Texas Instruments
TMCS1123
SBOSA24 – JULY 2023

TMCS1123 Precision Hall-Effect Current Sensor With ±1100V Reinforced Isolation Working Voltage, Overcurrent Detection and Ambient Field Rejection

1 Features

- High continuous current capability: 75 A_{RMS}
- Robust reinforced isolation
  - Withstand isolation voltage: 5000 V_{RMS}
  - Reinforced working voltage: 1100 V_{DC}
- High accuracy
  - Sensitivity error: 0.3%
  - Sensitivity drift: 20 ppm/°C
  - Offset error: 0.5 mV
  - Offset drift: 5 μV/°C
  - Linearity error: 0.1%
- Low lifetime drift: 0.5% (maximum)
- High immunity to external magnetic fields
- Precision zero-current reference output
- Signal bandwidth: 250 kHz
- Low propagation delay: 600 ns
- Fast overcurrent detection response: 500 ns
- Operating supply range: 3 V to 5.5 V
- Bidirectional and unidirectional current sensing
- Multiple sensitivity options:
  - TMCS1123x1: 25 mV/A
  - TMCS1123x2: 50 mV/A
  - TMCS1123x3: 75 mV/A
  - TMCS1123x4: 100 mV/A
  - TMCS1123x5: 150 mV/A
- Safety related certifications (planned)
  - UL 1577 Component Recognition Program
  - IEC/CB 62368-1

2 Applications

- Solar Energy
- Motor control
- EV charging
- Power supplies
- Industrial AC/DC
- Overcurrent protection

3 Description

The TMCS1123 is a galvanically isolated Hall-effect current sensor with industry leading isolation and accuracy. An output voltage proportional to the input current is provided with excellent linearity and low drift at all sensitivity options. Precision signal conditioning circuitry with built-in drift compensation is capable of less than 1.75% maximum total error over temperature and lifetime with no system level calibration, or less than 1% maximum total error with a one-time room temperature calibration (including both lifetime and temperature drift).

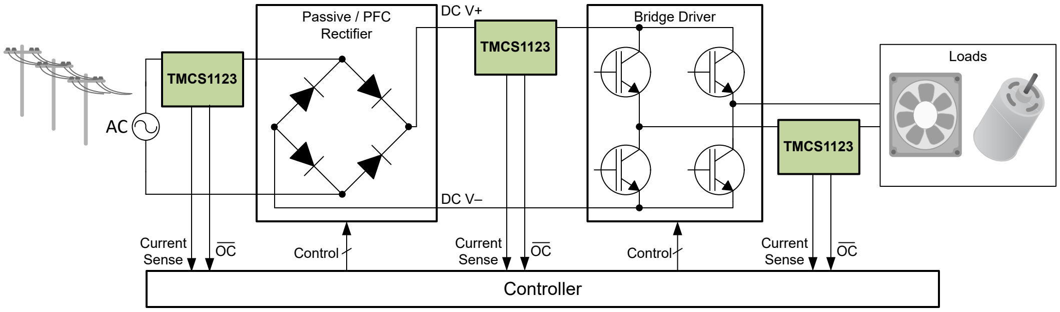
AC or DC input current flows through an internal conductor generating a magnetic field measured by integrated on-chip Hall-effect sensors. Core-less construction eliminates the need for magnetic concentrators. Differential Hall sensors reject interference from stray external magnetic fields. Low conductor resistance increases measurable current ranges up to ± 96A while minimizing power loss and easing thermal dissipation requirements. Insulation capable of withstanding 5000V_{RMS}, coupled with minimum 8.1 mm creepage and clearance provide up to 1100V_{DC} reliable lifetime reinforced working voltage. Integrated shielding enables excellent common-mode rejection and transient immunity.

Fixed sensitivity allows the TMCS1123 to operate from a single 3V to 5.5V power supply, eliminates ratiometry errors, and improves supply noise rejection.

Package Information(1)

PART NUMBER	PACKAGE	PACKAGE SIZE(2)
TMCS1123	SOIC (10)	10.3 mm × 10.3 mm

(1) For all available packages, see the package option addendum at the end of the data sheet.
(2) The package size (length × width) is a nominal value and includes pins, where applicable.



Typical Application

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4 Revision History

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

DATE	REVISION	NOTES
July 2023	*	Initial Release

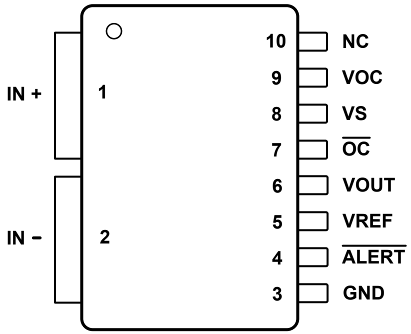
5 Device Comparison

Table 5-1. Device Comparison

PRODUCT	SENSITIVITY	ZERO CURRENT OUTPUT VOLTAGE	I_{IN} LINEAR MEASUREMENT RANGE(1)	
			V_S = 5 V	V_S = 3.3 V
TMCS1123A1	25 mV/A	2.5 V	±96 A(2)	–96 A to 28 A(2)
TMCS1123A2	50 mV/A		±48 A(2)	–48 A to 14 A(2)
TMCS1123A3	75 mV/A		±32 A	–32 A to 9.3 A
TMCS1123A4	100 mV/A		±24 A	–24 A to 7 A
TMCS1123A5	150 mV/A		±16 A	–16 A to 4.7 A
TMCS1123B1	25 mV/A	1.65 V	–62 A to 130 A(2)	±62 A(2)
TMCS1123B2	50 mV/A		–31 A to 65 A(2)	±31 A
TMCS1123B3	75 mV/A		–20.7 A to 43.3 A(2)	±20.7 A
TMCS1123B4	100 mV/A		–15.5 A to 32.5 A	±15.5 A
TMCS1123B5	150 mV/A		–10.3 A to 21.7 A	±10.3 A
TMCS1123C1	25 mV/A	0.33 V	–9.2 A to 183 A(2)	–9.2 A to 115 A(2)
TMCS1123C2	50 mV/A		–4.6 A to 91.4 A(2)	–4.6 A to 57.4 A(2)
TMCS1123C3	75 mV/A		–3.1 A to 60.9 A(2)	–3.1 A to 38.3 A(2)
TMCS1123C4	100 mV/A		–2.3 A to 45.7 A(2)	–2.3 A to 28.7 A
TMCS1123C5	150 mV/A		–1.5 A to 30.5 A	–1.5 A to 19.1 A

(1) Linear range limited by max output swing to power supply (3 V to 5.5 V) and ground, not by thermal limitations.
(2) Current levels must remain below both allowable continuous DC/RMS and transient peak current safe operating areas to not exceed device thermal limits.

6 Pin Configuration and Functions



Not to scale

Figure 6-1. DVG Package 10-Pin SOIC Top View

Table 6-1. Pin Functions

PIN		TYPE	DESCRIPTION
NO.	NAME		
1	IN+	Analog Input	Input current positive pin
2	IN–	Analog Input	Input current negative pin
3	GND	Analog	Ground
4	$\overline{\text{ALERT}}$	Digital Output	Sensor diagnostics PWM output, open-drain active low
5	VREF	Analog Output	Zero current output voltage reference
6	VOUT	Analog Output	Output voltage
7	$\overline{\text{OC}}$	Digital Output	Overcurrent output, open-drain active low
8	VS	Analog	Power supply
9	VOC	Analog Input	Overcurrent threshold. Sets overcurrent threshold.
10	NC	-	Reserved. Pin can be connected to GND, VS, or left floating if needed.

7 Specifications

7.1 Absolute Maximum Ratings

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

			MIN	MAX	UNIT
V_S	Supply voltage		GND – 0.3	6	V
	Analog input	VREF	GND – 0.3	$(V_S) + 0.3$	V
	NC Input	NC	GND – 0.3	$(V_S) + 0.3$	V
	Analog output	VOUT	GND – 0.3	$(V_S) + 0.3$	V
T_J	Junction temperature		–65	165	°C
T_{stg}	Storage temperature		–65	165	°C

(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.

7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[1]	±2000	V
		Charged-device model (CDM), per ANSI/ESDA/JEDEC JS-002[2]	±1000	

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

7.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V_S	Operating supply voltage	3	5	5.5	V
T_A (1)	Operating free-air temperature	–40		125	°C

(1) Input current safe operating area is constrained by junction temperature. Recommended condition based on use with the *TMCS1123xEVM*. Input current rating is derated for elevated ambient temperatures.

7.4 Thermal Information

THERMAL METRIC[1]		TMCS1123[2]	UNIT
		DVG (SOIC-W-10)	
		10 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	27.9	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	26.8	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	10.1	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	4.4	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	8.3	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.
(2) Applies when device is mounted on *TMCS1123xEVM*. For more details, see the Safe Operating Area section.

7.5 Insulation Specifications

PARAMETER		TEST CONDITIONS	VALUE	UNIT
GENERAL				
CLR	External clearance(1)	Shortest terminal-to-terminal distance through air	8.1	mm
CPG	External creepage(1)	Shortest terminal-to-terminal distance across the package surface	8.1	mm
CTI	Comparative tracking index	DIN EN 60112; IEC 60112	600	V
	Material group	According to IEC 60664-1	I	
	Overvoltage category per IEC 60664-1	Rated mains voltage ≤ 150 V_{RMS}	I-IV	
		Rated mains voltage ≤ 300 V_{RMS}	I-IV	
		Rated mains voltage ≤ 600 V_{RMS}	I-IV	
V_{IORM}	Maximum repetitive peak isolation voltage	AC voltage (bipolar), Basic Isolation	2070	V_{PK}
		AC voltage (bipolar), Reinforced Isolation	1100	
V_{IOWM}	Maximum basic isolation working voltage	AC voltage (sine wave)	1464	V_{RMS}
		DC voltage	2070	V_{DC}
	Maximum reinforced isolation working voltage	AC voltage (sine wave)	778	V_{RMS}
		DC voltage	1100	V_{DC}
V_{IOTM}	Maximum transient isolation voltage	$V_{TEST} = \sqrt{2} \times V_{ISO}$, t = 60 s (qualification); $V_{TEST} = 1.2 \times V_{IOTM}$, t = 1 s (100% production)	7071	V_{PK}
V_{IOSM}	Maximum surge isolation voltage(2)	Test method per IEC 62368-1, 1.2/50 µs waveform, $V_{TEST} = 1.3 \times V_{IOSM}$ (qualification)	10000	V_{PK}
q_{pd}	Apparent charge(3)	Method a: After I/O safety test subgroup 2/3, $V_{ini} = V_{IOTM}$, t_{ini} = 60 s; $V_{pd(m)} = 1.2 \times V_{IORM}$, t_m = 10 s	≤5	pC
		Method a: After environmental tests subgroup 1, $V_{ini} = V_{IOTM}$, t_{ini} = 60 s; $V_{pd(m)} = 1.2 \times V_{IORM}$, t_m = 10 s	≤5	
		Method b3: At routine test (100% production) and preconditioning (type test) $V_{ini} = 1.2 \times V_{IOTM}$, t_{ini} = 1 s; $V_{pd(m)} = 1.2 \times V_{IOTM}$, t_m = 1 s	≤5	
C_{IO}	Barrier capacitance, input to output(4)	$V_{IO} = 0.4 \sin(2\pi ft)$, f = 1 MHz	0.6	pF
R_{IO}	Isolation resistance, input to output(4)	V_{IO} = 500 V, T_A = 25°C	$>10^{12}$	Ω
		V_{IO} = 500 V, 100°C ≤ T_A ≤ 125°C	$>10^{11}$	Ω
		V_{IO} = 500 V at T_S = 150°C	$>10^{9}$	Ω
	Pollution degree		2	
UL 1577				
V_{ISO}	Withstand isolation voltage	$V_{TEST} = V_{ISO}$, t = 60 s (qualification); $V_{TEST} = 1.2 \times V_{ISO}$, t = 1 s (100% production)	5000	V_{RMS}

(1) Apply creepage and clearance requirements according to the specific equipment isolation standards of an application. Take care to maintain the creepage and clearance distance of the board design to make sure that the mounting pads of the isolator on the printed circuit board do not reduce this distance. Creepage and clearance on a printed circuit board become equal in certain cases. Techniques such as inserting grooves, ribs, or both on a printed circuit board are used to help increase these specifications.
(2) Testing is carried out in air or oil to determine the intrinsic surge immunity of the isolation barrier.
(3) Apparent charge is electrical discharge caused by a partial discharge (pd).
(4) All pins on each side of the barrier tied together creating a two-terminal device

7.6 Electrical Characteristics

at T_A = 25°C (unless otherwise noted)

PARAMETERS		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
R_{IN}	Input Conductor Resistance	IN+ to IN–		0.67		mΩ
R_{IN}	Input conductor resistance temperature drift	T_A= –40ºC to +125ºC		2.1		µΩ/°C
$I_{IN,MAX}$	Maximum Continuous Input Current[1]	T_A= 25ºC		82		A_{RMS}
		T_A= 125ºC		44		A_{RMS}
OUTPUT						
S	Sensitivity	TMCS1123x1		25		mV/A
		TMCS1123x2		50		
		TMCS1123x3		75		
		TMCS1123x4		100		
		TMCS1123x5		150		
	Sensitivity Error	0.05 V ≤ V_{OUT} ≤ V_S − 0.2 V		±0.3%	±0.75%	
	Sensitivity Thermal Drift	0.05 V ≤ V_{OUT} ≤ V_S − 0.2 V, T_A = −40°C to +125°C		±20	±50	ppm/°C
	Sensitivity Lifetime Drift	0.05 V ≤ V_{OUT} ≤ V_S − 0.2 V		±0.2%	±0.5%	
	Nonlinearity Error	V_{OUT} = 0.1 V to V_S – 0.1 V		±0.1%		
$V_{OUT,0A}$	Zero Current Output Voltage	TMCS1123Ax, I_{IN} = 0A		2.5		V
		TMCS1123Bx, I_{IN} = 0A		1.65		
		TMCS1123Cx, I_{IN} = 0A		0.33		
V_{OE}	Output Voltage Offset Error	TMCS1123x1, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A		±0.5	±1.5	mV
		TMCS1123x2, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A		±0.7	±2.1	
		TMCS1123x3, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A		±1	±3	
		TMCS1123x4, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A		±1.5	±4.5	
		TMCS1123x5, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A		±2	±6	
	Output Voltage Offset Drift	TMCS1123x1, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A, T_A = –40°C to 125°C		±10	±15	µV/°C
		TMCS1123x2, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A, T_A = –40°C to 125°C		±15	±20	
		TMCS1123x3, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A, T_A = –40°C to 125°C		±20	±30	
		TMCS1123x4, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A, T_A = –40°C to 125°C		±30	±45	
		TMCS1123x5, $V_{OUT,0A}$ − V_{REF}, I_{IN} = 0A, T_A = –40°C to 125°C		±40	±60	
PSRR	Power Supply Rejection Ratio	V_S = 3 V to 5.5 V, T_A= –40ºC to +125ºC		±1	±2	mV/V
CMTI	Common Mode Transient Immunity	V_{CM} = 1000V, ΔV_{OUT} < 200mV, 1µs	75	150		kV/µs
CMRR	Common Mode Rejection Ratio, RTI	DC to 60Hz		5		µA/V
CMFR	Common Mode Field Rejection	External Field, DC to 1kHz			0.01	A/mT
	Input Noise Density	Input Referred, Full Bandwidth		150		µA/√Hz
C_L	Output capacitive load	VOUT to GND		1		nF
	Short circuit output current	VOUT short to GND, short to V_S		90		mA
$Swing_{VS}$	Swing to V_S power supply rail	R_L = 10 kΩ to GND, T_A= –40ºC to +125ºC		V_S – 0.02	V_S – 0.1	V
$Swing_{GND}$	Swing to GND			V_{GND} + 5	V_{GND} + 10	mV

7.6 Electrical Characteristics (continued)

at T_A = 25°C (unless otherwise noted)

PARAMETERS		TEST CONDITIONS	MIN	TYP	MAX	UNIT
BANDWIDTH & RESPONSE						
BW	Analog Bandwidth			250		kHz
SR	Slew Rate	Output rate of change between reaching 10% and 90% of final value as shown in Figure 8-2 with a 1µs input step and a 1V output transition, C_L = 1 nF.		5		V/µs
t_r	Response Time	Time between input and output reaching 90% of final values, as shown in Figure 8-2 with a 1µs input step and a 1V output transition, C_L = 1 nF.		1		µs
t_{pd}	Propagation Delay	Time between input and output reaching 10% of final values as shown in Figure 8-2 with a 1µs input step and a 1V output transition, C_L = 1 nF.		0.6		µs
	Current Overload Recovery Time			10		µs
INTEGRATED REFERENCE						
V_{REF}	Reference Output Voltage	TMCS1123Ax		2.5		V
		TMCS1123Bx		1.65		
		TMCS1123Cx		0.33		
	Reference Output Voltage Error	TMCS1123Ax		±0.04%	±0.2%	
		TMCS1123Bx				
		TMCS1123Cx		±0.08%	±0.4%	
	Reference Output Voltage Drift	T_A = –40°C to 125°C		8	40	ppm/°C
	Reference Output Voltage PSRR	V_S = 3 V to 5.5 V		20	200	µV/V
	Reference Output Voltage Capacitive Load				20	nF
OVER CURRENT DETECTION						
V_{OC}	Over Current Detection Threshold Voltage	V_{OC} = S x I_{OC} / 2.5	0.3		V_S	V
	Over Current Hysteresis	TMCS1123x1		5		A
		TMCS1123x2		3.5		
		TMCS1123x3		3.5		
		TMCS1123x4		2.5		
		TMCS1123x5		2.5		
	I_{OC} error	T_A = 25°C		±5%	±10%	
		T_A = –40°C to 125°C		±7%	±15%	
	Over Current Detection Response Time	I_{IN} step = 120% of I_{OC}		0.5	1	µs
DIAGNOSTICS						
$\overline{\text{ALERT}}$	Output Frequency			10		kHz
	Output Duty Cycle, Active Low	Thermal Alert		80		%
		Sensor Alert		50		
		Thermal & Sensor Alert		20		
POWER SUPPLY						
V_S	Supply voltage	T_A = –40ºC to +125ºC	3.0		5.5	V
I_Q	Quiescent current	T_A = 25ºC		10.5	14	mA
		T_A = –40ºC to +125ºC			14.5	mA
	Power on time	Time from V_S > 3 V to valid output		25		ms

(1) Thermally limited by junction temperature. Applies when device mounted on *TMCS1123xEVM*. For more details, see the *Safe Operating Area* section.

8 Parameter Measurement Information

8.1 Accuracy Parameters

The ideal first-order transfer function of the TMCS1123 is given by Equation 1, where the output voltage is a linear function of input current. The accuracy of the device is quantified both by the error terms in the transfer function parameters, as well as by nonidealities that introduce additional error terms not in the simplified linear model. See *Total Error Calculation Examples* for example calculations of total error, including all device error terms.

$$\mathbf{V_{OUT} = (S \times I_{IN}) + V_{REF}} \qquad (1)$$

where

- V_{OUT} is the analog output voltage.
- S is the sensitivity of the device.
- I_{IN} is the isolated input current.
- V_{REF} is the reference output voltage for the device variant.

8.1.1 Sensitivity Error

Sensitivity is the proportional change in the sensor output voltage due to a change in the input conductor current. This sensitivity is the slope of the first-order transfer function of the sensor (see Figure 8-1). The sensitivity of the TMCS1123 is tested and calibrated at the factory for high accuracy.

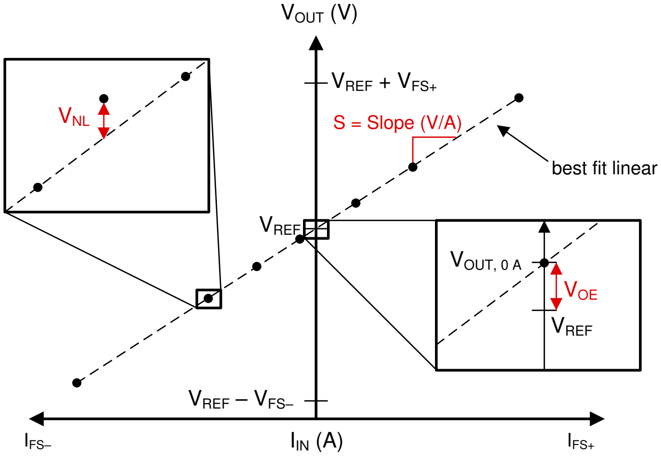


Figure 8-1. Sensitivity, Offset, and Nonlinearity Error

Deviation from ideal sensitivity is quantified by sensitivity error, defined in Equation 2 as the percent variation of the best-fit measured sensitivity from the ideal sensitivity.

$$\mathbf{e_S = [(S_{fit} - S_{ideal}) / S_{ideal}] \times 100\%} \qquad (2)$$

where

- e_S is the sensitivity error.
- S_{fit} is the best fit sensitivity.
- S_{Ideal} is the ideal sensitivity.

Sensitivity thermal drift is the change in sensitivity with temperature and is reported in ppm/°C. To calculate sensitivity error at any given temperature, T, use Equation 3 to multiply the sensitivity thermal drift by the change in temperature and add it to sensitivity error at 25°C.

$$e_S(T) = e_{S,25°C} + (S_{drift,thermal} \times \Delta T \times 100\%) \qquad (3)$$

where

- $S_{drift,thermal}$ is the sensitivity drift over temperature.
- ΔT is the change in temperature from 25°C.

Sensitivity lifetime drift is the change in sensitivity due to operational and environmental stresses over the entire lifetime of the device, and is reported as a worst-case percentage change in sensitivity over lifetime at 25°C.

8.1.2 Offset Error and Offset Error Drift

Offset error is the deviation from the ideal output with zero input current flowing through the current sensor and most often limits measurement accuracy at low input current levels. Offset error can be referred to the output as offset voltage error or referred to the input as offset current error. When divided by device sensitivity, S, output voltage offset error V_{OE} is input referred as input current offset error I_{OS} (see Equation 4). Offset error referred to the input (RTI) allows for more direct comparisons or offset error with input current. Regardless of whether offset error is referred to the input as current offset error I_{OS}, or the output as voltage offset error V_{OE}, offset error is a single error source and should only be included once in either input referred, or output referred error calculations.

$$I_{OS} = V_{OE} / S \tag{4}$$

The output voltage offset error V_{OE} of the TMCS1123 is the difference between the zero current output voltage $V_{OUT,0A}$ and the reference voltage V_{REF} (see Equation 5).

$$V_{OE} = V_{OUT.0A} - V_{REF} \tag{5}$$

The output offset error V_{OE} includes offset errors in the internal reference, magnetic offset error in the Hall sensor and offset voltage errors in the signal chain. The internal reference voltage is brought out to pin VREF to remove the errors in the internal reference at system level.

Offset drift is the change in the offset as a function of temperature, T. Output offset drift is reported in µV/°C. To calculate offset error at any given temperature, multiply the offset drift by the change in temperature and add it to offset error at 25°C (see Equation 6).

$$V_{OE}(T) = V_{OE,25°C} + (V_{OE,drift} \times \Delta T) \tag{6}$$

where

- $V_{OE,drift}$ is the specified output-referred device offset drift in µV/°C.
- ΔT is the temperature change from 25°C.

8.1.3 Nonlinearity Error

Nonlinearity is the deviation of the output voltage from a linear relationship to the input current. Nonlinearity voltage, as shown in Figure 8-1, is the maximum voltage deviation from the best-fit line based on measured parameters (see Equation 7).

$$V_{NL} = V_{OUT,MEAS} – (I_{MEAS} \times S_{fit} + V_{OUT,0A}) \tag{7}$$

where

- $V_{OUT,MEAS}$ is the voltage output at maximum deviation from best fit.
- I_{MEAS} is the input current at maximum deviation from best fit.
- S_{fit} is the best-fit sensitivity of the device.
- $V_{OUT,0A}$ is the device zero current output voltage.

Nonlinearity error for the TMCS1123 is specified as a percentage of the full-scale output range, V_{FS} (see Equation 8).

$$e_{NL} = V_{NL} / V_{FS} \times 100\% \tag{8}$$

8.1.4 Power Supply Rejection Ratio

Power supply rejection ratio (PSRR) is the change in device offset due to variation of supply voltage from the nominal 5 V. Use Equation 9 to calculate the error contribution at the input current of interest.

$$e_{PSRR}(\%) = \left| \frac{\frac{PSRR * (V_S - 5)}{S}}{I_{IN}} \right| \tag{9}$$

where

- V_S is the operational supply voltage.
- S is the device sensitivity.

8.1.5 Common-Mode Rejection Ratio

Common-mode rejection ratio (CMRR) quantifies the effective input current error due to a varying voltage on the isolated input of the device. Due to magnetic coupling and galvanic isolation of the current signal, the TMCS1123 has very high rejection of input common-mode voltage. Use Equation 10 to calculate the percent error contribution from the input common-mode variation.

$$e_{CMRR}(\%) = \left| \frac{CMRR * V_{CM}}{I_{IN}} \right| \tag{10}$$

where

- V_{CM} is the maximum operational AC or DC voltage on the input of the device.

8.2 Transient Response Parameters

Figure 8-2 shows the critical TMCS1123 transient response parameters. . Propagation delay, t_{pd}, is the time period between the input current waveform reaching 10% of its final value and the output voltage, V_{OUT}, reaching 10% of its final value. Response time, t_r, is the time period between the input current reaching 90% of its final value and the output voltage reaching 90% of its final value, for an input current step sufficient to cause a 1V change in the output voltage. Slew rate, SR, is defined as the maximum rate of change in the output voltage during the sufficiently fast input current step.

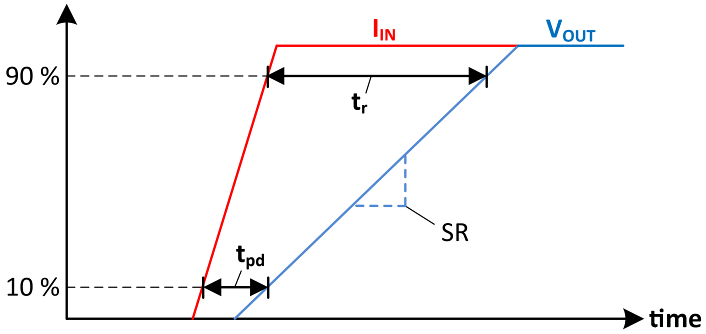


Figure 8-2. Transient Step Response

8.2.1 CMTI, Common-Mode Transient Immunity

CMTI is the capability of the device to tolerate a rising or falling voltage step on the input without disturbance on the output signal. The device is specified for the maximum common-mode transition rate under which the output signal will not experience a greater than 200-mV disturbance that lasts longer than 1 µs. Higher edge rates than the specified CMTI can be supported with sufficient filtering or blanking time after common-mode transitions.

8.3 Safe Operating Area

The isolated input current safe operating area (SOA) of the TMCS1123 is constrained by self-heating due to power dissipation in the input conductor. Depending upon the use case, the SOA is constrained by multiple conditions, including exceeding maximum junction temperature, Joule heating in the leadframe, or leadframe fusing under extremely high currents. These mechanisms depend on pulse duration, amplitude, and device thermal states.

Current SOA strongly depends on the thermal environment and design of the system-level board. Multiple thermal variables control the transfer of heat from the device to the surrounding environment, including air flow, ambient temperature, and printed circuit board (PCB) construction and design. All ratings are for a single TMCS1123 device mounted on the TMCS1123xEVM with no air flow under specified ambient temperature conditions. Device use profiles must satisfy continuous current conduction SOA capabilities for the thermal environment planned for system operation.

8.3.1 Continuous DC or Sinusoidal AC Current

The longest thermal time constants of device packaging and PCBs are in the order of seconds; therefore, any continuous DC or sinusoidal AC periodic waveform with a frequency higher than 1 Hz can be evaluated based on the RMS continuous-current levels. The continuous-current capability has a strong dependence upon the operating ambient temperature range expected in operation. Figure 8-3 shows the maximum continuous current-handling capability of the device on the TMCS1123xEVM. Current capability falls off at higher ambient temperatures because of the reduced thermal transfer from junction-to-ambient and increased power dissipation in the leadframe. By improving the thermal design of an application, the SOA can be extended to higher currents at elevated temperatures. Using larger and heavier copper power planes, providing air flow over the board, or adding heat sinking structures to the area of the device can all improve thermal performance.

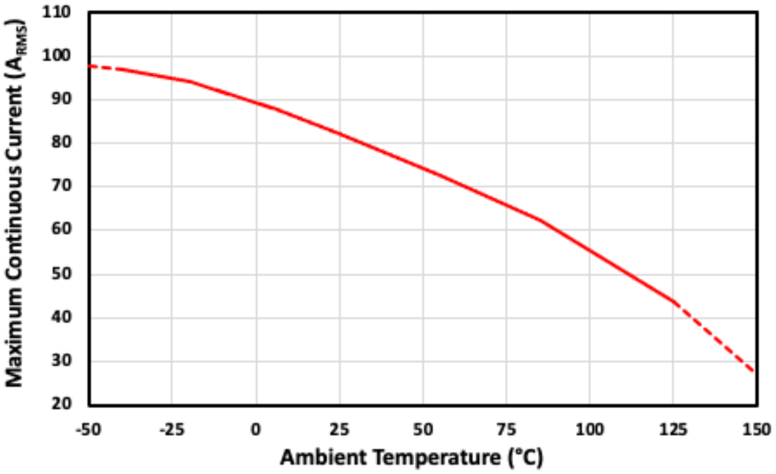


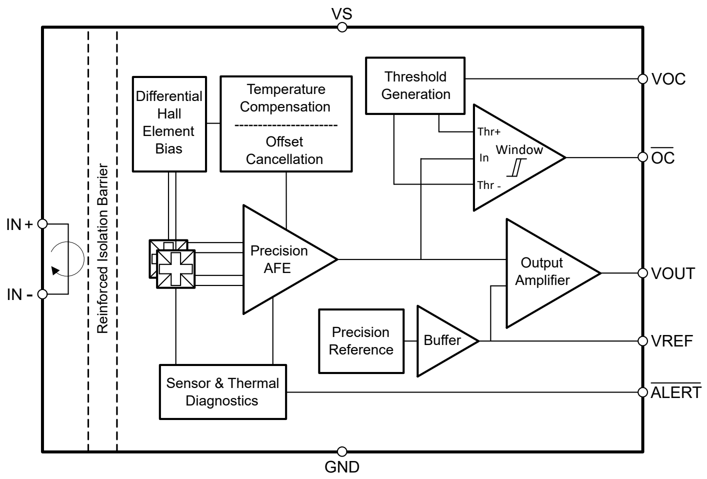
Figure 8-3. Maximum Continuous RMS Current vs Ambient Temperature

9 Detailed Description

9.1 Overview

The TMCS1123 is a precision Hall-effect current sensor, featuring up to 1100V reinforced isolation working voltage, ambient field rejection, high current carrying capability with less than 1.75% maximum total lifetime error with no system level calibration, or less than 1% maximum total error with a one-time room temperature calibration (including both temperature and lifetime drift). Numerous device options are provided for both unidirectional and bidirectional current measurements. Input current flows through a conductor between the isolated input current pins. The conductor has a 0.67mΩ resistance at room temperature and accommodates up to $40A_{RMS}$ continuous current at 125°C ambient temperature when used with printed circuit boards of comparable thermal design as the TMCS1123xEVM. The low-ohmic leadframe path reduces power dissipation compared to alternative current measurement methodologies, and does not require any external passive components, isolated supplies, or control signals on the high-voltage side. The magnetic field generated by the input current is sensed by a Hall sensor and amplified by a precision signal chain. The device can be used for both AC and DC current measurements and has a bandwidth of 250 kHz. There are multiple bidirectional and unidirectional fixed-sensitivity device variants to choose from, providing a wide option of linear sensing ranges from ±10 A to ±96 A, and the TMCS1123 can operate with a low voltage supply from 3 V to 5.5 V. The TMCS1123 is optimized for high accuracy and temperature stability, with both offset and sensitivity compensated across the entire operating temperature range.

9.2 Functional Block Diagram



9.3 Feature Description

9.3.1 Current Input

Input current to the TMCS1123 passes through the isolated high-voltage side of the package leadframe in to and out of the IN+ and IN– pins. The current flowing through the package generates a magnetic field that is proportional to the input current, which is measured by an integrated on-chip galvanically isolated, precision, Hall sensor. As a result of the electrostatic shielding on the Hall sensor die, only the magnetic field generated by the input current is measured, thus limiting input voltage switching pass-through to the circuitry. This configuration allows for direct measurement of currents with high-voltage transients without signal distortion on the current-sensor output. The leadframe conductor has a nominal resistance of 0.67 mΩ at 25°C, and has a typical positive temperature coefficient as defined in *Electrical Characteristics*.

9.3.2 Input Isolation

The separation between the input conductor and the Hall sensor die due to the TMCS1123 construction provides inherent galvanic isolation between package pins 1 and 2 on the high-voltage input side, and package pins 3 through 10 on the low-voltage output side. Insulation capability is defined according to certification agency definitions and using industry-standard test methods as defined in *Insulation Specifications*. Assessment of device lifetime working voltages follow the VDE 0884-11 standard for reinforced insulation, requiring timedependent dielectric breakdown (TDDB) data-projection failure rates of less than 1 part per million (ppm), and a minimum insulation lifetime of 30 years. The VDE standard also requires additional safety margins of 20% for working voltage, and 30% for insulation lifetime, translating into a minimum required lifetime of 39 years at 900 V_{RMS} for the TMCS1123.

9.3.3 Ambient Field Rejection

The TMCS1123 is designed to provide high levels of current measurement accuracy in harsh environments. Immunity to interference from stray magnetic fields allows for use in close proximity to high current carrying traces, motor windings, inductors, or any other erroneous source of stray magnetic fields. The TMCS1123 incorporates differential Hall sensors that are strategically located and configured to reject interference from stray external magnetic fields. Ambient Field Rejection (AFR) limited only by Hall element matching and package leadframe coupling reduces errors from stray fields by more than 40 dB.

9.3.4 High-Precision Signal Chain

The TMCS1123 uses a precision, low-drift signal chain with proprietary sensor linearization techniques to provide a highly accurate and stable current measurement across the full temperature range and lifetime of the device. The device is fully tested and calibrated at the factory to account for any variations in either silicon processing, assembly or packaging of the device. The full signal chain provides a fixed sensitivity voltage output that is proportional to the current flowing through the leadframe of the isolated input.

9.3.4.1 Temperature Stability

The TMCS1123 includes a proprietary temperature compensation technique which results in significantly improved parametric drift across the full temperature range. This compensation technique accounts for changes in ambient temperature, self-heating, and package stress. A zero-drift signal chain architecture along with Hall sensor temperature compensation methods enable stable sensitivity while minimizing offset errors across temperature. System-level performance is drastically improved across required operating conditions.

9.3.4.2 Lifetime and Environmental Stability

In addition to large thermal drift, typical magnetic current sensors suffer an additional 2% to 3% drift in sensitivity due to aging over the lifetime of the device. The same proprietary compensation techniques used in the TMCS1123 to reduce temperature drift are also used to greatly reduce lifetime drift due to aging from stress and environmental conditions especially at high operating temperatures. As shown in the *Electrical Characteristics*, the TMCS1123 has industry leading lifetime sensitivity drift realized after Highly Accelerated Stress Tests (HAST) at 130°C and 85% relative humidity (RH) during standard three lot AEC-Q100 qualifications. Low sensitivity and offset drift within the bounds specified in the *Electrical Characteristics* are also observed after 1000 hour, 125°C high temperature operating life stress tests are performed as prescribed by AEC-Q100 qualifications. These tests mimic typical device lifetime operation, and show device performance variation due to aging is vastly improved compared with typical magnetic current sensors.

9.3.5 Internal Reference Voltage

The TMCS1123 has a precision internal reference that determines the zero-current output voltage, $V_{OUT,0A}$. Overall current sensing dynamic range can be optimized with three different zero-current output voltage options to choose from, as listed in the *Device Comparison* table. These extremely low-drift precision zero-current reference options provide for either bidirectional or unidirectional current measurements using various supply voltages ranging between 3 V to 5.5 V as described in Equation 11, Equation 12, and Equation 13.

$$\text{TMCS1123Ax} \rightarrow V_{OUT,0A} = V_{REF} = 2.5\text{ V; intended for bidirectional current sensing with 5V supplies} \tag{11}$$

$$\text{TMCS1123Bx} \rightarrow V_{OUT,0A} = V_{REF} = 1.65\text{ V; intended for bidirectional current sensing with 3.3V supplies} \tag{12}$$

$$\text{TMCS1123Cx} \rightarrow V_{OUT,0A} = V_{REF} = 0.33\text{ V; intended for unidirectional current sensing with either 3.3V or 5V supplies} \tag{13}$$

9.3.6 Current-Sensing Measurable Ranges

The zero-current reference voltage, V_{REF}, along with device sensitivity, S, and supply voltage, V_S, determine the linear input current measurement range of the device as listed in the *Device Comparison* table. The maximum linear output voltage, $V_{OUT,max}$, is limited by the exceptional near-to-supply output voltage swing, $Swing_{VS}$, of the TMCS1123 as defined in the *Electrical Characteristics* table and shown in Equation 14.

$$V_{OUT,max} = V_S - Swing_{VS} \tag{14}$$

The minimum linear output voltage, $V_{OUT,min}$, is limited by the exceptional near-to-ground linear output swing, $Swing_{GND}$, as is also defined in the *Electrical Characteristics* table and shown in Equation 15.

$$V_{OUT,min} = Swing_{GND} \tag{15}$$

Overall maximum dynamic range can be optimized with proper device selection by referring minimum and maximum linear output voltage swing to minimum and maximum linear input current range by dividing output voltage by sensitivity, S (see Equation 16 and Equation 17).

$$I_{IN,MAX+} = (V_{OUT,max} - V_{OUT,0A}) / S \tag{16}$$

$$I_{IN,MAX-} = (V_{OUT,0A} - V_{OUT,min}) / S \tag{17}$$

where

- $I_{IN,MAX+}$ is the maximum linear measurable positive input current.
- $I_{IN,MAX-}$ is the maximum linear measurable negative input current.
- S is the sensitivity of the device variant.
- $V_{OUT,0A}$ is the appropriate zero current output voltage.

As an example for determining linear input current measurement range, consider the TMCS1123A2, TMCS1123B2 and TMCS1123C2, all with 50 mV/A sensitivity as shown in the *Device Comparison* table. When used with a 5V supply, the TMCS1123A2 has a balanced ±48A bidirectional linear current measurement range about the 2.5V zero-current output reference voltage, V_{REF}, as shown in Figure 9-1. When used with a 3.3V supply, the TMCS1123B2 has a balanced ±31A bidirectional linear current measurement range about the 1.65V zero-current output reference voltage. If used with a 5V supply, the linear current measurement range of the TMCS1123B2 can be extended from –31 A to +65 A as shown in Figure 9-1. The TMCS1123C2 with a 0.33V zero-current reference voltage is intended for measuring unidirectional currents. When used with a 3.3V supply the TMCS1123C2 has a unidirectional linear current measurement range from –5 A to +57 A which can be extended from –5 A to +91.4 A when used with a 5V supply.

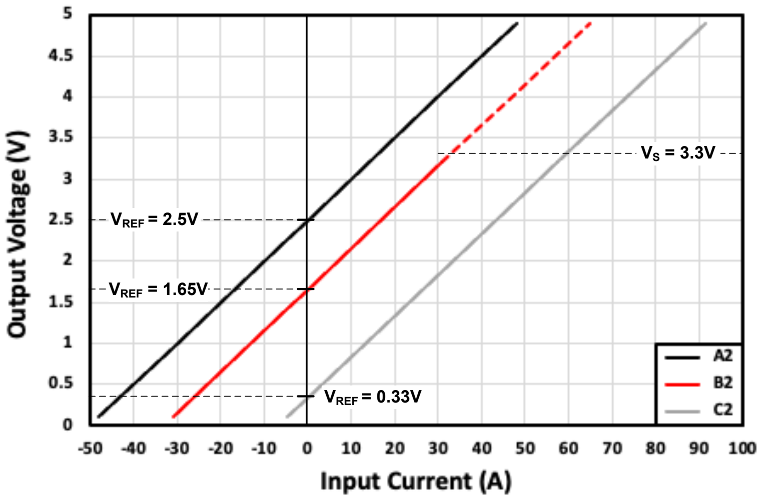


Figure 9-1. Output Voltage Relationship to Input Current for TMCS1123x2

9.3.7 Overcurrent Detection

In addition to a fast precision analog signal response, the TMCS1123 also offers an even faster digital overcurrent response. The Overcurrent Detection (OCD) circuit provides a comparator output that can be used to trigger a warning or system shutdown to prevent damage that may occur in the event of excessive current flow caused by shorts circuits, motor stalls, or other system conditions. This fast digital response can be configured on both bidirectional and unidirectional devices to trip at user defined overcurrent thresholds, I_{OC}, between half and more than twice the full-scale current I_{FS} defined as Equation 18.

$$I_{FS} = V_{REF} / S \qquad (18)$$

where

- V_{REF} is the reference voltage
- S is the device sensitivity in mV/A.

Use of this fast digital output $\overline{OC}$ in addition to the precision analog output VOUT allows for optimization of control-loop dynamic range.

The desired overcurrent threshold I_{OC} can be set by applying an external voltage V_{OC} to the VOC pin according to Equation 19 regardless of reference voltage, V_{REF}.

$$V_{OC} = S \times I_{OC} / 2.5 \qquad (19)$$

A simple external resistor divider circuit can be used to set the desired overcurrent threshold, I_{OC}, as shown in Figure 9-2. In this example, use Equation 20 to calculate the full-scale current, IFS, on the bidirectional TMCS1123B3.

$$I_{FS} = \pm V_{REF} / S = \pm 1.65V / 75mV/A = \pm 22A \qquad (20)$$

where

- Reference voltage V_{REF} = 1.65 V
- Sensitivity S = 75 mV/A.

To set the desired overcurrent threshold to I_{OC} = ±50 A, resistors R1 and R2 should be sized to apply a voltage V_{OC} = 1.5 V to the VOC pin (see Equation 21).

$$V_{OC} = I_{OC} \times S / 2.5 = 50A \times 75 mV/A / 2.5V = 1.5 V \qquad (21)$$

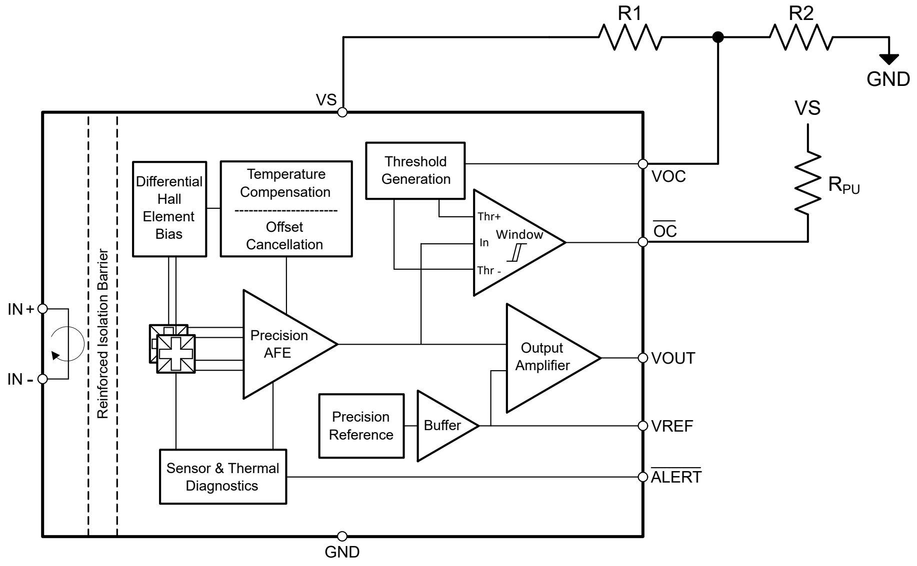


Figure 9-2. User Configurable Overcurrent Threshold

Figure 9-3 shows the overcurrent digital output $\overline{OC}$ response as active-low. When the input current exceeds $\pm I_{OC}$ the fast $\overline{OC}$ pin is pulled low. The input current must return to within $\pm I_{OC}$ by more than a hysteresis current I_{Hys} before the $\overline{OC}$ pin resets back to the normal high-state.

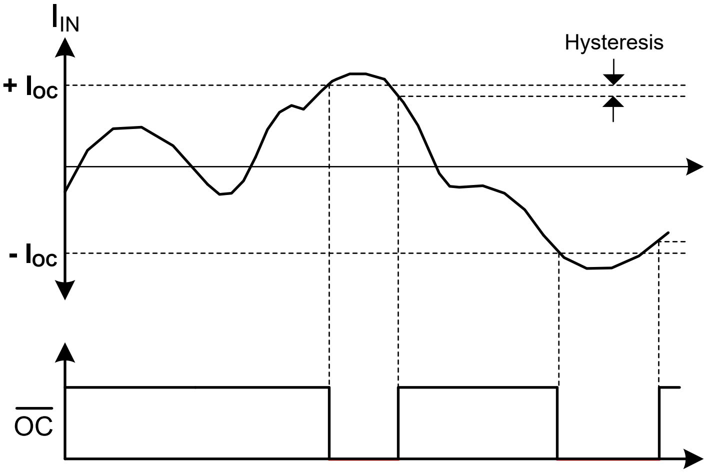


Figure 9-3. Overcurrent Detection Diagram

9.3.8 Sensor Diagnostics

Built-in self-diagnostic features are incorporated in the TMCS1123 to warn when operating conditions might invalidate current sensor measurements. Two critical conditions being monitored are sensor temperature and sensitivity.

Thermal Alert

High levels of input current can generate excessive heat inside the TMCS1123. A thermal alert occurs when internal temperature is close to or has exceeded the maximum allowed 165°C junction temperature.

Sensor Alert

In addition to temperature, sensor sensitivity and offset are constantly being monitored inside the TMCS1123. A sensor alert occurs in the unlikely event Hall sensor sensitivity or offset is out of range compared with factory set limits.

The active-low 10kHz PWM output signal shown in Figure 9-4 can be decoded to indicate which, neither, or both of the thermal and sensor operating condition warnings exist.

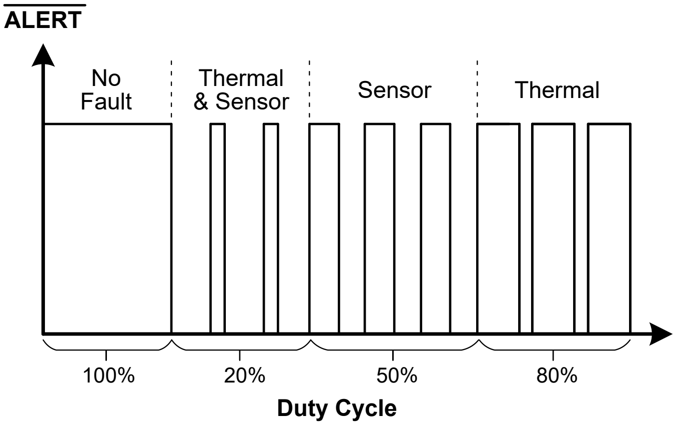


Figure 9-4. Sensor Diagnostics Waveform

9.4 Device Functional Modes

9.4.1 Power-Down Behavior

As a result of the inherent galvanic isolation of the device, very little consideration must be paid to powering down the device, as long as the limits in the *Absolute Maximum Ratings* table are not exceeded on any pins. The isolated current input and the low-voltage signal chain can be decoupled in operational behavior, as either can be energized with the other shut down, as long as the isolation barrier capabilities are not exceeded. The low-voltage power supply can be powered down while the isolated input is still connected to an active high-voltage signal or system.

10 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.

10.1 Application Information

The key feature sets of the TMCS1123 provide significant advantages in any application where an isolated current measurement is required.

- Galvanic isolation provides a high isolated working voltage and excellent immunity to input voltage transients.
- Hall based measurement simplifies system level solution without the need for a power supply on the high-voltage (HV) side.
- An input current path through the low impedance conductor minimizes power dissipation.
- Excellent accuracy and low temperature drift eliminate the need for multipoint calibrations without sacrificing system performance.
- A wide operating supply range enables a single device to function across a wide range of voltage levels.

These advantages increase system-level performance while minimizing complexity for any application where precision current measurements must be made on isolated currents. Specific examples and design requirements are detailed in the following section.

10.1.1 Total Error Calculation Examples

Total error can be calculated for any arbitrary device condition and current level. Error sources considered should include input-referred offset current, power-supply rejection, input common-mode rejection, sensitivity error, nonlinearity, and the error caused by any external fields. Compare each of these error sources in percentage terms, as some are significant drivers of error and some have inconsequential impact to current error. Offset (Equation 22), CMRR (Equation 23), PSRR (Equation 24), and external field error (Equation 25) are all referred to the input, and so, are divided by the actual input current I_{IN} to calculate percentage errors. For calculations of sensitivity error and nonlinearity error, the percentage limits explicitly specified in the *Electrical Characteristics* table can be used.

$$e_{Ios}(\%) = I_{OS} / I_{IN} = V_{OE} / (S * I_{IN}) \tag{22}$$

$$e_{CMRR}(\%) = \left| \frac{CMRR * V_{CM}}{I_{IN}} \right| \tag{23}$$

$$e_{PSRR}(\%) = \left| \frac{\frac{PSRR * (V_S - 5)}{S}}{I_{IN}} \right| \tag{24}$$

$$e_{Bext}(\%) = B_{EXT} * CMFR / I_{IN} \tag{25}$$

When calculating error contributions across temperature, only offset error and sensitivity error contributions vary significantly. To determine the offset error across temperature, use Equation 26 to calculate total input-referred offset error current, I_{OS}, at any ambient temperature, T_A.

$$e_{I_{OS},\Delta T}(\%) = \frac{I_{OS,25^\circ C} + I_{OS,drift}\left(\frac{\mu A}{^\circ C}\right) \times \Delta T}{I_{IN}} \tag{26}$$

where

- Change in temperature, $\Delta T = T_A - 25°C$.
- Input referred offset current, $I_{OS,25°C} = V_{OE,25°C} / S$.
- Input referred offset drift, $I_{OS,drift} = V_{OE,drift} / S$.
- Output referred offset error, $V_{OE} = V_{OUT,0A} - V_{REF}$.
- S is the sensitivity of the device variant.

Sensitivity error is specified in the *Electrical Characteristics* table at 25°C along with variation over temperature as sensitivity thermal drift in ppm/°C. To determine the sensitivity error across temperature, use Equation 27 to calculate sensitivity error at any ambient temperature, T_A, over the given application operating ambient temperature range between –40°C and 125°C.

$$e_S = e_{S,25°C} + (e_{S,drift} * \Delta T) \tag{27}$$

To accurately calculate the total expected error of the device, the contributions from each of the individual components above must be understood in reference to operating conditions. To account for the individual error sources that are statistically uncorrelated, use a root sum square (RSS) error calculation to calculate total error. For the TMCS1123, only the input referred offset current (I_{OS}), CMRR, and PSRR are statistically correlated. These error terms are lumped in an RSS calculation to reflect this nature, as shown in Equation 28 for room temperature and Equation 29 for across a given temperature range. The same methodology can be applied for calculating typical total error by using the appropriate error term specification.

$$e_{RSS}(\%) = \sqrt{\left(e_{I_{OS}} + e_{PSRR} + e_{CMRR}\right)^2 + e_{B_{EXT}}{}^2 + e_S{}^2 + e_{NL}{}^2} \tag{28}$$

$$e_{RSS,\Delta T}(\%) = \sqrt{\left(e_{I_{OS,\Delta T}} + e_{PSRR} + e_{CMRR}\right)^2 + e_{B_{EXT}}{}^2 + e_{S,\Delta T}{}^2 + e_{NL}{}^2} \tag{29}$$

The total error calculation has a strong dependence on the actual input current; therefore, always calculate total error across the dynamic range that is required. These curves asymptotically approach the sensitivity and nonlinearity error at high current levels, and approach infinity at low current levels due to offset error terms with input current in the denominator. Key figures of merit for any current-measurement system include the total error percentage at full-scale current, as well as the dynamic range of input current over which the error remains below some key level. Figure 10-1 shows the RSS maximum total error as a function of input current for a TMCS1123A4 at room temperature and across the full temperature range with V_S of 5 V.

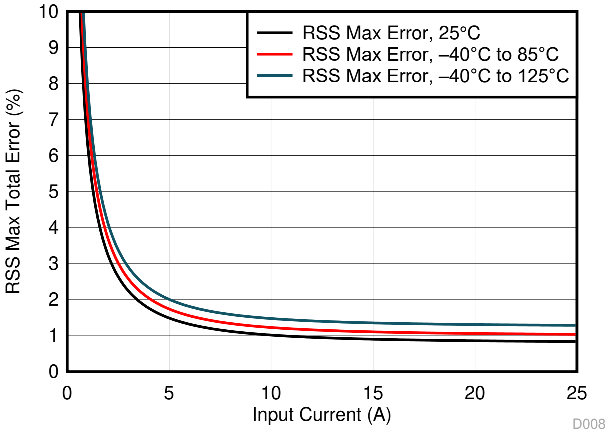


Figure 10-1. RSS Error vs Input Current

10.1.1.1 Room Temperature Error Calculations

For room-temperature total-error calculations, specifications across temperature and drift are ignored. As an example, consider a TMCS1123B2 with a supply voltage (V_S) of 3.3 V and a worst-case common-mode excursion of 600 V to calculate operating-point-specific parameters. Consider a measurement error due to an external 400µT magnetic field generated by a $20A_{DC}$ current flowing through an adjacent trace or conductor that is 10 mm away. The full-scale current range of the device in specified conditions is slightly greater than ±31 A, as shown in the *Device Comparison* table; therefore, calculating error at both 25 A and 12.5 A highlights error dependencies on the input-current level. Table 10-1 shows the individual error components and RSS maximum total error calculations at room temperature under the conditions specified. Relative to other errors, the additional errors from CMRR, external ambient magnetic fields B_{EXT} and nonlinearity are negligible, and can typically be excluded from total error calculations.

Table 10-1. Total Error Calculation: Room Temperature Example

ERROR COMPONENT	SYMBOL	EQUATION	% TOTAL ERROR AT I_{IN} = 25 A	% TOTAL ERROR AT I_{IN} = 12.5 A
Input offset error	e_{Ios}	$e_{I_{OS}}(\%) = \frac{I_{OS}}{I_{IN}}$	0.17%	0.34%
PSRR error	e_{PSRR}	$e_{PSRR}(\%) = \left\lvert \frac{\frac{PSRR * (V_S - 5)}{S}}{I_{IN}} \right\rvert$	0.27%	0.54%
CMRR error	e_{CMRR}	$e_{CMRR}(\%) = \left\lvert \frac{CMRR * V_{CM}}{I_{IN}} \right\rvert$	0.01%	0.02%
External Field error	e_{Bext}	$e_{Bext}(\%) = B_{EXT} * CMFR / I_{IN}$	0.02%	0.03%
Sensitivity error	e_S	Specified in *Electrical Characteristics*	0.75%	0.75%
Nonlinearity error	e_{NL}	Specified in *Electrical Characteristics*	0.1%	0.1%
RSS total error	e_{RSS}	$e_{RSS}(\%) = \sqrt{(e_{I_{OS}} + e_{PSRR} + e_{CMRR})^2 + e_{B_{EXT}}{}^2 + e_S{}^2 + e_{NL}{}^2}$	0.88%	1.18%

10.1.1.2 Full Temperature Range Error Calculations

To calculate total error across any specific temperature range, Equation 28 and Equation 29 should be used for RSS maximum total errors, similar to the example for room temperatures. Conditions from the example in *Room Temperature Error Calculations* have been replaced with their respective equations and error components for a –40°C to 85°C temperature range below in Table 10-2.

Table 10-2. Total Error Calculation: –40°C to 85°C Example

ERROR COMPONENT	SYMBOL	EQUATION	% MAX TOTAL ERROR AT I_{IN} = 25 A	% MAX TOTAL ERROR AT I_{IN} = 12.5 A
Input offset error	$e_{Ios,\Delta T}$	$e_{I_{OS},\Delta T}(\%) = \frac{I_{OS,25°C} + I_{OS,drift}\left(\frac{\mu A}{°C}\right) \times \Delta T}{I_{IN}}$	0.26%	0.53%
PSRR error	e_{PSRR}	$e_{PSRR}(\%) = \left\lvert \frac{\frac{PSRR * (V_S - 5)}{S}}{I_{IN}} \right\rvert$	0.27%	0.54%
CMRR error	e_{CMRR}	$e_{CMRR}(\%) = \left\lvert \frac{CMRR * V_{CM}}{I_{IN}} \right\rvert$	0.01%	0.02%
External Field error	e_{Bext}	$e_{Bext}(\%) = B_{EXT} * CMFR / I_{IN}$	0.02%	0.03%
Sensitivity error	$e_{S,\Delta T}$	Specified in *Electrical Characteristics*	1.05%	1.05%
Nonlinearity error	e_{NL}	Specified in *Electrical Characteristics*	0.1%	0.1%
RSS total error	$e_{RSS,\Delta T}$	$e_{RSS,\Delta T}(\%) = \sqrt{(e_{I_{OS,\Delta T}} + e_{PSRR} + e_{CMRR})^2 + e_{B_{EXT}}{}^2 + e_{S,\Delta T}{}^2 + e_{NL}{}^2}$	1.19%	1.52%

10.2 Typical Application

Inline sensing of inductive load currents, such as motor phases, provides significant benefits to the performance of a control systems, allowing advanced control algorithms and diagnostics with minimal postprocessing. A primary challenge to inline sensing is that the current sensor is subjected to full HV supply-level PWM transients driving the load. The inherent isolation of an in-package Hall-effect current sensor topology helps overcome this challenge, providing high common-mode immunity, as well as isolation between the high-voltage motor drive levels and the low-voltage control circuitry. Figure 10-2 shows the use of the TMCS1123 in such an application, driving the inductive load presented by a three phase motor.

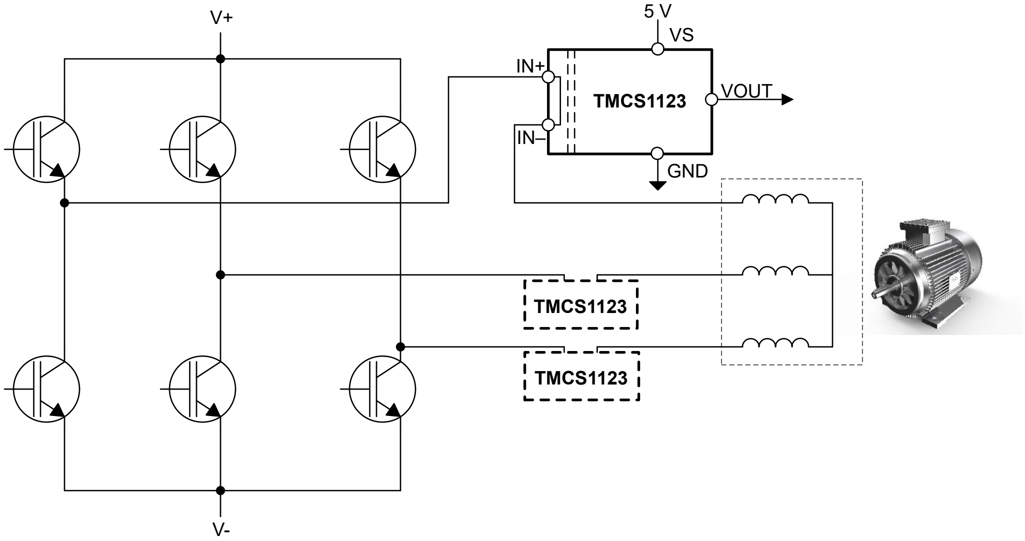


Figure 10-2. Inline Motor Phase Current Sensing

10.2.1 Design Requirements

For current sensing of a three-phase motor application, make sure to provide linear sensing across the expected current range, and make sure that the device remains within working thermal constraints. A single TMCS1123 for each phase can be used, or two phases can be measured, and the third phase calculated on the motor-controller host processor. For this example, consider a nominal supply of 5 V but a minimum of 4.9 V to include for some supply variation. Maximum output swings are defined according to TMCS1123 specifications, and a full-scale current measurement of ±20 A is required.

Table 10-3. Example Application Design Requirements

DESIGN PARAMETER	EXAMPLE VALUE
$V_{S,nom}$	5 V
$V_{S,min}$	4.9 V
$I_{IN,FS}$	±20 A

10.2.2 Detailed Design Procedure

The primary design parameter for using the TMCS1123 is the optimum sensitivity variant based on the required measured current levels and the selected supply voltage. Because positive and negative currents are measured in this in-line motor load current application example, select a bidirectional variant. The TMCS1123 has a precision internal reference voltage that determines the zero-current output voltage, $V_{OUT,0A}$. The internal reference voltage on TMCS1123(A1-A5) variants, with zero-current output voltage $V_{OUT,0A}$ = 2.5 V is intended for bidirectional current measurements when used with 5V power supplies. The internal reference voltage on TMCS1123(B1-B5) variants, with zero-current output voltage $V_{OUT,0A}$ = 1.65V is intended for bidirectional current measurements when used with 3.3V power supplies. Further consideration of noise and integration with an ADC can be explored, but is beyond the scope of this application design example. The TMCS1123 output voltage V_{OUT} is proportional to the input current I_{IN} as defined by Equation 30 with output offset set by $V_{OUT,0A}$.

$$V_{OUT} = I_{IN} \times S + V_{OUT,0A} \tag{30}$$

Design of the sensing solution focuses on maximizing the sensitivity of the device while maintaining linear measurement over the expected current input range. The TMCS1123 has a slightly smaller linear output range to the supply than to ground; therefore, the measurable current range is always constrained by the positive swing to supply, $Swing_{VS}$. To account for the operating margin, consider the minimum possible supply voltage $V_{S,min}$. With the previous parameters, the maximum linear output voltage $V_{OUT,max}$ is defined by Equation 31.

$$V_{OUT,max} = V_{S,min} - Swing_{VS} \tag{31}$$

Design parameters for this example application are shown in Table 10-4 along with the calculated output range.

Table 10-4. Example Application Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
$Swing_{VS}$	0.1 V
$V_{OUT,max}$	4.8 V
$V_{OUT,0A}$	2.5 V
$V_{OUT,max} - V_{OUT,0A}$	2.3 V

These design parameters result in a maximum positive linear output voltage swing of ±2.3 V about $V_{OUT,0A}$ = 2.5 V. To determine which sensitivity variant of the TMCS1123 most fully uses this linear range, calculate the maximum current range by Equation 32 for a bidirectional current $\pm I_{IN,max}$).

$$I_{IN,max} = (V_{OUT,max} - V_{OUT,0A}) / S_{A<x>} \tag{32}$$

where

- $S_{A<x>}$ is the sensitivity of the relevant A1-A5 variant.

Table 10-5 shows such calculation for each gain variant of the TMCS1123 with the appropriate sensitivities.

Table 10-5. Maximum Full-Scale Current Ranges With 2.3V Positive Output Swing

SENSITIVITY VARIANT	SENSITIVITY	$I_{IN,max}$
TMCS1123A1	25 mV/A	±96 A
TMCS1123A2	50 mV/A	±48 A
TMCS1123A3	75 mV/A	±32 A
TMCS1123A4	100 mV/A	±24 A
TMCS1123A5	150 mV/A	±16 A

In general, the highest sensitivity variant that provides for the desired full-scale current range is selected. For the design parameters in this example, the TMCS1123A4 with a sensitivity of 0.1 V/A is the proper selection because the maximum calculated ±24A linear measurable range is sufficient for the desired ±20A full-scale current range.

10.3 Power Supply Recommendations

The TMCS1123 only requires a power supply (V_S) on the low-voltage isolated side, which powers the analog circuitry independent of the isolated current input. V_S determines the full-scale output range of the analog output V_{OUT}, and can be supplied with any voltage between 3 V and 5.5 V. To filter noise in the power-supply path, place a low-ESR decoupling capacitor of 0.1 µF between V_S and GND pins as close as possible to the supply and ground pins of the device. To compensate for noisy or high-impedance power supplies, add more decoupling capacitance.

The TMCS1123 power supply V_S can be sequenced independently of current flowing through the input. However, there is a typical 25ms delay between V_S reaching the recommended operating voltage and the analog output being valid. Within this delay V_{OUT} transfers from a high impedance state to the active drive state, during which time the output voltage could transition between GND and V_S. If this behavior must be avoided, a stable supply voltage to V_S should be provided for longer than 25 ms prior to applying input current.

10.4 Layout

10.4.1 Layout Guidelines

The TMCS1123 is specified for a continuous current handling capability on the TMCS1123xEVM which uses 4-oz copper pour planes. This current capability is fundamentally limited by the maximum device junction temperature and the thermal environment, primarily the PCB layout and design. To maximize current-handling capability and thermal stability of the device, take care with PCB layout and construction to optimize the thermal capability. Efforts to improve the thermal performance beyond the design and construction of the TMCS1123xEVM can result in increased continuous-current capability due to higher heat transfer to the ambient environment. Keys to improving thermal performance of the PCB include:

- Use large copper planes for both input current path and isolated power planes and signals.
- Use heavier copper PCB construction.
- Place thermal via *farms* around the isolated current input.
- Provide airflow across the surface of the PCB.

10.4.2 Layout Example

An example layout, shown in Figure 10-3, is from the *TMCS1123xEVM User's Guide*. Device performance is targeted for thermal and magnetic characteristics of this layout, which provides optimal current flow from the terminal connectors to the device input pins while large copper planes enhance thermal performance.

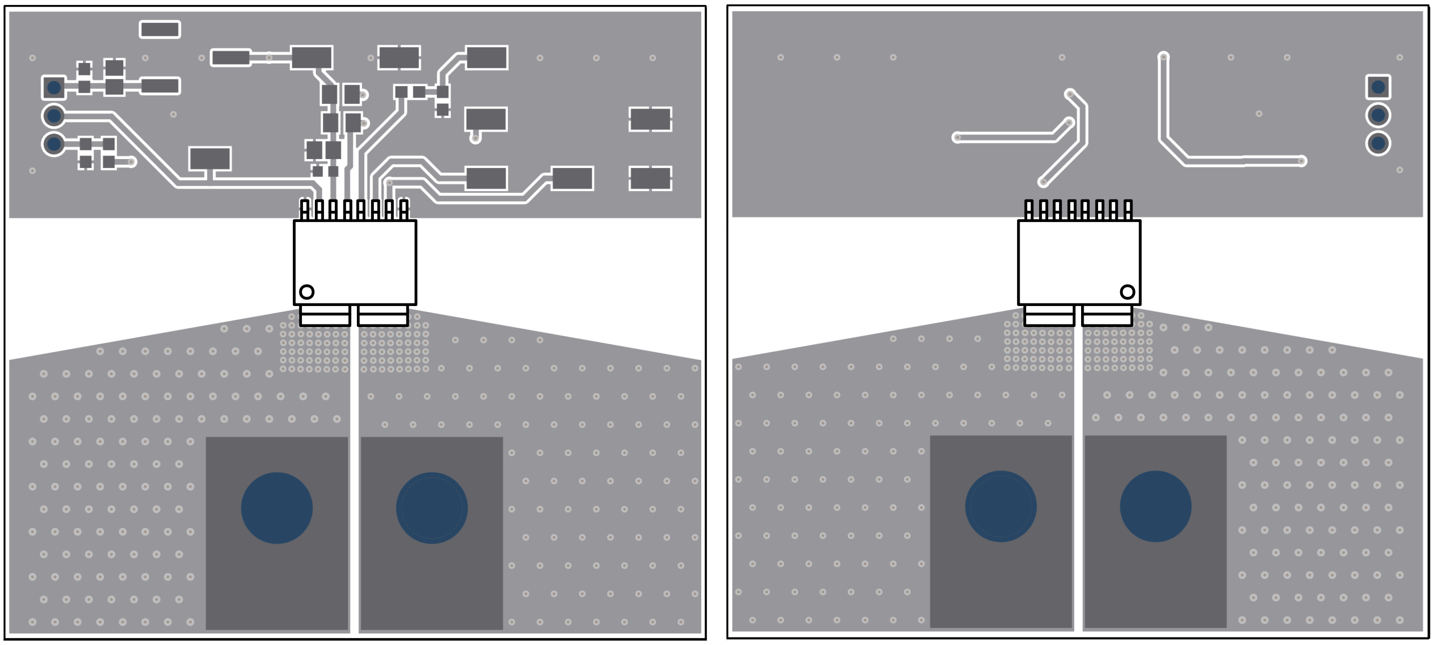


Figure 10-3. Recommended Board Top (Left) and Bottom (Right) Plane Layout

11 Device and Documentation Support

11.1 Device Support

11.1.1 Development Support

For development tool support see the following:

- TMCS1123xEVM

11.2 Documentation Support

11.2.1 Related Documentation

For related documentation see the following:

- Texas Instruments, *TMCS1123xEVM User's Guide*
- Texas Instruments, *Isolation Glossary*

11.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Subscribe to updates* 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.

11.4 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.

11.5 Trademarks

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

11.6 Electrostatic Discharge Caution

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

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

11.7 Glossary

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

12 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.

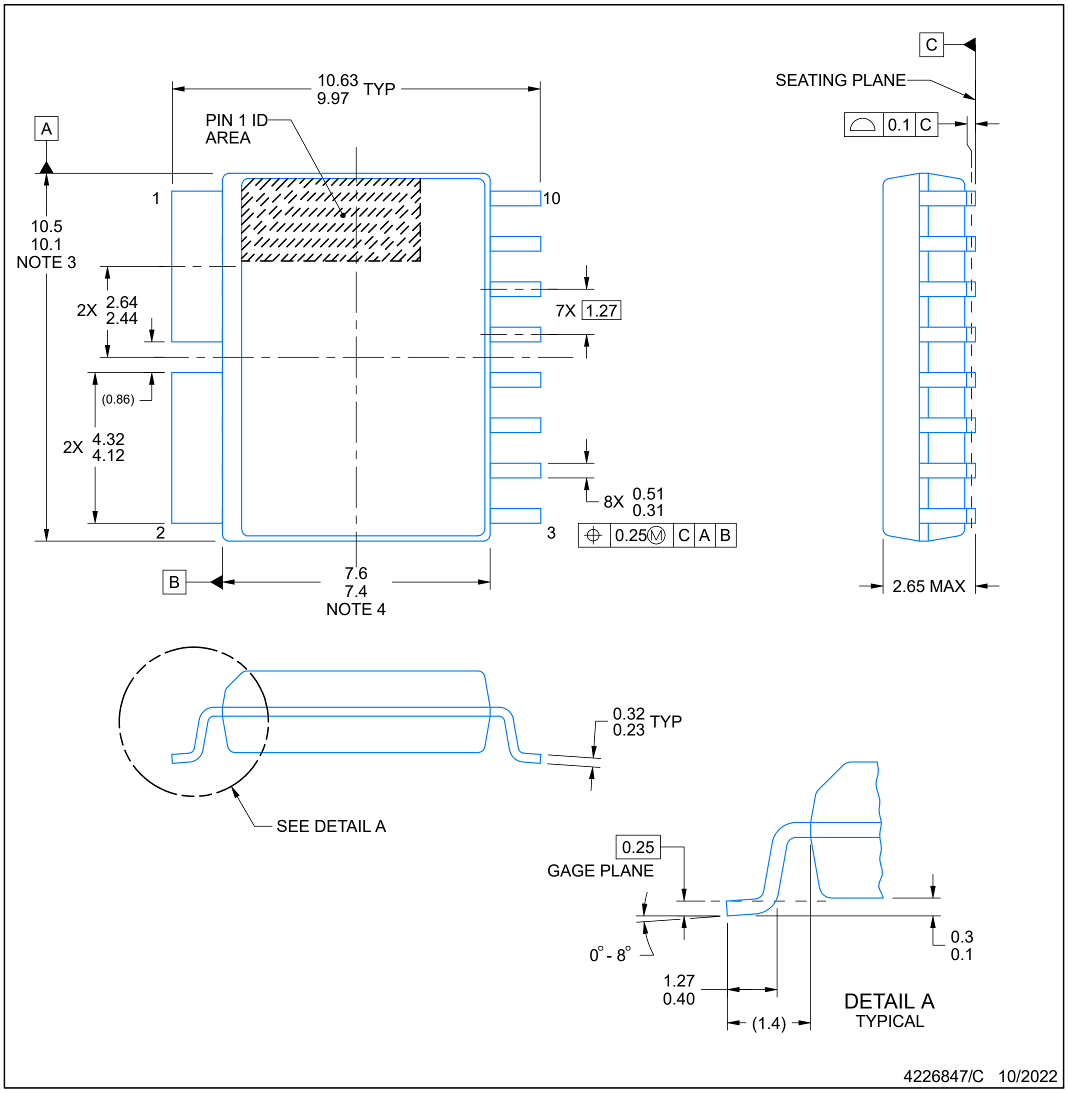
ADVANCE INFORMATION

PACKAGE OUTLINE

DVG0010A

SOIC - 2.65 mm max height

SMALL OUTLINE PACKAGE



NOTES:

1. All linear dimensions are in millimeters. Dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm, per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm, per side.
5. Reference JEDEC registration MS-013.

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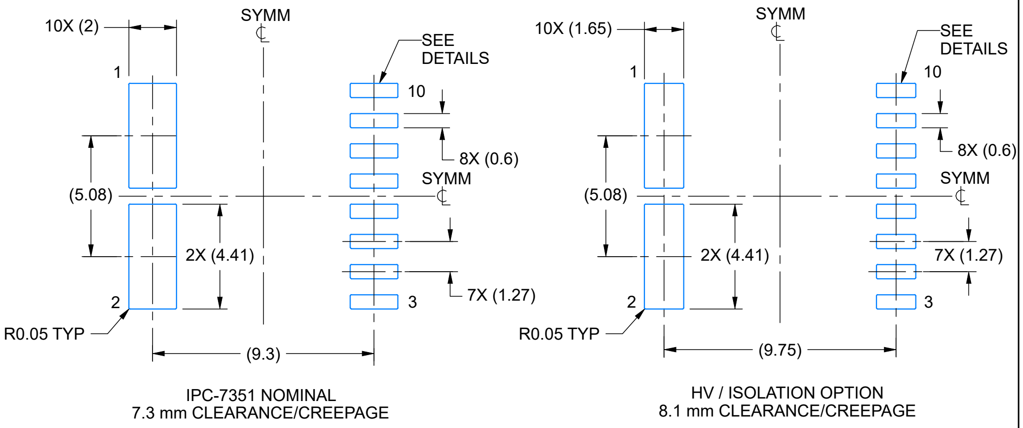
EXAMPLE BOARD LAYOUT

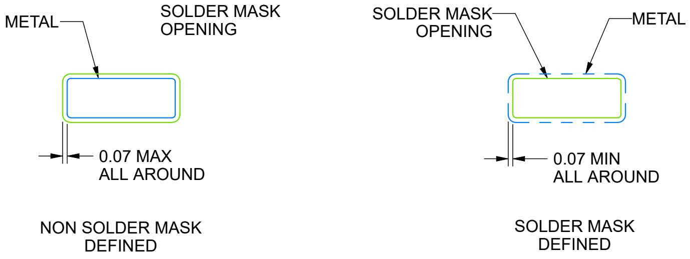
DVG0010A

SOIC - 2.65 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE
SCALE:4X



SOLDER MASK DETAILS

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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.

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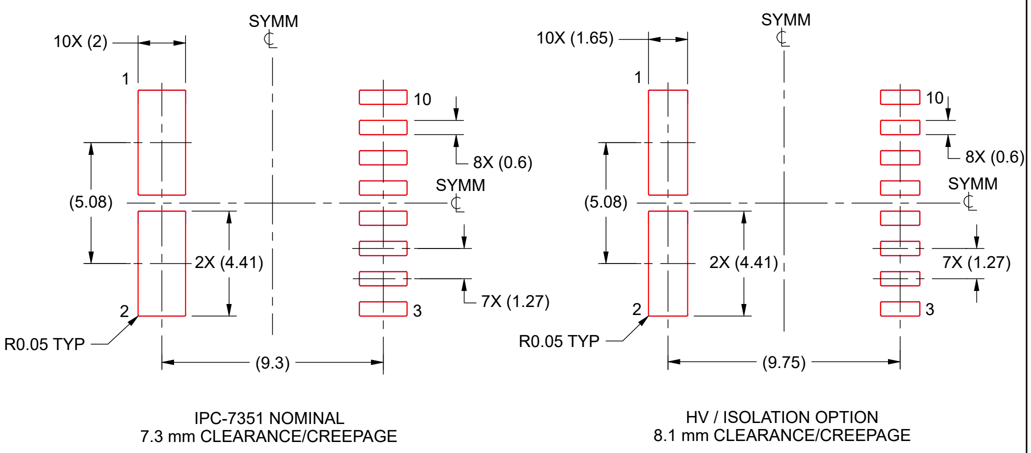
ADVANCE INFORMATION

EXAMPLE STENCIL DESIGN

DVG0010A **SOIC - 2.65 mm max height**

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:4X

4226847/C 10/2022

NOTES: (continued)

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

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12.1 Package Option Addendum

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)
PMCS1123A1Q DVGR	ACTIVE	SOIC	DVG	10	2000	RoHS & Green	SN	Level-2-260C-1 YEAR	-40 to 125	PMCS1123A1
PMCS1123A2Q DVGR	ACTIVE	SOIC	DVG	10	2000	RoHS & Green	SN	Level-2-260C-1 YEAR	-40 to 125	PMCS1123A2
PMCS1123A4Q DVGR	ACTIVE	SOIC	DVG	10	2000	RoHS & Green	SN	Level-2-260C-1 YEAR	-40 to 125	PMCS1123A4
PMCS1123B1Q DVGR	ACTIVE	SOIC	DVG	10	2000	RoHS & Green	SN	Level-2-260C-1 YEAR	-40 to 125	PMCS1123B1
PMCS1123B2Q DVGR	ACTIVE	SOIC	DVG	10	2000	RoHS & Green	SN	Level-2-260C-1 YEAR	-40 to 125	PMCS1123B2
PMCS1123C5Q DVGR	ACTIVE	SOIC	DVG	10	2000	RoHS & Green	SN	Level-2-260C-1 YEAR	-40 to 125	PMCS1123C5

(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.
PRE_PROD Unannounced device, not in production, not available for mass market, nor on the web, samples not available.
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) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material).

(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.

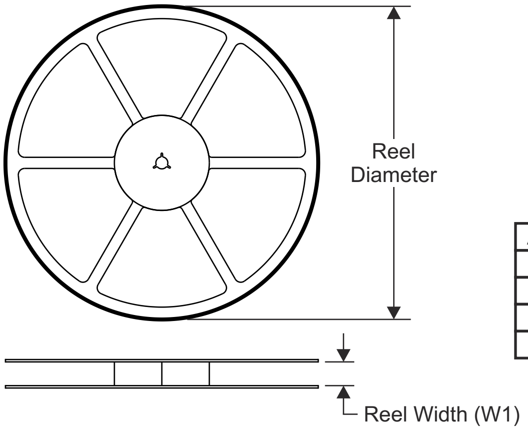
(5) Multiple Device markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(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.

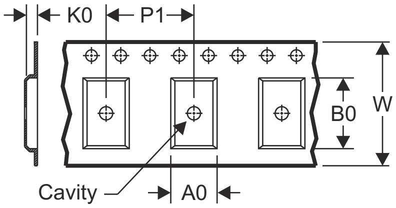
ADVANCE INFORMATION

12.2 Tape and Reel Information

REEL DIMENSIONS

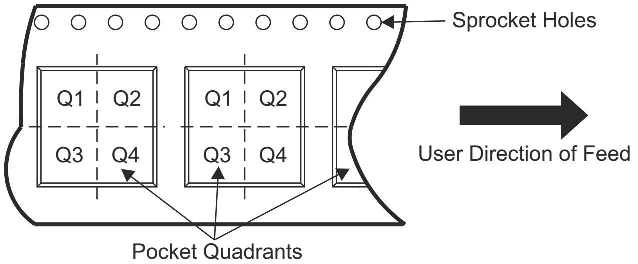


TAPE DIMENSIONS



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

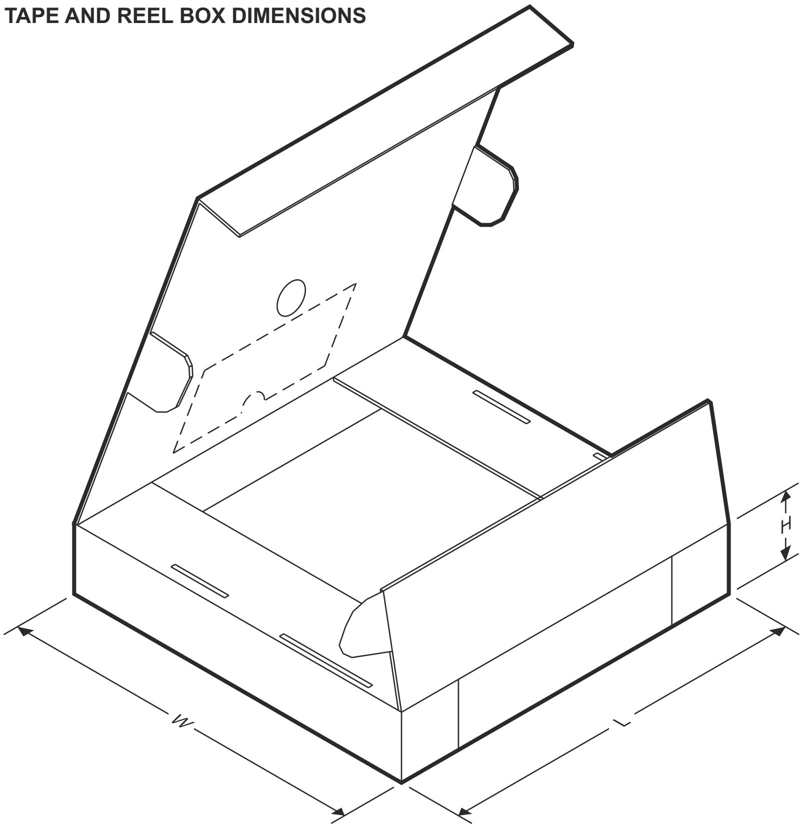
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



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
PMCS1123A1QDVGR	SOIC	DVG	10	2000	330	16.4	10.75	10.7	2.7	12	16	Q1
PMCS1123A2QDVGR	SOIC	DVG	10	2000	330	16.4	10.75	10.7	2.7	12	16	Q1
PMCS1123A4QDVGR	SOIC	DVG	10	2000	330	16.4	10.75	10.7	2.7	12	16	Q1
PMCS1123B1QDVGR	SOIC	DVG	10	2000	330	16.4	10.75	10.7	2.7	12	16	Q1
PMCS1123B2QDVGR	SOIC	DVG	10	2000	330	16.4	10.75	10.7	2.7	12	16	Q1
PMCS1123C5QDVGR	SOIC	DVG	10	2000	330	16.4	10.75	10.7	2.7	12	16	Q1

ADVANCE INFORMATION

TAPE AND REEL BOX DIMENSIONS



Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
PMCS1123A1QDVGR	SOIC	DVG	10	2000	350	350	43
PMCS1123A2QDVGR	SOIC	DVG	10	2000	350	350	43
PMCS1123A4QDVGR	SOIC	DVG	10	2000	350	350	43
PMCS1123B1QDVGR	SOIC	DVG	10	2000	350	350	43
PMCS1123B2QDVGR	SOIC	DVG	10	2000	350	350	43
PMCS1123C5QDVGR	SOIC	DVG	10	2000	350	350	43

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
PMCS1123A1QDVGR	ACTIVE	SOIC	DVG	10	2000	TBD	Call TI	Call TI	-40 to 125		Samples
PMCS1123A2QDVGR	ACTIVE	SOIC	DVG	10	2000	TBD	Call TI	Call TI	-40 to 125		Samples
PMCS1123A4QDVGR	ACTIVE	SOIC	DVG	10	2000	TBD	Call TI	Call TI	-40 to 125		Samples
PMCS1123B1QDVGR	ACTIVE	SOIC	DVG	10	2000	TBD	Call TI	Call TI	-40 to 125		Samples
PMCS1123B2QDVGR	ACTIVE	SOIC	DVG	10	2000	TBD	Call TI	Call TI	-40 to 125		Samples
PMCS1123C5QDVGR	ACTIVE	SOIC	DVG	10	2000	TBD	Call TI	Call TI	-40 to 125		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 finish/Ball material - Orderable Devices 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.

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