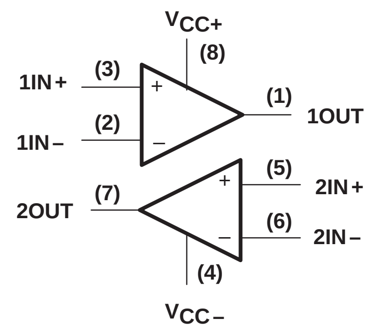
Component values shown are nominal.

TL082Y chip information

These chips, when properly assembled, display characteristics similar to the TL082. Thermal compression or ultrasonic bonding may be used on the doped-aluminum bonding pads. Chips may be mounted with conductive epoxy or a gold-silicon preform.

BONDING PAD ASSIGNMENTS





CHIP THICKNESS: 15 TYPICAL

BONDING PADS: 4 × 4 MINIMUM

$T_J$max = 150°C

TOLERANCES ARE ±10%.

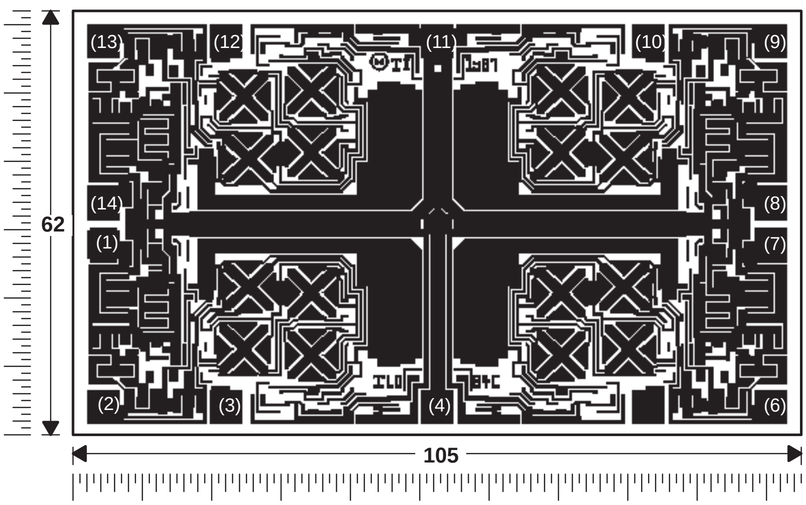
ALL DIMENSIONS ARE IN MILS.

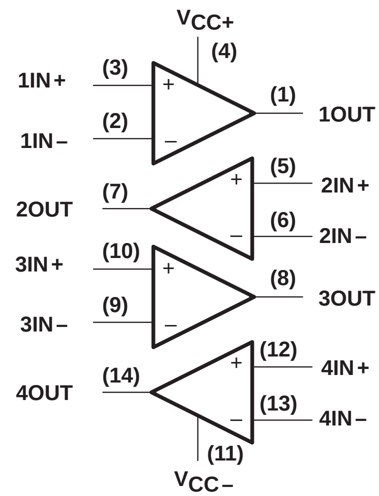
PIN (4) IS INTERNALLY CONNECTED TO BACKSIDE OF CHIP.

TL084Y chip information

These chips, when properly assembled, display characteristics similar to the TL084. Thermal compression or ultrasonic bonding may be used on the doped-aluminum bonding pads. Chips may be mounted with conductive epoxy or a gold-silicon preform.

BONDING PAD ASSIGNMENTS





CHIP THICKNESS: 15 TYPICAL

BONDING PADS: 4 × 4 MINIMUM

$T_J$max = 150°C

TOLERANCES ARE ±10%.

ALL DIMENSIONS ARE IN MILS.

PIN (11) IS INTERNALLY CONNECTED TO BACKSIDE OF CHIP.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

		TL08_C TL08_AC TL08_BC	TL08_I	TL084Q	TL08_M	UNIT
Supply voltage, V_{CC+} (see Note 1)		18	18	18	18	V
Supply voltage V_{CC-} (see Note 1)		–18	–18	–18	–18	V
Differential input voltage, V_{ID} (see Note 2)		± 30	± 30	± 30	± 30	V
Input voltage, V_I (see Notes 1 and 3)		±15	±15	±15	±15	V
Duration of output short circuit (see Note 4)		unlimited	unlimited	unlimited	unlimited	
Continuous total power dissipation		See Dissipation Rating Table				
Operating free-air temperature range, T_A		0 to 70	– 40 to 85	– 40 to 125	– 55 to 125	°C
Storage temperature range, T_{stg}		– 65 to 150	– 65 to 150	– 65 to 150	– 65 to 150	°C
Case temperature for 60 seconds, T_C	FK package				260	°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds	J or JG package				300	°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	D, N, P, or PW package	260	260	260		°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. All voltage values, except differential voltages, are with respect to the midpoint between V_{CC+} and V_{CC-}.
2. Differential voltages are at IN+ with respect to IN–.
3. The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 V, whichever is less.
4. The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

DISSIPATION RATING TABLE

PACKAGE	$T_A \leq 25°C$ POWER RATING	DERATING FACTOR	DERATE ABOVE T_A	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING	$T_A = 125°C$ POWER RATING
D (8 pin)	680 mW	5.8 mW/°C	32°C	460 mW	373 mW	N/A
D (14 pin)	680 mW	7.6 mW/°C	60°C	604 mW	490 mW	186 mW
FK	680 mW	11.0 mW/°C	88°C	680 mW	680 mW	273 mW
J	680 mW	11.0 mW/° C	88°C	680 mW	680 mW	273 mW
JG	680 mW	8.4 mW/°C	69°C	672 mW	546 mW	210 mW
N	680 mW	9.2 mW/°C	76°C	680 mW	597 mW	N/A
P	680 mW	8.0 mW/°C	65°C	640 mW	520 mW	N/A
PW (8 pin)	525 mW	4.2 mW/°C	25°C	336 mW	N/A	N/A
PW (14 pin)	700 mW	5.6 mW/°C	25°C	448 mW	N/A	N/A
U	675 mW	5.4 mW/°C	25°C	432 mW	351 mW	135 mW
W	680 mW	8.0 mW/°C	65°C	640 mW	520 mW	200 mW

electrical characteristics, $V_{CC\pm}$ = ±15 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	T_A†	TL081C TL082C TL084C			TL081AC TL082AC TL084AC			TLO81BC TL082BC TL084BC			TL081I TL082I TL084I			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	V_O = 0, R_S = 50 Ω	25°C		3	15		3	6		2	3		3	6	mV
			Full range			20			7.5			5			9	
α_{VIO}	Temperature coefficient of input offset voltage	V_O = 0, R_S = 50 Ω	Full range		18			18			18			18		μV/°C
I_{IO}	Input offset current‡	V_O = 0	25°C		5	200		5	100		5	100		5	100	pA
			Full range			2			2			2			10	nA
I_{IB}	Input bias current‡	V_O = 0	25°C		30	400		30	200		30	200		30	200	pA
			Full range			10			7			7			20	nA
V_{ICR}	Common-mode input voltage range		25°C	±11	–12 to 15		±11	–12 to 15		±11	–12 to 15		±11	–12 to 15		V
V_{OM}	Maximum peak output voltage swing	R_L = 10 kΩ	25°C	±12	±13.5		±12	±13.5		±12	±13.5		±12	±13.5		V
		R_L ≥ 10 kΩ	Full range	±12			±12			±12			±12			
		R_L ≥ 2 kΩ		±10	±12		±10	±12		±10	±12		±10	±12		
A_{VD}	Large-signal differential voltage amplification	V_O = ±10 V, R_L ≥ 2 kΩ	25°C	25	200		50	200		50	200		50	200		V/mV
		V_O = ±10 V, R_L ≥ 2 kΩ	Full range	15			25			25			25			
B_1	Unity-gain bandwidth		25°C		3			3			3			3		MHz
r_i	Input resistance		25°C		10^{12}			10^{12}			10^{12}			10^{12}		Ω
CMRR	Common-mode rejection ratio	V_{IC} = V_{ICR}min, V_O = 0, R_S = 50 Ω	25°C	70	86		75	86		75	86		75	86		dB
k_{SVR}	Supply voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	V_{CC} = ±15 V to ± 9 V, V_O = 0, R_S = 50 Ω	25°C	70	86		80	86		80	86		80	86		dB
I_{CC}	Supply current (per amplifier)	V_O = 0, No load	25°C		1.4	2.8		1.4	2.8		1.4	2.8		1.4	2.8	mA
V_{O1}/V_{O2}	Crosstalk attenuation	A_{VD} = 100	25°C		120			120			120			120		dB

† All characteristics are measured under open-loop conditions with zero common-mode voltage unless otherwise specified. Full range for T_A is 0°C to 70°C for TL08_C, TL08_AC, TL08_BC and –40°C to 85°C for TL08_I.

‡ Input bias currents of a FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive as shown in Figure 17. Pulse techniques must be used that maintain the junction temperature as close to the ambient temperature as possible.

electrical characteristics, $V_{CC\pm} = \pm15$ V (unless otherwise noted)

PARAMETER		TEST CONDITIONS†	T_A	TL081M, TL082M			TL084Q, TL084M			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	$V_O = 0$, $R_S = 50\ \Omega$	25°C		3	6		3	9	mV
			Full range			9			15	
α_{VIO}	Temperature coefficient of input offset voltage	$V_O = 0$ $R_S = 50\ \Omega$	Full range		18			18		μV/°C
I_{IO}	Input offset current‡	$V_O = 0$	25°C		5	100		5	100	pA
			125°C			20			20	nA
I_{IB}	Input bias current‡	$V_O = 0$	25°C		30	200		30	200	pA
			125°C			50			50	nA
V_{ICR}	Common-mode input voltage range		25°C	±11	±12 to 15		±11	±12 to 15		V
V_{OM}	Maximum peak output voltage swing	$R_L = 10\ k\Omega$	25°C	±12	±13.5		±12	±13.5		V
		$R_L \geq 10\ k\Omega$	Full range	±12			±12			
		$R_L \geq 2\ k\Omega$		±10	±12		±10	±12		
A_{VD}	Large-signal differential voltage amplification	$V_O = \pm10$ V, $R_L \geq 2\ k\Omega$	25°C	25	200		25	200		V/mV
		$V_O = \pm10$ V, $R_L \geq 2\ k\Omega$	Full range	15			15			
B_1	Unity-gain bandwidth		25°C		3			3		MHz
r_i	Input resistance		25°C		10^{12}			10^{12}		Ω
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICR}$min, $V_O = 0$, $R_S = 50\ \Omega$	25°C	80	86		80	86		dB
k_{SVR}	Supply voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	$V_{CC} = \pm15$ V to ±9 V, $V_O = 0$, $R_S = 50\ \Omega$	25°C	80	86		80	86		dB
I_{CC}	Supply current (per amplifier)	$V_O = 0$, No load	25°C		1.4	2.8		1.4	2.8	mA
V_{O1}/V_{O2}	Crosstalk attenuation	$A_{VD} = 100$	25°C		120			120		dB

† All characteristics are measured under open-loop conditions with zero common-mode input voltage unless otherwise specified.
‡ Input bias currents of a FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive as shown in Figure 17. Pulse techniques must be used that maintain the junction temperatures as close to the ambient temperature as is possible.

operating characteristics, $V_{CC\pm} = \pm15$ V, $T_A = 25°C$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS				MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	$V_I = 10$ V,	$R_L = 2\ k\Omega$,	$C_L = 100$ pF,	See Figure 1	8*	13		V/μs
		$V_I = 10$ V, $T_A = -55°C$ to 125°C,	$R_L = 2\ k\Omega$, See Figure 1	$C_L = 100$ pF,		5*			
t_r	Rise time	$V_I = 20$ mV,	$R_L = 2\ k\Omega$,	$C_L = 100$ pF,	See Figure 1		0.05		μs
	Overshoot factor						20%		
V_n	Equivalent input noise voltage	$R_S = 20\ \Omega$	f = 1 kHz				18		nV/√Hz
			f = 10 Hz to 10 kHz				4		μV
I_n	Equivalent input noise current	$R_S = 20\ \Omega$,	f = 1 kHz				0.01		pA/√Hz
THD	Total harmonic distortion	$V_I$rms = 6 V, f = 1 kHz	$A_{VD} = 1$,	$R_S \leq 1\ k\Omega$,	$R_L \geq 2\ k\Omega$,		0.003%		

*On products compliant to MIL-PRF-38535, this parameter is not production tested.

electrical characteristics, $V_{CC\pm}$ = ±15 V, T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS†		TL082Y, TL084Y			UNIT
				MIN	TYP	MAX	
V_{IO}	Input offset voltage	V_O = 0,	R_S = 50 Ω		3	15	mV
α_{VIO}	Temperature coefficient of input offset voltage	V_O = 0,	R_S = 50 Ω		18		μV/°C
I_{IO}	Input offset current‡	V_O = 0,			5	200	pA
I_{IB}	Input bias current‡	V_O = 0,			30	400	pA
V_{ICR}	Common-mode input voltage range			±11	–12 to 15		V
V_{OM}	Maximum peak output voltage swing	R_L = 10 kΩ,		±12	±13.5		V
A_{VD}	Large-signal differential voltage amplification	V_O = ±10 V,	R_L ≥ 2 kΩ	25	200		V/mV
B_1	Unity-gain bandwidth				3		MHz
r_i	Input resistance				10^{12}		Ω
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICR}$min, R_S = 50 Ω	V_O = 0,	70 70	86 86		dB
k_{SVR}	Supply voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	V_{CC} = ±15 V to ± 9 V, V_O = 0,	R_S = 50 Ω	70 70	86 86		dB
I_{CC}	Supply current (per amplifier)	V_O = 0,	No load		1.4	2.8	mA
V_{O1}/V_{O2}	Crosstalk attenuation	A_{VD} = 100			120		dB

† All characteristics are measured under open-loop conditions with zero common-mode voltage unless otherwise specified.
‡ Input bias currents of a FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive as shown in Figure 17. Pulse techniques must be used that maintain the junction temperature as close to the ambient temperature as possible.

operating characteristics, $V_{CC\pm}$ = ±15 V, T_A = 25°C

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	V_I = 10 V, R_L = 2 kΩ, C_L = 100 pF, See Figure 1		8	13		V/μs
t_r	Rise time	V_I = 20 mV, R_L = 2 kΩ, C_L = 100 pF, See Figure 1			0.05		μs
	Overshoot factor				20%		
V_n	Equivalent input noise voltage	R_S = 20 Ω	f = 1 kHz		18		nV/√Hz
			f = 10 Hz to 10 kHz		4		μV
I_n	Equivalent input noise current	R_S = 20 Ω,	f = 1 kHz		0.01		pA/√Hz
THD	Total harmonic distortion	$V_I$rms = 6 V, A_{VD} = 1, R_S ≤ 1 kΩ, R_L ≥ 2 kΩ, f = 1 kHz			0.003%		

PARAMETER MEASUREMENT INFORMATION

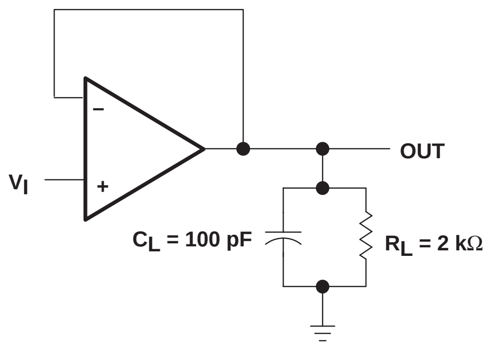


Figure 1

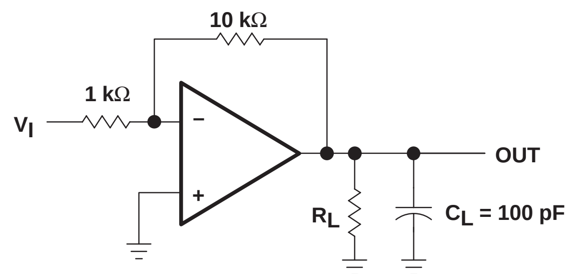


Figure 2

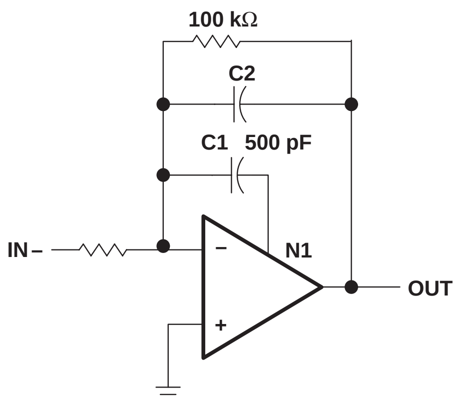


Figure 3

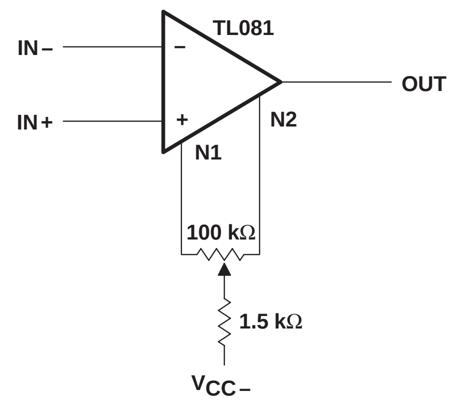


Figure 4

TYPICAL CHARACTERISTICS

Table of Graphs

			FIGURE
V_{OM}	Maximum peak output voltage	vs Frequency vs Free-air temperature vs Load resistance vs Supply voltage	5, 6, 7 8 9 10
A_{VD}	Large-signal differential voltage amplification	vs Free-air temperature vs Frequency	11 12
A_{VD}	Differential voltage amplification	vs Frequency with feed-forward compensation	13
P_D	Total power dissipation	vs Free-air temperature	14
I_{CC}	Supply current	vs Free-air temperature vs Supply voltage	15 16
I_{IB}	Input bias current	vs Free-air temperature	17
	Large-signal pulse response	vs Time	18
V_O	Output voltage	vs Elapsed time	19
CMRR	Common-mode rejection ratio	vs Free-air temperature	20
V_n	Equivalent input noise voltage	vs Frequency	21
THD	Total harmonic distortion	vs Frequency	22

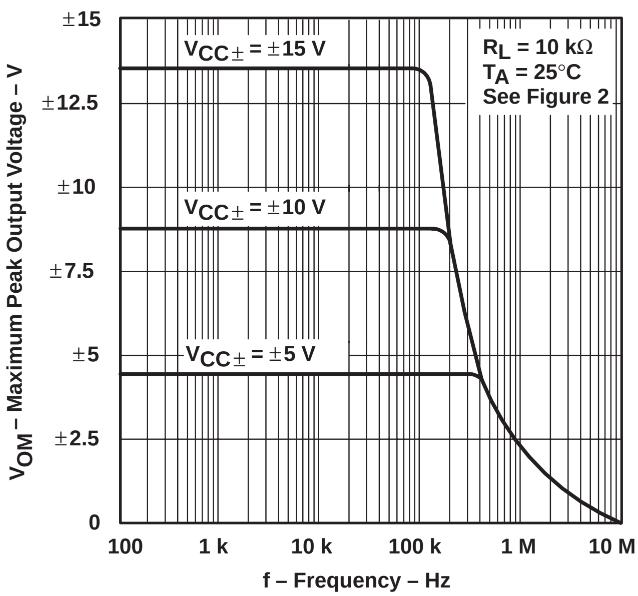


Figure 5

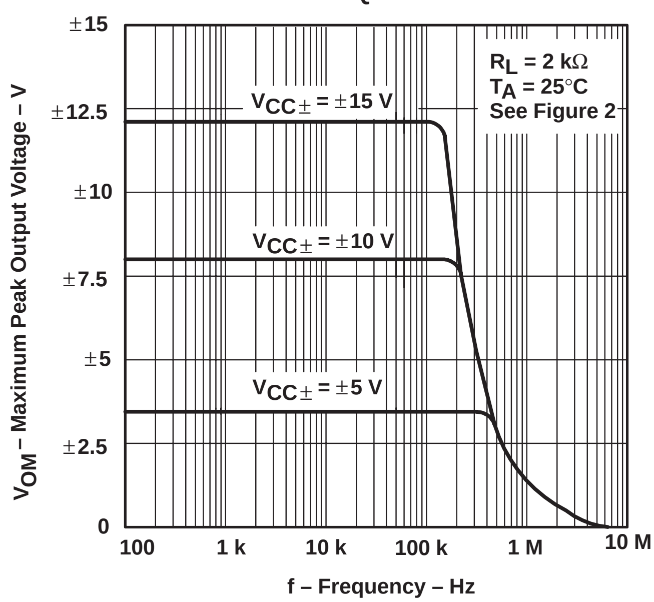


Figure 6

TYPICAL CHARACTERISTICS†

MAXIMUM PEAK OUTPUT VOLTAGE
vs
FREQUENCY

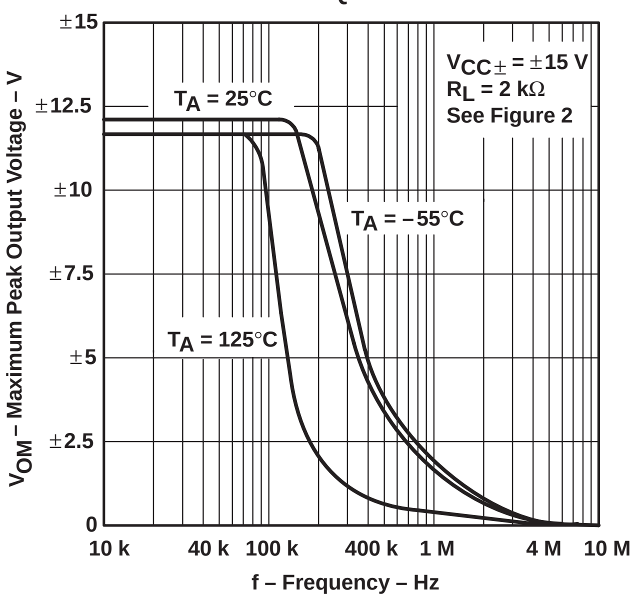


Figure 7

MAXIMUM PEAK OUTPUT VOLTAGE
vs
FREE-AIR TEMPERATURE

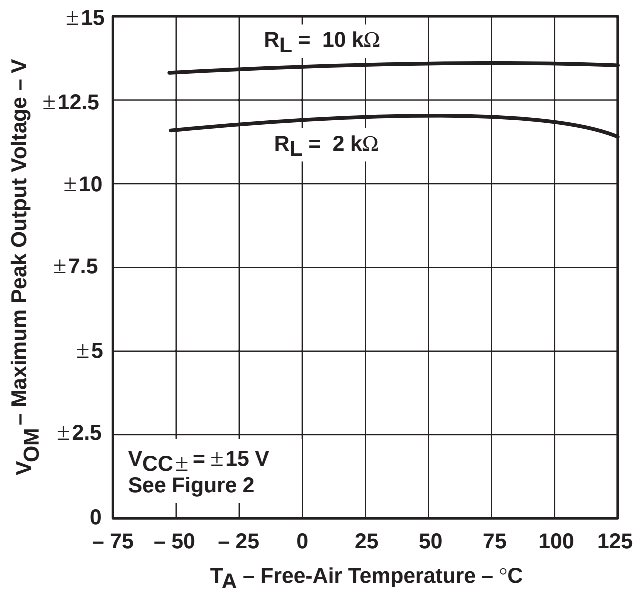


Figure 8

MAXIMUM PEAK OUTPUT VOLTAGE
vs
LOAD RESISTANCE

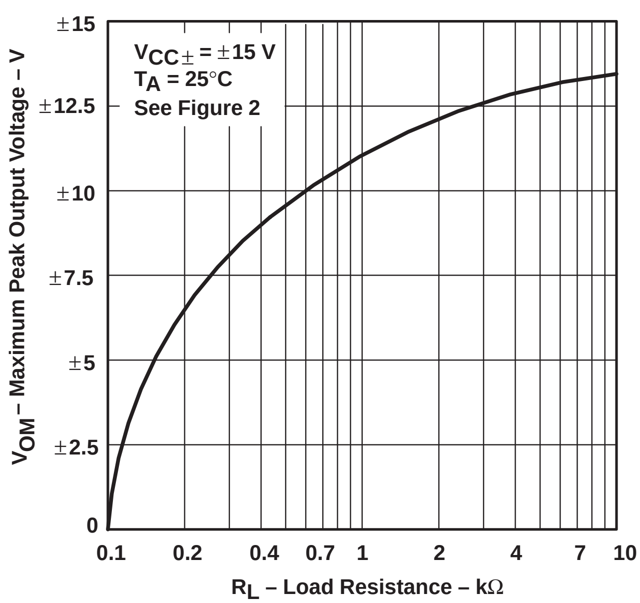


Figure 9

MAXIMUM PEAK OUTPUT VOLTAGE
vs
SUPPLY VOLTAGE

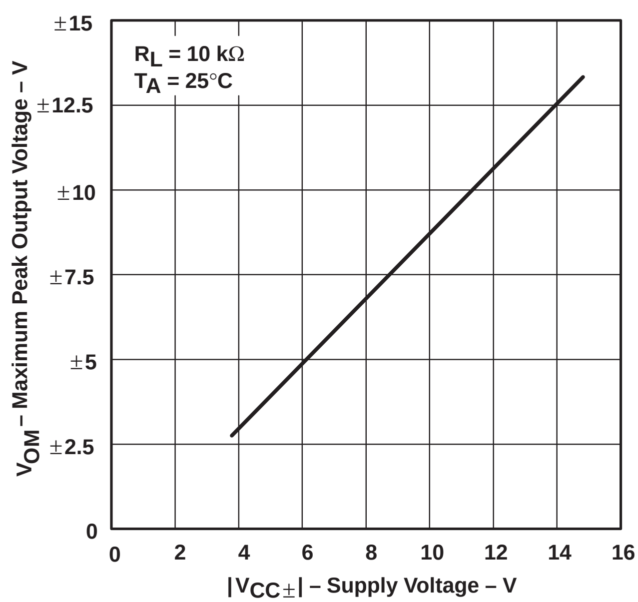


Figure 10

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION vs FREE-AIR TEMPERATURE

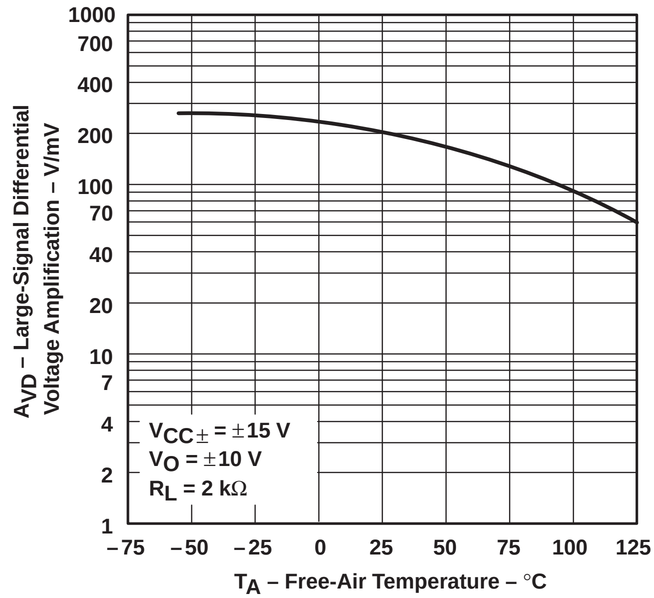


Figure 11

LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION vs FREQUENCY

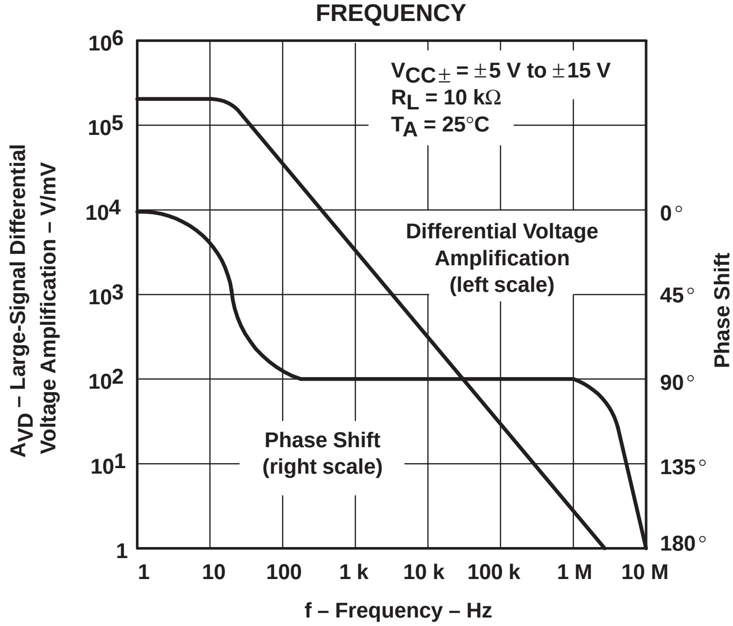


Figure 12

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

DIFFERENTIAL VOLTAGE AMPLIFICATION
vs
FREQUENCY WITH FEED-FORWARD COMPENSATION

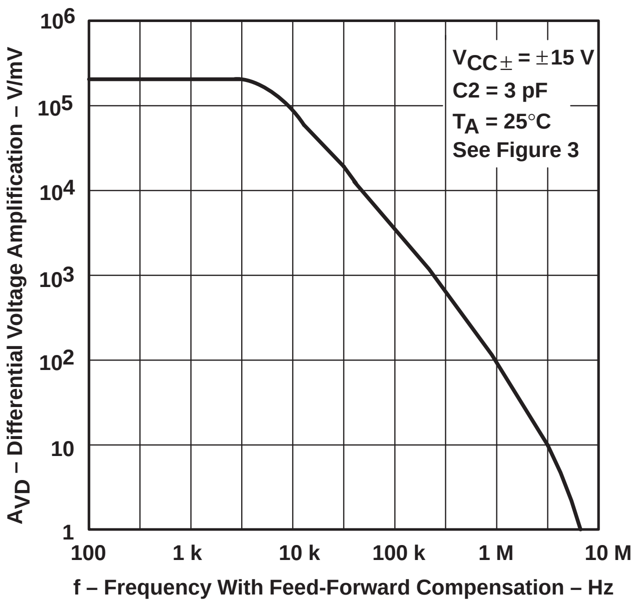


Figure 13

TOTAL POWER DISSIPATION
vs
FREE-AIR TEMPERATURE

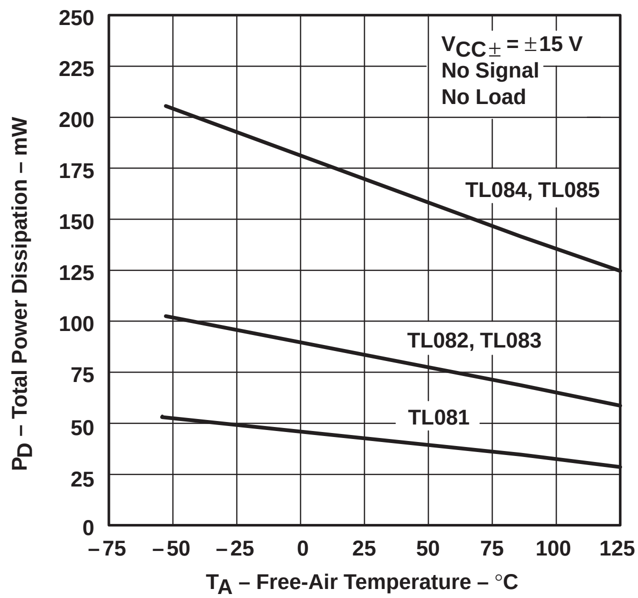


Figure 14

SUPPLY CURRENT PER AMPLIFIER
vs
FREE-AIR TEMPERATURE

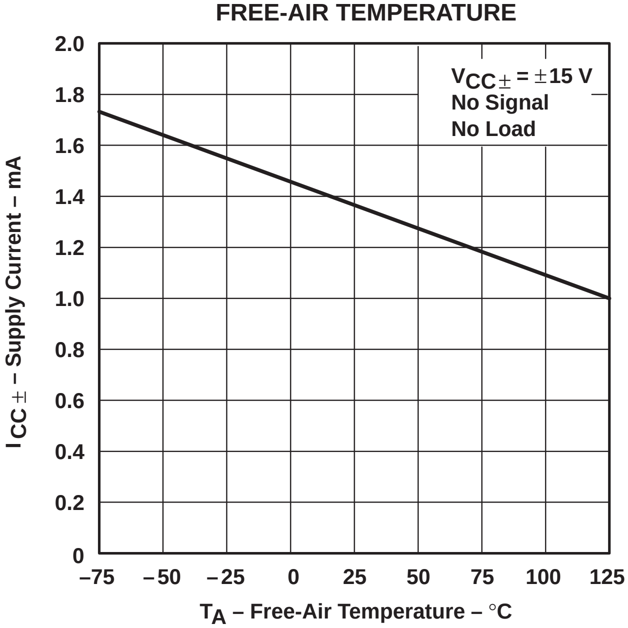


Figure 15

SUPPLY CURRENT
vs
SUPPLY VOLTAGE

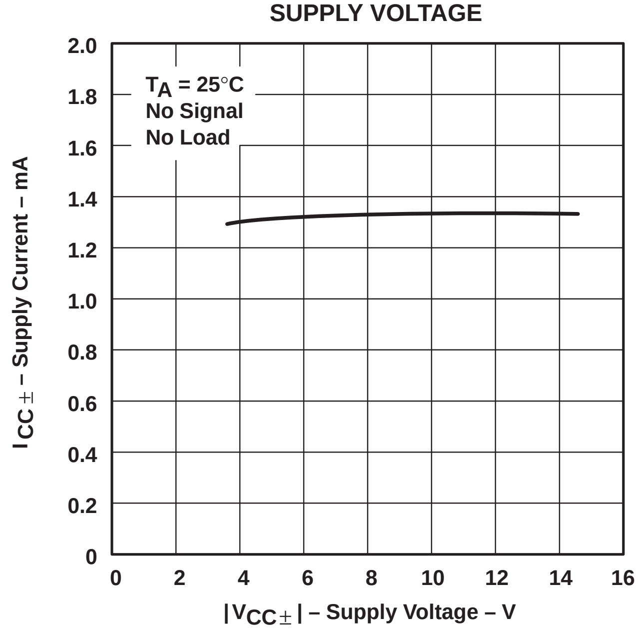


Figure 16

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

INPUT BIAS CURRENT vs FREE-AIR TEMPERATURE

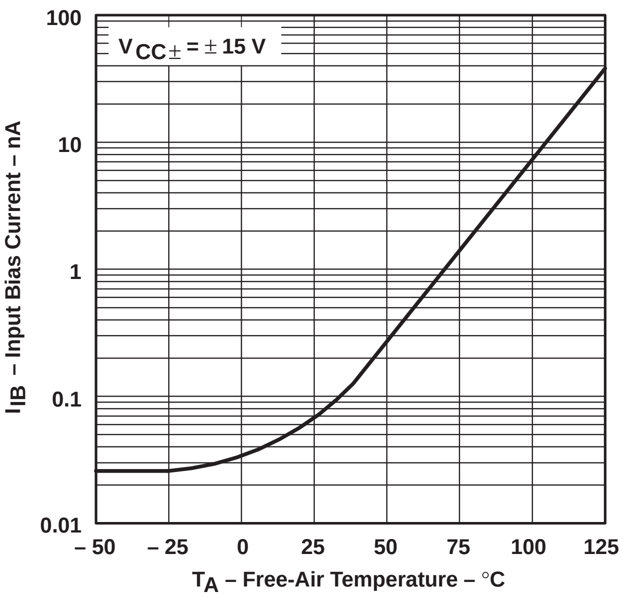


Figure 17

VOLTAGE-FOLLOWER LARGE-SIGNAL PULSE RESPONSE

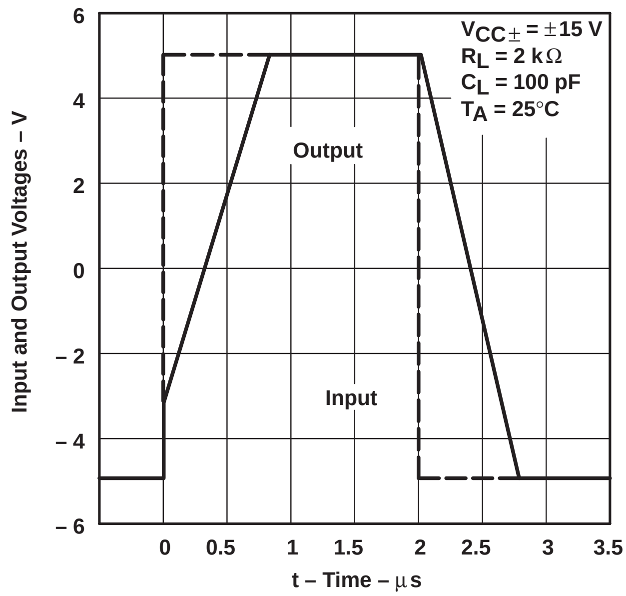


Figure 18

OUTPUT VOLTAGE vs ELAPSED TIME

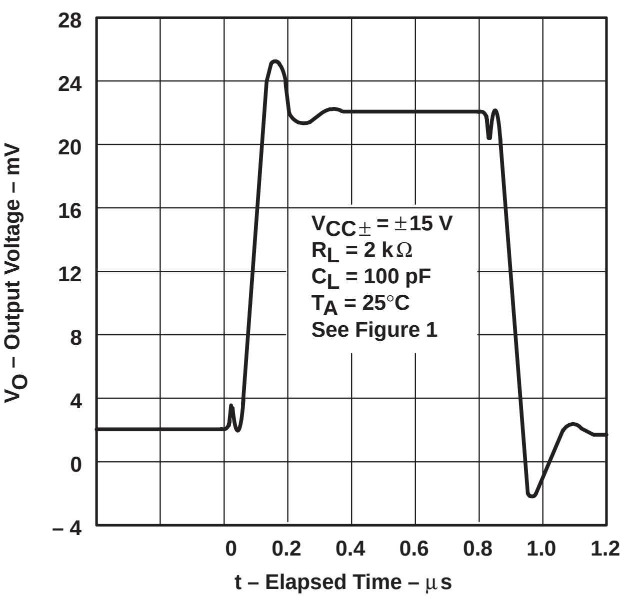


Figure 19

COMMON-MODE REJECTION RATIO vs FREE-AIR TEMPERATURE

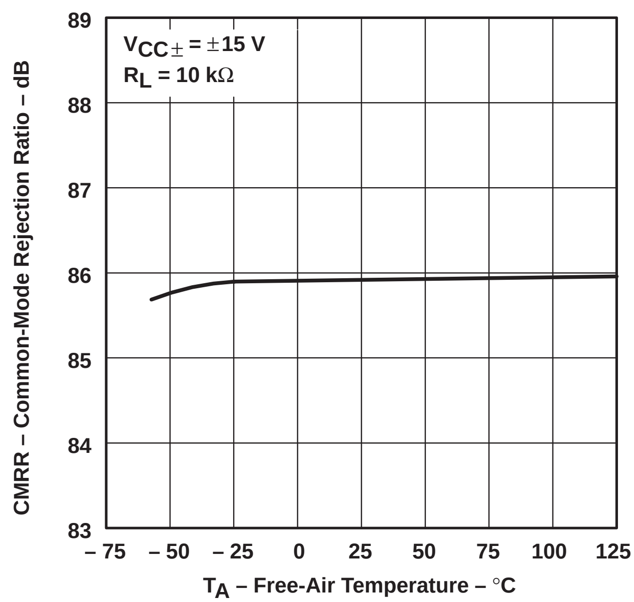


Figure 20

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

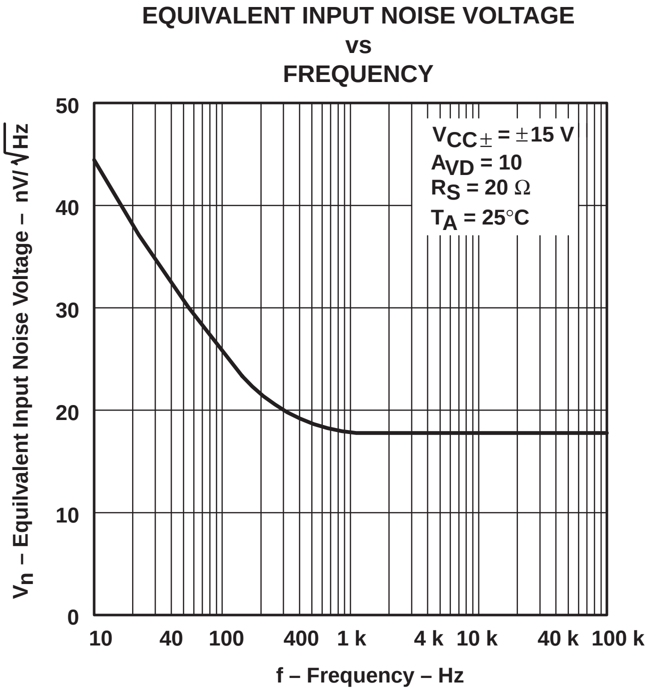


Figure 21

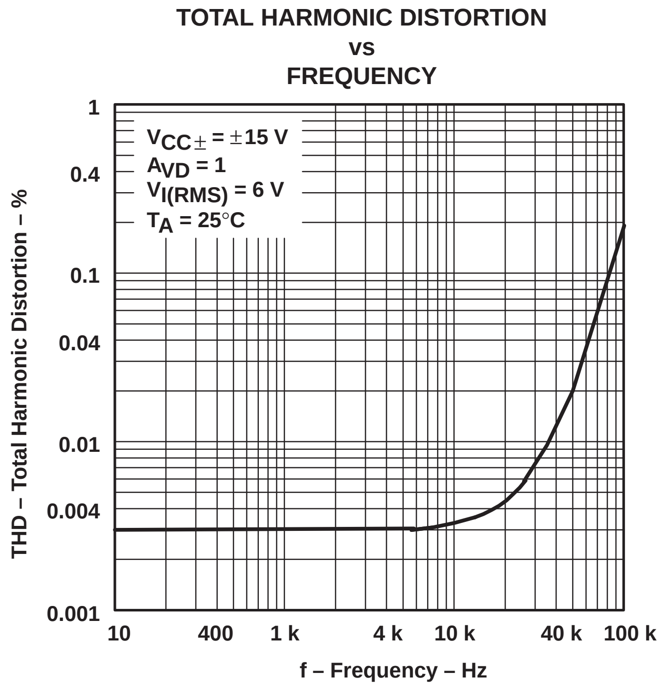


Figure 22

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

APPLICATION INFORMATION

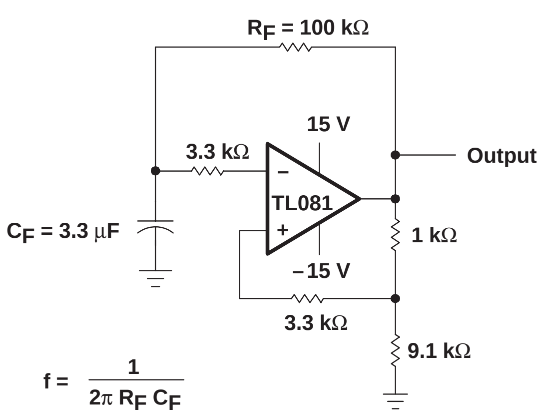


Figure 23

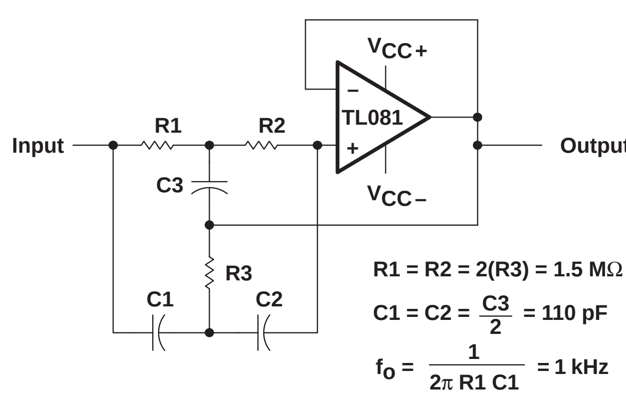


Figure 24

APPLICATION INFORMATION

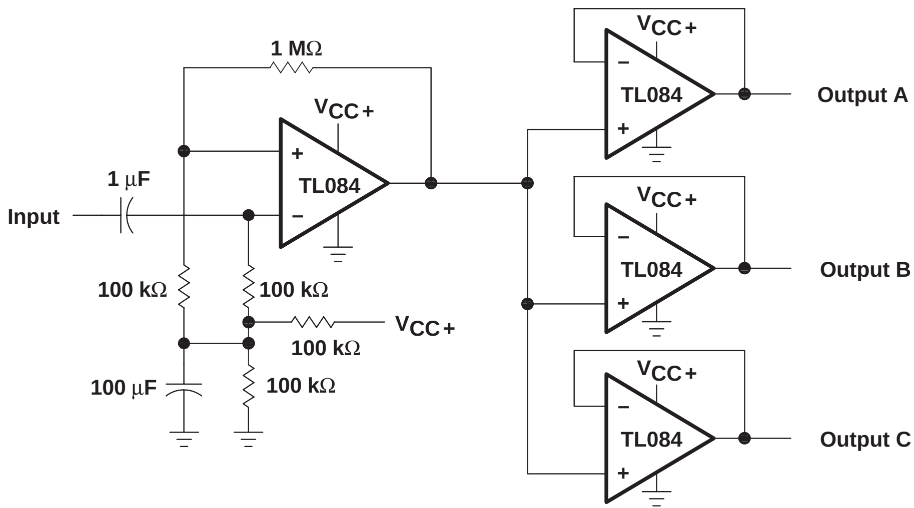
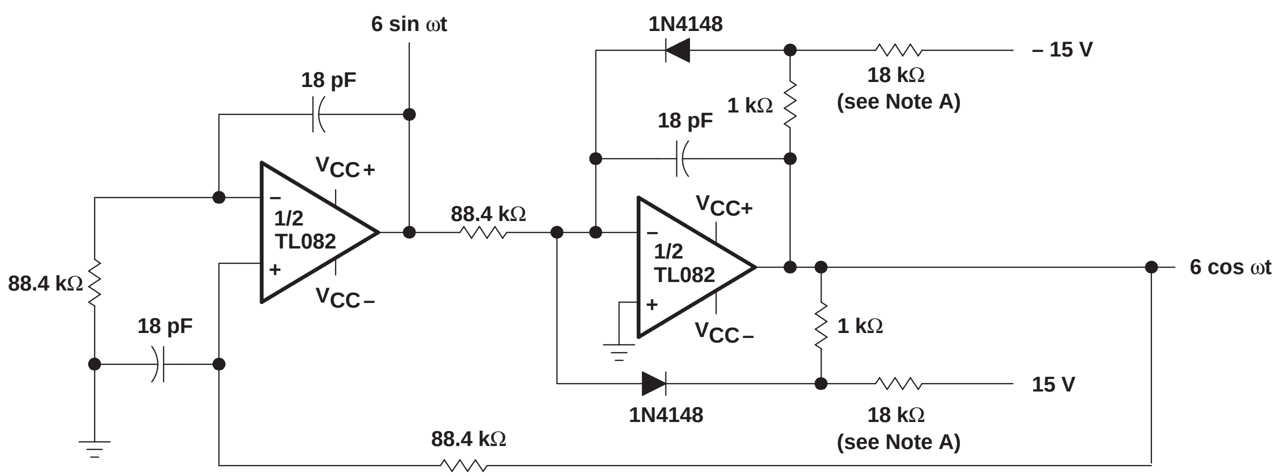


Figure 25. Audio-Distribution Amplifier



NOTE A: These resistor values may be adjusted for a symmetrical output.

Figure 26. 100-KHz Quadrature Oscillator

APPLICATION INFORMATION

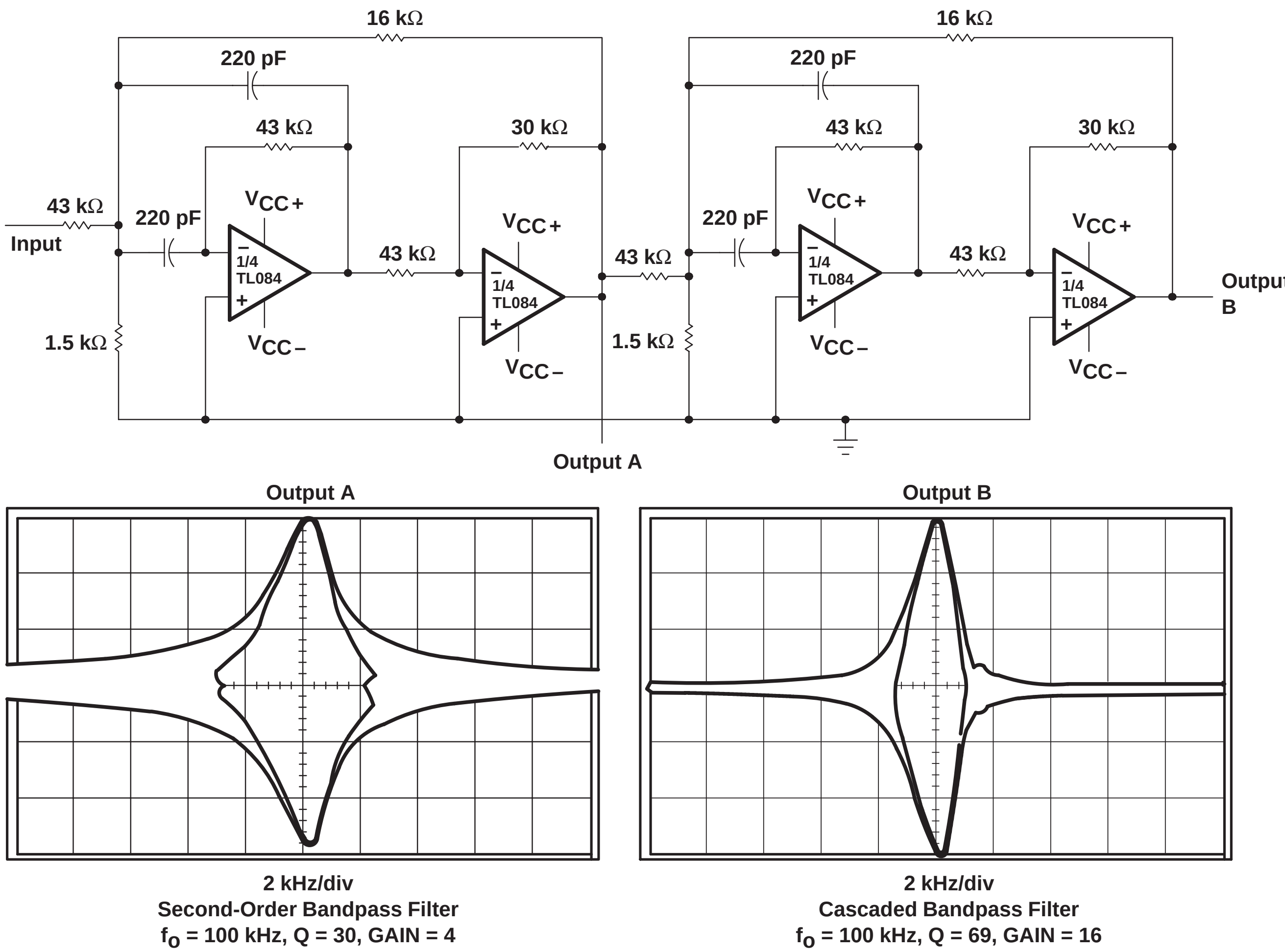
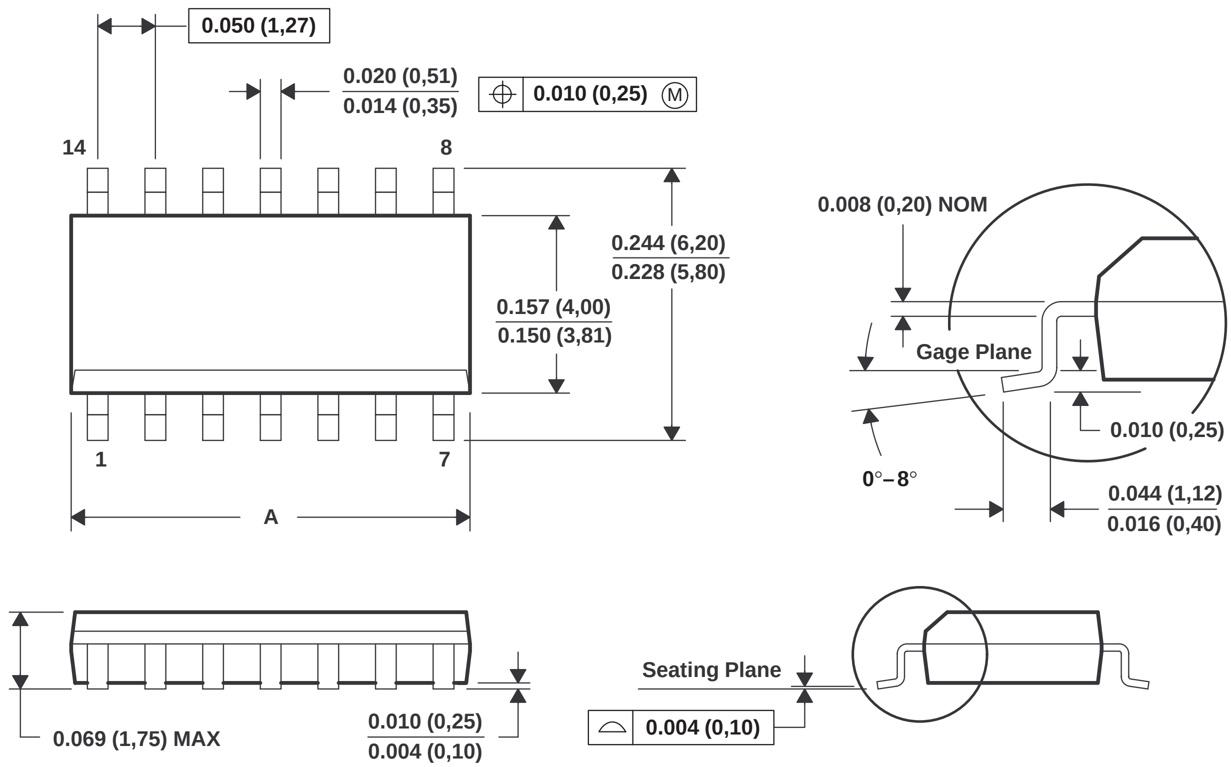


Figure 27. Positive-Feedback Bandpass Filter

MECHANICAL DATA

D (R-PDSO-G)** **PLASTIC SMALL-OUTLINE PACKAGE**

14 PIN SHOWN



PINS ** / DIM	8	14	16
A MAX	0.197 (5,00)	0.344 (8,75)	0.394 (10,00)
A MIN	0.189 (4,80)	0.337 (8,55)	0.386 (9,80)

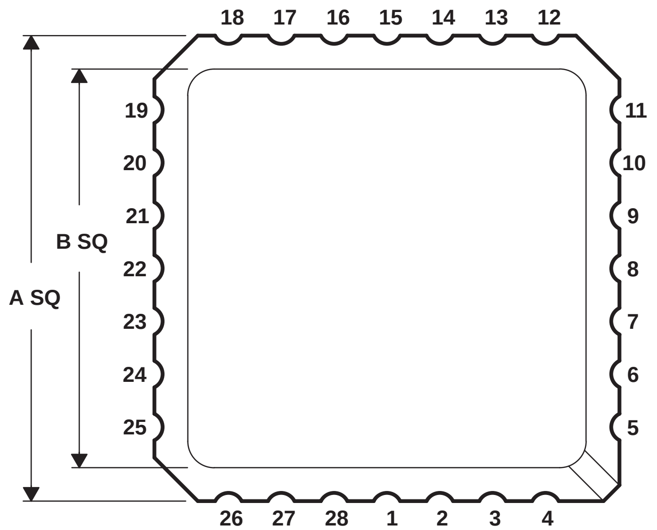
4040047/D 10/96

NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion, not to exceed 0.006 (0,15).
D. Falls within JEDEC MS-012

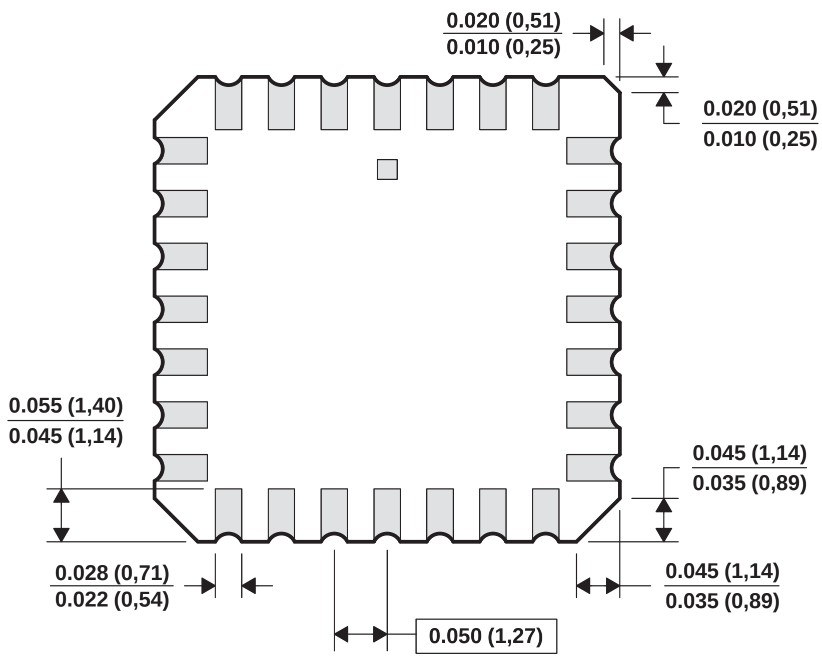
MECHANICAL DATA

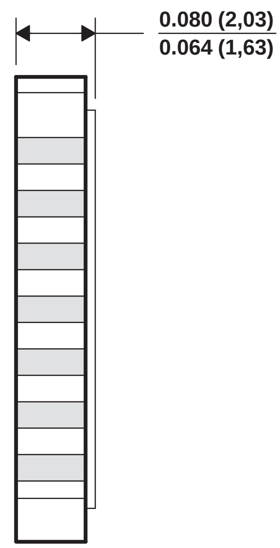
FK (S-CQCC-N)** **LEADLESS CERAMIC CHIP CARRIER**

28 TERMINAL SHOWN



NO. OF TERMINALS **	A		B	
	MIN	MAX	MIN	MAX
20	0.342 (8,69)	0.358 (9,09)	0.307 (7,80)	0.358 (9,09)
28	0.442 (11,23)	0.458 (11,63)	0.406 (10,31)	0.458 (11,63)
44	0.640 (16,26)	0.660 (16,76)	0.495 (12,58)	0.560 (14,22)
52	0.739 (18,78)	0.761 (19,32)	0.495 (12,58)	0.560 (14,22)
68	0.938 (23,83)	0.962 (24,43)	0.850 (21,6)	0.858 (21,8)
84	1.141 (28,99)	1.165 (29,59)	1.047 (26,6)	1.063 (27,0)





4040140 / D 10/96

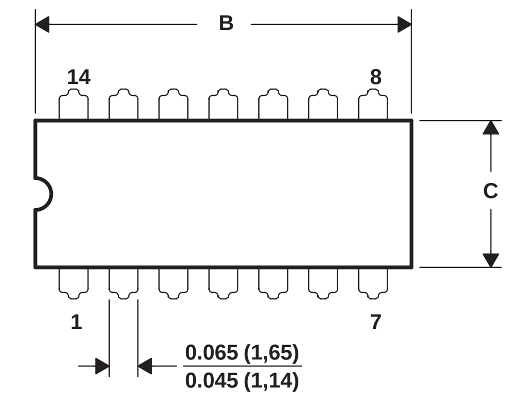
NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a metal lid.
D. The terminals are gold plated.
E. Falls within JEDEC MS-004

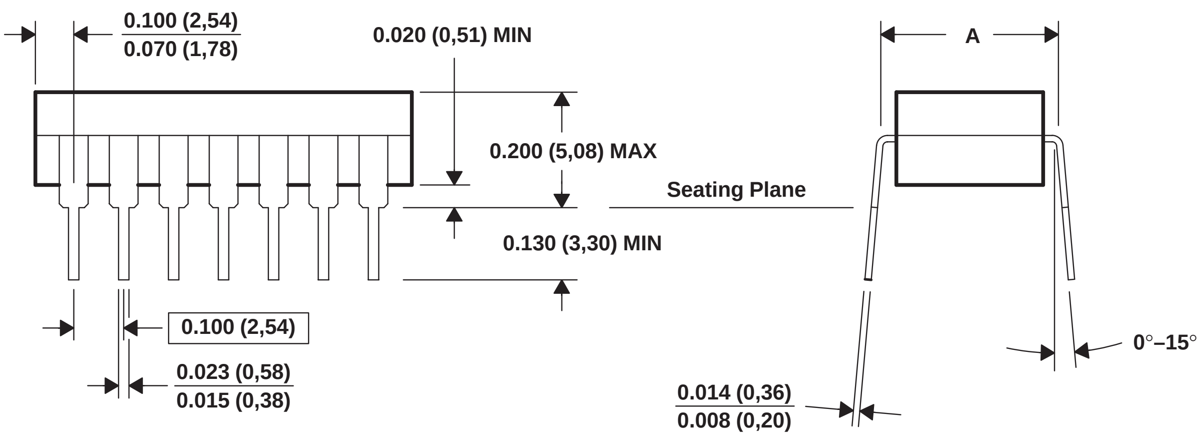
MECHANICAL DATA

J (R-GDIP-T)** **CERAMIC DUAL-IN-LINE PACKAGE**

14 PIN SHOWN

DIM \ PINS **	14	16	18	20
A MAX	0.310 (7,87)	0.310 (7,87)	0.310 (7,87)	0.310 (7,87)
A MIN	0.290 (7,37)	0.290 (7,37)	0.290 (7,37)	0.290 (7,37)
B MAX	0.785 (19,94)	0.785 (19,94)	0.910 (23,10)	0.975 (24,77)
B MIN	0.755 (19,18)	0.755 (19,18)	—	0.930 (23,62)
C MAX	0.300 (7,62)	0.300 (7,62)	0.300 (7,62)	0.300 (7,62)
C MIN	0.245 (6,22)	0.245 (6,22)	0.245 (6,22)	0.245 (6,22)



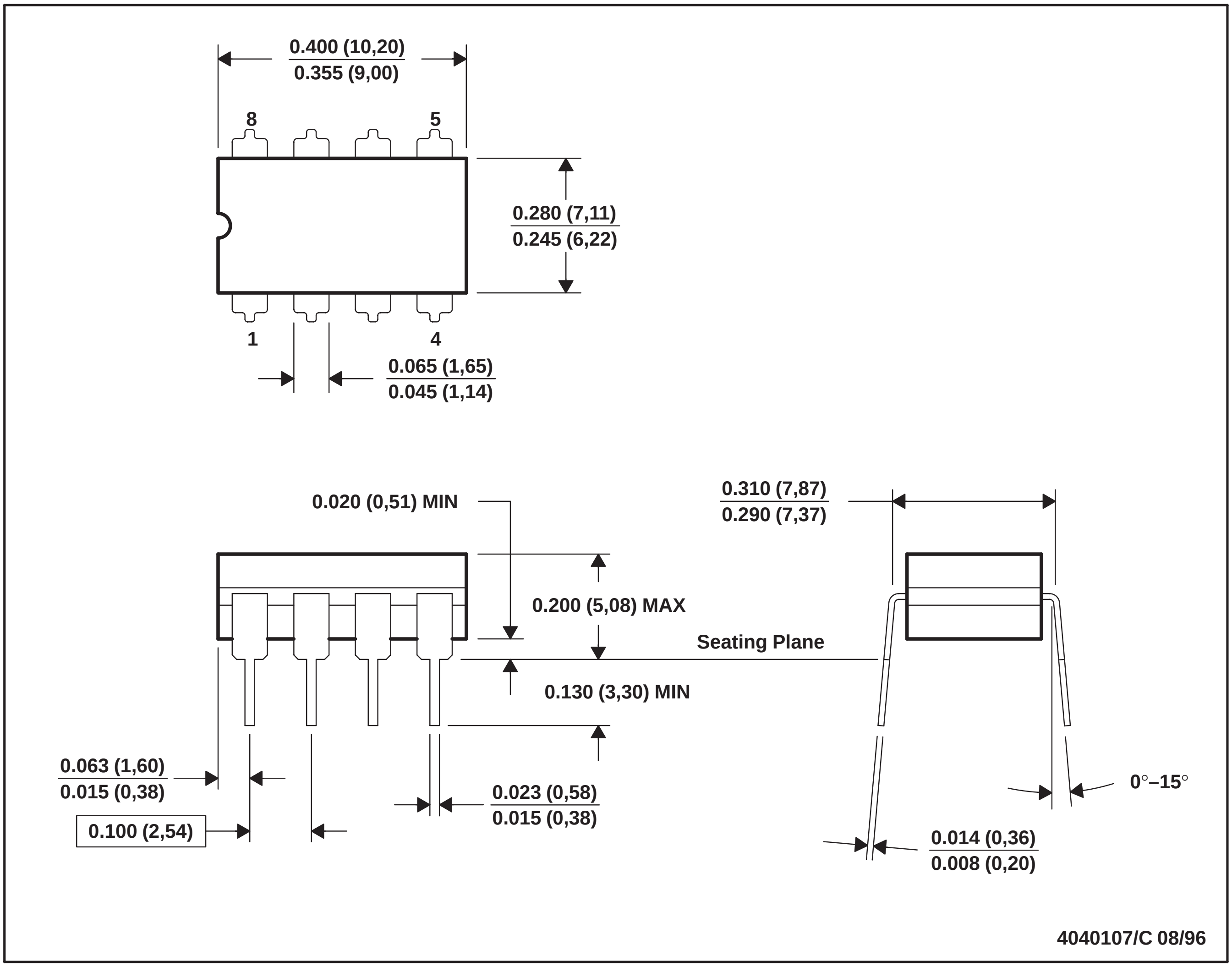


4040083/D 08/98

NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. This package can be hermetically sealed with a ceramic lid using glass frit.
- D. Index point is provided on cap for terminal identification only on press ceramic glass frit seal only.
- E. Falls within MIL STD 1835 GDIP1-T14, GDIP1-T16, GDIP1-T18, GDIP1-T20, and GDIP1-T22.

MECHANICAL DATA

JG (R-GDIP-T8) **CERAMIC DUAL-IN-LINE PACKAGE**



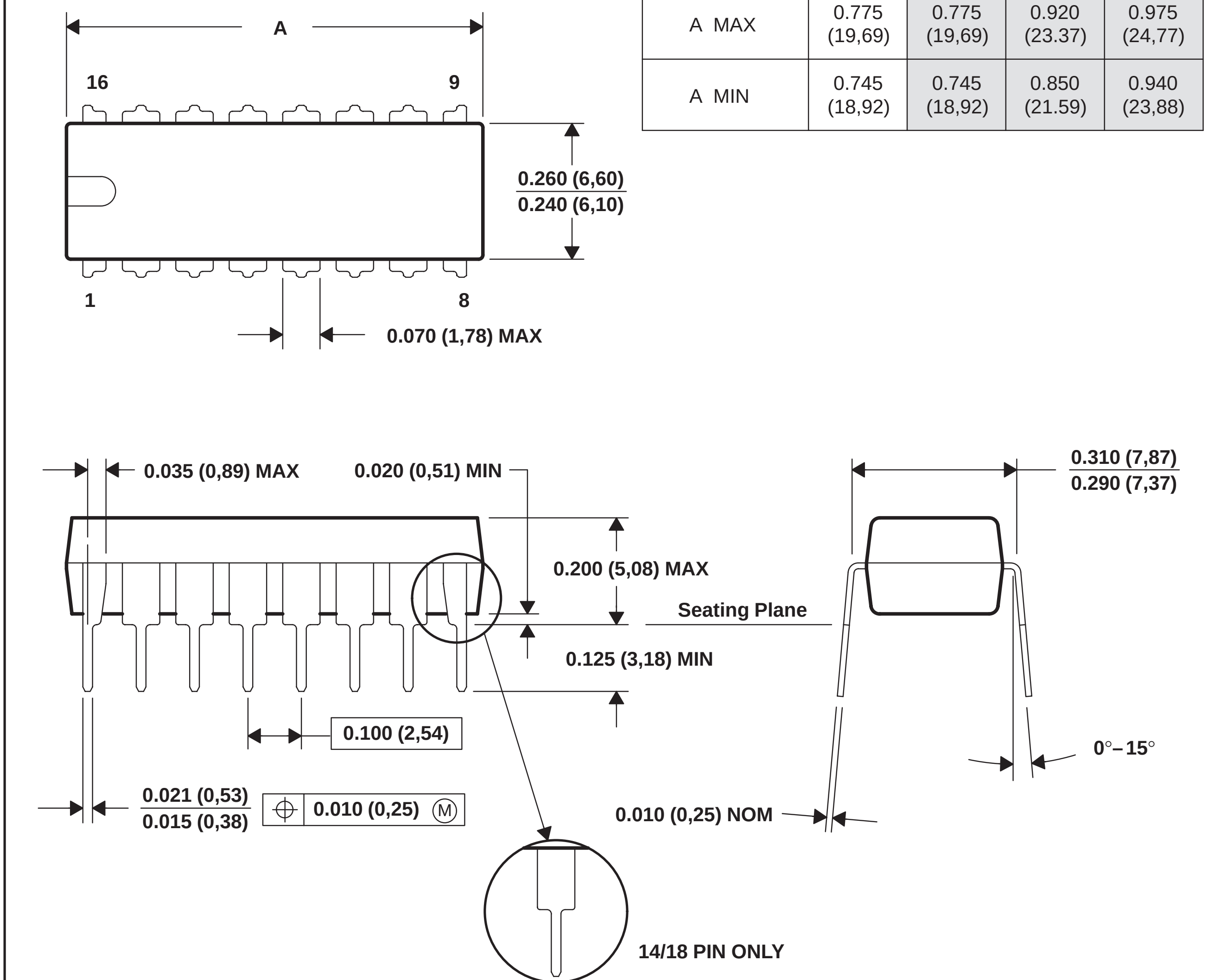
NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a ceramic lid using glass frit.
D. Index point is provided on cap for terminal identification only on press ceramic glass frit seal only.
E. Falls within MIL-STD-1835 GDIP1-T8

MECHANICAL DATA

N (R-PDIP-T)** **PLASTIC DUAL-IN-LINE PACKAGE**

16 PIN SHOWN

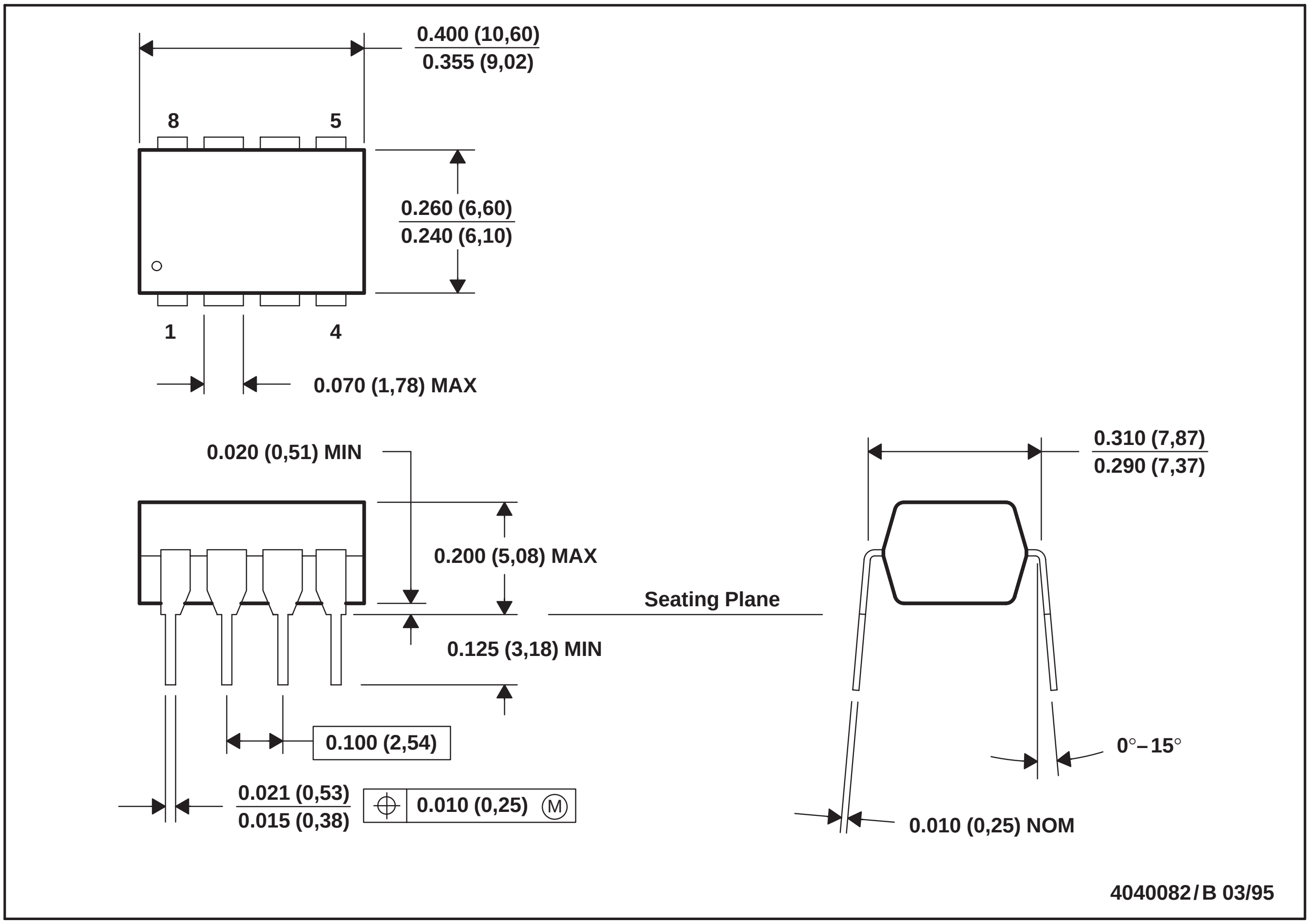
PINS ** / DIM	14	16	18	20
A MAX	0.775 (19,69)	0.775 (19,69)	0.920 (23.37)	0.975 (24,77)
A MIN	0.745 (18,92)	0.745 (18,92)	0.850 (21.59)	0.940 (23,88)



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001 (20 pin package is shorter then MS-001.)

MECHANICAL DATA

P (R-PDIP-T8) **PLASTIC DUAL-IN-LINE PACKAGE**

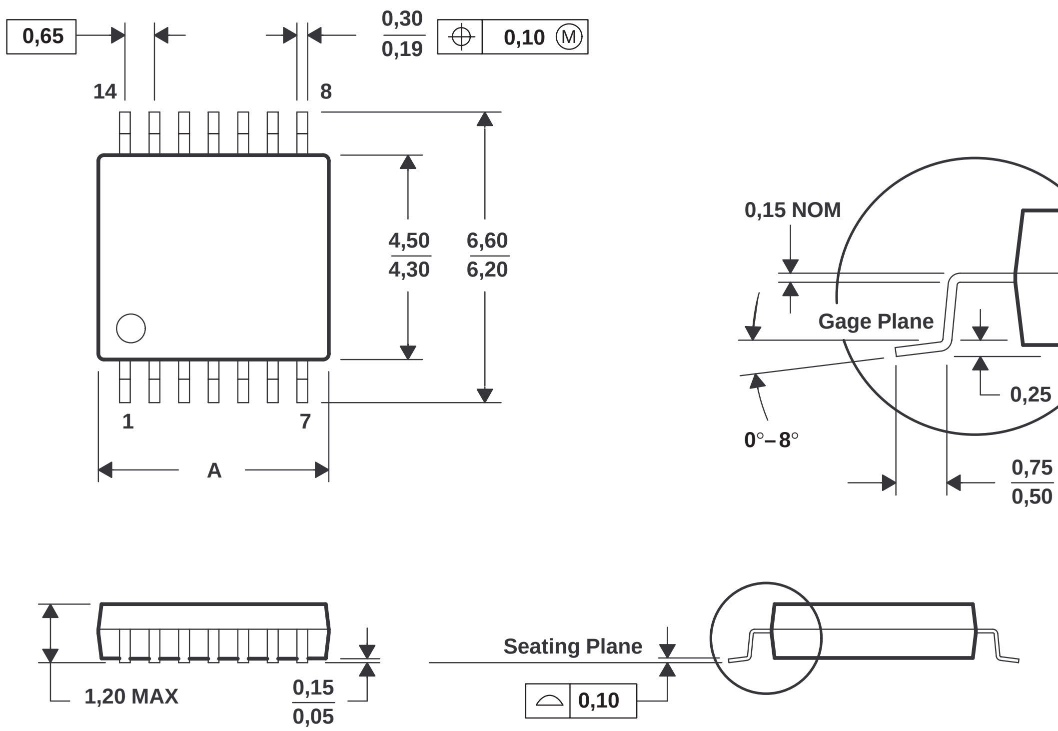


NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001

MECHANICAL DATA

PW (R-PDSO-G)** **PLASTIC SMALL-OUTLINE PACKAGE**

14 PIN SHOWN



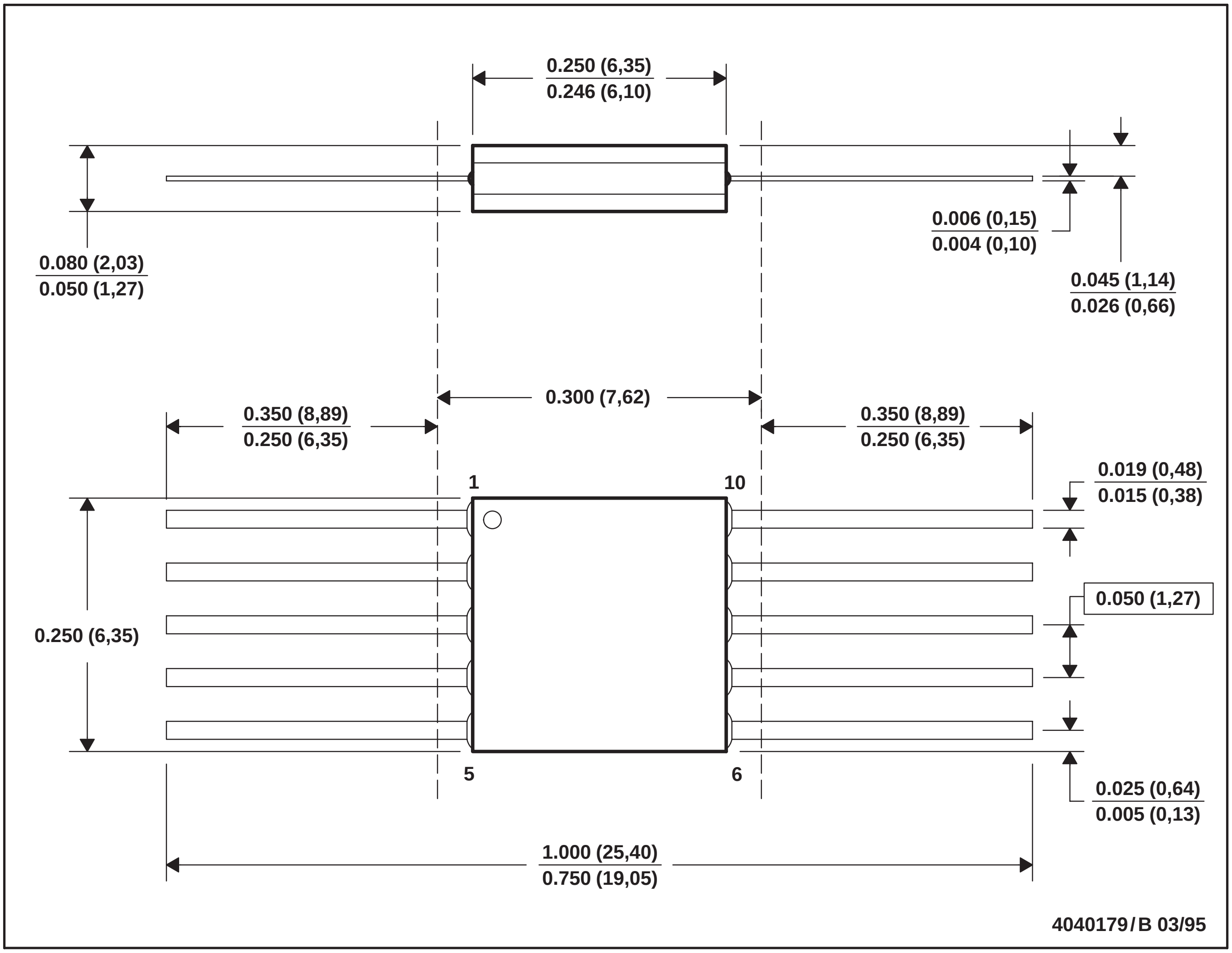
PINS ** / DIM	8	14	16	20	24	28
A MAX	3,10	5,10	5,10	6,60	7,90	9,80
A MIN	2,90	4,90	4,90	6,40	7,70	9,60

4040064 / E 08/96

NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion not to exceed 0,15.
D. Falls within JEDEC MO-153

MECHANICAL DATA

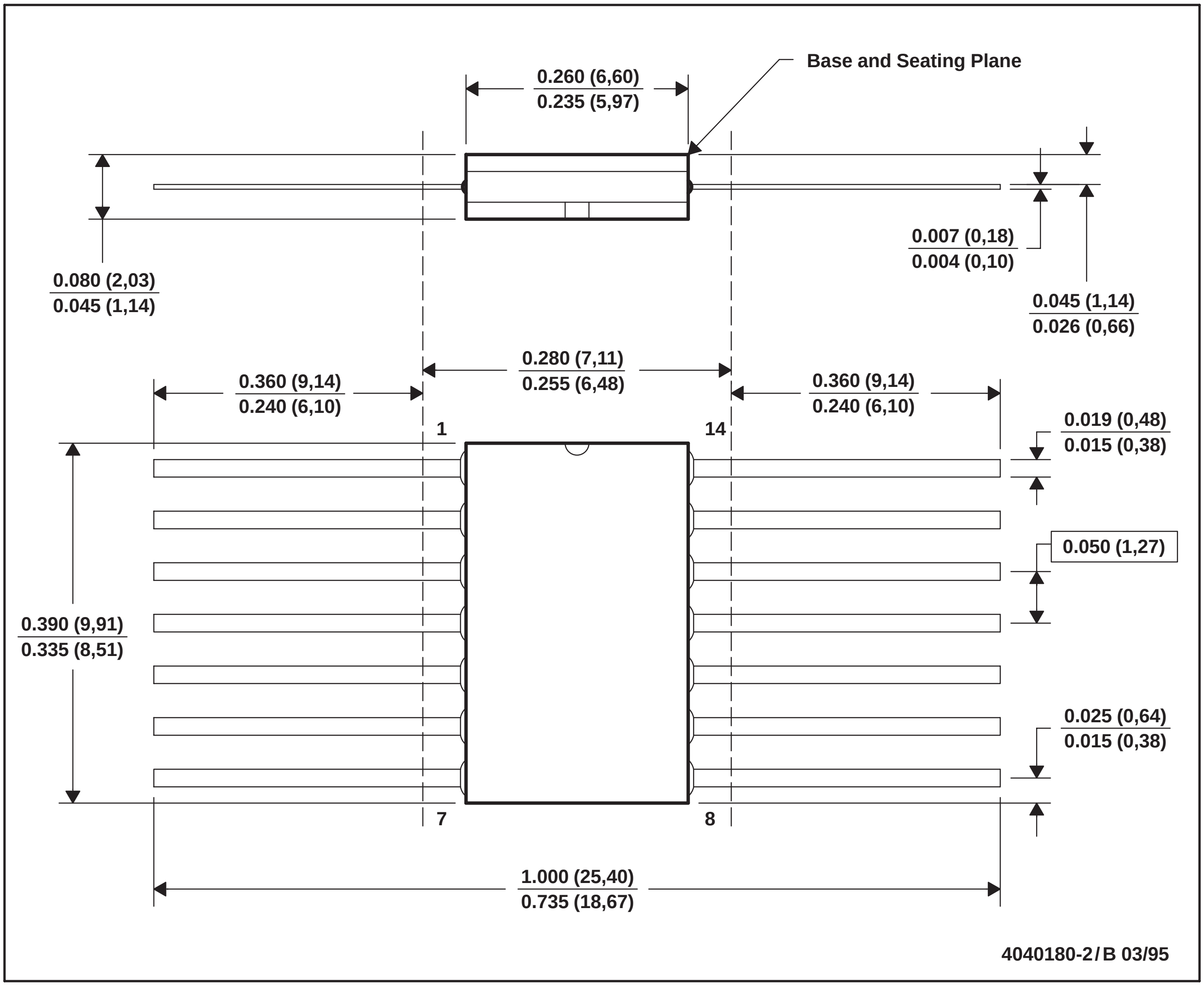
U (S-GDFP-F10) **CERAMIC DUAL FLATPACK**



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a ceramic lid using glass frit.
D. Index point is provided on cap for terminal identification only.
E. Falls within MIL STD 1835 GDFP1-F10 and JEDEC MO-092AA

MECHANICAL DATA

W (R-GDFP-F14) **CERAMIC DUAL FLATPACK**



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a ceramic lid using glass frit.
D. Index point is provided on cap for terminal identification only.
E. Falls within MIL STD 1835 GDFP1-F14 and JEDEC MO-092AB

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