

## FEATURES

- **Tiny: 8 DACs in the Board Space of an SO-8**
- **Micropower: 56 $\mu$ A per DAC Plus 1 $\mu$ A Sleep Mode for Extended Battery Life**
- Pin Compatible 8-Bit LTC1665 and 10-Bit LTC1660
- Wide 2.7V to 5.5V Supply Range
- **Rail-to-Rail Voltage Outputs Drive 1000pF**
- Reference Range Includes Supply for Ratiometric 0V-to- $V_{CC}$  Output
- **Reference Input Impedance is Constant—Eliminates External Buffer**

## APPLICATIONS


- Mobile Communications
- Remote Industrial Devices
- Automatic Calibration for Manufacturing
- Portable Battery-Powered Instruments
- Trim/Adjust Applications

## DESCRIPTION

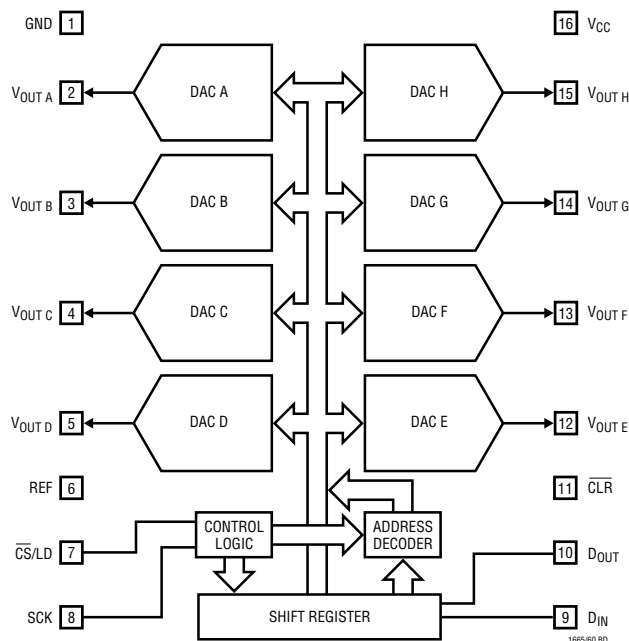
The 8-bit LTC<sup>®</sup>1665 and 10-bit LTC1660 integrate eight accurate, serially addressable digital-to-analog converters (DACs) in tiny 16-pin narrow SSOP packages. Each buffered DAC draws just 56 $\mu$ A total supply current, yet is capable of supplying DC output currents in excess of 5mA and reliably driving capacitive loads to 1000pF. Sleep mode further reduces total supply current to 1 $\mu$ A.

Linear Technology's proprietary, inherently monotonic voltage interpolation architecture provides excellent linearity while allowing for an exceptionally small external form factor.

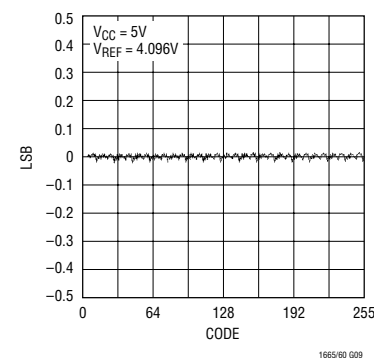
Ultralow supply current, power-saving Sleep mode and extremely compact size make the LTC1665 and LTC1660 ideal for battery-powered applications, while their ease of use, high performance and wide supply range make them excellent choices as general purpose converters.

 LTC and LT are registered trademarks of Linear Technology Corporation.

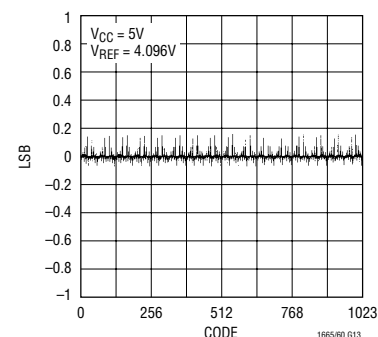
## BLOCK DIAGRAM



LTC1665 Differential Nonlinearity (DNL)



LTC1660 Differential Nonlinearity (DNL)



## ABSOLUTE MAXIMUM RATINGS

(Note 1)

|  |                              |
|--|------------------------------|
| $V_{CC}$ to GND  | -0.2V to 7.5V                |
| Logic Inputs to GND                                    | -0.2V to 7.5V                |
| $V_{OUT A}, V_{OUT B} \dots V_{OUT H}$ ,<br>REF to GND | -0.2V to ( $V_{CC} + 0.2V$ ) |
| Maximum Junction Temperature                           | 125°C                        |
| Operating Temperature Range                            |                              |
| LTC1665C/LTC1660C                                      | 0°C to 70°C                  |
| LTC1665I/LTC1660I                                      | -40°C to 85°C                |
| Storage Temperature Range                              | -65°C to 150°C               |
| Lead Temperature (Soldering, 10 sec)                   | 300°C                        |

## PACKAGE/ORDER INFORMATION

|   |  |
|---|--|
| <p style="text-align: center;">TOP VIEW</p> <p>GN PACKAGE      N PACKAGE<br/>16-LEAD PLASTIC SSOP      16-LEAD PDIP</p> <p><math>T_{JMAX} = 125^{\circ}C, \theta_{JA} = 150^{\circ}C/W</math> (GN)<br/><math>T_{JMAX} = 125^{\circ}C, \theta_{JA} = 100^{\circ}C/W</math> (N)</p> | ORDER PART NUMBER  |
|   | <p>LTC1665CGN<br/>LTC1665CN<br/>LTC1665IGN<br/>LTC1665IN<br/>LTC1660CGN<br/>LTC1660CN<br/>LTC1660IGN<br/>LTC1660IN</p> |
|   | GN PART MARKING  |
|   | <p>1665    1660<br/>1665I   1660I</p>  |

Consult factory for Military grade parts.

## ELECTRICAL CHARACTERISTICS

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

| SYMBOL          | PARAMETER                                | CONDITIONS                            | LTC1665 |     |       | LTC1660 |     |               | UNITS             |
|-----------------|--|---------------------------------------|---------|-----|-------|---------|-----|---------------|-------------------|
|                 |  |                                       | MIN     | TYP | MAX   | MIN     | TYP | MAX           |                   |
| <b>Accuracy</b> |  |                                       |         |     |       |         |     |               |                   |
|                 | Resolution                               |                                       | ●       | 8   |       |         | 10  |               | Bits              |
|                 | Monotonicity                             | $V_{REF} \leq V_{CC} - 0.1V$ (Note 2) | ●       | 8   |       |         | 10  |               | Bits              |
| DNL             | Differential Nonlinearity                | $V_{REF} \leq V_{CC} - 0.1V$ (Note 2) | ●       |     | ±0.1  | ±0.5    |     | ±0.2    ±0.75 | LSB               |
| INL             | Integral Nonlinearity                    | $V_{REF} \leq V_{CC} - 0.1V$ (Note 2) | ●       |     | ±0.2  | ±1.0    |     | ±0.6    ±2.5  | LSB               |
| $V_{OS}$        | Offset Error                             | (Note 7)                              | ●       |     | ±10   | ±30     |     | ±10    ±30    | mV                |
|                 | $V_{OS}$ Temperature Coefficient         |                                       | ●       |     | ±15   |         |     | ±15           | $\mu V/^{\circ}C$ |
| FSE             | Full-Scale Error                         | $V_{CC} = 5V, V_{REF} = 4.096V$       | ●       |     | ±1    | ±4      |     | ±3    ±15     | LSB               |
|                 | Full-Scale Error Temperature Coefficient |                                       | ●       |     | ±30   |         |     | ±30           | $\mu V/^{\circ}C$ |
| PSR             | Power Supply Rejection                   | $V_{REF} = 2.5V$                      |         |     | 0.045 |         |     | 0.18          | LSB/V             |

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

| SYMBOL                 | PARAMETER               | CONDITONS                 | MIN | TYP   | MAX      | UNITS      |
|------------------------|-------------------------|---------------------------|-----|-------|----------|------------|
| <b>Reference Input</b> |                         |                           |     |       |          |            |
|                        | Input Voltage Range     |                           | ●   | 0     | $V_{CC}$ | V          |
|                        | Resistance              | Not in Sleep Mode         | ●   | 35    | 65       | k $\Omega$ |
|                        | Capacitance             | (Note 6)                  |     | 15    |          | pF         |
| $I_{REF}$              | Reference Current       | Sleep Mode                | ●   | 0.001 | 1        | $\mu A$    |
| <b>Power Supply</b>    |                         |                           |     |       |          |            |
| $V_{CC}$               | Positive Supply Voltage | For Specified Performance | ●   | 2.7   | 5.5      | V          |
| $I_{CC}$               | Supply Current          | $V_{CC} = 5V$ (Note 3)    | ●   |       | 450      | $\mu A$    |
|                        |                         | $V_{CC} = 3V$ (Note 3)    | ●   |       | 340      | $\mu A$    |
|                        |                         | Sleep Mode (Note 3)       | ●   |       | 1        | $\mu A$    |

## ELECTRICAL CHARACTERISTICS

The ● denotes 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  $5.5\text{V}$ ,  $V_{REF} \leq V_{CC}$ ,  $V_{OUT}$  unloaded, unless otherwise noted.

| SYMBOL                | PARAMETER                    | CONDITIONS   | MIN    | TYP          | MAX        | UNITS |  |
|-----------------------|------------------------------|--|--------|--------------|------------|-------|--|
| <b>DC Performance</b> |                              |  |        |              |            |       |  |
|                       | Short-Circuit Current Low    | $V_{OUT} = 0\text{V}$ , $V_{CC} = 5.5\text{V}$ , $V_{REF} = 5.1\text{V}$ , Code = Full Scale | ●      | 10           | 30         | 100   | mA   |
|                       | Short-Circuit Current High   | $V_{OUT} = V_{CC} = 5.5\text{V}$ , $V_{REF} = 5.1\text{V}$ , Code = 0                        | ●      | 10           | 27         | 120   | mA   |
| <b>AC Performance</b> |                              |  |        |              |            |       |  |
|                       | Voltage Output Slew Rate     | Rising (Notes 4, 5)<br>Falling (Notes 4, 5)  |        | 0.60<br>0.25 |            |       | $\text{V}/\mu\text{s}$<br>$\text{V}/\mu\text{s}$ |
|                       | Voltage Output Settling Time | To $\pm 0.5\text{LSB}$ (Notes 4, 5)  |        | 30           |            |       | $\mu\text{s}$                                    |
|                       | Capacitive Load Driving      |  |        | 1000         |            |       | pF   |
| <b>Digital I/O</b>    |                              |  |        |              |            |       |  |
| $V_{IH}$              | Digital Input High Voltage   | $V_{CC} = 2.7\text{V}$ to $5.5\text{V}$<br>$V_{CC} = 2.7\text{V}$ to $3.6\text{V}$           | ●<br>● | 2.4<br>2.0   |            |       | V<br>V   |
| $V_{IL}$              | Digital Input Low Voltage    | $V_{CC} = 4.5\text{V}$ to $5.5\text{V}$<br>$V_{CC} = 2.7\text{V}$ to $5.5\text{V}$           | ●<br>● |              | 0.8<br>0.6 |       | V<br>V   |
| $V_{OH}$              | Digital Output High Voltage  | $I_{OUT} = -1\text{mA}$ , $D_{OUT}$ Only   | ●      | $V_{CC} - 1$ |            |       | V  |
| $V_{OL}$              | Digital Output Low Voltage   | $I_{OUT} = 1\text{mA}$ , $D_{OUT}$ Only  | ●      |              | 0.4        |       | V  |
| $I_{LK}$              | Digital Input Leakage        | $V_{IN} = \text{GND}$ to $V_{CC}$  | ●      |              | $\pm 10$   |       | $\mu\text{A}$                                    |
| $C_{IN}$              | Digital Input Capacitance    | (Note 6)   | ●      |              | 10         |       | pF   |

## TIMING CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (See Figure 1)

| SYMBOL   | PARAMETER  | CONDITIONS  | MIN         | TYP | MAX                  | UNITS             |    |
|--|--|---|-------------|-----|----------------------|-------------------|----|
| <b><math>V_{CC} = 4.5\text{V}</math> to <math>5.5\text{V}</math></b> |  |   |             |     |                      |                   |    |
| $t_1$  | $D_{IN}$ Valid to SCK Setup                                |   | ●           | 40  | 15                   | ns                |    |
| $t_2$  | $D_{IN}$ Valid to SCK Hold                                 |   | ●           | 0   | -11                  | ns                |    |
| $t_3$  | SCK High Time  | (Note 6)  | ●           | 30  | 5                    | ns                |    |
| $t_4$  | SCK Low Time   | (Note 6)  | ●           | 30  | 7                    | ns                |    |
| $t_5$  | $\overline{\text{CS}}/\text{LD}$ Pulse Width               | (Note 6)  | ●           | 80  | 30                   | ns                |    |
| $t_6$  | LSB SCK High to $\overline{\text{CS}}/\text{LD}$ High      | (Note 6)  | ●           | 30  | 4                    | ns                |    |
| $t_7$  | $\overline{\text{CS}}/\text{LD}$ Low to SCK High           | (Note 6)  | ●           | 80  | 26                   | ns                |    |
| $t_8$  | $D_{OUT}$ Propagation Delay                                | $C_{LOAD} = 15\text{pF}$ (Note 6)   | ●           | 5   | 26                   | 80                | ns |
| $t_9$  | SCK Low to $\overline{\text{CS}}/\text{LD}$ Low            | (Note 6)  | ●           | 20  | 0                    | ns                |    |
| $t_{10}$   | $\overline{\text{CLR}}$ Pulse Width                        | (Note 6)  | ●           | 100 | 37                   | ns                |    |
| $t_{11}$   | $\overline{\text{CS}}/\text{LD}$ High to SCK Positive Edge | (Note 6)  | ●           | 30  | 0                    | ns                |    |
|  | SCK Frequency  | Continuous Square Wave (Note 6)<br>Continuous 23% Duty Cycle Pulse (Note 6)<br>Gated Square Wave (Note 6) | ●<br>●<br>● |     | 5.00<br>7.69<br>16.7 | MHz<br>MHz<br>MHz |    |
| <b><math>V_{CC} = 2.7\text{V}</math> to <math>5.5\text{V}</math></b> |  |   |             |     |                      |                   |    |
| $t_1$  | $D_{IN}$ Valid to SCK Setup                                | (Note 6)  | ●           | 60  | 20                   | ns                |    |
| $t_2$  | $D_{IN}$ Valid to SCK Hold                                 | (Note 6)  | ●           | 0   | -14                  | ns                |    |
| $t_3$  | SCK High Time  | (Note 6)  | ●           | 50  | 8                    | ns                |    |
| $t_4$  | SCK Low Time   | (Note 6)  | ●           | 50  | 12                   | ns                |    |
| $t_5$  | $\overline{\text{CS}}/\text{LD}$ Pulse Width               | (Note 6)  | ●           | 100 | 30                   | ns                |    |

# LTC1665/LTC1660

## TIMING CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (See Figure 1)

| SYMBOL   | PARAMETER  | CONDITIONS                               | MIN | TYP | MAX  | UNITS |    |
|----------|--|--|-----|-----|------|-------|----|
| $t_6$    | LSB SCK High to $\overline{\text{CS}}/\text{LD}$ High      | (Note 6)                                 | ●   | 50  | 5    | ns    |    |
| $t_7$    | $\overline{\text{CS}}/\text{LD}$ Low to SCK High           | (Note 6)                                 | ●   | 100 | 27   | ns    |    |
| $t_8$    | $D_{\text{OUT}}$ Propagation Delay                         | $C_{\text{LOAD}} = 15\text{pF}$ (Note 6) | ●   | 5   | 47   | 150   | ns |
| $t_9$    | SCK Low to $\overline{\text{CS}}/\text{LD}$ Low            | (Note 6)                                 | ●   | 30  | 0    | ns    |    |
| $t_{10}$ | CLR Pulse Width  | (Note 6)                                 | ●   | 120 | 41   | ns    |    |
| $t_{11}$ | $\overline{\text{CS}}/\text{LD}$ High to SCK Positive Edge | (Note 6)                                 | ●   | 30  | 0    | ns    |    |
|          | SCK Frequency  | Continuous Square Wave (Note 6)          | ●   |     | 3.85 | MHz   |    |
|          |  | Continuous 28% Duty Cycle Pulse          | ●   |     | 5.55 | MHz   |    |
|          |  | Gated Square Wave                        | ●   |     | 10   | MHz   |    |

**Note 1:** Absolute maximum ratings are those values beyond which the life of a device may be impaired.

**Note 2:** Nonlinearity and monotonicity are defined from code 4 to code 255 for the LTC1665 and from code 20 to code 1023 for the LTC1660. See Applications Information.

**Note 3:** Digital inputs at 0V or  $V_{\text{CC}}$ .

**Note 4:** Load is  $10\text{k}\Omega$  in parallel with  $100\text{pF}$ .

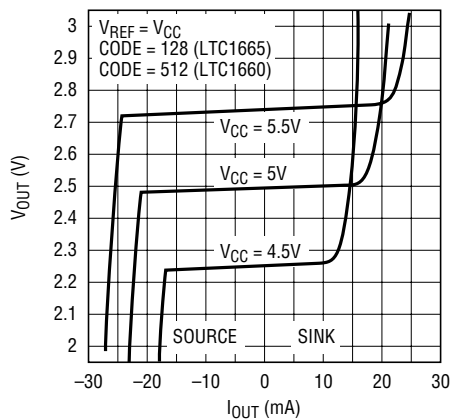
**Note 5:**  $V_{\text{CC}} = V_{\text{REF}} = 5\text{V}$ . DAC switched between  $0.1V_{\text{FS}}$  and  $0.9V_{\text{FS}}$ , i.e., codes 26 and 230 for the LTC1665 or codes 102 and 922 for the LTC1660.

**Note 6:** Guaranteed by design and not production tested.

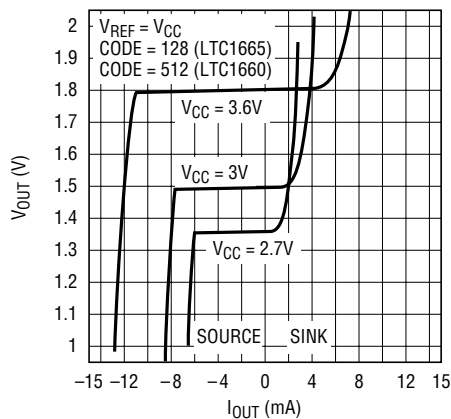
**Note 7:** Measured at code 4 for the LTC1665 and code 20 for the LTC1660.

## TYPICAL PERFORMANCE CHARACTERISTICS (LTC1665/LTC1660)

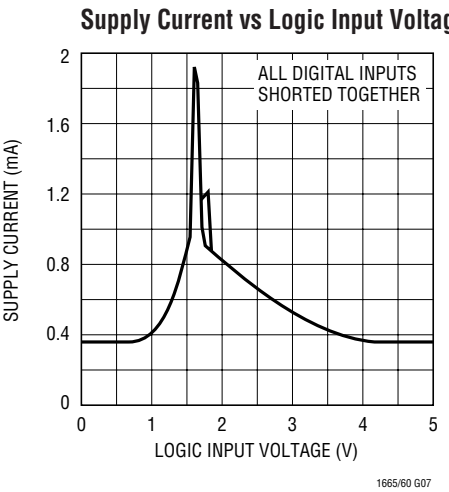
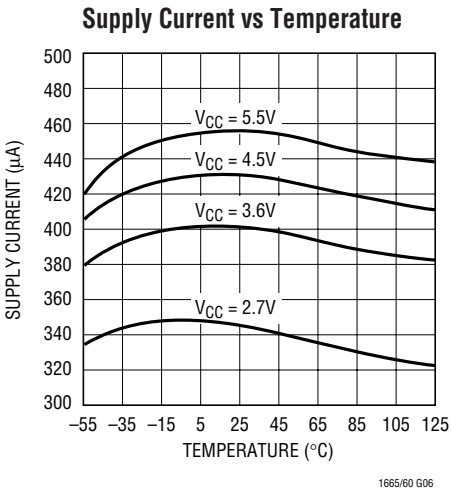
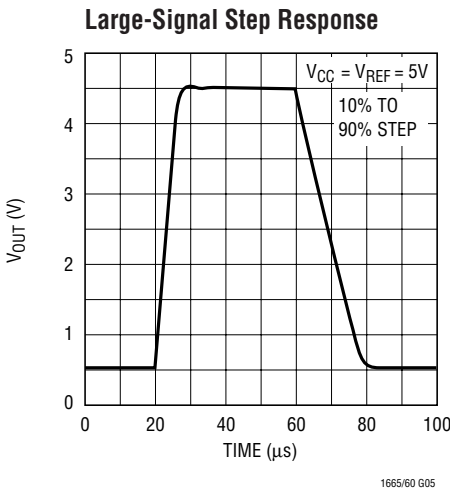
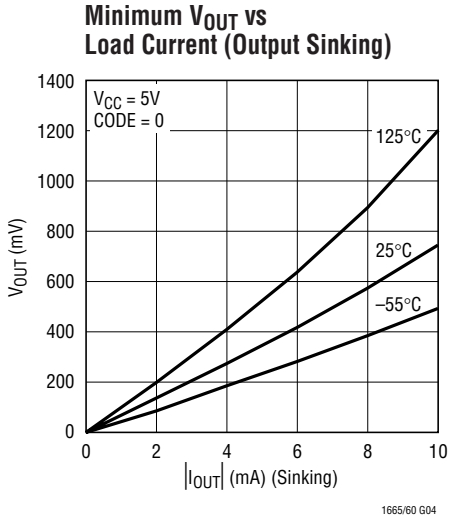
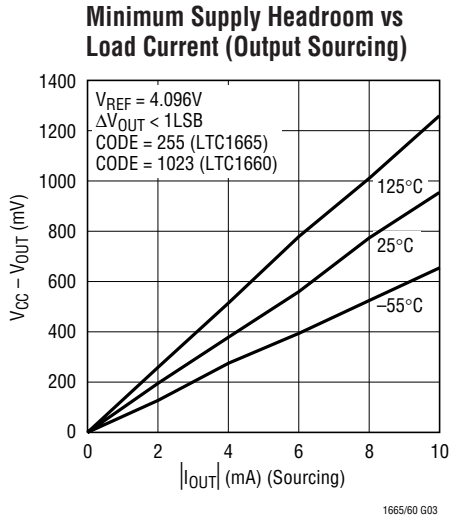
Midscale Output Voltage vs Load Current



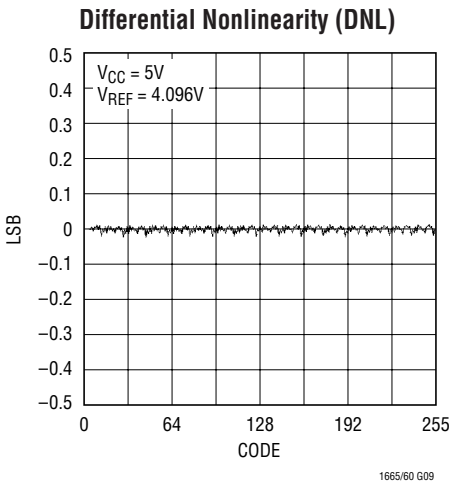
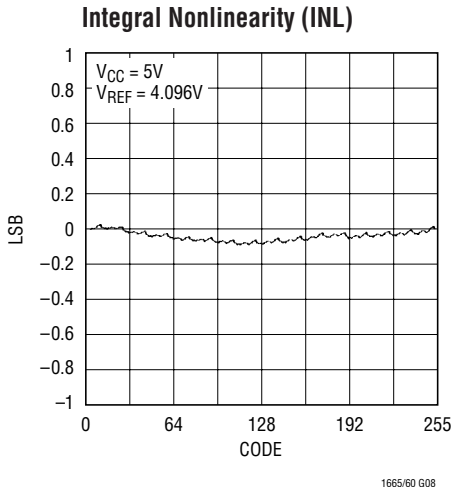
Midscale Output Voltage vs Load Current



**TYPICAL PERFORMANCE CHARACTERISTICS** (LTC1665/LTC1660)

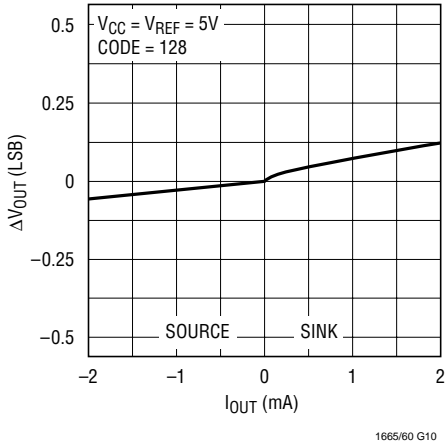


**TYPICAL PERFORMANCE CHARACTERISTICS** (LTC1665)

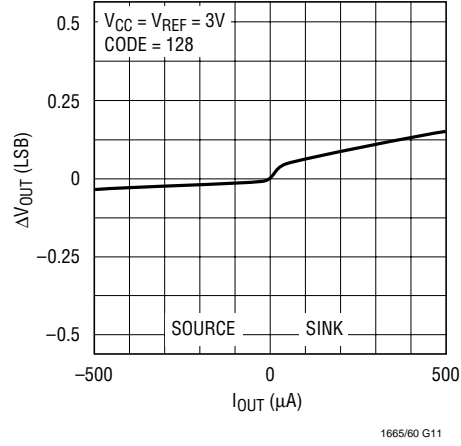


**TYPICAL PERFORMANCE CHARACTERISTICS (LTC1665)**

**Load Regulation vs Output Current**

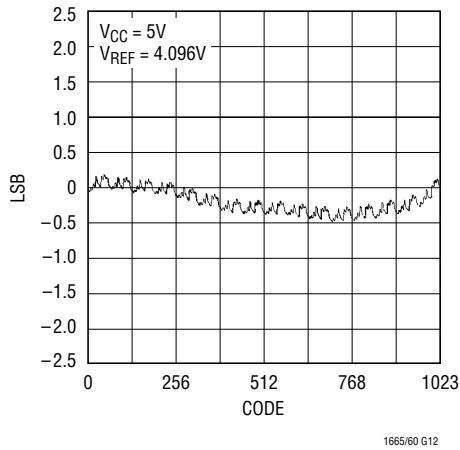


**Load Regulation vs Output Current**

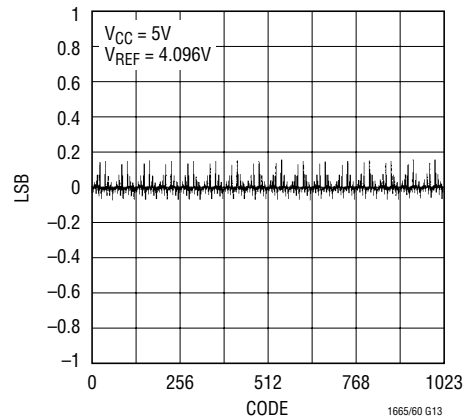


**TYPICAL PERFORMANCE CHARACTERISTICS (LTC1660)**

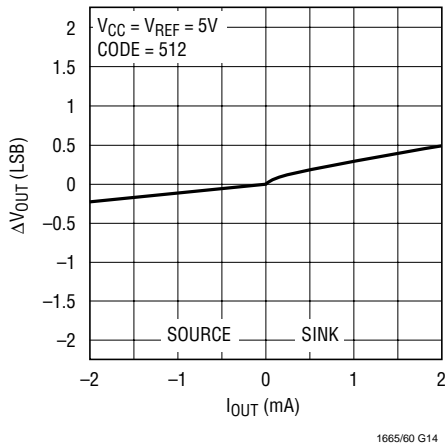
**Integral Nonlinearity (INL)**



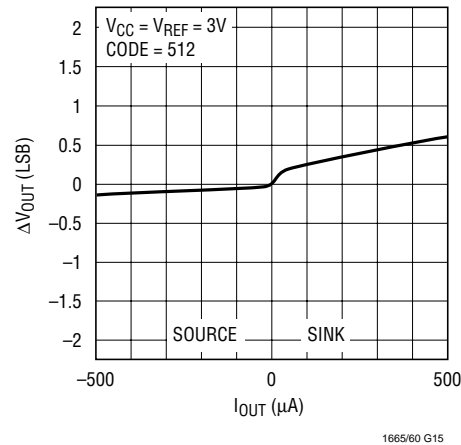
**Differential Nonlinearity (DNL)**



**Load Regulation vs Output Current**



**Load Regulation vs Output Current**



## PIN FUNCTIONS (LTC1665/LTC1660)

**GND (Pin 1):** System Ground.

**V<sub>OUT A</sub> to V<sub>OUT H</sub> (Pins 2-5 and 12-15):** DAC Analog Voltage Outputs. The output range is

$$0 \text{ to } \left(\frac{255}{256}\right)V_{\text{REF}} \text{ for the LTC1665}$$

$$0 \text{ to } \left(\frac{1023}{1024}\right)V_{\text{REF}} \text{ for the LTC1660}$$

**REF (Pin 6):** Reference Voltage Input.  $0V \leq V_{\text{REF}} \leq V_{\text{CC}}$ .

**$\overline{\text{CS/LD}}$  (Pin 7):** Serial Interface Chip Select/Load Input. When  $\overline{\text{CS/LD}}$  is low, SCK is enabled for shifting data on D<sub>IN</sub> into the register. When  $\overline{\text{CS/LD}}$  is pulled high, SCK is disabled and data is loaded from the shift register into the specified DAC register(s), updating the analog output(s). CMOS and TTL compatible.

**SCK (Pin 8):** Serial Interface Clock Input. CMOS and TTL compatible.

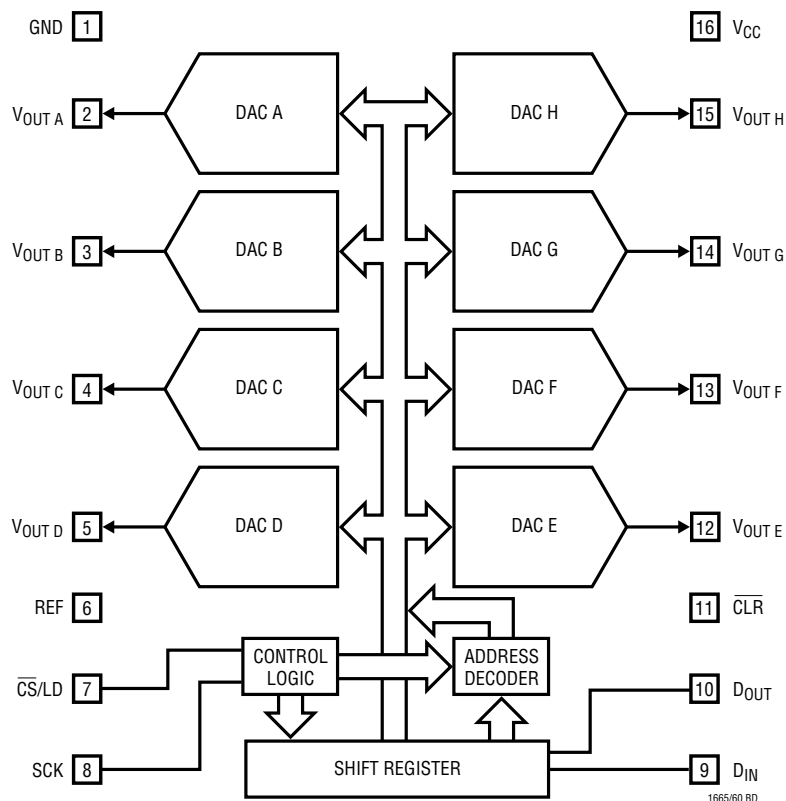
**D<sub>IN</sub> (Pin 9):** Serial Interface Data Input. Data on the D<sub>IN</sub> pin is shifted into the 16-bit register on the rising edge of SCK. CMOS and TTL compatible.

**D<sub>OUT</sub> (Pin 10):** Serial Interface Data Output. Data appears on D<sub>OUT</sub> 16 positive SCK edges after being applied to D<sub>IN</sub>. May be tied to D<sub>IN</sub> of another LTC1665/LTC1660 for daisy-chain operation. CMOS and TTL compatible.

**$\overline{\text{CLR}}$  (Pin 11):** Asynchronous Clear Input. All internal shift and DAC registers are cleared to zero at the falling edge of the  $\overline{\text{CLR}}$  signal, forcing the analog outputs to zero scale. CMOS and TTL compatible.

**V<sub>CC</sub> (Pin 16):** Supply Voltage Input.  $2.7V \leq V_{\text{CC}} \leq 5.5V$ .

## BLOCK DIAGRAM



## TIMING DIAGRAM

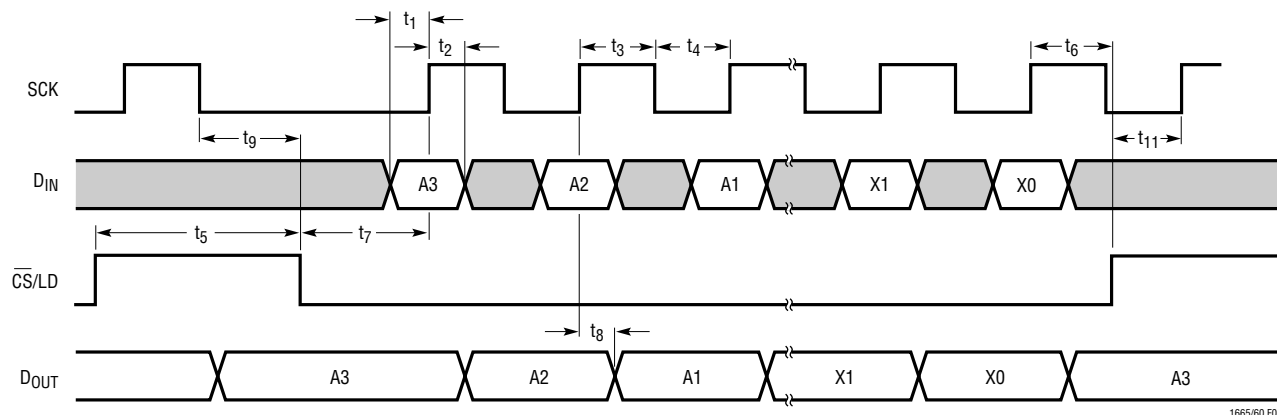


Figure 1

## OPERATION

## Transfer Function

The transfer function is

$$V_{\text{OUT(IDEAL)}} = \left( \frac{k}{256} \right) V_{\text{REF}} \text{ for the LTC1665}$$

$$V_{\text{OUT(IDEAL)}} = \left( \frac{k}{1024} \right) V_{\text{REF}} \text{ for the LTC1660}$$

where  $k$  is the decimal equivalent of the binary DAC input code and  $V_{\text{REF}}$  is the voltage at REF (Pin 6).

## Power-On Reset

The LTC1665 clears the outputs to zero scale when power is first applied, making system initialization consistent and repeatable.

## Power Supply Sequencing

The voltage at REF (Pin 6) should be kept within the range  $-0.2\text{V} \leq V_{\text{REF}} \leq V_{\text{CC}} + 0.2\text{V}$  (see Absolute Maximum Ratings). Particular care should be taken to observe these limits during power supply turn-on and turn-off sequences, when the voltage at  $V_{\text{CC}}$  (Pin 16) is in transition.

## Serial Interface

Referring to Figure 2a (2b): With  $\overline{\text{CS/LD}}$  held low, data on the  $\text{D}_{\text{IN}}$  input is shifted into the 16-bit shift register on the positive edge of SCK. The 4-bit DAC address, A3-A0, is loaded first (see Table 2), then the 8-bit (10-bit) input code, D7-D0 (D9-D0), ordered MSB-to-LSB in each case. Four (two) don't-care bits, X3-X0 (X1-X0), are loaded last. When the full 16-bit input word has been shifted in,  $\overline{\text{CS/LD}}$  is pulled high, loading the DAC register with the word and causing the addressed DAC output(s) to update. The clock is disabled internally when  $\overline{\text{CS/LD}}$  is high. Note: SCK must be low before  $\overline{\text{CS/LD}}$  is pulled low.

The buffered serial output of the shift register is available on the  $\text{D}_{\text{OUT}}$  pin, which swings from GND to  $V_{\text{CC}}$ . Data appears on  $\text{D}_{\text{OUT}}$  16 positive SCK edges after being applied to  $\text{D}_{\text{IN}}$ .

Multiple LTC1665/LTC1660's can be controlled from a single 3-wire serial port (i.e., SCK,  $\text{D}_{\text{IN}}$  and  $\overline{\text{CS/LD}}$ ) by using the included "daisy-chain" facility. A series of  $m$  chips is configured by connecting each  $\text{D}_{\text{OUT}}$  (except the last) to  $\text{D}_{\text{IN}}$  of the next chip, forming a single  $16m$ -bit shift register. The SCK and  $\overline{\text{CS/LD}}$  signals are common to all



## OPERATION

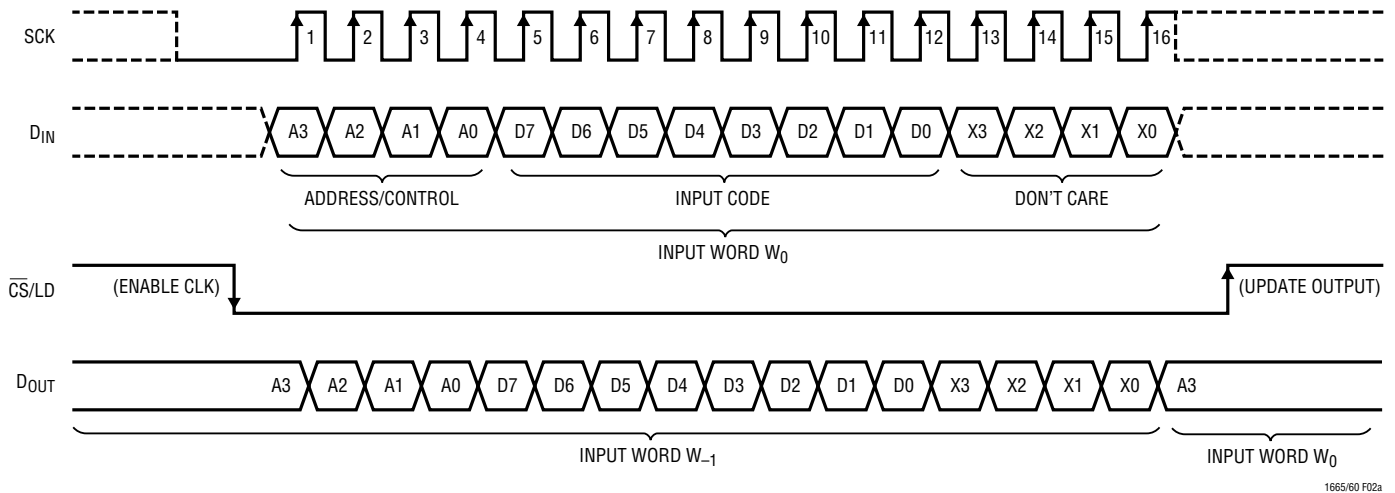


Figure 2a. LTC1665 Register Loading Sequence

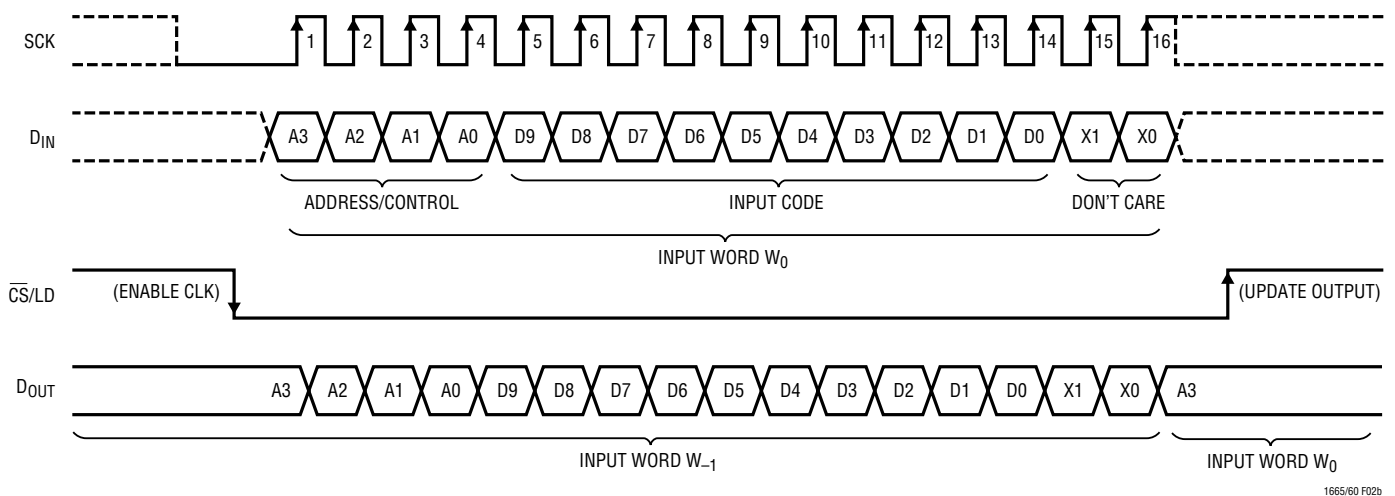


Figure 2b. LTC1660 Register Loading Sequence

Table 1a. LTC1665 Input Word

|                 |    |    |    |            |    |    |    |    |    |    |    |            |    |    |    |
|-----------------|----|----|----|------------|----|----|----|----|----|----|----|------------|----|----|----|
| A3              | A2 | A1 | A0 | D7         | D6 | D5 | D4 | D3 | D2 | D1 | D0 | X3         | X2 | X1 | X0 |
| Address/Control |    |    |    | Input Code |    |    |    |    |    |    |    | Don't Care |    |    |    |

Table 1b. LTC1660 Input Word

|                 |    |    |    |            |    |    |    |    |    |    |    |    |    |    |            |
|-----------------|----|----|----|------------|----|----|----|----|----|----|----|----|----|----|------------|
| A3              | A2 | A1 | A0 | D9         | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | X1 | X0         |
| Address/Control |    |    |    | Input Code |    |    |    |    |    |    |    |    |    |    | Don't Care |

chips in the chain. In use,  $\overline{CS/LD}$  is held low while  $m$  16-bit words are clocked to  $D_{IN}$  of the first chip;  $\overline{CS/LD}$  is then pulled high, updating all of them simultaneously.

### Sleep Mode

DAC address 1110<sub>b</sub> is reserved for the special Sleep instruction (see Table 2). In this mode, the digital interface stays active while the analog circuits are disabled; static power consumption is thus virtually eliminated. The reference input and analog outputs are set in a high impedance

## OPERATION

Table 2. DAC Address/Control Functions

| ADDRESS/CONTROL |          |          |          | DAC STATUS   | SLEEP STATUS |
|-----------------|----------|----------|----------|--|--------------|
| A3              | A2       | A1       | A0       |  |              |
| 0               | 0        | 0        | 0        | No Change  | Wake         |
| 0               | 0        | 0        | 1        | Load DAC A   | Wake         |
| 0               | 0        | 1        | 0        | Load DAC B   | Wake         |
| 0               | 0        | 1        | 1        | Load DAC C   | Wake         |
| 0               | 1        | 0        | 0        | Load DAC D   | Wake         |
| 0               | 1        | 0        | 1        | Load DAC E   | Wake         |
| 0               | 1        | 1        | 0        | Load DAC F   | Wake         |
| 0               | 1        | 1        | 1        | Load DAC G   | Wake         |
| 1               | 0        | 0        | 0        | Load DAC H   | Wake         |
| 1               | 0        | 0        | 1        | No Change  | Wake         |
| 1               | 0        | 1        | 0        | No Change  | Wake         |
| 1               | 0        | 1        | 1        | No Change  | Wake         |
| 1               | 1        | 0        | 0        | No Change  | Wake         |
| 1               | 1        | 0        | 1        | No Change  | Wake         |
| <b>1</b>        | <b>1</b> | <b>1</b> | <b>0</b> | <b>No Change</b>                                   | <b>Sleep</b> |
| 1               | 1        | 1        | 1        | Load <b>ALL</b> DACs<br>with Same<br>8/10-Bit Code | Wake         |

state and all DAC settings are retained in memory so that when Sleep mode is exited, the outputs of DACs not updated by the Wake command are restored to their last active state.

Sleep mode is initiated by performing a load sequence to address  $1110_b$  (the DAC input word D7-D0 [D9-D0] is ignored). Once in Sleep mode, a load sequence to any other address (including “No Change” addresses  $0000_b$  and  $1001-1101_b$ ) causes the LTC1665/LTC1660 to Wake. It is possible to keep one or more chips of a daisy chain in continuous Sleep mode by giving the Sleep instruction to these chips each time the active chips in the chain are updated.

### Voltage Outputs

Each of the eight rail-to-rail output amplifiers contained in these parts can source or sink up to 5mA. The outputs swing to within a few millivolts of either supply rail when unloaded and have an equivalent output resistance of  $85\Omega$  when driving a load to the rails. The output amplifiers are stable driving capacitive loads up to 1000pF.

A small resistor placed in series with the output can be used to achieve stability for any load capacitance. A  $1\mu\text{F}$  load can be successfully driven by inserting a  $20\Omega$  resistor; a  $2.2\mu\text{F}$  load needs only a  $10\Omega$  resistor. In either case, larger values of resistance, capacitance or both may be safely substituted for the values given.

### Rail-to-Rail Output Considerations

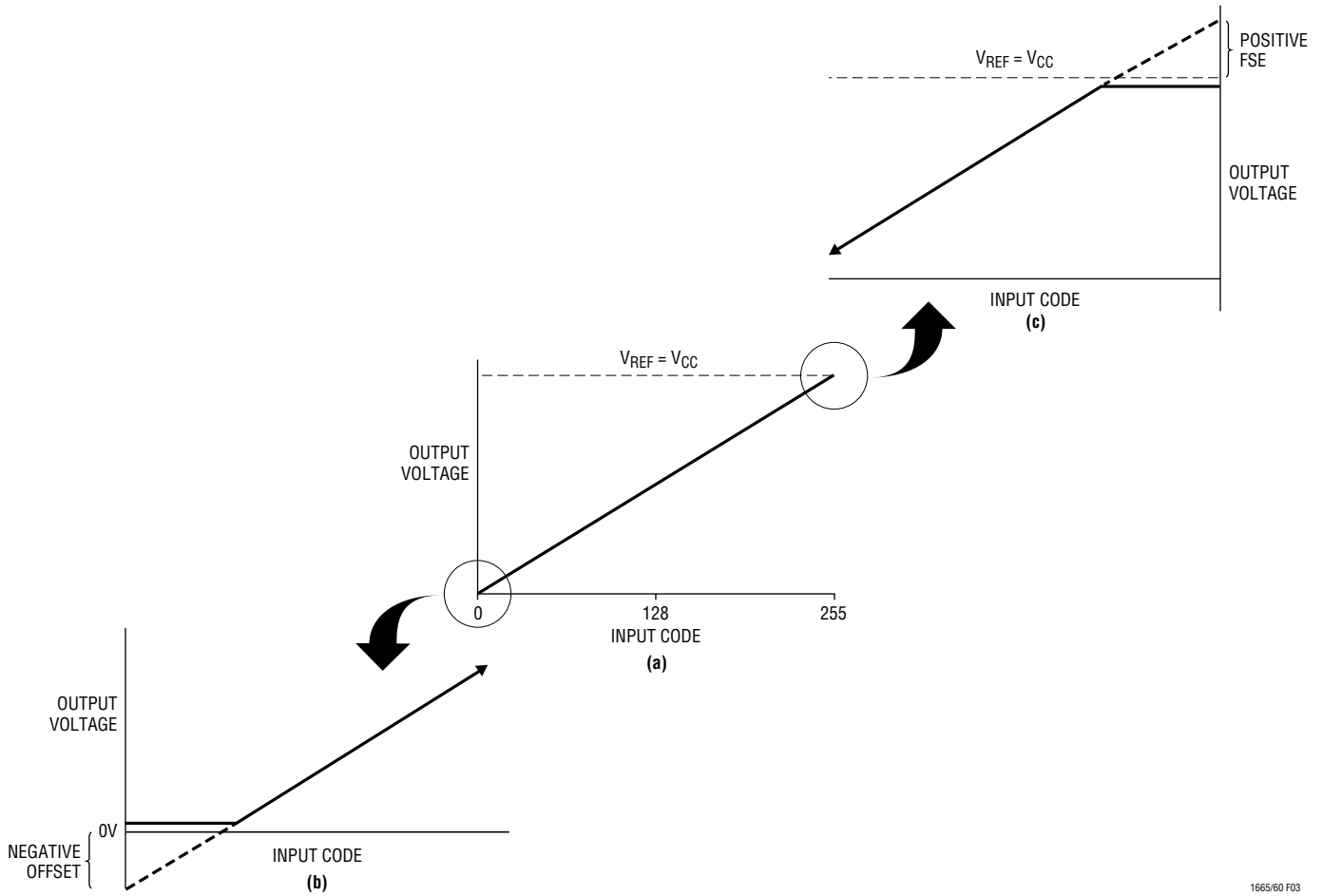
In any rail-to-rail output voltage DAC, the output is limited to voltages within the supply range.

If the DAC offset is negative, the output for the lowest codes limits at 0V as shown in Figure 3b.

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 3c. No full-scale limiting can occur if  $V_{REF}$  is less than  $V_{CC} - \text{FSE}$ .

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

**OPERATION**

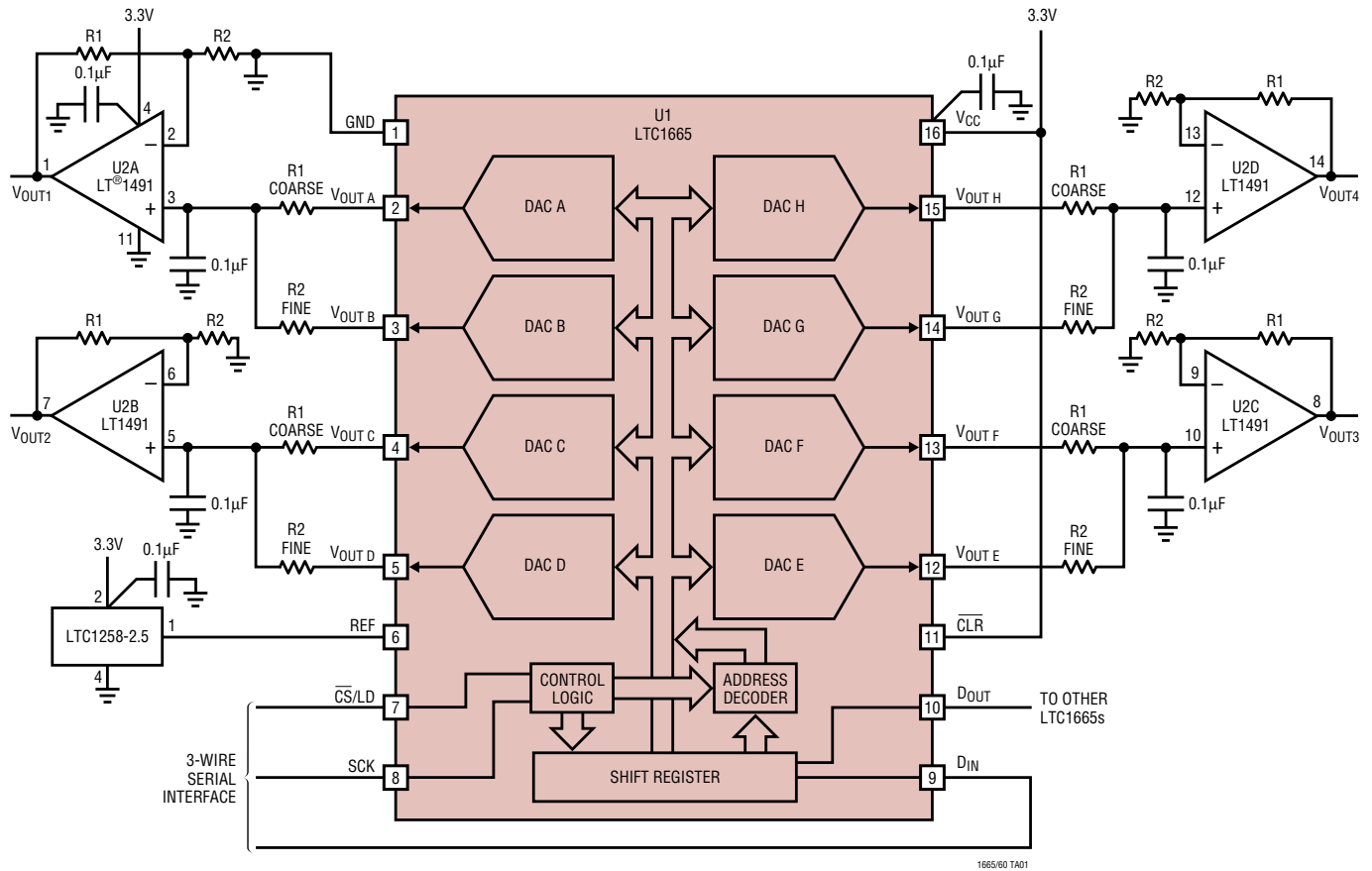


1665/60 F03

**Figure 3. Effects of Rail-to-Rail Operation On a DAC Transfer Curve. (a) Overall Transfer Function (b) Effect of Negative Offset for Codes Near Zero Scale (c) Effect of Positive Full-Scale Error for Input Codes Near Full Scale When  $V_{REF} = V_{CC}$**

TYPICAL APPLICATIONS

A Low Power Quad Trim Circuit with Coarse/Fine Adjustment



$$R2 \gg R1$$

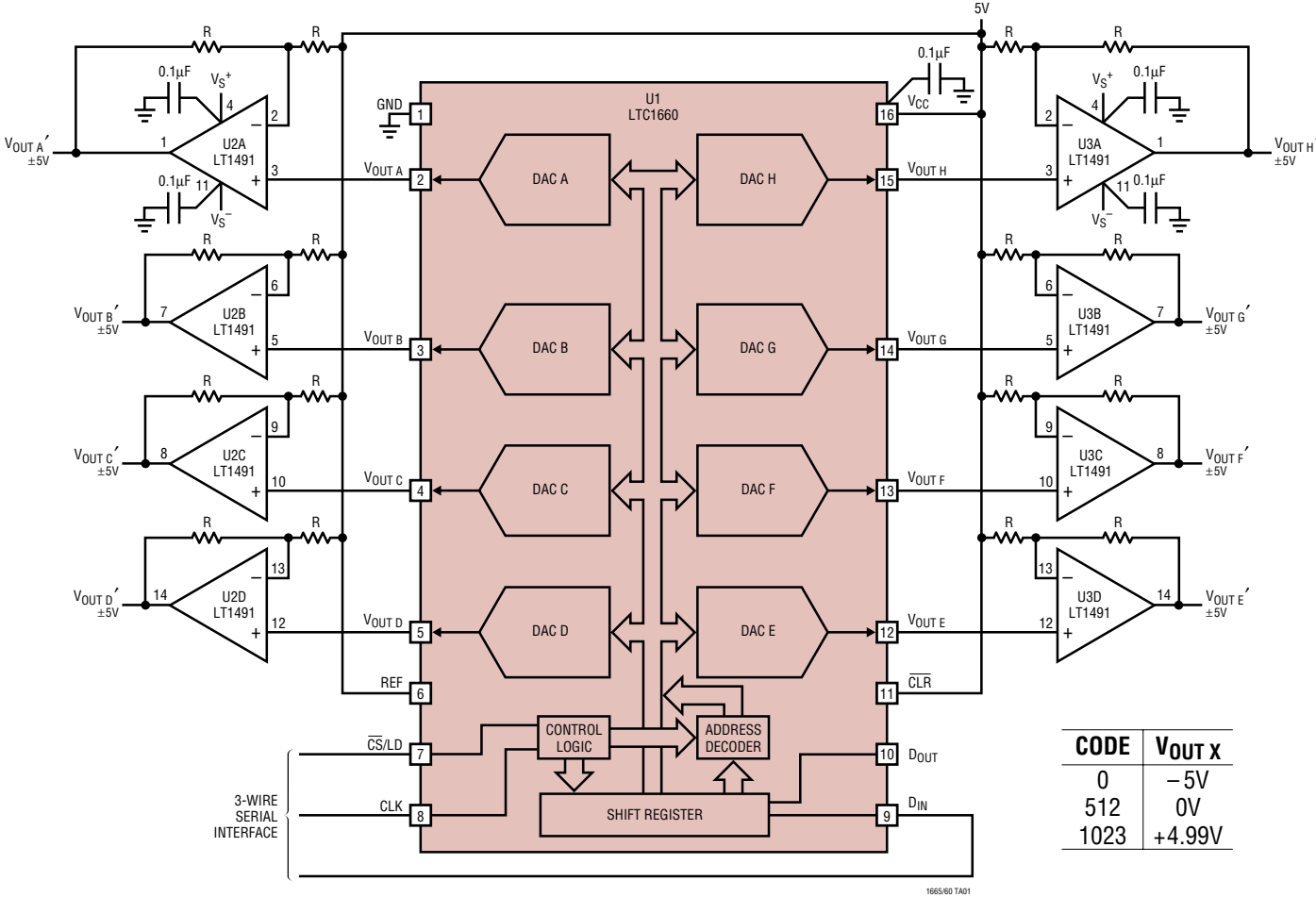
$$V_{OUT1} = V_{OUTA} + \left(\frac{R1}{R2}\right) V_{OUTB}$$

Similarly  $V_{OUT2}$ ,  $V_{OUT3}$ ,  $V_{OUT4}$

Example: For  $R1 = 110\Omega$  and  $R2 = 11k$ ,  
 $V_{OUT1} = V_{OUTA} + 0.01 V_{OUTB}$

TYPICAL APPLICATIONS

An 8-Channel Bipolar Output Voltage Circuit Configuration

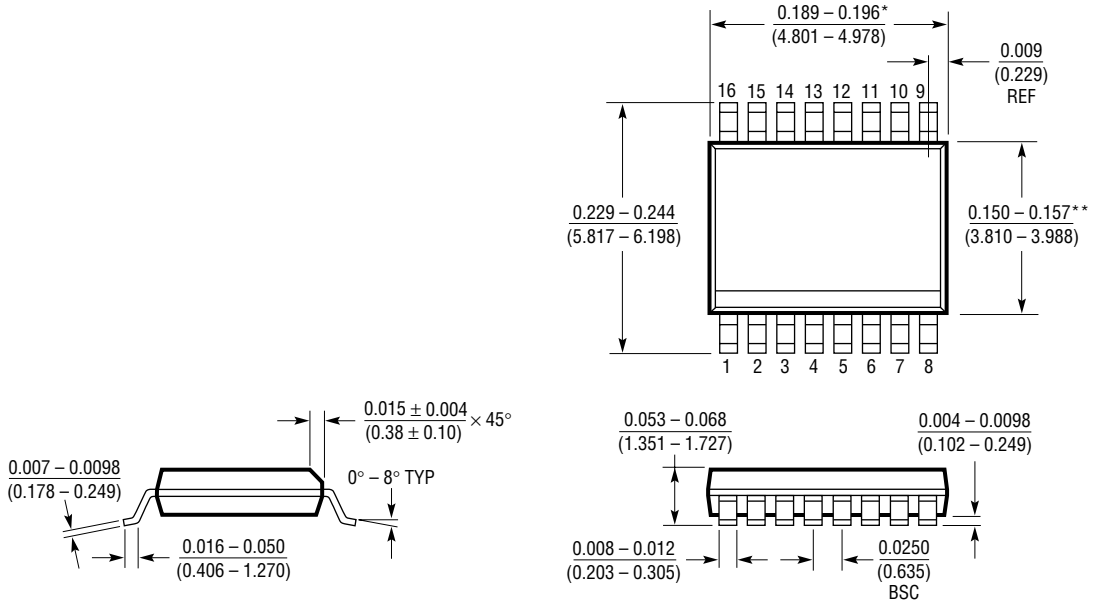


| CODE | V <sub>OUT X</sub> |
|------|--------------------|
| 0    | -5V                |
| 512  | 0V                 |
| 1023 | +4.99V             |

**PACKAGE DESCRIPTION**

Dimensions in inches (millimeters) unless otherwise noted.

**GN Package**  
**16-Lead Plastic SSOP (Narrow 0.150)**  
 (LTC DWG # 05-08-1641)



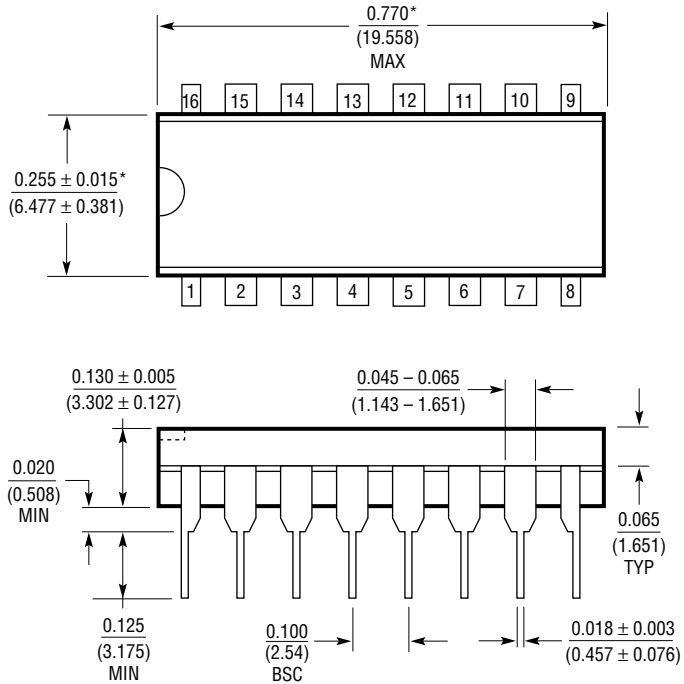
- \* DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE
- \*\* DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

GN16 (SSOP) 1098

**PACKAGE DESCRIPTION**

Dimensions in inches (millimeters) unless otherwise noted.

**N Package**  
**16-Lead PDIP (Narrow 0.300)**  
 (LTC DWG # 05-08-1510)

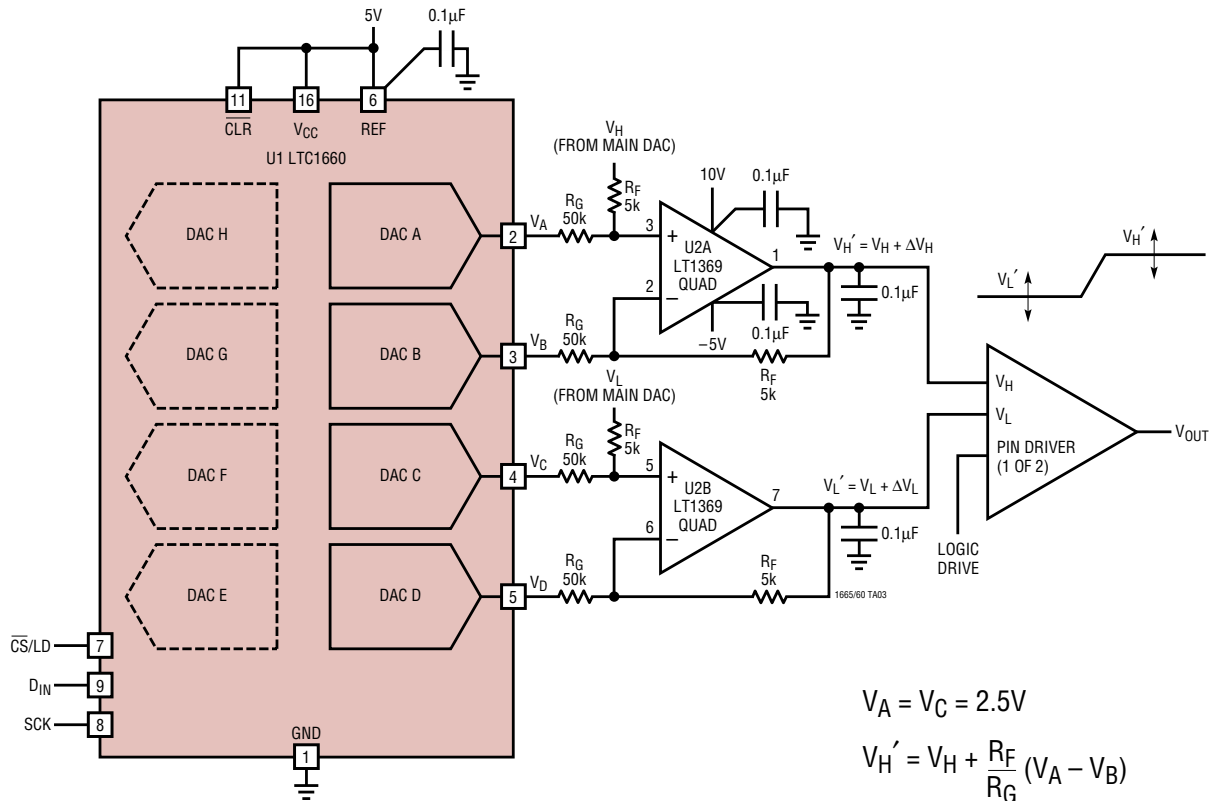


\*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.  
 MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 INCH (0.254mm)

N16 1098

## TYPICAL APPLICATION

### A Pin Driver $V_H$ and $V_L$ Adjustment Circuit for ATE Applications



Note: DACs E Through H Can Be Configured for a Second Pin Driver With U2C and U2D of the LT1369

| CODE A | CODE B | $\Delta V_H, \Delta V_L$ |
|--------|--------|--------------------------|
| 512    | 1023   | -250mV                   |
| 512    | 512    | 0                        |
| 512    | 0      | +250mV                   |

$$V_A = V_C = 2.5V$$

$$V_H' = V_H + \frac{R_F}{R_G} (V_A - V_B)$$

$$V_L' = V_L + \frac{R_F}{R_G} (V_C - V_D)$$

For Resistor Values Shown:  
Adjustment Range =  $\pm 250mV$   
Adjustment Step Size =  $500\mu V$

## RELATED PARTS

| PART NUMBER      | DESCRIPTION   | COMMENTS  |
|------------------|---|---|
| LTC1661          | Dual 10-Bit $V_{OUT}$ DAC in 8-Lead MSOP Package  | $V_{CC} = 2.7V$ to $5.5V$ Micropower Rail-to-Rail Output  |
| LTC1663          | Single 10-Bit $V_{OUT}$ DAC in SOT-23 Package   | $V_{CC} = 2.7V$ to $5.5V$ , Internal Reference, $60\mu A$   |
| LTC1446/LTC1446L | Dual 12-Bit $V_{OUT}$ DACs in SO-8 Package with Internal Reference                          | LTC1446: $V_{CC} = 4.5V$ to $5.5V$ , $V_{OUT} = 0V$ to $4.095V$<br>LTC1446L: $V_{CC} = 2.7V$ to $5.5V$ , $V_{OUT} = 0V$ to $2.5V$ |
| LTC1448          | Dual 12-Bit $V_{OUT}$ DAC in SO-8 Package   | $V_{CC} = 2.7V$ to $5.5V$ , External Reference Can Be Tied to $V_{CC}$  |
| 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 $4.095V$<br>LTC1454L: $V_{CC} = 2.7V$ to $5.5V$ , $V_{OUT} = 0V$ to $2.5V$ |
| 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 $4.095V$<br>LTC1458L: $V_{CC} = 2.7V$ to $5.5V$ , $V_{OUT} = 0V$ to $2.5V$ |
| LTC1590          | Dual 12-Bit $I_{OUT}$ DAC in SO-16 Package  | $V_{CC} = 4.5V$ to $5.5V$ , 4-Quadrant Multiplication   |
| LTC1659          | Single Rail-to-Rail 12-Bit $V_{OUT}$ DAC in 8-Lead MSOP Package<br>$V_{CC}: 2.7V$ to $5.5V$ | Low Power Multiplying $V_{OUT}$ DAC. Output Swings from GND to REF. REF Input Can Be Tied to $V_{CC}$                             |
| LT1460           | Micropower Precision Series Reference, 2.5V, 5V, 10V Versions                               | 0.075% Max, $10ppm/^{\circ}C$ Max, Only $130\mu A$ Supply Current   |