SGM8194
Bidirectional, Low Power, Zero-Drift, Precision Current-Sense Amplifier

GENERAL DESCRIPTION

The SGM8194 series is a low power, high DC and AC CMRR, voltage output current-sense amplifier. This device is designed to provide optimal performance in battery management systems requiring over-current protection and precision current measurement. The SGM8194 can sense voltage drops across current-sense resistor with common mode voltage from -0.1V to 40V. The common mode voltage is independent with the power supply voltage due to its AC coupling and related signal sampling structure.

The SGM8194 features low input bias current, low offset voltage and zero-drift. The dynamic range is extended due to the latter two features when measuring current. Larger current-sense resistor can be used in mA level measurement application and it provides accurate current measurements. Small current-sense resistor is always used to reduce power loss in power efficiency sensitive systems. The SGM8194 can provide accurate current measurements in system where small current-sense resistor is used.

The SGM8194 series provides three fixed gains: 50V/V, 100V/V and 200V/V. It operates with a single power supply from 2.1V to 5.5V. When this device is enabled, it draws a 60μA typical power supply current, and it consumes only 10nA when disabled.

The SGM8194 is available in Green UTQFN-1.8×1.4-10L and SC70-6 packages. It is rated over the -40℃ to +125℃ temperature range.

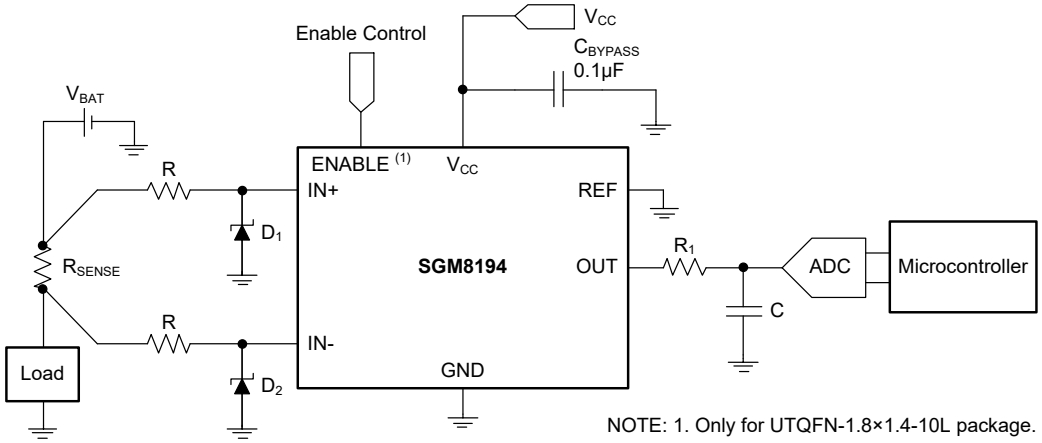
FEATURES

- **Operating Power Supply Range: 2.1V to 5.5V**
- **Common Mode Voltage Range: -0.1V to 40V**
- **CMRR: 150dB (TYP)**
- **Low Offset Voltage:**
  - **SGM8194A2: ±55μV (MAX)**
  - **SGM8194C3/A3/A4: ±50μV (MAX)**
- **Low Bias Current: ±0.5nA (TYP)**
- **Supply Current: 60μA (TYP)**
- **Shutdown Current: 10nA (TYP)**
- **Choice of Gains:**
  - **SGM8194A2 Gain: 50V/V**
  - **SGM8194C3 Gain: 100V/V**
  - **SGM8194A3 Gain: 100V/V**
  - **SGM8194A4 Gain: 200V/V**
- **Gain Error:**
  - **±0.55% (MAX) for SGM8194A2**
  - **±0.4% (MAX) for SGM8194A3/A4 (SC70-6 Package)**
  - **±0.45% (MAX) for SGM8194C3/A4 (UTQFN-1.8×1.4-10L Package)**
- **Supports Bidirectional Current Sense**
- **-40℃ to +125℃ Operating Temperature Range**
- **Available in Green UTQFN-1.8×1.4-10L and SC70-6 Packages**

APPLICATIONS

Battery Fuel Gauge
Notebook PC
Tablet PC

TYPICAL APPLICATION



NOTE: 1. Only for UTQFN-1.8×1.4-10L package.

Figure 1. Typical Application Circuit for Battery-Powered System

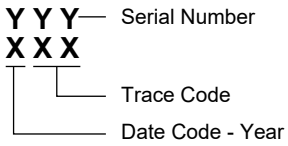
PACKAGE/ORDERING INFORMATION

MODEL	PACKAGE DESCRIPTION	SPECIFIED TEMPERATURE RANGE	ORDERING NUMBER	PACKAGE MARKING	PACKING OPTION
SGM8194A2 (Gain = 50V/V)	SC70-6	-40℃ to +125℃	SGM8194A2XC6G/TR	1FSXX	Tape and Reel, 3000
	UTQFN-1.8×1.4-10L	-40℃ to +125℃	SGM8194A2XUWQ10G/TR	SXI XXX	Tape and Reel, 3000
SGM8194C3 (Gain = 100V/V)	UTQFN-1.8×1.4-10L	-40℃ to +125℃	SGM8194C3XUWQ10G/TR	SXJ XXX	Tape and Reel, 3000
SGM8194A3 (Gain = 100V/V)	SC70-6	-40℃ to +125℃	SGM8194A3XC6G/TR	07VXX	Tape and Reel, 3000
SGM8194A4 (Gain = 200V/V)	UTQFN-1.8×1.4-10L	-40℃ to +125℃	SGM8194A4XUWQ10G/TR	SXK XXX	Tape and Reel, 3000
	SC70-6	-40℃ to +125℃	SGM8194A4XC6G/TR	07WXX	Tape and Reel, 3000

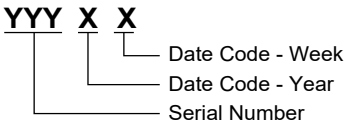
MARKING INFORMATION

NOTE: XX = Date Code. XXX = Date Code and Trace Code.

UTQFN-1.8×1.4-10L



SC70-6



Green (RoHS & HSF): SG Micro Corp defines "Green" to mean Pb-Free (RoHS compatible) and free of halogen substances. If you have additional comments or questions, please contact your SGMICRO representative directly.

ABSOLUTE MAXIMUM RATINGS

Supply Voltage, V_{CC} 6V
(V_{IN+}) - (V_{IN-}) Differential (1) ..... -42V to 42V
V_{IN+}, V_{IN-}, Relative to GND ..... GND - 0.3V to 42V
ENABLE, V_{ENABLE} ..... GND - 0.3V to 6V
REF, OUT ..... GND - 0.3V to V_{CC} + 0.3V
Package Thermal Resistance
UTQFN-1.8×1.4-10L, θ_{JA} ..... 110.8℃/W
UTQFN-1.8×1.4-10L, θ_{JB} ..... 29.7℃/W
SC70-6, θ_{JA} ..... 134.6℃/W
SC70-6, θ_{JB} ..... 44.7℃/W
Junction Temperature ..... +150℃
Storage Temperature Range ..... -65℃ to +150℃
Lead Temperature (Soldering, 10s) ..... +260℃
ESD Susceptibility (2) (3)
HBM (for UTQFN-1.8×1.4-10L Package) ..... ±4000V
HBM (for SC70-6 Package) ..... ±5000V
CDM ..... ±1000V

NOTES:

1. V_{IN+} and V_{IN-} indicates the voltage at the two input pins IN+ and IN- of the current-sense amplifier.

2. For human body model (HBM), all pins comply with ANSI/ESDA/JEDEC JS-001 specifications.

3. For charged device model (CDM), all pins comply with ANSI/ESDA/JEDEC JS-002 specifications.

RECOMMENDED OPERATING CONDITIONS

Operating Supply Voltage, V_{CC} ..... 2.1V to 5.5V
Input Common Mode Range, V_{CM} ..... GND - 0.1V to 40V
Input Pin Voltage Range, V_{IN+}, V_{IN-} ..... GND - 0.1V to 40V
Differential Input Voltage, V_{SENSE} = V_{IN+} - V_{IN-}
..... -(V_{CC} - 0.2V)/Gain to (V_{CC} - 0.2V)/Gain
Reference Pin Voltage Range, V_{REF} ..... GND to V_{CC}
Operating Temperature Range ..... -40℃ to +125℃

OVERSTRESS CAUTION

Stresses beyond those listed in Absolute Maximum Ratings may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect reliability. Functional operation of the device at any conditions beyond those indicated in the Recommended Operating Conditions section is not implied.

ESD SENSITIVITY CAUTION

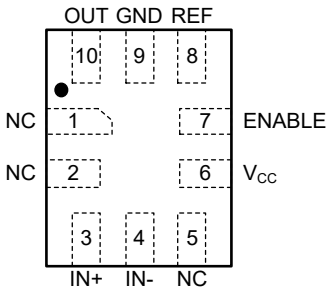
This integrated circuit can be damaged if ESD protections are not considered carefully. SGMICRO recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage. ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because even small parametric changes could cause the device not to meet the published specifications.

DISCLAIMER

SG Micro Corp reserves the right to make any change in circuit design, or specifications without prior notice.

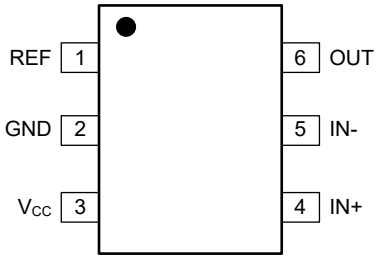
PIN CONFIGURATIONS

(TOP VIEW)



UTQFN-1.8×1.4-10L

(TOP VIEW)



SC70-6

PIN DESCRIPTION

PIN		NAME	TYPE	FUNCTION
UTQFN-1.8×1.4-10L	SC70-6			
1, 2, 5	—	NC	—	No Connection.
3	4	IN+	Analog Input	Non-Inverting Input of the Current-Sense Amplifier. To measure the current with high-side mode, please put this pin at the bus side of the sense resistor. To measure the current with low-side mode, please put this pin at the load side of the sense resistor.
4	5	IN-	Analog Input	Inverting Input of the Current-Sense Amplifier. To measure the current with high-side mode, please put this pin at the load side of the sense resistor. To measure the current with low-side mode, please put this pin at the ground side of the sense resistor.
6	3	V_{CC}	—	Power Supply. Voltage range is from 2.1V to 5.5V.
7	—	ENABLE	Digital Input	Enable Function. UTQFN-1.8×1.4-10L package only. Pull this pin to V_{CC} to enable the device by a pull-up resistor, and the device operates as a current-sense amplifier. Pull this pin to GND to disable the device, and the device turns into shutdown mode. Also, the shutdown current is extremely low and the high-impedance property is shown at the output. Connect this pin to V_{CC} if not used, and do not leave it floating, which means that this pin should be driven externally.
8	1	REF	Analog Input	Reference Input. Bidirectional current-sense can be realized if an external voltage is applied to this pin.
9	2	GND	—	Ground.
10	6	OUT	Analog Output	Output Pin. This pin is an analog voltage output pin, where $V_{OUT} = G \times (V_{IN+} - V_{IN-}) + V_{REF}$.

ELECTRICAL CHARACTERISTICS

(V_{CC} = 2.1V to 5V, V_{IN+} = 12V, V_{SENSE} = V_{IN+} - V_{IN-}, V_{REF} = V_{CC}/2, and V_{ENABLE} = V_{CC}, Full = -40℃ to +125℃, typical values are at T_A = +25℃, unless otherwise noted.)

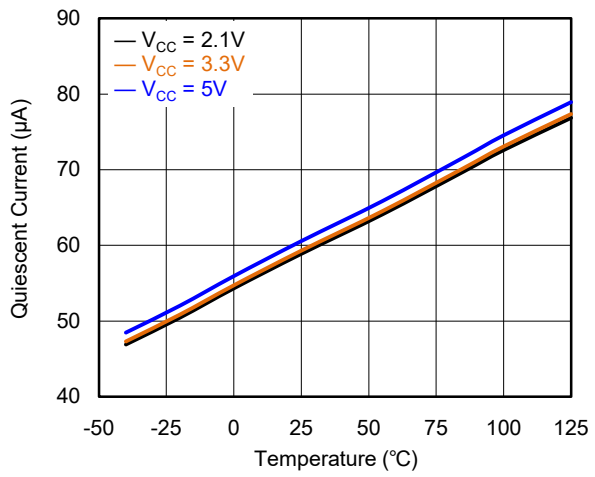
PARAMETER	SYMBOL	CONDITIONS		TEMP	MIN	TYP	MAX	UNITS
Input Characteristics								
Input Offset Voltage, RTI (1)	V_{OS}	V_{CC} = 2.1V, V_{SENSE} = 0mV	SGM8194A2	+25℃		±20	±55	μV
			SGM8194C3/A3/A4	+25℃		±15	±50	
Input Offset Voltage Drift, RTI	$\Delta V_{OS}/\Delta T$	V_{SENSE} = 0mV		Full		150	460	nV/℃
Input Bias Current	I_B	V_{SENSE} = 0mV		+25℃		±0.5	2	nA
Input Offset Current	I_{OS}	V_{SENSE} = 0mV		+25℃		±0.05		nA
Common Mode Rejection Ratio, RTI	CMRR	V_{SENSE} = 0mV, V_{IN+} = -0.1V to 40V		Full	120	150		dB
Output Characteristics								
Gain	G	SGM8194A2		+25℃		50		V/V
		SGM8194C3/SGM8194A3		+25℃		100		
		SGM8194A4		+25℃		200		
Gain Error	GE	V_{OUT} = 0.1V to V_{CC} - 0.1V	SGM8194A2	+25℃		0.01	±0.55	%
			SGM8194A3/A4: SC70-6	+25℃		0.01	±0.4	
			SGM8194C3/A4: UTQFN-1.8×1.4-10L	+25℃		0.01	±0.45	
Gain Error Drift				Full		10	20	ppm/℃
Nonlinearity Error		V_{CC} = 5V, V_{OUT} = 0.1V to V_{CC} - 0.1V		+25℃		±0.1		%
Reference Voltage Rejection Ratio, RTI	RVRR	V_{REF} = 0.1V to V_{CC} - 0.1V	SGM8194A2	Full		20	±85	μV/V
			SGM8194C3/A3/A4	Full		10	±50	
Maximum Capacitive Load		No sustained oscillation		+25℃		1		nF
Swing to V_{CC} Power Supply Rail	V_{SP}	V_{CC} = 2.1V, R_L = 10kΩ to GND		Full	V_{CC} - 0.07	V_{CC} - 0.05		V
Swing to GND	V_{SN}	V_{CC} = 2.1V, V_{SENSE} = -20mV, V_{REF} = 0V, R_L = 10kΩ to GND		Full		0.01	1	mV
Zero Current Output Voltage	V_{ZL}	V_{CC} = 2.1V, V_{SENSE} = 0mV, V_{REF} = 0V, R_L = 10kΩ to GND		Full		1.5	18	mV
Frequency Response								
Bandwidth	BW	C_{LOAD} = 10pF	SGM8194A2	+25℃		37		kHz
			SGM8194C3/A3	+25℃		30		
			SGM8194A4	+25℃		22		
Slew Rate	SR	V_{CC} = 5V, V_{OUT} = 0.5V to 4.5V	SGM8194A2	+25℃		0.15		V/μs
			SGM8194C3/A3/A4	+25℃		0.2		
Settling Time	t_S	From current step to within 1% of final value		+25℃		90		μs
Noise, RTI (1)								
Voltage Noise Density	e_n	f = 1kHz		+25℃		75		nV/√Hz
Enable (UTQFN-1.8×1.4-10L Package Only)								
Leakage Input Current	I_{EN}	0V ≤ V_{ENABLE} ≤ V_{CC}		+25℃		15	800	nA
High-Level Input Voltage	V_{IH}			+25℃	0.7 × V_{CC}			V
Low-Level Input Voltage	V_{IL}			+25℃			0.3 × V_{CC}	V
Hysteresis	V_{HYS}			+25℃		150		mV
Output Leakage when Disabled	I_{ODIS}	V_{CC} = 5V, V_{OUT} = 0V to 5V, V_{ENABLE} = 0V		+25℃		2	4	μA
Power Supply								
Quiescent Current	I_Q	V_{CC} = 2.1V, V_{SENSE} = 0mV, I_{OUT} = 0mA		+25℃		60	80	μA
Quiescent Current when Disabled	I_{QDIS}	V_{ENABLE} = 0V, V_{SENSE} = 0mV		+25℃		10	100	nA
Power Supply Rejection Ratio, RTI	PSRR	V_{CC} = 2.1V to 5.5V, V_{SENSE} = 0mV	SGM8194A2	+25℃		10	±35	μV/V
			SGM8194C3/A3/A4	+25℃		5	±20	

NOTE: 1. RTI = Referred-to-input.

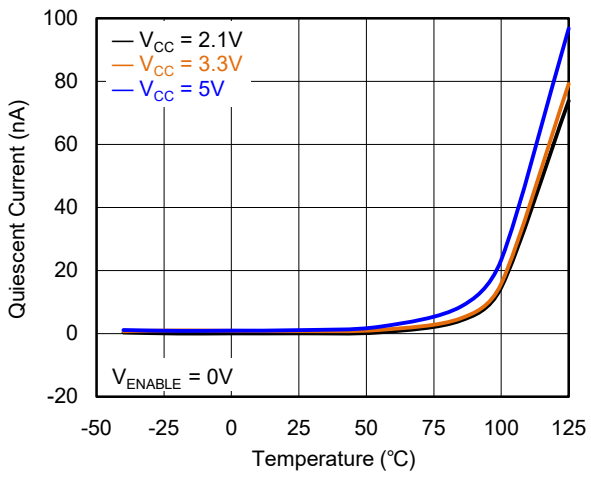
TYPICAL PERFORMANCE CHARACTERISTICS

At T_A = +25℃, V_{CC} = 5V, V_{IN+} = 12V, V_{REF} = V_{CC}/2, V_{ENABLE} = V_{CC}, and for all gain options, unless otherwise noted.

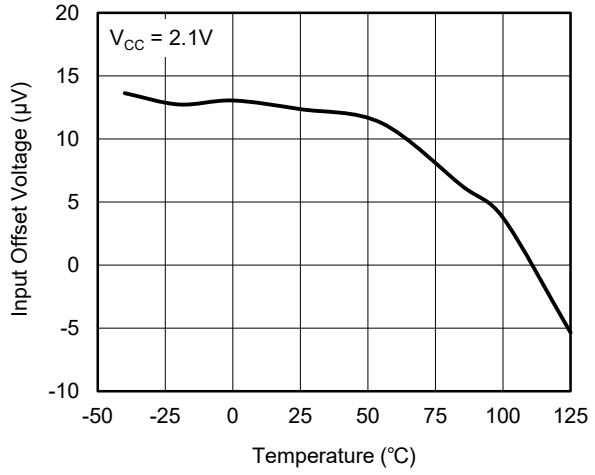
Quiescent Current vs. Temperature (Enabled)



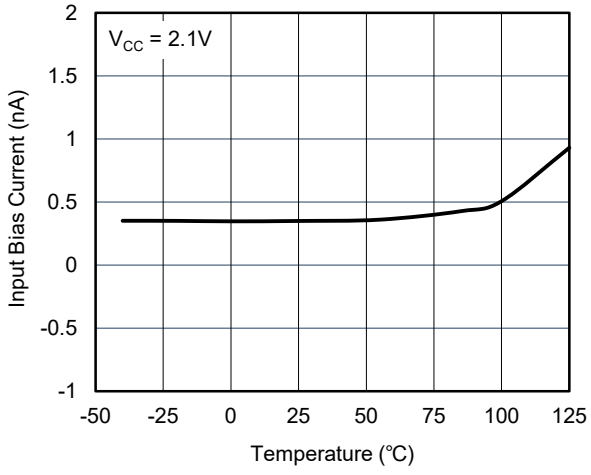
Quiescent Current vs. Temperature (Disabled)



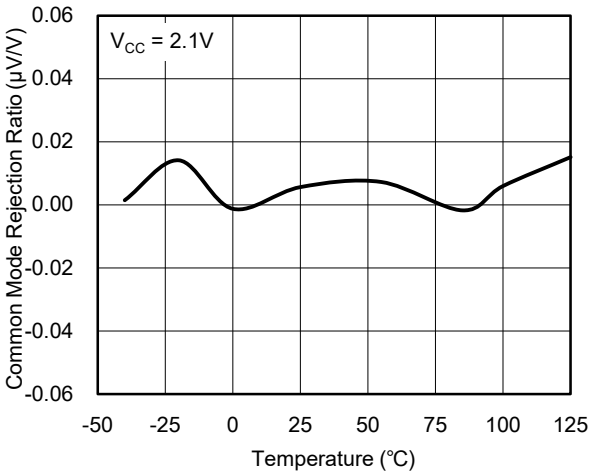
Input Offset Voltage vs. Temperature



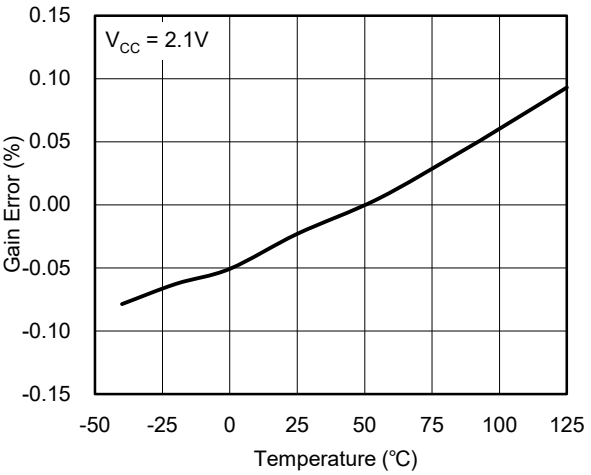
Input Bias Current vs. Temperature



CMRR vs. Temperature



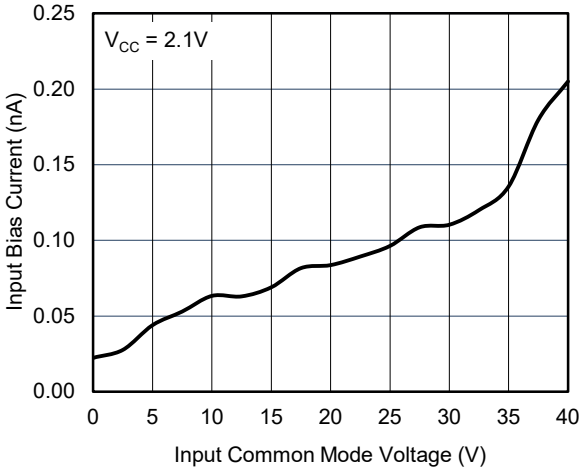
Gain Error vs. Temperature



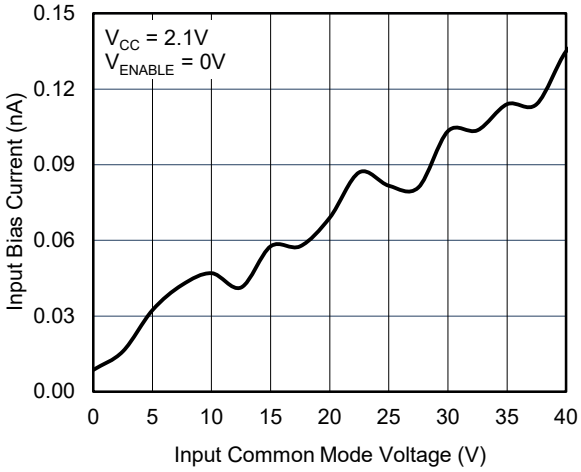
TYPICAL PERFORMANCE CHARACTERISTICS (continued)

At T_A = +25℃, V_{CC} = 5V, V_{IN+} = 12V, V_{REF} = V_{CC}/2, V_{ENABLE} = V_{CC}, and for all gain options, unless otherwise noted.

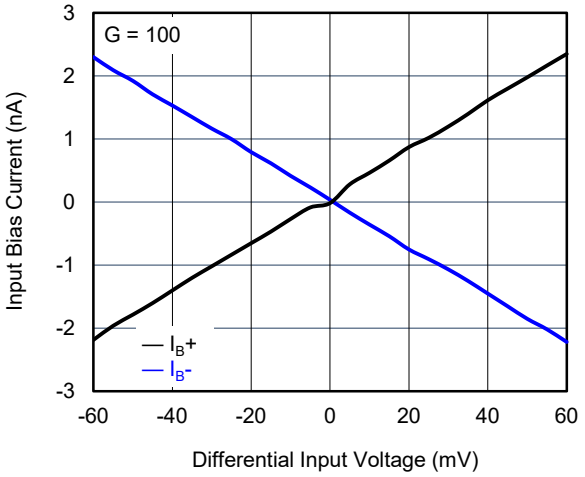
Input Bias Current vs. Input Common Mode Voltage



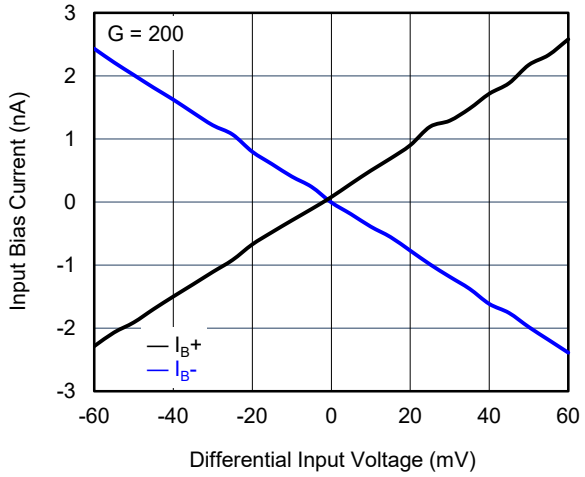
Input Bias Current vs. Input Common Mode Voltage (Shutdown)



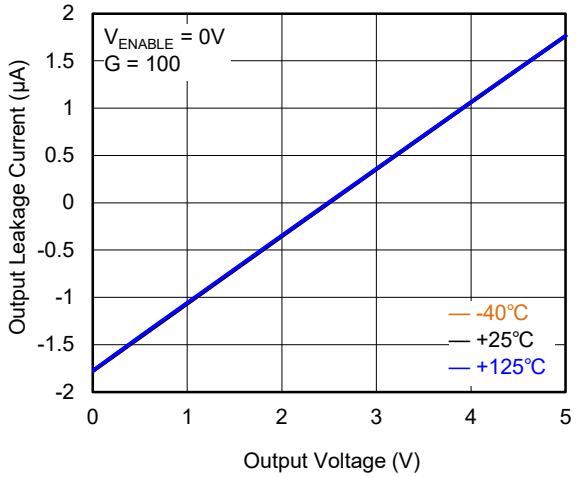
Input Bias Current vs. Differential Input Voltage



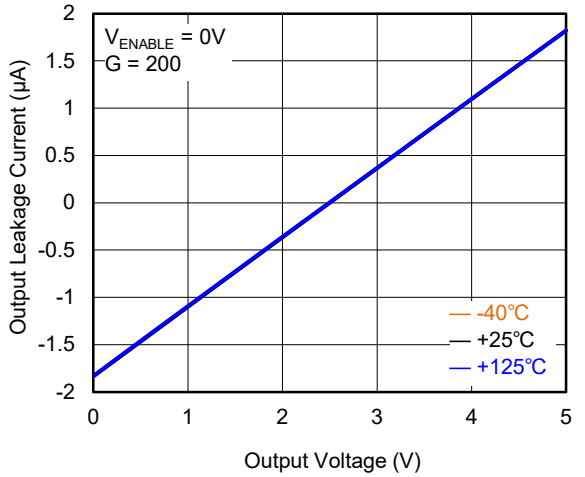
Input Bias Current vs. Differential Input Voltage



Output Leakage Current vs. Output Voltage



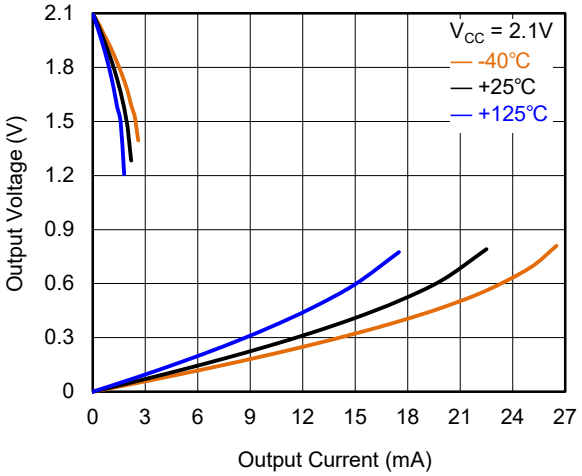
Output Leakage Current vs. Output Voltage



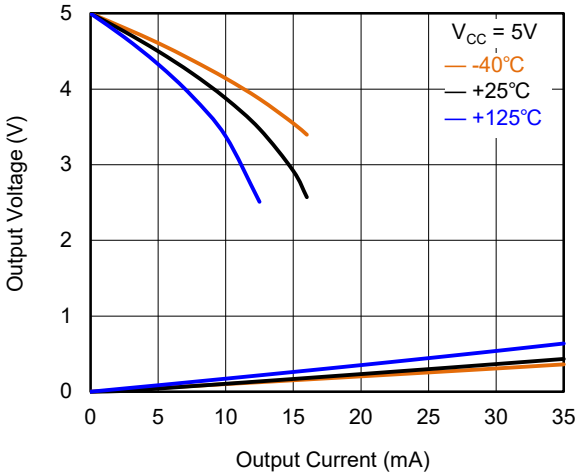
TYPICAL PERFORMANCE CHARACTERISTICS (continued)

At T_A = +25℃, V_{CC} = 5V, V_{IN+} = 12V, V_{REF} = V_{CC}/2, V_{ENABLE} = V_{CC}, and for all gain options, unless otherwise noted.

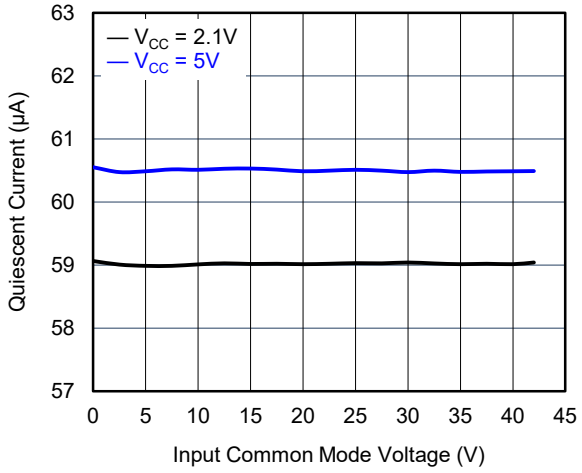
Output Voltage Swing vs. Output Current



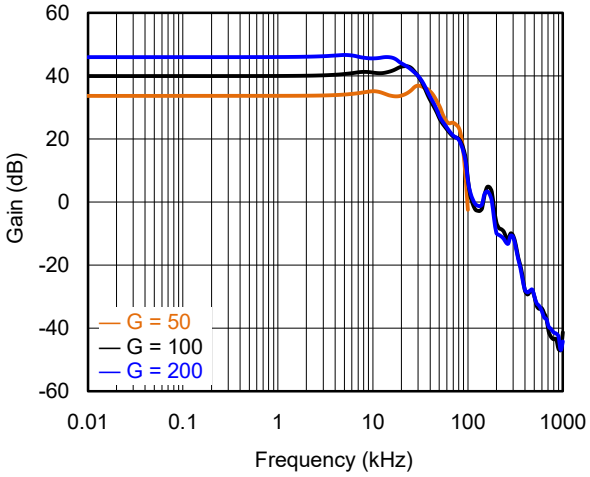
Output Voltage Swing vs. Output Current



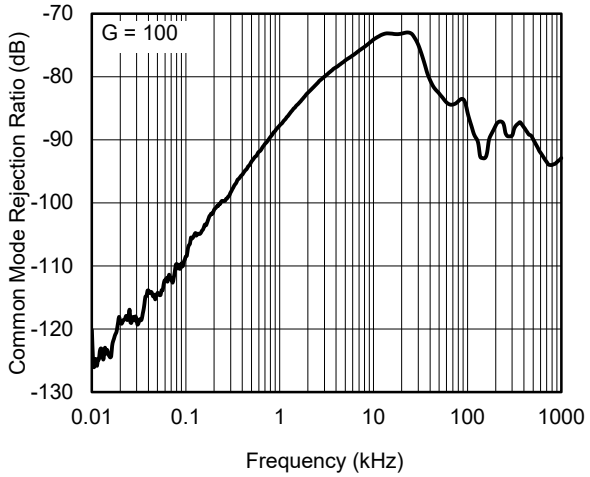
Quiescent Current vs. Input Common Mode Voltage



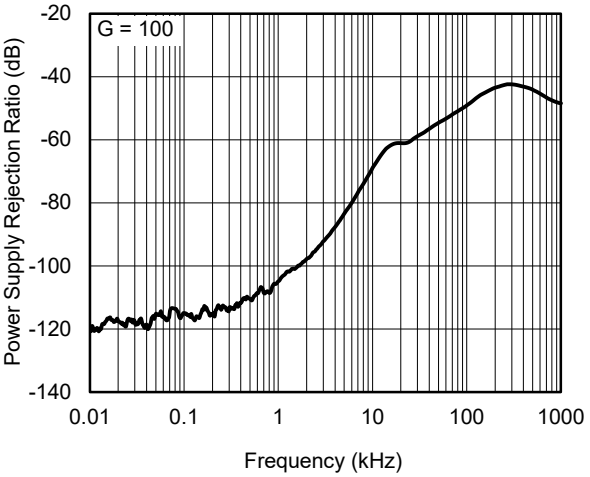
Gain vs. Frequency



CMRR vs. Frequency



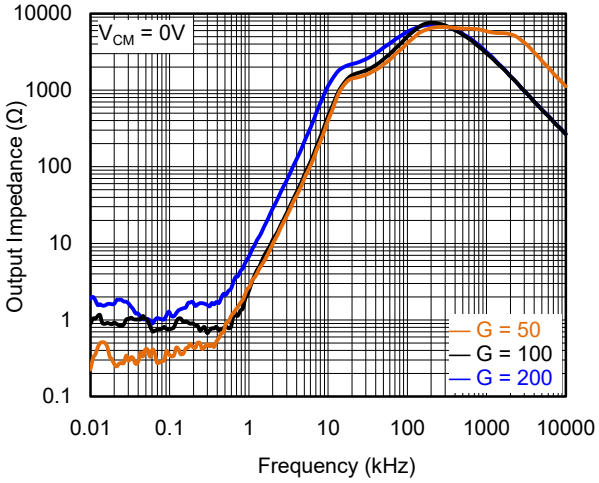
PSRR vs. Frequency



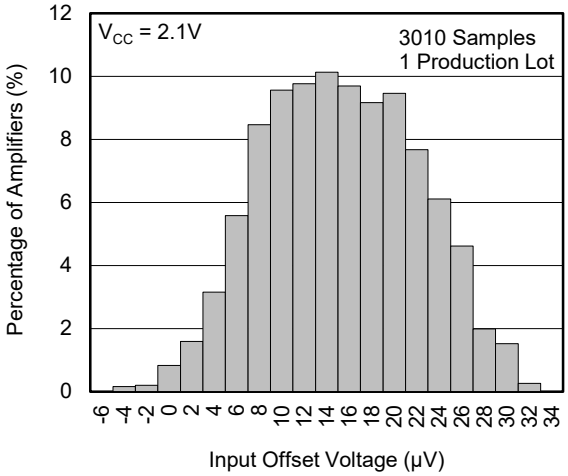
TYPICAL PERFORMANCE CHARACTERISTICS (continued)

At T_A = +25℃, V_{CC} = 5V, V_{IN+} = 12V, V_{REF} = V_{CC}/2, V_{ENABLE} = V_{CC}, and for all gain options, unless otherwise noted.

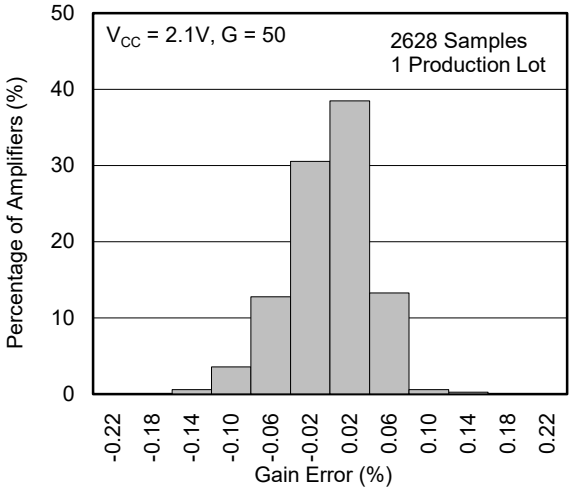
Output Impedance vs. Frequency



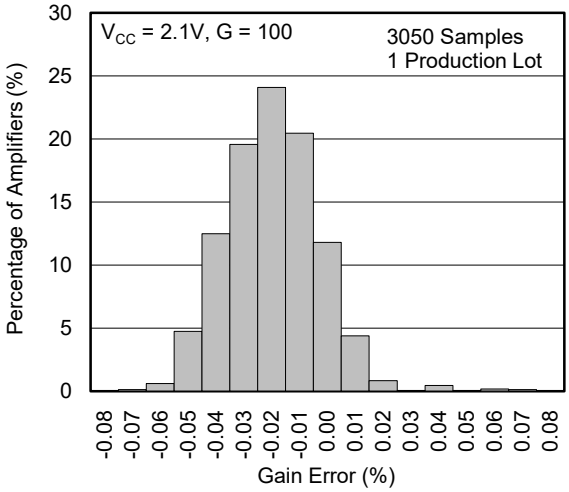
Input Offset Voltage Production Distribution



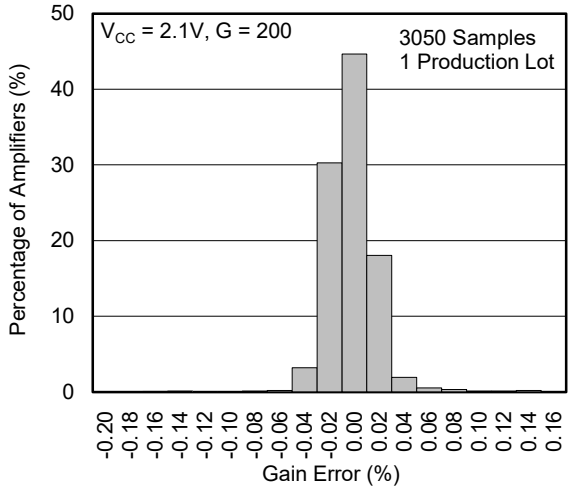
Gain Error Production Distribution



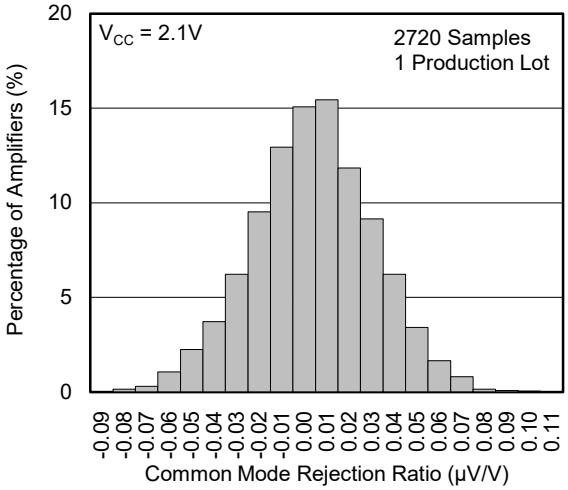
Gain Error Production Distribution



Gain Error Production Distribution



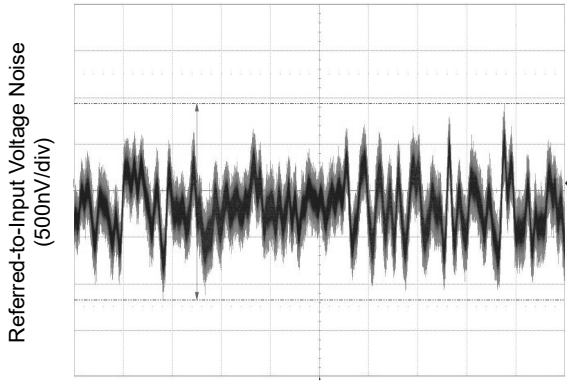
Common Mode Rejection Production Distribution



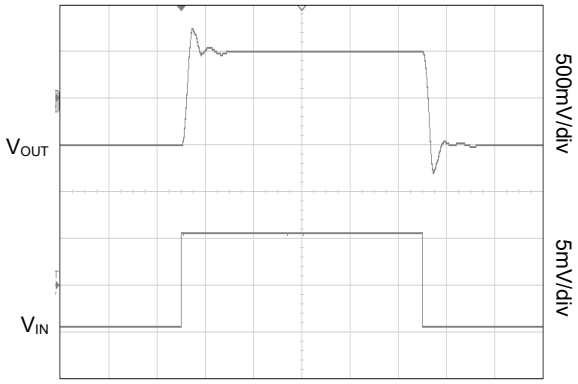
TYPICAL PERFORMANCE CHARACTERISTICS (continued)

At T_A = +25℃, V_{CC} = 5V, V_{IN+} = 12V, V_{REF} = V_{CC}/2, V_{ENABLE} = V_{CC}, and G = 100, unless otherwise noted.

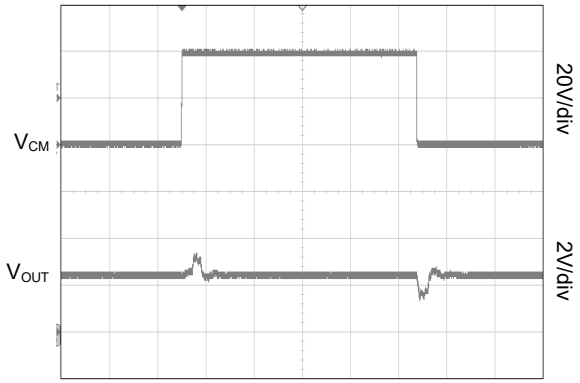
0.1Hz to 10Hz Voltage Noise (Referred-to-Input)



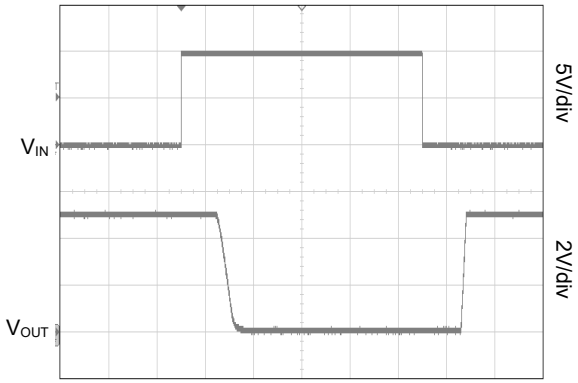
Step Response



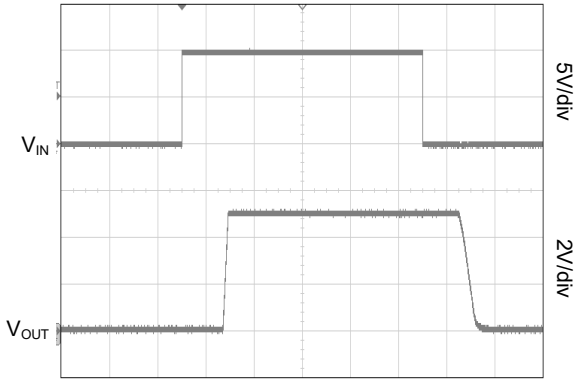
Common Mode Voltage Transient Response



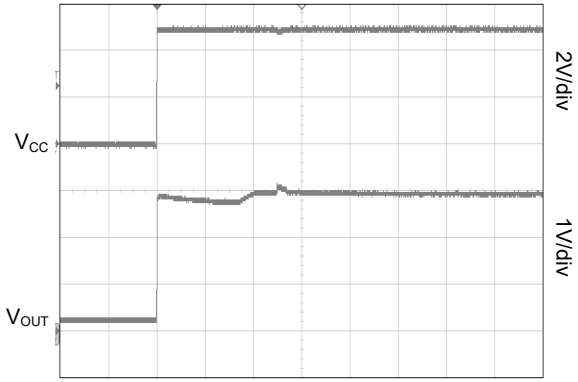
Inverting Differential Input Overload



Non-Inverting Differential Input Overload



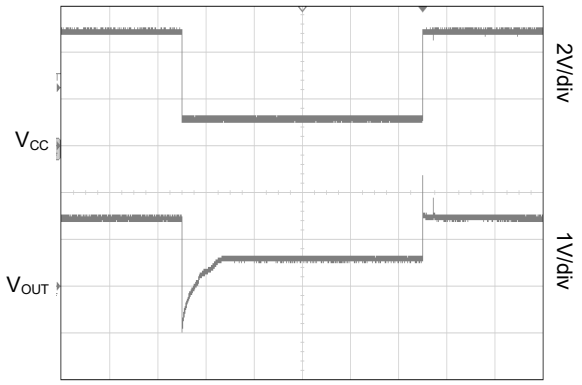
Start-Up Response



TYPICAL PERFORMANCE CHARACTERISTICS (continued)

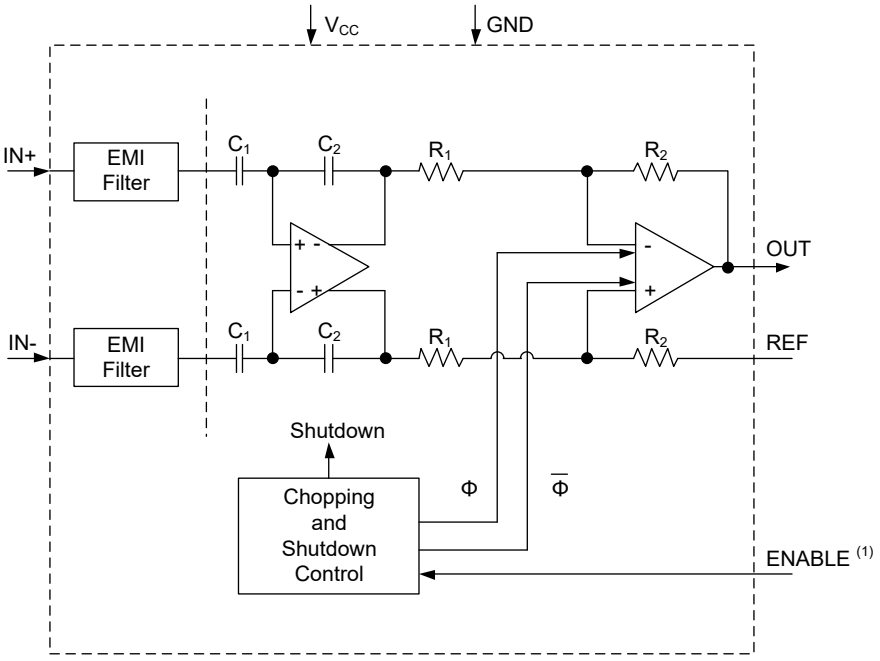
At T_A = +25℃, V_{CC} = 5V, V_{IN+} = 12V, V_{REF} = V_{CC}/2, V_{ENABLE} = V_{CC}, and G = 100, unless otherwise noted.

Brownout Recovery



Time (100μs/div)

FUNCTIONAL BLOCK DIAGRAM



NOTE: 1. Only for UTQFN-1.8×1.4-10L package.

Figure 2. Block Diagram

DETAILED DESCRIPTION

The SGM8194 is a high precision current-sense amplifier, which features extreme low offset voltage (V_{OS}) and bias current (I_B). The device also has the advantages of high common mode voltage (40V), high AC and DC CMRR. The UTQFN-1.8×1.4-10L package has an ENABLE pin, so the users can launch or shutdown the device with this pin externally. SGM8194 can measure the current with the common mode voltage which is much higher than the supply voltage. For example, the device can measure the current for a 40V system (common mode voltage) with 2.1V power supply voltage. When the ENABLE pin is in low state, the current which is from the power supply is dropped to 10nA. If the users desire to measure the current with lower current consumption and higher accuracy, SGM8194 is a good choice for both high- and low-side applications.

Feature Description

Precision Current Measurement

The accurate measurement can be allowed by SGM8194 for a wide range of common mode voltage because of the extreme low V_{OS} (±55μV (MAX) for SGM8194A2, ±50μV (MAX) for SGM8194C3/A3/A4) and gain error. The advantage of low V_{OS} is that the device can measure the current accurately for low sense voltage (V_{IN+} - V_{IN-}). Also, low V_{OS} of the device can allow low shunt resistance (R_{SENSE}) so the power loss at the measured circuit and the power efficiency is enhanced.

The maximum gain error is ±0.55% for SGM8194A2, ±0.4% for SGM8194A3/A4 (SC70-6 package), and ±0.45% for SGM8194C3/A4 (UTQFN-1.8×1.4-10L package). If the V_{SENSE} is much greater than V_{OS}, the gain error is dominant. If the output voltage for the measured current is approaching the full-scale of it, the total error is much closer to the gain error.

DETAILED DESCRIPTION (continued)

Low Input Bias Current

Compared with other current-sense amplifiers, the most significant advantage of SGM8194 is the extreme low bias current (I_B). The advantages of low I_B are shown as below:

One of the benefits is that low I_B can reduce the current consumption in both operation and shutdown mode. Typically, the I_B of normal current-sense amplifier is several microamps. The source of I_B is from the internal resistance and the needed current to bias the amplifier. In order to decrease the bias current I_B, the internal capacitance which is followed by a differential amplifier is taken into account.

For the second advantage of low I_B, it allows SGM8194 to use input filtering to filter out the noise from the measured line. For the classical topology of the current-sense monitor, the input filtering can increase the gain error dramatically as the effect of I_B. However, due to the extreme low I_B of the device, there is little effect on the output accuracy of SGM8194.

For the third advantage of low I_B, it allows SGM8194 to support larger current shunt resistor (R_{SENSE}), which means that the monitored current can be 1μA.

Low Quiescent Current with Output Enable

The quiescent current of 60μA is significant small although the small-signal bandwidth of 22kHz (G = 200V/V) is useful for a large range of applications. The above advantages can make SGM8194 operate in portable devices with better performance. In some applications, the current of the system needs to be measured periodically, rather than measuring all the time, so that it can use the ENABLE pin to switch the device for launching and disabling the device. The supply current is 10nA if SGM8194 is in shutdown mode.

Bidirectional Current Monitoring

The SGM8194 can measure the current with positive and negative directions by applying REF pin. For instance, if the direction of current flowing is positive, the output voltage will be greater than V_{REF}, and vice versa. The following equation shows the relationship between I_{LOAD} and V_{REF}.

$$V_{OUT} = (I_{LOAD} \times R_{SENSE} \times G) + V_{REF} \quad (1)$$

where:

I_{LOAD} is the measured current.

R_{SENSE} is the current-sense resistor.

G is the selected gain of SGM8194.

V_{REF} is the voltage of external offset at the REF pin.

High-side and Low-side Current Sense

The allowed common mode voltage at the input pins of SGM8194 is from -0.1V to 40V. If SGM8194 is used in high-side mode, the common mode voltage could be much larger than V_{CC}.

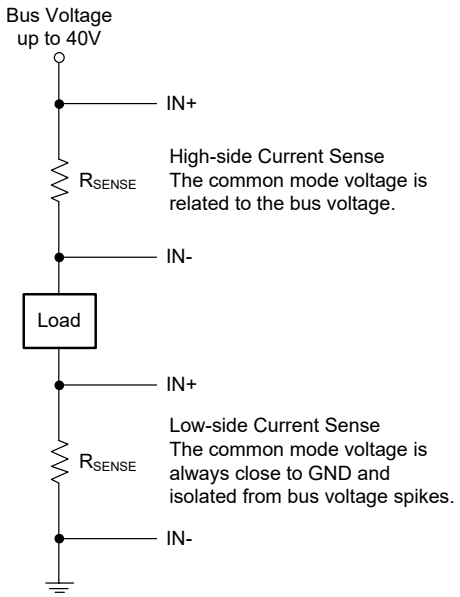


Figure 3. The Typical Connections of High-side and Low-side Mode

High Common Mode Rejection

The internal capacitance is coupled at the front end of the amplifier, which means that the DC voltage is blocked by this structure and provides high common mode rejection. The typical common mode rejection ratio (CMRR) of SGM8194 is 150dB. This ability can make little change of V_{OS} for both high- and low-side of common mode voltages.

Rail-to-Rail Output Swing

If the output voltage is approaching to the upper and lower supply rail, the linearity of the current-sense monitor can also be guaranteed. The V_{SP} (positive output swing from rail) of SGM8194 is V_{CC} - 0.05V and V_{SN} (negative output swing from rail) of SGM8194 is 0.01mV. For a 2.1V power supply application, small V_{SP} and V_{SN} are essential to provide a larger range of current measurement.

DETAILED DESCRIPTION (continued)

Device Functional Modes

Normal Operation

The following recommends should be met for operating SGM8194:

◆ The device should be powered within the voltage range from 2.1V to 5.5V.

◆ The supported common mode voltage range is from -0.1V to 40V.

◆ The maximum output voltage ($G \times V_{SENSE} + V_{REF}$) should be less than V_{CC} - 0.1V.

◆ The minimum output voltage ($G \times V_{SENSE} + V_{REF}$) should be greater than GND + 0.1V.

◆ The ENABLE pin should be externally driven or connected to V_{CC}.

For the typical application, the output voltage of SGM8194 is equal to the reference voltage (V_{REF}) plus the amplified differential voltage (V_{IN+} - V_{IN-}).

Unidirectional Mode

The voltage level of V_{REF} depends on whether the device can work bidirectional or unidirectional only. For the most commonly used case, the REF pin is connected to GND directly to make sure that the output voltage is close to 0V if no current flowing, which is unidirectional mode. If the current starts flowing, the output voltage is increased accordingly.

The linear range of SGM8194 depends on how close the output voltage can make if there is no current flowing. For lots of unidirectional applications (V_{REF} = 0V), the output voltage is close to 0V if there is no current flowing. However, if the differential input voltage multiplies the gain of SGM8194, and the value is less than 0V, the V_{REF} should be biased accordingly to make the output voltage within the linear region of operation. Moreover, the REF pin should be buffered by an external amplifier to limit the errors caused by the common mode rejection.

In some applications, the REF pin is connected to the power supply pin (V_{CC}), which means that the output voltage will be saturated at V_{CC} - 0.05V when there is no differential input voltage (no current flowing). And this method is similar to the case when REF pin is connected to the ground. For the application where V_{REF} = V_{CC}, the differential input should be negative, and the output level will decrease when the absolute value of negative input is increasing. However, the users need to make sure that the voltage applied to REF pin is less than or equal to the power supply voltage.

For another use of unidirectional application, the REF pin can be used to level shift the output voltage of SGM8194. In Figure 5, the GND pin is connected to -3.3V while the input differential voltage is biased at -3.3V as well, and this application is widely used in optical networking cards. The GND pin can be connected to a negative voltage as long as the input common mode voltage does not break the rule of specification. From the circuit, an ADC which is powered by positive supply voltage is connected at the end of the SGM8194 output. In order to protect the ADC from damage, the REF pin should be connected to GND to ensure that the output voltage level is positive. Since the output signal cannot be negative, the positive power supply must be powered up first, and then the negative power supply.

DETAILED DESCRIPTION (continued)

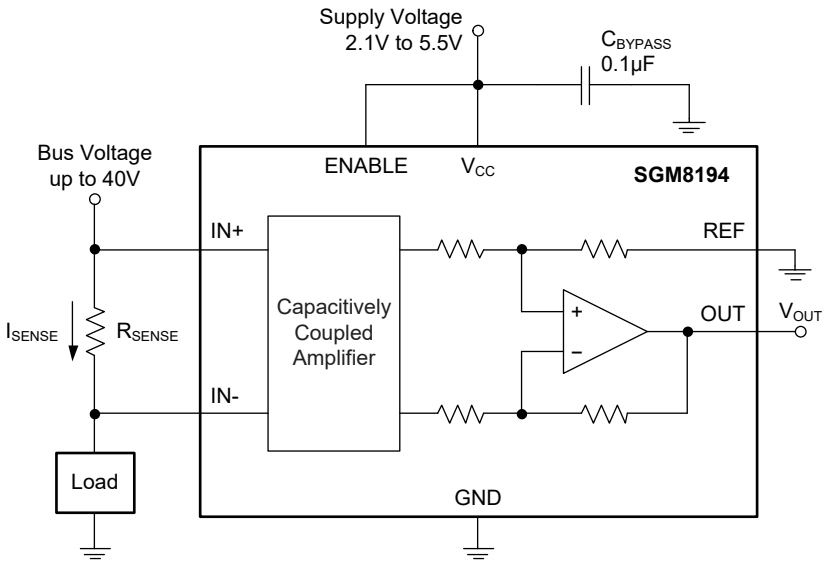


Figure 4. Typical Application of Unidirectional Mode

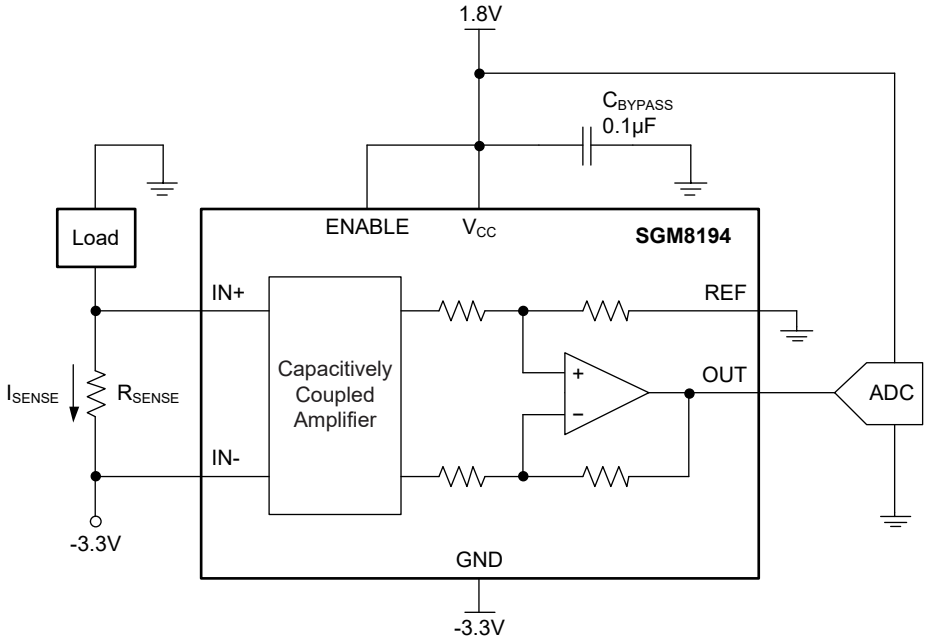


Figure 5. Level Shift Output Voltage with the REF Pin

DETAILED DESCRIPTION (continued)

Bidirectional Mode

Bidirectional application indicates that the current shunt monitor of SGM8194 can measure the current for two different directions. For this special case, the REF pin can be set anywhere between 0V and V_{CC} for the bias of output voltage. For simplification, it is recommended that V_{REF} = V_{CC}/2 should be a typical voltage point. However, if the absolute values of positive and negative current are not equal, the voltage of REF pin should be set other than V_{CC}/2.

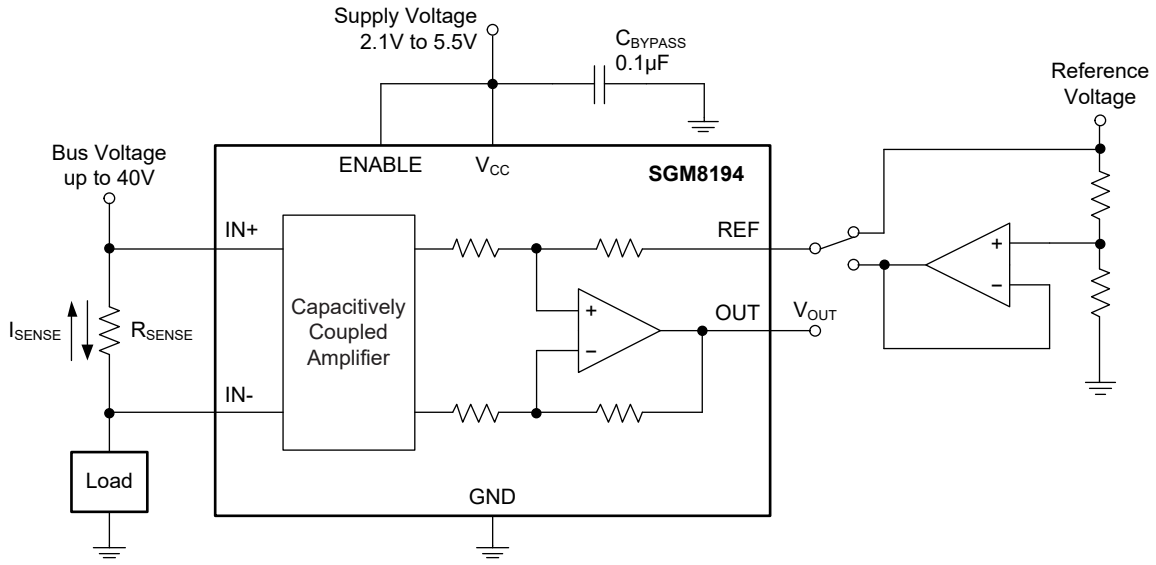


Figure 6. Application of Bidirectional Mode

Input Differential Overload

The users need to make sure that the differential input voltage multiplies gain is less than the maximum output swing of the amplifier, otherwise, it does not guarantee the accuracy of the application. For normal operation, if the differential input signal is overloaded, then please reduce the resistance of the shunt resistor. Moreover, if the overloaded condition is periodical or time-limited, the output can recover to normal with the time period of 160μs after the overload condition is disappear, which is the overload recovery time.

Shutdown

If the ENABLE pin is pulled to low level, SGM8194 will be in shutdown mode. When in shutdown mode, the quiescent current is 10nA (TYP) and the output of the current-sense amplifier is in high-impedance. By controlling the ENABLE pin of the device, the lifetime of the battery will be enhanced as the quiescent current in shutdown mode is significant small. Pulling up (to V_{CC}) the ENABLE pin can operate the device and the settling time of the output signal is around 300μs.

The high-impedance will be shown at the output when shutdown mode starts. Therefore, connecting the several SGM8194 together to the input of ADC is a good choice. Also, in this mode, only one of the amplifiers can operate, and these amplifiers should share only one power supply.

DETAILED DESCRIPTION (continued)

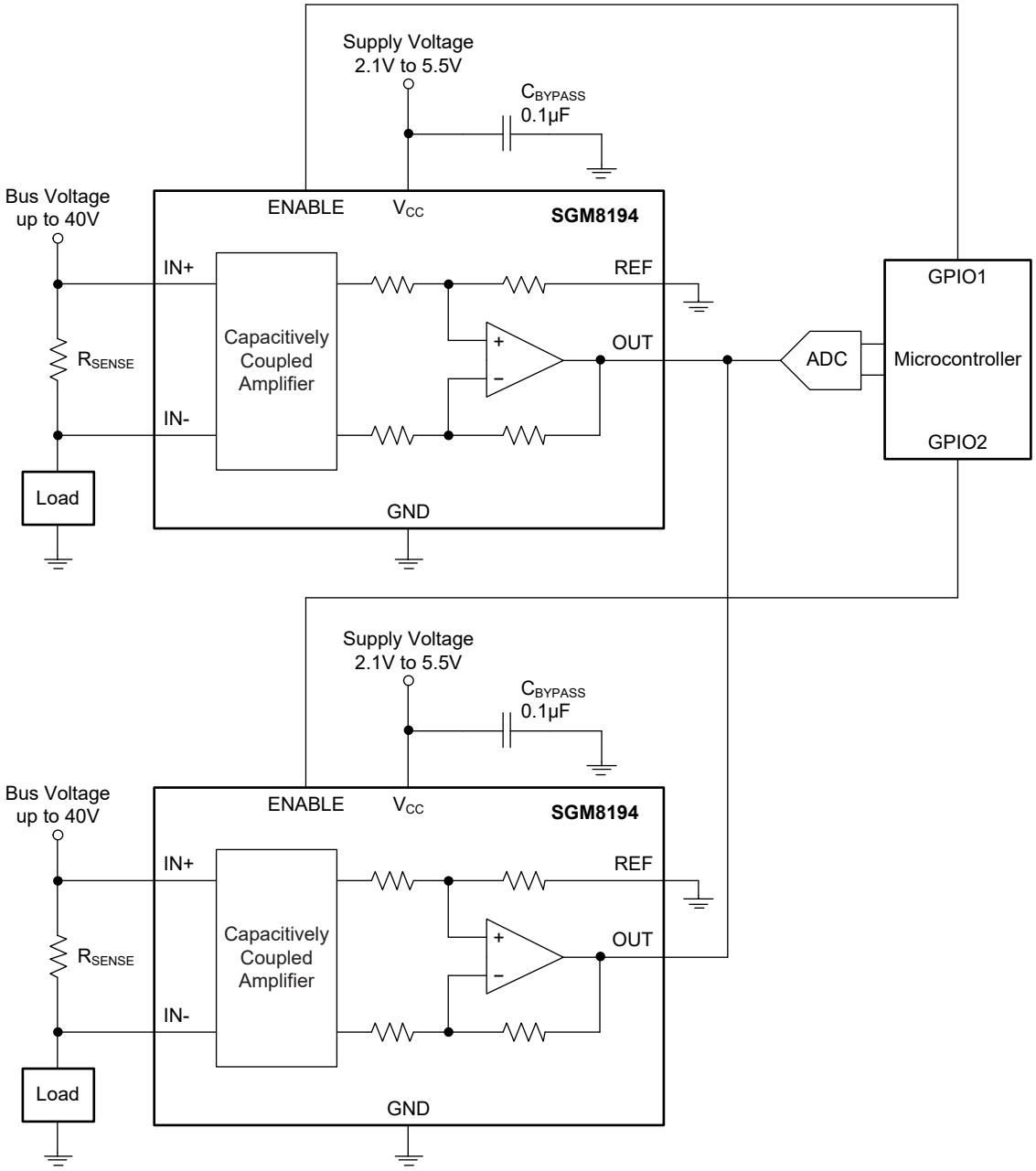


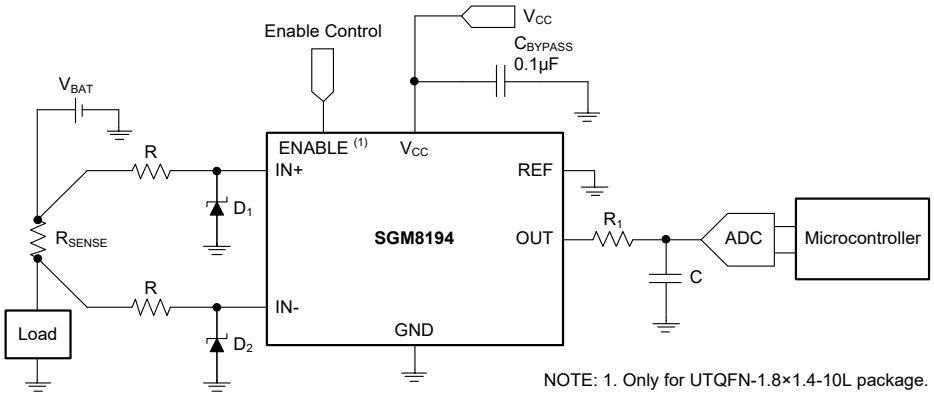
Figure 7. Multiplexing Multiple Devices with the ENABLE Pin

APPLICATION INFORMATION

The current-sense amplifier can amplify the differential input voltage which is across R_{SENSE}. The accuracy of the measurement can be guaranteed over a wide range of common mode voltage because of the high common mode rejection.

Basic Connections

The typical connection is shown in Figure 8. SGM8194 should be placed as close as possible to the shunt resistor with the connection of Kelvin. Also, the ENABLE pin of SGM8194 must be controlled externally or pulled up to V_{CC}.



NOTE: Connecting REF pin to the reference input of ADC is a good choice to decrease the offset from the ground. If a SAR ADC is taken into account, the output should be buffered by an amplifier at the front end of the input of ADC.

Figure 8. Typical Application Circuit for Battery-Powered System

R_{SENSE} and Selecting Device Gain

To improve the accuracy of current-sense amplifier when measuring the flowing current, a larger shunt resistor should be taken into account as the differential input voltage is maximized when current flowing. Therefore the output error caused by offset voltage is decreased. However, the shunt resistor is limited by the maximum allowable power dissipation. The following equation illustrates the maximum allowable R_{SENSE}:

$$R_{SENSE} < \frac{PD_{MAX}}{I_{MAX}^2} \quad (2)$$

where:

PD_{MAX} is the maximum power dissipation of a given R_{SENSE}.

I_{MAX} is the maximum value of the measured current.

The other limitation of the shunt resistor is the maximum output swing. To guarantee that the current-sense amplifier is operated within the linear region, the both positive and negative swing should be taken into account. The following equation illustrates the maximum allowable R_{SENSE}.

$$I_{MAX} \times R_{SENSE} \times G < V_{SP} - V_{REF} \quad (3)$$

where:

I_{MAX} is the maximum value of the measured current.

G is the selected gain of SGM8194.

V_{SP} is the voltage of positive output swing.

V_{REF} is the voltage of external offset at the REF pin.

To guarantee that the selected R_{SENSE} will not cause the output voltage to meet the maximum level of output swing, the users need to select R_{SENSE} accordingly. According to the equation of maximum power dissipation, if the selected R_{SENSE} is large for the allowable output swing, then it is recommended that selecting a lower gain of SGM8194 should be a good choice.

The negative output swing will limit the smallest size of R_{SENSE}. The calculation of the smallest R_{SENSE} is shown as below:

$$I_{MIN} \times R_{SENSE} \times G > V_{SN} - V_{REF} \quad (4)$$

where:

I_{MIN} is the minimum value of the measured current.

G is the selected gain of SGM8194.

V_{SN} is the voltage of negative output swing.

V_{REF} is the voltage of external offset at the REF pin.

Other than adjusting the value of R_{SENSE}, the users can also apply external voltage accordingly.

APPLICATION INFORMATION (continued)

Signal Conditioning

For noisy input applications, using a filter at the input is a good choice for accurate measurement. Also, the bias current of SGM8194 is extremely low. It is recommended to add a differential filter at the input of SGM8194, which will not affect the measurement accuracy. The advantage of adding input filter is that the input noise will not be amplified to the output stage. Figure 9 illustrates the circuit of adding a filter at the input of the device.

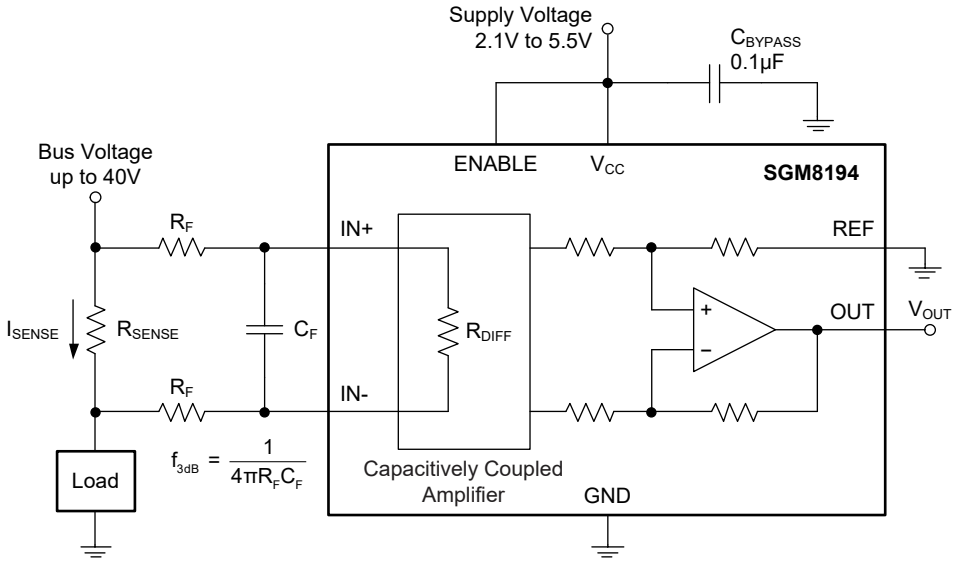


Figure 9. Filtering at Input

The maximum of R_F is limited by the resistance of R_{DIFF}. Figure 10 shows how the input impedance R_{DIFF} changes with the increasing of temperature.

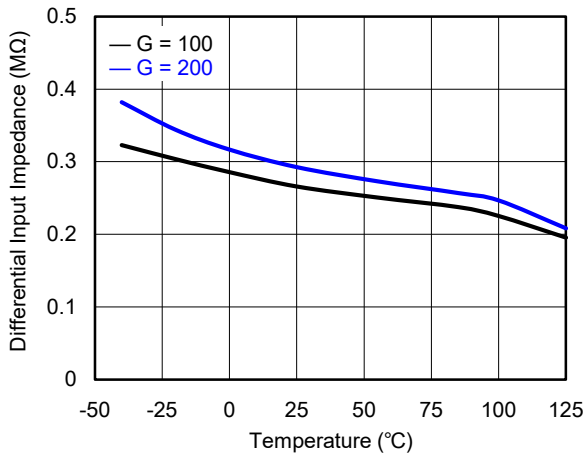


Figure 10. Differential Input Impedance vs. Temperature

If the input differential voltage V_{SENSE} increases with the increasing of measured current, the voltage drop between R_{DIFF} is increased as well. This voltage drop will increase the gain error of the current-sense amplifier. The error which is caused the divider of resistor is shown as below:

$$\text{Error (\%)} = \left(1 - \frac{R_{DIFF}}{R_{SENSE} + R_{DIFF} + (2 \times R_F)}\right) \times 100 \quad (5)$$

where:

R_{DIFF} is the differential input impedance.

R_F is the resistor which consists of the input filter.

Inside the device, there is an amplifier with capacitive feedback to guarantee the precision of DC. For example, the significant high differential input voltage (10mV or higher) with the time period of (higher or equal to hundreds of nanoseconds) would be amplified by the current-sense monitor, although the input transient is much larger than the bandwidth of SGM8194. So, the input filter should be taken into account to avoid these kinds of amplified input transient.

APPLICATION INFORMATION (continued)

The advantage of high R_{DIFF} and low I_B allows the application of input filter without affecting the accuracy of the measurement. For instance, if the users desire to design an RC filter at the input of SGM8194 with the corner frequency of 36.2kHz, the R_F and C_F which are 100Ω and 22nF respectively should be taken into account, which means that the unwanted signal can be filtered by it without influencing the bandwidth of SGM8194. Moreover, increasing the value of C_F can decrease the corner frequency.

Adding an RC filter at the output stage can also filter the noise from the common mode in high frequency. This RC filter is used to eliminate the noise from both common mode and differential, and the internal noise from the device as well. Also, the load impendence limits the allowable resistance of the output RC filter as there is a small voltage drop across the resistor of the RC filter.

Common Mode Voltage Transients

The SGM8194 can be powered by the common mode voltage whose power-on transient is higher than its absolute maximum value, especially for the application of automotive industry. For instance, it can be used at the case where the common mode voltage is negative. In this case, a Zener diode and a resistor can be used to prevent the current shunt monitor from negative common mode voltage. For instance, if a 1kΩ or less resistor is selected, the allowable common mode voltage could be as low as -5V, and the ESD current will be limited to 5mA. Using the application in Figure 11 is a good choice for more positive or negative voltage. It is recommended that the users use the Zener diodes or Zener-type transient absorbers rather than any others because of the significant time delay. However, any Zener diode needs extra operational resistors to provide the operating current, so the 100Ω resistors are selected (any large external resistor will affect the gain). Also, 100Ω resistors and a Zener diode with lowest rating of power are enough for handling the short-term transient in most applications.

If the low power Zener diode cannot protect the current shunt monitor from supply transient, a Transzorb with high power and back-to-back diodes must be taken into account in this case. For the applications of Figure 11 and Figure 12, the total area which is occupied by SGM8194 itself and its protective components is slightly larger than the MSOP-8 package, and smaller than SOIC-8 package.

APPLICATION INFORMATION (continued)

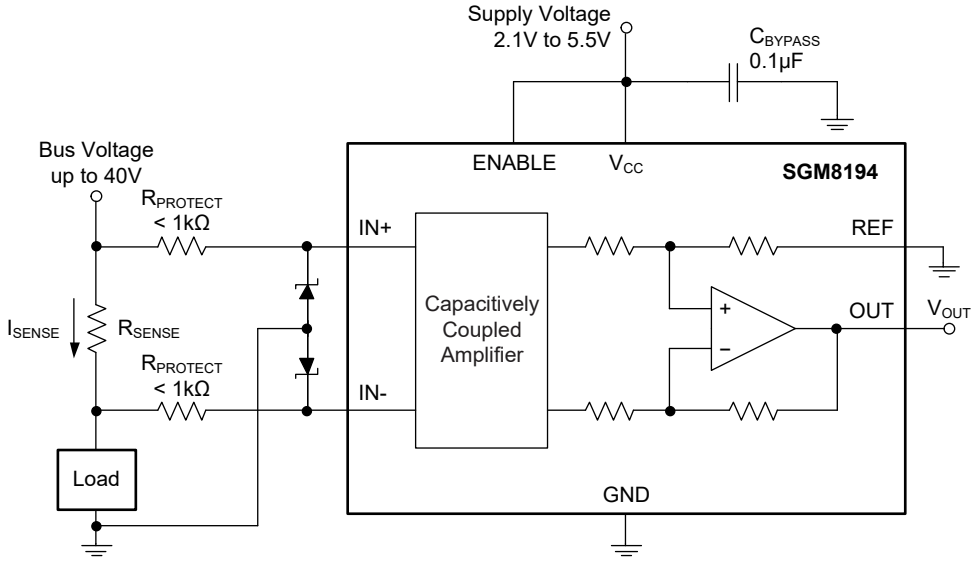


Figure 11. Using Dual Zener Diodes for Absorbing Supply Transient

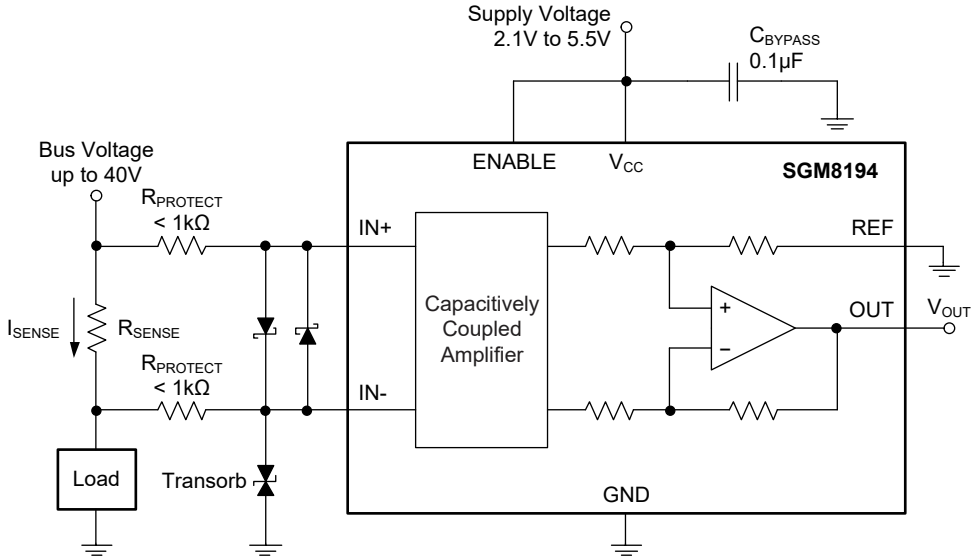


Figure 12. Using Transzorb and Input Clamps for Absorbing Supply Transient

APPLICATION INFORMATION (continued)

Typical Applications

Due to the extreme low input bias current of SGM8194, the measured current can be also extremely low. If the microamp current is required to be measured accurately, a large shunt resistor is required between two inputs for reducing the error caused by the offset voltage. The circuit shown in Figure 13 illustrates how to measure the low value current. For better accuracy, the shunt resistor which is at two inputs of SGM8194 should be less than or equal to 1kΩ.

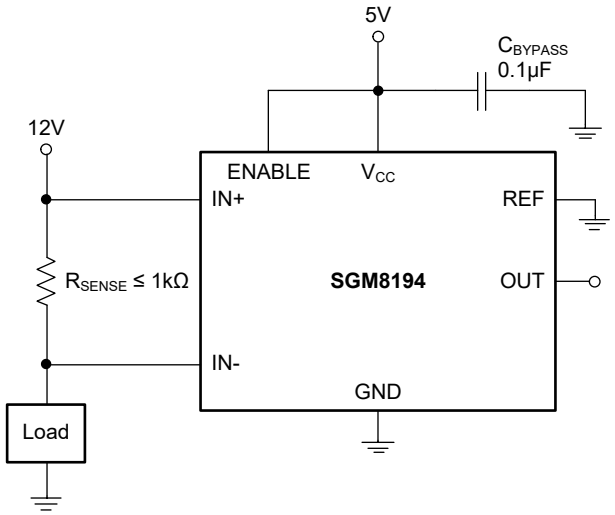


Figure 13. Microamp Current Measurement

Design Requirements

The requirement for low value current measurement is shown in the following table.

Table 1. Parameters of Low Value Current Measurement

Design Parameter	Example Value
Power Supply Voltage (V_{CC})	5V
Bus Supply Rail (V_{CM})	12V
Minimum Sense Current (I_{MIN})	1μA
Maximum Sense Current (I_{MAX})	37.5μA
Device Gain (G)	100V/V
Reference Voltage (V_{REF})	0V
Amplifier Current in Disabled State	< 1μA

Detailed Design Procedure

According to the selected gain, measured current and the power supply voltage of the application, the maximum value of R_{SENSE} needs to ensure that the output voltage is within the output swing. With the given parameters and the following equation, the calculated maximum R_{SENSE} is equal to 1.321kΩ.

$$R_{SENSE} < \frac{V_{SP}}{I_{MAX} \times G} \quad (6)$$

However, the recommendation for the shunt resistor is 1kΩ, which is the resistance that the users must be taken into account. Also, for the minimum current measurement, the users need to guarantee that the minimum value of output value is beyond the minimum output swing to GND. After calculation, with the minimum measured current, the calculated output voltage is 100mV, which is greater than its lowest output swing to GND.

$$V_{OUT(MIN)} = I_{MIN} \times R_{SENSE} \times G \quad (7)$$

Application Curve

Figure 14 illustrates the output voltage while measuring 10μA flowing current when launch or shutdown the device with ENABLE pin.

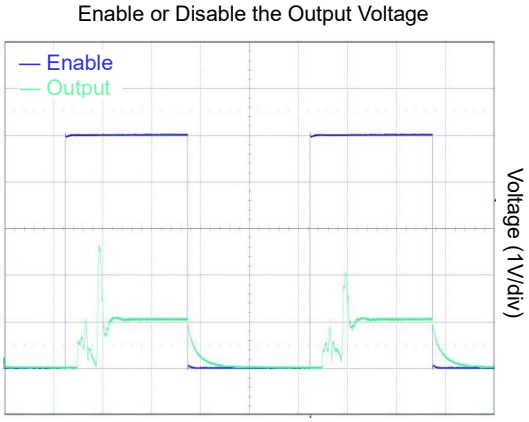


Figure 14. Enable or Disable the Output Voltage

APPLICATION INFORMATION (continued)

Power Supply Recommendations

The SGM8194 can accurately measure the current when the common mode voltage exceeds the power supply voltage presented at the V_{CC} pin. For example, the V_{CC} power supply can be 5V and the load or common mode power supply voltage is allowed to reach up to 40V. The output voltage range is limited by the level of the power supply.

Layout Guidelines

◆ The Kelvin or 4-wire connection should be taken into account between the shunt resistor and the input pins of the current-sense amplifier. The advantage of this kind of connection is to ensure that the measured resistance between IN+ and IN- is the shunt resistor only. The additional resistance would be detected if the poor routing is used. If the significant low resistance is taken into account as the shunt resistor, the output voltage will be significant high once the additional peak current takes place.

◆ The bypass capacitor should be close to the V_{CC} pin and GND, and 0.1μF bypass capacitor is recommended. For the noisy or high-impedance power supply, additional decoupling capacitor can also be taken into account.

◆ Moreover, the trace between the shunt resistor and the input pins of SGM8194 should be short. Also, if the input filter is considered, please place it as close as possible to the IN+ and IN- pins of SGM8194.

REVISION HISTORY

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

NOVEMBER 2025 – REV.A.3 to REV.A.4	Page
Updated Package/Ordering Information section	2

JUNE 2025 – REV.A.2 to REV.A.3	Page
Added SGM8194A2 information	All
Updated Absolute Maximum Ratings section	2

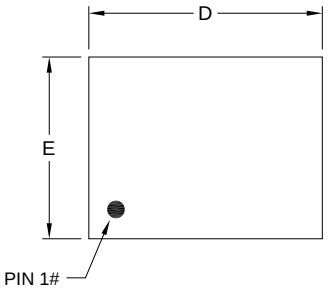
DECEMBER 2023 – REV.A.1 to REV.A.2	Page
Updated Package/Ordering Information section	2

OCTOBER 2023 – REV.A to REV.A.1	Page
Added UTQFN-1.8×1.4-10L package	All
Updated Electrical Characteristics section	4
Updated Typical Performance Characteristics section	5, 6

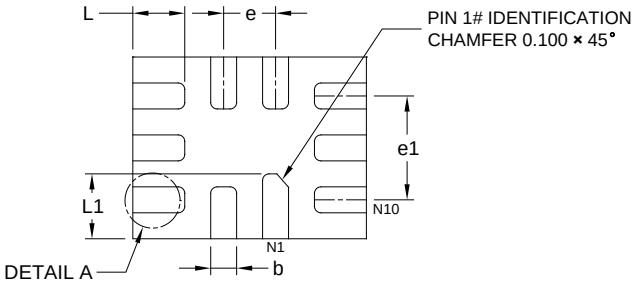
Changes from Original (JUNE 2023) to REV.A	Page
Changed from product preview to production data	All

PACKAGE OUTLINE DIMENSIONS

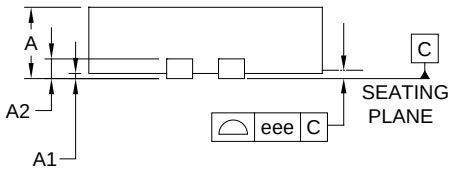
UTQFN-1.8×1.4-10L



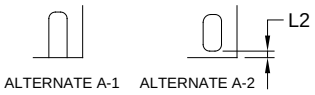
TOP VIEW



BOTTOM VIEW

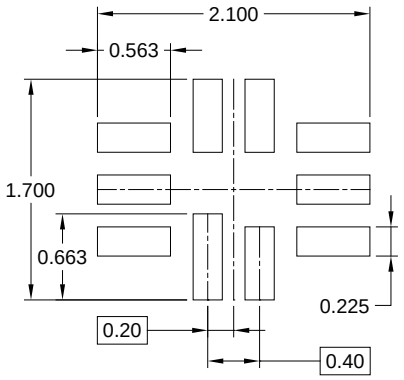


SIDE VIEW



DETAIL A

ALTERNATE TERMINAL CONSTRUCTION



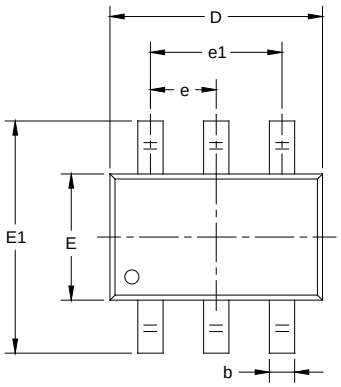
RECOMMENDED LAND PATTERN (Unit: mm)

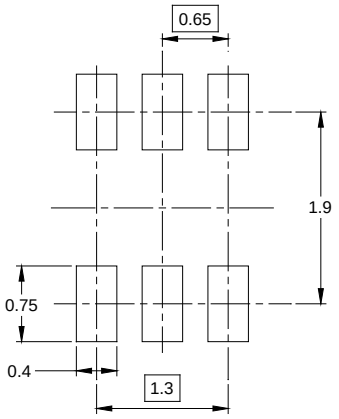
Symbol	Dimensions In Millimeters		
	MIN	MOD	MAX
A	0.450	-	0.600
A1	0.000	-	0.050
A2	0.152 REF		
b	0.150	0.200	0.250
D	1.750	1.800	1.850
E	1.350	1.400	1.450
e	0.400 TYP		
e1	0.800 REF		
L	0.350	0.400	0.450
L1	0.450	0.500	0.550
L2	0.000	-	0.100
eee	-	0.080	-

NOTE: This drawing is subject to change without notice.

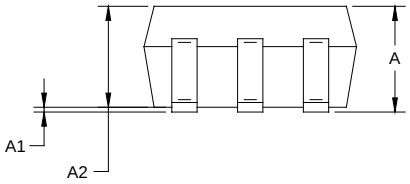
PACKAGE OUTLINE DIMENSIONS

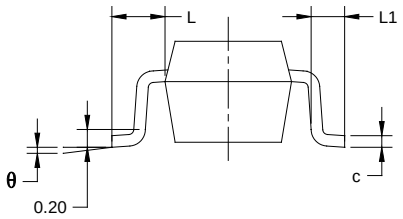
SC70-6





RECOMMENDED LAND PATTERN (Unit: mm)



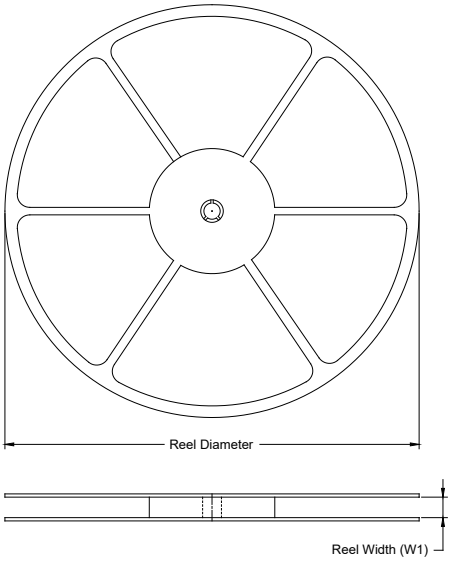


Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.800	1.100	0.031	0.043
A1	0.000	0.100	0.000	0.004
A2	0.800	1.000	0.031	0.039
b	0.150	0.350	0.006	0.014
c	0.080	0.220	0.003	0.009
D	2.000	2.200	0.079	0.087
E	1.150	1.350	0.045	0.053
E1	2.150	2.450	0.085	0.096
e	0.65 TYP		0.026 TYP	
e1	1.300 BSC		0.051 BSC	
L	0.525 REF		0.021 REF	
L1	0.260	0.460	0.010	0.018
θ	0°	8°	0°	8°

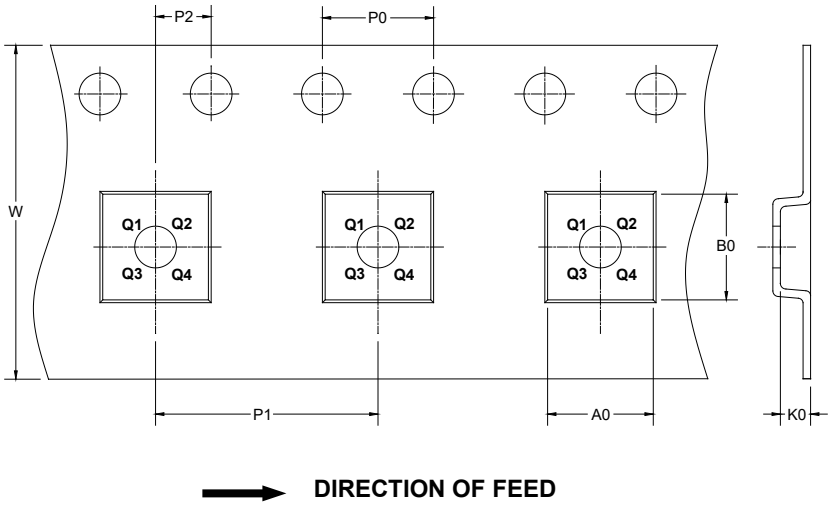
NOTES:
1. Body dimensions do not include mode flash or protrusion.
2. This drawing is subject to change without notice.

TAPE AND REEL INFORMATION

REEL DIMENSIONS



TAPE DIMENSIONS



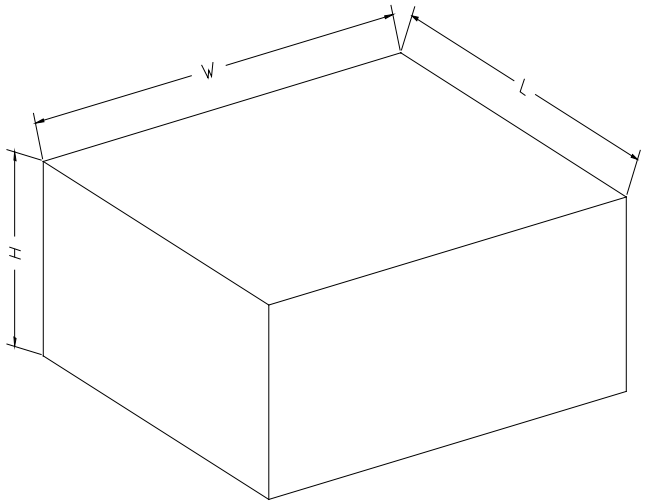
NOTE: The picture is only for reference. Please make the object as the standard.

KEY PARAMETER LIST OF TAPE AND REEL

Package Type	Reel Diameter	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	P1 (mm)	P2 (mm)	W (mm)	Pin1 Quadrant
UTQFN-1.8×1.4-10L	7″	9.0	1.75	2.10	0.70	4.0	4.0	2.0	8.0	Q1
SC70-6	7″	9.5	2.40	2.50	1.20	4.0	4.0	2.0	8.0	Q3

DD0001

CARTON BOX DIMENSIONS



NOTE: The picture is only for reference. Please make the object as the standard.

KEY PARAMETER LIST OF CARTON BOX

Reel Type	Length (mm)	Width (mm)	Height (mm)	Pizza/Carton
7″ (Option)	368	227	224	8
7″	442	410	224	18

DD0002