TMCS1100 High-Precision, Isolated Current Sensor With External Reference

1 Features

- Total error current sensing: < 1%
  - Sensitivity error: ±0.3%, –40ºC to +125ºC
  - Offset error: ±10.5 mA, –40ºC to +125ºC
  - Offset current drift: 0.01 mA/°C
  - Linearity over temperature: 0.1% typ
- UL1577, VDE 0884-11, 60950 certifications planned
  - 600-V_{DC}/V_{PK} working isolation
  - 3-kV_{RMS} withstand isolation
- Bidirectional and unidirectional linear current sensing
- External reference voltage enables variable measurable ranges and differential signal chains
- Operating supply range: 3 V to 5.5 V
- Signal bandwidth: 80-kHz
- Multiple sensitivity options:
  - TMCS1100A1: 50 mV/A
  - TMCS1100A2: 100 mV/A
  - TMCS1100A3: 200 mV/A
  - TMCS1100A4: 400 mV/A

2 Applications

- Motor and load control
- Inverter and H-bridge current measurements
- Power factor correction
- Overcurrent protection
- DC and ac power monitoring

3 Description

The TMCS1100 is a galvanically isolated Hall-effect current sensor capable of dc or ac current measurement with high accuracy, excellent linearity, and temperature stability. A low-drift, temperature-compensated signal chain provides < 1% full-scale error across the entire device temperature range.

The input current flows through an internal 1.8-mΩ conductor that generates a magnetic field measured by an integrated Hall-effect sensor. This structure eliminates external concentrators and simplifies PCB design. Low conductor resistance minimizes power loss and thermal dissipation. Inherent galvanic insulation provides a 600-V basic working isolation and 3-kV dielectric withstand isolation between the current path and circuitry. Integrated electrical shielding enables excellent common-mode rejection and transient immunity protection.

The output voltage is proportional to the input current with four sensitivity options. Fixed sensitivity allows the TMCS1100 to operate from a single 3-V to 5.5-V power supply, eliminates ratiometry errors, and improves supply noise rejection. The current polarity is considered positive when flowing into the positive input pin. The VREF input pin provides a variable zero-current output voltage, enabling bidirectional or unidirectional current sensing.

The TMCS1100 draws a maximum supply current of 5 mA, and all sensitivity options are specified over the operating temperature range of –40°C to +125°C.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TMCS1100	SOIC (8)	4.90 mm x 3.90 mm

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

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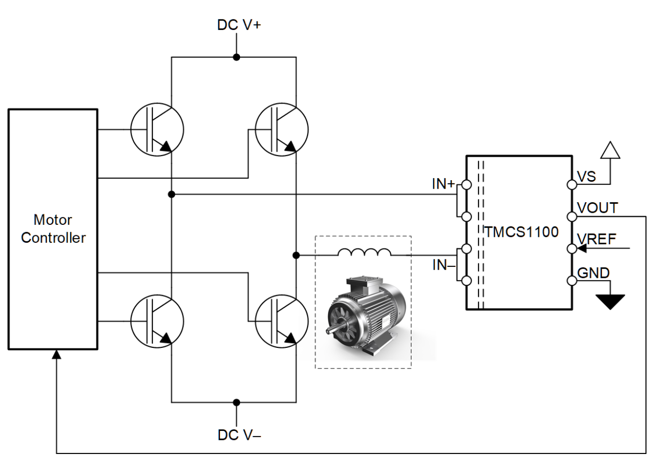
Typical Application



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4 Revision History

DATE	REVISION	NOTES
September 2019	*	Initial release

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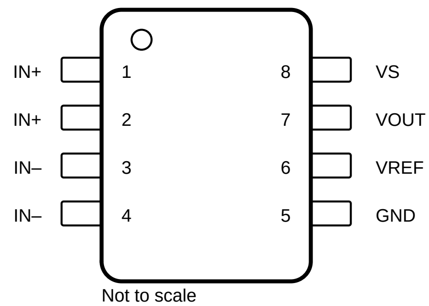
5 Device Comparison Table

PRODUCT	SENSITIVITY	BIDIRECTIONAL LINEAR MEASUREMENT RANGE, $V_{REF} = V_S / 2$ (1)		UNIDIRECTIONAL LINEAR MEASUREMENT RANGE, $V_{REF} = V_{GND}$ (1)	
	$\Delta V_{OUT} / \Delta I_{IN+, IN-}$	V_S = 5 V	V_S = 3.3 V	V_S = 5 V	V_S = 3.3 V
TMCS1100A1	50 mV/A	±46 A (2)	±29 A (2)	1 A to 96 A (2)	1 A to 61 A (2)
TMCS1100A2	100 mV/A	±23 A (2)	±14.5 A	0.5 A to 48 A (2)	0.5 A to 31 A (2)
TMCS1100A3	200 mV/A	±11.5 A	±7.25 A	0.25 A to 24 A (2)	0.25 A to 15.5 A
TMCS1100A4	400 mV/A	±5.75 A	±3.625 A	0.125 A to 12 A	0.125 A to 7.75 A

(1) Linear range limited by swing to supply and ground.
(2) Current levels must remain below both allowable continuous DC/RMS and transient peak current safe operating areas.

6 Pin Configuration and Functions

D Package
8-Pin SOIC
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
1	IN+	Analog input	Input current positive pin
2	IN+	Analog input	Input current positive pin
3	IN–	Analog input	Input current negative pin
4	IN–	Analog input	Input current negative pin
5	GND	Analog	Ground
6	VREF	Analog input	Zero current output voltage reference
7	VOUT	Analog output	Output voltage
8	VS	Analog	Power supply

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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
	Analog output	VOUT	GND – 0.3	(V_S) + 0.3	V
T_J	Junction temperature		–65	150	°C
T_{stg}	Storage temperature		–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

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 JEDEC specification JESD22-C101(2)	±1000	

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

7.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V_{IN+},$V_{IN–}$ (1)	Input voltage	–600		600	V_{PK}
I_{IN} (2)	Input current (Continuous dc or rms current)	–20		20	A
V_S	Operating supply voltage, TMCS1100A1-3	3	5	5.5	V
V_S	Operating supply voltage, TMCS1100A4	4.5	5	5.5	V
T_A	Operating free-air temperature	–40		125	°C

(1) V_{IN+} and $V_{IN–}$ refer to the voltage at input current pins IN+ and IN–, relative to pin 5 (GND).
(2) Input current safe operating area is constrained by junction temperature. Recommended condition based on the TMCS1100EVM. Rating is derated for elevated ambient temperatures.

7.4 Thermal Information

THERMAL METRIC(1)		TMCS1100 D (SOIC) 8 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	36.6	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	50.7	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	9.6	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	–0.1	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	11.7	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	°C/W

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

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7.5 Insulation Specifications

PARAMETER		TEST CONDITIONS	VALUE	UNIT
GENERAL				
CLR	External clearance(1)	Shortest terminal-to-terminal distance through air	4	mm
CPG	External creepage(1)	Shortest terminal-to-terminal distance across the package surface	4	mm
DTI	Distance through the insulation	Minimum internal gap (internal clearance)	60	µm
CTI	Comparative tracking index	DIN EN 60112 (VDE 0303-11); IEC 60112	600	V
	Material group		II	
	Overvoltage category	Rated mains voltage ≤ 150 V_{RMS}	I-IV	
		Rated mains voltage ≤ 300 V_{RMS}	I-III	
		Rated mains voltage ≤ 600 V_{RMS}	I-II	
DIN V VDE V 0884-11:2017-01(2)				
V_{IORM}	Maximum repetitive peak isolation voltage	AC voltage (bipolar)	600	V_{PK}
V_{IOWM}	Maximum working isolation voltage	AC voltage (sine wave)	424	V_{RMS}
		DC voltage	600	V_{DC}
V_{IOTM}	Maximum transient isolation voltage	V_{TEST} = V_{IOTM}, t = 60 s (qualification); V_{TEST} = 1.2 × V_{IOTM}, t = 1 s (100% production)	4242	V_{PK}
V_{IOSM}	Maximum surge isolation voltage(3)	Test method per IEC 62368-1, 1.2/50 µs waveform, V_{TEST} = 1.3 × V_{IOSM} (qualification)	6000	V_{PK}
q_{pd}	Apparent charge(4)	Method a: After I/O safety test subgroup 2/3, V_{ini} = V_{IOTM}, t_{ini} = 60 s; $V_{pd(m)}$ = 1.2 × 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 × V_{IORM}, t_m = 10 s	5	
		Method b3: At routine test (100% production) and preconditioning (type test) V_{ini} = 1.2 × V_{IOTM}, t_{ini} = 1 s; $V_{pd(m)}$ = 1.2 × V_{IOTM}, t_m = 1 s	5	
	Pollution degree		2	
UL 1577				
V_{ISO}	Withstand isolation voltage	V_{TEST} = V_{ISO}, t = 60 s (qualification); V_{TEST} = 1.2 × V_{ISO}, t = 1 s (100% production)	3000	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) This coupler is for *basic electrical insulation* only within the maximum operating ratings. Compliance with the safety ratings is by means of protective circuits.
(3) Testing is carried out in air or oil to determine the intrinsic surge immunity of the isolation barrier.
(4) Apparent charge is electrical discharge caused by a partial discharge (pd).

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7.6 Electrical Characteristics

at T_A = 25°C, V_S = 5 V, V_{REF} = 2.5 V (unless otherwise noted)

PARAMETERS		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
	Sensitivity	TMCS1100A1		50		mV/A
		TMCS1100A2		100		mV/A
		TMCS1100A3		200		mV/A
		TMCS1100A4		400		mV/A
	Sensitivity error	0.05 V ≤ V_{OUT} ≤ V_S – 0.2 V		±0.1%	±0.35%	
	Sensitivity error	0.05 V ≤ V_{OUT} ≤ V_S – 0.2 V, T_A= –40ºC to +125ºC		±0.3%	±0.65%	
	Sensitivity error drift	0.05 V ≤ V_{OUT} ≤ V_S – 0.2 V		±20	±30	ppm/°C
V_{OE}	Output voltage offset error	TMCS1100A1		±1	±2.5	mV
		TMCS1100A2		±1.2	±4.5	mV
		TMCS1100A3		±1.4	±7.5	mV
		TMCS1100A4		±2.25	±12	mV
	Output voltage offset error	TMCS1100A1, T_A= –40ºC to +125ºC		±1.5	±4	mV
		TMCS1100A2, T_A= –40ºC to +125ºC		±2	±6	mV
		TMCS1100A3, T_A= –40ºC to +125ºC		±2.4	±10	mV
		TMCS1100A4, T_A= –40ºC to +125ºC		±4.2	±20	mV
I_{OS}	Offset error, RTI[1]	TMCS1100A1		±20	±50	mA
		TMCS1100A2		±12	±45	mA
		TMCS1100A3		±7	±37.5	mA
		TMCS1100A4		±5.6	±30	mA
	Offset error, RTI[1]	TMCS1100A1, T_A= –40ºC to +125ºC		±30	±80	mA
		TMCS1100A2, T_A= –40ºC to +125ºC		±20	±60	mA
		TMCS1100A3, T_A= –40ºC to +125ºC		±12	±50	mA
		TMCS1100A4, T_A= –40ºC to +125ºC		±10.5	±50	mA
	Offset error drift, RTI[1]	TMCS1100A1, T_A= –40ºC to +125ºC		±20		µA/°C
		TMCS1100A2, T_A= –40ºC to +125ºC		±14		µA/°C
		TMCS1100A3, T_A= –40ºC to +125ºC		±10		µA/°C
		TMCS1100A4, T_A= –40ºC to +125ºC		±10.75		µA/°C
PSRR	Power-supply rejection ratio	V_S = 3 V to 5.5 V, T_A= –40ºC to +125ºC		1		mV/V
	Nonlinearity error	V_{OUT} = 0.5 V to V_S – 0.5 V		±0.1%		
CMTI	Common mode transient immunity			25		kV/µs
CMRR	Common mode rejection ratio, RTI[1]			0.1		uA/V
	Zero current V_{OUT}			V_{REF}		V
RVRR	Reference voltage rejection ratio, output referred	V_{REF} = 0.5 V to 4.5 V		1	5	mV/V
	Noise density, RTI[1]	TMCS1100A1		380		µA/√Hz
		TMCS1100A2		330		µA/√Hz
		TMCS1100A3		300		µA/√Hz
		TMCS1100A4		225		µA/√Hz
INPUT						
R_{IN}	Input conductor resistance	IN+ to IN–		1.8		mΩ
	Input conductor resistance drift	T_A= –40ºC to +125ºC		7		µΩ/°C
G	Magnetic coupling factor	T_A= 25ºC		1.2		mT/A
I_{IN}	Maximum continuous RMS current [2]	T_A= 25ºC	30			A
I_{IN}	Maximum continuous RMS current [2]	T_A= 85ºC	25			A
I_{IN}	Maximum continuous RMS current [2]	T_A= 105ºC	22.5			A

(1) RTI = referred-to-input. Output voltage is divided by device sensitivity to refer signal to input current. See the *Parameter Measurement Information* section.
(2) Thermally limited by junction temperature. Applies when device mounted on TMCS1100EVM. For more details, see the *Safe Operating Area* section.

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Electrical Characteristics (continued)

at T_A = 25°C, V_S = 5 V, V_{REF} = 2.5 V (unless otherwise noted)

PARAMETERS		TEST CONDITIONS	MIN	TYP	MAX	UNIT
I_{IN}	Maximum continuous RMS current (2)	T_A= 125ºC	16			A
V_{REF}	Reference input voltage		V_{GND}		V_S	V
	V_{REF} input current	VREF = GND, VS		±1	±5	µA
	V_{REF} external source impedance	Maximum source impedance of external circuit driving V_{REF}			5	kΩ
VOLTAGE OUTPUT						
Z_{OUT}	Closed loop output impedance	f = 1 Hz to 1 kHz		0.2		Ω
		f = 10 kHz		2		Ω
	Maximum capacitive load	No sustained oscillation		1		nF
	Short circuit output current	VOUT short to ground, short to V_S		90		mA
	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 to GND	R_L = 10 kΩ to GND, T_A= –40ºC to +125ºC		5	10	mV
FREQUENCY RESPONSE						
BW	Bandwidth (3)	–3-dB Bandwidth		80		kHz
	Nyquist Frequency (3)			125		kHz
SR	Slew rate	Slew rate of output amplifier during single transient step.		1.5		V/µs
t_r	Response time	Time between the input current step reaching 90% of final value to the sensor output reaching 90% of its final value, for a 1V output transition.		6.5		µs
t_p	Propagation delay	Time between the input current step reaching 10% of final value to the sensor output reaching 10% of its final value, for a 1V output transition.		4		µs
$t_{r,SC}$	Short-circuit response time	Time between the input current step reaching 90% of final value to the sensor output reaching 90% of its final value. Input current step amplitude is twice full scale linear range.		5		µs
$t_{p,SC}$	Short-circuit propagation delay	Time between the input current step reaching 10% of final value to the sensor output reaching 10% of its final value. Input current step amplitude is twice full scale linear range.		3		µs
POWER SUPPLY						
I_Q	Quiescent current	T_A = 25ºC		4.25	5	mA
		T_A = –40ºC to +125ºC			6	mA

(3) Refer to the *Transient Response* section for details of frequency response of the device.

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8 Parameter Measurement Information

8.1 Accuracy Parameters

The ideal first-order transfer function of the TMCS1100 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.

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

where

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

8.1.1 Sensitivity, Sensitivity Error, and Drift

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, as shown in Figure 1. The sensitivity of the TMCS1100 is tested and calibrated at the factory for high accuracy.

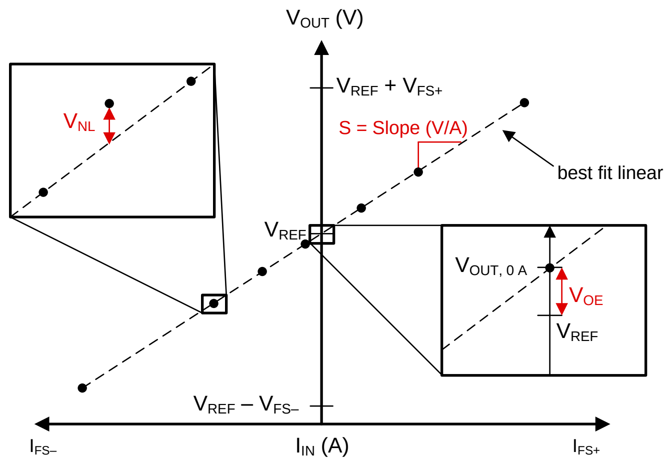

Figure 1. Sensitivity, Offset, and Nonlinearity Error

Deviation from ideal sensitivity is quantified by sensitivity error. Sensitivity error is defined as the percent variation of the best-fit measured sensitivity from the ideal sensitivity, based on the variant of the TMCS1100. When specified over a temperature range, this is the worst-case sensitivity error at any temperature within the range.

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

where

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

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Accuracy Parameters (continued)

Sensitivity error drift is the worst-case change in sensitivity error per degree Celsius change in ambient temperature. This parameter is reported in ppm/°C. To convert sensitivity error drift to a percentage for a given change in temperature, multiply the drift by the change in temperature and convert to percentage, as in Equation 3.

$$e_{S,\Delta T}(\%) = S_{drift}\left(\frac{ppm}{°C}\right) \times \Delta T \times 1000$$

where

- S_{drift} is the sensitivity error drift.
- ΔT is the temperature range from 25°C. (3)

8.1.2 Offset Error and Drift

Offset error is the deviation from the ideal output voltage with zero input current through the device. Offset error can be referred to the output as a voltage error V_{OE} or referred to the input as a current offset error I_{OS}; however, offset error is a single error source and must only be included once in error calculations.

The output voltage offset error of the TMCS1100 is the error in the zero current output voltage from the VREF pin voltage.

$$V_{OE} = V_{OUT,0A} - V_{REF}$$

where

- $V_{OUT,0A}$ is the device output voltage with zero input current. (4)

The total offset error includes multiple individual error sources: errors from the VREF pin potential to VOUT, the magnetic offset of the Hall sensor, and any offset voltage errors of the signal chain.

The input referred (RTI) offset error is the output voltage offset error divided by the sensitivity of the device, shown in Equation 5. Refer the offset error to the input of the device to allow for easier total error calculations and direct comparison to input current levels. However the calculations are done, the error sources quantified by V_{OE} and I_{OS} are the same, and must only be included once for error calculations.

$$I_{OS} = V_{OE} / S \tag{5}$$

Offset error specifications are defined at both room temperature and across the full temperature range. Offset error specified over a temperature range is the worst-case sensitivity error at any temperature within the range, and must not be considered as additive to room temperature offset error. Offset error drift is the worst-case rate of change in a device offset across the temperature spectrum, and is used to calculate maximum offset error across an arbitrary temperature range in the same manner as sensitivity drift, and as described in the *Total Error Calculation Examples* section.

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 1, is the maximum voltage deviation from the best-fit line based on measured parameters, calculated by Equation 6.

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

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. (6)

Nonlinearity error (e_{NL}) for the TMCS1100 is the nonlinearity voltage specified as a percentage of the full-scale output range (V_{FS}), as shown in Equation 7.

$$e_{NL} = 100\% * \frac{V_{NL}}{V_{FS}} \tag{7}$$

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Accuracy Parameters (continued)

8.1.4 Reference Voltage Rejection Ratio

The zero current output voltage for the TMCS1100 is derived from sampling an external voltage on the VREF pin. Ideally, the zero current output voltage directly tracks V_{REF}; however, slight internal tolerances and mismatches can cause minor errors. When the reference voltage deviates from half of the supply, an additional effective output offset error is introduced into the device transfer function.

8.1.5 External Magnetic Field Errors

The TMCS1100 does not have stray field-rejection capabilities, so external magnetic fields from adjacent high-current traces or nearby magnets can impact the output measurement. The total sensitivity (S) of the device is comprised of the initial transformation of input current to magnetic field quantified as the magnetic coupling factor (G), as well as the sensitivity of the Hall element and the analog circuitry that is factory calibrated to provide a final sensitivity. The output voltage is proportional to the input current by the device sensitivity, as defined in Equation 8.

$$S = G * S_{Hall} * A_V \tag{8}$$

where

- S is the TMCS1100 sensitivity in mV/A.
- G is the magnetic coupling factor in mT/A.
- S_{Hall} is the senitivity of the Hall plate in mV/mT.
- A_V is the analog circuitry gain in V/V.

An external field, B_{EXT}, is measured by the Hall sensor and signal chain, in addition to the field generated by the leadframe current, and is added as an extra input term in the total output voltage function:

$$V_{OUT} = B_{EXT} * S_{Hall} * A_V + I_{IN} * G * S_{Hall} * A_V + V_{OUT,0A} \tag{9}$$

Observable from Equation 9 is that the impact of an external field is an additional equivalent input current signal, I_{BEXT}, shown in Equation 10. This effective additional input current has no dependence on Hall or analog circuitry sensitivity, so all gain variants have equivalent input-referred current error due to external magnetic fields.

$$I_{B_{EXT}} = \frac{B_{EXT}}{G} \tag{10}$$

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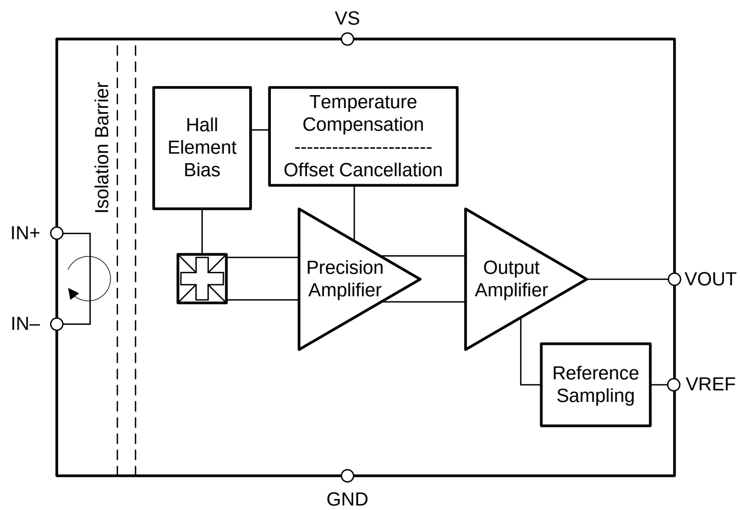
9 Detailed Description

9.1 Overview

The TMCS1100 is a Hall-sensor-based precision current sensor, featuring a 600-V basic isolation working voltage, < 1% full-scale error across temperature, and an external reference voltage enabling unidirectional or bidirectional current sensing. Input current flows through a conductor between the isolated input current pins. The conductor has a 1.8-mΩ resistance at room temperature for low power dissipation and a 20-A RMS continuous current handling capability up to 125°C ambient temperature on the TMCS1100EVM. 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 80 kHz. There are four fixed-sensitivity device variants for a wide option of linear sensing ranges, and the TMCS1100 can operate with a low voltage supply from 3 V to 5.5 V. The TMCS1100 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 TMCS1100 passes through the isolated side of the package leadframe through the IN+ and IN– pins. The current flow through the package generates a magnetic field that is proportional to the input current, and measured by a galvanically isolated, precision, Hall sensor IC. The low-ohmic leadframe path reduces power dissipation compared to alternative current measurement methodologies, and does not require any passive external components on the high-voltage side. In addition, no isolated supplies or control signals are needed on the high-voltage side, further simplifying implementation. 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 current input leadframe conductor has a nominal resistance of 1.8 mΩ at 25°C. The leadframe is composed of copper; therefore, the leadframe has a positive temperature coefficient that causes resistance to increase at higher temperatures. A typical temperature coefficient is 3300 ppm/°C, causing a 33% rise in resistivity for every 100°C of leadframe temperature change from room temperature.

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Feature Description (continued)

9.3.2 Input Isolation

The separation between the input conductor and the Hall sensor die due to the TMCS1100 construction provides inherent galvanic isolation between package pins 1-4 and pins 5-8. Insulation capability is defined according to certification agency definitions and using industry-standard test methods as defined in the *Insulation Specifications* table. Assessment of device lifetime working voltages follow the VDE 0884-11 standard for basic insulation, requiring time-dependent dielectric breakdown (TDDB) data-projection failure rates of less than 1000 part per million (ppm), and a minimum insulation lifetime of 20 years. The VDE standard also requires an additional safety margin of 20% for working voltage, and a 30% margin for insulation lifetime, translating into a minimum required lifetime of 26 years at 509 V_{RMS}.

Figure 2 shows the intrinsic capability of the isolation barrier to withstand high-voltage stress over the lifetime of the device. Based on the TDDB data, the intrinsic capability of these devices is 424 V_{RMS} with a lifetime of > 100 years. Other factors (such as package size, pollution degree, material group, and so on) can further limit the working voltage of the component in an end system. The working voltage of the D-8 package is specified up to 424 V_{RMS}. However, at lower working voltages, the corresponding insulation barrier lifetime is much longer.

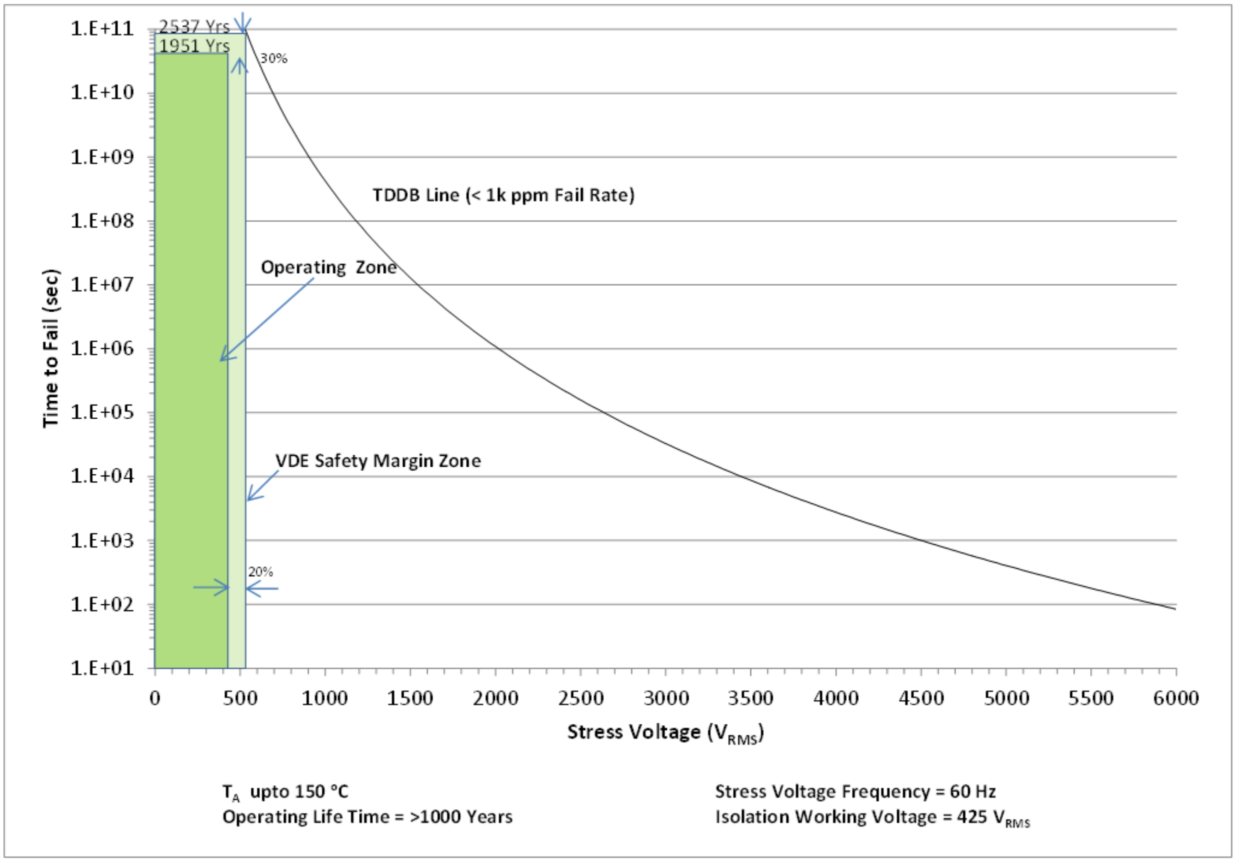

Figure 2. Insulation Lifetime

9.3.3 High-Precision Signal Chain

The TMCS1100 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 of the device. The device is fully tested and calibrated at the factory to account for any variations in either silicon or packaging process variations. The full signal chain provides a fixed sensitivity voltage output that is proportional to the current through the leadframe of the isolated input.

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Feature Description (continued)

9.3.3.1 Temperature Stability

System calibration at room temperature is a common practice for many applications. This initial calibration results in a very accurate measurement under the conditions at which calibration was performed because individual components of the total error are eliminated. As the ambient temperature changes as a result of device self-heating or environmental conditions, any drift in critical system parameters will reintroduce these errors into the system performance. For many systems, this drift in performance across temperature is the primary contributor to performance degradation at the system level. These variations in component parametric performance must be accounted for in total system error calculations. The TMCS1100 includes a proprietary temperature compensation technique, and results in best in industry parametric drift across the full temperature range. A zero-drift signal chain architecture and Hall sensor temperature stabilization methods enable stable sensitivity and minimize offset errors across temperature, and drastically improves system-level performance across the required operating conditions.

Figure 3 shows the offset error across the full device ambient temperature range. Figure 4 shows the typical sensitivity. There are no other external components introducing errors sources; therefore, the high intrinsic accuracy and stability over temperature directly translates to system-level performance. As a result of this high precision, even a system with no calibration can reach < 1% of total error current-sensing capability.

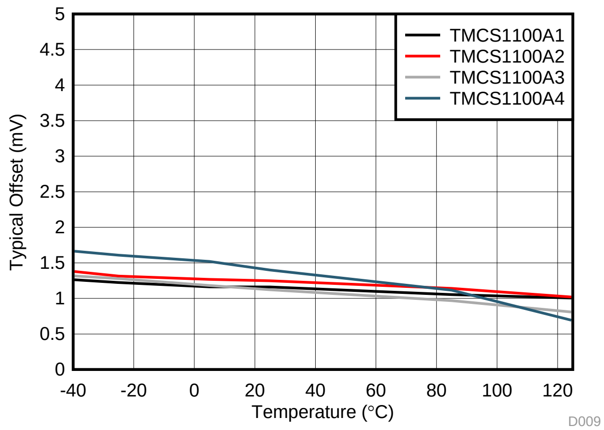

Figure 3. Offset Error Drift Across Temperature

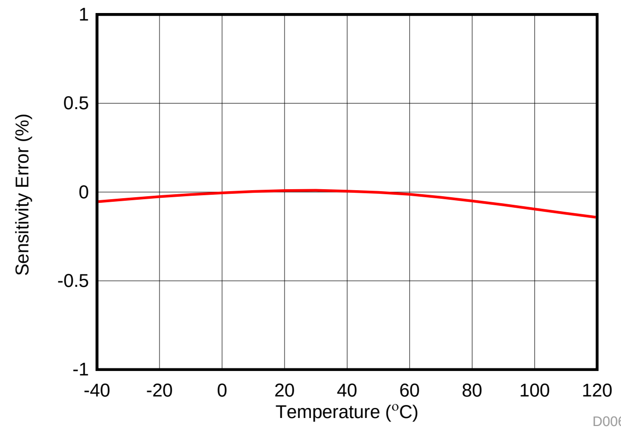

Figure 4. Sensitivity Drift Across Temperature

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Feature Description (continued)

9.3.3.2 Transient Response

The TMCS1100 signal chain is a discrete time-sampled system with a typical sampling frequency of 250 kHz. Any variation in the input current signal over this sampling period is averaged. As such, the device has an effective Nyquist frequency of 125 kHz. At the end of each integration cycle, the signal propagates through the remainder of the signal chain to the output. Depending on the alignment of a change in input current relative to the sampling window, the output might not settle to the final signal until the second integration cycle. Figure 5 shows a typical output waveform response to ramp and step input currents. For a slowly varying input current signal, the output is a discrete time representation with a phase delay of the integration sampling window.

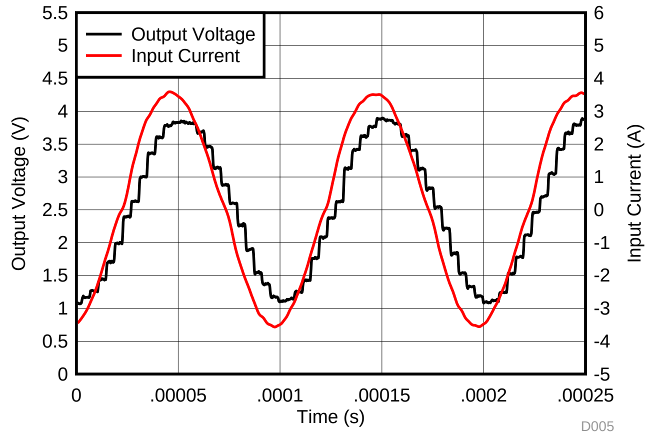

Figure 5. Precision Signal-Chain Response Behavior

Transient response to an input current step is critical for overcurrent of fault-condition detection. As a result of the TMCS1100 discrete time signal chain, the transient response to step input events varies depending on the relative timing of the event to the sampling window. Figure 6 shows two transient waveforms to an input-current step event, but occurring at different times during the sampling interval. With *Vout1*, the event occurs near the beginning of the 4-µs sampling interval, so more of the high-current signal is averaged into the first 4-µs output value. If the event occurs closer to the end of the sampling interval, as with *Vout2*, the initial output response is smaller, but occurs closer to the input current step. In both cases, the full transition of the output takes two sampling intervals to reach the final output value. The timing of the current event relative to the sampling window determines the proportional amplitude of the first and second sampling intervals.

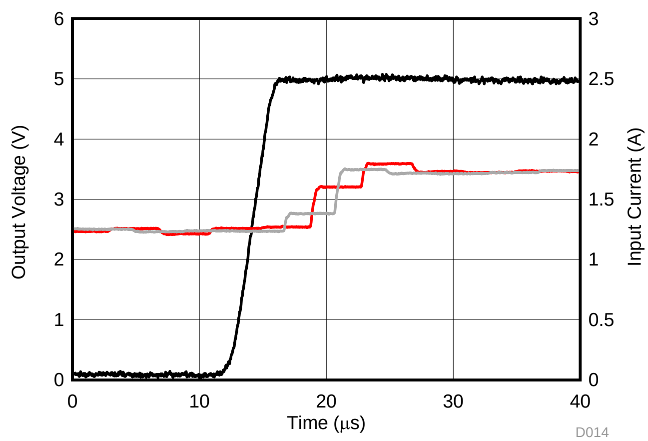

Figure 6. Transient Response to Input-Current Step Sufficient for 1-V Output Swing

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Feature Description (continued)

The output value is effectively an average over the sampling window; therefore, a large-enough current transient can drive the output voltage to the full range in the first sample response. This condition is likely to be true in the case of a short-circuit or fault event. Figure 7 shows an input-current step of 100 A, and the output response of an TMCS1100A3B. In the case of *Vout1*, the event occurs near the beginning of a sampling window, and so the output transitions to full scale in the first integrator output sample. In the case of *Vout2*, the event occurs near the end of an integration cycle, so there are two distinct output transitions. The relative timing and size of the input current transition determines whether the output transitions to full scale in a single cycle. In either case, the total response time is approximately one integration period.

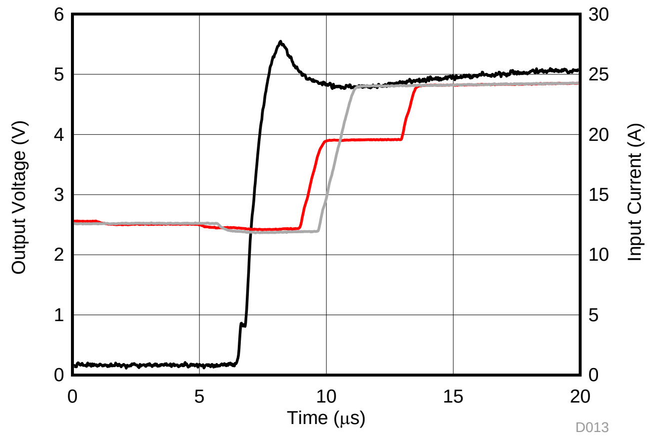

Figure 7. Transient Response to a Large Input Current Step

9.3.4 External Reference Voltage Input

The reference voltage provided externally to the TMCS1100 on the VREF pin determines the zero current output voltage, $V_{OUT,0A}$. This zero-current output level along with sensitivity determine the measurable input current range of the device, and allows for unidirectional or bidirectional sensing, as described in the *Absolute Maximum Ratings* table. Figure 8 illustrates the transfer function of the TMCS1100A2 with varying V_{REF} voltages of 0 V, 1.25 V, and 2.5 V. By shifting the zero current output voltage of the device, the dynamic range of measurable input current can be modified.

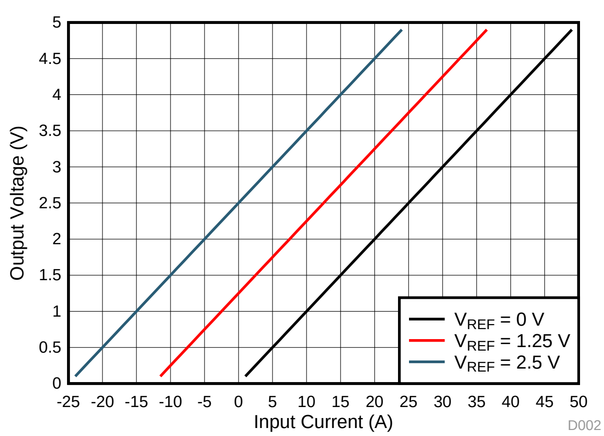

Figure 8. Output Voltage Relationship to Input Current With Varying VREF Voltages

The input voltage on this pin can be provided by any external voltage source or potential, such as a discrete precision reference, a voltage divider, ADC reference, or ground. The VREF pin is sampled by the internal circuitry at approximately 1 MHz, then buffered and provided to the signal chain of the device. An apparent dc load of approximately 1 µA will be observed by the external reference. In order to prevent errors due to sampling settling, keep the source impedance below the level specified in *Electrical Characteristics*.

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Feature Description (continued)

9.3.5 Current-Sensing Measurable Ranges

The TMCS1100 can be configured to allow for bidirectional or unidirectional measurable current ranges based on the external voltage on the VREF pin. The output voltage is a first-order linear function of the input current, as shown in Equation 1, and is only limited by V_{OUT} swing to either supply or ground. Linear output swing range to both V_S and GND is calculated by equations Equation 11 and Equation 12.

$$V_{OUT,max} = V_S - Swing_{VS} \quad (11)$$

$$V_{OUT,min} = Swing_{GND} \quad (12)$$

Rearranging the transfer function of the device to solve for input current, and substituting $V_{OUT,max}$ and $V_{OUT,min}$ yields the maximum and minimum measurable input current ranges as shown in Equation 13 and Equation 14.

$$I_{IN,MAX+} = (V_{OUT,max} - V_{REF}) / S \quad (13)$$

$$I_{IN,MAX-} = (V_{REF} - V_{OUT,min}) / S$$

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. (14)

Setting V_{REF} to the middle of the output swing range provides bidirectional measurement capability, whereas setting V_{REF} close to the ground provides a unidirectional measurement. Custom ranges with nonuniform positive and negative input current ranges can be achieved by appropriately scaling the V_{REF} potential relative to the full output voltage range.

9.4 Device Functional Modes

9.4.1 Power-Down Mode

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.

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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. Customers should validate and test their design implementation to confirm system functionality.

10.1 Application Information

The key feature sets of the TMCS1100 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.
- An external reference input maximizes flexibility for unidirectional or bidirectional measurement with custom dynamic ranges, and improves accuracy at the system level.
- 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.

ADVANCE INFORMATION

Application Information (continued)

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, V_{REF} to V_{OUT} gain error, 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 15), CMRR (Equation 16), PSRR (Equation 17), VREF gain error (Equation 18), and external field error (Equation 19) are all referred to the input, and so, are divided by the actual input current I_{IN} to arrive percentage errors. For calculations of sensitivity error and nonlinearity error, the percentage limits explicitly specified in the *Electrical Characteristics* table can be used.

$$e_{I_{OS}}(\%) = \frac{I_{OS}}{I_{IN}} \tag{15}$$

$$e_{CMRR}(\%) = \left| \frac{CMRR * V_{CM}}{I_{IN}} \right| \tag{16}$$

$$e_{PSRR}(\%) = \left| \frac{PSRR * (V_S - 5)}{I_{IN}} \right| \tag{17}$$

$$e_{V_{REF}}(\%) = \frac{\left| \dfrac{RVRR \times (V_{REF} - \frac{V_S}{2})}{S} \right|}{I_{IN}} \tag{18}$$

$$e_{B_{EXT}}(\%) = \frac{\left| \dfrac{B_{EXT}}{G} \right|}{I_{IN}} \tag{19}$$

When calculating error contributions across temperature, only the input offset current and sensitivity error contributions vary significantly. In both cases, specifications for both the maximum device temperature range and the parameter drift across temperature are provided. For determining actual performance limits across a narrower temperature range than the specified –40°C to +125°C, use Equation 20 and Equation 21 for offset error and sensitivity error, respectively. In both of these calculations, the maximum specified drift for the parameter can be multiplied by the desired temperature deviation from room temperature (ΔT). Use the smaller value of this drift calculation and the specified range over the full temperature range. The sensitivity drift ($e_{S,drift}$) is specified in ppm/°C, and must be converted to percentage error.

$$e_{I_{OS,\Delta T}}(\%) = \frac{\min\left[I_{OS,RT} + I_{OS,drift} * \Delta T ; I_{OS,FT} \right]}{I_{IN}} \tag{20}$$

$$e_{S_{\Delta T}}(\%) = \min\left[e_S + e_{S,drift} * 1000 * \Delta T ; e_{S,FT} \right] \tag{21}$$

In order 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. There are two separate ways to calculate total error for any particular system. In a worst case scenario, each error term would be at its absolute maximum with the same polarity. In such a case, the total system error would be a mathematical summation of each individual error source, as shown in Equation 22 for room temperature. For across temperature worst case error, the input referred offset and sensitivity error for the relevant range should be substituted in place of the room temperature values, as in Equation 23.

$$e_{worst}(\%) = e_{I_{OS}} + e_{PSRR} + e_{CMRR} + e_{V_{REF}} + e_{B_{EXT}} + e_S + e_{NL} \tag{22}$$

$$e_{worst,\Delta T}(\%) = e_{I_{OS,\Delta T}} + e_{PSRR} + e_{CMRR} + e_{V_{REF}} + e_{B_{EXT}} + e_{S,\Delta T} + e_{NL} \tag{23}$$

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Application Information (continued)

Because the statistical probability of any device actually existing in this worst case corner is insignificant, a better methodology is to use a root sum squared (RSS) calculation for uncorrelated error sources. This method takes into account the statistically uncorrelated nature of the individual error terms to provide a more realistic total error based on the distributions of each error component. For the TMCS1100, only the input referred offset current (I_{OS}), CMRR, and PSRR are statistically correlated. These error terms are lumped in an RSS calculation in order to reflect this nature, as shown in Equation 24 for room temperature and Equation 25 for across a given temperature range.

$$e_{RSS}(\%) = \sqrt{\left(e_{I_{OS}} + e_{PSRR} + e_{CMRR}\right)^2 + e_{V_{REF}}{}^2 + e_{B_{EXT}}{}^2 + e_S{}^2 + e_{NL}{}^2} \quad (24)$$

$$e_{RSS,\Delta T}(\%) = \sqrt{\left(e_{I_{OS,\Delta T}} + e_{PSRR} + e_{CMRR}\right)^2 + e_{V_{REF}}{}^2 + e_{B_{EXT}}{}^2 + e_{S,\Delta T}{}^2 + e_{NL}{}^2} \quad (25)$$

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 because of 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 9 illustrates the total RSS error as a function of input current for a TMCS1100A2 at room temperature and across the full temperature range with V_S of 5 V.

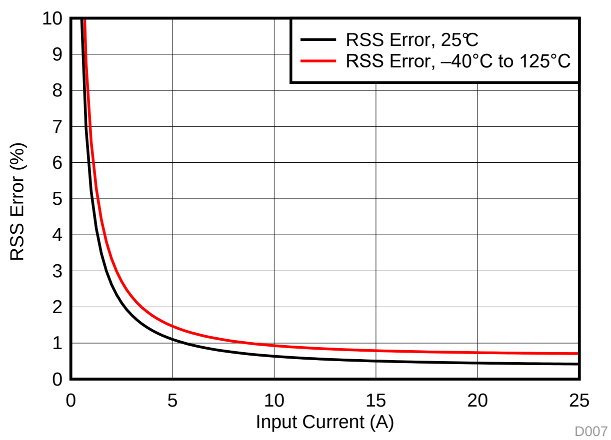

Figure 9. RSS Error vs Input Current

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Application Information (continued)

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 TMCS1100A2 with a supply voltage (V_S) of 3.3 V, a V_{REF} of 1.5 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 magnetic field of 30 µT, roughly the Earth's magnetic field strength. The full-scale current range of the device in specified conditions is slightly greater than 15 A; therefore, calculate error at both 15 A and 7.5 A to highlight error dependence on the input-current level. Table 1 shows the individual error components, and the worst-case and RSS total error calculations at room temperature under the conditions specified. Relative to other errors, the additional error from CMRR and PSRR are negligible, and can typically be ignored for total error calculations.

Table 1. Total Error Calculation: Room Temperature Example

ERROR COMPONENT	SYMBOL	EQUATION	% TOTAL ERROR AT I_{IN} = 15 A	% TOTAL ERROR AT I_{IN} = 7.5 A
Input offset error	e_{Ios}	$e_{I_{OS}}(\%) = \frac{I_{OS}}{I_{IN}}$	0.3%	0.6%
CMRR error	e_{CMRR}	$e_{CMRR}(\%) = \left\lvert \frac{CMRR * V_{CM}}{I_{IN}} \right\rvert$	0.00%	0.01%
PSRR error	e_{PSRR}	$e_{PSRR}(\%) = \left\lvert \frac{PSRR * (V_S - 5)}{I_{IN}} \right\rvert$	0.11%	0.23%
V_{REF} error	e_{VREF}	$e_{V_{REF}}(\%) = \frac{\left\lvert \frac{RVRR \times (V_{REF} - \frac{V_S}{2})}{S} \right\rvert}{I_{IN}}$	0.05%	0.10%
External Field error	e_{Bext}	$e_{B_{EXT}}(\%) = \frac{\left\lvert \frac{B_{EXT}}{G} \right\rvert}{I_{IN}}$	0.17%	0.33%
Sensitivity error	e_S	Specified in Electrical Characteristics	0.35%	0.35%
Nonlinearity error	e_{NL}	Specified in Electrical Characteristics	0.1%	0.1%
Worst-case total error	e_{worst}	$e_{worst}(\%) = e_{I_{OS}} + e_{PSRR} + e_{CMRR} + e_{V_{REF}} + e_{B_{EXT}} + e_S + e_{NL}$	1.1%	1.7%
RSS total error	e_{RSS}	$e_{RSS}(\%) = \sqrt{(e_{I_{OS}} + e_{PSRR} + e_{CMRR})^2 + e_{V_{REF}}{}^2 + e_{B_{EXT}}{}^2 + e_S{}^2 + e_{NL}{}^2}$	0.58%	0.97%

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10.1.2 Safe Operating Area

The isolated input current safe operating area (SOA) of the TMCS1100 is constrained by input conductor thermal dissipation causing die junction temperature to exceed maximum T_J rating of 150°C. Continuous current capability refers to the ability of the device to conduct a given dc or rms current (if a periodic or ac waveform) continuously through the device at a given ambient temperature. The TMCS1100 can tolerate much higher transient short-duration currents, which are limited by different thermal mechanisms, such as fusing of the leadframe. These mechanisms depend on pulse duration, amplitude, and device thermal states.

Current capability for both rms and short-duration pulses depend on the thermal environment and design of the system-level board. All thermal and SOA ratings are for a single TMCS1100 device on the TMCS1100EVM, with no air flow in the specified ambient temperature conditions. Device use profiles must satisfy both continuous conduction and short-duration transient SOA capabilities for the thermal environment under which the system will be operated.

10.1.2.1 Continuous-Current Capability

The continuous-current capability of the TMCS1100 is constrained by the maximum junction temperature because of the power dissipation in the input conductor and die. Multiple thermal variables control the transfer of heat from the device to the surrounding environment, including air flow, ambient temperature, and PCB construction and design. The longest thermal time constants of the device packaging and board are on the order of seconds; therefore, any continuous periodic waveform with a frequency higher than 1 Hz can be evaluated based on the rms continuous-current level.

The continuous-current capability is thermally constrained; therefore, the capability of the device varies across the operating ambient temperature range.Figure 10 shows the maximum current-handling capability of the device on the TMCS100EVM. Current capability falls off at higher ambient temperatures because of the reduced thermal transfer from junction-to-ambient and a leadframe positive temperature coefficient that causes increased power dissipation. 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.

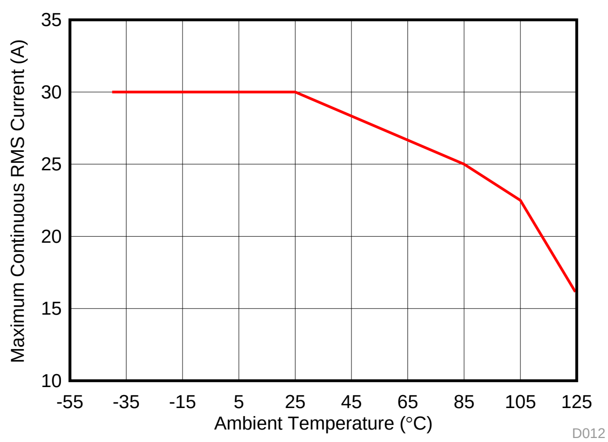

Figure 10. Maximum Continuous RMS Current vs Ambient Temperature

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10.1.2.2 Short-Duration Current Capability

Higher-current events that are shorter duration can be tolerated by the TMCS1100, because the junction temperature does not reach thermal equilibrium within the pulse duration. Figure 11 shows the short-circuit duration curve for the device for single current-pulse events, where the leadframe resistance changes after stress. This level is reached before a leadframe fusing event, but is a fundamental limit to current-handling capability of the leadframe. For long-duration pulses, the current capability approaches the continuous rms limit at the given ambient temperature. For repetitive pulsed events, the current levels must satisfy both the short-duration current capability and the rms continuous current levels for the duration of the subsequent pulse events.

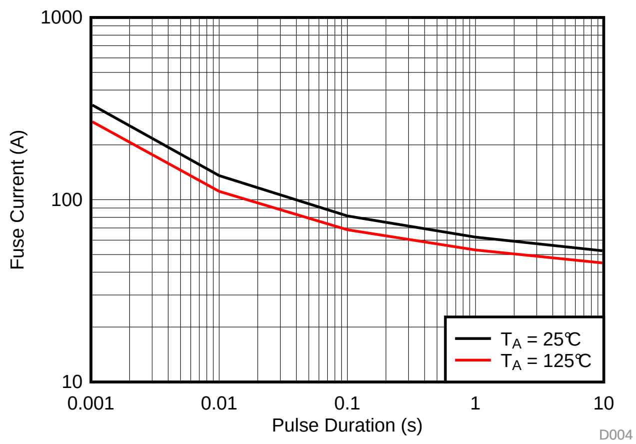

Figure 11. Single-Pulse Leadframe Capability

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10.2 Typical Application

Inline sensing of motor phase current provides significant benefits to the performance of a motor control system, allowing advanced control algorithms and diagnostics with minimal postprocessing. A primary challenge to inline sensing for motor drives is that the current sensor is subjected to full HV supply-level PWM transients driving the motor phase. 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 12 illustrates the use of the TMCS1100 in such an application.

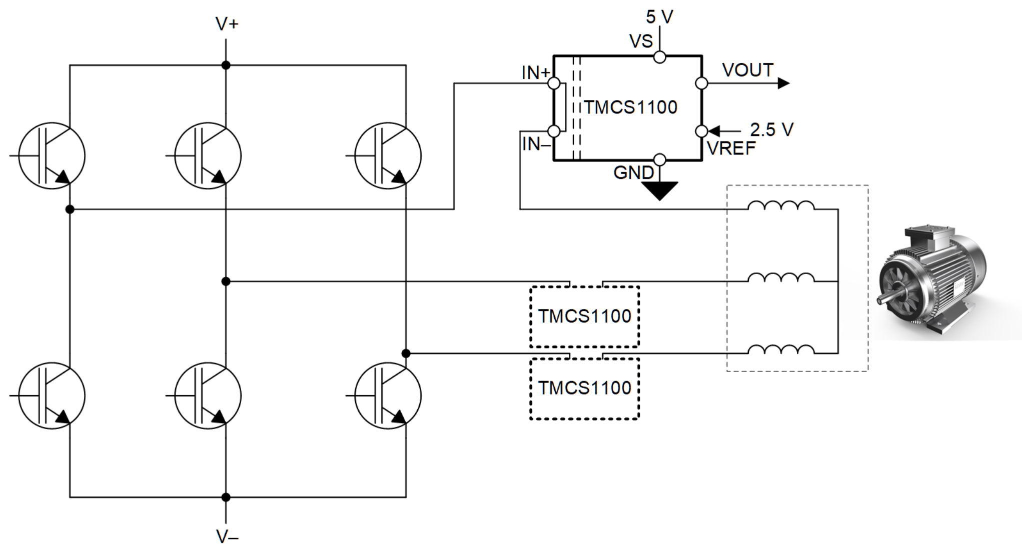

Figure 12. Inline Motor Phase Current Sensing

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 TMCS1100 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 TMCS1100 specifications, and a full-scale current measurement of ±20 A is required.

Table 2. Example Application Design Requirements

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

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10.2.2 Detailed Design Procedure

The TMCS1100 application design procedure has two key design parameters: the sensitivity version chosen (A1-A4) and the reference voltage input. Further consideration of noise and integration with an ADC can be explored, but is beyond the scope of this application design example. The TMCS1100 transfer function is effectively a transimpedance with a variable offset set by V_{REF}, defined by Equation 26.

$$V_{OUT} = I_{IN} \times S + V_{REF} \quad (26)$$

Design of the sensing solution first focuses on maximizing the sensitivity of the device while maintaining linear measurement over the expected current input range. The linear output voltage range is constrained by the TMCS1100 linear swing to ground, $Swing_{GND}$, and swing to supply, $Swing_{VS}$. With the previous parameters, the maximum linear output voltage range is the range between $V_{OUT,max}$ and $V_{OUT,min}$, as defined by Equation 27 and Equation 28.

$$V_{OUT,max} = V_{S,min} - Swing_{V_S} \quad (27)$$

$$V_{OUT,min} = Swing_{GND} \quad (28)$$

For a bidirectional motor phase current-sensing application, a sufficient linear output voltage range is required from V_{REF} to both ground and the power supply. Design parameters for this example application are shown in Table 3 along with the calculated output range.

Table 3. Example Application Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
$Swing_{VS}$	0.2 V
$Swing_{GND}$	0.05 V
$V_{OUT,max}$	4.7 V
$V_{OUT,min}$	0.05 V
$V_{OUT,max}$ - $V_{OUT,min}$	4.65 V

These design parameters result in a maximum linear output voltage swing of 4.65 V. To determine which sensitivity variant of the TMCS1100 most fully uses this linear range, calculate the maximum current range by Equation 29 for a unidirectional current ($I_{U,MAX}$), and Equation 30 for a bidirectional current ($I_{B,MAX}$).

$$I_{U,MAX} = \frac{V_{OUT,max} - V_{OUT,min}}{S_{A<x>}} \quad (29)$$

$$I_{B,MAX} = \frac{V_{OUT,max} - V_{OUT,min}}{2 \times S_{A<x>}}$$

where

- $S_{A<x>}$ is the sensitivity of the relevant A1-A4 variant. (30)

Table 4 shows such calculation for each gain variant of the TMCS1100 with the appropriate sensitivities.

Table 4. Maximum Full-Scale Current Ranges With 4.65-V Output Range

SENSITIVITY VARIANT	SENSITIVITY	$I_{U,MAX}$	$I_{B,MAX}$
TMCS1100A1	50 mV/A	93 A	±46.5 A
TMCS1100A2	100 mV/A	46.5 A	±23.2A
TMCS1100A3	200 mV/A	23.2 A	±11.6A
TMCS1100A4	400 mV/A	11.6 A	±5.8 A

In general, select the highest sensitivity variant that provides for the desired full-scale current range. For the design parameters in this example, the TMCS1100A2 with a sensitivity of 0.1 V/A is the proper selection because the maximum-calculated ±23.2 A linear measurable range is sufficient for the desired ±20-A full-scale current.

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After selecting the appropriate sensitivity variant for the application, the zero-current reference voltage defined by the V_{REF} input pin is defined. Manipulating Equation 26 and using the linear range defined by $V_{OUT,max}$, $V_{OUT,min}$, and the full-scale input current, $I_{IN,FS}$, calculate the maximum and minimum V_{REF} voltages allowed to remain within the linear measurement range, shown in Equation 31 and Equation 32.

$$V_{REF,max} = V_{OUT,max} - \left|I_{IN,FS}\right| \times S \quad (31)$$

$$V_{REF,min} = V_{OUT,min} + \left|I_{IN,FS}\right| \times S \quad (32)$$

Any value of V_{REF} can be chosen between $V_{REF,max}$ and $V_{REF,min}$ in order to maintain the required linear sensing range. If the allowable V_{REF} range is not wide enough or does not include a desired V_{REF} voltage, the analysis must be repeated with a lower sensitivity variant of the TMCS1100. Equation 26 can be manipulated to solve for the maximum allowable current in either direction by using the selected V_{REF} voltage and the maximum linear voltage ranges as in Equation 33 and Equation 34.

$$I_{MAX+} = \frac{V_{OUT,max} - V_{REF}}{S} \quad (33)$$

$$I_{MAX-} = \frac{V_{OUT,min} - V_{REF}}{S} \quad (34)$$

Table 5 shows the respective values for the example design parameters in Table 3. In this case, a V_{REF} of 2.5 V has been selected such that the zero current output is half of the nominal power supply. This example V_{REF} design value provides a linear input current-sensing range of –24.5 A to +22 A, with the positive current defined as current flowing into the IN+ pin.

Table 5. Example VREF Limits and Associated Current Ranges

REFERENCE PARAMETER	EXAMPLE VALUE	MAXIMUM LINEAR CURRENT SENSING RANGE	
		I_{MAX+}	I_{MAX-}
$V_{REF,min}$	2.05 V	26.5 A	–20 A
$V_{REF,max}$	2.7 V	20 A	–26.5 A
Selected V_{REF}	2.5 V	22 A	–24.5 A

The transfer function of the TMCS1100 linear sensing range for these design parameters is shown in Figure 13.

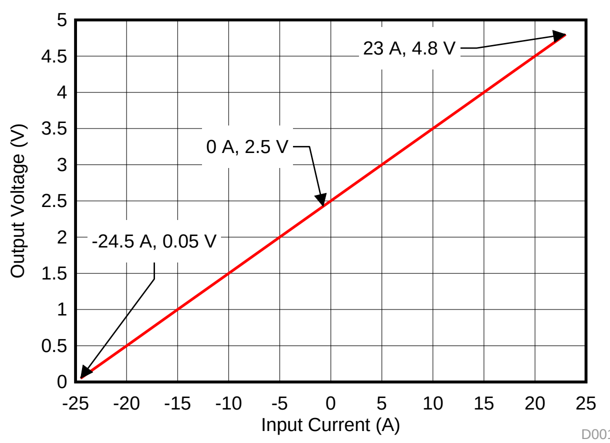

Figure 13. Application Example Design Transfer Curve

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After selecting a V_{REF} for the application design, an appropriate source must be defined. Multiple implementations are possible, but could include:

- Resistor divider from the supply voltage
- Resistor divider from an ADC full-scale reference
- Dedicated or preexisting voltage reference IC
- DAC or reference voltage from a system microcontroller

Each of these options has benefits, and the error terms, noise, simplicity, and cost of each implementation must be weighed. In the current design example, any of these options are potentially available as a 2.5-V V_{REF} is midrail of the power supply, a common IC reference voltage, and might already be available in the system. If the primary consideration for the current application design is to maximize precision while minimizing temperature drift and noise, a dedicated voltage reference must be chosen. For this case, the LM4030C-2.5 can be chosen for to optimize system accuracy without significant cost addition. Figure 14 depicts the current-sense system design as discussed.

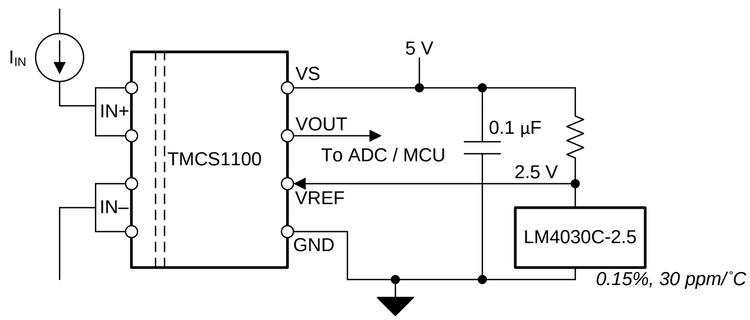

Figure 14. TMCS1100 Example Current-Sense System Design

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11 Power Supply Recommendations

The TMCS1100 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 uF 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.

12 Layout

12.1 Layout Guidelines

The TMCS1100 is specified for a continuous current handling capability of 20-A across the full ambient temperature range of –40°C to +125°C on the TMCS1100EVM, which uses 3-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 TMCS1100EVM 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.

The TMCS1100 senses external magnetic fields, so make sure to minimize adjacent high-current traces in close proximity to the device. The input current trace can contribute additional magnetic field to the sensor if the input current traces are routed parallel to the vertical axis of the package. Figure 15 illustrates the most optimal input current routing into the TMCS1100. As the angle that the current approaches the device deviates from 0° to the horizontal axis, the current trace contributes some additional magnetic field to the sensor, increasing the effective sensitivity of the device. If current must be routed parallel to the package vertical axis, move the routing away from the package to minimize the impact to the sensitivity of the device. Terminate the input current path directly underneath the package lead footprint, and use a merged copper input trace for both the IN+ and IN– inputs.

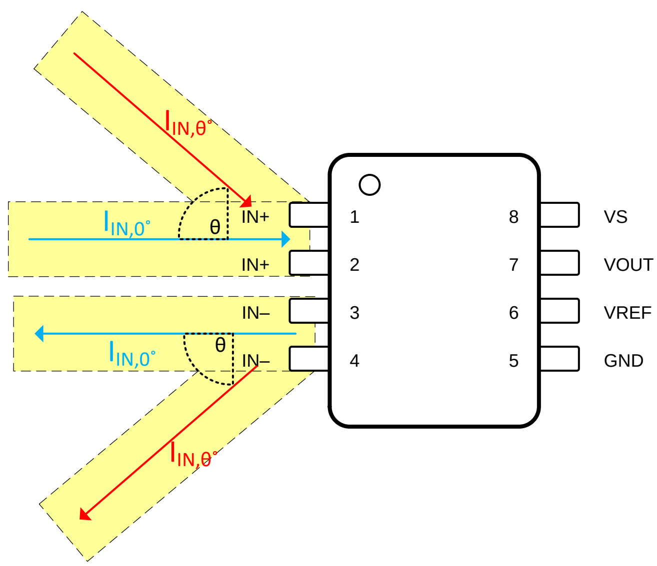

Figure 15. Magnetic Field Generated by Input Current Trace

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Layout Guidelines (continued)

In addition to thermal and magnetic optimization, make sure to consider the PCB design required creepage and clearance for system-level isolation requirements. Maintain required creepage between solder stencils, as shown in Figure 16, if possible. If not possible to maintain required PCB creepage between the two isolated sides at board level, add additional slots or grooves to the board. If more creepage and clearance is required for system isolation levels than is provided by the package, the entire device and solder mask can be encapsulated with an overmold compound to meet system-level requirements.

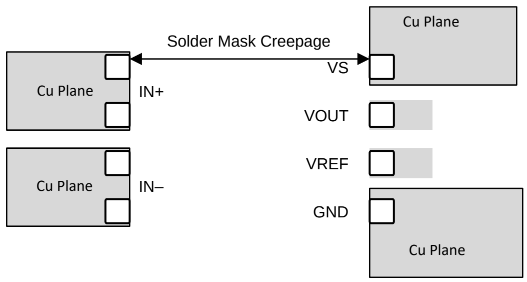

Figure 16. Layout for System Creepage Requirements

12.2 Layout Example

An example layout, shown in Figure 17, is from the TMCS1100EVM. Device performance is targeted for thermal and magnetic characteristics of this layout, subject to change.

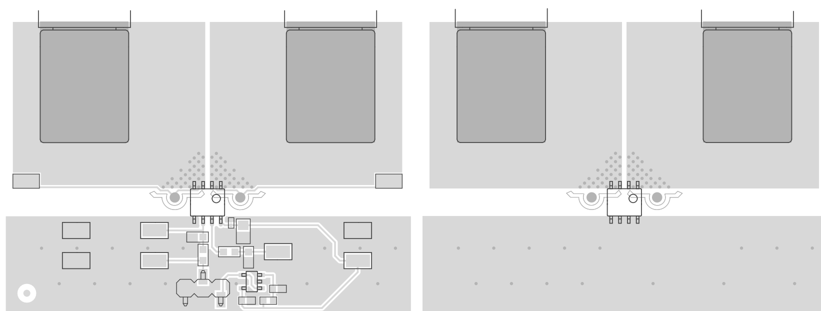

Figure 17. Recommended Board Top (Left) and Bottom (Right) Plane Layout

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13 Device and Documentation Support

13.1 Device Support

13.1.1 Development Support

For development tool support see the following:

- TMCS1100EVM
- TMCS1100 TI-TINA Model
- TMCS1100 TINA-TI Reference Design

13.2 Documentation Support

13.2.1 Related Documentation

For related documentation see the following:

- Texas Instruments, *TMCS1100EVM users's guide*
- Texas Instruments, *Enabling Precision Current Sensing Designs with Nonratiometric Magnetic Current Sensors*
- Texas Instruments, *Low-Drift, Precision, In-Line Isolated Magnetic Motor Current Measurements*
- Texas Instruments, *Isolation Glossary*

13.3 Receiving Notification of Documentation Updates

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

13.4 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.

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13.5 Trademarks

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13.6 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.

13.7 Glossary

SLYZ022 — *TI Glossary*.

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

14 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.

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
PMCS1100A1QDR	ACTIVE	SOIC	D	8	2500	TBD	Call TI	Call TI	-40 to 125		Samples
PMCS1100A2QDR	ACTIVE	SOIC	D	8	2500	TBD	Call TI	Call TI	-40 to 125		Samples
PMCS1100A3QDR	ACTIVE	SOIC	D	8	2500	TBD	Call TI	Call TI	-40 to 125		Samples
PMCS1100A4QDR	ACTIVE	SOIC	D	8	2500	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/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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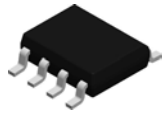
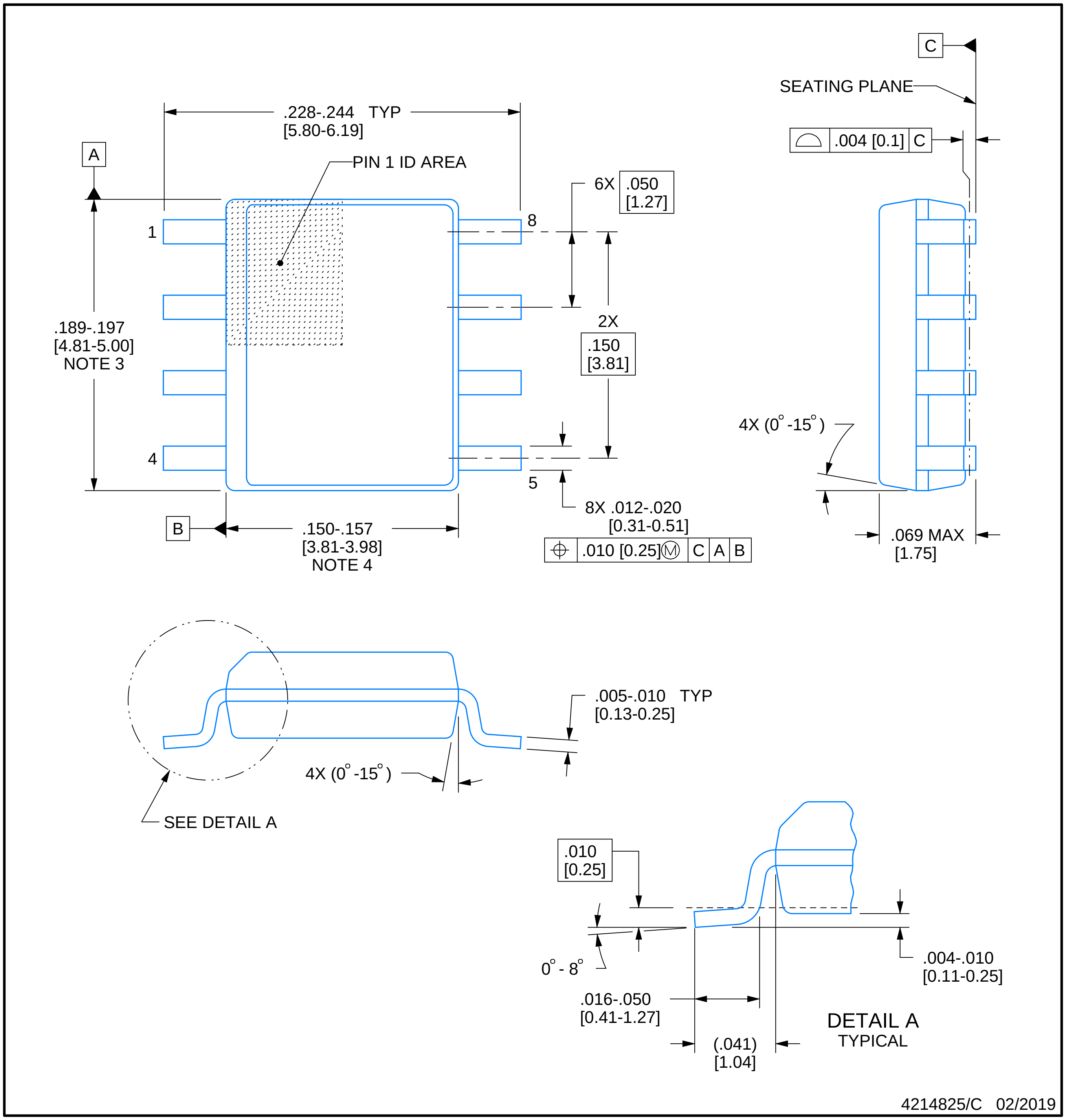


PACKAGE OUTLINE

D0008A

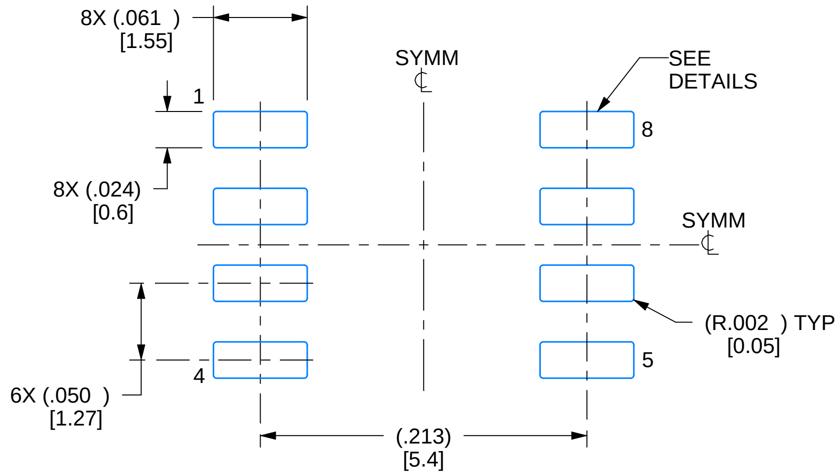
SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT

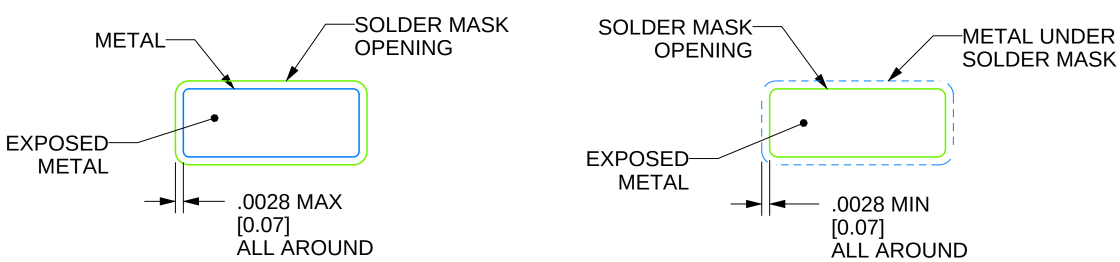


NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X



NON SOLDER MASK DEFINED

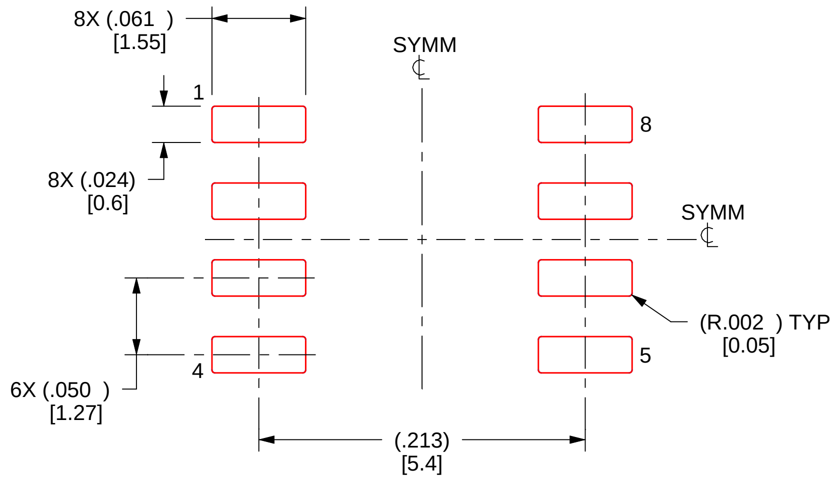
SOLDER MASK DEFINED

SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

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



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

4214825/C 02/2019

NOTES: (continued)

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

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