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Instruction Manual

Advanced Physics Lab
Electronics A+D

Modern Aspect of Data Taking and Processing with a Microcontroller

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Abstract

The experiment "Digital Electronic" provides an introduction into modern data taking by operating simple digital circuits utilising an Arduino board. This manual will inform you about the Arduino board, the installation of the required software and the electrical components you will have to use. Basic knowledge on electronics, how to use oscilloscopes, bread boards and power supplies is recommended.

During the experiment you will learn how to build a circuit that measures the temperature, how to operate it using the Arduino board and to modify and improve it using more components.

In case you should already have previous knowledge we will provide many more material and own ideas on implementation are very welcome and can be built consulting the assistants.

ETH Zürich, Switzerland, September 26, 2018

Contents

1 Introduction

Arduino is a computer company, project and user community based on easy-to-use hardware and software, that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control objects in the physical and digital world. All products are distributed as open-source hardware and software, and it's licences permit the manufacture of Arduino boards and software distribution by anyone. The boards are commercially available in preassembled form, or as do-it-yourself (DIY) kits.

The Arduino project started in 2003 as a program for students without a background in electronics and programming at the Interaction Design Institute in Ivrea (Italy). The aim was to provide a low-cost and easy way for novices and professionals to create devices that interact with their environment using sensors and actuators. The actual name Arduino comes from a bar in Ivrea, where some of the founders of the project used to meet. The bar was named after Arduin of Ivrea, who was the margrave of the March of Ivrea and King of Italy from 1002 to 1014 [**?**].

In order to work with the Arduino Boards the Arduino programming language, based on Wiring, and the Arduino Software (IDE), based on the Processing are used [**?**]. Both Wiring and Processing are programming languages using a simplified dialect of features from the programming languages C and C++.

1.1 Arduino Board

The original boards were produced by the Italian company Smart Projects but as of 2018, 22 versions of the Arduino hardware have been commercially produced. The information and specifications of these boards can be found on this website. During this Lab you will work the Arduino Uno shown in Figure 1.

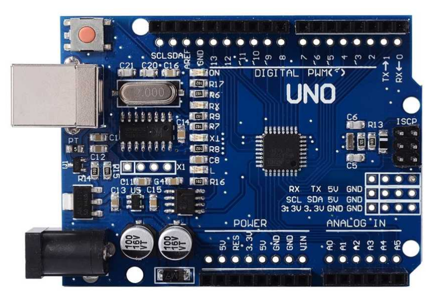


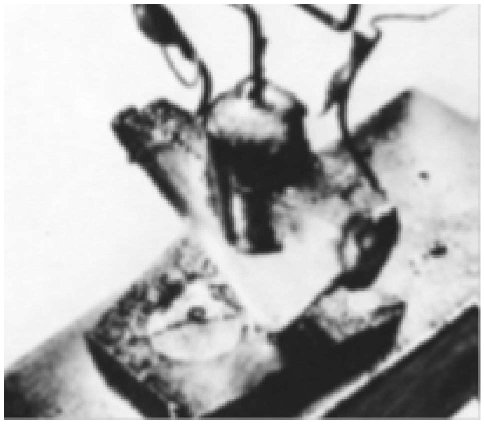
Figure 1: Arduino Uno.

The Arduino Boards use a variety of microprocessors and controllers and are equipped with sets of digital and analogue input/output (I/O) pins that may be interfaced to various expansion boards or Breadboards (shields) and other circuits. The boards feature serial communications interfaces, Universal Serial Bus (USB) on some models, which are also used for loading programs from personal computers.

Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell the board what to do by sending a set of instructions to the microcontroller.

1.2 Transistor

The invention of the transistor was announced in 1948 by the American physicists, J. Bardeen and W. H. Brattain as a new type of amplifying device made from semiconducting crystals. At that time almost no one could have foreseen the revolutionary developments that were to follow, developments so important and far-reaching as to change the whole outlook of the science and technology of electronics. The physical principles of a transistor had been worked out in conjunction with their colleague, W. Shockley. In recognition of their work the three physicists were awarded jointly the Nobel Prize for Physics in 1956.



(a) Point-contact transistor.

(b) Bardeen, Brattain and Shockley.

The term "transistor" is a combination from the words *trans*former and res*istor*, since the device is made from resistor material and transformer action is involved in the operation. In the beginning only point-contact transistors existed, but due to their vulnerability to mechanical shock they were soon replaced by junction transistors which are firmly established now [**?**].

The transistor is the key active component in practically all modern electronics. It is considered as one of the greatest inventions of the 20th century. Its importance in today's society rests on its ability to be mass-produced using a highly automated process that achieves astonishingly low per-transistor costs (10 femto$/transistor) [**?**].

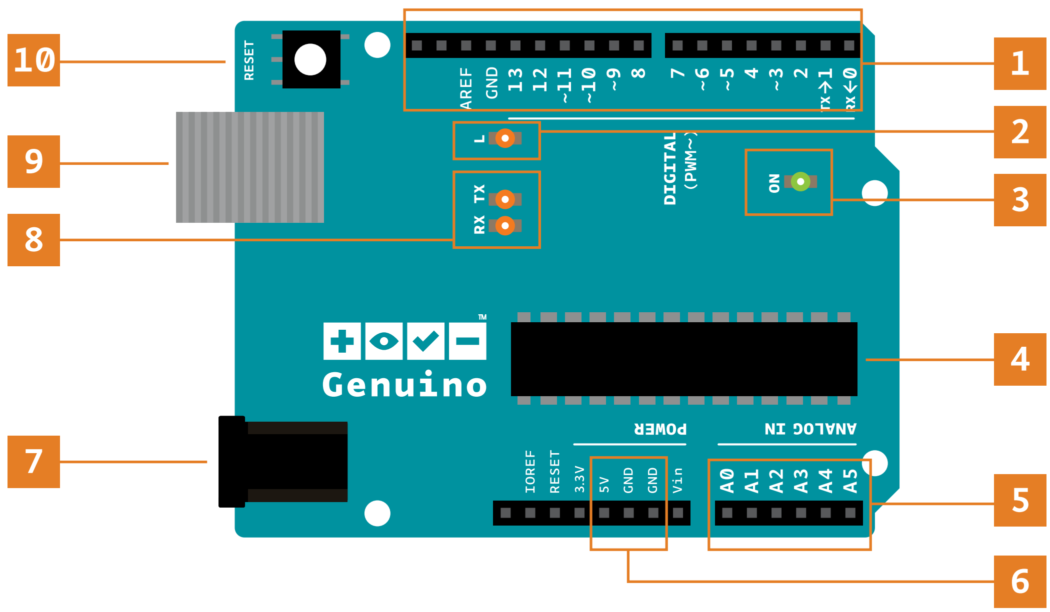
Although billions of individually packaged (discrete) transistors are produced every year the vast majority of transistors are now produced in integrated circuits (ICs). A logic gate consists of up to about twenty transistors whereas an advanced microprocessor, as of 2009, can use as many as 3 billion transistors. In 2014, about 10 billion transistors were built for each single person on Earth [**?**].

The working principle of the transistor will be covered in subsection 2.9.

2 Basics

This section will give you the basic information about the components we are using in this lab.

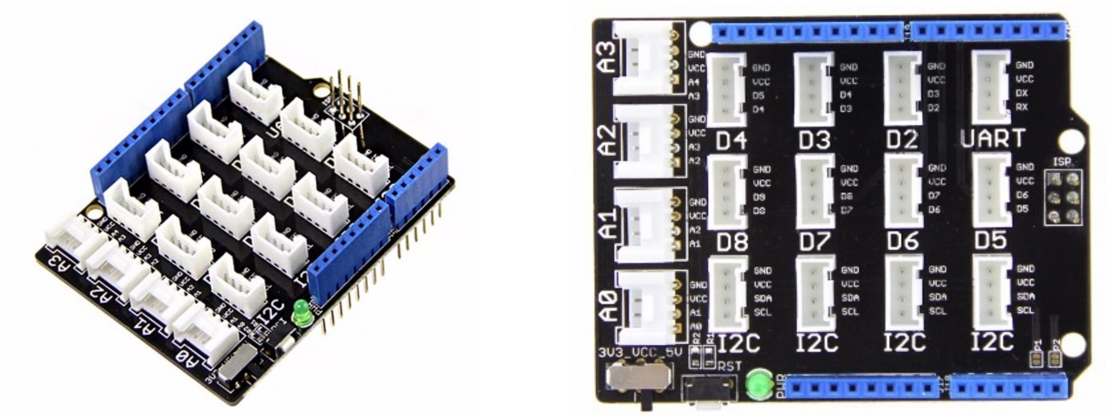
2.1 Arduino Uno



1. **Digital pins:** used with `digitalRead()`, `digitalWrite()`, and `analogWrite()` methods, `analogWrite()` only works on pins with the pulse width modulation (PWM) symbol
2. **Pin 13 LED:** only built-in actuator
3. **Power LED**
4. **ATmega microcontroller**
5. **Analogue in:** used with `analogWrite()` method
6. **GND and 5V pins:** provide 5 V power and ground (GND) to the circuits
7. **Power connector:** additional power supply, accepted voltages: $7 \sim 12\,\mathrm{V}$
8. **TX and RX LEDs:** indicate communication between Arduino and computer
9. **USB port:** used for powering and communication with computer
10. **Reset button:** resets the ATmega microcontroller

2.2 Grove Base Shield

The so called shields are printed circuit expansion boards, which plug into the normally supplied Arduino pin headers. The Grove Base Shield is one example that simplifies projects that require a lot of sensors or LEDs. With the Grove connectors on the base board, one can add all the Grove modules to the Arduino Uno very conveniently.



(a) Side view. (b) Top view.

Figure 3: Grove shield.

There are 16 Grove connectors on the Base Shield which are shown in Table 1. Apart from the connectors the board also consists of a reset (RST) button, a green LED to indicating power status, a toggle switch and four rows of pinouts, which is equivalent to the pinout of the Arduino.

Specification	Name	Quantity
Analog	A0/A1/A2/A3	4
Digital	D2/D3/D4/D5/D6/D7/D8	7
UART	UART	1
I2C	I2C	4

Table 1: Base Shield connectors.

Every Grove connector has four wires, one of which is the voltage common collector (VCC). Since some micro-controller main boards need need different supply voltages the power toggle switch allows you to select the suitable voltage. In the case of the Arduino Uno a voltage of 5 V is required [**?**].

2.3 The Software

2.3.1 Arduino IDE

All you require to write programs and upload them to your board is the Arduino Software (IDE). There are two options how to use it:

1. Online IDE

- no installation required
  - needs plugin if you want to upload sketches from Linux
- requires you to create account with e-mail verification
- save sketches in cloud (available from all devices)
- always most up-to-date version
- instructions on the website

2. Desktop IDE

- if you want to work offline
- installation usually very straightforward and in has general no dependencies
- if you need help, follow installation instructions depending on your operating system (OS)
  - Linux
  - Mac OS X
  - Windows

2.3.2 Board Drivers

First the Arduino board has to be connected to the computer via the USB cable which will power the board indicated by the green power (PWR) LED. The board drivers should then install automatically in Linux, Mac OS X and Windows. If the board was not properly recognised, follow these instructions.

2.4 Programming

In order to get a feeling for the programming language it is recommended to have a look at the examples first which can be found under: **`File > Examples`**
A list of the most common methods is shown in Table 2. For more information look at the detailed description.

Category	Method Syntax	Description
Sketch	setup()	called once at the start of the sketch, used to initialise variables, pin modes, etc.
	loop()	loops consecutively after setup was called
Digital I/O	digitalRead(pin)	reads the value from the digital pin (HIGH or LOW)
	digitalWrite(pin, value)	writes HIGH or LOW value to the digital pin
	pinMode(pin, mode)	configures the pin as INPUT or OUTPUT
Analogue I/O	analogRead(pin)	reads the value (0-1023) from the pin
	analogWrite(pin, value)	writes an analogue value (PWM wave) to the pin
	analogReference(type)	configures the reference voltage used for analogue input
Advanced I/O	tone(pin, f, duration)	generates a square wave of frequency f [Hz] for a duration [ms]
	pulseIn(pin, value)	returns the time [ms] of a pulse, if value is HIGH: waits until HIGH and stops when LOW
Time	delay(time)	pauses the program for a time [ms]
	micros()	returns time since starting the program [µs]
	millis()	returns time since starting the program [ms]
Math	constrain(x, a, b)	constrains a number x to be in range [a, b]
	map(x, a, b, c, d)	re-maps x from range [a, b] to range [c, d]
	random(a, b)	returns pseudo-random number in range [a, b]
	abs(value)	return the absolute value
	⋮	further general math commands
Serial	Serial.begin(speed)	initialise serial communication at speed [bit/s]
	Serial.print(value)	prints the value to the serial port
	Serial.println(value)	prints the value to the serial port with [\r\n]
	Serial.read()	reads incoming serial data

Table 2: Most common methods for controlling the Arduino board and performing computations.

2.5 Project Management with

Git is a version control system for tracking changes in computer files and coordinating work on those files among multiple people. It is primarily used for source code management in software development, but it can be used to keep track of changes in any set of files [?].

2.6 Voltage Divider

A voltage divider is a passive linear circuit that produces an output voltage V_{out} that is a fraction of its input voltage V_{in}. Voltage division is the result of distributing the input voltage among the components of the divider. A simple example of a voltage divider is two resistors connected in series, with V_{in} across the resistor pair and V_{out} emerging from the connection between them as shown in Figure 4.

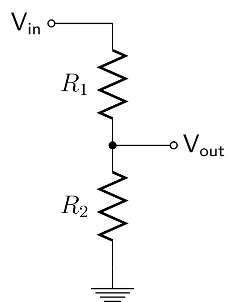


Figure 4: Voltage divider.

Resistor voltage dividers are commonly used to create reference voltages, or to reduce the magnitude of a voltage so it can be measured. Using Ohm's law one can easily derive the formula for V_{out}:

$$V_{\text{out}} = \frac{R_2}{R_1 + R_2} \cdot V_{\text{in}} \tag{1}$$

2.7 Thermistor

If, for a given temperature, the current is directly proportional to the applied voltage the electrical component is said to obey Ohm's law. Such components are called linear resistors. If a component does not meet this requirement it is termed a non-linear resistor, which falls into two classes – the temperature-sensitive type and the voltage-sensitive type. The temperature-sensitive types are often known as thermistors and change the resistance very reproducible. The word is a portmanteau of *THERM*ally-sensitive and res*ISTOR*.

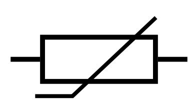


Figure 5: Electronic symbol of the thermistor

They consist of the sintered oxides of manganese and nickel with small amounts of copper, cobalt or iron added to vary the properties and the physical shape is usually a bead, rod or a disc. The electronic symbol is shown in Figure 5. The resistance is given by

$$R = R_0 \cdot \mathrm{e}^{-B\left(\frac{1}{T_0}-\frac{1}{T}\right)} \tag{2}$$

where B is a constant depending upon the composition and physical size, T is the temperature in °K, and R_0 the resistance at ambient room temperature T_0 (25 °C = 298.15 K). Thermistors can be classified into two types, depending on the classification of B. If B is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (PTC) thermistor, or posistor. If B is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (NTC) thermistor.

2.8 Temperature Sensor

Thermistors have very widespread applications as thermometers. We know that a NTC thermistor varies its resistance as a function of the temperature, but resistance is not the easiest parameter to measure. In our case we want to feed a signal into an analogue-to-digital converter (ADC) to treat it numerically and compute the actual temperature. Now, the ADC of the Arduino requires a voltage at it's input.

An easy solution is to install the NTC in a voltage divider as shown in subsection 2.6. It requires only one additional fixed resistor R_0. V_{in} is the reference voltage used of the ADC and V_{out} the measured voltage. So what you will measure in the end is just a digital 10 bit value corresponding to the divided voltage where the maximum of $2^{10} - 1 = 1023$ corresponds to V_{in}. In order to convert it into the resistance of the thermistor we have to use Equation 1:

$$R = \left(\frac{V_{\text{in}}}{V_{\text{out}}} - 1\right) \cdot R_0 = \left(\frac{1023}{V_{\text{meas}}} - 1\right) \cdot R_0 \tag{3}$$

Now we need to convert the resistance into the temperature using Equation 2:

$$\frac{1}{T} = \frac{\ln\left(\frac{R}{R_0}\right)}{B} + \frac{1}{T_0} \tag{4}$$

Note that this temperature will be in Kelvin!

2.9 Bipolar Junction Transistor

A bipolar junction transistor (BJT) is a type of transistor that uses both electron and hole charge carriers. For their operation, BJTs use two junctions between two semiconductor types, n-type and p-type and thus can be manufactured in two types, NPN and PNP. The basic function of a BJT is to amplify current which allows it to be used as amplifiers or switches, giving them wide applicability in electronic equipment.

2.9.1 Working Principle

Since a transistor consists of two pn junctions within a single crystal, transistor action can be explained with Figure 8. For diagrammatic purposes the base region is shown fairly thick, but in fact the pn junctions are very closely spaced and the active portion of the base is very thin.

The charge flow in a BJT is due to diffusion of charge carriers across a junction between two regions of different charge concentrations. The regions of a BJT are called emitter, collector, and base. Typically, the emitter region is heavily doped compared to the other two layers, whereas the majority charge carrier concentrations in base and collector layers are about the same.

In the absence of any external applied voltages the collector and emitter depletion layers are about the same thickness, the widths depending upon the relative doping of the collector, emitter and base regions. During normal transistor operation the emitter-base junction is forward biased so that current flows easily in the input or signal circuit. The bias voltage V_{BE} is about 200 mV for germanium transistors and about 400 mV for silicon devices. The collector-base junction is reverse-biased by the main supply voltage V_{CB} typically with 4.5 V, 6 V and 9 V. The collector junction is therefore heavily reversed-biased and the depletion layer there is quite thick.

The injection of a hole into the base region by a signal source will now be considered. Once in the base, the hole attracts an electron from the emitter region. The recombination of the hole and electron is not likely to occur however, since the base region is lightly doped compared with the emitter region and so the lifetime of the electron in the base region is quite long. In addition the base is extremely thin so the electron, instead of combining with the signal hole or with a hole of the p-type base material, diffuses into the collector-base junction. The electron then comes under the influence of the strong field there and is swept into the collector and hence into the load circuit. In a good transistor many electrons pass into the collector region before eventually the signal hole is eliminated by combination with an electron. A small signal current can thus give rise to a large load current i_C, and so current amplification has taken place. In practical transistors for every hole injected into the base 50 to 250 electrons may be influenced to flow into the collector region. The current gain or amplification is therefore 50 to 250. It is usually given by the symbol β.

An PNP transistor behaves in a similar fashion except that electrons are injected into the base and holes flow from the emitter into the collector. To maintain the correct bias conditions the polarity of the external voltages must be reversed.

Figure 9 shows the three basic transistor arrangements. The common emitter mode is the most commonly used arrangement for voltage amplification because very little current is required from the signal source.

The common base mode of operation is also capable of voltage amplification. This is achieved by the use of high values of load resistor. The transistor is able to maintain the current through the load because the device is a good constant current generator [?].

2.9.2 Common Collector

The common collector circuit shown in Figure 9c has a voltage gain of a little less than unity and so is useless as a voltage amplifier. However this circuit has very important impedance matching properties and is typically used as a voltage buffer. In this circuit the base serves as the input, the emitter is the output, and the collector is common to both.

The voltage gain is just a little less than one since the emitter voltage is constrained at the voltage drop over the diode of about 0.6 V (for silicon) below the base. The transistor continuously monitors V_D and adjusts its emitter voltage almost equal (less V_{BEO}) to the input voltage by passing the according collector current through the emitter resistor R_E. As a result, the output voltage follows the input voltage variations from V_{BEO} up to V_+; hence also the name, emitter follower. This circuit is useful because it has a large input impedance, so it will not load down the previous circuit and a small output impedance, so it can drive low-resistance loads

2.10 Operational Amplifier

Should be covered in AP next semester

2.11 PID Controller

A proportional–integral–derivative (PID) controller is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value *et* as the difference between a desired setpoint (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively) which give the controller its name.

In practical terms it automatically applies accurate and responsive correction to a control function. An everyday example is the cruise control on a road vehicle; where external influences such as gradients would cause speed changes, and the driver has the ability to alter the desired set speed. The PID algorithm restores the actual speed to the desired speed in the optimum way, without delay or overshoot, by controlling the power output of the vehicle's engine [**?**].

3 Setup and Experimental Procedure

The Digital Electronics Lab is meant to be very open in implementation. The aim will be to build an automated cooling system. We will guide you through this process step by step, but you are also encouraged to bring in your own ideas of other possible implementations!

3.1 Experimental Material

You will find the following objects on your test stand:

- 1 Arduino Uno Board
- 1 Oscilloscope
- 2 Probes
- 1 Multimeter
- 1 USB Type B cable
- 1 Breadboard
- 1 Grove Starter Kit for Arduino

  - 1 Base Shield
  - 1 LCD RGB Backlight
  - 1 Smart Relay
  - 1 Buzzer
  - 1 Sound Sensor
  - 1 Touch Sensor
  - 1 Rotary Angle Sensor
  - 1 Temperature Sensor
  - 1 LED Module
  - 3 Dip LEDs (red, green, blue)
  - 1 Light Sensor
  - 1 Button
  - 1 Mini Servo
  - 10 Grove Cables

- 1 3-pin fan
- 1 operational amplifier (LM358)
- 1 NPN transistor (BC547)
- 1 NTC thermistor (B57164-K104-J)

In addition you should bring a lab book to note down everything what you do and measure (immediately after the execution). Please write clearly and meticulously since it will greatly help you to find mistakes and to write your report!

3.2 Setting up the Arduino

3.2.1 Software installation

We highly recommend you to install the Arduino IDE on your machine so that you can access it any time. If you should have trouble with the installation or you prefer to not use your computer for the experiment, you can use one of the Windows XP machines provided to you, which have the Arduino IDE and all necessary drivers pre-installed. These machines do not have internet connection, so you have to bring a portable USB drive to copy the data.

- install IDE following subsection 2.3

3.2.2 Connect the Arduino

- connect the Arduino to your computer and check if it is recognised by the IDE
  - select the correct port: **`Tools > Port`**
  - get board info: **`Tools > Get Board Info`**

3.2.3 Your First Sketch

- (optional) set your sketchbook location
  - you can link it to your IDE: **File > Preferences > Sketchbook Location**
- create a new sketch with **File > New**, it will look like this:

```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

Now we want to turn on the LED on the Arduino board, which is connected to the special pin LED_BUILTIN. Since use this pin as an output, we have to set the pin mode during the setup() function to OUTPUT. Afterwards we can use the method digitalWrite() to set the pin to HIGH, (corresponding to 5V), which will turn on the LED on the board. We don't need to use the loop() method for this simple sketch, but we will use it later.

```
void setup() {
  pinMode(LED_BUILTIN, OUTPUT);
  digitalWrite(LED_BUILTIN, HIGH);
}

void loop() {
  // put your main code here, to run repeatedly:

}
```

That's it. All the methods and constants we use in this script are already defined and don't have to be imported explicitly. There is a long list of such pre-defined constants, make sure to not redefine them when adding new constants or variables! We are now ready to test the communication of the Arduino board with the computer and test if flashing the code works. Make sure to select the correct Port and choose "Arduino/Genuino Uno" as board type if not already selected.

- compile the code
- upload the code to the Arduino
- add the sketch folder to a git repository

3.3 Blinking LED on Bread Board

That was easy (but boring...). As next step we want to have a blinking external LED on the breadboard. Since it should continue blinking forever, we will use the loop() function now.

- supply the Breadboard with 5 V from the Arduino
- connect a LED to the breadboard with appropriate resistor (220 Ohm) and to a digital pin
- write a sketch (`Blink.ino`) that makes the LED blink with a frequency of 1 Hz using the `delay(int nMicroSeconds)` method, which pauses the execution for `nMicroSeconds` microsenconds.

Upload your sketch now to the Arduino and test it.

- connect a second LED on the breadboard to a different pin
- write a sketch (`Blink2.ino`) that makes the second LED blink in a different pattern than the first one
  - why is `delay()` not working anymore?
  - use a timer with `micros()` which returns a microseconds counter

3.4 Grove Temperature Sensor

In this experiment you will work with the Grove - Temperature Sensor V1.2. It uses a NTC thermistor to detect the ambient temperature. The specifications are shown in Table 3.

Specification	Value
Operating voltage	$3.3 \sim 5.0\,\mathrm{V}$
Zero power resistance	$(100 \pm 1)\,\mathrm{k\Omega}$
Operating temperature range	$-40 \sim +125\,°\mathrm{C}$
Nominal B-constant	$4250 \sim 4299\,\mathrm{K}$

Table 3: Grove-Temperature Sensor V1.2 specifications.

- connect the Grove Base Shield to your Arduino
- connect the Grove Temperature Sensor to the shield
  - figure out which connector to choose on the shield
- write a sketch (`GroveTemp.ino`) that measures the ambient temperature
  - read the voltage value from the sensor
  - convert the voltage into the corresponding resistance
  - convert the resistance into a temperature in °C
  - write the temperature to the serial interface every second
  - look at the data with the Arduino Serial Monitor:
    `Tools > Serial Monitor` (Ctrl+Shift+M)
  - look at the data with the Arduino Serial Plotter:
    `Tools > Serial Plotter` (Ctrl+Shift+P)

The serial connection has to be enabled during the `setup()` function with `Serial.begin(9600);` where 9600 is the baud rate. It is 9600 by default in the Serial Plotter and Serial monitor utilities, so it is convenient to use this.

3.5 Grove Display and Potentiometer

As a next step, we will add two more components from the Grove kit: a display to output the current temperature read by the sensor and a potentiometer to set the threshold for our two-point temperature control later.

- add the display to your project
  - install the libraries from

    look at the example code on the above website, especially on how to include the libraries in your project and how to initialize it during the `setup()` routine
  - make sure the "3V3_VCC_5V" switch on the Grove shield is set to 5V, otherwise the display will not work correctly
  - connect the Grove LCD RGB Backlight display to your Grove shield
  - modify your project such that the measured temperature is printed on the display every second
- define a fixed threshold in your code, e.g. 30 degrees above which a LED is turned on. (As alternative you can change the background color of your display). Test if your project is working.
- now we want to make the threshold controllable without recompiling our project. For this purpose, connect the potentiometer (Grove Rotary Angle Sensor) to the Grove shield.
  - read the description at

    read-out the sensor with `analogRead()`
  - to map the ADCs which range from 0 to 1023 to a reasonable temperature range (a, b), e.g. 20 to 40 degrees, the function `map(degrees, 0, 1023, a, b)` can be used for convenience
- indicate the status below/above threshold also in the output to the serial interface, e.g. add a second number (0 = below threshold, 50 = above threshold) separated by a space
- test your code by varying the threshold below/above the room temperature
  - the serial plotter should now draw a second line indicating whether below or above threshold. Vary your threshold slowly below and above the room temperature and make a screenshot of the resulting graph.
- optional: while turning the potentiometer, you can also print the threshold temperature on the display in the second row below the measured temperature

3.6 Data Handling

Even though one can use the Arduino IDE to look at the values from the temperature sensor, there is no way to save them. That is why we encourage you to write a short program to save the data to file so that you can use it afterwards. We recommend you to use python for this purpose, but feel free to use whatever you have the most experience with.

Once a sketch is uploaded to the microprocessor the Arduino will perform the loop until it is disconnected from power or overwritten by a new sketch. Note down the port number or name, which can be seen under ”Tools” in the Arduino IDE. In order to read the data externally from the serial port you have to close the Arduino serial tools (Serial Monitor, Serial Plotter, ...).

3.6.1 With Python

Example code in python:

- open the serial port
  - `from serial import Serial`
  - `arduino = Serial('/dev/<arduino_portname>')`
  - you can find the name of the port in the Arduino IDE
  - read a single line using the serial method `arduino.readline().decode('utf-8')`
- print the line in the terminal using `print`
- write the data to a text file (`data.txt`), every value on a single line
  - if you have trouble handling files in python follow this guide
- your program should repeat this until you terminate it e.g. by pressing CTRL+C.

3.6.2 On Windows XP lab computers

If your port is COM3, you can type the following simple command into a command shell (Start > Run > cmd):

```
type com3: > output.log
```

There is a small delay in writing as data is written in blocks. It can also happen that the last line is incomplete, take this into account in the analysis of the file. You can stop the program by pressing CTRL+break in the command shell. You can use a USB stick to transfer the resulting file to your personal computer to proceed with the analysis.

3.6.3 bash (Linux, Mac OSX

If you use Linux or Mac, you can do all of the above with a single line of bash. Instead of ”/dev/cu.usbmodem14141” put your device name (which is listed as port in the Arduino IDE), which can be different from this.

```
while read -r line; do echo $line; done < /dev/cu.usbmodem14141 | tee "output.txt"
```

3.7 Building Your Own Temperature Sensor

In this task you will build your own temperature sensor using discrete components. The B57164-K104-J thermistor has the specifications listed in Table 4.

Specification	Value
Operating voltage	$3.3 \sim 5.0\,\mathrm{V}$
Zero power resistance	$(100 \pm 5)\,\mathrm{k\Omega}$
Operating temperature range	$-55 \sim +125\,°\mathrm{C}$
Nominal B-constant	$(4600 \pm 1340)\,\mathrm{K}$

Table 4: B57164-K104-J specifications.

- build a voltage divider circuit to convert the resistance into a measurable voltage
- use the LM358 operational amplifier to increase the outgoing signal (why do we need it?)
- reproduce the temperature measurements from subsection 3.5

You can copy the schematics from , which shows the easiest way how to use the op-amp.

3.8 Building a Heating System

Since it is boring to measure a constant temperature, we build a simple heat load of 0.2-0.25 W with a couple of resistors.

- calculate the resistors needed to have the correct power dissipation.
- bring the heating resistor and the temperature sensor close together to have as good thermal contact as possible.
- create a plot of the temperature vs. time (starting from room temperature) and measure the time constant of the temperature rise and estimate the equilibrium temperature.

3.9 Building a Cooling System

Many electrical components will produce heat under load and may break at critical temperatures. That is why many of complex systems like computers require cooling. You will now build a system that controls a fan and can regulate it's rotation speed.

- connect the fan to the breadboard, for the 4 pin header, the following conventions are used:
  - black: ground
  - yellow: 5V
  - green: tacho read-out (will be used later)
  - blue: PWM control

- keep in mind that only a few of the digital pins (marked by ”” on the board) are able to use PWM, e.g. use digital pin 11

Now we can finally build the full two-point controller.

- define a low and high threshold, e.g. use the potentiometer for the high threshold and set the lower threshold a few degrees lower than the high one.
- set the duty cycle of the fan to 100% when above the high threshold
- set the duty cycle of the fan to 0% when below the low threshold
- setting the PWM duty-cycle can be done using the `analogWrite()` function
- if thresholds are set reasonably, you will see an oscillatory behavior. **Create a plot of temperature vs. time which shows multiple periods.**

Experiment with different set-points, what is the advantage of having two setpoints instead of a single threshold above we turn cooling on? What are the draw-backs of the two-point controller?

3.10 Read Out the Fan Speed

We now wan to use the built-in Hall Effect Sensor (HES) of the fan to measure its rotation speed. In every rotation this sensor will produce two pulses we can count and then convert to revolutions per minute (**RPM**). The maximum (for 100% duty cycle) according to the datasheet is 1900 RPM, with a tolerance of 10%, the minimum is around 230 RPM.

- calculate a rough estimate for the minimum frequency needed for reading the voltage on the tacho pin and be able to count the pulses? (Use Nyquist theorem) In practice, a much higher frequency should be used than the limit calculated above
- check the Arduino reference of `analogRead()` for the maximum frequency. Since we also have to do other work in the `loop()` function, the frequency should be also much less than the maximum. Make a reasonable choice.
- what is the expected uncertainty on the minimum and maximum RPM if we count pulses for 1 second?
- connect the tacho (green wire) of the fan to an analog pin of the Arduino, using a 10k pull-up resistor to 5V. (optional: figure out how to use internal pull-up resistor of the Arduino instead of a discrete component)
- what is the role of the pull-up resistor?
- count the pulses of the HES and convert the result to RPM. Is it within the range expected by the datasheet numbers?
- write the revolutions per minute (RPM) value to the serial output

3.11 Final measurements

Now that our device has all basic functionalities, we can perform some measurements with it.

- plot the fan RPM vs. the duty cycle. Which is the minimum duty cycle above which the fan starts to spin, and at which RPM? What is the maximum RPM for full duty-cycle?
- plot the equilibrium temperature vs. the duty cycle and the equilibrium temperature vs. the fan RPM. Make sure you measure long enough for each data point and give a reasonable estimate for the uncertainty that you obtain on the equilibrium value.

Scanning the points for the different duty cycles should be done without flashing the device in between. Instead, the measurement programme (e.g. number of steps, seconds per step etc.) should be programmed into the Arduino or, alternatively, controlled by a Python program running on the computer which changes the parameters via the serial interface (see "Bi-directional communication with the computer" section below).

3.12 Building a PID Controller (Advanced)

We have seen that with the two-point controller above, we could not exactly stabilize to a constant temperature and were suffering from under- and overshoot. Using a PID controller can overcome both issues.

- implement a PID controller
- regulate cooling by the PWM duty-cycle of your fan
- tune your three parameters to have reasonably stable operation. (Perfect tuning is very complicated and does not have to done here.)
- create some plots with temperature vs. time, starting from different initial temperatures, which show converging temperature.

The output of the PID controller consists of three different terms, each having a tuneable coefficient.

- proportional: proportional to the error, which is `error = temperature - setpoint`
- integral: proportional to the sum of all errors of previous steps
- derivative: proportional to the difference in error compared to last step

In practice, there are few more things to consider

- using a timer, perform the PID calculations between every 100 ms and every second. You should not use longer values to be fast enough in response and not too much shorter values to be not susceptible to noise.
- use a discrete digital low-pass filter on your measured temperature if it is noisy.
- convert your PID response to a duty_cycle between 0 and 255 to be used in `analogWrite(PIN_FAN_PWM, duty_cycle);`

A low-pass filter can be used to filter out high frequency fluctuations (noise) on the measured temperature. It can be implemented in it's simplest form with

```
temperature = (1-LOWPASS_ALPHA) * temperature + LOWPASS_ALPHA * (
    temperature_current - temperature);
```

where temperature_current is the actual reading from the sensor and temperature (which has to be properly initialized once to be the sensor reading!) the output of the filter. LOWPASS_ALPHA controls the cut-off frequency of the lowpass filter and obviously depends on how often per seconds we measure. Set it to a reasonable value which suppresses the noise and is still fast enough for the timescale of temperature changes we expect (roughly few degrees per second). It can also be computed analytically:

$$\alpha = \frac{\Delta t}{\tau + \Delta t} \tag{5}$$

where τ is the characteristic time constant of the low-pass filter (corresponds to RC time of a RC filter). Setting $\alpha = 0$ makes it infinitely fast, so as consequence disables the filter, where $\alpha = 1$ would make it infinitely slow, so the result would stay constant.

3.13 Bi-directional communication with the computer (Advanced)

Until now we only read values from the device, but we can also write commands from the computer to the Arduino using the serial interface.

- instead of using the potentiometer to set the threshold, implement a way to set the threshold via serial commands
- one can use the SCPI protocol as a reference, e.g. set the threshold to 32 degrees with the command "SET:THR 32"
- which other commands are necessary to run the measurements from above section without hardcoding the measurement programme (e.g. number of steps, seconds per step etc.)?
- write a Python script to perform the measurements from above section via sending SCPI style commands to the Arduino

4 Analysis / Protocol

The analysis and the following protocol should be done such that the reader is able to reconstruct the described circuit and is able to proof that it is working correctly. That includes besides the exact description of all the used parts:

- A link to the repository with all the used sketches. The code should be written in a readable fashion according to C++ coding guidelines with meaningful denotations and sufficient comments.
- Circuit diagrams of **ALL** circuits. A circuit diagram consists of international standardised symbols for all parts in the circuit.

Besides you should answer all questions posed in section 3 describing the approach. Do not forget the results and a conclusion!

List of Figures

List of Tables

List of Acronyms

IDE integrated development environment

DIY do-it-yourself

USB Universal Serial Bus

I/O input/output

GND ground

RST reset

PWR power

IC integrated circuit

VCC voltage common collector

OS operating system

PTC positive temperature coefficient

NTC negative temperature coefficient

ADC analogue-to-digital converter

BJT bipolar junction transistor

PWM pulse width modulation

PID proportional–integral–derivative

RPM revolutions per minute

LM358, LM258, LM158, LM2904 Dual Operational Amplifiers

1 Features

- Wide Supply Ranges
  - Single Supply: 3 V to 32 V (26 V for LM2904)
  - Dual Supplies: ±1.5 V to ±16 V (±13 V for LM2904)
- Low Supply-Current Drain, Independent of Supply Voltage: 0.7 mA Typical
- Wide Unity Gain Bandwidth: 0.7 MHz
- Common-Mode Input Voltage Range Includes Ground, Allowing Direct Sensing Near Ground
- Low Input Bias and Offset Parameters
  - Input Offset Voltage: 3 mV Typical
    A Versions: 2 mV Typical
  - Input Offset Current: 2 nA Typical
  - Input Bias Current: 20 nA Typical
    A Versions: 15 nA Typical
- Differential Input Voltage Range Equal to Maximum-Rated Supply Voltage: 32 V (26 V for LM2904)
- Open-Loop Differential Voltage Gain: 100 dB Typical
- Internal Frequency Compensation
- On Products Compliant to MIL-PRF-38535, All Parameters are Tested Unless Otherwise Noted. On All Other Products, Production Processing Does Not Necessarily Include Testing of All Parameters.

2 Applications

- Blu-ray Players and Home Theaters
- Chemical and Gas Sensors
- DVD Recorder and Players
- Digital Multimeter: Bench and Systems
- Digital Multimeter: Handhelds
- Field Transmitter: Temperature Sensors
- Motor Control: AC Induction, Brushed DC, Brushless DC, High-Voltage, Low-Voltage, Permanent Magnet, and Stepper Motor
- Oscilloscopes
- TV: LCD and Digital
- Temperature Sensors or Controllers Using Modbus
- Weigh Scales

3 Description

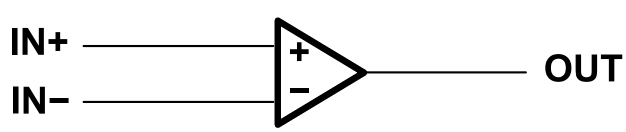
These devices consist of two independent, high-gain frequency-compensated operational amplifiers designed to operate from a single supply or split supply over a wide range of voltages.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LMx58, LMx58x, LM2904, LM2904V	VSSOP (8)	3.00 mm × 3.00 mm
	SOIC (8)	4.90 mm × 3.90 mm
	SO (8)	5.20 mm × 5.30 mm
	TSSOP (8)	3.00 mm × 4.40 mm
	PDIP (8)	9.81 mm × 6.35 mm
LMx58, LMx58x, LM2904V	CDIP (8)	9.60 mm × 6.67 mm
	LCCC (20)	8.89 mm × 8.89 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Symbol (Each Amplifier)



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4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

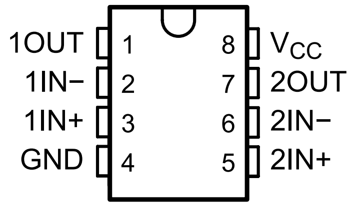
Changes from Revision T (April 2015) to Revision U	**Page**
• Changed data sheet title	1
• Added *Receiving Notification of Documentation Updates* section and *Community Resources* section	17

Changes from Revision S (January 2014) to Revision T	**Page**
• Added *Applications* section, *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section	1

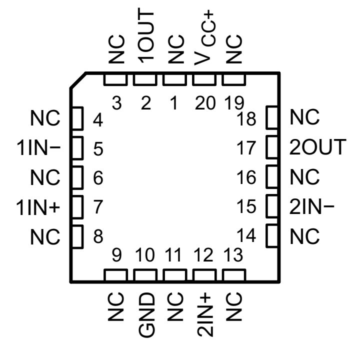
Changes from Revision R (July 2010) to Revision S	**Page**
• Converted this data sheet from the QS format to DocZone using the PDF on the web	1
• Deleted *Ordering Information* table	1
• Updated *Features* to include Military Disclaimer	1
• Added Typical Characteristics section	9
• Added ESD warning	17

5 Pin Configuration and Functions

D, DGK, P, PS, PW and JG Package
8-Pin SOIC, VSSOP, PDIP, SO, TSSOP and CDIP
(Top View)



FK Package
20-Pin LCCC
(Top View)



NC - No internal connection

Pin Functions

PIN			I/O	DESCRIPTION
NAME	LCCC NO.	SOIC, SSOP, CDIP, PDIP SO, TSSOP, CFP NO.		
1IN–	5	2	I	Negative input
1IN+	7	3	I	Positive input
1OUT	2	1	O	Output
2IN–	15	6	I	Negative input
2IN+	12	5	I	Positive input
2OUT	17	7	O	Output
GND	10	4	—	Ground
NC	1	—	—	Do not connect
	3			
	4			
	6			
	8			
	9			
	11			
	13			
	14			
	16			
	18			
	19			
V_{CC}	—	8	—	Power supply
V_{CC+}	20	—	—	Power supply

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

				LMx58, LMx58x, LM2904V		LM2904		UNIT
				MIN	MAX	MIN	MAX	
V_{CC}		Supply voltage(2)		–0.3	±16 or 32	–0.3	±13 or 26	V
V_{ID}		Differential input voltage(3)		–32	32	–26	26	V
V_I	either input	Input voltage		–0.3	32	–0.3	26	V
		Duration of output short circuit (one amplifier) to ground at (or below) T_A = 25°C, V_{CC} ≤ 15 V(4)			Unlimited		Unlimited	s
T_A		Operating free air temperature	LM158, LM158A	–55	125			°C
			LM258, LM258A	–25	85			
			LM358, LM358A	0	70			
			LM2904	–40	125	–40	125	
T_J		Operating virtual junction temperature			150		150	°C
		Case temperature for 60 seconds	FK package		260			°C
		Lead temperature 1.6 mm (1/16 inch) from case for 60 seconds	JG package		300		300	°C
T_{stg}		Storage temperature		–65	150	–65	150	°C

(1) 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.
(2) All voltage values (except differential voltages and V_{CC} specified for the measurement of I_{OS}) are with respect to the network GND.
(3) Differential voltages are at IN+, with respect to IN−.
(4) Short circuits from outputs to V_{CC} can cause excessive heating and eventual destruction.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	±500	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101(2)	±1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

			LMx58, LMx58x, LM2904V		LM2904		UNIT
			MIN	MAX	MIN	MAX	
V_{CC}	Supply voltage		3	30	3	26	V
V_{CM}	Common-mode voltage		0	V_{CC} – 2	0	V_{CC} – 2	V
T_A	Operating free air temperature	LM158	–55	125			°C
		LM2904	–40	125	–40	125	
		LM358	0	70			
		LM258	–25	85			

6.4 Thermal Information

THERMAL METRIC(1)		LMx58, LMx58x, LM2904V, LM2904					LMx58, LMx58x, LM2904 V	LMx58, LMx58x, LM2904 V	UNIT
		D (SOIC)	DGK (VSSOP)	P (PDIP)	PS (SO)	PW (TSSOP)	FK (LCCC)	JG (CDIP)	
		8 PINS	8 PINS	8 PINS	8 PINS	8 PINS	20 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	97	172	85	95	149	—	—	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	72.2	—	—	—	—	5.61	14.5	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.

6.5 Electrical Characteristics for LMx58

at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS(1)		T_A(2)	LM158 LM258 MIN	LM158 LM258 TYP(3)	LM158 LM258 MAX	LM358 MIN	LM358 TYP(3)	LM358 MAX	UNIT
V_{IO}	Input offset voltage	V_{CC} = 5 V to MAX, V_{IC} = $V_{ICR(min)}$, V_O = 1.4 V		25°C		3	5		3	7	mV
				Full range			7			9	
αV_{IO}	Average temperature coefficient of input offset voltage			Full range		7			7		µV/°C
I_{IO}	Input offset current	V_O = 1.4 V		25°C		2	30		2	50	nA
				Full range			100			150	
αI_{IO}	Average temperature coefficient of input offset current			Full range		10			10		pA/°C
I_{IB}	Input bias current	V_O = 1.4 V		25°C		–20	–150		–20	–250	nA
				Full range			–300			–500	
V_{ICR}	Common-mode input voltage range	V_{CC} = 5 V to MAX		25°C	0 to V_{CC} – 1.5			0 to V_{CC} – 1.5			V
				Full range	0 to V_{CC} – 2			0 to V_{CC} – 2			
V_{OH}	High-level output voltage	R_L ≥ 2 kΩ		25°C	V_{CC} – 1.5			V_{CC} – 1.5			V
		R_L ≥ 10 kΩ		25°C							
		V_{CC} = MAX	R_L = 2 kΩ	Full range	26			26			
			R_L ≥ 10 kΩ	Full range	27	28		27	28		
V_{OL}	Low-level output voltage	R_L ≤ 10 kΩ		Full range		5	20		5	20	mV
A_{VD}	Large-signal differential voltage amplification	V_{CC} = 15 V, V_O = 1 V to 11 V, R_L ≥ 2 kΩ		25°C	50	100		25	100		V/mV
				Full range	25			15			
CMRR	Common-mode rejection ratio	V_{CC}= 5 V to MAX, V_{IC} = $V_{ICR(min)}$		25°C	70	80		65	80		dB
k_{SVR}	Supply-voltage rejection ratio (ΔV_{DD} /ΔV_{IO})	V_{CC} = 5 V to MAX		25°C	65	100		65	100		dB
V_{O1}/ V_{O2}	Crosstalk attenuation	f = 1 kHz to 20 kHz		25°C		120			120		dB
I_O	Output current	V_{CC} = 15 V, V_{ID} = 1 V, V_O = 0	Source	25°C	–20	–30		–20	–30		mA
				Full range	–10			–10			
		V_{CC} = 15 V, V_{ID} = –1 V, V_O = 15 V	Sink	25°C	10	20		10	20		
				Full range	5			5			
		V_{ID} = –1 V, V_O = 200 mV		25°C	12	30		12	30		µA
I_{OS}	Short-circuit output current	V_{CC} at 5 V, GND at –5 V, V_O = 0		25°C		±40	±60		±40	±60	mA

(1) All characteristics are measured under open-loop conditions, with zero common-mode input voltage, unless otherwise specified. MAX V_{CC} for testing purposes is 26 V for LM2902 and 30 V for the others.
(2) Full range is –55°C to 125°C for LM158, –25°C to 85°C for LM258, and 0°C to 70°C for LM358, and –40°C to 125°C for LM2904.
(3) All typical values are at T_A = 25°C

Electrical Characteristics for LMx58 (continued)

at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS(1)	T_A(2)	LM158 LM258 MIN	LM158 LM258 TYP(3)	LM158 LM258 MAX	LM358 MIN	LM358 TYP(3)	LM358 MAX	UNIT
I_{CC}	Supply current (two amplifiers)	V_O = 2.5 V, No load	Full range		0.7	1.2		0.7	1.2	mA
		V_{CC} = MAX, V_O = 0.5 V_{CC}, No load	Full range		1	2		1	2	

6.6 Electrical Characteristics for LM2904

at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS(1)		T_A(2)	LM2904 MIN	LM2904 TYP(3)	LM2904 MAX	UNIT
V_{IO}	Input offset voltage	V_{CC} = 5 V to MAX, V_{IC} = $V_{ICR(min)}$, V_O = 1.4 V	Non-A-suffix devices	25°C		3	7	mV
				Full range			10	
			A-suffix devices	25°C		1	2	
				Full range			4	
αV_{IO}	Average temperature coefficient of input offset voltage			Full range		7		μV/°C
I_{IO}	Input offset current	V_O = 1.4 V	Non-V device	25°C		2	50	nA
				Full range			300	
			V-suffix device	25°C		2	50	
				Full range			150	
αI_{IO}	Average temperature coefficient of input offset current			Full range		10		pA/°C
I_{IB}	Input bias current	V_O = 1.4 V		25°C		–20	–250	nA
				Full range			–500	
V_{ICR}	Common-mode input voltage range	V_{CC} = 5 V to MAX		25°C	0 to V_{CC} – 1.5			V
				Full range	0 to V_{CC} – 2			
V_{OH}	High-level output voltage	R_L ≥ 10 kΩ		25°C	V_{CC} – 1.5			V
		V_{CC} = MAX, Non-V device	R_L = 2 kΩ	Full range	22			
			R_L ≥ 10 kΩ	Full range	23	24		
		V_{CC} = MAX V-suffix device	R_L = 2 kΩ	Full range	26			
			R_L ≥ 10 kΩ	Full range	27	28		
V_{OL}	Low-level output voltage	R_L ≤ 10 kΩ		Full range		5	20	mV
A_{VD}	Large-signal differential voltage amplification	V_{CC} = 15 V, V_O = 1 V to 11 V, R_L ≥ 2 kΩ		25°C	25	100		V/mV
				Full range	15			
CMRR	Common-mode rejection ratio	V_{CC} = 5V to MAX, V_{IC} = $V_{ICR(min)}$	Non-V device	25°C	50	80		dB
			V-suffix device	25°C	65	80		
k_{SVR}	Supply-voltage rejection ratio (ΔV_{CC} /ΔV_{IO})	V_{CC} = 5 V to MAX		25°C	65	100		dB
V_{O1}/ V_{O2}	Crosstalk attenuation	f = 1 kHz to 20 kHz		25°C		120		dB
I_O	Output current	V_{CC} = 15 V, V_{ID} = 1 V, V_O = 0	Source	25°C	–20	–30		mA
				Full range	–10			
		V_{CC} = 15 V, V_{ID} = –1 V, V_O = 15 V	Sink	25°C	10	20		
				Full range	5			
		V_{ID} = –1 V, V_O = 200 mV	Non-V device	25°C		30		μA
			V-suffix device	25°C	12	40		
I_{OS}	Short-circuit output current	V_{CC} at 5 V, V_O = 0, GND at −5 V		25°C		±40	±60	mA
I_{CC}	Supply current (four amplifiers)	V_O = 2.5 V, No load		Full range		0.7	1.2	mA
		V_{CC} = MAX, V_O = 0.5 V_{CC}, No load		Full range		1	2	

(1) All characteristics are measured under open-loop conditions, with zero common-mode input voltage, unless otherwise specified. MAX V_{CC} for testing purposes is 26 V for LM2902 and 32 V for LM2902V.
(2) Full range is –55°C to 125°C for LM158, –25°C to 85°C for LM258, 0°C to 70°C for LM358, and –40°C to 125°C for LM2904.
(3) All typical values are at T_A = 25°C.

6.7 Electrical Characteristics for LM158A and LM258A

at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS(1)		T_A(1)	LM158A			LM258A			UNIT
					MIN	TYP(2)	MAX	MIN	TYP(2)	MAX	
V_{IO}	Input offset voltage	V_{CC} = 5 V to 30 V, $V_{IC} = V_{ICR(min)}$, V_O = 1.4 V		25°C			2		2	3	mV
				Full range			4			4	
αV_{IO}	Average temperature coefficient of input offset voltage			Full range		7	15(3)		7	15	µA/°C
I_{IO}	Input offset current	V_O = 1.4 V		25°C		2	10		2	15	nA
				Full range			30			30	
αI_{IO}	Average temperature coefficient of input offset current			Full range		10	200		10	200	pA/°C
I_{IB}	Input bias current	V_O = 1.4 V		25°C		–15	–50		–15	–80	nA
				Full range			–100			–100	
V_{ICR}	Common-mode input voltage range	V_{CC} = 30 V		25°C	0 to V_{CC} – 1.5			0 to V_{CC} – 1.5			V
				Full range	0 to V_{CC} – 2			0 to V_{CC} – 2			
V_{OH}	High-level output voltage	R_L ≥ 2 kΩ		25°C	V_{CC} – 1.5			V_{CC} – 1.5			V
		V_{CC} = 30 V	R_L= 2kΩ	Full range	26			26			
			R_L≥ 10kΩ	Full range	27	28		27	28		
V_{OL}	Low-level output voltage	R_L ≤ 10 kΩ		Full range		5	20		5	20	mV
A_{VD}	Large-signal differential voltage amplification	V_{CC} = 15 V, V_O = 1 V to 11 V, R_L ≥ 2 kΩ		25°C	50	100		50	100		V/mV
				Full range	25			25			
CMRR	Common-mode rejection ratio			25°C	70	80		70	80		dB
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_D / \Delta V_{IO}$)			25°C	65	100		65	100		dB
V_{O1}/ V_{O2}	Crosstalk attenuation	f = 1 kHz to 20 kHz		25°C		120			120		dB
I_O	Output current	V_{CC} = 15 V, V_{ID} = 1 V, V_O = 0	Source	25°C	–20	–30	–60	–20	–30	−60	mA
				Full range	–10			–10			
		V_{CC} = 15 V, V_{ID} = –1 V, V_O = 15 V	Sink	25°C	10	20		10	20		
				Full range	5			5			
		V_{ID} = −1 V, V_O = 200 mV		25°C	12	30		12	30		µA
I_{OS}	Short-circuit output current	V_{CC} at 5 V, GND at –5 V, V_O = 0		25°C		±40	±60		±40	±60	mA
I_{CC}	Supply current (four amplifiers)	V_O = 2.5 V, No load		Full range		0.7	1.2		0.7	1.2	mA
		V_{CC} = MAX V, V_O = 0.5 V, No load		Full range		1	2		1	2	

(1) All characteristics are measured under open-loop conditions, with zero common-mode input voltage, unless otherwise specified. MAX V_{CC} for testing purposes is 26 V for LM2904 and 30 V for others.
(2) All typical values are at T_A = 25°C.
(3) On products compliant to MIL-PRF-38535, this parameter is not production tested.

6.8 Electrical Characteristics for LM358A

at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS(1)	T_A(2)	LM358A			UNIT
				MIN	TYP(3)	MAX	
V_{IO}	Input offset voltage	V_{CC} = 5 V to 30 V, $V_{IC} = V_{ICR(min)}$, V_O = 1.4 V	25°C		2	3	mV
			Full range			5	

(1) All characteristics are measured under open-loop conditions, with zero common-mode input voltage, unless otherwise specified. MAX V_{CC} for testing purposes is 26 V for LM2904 and 30 V for others.
(2) All characteristics are measured under open-loop conditions, with zero common-mode input voltage, unless otherwise specified. MAX V_{CC} for testing purposes is 26 V for LM2904 and 30 V for others.
(3) All typical values are at T_A = 25°C.

Electrical Characteristics for LM358A (continued)

at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS(1)		T_A(2)	LM358A MIN	LM358A TYP(3)	LM358A MAX	UNIT
αV_{IO}	Average temperature coefficient of input offset voltage			Full range		7	20	µA/°C
I_{IO}	Input offset current	V_O = 1.4 V		25°C		2	30	nA
				Full range			75	
αI_{IO}	Average temperature coefficient of input offset current			Full range		10	300	pA/°C
I_{IB}	Input bias current	V_O = 1.4 V		25°C		–15	–100	nA
				Full range			–200	
V_{ICR}	Common-mode input voltage range	V_{CC} = 30 V		25°C	0 to V_{CC} – 1.5			V
				Full range	0 to V_{CC} – 2			
V_{OH}	High-level output voltage	R_L ≥ 2 kΩ		25°C	V_{CC} – 1.5			V
		V_{CC} = 30 V	R_L= 2kΩ	Full range	26			
			R_L≥ 10kΩ	Full range	27	28		
V_{OL}	Low-level output voltage	R_L ≤ 10 kΩ		Full range		5	20	mV
A_{VD}	Large-signal differential voltage amplification	V_{CC} = 15 V, V_O = 1 V to 11 V, R_L ≥ 2 kΩ		25°C	25	100		V/mV
				Full range	15			
CMRR	Common-mode rejection ratio			25°C	65	80		dB
k_{SVR}	Supply-voltage rejection ratio (ΔV_{DD} /ΔV_{IO})			25°C	65	100		dB
V_{O1}/ V_{O2}	Crosstalk attenuation	f = 1 kHz to 20 kHz		25°C		120		dB
I_O	Output current	V_{CC} = 15 V, V_{ID} = 1 V, V_O = 0	Source	25°C	–20	–30	−60	mA
				Full range	–10			
		V_{CC} = 15 V, V_{ID} = –1 V, V_O = 15 V	Sink	25°C	10	20		
				Full range	5			
		V_{ID} = –1 V, V_O = 200 mV		25°C		30		µA
I_{OS}	Short-circuit output current	V_{CC} at 5 V, GND at –5 V, V_O = 0		25°C		±40	±60	mA
I_{CC}	Supply current (four amplifiers)	V_O = 2.5 V, No load		Full range		0.7	1.2	mA
		V_{CC} = MAX V, V_O = 0.5 V, No load		Full range		1	2	

6.9 Operating Conditions

V_{CC} = ±15 V, T_A = 25°C

PARAMETER		TEST CONDITIONS	TYP	UNIT
SR	Slew rate at unity gain	R_L = 1 MΩ, C_L = 30 pF, V_I = ±10 V (see Figure 11)	0.3	V/µs
B_1	Unity-gain bandwidth	R_L = 1 MΩ, C_L = 20 pF (see Figure 11)	0.7	MHz
V_n	Equivalent input noise voltage	R_S = 100 Ω, V_I = 0 V, f = 1 kHz (see Figure 12)	40	nV/√Hz

6.10 Typical Characteristics

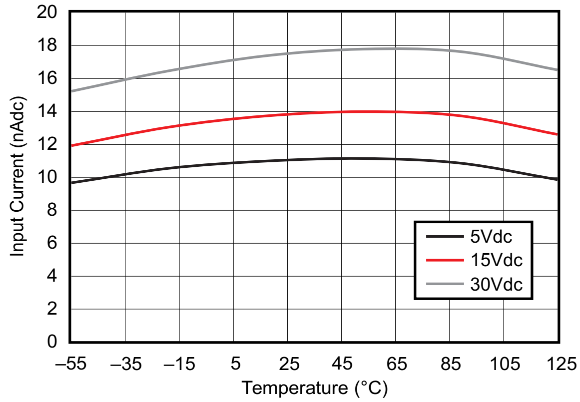


Figure 1. Input Current vs. Temperature

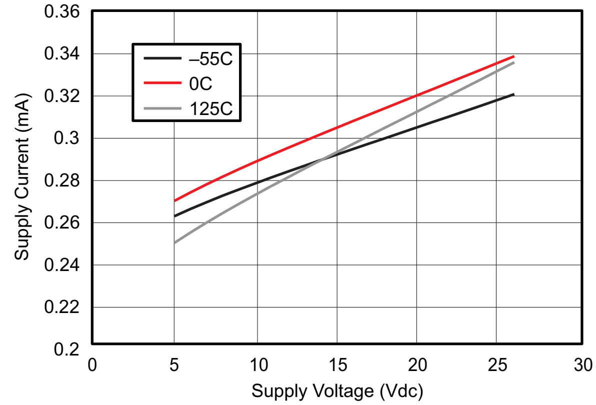


Figure 2. Supply Current vs. Supply Voltage

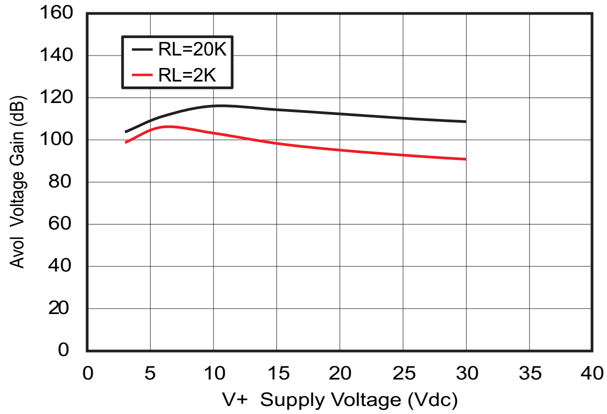


Figure 3. Voltage Gain vs. Supply Voltage

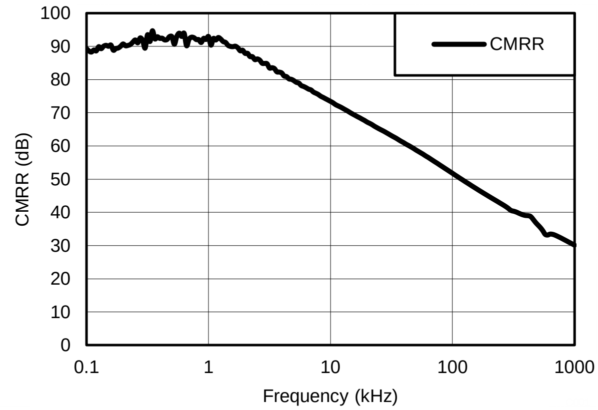


Figure 4. Common-mode Rejection Ratio vs. Frequency

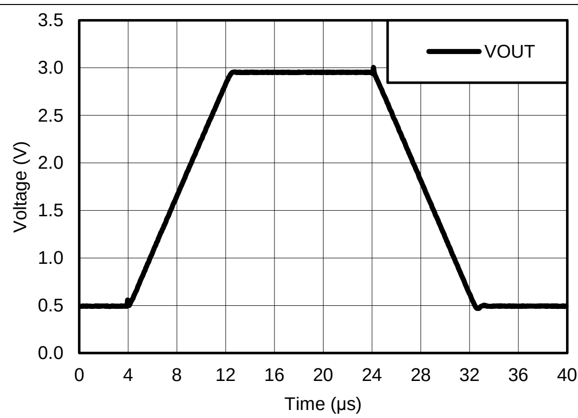


Figure 5. Voltage Follower Large Signal Response (50 pF)

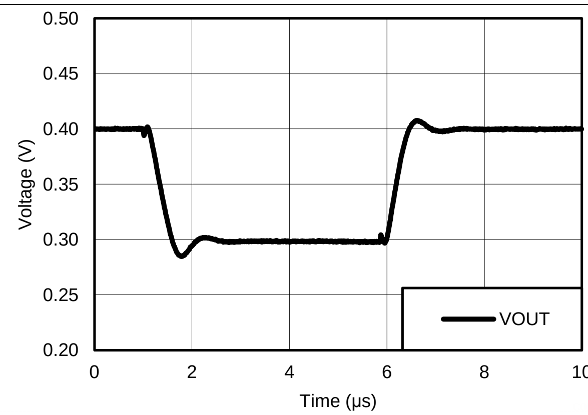


Figure 6. Voltage Follower Small Signal Response (50 pF)

Typical Characteristics (continued)

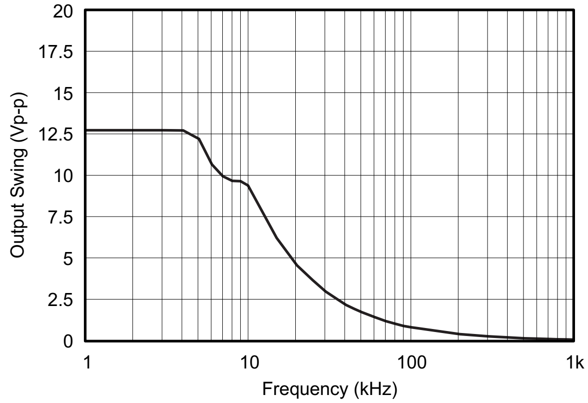


Figure 7. Maximum Output Swing vs. Frequency (V_{CC} = 15 V)

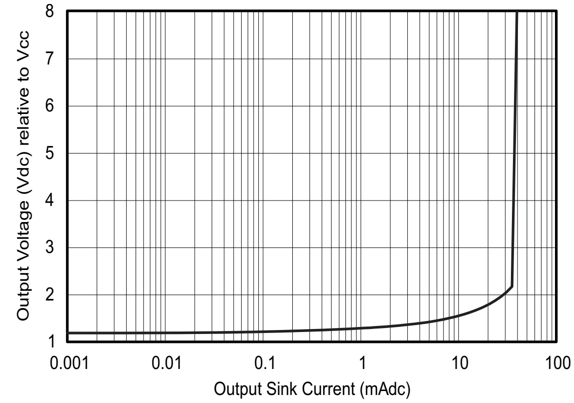


Figure 8. Output Sourcing Characteristics

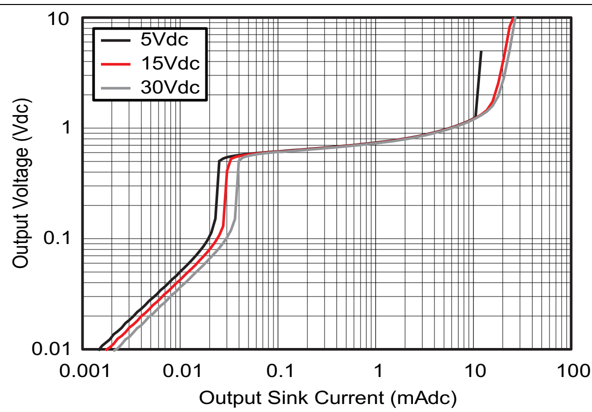


Figure 9. Output Sinking Characteristics

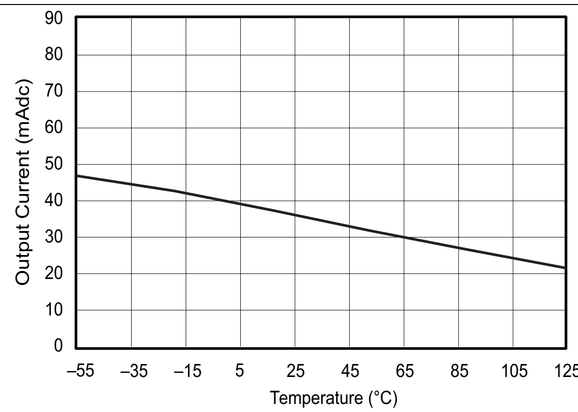


Figure 10. Source Current Limiting

7 Parameter Measurement Information

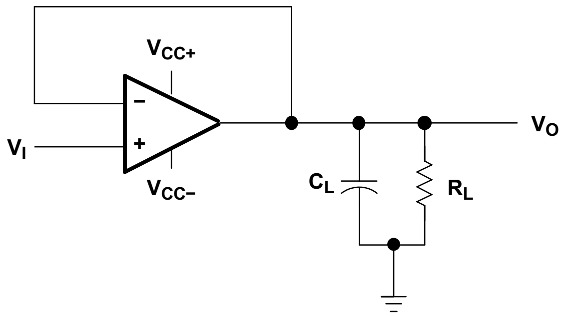


Figure 11. Unity-Gain Amplifier

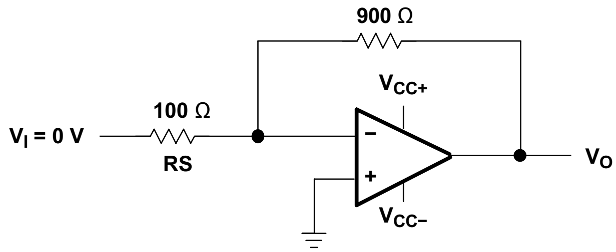


Figure 12. Noise-Test Circuit

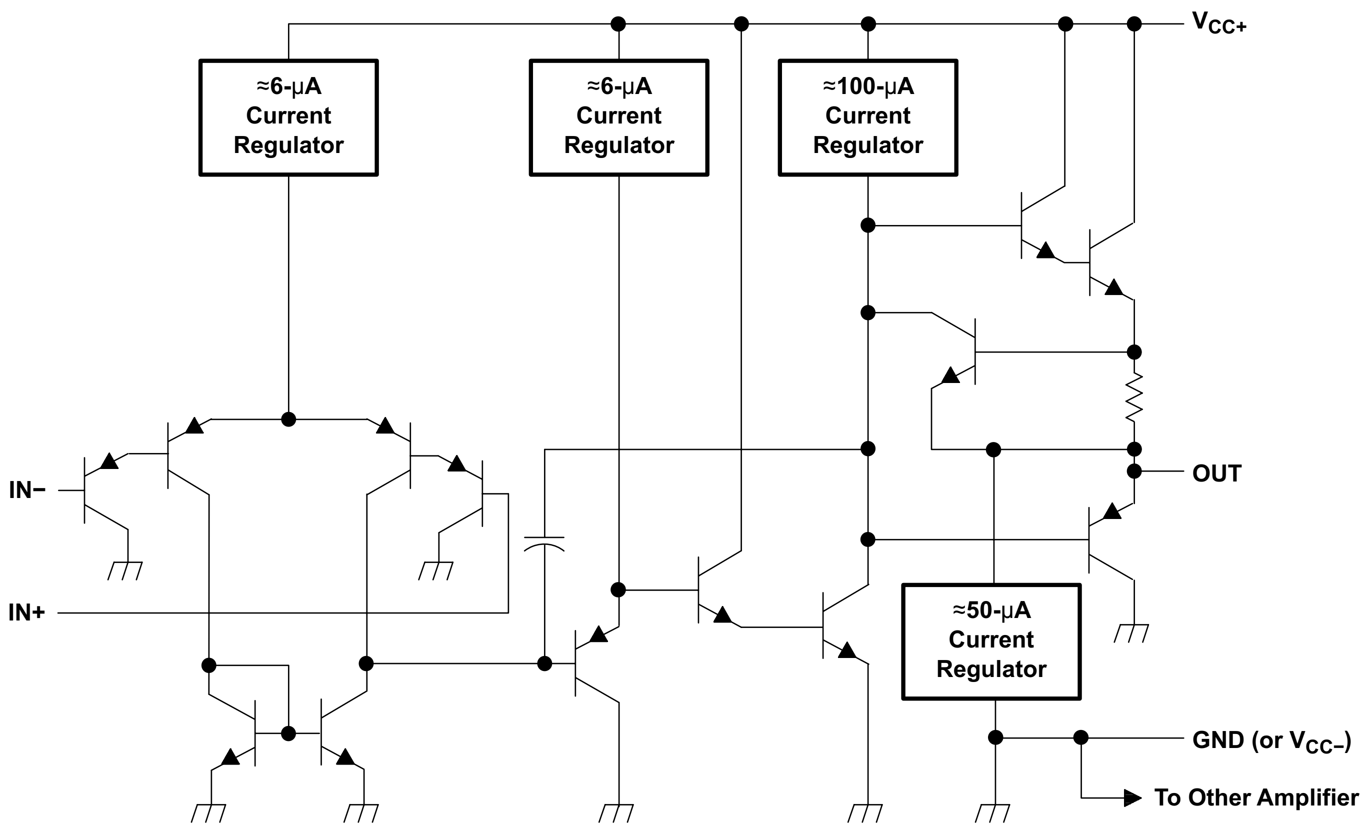
8 Detailed Description

8.1 Overview

These devices consist of two independent, high-gain frequency-compensated operational amplifiers designed to operate from a single supply over a wide range of voltages. Operation from split supplies also is possible if the difference between the two supplies is 3 V to 32 V (3 V to 26 V for the LM2904 device), and V_{CC} is at least 1.5 V more positive than the input common-mode voltage. The low supply-current drain is independent of the magnitude of the supply voltage.

Applications include transducer amplifiers, DC amplification blocks, and all the conventional operational amplifier circuits that now can be implemented more easily in single-supply-voltage systems. For example, these devices can be operated directly from the standard 5-V supply used in digital systems and easily can provide the required interface electronics without additional ±5-V supplies.

8.2 Functional Block Diagram



COMPONENT COUNT	
Epi-FET	1
Diodes	2
Resistors	7
Transistors	51
Capacitors	2

8.3 Feature Description

8.3.1 Unity-Gain Bandwidth

The unity-gain bandwidth is the frequency up to which an amplifier with a unity gain may be operated without greatly distorting the signal. These devices have a 0.7-MHz unity-gain bandwidth.

8.3.2 Slew Rate

The slew rate is the rate at which an operational amplifier can change its output when there is a change on the input. These devices have a 0.3-V/μs slew rate.

8.3.3 Input Common Mode Range

The valid common mode range is from device ground to V_{CC} - 1.5 V (V_{CC} - 2 V across temperature). Inputs may exceed V_{CC} up to the maximum V_{CC} without device damage. At least one input must be in the valid input common mode range for output to be correct phase. If both inputs exceed valid range then output phase is undefined. If either input is less than -0.3 V then input current should be limited to 1mA and output phase is undefined.

8.4 Device Functional Modes

These devices are powered on when the supply is connected. This device can be operated as a single supply operational amplifier or dual supply amplifier depending on the application.

9 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

9.1 Application Information

The LMx58 and LM2904 operational amplifiers are useful in a wide range of signal conditioning applications. Inputs can be powered before V_{CC} for flexibility in multiple supply circuits.

9.2 Typical Application

A typical application for an operational amplifier in an inverting amplifier. This amplifier takes a positive voltage on the input, and makes it a negative voltage of the same magnitude. In the same manner, it also makes negative voltages positive.

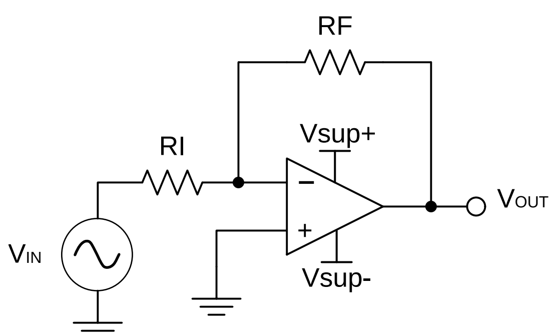


Figure 13. Application Schematic

9.2.1 Design Requirements

The supply voltage must be chosen such that it is larger than the input voltage range and output range. For instance, this application will scale a signal of ±0.5 V to ±1.8 V. Setting the supply at ±12 V is sufficient to accommodate this application.

9.2.2 Detailed Design Procedure

Determine the gain required by the inverting amplifier using Equation 1 and Equation 2:

$$A_v = \frac{VOUT}{VIN} \tag{1}$$

$$A_v = \frac{1.8}{-0.5} = -3.6 \tag{2}$$

Once the desired gain is determined, choose a value for RI or RF. Choosing a value in the kilohm range is desirable because the amplifier circuit will use currents in the milliamp range. This ensures the part will not draw too much current. This example will choose 10 kΩ for RI which means 36 kΩ will be used for RF. This was determined by Equation 3.

$$A_v = -\frac{RF}{RI} \tag{3}$$

Typical Application (continued)

9.2.3 Application Curve

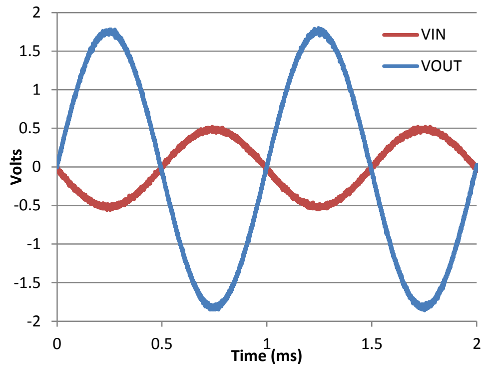


Figure 14. Input and Output Voltages of the Inverting Amplifier

10 Power Supply Recommendations

CAUTION

Supply voltages larger than 32 V for a single supply (26 V for the LM2904), or outside the range of ±16 V for a dual supply (±13 V for the LM2904) can permanently damage the device (see the *Absolute Maximum Ratings*).

Place 0.1-µF bypass capacitors close to the power-supply pins to reduce errors coupling in from noisy or high impedance power supplies. For more detailed information on bypass capacitor placement, refer to the *Layout*.

11 Layout

11.1 Layout Guidelines

For best operational performance of the device, use good PCB layout practices, including:

- Noise can propagate into analog circuitry through the power pins of the circuit as a whole, as well as the operational amplifier. Bypass capacitors are used to reduce the coupled noise by providing low impedance power sources local to the analog circuitry.
  - Connect low-ESR, 0.1-µF ceramic bypass capacitors between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from V+ to ground is applicable for single supply applications.
- Separate grounding for analog and digital portions of circuitry is one of the simplest and most-effective methods of noise suppression. One or more layers on multilayer PCBs are usually devoted to ground planes. A ground plane helps distribute heat and reduces EMI noise pickup. Make sure to physically separate digital and analog grounds, paying attention to the flow of the ground current.
- To reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. If it is not possible to keep them separate, it is much better to cross the sensitive trace perpendicular as opposed to in parallel with the noisy trace.
- Place the external components as close to the device as possible. Keeping RF and RG close to the inverting input minimizes parasitic capacitance, as shown in *Layout Examples*.
- Keep the length of input traces as short as possible. Always remember that the input traces are the most sensitive part of the circuit.
- Consider a driven, low-impedance guard ring around the critical traces. A guard ring can significantly reduce leakage currents from nearby traces that are at different potentials.

11.2 Layout Examples

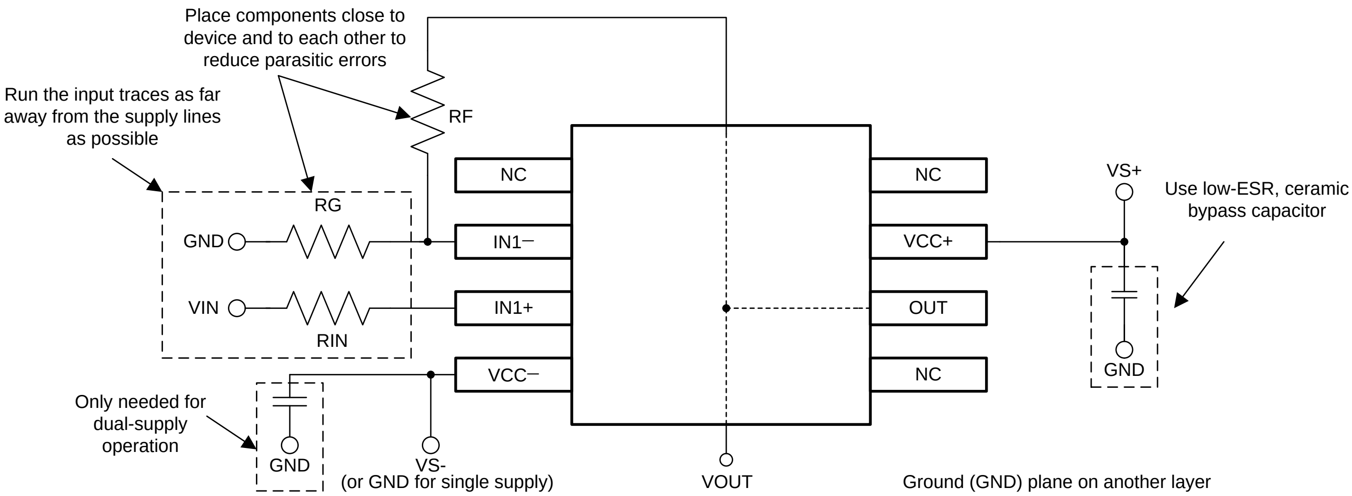


Figure 15. Operational Amplifier Board Layout for Noninverting Configuration

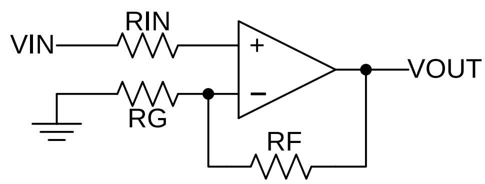


Figure 16. Operational Amplifier Schematic for Noninverting Configuration

12 Device and Documentation Support

12.1 Documentation Support

12.1.1 Related Documentation

- *Circuit Board Layout Techniques*, SLOA089.

12.2 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 1. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
LM158	Click here	Click here	Click here	Click here	Click here
LM158A	Click here	Click here	Click here	Click here	Click here
LM258	Click here	Click here	Click here	Click here	Click here
LM258A	Click here	Click here	Click here	Click here	Click here
LM358	Click here	Click here	Click here	Click here	Click here
LM358A	Click here	Click here	Click here	Click here	Click here
LM2904	Click here	Click here	Click here	Click here	Click here
LM2904V	Click here	Click here	Click here	Click here	Click here

12.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

12.4 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

12.5 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

12.6 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

12.7 Glossary

SLYZ022 — *TI Glossary.*

This glossary lists and explains terms, acronyms and definitions.

13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser based versions of this data sheet, refer to the left hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
5962-87710012A	ACTIVE	LCCC	FK	20	1	TBD	POST-PLATE	N / A for Pkg Type	-55 to 125	5962-87710012A LM158FKB	Samples
5962-8771001PA	ACTIVE	CDIP	JG	8	1	TBD	A42	N / A for Pkg Type	-55 to 125	8771001PA LM158	Samples
5962-87710022A	ACTIVE	LCCC	FK	20	1	TBD	POST-PLATE	N / A for Pkg Type	-55 to 125	5962-87710022A LM158AFKB	Samples
5962-8771002PA	ACTIVE	CDIP	JG	8	1	TBD	A42	N / A for Pkg Type	-55 to 125	8771002PA LM158A	Samples
LM158AFKB	ACTIVE	LCCC	FK	20	1	TBD	POST-PLATE	N / A for Pkg Type	-55 to 125	5962-87710022A LM158AFKB	Samples
LM158AJG	ACTIVE	CDIP	JG	8	1	TBD	A42	N / A for Pkg Type	-55 to 125	LM158AJG	Samples
LM158AJGB	ACTIVE	CDIP	JG	8	1	TBD	A42	N / A for Pkg Type	-55 to 125	8771002PA LM158A	Samples
LM158FKB	ACTIVE	LCCC	FK	20	1	TBD	POST-PLATE	N / A for Pkg Type	-55 to 125	5962-87710012A LM158FKB	Samples
LM158JG	ACTIVE	CDIP	JG	8	1	TBD	A42	N / A for Pkg Type	-55 to 125	LM158JG	Samples
LM158JGB	ACTIVE	CDIP	JG	8	1	TBD	A42	N / A for Pkg Type	-55 to 125	8771001PA LM158	Samples
LM258AD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	LM258A	Samples
LM258ADGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU NIPDAUAG	Level-1-260C-UNLIM	-25 to 85	(M3L, M3P, M3S, M3 U)	Samples
LM258ADGKRG4	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	(M3L, M3P, M3S, M3 U)	Samples
LM258ADR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	-25 to 85	LM258A	Samples
LM258ADRE4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	LM258A	Samples
LM258ADRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	LM258A	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM258AP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU | CU SN	N / A for Pkg Type	-25 to 85	LM258AP	Samples
LM258APE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-25 to 85	LM258AP	Samples
LM258D	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	LM258	Samples
LM258DE4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	LM258	Samples
LM258DG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	LM258	Samples
LM258DGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU NIPDAUAG	Level-1-260C-UNLIM	-25 to 85	(M2L, M2P, M2S, M2 U)	Samples
LM258DGKRG4	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	(M2L, M2P, M2S, M2 U)	Samples
LM258DR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	-25 to 85	LM258	Samples
LM258DRE4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	LM258	Samples
LM258DRG3	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-25 to 85	LM258	Samples
LM258DRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-25 to 85	LM258	Samples
LM258P	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU | CU SN	N / A for Pkg Type	-25 to 85	LM258P	Samples
LM258PE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-25 to 85	LM258P	Samples
LM2904AVQDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904AV	Samples
LM2904AVQDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904AV	Samples
LM2904AVQPWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904AV	Samples
LM2904AVQPWRG4	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904AV	Samples
LM2904D	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	LM2904	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM2904DE4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	LM2904	Samples
LM2904DG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	LM2904	Samples
LM2904DGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU NIPDAUAG	Level-1-260C-UNLIM	-40 to 125	(MBL, MBP, MBS, MB U)	Samples
LM2904DGKRG4	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	(MBL, MBP, MBS, MB U)	Samples
LM2904DR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	-40 to 125	LM2904	Samples
LM2904DRE4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	LM2904	Samples
LM2904DRG3	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	LM2904	Samples
LM2904DRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	LM2904	Samples
LM2904P	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU | CU SN	N / A for Pkg Type	-40 to 125	LM2904P	Samples
LM2904PE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 125	LM2904P	Samples
LM2904PSR	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904	Samples
LM2904PW	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904	Samples
LM2904PWG4	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904	Samples
LM2904PWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	-40 to 125	L2904	Samples
LM2904PWRG3	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	L2904	Samples
LM2904PWRG4-JF	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904	Samples
LM2904QDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2904Q1	Samples
LM2904QDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2904Q1	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM2904VQDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904V	Samples
LM2904VQDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904V	Samples
LM2904VQPWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904V	Samples
LM2904VQPWRG4	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L2904V	Samples
LM358AD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358A	Samples
LM358ADE4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358A	Samples
LM358ADG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358A	Samples
LM358ADGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU NIPDAUAG	Level-1-260C-UNLIM	0 to 70	(M6L, M6P, M6S, M6 U)	Samples
LM358ADGKRG4	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	(M6L, M6P, M6S, M6 U)	Samples
LM358ADR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	0 to 70	LM358A	Samples
LM358ADRE4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358A	Samples
LM358ADRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358A	Samples
LM358AP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU | CU SN	N / A for Pkg Type	0 to 70	LM358AP	Samples
LM358APE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	LM358AP	Samples
LM358APW	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	L358A	Samples
LM358APWE4	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	L358A	Samples
LM358APWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	0 to 70	L358A	Samples
LM358APWRG4	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	L358A	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM358D	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358	Samples
LM358DE4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358	Samples
LM358DG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358	Samples
LM358DGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU NIPDAUAG	Level-1-260C-UNLIM	0 to 70	(M5L, M5P, M5S, M5 U)	Samples
LM358DGKRG4	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	(M5L, M5P, M5S, M5 U)	Samples
LM358DR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	0 to 70	LM358	Samples
LM358DRE4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358	Samples
LM358DRG3	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM358	Samples
LM358DRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	LM358	Samples
LM358P	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU | CU SN	N / A for Pkg Type	0 to 70	LM358P	Samples
LM358PE3	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU SN	N / A for Pkg Type	0 to 70	LM358P	Samples
LM358PE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	LM358P	Samples
LM358PSR	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	L358	Samples
LM358PW	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	L358	Samples
LM358PWG4	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	L358	Samples
LM358PWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	0 to 70	L358	Samples
LM358PWRG3	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	L358	Samples
LM358PWRG4	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	L358	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM358PWRG4-JF	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	L358	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

OTHER QUALIFIED VERSIONS OF LM258A, LM2904 :

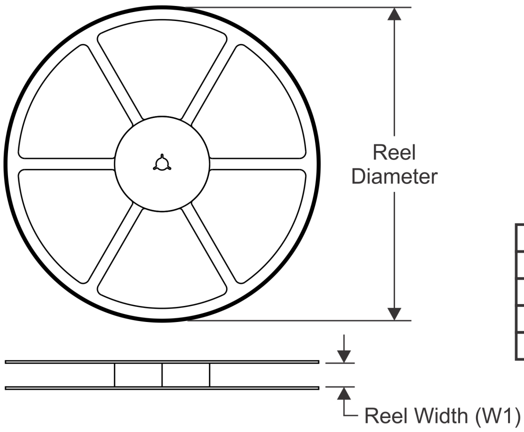
- Automotive: LM2904-Q1

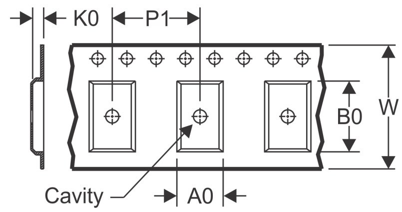
- Enhanced Product: LM258A-EP, LM2904-EP

NOTE: Qualified Version Definitions:

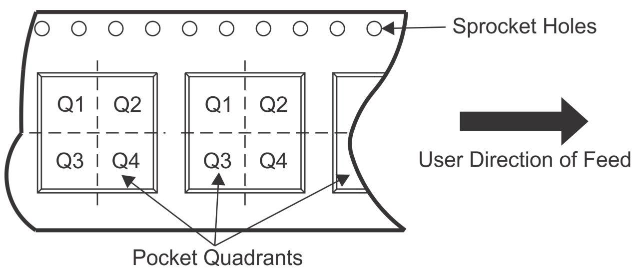
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects
- Enhanced Product - Supports Defense, Aerospace and Medical Applications

TAPE AND REEL INFORMATION





A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers



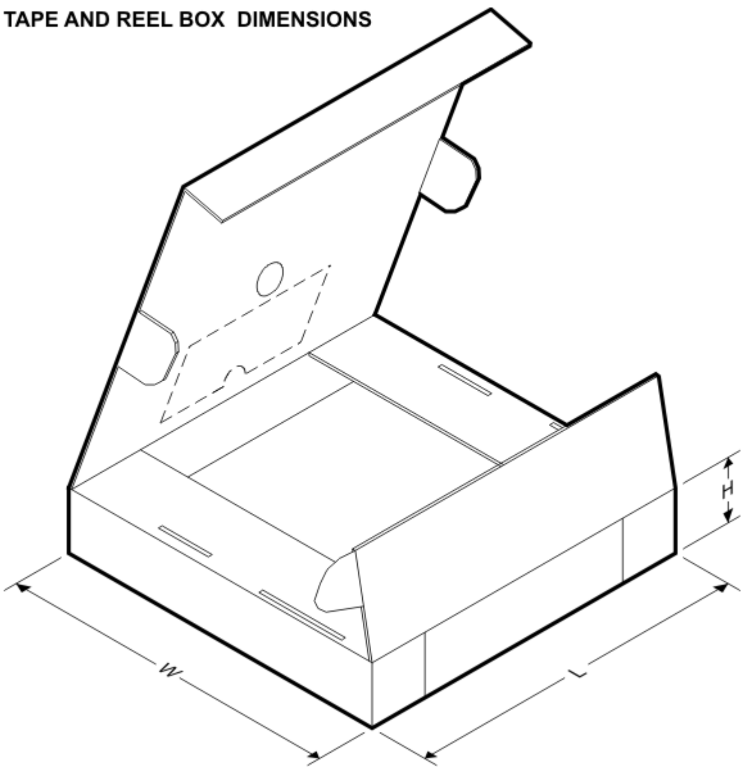
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM258ADGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM258ADGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM258ADR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258ADR	SOIC	D	8	2500	330.0	15.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258ADR	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
LM258ADR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258ADRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258ADRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258DGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM258DGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM258DR	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
LM258DR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258DR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258DR	SOIC	D	8	2500	330.0	15.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258DRG3	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
LM258DRG3	SOIC	D	8	2500	330.0	15.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258DRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM258DRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM2904AVQDR	SOIC	D	8	2500	330.0	12.5	6.4	5.2	2.1	8.0	12.0	Q1
LM2904AVQDRG4	SOIC	D	8	2500	330.0	12.5	6.4	5.2	2.1	8.0	12.0	Q1
LM2904AVQPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM2904AVQPWRG4	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM2904DGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM2904DGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM2904DGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM2904DR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM2904DR	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
LM2904DR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM2904DRG3	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
LM2904DRG3	SOIC	D	8	2500	330.0	15.4	6.4	5.2	2.1	8.0	12.0	Q1
LM2904DRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM2904DRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM2904PSR	SO	PS	8	2000	330.0	16.4	8.2	6.6	2.5	12.0	16.0	Q1
LM2904PWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM2904PWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM2904PWRG3	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM2904PWRG4-JF	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM2904QDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM2904VQDR	SOIC	D	8	2500	330.0	12.5	6.4	5.2	2.1	8.0	12.0	Q1
LM2904VQPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM2904VQPWRG4	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM358ADGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM358ADGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM358ADR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358ADR	SOIC	D	8	2500	330.0	15.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358ADR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358ADR	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
LM358ADRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358ADRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358APWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM358APWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM358APWRG4	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM358DGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM358DGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM358DGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM358DR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358DR	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
LM358DR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358DR	SOIC	D	8	2500	330.0	15.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358DRG3	SOIC	D	8	2500	330.0	12.8	6.4	5.2	2.1	8.0	12.0	Q1
LM358DRG3	SOIC	D	8	2500	330.0	15.4	6.4	5.2	2.1	8.0	12.0	Q1

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM358DRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358DRG4	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LM358PSR	SO	PS	8	2000	330.0	16.4	8.2	6.6	2.5	12.0	16.0	Q1
LM358PWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM358PWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM358PWRG3	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM358PWRG4	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
LM358PWRG4-JF	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

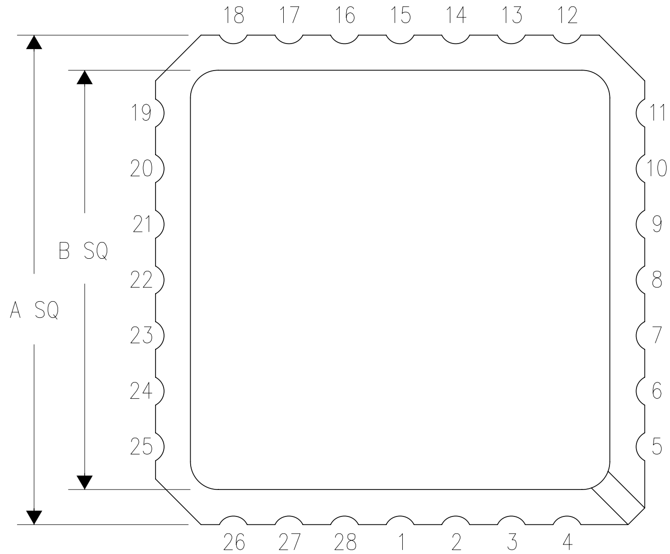
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM258ADGKR	VSSOP	DGK	8	2500	332.0	358.0	35.0
LM258ADGKR	VSSOP	DGK	8	2500	364.0	364.0	27.0
LM258ADR	SOIC	D	8	2500	367.0	367.0	35.0
LM258ADR	SOIC	D	8	2500	333.2	345.9	28.6
LM258ADR	SOIC	D	8	2500	364.0	364.0	27.0
LM258ADR	SOIC	D	8	2500	340.5	338.1	20.6
LM258ADRG4	SOIC	D	8	2500	340.5	338.1	20.6
LM258ADRG4	SOIC	D	8	2500	367.0	367.0	35.0
LM258DGKR	VSSOP	DGK	8	2500	364.0	364.0	27.0

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM258DGKR	VSSOP	DGK	8	2500	332.0	358.0	35.0
LM258DR	SOIC	D	8	2500	364.0	364.0	27.0
LM258DR	SOIC	D	8	2500	340.5	338.1	20.6
LM258DR	SOIC	D	8	2500	367.0	367.0	35.0
LM258DR	SOIC	D	8	2500	333.2	345.9	28.6
LM258DRG3	SOIC	D	8	2500	364.0	364.0	27.0
LM258DRG3	SOIC	D	8	2500	333.2	345.9	28.6
LM258DRG4	SOIC	D	8	2500	340.5	338.1	20.6
LM258DRG4	SOIC	D	8	2500	367.0	367.0	35.0
LM2904AVQDR	SOIC	D	8	2500	340.5	338.1	20.6
LM2904AVQDRG4	SOIC	D	8	2500	340.5	338.1	20.6
LM2904AVQPWR	TSSOP	PW	8	2000	367.0	367.0	35.0
LM2904AVQPWRG4	TSSOP	PW	8	2000	367.0	367.0	35.0
LM2904DGKR	VSSOP	DGK	8	2500	364.0	364.0	27.0
LM2904DGKR	VSSOP	DGK	8	2500	332.0	358.0	35.0
LM2904DGKR	VSSOP	DGK	8	2500	358.0	335.0	35.0
LM2904DR	SOIC	D	8	2500	340.5	338.1	20.6
LM2904DR	SOIC	D	8	2500	364.0	364.0	27.0
LM2904DR	SOIC	D	8	2500	367.0	367.0	35.0
LM2904DRG3	SOIC	D	8	2500	364.0	364.0	27.0
LM2904DRG3	SOIC	D	8	2500	333.2	345.9	28.6
LM2904DRG4	SOIC	D	8	2500	367.0	367.0	35.0
LM2904DRG4	SOIC	D	8	2500	340.5	338.1	20.6
LM2904PSR	SO	PS	8	2000	367.0	367.0	38.0
LM2904PWR	TSSOP	PW	8	2000	367.0	367.0	35.0
LM2904PWR	TSSOP	PW	8	2000	364.0	364.0	27.0
LM2904PWRG3	TSSOP	PW	8	2000	364.0	364.0	27.0
LM2904PWRG4-JF	TSSOP	PW	8	2000	367.0	367.0	35.0
LM2904QDR	SOIC	D	8	2500	367.0	367.0	38.0
LM2904VQDR	SOIC	D	8	2500	340.5	338.1	20.6
LM2904VQPWR	TSSOP	PW	8	2000	367.0	367.0	35.0
LM2904VQPWRG4	TSSOP	PW	8	2000	367.0	367.0	35.0
LM358ADGKR	VSSOP	DGK	8	2500	364.0	364.0	27.0
LM358ADGKR	VSSOP	DGK	8	2500	332.0	358.0	35.0
LM358ADR	SOIC	D	8	2500	340.5	338.1	20.6
LM358ADR	SOIC	D	8	2500	333.2	345.9	28.6
LM358ADR	SOIC	D	8	2500	367.0	367.0	35.0
LM358ADR	SOIC	D	8	2500	364.0	364.0	27.0
LM358ADRG4	SOIC	D	8	2500	340.5	338.1	20.6
LM358ADRG4	SOIC	D	8	2500	367.0	367.0	35.0
LM358APWR	TSSOP	PW	8	2000	364.0	364.0	27.0
LM358APWR	TSSOP	PW	8	2000	367.0	367.0	35.0
LM358APWRG4	TSSOP	PW	8	2000	367.0	367.0	35.0
LM358DGKR	VSSOP	DGK	8	2500	332.0	358.0	35.0

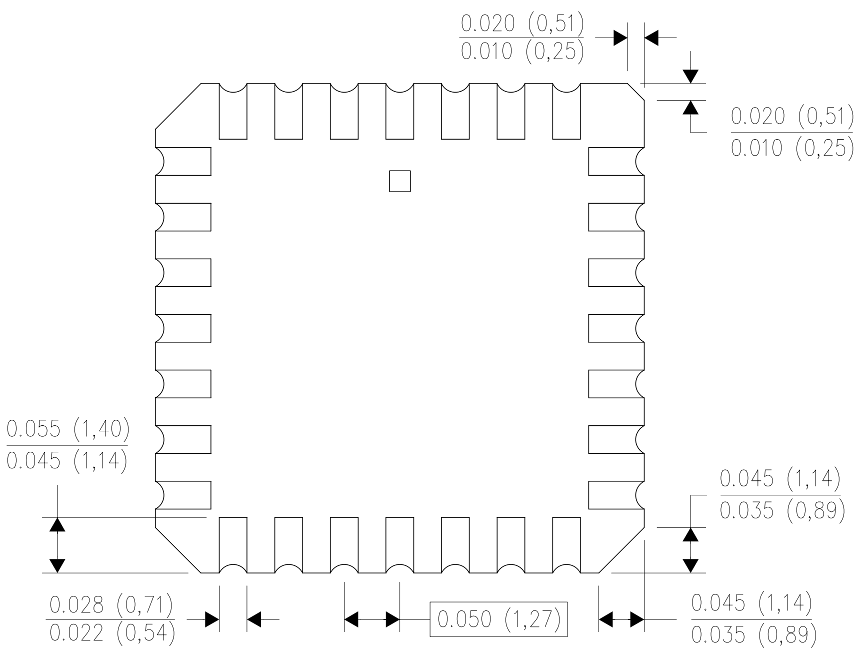
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM358DGKR	VSSOP	DGK	8	2500	358.0	335.0	35.0
LM358DGKR	VSSOP	DGK	8	2500	364.0	364.0	27.0
LM358DR	SOIC	D	8	2500	367.0	367.0	35.0
LM358DR	SOIC	D	8	2500	364.0	364.0	27.0
LM358DR	SOIC	D	8	2500	340.5	338.1	20.6
LM358DR	SOIC	D	8	2500	333.2	345.9	28.6
LM358DRG3	SOIC	D	8	2500	364.0	364.0	27.0
LM358DRG3	SOIC	D	8	2500	333.2	345.9	28.6
LM358DRG4	SOIC	D	8	2500	340.5	338.1	20.6
LM358DRG4	SOIC	D	8	2500	367.0	367.0	35.0
LM358PSR	SO	PS	8	2000	367.0	367.0	38.0
LM358PWR	TSSOP	PW	8	2000	367.0	367.0	35.0
LM358PWR	TSSOP	PW	8	2000	364.0	364.0	27.0
LM358PWRG3	TSSOP	PW	8	2000	364.0	364.0	27.0
LM358PWRG4	TSSOP	PW	8	2000	367.0	367.0	35.0
LM358PWRG4-JF	TSSOP	PW	8	2000	367.0	367.0	35.0

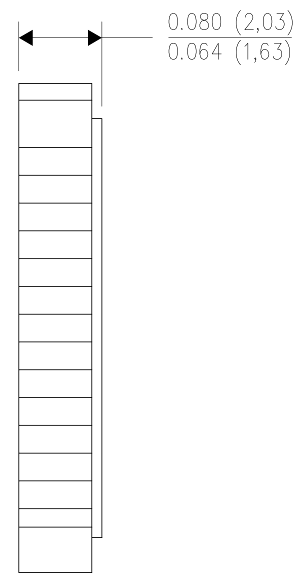
FK (S-CQCC-N**) LEADLESS CERAMIC CHIP CARRIER

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	0.740 (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)

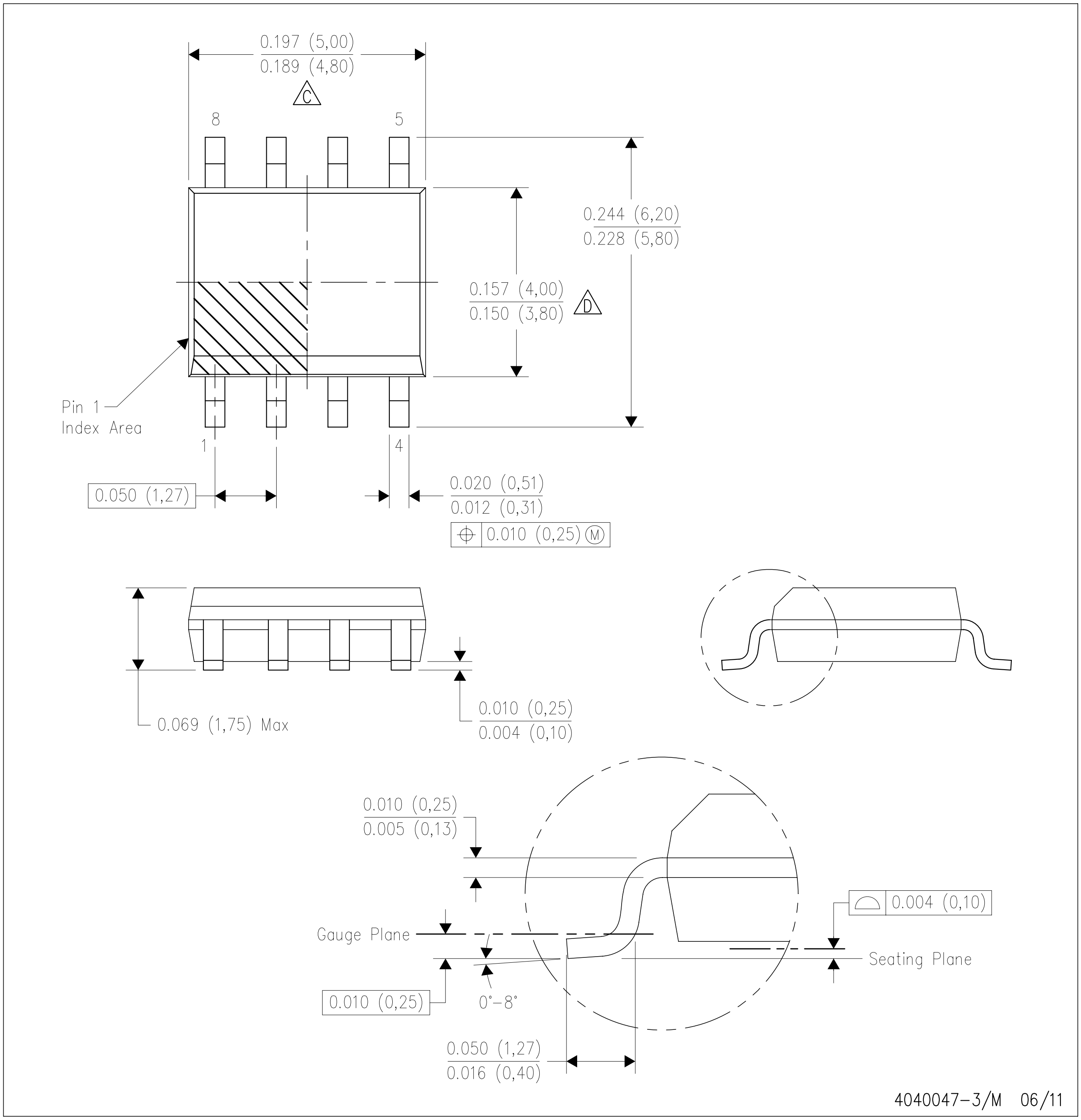




4040140/D 01/11

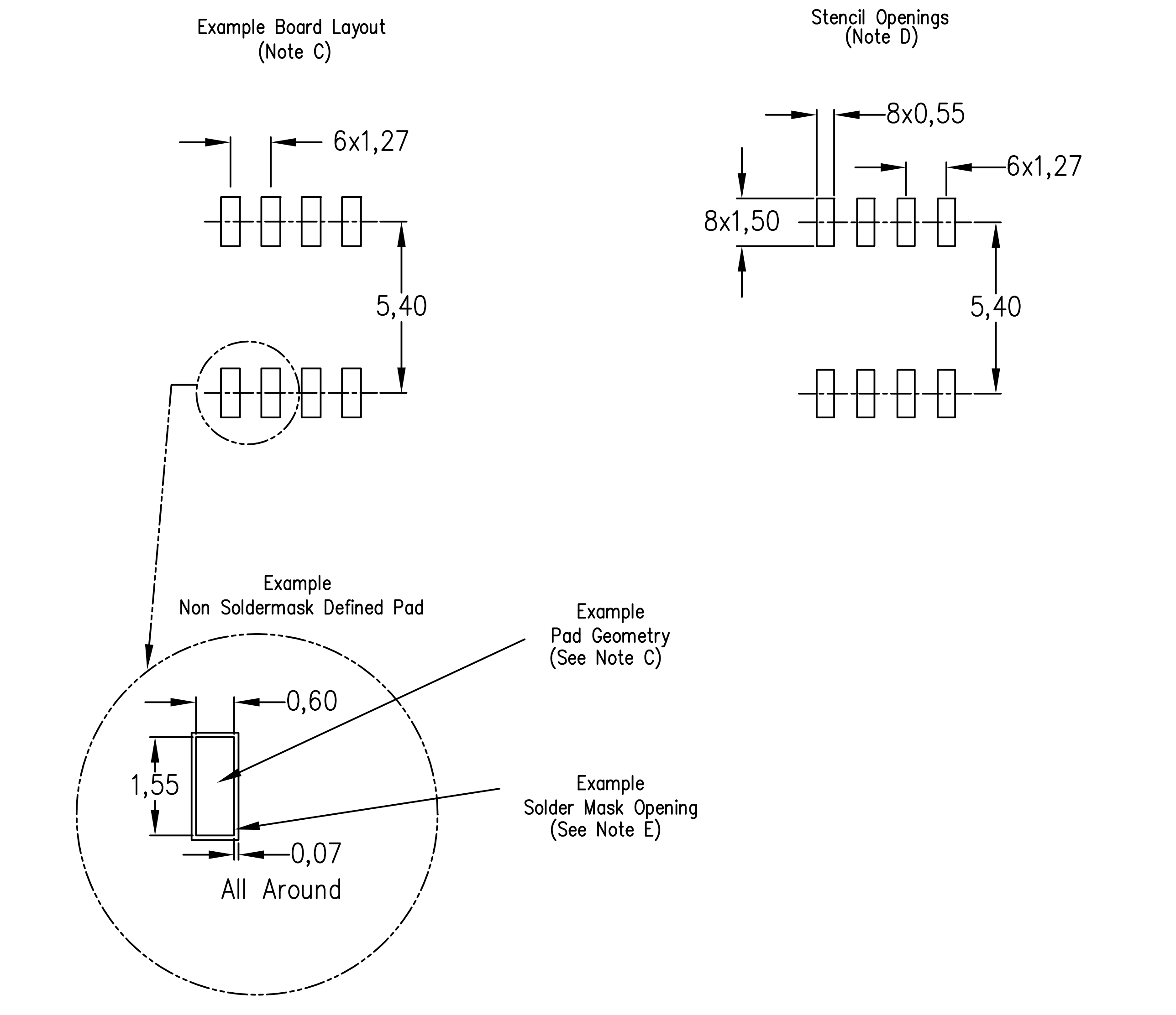
NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a metal lid.
D. Falls within JEDEC MS-004

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
- D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
- E. Reference JEDEC MS–012 variation AA.

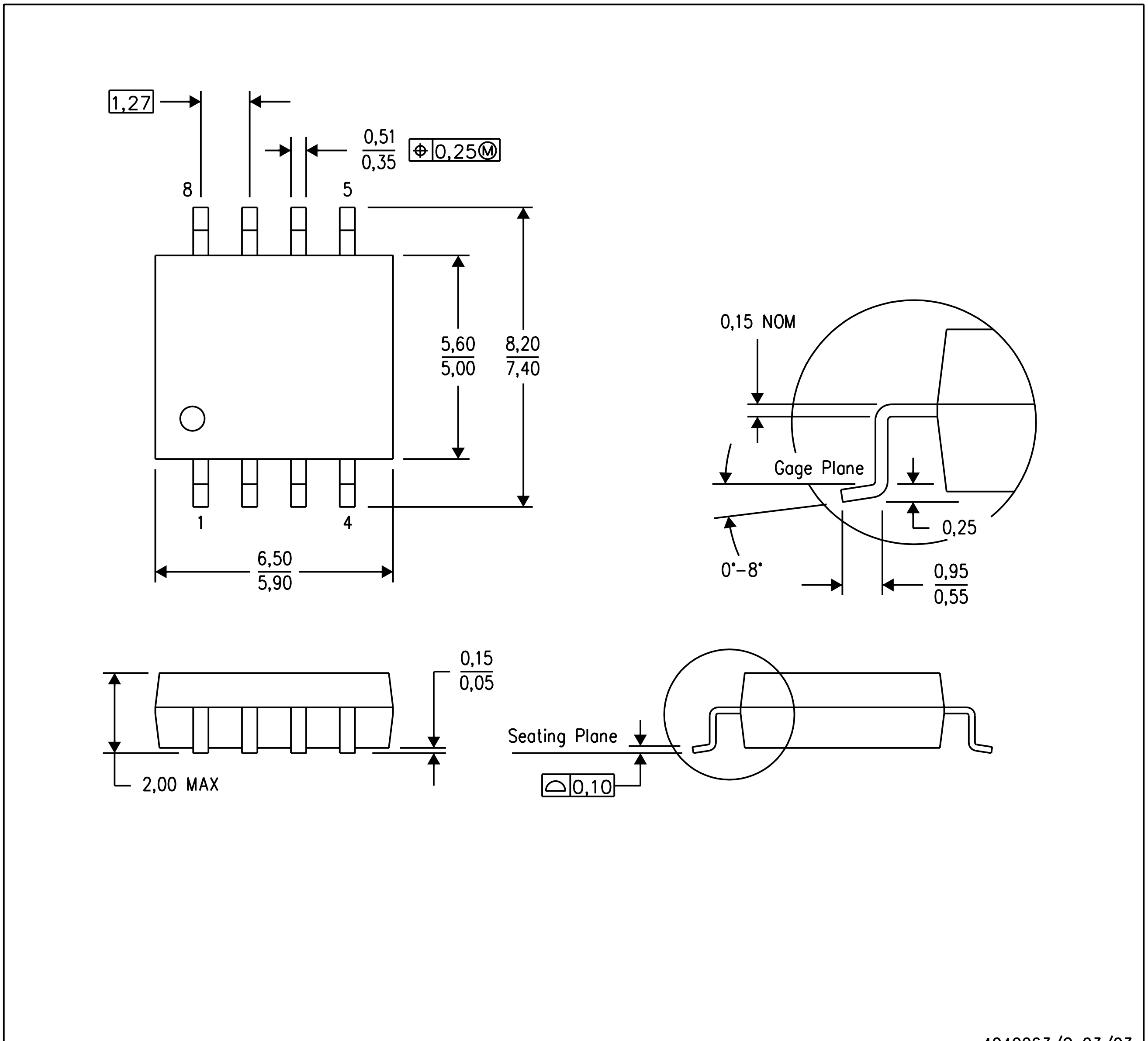
D (R-PDSO-G8) PLASTIC SMALL OUTLINE



4211283-2/E 08/12

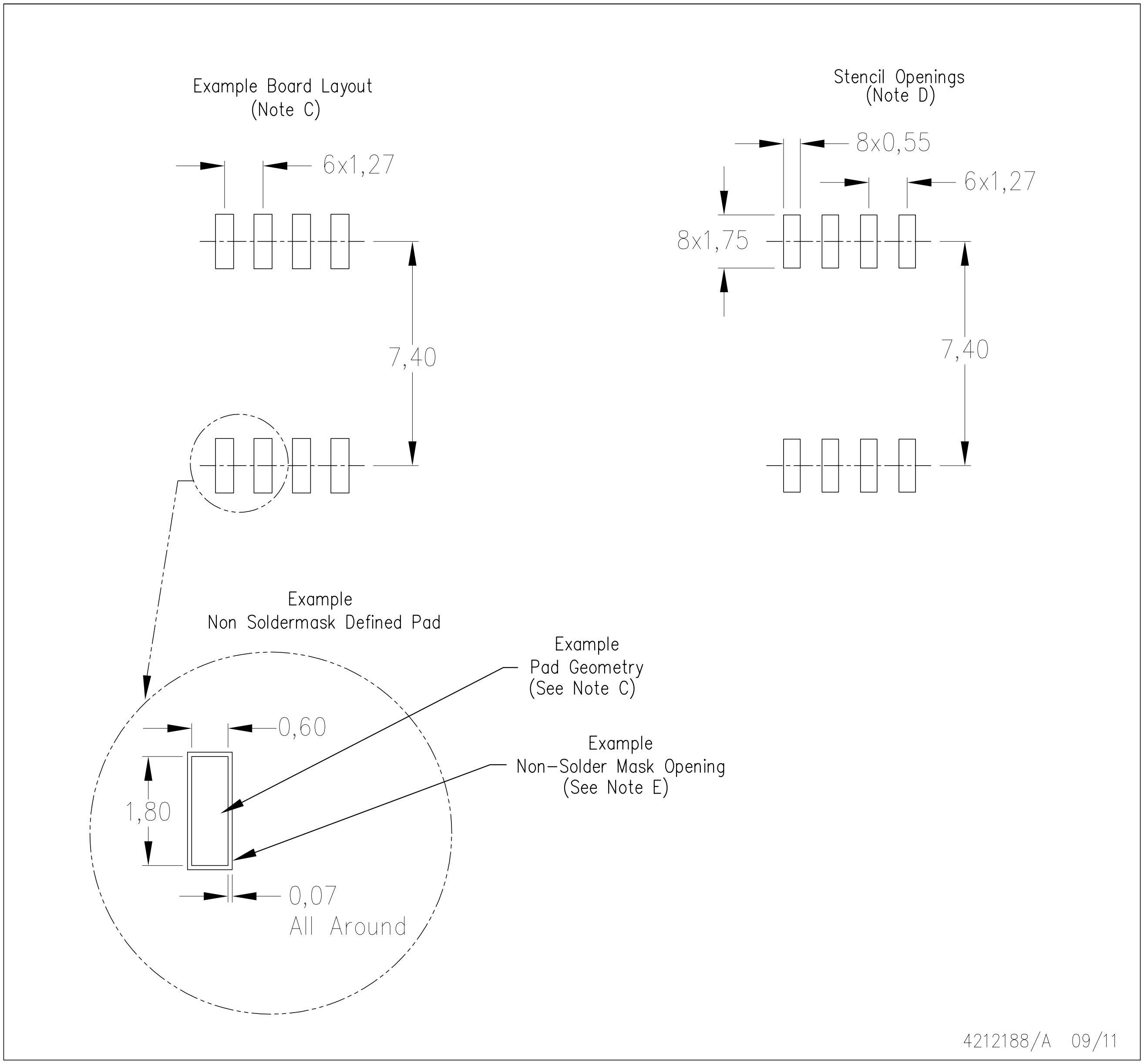
NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC-7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

PS (R-PDSO-G8) **PLASTIC SMALL-OUTLINE PACKAGE**



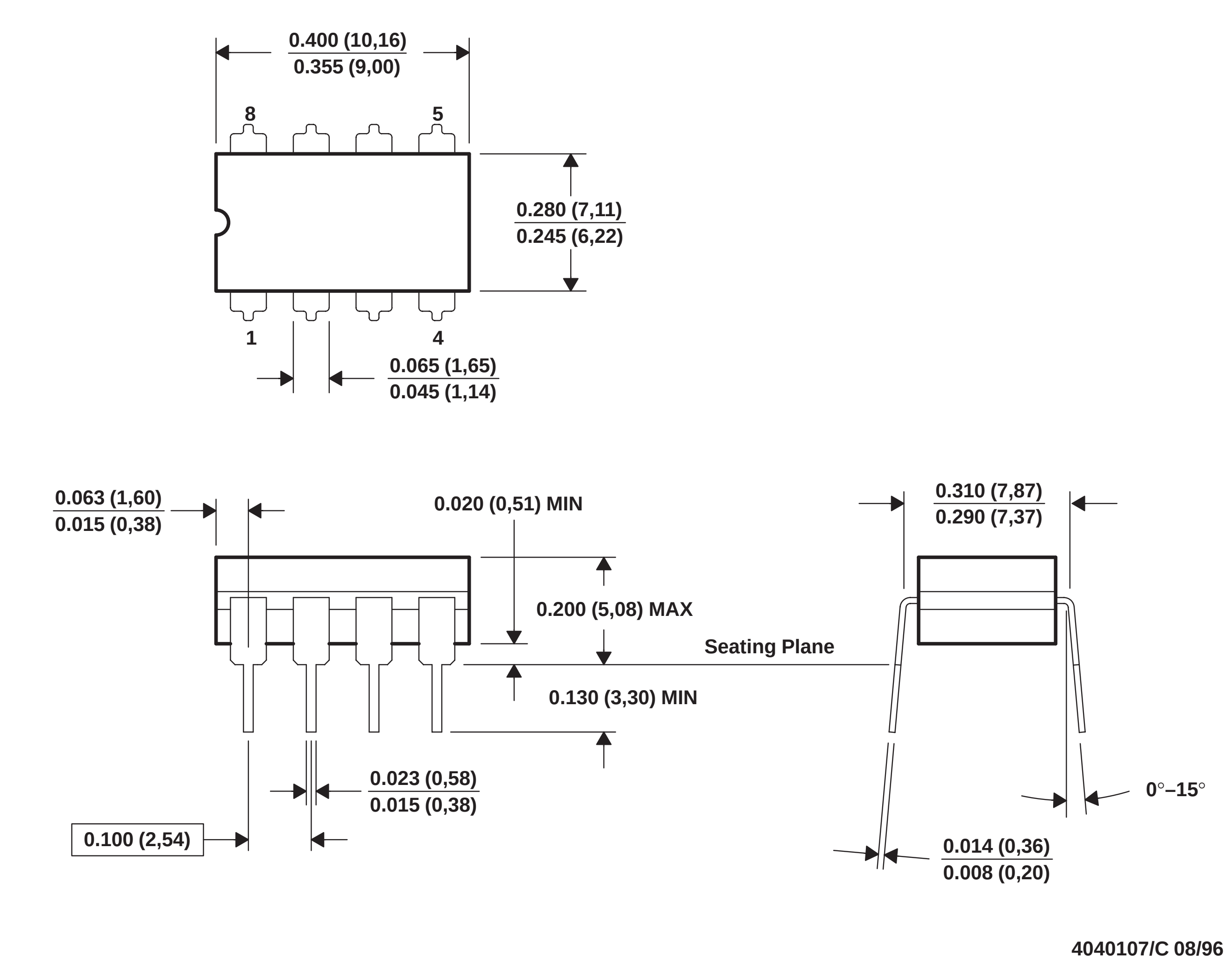
NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion, not to exceed 0,15.

PS (R-PDSO-G8) PLASTIC SMALL OUTLINE



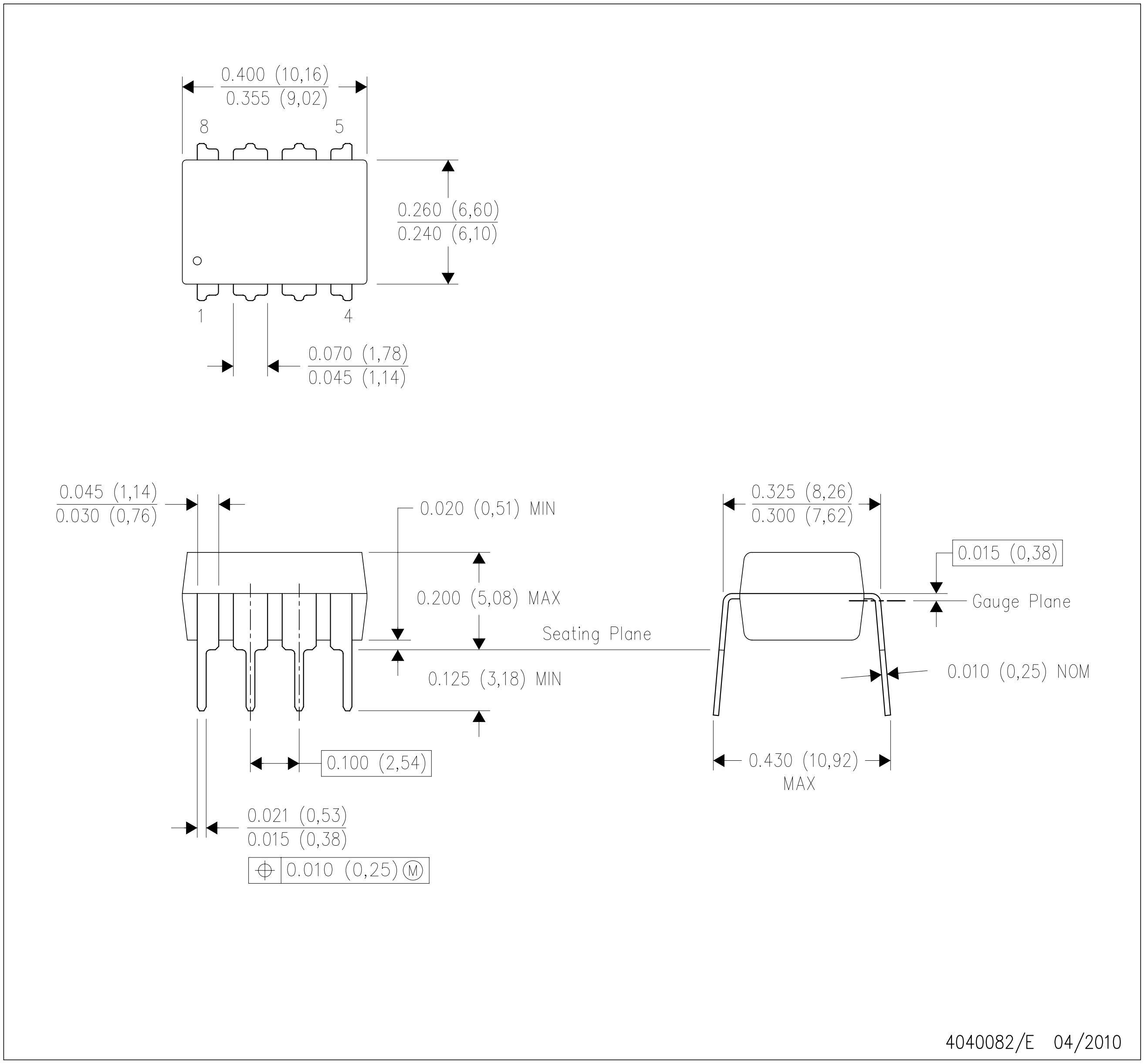
NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC-7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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



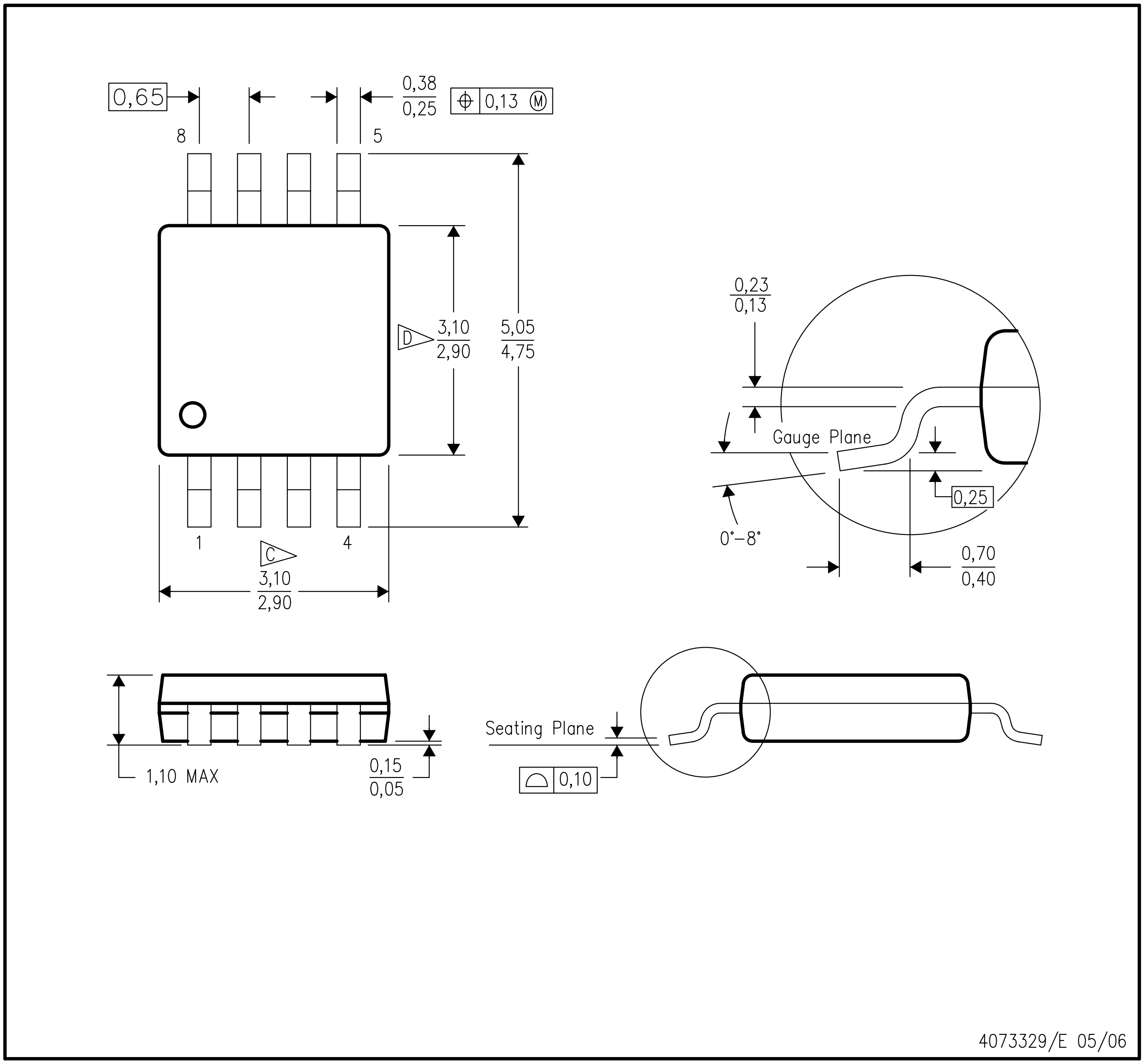
NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a ceramic lid using glass frit.
D. Index point is provided on cap for terminal identification.
E. Falls within MIL STD 1835 GDIP1-T8

P (R–PDIP–T8) PLASTIC DUAL–IN–LINE PACKAGE



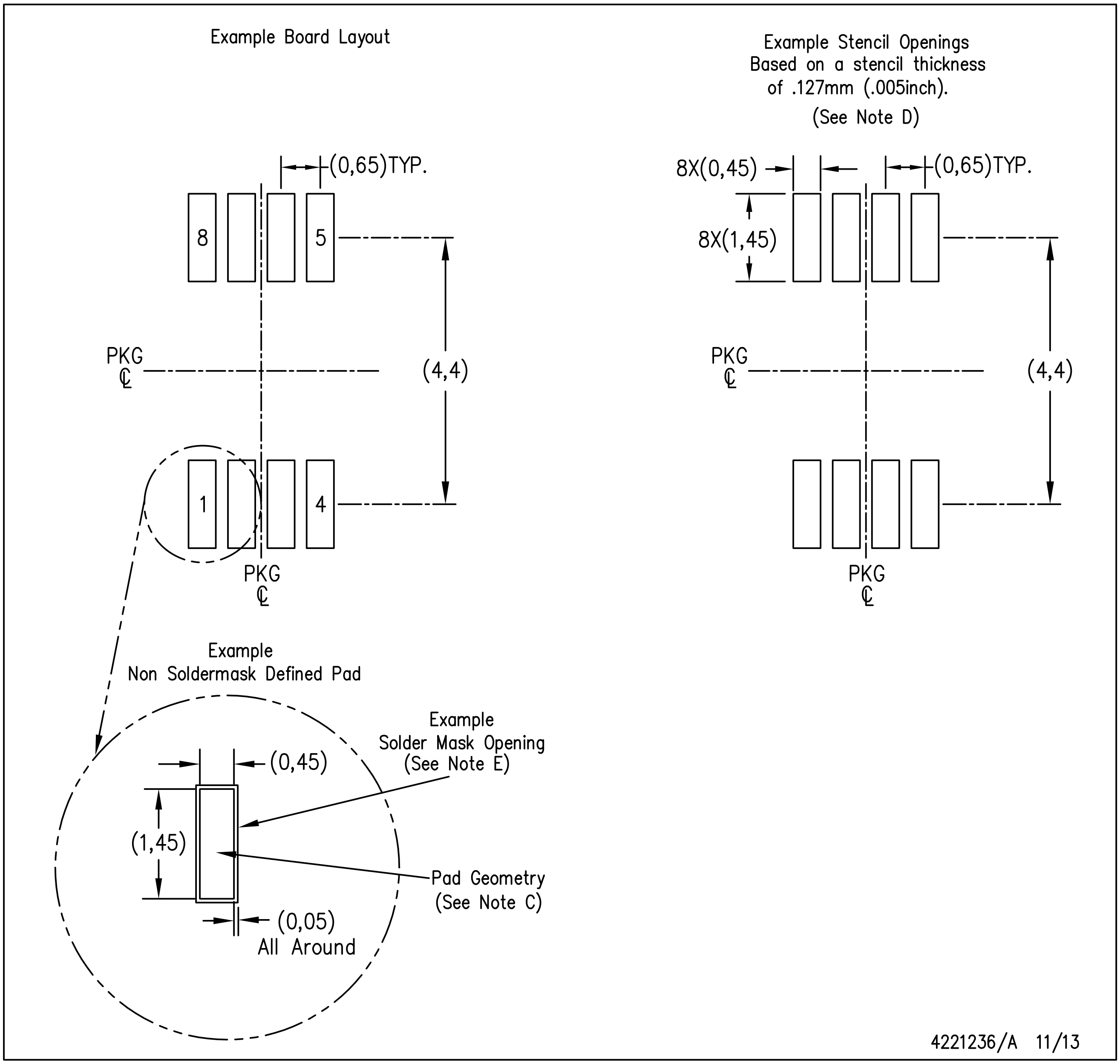
NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS–001 variation BA.

DGK (S-PDSO-G8) PLASTIC SMALL-OUTLINE PACKAGE

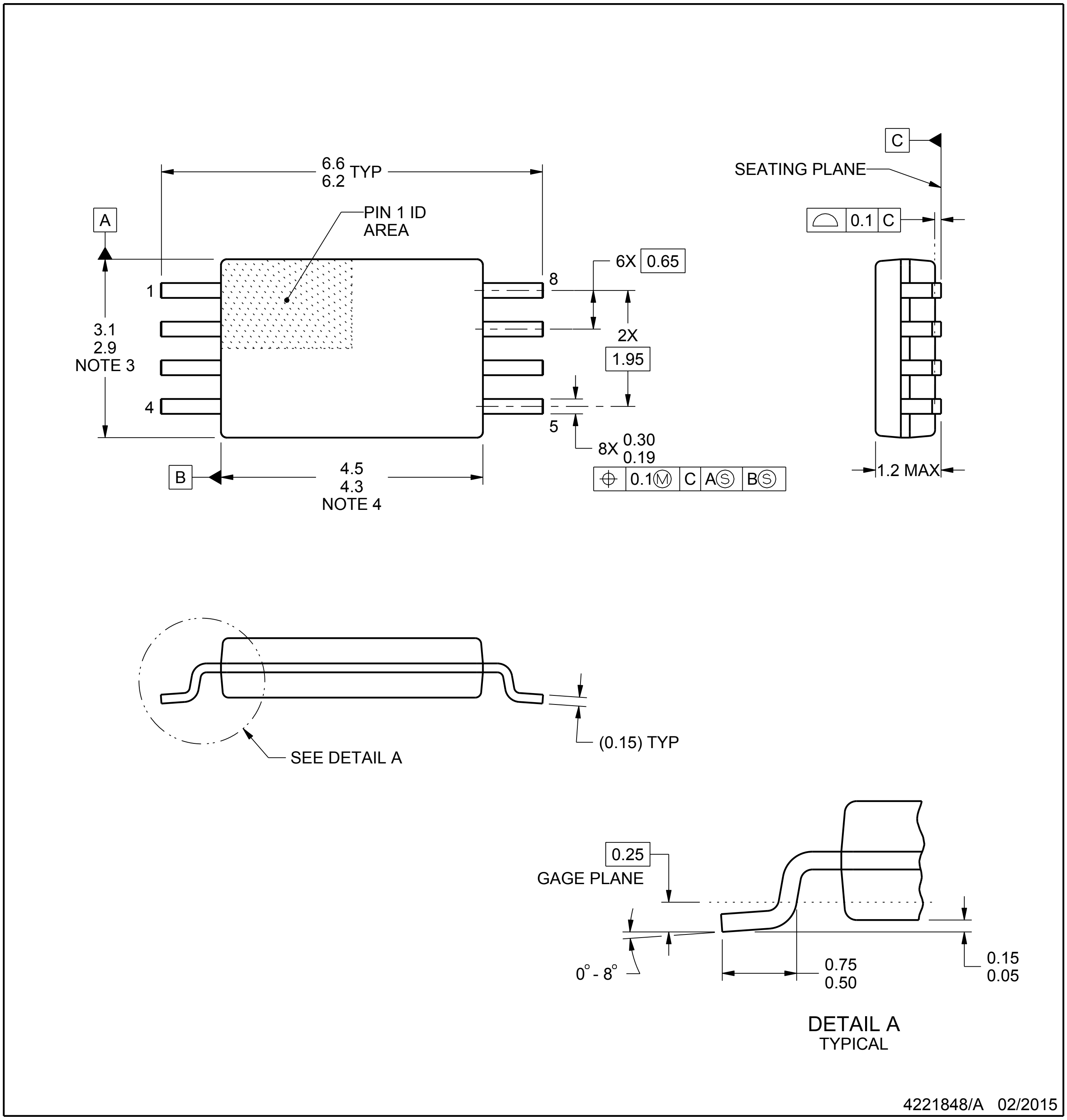


NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
- D. Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.
- E. Falls within JEDEC MO–187 variation AA, except interlead flash.

DGK (S–PDSO–G8) PLASTIC SMALL OUTLINE PACKAGE

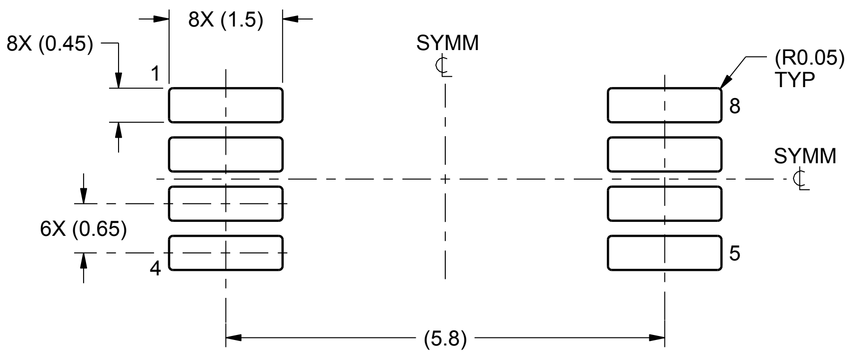


NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC–7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525 for other stencil recommendations.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

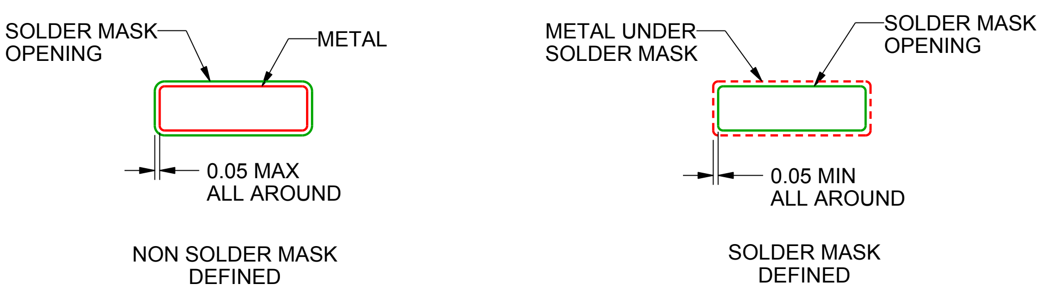


NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153, variation AA.



LAND PATTERN EXAMPLE
SCALE:10X

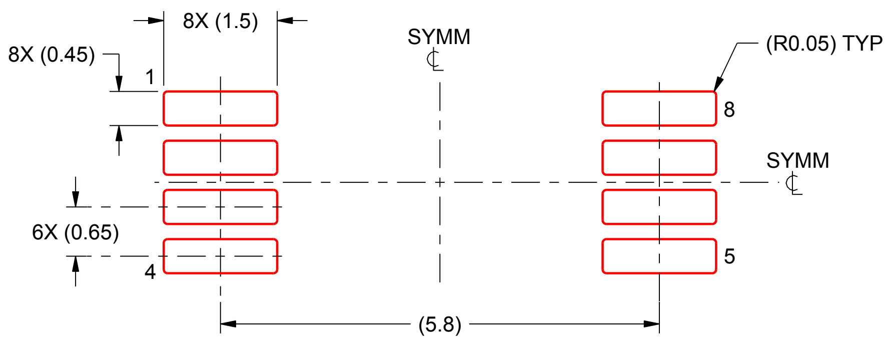


SOLDER MASK DETAILS
NOT TO SCALE

4221848/A 02/2015

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:10X

4221848/A 02/2015

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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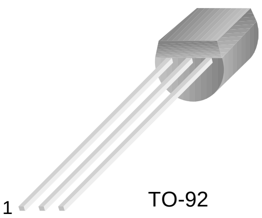
FAIRCHILD SEMICONDUCTOR®

BC546/547/548/549/550

Switching and Applications

- High Voltage: BC546, V_{CEO}=65V
- Low Noise: BC549, BC550
- Complement to BC556 ... BC560



1 TO-92

1. Collector 2. Base 3. Emitter

NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_a=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : BC546 : BC547/550 : BC548/549	80 50 30	V V V
V_{CEO}	Collector-Emitter Voltage : BC546 : BC547/550 : BC548/549	65 45 30	V V V
V_{EBO}	Emitter-Base Voltage : BC546/547 : BC548/549/550	6 5	V V
I_C	Collector Current (DC)	100	mA
P_C	Collector Power Dissipation	500	mW
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	-65 ~ 150	°C

Electrical Characteristics T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
I_{CBO}	Collector Cut-off Current	V_{CB}=30V, I_E=0			15	nA
h_{FE}	DC Current Gain	V_{CE}=5V, I_C=2mA	110		800	
V_{CE} (sat)	Collector-Emitter Saturation Voltage	I_C=10mA, I_B=0.5mA I_C=100mA, I_B=5mA		90 200	250 600	mV mV
V_{BE} (sat)	Base-Emitter Saturation Voltage	I_C=10mA, I_B=0.5mA I_C=100mA, I_B=5mA		700 900		mV mV
V_{BE} (on)	Base-Emitter On Voltage	V_{CE}=5V, I_C=2mA V_{CE}=5V, I_C=10mA	580	660	700 720	mV mV
f_T	Current Gain Bandwidth Product	V_{CE}=5V, I_C=10mA, f=100MHz		300		MHz
C_{ob}	Output Capacitance	V_{CB}=10V, I_E=0, f=1MHz		3.5	6	pF
C_{ib}	Input Capacitance	V_{EB}=0.5V, I_C=0, f=1MHz		9		pF
NF	Noise Figure : BC546/547/548 : BC549/550 : BC549 : BC550	V_{CE}=5V, I_C=200μA f=1KHz, R_G=2KΩ V_{CE}=5V, I_C=200μA R_G=2KΩ, f=30~15000MHz		2 1.2 1.4 1.4	10 4 4 3	dB dB dB dB

h_{FE} Classification

Classification	A	B	C
h_{FE}	110 ~ 220	200 ~ 450	420 ~ 800

Typical Characteristics

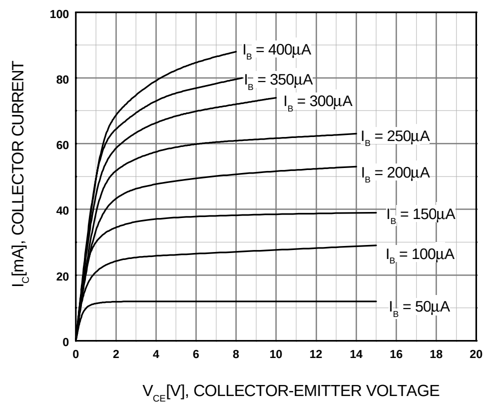


Figure 1. Static Characteristic

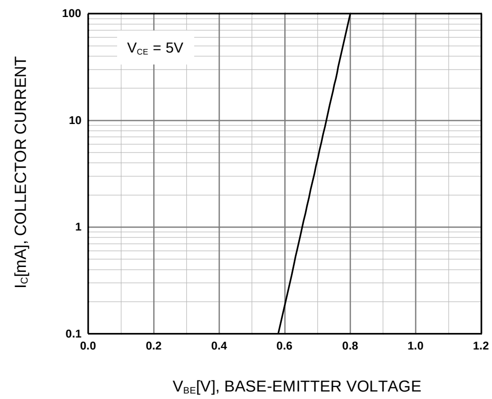


Figure 2. Transfer Characteristic

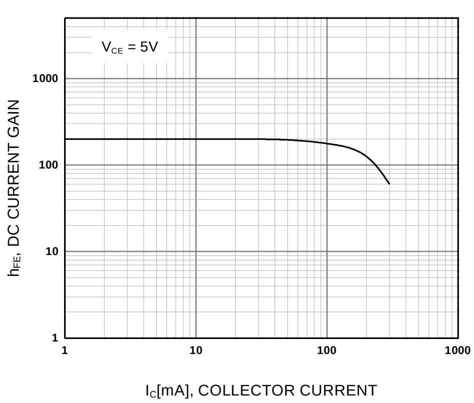


Figure 3. DC current Gain

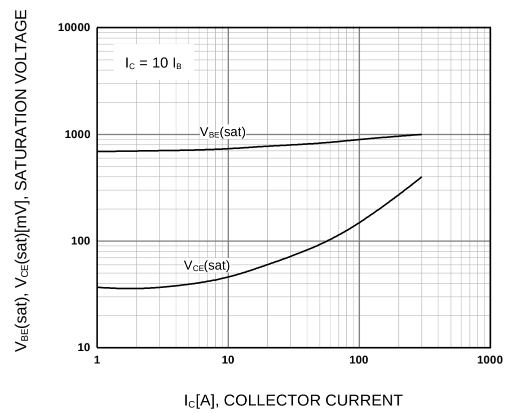


Figure 4. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage

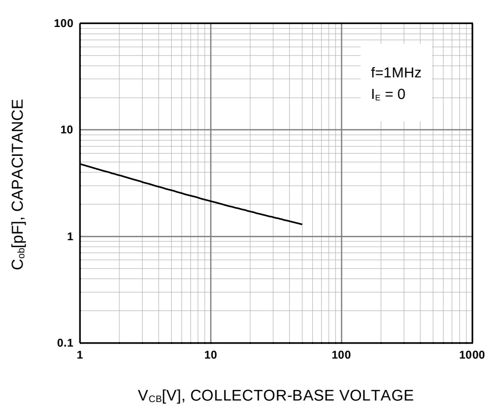


Figure 5. Output Capacitance

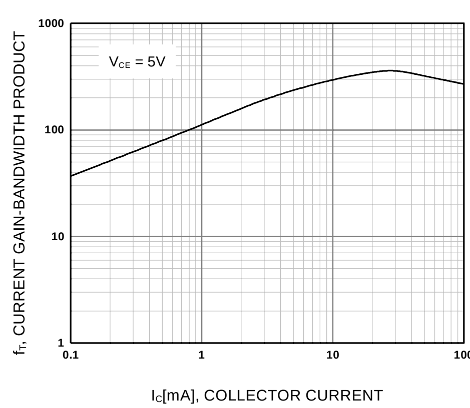
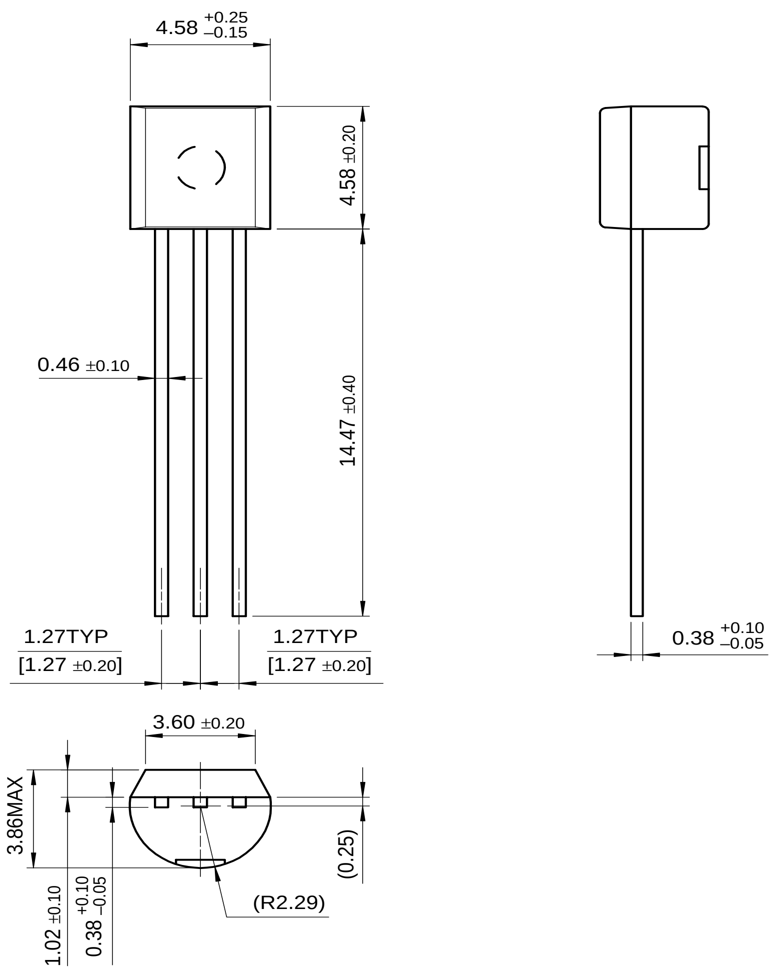


Figure 6. Current Gain Bandwidth Product

Package Dimensions

TO-92



Dimensions in Millimeters

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CoolFET™	FASTr™	MicroFET™	PowerTrench®	SuperSOT™-6
CROSSVOLT™	FRFET™	MicroPak™	QFET™	SuperSOT™-8
DOME™	GlobalOptoisolator™	MICROWIRE™	QS™	SyncFET™
EcoSPARK™	GTO™	MSX™	QT Optoelectronics™	TinyLogic™
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PRODUCT STATUS DEFINITIONS

Definition of Terms

Datasheet Identification	Product Status	Definition
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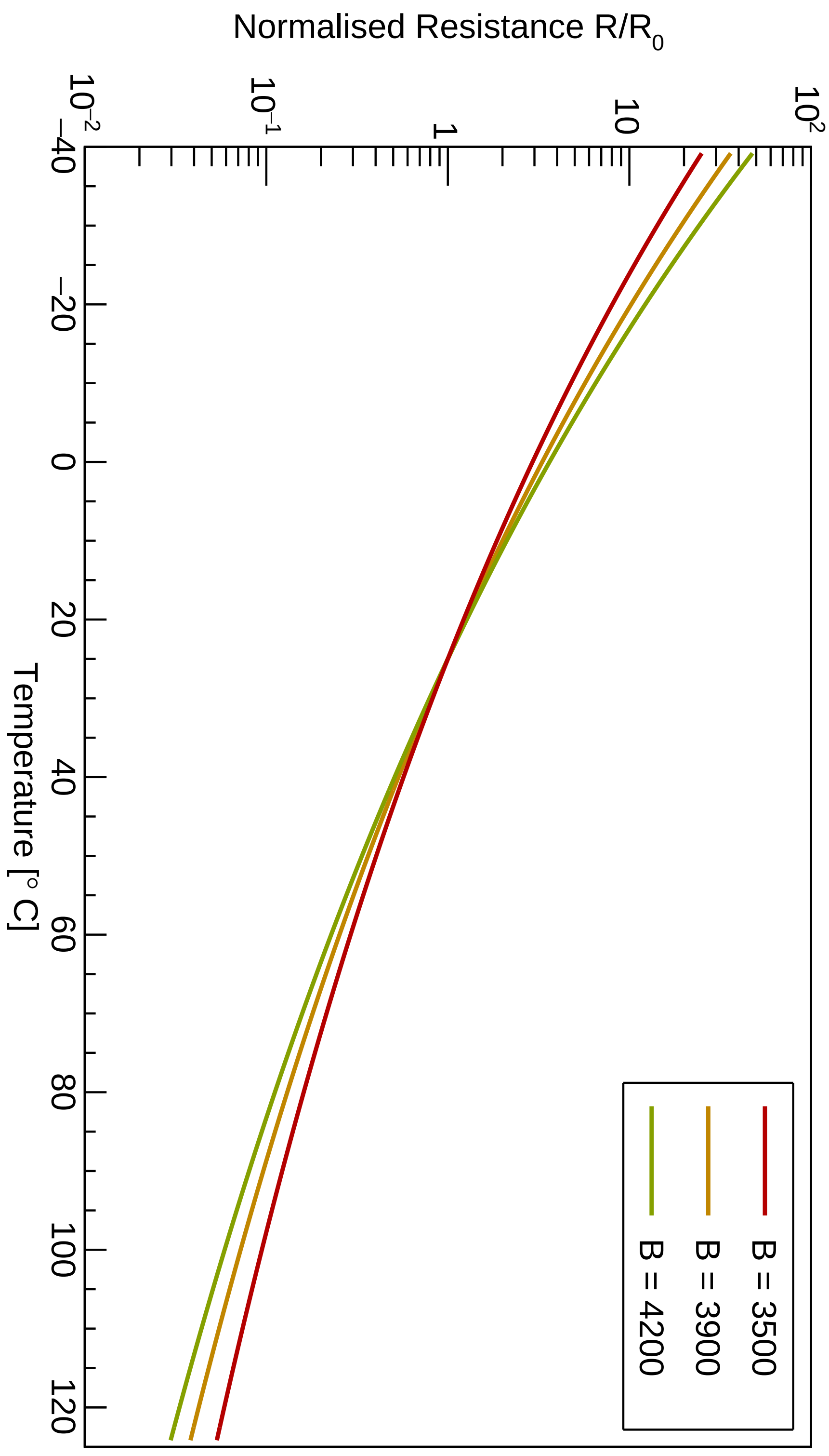


Figure 6: Resistance/temperature characteristic of a NTC thermistor.

(a) NPN (b) PNP

Figure 7: Electronic symbols of the BJT.

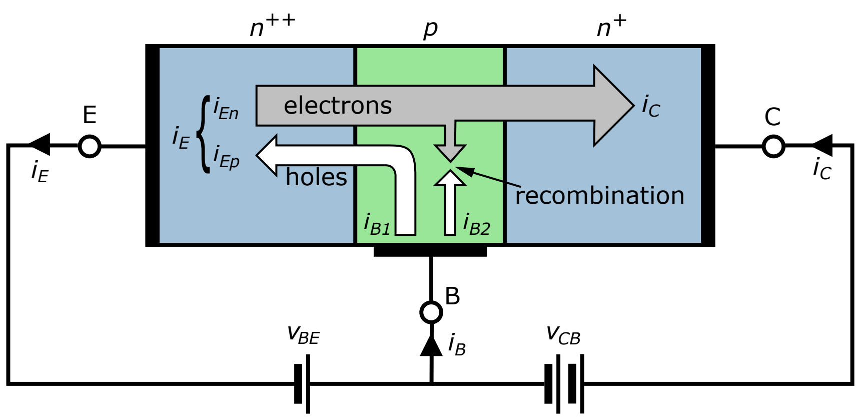
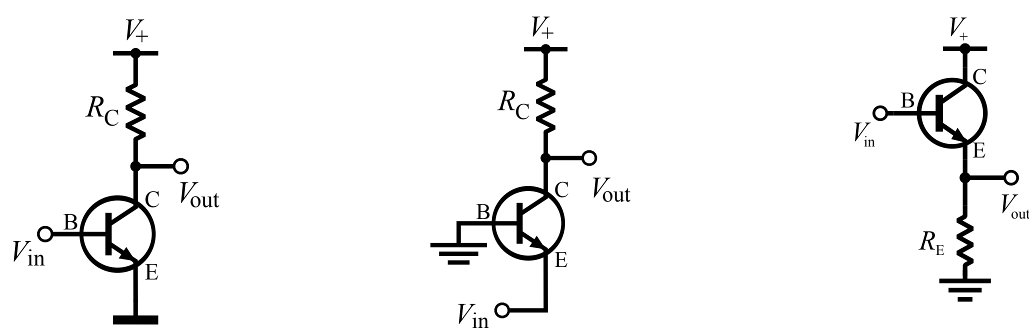


Figure 8: Diagrammatic representation of the amplifying action of a transistor.



(a) Common emitter. (b) Common base. (c) Common collector.

Figure 9: The three basic amplifier arrangements.