Developing an Automated Microclimate Ecosystem

Calibration of a Light Sensor Circuit

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1 Introduction

We all know that weather conditions like the amount of annual sunlight, the average temperature, humidity, and precipitation, differ based on location. As humans, we know that when we travel away from our natural habitat we feel the effects. For example, if you are from the northern portion of the United States and you were to travel to the southern portion of the United States, the heat and humidity would greatly differ from the weather conditions you are accustomed to, possibly causing you to feel uncomfortable and limiting your time spent outdoors. If you were from a northwestern city in the United States, like Seattle, Washington, and were to travel to a southeastern city in the United States, like Orlando, Florida, you would most likely not be used to the annual amount of sunny days.

These changes could possibly make you feel uncomfortable; maybe you would even change your daily habits to fit this change in weather. If humans are effected by weather changes, are animals affected as well? To be able to study the effect weather changes could have on an animal, a system has to be developed to recreate their native environment in a controlled situation, even when the surrounding environment differs. To be able to create this microclimate, data is needed to be able to determine how a particular sensor reacts to light.

A photodiode, a device which creates a voltage based on its exposure to light, is connected to a Rasberry Pi which records the change in voltage. A program is used to collect reported solar radiation data from Weather Underground along with the photodiode voltage. The correlation between the two can be used to calibrate the output of the photodiode sensor. This calibration can be used in a microclimate environment to recreate the light intensity using artificial lighting that mimics any location on the Earth. This thesis presents the study of a photodiode and the comparison of the data to the reported real time solar radiation collected from personal a weather station on Weather Underground.

2 Background

The entirety of the system is controlled with a Rasberry Pi (RPi). A RPi is a small, low cost computer. The RPi can perform the usual tasks that any other computer can do, like access the Internet, display graphics and videos, and play games [1]. In addition, this small device can be used to interact with other devices. These devices can be a multiple of things, such as light sensors, motion sensors, and light emitting photodiodes. The device also allows the user to create customized programs to achieve nearly any project they can imagine in a programming platform called Python.

The program used to conduct the experiment is written in Python. Python is a powerful, diverse, and open source programming language. Python can be used in a multitude of forms, like web development, database analysis, scientific applications, game development, and graphical user interfaces [2].

3 Experimental Setup

The experimental setup uses a RPi. Data is collected by running a Python script on the RPi which extracts the reported data from the HTML code of the Weather Underground website for a specified personal weather station (PWS). The weather variables being reported in real time are then stored within the program. Connected to the RPi is a photodiode, which gives off a voltage based off the light intensity outside. The voltage data and weather station data is then collected simultaneously. The collected data is then transferred to an HTML script and displayed on a graphical user interface (GUI). The following sections will detail each individual component of the system. Appendix A contains data sheets for all hardware included.

3.1 Hardware

3.1.1 Photodiode Circuit

The circuit in Figure 1 consists of a VTB8440B semiconductor photodiode. The sensor has a spectral wavelength range of 330 to 720 nm [3]. This spectral range covers a portion of the UVA spectrum which spans from 315 to 400 nm, and the majority of the visible light spectrum which spans from 380 to 780 nm. The spectral range also covers a small portion of the infrared spectrum, but the photodiode incorporates an infrared rejection filter

The current from the photodiode is translated into a voltage through a LMC6042 operational amplifier (opamp) [4]. The opamp is powered with an external 9V battery source due to the fact that the RPi outputs only either 3.3 or 5V. A LM385 bandgap voltage reference diode is used to create a constant voltage of 1.2V, which is then run to the non-inverting input of the opamp [5]. This offset ensures the opamps output remains above zero volts when the current of the photodiode is zero [6]. A 8.2kΩ resistor is connected between the inverting input and the opamp output creating negative feedback. The output from the opamp is then run through a potential divider circuit consisting of two 10kΩ resistors. The combination of the resistors ensures that the read voltage out is less than 5V even in the sunniest conditions [6].

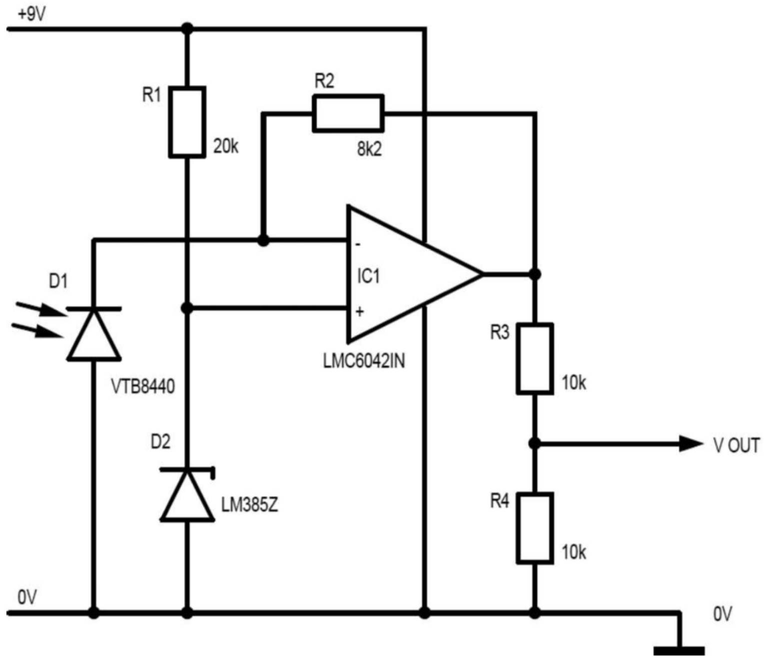


Figure 1: Photodiode circuit diagram.

In addition to the photodiode, a photoresistor was added to compare the differences between the two sensors. A voltage divider circuit was created with a 10kΩ resistor and a 10kΩ photoresistor. The circuit is powered from the 5V rail of the RPi as seen in Figure 2.

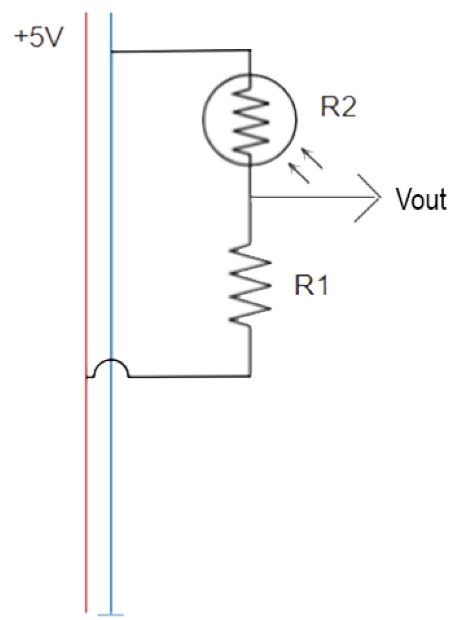


Figure 2: Photoresistor circuit diagram.

The voltages out from the photodiode and the photoresistor circuits are analog inputs. Because the RPi only allows for digital inputs, the voltages out are converted to digital inputs using the MCP3008, an 8 channel, 10-bit, analog to digital converter (ADC) [7]. The output from the ADC chip is then connected to GPIO pins connected to the RPi as seen in Figure 3.

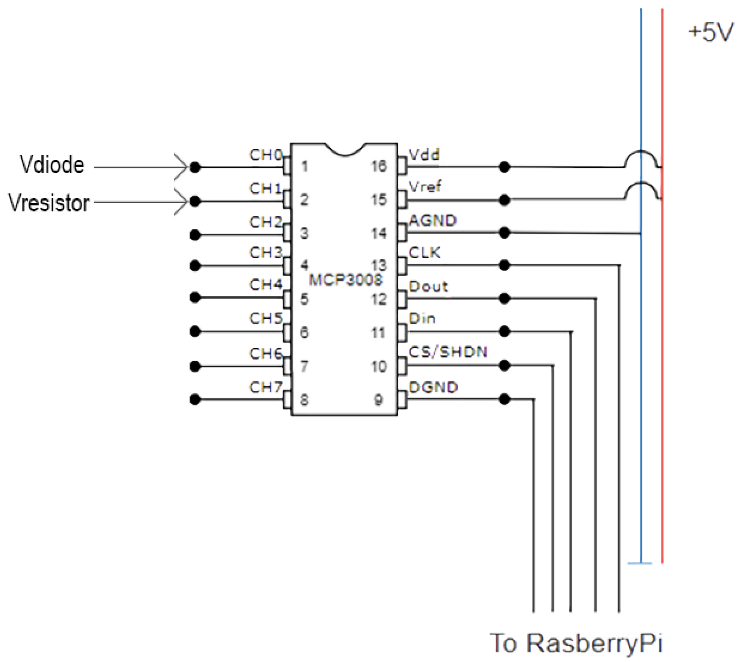


Figure 3: ADC circuit diagram.

3.2 Software

3.2.1 Weather Underground

Data is collected from the website `https://www.weatherunderground.com`. Weather Underground's site consists of a global network of over 250,000 personal weather stations (PWS) [8]. These weather stations report weather variables like solar radiation, temperature, humidity, precipitation, and UV index. Because these are personal weather stations, they differ by makes and models and may only report certain weather variables compared to other PWS's. With this global network, the user is able to find a PWS that is located in the native environment for the subject that is being studied.

3.2.2 Weather Station Data

For the experimental setup, weather data was collected from the PWS KARCONWA57, located in Conway, Arkansas. The reason for using this particular weather station is because the photodiode data collection site was within a 3-mile distance from the PWS, ensuring that the current conditions for the PWS matched the current conditions of the photodiode voltage collection site. The main focus of the data collection from Weather Underground was to collect reliable solar radiation data that could be compared to the photodiode voltage data accurately. Temperature, precipitation, and weather conditions were also collected from the PWS.

3.2.3 Collection of Reported Data

Collection of the solar radiation data and other data points was achieved by creating a Python script. Four Python packages were imported within the code: urlib.request, time, JSON, and webbrowser. Starting at the beginning of the script, a text prompt appears asking the user to "Input Weather Station 1 ID." The prompt in addition provides the user with the link to Weather Undergrounds wundermap, which displays an interactive map for the user to find the desired weather station. Several arrays are then defined which are used to store the desired data variables such as solar radiation and voltage.

A while loop is then implemented to allow the code to run as long as the user specifies. urllib.request gives the script the ability to open the specified URL given by the user. The JSON package is then used to create a python dictionary of the JSON script from the weather underground API URL. From this dictionary, reported weather variables can be defined from the specified JSON values. These found values are than stored within their own arrays and saved to a data file.

The readadc_channel_0 function is then called to allow the analog voltage running to the ADC chip to be read by the RPi. From this function, a 10 digit integer is outputted and inputted into the calc_volts_0 function, which calculates a voltage readout from the ADC chips integer output. This voltage is then stored within its specified array and written in a file along with the Weather Underground data.

All of the collected variables are then transferred into a HTML file. This file is then able to be opened by the internet browser on the RPi and displays the information as a graphical user interface (GUI). The GUI displays the local current time as well as the last updated time for the PWS, icons representing the current weather condition, solar radiation, voltage output from the photodiode, current temperature readings, and current precipitation measurements. Figure 4 shows the data that is included on the GUI. Appendix C contains the HTML code created for the GUI.

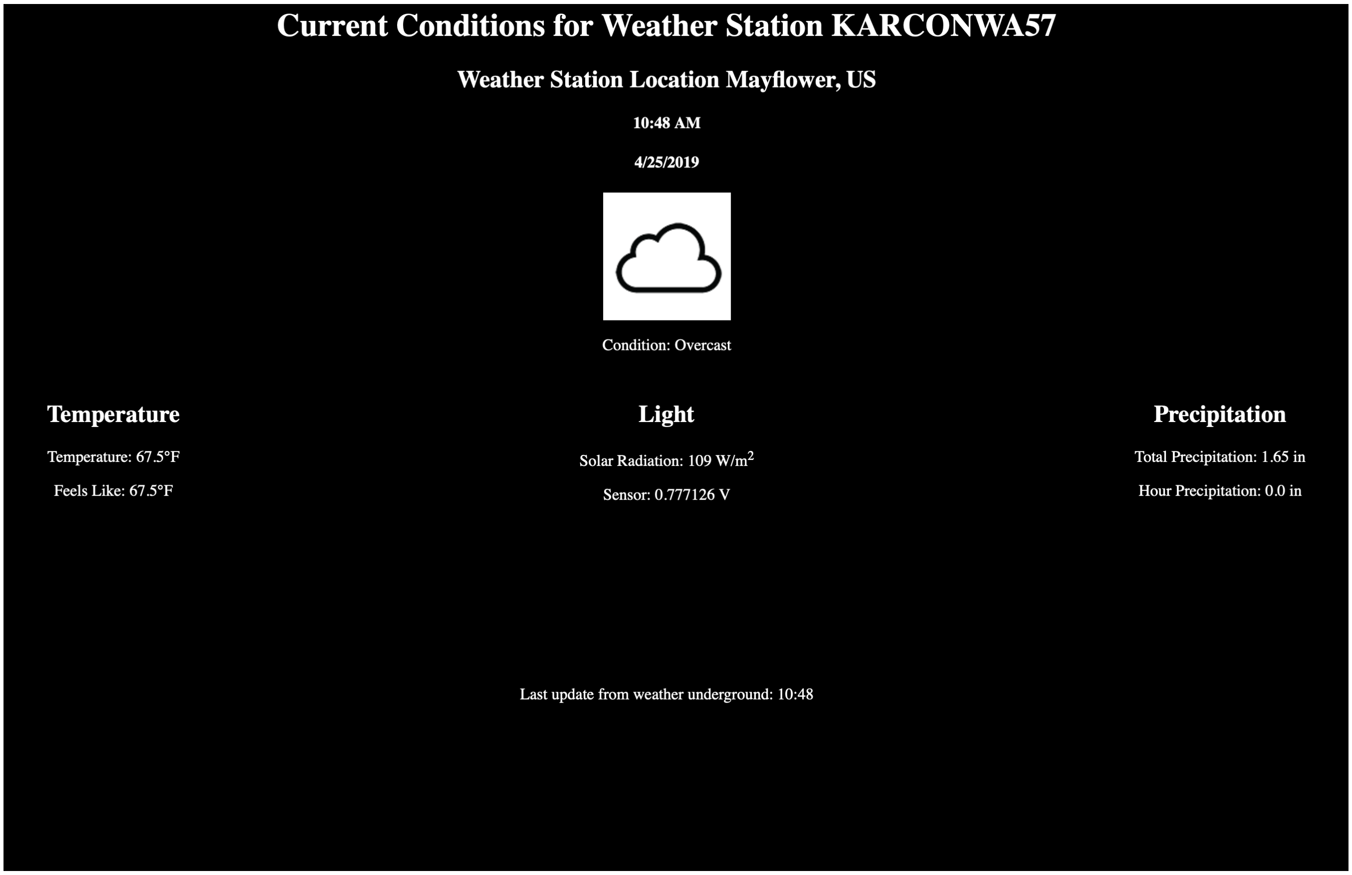


Figure 4: Graphical user interface.

The time package imported then allows the program to pause and sleep for a specified amount of time. Once this time is reached, the loop begins from the beginning, reading and saving the weather underground values, photodiode voltage value, and updating the GUI. The entirety of the code can be seen in Appendix B.

4 Data Analysis

The following sections present the comparison of solar radiation data collected from the Weather Underground PWS KARCONWA57 and the photodiode voltage data collected at the collection site for a sunny day and a cloudy day.

4.1 Sunny Day Data

On April 9, 2019 data was collected with the designed experimental setup. The data collection began before sunrise and after sunset for the day, running approximately 21 hours, and data was collected from Weather Underground and the photodiode every 15 minutes. Figure 5 displays the collected data with the PWS solar radiation data represented by the blue points and the recorded voltage from the photodiode represented by the red points.

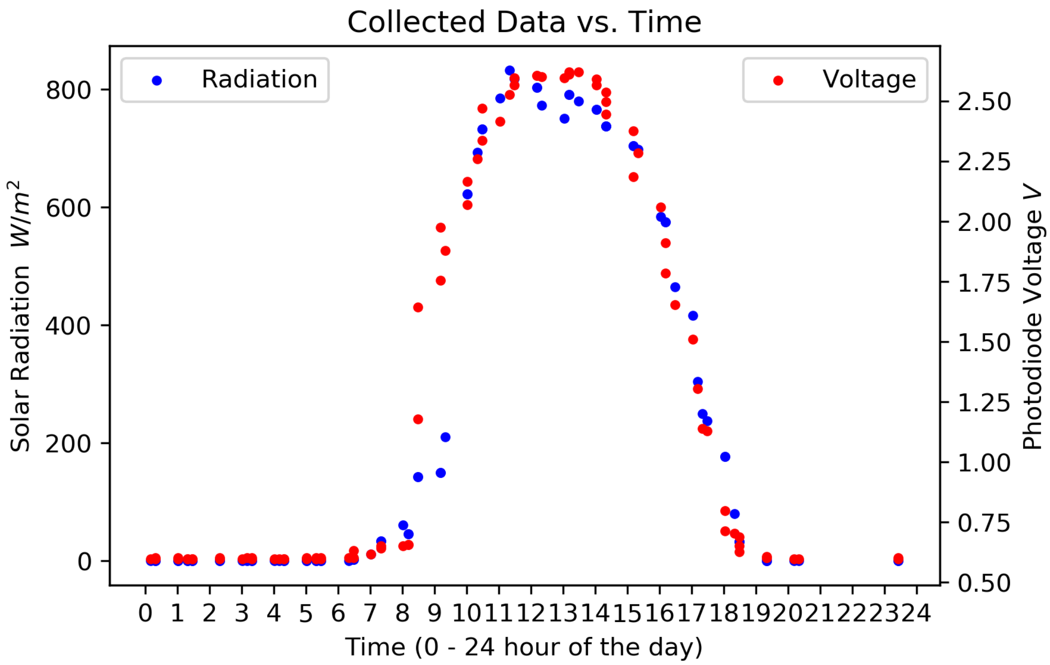


Figure 5: Solar radiation and photodiode voltage for a sunny day.

For comparison, data from a photoresistor was collected at the same time intervals on the same day to determine the difference in sensitivity of the two sensors. In Figure 6 the solar radiation data from weather underground is represented by the blue points and the voltage from the photoresistor is represented by the red points.

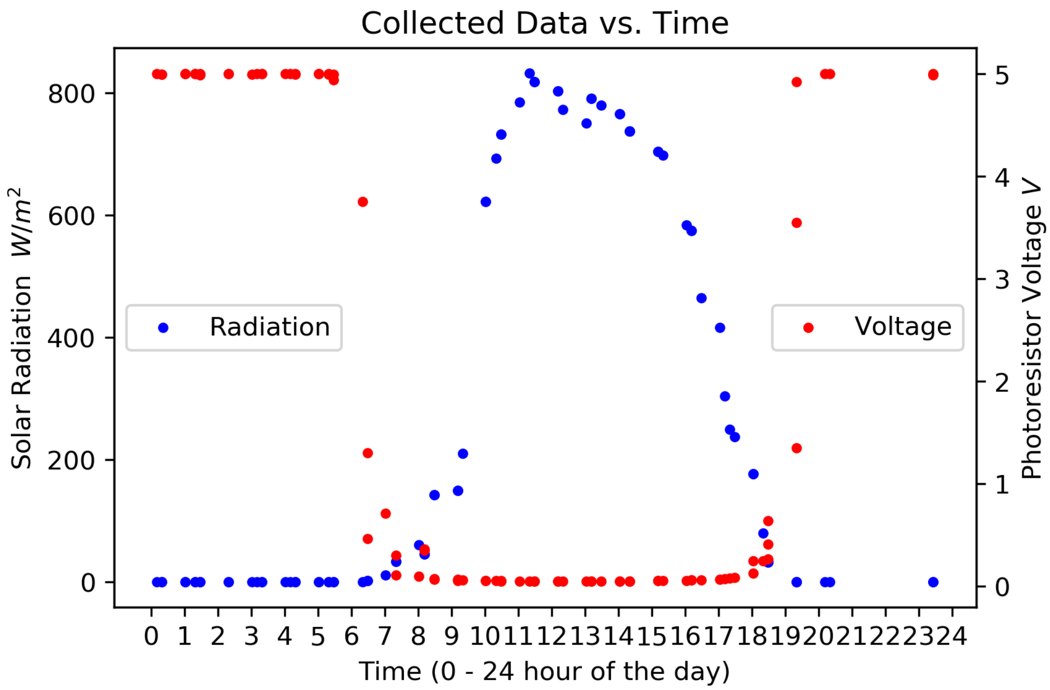


Figure 6: Solar radiation and photoresistor voltage for a sunny day.

4.2 Cloudy Day Data

Data was collected with the photodiode on April 23, 2019, a mostly cloudy day, with the experimental setup. Data collection was collected with the same parameters as the sunny day data. Figure 7 displays the solar radiation collected from Weather Underground by the blue points and the photodiode voltage collected by the red points.

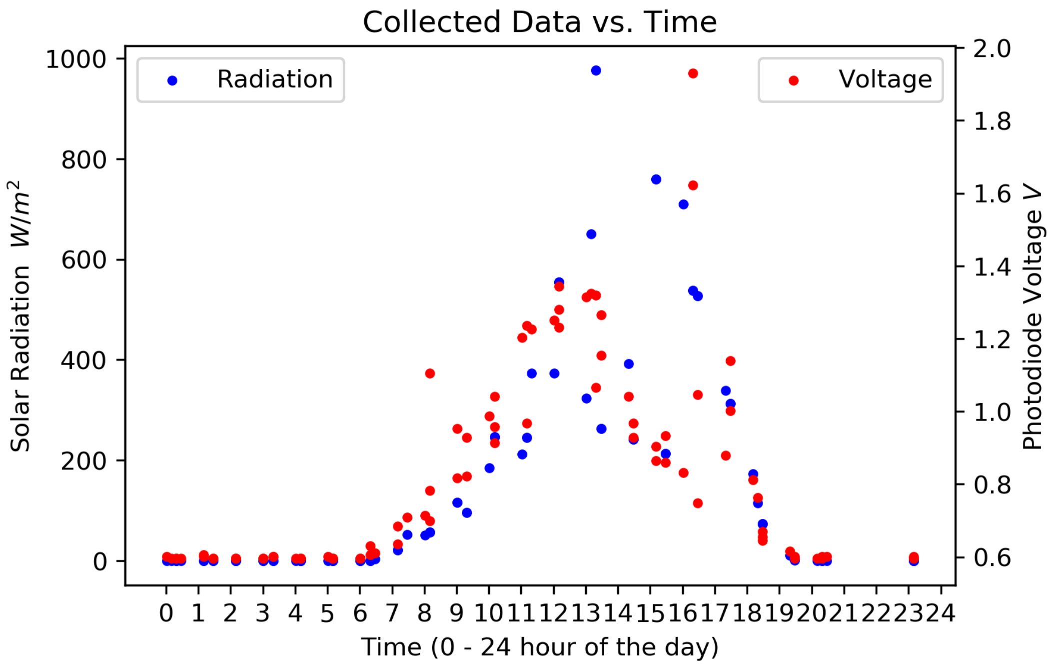


Figure 7: Solar radiation and photodiode voltage for a cloudy day.

For comparison, data from the photoresistor was collected on the same day during the same time intervals as the photodiode. Figure 8 displays the solar radiation data collected from Weather Underground by the blue points and the photoresistor voltage by the red points.

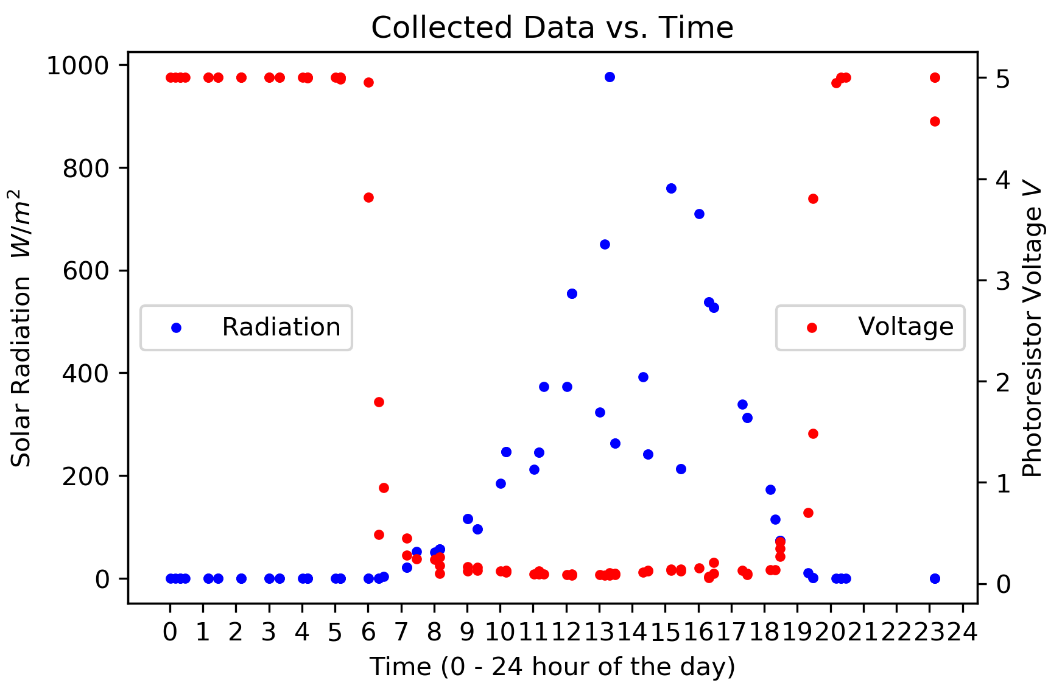


Figure 8: Solar radiation and photoresistor voltage for a cloudy day.

4.3 Results

By comparing graphs of the photodiode and photoresistor, it is clear that that photodiode is the better option. The photoresistor predominantly just responds to light. It is a much more useful sensor if the user would just like to know if a light is on or off. By examining the photodiode data, the voltage output follows the changes in solar radiation very closely. There are some small differences in the data for the sunny day. This error can be attributed to four factors.

First there exists a margin of error from the 10-bit ADC chip. The chip's voltage reference is from the 5V rail creating a margin of error of 0.005V as shown in Equation 1.

$$\begin{aligned} V_{error} &= \pm \frac{V_{ref}}{2^{10}} \\ &= \pm \frac{5V}{1024} \\ &\approx \pm 0.005V \end{aligned} \tag{1}$$

This margin of error is very small compared to the voltage range of the photodiode. The error bar for each data point graphed is nearly the magnitude of the data point itself as seen in Figure 9.

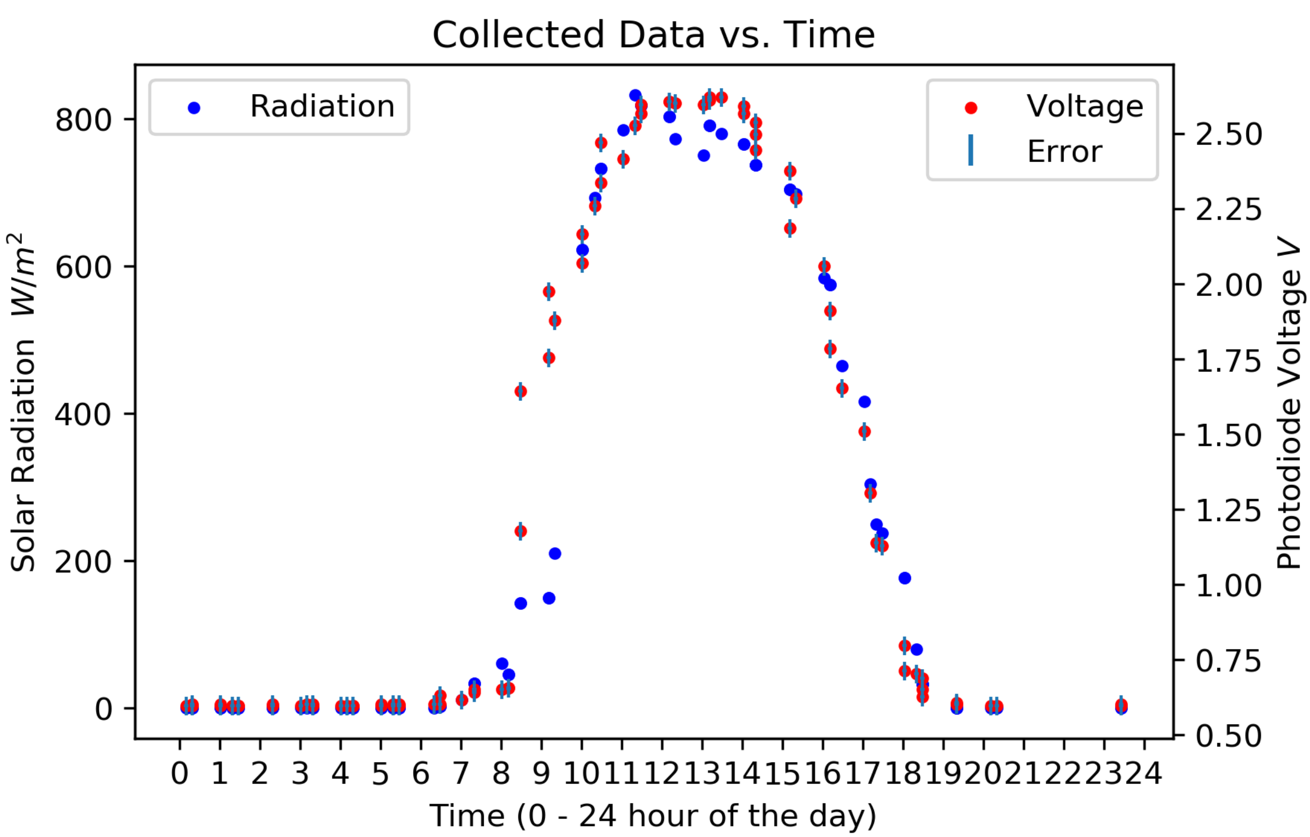


Figure 9: Solar radiation and photodiode voltage including margin of error from the ADC chip.

Second the circuit for the photodiode does not allow the voltage out to be 0. From the data with no light, it is approximately 0.6V. This means that when the PWS reports 0 $\frac{W}{m^2}$, the voltage from the photodiode is reporting 0.6V, creating a small offset between data points.

The third factor is the difference in collection sites. Even though the photodiode data collection was conducted within a reasonable distance from the weather station used to collect reported solar radiation data, the two systems were not set up exactly the same. It is reasonable to assume that the PWS is located in an elevated position to be able to receive accurate data and avoid obstruction of this data from elements like houses, trees, and humans. It can also be assumed because of this fact that there is a possibility of less natural light disturbance. For example, shadows created from trees or the peak of a house.

The fourth reason for discrepancy is that the type of instrumentation used by this particular PWS is not public knowledge. Because of this, there is no way of knowing how high of quality or low of quality the equipment being used at this particular PWS is. The margin of error for the equipment could be very small or very large.

Even with these slight discrepancies between the measured voltage from the light intensity and the reported solar radiation data from the PWS, the data shows that the photodiode would be able to be used within an environment to measure light intensity. From the data collected, the photodiode can be calibrated and be used in a microclimate environment to recreate the light intensity using artificial lighting that mimics any location on the Earth.

5 Conclusion

The experimental setup created and the data collected has provided a basic platform to aid in the creation of an automated microclimate ecosystem. From the data, it is evident that the photodiode voltage change corresponds with the change in reported solar radiation. Due to the sensors small size, it would be an excellent choice for use within an environment and would not interfere with the subjects habitat. The Python script performs as designed and allows for expansion of weather variables data collection. The GUI gives the user the ability to view the collected data in a clear and concise manner.

The complete creation of an automated microclimate ecosystem will require the implementation of additional components such as light control, temperature control, precipitation and humidity control. The next major milestone will be light automation. Light automation was not tested in this thesis due to the fact that the light sources that have been tested with the photodiode do not posses the correct light spectrum to produce a similar voltage response like sunlight does from the photodiode. There are a few options that could be used to solve this problem, such as a combination of light sources or the creation of a scale factor of the photodiodes response to a particular light source. These lighting options will need to be explored to find the optimal conditions for the subject being studied.

Once the lighting automation is created, another major addition to the system will be a fail safe for the system. Multiple times during data collection, the HTML file for the Weather Underground PWS could not be found due to internet connection issues. When the file was not found by the program it caused the entire system to crash. A fail safe will need to be implemented to allow for the light control to continue to operate until a connection can be reestablished with the Weather Underground site.

Once this light source has been found, the calibrated photodiode can be used to compare the reported solar radiation for a particular PWS and adjust the light source to meet the corresponding voltage that should be produced from the photodiode. With this automated lighting system, it will allow the observation of behavioral differences of the animal within it's natural habitat.

6 Acknowledgments

I would personally like to thank my research advisor Dr. William Slaton for his guidance and advice throughout the entire project. I would also like to thank Mrs. Ashley Beyerl for being the second reader and providing invaluable comments on this thesis. Special thanks to the University of Central Arkansas Department of Physics and Astronomy for allowing me to participate in undergraduate research.

7 References

[1] *What is a Rasberry Pi?* URL: https://www.raspberrypi.org/help/what-%20is-a-raspberry-pi/. accessed: 04.20.2019.

[2] *About*. URL: https://www.python.org/about/. accessed: 04.20.2019.

[3] *VTB8440BH Data Sheet*. URL: https://media.digikey.com/pdf/Data%20Sheets/Excelitas%20PDFs/VTB8440BH,_8441BH.pdf. accessed 04.23.2019.

[4] *LMC6042 Data Sheet*. URL: http://www.ti.com/lit/ds/symlink/lmc6042.pdf. accessed 04.23.2019.

[5] *LM385 Data Sheet*. URL: http://www.ti.com/lit/ds/symlink/lm385-1.2-n.pdf. accessed 04.23.2019.

[6] K. A. Nicoll R. G. Harrison. "Balloon-borne disposable radiometer for cloud detection". In: *Review of Scientific Instruments* 83.2 (2012), p. 025111. DOI: https://doi.org/10.1063/1.368525.

[7] *MCP3008 Data Sheet*. URL: http://ww1.microchip.com/downloads/en/DeviceDoc/21295d.pdf. accessed 04.23.2019.

[8] *About Our Data*. URL: https://www.wunderground.com/about/data. accessed: 04.20.2019.

A Data Sheets

LM185-1.2-N/LM285-1.2-N/LM385-1.2-N Micropower Voltage Reference Diode

Check for Samples: LM185-1.2-N, LM285-1.2-N, LM385-1.2-N

FEATURES

- **±1% and 2% Initial Tolerance**
- **Operating Current of 10μA to 20mA**
- **1Ω Dynamic Impedance**
- **Low Temperature Coefficient**
- **Low Voltage Reference—1.235V**
- **2.5V Device and Adjustable Device Also Available**
- **LM185-2.5 Series and LM185 Series, respectively**

DESCRIPTION

The LM185-1.2-N/LM285-1.2-N/LM385-1.2-N are micropower 2-terminal band-gap voltage regulator diodes. Operating over a 10μA to 20mA current range, they feature exceptionally low dynamic impedance and good temperature stability. On-chip trimming is used to provide tight voltage tolerance. Since the LM185-1.2-N band-gap reference uses only transistors and resistors, low noise and good long term stability result.

Careful design of the LM185-1.2-N has made the device exceptionally tolerant of capacitive loading, making it easy to use in almost any reference application. The wide dynamic operating range allows its use with widely varying supplies with excellent regulation.

The extremely low power drain of the LM185-1.2-N makes it useful for micropower circuitry. This voltage reference can be used to make portable meters, regulators or general purpose analog circuitry with battery life approaching shelf life.

Further, the wide operating current allows it to replace older references with a tighter tolerance part.

The LM185-1.2-N is rated for operation over a −55°C to 125°C temperature range while the LM285-1.2-N is rated −40°C to 85°C and the LM385-1.2-N 0°C to 70°C. The LM185-1.2-N/LM285-1.2-N are available in a hermetic TO package and the LM285-1.2-N/LM385-1.2-N are also available in a low-cost TO-92 molded package, as well as SOIC and SOT-23.

CONNECTION DIAGRAM

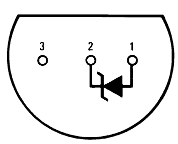
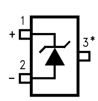


Figure 1. T0-92 Package (LP) (Bottom View)



* Pin 3 is attached to the Die Attach Pad (DAP) and should be connected to Pin 2 or left floating.

Figure 2. SOT-23

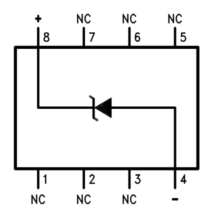


Figure 3. SOIC Package

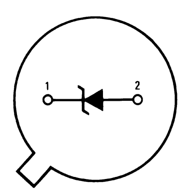


Figure 4. TO Package (NDV) (Bottom View)

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ABSOLUTE MAXIMUM RATINGS[1][2][3]

Reverse Current	30mA
Forward Current	10mA
Operating Temperature Range [4]	
LM185-1.2-N	−55°C to +125°C
LM285-1.2-N	−40°C to +85°C
LM385-1.2-N	0°C to 70°C
ESD Susceptibility [5]	2kV
Storage Temperature	−55°C to +150°C
Soldering Information	
TO-92 package: 10 sec.	260°C
TO package:10 sec.	300°C
SOIC and SOT-23 Pkg.	
Vapor phase (60 sec.)	215°C
Infrared (15 sec.)	220°C
See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.	

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional. For specifications and test conditions, see the Electrical Characteristics. The specifications apply only for the test conditions listed.
(2) Refer to RETS185H-1.2 for military specifications.
(3) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
(4) For elevated temperature operation, see Table 1.
(5) The human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin.

Table 1. $T_{J(max)}$ for Elevated Temperature Operation

DEVICE	$T_{J(max)}$ (°C)
LM185-1.2-N	150
LM285-1.2-N	125
LM385-1.2-N	100

ELECTRICAL CHARACTERISTICS[1]

Parameter	Conditions	Typ	LM185-1.2-N LM185BX-1.2-N LM185BY-1.2-N LM285-1.2-N LM285BX-1.2-N LM285BY-1.2-N		LM385B-1.2-N LM385BX-1.2-N LM385BY-1.2-N		LM385-1.2-N		Units (Limit)
			Tested Limit [2] [3]	Design Limit [4]	Tested Limit [2]	Design Limit [4]	Tested Limit [2]	Design Limit [4]	
Reverse Breakdown	T_A = 25°C,	1.235	1.223		1.223		1.205		V(Min)
Voltage	10μA ≤ I_R ≤ 20mA		1.247		1.247		1.260		V(Max)
Minimum Operating Current		8	10	**20**	15	**20**	15	**20**	μA
	LM385M3-1.2-N						10	**15**	(Max)
Reverse Breakdown Voltage Change with Current	10μA ≤ I_R ≤ 1mA		1	**1.5**	1	**1.5**	1	**1.5**	mV (Max)
	1mA ≤ I_R ≤ 20mA		10	**20**	20	**25**	20	**25**	mV (Max)
Reverse Dynamic Impedance	I_R = 100μA, f = 20Hz	1							Ω
Wideband Noise (rms)	I_R = 100μA, 10Hz ≤ f ≤ 10kHz	60							μV
Long Term Stability	I_R = 100μA, T = 1000 Hr, T_A = 25°C ±0.1°C	20							ppm
Average Temperature Coefficient [5]	I_R = 100μA								
	X Suffix		**30**		**30**				ppm/°C
	Y Suffix		**50**		**50**				ppm/°C
	All Others			**150**		**150**		**150**	ppm/°C (Max)

(1) Parameters identified with boldface type apply at temperature extremes. All other numbers apply at $T_A = T_J$ = 25°C.
(2) Production tested.
(3) A military RETS electrical specification is available on request.
(4) Specified by design. Not production tested. These limits are not used to calculate average outgoing quality levels.
(5) The average temperature coefficient is defined as the maximum deviation of reference voltage at all measured temperatures between the operating T_{MAX} and T_{MIN}, divided by $T_{MAX} - T_{MIN}$. The measured temperatures are −55°C, −40°C, 0°C, 25°C, 70°C, 85°C, 125°C.

THERMAL CHARACTERISTICS

Thermal Resistance	TO-92	TO	SOIC	SOT-23
θ_{JA} (junction to ambient)	180°C/W (0.4″ leads) 170°C/W (0.125″ leads)	440°C/W	165°C/W	283°C/W
θ_{JC} (junction to case)	N/A	80°C/W	N/A	N/A

TYPICAL PERFORMANCE CHARACTERISTICS

Reverse Characteristics

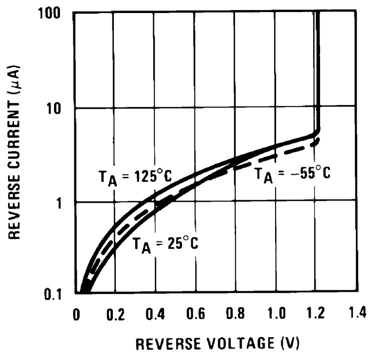


Figure 5.

Reverse Characteristics

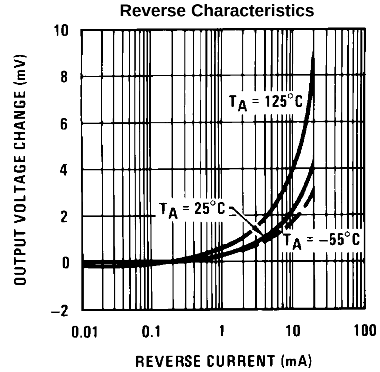


Figure 6.

Forward Characteristics

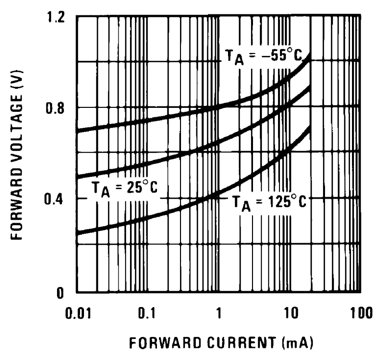


Figure 7.

Temperature Drift of 3 Representative Units

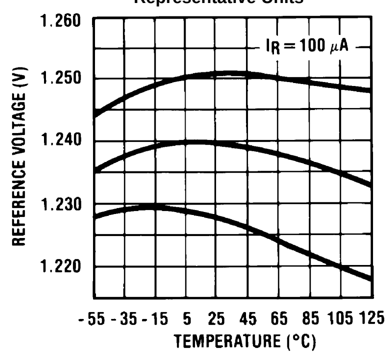


Figure 8.

Reverse Dynamic Impedance

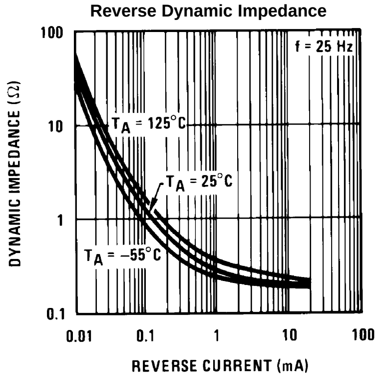


Figure 9.

Reverse Dynamic Impedance

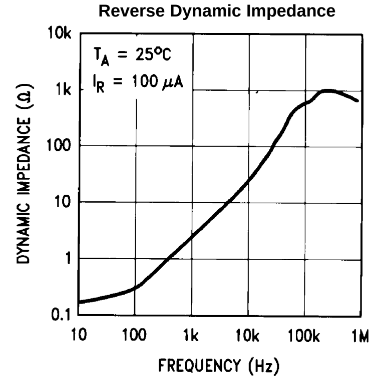


Figure 10.

TYPICAL PERFORMANCE CHARACTERISTICS (continued)

Noise Voltage

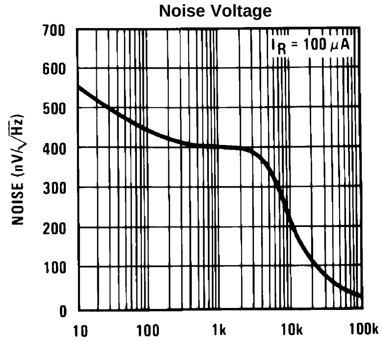


Figure 11.

Filtered Output Noise

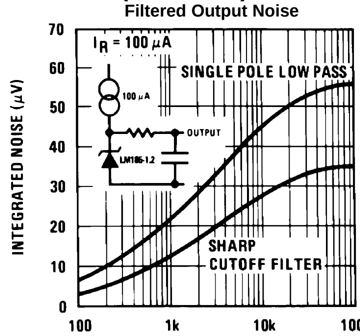


Figure 12.

Response Time

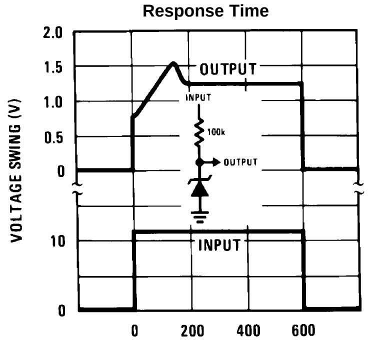


Figure 13.

TYPICAL APPLICATIONS

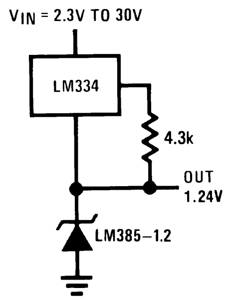


Figure 14. Wide Input Range Reference

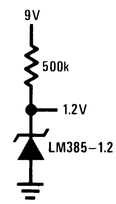


Figure 15. Micropower Reference from 9V Battery

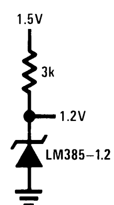
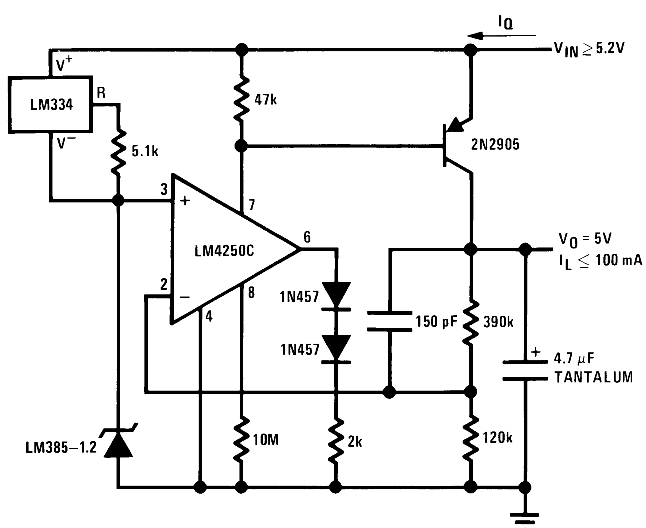
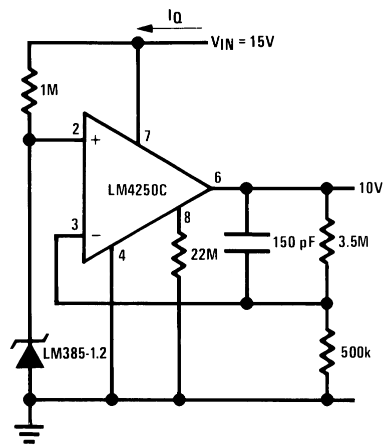


Figure 16. Reference from 1.5V Battery



*I_Q ≃ 30μA

Figure 17. Micropower* 5V Regulator



*I_Q ≈20μA standby current

Figure 18. Micropower* 10V Reference

*$I_{OUT} = \frac{1.23V}{R2}$

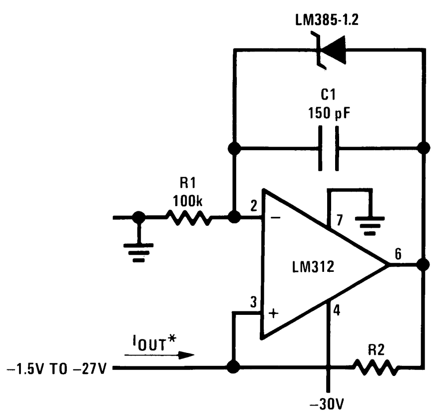


Figure 19.

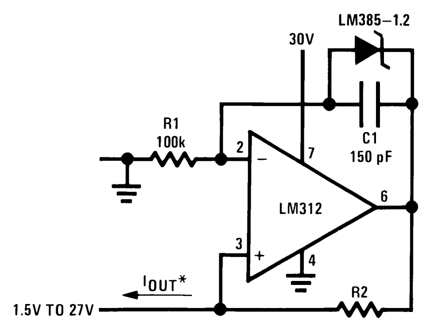
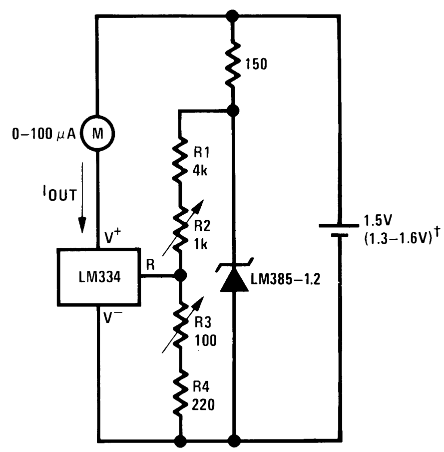


Figure 20. Precision 1μA to 1mA Current Sources

METER THERMOMETERS



Calibration

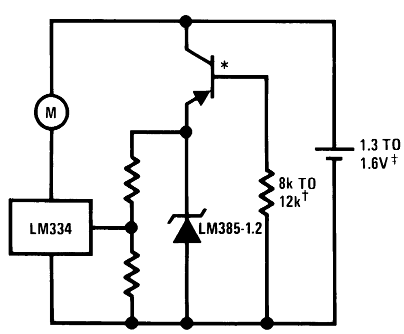
1. Short LM385-1.2-N, adjust R3 for I_{OUT}= temp at 1µA/°K
2. Remove short, adjust R2 for correct reading in centigrade

†I_Q at 1.3V≈500µA

I_Q at 1.6V≈2.4mA

Figure 21. 0°C−100°C Thermometer

Figure 22.

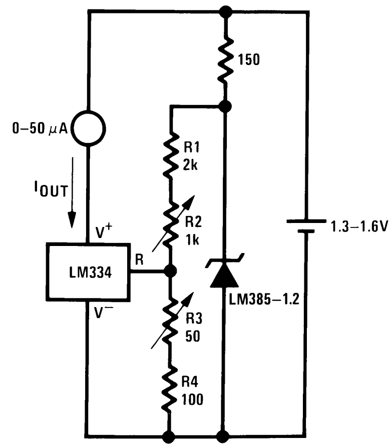


*2N3638 or 2N2907 select for inverse H_{FE} ≃ 5

†Select for operation at 1.3V

‡I_Q ≃ 600µA to 900µA

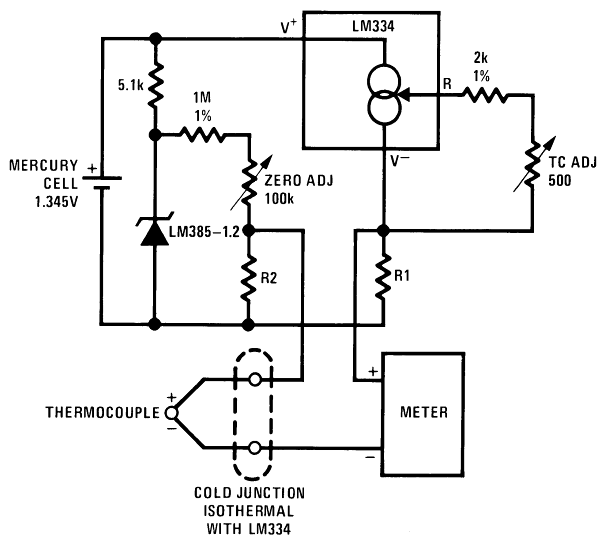
Figure 23. Lower Power Thermometer



Calibration

1. Short LM385-1.2-N, adjust R3 for I_{OUT}= temp at 1.8μA/°K
2. Remove short, adjust R2 for correct reading in °F

Figure 24. 0°F−50°F Thermometer



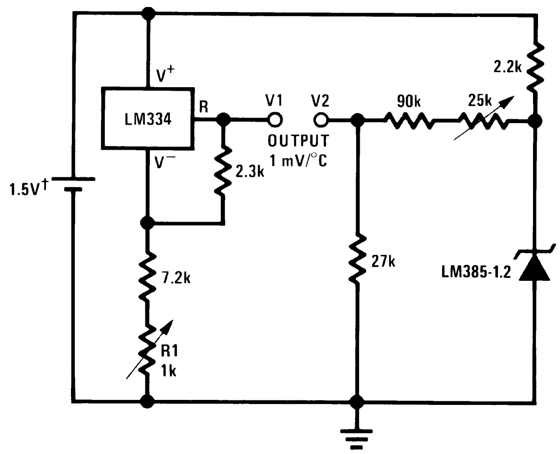
Adjustment Procedure

1. Adjust TC ADJ pot until voltage across R1 equals Kelvin temperature multiplied by the thermocouple Seebeck coefficient.
2. Adjust zero ADJ pot until voltage across R2 equals the thermocouple Seebeck coefficient multiplied by 273.2.

Figure 25. Micropower Thermocouple Cold Junction Compensator

Thermocouple Type	Seebeck Coefficient (μV/°C)	R1 (Ω)	R2 (Ω)	Voltage Across R1 @ 25°C (mV)	Voltage Across R2 (mV)
J	52.3	523	1.24k	15.60	14.32
T	42.8	432	1k	12.77	11.78
K	40.8	412	953Ω	12.17	11.17
S	6.4	63.4	150Ω	1.908	1.766

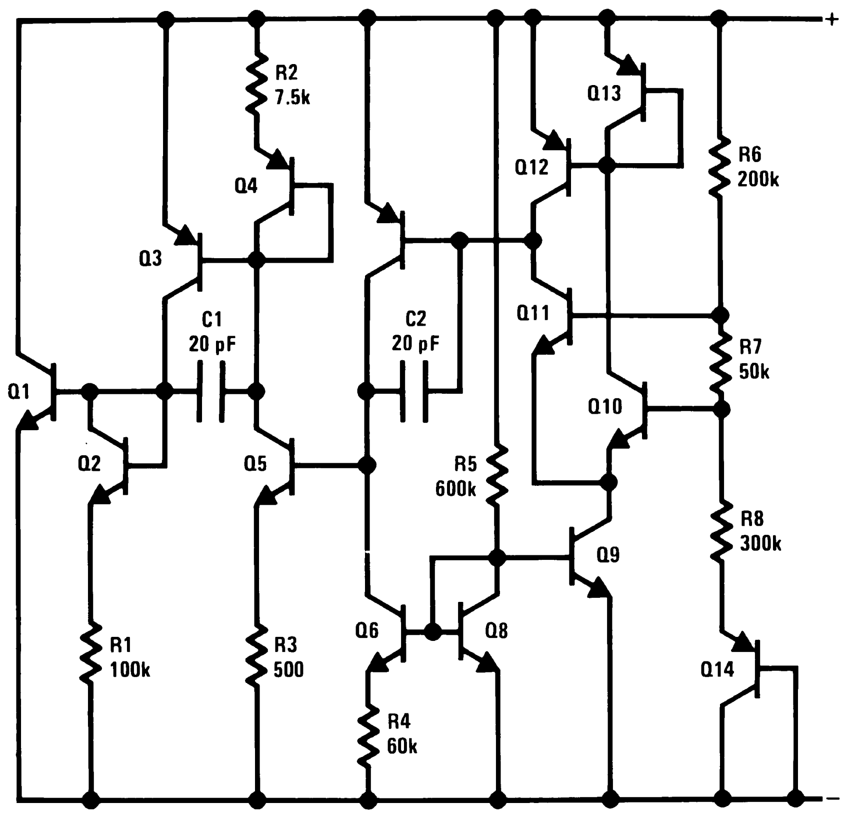
Typical supply current 50μA



Calibration
1. Adjust R1 so that V1 = temp at 1mV/°K
2. Adjust V2 to 273.2mV
†I_Q for 1.3V to 1.6V battery voltage = 50μA to 150μA

Figure 26. Centigrade Thermometer

SCHEMATIC DIAGRAM



REVISION HISTORY

Changes from Revision D (April 2013) to Revision E	Page
• Changed layout of National Data Sheet to TI format	11

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
LM185BYH-1.2/NOPB	ACTIVE	TO	NDU	2	1000	Green (RoHS & no Sb/Br)	Call TI | POST-PLATE	Level-1-NA-UNLIM	-55 to 125	(LM185BYH1.2, LM1 85BYH1.2)	Samples
LM185H-1.2/NOPB	ACTIVE	TO	NDU	2	1000	Green (RoHS & no Sb/Br)	Call TI | POST-PLATE	Level-1-NA-UNLIM	-55 to 125	(LM185H1.2, LM185 H1.2)	Samples
LM285BXM-1.2/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	285BX M1.2	Samples
LM285BXMX-1.2/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	285BX M1.2	Samples
LM285BXZ-1.2/LFT4	ACTIVE	TO-92	LP	3	2000	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type		285BX Z-1.2	Samples
LM285BXZ-1.2/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type	-40 to 85	285BX Z-1.2	Samples
LM285BYM-1.2/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	285BY M1.2	Samples
LM285BYMX-1.2/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	285BY M1.2	Samples
LM285M-1.2/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	LM285 M1.2	Samples
LM285MX-1.2/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	LM285 M1.2	Samples
LM285Z-1.2/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type	-40 to 85	LM28 5Z-1.2	Samples
LM385BM-1.2/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM385 BM1.2	Samples
LM385BMX-1.2	NRND	SOIC	D	8	2500	TBD	Call TI	Call TI	0 to 70	LM385 BM1.2	
LM385BMX-1.2/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM385 BM1.2	Samples
LM385BXM-1.2/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	385BX M1.2	Samples
LM385BXMX-1.2/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	385BX M1.2	Samples
LM385BXZ-1.2/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type	0 to 70	385BX Z-1.2	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
LM385BYM-1.2/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	385BY M1.2	Samples
LM385BYMX-1.2/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	385BY M1.2	Samples
LM385BYZ-1.2/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type	0 to 70	385BY Z-1.2	Samples
LM385BZ-1.2/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type	0 to 70	LM385 BZ1.2	Samples
LM385M-1.2	NRND	SOIC	D	8	95	TBD	Call TI	Call TI	0 to 70	LM385 M1.2	
LM385M-1.2/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM385 M1.2	Samples
LM385M3-1.2	NRND	SOT-23	DBZ	3	1000	TBD	Call TI	Call TI	0 to 70	R11	
LM385M3-1.2/NOPB	ACTIVE	SOT-23	DBZ	3	1000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	R11	Samples
LM385M3X-1.2	NRND	SOT-23	DBZ	3	3000	TBD	Call TI	Call TI	0 to 70	R11	
LM385M3X-1.2/NOPB	ACTIVE	SOT-23	DBZ	3	3000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	R11	Samples
LM385MX-1.2/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM385 M1.2	Samples
LM385Z-1.2/LFT3	ACTIVE	TO-92	LP	3	2000	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type		LM385 Z-1.2	Samples
LM385Z-1.2/LFT4	ACTIVE	TO-92	LP	3	2000	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type		LM385 Z-1.2	Samples
LM385Z-1.2/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	CU SN	N / A for Pkg Type	0 to 70	LM385 Z-1.2	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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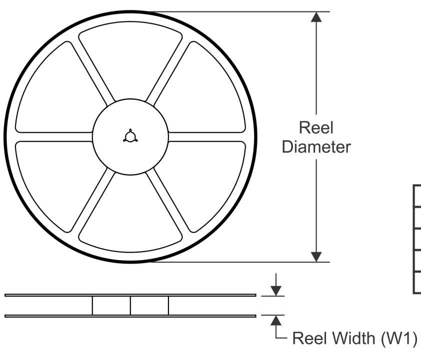
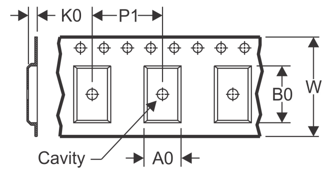
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

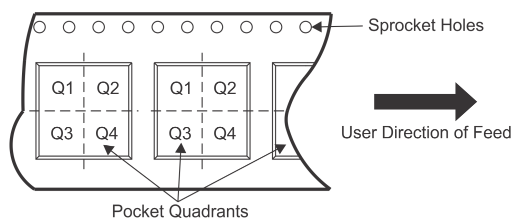


TAPE DIMENSIONS



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

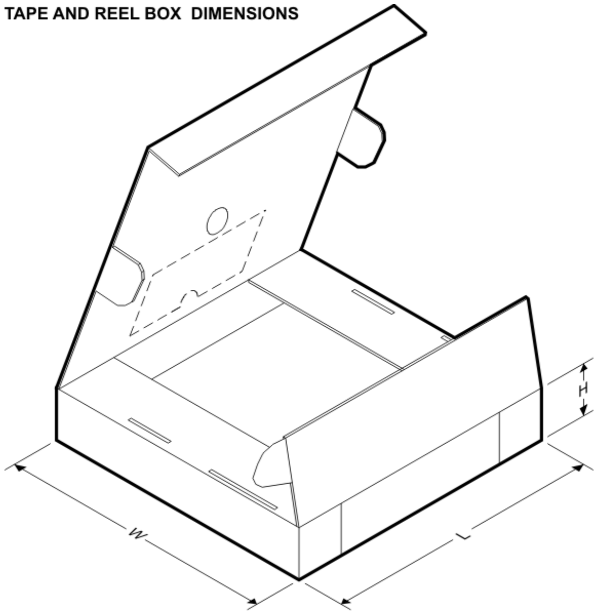
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

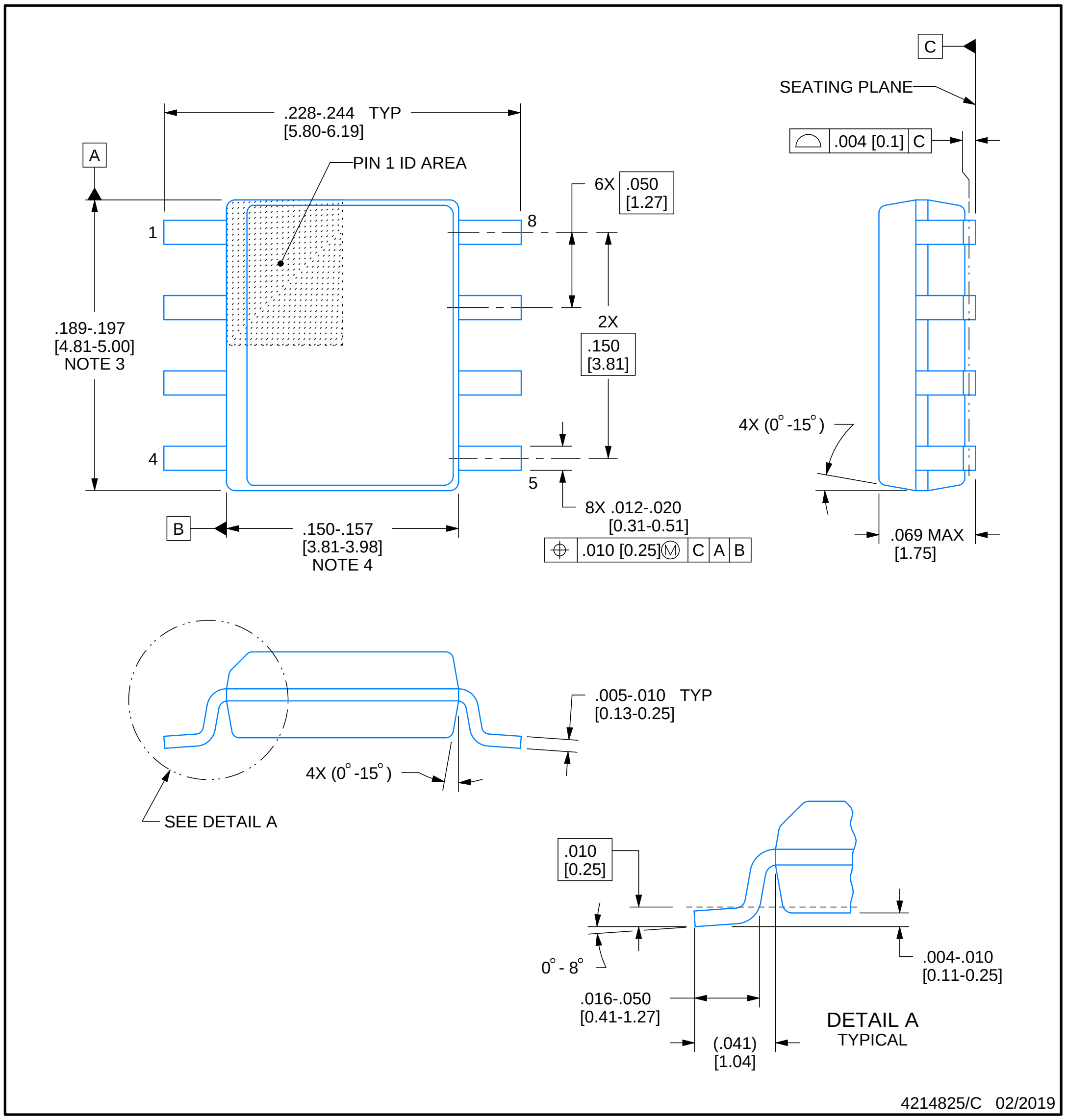
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM285BXMX-1.2/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM285BYMX-1.2/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM285MX-1.2/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM385BMX-1.2	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM385BMX-1.2/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM385BXMX-1.2/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM385BYMX-1.2/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM385M3-1.2	SOT-23	DBZ	3	1000	178.0	8.4	3.3	2.9	1.22	4.0	8.0	Q3
LM385M3-1.2/NOPB	SOT-23	DBZ	3	1000	178.0	8.4	3.3	2.9	1.22	4.0	8.0	Q3
LM385M3X-1.2	SOT-23	DBZ	3	3000	178.0	8.4	3.3	2.9	1.22	4.0	8.0	Q3
LM385M3X-1.2/NOPB	SOT-23	DBZ	3	3000	178.0	8.4	3.3	2.9	1.22	4.0	8.0	Q3
LM385MX-1.2/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



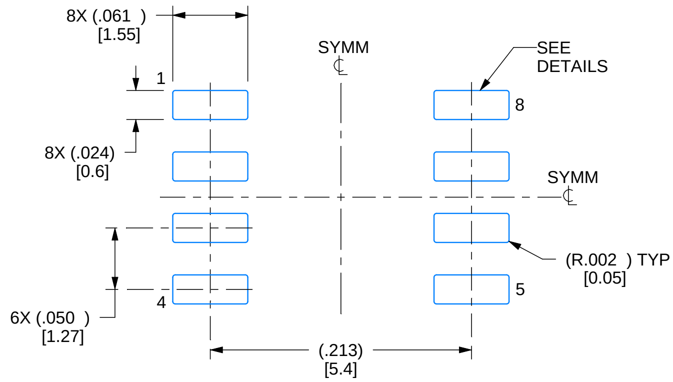
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM285BXMX-1.2/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM285BYMX-1.2/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM285MX-1.2/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM385BMX-1.2	SOIC	D	8	2500	367.0	367.0	35.0
LM385BMX-1.2/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM385BXMX-1.2/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM385BYMX-1.2/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM385M3-1.2	SOT-23	DBZ	3	1000	210.0	185.0	35.0
LM385M3-1.2/NOPB	SOT-23	DBZ	3	1000	210.0	185.0	35.0
LM385M3X-1.2	SOT-23	DBZ	3	3000	210.0	185.0	35.0
LM385M3X-1.2/NOPB	SOT-23	DBZ	3	3000	210.0	185.0	35.0
LM385MX-1.2/NOPB	SOIC	D	8	2500	367.0	367.0	35.0

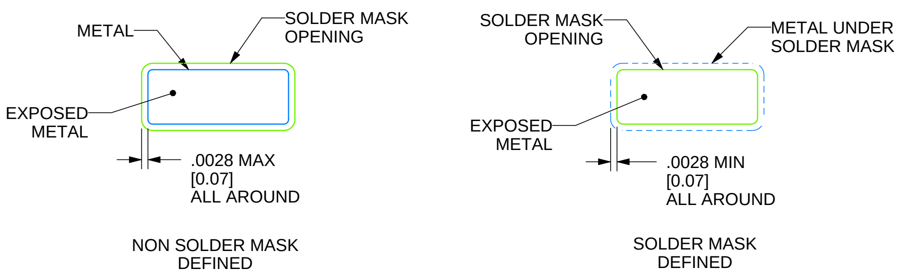


NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. 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 .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X

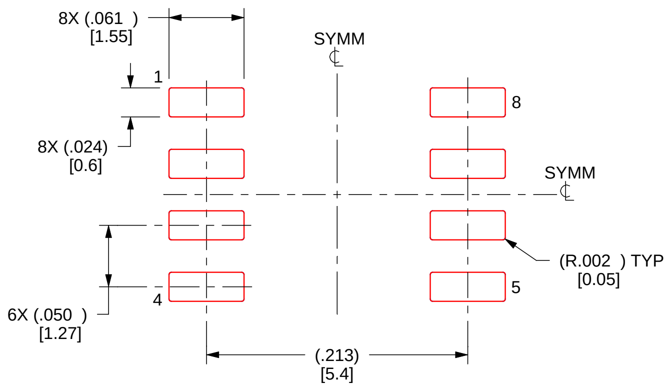


SOLDER MASK DETAILS

4214825/C 02/2019

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 .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

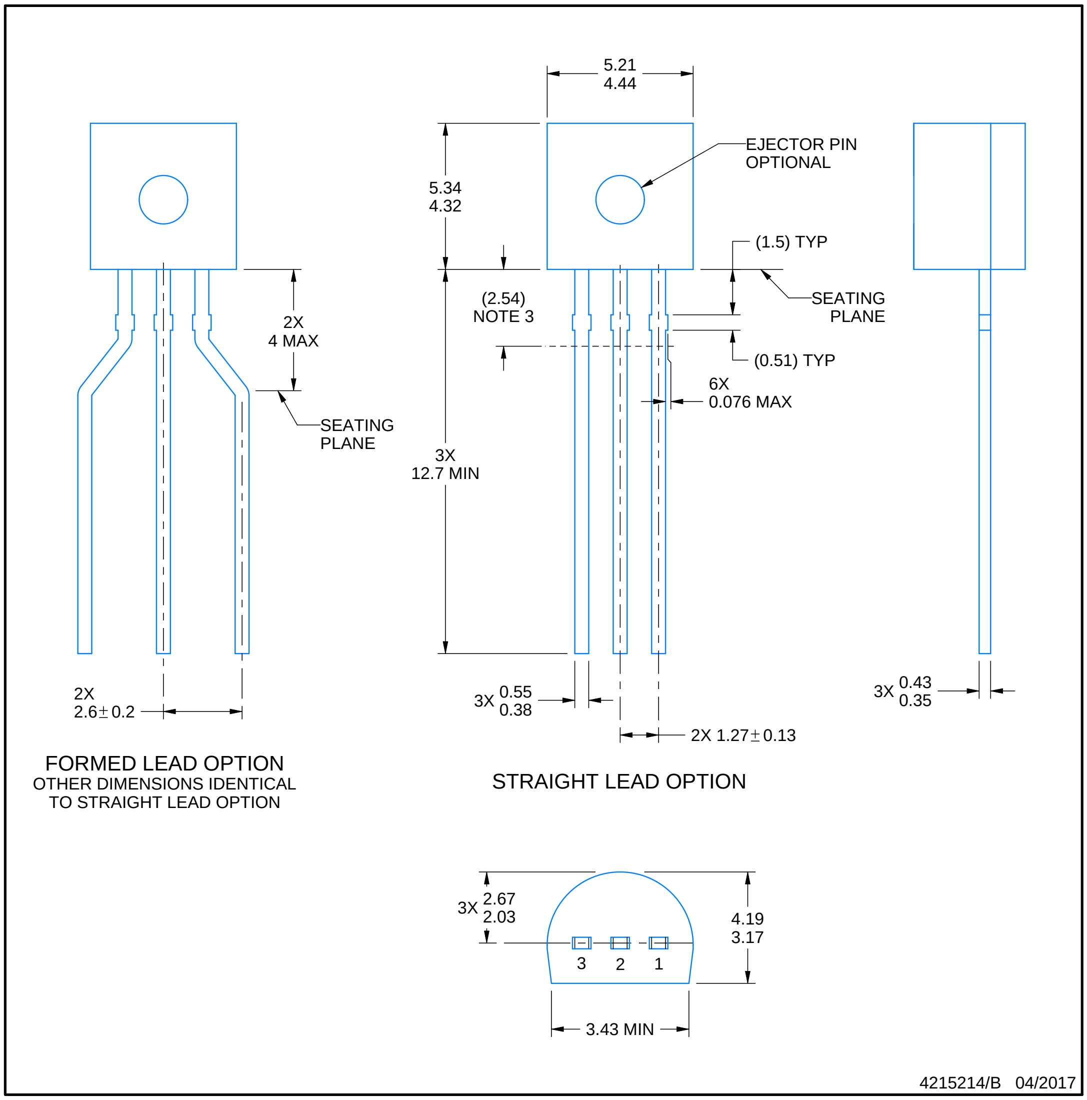
8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

LP 3 **TO-92 - 5.34 mm max height**

TRANSISTOR OUTLINE

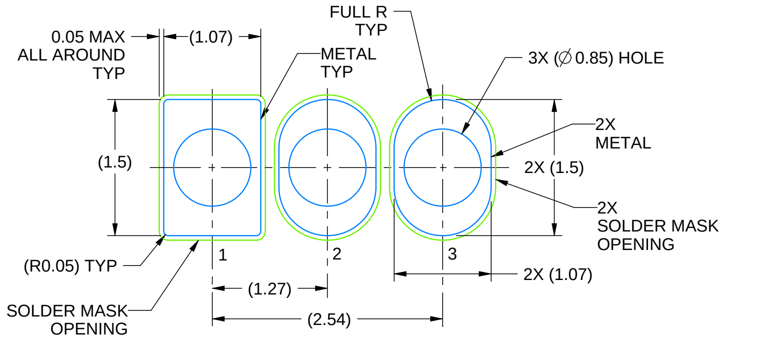
Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

4040001-2/F

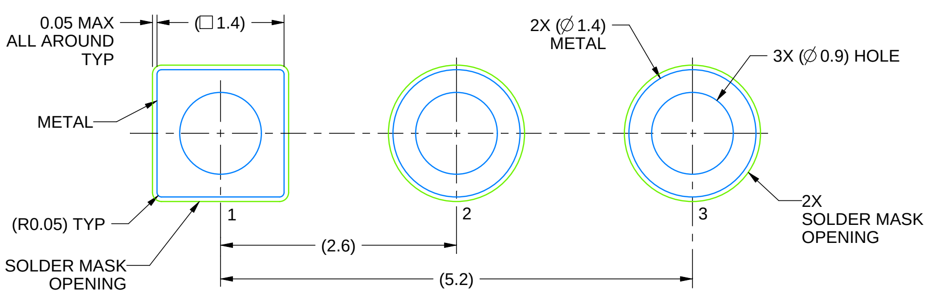


NOTES:

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. Lead dimensions are not controlled within this area.
4. Reference JEDEC TO-226, variation AA.
5. Shipping method:
   a. Straight lead option available in bulk pack only.
   b. Formed lead option available in tape and reel or ammo pack.
   c. Specific products can be offered in limited combinations of shipping medium and lead options.
   d. Consult product folder for more information on available options.

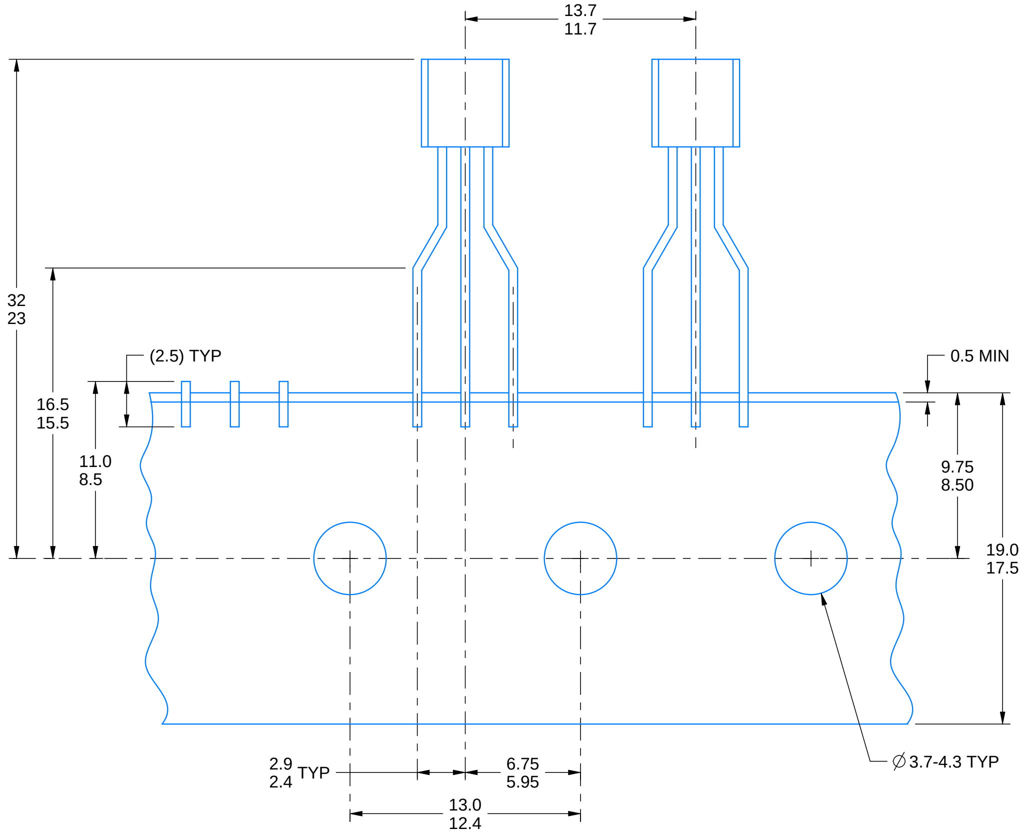


LAND PATTERN EXAMPLE
STRAIGHT LEAD OPTION
NON-SOLDER MASK DEFINED
SCALE:15X



LAND PATTERN EXAMPLE
FORMED LEAD OPTION
NON-SOLDER MASK DEFINED
SCALE:15X

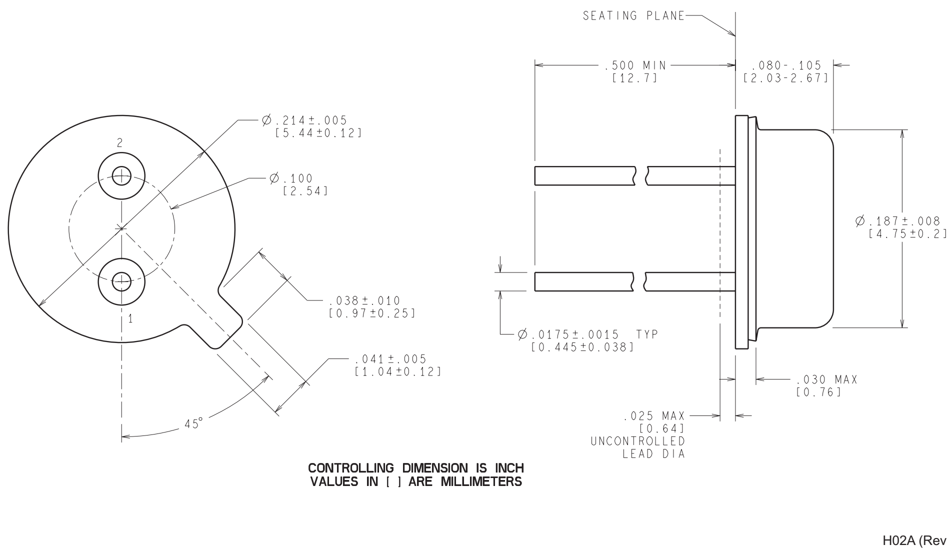
4215214/B 04/2017



FOR FORMED LEAD OPTION PACKAGE

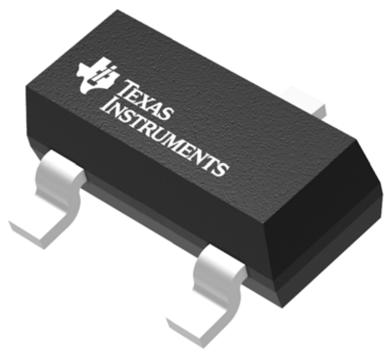
4215214/B 04/2017

NDU0002A

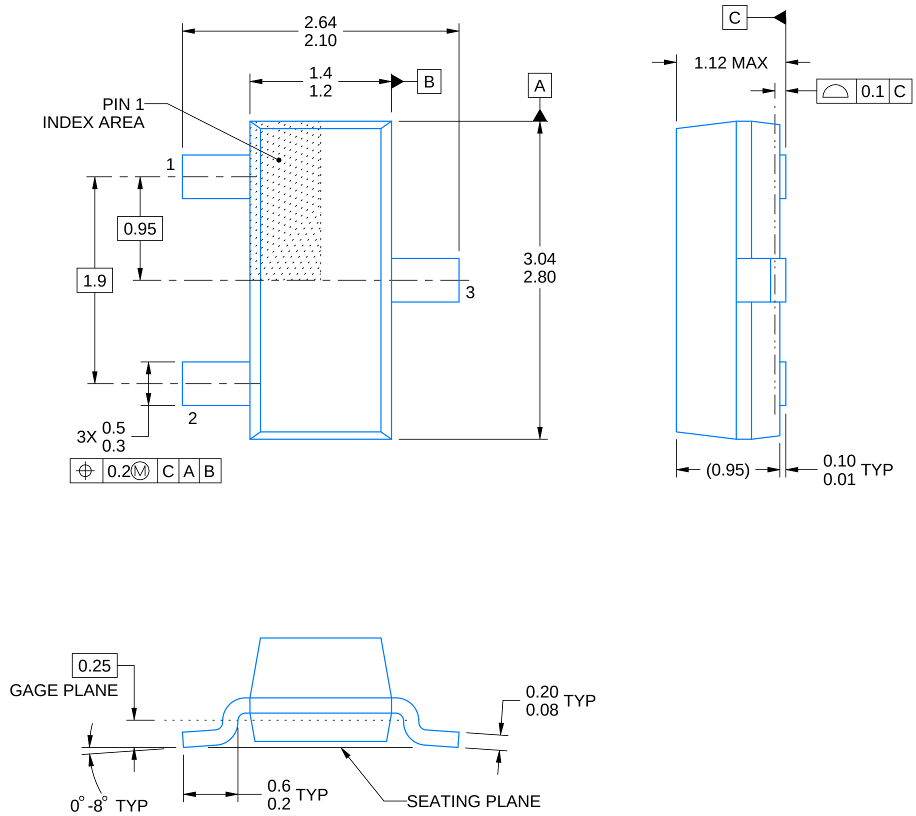

SEATING PLANE
.500 MIN
[12.7]
.080-.105
[2.03-2.67]
Ø.214±.005
[5.44±0.12]
2
Ø.100
[2.54]
Ø.187±.008
[4.75±0.2]
.038±.010
[0.97±0.25]
1
Ø.0175±.0015 TYP
[0.445±0.038]
.041±.005
[1.04±0.12]
.030 MAX
[0.76]
45°
.025 MAX
[0.64]
UNCONTROLLED
LEAD DIA
CONTROLLING DIMENSION IS INCH
VALUES IN [ ] ARE MILLIMETERS
H02A (Rev F)

DBZ 3 SOT-23 - 1.12 mm max height

SMALL OUTLINE TRANSISTOR



Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.



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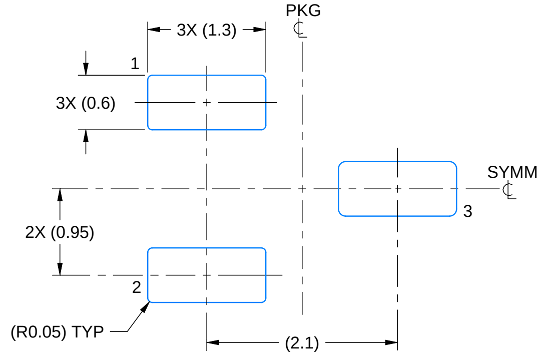
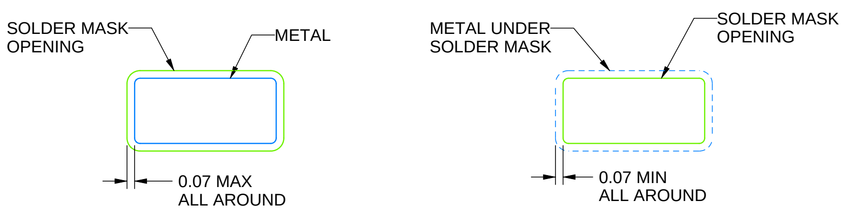
NOTES:

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. Reference JEDEC registration TO-236, except minimum foot length.



LAND PATTERN EXAMPLE
SCALE:15X



NON SOLDER MASK DEFINED (PREFERRED)

SOLDER MASK DEFINED

SOLDER MASK DETAILS

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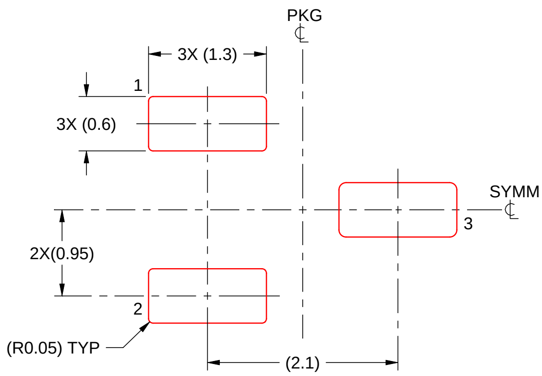
NOTES: (continued)

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



SOLDER PASTE EXAMPLE
BASED ON 0.125 THICK STENCIL
SCALE:15X

4214838/C 04/2017

NOTES: (continued)

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

MCP3004/3008

2.7V 4-Channel/8-Channel 10-Bit A/D Converters with SPI Serial Interface

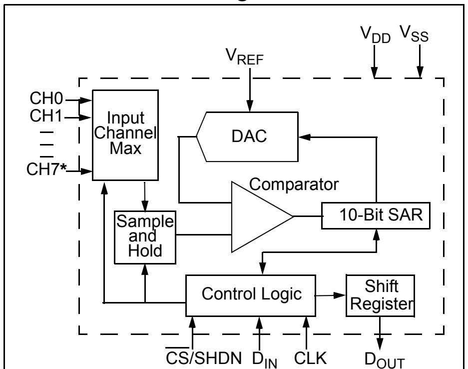
Features

- 10-bit resolution
- ± 1 LSB max DNL
- ± 1 LSB max INL
- 4 (MCP3004) or 8 (MCP3008) input channels
- Analog inputs programmable as single-ended or pseudo-differential pairs
- On-chip sample and hold
- SPI serial interface (modes 0,0 and 1,1)
- Single supply operation: 2.7V - 5.5V
- 200 ksps max. sampling rate at V_{DD} = 5V
- 75 ksps max. sampling rate at V_{DD} = 2.7V
- Low power CMOS technology
- 5 nA typical standby current, 2 µA max.
- 500 µA max. active current at 5V
- Industrial temp range: -40°C to +85°C
- Available in PDIP, SOIC and TSSOP packages

Applications

- Sensor Interface
- Process Control
- Data Acquisition
- Battery Operated Systems

Functional Block Diagram

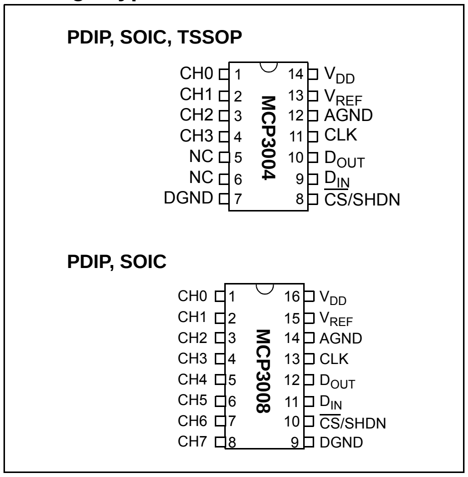


*** Note:** Channels 4-7 are available on MCP3008 Only

Description

The Microchip Technology Inc. MCP3004/3008 devices are successive approximation 10-bit Analog-to-Digital (A/D) converters with on-board sample and hold circuitry. The MCP3004 is programmable to provide two pseudo-differential input pairs or four single-ended inputs. The MCP3008 is programmable to provide four pseudo-differential input pairs or eight single-ended inputs. Differential Nonlinearity (DNL) and Integral Nonlinearity (INL) are specified at ±1 LSB. Communication with the devices is accomplished using a simple serial interface compatible with the SPI protocol. The devices are capable of conversion rates of up to 200 ksps. The MCP3004/3008 devices operate over a broad voltage range (2.7V - 5.5V). Low-current design permits operation with typical standby currents of only 5 nA and typical active currents of 320 µA. The MCP3004 is offered in 14-pin PDIP, 150 mil SOIC and TSSOP packages, while the MCP3008 is offered in 16-pin PDIP and SOIC packages.

Package Types



NOTES:

1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

V_{DD} 7.0V
All Inputs and Outputs w.r.t. V_{SS} ....– 0.6V to V_{DD} + 0.6V
Storage Temperature ....–65°C to +150°C
Ambient temperature with power applied.......–65°C to +150°C
Soldering temperature of leads (10 seconds) .... +300°C
ESD Protection On All Pins (HBM)....................≥ 4 kV

† Notice: Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL SPECIFICATIONS

Electrical Characteristics: Unless otherwise noted, all parameters apply at V_{DD} = 5V, V_{REF} = 5V, T_A = -40°C to +85°C, f_{SAMPLE} = 200 ksps and f_{CLK} = 18*f_{SAMPLE}. Unless otherwise noted, typical values apply for V_{DD} = 5V, T_A = +25°C.

Parameter	Sym	Min	Typ	Max	Units	Conditions
Conversion Rate						
Conversion Time	t_{CONV}	—	—	10	clock cycles	
Analog Input Sample Time	t_{SAMPLE}		1.5		clock cycles	
Throughput Rate	f_{SAMPLE}	—	—	200 75	ksps ksps	V_{DD} = V_{REF} = 5V V_{DD} = V_{REF} = 2.7V
DC Accuracy						
Resolution			10		bits	
Integral Nonlinearity	INL	—	±0.5	±1	LSB	
Differential Nonlinearity	DNL	—	±0.25	±1	LSB	No missing codes over temperature
Offset Error		—	—	±1.5	LSB	
Gain Error		—	—	±1.0	LSB	
Dynamic Performance						
Total Harmonic Distortion		—	-76		dB	V_{IN} = 0.1V to 4.9V@1 kHz
Signal-to-Noise and Distortion (SINAD)		—	61		dB	V_{IN} = 0.1V to 4.9V@1 kHz
Spurious Free Dynamic Range		—	78		dB	V_{IN} = 0.1V to 4.9V@1 kHz
Reference Input						
Voltage Range		0.25	—	V_{DD}	V	Note 2
Current Drain		—	100 0.001	150 3	µA µA	 $\overline{CS}$ = V_{DD} = 5V
Analog Inputs						
Input Voltage Range for CH0 or CH1 in Single-Ended Mode		V_{SS}	—	V_{REF}	V	
Input Voltage Range for IN+ in pseudo-differential mode		IN-	—	V_{REF}+IN-		
Input Voltage Range for IN- in pseudo-differential mode		V_{SS}-100	—	V_{SS}+100	mV	

Note 1: This parameter is established by characterization and not 100% tested.
2: See graphs that relate linearity performance to V_{REF} levels.
3: Because the sample cap will eventually lose charge, effective clock rates below 10 kHz can affect linearity performance, especially at elevated temperatures. See **Section 6.2 “Maintaining Minimum Clock Speed”**, “Maintaining Minimum Clock Speed”, for more information.

ELECTRICAL SPECIFICATIONS (CONTINUED)

Electrical Characteristics: Unless otherwise noted, all parameters apply at V_{DD} = 5V, V_{REF} = 5V, T_A = -40°C to +85°C, f_{SAMPLE} = 200 ksps and f_{CLK} = 18*f_{SAMPLE}. Unless otherwise noted, typical values apply for V_{DD} = 5V, T_A = +25°C.

Parameter	Sym	Min	Typ	Max	Units	Conditions
Leakage Current		—	0.001	±1	µA	
Switch Resistance		—	1000	—	Ω	See Figure 4-1
Sample Capacitor		—	20	—	pF	See Figure 4-1
Digital Input/Output						
Data Coding Format		Straight Binary				
High Level Input Voltage	V_{IH}	0.7 V_{DD}	—	—	V	
Low Level Input Voltage	V_{IL}		—	0.3 V_{DD}	V	
High Level Output Voltage	V_{OH}	4.1	—	—	V	I_{OH} = -1 mA, V_{DD} = 4.5V
Low Level Output Voltage	V_{OL}	—	—	0.4	V	I_{OL} = 1 mA, V_{DD} = 4.5V
Input Leakage Current	I_{LI}	-10	—	10	µA	V_{IN} = V_{SS} or V_{DD}
Output Leakage Current	I_{LO}	-10	—	10	µA	V_{OUT} = V_{SS} or V_{DD}
Pin Capacitance (All Inputs/Outputs)	C_{IN}, C_{OUT}	—	—	10	pF	V_{DD} = 5.0V (**Note 1**) T_A = 25°C, f = 1 MHz
Timing Parameters						
Clock Frequency	f_{CLK}	—	—	3.6 1.35	MHz MHz	V_{DD} = 5V (**Note 3**) V_{DD} = 2.7V (**Note 3**)
Clock High Time	t_{HI}	125	—	—	ns	
Clock Low Time	t_{LO}	125	—	—	ns	
$\overline{CS}$ Fall To First Rising CLK Edge	t_{SUCS}	100	—	—	ns	
$\overline{CS}$ Fall To Falling CLK Edge	t_{CSD}	—	—	0	ns	
Data Input Setup Time	t_{SU}	50	—	—	ns	
Data Input Hold Time	t_{HD}	50	—	—	ns	
CLK Fall To Output Data Valid	t_{DO}	—	—	125 200	ns ns	V_{DD} = 5V, See Figure 1-2 V_{DD} = 2.7V, See Figure 1-2
CLK Fall To Output Enable	t_{EN}	—	—	125 200	ns ns	V_{DD} = 5V, See Figure 1-2 V_{DD} = 2.7V, See Figure 1-2
$\overline{CS}$ Rise To Output Disable	t_{DIS}	—	—	100	ns	See Test Circuits, Figure 1-2
$\overline{CS}$ Disable Time	t_{CSH}	270	—	—	ns	
D_{OUT} Rise Time	t_R	—	—	100	ns	See Test Circuits, Figure 1-2 (**Note 1**)
D_{OUT} Fall Time	t_F	—	—	100	ns	See Test Circuits, Figure 1-2 (**Note 1**)

Note 1: This parameter is established by characterization and not 100% tested.
2: See graphs that relate linearity performance to V_{REF} levels.
3: Because the sample cap will eventually lose charge, effective clock rates below 10 kHz can affect linearity performance, especially at elevated temperatures. See **Section 6.2 "Maintaining Minimum Clock Speed"**, "Maintaining Minimum Clock Speed", for more information.

ELECTRICAL SPECIFICATIONS (CONTINUED)

Parameter	Sym	Min	Typ	Max	Units	Conditions
Electrical Characteristics: Unless otherwise noted, all parameters apply at V_{DD} = 5V, V_{REF} = 5V, T_A = -40°C to +85°C, f_{SAMPLE} = 200 ksps and f_{CLK} = 18*f_{SAMPLE}. Unless otherwise noted, typical values apply for V_{DD} = 5V, T_A = +25°C.						
Power Requirements						
Operating Voltage	V_{DD}	2.7	—	5.5	V	
Operating Current	I_{DD}	—	425 225	550	µA	V_{DD} = V_{REF} = 5V, D_{OUT} unloaded V_{DD} = V_{REF} = 2.7V, D_{OUT} unloaded
Standby Current	I_{DDS}	—	0.005	2	µA	$\overline{CS}$ = V_{DD} = 5.0V

Note 1: This parameter is established by characterization and not 100% tested.
2: See graphs that relate linearity performance to V_{REF} levels.
3: Because the sample cap will eventually lose charge, effective clock rates below 10 kHz can affect linearity performance, especially at elevated temperatures. See **Section 6.2 "Maintaining Minimum Clock Speed"**, "Maintaining Minimum Clock Speed", for more information.

TEMPERATURE CHARACTERISTICS

Parameters	Sym	Min	Typ	Max	Units	Conditions
Electrical Specifications: Unless otherwise indicated, V_{DD} = +2.7V to +5.5V, V_{SS} = GND.						
Temperature Ranges						
Specified Temperature Range	T_A	-40	—	+85	°C	
Operating Temperature Range	T_A	-40	—	+85	°C	
Storage Temperature Range	T_A	-65	—	+150	°C	
Thermal Package Resistances						
Thermal Resistance, 14L-PDIP	θ_{JA}	—	70	—	°C/W	
Thermal Resistance, 14L-SOIC	θ_{JA}	—	108	—	°C/W	
Thermal Resistance, 14L-TSSOP	θ_{JA}	—	100	—	°C/W	
Thermal Resistance, 16L-PDIP	θ_{JA}	—	70	—	°C/W	
Thermal Resistance, 16L-SOIC	θ_{JA}	—	90	—	°C/W	

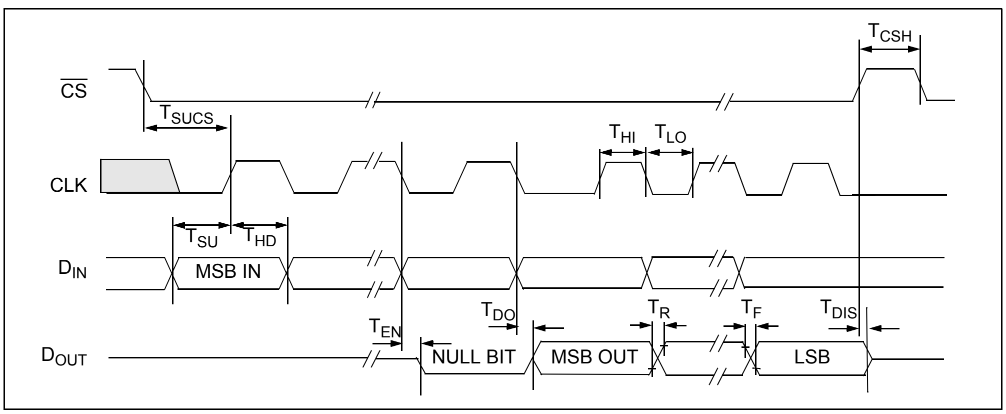


FIGURE 1-1: *Serial Interface Timing.*

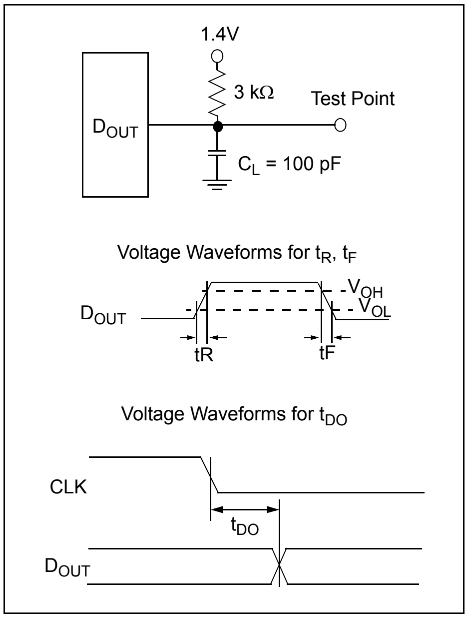


FIGURE 1-2: *Load Circuit for t_R, t_F, t_{DO}.*

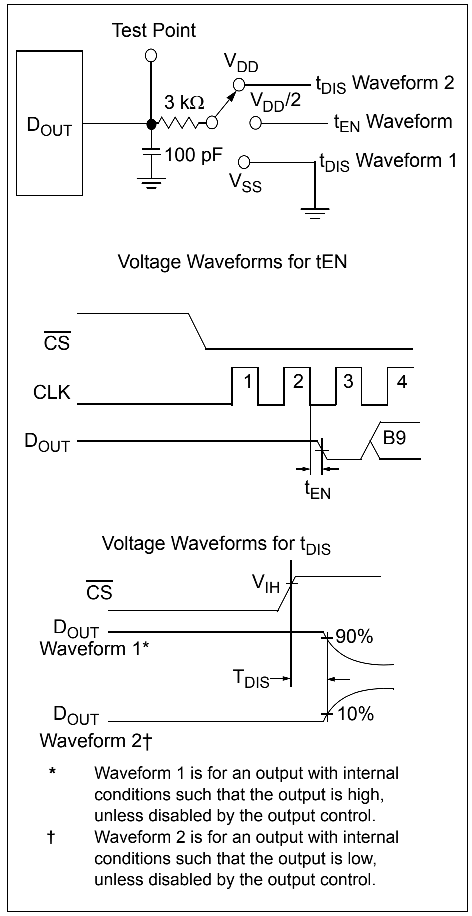


FIGURE 1-3: *Load circuit for t_{DIS} and t_{EN}.*

2.0 TYPICAL PERFORMANCE CHARACTERISTICS

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range.

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18^* f_{SAMPLE}$, $T_A = +25°C$.

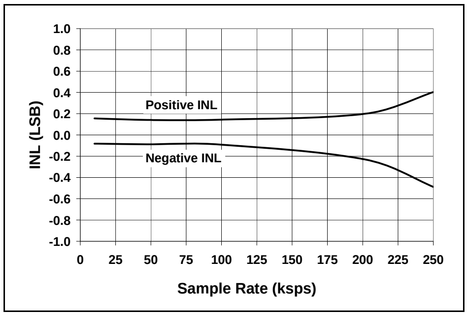


FIGURE 2-1: *Integral Nonlinearity (INL) vs. Sample Rate.*

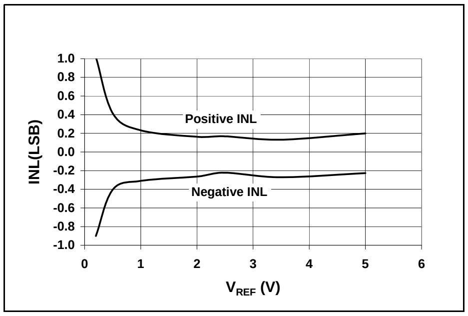


FIGURE 2-2: *Integral Nonlinearity (INL) vs. V_{REF}*

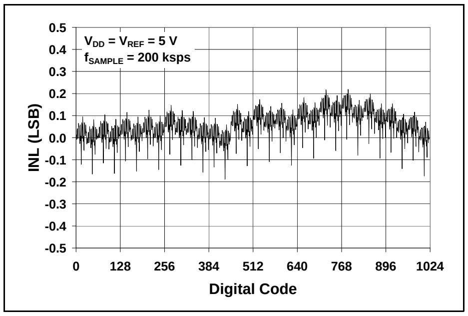


FIGURE 2-3: *Integral Nonlinearity (INL) vs. Code (Representative Part).*

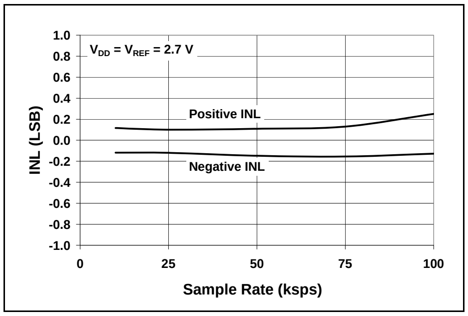


FIGURE 2-4: *Integral Nonlinearity (INL) vs. Sample Rate (V_{DD} = 2.7V).*

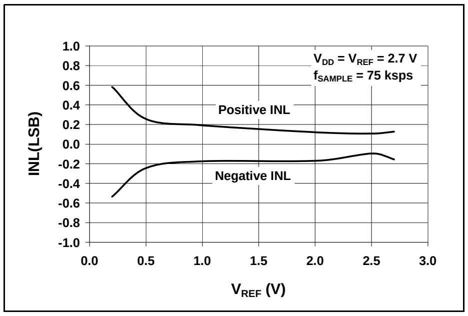


FIGURE 2-5: *Integral Nonlinearity (INL) vs. V_{REF} (V_{DD} = 2.7V).*

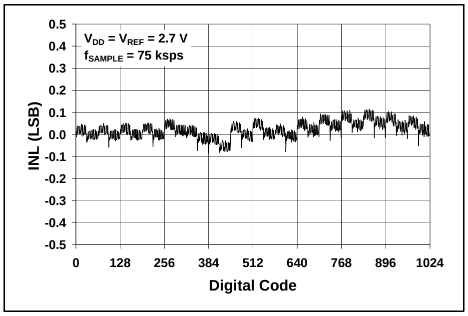


FIGURE 2-6: *Integral Nonlinearity (INL) vs. Code (Representative Part, V_{DD} = 2.7V).*

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18^* f_{SAMPLE}$, $T_A = +25°C$.

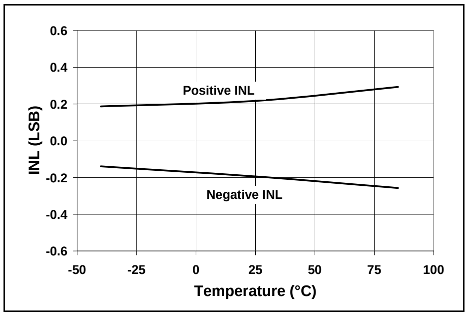


FIGURE 2-7: Integral Nonlinearity (INL) vs. Temperature.

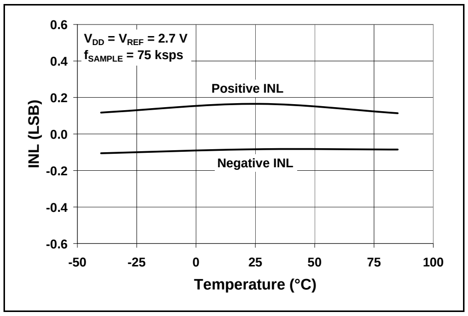


FIGURE 2-10: Integral Nonlinearity (INL) vs. Temperature (V_{DD} = 2.7V).

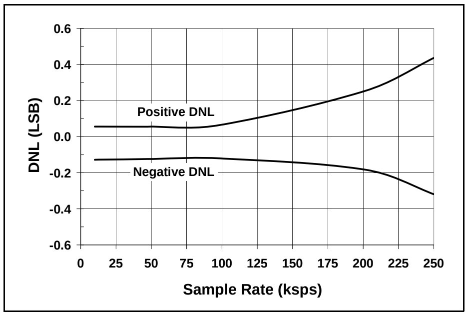


FIGURE 2-8: Differential Nonlinearity (DNL) vs. Sample Rate.

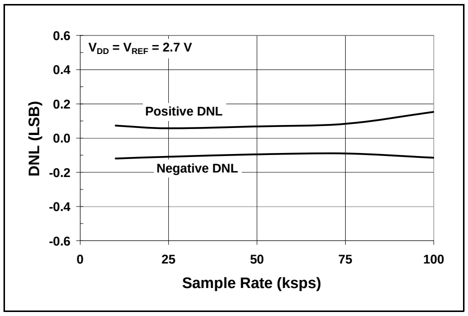


FIGURE 2-11: Differential Nonlinearity (DNL) vs. Sample Rate (V_{DD} = 2.7V).

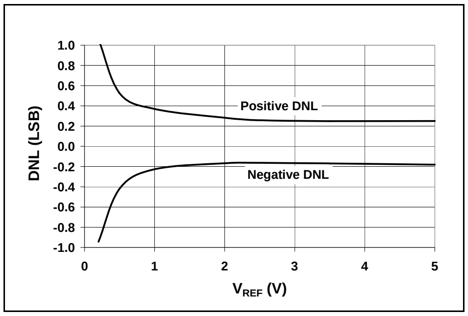


FIGURE 2-9: Differential Nonlinearity (DNL) vs. V_{REF}

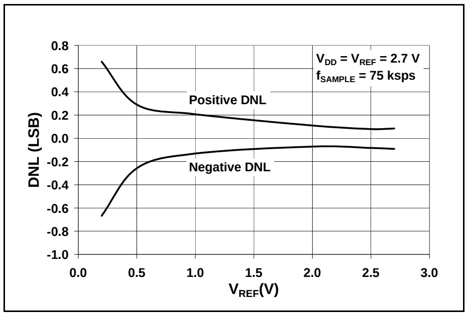


FIGURE 2-12: Differential Nonlinearity (DNL) vs. V_{REF} (V_{DD} = 2.7V).

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18^* f_{SAMPLE}$, $T_A = +25°C$.

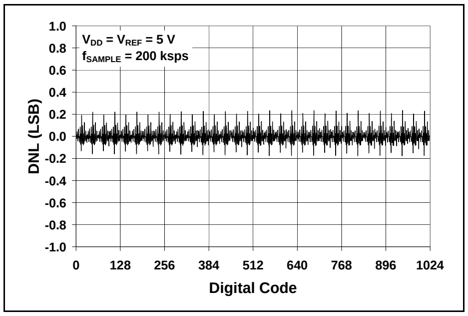


FIGURE 2-13: *Differential Nonlinearity (DNL) vs. Code (Representative Part).*

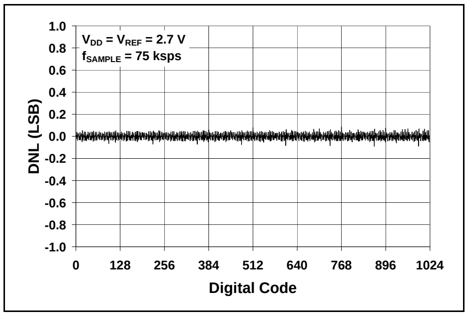


FIGURE 2-16: *Differential Nonlinearity (DNL) vs. Code (Representative Part, V_{DD} =2.7V).*

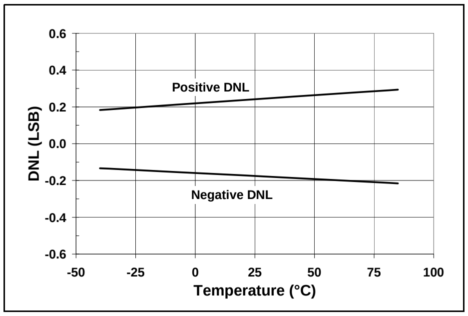


FIGURE 2-14: *Differential Nonlinearity (DNL) vs. Temperature.*

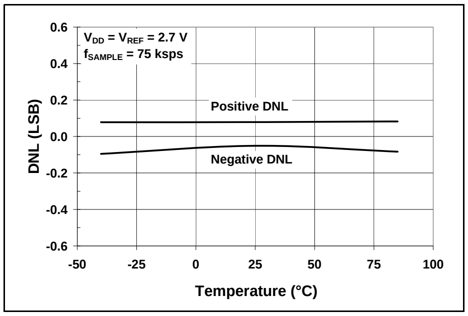


FIGURE 2-17: *Differential Nonlinearity (DNL) vs. Temperature (V_{DD} = 2.7V).*

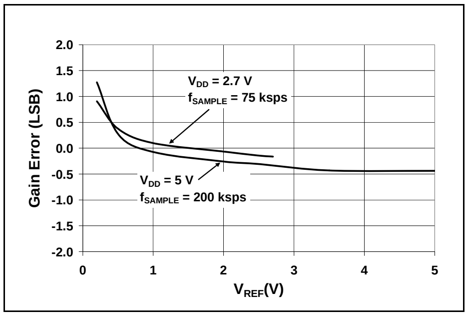


FIGURE 2-15: *Gain Error vs. V_{REF}*

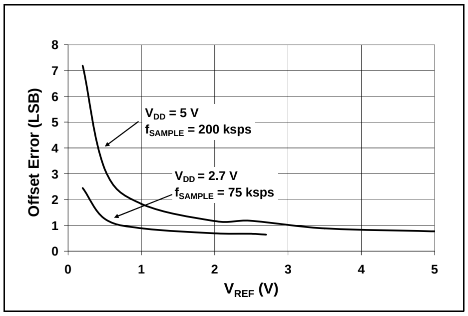


FIGURE 2-18: *Offset Error vs. V_{REF}*

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18^* f_{SAMPLE}$, $T_A = +25°C$.

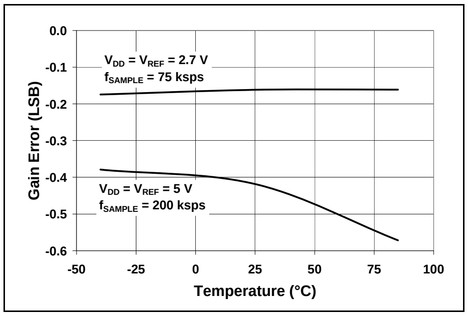


FIGURE 2-19: *Gain Error vs. Temperature.*

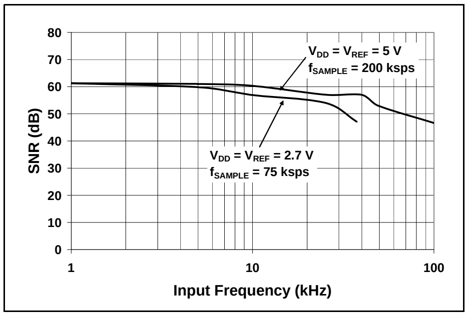


FIGURE 2-20: *Signal-to-Noise (SNR) vs. Input Frequency.*

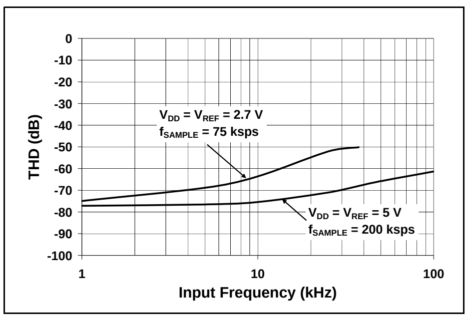


FIGURE 2-21: *Total Harmonic Distortion (THD) vs. Input Frequency.*

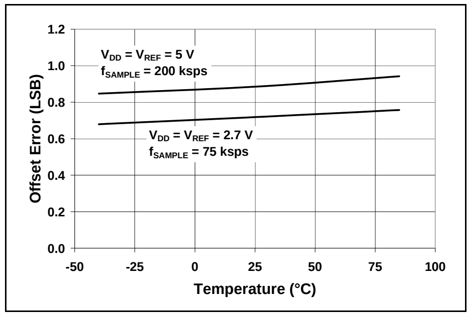


FIGURE 2-22: *Offset Error vs. Temperature.*

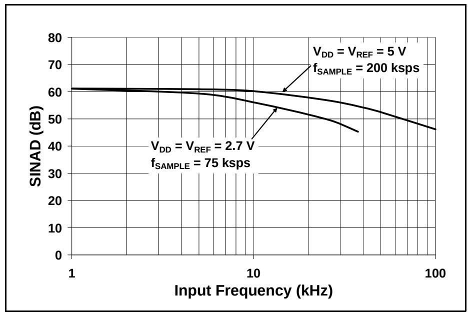


FIGURE 2-23: *Signal-to-Noise and Distortion (SINAD) vs. Input Frequency.*

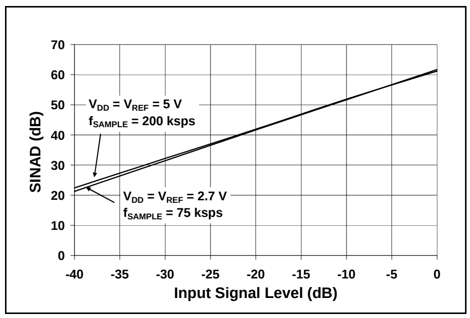


FIGURE 2-24: *Signal-to-Noise and Distortion (SINAD) vs. Input Signal Level.*

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18^* f_{SAMPLE}$, $T_A = +25°C$.

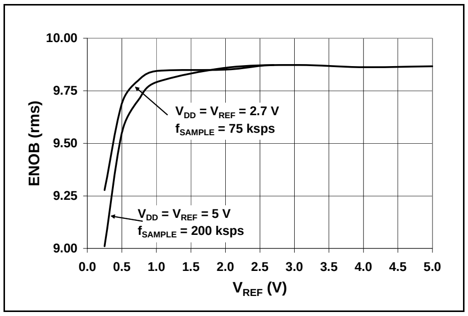


FIGURE 2-25: *Effective Number of Bits (ENOB) vs.* V_{REF}

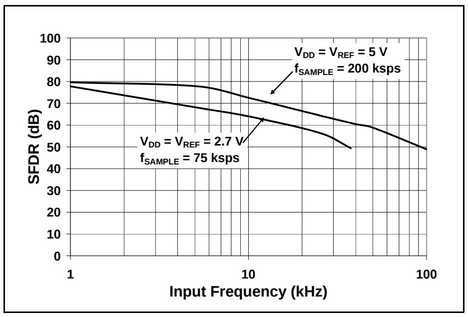


FIGURE 2-26: *Spurious Free Dynamic Range (SFDR) vs. Input Frequency.*

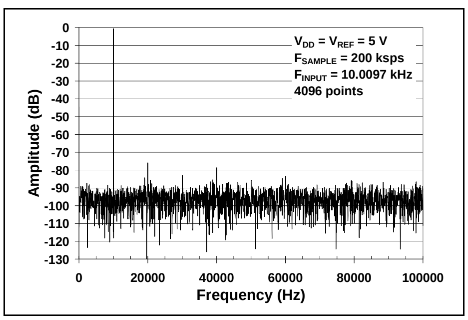


FIGURE 2-27: *Frequency Spectrum of 10 kHz Input (Representative Part).*

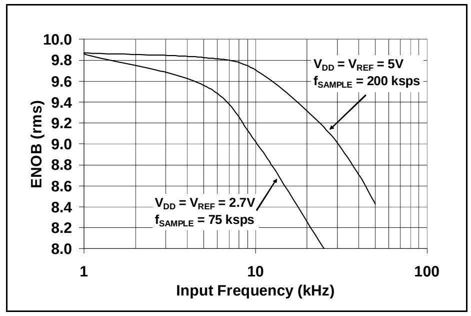


FIGURE 2-28: *Effective Number of Bits (ENOB) vs. Input Frequency.*

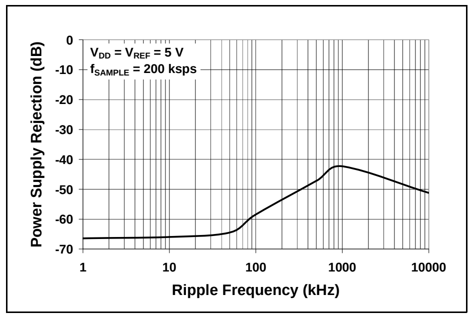


FIGURE 2-29: *Power Supply Rejection (PSR) vs. Ripple Frequency.*

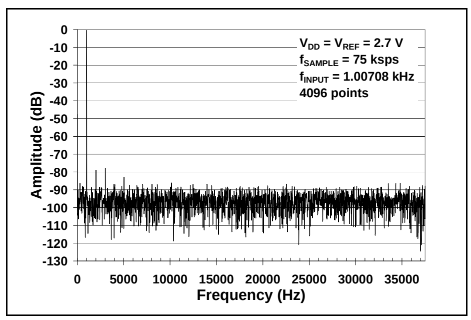


FIGURE 2-30: *Frequency Spectrum of 1 kHz Input (Representative Part,* $V_{DD} = 2.7V$*).*

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18^* f_{SAMPLE}$, $T_A = +25°C$.

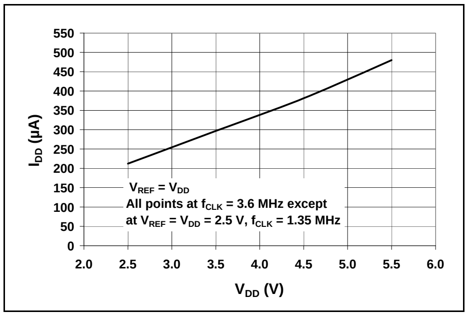


FIGURE 2-31: *I_{DD} vs. V_{DD}.*

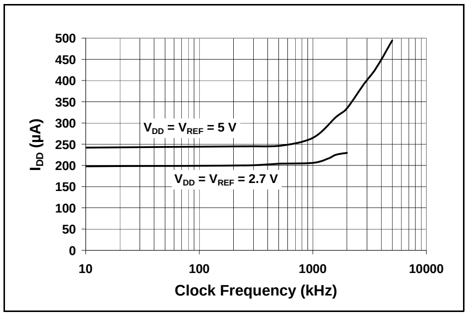


FIGURE 2-32: *I_{DD} vs. Clock Frequency.*

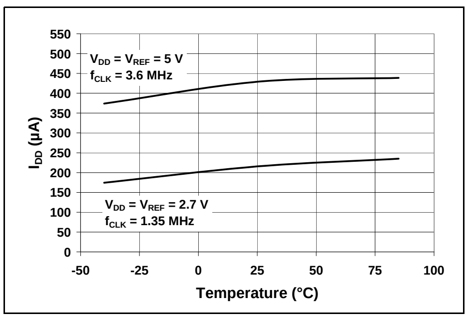


FIGURE 2-33: *I_{DD} vs. Temperature.*

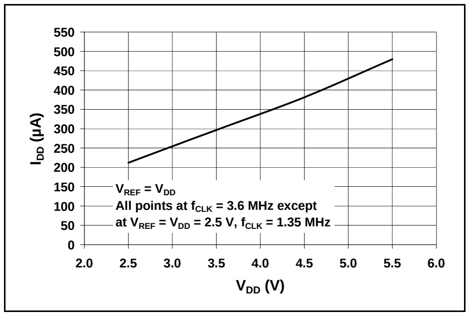


FIGURE 2-34: *I_{REF} vs. V_{DD}.*

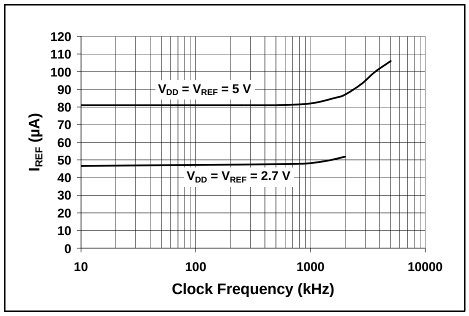


FIGURE 2-35: *I_{REF} vs. Clock Frequency.*

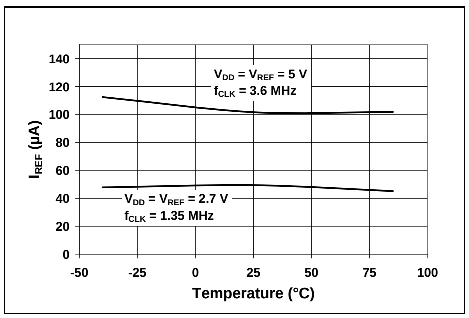


FIGURE 2-36: *I_{REF} vs. Temperature.*

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18^* f_{SAMPLE}$, $T_A = +25°C$.

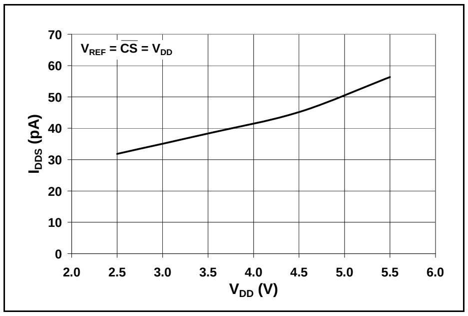


FIGURE 2-37: *I_{DDS} vs. V_{DD}.*

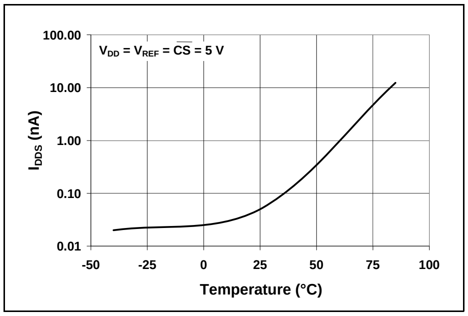


FIGURE 2-38: *I_{DDS} vs. Temperature.*

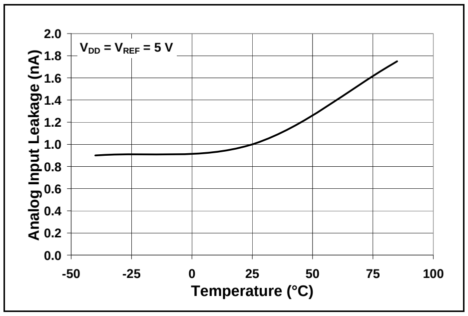


FIGURE 2-39: *Analog Input Leakage Current vs. Temperature.*

NOTES:

3.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in Table 3-1. Additional descriptions of the device pins follows.

TABLE 3-1: PIN FUNCTION TABLE

MCP3004	MCP3008	Symbol	Description
PDIP, SOIC, TSSOP	PDIP, SOIC		
1	1	CH0	Analog Input
2	2	CH1	Analog Input
3	3	CH2	Analog Input
4	4	CH3	Analog Input
–	5	CH4	Analog Input
–	6	CH5	Analog Input
–	7	CH6	Analog Input
–	8	CH7	Analog Input
7	9	DGND	Digital Ground
8	10	$\overline{CS}$/SHDN	Chip Select/Shutdown Input
9	11	D_{IN}	Serial Data In
10	12	D_{OUT}	Serial Data Out
11	13	CLK	Serial Clock
12	14	AGND	Analog Ground
13	15	V_{REF}	Reference Voltage Input
14	16	V_{DD}	+2.7V to 5.5V Power Supply
5,6	–	NC	No Connection

3.1 Digital Ground (DGND)

Digital ground connection to internal digital circuitry.

3.2 Analog Ground (AGND)

Analog ground connection to internal analog circuitry.

3.3 Analog inputs (CH0 - CH7)

Analog inputs for channels 0 - 7, respectively, for the multiplexed inputs. Each pair of channels can be programmed to be used as two independent channels in single-ended mode or as a single pseudo-differential input where one channel is IN+ and one channel is IN. See **Section 4.1 “Analog Inputs”**, “Analog Inputs”, and **Section 5.0 “Serial Communication”**, “Serial Communication”, for information on programming the channel configuration.

3.4 Serial Clock (CLK)

The SPI clock pin is used to initiate a conversion and clock out each bit of the conversion as it takes place. See **Section 6.2 “Maintaining Minimum Clock Speed”**, “Maintaining Minimum Clock Speed”, for constraints on clock speed.

3.5 Serial Data Input (D_{IN})

The SPI port serial data input pin is used to load channel configuration data into the device.

3.6 Serial Data Output (D_{OUT})

The SPI serial data output pin is used to shift out the results of the A/D conversion. Data will always change on the falling edge of each clock as the conversion takes place.

3.7 Chip Select/Shutdown ($\overline{CS}$/SHDN)

The $\overline{CS}$/SHDN pin is used to initiate communication with the device when pulled low. When pulled high, it will end a conversion and put the device in low-power standby. The $\overline{CS}$/SHDN pin must be pulled high between conversions.

NOTES:

4.0 DEVICE OPERATION

The MCP3004/3008 A/D converters employ a conventional SAR architecture. With this architecture, a sample is acquired on an internal sample/hold capacitor for 1.5 clock cycles starting on the first rising edge of the serial clock once $\overline{CS}$ has been pulled low. Following this sample time, the device uses the collected charge on the internal sample and hold capacitor to produce a serial 10-bit digital output code. Conversion rates of 100 ksps are possible on the MCP3004/3008. See **Section 6.2 "Maintaining Minimum Clock Speed"**, "Maintaining Minimum Clock Speed", for information on minimum clock rates. Communication with the device is accomplished using a 4-wire SPI-compatible interface.

4.1 Analog Inputs

The MCP3004/3008 devices offer the choice of using the analog input channels configured as single-ended inputs or pseudo-differential pairs. The MCP3004 can be configured to provide two pseudo-differential input pairs or four single-ended inputs. The MCP3008 can be configured to provide four pseudo-differential input pairs or eight single-ended inputs. Configuration is done as part of the serial command before each conversion begins. When used in the pseudo-differential mode, each channel pair (i.e., CH0 and CH1, CH2 and CH3 etc.) are programmed as the IN+ and IN- inputs as part of the command string transmitted to the device. The IN+ input can range from IN- to (V_{REF} + IN-). The IN- input is limited to ±100 mV from the V_{SS} rail. The IN- input can be used to cancel small signal common-mode noise, which is present on both the IN+ and IN- inputs.

When operating in the pseudo-differential mode, if the voltage level of IN+ is equal to or less than IN-, the resultant code will be `000h`. If the voltage at IN+ is equal to or greater than {[V_{REF} + (IN-)] - 1 LSB}, then the output code will be `3FFh`. If the voltage level at IN- is more than 1 LSB below V_{SS}, the voltage level at the IN+ input will have to go below V_{SS} to see the `000h` output code. Conversely, if IN- is more than 1 LSB above V_{SS}, the `3FFh` code will not be seen unless the IN+ input level goes above V_{REF} level.

For the A/D converter to meet specification, the charge holding capacitor (C_{SAMPLE}) must be given enough time to acquire a 10-bit accurate voltage level during the 1.5 clock cycle sampling period. The analog input model is shown in Figure 4-1.

This diagram illustrates that the source impedance (R_S) adds to the internal sampling switch (R_{SS}) impedance, directly affecting the time that is required to charge the capacitor (C_{SAMPLE}). Consequently, larger source impedances increase the offset, gain and integral linearity errors of the conversion (see Figure 4-2).

4.2 Reference Input

For each device in the family, the reference input (V_{REF}) determines the analog input voltage range. As the reference input is reduced, the LSB size is reduced accordingly.

EQUATION 4-1: LSB SIZE CALCULATION

$$LSB\ Size = \frac{V_{REF}}{1024}$$

The theoretical digital output code produced by the A/D converter is a function of the analog input signal and the reference input, as shown below.

EQUATION 4-2: DIGITAL OUTPUT CODE CALCULATION

$$Digital\ Output\ Code = \frac{1024 \times V_{IN}}{V_{REF}}$$

Where:

V_{IN} = analog input voltage

V_{REF} = analog input voltage

When using an external voltage reference device, the system designer should always refer to the manufacturer's recommendations for circuit layout. Any instability in the operation of the reference device will have a direct effect on the operation of the A/D converter.

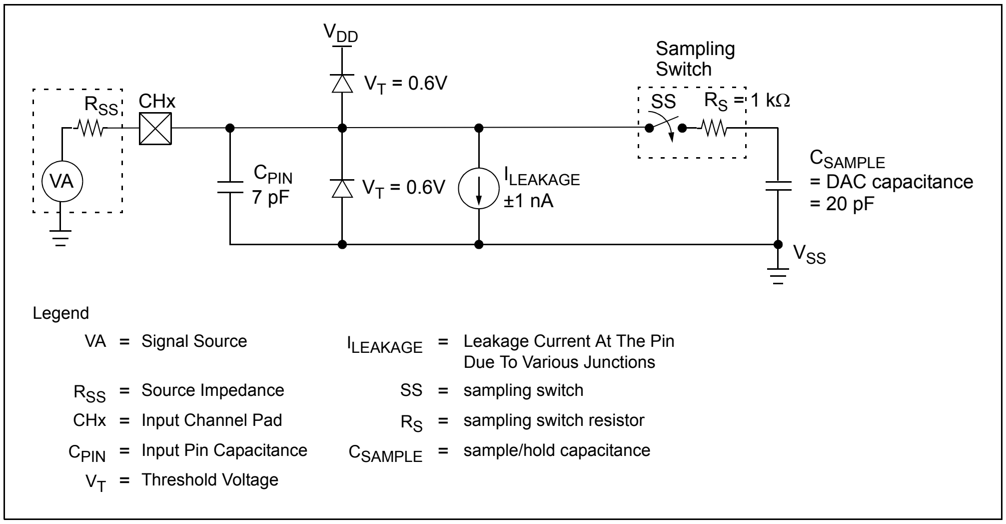


FIGURE 4-1: *Analog Input Model.*

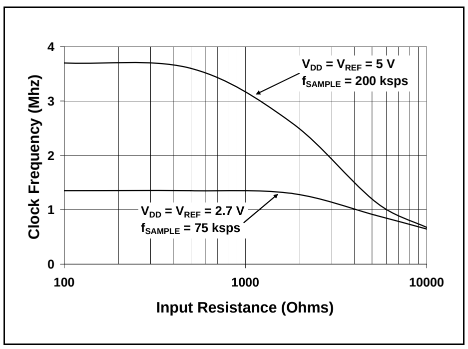


FIGURE 4-2: *Maximum Clock Frequency vs. Input resistance (R_S) to maintain less than a 0.1 LSB deviation in INL from nominal conditions.*

5.0 SERIAL COMMUNICATION

Communication with the MCP3004/3008 devices is accomplished using a standard SPI-compatible serial interface. Initiating communication with either device is done by bringing the $\overline{CS}$ line low (see Figure 5-1). If the device was powered up with the $\overline{CS}$ pin low, it must be brought high and back low to initiate communication. The first clock received with $\overline{CS}$ low and D_{IN} high will constitute a start bit. The SGL/$\overline{DIFF}$ bit follows the start bit and will determine if the conversion will be done using single-ended or differential input mode. The next three bits (D0, D1 and D2) are used to select the input channel configuration. Table 5-1 and Table 5-2 show the configuration bits for the MCP3004 and MCP3008, respectively. The device will begin to sample the analog input on the fourth rising edge of the clock after the start bit has been received. The sample period will end on the falling edge of the fifth clock following the start bit.

Once the D0 bit is input, one more clock is required to complete the sample and hold period (D_{IN} is a "don't care" for this clock). On the falling edge of the next clock, the device will output a low null bit. The next 10 clocks will output the result of the conversion with MSB first, as shown in Figure 5-1. Data is always output from the device on the falling edge of the clock. If all 10 data bits have been transmitted and the device continues to receive clocks while the $\overline{CS}$ is held low, the device will output the conversion result LSB first, as is shown in Figure 5-2. If more clocks are provided to the device while $\overline{CS}$ is still low (after the LSB first data has been transmitted), the device will clock out zeros indefinitely.

If necessary, it is possible to bring $\overline{CS}$ low and clock in leading zeros on the D_{IN} line before the start bit. This is often done when dealing with microcontroller-based SPI ports that must send 8 bits at a time. Refer to **Section 6.1 "Using the MCP3004/3008 with Microcontroller (MCU) SPI Ports"**, "Using the MCP3004/3008 with Microcontroller (MCU) SPI Ports", for more details on using the MCP3004/3008 devices with hardware SPI ports.

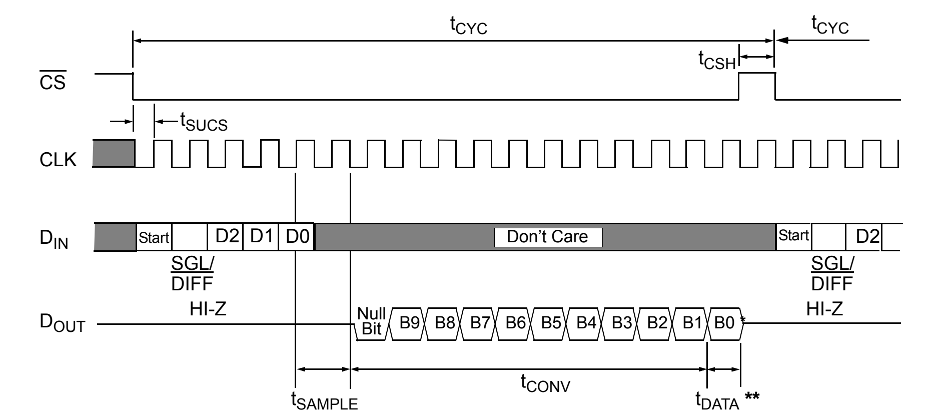
TABLE 5-1: CONFIGURE BITS FOR THE MCP3004

Control Bit Selections				Input Configuration	Channel Selection
Single/$\overline{Diff}$	D2*	D1	D0		
1	X	0	0	single-ended	CH0
1	X	0	1	single-ended	CH1
1	X	1	0	single-ended	CH2
1	X	1	1	single-ended	CH3
0	X	0	0	differential	CH0 = IN+ CH1 = IN-
0	X	0	1	differential	CH0 = IN- CH1 = IN+
0	X	1	0	differential	CH2 = IN+ CH3 = IN-
0	X	1	1	differential	CH2 = IN- CH3 = IN+

* D2 is "don't care" for MCP3004

TABLE 5-2: CONFIGURE BITS FOR THE MCP3008

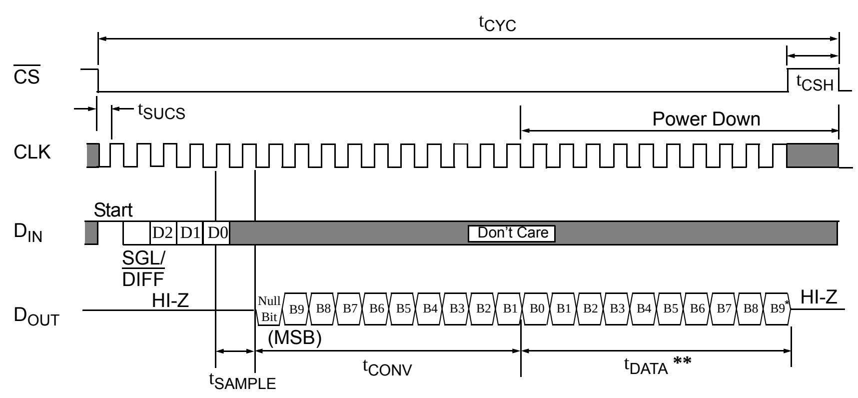
Control Bit Selections				Input Configuration	Channel Selection
Single/$\overline{Diff}$	D2	D1	D0		
1	0	0	0	single-ended	CH0
1	0	0	1	single-ended	CH1
1	0	1	0	single-ended	CH2
1	0	1	1	single-ended	CH3
1	1	0	0	single-ended	CH4
1	1	0	1	single-ended	CH5
1	1	1	0	single-ended	CH6
1	1	1	1	single-ended	CH7
0	0	0	0	differential	CH0 = IN+ CH1 = IN-
0	0	0	1	differential	CH0 = IN- CH1 = IN+
0	0	1	0	differential	CH2 = IN+ CH3 = IN-
0	0	1	1	differential	CH2 = IN- CH3 = IN+
0	1	0	0	differential	CH4 = IN+ CH5 = IN-
0	1	0	1	differential	CH4 = IN- CH5 = IN+
0	1	1	0	differential	CH6 = IN+ CH7 = IN-
0	1	1	1	differential	CH6 = IN- CH7 = IN+



* After completing the data transfer, if further clocks are applied with CS low, the A/D converter will output LSB first data, then followed with zeros indefinitely. See Figure 5-2 below.

** t_{DATA}: during this time, the bias current and the comparator powers down while the reference input becomes a high-impedance node.

FIGURE 5-1: *Communication with the MCP3004 or MCP3008.*



* After completing the data transfer, if further clocks are applied with CS low, the A/D converter will output zeros indefinitely.

** t_{DATA}: During this time, the bias circuit and the comparator powers down while the reference input becomes a high-impedance node, leaving the CLK running to clock out LSB first data or zeroes.

FIGURE 5-2: *Communication with MCP3004 or MCP3008 in LSB First Format.*

6.0 APPLICATIONS INFORMATION

6.1 Using the MCP3004/3008 with Microcontroller (MCU) SPI Ports

With most microcontroller SPI ports, it is required to send groups of eight bits. It is also required that the microcontroller SPI port be configured to clock out data on the falling edge of clock and latch data in on the rising edge. Because communication with the MCP3004/3008 devices may not need multiples of eight clocks, it will be necessary to provide more clocks than are required. This is usually done by sending 'leading zeros' before the start bit. As an example, Figure 6-1 and Figure 6-2 shows how the MCP3004/3008 can be interfaced to a MCU with a hardware SPI port. Figure 6-1 depicts the operation shown in SPI Mode 0,0, which requires that the SCLK from the MCU idles in the 'low' state, while Figure 6-2 shows the similar case of SPI Mode 1,1, where the clock idles in the 'high' state.

As is shown in Figure 6-1, the first byte transmitted to the A/D converter contains seven leading zeros before the start bit. Arranging the leading zeros this way induces the 10 data bits to fall in positions easily manipulated by the MCU. The MSB is clocked out of the A/D converter on the falling edge of clock number 14. Once the second eight clocks have been sent to the device, the MCU receive buffer will contain five unknown bits (the output is at high-impedance for the first two clocks), the null bit and the highest order 2 bits of the conversion. Once the third byte has been sent to the device, the receive register will contain the lowest order eight bits of the conversion results. Employing this method ensures simpler manipulation of the converted data.

Figure 6-2 shows the same thing in SPI Mode 1,1, which requires that the clock idles in the high state. As with mode 0,0, the A/D converter outputs data on the falling edge of the clock and the MCU latches data from the A/D converter in on the rising edge of the clock.

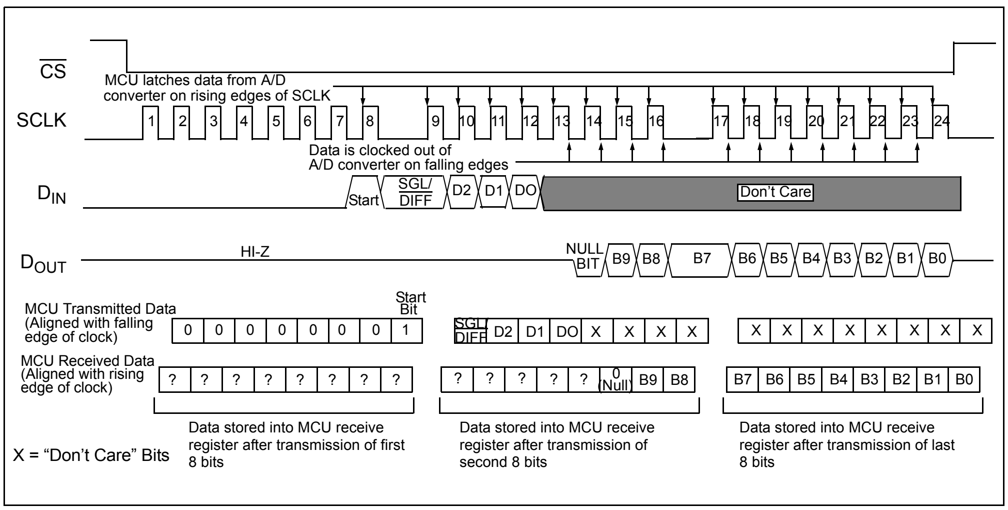


FIGURE 6-1: *SPI Communication with the MCP3004/3008 using 8-bit segments (Mode 0,0: SCLK idles low).*

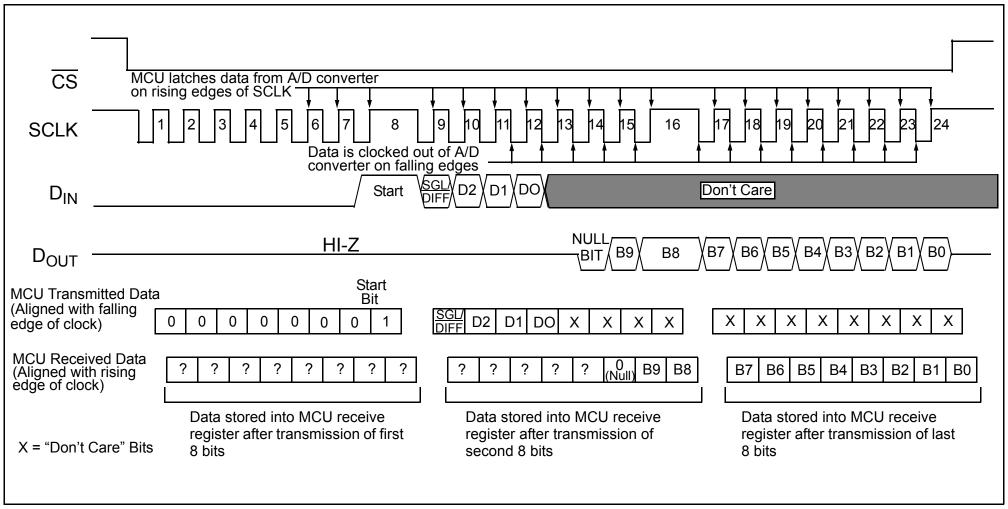


FIGURE 6-2: *SPI Communication with the MCP3004/3008 using 8-bit segments (Mode 1,1: SCLK idles high).*

6.2 Maintaining Minimum Clock Speed

When the MCP3004/3008 initiates the sample period, charge is stored on the sample capacitor. When the sample period is complete, the device converts one bit for each clock that is received. It is important for the user to note that a slow clock rate will allow charge to bleed off the sample capacitor while the conversion is taking place. At 85°C (worst case condition), the part will maintain proper charge on the sample capacitor for at least 1.2 ms after the sample period has ended. This means that the time between the end of the sample period and the time that all 10 data bits have been clocked out must not exceed 1.2 ms (effective clock frequency of 10 kHz). Failure to meet this criterion may introduce linearity errors into the conversion outside the rated specifications. It should be noted that during the entire conversion cycle, the A/D converter does not require a constant clock speed or duty cycle, as long as all timing specifications are met.

6.3 Buffering/Filtering the Analog Inputs

If the signal source for the A/D converter is not a low-impedance source, it will have to be buffered or inaccurate conversion results may occur (see Figure 4-2). It is also recommended that a filter be used to eliminate any signals that may be aliased back in to the conversion results, as is illustrated in Figure 6-3, where an op amp is used to drive, filter and gain the analog input of the MCP3004/3008. This amplifier provides a low-impedance source for the converter input, plus a low-pass filter, which eliminates unwanted high-frequency noise.

Low-pass (anti-aliasing) filters can be designed using Microchip's free interactive FilterLab® software. FilterLab will calculate capacitor and resistors values, as well as determine the number of poles that are required for the application. For more information on filtering signals, see AN699, *"Anti-Aliasing Analog Filters for Data Acquisition Systems"*.

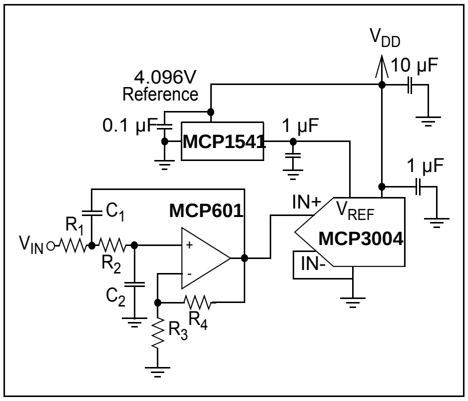


FIGURE 6-3: *The MCP601 Operational Amplifier is used to implement a second order anti-aliasing filter for the signal being converted by the MCP3004.*

6.4 Layout Considerations

When laying out a printed circuit board for use with analog components, care should be taken to reduce noise wherever possible. A bypass capacitor should always be used with this device and should be placed as close as possible to the device pin. A bypass capacitor value of 1 µF is recommended.

Digital and analog traces should be separated as much as possible on the board, with no traces running underneath the device or bypass capacitor. Extra precautions should be taken to keep traces with high-frequency signals (such as clock lines) as far as possible from analog traces.

Use of an analog ground plane is recommended in order to keep the ground potential the same for all devices on the board. Providing V_{DD} connections to devices in a "star" configuration can also reduce noise by eliminating return current paths and associated errors (see Figure 6-4). For more information on layout tips when using A/D converters, refer to AN688, *"Layout Tips for 12-Bit A/D Converter Applications"*.

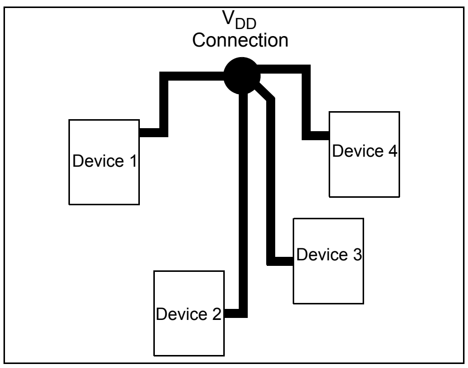


FIGURE 6-4: *V_{DD} traces arranged in a 'Star' configuration in order to reduce errors caused by current return paths.*

6.5 Utilizing the Digital and Analog Ground Pins

The MCP3004/3008 devices provide both digital and analog ground connections to provide additional means of noise reduction. As is shown in Figure 6-5, the analog and digital circuitry is separated internal to the device. This reduces noise from the digital portion of the device being coupled into the analog portion of the device. The two grounds are connected internally through the substrate which has a resistance of 5 -10Ω.

If no ground plane is utilized, both grounds must be connected to V_{SS} on the board. If a ground plane is available, both digital and analog ground pins should be connected to the analog ground plane. If both an analog and a digital ground plane are available, both the digital and the analog ground pins should be connected to the analog ground plane. Following these steps will reduce the amount of digital noise from the rest of the board being coupled into the A/D converter.

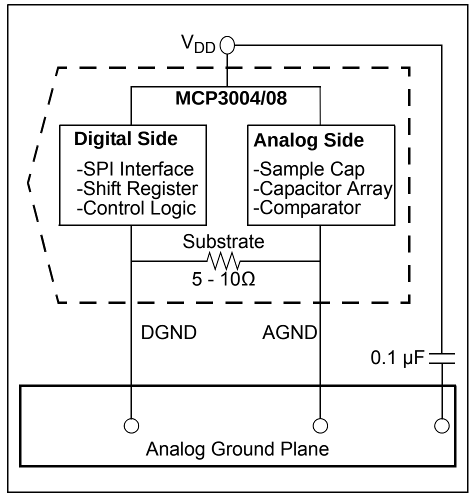


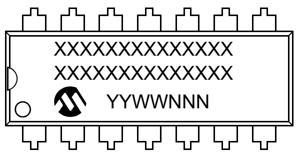
FIGURE 6-5: *Separation of Analog and Digital Ground Pins.*

NOTES:

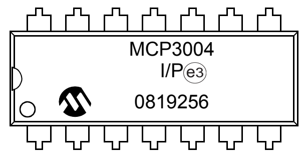
7.0 PACKAGING INFORMATION

7.1 Package Marking Information

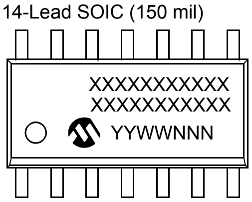
14-Lead PDIP (300 mil)



Example:



14-Lead SOIC (150 mil)



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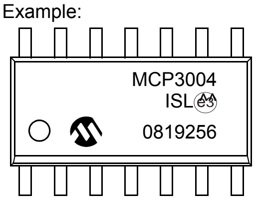
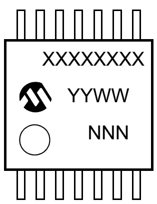


14-Lead TSSOP (4.4mm) *



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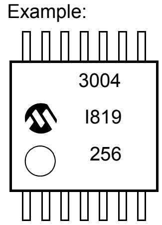
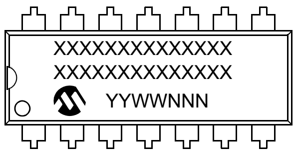


Legend:	XX...X	Customer-specific information
	Y	Year code (last digit of calendar year)
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week '01')
	NNN	Alphanumeric traceability code
	e3	Pb-free JEDEC designator for Matte Tin (Sn)
	*	This package is Pb-free. The Pb-free JEDEC designator (e3) can be found on the outer packaging for this package.

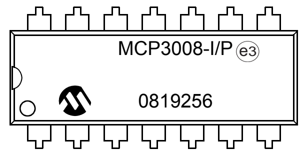
Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line, thus limiting the number of available characters for customer-specific information.

Package Marking Information (Continued)

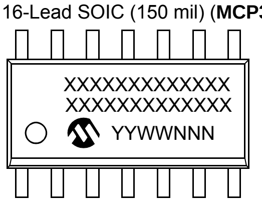
16-Lead PDIP (300 mil) (**MCP3008**)



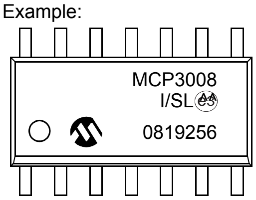
Example:



16-Lead SOIC (150 mil) (**MCP3008**)

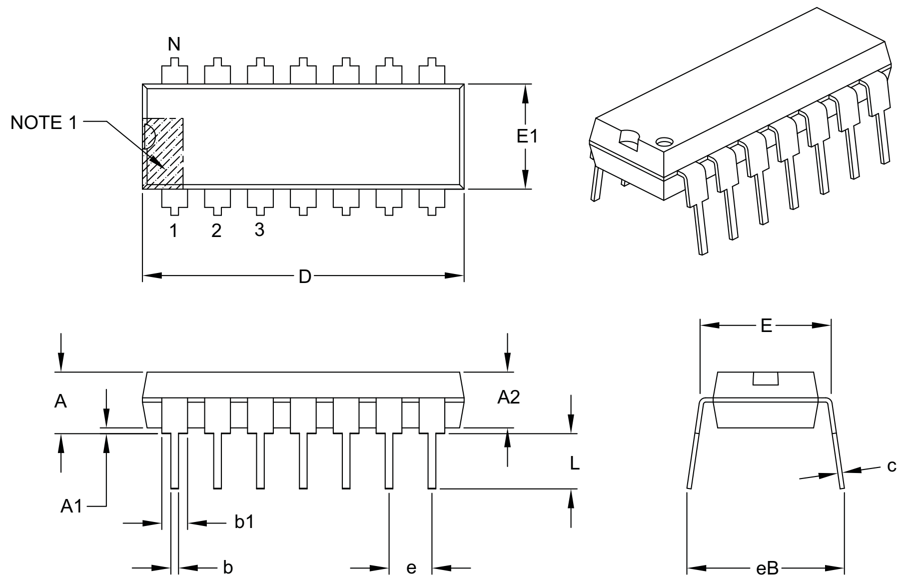


Example:



14-Lead Plastic Dual In-Line (P) – 300 mil Body [PDIP]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



Units		INCHES		
Dimension Limits		MIN	NOM	MAX
Number of Pins	N		14	
Pitch	e		.100 BSC	
Top to Seating Plane	A	–	–	.210
Molded Package Thickness	A2	.115	.130	.195
Base to Seating Plane	A1	.015	–	–
Shoulder to Shoulder Width	E	.290	.310	.325
Molded Package Width	E1	.240	.250	.280
Overall Length	D	.735	.750	.775
Tip to Seating Plane	L	.115	.130	.150
Lead Thickness	c	.008	.010	.015
Upper Lead Width	b1	.045	.060	.070
Lower Lead Width	b	.014	.018	.022
Overall Row Spacing §	eB	–	–	.430

Notes:

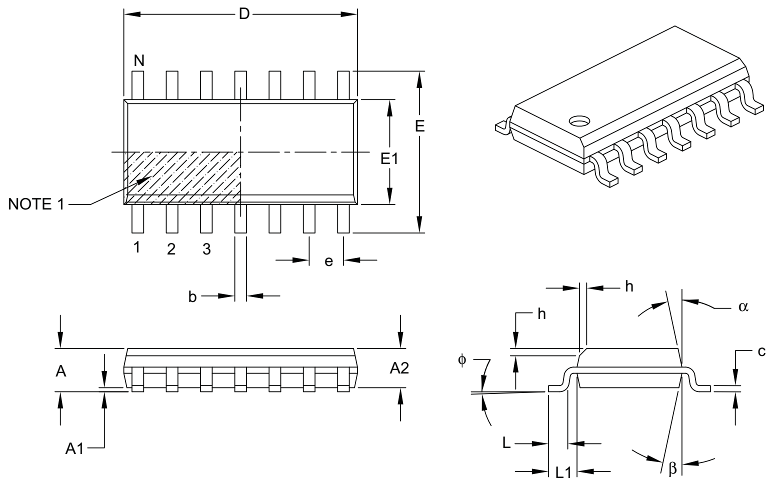
1. Pin 1 visual index feature may vary, but must be located with the hatched area.
2. § Significant Characteristic.
3. Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" per side.
4. Dimensioning and tolerancing per ASME Y14.5M.

   BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing C04-005B

14-Lead Plastic Small Outline (SL) – Narrow, 3.90 mm Body [SOIC]

Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



		Units	MILLIMETERS		
		Dimension Limits	MIN	NOM	MAX
Number of Pins	N			14	
Pitch	e			1.27 BSC	
Overall Height	A		–	–	1.75
Molded Package Thickness	A2		1.25	–	–
Standoff §	A1		0.10	–	0.25
Overall Width	E			6.00 BSC	
Molded Package Width	E1			3.90 BSC	
Overall Length	D			8.65 BSC	
Chamfer (optional)	h		0.25	–	0.50
Foot Length	L		0.40	–	1.27
Footprint	L1			1.04 REF	
Foot Angle	φ		0°	–	8°
Lead Thickness	c		0.17	–	0.25
Lead Width	b		0.31	–	0.51
Mold Draft Angle Top	α		5°	–	15°
Mold Draft Angle Bottom	β		5°	–	15°

Notes:

1. Pin 1 visual index feature may vary, but must be located within the hatched area.
2. § Significant Characteristic.
3. Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.15 mm per side.
4. Dimensioning and tolerancing per ASME Y14.5M.

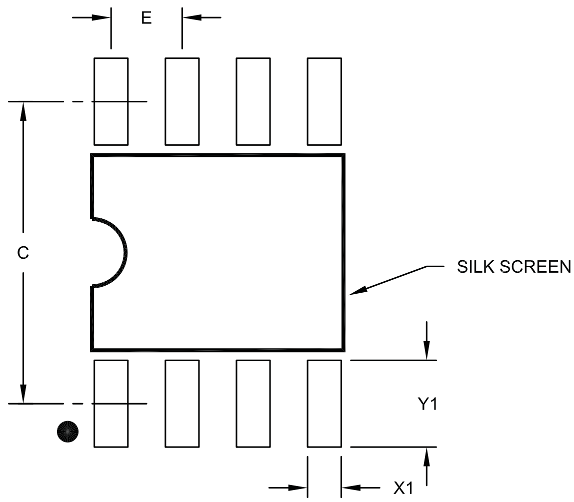
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-065B

8-Lead Plastic Small Outline (SN) – Narrow, 3.90 mm Body [SOIC]

Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



RECOMMENDED LAND PATTERN

Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Contact Pitch	E		1.27 BSC	
Contact Pad Spacing	C		5.40	
Contact Pad Width (X8)	X1			0.60
Contact Pad Length (X8)	Y1			1.55

Notes:

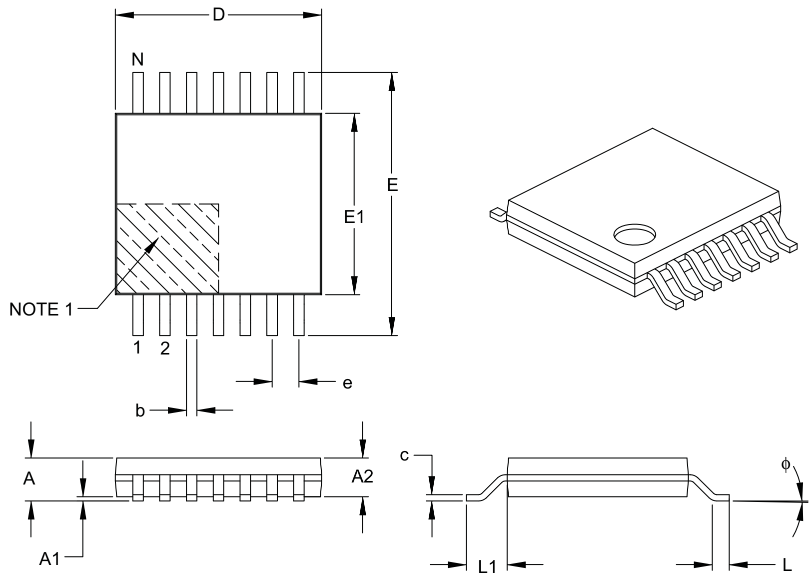
1. Dimensioning and tolerancing per ASME Y14.5M

BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2057A

14-Lead Plastic Thin Shrink Small Outline (ST) – 4.4 mm Body [TSSOP]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



		Units	MILLIMETERS	
	Dimension Limits	MIN	NOM	MAX
Number of Pins	N		14	
Pitch	e		0.65 BSC	
Overall Height	A	–	–	1.20
Molded Package Thickness	A2	0.80	1.00	1.05
Standoff	A1	0.05	–	0.15
Overall Width	E		6.40 BSC	
Molded Package Width	E1	4.30	4.40	4.50
Molded Package Length	D	4.90	5.00	5.10
Foot Length	L	0.45	0.60	0.75
Footprint	L1		1.00 REF	
Foot Angle	φ	0°	–	8°
Lead Thickness	c	0.09	–	0.20
Lead Width	b	0.19	–	0.30

Notes:

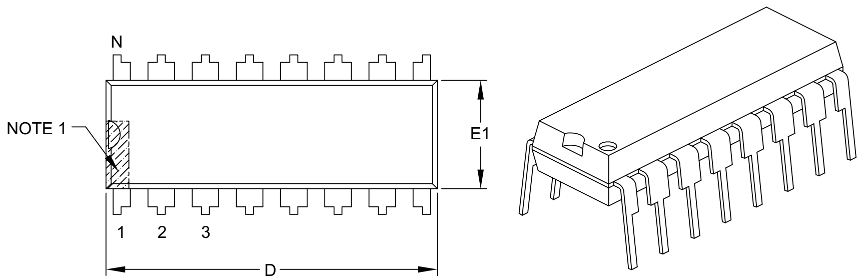
1. Pin 1 visual index feature may vary, but must be located within the hatched area.
2. Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.15 mm per side.
3. Dimensioning and tolerancing per ASME Y14.5M.

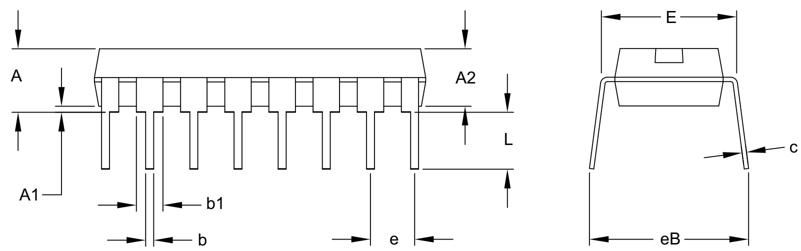
BSC: Basic Dimension. Theoretically exact value shown without tolerances.
REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-087B

16-Lead Plastic Dual In-Line (P) – 300 mil Body [PDIP]

Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging





Units		INCHES		
Dimension Limits		MIN	NOM	MAX
Number of Pins	N		16	
Pitch	e		.100 BSC	
Top to Seating Plane	A	–	–	.210
Molded Package Thickness	A2	.115	.130	.195
Base to Seating Plane	A1	.015	–	–
Shoulder to Shoulder Width	E	.290	.310	.325
Molded Package Width	E1	.240	.250	.280
Overall Length	D	.735	.755	.775
Tip to Seating Plane	L	.115	.130	.150
Lead Thickness	c	.008	.010	.015
Upper Lead Width	b1	.045	.060	.070
Lower Lead Width	b	.014	.018	.022
Overall Row Spacing §	eB	–	–	.430

Notes:

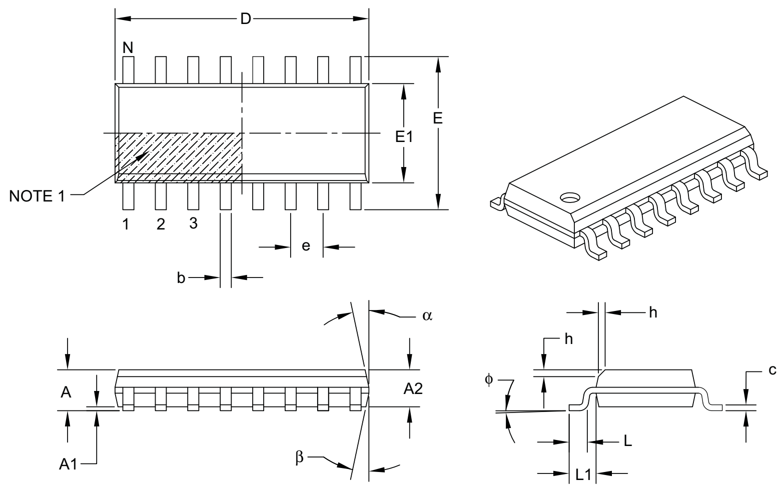
1. Pin 1 visual index feature may vary, but must be located within the hatched area.
2. § Significant Characteristic.
3. Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" per side.
4. Dimensioning and tolerancing per ASME Y14.5M.

   BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing C04-017B

16-Lead Plastic Small Outline (SL) – Narrow, 3.90 mm Body [SOIC]

Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



		Units	MILLIMETERS		
		Dimension Limits	MIN	NOM	MAX
Number of Pins	N		16		
Pitch	e		1.27 BSC		
Overall Height	A		–	–	1.75
Molded Package Thickness	A2		1.25	–	–
Standoff §	A1		0.10	–	0.25
Overall Width	E		6.00 BSC		
Molded Package Width	E1		3.90 BSC		
Overall Length	D		9.90 BSC		
Chamfer (optional)	h		0.25	–	0.50
Foot Length	L		0.40	–	1.27
Footprint	L1		1.04 REF		
Foot Angle	φ		0°	–	8°
Lead Thickness	c		0.17	–	0.25
Lead Width	b		0.31	–	0.51
Mold Draft Angle Top	α		5°	–	15°
Mold Draft Angle Bottom	β		5°	–	15°

Notes:

1. Pin 1 visual index feature may vary, but must be located within the hatched area.
2. § Significant Characteristic.
3. Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.15 mm per side.
4. Dimensioning and tolerancing per ASME Y14.5M.

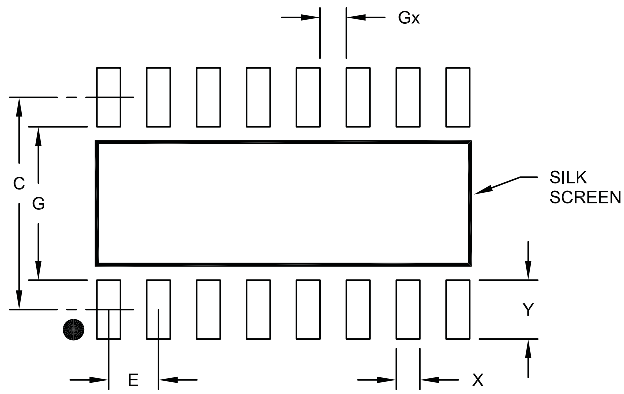
   BSC: Basic Dimension. Theoretically exact value shown without tolerances.

   REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-108B

16-Lead Plastic Small Outline (SL) - Narrow, 3.90 mm Body [SOIC]

Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



RECOMMENDED LAND PATTERN

Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Contact Pitch	E		1.27 BSC	
Contact Pad Spacing	C		5.40	
Contact Pad Width	X			0.60
Contact Pad Length	Y			1.50
Distance Between Pads	Gx	0.67		
Distance Between Pads	G	3.90		

Notes:

1. Dimensioning and tolerancing per ASME Y14.5M

   BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2108A

NOTES:

APPENDIX A: REVISION HISTORY

Revision D (December 2008)

The following is the list of modifications:

1. Updates to **Section 7.0 "Packaging Information"**.

Revision C (January 2007)

The following is the list of modifications:

1. Updates to the packaging diagrams.

Revision B (May 2002)

The following is the list of modifications:

1. Undocumented changes.

Revision A (February 2000)

- Initial release of this document.

NOTES:

PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

PART NO.	X	/XX
Device	Temperature Range	Package

Device	MCP3004:	4-Channel 10-Bit Serial A/D Converter
	MCP3004T:	4-Channel 10-Bit Serial A/D Converter (Tape and Reel)
	MCP3008:	8-Channel 10-Bit Serial A/D Converter
	MCP3008T:	8-Channel 10-Bit Serial A/D Converter (Tape and Reel)
Temperature Range	I	= -40°C to +85°C (Industrial)
Package	P	= Plastic DIP (300 mil Body), 14-lead, 16-lead
	SL	= Plastic SOIC (150 mil Body), 14-lead, 16-lead
	ST	= Plastic TSSOP (4.4mm), 14-lead

Examples:

a) MCP3004-I/P: Industrial Temperature, PDIP package.
b) MCP3004-I/SL: Industrial Temperature, SOIC package.
c) MCP3004-I/ST: Industrial Temperature, TSSOP package.
d) MCP3004T-I/ST: Industrial Temperature, TSSOP package, Tape and Reel.
a) MCP3008-I/P: Industrial Temperature, PDIP package.
b) MCP3008-I/SL: Industrial Temperature, SOIC package.

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- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
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- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

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01/02/08

LMC6042 CMOS Dual Micropower Operational Amplifier

Check for Samples: LMC6042

FEATURES

- **Low Supply Current: 10 μA/Amp (typ)**
- **Operates from 4.5V to 15V Single Supply**
- **Ultra Low Input Current: 2 fA (typ)**
- **Rail-to-Rail Output Swing**
- **Input Common-Mode Range Includes Ground**

APPLICATIONS

- **Battery Monitoring and Power Conditioning**
- **Photodiode and Infrared Detector Preamplifier**
- **Silicon Based Transducer Systems**
- **Hand-Held Analytic Instruments**
- **pH Probe Buffer Amplifier**
- **Fire and Smoke Detection Systems**
- **Charge Amplifier for Piezoelectric Transducers**

DESCRIPTION

Ultra-low power consumption and low input-leakage current are the hallmarks of the LMC6042. Providing input currents of only 2 fA typical, the LMC6042 can operate from a single supply, has output swing extending to each supply rail, and an input voltage range that includes ground.

The LMC6042 is ideal for use in systems requiring ultra-low power consumption. In addition, the insensitivity to latch-up, high output drive, and output swing to ground without requiring external pull-down resistors make it ideal for single-supply battery-powered systems.

Other applications for the LMC6042 include bar code reader amplifiers, magnetic and electric field detectors, and hand-held electrometers.

This device is built with TI's advanced Double-Poly Silicon-Gate CMOS process.

See the LMC6041 for a single, and the LMC6044 for a quad amplifier with these features.

Connection Diagram

Figure 1. 8-Pin PDIP/SOIC

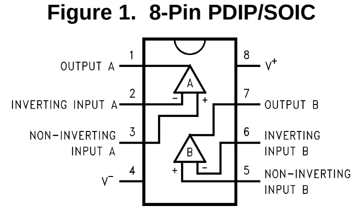
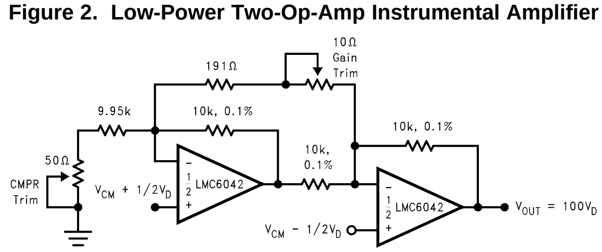


Figure 2. Low-Power Two-Op-Amp Instrumental Amplifier



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

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.

Absolute Maximum Ratings (1)(2)

Differential Input Voltage	±Supply Voltage
Supply Voltage ($V^+ - V^-$)	16V
Output Short Circuit to V^+	See (3)
Output Short Circuit to V^-	See (4)
Lead Temperature (Soldering, 10 seconds)	260°C
Current at Input Pin	±5 mA
Current at Output Pin	±18 mA
Current at Power Supply Pin	35 mA
Power Dissipation	See (5)
Storage Temperature Range	−65°C to +150°C
Junction Temperature (5)	110°C
ESD Tolerance (6)	500V
Voltage at Input/Output Pin	(V^+) + 0.3V, (V^-) − 0.3V

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Conditions indicate conditions for which the device is intended to be functional, but do not ensure specific performance limits. For ensured specifications and test conditions, see the Electrical Characteristics. The ensured specifications apply only for the test conditions listed.
(2) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
(3) Do not connect output to $V^+$when V^+ is greater than 13V or reliability may be adversely affected.
(4) Applies to both single-supply operation. Continuous short circuit operation at elevated ambient temperature can result in exceeding the maximum allowed junction temperature of 110°C. Output currents in excess of ±30 mA over long term may adversely affect reliability.
(5) The maximum power dissipation is a function of $T_{J(Max)}$, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(Max)} - T_A)/\theta_{JA}$.
(6) Human body model, 1.5 kΩ in series with 100 pF.

Operating Ratings

Temperature Range	LMC6042AI, LMC6042I	$-40°C \leq T_J \leq +85°C$
Supply Voltage		$4.5V \leq V^+ \leq 15.5V$
Power Dissipation		See (1)
Thermal Resistance (θ_{JA}), (2)	8-Pin PDIP	101°C/W
	8-Pin SOIC	165°C/W
	8-Pin CDIP	115°C/W

(1) For operating at elevated temperatures the device must be derated based on the thermal resistance θ_{JA} with $P_D = (T_J - T_A)/\theta_{JA}$.
(2) All numbers apply for packages soldered directly into a PC board.

Electrical Characteristics

Unless otherwise specified, all limits ensured for $T_A = T_J = 25°C$. **Boldface** limits apply at the temperature extremes. $V^+ = 5V$, $V^- = 0V$, $V_{CM} = 1.5V$, $V_O = V^+/2$ and $R_L > 1M$ unless otherwise specified.

Symbol	Parameter	Conditions	Typical (1)	LMC6042AI Limit (2)	LMC6042I Limit (2)	Units (Limit)
V_{OS}	Input Offset Voltage		1	3	6	mV
				3.3	**6.3**	Max
TCV_{OS}	Input Offset Voltage Average Drift		1.3			μV/°C
I_B	Input Bias Current		0.002	**4**	**4**	pA (Max)
I_{OS}	Input Offset Current		0.001	**2**	**2**	pA (Max)
R_{IN}	Input Resistance		>10			TeraΩ

(1) Typical values represent the most likely parametric norm.
(2) All limits are specified at room temperature (standard type face) or at operating temperature extremes (bold face type).

Electrical Characteristics (continued)

Unless otherwise specified, all limits ensured for $T_A = T_J = 25°C$. **Boldface** limits apply at the temperature extremes. $V^+ = 5V$, $V^- = 0V$, $V_{CM} = 1.5V$, $V_O = V^+/2$ and $R_L > 1M$ unless otherwise specified.

Symbol	Parameter	Conditions		Typical (1)	LMC6042AI Limit (2)	LMC6042I Limit (2)	Units (Limit)
CMRR	Common Mode Rejection Ratio	$0V \le V_{CM} \le 12.0V$ $V^+ = 15V$		75	68 **66**	62 **60**	dB Min
+PSRR	Positive Power Supply Rejection Ratio	$5V \le V^+ \le 15V$ $V_O = 2.5V$		75	68 **66**	62 **60**	dB Min
−PSRR	Negative Power Supply Rejection Ratio	$0V \le V^- \le -10V$ $V_O = 2.5V$		94	84 **83**	74 **73**	dB Min
CMR	Input Common-Mode Voltage Range	$V^+ = 5V$ and 15V For CMRR ≥ 50 dB		−0.4	−0.1 **0**	−0.1 **0**	V Max
				$V^+-1.9V$	$V^+-2.3V$ **$V^+-2.5V$**	$V^+-2.3V$ **$V^+-2.4V$**	V Min
A_V	Large Signal Voltage Gain	$R_L = 100\ k\Omega$ (3)	Sourcing	1000	400 **300**	300 **200**	V/mV Min
			Sinking	500	180 **120**	90 **70**	V/mV Min
		$R_L = 25\ k\Omega$ (3)	Sourcing	1000	200 **160**	100 **80**	V/mV Min
			Sinking	250	100 **60**	50 **40**	V/mV Min
V_O	Output Swing	$V^+ = 5V$ $R_L = 100\ k\Omega$ to $V^+/2$		4.987	4.970 **4.950**	4.940 **4.910**	V Min
				0.004	0.030 **0.050**	0.060 **0.090**	V Max
		$V^+ = 5V$ $R_L = 25\ k\Omega$ to $V^+/2$		4.980	4.920 **4.870**	4.870 **4.820**	V Min
				0.010	0.080 **0.130**	0.130 **0.180**	V Max
		$V^+ = 15V$ $R_L = 100\ k\Omega$ to $V^+/2$		14.970	14.920 **14.880**	14.880 **14.820**	V Min
				0.007	0.030 **0.050**	0.060 **0.090**	V Max
		$V^+ = 15V$ $R_L = 25\ k\Omega$ to $V^+/2$		14.950	14.900 **14.850**	14.850 **14.800**	V Min
				0.022	0.100 **0.150**	0.150 **0.200**	V Max
I_{SC}	Output Current $V^+ = 5V$	Sourcing, $V_O = 0V$		22	16 **10**	13 **8**	mA Min
		Sinking, $V_O = 5V$		21	16 **8**	13 **8**	mA Min
I_{SC}	Output Current $V^+ = 15V$	Sourcing, $V_O = 0V$		40	15 **10**	15 **10**	mA Min
		Sinking, $V_O = 13V$ (4)		39	24 **8**	21 **8**	mA Min

(3) $V^+ = 15V$, $V_{CM} = 7.5V$ and R_L connected to 7.5V. For Sourcing tests, $7.5V \le V_O \le 11.5V$. For Sinking tests, $2.5V \le V_O \le 7.5V$.
(4) Do not connect output to V^+ when V^+ is greater than 13V or reliability may be adversely affected.

Electrical Characteristics (continued)

Unless otherwise specified, all limits ensured for $T_A = T_J = 25°C$. **Boldface** limits apply at the temperature extremes. $V^+ = 5V$, $V^- = 0V$, $V_{CM} = 1.5V$, $V_O = V^+/2$ and $R_L > 1M$ unless otherwise specified.

Symbol	Parameter	Conditions	Typical (1)	LMC6042AI	LMC6042I	Units (Limit)
				Limit (2)	Limit (2)	
I_S	Supply Current	Both Amplifiers	20	34	45	μA
		$V_O = 1.5V$		**39**	**50**	Max
		Both Amplifiers	26	44	56	μA
		$V^+ = 15V$		**51**	**65**	Max

AC Electrical Characteristics

Unless otherwise specified, all limits ensured for $T_A = T_J = 25°C$. **Boldface** limits apply at the temperature extremes. $V^+ = 5V$, $V^- = 0V$, $V_{CM} = 1.5V$, $V_O = V^+/2$ and $R_L > 1M$ unless otherwise specified.

Symbol	Parameter	Conditions	Typ (1)	LMC6042AI	LMC6042I	Units (Limit)
				Limit (2)	Limit (2)	
SR	Slew Rate	See (3)	0.02	0.015	0.010	V/μs
				0.010	**0.007**	Min
GBW	Gain-Bandwidth Product		100			kHz
φ_m	Phase Margin		60			Deg
	Amp-to-Amp Isolation	See (4)	115			dB
e_n	Input-Referred Voltage Noise	f = 1 kHz	83			$nV/\sqrt{Hz}$
i_n	Input-Referred Current Noise	f = 1 kHz	0.0002			$pA/\sqrt{Hz}$
T.H.D.	Total Harmonic Distortion	f = 1 kHz, $A_V = -5$ $R_L = 100\ k\Omega$, $V_O = 2\ V_{PP}$ ±5V Supply	0.01			%

(1) Typical values represent the most likely parametric norm.
(2) All limits are ensured at room temperature (standard type face) or at operating temperature extremes (bold face type).
(3) $V^+ = 15V$. Connected as Voltage Follower with 10V step input. Number specified is the slower of the positive and negative slew rates.
(4) Input referred $V^+ = 15V$ and $R_L = 100\ k\Omega$ connected to $V^+/2$. Each amp excited in turn with 100 Hz to produce $V_O = 12\ V_{PP}$.

Typical Performance Characteristics

$V_S = \pm 7.5V$, $T_A = 25°C$ unless otherwise specified

Supply Current vs Supply Voltage

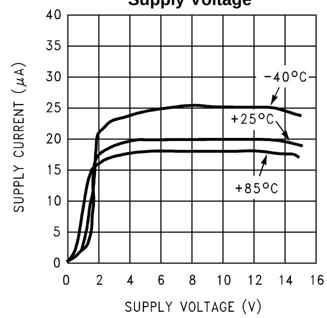


Figure 3.

Offset Voltage vs Temperature of Five Representative Units

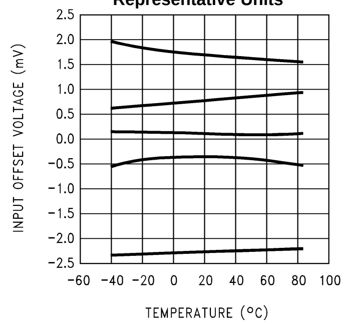


Figure 4.

Input Bias Current vs Temperature

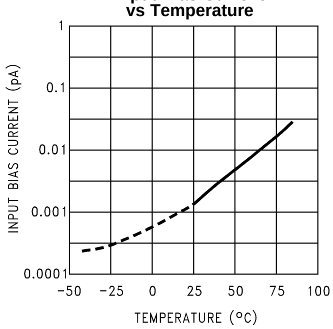


Figure 5.

Input Bias Current vs Input Common-Mode Voltage

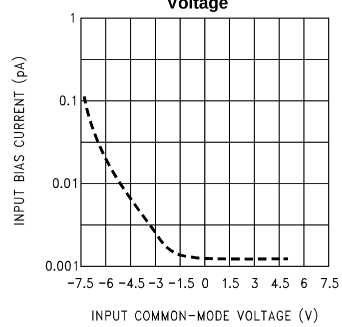


Figure 6.

Input Bias Current Voltage Range vs Temperature

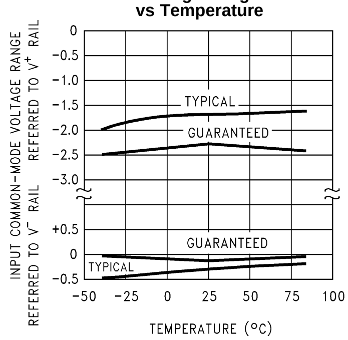


Figure 7.

Output Characteristics Current Sinking

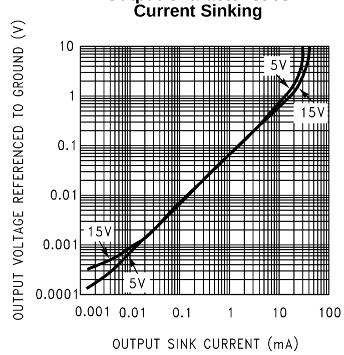


Figure 8.

Typical Performance Characteristics (continued)

V_S = ±7.5V, T_A = 25°C unless otherwise specified

Output Characteristics Current Sourcing

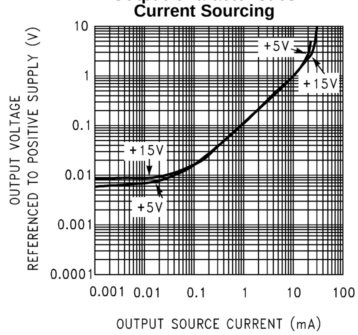


Figure 9.

Input Voltage Noise vs Frequency

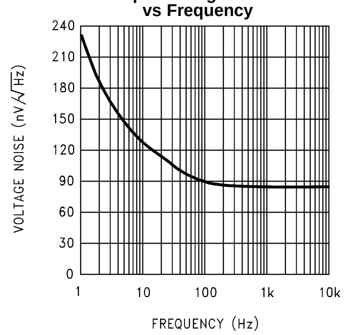


Figure 10.

Crosstalk Rejection vs Frequency

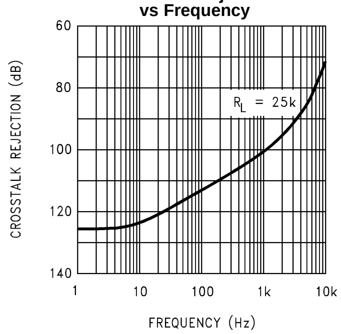


Figure 11.

CMRR vs Frequency

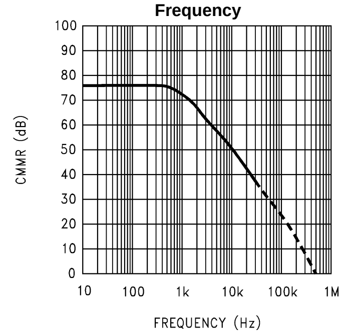


Figure 12.

CMRR vs Temperature

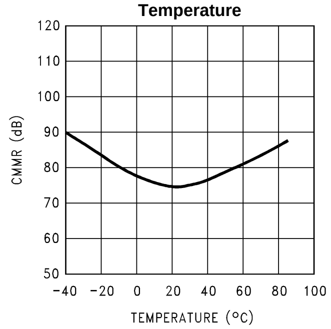


Figure 13.

Power Supply Rejection Ratio vs Frequency

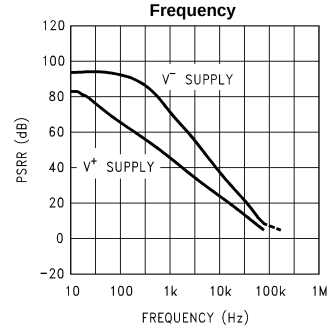


Figure 14.

Typical Performance Characteristics (continued)

V_S = ±7.5V, T_A = 25°C unless otherwise specified

Open-Loop Voltage Gain vs Temperature

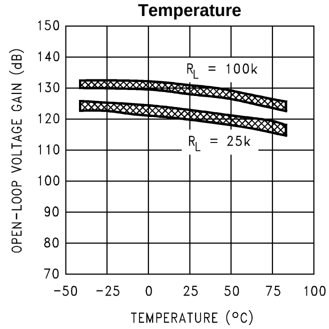


Figure 15.

Open-Loop Frequency Response

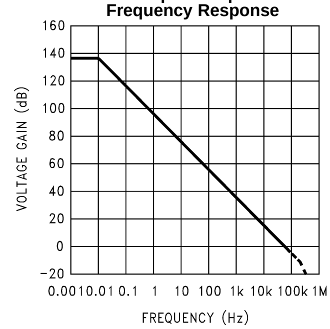


Figure 16.

Gain and Phase Responses vs Load Capacitance

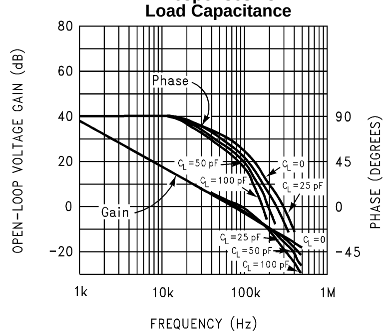


Figure 17.

Gain and Phase Response vs Temperature

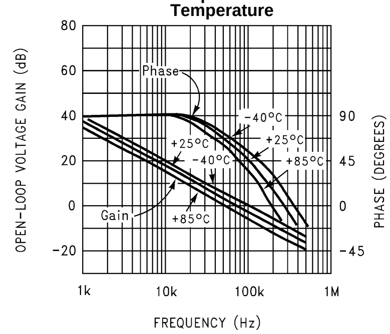


Figure 18.

Gain Error (V_{OS} vs V_{OUT})

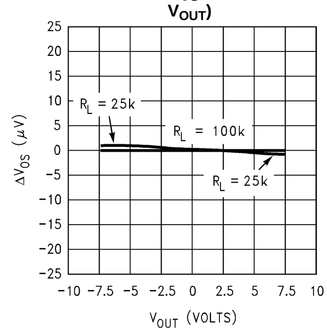


Figure 19.

Common-Mode Error vs Common-Mode Voltage of 3 Representative Units

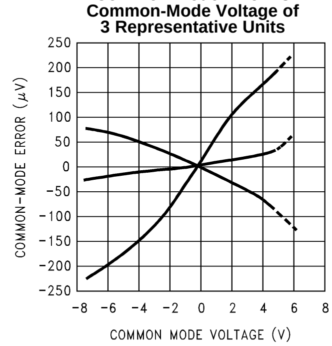


Figure 20.

Typical Performance Characteristics (continued)

V_S = ±7.5V, T_A = 25°C unless otherwise specified

Non-Inverting Slew Rate vs Temperature

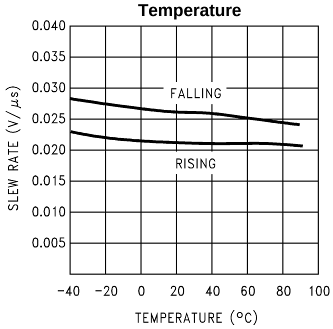


Figure 21.

Inverting Slew Rate vs Temperature

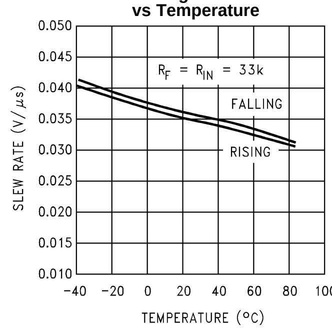


Figure 22.

Non-Inverting Large Signal Pulse Response (A_V = +1)

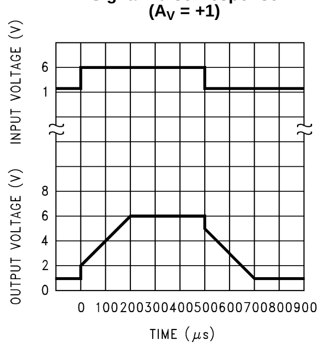


Figure 23.

Non-Inverting Small Signal Pulse Response

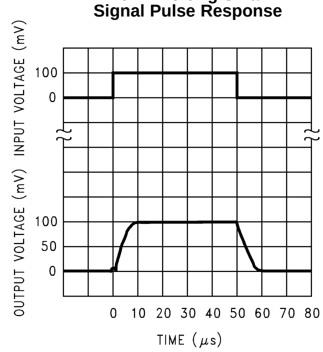


Figure 24.

Inverting Large-Signal Pulse Response

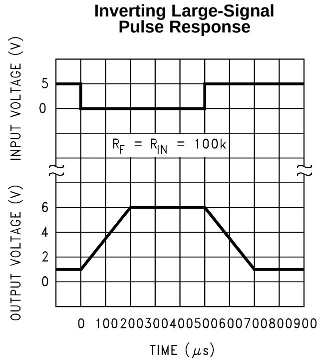


Figure 25.

Inverting Small Signal Pulse Response

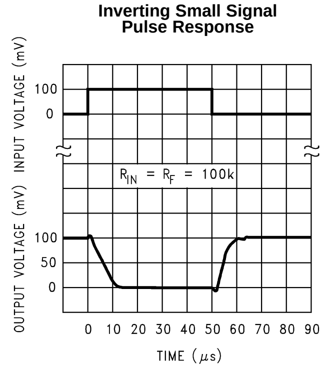


Figure 26.

Typical Performance Characteristics (continued)

V_S = ±7.5V, T_A = 25°C unless otherwise specified

Stability vs Capacitive Load

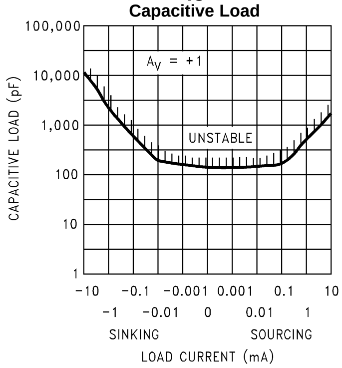


Figure 27.

Stability vs Capacitive Load

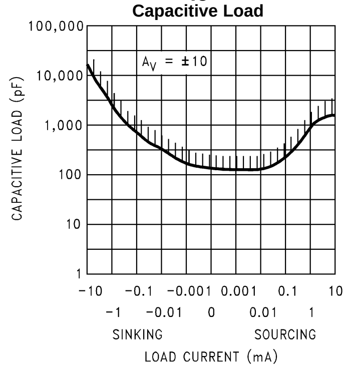


Figure 28.

APPLICATIONS HINTS

AMPLIFIER TOPOLOGY

The LMC6042 incorporates a novel op-amp design topology that enables it to maintain rail-to-rail output swing even when driving a large load. Instead of relying on a push-pull unity gain output buffer stage, the output stage is taken directly from the internal integrator, which provides both low output impedance and large gain. Special feed-forward compensation design techniques are incorporated to maintain stability over a wider range of operating conditions than traditional micropower op-amps. These features make the LMC6042 both easier to design with, and provide higher speed than products typically found in this ultra-low power class.

COMPENSATING FOR INPUT CAPACITANCE

It is quite common to use large values of feedback resistance with amplifiers with ultra-low input curent, like the LMC6042.

Although the LMC6042 is highly stable over a wide range of operating conditions, certain precautions must be met to achieve the desired pulse response when a large feedback resistor is used. Large feedback resistors and even small values of input capacitance, due to transducers, photodiodes, and circuit board parasitics, reduce phase margins.

When high input impedances are demanded, guarding of the LMC6042 is suggested. Guarding input lines will not only reduce leakage, but lowers stray input capacitance as well. (See Printed-Circuit-Board Layout for High Impedance Work).

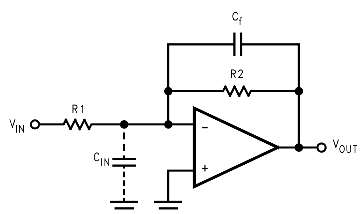


Figure 29. Cancelling the Effect of Input Capacitance

The effect of input capacitance can be compensated for by adding a capacitor. Place a capacitor, C_f, around the feedback resistor (as in Figure 29) such that:

$$\frac{1}{2\pi R1\,C_{IN}} \geq \frac{1}{2\pi R2\,C_f} \quad (1)$$

or

$$R1\,C_{IN} \leq R2\,C_f \quad (2)$$

Since it is often difficult to know the exact value of C_{IN}, C_f can be experimentally adjusted so that the desired pulse response is achieved. Refer to the LMC660 and the LMC662 for a more detailed discussion on compensating for input capacitance.

CAPACITIVE LOAD TOLERANCE

Direct capacitive loading will reduce the phase margin of many op-amps. A pole in the feedback loop is created by the combination of the op-amp's output impedance and the capacitive load. This pole induces phase lag at the unity-gain crossover frequency of the amplifier resulting in either an oscillatory or underdamped pulse response. With a few external components, op amps can easily indirectly drive capacitive loads, as shown in Figure 30.

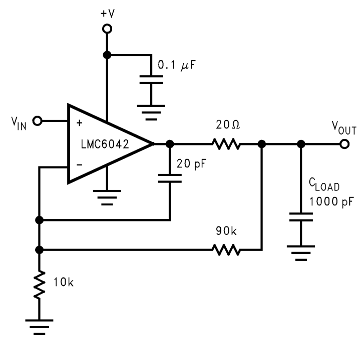


Figure 30. LMC6042 Noninverting Gain of 10 Amplifier, Compensated to Handle Capacitive Loads

In the circuit of Figure 30, R1 and C1 serve to counteract the loss of phase margin by feeding the high frequency component of the output signal back to the amplifier's inverting input, thereby preserving phase margin in the overall feedback loop.

Capacitive load driving capability is enhanced by using a pull up resistor to V^+ (Figure 31). Typically a pull up resistor conducting 10 µA or more will significantly improve capacitive load responses. The value of the pull up resistor must be determined based on the current sinking capability of the amplifier with respect to the desired output swing. Open loop gain of the amplifier can also be affected by the pull up resistor (see Electrical Characteristics).

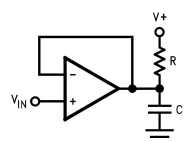


Figure 31. Compensating for Large Capacitive Loads with a Pull Up Resistor

PRINTED-CIRCUIT-BOARD LAYOUT FOR HIGH-IMPEDANCE WORK

It is generally recognized that any circuit which must operate with less than 1000 pA of leakage current requires special layout of the PC board. When one wishes to take advantage of the ultra-low bias current of the LMC6042, typically less than 2 fA, it is essential to have an excellent layout. Fortunately, the techniques of obtaining low leakages are quite simple. First, the user must not ignore the surface leakage of the PC board, even though it may sometimes appear acceptably low, because under conditions of high humidity or dust or contamination, the surface leakage will be appreciable.

To minimize the effect of any surface leakage, lay out a ring of foil completely surrounding the LMC6042's inputs and the terminals of capacitors, diodes, conductors, resistors, relay terminals etc. connected to the op-amp's inputs, as in Figure 32. To have a significant effect, guard rings should be placed on both the top and bottom of the PC board. This PC foil must then be connected to a voltage which is at the same voltage as the amplifier inputs, since no leakage current can flow between two points at the same potential. For example, a PC board trace-to-pad resistance of $10^{12}\Omega$, which is normally considered a very large resistance, could leak 5 pA if the trace were a 5V bus adjacent to the pad of the input. This would cause a 100 times degradation from the LMC6042's actual performance. However, if a guard ring is held within 5 mV of the inputs, then even a resistance of $10^{11}\Omega$ would cause only 0.05 pA of leakage current. See Figure 36 for typical connections of guard rings for standard op-amp configurations.

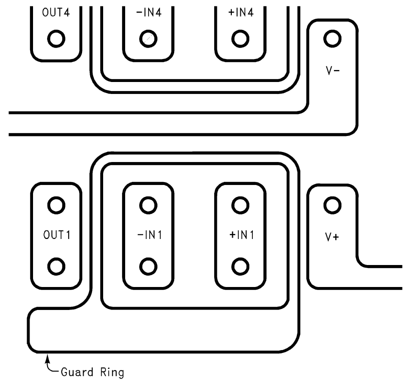


Figure 32. Example of Guard Ring in P.C. Board Layout

Figure 33. Inverting Amplifier

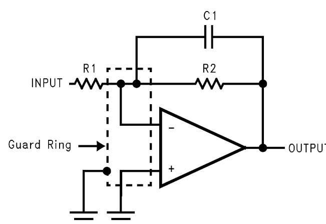


Figure 34. Non-Inverting Amplifier

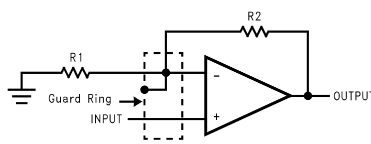


Figure 35. Follower

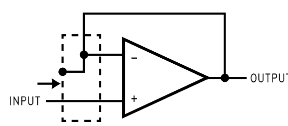
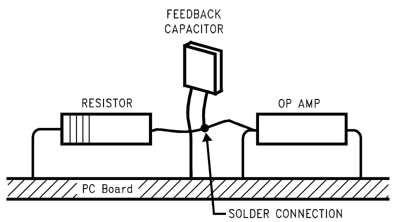


Figure 36. Typical Connections of Guard Rings

The designer should be aware that when it is inappropriate to lay out a PC board for the sake of just a few circuits, there is another technique which is even better than a guard ring on a PC board: Don't insert the amplifier's input pin into the board at all, but bend it up in the air and use only air as an insulator. Air is an excellent insulator. In this case you may have to forego some of the advantages of PC board construction, but the advantages are sometimes well worth the effort of using point-to-point up-in-the-air wiring. See Figure 37.



(Input pins are lifted out of PC board and soldered directly to components. All other pins connected to PC board.)

Figure 37. Air Wiring

Typical Single-Supply Applications

($V^+ = 5.0\ V_{DC}$)

The extremely high input impedance, and low power consumption, of the LMC6042 make it ideal for applications that require battery-powered instrumentation amplifiers. Examples of these types of applications are hand-held pH probes, analytic medical instruments, magnetic field detectors, gas detectors, and silicon based pressure transducers.

The circuit in Figure 38 is recommended for applications where the common-mode input range is relatively low and the differential gain will be in the range of 10 to 1000. This two op-amp instrumentation amplifier features an independent adjustment of the gain and common-mode rejection trim, and a total quiescent supply current of less than 20 µA. To maintain ultra-high input impedance, it is advisable to use ground rings and consider PC board layout an important part of the overall system design (see Printed-Circuit-Board Layout for High Impedance Work). Referring to Figure 38, the input voltages are represented as a common-mode input V_{CM} plus a differential input V_D.

Rejection of the common-mode component of the input is accomplished by making the ratio of R1/R2 equal to R3/R4. So that where,

$$\frac{R3}{R4} = \frac{R2}{R1}$$

$$V_{OUT} = \frac{R4}{R3}\left(1 + \frac{R3}{R4} + \frac{R2 + R3}{R0}\right) V_D \tag{3}$$

A suggested design guideline is to minimize the difference of value between R1 through R4. This will often result in improved resistor tempco, amplifier gain, and CMRR over temperature. If RN = R1 = R2 = R3 = R4 then the gain equation can be simplified:

$$V_{OUT} = 2\left(1 + \frac{RN}{R0}\right) V_D \tag{4}$$

Due to the “zero-in, zero-out” performance of the LMC6042, and output swing rail-rail, the dynamic range is only limited to the input common-mode range of 0V to $V_S - 2.3V$, worst case at room temperature. This feature of the LMC6042 makes it an ideal choice for low-power instrumentation systems.

A complete instrumentation amplifier designed for a gain of 100 is shown in Figure 39. Provisions have been made for low sensitivity trimming of CMRR and gain.

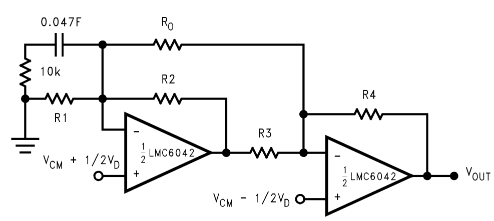


Figure 38. Two Op-Amp Instrumentation Amplifier

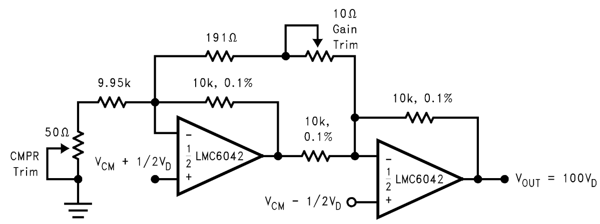


Figure 39. Low-Power Two-Op-Amp Instrumentation Amplifier

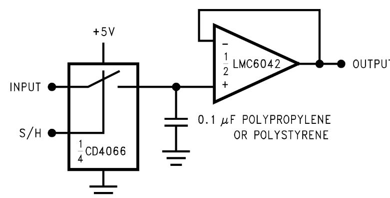


Figure 40. Low-Leakage Sample and Hold

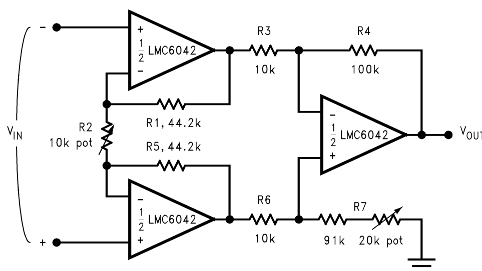


Figure 41. Instrumentation Amplifier

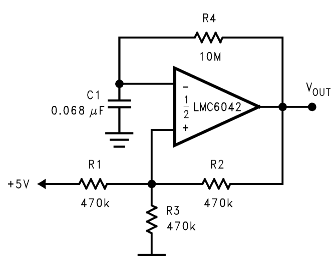


Figure 42. 1 Hz Square Wave Oscillator

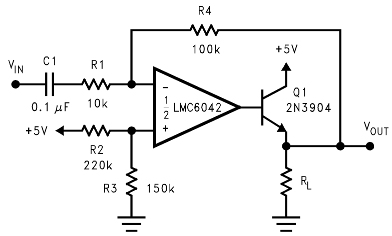


Figure 43. AC Coupled Power Amplifier

REVISION HISTORY

Changes from Revision D (March 2013) to Revision E	Page
• Changed layout of National Data Sheet to TI format	15

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
LMC6042AIJ	ACTIVE	CDIP	NAB	8	40	TBD	Call TI	Call TI		LMC6042AIJ	Samples
LMC6042AIM	NRND	SOIC	D	8	95	TBD	Call TI	Call TI	-40 to 85	LMC60 42AIM	
LMC6042AIM/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	LMC60 42AIM	Samples
LMC6042AIMX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	LMC60 42AIM	Samples
LMC6042AIN/NOPB	ACTIVE	PDIP	P	8	40	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 85	LMC60 42AIN	Samples
LMC6042IM/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	LMC60 42IM	Samples
LMC6042IMX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	LMC60 42IM	Samples
LMC6042IN/NOPB	ACTIVE	PDIP	P	8	40	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 85	LMC60 42IN	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.

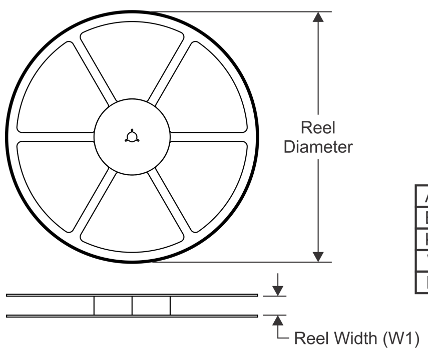
(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

[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.

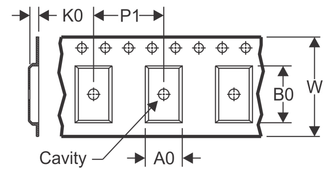
[6] Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

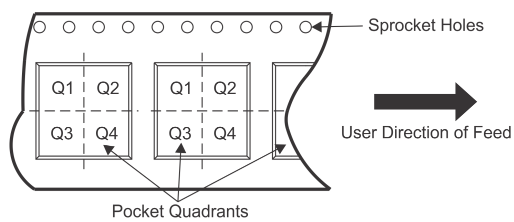


TAPE DIMENSIONS



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

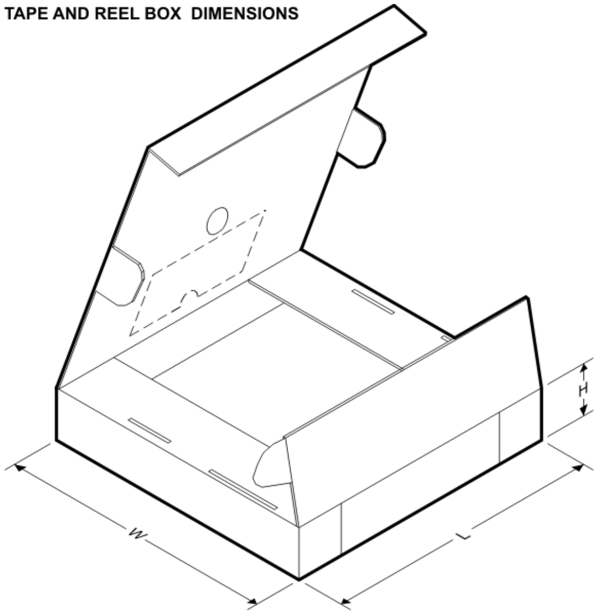
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
LMC6042AIMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LMC6042IMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1

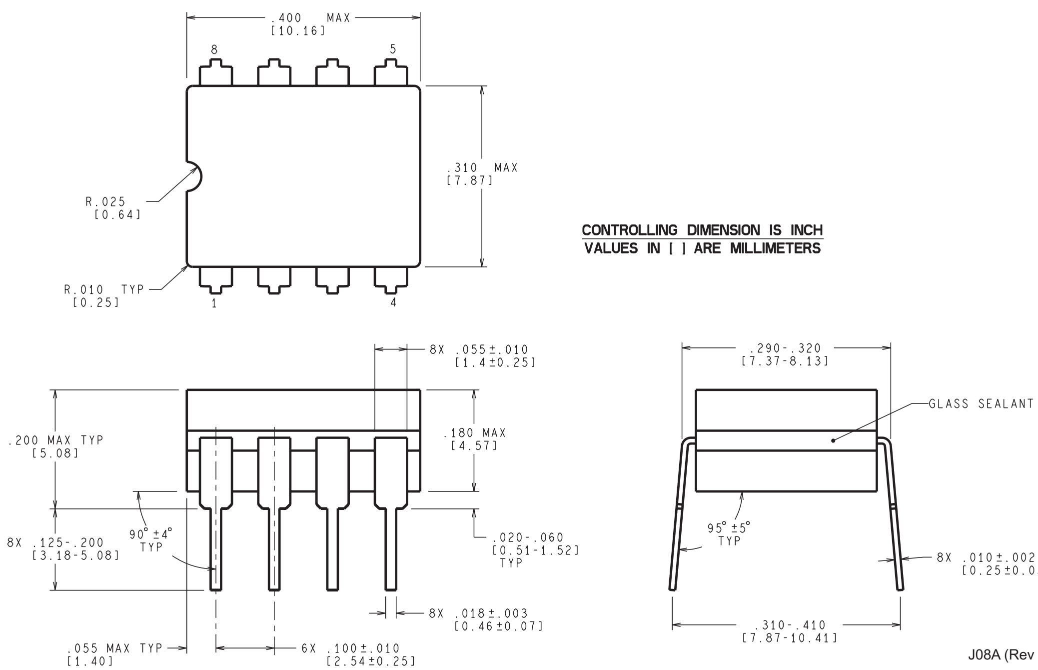
TAPE AND REEL BOX DIMENSIONS



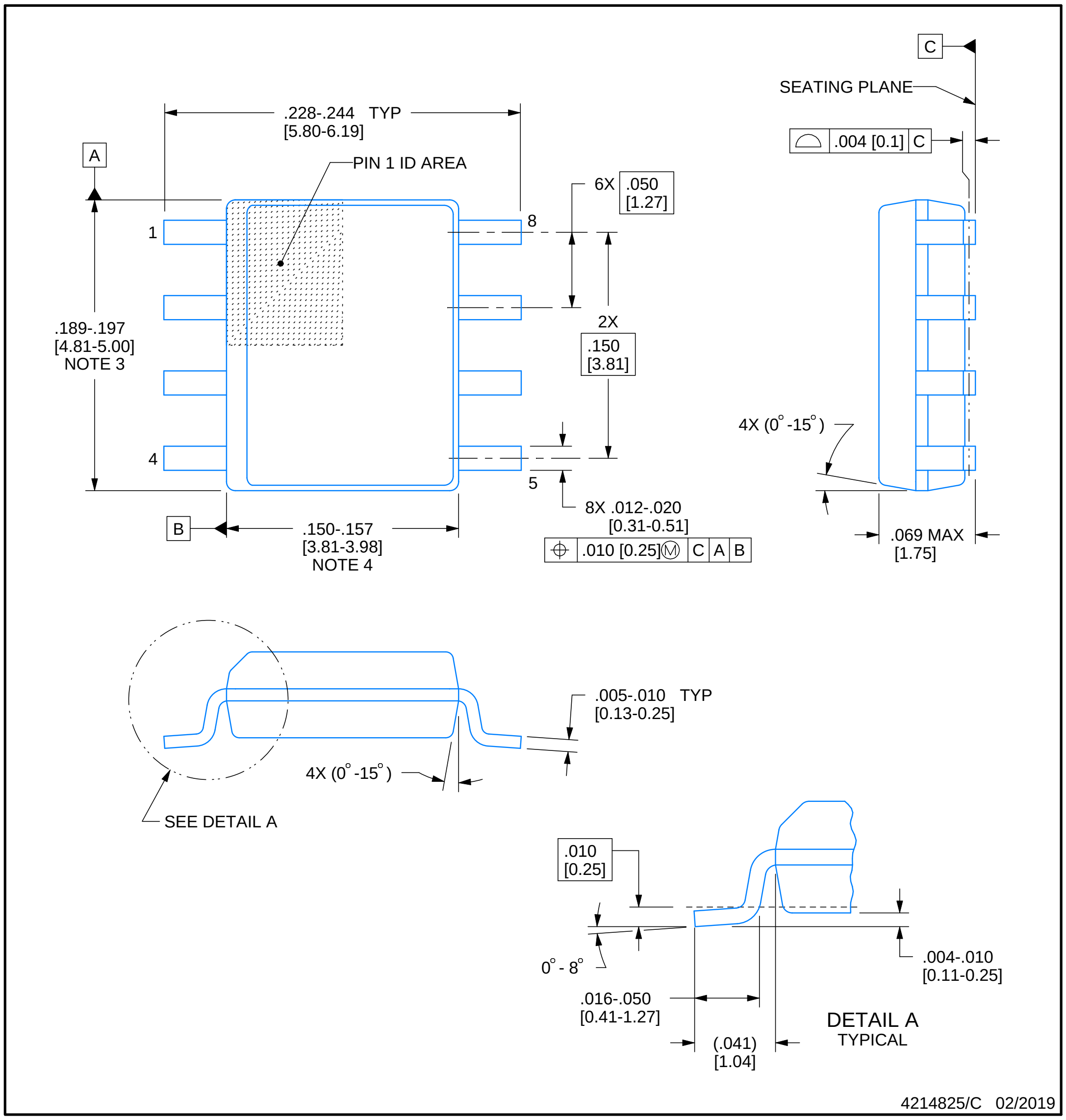
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LMC6042AIMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LMC6042IMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0

NAB0008A



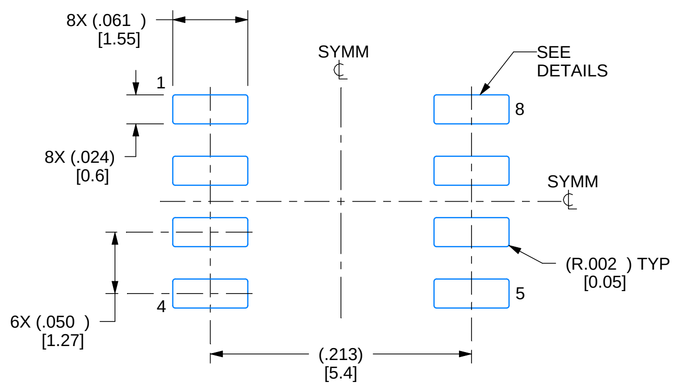
J08A (Rev M)



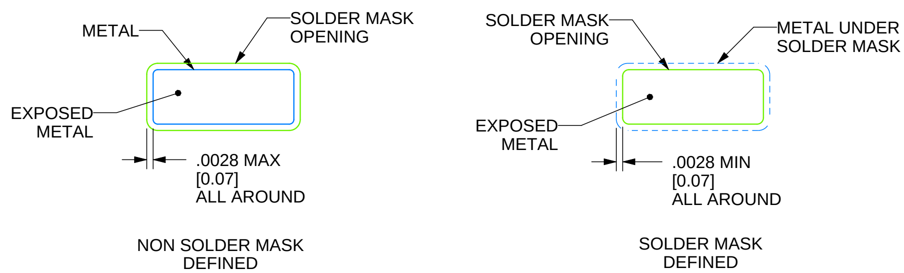
4214825/C 02/2019

NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. 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 .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X

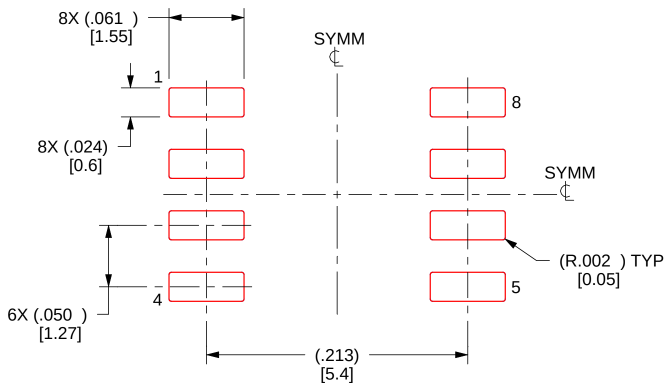


SOLDER MASK DETAILS

4214825/C 02/2019

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.



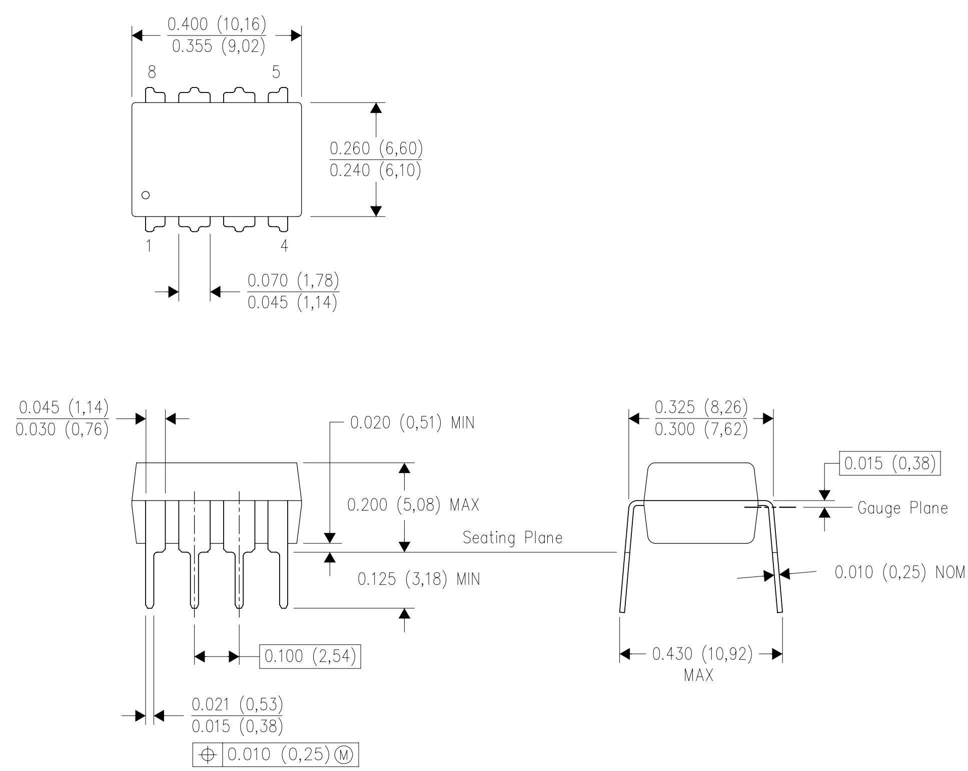
SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

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.

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

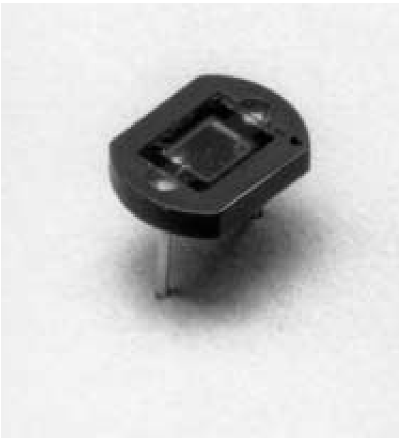


4040082/E 04/2010

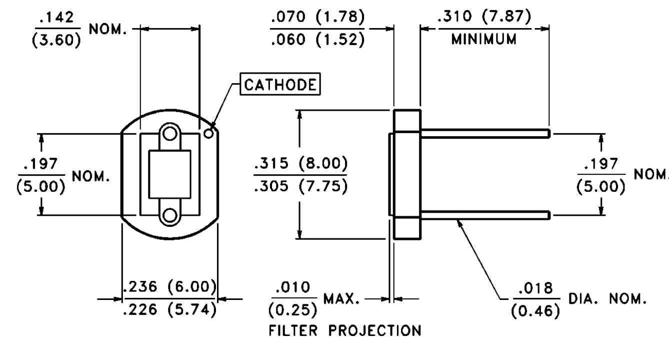
NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS–001 variation BA.

VTB Process Photodiode

VTB8440BH, 8441BH



PACKAGE DIMENSIONS inch (mm)



CASE 21F 8 mm CERAMIC
CHIP ACTIVE AREA: .008 in^2 (5.16 mm^2)

PRODUCT DESCRIPTION

Planar silicon photodiode in recessed ceramic package. The package incorporates an infrared rejection filter. These diodes have very high shunt resistance and have good blue response.

ABSOLUTE MAXIMUM RATINGS

Storage Temperature:	-20°C to 75°C
Operating Temperature:	-20°C to 75°C

ELECTRO-OPTICAL CHARACTERISTICS @ 25°C (See also VTB curves, pages 21-22)

SYMBOL	CHARACTERISTIC	TEST CONDITIONS	VTB8440BH			VTB8441BH			UNITS
			Min.	Typ.	Max.	Min.	Typ.	Max.	
I_{SC}	Short Circuit Current	H = 100 fc, 2850 K	4	5		4	5		µA
TC I_{SC}	I_{SC} Temperature Coefficient	2850 K		.02	.08		.02	.08	%/°C
V_{OC}	Open Circuit Voltage	H = 100 fc, 2850 K		420			420		mV
TC V_{OC}	V_{OC} Temperature Coefficient	2850 K		-2.0			-2.0		mV/°C
I_D	Dark Current	H = 0, VR = 2.0 V			2000			100	pA
R_{SH}	Shunt Resistance	H = 0, V = 10 mV		.07			1.4		GΩ
TC R_{SH}	R_{SH} Temperature Coefficient	H = 0, V = 10 mV		-8.0			-8.0		%/°C
C_J	Junction Capacitance	H = 0, V = 0		1.0			1.0		nF
λ_{range}	Spectral Application Range		330		720	330		720	nm
λ_p	Spectral Response - Peak			580			580		nm
V_{BR}	Breakdown Voltage		2	40		2	40		V
$\theta_{1/2}$	Angular Resp. - 50% Resp. Pt.			±50			±50		Degrees
NEP	Noise Equivalent Power		1.1×10^{-13} (Typ.)			2.4×10^{-14} (Typ.)			$W/\sqrt{Hz}$
D*	Specific Detectivity		2.2×10^{12} (Typ.)			9.7×10^{12} (Typ.)			$cm\sqrt{Hz}/W$

B Python Code

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-

import urllib.request
import time
import json
import webbrowser
import RPi.GPIO as GPIO
import time

CS = 29
CLK = 31
DOUT = 33
DIN = 40

GPIO.setmode(GPIO.BOARD)
GPIO.setup(CS, GPIO.OUT)
GPIO.setup(CLK, GPIO.OUT)
GPIO.setup(DOUT, GPIO.IN)
GPIO.setup(DIN, GPIO.OUT)

def readADC_channel_0():

    d0 = ''

    GPIO.output(CS, False)

    GPIO.output(DIN, True)

    GPIO.output(CLK, False)
    GPIO.output(CLK, True)
    GPIO.output(CLK, False)


    din_control = '1000'
    for n in din_control:
        if n == '1':
            GPIO.output(DIN, True)

        else:
            GPIO.output(DIN, False)

        GPIO.output(CLK, False)
        GPIO.output(CLK, True)
        GPIO.output(CLK, False)

    GPIO.output(CLK, False)
    GPIO.output(CLK, True)
    GPIO.output(CLK, False)

    for n in range(0,10):
```

```
        GPIO.output(CLK, False)
        GPIO.output(CLK, True)
        GPIO.output(CLK, False)

        DOUT_state = GPIO.input(DOUT)
        if DOUT_state == True:
            d0 = d0 + '1'

        else:
            d0 = d0 + '0'

    GPIO.output(CS, True)
    GPIO.output(DIN, False)

    return d0

def readADC_channel_1():

    d1 = ''

    GPIO.output(CS, False)

    GPIO.output(DIN, True)

    GPIO.output(CLK, False)
    GPIO.output(CLK, True)
    GPIO.output(CLK, False)


    din_control = '1001'
    for n in din_control:
        if n == '1':
            GPIO.output(DIN, True)

        else:
            GPIO.output(DIN, False)

        GPIO.output(CLK, False)
        GPIO.output(CLK, True)
        GPIO.output(CLK, False)

    GPIO.output(CLK, False)
    GPIO.output(CLK, True)
    GPIO.output(CLK, False)

    for n in range(0,10):
        GPIO.output(CLK, False)
        GPIO.output(CLK, True)
        GPIO.output(CLK, False)

        DOUT_state = GPIO.input(DOUT)
        if DOUT_state == True:
            d1 = d1 + '1'

```

```
        else:
            d1 = d1 + '0'

    GPIO.output(CS, True)
    GPIO.output(DIN, False)

    return d1


def calc_volts_0(d0):

    d0_int = int(d0,2)
    volts_0 = 5.0*d0_int / 1023
    volts_0 = round(volts_0, 6)

    return volts_0


def calc_volts_1(d1):

    d1_int = int(d1,2)
    volts_1 = 5.0*d1_int / 1023
    volts_1 = round(volts_1, 3)

    return volts_1



ID1 = input("Input Weather Station 1 ID: \n\nTo find weather station ID's, go to:\nhttps://www.wunderground.com/wundermap?lat=35.1&lon=-92.35&cm_ven=localwx_wumap\n").upper()

current_temp_data = []
feelslike_temp_data = []
solarradiation_data = []
hour_data = []
minute_data = []
second_data = []
hr_precip_data = []
precip_today_data = []
sensor_data = []
resistor_data = []

try:
    FN = True
    check = 0
    while FN == True:

        weather = ('https://api-ak.wunderground.com/api/d8585d80376a429e/conditions/labels/lang:EN/units:english/bestfct:1/v:2.0/q/pws:'+ID1+'.json')

        now = time.localtime()
        hour_local = now[3]
        minute_local = now[4]
```

```
        if minute_local<10:
            minute_local = '0' + str(minute_local)
        if hour_local>=12:
            hour_local -= 12
            local_time = str(hour_local) + ':' + str(minute_local) + ' PM'
        else:
            local_time = str(hour_local) + ':' + str(minute_local) + ' AM'


        weather = json.loads(urllib.request.urlopen(weather).read().decode('utf8'))

        weather_icon = weather['current_observation']['icon']

        latitude = weather['response']['location']['latitude']

        longitude = weather['response']['location']['longitude']

        year = weather['response']['date']['year']

        month = weather['response']['date']['month']

        day = weather['response']['date']['day']

        city_name =  weather['response']['location']['city'] + ", " + weather['response']['location']['country']

        main_text = weather['current_observation']['condition']

        hour_json = weather['response']['date']['hour']
        hour_data.append(str(hour_json))

        min_json = weather['response']['date']['min']
        minute_data.append(str(min_json))

        sec_json = weather['response']['date']['sec']
        second_data.append(str(sec_json))

        temperature = weather['current_observation']['temperature']
        current_temp_data.append(str(temperature))

        feels_like = weather['current_observation']['feelslike']
        feelslike_temp_data.append(str(feels_like))

        solarradiation = weather['current_observation']['solarradiation']
        solarradiation_data.append(str(solarradiation))

        precip_today = weather['current_observation']['precip_today']
        precip_today_data.append(str(precip_today))

        hr_precip = weather['current_observation']['precip_1hr']
        hr_precip_data.append(str(hr_precip))

        d0 = readADC_channel_0()
        d1 = readADC_channel_1()
```

```
        float_vout_0 = calc_volts_0(d0)
        float_vout_1 = calc_volts_1(d1)
        vout_diode = str(float_vout_0)
        vout_resistor = str(float_vout_1)
        sensor_data.append(vout_diode)
        resistor_data.append(vout_resistor)

        print('\n')
        print(hour_json)
        print(min_json)
        print(year,'/',month,'/',day)

        print('\n')
        print('Latitude : ', latitude)
        print('Longitude: ', longitude)
        print(weather_icon)
        print(city_name)
        print(main_text)
        print(temperature)
        print(solarradiation)
        print('local time: ', local_time)
        print('\n')

        f = open('current_conditions.html','w')

        text_solarradiation = str(solarradiation)
        text_precip_today = str(precip_today)
        text_hr_precip = str(hr_precip)
        text_temperature = str(temperature)
        text_feels_like = str(feels_like)
        text_sensor_data = vout_diode
        text_month = str(month)
        text_day = str(day)
        text_year = str(year)
        text_hr = str(hour_json)
        text_min = str(min_json)


        message = """<html>
        <head>
        <style>body {background-color: black; color: white; text-align: center}
        h1 {color: white}
        image {width: 100%}
        * {
            box-sizing: border-box;
        }

        .column {
        float: left;
        width: 33.33%;
        padding: 10px;
        height: 300px;
        }

```

```
        .row:after {
        content: "";
        display: table;
        clear: both;
        }
        </style></head>
        <title>Current Conditions</title>
        <body>
        <h1>Current Conditions for Weather Station """+ID1+"""</h1>
        <h2>Weather Station Location """+city_name+"""<br></h2>
        <h4>"""+local_time+"""<br></h4>
        <h4>"""+text_month+"""/"""+text_day+"""/"""+text_year+"""<br></h4>
        <p><img src="icons/"""+weather_icon+""".bmp" alt="Weather Icon Not Found"></p>
        <p>Condition: """+main_text+"""</p>
        <div class="row">
        <div class="column">
        <h2>Temperature</h2>
        <p>Temperature: """+text_temperature+"""&degF</p>
        <p>Feels Like: """+text_feels_like+"""&degF</p>
        </div>

        <div class="column">
        <h2>Light</h2>
        <p>Solar Radiation: """+text_solarradiation+""" W/m<sup>2</sup></p>
        <p>Sensor: """+text_sensor_data+""" V</p>
        </div>

        <div class="column">
        <h2>Precipitation</h2>
        <p>Total Precipitation: """+text_precip_today+""" in</p>
        <p>Hour Precipitation: """+text_hr_precip+""" in</p>
        </div>
        </div>

        <p>Last update from weather underground: """+text_hr+""":"""+text_min+""" </p>

        </body>
        </html>"""

        f.write(message)
        f.close()

        webbrowser.open('current_conditions.html')
        check = check + 1
        time.sleep(5)

        if check == 5:
            FN = False


    datafile_radiation = open("Diode Sensor Data for Timed Run 1.txt", "w")
    for n in range (len(solarradiation_data)):
```

```
        datafile_radiation.write(str(hour_data[n] + '\t' + minute_data[n] + '\t' +
    second_data[n] + '\t' + solarradiation_data[n] + '\t' + sensor_data[n] + '\n'))

    datafile_radiation.close()


    datafile_radiation = open("Resistor Sensor Data for Timed Run 1.txt", "w")
    for n in range (len(solarradiation_data)):
        datafile_radiation.write(str(hour_data[n] + '\t' + minute_data[n] + '\t' +
    second_data[n] + '\t' + solarradiation_data[n] + '\t' + resistor_data[n] + '\n'))

    datafile_radiation.close()


    datafile_other = open("Other Data for Timed Run 1.txt", "w")
    for n in range (len(solarradiation_data)):
        datafile_other.write(str(hour_data[n] + '\t' + minute_data[n] + '\t' +
    second_data[n] + '\t' + current_temp_data[n] + '\t' + hr_precip_data[n] + '\t' +
    precip_today_data[n] + '\n'))

    datafile_other.close()

except KeyboardInterrupt:
    print('The program has been shut down')

finally:
    GPIO.cleanup()
```

C HTML Code

```
<html>
        <head>
        <style>body {background-color: black; color: white; text-align: center}
        h1 {color: white}
        image {width: 100%}
        * {
            box-sizing: border-box;
        }


        .column {
        float: left;
        width: 33.33%;
        padding: 10px;
        height: 300px;
        }


        .row:after {
        content: "";
        display: table;
        clear: both;
        }
        </style></head>
        <title>Current Conditions</title>
        <body>
        <h1>Current Conditions for Weather Station KARCONWA57</h1>
        <h2>Weather Station Location Mayflower, US<br></h2>
        <h4>10:48 AM<br></h4>
        <h4>4/25/2019<br></h4>
        <p><img src="icons/cloudy.bmp" alt="Weather Icon Not Found" ></p>
        <p>Condition: Overcast</p>
        <div class="row">
        <div class="column">
        <h2>Temperature</h2>
        <p>Temperature: 67.5&degF</p>
        <p>Feels Like: 67.5&degF</p>
        </div>

        <div class="column">
        <h2>Light</h2>
        <p>Solar Radiation: 109 W/m<sup>2</sup></p>
        <p>Sensor: 0.777126 V</p>
        </div>

        <div class="column">
        <h2>Precipitation</h2>
        <p>Total Precipitation: 1.65 in</p>
        <p>Hour Precipitation: 0.0 in</p>
        </div>
        </div>
```

```
    <p>Last update from weather underground: 10:48 </p>

    </body>
    </html>
```