Click here to ask an associate for production status of specific part numbers.

Bidirectional, On-The-Fly Programmable Gain, Current-Sense Amplifier with Wide Measurement Range

MAX49918

General Description

The MAX49918 is a high-precision current-sense amplifier (CSA) with an I^2C programmable gain option from 10V/V to 200V/V in 8 steps. The multiple programmable gain options offer maximum flexibility for the user to change gain on-the-fly.

The IC operating input common-mode range from -5V to +70V, with protections that extend down to -6V and up to +80V, thus providing protection against reverse-battery and high-voltage spikes.

The low input offset of ±1μV (typ) and low gain error of ±0.01% (typ) make this device best-suited for high-precision current measurements.

The IC operates from a supply voltage of +2.7V to +5.5V with a typical quiescent supply at 0.7mA. The device operates over the full -40°C to +125°C temperature range.

The IC features bidirectional current sensing and is offered in a 3mm x 3mm, 10-pin TDFN package.

Applications

- Monitoring Distinct Current Levels
- Using the Same Current-Sense Resistors Across Multiple System Variants
- Requires a Non-Typical Gain Value Due to Sense Resistor Constraints
- H-Bridge Motor and Solenoid Current Sensing
- Battery Current Monitoring
- High- and Low-Side Precision Current Sensing

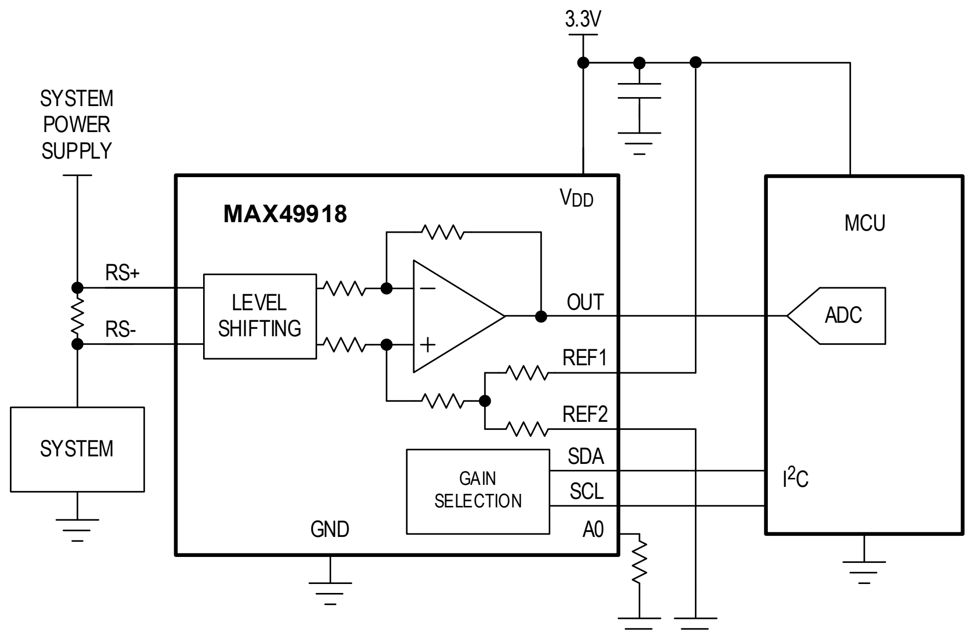
Benefits and Features

- Programmable Gain Options through I^2C from 10V/V to 200V/V (8 steps)
- ±1μV (typ) Input Offset Voltage for REF1 = REF2 = $V_{DD}/2$
- ±5μV (typ) Input Offset Voltage for REF1 = V_{DD} and REF2 = GND at Gain = 20V/V
- ±0.01% (typ) Gain Error
- -5V to +70V Input Voltage Range
- -6V to +80V Protective Immunity
- 70kHz, -3dB Bandwidth at Gain = 20V/V
- 145dB DC CMRR
- Rail-to-Rail Output
- 3mm x 3mm, TDFN-10 Package
- -40°C to +125°C Temperature Range

Ordering Information ***appears at end of data sheet.***

19-101747; Rev 0; 9/23

Simplified Block Diagram



Absolute Maximum Ratings

RS+ and RS- to GND .... -6V to +80V

RS+ to RS- .... ±2V

V_{DD} to GND .... -0.3V to +6V

OUT, REF1, REF2 to GND .... -0.3V to V_{DD} + 0.3V

Continuous Current into Pins.. ±10mA

Continuous Power Dissipation (Multi Layer Board) (T_A = +70°C, derate 24.4mW/°C above +70°C)................ 1951.2mW

Operating Temperature Range....................... -40°C to +125°C

Storage Temperature Range.......................... -65°C to +150°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Package Information

10 TDFN

Package Code	T1033+1C
Outline Number	*21-0137*
Land Pattern Number	*90-0003*
Thermal Resistance, Four-Layer Board:	
Junction to Ambient (θ_{JA})	41°C/W
Junction to Case Thermal Resistance (θ_{JC})	9°C/W

For the latest package outline information and land patterns (footprints), go to www.maximintegrated.com/packages. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

Electrical Characteristics

(V_{CM} = V_{RS+} = V_{RS-} = +50V, V_{DD} = +3.3V, V_{SENSE} = V_{RS+} - V_{RS-} = 0V, V_{REF1} = V_{DD}/2, V_{REF2} = V_{DD}/2, G = 20V/V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C (Note 1))

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
POWER SUPPLY CHARACTERISTICS						
Supply Voltage	V_{DD}	Guaranteed by PSRR	2.7		5.5	V
Supply Current	I_{DD}	No loads		0.7	1	mA
Power-Up Time	t_{PWR_UP}	Output settles to 1%		200		µs
CURRENT-SENSE AMPLIFIER						
DC CHARACTERISTICS						
Input Protected Common-Mode Range	V_{CM_P}		-6		+80	V
Input Common-Mode Range	V_{CM}	Guaranteed by CMRR	-5		+70	V
Input Bias Current (Note 2)	I_{RS+}, I_{RS-}			0.5	150	nA
Input Offset Current (Note 2)	I_{RS+} - I_{RS-}			0.1	50	nA
Input Leakage Current (Note 2)	I_{RS+}, I_{RS-}	V_{DD} = 0V, $V_{RS\pm}$ = 70V		1	200	nA
Input Offset Voltage	V_{OS}	For all gain options, T_A = +25°C		±1	±10	µV
		For all gain options, -40°C ≤ T_A ≤ +125°C			±50	
		V_{REF1} = V_{DD}, V_{REF2} = GND, T_A = +25°C		±5	±40	
		V_{REF1} = V_{DD}, V_{REF2} = GND, -40°C ≤ T_A ≤ +125°C			±80	
Input Offset Voltage Drift (Note 2)	TCV_{OS}			50	400	nV/°C
Power Supply Rejection Ratio	PSRR	2.7V ≤ V_{DD} ≤ 5.5V; -40°C ≤ T_A ≤ +125°C	95	125		dB
Common-Mode Rejection Ratio	CMRR	-5V ≤ V_{CM} ≤ +70V; -40°C ≤ T_A ≤ +125°C	130	145		dB
Reference Voltage Rejection Ratio	RRRR	V_{REF} = 1.5V to 2.5V; -40°C ≤ T_A ≤ +125°C	90	115		dB
Input Capacitance	C_{IN}	RS+, RS- input		4.5		pF
Gain (Note 3)	G	I²C Programmable		10 20 40 50 80 100 160 200		V/V
Gain Switching Time	t_{GAIN}	Settle within 1% of the 1V final value		25		µs
Gain Error	GE	For all gain options, T_A = +25°C		±0.01	±0.1	%
		For all gain options, -40°C ≤ T_A ≤ +125°C			±0.2	
Nonlinearity Error		10mV ≤ V_{SENSE} ≤ 100mV; G = 10V/V		0.01		%
Output Resistance	R_{OUT}	V_{OUT} = V_{DD}/2, I_{OUT} = ±500µA		0.3		Ω

(V_{CM} = V_{RS+} = V_{RS-} = +50V, V_{DD} = +3.3V, V_{SENSE} = V_{RS+} - V_{RS-} = 0V, V_{REF1} = V_{DD}/2, V_{REF2} = V_{DD}/2, G = 20V/V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C (Note 1))

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Output Voltage Swing High	V_{OH}	Source 500µA		V_{DD} - 0.015			V
Output Voltage Swing Low	V_{OL}	Sink 500µA				15	mV
Output Voltage Swing High	V_{OH}	No Load		V_{DD} - 0.004			V
Output Voltage Swing Low	V_{OL}	No Load				4	mV
Output Short-Circuit Current	I_{SC}	Shorted to either V_{DD} or GND			55		mA
AC CHARACTERISTICS							
Signal Bandwidth	BW_{-3dB}	G = 10V/V	V_{SENSE} = $1V_{PP}$/G		75		kHz
		G = 20V/V	V_{SENSE} = $1V_{PP}$/G		70		
		G = 40V/V	V_{SENSE} = $1V_{PP}$/G		60		
		G = 50V/V	V_{SENSE} = $1V_{PP}$/G		55		
		G = 80V/V	V_{SENSE} = $1V_{PP}$/G		45		
		G = 100V/V	V_{SENSE} = $1V_{PP}$/G		40		
		G = 160V/V	V_{SENSE} = $1V_{PP}$/G		30		
		G =200V/V	V_{SENSE} = $1V_{PP}$/G		25		
Output Slew Rate	SR	$2V_{PP}$ output square wave, centered at V_{DD}/2			0.3		V/µs
AC Power Supply Rejection Ratio	AC PSRR	f = 200kHz, $100mV_{PP}$ sine wave			35		dB
AC Common-Mode Rejection Ratio	AC CMRR	f = 200kHz, $100mV_{PP}$ sine wave			60		dB
Capacitive Load Stability	C_{LOAD}	With 250Ω isolation resistor			20		nF
		Without any isolation resistor			200		pF
Input Voltage Noise Density	e_n	At 1kHz			100		nV/Hz
Settling Time (Settling to 0.1%)	t_S	V_{SENSE} steps from -50mV to 50mV			20		µs
I^2C INTERFACE TIMING (400kHz I^2C)							
SCL Clock Frequency	f_{SCL}					400	kHz
START Hold Time	$t_{HD:STA}$			600			ns
START Setup Time	$t_{SU:STA}$	90% of SCL to 90% of SDA		600			ns
Clock Low Period	t_{LOW}			1.3			µs
Clock High Period	t_{HIGH}			600			ns
Data Setup Time	$t_{SU:DAT}$	10% of SDA to 10% of SCL		100			ns
Data Hold Time	$t_{HD:DAT}$	10% of SDA to 10% of SCL		0		900	ns
SCL Max Rise and Fall Time	t_R, t_F				300		ns
SDA Max Rise and Fall Time	t_R, t_F				300		ns
STOP Condition Setup Time	$t_{SU:STO}$	90% of SCL to 10% of SDA		600			ns

($V_{CM} = V_{RS+} = V_{RS-}$ = +50V, V_{DD} = +3.3V, $V_{SENSE} = V_{RS+} - V_{RS-}$ = 0V, $V_{REF1} = V_{DD}/2$, $V_{REF2} = V_{DD}/2$, G = 20V/V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C (Note 1))

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
DC LOGIC CHARACTERISTICS (SDA, SCL, A0)						
Input Voltage High	V_{IH}		70			% of V_{DD}
Input Voltage Low	V_{IL}				30	% of V_{DD}
Output Voltage Low	V_{OL}				0.4	V
Input Capacitance	C_{IN}			3		pF

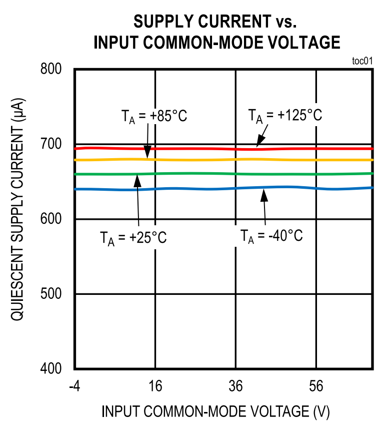
Note 1: All devices are 100% production tested at T_A = +25°C. Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization.

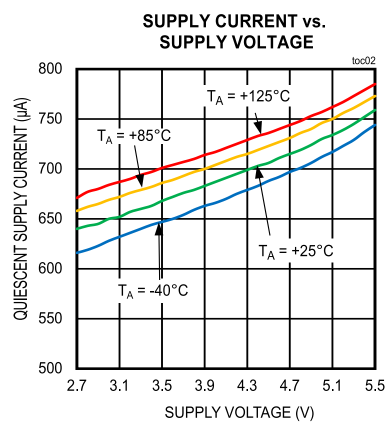
Note 2: Guaranteed by design and bench characterization.

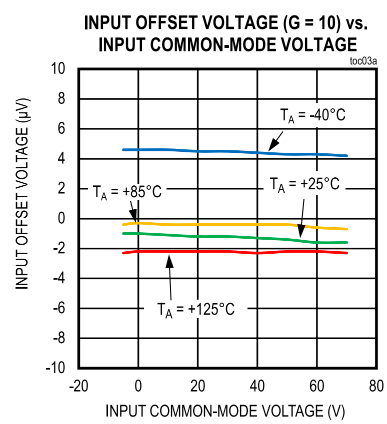
Note 3: Gain is calculated based on two points measurements: V_{SENSE1} and V_{SENSE2}. V_{SENSE1} = -1V/Gain and V_{SENSE2} = 1V/Gain.

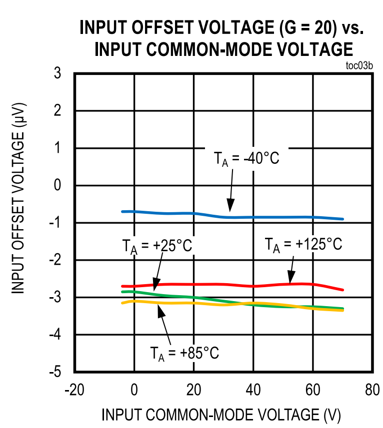
Typical Operating Characteristics

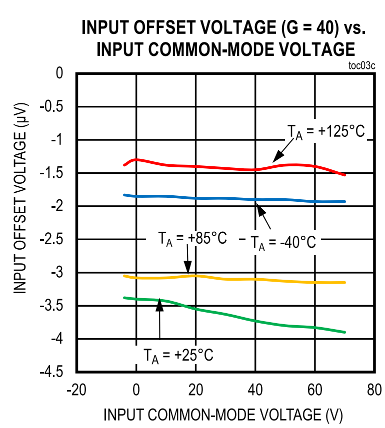
($V_{CM} = V_{RS+} = V_{RS-}$ = +50V, V_{DD} = +3.3V, $V_{SENSE} = V_{RS+} - V_{RS-}$ = 0V, $V_{REF1} = V_{DD}/2$, $V_{REF2} = V_{DD}/2$, G = 20V/V, T_A = +25°C, unless otherwise noted.)

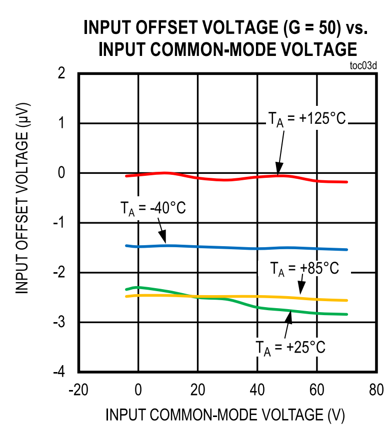






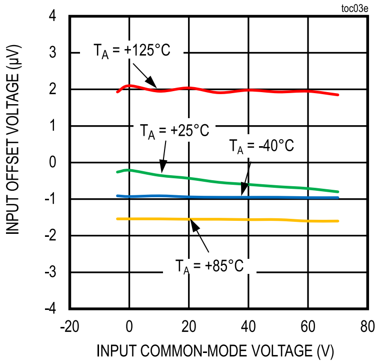




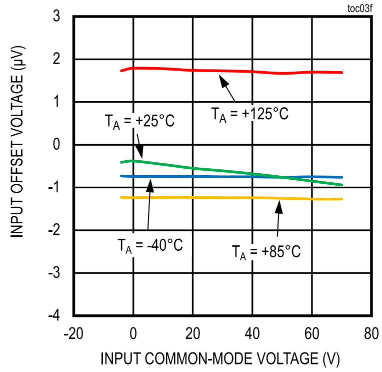


(V_{CM} = V_{RS+} = V_{RS-} = +50V, V_{DD} = +3.3V, V_{SENSE} = V_{RS+} - V_{RS-} = 0V, V_{REF1} = V_{DD}/2, V_{REF2} = V_{DD}/2, G = 20V/V, T_A = +25°C, unless otherwise noted.)

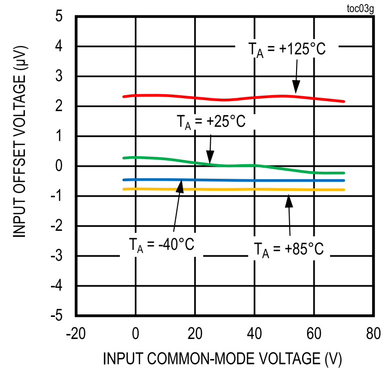
INPUT OFFSET VOLTAGE (G = 80) vs. INPUT COMMON-MODE VOLTAGE



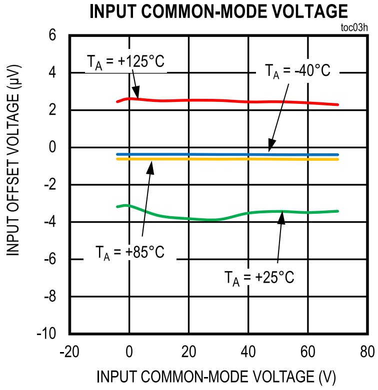
INPUT OFFSET VOLTAGE (G = 100) vs. INPUT COMMON-MODE VOLTAGE



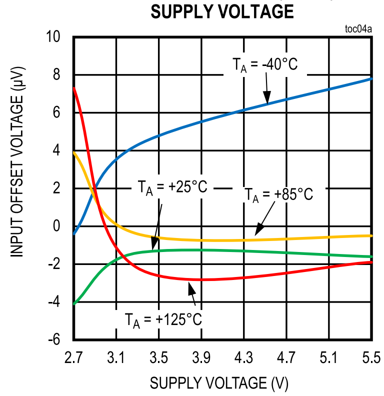
INPUT OFFSET VOLTAGE (G = 160) vs. INPUT COMMON-MODE VOLTAGE



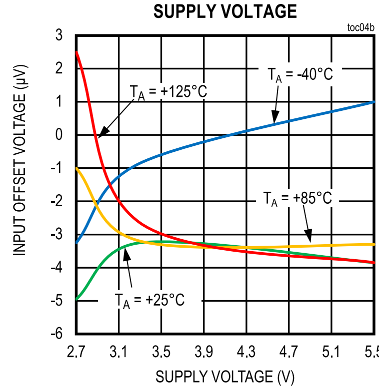
INPUT OFFSET VOLTAGE (G = 200) vs. INPUT COMMON-MODE VOLTAGE



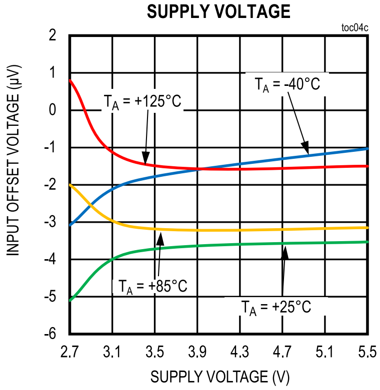
INPUT OFFSET VOLTAGE (G = 10) vs. SUPPLY VOLTAGE



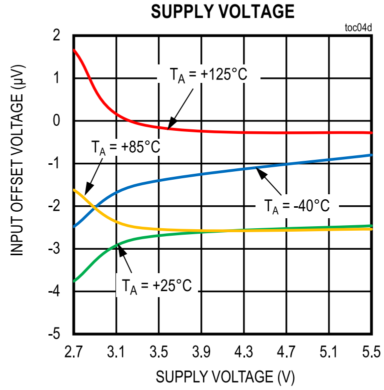
INPUT OFFSET VOLTAGE (G = 20) vs. SUPPLY VOLTAGE



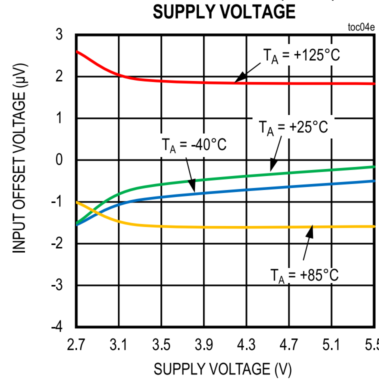
INPUT OFFSET VOLTAGE (G = 40) vs. SUPPLY VOLTAGE



INPUT OFFSET VOLTAGE (G = 50) vs. SUPPLY VOLTAGE

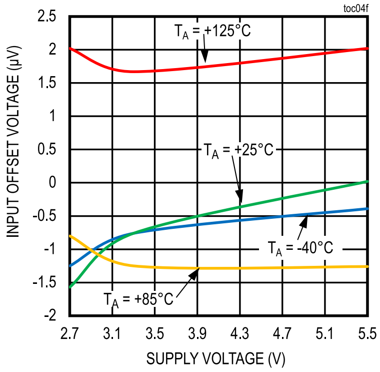


INPUT OFFSET VOLTAGE (G = 80) vs. SUPPLY VOLTAGE

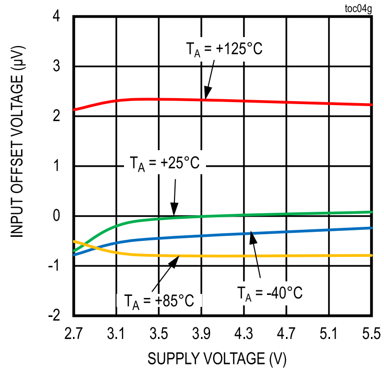


($V_{CM} = V_{RS+} = V_{RS-}$ = +50V, V_{DD} = +3.3V, $V_{SENSE} = V_{RS+} - V_{RS-}$ = 0V, $V_{REF1} = V_{DD}/2$, $V_{REF2} = V_{DD}/2$, G = 20V/V, T_A = +25°C, unless otherwise noted.)

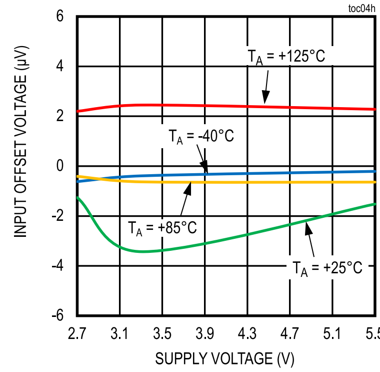
INPUT OFFSET VOLTAGE (G = 100) vs. SUPPLY VOLTAGE



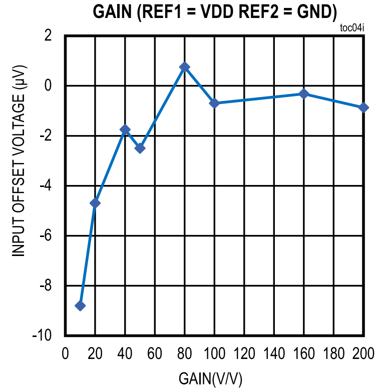
INPUT OFFSET VOLTAGE (G = 160) vs. SUPPLY VOLTAGE



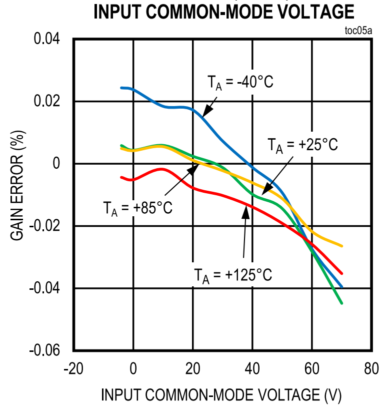
INPUT OFFSET VOLTAGE (G = 200) vs. SUPPLY VOLTAGE



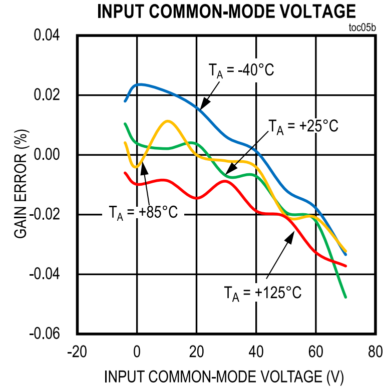
INPUT OFFSET VOLTAGE vs. GAIN (REF1 = VDD REF2 = GND)



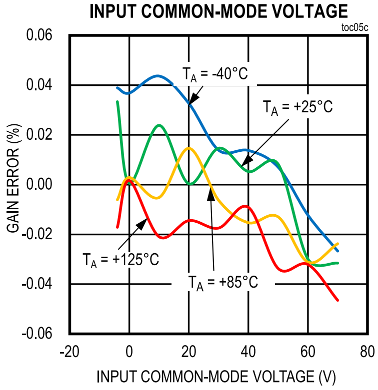
GAIN ERROR (G = 10) vs. INPUT COMMON-MODE VOLTAGE



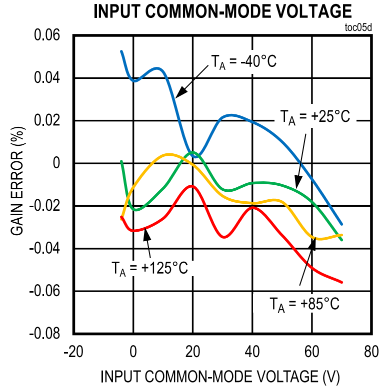
GAIN ERROR (G = 20) vs. INPUT COMMON-MODE VOLTAGE



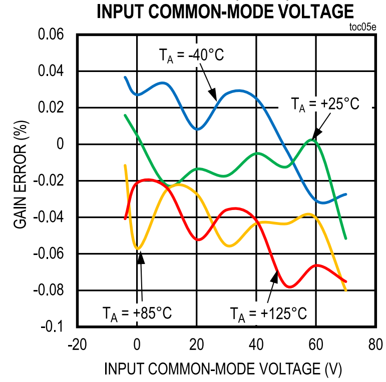
GAIN ERROR (G = 40) vs. INPUT COMMON-MODE VOLTAGE



GAIN ERROR (G = 50) vs. INPUT COMMON-MODE VOLTAGE

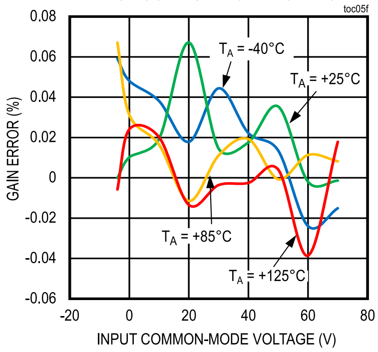


GAIN ERROR (G = 80) vs. INPUT COMMON-MODE VOLTAGE

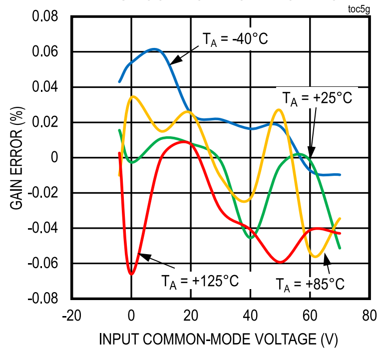


(V_{CM} = V_{RS+} = V_{RS-} = +50V, V_{DD} = +3.3V, V_{SENSE} = V_{RS+} - V_{RS-} = 0V, V_{REF1} = V_{DD}/2, V_{REF2} = V_{DD}/2, G = 20V/V, T_A = +25°C, unless otherwise noted.)

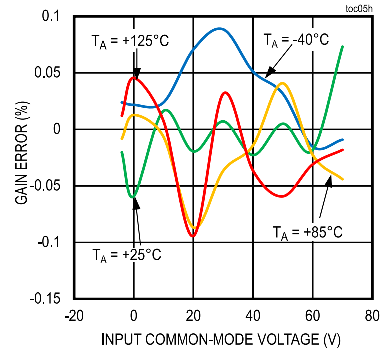
GAIN ERROR (G = 100) vs. INPUT COMMON-MODE VOLTAGE



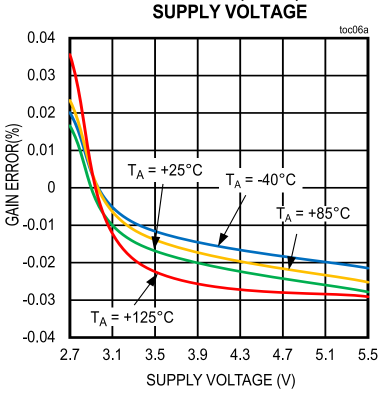
GAIN ERROR (G = 160) vs. INPUT COMMON-MODE VOLTAGE



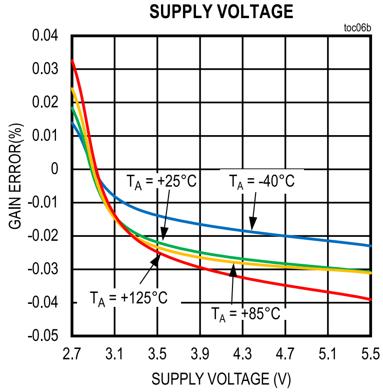
GAIN ERROR (G = 200) vs. INPUT COMMON-MODE VOLTAGE



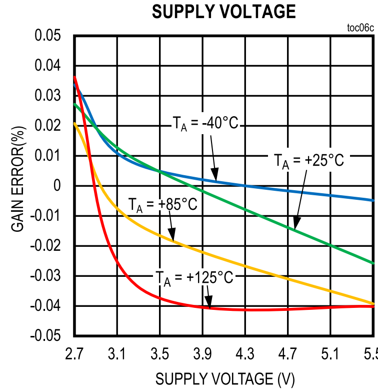
GAIN ERROR (G = 10) vs. SUPPLY VOLTAGE



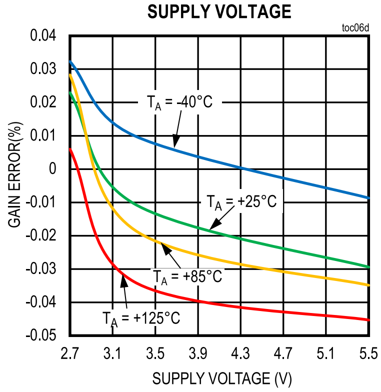
GAIN ERROR (G = 20) vs. SUPPLY VOLTAGE



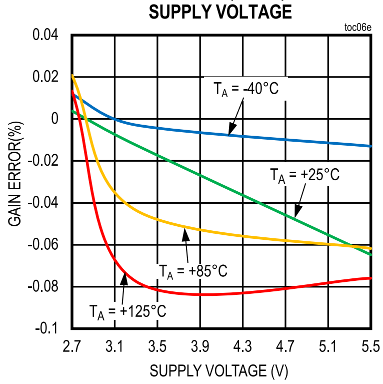
GAIN ERROR (G = 40) vs. SUPPLY VOLTAGE



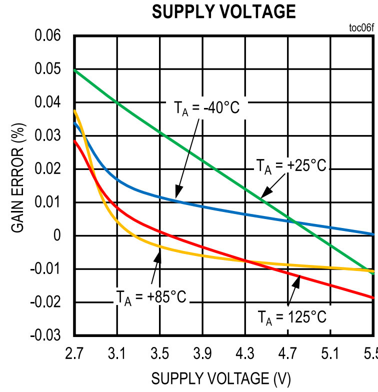
GAIN ERROR (G = 50) vs. SUPPLY VOLTAGE



GAIN ERROR (G = 80) vs. SUPPLY VOLTAGE

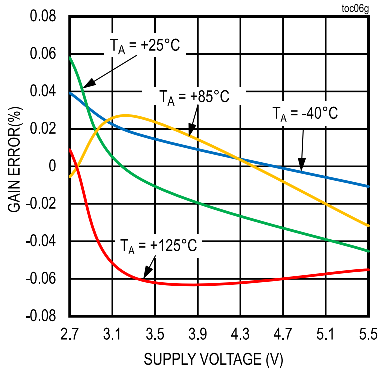


GAIN ERROR (G = 100) vs. SUPPLY VOLTAGE

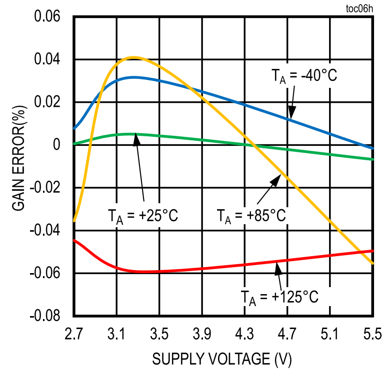


($V_{CM} = V_{RS+} = V_{RS-}$ = +50V, V_{DD} = +3.3V, $V_{SENSE} = V_{RS+} - V_{RS-}$ = 0V, $V_{REF1} = V_{DD}/2$, $V_{REF2} = V_{DD}/2$, G = 20V/V, T_A = +25°C, unless otherwise noted.)

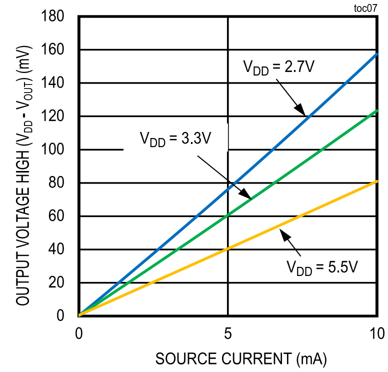
GAIN ERROR (G = 160) vs. SUPPLY VOLTAGE



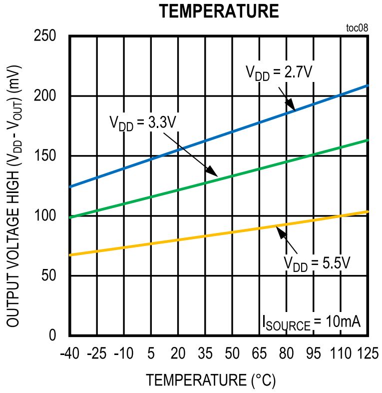
GAIN ERROR (G = 200) vs. SUPPLY VOLTAGE



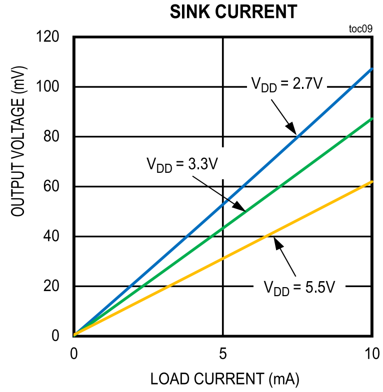
OUTPUT VOLTAGE HIGH vs. SOURCE CURRENT



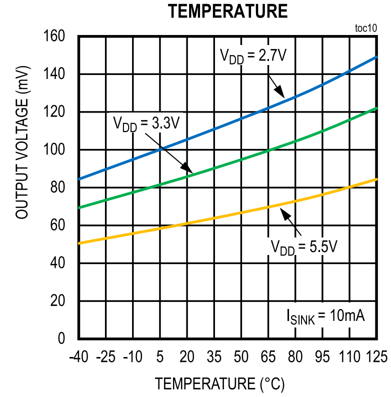
OUTPUT VOLTAGE HIGH vs. TEMPERATURE



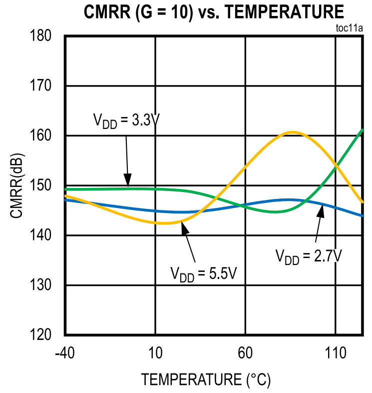
OUTPUT VOLTAGE LOW vs. SINK CURRENT



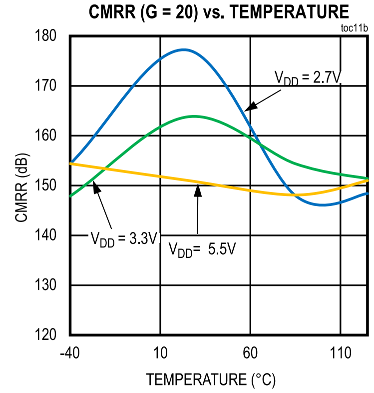
OUTPUT VOLTAGE LOW vs. TEMPERATURE



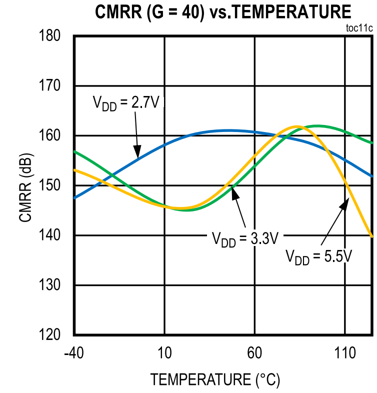
CMRR (G = 10) vs. TEMPERATURE



CMRR (G = 20) vs. TEMPERATURE

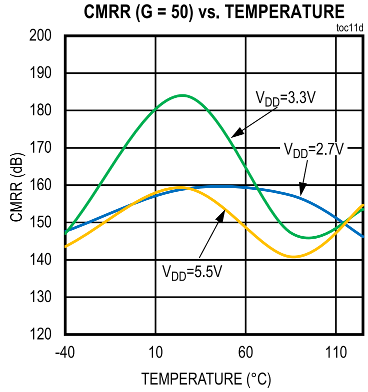


CMRR (G = 40) vs.TEMPERATURE

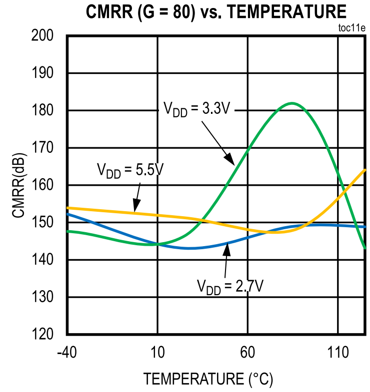


($V_{CM} = V_{RS+} = V_{RS-} = +50V$, $V_{DD} = +3.3V$, $V_{SENSE} = V_{RS+} - V_{RS-} = 0V$, $V_{REF1} = V_{DD}/2$, $V_{REF2} = V_{DD}/2$, G = 20V/V, $T_A = +25°C$, unless otherwise noted.)

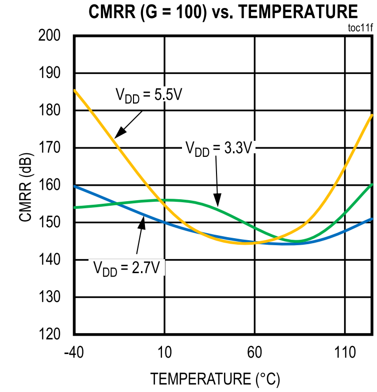
CMRR (G = 50) vs. TEMPERATURE



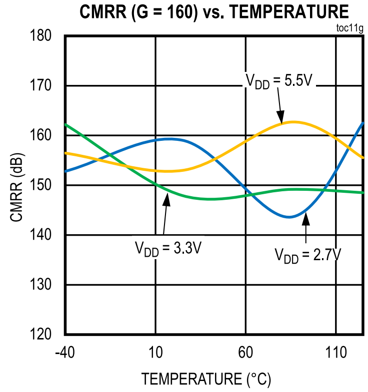
CMRR (G = 80) vs. TEMPERATURE



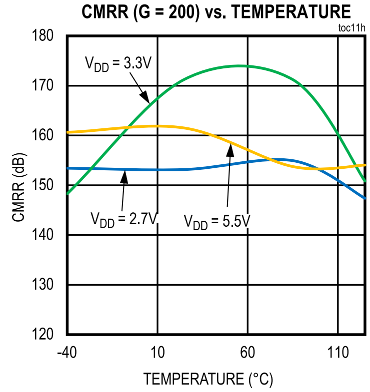
CMRR (G = 100) vs. TEMPERATURE



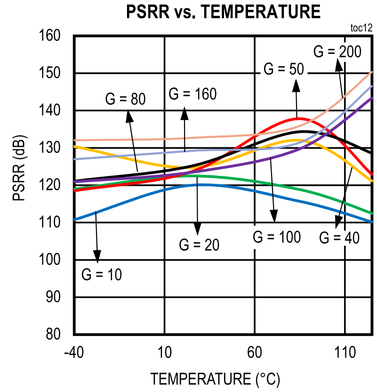
CMRR (G = 160) vs. TEMPERATURE



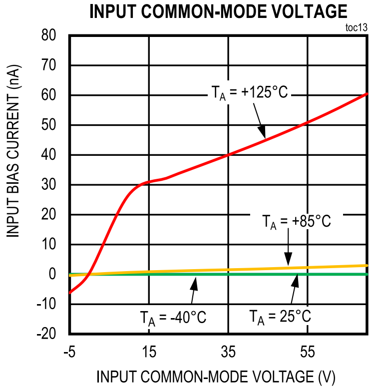
CMRR (G = 200) vs. TEMPERATURE



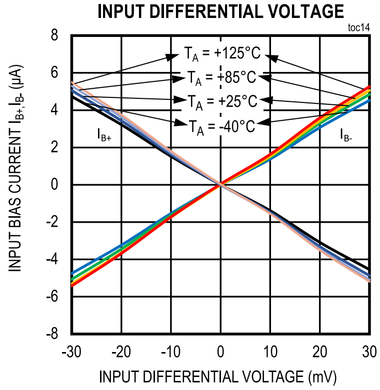
PSRR vs. TEMPERATURE



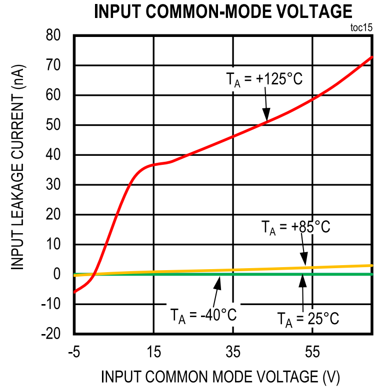
INPUT BIAS CURRENT vs. INPUT COMMON-MODE VOLTAGE



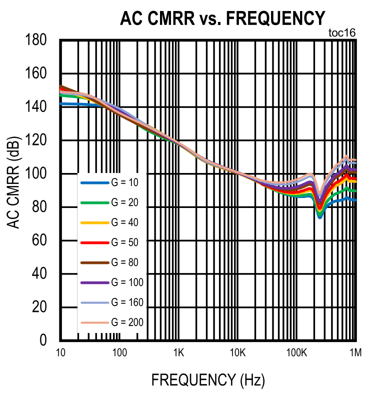
INPUT BIAS CURRENT vs. INPUT DIFFERENTIAL VOLTAGE

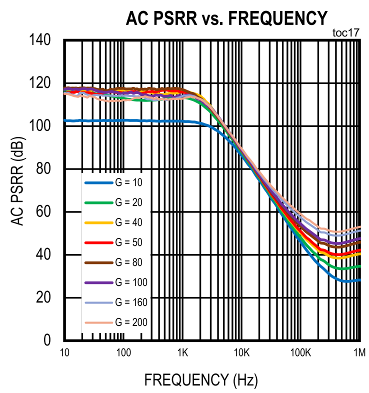


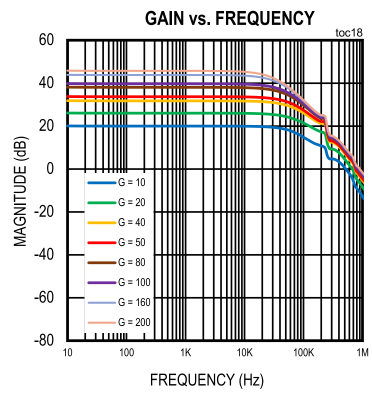
INPUT LEAKAGE CURRENT vs. INPUT COMMON-MODE VOLTAGE

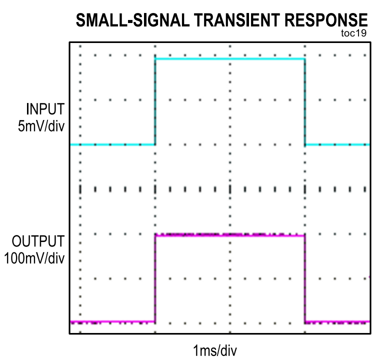


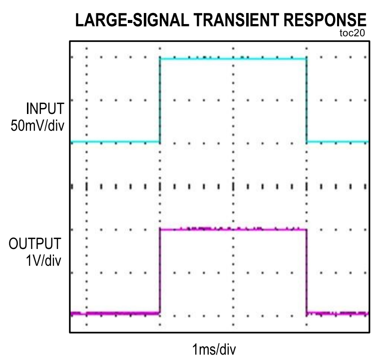
(V_{CM} = V_{RS+} = V_{RS-} = +50V, V_{DD} = +3.3V, V_{SENSE} = V_{RS+} - V_{RS-} = 0V, V_{REF1} = V_{DD}/2, V_{REF2} = V_{DD}/2, G = 20V/V, T_A = +25°C, unless otherwise noted.)

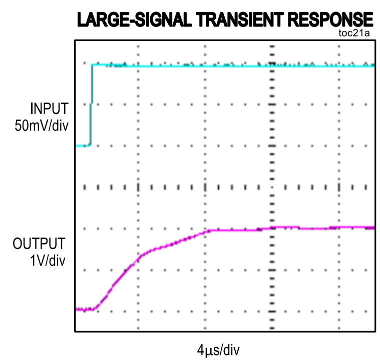


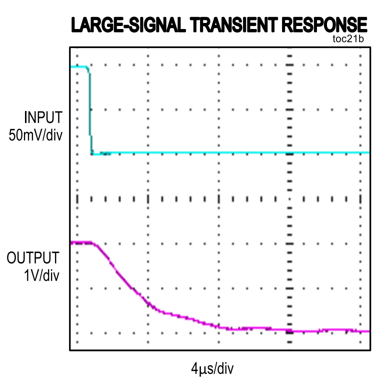


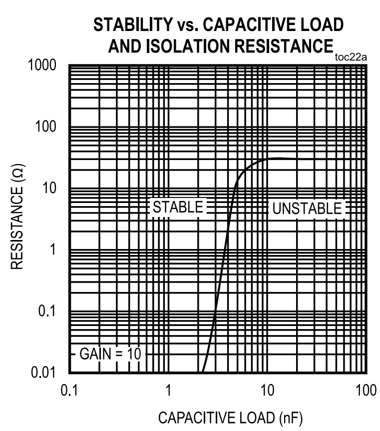


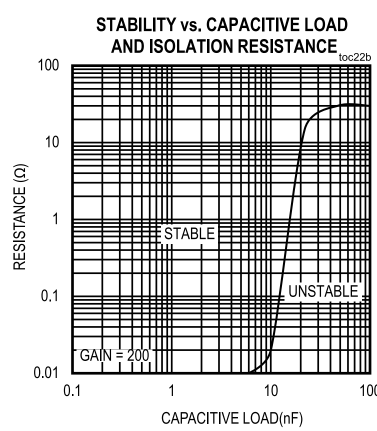




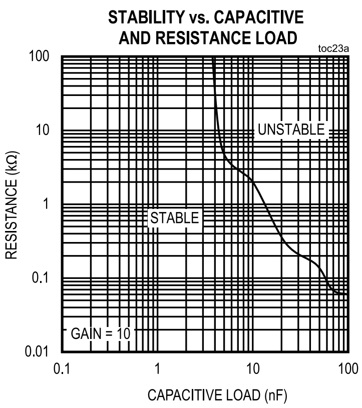


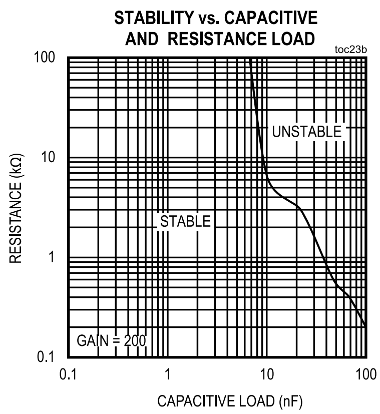


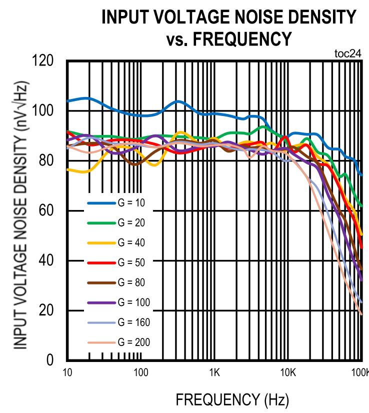




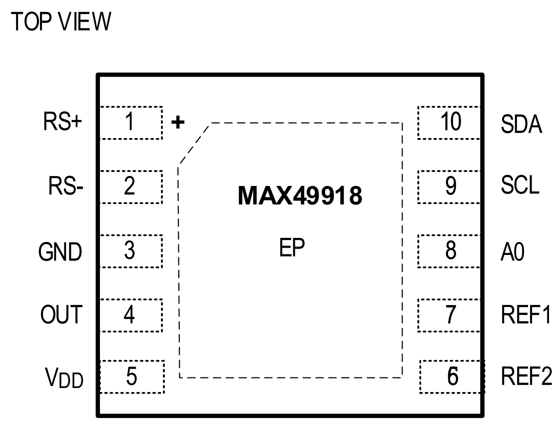
(V_{CM} = V_{RS+} = V_{RS-} = +50V, V_{DD} = +3.3V, V_{SENSE} = V_{RS+} - V_{RS-} = 0V, V_{REF1} = V_{DD}/2, V_{REF2} = V_{DD}/2, G = 20V/V, T_A = +25°C, unless otherwise noted.)







Pin Configurations



TDFN-10
3mm x 3mm

Pin Descriptions

PIN	NAME	FUNCTION
1	RS+	Positive Current-Sensing Input. Power side connects to external sense resistor.
2	RS-	Negative Current-Sensing Input. Load side connects to external sense resistor.
3	GND	Ground. Should be connected to a solid ground plane for best performance.
4	OUT	Current-Sense Voltage Output. V_{OUT} is proportional to V_{SENSE}.
5	VDD	Supply Voltage Input. Bypass V_{DD} to GND with a 0.1µF capacitor.
6	REF2	Reference 2 Input. REF2 and REF1 determine whether the device is used as uni or bidirectional.
7	REF1	Reference 1 Input. REF2 and REF1 determine whether the device is used as uni or bidirectional.
8	A0	I^2C Address as explained in the *Detailed Description* section.
9	SCL	I^2C Clock.
10	SDA	I^2C Data.
-	EP	Exposed Pad. Internally connected to GND.

Detailed Description

The MAX49918 is a high-precision current-sense amplifier (CSA) with an I^2C programmable gain option from 10V/V to 200V/V in 8 steps. The multiple programmable gain options offer maximum flexibility for the user to change gain on-the-fly.

The MAX49918 operating input common-mode ranges from -5V to +70V, with protections that extend down to -6V and up to +80V, thus providing protection against reverse-battery and high-voltage spikes.

The low input offset of ±1µV(typ) and low gain error of ±0.01%(typ) make the device well-suited for high-precision current measurements.

The MAX49918 operates from a supply voltage of +2.7V to +5.5V, with a typical quiescent supply at 0.7mA.

Programmable Gain

The MAX49918 features a programmable gain through I^2C. There are eight gain options with the following values in V/V: 10, 20, 40, 50, 80, 100, 160, and 200.

I^2C Device Address

The MAX49918 uses an input pin (A0) that determines the least-significative bit (LSB) of the I^2C device address word below.

BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
1	1	0	0	1	0	A0

I^2C Gain register

The register address to set the gain is 0x00. And the data to set the gain is in the table below.

GAIN	10	20	40	50	80	100	160	200
DATA (Hex)	0	1	2	3	4	5	6	7

Application Information

Output Voltage

The MAX49918 has two reference inputs (REF1 and REF2) to set the device in either unidirectional or bidirectional operation mode. Connect the REF1 and REF2 inputs to low-impedance voltage source(s) to set the MAX49918 output (V_{OUT}) reference level. Do not connect REF1 and REF2 inputs to any voltages lower than GND or higher than VDD. V_{REF} is defined as the average voltage of V_{REF1} and V_{REF2}, i.e., the output voltage refers to $V_{REF} = (V_{REF1} + V_{REF2})/2$.

Use the following equation to set the gain:

$V_{OUT} = V_{SENSE} \times GAIN + V_{REF}$

Where $V_{SENSE} = V_{RS+} - V_{RS-}$, and GAIN is the voltage gain of the MAX49918.

Ground-Referenced Output

Connect REF1 and REF2 inputs together and to ground. In this mode, the output is referenced to ground, and the output is taken to ground when the voltage drop across R_{SENSE} is 0V. The output voltage then increases proportionally to the voltage drop (V_{SENSE}) from RS+ to RS-.

V_{DD}-Referenced Output

Connect REF1 and REF2 inputs together and to V_{DD}. In this mode, the output is referenced to V_{DD}, or the output is taken to V_{DD} when the V_{SENSE} is 0V. The input V_{SENSE} must be negative to decrease the output voltage.

Setting Output to Mid-Supply Voltage

Connect REF1 to V_{DD} and REF2 to ground. In this mode, it creates a ratio-metric offset to the supply voltage, which means if V_{DD} increases or decreases, the output remains at $V_{DD}/2$ when there is no V_{SENSE}. This configuration is useful when external references are not available for offsetting the output.

Setting Output to Mid-External Reference

Connect one reference input pin to a reference voltage source and the other to ground. In this case, V_{OUT} refers to the external reference voltage divided by 2.

Setting Output to External Reference

Connect both reference input pins together to a reference voltage, which creates an output voltage equal to the reference voltage when the voltage drop across R_{SENSE} is zero. The output decreases when the input V_{SENSE} is negative. The output increases when the input V_{SENSE} is positive.

Ordering Information

PART NUMBER	DIE TYPE	PACKAGE	PACKAGE CODE
MAX49918IATB+T	OW05A-0A	TDFN-CU	T1033+1C

T = Tape-and-reel.

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	9/23	Initial release	—