LM50-Q1 and LM50HV-Q1 - Automotive (Grade 1, Grade 0), Industry-Standard (10mV/°C) Analog Temperature Sensor with ±2°C or ±3°C Accuracy, in SOT-23 Package

1 Features

- AEC-Q100 Qualified for automotive applications
  - LM50-Q1 (Grade-1): –40°C to +125°C
  - LM50HV-Q1 (Grade-0): –40°C to +150°C
- Functional safety-capable
  - Documentation available to aid system design
- Industry-Standard Sensor Gain/Offset:
  - 10mV/°C, 500mV at 0°C
- LM50HV-Q1 (Next-generation):
  - Wide supply range: 3V to 36V
  - ±2°C (Max) accuracy over 20°C to 70°C
  - ±2.5°C (Max) accuracy over 0°C to 100°C
  - ±3°C (Max) accuracy over −20°C to 125°C
  - ±3.5°C (Max) accuracy over −40°C to 150°C
  - Quiescent Current (Typ): 52µA
- LM50-Q1:
  - Operating supply range: 4.5V to 10V
  - ±3°C (Max) accuracy at 25°C
  - ±4°C (Max) accuracy over −40°C to 125°C
  - Quiescent Current (Typ): 95µA
- Available in Standard SOT23-3 package
- DC Output Impedance: 2kΩ/4kΩ (Typ/Max)
  - Enables driving large capacitive loads
- UL Recognized Component (LM50-Q1)

2 Applications

- HEV/EV OBC & DC/DC converter
- Electronic power steering (EPS)
- Braking systems
- In-cabin sensing
- HVAC System
- Power Supply Modules

3 Description

The LM50-Q1 (Grade-1) and LM50HV-Q1 (Grade-0) devices are AEC-Q100 automotive-grade analog temperature sensor that can measure temperature up to 125°C and 150°C, respectively, using a single positive supply. Unlike NTC thermistors, LM50-Q1 and LM50HV-Q1 do not require any external calibration, trimming or software linearization leading to simplifying the circuitry requirements. The output voltage of the devices are linearly proportional to temperature (10mV/°C) and has a DC offset of 500mV at 0°C. The offset allows reading negative temperatures without the need for a negative supply. The output voltage of these devices ranges from 100mV (at -40°C) to 1.75V (at 125°C) and 2V (at 150°C only for LM50HV-Q1), simplifying automotive ADC interfacing (including ADC integrated in MCU).

LM50HV-Q1 is designed for LDO-less application due to stable functionality across wide supply range of 3V to 36V. Trimming and calibration of LM50-Q1 and LM50HV-Q1 at the wafer level provide low cost and consistent accuracy: LM50-Q1 (±4°C across –40°C to 125°C) and LM50HV-Q1 (±3°C across –20°C to 125°C, ±3.5°C across –40°C to 150°C). Functional safety documentation is also available.

Package Information

PART NUMBER	PACKAGE(1)	PACKAGE SIZE(2)
LM50-Q1 and LM50HV-Q1	DBZ (SOT-23, 3)	2.37mm × 2.92mm

(1) For more information, see Section 11.
(2) The package size (length × width) is a nominal value and includes pins, where applicable.

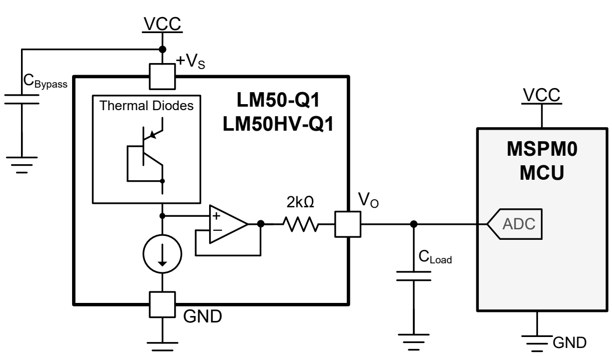

Figure 3-1. Simplified Schematic

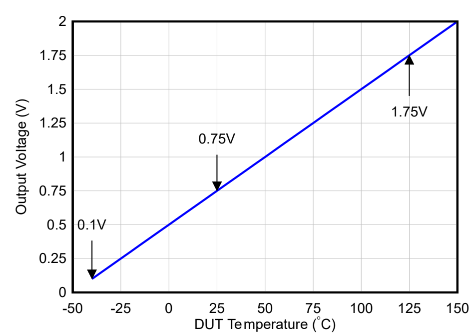

Figure 3-2. Full-Range LM50-Q1 (–40°C to 125°C) and LM50HV-Q1 (–40°C to 150°C)

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4 Device Comparison

Table 4-1. Device Comparison

Feature	LM50HV-Q1	LM50-Q1 [1]	TMP235-Q1	TMP236-Q1	LM60-Q1 [1]	LMT86-Q1	LMT87-Q1	LM94022-Q1
Sensor gain (mV/°C)	10	10	10	19.5	6.25	–10.9	–13.6	–5.5/–8.2 –10.9/–13.6
Sensor gain type	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Pin-Set
Offset at 0°C (mV)	500	500	500	400	424	2103	2637	1.034/1.57 2.1/2.63
Temp Range (°C)	-40 to 150	-40 to 125	-40 to 150	-10 to 125	-40 to 125	-50 to 150	-50 to 150	-50 to 150
Power Supply Specifications								
V_{DD} (V)	3 to 36	4.5 to 10	2.3 to 5.5	3.1 to 5.5	2.7 to 10	2.2 to 5.5	2.7 to 5.5	1.5/1.8/ 2.2/2.7 to 5.5
I_Q (typ) (µA)	52	95	9	10	82	5.4	5.4	5.4
Automotive Specifications								
Automotive Grade	Grade-0	Grade-1	Grade-0	Grade-1	Grade-1	Grade-0	Grade-0	Grade-0
Functional Safety Capable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Temperature Accuracy								
25°C (typ)	±1	-	±0.5	±0.5	-	±0.3	±0.3	-
-50°C (max)	-	-	-	-	-	±2.7	±2.7	±1.8
-40°C (max)	±3.5	±4	±2.5	-	±4	±2.7	±2.7	±1.8
-25°C (max)	±3.5	±3.8	±2.5	-	±3.8	±2.7	±2.7	±1.8
-20°C (max)	±3	±3.7	±2.5	-	±3.7	±2.7	±2.7	±1.8
-10°C (max)	±3	±3.5	±2.5	±2.5	±3.5	±2.7	±2.7	±1.8
0°C (max)	±2.5	±3.4	-1.5/1.2	±1.5	±3.4	±2.7	±2.7	±1.8
20°C (max)	±2	±3.1	-1.5/1.2	±1.5	±3.1	±2.7	±2.7	±1.5
25°C (max)	±2	±3	-1.5/1.2	±1.5	±3	±2.7	±2.7	±1.5
40°C (max)	±2	±3.15	-1.5/1.2	±1.5	±3.15	±2.7	±2.7	±1.5
70°C (max)	±2	±3.45	-1.5/1.2	±1.5	±3.45	±2.7	±2.7	±1.8
85°C (max)	±2.5	±3.6	±2.5	±2.5	±3.6	±2.7	±2.7	±2.1
90°C (max)	±2.5	±3.65	±2.5	±2.5	±3.65	±2.7	±2.7	±2.1
100°C (max)	±2.5	±3.75	±2.5	±2.5	±3.75	±2.7	±2.7	±2.4
120°C (max)	±3	±3.95	±2.5	±2.5	±3.95	±2.7	±2.7	±2.4
125°C (max)	±3	±4	±2.5	±2.5	±4	±2.7	±2.7	±2.7
150°C (max)	±3.5	-	±2.5	-	-	±2.7	±2.7	±2.7
Packaging Dimension								
Dimensions [mm × mm × mm]	**SOT23** (3-pin) 2.4 × 2.9 × 1.1		**SOT23** (3-pin) 2.4 × 2.9 × 1.1 **SC70** (5-pin) 2.1 × 2.0 × 1.1	**SOT23** (3-pin) 2.4 × 2.9 × 1.1		**SC70** (5-pin) 2.1 × 2.0 × 1.1		

1. LM50-Q1 and LM60-Q1 temperature accuracy limits come from the "Accuracy vs Temperature" plot.

Table 4-2. LM50-Q1 and LM50HV-Q1 Devices Orderable Options

DEVICE NAME	PART NUMBER	ACCURACY OVER TEMPERATURE	SPECIFIED TEMPERATURE RANGE	SUPPLY RANGE	PACKAGE
LM50-Q1	LM50QIM3X/NOPB	±4°C	$-40°C \le T_A \le +125°C$ (Both legacy & new chip)	4.5V to 10V	SOT-23 (DBZ) 3-pin
LM50HV-Q1	LM50HVQDBZRQ1	±2°C	$20°C \le T_A \le +70°C$	3V to 36V	
		±2.5°C	$0°C \le T_A \le +100°C$		
		±3°C	$-20°C \le T_A \le +125°C$		
		±3.5°C	$-40°C \le T_A \le +125°C$		
	LM50HVEDBZRQ1	±2°C	$20°C \le T_A \le +70°C$		
		±2.5°C	$0°C \le T_A \le +100°C$		
		±3°C	$-20°C \le T_A \le +125°C$		
		±3.5°C	$-40°C \le T_A \le +150°C$		

Table 4-3. LM50-Q1 and LM50HV-Q1 Devices Nomenclature Detail

PRODUCT	DESCRIPTION
LM50**xlyyy**	**x** indicates that the device has **Q** (grade-1 device in accordance with the AEC-Q100 standard) variant. This device can ship with the legacy chip (CSO: GF6 or SHE) or the new chip (CSO: RFB) with different *chip source origin (CSO)*. The reel packaging label provides date code information to distinguish which chip is being used. Device performance for new and legacy chips is denoted throughout the document. **yyy** indicates the package type of the device which is **M3X/NOPB** in DBZ (SOT-23 3-pin).
LM50HV**x yyy**RQ1	**x** indicates that the device has **Q** (grade-1) or **E** (grade-0) variant in accordance with the AEC-Q100 standard. LM50HV-Q1 has only CSO: RFB. **yyy** indicates that the package type of the device is **DBZ** (SOT-23 3-pin).

5 Pin Configuration and Functions

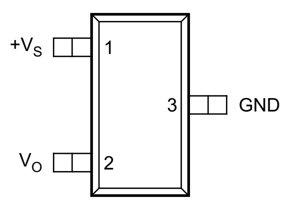


Figure 5-1. DBZ Package 3-Pin SOT-23 Top View

Table 5-1. Pin Functions

PIN		TYPE	DESCRIPTION
NO.	**NAME**		
1	$+V_S$	Power	Positive power supply pin.
2	V_O	Output	Temperature sensor analog output.
3	GND	Ground	Device ground pin, connected to power supply negative terminal.

6 Specifications

6.1 Absolute Maximum Ratings

Over operating free-air temperature range unless otherwise noted[(1)]

		MIN	MAX	UNIT
Supply voltage, $+V_S$	LM50-Q1	-0.2	12	V
	LM50HV-Q1	-0.2	39.6	
Output voltage, V_O	LM50-Q1	-1	$+V_S + 0.6$[(2)]	V
	LM50HV-Q1	-0.3	$+V_S + 0.3$[(2)]	
Output current, I_{OUT}			10	mA
Maximum junction temperature, T_J			150	°C
Storage temperature, T_{stg}	LM50-Q1	-65	150	°C
	LM50HV-Q1	-65	175	

(1) Operation outside the *Absolute Maximum Ratings* may cause permanent device damage. *Absolute Maximum Ratings* do not imply functional operation of the device at these or any other conditions beyond those listed under *Recommended Operating Conditions*. If used outside the *Recommended Operating Conditions* but within the *Absolute Maximum Ratings*, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.
(2) Maximum voltage must not exceed 12V for LM50-Q1 and 39.6V for LM50HV-Q1.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$, Electrostatic discharge	LM50-Q1	Human-body model (HBM), per AEC Q100-002[(1)]	±2000	V
	LM50HV-Q1		±2500	
	LM50-Q1	Charged-device model (CDM), per AEC Q100-011	±750	V
	LM50HV-Q1		±1000	

(1) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

6.3 Recommended Operating Conditions

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

			MIN	MAX	UNIT
$+V_S$	Supply voltage	LM50-Q1	4.5	10	V
		LM50HV-Q1	3	36	
T_{MIN},T_{MAX}	Specified temperature	LM50-Q1	-40	125	°C
		LM50HV-Q1	-40	150	

6.4 Thermal Information

THERMAL METRIC[(1)]		LM50-Q1		LM50HV-Q1	UNIT
		DBZ (SOT-23) Legacy chip	DBZ (SOT-23) New chip	DBZ (SOT-23)	
		3 PINS	3 PINS	3 PINS	
$R_{θJA}$	Junction-to-ambient thermal resistance	291.9	240.6	240.6	°C/W
$R_{θJC(top)}$	Junction-to-case (top) thermal resistance	114.3	144.5	144.5	°C/W
$R_{θJB}$	Junction-to-board thermal resistance	62.3	72.3	72.3	°C/W
$Ψ_{JT}$	Junction-to-top characterization parameter	7.4	28.7	28.7	°C/W
$Ψ_{JB}$	Junction-to-board characterization parameter	61	71.7	71.7	°C/W

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

6.5 Electrical Characteristics: LM50-Q1

LM50-Q1: $+V_S$ = 5V (DC) and I_{LOAD} = 0.5μA, $T_A = T_J$ = 25°C (unless otherwise noted)[(1)]

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
SENSOR ACCURACY							
T_{ACY}	Temperature accuracy[(2)]	T_A = 25°C	LM50-Q1	-3		3	°C
		$T_A = T_{MAX}$ = 125°C		-4		4	
		$T_A = T_{MIN}$ = -40°C		-4		4	
SENSOR OUTPUT							
$V_{0°C}$	Output voltage offset at 0°C				500		mV
T_C	Temperature coefficient (sensor gain)	$T_A = T_J = T_{MIN}$ to T_{MAX}		9.7	10	10.3	mV/°C
V_{ONL}	Output Nonlinearity[(3)]	$T_A = T_J = T_{MIN}$ to T_{MAX}	LM50-Q1	-0.8		0.8	°C
Z_{OUT}	Output impedance	$T_A = T_J = T_{MIN}$ to T_{MAX}			2000	4000	Ω
T_{ON}	Turn-On Time		LM50-Q1 (Legacy chip)		5		µs
			LM50-Q1 (New chip)		30		
T_{LTD}	Long-term stability and drift[(4)]	T_J = 125°C for 1000 hours	LM50-Q1		±0.08		°C
POWER SUPPLY							
I_{DD}	Operating current	$T_A = T_{MIN}$ to T_{MAX} 4.5V ≤ $+V_S$ ≤ 10V	LM50-Q1 (Legacy chip)		95	180	µA
			LM50-Q1 (New chip)		52	90	
PSR	Line regulation[(5)]	$T_A = T_{MIN}$ to T_{MAX} 4.5V ≤ $+V_S$ ≤ 10V	LM50-Q1	-1.2		1.2	mV/V
ΔI_{DD}	Change of quiescent current	$T_A = T_{MIN}$ to T_{MAX} 4.5V ≤ $+V_S$ ≤ 10V	LM50-Q1 (Legacy chip)			2	µA
			LM50-Q1 (New chip)			8	
I_{DD_TEMP}	Temperature coefficient of quiescent current	$T_A = T_{MIN}$ to T_{MAX} 4.5V ≤ $+V_S$ ≤ 10V	LM50-Q1		2		µA/°C

(1) Limits are specified to TI's AOQL (Average Outgoing Quality Level).
(2) Accuracy is defined as the error between the output voltage and 10mv/°C multiplied by case temperature of the device plus 500mV, at specified conditions of voltage, current, and temperature (expressed in °C).
(3) Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the rated temperature range of the device.
(4) For best long-term stability, any precision circuit provides best results if the unit is aged at a warm temperature, and/or temperature cycled for at least 46 hours before long-term life test begins. This is especially true when a small (Surface-Mount) part is wave-soldered; allow time for stress relaxation to occur. The majority of the drift occurs in the first 1000 hours at elevated temperatures. The drift after 1000 hours does not continue at the first 1000 hour rate.
(5) Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

6.6 Electrical Characteristics: LM50HV-Q1

LM50HV-Q1 : $+V_S$ = 3V to 36V (DC) and no I_{LOAD}, T_A = -40°C to 150°C (unless otherwise noted); Typical specifications are at T_A = 25°C and $+V_S$ = 5V (unless otherwise noted)(1)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
SENSOR ACCURACY							
T_{ACY}	Temperature accuracy(2)	T_A = 25°C	LM50HV-Q1		±1		°C
		T_A = 20°C to 70°C		-2		2	
		T_A = 0°C to 100°C		-2.5		2.5	
		T_A = -20°C to 125°C		-3		3	
		T_A = -40°C to 125°C		-3.5		3.5	
		T_A = -40°C to 150°C		-3.5		3.5	
SENSOR OUTPUT							
$V_{0°C}$	Output voltage offset at 0°C				500		mV
T_C	Temperature coefficient (sensor gain)	T_A = -40°C to 150°C		9.7	10	10.3	mV/°C
V_{ONL}	Output Nonlinearity(3)	T_A = -40°C to 150°C		-1.2		1.2	°C
Z_{OUT}	Output impedance	T_A = -40°C to 150°C			2000	4000	Ω
T_{ON}	Turn-On Time	T_A = 25°C, No C_{Load}, t_r = 1µs of $+V_S$ step			40		µs
T_{LTD}	Long-term stability and drift(4)	T_J = 150°C for 300 hours			±0.25		°C
C_{LOAD}	Capacitive load drive	R_l = 0Ω				1	µF
t_{RESP_L}	Response time (Stirred Liquid)	τ = 63% for step response (0.5in × 0.5in, 2-layer 62-mil PCB)	From 22°C to 100°C		1.7		s
t_{RESP_A}	Response time (Still Air)		From 18°C to 100°C		15.6		
POWER SUPPLY							
I_{DD}	Operating current	T_A = -40°C to 150°C 3V ≤ $+V_S$ ≤ 36V			52	130	µA
I_{OUT-SC}	Output short-circuit current limit	V_O short-circuit source current				1	mA
PSR	Line regulation(5)	T_A = -40°C to 150°C 3V ≤ $+V_S$ ≤ 36V		-0.6		0.6	mV/V
PSRR	Power supply rejection ratio	T_A = 25°C $+V_S$ = 3.3V, 5V and 12V	f = 1MHz		-25		dB
			f = 100kHz		-40		
ΔI_{DD}	Change of quiescent current	T_A = -40°C to 150°C 3V ≤ $+V_S$ ≤ 36V				30	µA
I_{DD_TEMP}	Temperature coefficient of quiescent current	T_A = -40°C to 150°C 3V ≤ $+V_S$ ≤ 36V			0.3		µA/°C
V_{ON-TH}	Turn-on threshold voltage	T_A = -40°C to 150°C			2.1	2.8	V
V_{OFF-TH}	Temperature coefficient of quiescent current	T_A = -40°C to 150°C		1.7	2.1		V

(1) Limits are specified to TI's AOQL (Average Outgoing Quality Level).
(2) Accuracy is defined as the error between the output voltage and 10mv/°C multiplied by case temperature of the device plus 500mV, at specified conditions of voltage, current, and temperature (expressed in °C).
(3) Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the rated temperature range of the device.
(4) Long term stability and drift is determined using accelerated operational life testing at a junction temperature of 150°C.
(5) Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

6.7 Typical Characteristics (LM50-Q1)

To generate these curves the device is mounted to a printed circuit board as shown in Figure 8-14 or Layout Example.

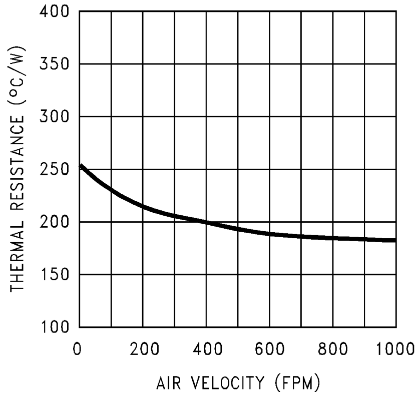


Figure 6-1. Thermal Resistance Junction-to-Ambient (Legacy chip)

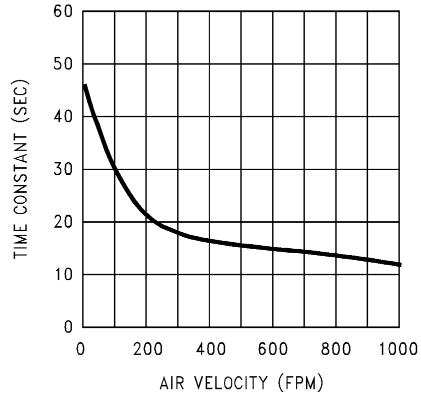


Figure 6-2. Thermal Time Constant (Legacy chip)

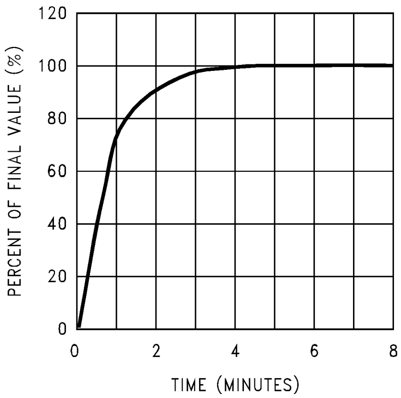


Figure 6-3. Thermal Response in Still Air With Heat Sink (Legacy chip)

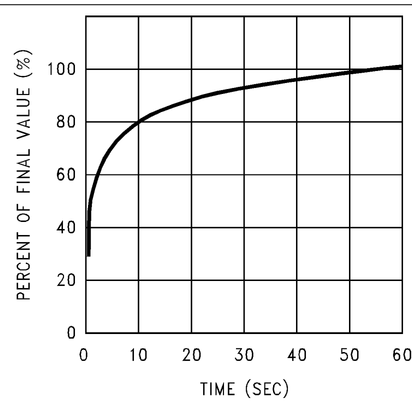


Figure 6-4. Thermal Response in Stirred Oil Bath With Heat Sink (Legacy chip)

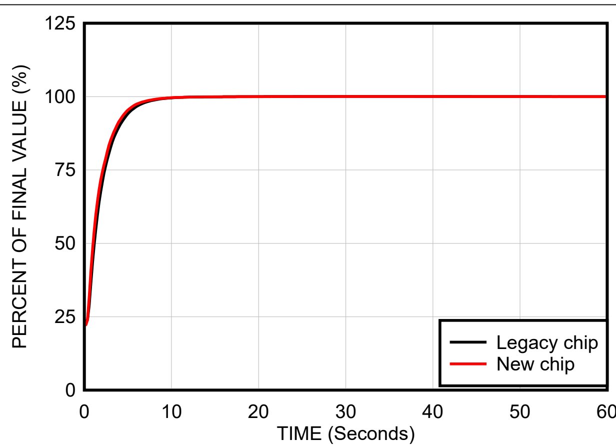


Figure 6-5. Thermal Response in Stirred Oil Bath With Heat Sink (0.5 inches × 0.5 inches PCB board)

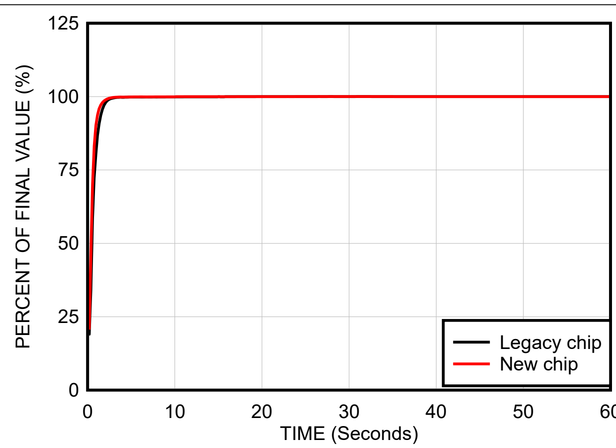


Figure 6-6. Thermal Response in Stirred Oil Bath Without Heat Sink

6.7 Typical Characteristics (LM50-Q1) (continued)

To generate these curves the device is mounted to a printed circuit board as shown in Figure 8-14 or Layout Example.

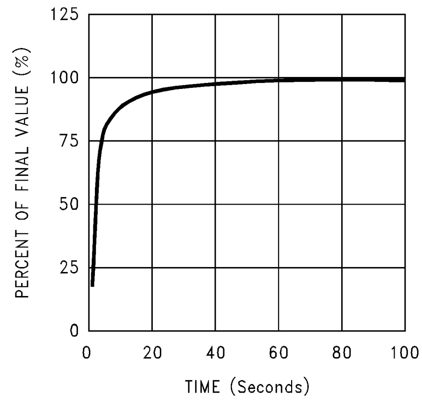


Figure 6-7. Thermal Response in Still Air Without a Heat Sink (Legacy chip)

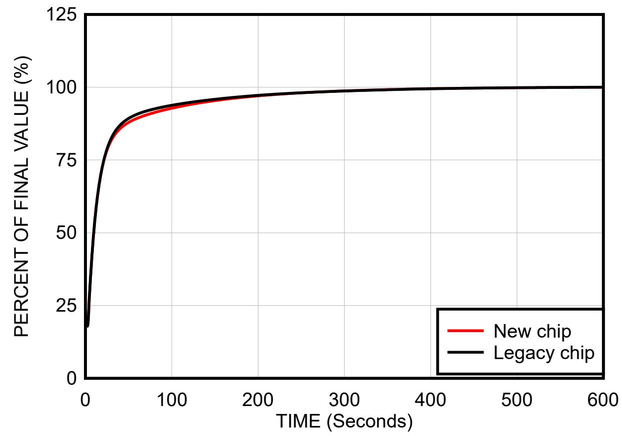


Figure 6-8. Thermal Response in Still Air Without a Heat Sink (Both Legacy and New Chip in the New Test Setup)

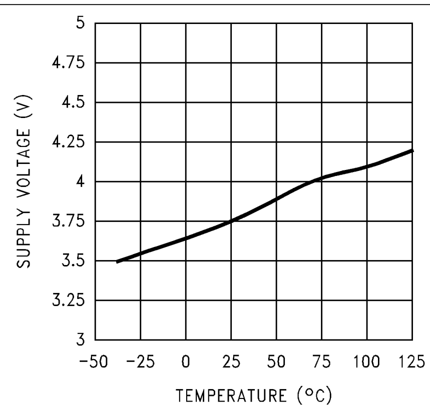


Figure 6-9. Start-Up Voltage vs Temperature (Legacy chip)

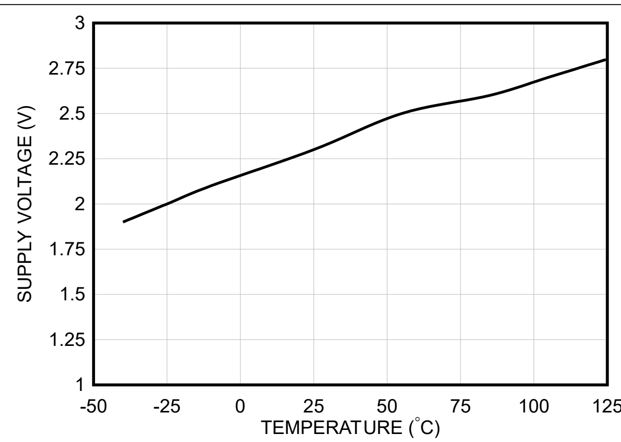


Figure 6-10. Start-Up Voltage vs Temperature (New chip)

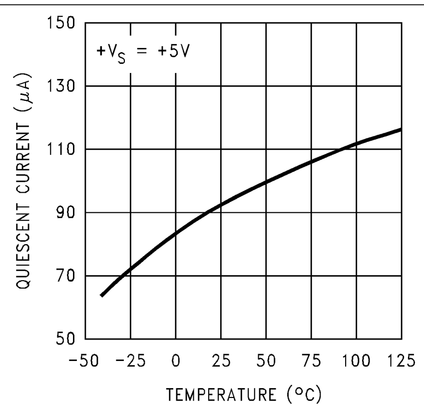


Figure 6-11. Quiescent Current vs Temperature (Legacy chip)

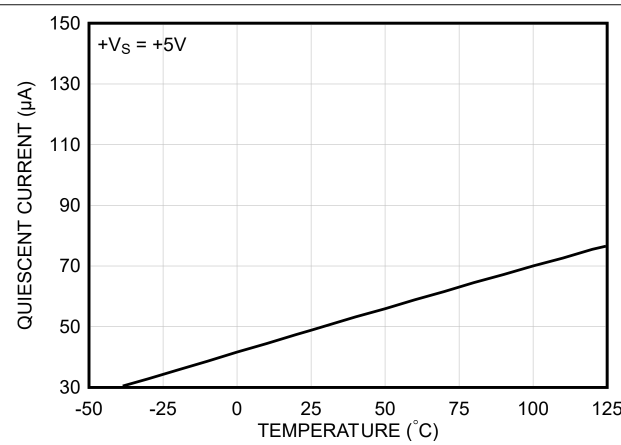


Figure 6-12. Quiescent Current vs Temperature (New chip)

6.7 Typical Characteristics (LM50-Q1) (continued)

To generate these curves the device is mounted to a printed circuit board as shown in Figure 8-14 or Layout Example.

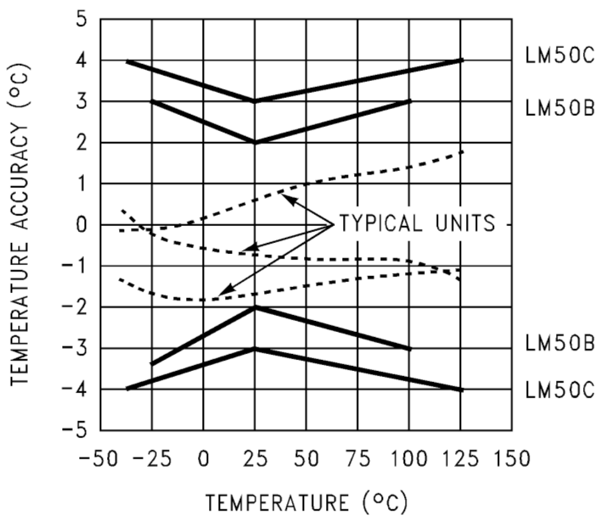


Figure 6-13. Accuracy vs Temperature (Legacy chip)

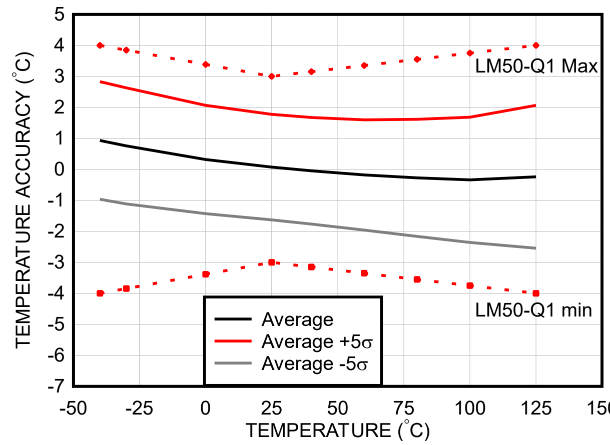


Figure 6-14. Accuracy vs Temperature (New chip)

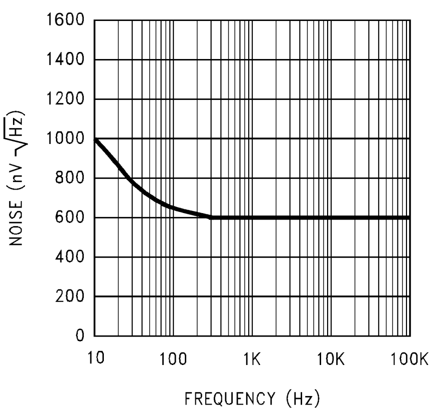


Figure 6-15. Noise Voltage (Legacy chip)

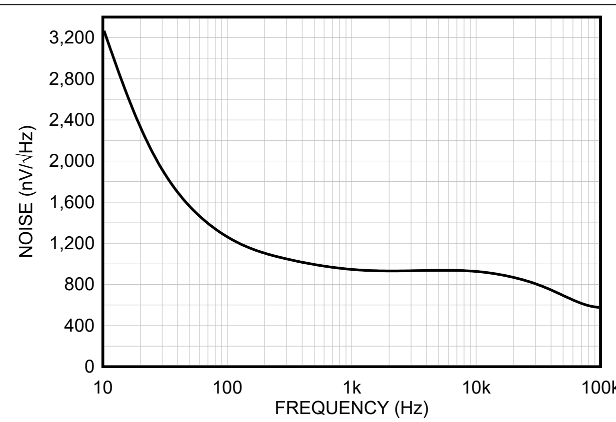


Figure 6-16. Noise Voltage (New chip)

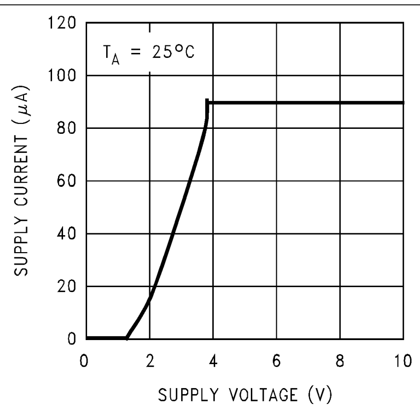


Figure 6-17. Supply Current vs Supply Voltage (Legacy chip)

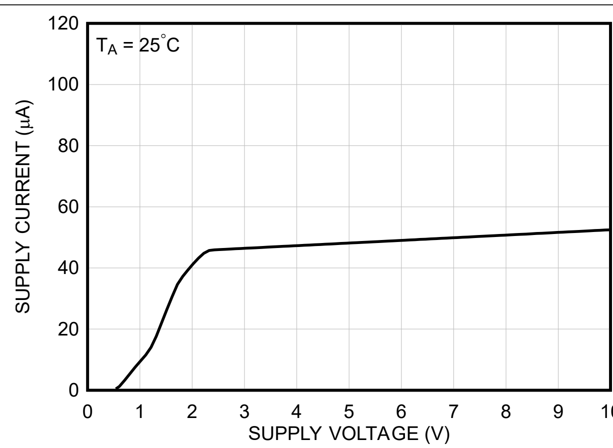


Figure 6-18. Supply Current vs Supply Voltage (New chip)

6.7 Typical Characteristics (LM50-Q1) (continued)

To generate these curves the device is mounted to a printed circuit board as shown in Figure 8-14 or Layout Example.

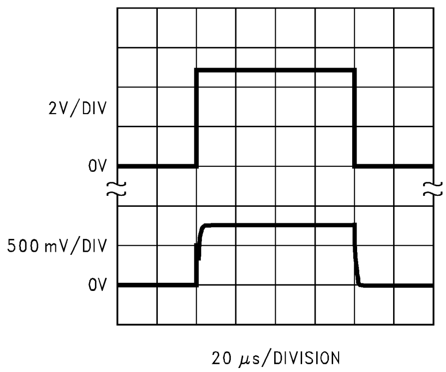


Figure 6-19. Start-Up Response (Legacy chip)

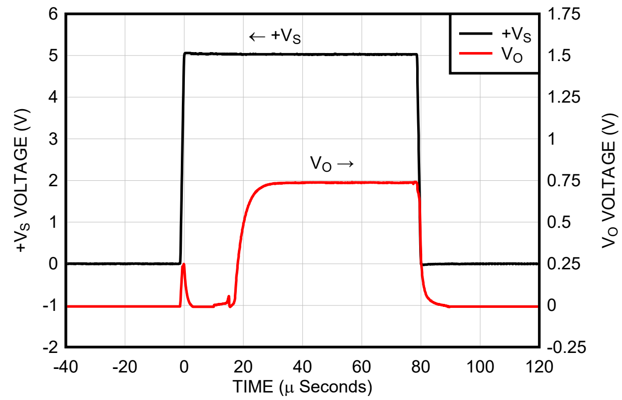
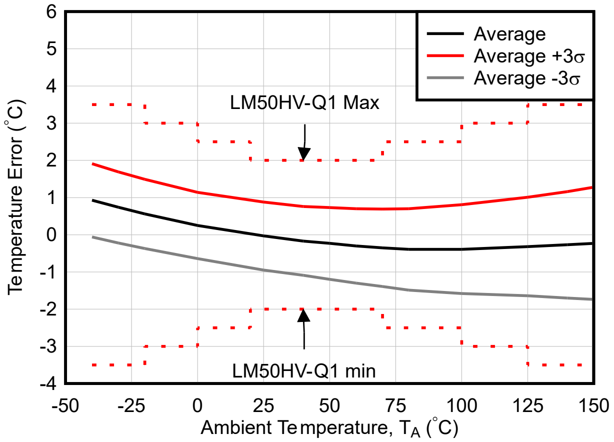


Figure 6-20. Start-Up Response (New chip)

6.8 Typical Characteristics (LM50HV-Q1)

At T_A = 25°C and $+V_S$ = 5V (unless otherwise noted)



+VS = 5V and No ILoad

Figure 6-21. Accuracy vs Ambient Temperature

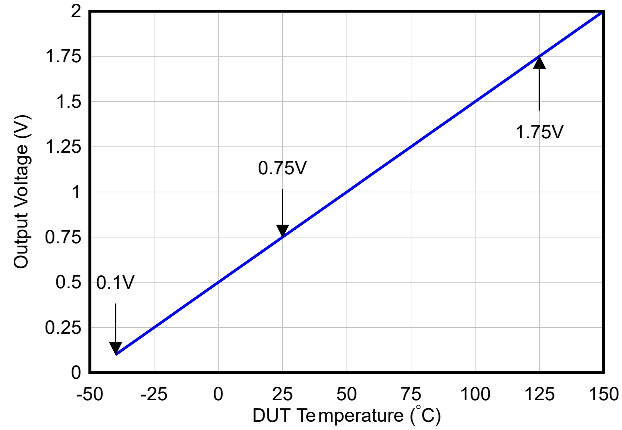


Figure 6-22. V_O vs Ambient Temperature

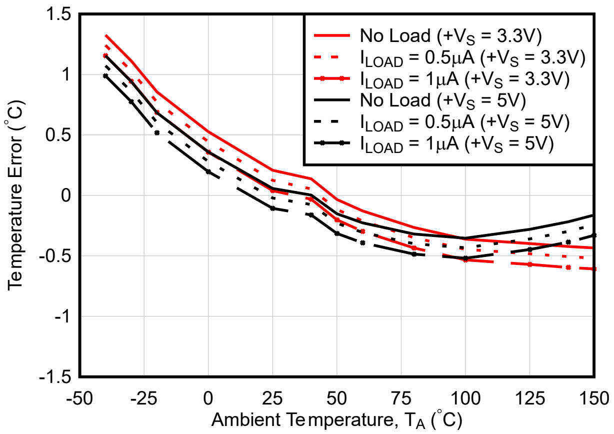


Figure 6-23. Accuracy vs Ambient Temperature with different loads

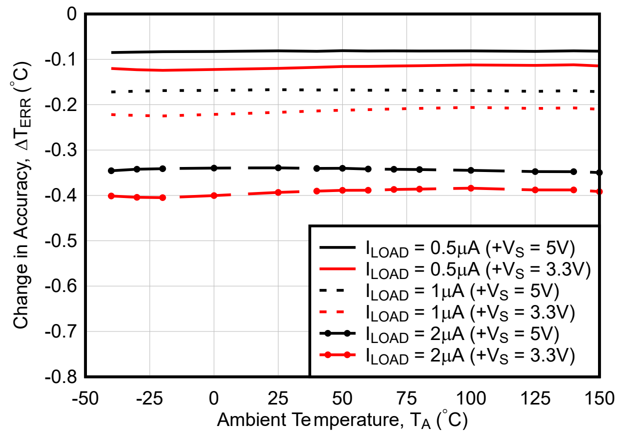


Figure 6-24. Change in Accuracy vs Temperature

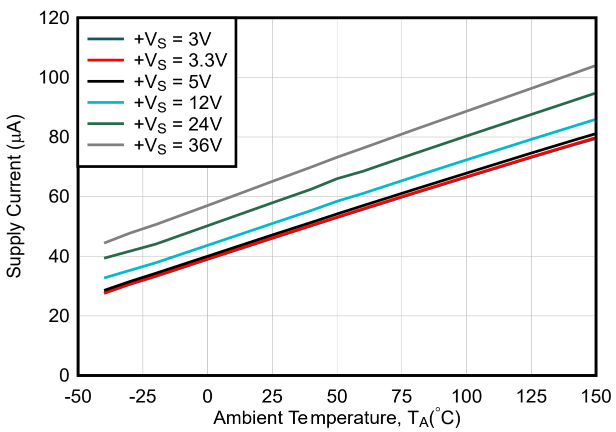


Figure 6-25. Supply Current vs Ambient Temperature

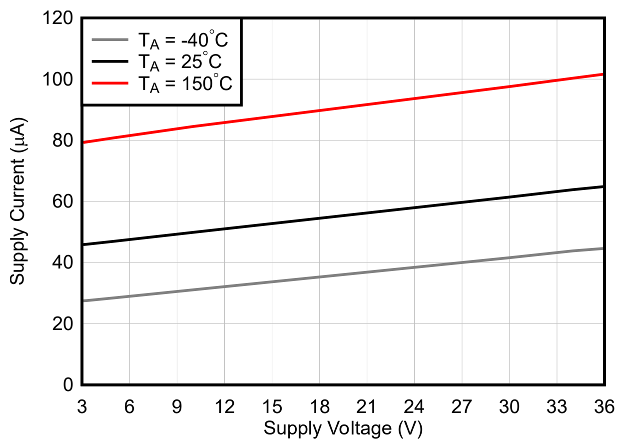
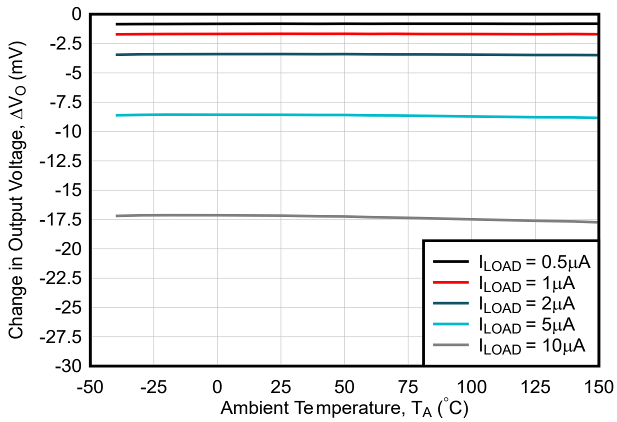


Figure 6-26. Supply Current vs Supply Voltage

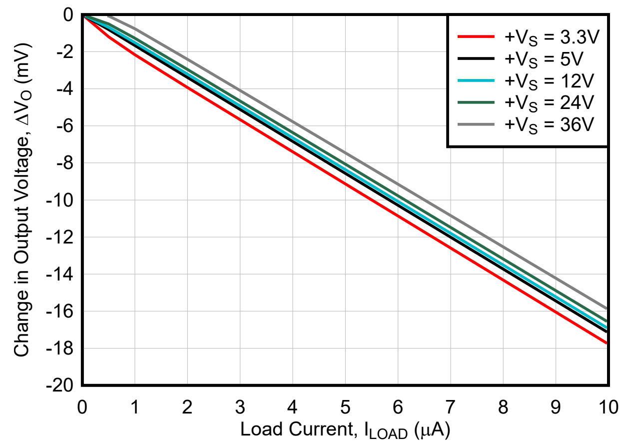
6.8 Typical Characteristics (LM50HV-Q1) (continued)

At T_A = 25°C and $+V_S$ = 5V (unless otherwise noted)



$+V_S$ = 5V

Figure 6-27. Load Regulation vs Ambient Temperature



T_A = 25°C

Figure 6-28. Change in Output Voltage vs Load Current

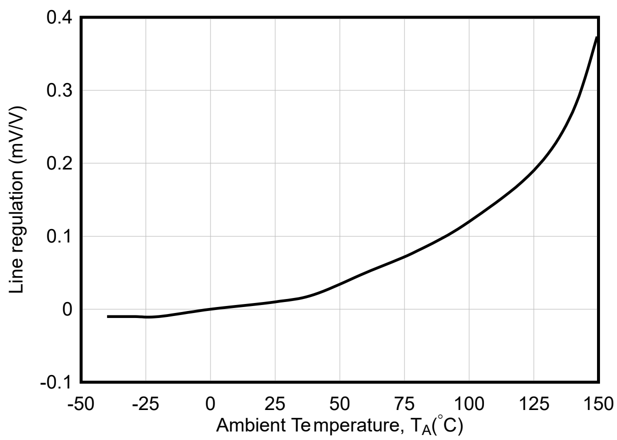


Figure 6-29. Line Regulation vs Ambient Temperature

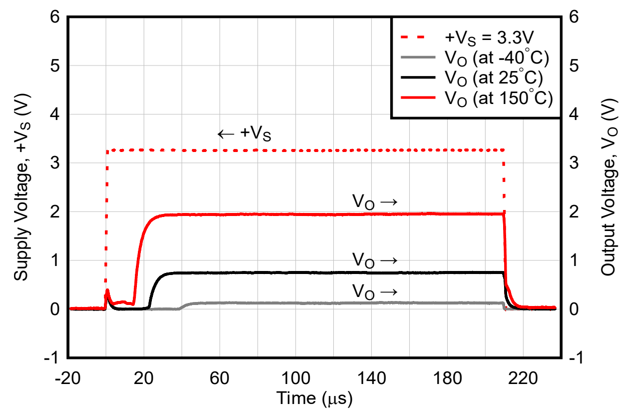
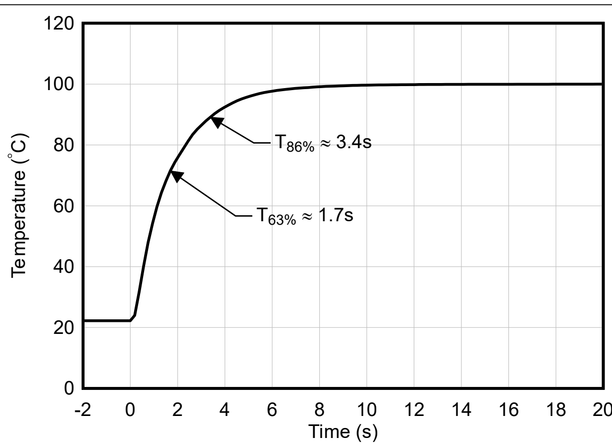
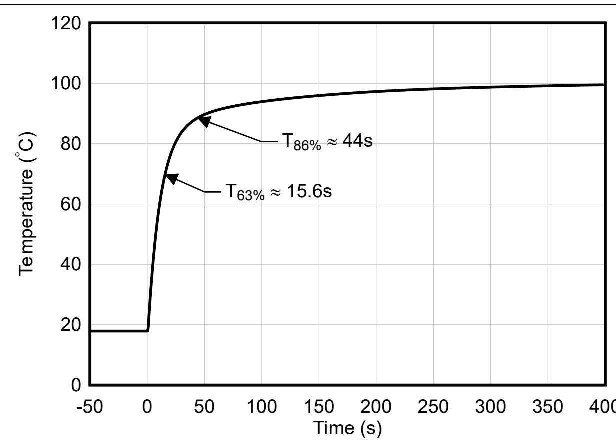


Figure 6-30. Start-up response to $+V_S$ = 3.3V Step (When t_r = 1µs, No C_{Load} and $C_{By\text{-}pass}$)



2-layer 62-mil Rigid PCB 2oz. Copper

Figure 6-31. Thermal Response in Stirred Oil Bath (0.5 inches × 0.5 inches PCB board)



2-layer 62-mil Rigid PCB 2oz. Copper

Figure 6-32. Thermal Response in Still Air (0.5 inches × 0.5 inches PCB board)

6.8 Typical Characteristics (LM50HV-Q1) (continued)

At T_A = 25°C and $+V_S$ = 5V (unless otherwise noted)

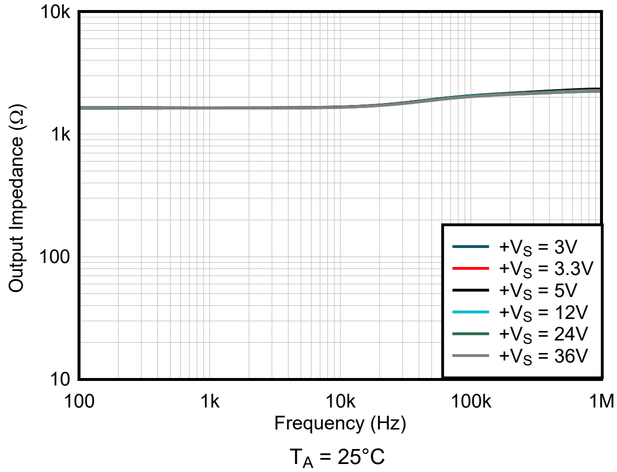


Figure 6-33. Output Impedance vs Frequency

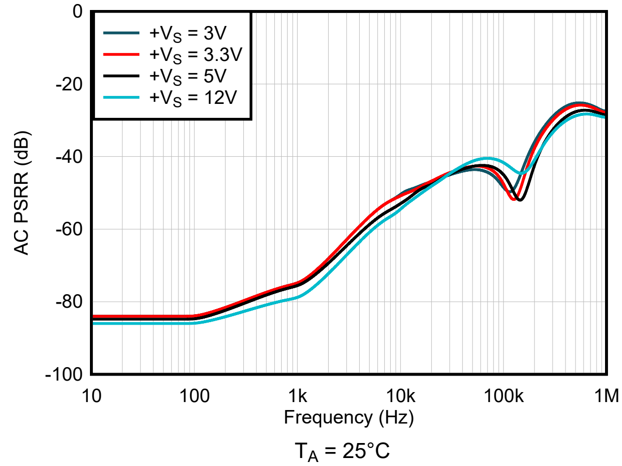


Figure 6-34. Power Supply Rejection Ratio vs Frequency

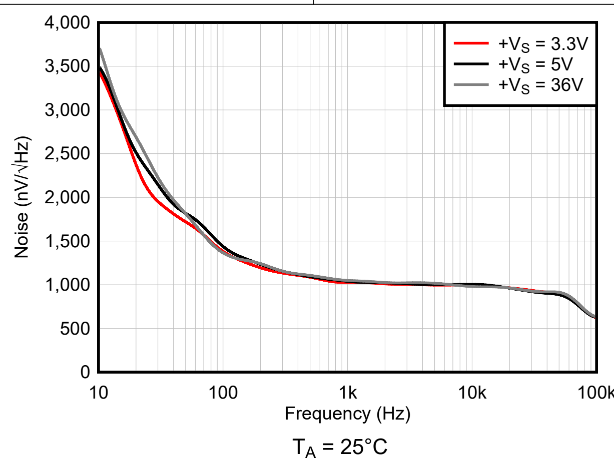


Figure 6-35. Output Noise Density

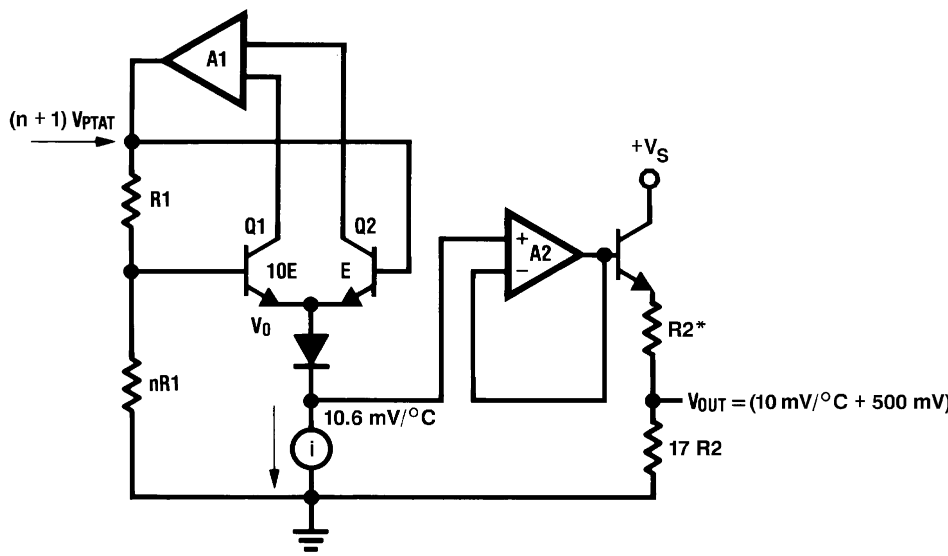
7 Detailed Description

7.1 Overview

The LM50-Q1 and LM50HV-Q1 devices are precision integrated-circuit temperature sensor that can sense a -40°C to 125°C (for LM50-Q1) or -40°C to 150°C (for LM50HV-Q1) temperature range using a single positive supply. The output voltage of the LM50-Q1 and LM50HV-Q1 has a positive temperature slope of 10mV/°C. A 500mV offset is included enabling negative temperature sensing when biased by a single supply.

The temperature-sensing element is comprised of a delta-V_{BE} architecture. The temperature-sensing element is then buffered by an amplifier and provided to the V_O pin. The amplifier has a simple class A output stage with typical 2kΩ output impedance as shown in the *Functional Block Diagram*.

7.2 Functional Block Diagram



*R2 ≅ 2k with a typical 1300ppm/°C drift.

7.3 Feature Description

7.3.1 LM50-Q1 and LM50HV-Q1Transfer Function

The LM50-Q1 and LM50HV-Q1 follow a simple linear transfer function to achieve the accuracy as listed in the *Section 6.5* and Section 6.6 tables.

Use Equation 1 to calculate the value of V_O.

$$V_O = 10mV/°C \times T\ °C + 500mV \quad (1)$$

where

- T is the temperature in °C
- V_O is the LM50-Q1 and LM50HV-Q1 output voltage

7.4 Device Functional Modes

The only functional mode of the device has an analog output directly proportional to temperature.

8 Application and Implementation

Note

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

8.1 Application Information

The LM50-Q1 and LM50HV-Q1 have a wide supply range and a 10mV/°C output slope with a 500mV DC offset. Therefore, these devices can be easily placed in many temperature-sensing applications where a single supply is required for positive and negative temperatures. The LM50HV-Q1 device is designed for LDO-less applications with power supply rails of 12V, 24V, 36V due to stable functionality across wide supply range of 3V to 36V.

8.2 Typical Application

8.2.1 Full-Range Centigrade Temperature Sensor

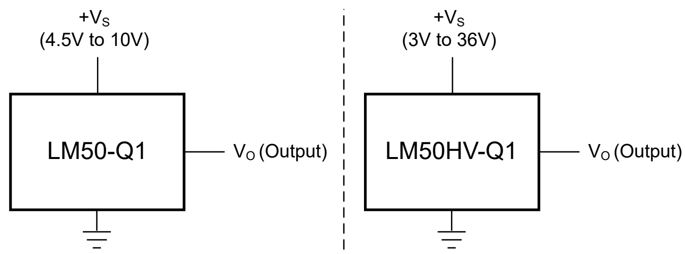


Figure 8-1. Full-Range Centigrade Temperature Sensor LM50-Q1 (–40°C to 125°C) and LM50HV-Q1 (–40°C to 150°C)

8.2.1.1 Design Requirements

For this design example, use the parameters listed in the *Design Parameters* table as the input parameters.

Table 8-1. Design Parameters

PARAMETER	VALUE (LM50-Q1)	VALUE (LM50HV-Q1)
Power supply voltage	4.5V to 10V	3V to 36V
Output impedance	4kΩ (maximum)	4kΩ (maximum)
Accuracy at 25°C	±3°C (maximum)	±1°C (typical)
Accuracy over 20°C to 70°C	±4°C (maximum)	±2°C (maximum)
Accuracy over 0°C to 100°C		±2.5°C (maximum)
Accuracy over –20°C to 125°C		±3°C (maximum)
Accuracy over –40°C to 125°C		±3.5°C (maximum)
Accuracy over –40°C to 150°C	-	±3.5°C (maximum)
Temperature slope	10mV/°C	10mV/°C

8.2.1.2 Detailed Design Procedure

The LM50-Q1 and LM50HV-Q1 are simple temperature sensors that provide an analog output. Therefore design requirements related to layout are more important than other requirements. See *Layout* for more information.

8.2.1.2.1 Capacitive Bypass and Loads

The LM50-Q1 and LM50HV-Q1 devices handle capacitive loading very well. Without any special precautions, the LM50-Q1 and LM50HV-Q1 can drive capacitive load up to 1µF. These devices have a nominal 2kΩ output impedance (shown in *Functional Block Diagram*). The temperature coefficient of the output resistors is approximately 1300ppm/°C. Taking into account this temperature coefficient and the initial tolerance of the resistors, the output impedance of the device does not exceed 4kΩ. In an extremely noisy environment adding filtering can be necessary to minimize noise pickup. TI recommends adding a 0.1µF capacitor between $+V_S$ and GND to bypass the power supply noise voltage. Adding a capacitor (C_{Load}) from V_O to ground can be necessary. A 1µF output capacitor with the 4kΩ output impedance forms a 40Hz low-pass filter. Because the thermal time constant of the LM50-Q1 and LM50HV-Q1 is much slower than the 25ms time constant formed by the RC, the overall response time of the device is not significantly affected. For much larger capacitors, this additional time lag increases the overall response time of the LM50-Q1 and LM50HV-Q1.

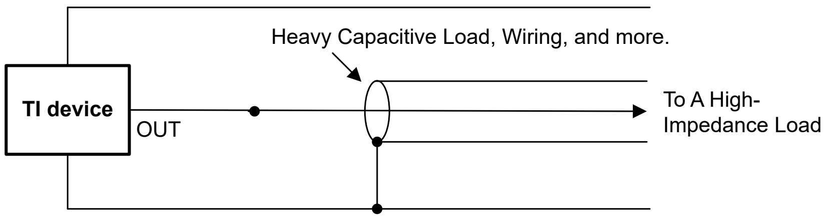


Figure 8-2. LM50-Q1 and LM50HV-Q1 No Decoupling Required for Capacitive Load

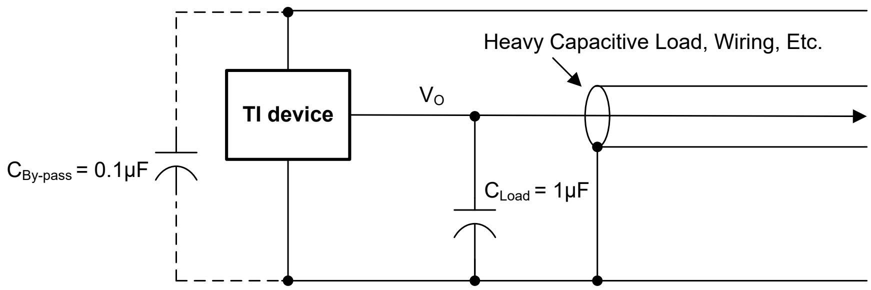


Figure 8-3. LM50-Q1 and LM50HV-Q1 With Filter for Noisy Environment

To avoid glitch of start-up power supply (input) response especially when $C_{By\text{-}pass}$ is not used (as shown in Figure 6-20, Figure 8-4 and Figure 8-5) on LM50-Q1 (new chip) and LM50HV-Q1 devices, a minimum C_{Load} must be placed between V_O and ground especially when LM50-Q1 (new chip) and LM50HV-Q1 devices are utilized in the comparator circuits.

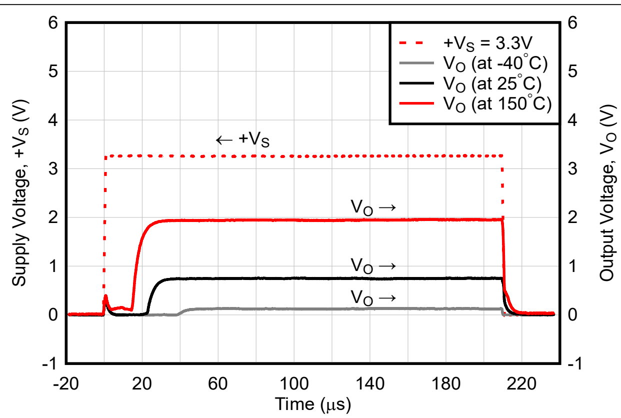


Figure 8-4. Start-up response to $+V_S$ = 3.3V Step (When t_r = 1µs, No C_{Load} and $C_{By\text{-}pass}$)

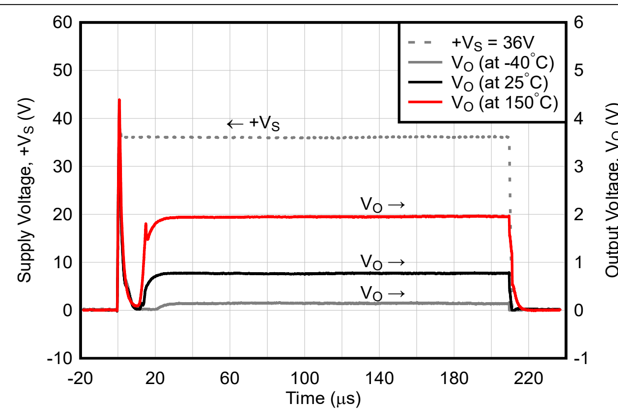


Figure 8-5. Start-up Response to $+V_S$ = 36V Step (When t_r = 1µs, No C_{Load} and $C_{By\text{-}pass}$)

The minimum C_{Load} capacitor is varied over different operating temperature range and power supply ramp rate as shown in the Table 8-2. Please noted that the rise time (t_r) can be translated to ramp rate of power supply (SR) by: SR (V/µs) = 0.8 × $+V_S$ (V) / t_r (µs).

Table 8-2. Minimum Required C_{Load} to Avoid Glitch Overshoot Over Power Supply Start-up Step Response (without $C_{By\text{-}pass}$)

Load Capacitance	$+V_S$ = 3.3V		$+V_S$ = 5V		$+V_S$ = 36V	
	t_r = 0.1µs	t_r = 1µs	t_r = 0.1µs	t_r = 1µs	t_r = 0.1µs	t_r = 1µs
C_{Load} (min) at T_A = -40°C	0.33nF	0.33nF	0.47nF	0.47nF	10nF	10nF
C_{Load} (min) at T_A = 25°C	0.02nF	NA	0.05nF	0.05nF	0.68nF	0.68nF
C_{Load} (min) at T_A = 150°C	NA	NA	NA	NA	0.12nF	0.12nF

Figure 8-6 and Figure 8-7 show start-up step response to 3.3V and 36V power supply with around 3.3V/µs ramp rate (without using $C_{By\text{-}pass}$). Each figure shows the output response to no load and minimum required C_{Load} when glitch overshoot is eliminated. The worst-case scenario (as shown in Table 8-2) is happened when operating temperature is -40°C.

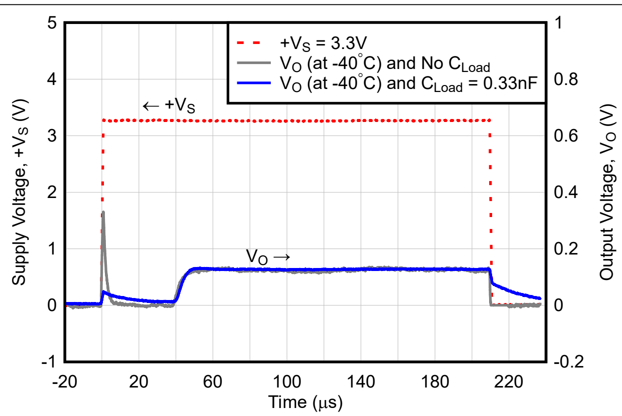


Figure 8-6. Start-up Response to $+V_S$ = 3.3V Step Without $C_{By\text{-}pass}$ When SR = 3.3V/µs (With No C_{Load} and C_{Load} = 0.33nF)

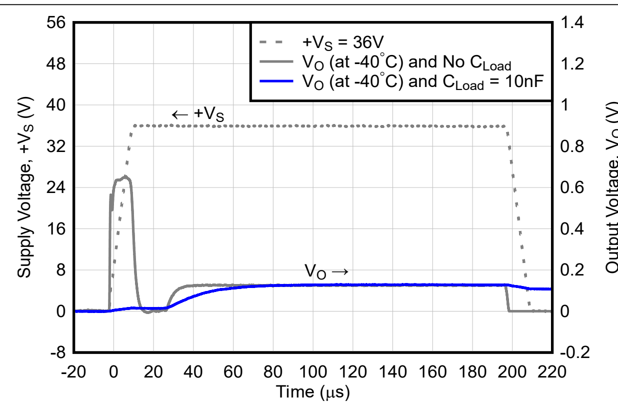


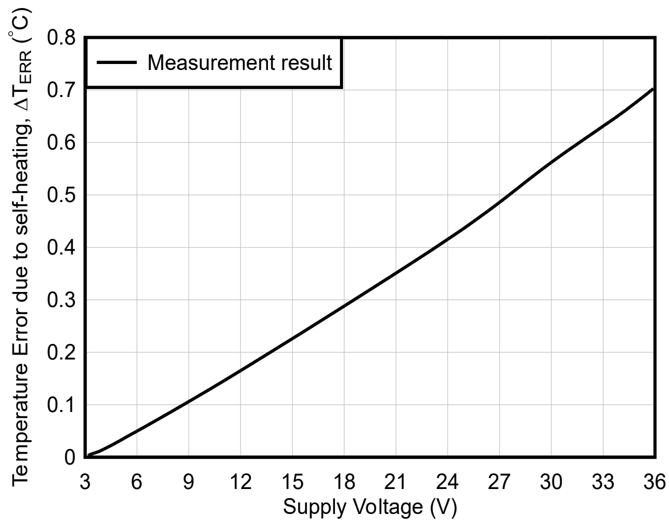
Figure 8-7. Start-up Response to $+V_S$ = 36V Step Without $C_{By\text{-}pass}$ When SR = 3.3V/µs (With No C_{Load} and C_{Load} = 10nF)

Note

TI suggests adding a minimum 0.1µF $C_{By\text{-}pass}$ (between $+V_S$ and GND) and/or a 0.1µF C_{Load} (between V_O and GND) capacitors to avoid supply noise and glitch overshoot.

8.2.1.2.2 LM50HV-Q1 Self-heating

The LM50HV-Q1 temperature accuracy error (due to self-heating) versus power supply is shown in Figure 8-8. The device is soldered to 30-gauge wire in this measurement and the temperature is read after consistently 10 minutes working of the device at 25°C. Since temperature error is directly proportional to thermal resistance (R_{th}) and power ($+V_S$ × I_{DD}), the temperature error is increased by changing power supply from 3V to 36V. By considering junction-to-ambient thermal resistance value in Section 6.4 and supply current vs supply voltage in Figure 6-26, temperature error around ±0.15°C must be expected (for up to 36V power supply) between calculated value (ΔT_{ERR} (°C) = R_{th} × ($+V_S$) × I_{DD}) and measured value shown in Figure 8-8. This possible deviation is due to hard controlling of air temperature and humidity, position of the device on the test setup and other factors which are addressed in *Analyzing PCB Thermal Resistance in High-Accuracy Temperature Sensors* application note.



The device soldered to 30 gauge wire. The accuracy is read after consistently 10min working of the device at 25°C.

Figure 8-8. Accuracy (Due to Self-heating) vs Supply Voltage

8.2.1.3 Application Curve

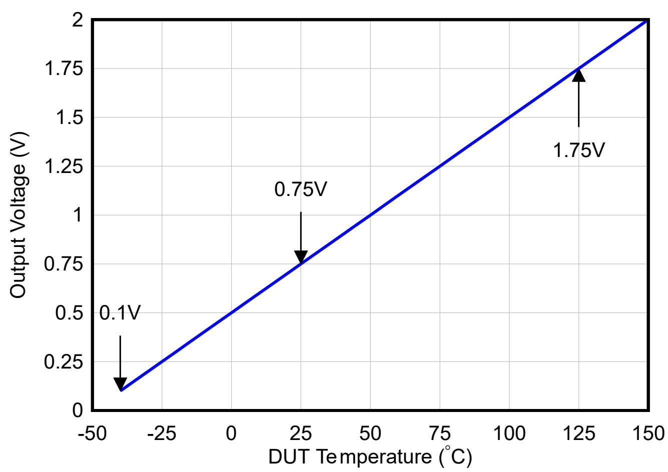


Figure 8-9. Output Transfer Function

8.3 System Examples

Figure 8-10 to Figure 8-12 show application circuit examples using the LM50-Q1 and LM50HV-Q1 devices. Figure 8-10 shows a Centigrade Thermostat or Fan Controller configuration based on Schmitt trigger circuit. LM50-Q1 and LM50HV-Q1 devices can detect the ambient temperature in which the upper and lower temperature thresholds can be adjusted by R1, R2 and R3 resistors.

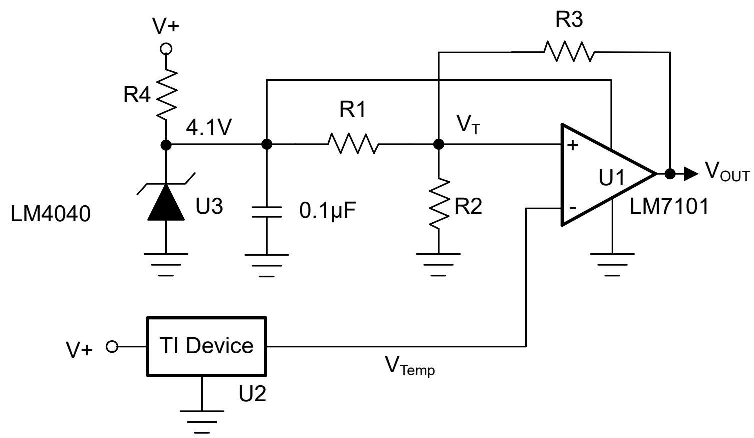
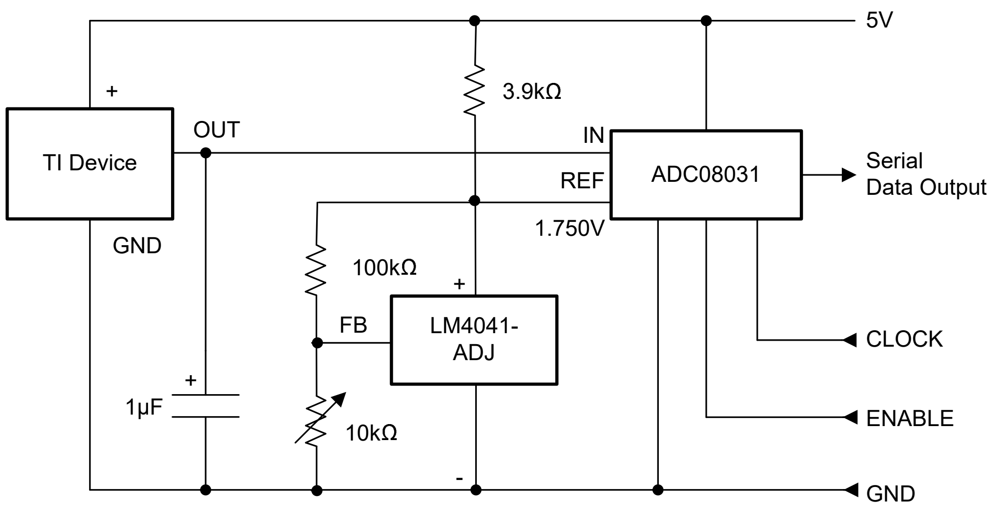


Figure 8-10. Centigrade Thermostat or Fan Controller

The LM50-Q1/LM50HV-Q1 output voltage can be digitized by using ADC and voltage reference (LM4041) as shown in Figure 8-11.

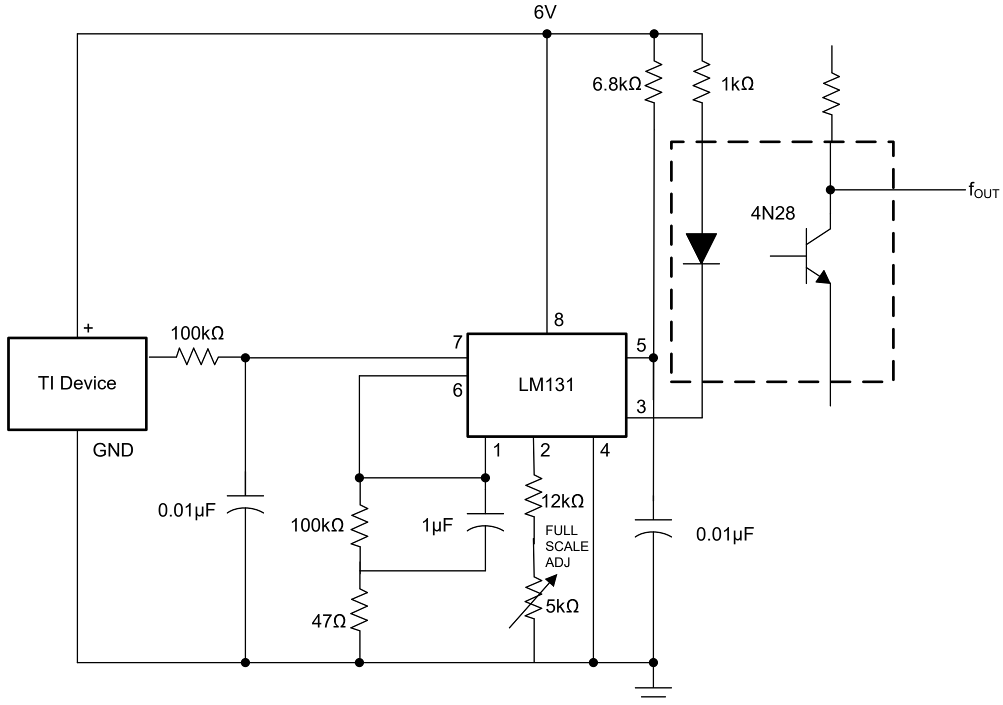


125°C full scale

Figure 8-11. Temperature To Digital Converter (Serial Output)

The temperature detected by LM50-Q1/LM50HV-Q1 can be converted to frequency by using LM131. The desired frequency range can be adjusted by selecting different values for resistors and capacitors while Figure 8-12 shows an example for converting -40°C to 125°C temperature range to 100Hz to 1.75kHz frequency range.

Customers must fully validate and test any circuit before implementing a design based on an example in this section. Unless otherwise noted, the design procedures in *Full-Range Centigrade Temperature Sensor* are applicable.



–40°C to 125°C; 100Hz to 1750Hz

Figure 8-12. LM50-Q1 and LM50HV-Q1 With Voltage-To-Frequency Converter and Isolated Output

8.4 Power Supply Recommendations

8.5 Layout

8.5.1 Layout Guidelines

The LM50-Q1 and LM50HV-Q1 can be applied easily in the same way as other integrated-circuit temperature sensors. The device can be glued or cemented to a surface and the temperature is within about 0.2°C (for power supply up to 10V) of the surface temperature.

This presumes that the ambient air temperature is approximately the same as the surface temperature; if the air temperature are much higher or lower than the surface temperature, the actual temperature of the LM50-Q1 and LM50HV-Q1 dies are at an intermediate temperature between the surface temperature and the air temperature.

To provide good thermal conductivity, the backside of the LM50-Q1 and LM50HV-Q1 dies are directly attached to the GND pin. The lands and traces to the device is part of the printed-circuit board, which is the object whose temperature is being measured. These printed-circuit board lands and traces do not cause the LM50-Q1 and LM50HV-Q1 temperature to deviate from the desired temperature.

Alternatively, the LM50-Q1 and LM50HV-Q1 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any device, the LM50-Q1 and LM50HV-Q1 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit can operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as HUMISEAL® and epoxy paints or dips are often used to verify that moisture cannot corrode the device or the connections.

8.5.2 Layout Example

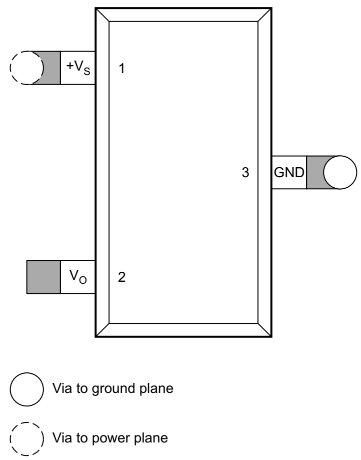


Figure 8-13. PCB Layout

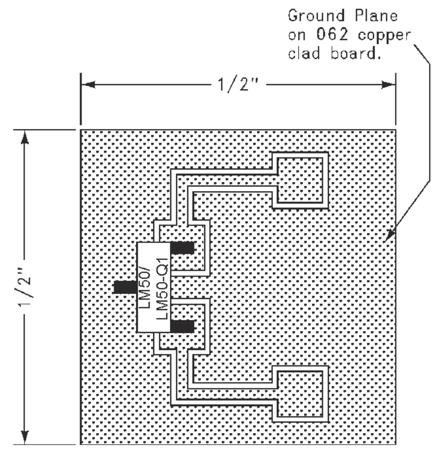


Figure 8-14. Printed-Circuit Board Used for Heat Sink to Generate Thermal Response Curves LM50-Q1 (Legacy Chip)

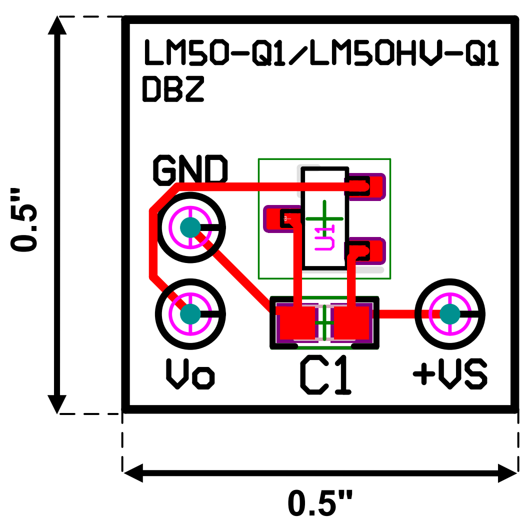


Figure 8-15. Printed-Circuit Board Used to Generate Thermal Response Curves [New Test Setup for LM50-Q1 (New Chip and Legacy Chip) and LM50HV-Q1]

8.5.3 Thermal Considerations

Table 8-3 summarizes the thermal resistance of the LM50-Q1 (Legacy chip) only for different conditions.

Table 8-3. Temperature Rise of LM50-Q1 (Legacy chip) only Due to Self-Heating

			$R_{\theta JA}$ (°C/W)
SOT-23	No heat sink(1)	Still air (Legacy chip)	291.9
		Moving air (Legacy chip)	-
	Small heat fin(2)	Still air (Legacy chip)	260
		Moving air (Legacy chip)	180

(1) Part soldered to 30 gauge wire.
(2) Heat sink used is 0.5inch, square printed-circuit board with 2oz foil; part attached as shown in Figure 8-14.

9 Device and Documentation Support

9.1 Documentation Support

Related Documentation

For related documentation see the following:

- Texas Instruments, *TMP23x-Q1 Automotive Grade, High-Accuracy Analog Output Temperature Sensors*, data sheet
- Texas Instruments, *ISOTMP35-Q1 Automotive ±1.5°C, 3-kVRMS Isolated Temperature Sensor With Analog Output With < 2 Seconds Response Time and 500VRMS Working Voltage*, data sheet
- Texas Instruments, *LM60-Q1 Automotive 2.7V, SOT-23 Temperature*, data sheet
- Texas Instruments, *LM50-Q1 Functional Safety User's Guide*, Functional safety information
- Texas Instruments, *Tiny Temperature Sensors for Remote Systems*, application note
- Texas Instruments, *Semiconductor Temperature Sensors Challenge Precision RTDs and Thermistors in Building Automation*, application note
- Texas Instruments, *LM50HV Evaluation Module*, EVM
- Texas Instruments, *LMT90 Temperature Sensor Evaluation Module*, EVM

9.2 Receiving Notification of Documentation Updates

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

9.3 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

9.4 Trademarks

TI E2E™ is a trademark of Texas Instruments.
HUMISEAL® is a registered trademark of Columbia Chase Corporation.
All trademarks are the property of their respective owners.

9.5 Electrostatic Discharge Caution

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

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

9.6 Glossary

TI Glossary — This glossary lists and explains terms, acronyms, and definitions.

10 Revision History

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

Changes from Revision * (May 2025) to Revision A (February 2026) — **Page**

- Updated the numbering format for tables, figures, and cross-references throughout the document................. 1
- Added the LM50HV-Q1 device throughout the document.. 1
- Updated the data sheet title...1
- Added DBZ package "*Thermal Information*" for the New chip..5
- Added "Turn-on Time" for both Legacy chip and New chip.. 6
- Added "*Operating current*" and "*Change of quiescent current*" for the New chip.. 6

11 Mechanical, Packaging, and Orderable Information

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

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
LM50QIM3/NOPB	Obsolete	Production	SOT-23 (DBZ) | 3	-	-	Call TI	Call TI	-40 to 125	T5Q
LM50QIM3X/NOPB	Active	Production	SOT-23 (DBZ) | 3	3000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	T5Q
LM50QIM3X/NOPB.A	Active	Production	SOT-23 (DBZ) | 3	3000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	T5Q
LM50QIM3X/NOPB.B	Active	Production	SOT-23 (DBZ) | 3	3000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	T5Q

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

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

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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

OTHER QUALIFIED VERSIONS OF LM50-Q1 :

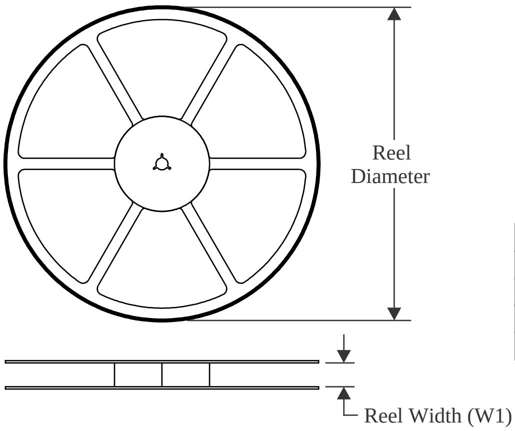
- Catalog : LM50

NOTE: Qualified Version Definitions:

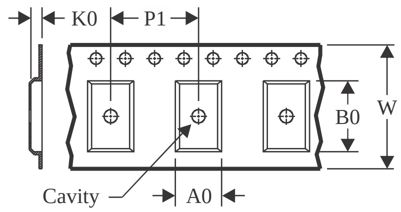
- Catalog - TI's standard catalog product

TAPE AND REEL INFORMATION

REEL DIMENSIONS

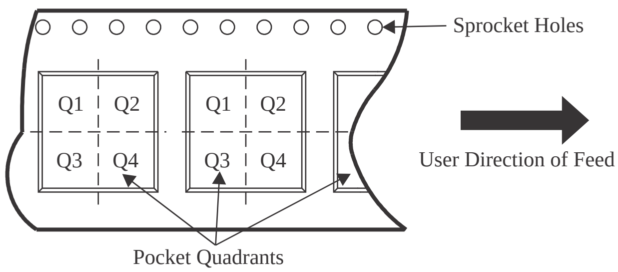


TAPE DIMENSIONS



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

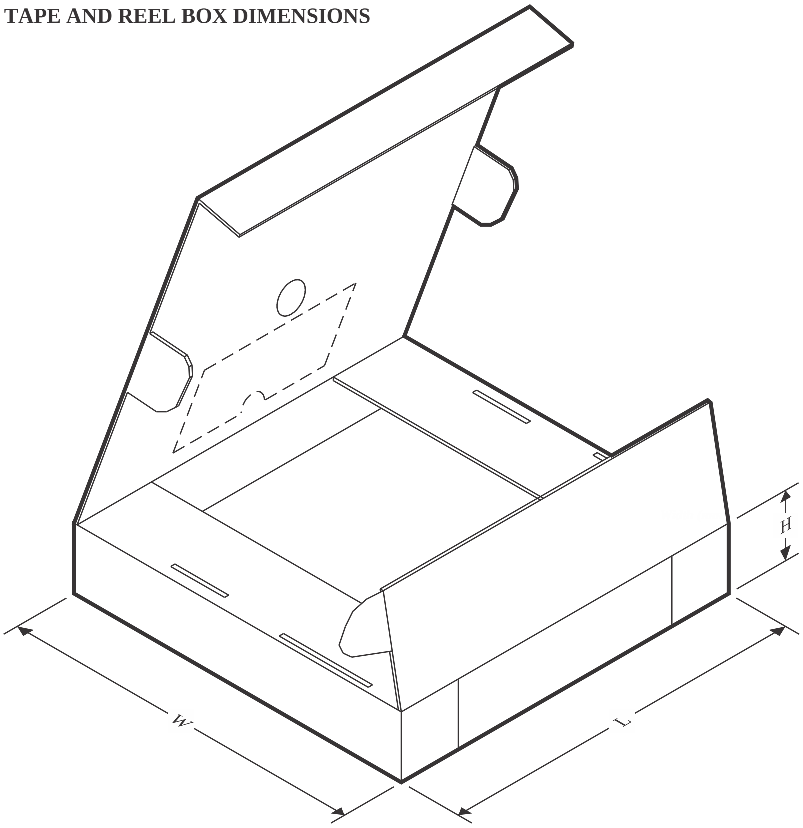
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

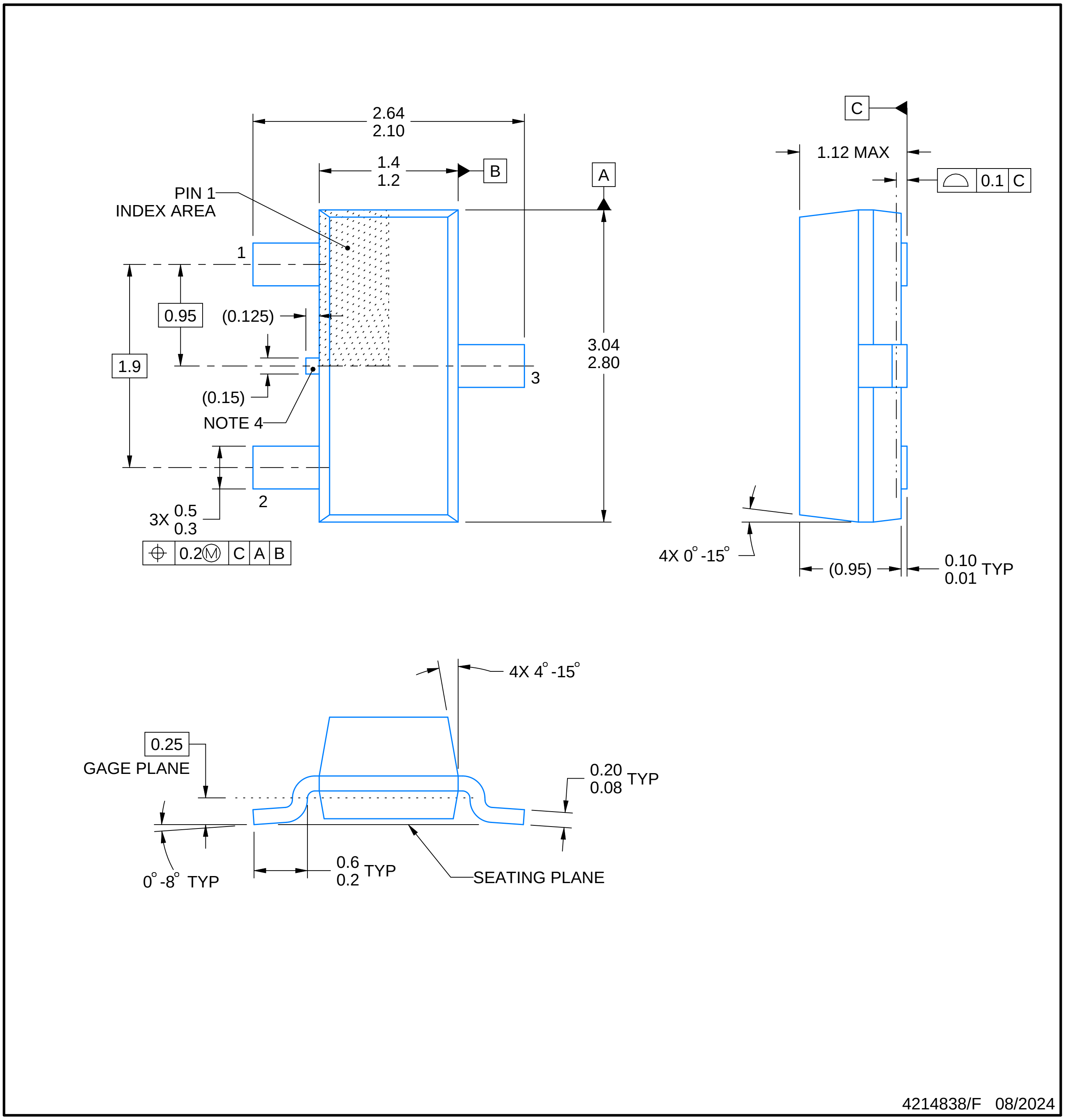
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM50QIM3X/NOPB	SOT-23	DBZ	3	3000	178.0	8.4	3.3	2.9	1.22	4.0	8.0	Q3

TAPE AND REEL BOX DIMENSIONS



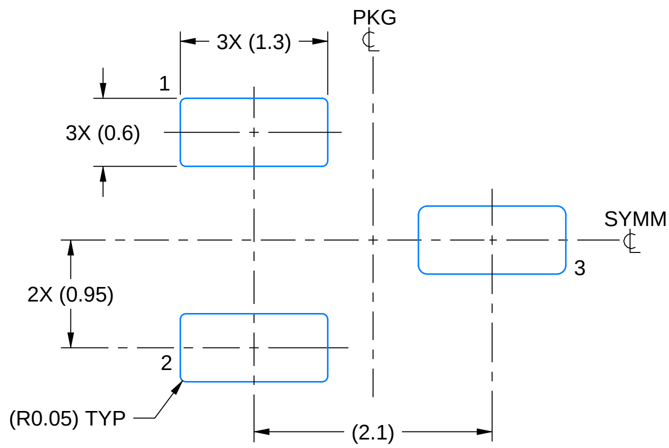
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM50QIM3X/NOPB	SOT-23	DBZ	3	3000	208.0	191.0	35.0

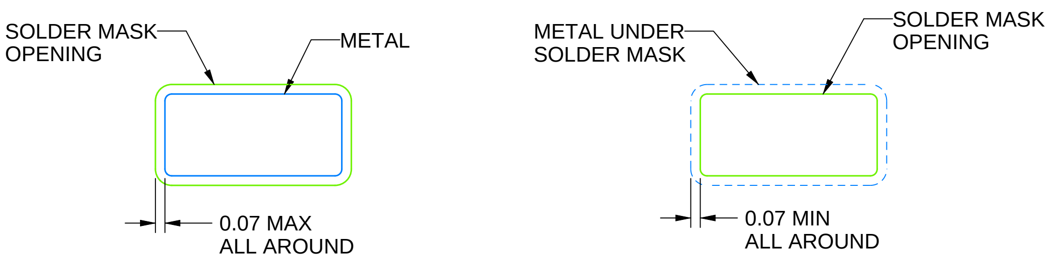


NOTES:

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.
4. Support pin may differ or may not be present.
5. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25mm per side



LAND PATTERN EXAMPLE
SCALE:15X



NON SOLDER MASK DEFINED (PREFERRED)

SOLDER MASK DEFINED

SOLDER MASK DETAILS

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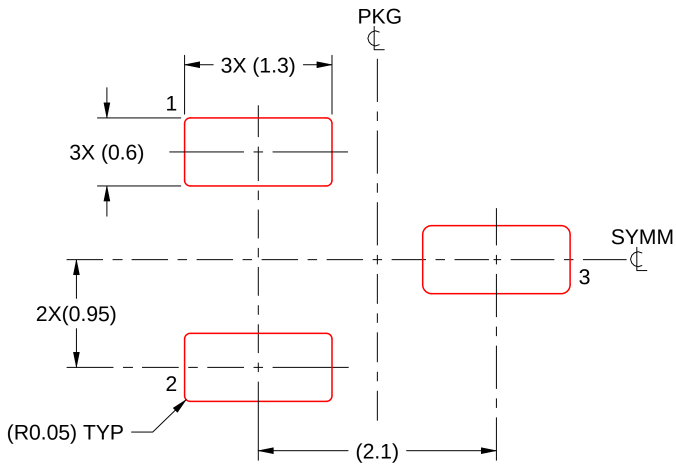
NOTES: (continued)

5. Publication IPC-7351 may have alternate designs.
6. 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

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NOTES: (continued)

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