

# 12-Bit Rail-to-Rail Micropower DAC in MSOP Package

## FEATURES

- Buffered True Rail-to-Rail Voltage Output
- Maximum DNL Error: 0.5LSB
- 12-Bit Resolution
- Supply Operation: 3V to 5V
- Output Swings from 0V to  $V_{REF}$
- $V_{REF}$  Can Tie to  $V_{CC}$
- Schmitt Trigger On Clock Input Allows Direct Optocoupler Interface
- Power-On Reset Clears DAC to 0V
- 3-Wire Cascadable Serial Interface
- Low Cost
- 8-Lead SO and MSOP Packages

## APPLICATIONS

- Digital Calibration
- Industrial Process Control
- Automatic Test Equipment
- Cellular Telephones

## DESCRIPTION

The LTC<sup>®</sup>1659 is a single supply, rail-to-rail voltage output, 12-bit digital-to-analog converter (DAC) in an MSOP package. It includes a rail-to-rail output buffer amplifier and an easy-to-use 3-wire cascadable serial interface.

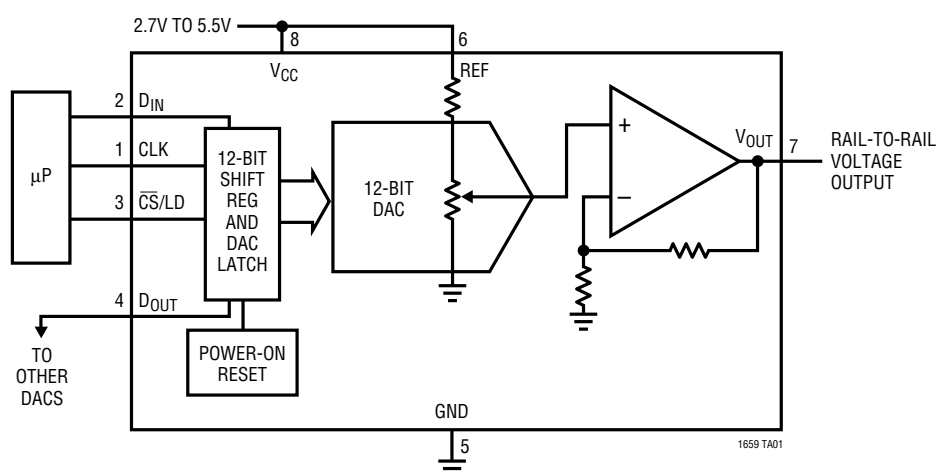
The LTC1659 output swings from 0V to REF. The REF input can be tied to  $V_{CC}$  which can range from 2.7V to 5.5V. This allows a rail-to-rail output swing from 0V to  $V_{CC}$ . The LTC1659 draws only 250 $\mu$ A from a 5V supply.

Its guaranteed  $\pm 0.5$ LSB maximum DNL makes the LTC1659 excel in calibration, control and trim/adjust applications. The low power supply current and the small MSOP package make the LTC1659 ideal for battery-powered applications.

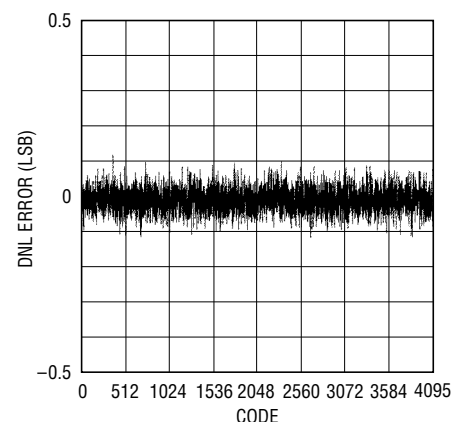
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## TYPICAL APPLICATION

Functional Block Diagram: 12-Bit Rail-to-Rail DAC



Differential Nonlinearity vs Input Code



1659 TA02

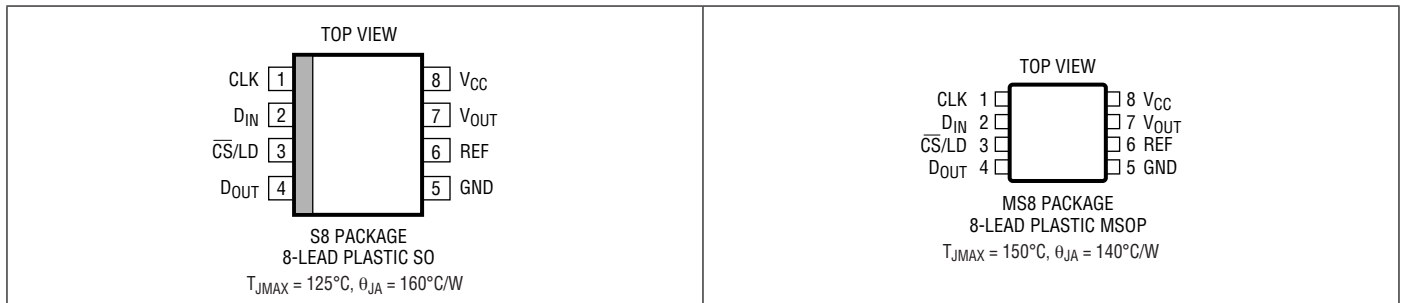
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# LTC1659

## ABSOLUTE MAXIMUM RATINGS (Note 1)

$V_{CC}$ to GND .....	-0.5V to 7.5V	Operating Temperature Range	
Logic Inputs to GND .....	-0.5V to 7.5V	LTC1659CS8 .....	0°C to 70°C
$V_{OUT}$ .....	-0.5V to $V_{CC} + 0.5V$	LTC1659IS8 .....	-40°C to 85°C
Maximum Junction Temperature .....	125°C	LTC1659CMS8 .....	0°C to 70°C
Storage Temperature Range .....	-65°C to 150°C	LTC1659IMS8 .....	-40°C to 85°C
		Lead Temperature (Soldering, 10 sec) .....	300°C

## PIN CONFIGURATION



## ORDER INFORMATION

LEAD FREE FINISH	TAPE AND REEL	PART MARKING*	PACKAGE DESCRIPTION	TEMPERATURE RANGE
LTC1659CS8#PBF	LTC1659CS8#TRPBF	1659	8-Lead Plastic SO	0°C to 70°C
LTC1659IS8#PBF	LTC1659IS8#TRPBF	1659I	8-Lead Plastic SO	-40°C to 85°C
LTC1659CMS8#PBF	LTC1659CMS8#TRPBF	LTCK	8-Lead Plastic MSOP	0°C to 70°C
LTC1659IMS8#PBF	LTC1659IMS8#TRPBF	LTCK	8-Lead Plastic MSOP	-40°C to 85°C

Consult LTC Marketing for parts specified with wider operating temperature ranges. \*The temperature grade is identified by a label on the shipping container. Consult LTC Marketing for information on non-standard lead based finish parts.

For more information on lead free part marking, go to: <http://www.linear.com/leadfree/>

For more information on tape and reel specifications, go to: <http://www.linear.com/tapeandreel/>

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{CC} = 2.7\text{V}$  to  $5.5\text{V}$ ,  $V_{OUT}$  unloaded,  $REF \leq V_{CC}$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$  unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>DAC</b>						
	Resolution		●	12		Bits
	Monotonicity		●	12		Bits
DNL	Differential Nonlinearity	$V_{REF} \leq V_{CC} - 0.1V$ (Note 2)	●		±0.5	LSB
INL	Integral Nonlinearity	$V_{REF} \leq V_{CC} - 0.1V$ (Note 2)	●		±5.0 ±5.5	LSB LSB

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**ELECTRICAL CHARACTERISTICS** The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{CC} = 2.7\text{V}$  to  $5.5\text{V}$ ,  $V_{OUT}$  unloaded,  $REF \leq V_{CC}$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$  unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
$V_{OS}$	Offset Error	Measured at Code 20	●			$\pm 12$ $\pm 18$	mV mV
$V_{OS\ TC}$	Offset Error Temperature Coefficient				$\pm 15$		$\mu\text{V}/^\circ\text{C}$
$V_{FS}$	Full-Scale Voltage	REF = 4.096V	●	4.070 4.060	4.095 4.095	4.120 4.130	V V
$V_{FS\ TC}$	Full-Scale Voltage Temperature Coefficient				10		ppm/ $^\circ\text{C}$
<b>Power Supply</b>							
$V_{CC}$	Positive Supply Voltage	For Specified Performance	●	2.7		5.5	V
$I_{CC}$	Supply Current	(Note 5)	●		240	450	$\mu\text{A}$
<b>Op Amp DC Performance</b>							
	Short-Circuit Current Low	$V_{OUT}$ Shorted to GND	●		70	120	mA
	Short-Circuit Current High	$V_{OUT}$ Shorted to $V_{CC}$	●		65	120	mA
	Output Impedance to GND	Input Code = 0	●		40	150	$\Omega$
	Output Line Regulation	Input Code = 4095, $V_{CC} = 4.5\text{V}$ to $5.5\text{V}$			0.1	1.5	LSB/V
<b>AC Performance</b>							
	Voltage Output Slew Rate	(Note 3)	●	0.5	1.0		V/ $\mu\text{s}$
	Voltage Output Settling Time	(Notes 3, 4) to $\pm 0.5\text{LSB}$			14		$\mu\text{s}$
	Digital Feedthrough				0.3		nV $\cdot$ s
<b>Reference Input</b>							
$R_{IN}$	REF Input Resistance		●	17	28	40	k $\Omega$
REF	REF Input Range	(Notes 6, 7)	●	0		$V_{CC}$	V
<b>Digital I/O</b>							
$V_{IH}$	Digital Input High Voltage	$V_{CC} = 5\text{V}$	●	2.4			V
$V_{IL}$	Digital Input Low Voltage	$V_{CC} = 5\text{V}$	●			0.8	V
$V_{OH}$	Digital Output High Voltage	$V_{CC} = 5\text{V}$ , $I_{OUT} = -1\text{mA}$ , $D_{OUT}$ Only	●	$V_{CC} - 1.0$			V
$V_{OL}$	Digital Output Low Voltage	$V_{CC} = 5\text{V}$ , $I_{OUT} = 1\text{mA}$ , $D_{OUT}$ Only	●			0.4	V
$V_{IH}$	Digital Input High Voltage	$V_{CC} = 3\text{V}$	●	2.0			V
$V_{IL}$	Digital Input Low Voltage	$V_{CC} = 3\text{V}$	●			0.6	V
$V_{OH}$	Digital Output High Voltage	$V_{CC} = 3\text{V}$ , $I_{OUT} = -1\text{mA}$ , $D_{OUT}$ Only	●	$V_{CC} - 0.7$			V
$V_{OL}$	Digital Output Low Voltage	$V_{CC} = 3\text{V}$ , $I_{OUT} = 1\text{mA}$ , $D_{OUT}$ Only	●			0.4	V
$I_{LEAK}$	Digital Input Leakage	$V_{IN} = \text{GND}$ to $V_{CC}$	●			$\pm 10$	$\mu\text{A}$
$C_{IN}$	Digital Input Capacitance	(Note 7)	●			10	pF

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{CC} = 2.7\text{V to } 5.5\text{V}$ ,  $V_{OUT}$  unloaded,  $REF \leq V_{CC}$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$  unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>Switching (<math>V_{CC} = 4.5\text{V to } 5.5\text{V}</math>)</b>						
$t_1$	$D_{IN}$ Valid to CLK Setup		●	40		ns
$t_2$	$D_{IN}$ Valid to CLK Hold		●	0		ns
$t_3$	CLK High Time	(Note 7)	●	40		ns
$t_4$	CLK Low Time	(Note 7)	●	40		ns
$t_5$	$\overline{CS}/LD$ Pulse Width	(Note 7)	●	50		ns
$t_6$	LSB CLK to $\overline{CS}/LD$	(Note 7)	●	40		ns
$t_7$	$\overline{CS}/LD$ Low to CLK	(Note 7)	●	20		ns
$t_8$	$D_{OUT}$ Output Delay	$C_{LOAD} = 15\text{pF}$	●	5	150	ns
$t_9$	CLK Low to $\overline{CS}/LD$ Low	(Note 7)	●	20		ns
<b>Switching (<math>V_{CC} = 2.7\text{V to } 5.5\text{V}</math>)</b>						
$t_1$	$D_{IN}$ Valid to CLK Setup		●	60		ns
$t_2$	$D_{IN}$ Valid to CLK Hold		●	0		ns
$t_3$	CLK High Time	(Note 7)	●	60		ns
$t_4$	CLK Low Time	(Note 7)	●	60		ns
$t_5$	$\overline{CS}/LD$ Pulse Width	(Note 7)	●	80		ns
$t_6$	LSB CLK to $\overline{CS}/LD$	(Note 7)	●	60		ns
$t_7$	$\overline{CS}/LD$ Low to CLK	(Note 7)	●	30		ns
$t_8$	$D_{OUT}$ Output Delay	$C_{LOAD} = 15\text{pF}$	●	10	220	ns
$t_9$	CLK Low to $\overline{CS}/LD$ Low	(Note 7)	●	30		ns

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** Nonlinearity is defined from code 20 to code 4095 (full scale). See Applications Information.

**Note 3:** Load is  $5\text{k}\Omega$  in parallel with  $100\text{pF}$ .

**Note 4:** DAC switched between all 1s and the code corresponding to  $V_{OS}$  for the part.

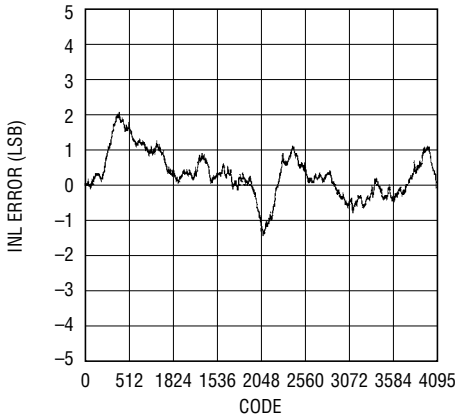
**Note 5:** Digital inputs at  $0\text{V}$  or  $V_{CC}$ .

**Note 6:**  $V_{OUT}$  can only swing from  $(\text{GND} + |V_{OS}|)$  to  $(V_{CC} - |V_{OS}|)$  when output is unloaded.

**Note 7:** Guaranteed by design, not subject to test.

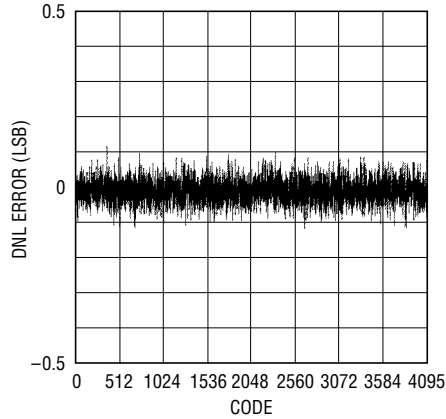
# TYPICAL PERFORMANCE CHARACTERISTICS

**Integral Nonlinearity (INL)**



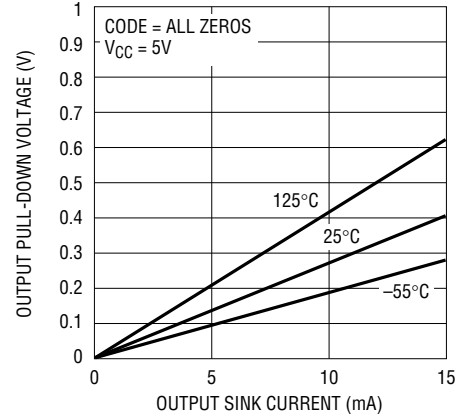
1659 • G01

**Differential Nonlinearity (DNL)**



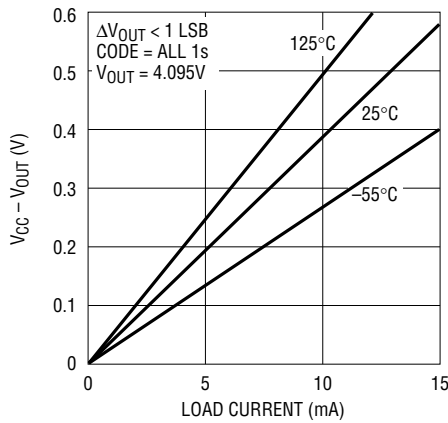
1659 • G02

**Minimum Output Voltage vs Output Sink Current**



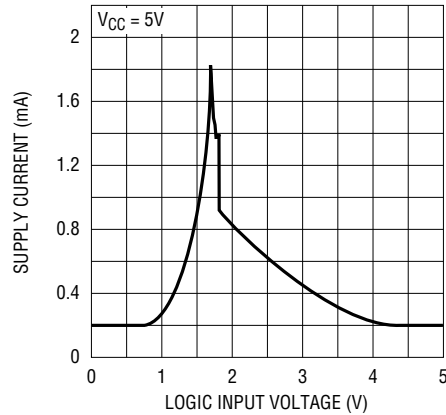
1659 • G03

**Supply Headroom for Full Output Swing vs Load Current**



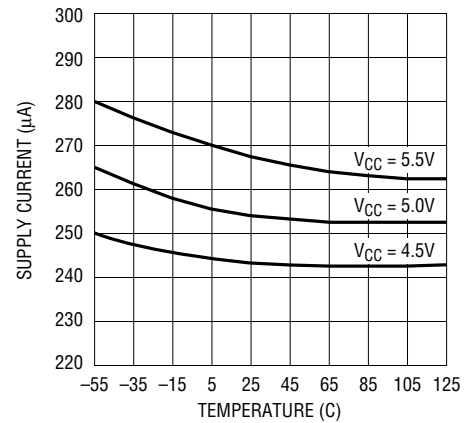
1659 • G04

**Supply Current vs Logic Input Voltage**



1659 • G05

**Supply Current vs Temperature**



1659 • G06

## PIN FUNCTIONS

**CLK (Pin 1):** Serial Interface Clock. Internal Schmitt trigger on this input allows direct optocoupler interface.

**D<sub>IN</sub> (Pin 2):** Serial Interface Data. Data on the D<sub>IN</sub> pin is latched into the shift register on the rising edge of the serial clock.

**$\overline{\text{CS/LD}}$  (Pin 3):** Serial Interface Enable and Load Control. When  $\overline{\text{CS/LD}}$  is low the CLK signal is enabled, so the data can be clocked in. When  $\overline{\text{CS/LD}}$  is pulled high, data is loaded from the shift register into the DAC register, updating the DAC output and the CLK is disabled internally.

**D<sub>OUT</sub> (Pin 4):** Output of the Shift Register which Becomes Valid on the Rising Edge of the Serial Clock.

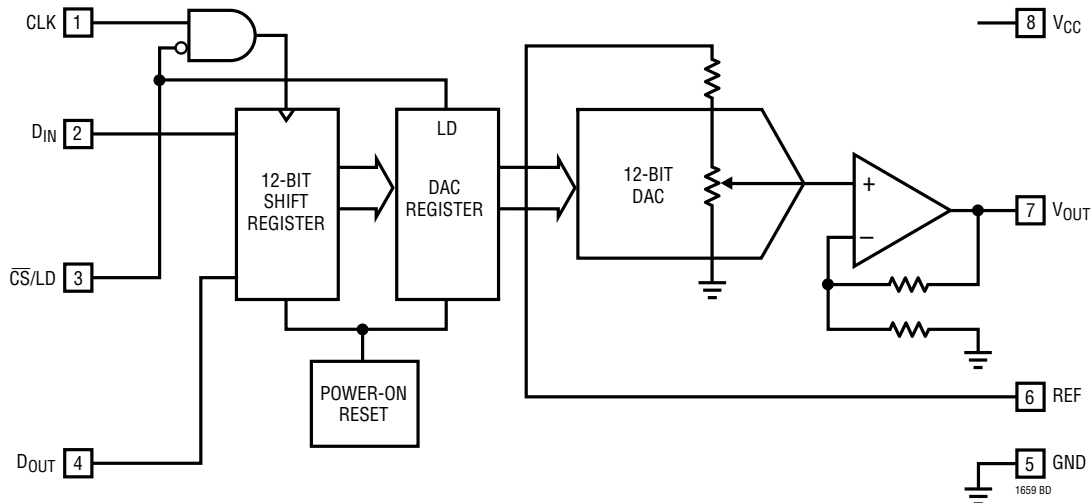
**GND (Pin 5):** Ground.

**REF (Pin 6):** Reference Input. This pin can be tied to V<sub>CC</sub>. The output will swing from 0V to REF. The typical input resistance is 28k.

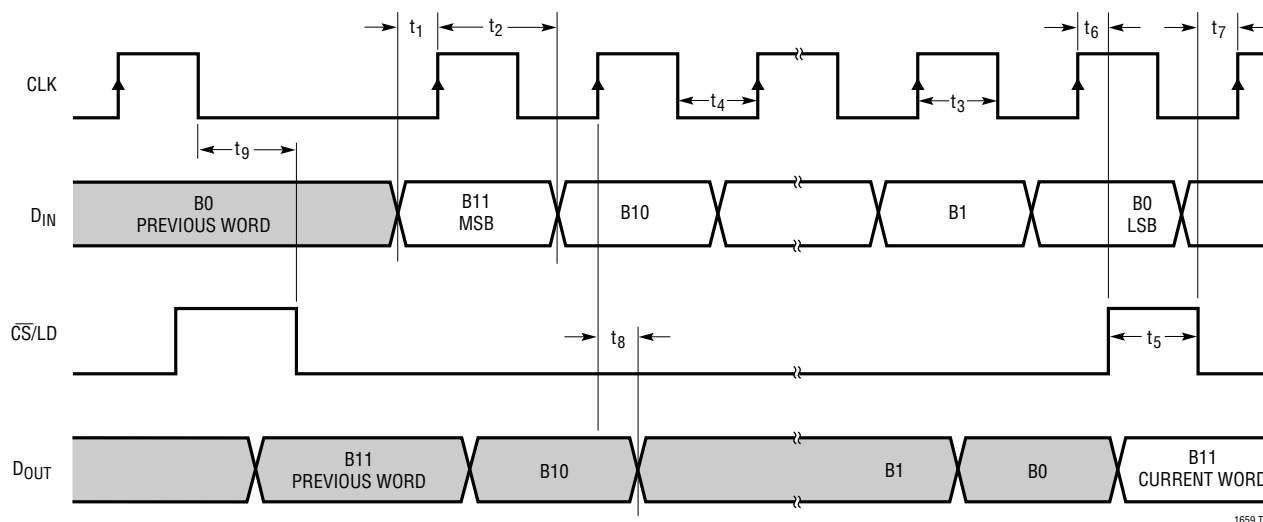
**V<sub>OUT</sub> (Pin 7):** Buffered DAC Output.

**V<sub>CC</sub> (Pin 8):** Positive Supply Input.  $2.7\text{V} \leq V_{\text{CC}} \leq 5.5\text{V}$ . Requires a bypass capacitor to ground.

## BLOCK DIAGRAM



## TIMING DIAGRAM



1659 TD

## DEFINITIONS

**Differential Nonlinearity (DNL):** The difference between the measured change and the ideal 1LSB change for any two adjacent codes. The DNL error between any two codes is calculated as follows:

$$DNL = (\Delta V_{OUT} - LSB) / LSB$$

where  $\Delta V_{OUT}$  is the measured voltage difference between two adjacent codes.

**Digital Feedthrough:** The glitch that appears at the analog output caused by AC coupling from the digital inputs when they change state. The area of the glitch is specified in (nV)(sec).

**Full-Scale Error (FSE):** The deviation of the actual full-scale voltage from ideal. FSE includes the effects of offset and gain errors (see Applications Information).

**Integral Nonlinearity (INL):** The deviation from a straight line passing through the endpoints of the DAC transfer curve (Endpoint INL). Because the output cannot go below zero, the linearity is measured between full scale and the lowest code which guarantees the output will be

greater than zero. The INL error at a given input code is calculated as follows:

$$INL = [V_{OUT} - V_{OS} - (V_{FS} - V_{OS})(code/4095)] / LSB$$

where  $V_{OUT}$  is the output voltage of the DAC measured at the given input code.

**Least Significant Bit (LSB):** The ideal voltage difference between two successive codes.

$$LSB = V_{REF} / 4096$$

**Resolution (n):** Defines the number of DAC output states ( $2^n$ ) that divide the full-scale range. Resolution does not imply linearity.

**Voltage Offset Error ( $V_{OS}$ ):** Nominally, the voltage at the output when the DAC is loaded with all zeros. A single supply DAC can have a true negative offset, but the output cannot go below zero (see Applications Information).

For this reason, single supply DAC offset is measured at the lowest code that guarantees the output will be greater than zero.

## OPERATION

### Serial Interface

The data on the  $D_{IN}$  input is loaded into the shift register on the rising edge of the clock. The MSB is loaded first. The DAC register loads the data from the shift register when  $\overline{CS}/LD$  is pulled high. The CLK is disabled internally when  $\overline{CS}/LD$  is high. Note: CLK must be low before  $\overline{CS}/LD$  is pulled low to avoid an extra internal clock pulse.

The buffered output of the 12-bit shift register is available on the  $D_{OUT}$  pin which swings from GND to  $V_{CC}$ . Multiple LTC1659s may be daisy-chained together by connecting the  $D_{OUT}$  pin to the  $D_{IN}$  pin of the next chip, while the CLK and  $\overline{CS}/LD$  signals remain common to all chips in the daisy chain. The serial data is clocked to all of the chips, then the  $\overline{CS}/LD$  signal is pulled high to update all of them simultaneously.

### Voltage Output

The LTC1659's rail-to-rail buffered output can source or sink 5mA over the entire operating temperature range while pulling to within 300mV of the positive supply voltage or ground. The output swings to within a few millivolts of either supply rail when unloaded and has an equivalent output resistance of 40 $\Omega$  when driving a load to the rails. The output can drive 1000pF without going into oscillation.

The output swings from 0V to the voltage at the REF pin, i.e., there is a gain of 1 from the REF to  $V_{OUT}$ . Please note if REF is tied to  $V_{CC}$  the output can only swing to ( $V_{CC} - V_{OS}$ ). See Applications Information.



## APPLICATIONS INFORMATION

### Rail-to-Rail Output Considerations

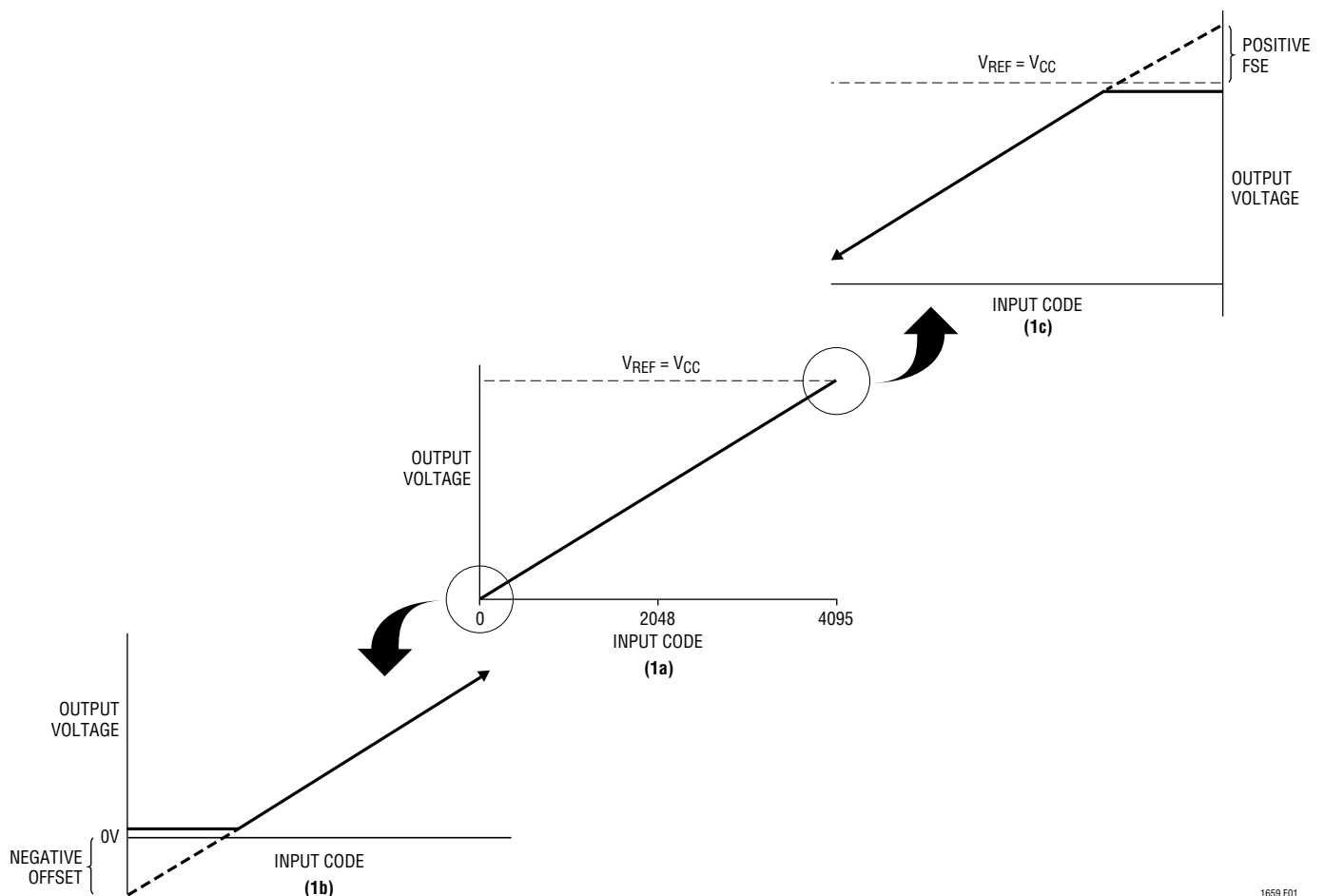
In any rail-to-rail DAC, the output swing is limited to voltages within the supply range.

If the DAC offset is negative, the output for the lowest codes limits at 0V as shown in Figure 1b.

Similarly, limiting can occur near full scale when the REF pin is tied to  $V_{CC}$ . If  $V_{REF} = V_{CC}$  and the DAC full-scale

error (FSE) is positive, the output for the highest codes limits at  $V_{CC}$  as shown in Figure 1c. No full-scale limiting can occur if  $V_{REF}$  is less than  $V_{CC} - FSE$ .

Offset and linearity are defined and tested over the region of the DAC transfer function where no output limiting can occur.



**Figure 1. Effects of Rail-to-Rail Operation on a DAC Transfer Curve**

**(1a) Overall Transfer Function**

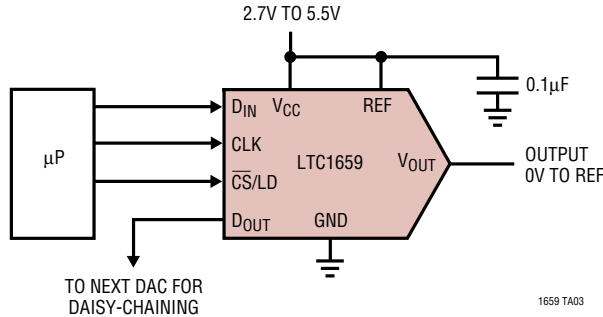
**(1b) Effect of Negative Offset for Codes Near Zero Scale**

**(1c) Effect of Positive Full-Scale Error for Input Codes Near Full Scale When  $V_{REF} = V_{CC}$**

1659 F01

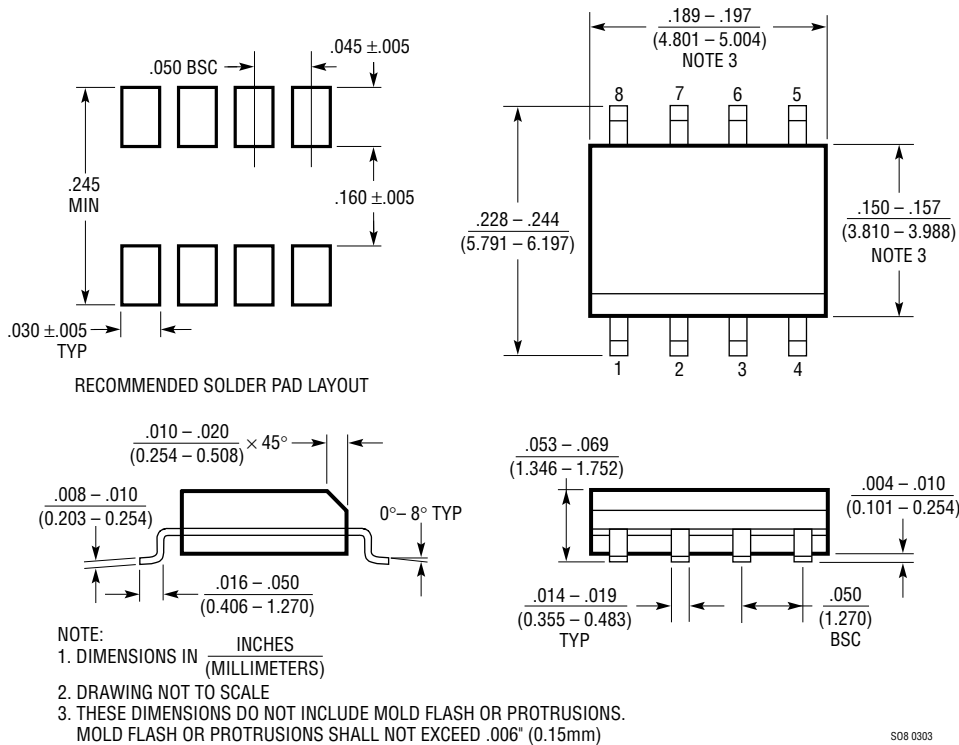
# TYPICAL APPLICATION

## 12-Bit, 3V to 5V Single Supply, Rail-to-Rail Voltage Output DAC



# PACKAGE DESCRIPTION

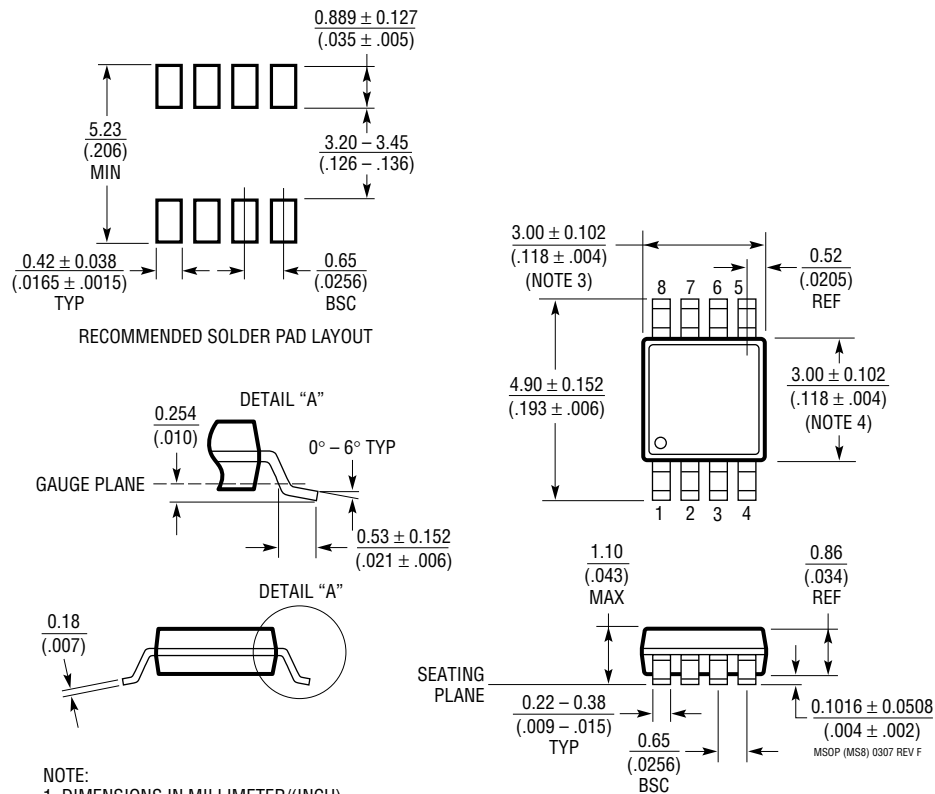
## S8 Package 8-Lead Plastic Small Outline (Narrow .150 Inch) (Reference LTC DWG # 05-08-1610)



# PACKAGE DESCRIPTION

## MS8 Package 8-Lead Plastic MSOP

(Reference LTC DWG # 05-08-1660 Rev F)

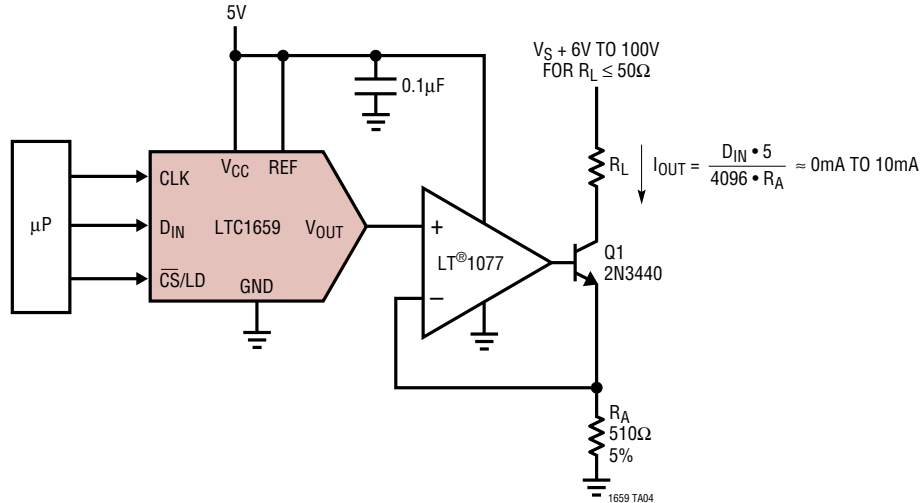


### NOTE:

1. DIMENSIONS IN MILLIMETER/(INCH)
2. DRAWING NOT TO SCALE
3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.  
MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.  
INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX

## TYPICAL APPLICATION

### Digitally Programmable Current Source



## RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LTC1257	Single 12-Bit $V_{OUT}$ DAC, Full Scale: 2.048V, $V_{CC}$ : 4.75V to 15.75V, Reference Can Be Overdriven Up to 12V, i.e., $FS_{MAX} = 12V$	5V to 15V Single Supply, Complete $V_{OUT}$ DAC in SO-8 Package
LTC1446/LTC1446L	Dual 12-Bit $V_{OUT}$ DACs in SO-8 Package	LTC1446: $V_{CC} = 4.5V$ to 5.5V, $V_{OUT} = 0V$ to 4.095V LTC1446L: $V_{CC} = 2.7V$ to 5.5V, $V_{OUT} = 0V$ to 2.5V
LTC1448	Dual 12-Bit $V_{OUT}$ DAC, $V_{CC}$ : 2.7V to 5.5V	Output Swings from GND to REF. REF Input Can Be Tied to $V_{CC}$
LTC1450/LTC1450L	Single 12-Bit $V_{OUT}$ DACs with Parallel Interface	LTC1450: $V_{CC} = 4.5V$ to 5.5V, $V_{OUT} = 0V$ to 4.095V LTC1450L: $V_{CC} = 2.7V$ to 5.5V, $V_{OUT} = 0V$ to 2.5V
LTC1451	Single Rail-to-Rail 12-Bit DAC, Full Scale: 4.095V, $V_{CC}$ : 4.5V to 5.5V, Internal 2.048V Reference Brought Out to Pin	5V, Low Power Complete $V_{OUT}$ DAC in SO-8 Package
LTC1452	Single Rail-to-Rail 12-Bit $V_{OUT}$ Multiplying DAC, $V_{CC}$ : 2.7V to 5.5V	Low Power, Multiplying $V_{OUT}$ DAC with Rail-to-Rail Buffer Amplifier in SO-8 Package
LTC1453	Single Rail-to-Rail 12-Bit $V_{OUT}$ DAC, Full Scale: 2.5V, $V_{CC}$ : 2.7V to 5.5V	3V, Low Power, Complete $V_{OUT}$ DAC in SO-8 Package
LTC1454/LTC1454L	Dual 12-Bit $V_{OUT}$ DACs in SO-16 Package with Added Functionality	LTC1454: $V_{CC} = 4.5V$ to 5.5V, $V_{OUT} = 0V$ to 4.095V LTC1454L: $V_{CC} = 2.7V$ to 5.5V, $V_{OUT} = 0V$ to 2.5V
LTC1456	Single Rail-to-Rail Output 12-Bit DAC with Clear Pin, Full Scale: 4.095V, $V_{CC}$ : 4.5V to 5.5V	Low Power, Complete $V_{OUT}$ DAC in SO-8 Package with Clear Pin
LTC1458/LTC1458L	Quad 12 Bit Rail-to-Rail Output DACs with Added Functionality	LTC1458: $V_{CC} = 4.5V$ to 5.5V, $V_{OUT} = 0V$ to 4.095V LTC1458L: $V_{CC} = 2.7V$ to 5.5V, $V_{OUT} = 0V$ to 2.5V