

## FEATURES

- **Ultralow Power: 1.5 $\mu$ A (Typ)  $I_{CC}$  per DAC Plus 0.05 $\mu$ A Sleep Mode for Extended Battery Life**
- **Tiny: Two 10-Bit DACs in an 8-Lead MSOP—Half the Size of an SO-8**
- Wide 2.7V to 5.5V Supply Range
- Double Buffered for Simultaneous DAC Updates
- **Rail-to-Rail Voltage Outputs Drive 1000pF**
- Reference Range Includes Supply for Ratiometric 0V-to- $V_{CC}$  Output
- Reference Input Impedance Is Code-Independent (7.1M $\Omega$  Typ)—Eliminates External Buffers
- 3-Wire Serial Interface with Schmitt Trigger Inputs
- Differential Nonlinearity:  $\pm 0.75$ LSB Max

## APPLICATIONS

- Mobile Communications
- Portable Battery-Powered Instruments
- Remote or Inaccessible Adjustments
- Digitally Controlled Amplifiers and Attenuators
- Factory or Field Calibration


## DESCRIPTION

The LTC<sup>®</sup>1662 is an ultralow power, fully buffered voltage output, dual 10-bit digital-to-analog converter (DAC). Each DAC channel draws just 1.7 $\mu$ A (typ) total supply-plus-reference operating current, yet is capable of supplying DC output currents in excess of 1mA and reliably driving capacitive loads of up to 1000pF. A programmable Sleep mode further reduces total operating current to 0.05 $\mu$ A.

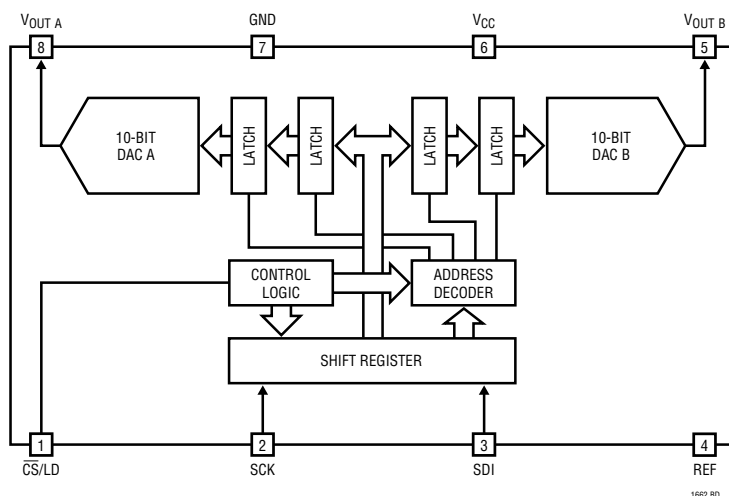
Linear Technology's proprietary, inherently monotonic architecture provides excellent linearity and an exceptionally small external form factor. The double-buffered input logic provides simultaneous update capability and can be used to write to the DACs without interrupting Sleep mode.

With its tiny operating current and exceptionally small size, the LTC1662 is ideal for use in the most power-constrained products. For most designs, there is no perceptible impact on the power budget; the LTC1662 draws many times less current than even a trimpot, while providing buffered, low impedance (0.5 $\Omega$  typical,  $V_{CC} = 5$ V) rail-to-rail outputs.

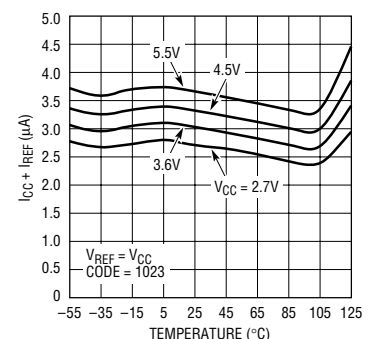
The LTC1662 is pin and software compatible with the LTC1661 dual, 60 $\mu$ A 10-bit DAC. It is available in 8-pin MSOP and PDIP packages and is specified over the industrial temperature range.

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## BLOCK DIAGRAM



**Total Supply-Plus-Reference Operating Current**



# LTC1662

## ABSOLUTE MAXIMUM RATINGS

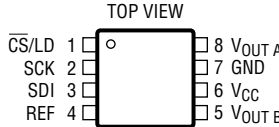
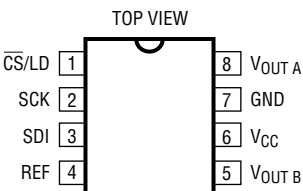
(Note 1)

|                                              |                              |
|----------------------------------------------|------------------------------|
| $V_{CC}$ to GND .....                        | -0.3V to 7.5V                |
| Logic Inputs to GND .....                    | -0.3V to 7.5V                |
| $V_{OUT A}$ , $V_{OUT B}$ , REF to GND ..... | -0.3V to ( $V_{CC} + 0.3V$ ) |
| Maximum Junction Temperature .....           | 125°C                        |
| Storage Temperature Range .....              | -65°C to 150°C               |

Operating Temperature Range

|                                            |               |
|--------------------------------------------|---------------|
| LTC1662C .....                             | 0°C to 70°C   |
| LTC1662I .....                             | -40°C to 85°C |
| Lead Temperature (Soldering, 10 sec) ..... | 300°C         |

## PACKAGE/ORDER INFORMATION

|                                                                                                                                                                                                     |                            |                                                                                                                                                                                                    |                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
|  <p>MS8 PACKAGE<br/>8-LEAD PLASTIC MSOP<br/><math>T_{JMAX} = 125^{\circ}C, \theta_{JA} = 150^{\circ}C/W</math></p> | ORDER PART NUMBER          |  <p>N8 PACKAGE<br/>8-LEAD PLASTIC DIP<br/><math>T_{JMAX} = 125^{\circ}C, \theta_{JA} = 100^{\circ}C/W</math></p> | ORDER PART NUMBER        |
|                                                                                                                                                                                                     | LTC1662CMS8<br>LTC1662IMS8 |                                                                                                                                                                                                    | LTC1662CN8<br>LTC1662IN8 |
|                                                                                                                                                                                                     | MS8 PART MARKING           |                                                                                                                                                                                                    |                          |
|                                                                                                                                                                                                     | LTKB<br>LTKC               |                                                                                                                                                                                                    |                          |

Consult factory for Military grade parts.

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range ( $T_A = T_{MIN}$  to  $T_{MAX}$ ), 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                                            | MIN | TYP   | MAX        | UNITS                    |
|------------------------|------------------------------------|-------------------------------------------------------|-----|-------|------------|--------------------------|
| <b>Accuracy</b>        |                                    |                                                       |     |       |            |                          |
|                        | Resolution                         |                                                       | ●   | 10    |            | Bits                     |
|                        | Monotonicity                       | (Note 2)                                              | ●   | 10    |            | Bits                     |
| DNL                    | Differential Nonlinearity          | (Note 2)                                              | ●   | ±0.12 | ±0.75      | LSB                      |
| INL                    | Integral Nonlinearity              | (Note 2)                                              | ●   | ±0.8  | ±4         | LSB                      |
| $V_{OS}$               | Offset Error                       | $V_{CC} = 5V, V_{REF} = 4.096V$ , Measured at Code 20 | ●   | ±5    | ±25        | mV                       |
| $V_{OS TC}$            | $V_{OS}$ Temperature Coefficient   |                                                       |     | ±15   |            | $\mu V/^{\circ}C$        |
| GE                     | Gain Error                         | $V_{CC} = 5V, V_{REF} = 4.096V$                       | ●   | ±1    | ±8         | LSB                      |
| GE TC                  | Gain Error Temperature Coefficient |                                                       |     | ±12   |            | $\mu V/^{\circ}C$        |
| PSR                    | Power Supply Rejection             | $V_{REF} = 2.5V$                                      |     | 0.18  |            | LSB/V                    |
| <b>Reference Input</b> |                                    |                                                       |     |       |            |                          |
|                        | Input Voltage Range                |                                                       | ●   | 0     | $V_{CC}$   | V                        |
|                        | Input Resistance                   | Active Mode<br>Sleep Mode                             | ●   | 3.9   | 7.1<br>2.5 | M $\Omega$<br>G $\Omega$ |
|                        | Input Capacitance                  |                                                       |     | 10    |            | pF                       |

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range ( $T_A = T_{MIN}$  to  $T_{MAX}$ ), 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>Power Supply</b>   |                              |                                                                               |       |            |              |                                |               |
| $V_{CC}$              | Positive Supply Voltage      | For Specified Performance                                                     | ● 2.7 |            | 5.5          | V                              |               |
| $I_{CC}$              | Supply Current               | $V_{CC} = 3\text{V}$ (Note 3)                                                 |       | 3.0        | 4.0          | $\mu\text{A}$                  |               |
|                       |                              | $V_{CC} = 5\text{V}$ (Note 3)                                                 |       | 3.5        | 4.5          | $\mu\text{A}$                  |               |
|                       |                              | $V_{CC} = 3\text{V}$ (Note 3)                                                 | ●     |            |              | 5.0                            | $\mu\text{A}$ |
|                       |                              | $V_{CC} = 5\text{V}$ (Note 3)                                                 | ●     |            |              | 5.5                            | $\mu\text{A}$ |
|                       | Sleep Mode Operating Current | Supply Plus Reference Current, $V_{CC} = V_{REF} = 5\text{V}$ (Note 3)        | ●     | 0.05       | 0.10<br>0.18 | $\mu\text{A}$<br>$\mu\text{A}$ |               |
| <b>DC Performance</b> |                              |                                                                               |       |            |              |                                |               |
|                       | Short-Circuit Current Low    | $V_{OUT} = 0\text{V}$ , $V_{CC} = V_{REF} = 5\text{V}$ , Code = 1023 (Note 7) | ●     | 5          | 12           | 70                             | $\text{mA}$   |
|                       | Short-Circuit Current High   | $V_{OUT} = V_{CC} = V_{REF} = 5\text{V}$ , Code = 0 (Note 7)                  | ●     | 3          | 10           | 80                             | $\text{mA}$   |
| <b>AC Performance</b> |                              |                                                                               |       |            |              |                                |               |
|                       | Voltage Output Slew Rate     | Rising (Notes 4, 5)                                                           |       | 20         |              | V/ms                           |               |
|                       |                              | Falling (Notes 4, 5)                                                          |       | 7          |              | V/ms                           |               |
|                       | Voltage Output Settling Time | Rising $0.1V_{FS}$ to $0.9V_{FS} \pm 0.5\text{LSB}$ (Notes 4, 5)              |       | 0.40       |              | ms                             |               |
|                       |                              | Falling $0.9V_{FS}$ to $0.1V_{FS} \pm 0.5\text{LSB}$ (Notes 4, 5)             |       | 0.75       |              | ms                             |               |
|                       | Capacitive Load Driving      |                                                                               |       | 1000       |              | pF                             |               |
| <b>Digital I/O</b>    |                              |                                                                               |       |            |              |                                |               |
| $V_{IH}$              | Digital Input High Voltage   | $V_{CC} = 2.7\text{V}$ to $5.5\text{V}$                                       | ●     | 2.4        |              | V                              |               |
|                       |                              | $V_{CC} = 2.7\text{V}$ to $3.6\text{V}$                                       | ●     | 2.0        |              | V                              |               |
| $V_{IL}$              | Digital Input Low Voltage    | $V_{CC} = 4.5\text{V}$ to $5.5\text{V}$                                       | ●     |            | 0.8          | V                              |               |
|                       |                              | $V_{CC} = 2.7\text{V}$ to $5.5\text{V}$                                       | ●     |            | 0.6          | V                              |               |
| $I_{LK}$              | Digital Input Leakage        | $V_{IN} = \text{GND}$ to $V_{CC}$                                             | ●     | $\pm 0.05$ | $\pm 1.0$    | $\mu\text{A}$                  |               |
| $C_{IN}$              | Digital Input Capacitance    |                                                                               |       | 1.5        |              | pF                             |               |

## TIMING CHARACTERISTICS

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

| SYMBOL                                                               | PARAMETER                                                  | CONDITIONS                             | MIN | TYP | MAX  | UNITS |
|----------------------------------------------------------------------|------------------------------------------------------------|----------------------------------------|-----|-----|------|-------|
| <b><math>V_{CC} = 4.5\text{V}</math> to <math>5.5\text{V}</math></b> |                                                            |                                        |     |     |      |       |
| $t_1$                                                                | SDI Setup                                                  | Relative to SCK Positive Edge          | ●   | 55  | 15   | ns    |
| $t_2$                                                                | SDI Hold                                                   | Relative to SCK Positive Edge          | ●   | 0   | -10  | ns    |
| $t_3$                                                                | SCK High Time                                              | (Note 6)                               | ●   | 30  | 14   | ns    |
| $t_4$                                                                | SCK Low Time                                               | (Note 6)                               | ●   | 30  | 14   | ns    |
| $t_5$                                                                | $\overline{\text{CS}}/\text{LD}$ Pulse Width               | (Note 6)                               | ●   | 100 | 27   | ns    |
| $t_6$                                                                | LSB SCK High to $\overline{\text{CS}}/\text{LD}$ High      | (Note 6)                               | ●   | 30  | 2    | ns    |
| $t_7$                                                                | $\overline{\text{CS}}/\text{LD}$ Low to SCK High           | (Note 6)                               | ●   | 20  | -21  | ns    |
| $t_9$                                                                | SCK Low to $\overline{\text{CS}}/\text{LD}$ Low            | (Note 6)                               | ●   | 0   | -5   | ns    |
| $t_{11}$                                                             | $\overline{\text{CS}}/\text{LD}$ High to SCK Positive Edge | (Note 6)                               | ●   | 20  | 0    | ns    |
|                                                                      | SCK Frequency                                              | Square Wave (Note 6)                   | ●   |     | 16.7 | MHz   |
| <b><math>V_{CC} = 2.7\text{V}</math> to <math>5.5\text{V}</math></b> |                                                            |                                        |     |     |      |       |
| $t_1$                                                                | SDI Setup                                                  | Relative to SCK Positive Edge (Note 6) | ●   | 75  | 20   | ns    |
| $t_2$                                                                | SDI Hold                                                   | Relative to SCK Positive Edge (Note 6) | ●   | 0   | -10  | ns    |
| $t_3$                                                                | SCK High Time                                              | (Note 6)                               | ●   | 50  | 15   | ns    |
| $t_4$                                                                | SCK Low Time                                               | (Note 6)                               | ●   | 50  | 15   | ns    |

## TIMING CHARACTERISTICS

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

| SYMBOL   | PARAMETER                                                  | CONDITIONS           | MIN   | TYP | MAX | UNITS |
|----------|------------------------------------------------------------|----------------------|-------|-----|-----|-------|
| $t_5$    | $\overline{\text{CS}}/\text{LD}$ Pulse Width               | (Note 6)             | ● 150 | 30  |     | ns    |
| $t_6$    | LSB SCK High to $\overline{\text{CS}}/\text{LD}$ High      | (Note 6)             | ● 50  | 3   |     | ns    |
| $t_7$    | $\overline{\text{CS}}/\text{LD}$ Low to SCK High           | (Note 6)             | ● 30  | -14 |     | ns    |
| $t_9$    | SCK Low to $\overline{\text{CS}}/\text{LD}$ Low            | (Note 6)             | ● 0   | -5  |     | ns    |
| $t_{11}$ | $\overline{\text{CS}}/\text{LD}$ High to SCK Positive Edge | (Note 6)             | ● 30  | 0   |     | ns    |
|          | SCK Frequency                                              | Square Wave (Note 6) | ●     |     | 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 and tested at  $V_{CC} = 5\text{V}$ ,  $V_{REF} = 4.096\text{V}$ , from code 20 to code 1023. See Figure 2.

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

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

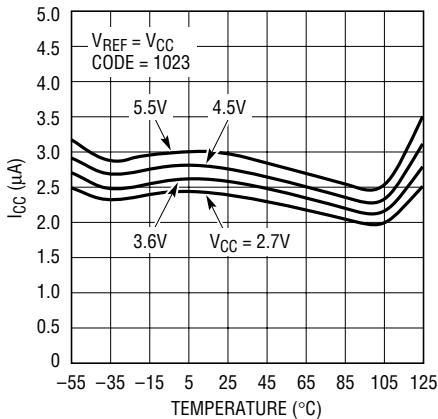
**Note 5:**  $V_{CC} = V_{REF} = 5\text{V}$ . DAC switched between  $0.1V_{FS}$  and  $0.9V_{FS}$ ; i.e., codes  $k = 102$  and  $k = 922$ .

**Note 6:** Guaranteed by design, not subject to test.

**Note 7:** One DAC output loaded.

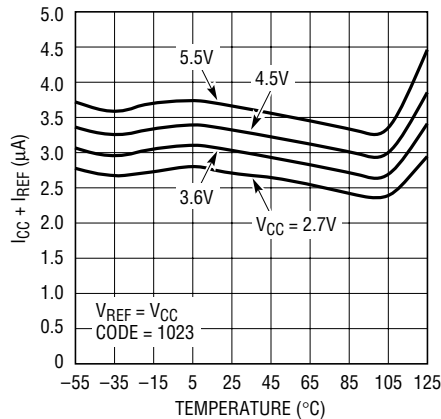
## TYPICAL PERFORMANCE CHARACTERISTICS

Supply Current vs Temperature



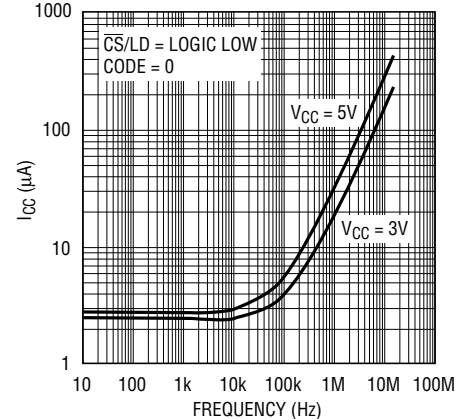
1662 G01

Total Supply-Plus-Reference Operating Current



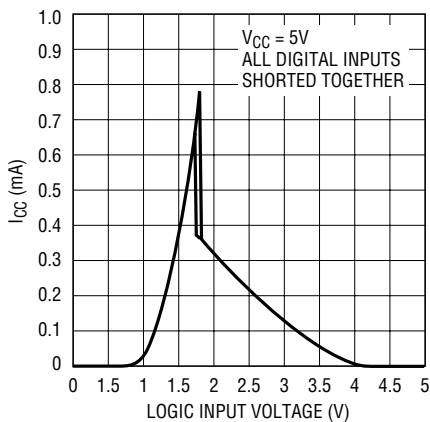
1662 G02

Supply Current vs Clock Frequency



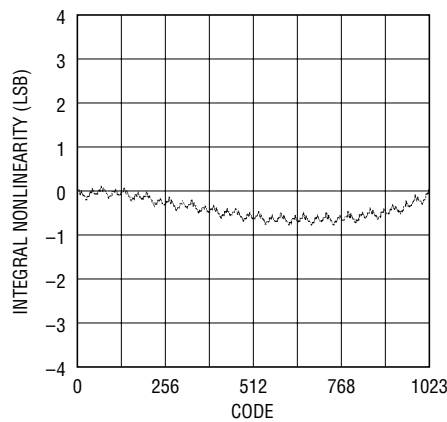
1662 G03

Supply Current vs Logic Input Voltage



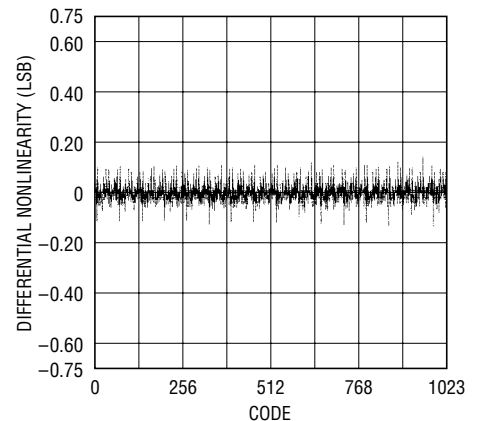
1662 G04

Integral Nonlinearity (INL)



1662 G05

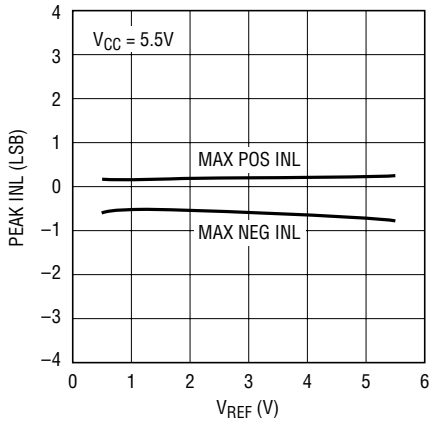
Differential Nonlinearity (DNL)



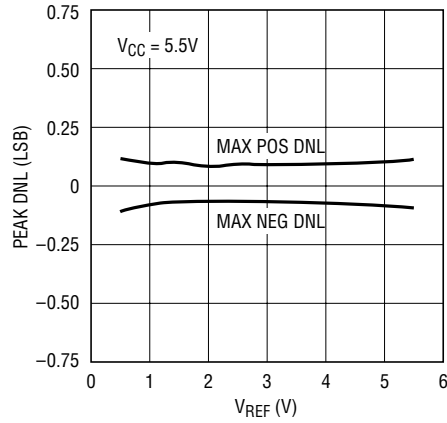
1662 G06

# TYPICAL PERFORMANCE CHARACTERISTICS

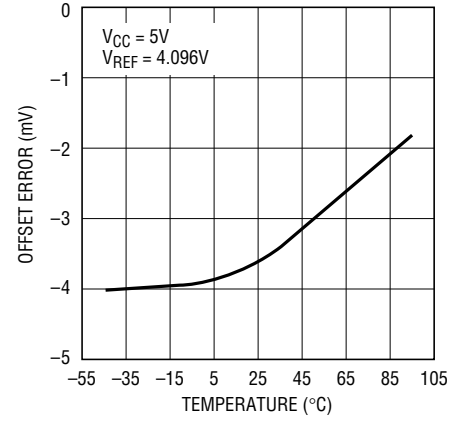
**Integral Nonlinearity (INL) vs Reference Voltage**



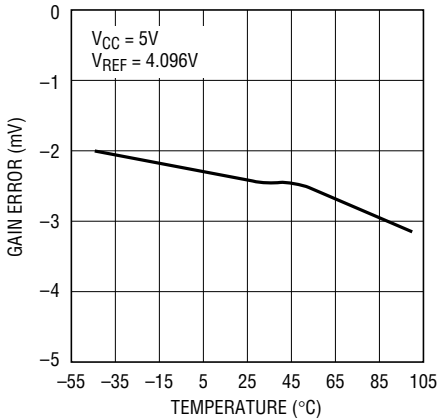
**Differential Nonlinearity (DNL) vs Reference Voltage**



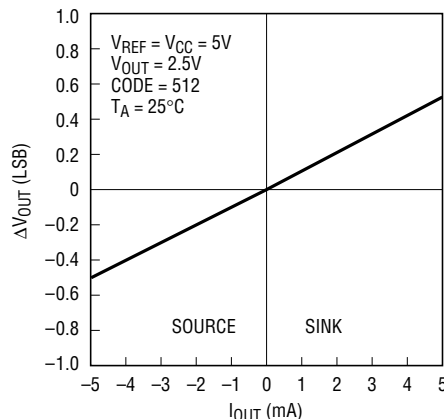
**Offset Voltage vs Temperature**



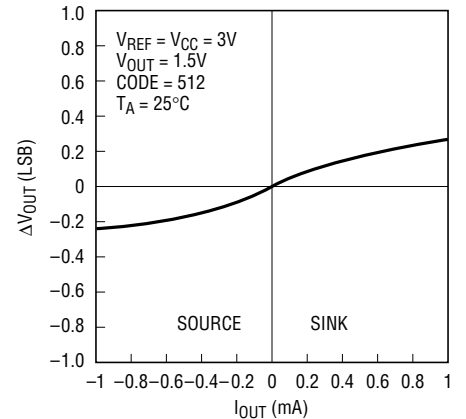
**Gain Error vs Temperature**



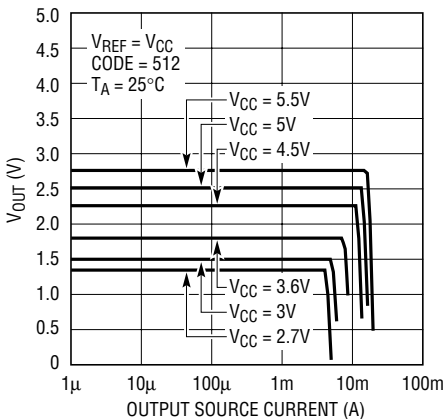
**Load Regulation vs Output Current at 5V**



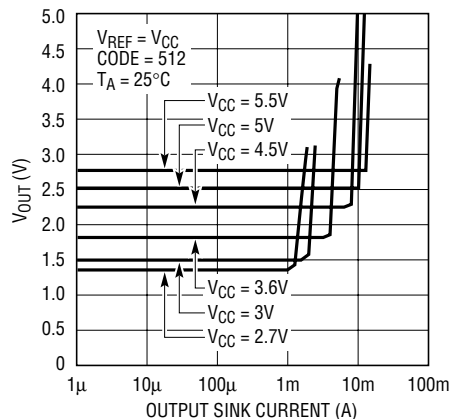
**Load Regulation vs Output Current at 3V**



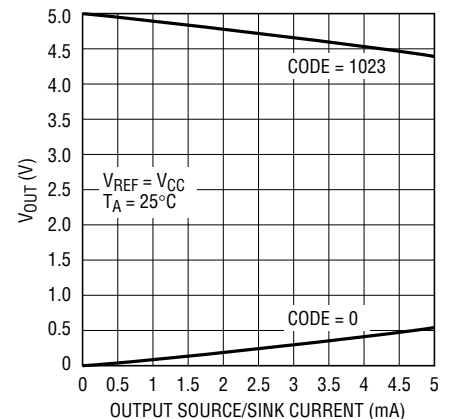
**Output Amplifier Current Sourcing Capability (Midscale)**



**Output Amplifier Current Sinking Capability (Midscale)**

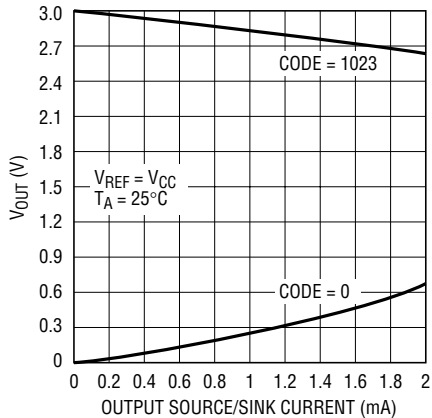


**Max/Min Output Voltage vs Source/Sink Output Current (VCC = 5V)**



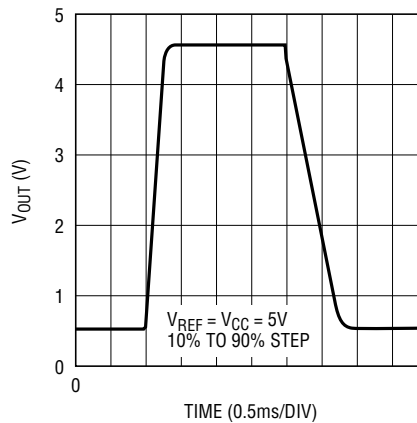
## TYPICAL PERFORMANCE CHARACTERISTICS

Max/Min Output Voltage vs Source/Sink Output Current ( $V_{CC} = 3V$ )



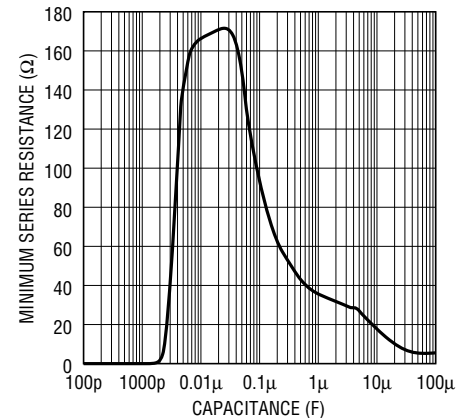
1662 G16

Large-Signal Step Response



1662 G17

Output Minimum Series Resistance vs Load Capacitance



1662 G18

## PIN FUNCTIONS

**$\overline{CS/LD}$  (Pin 1):** Serial Interface Chip Select/Load Input. When  $\overline{CS/LD}$  is low, SCK is enabled for shifting data on SDI into the register. When  $\overline{CS/LD}$  is pulled high, SCK is disabled and the operation(s) specified in the Control code, A3-A0, is (are) performed. CMOS and TTL compatible.

**SCK (Pin 2):** Serial Interface Clock Input. CMOS and TTL compatible.

**SDI (Pin 3):** Serial Interface Data Input. Input word data on the SDI pin is shifted into the 16-bit register on the rising edge of SCK. CMOS and TTL compatible.

**REF (Pin 4):** Reference Voltage Input.  $0V \leq V_{REF} \leq V_{CC}$ .

**$V_{OUT A}$ ,  $V_{OUT B}$  (Pins 8,5):** DAC Analog Voltage Outputs. The output range is

$$0 \leq V_{OUTA}, V_{OUTB} \leq V_{REF} \left( \frac{1023}{1024} \right)$$

**$V_{CC}$  (Pin 6):** Supply Voltage Input.  $2.7V \leq V_{CC} \leq 5.5V$ .

**GND (Pin 7):** System Ground.

## 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.

**Full-Scale Error (FSE):** The deviation of the actual full-scale voltage from ideal. FSE includes the effects of offset and gain errors (see Figure 2).

**Gain Error (GE):** The deviation from the slope of the ideal DAC transfer function, expressed in LSBs at full scale.

**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:

$$INL = [V_{OUT} - V_{OS} - (V_{FS} - V_{OS})(code/1023)] / LSB$$

## DEFINITIONS

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.

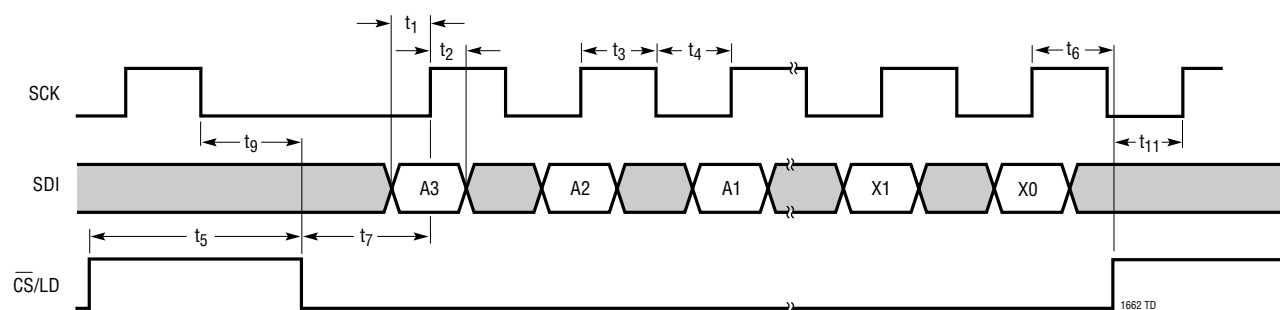
$$LSB = V_{REF}/1024$$

**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 Figure 2).

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

## TIMING DIAGRAM



## OPERATION

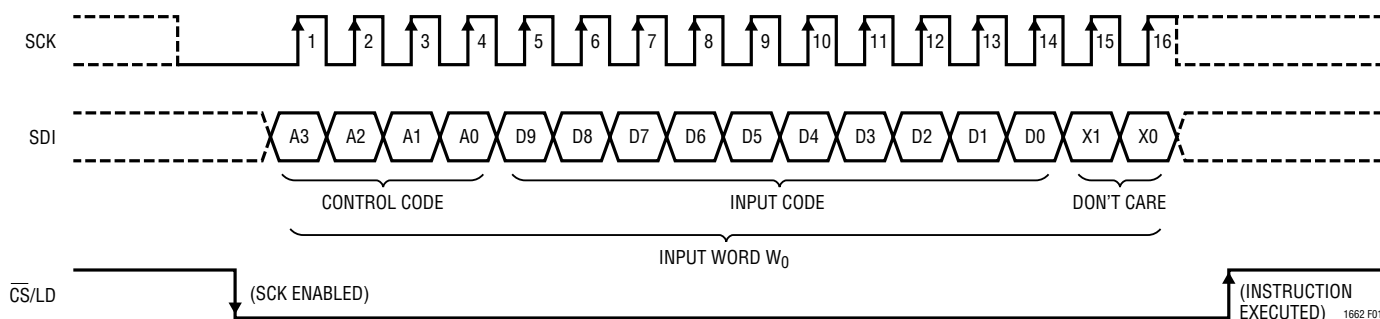


Figure 1. Register Loading Sequence

## OPERATION

**Table 1. DAC Control Functions**

| CONTROL |    |    |    | INPUT REGISTER STATUS                | DAC REGISTER STATUS | POWER-DOWN STATUS (SLEEP/WAKE) | COMMENTS                                                                                                                       |
|---------|----|----|----|--------------------------------------|---------------------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| A3      | A2 | A1 | A0 |                                      |                     |                                |                                                                                                                                |
| 0       | 0  | 0  | 0  | No Change                            | No Update           | No Change                      | No Operation. Power-Down Status Unchanged (Part Stays In Wake or Sleep Mode)                                                   |
| 0       | 0  | 0  | 1  | Load DAC A                           | No Update           | No Change                      | Load Input Register A with Data. DAC Outputs Unchanged. Power-Down Status Unchanged                                            |
| 0       | 0  | 1  | 0  | Load DAC B                           | No Update           | No Change                      | Load Input Register B with Data. DAC Outputs Unchanged. Power-Down Status Unchanged                                            |
| 1       | 0  | 0  | 0  | No Change                            | Update Outputs      | Wake                           | Load Both DAC Regs with Existing Contents of Input Regs. Outputs Update. Part Wakes Up                                         |
| 1       | 0  | 0  | 1  | Load DAC A                           | Update Outputs      | Wake                           | Load Input Reg A. Load DAC Regs with New Contents of Input Reg A and Existing Contents of Reg B. Outputs Update. Part Wakes Up |
| 1       | 0  | 1  | 0  | Load DAC B                           | Update Outputs      | Wake                           | Load Input Reg B. Load DAC Regs with Existing Contents of Input Reg A and New Contents of Reg B. Outputs Update. Part Wakes Up |
| 1       | 1  | 0  | 1  | No Change                            | No Update           | Wake                           | Part Wakes Up. Input and DAC Regs Unchanged. DAC Outputs Reflect Existing Contents of DAC Regs                                 |
| 1       | 1  | 1  | 0  | No Change                            | No Update           | Sleep                          | Part Goes to Sleep. Input and DAC Regs Unchanged. DAC Outputs Set to High Impedance State                                      |
| 1       | 1  | 1  | 1  | Load DACs A, B with Same 10-Bit Code | Update Outputs      | Wake                           | Load Both Input Regs. Load Both DAC Regs with New Contents of Input Regs. Outputs Update. Part Wakes Up                        |

**Note:** All control codes other than those shown are undefined and not subject to test.

### Transfer Function

The transfer function for the LTC1662 is:

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

where  $k$  is the decimal equivalent of the binary DAC input code D9-D0 and  $V_{\text{REF}}$  is the voltage at REF (Pin 4).

### Power-On Reset

The LTC1662 actively 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 4) should be kept within the range  $-0.3V \leq V_{\text{REF}} \leq V_{\text{CC}} + 0.3V$  (see Absolute Maximum Ratings). Particular care should be taken during power supply turn-on and turn-off sequences, when the voltage

at  $V_{\text{CC}}$  (Pin 6) is in transition. If it is not possible to sequence the supplies, clamp the voltage at REF by connecting a Schottky diode between Pin 4 (anode) and Pin 6 (cathode).

### Serial Interface

See Table 2. The 16-bit Input word consists of the 4-bit Control code, the 10-bit Input code and two don't-care bits.

**Table 2. LTC1662 Input Word**

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

After the Input word is loaded into the register (see Figure 1), it is internally converted from serial to parallel format. The parallel 10-bit-wide Input code data path is then buffered by two latch registers.



## OPERATION

The first of these, the Input Register, is used for loading new input codes. The second buffer, the DAC Register, is used for updating the DAC outputs. Each DAC has its own 10-bit Input Register and 10-bit DAC Register.

By selecting the appropriate 4-bit Control code (see Table 1) it is possible to perform single operations, such as loading one DAC or changing Power-Down status (Sleep/Wake). In addition, some Control codes perform two or more operations at the same time. For example, one such code loads DAC A, updates both outputs and Wakes the part up. The DACs can be loaded separately or together, but the outputs are always updated together.

### Register Loading Sequence

See Figure 1. With  $\overline{\text{CS/LD}}$  held low, data on the SDI input is shifted into the 16-bit Shift Register on the positive edge of SCK. The 4-bit Control code, A3-A0, is loaded first, then the 10-bit Input code, D9-D0, ordered MSB-to-LSB in each case. Two don't-care bits, X1 and X0, are loaded last. When the full 16-bit Input word has been shifted in,  $\overline{\text{CS/LD}}$  is pulled high, causing the system to respond according to Table 1. The clock is disabled internally when  $\overline{\text{CS/LD}}$  is high. Note: SCK must be low when  $\overline{\text{CS/LD}}$  is pulled low.

### Sleep Mode

DAC control code 1110<sub>b</sub> is reserved for the special Sleep instruction (see Table 1). In this mode, static power consumption is greatly reduced. The reference input and analog outputs are set in a high impedance 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 using control code 1110<sub>b</sub> (the DAC input code D9-D0 is ignored).

To save instruction cycles, the DACs may be prepared with new input codes during Sleep (control codes 0001<sub>b</sub> and 0010<sub>b</sub>); then, a single command (1000<sub>b</sub>) can be used both to wake the part and to update the output values.

Alternatively, one DAC may be loaded with a new input code during Sleep; then with just one command, the other DAC is loaded, the part is awakened and both outputs are updated.

For example, control code 0001<sub>b</sub> is used to load DAC A during Sleep. Then Control code 0101<sub>b</sub> loads DAC B, wakes the part and simultaneously updates both DAC outputs.

### Voltage Outputs

Each of the rail-to-rail output amplifiers contained in the LTC1662 can typically source or sink at least 1mA ( $V_{CC} = 5V$ ). The outputs swing to within a few millivolts of either supply when unloaded and have an equivalent output resistance of 130Ω (typical) when driving a load to the rails. The output amplifiers are stable driving capacitive loads of up to 1000pF.

A small resistor placed in series with the output can be used to achieve stability for any load capacitance. Please see the Output Minimum Resistance vs Load Capacitance curve in the Typical Performance Characteristics section.

### 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 2b.

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 ( $FSE = V_{OS} + GE$ ) is positive, the output for the highest codes limits at  $V_{CC}$  as shown in Figure 2c. 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.

**OPERATION**

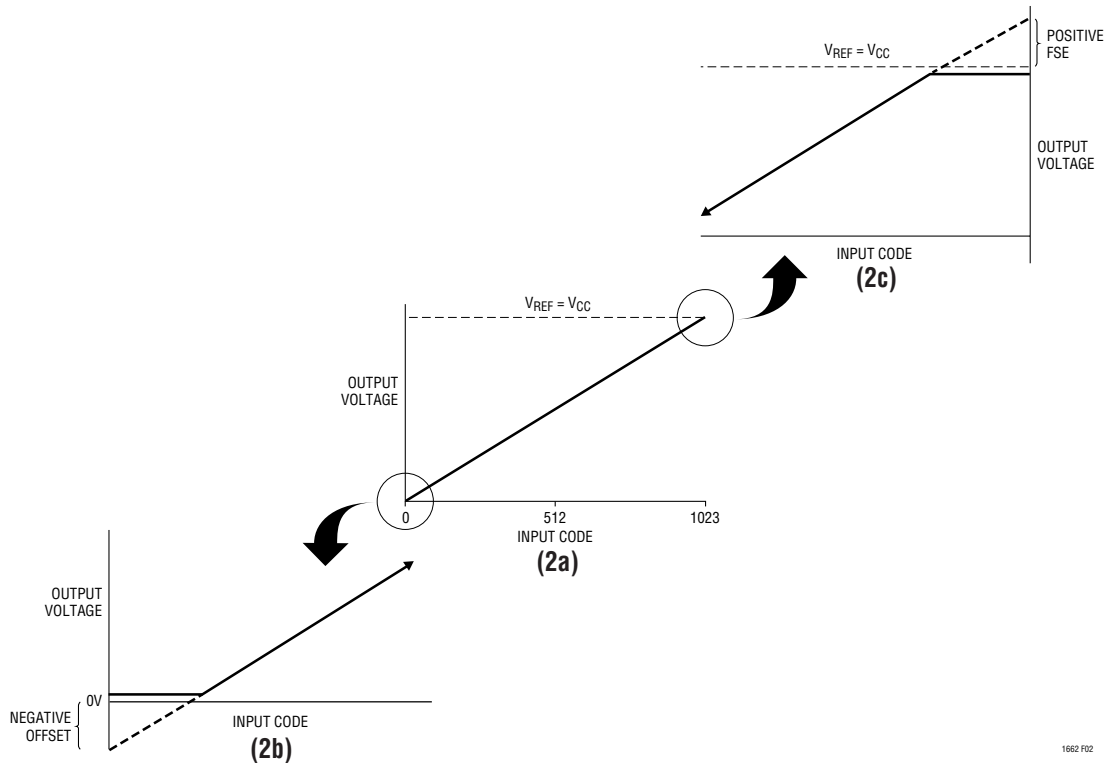
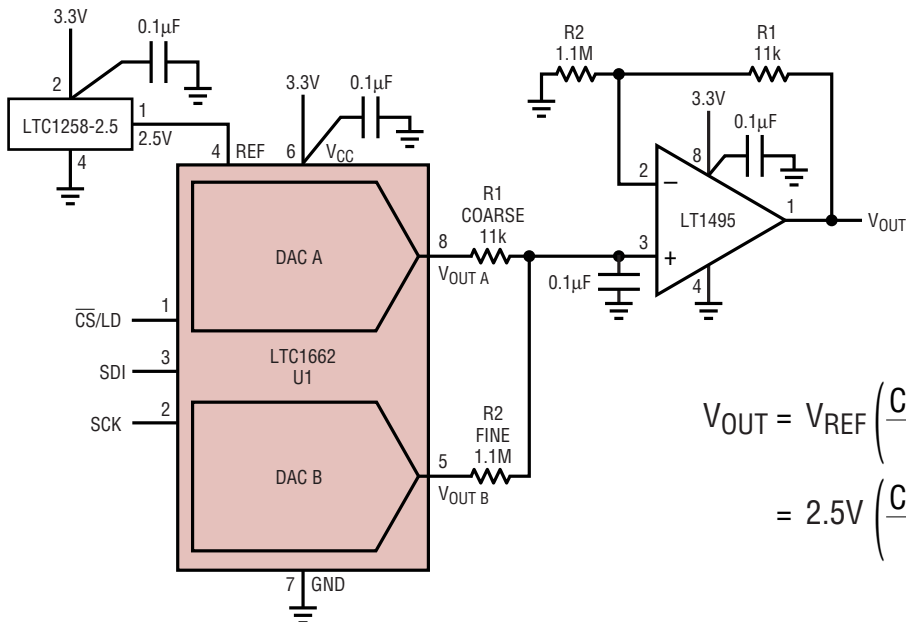


Figure 2. Effects of Rail-to-Rail Operation On a DAC Transfer Curve. (a) Overall Transfer Function (b) Effect of Negative Offset for Codes Near Zero Scale (c) Effect of Positive Full-Scale Error for Input Codes Near Full Scale When  $V_{REF} = V_{CC}$

**TYPICAL APPLICATIONS**

Micropower Trim Circuit with Coarse/Fine Adjustment. Total Supply Current Is  $9.5\mu A$

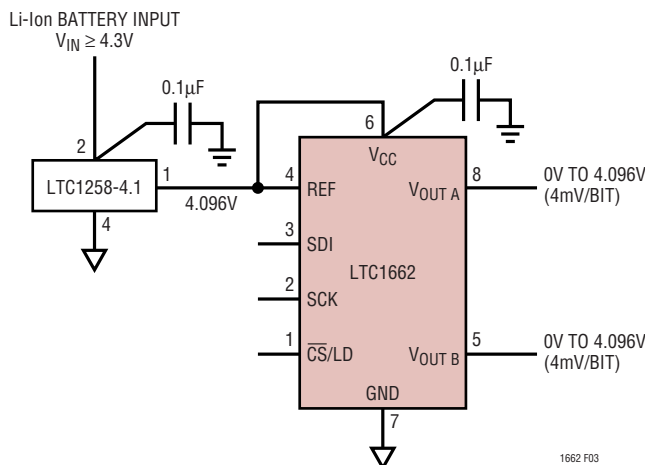


$$\begin{aligned}
 V_{OUT} &= V_{REF} \left( \frac{CODE A}{1024} + \frac{R1}{R2} \cdot \frac{CODE B}{1024} \right) \\
 &= 2.5V \left( \frac{CODE A}{1024} + \frac{1}{100} \cdot \frac{CODE B}{1024} \right)
 \end{aligned}$$

1662 F04

# TYPICAL APPLICATIONS

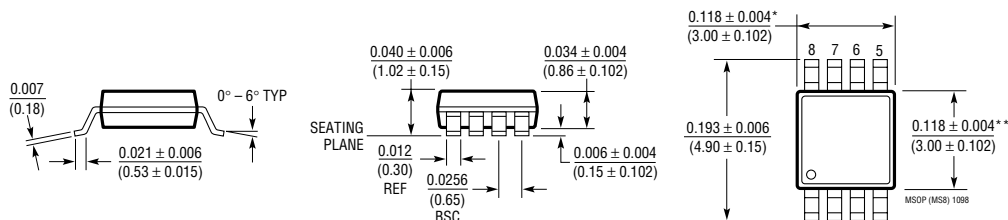
Using the LTC1258 and the LTC1662 In a Portable Application Powered by a Single Li-Ion Battery. Total Supply Current Is 8.2μA



# PACKAGE DESCRIPTION

Dimensions in inches (millimeters) unless otherwise noted.

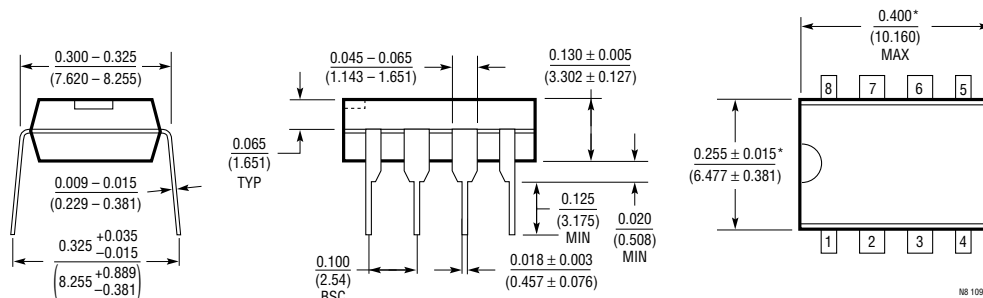
## MS8 Package 8-Lead Plastic MSOP (LTC DWG # 05-08-1660)



\* DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

\*\* DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS. INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

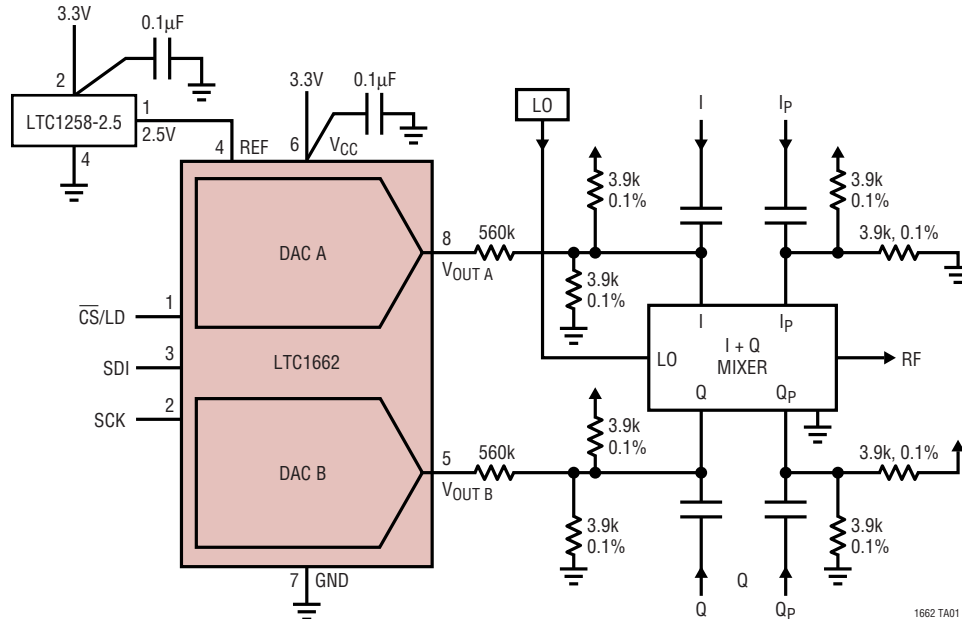
## N8 Package 8-Lead PDIP (Narrow 0.300) (LTC DWG # 05-08-1510)



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

## TYPICAL APPLICATION

Ultralow Power DAC Optimizes Mixer Performance



1662 TA01

## RELATED PARTS

| PART NUMBER      | DESCRIPTION                                                                                 | COMMENTS                                                                                                                          |
|------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| LTC1661          | Dual 10-Bit $V_{OUT}$ DAC in 8-Lead MSOP Package                                            | $V_{CC} = 2.7V$ to $5.5V$ , $60\mu A$ per DAC, Rail-to-Rail Output                                                                |
| LTC1663          | Single 10-Bit $V_{OUT}$ DAC with 2-Wire Interface in SOT-23 Package                         | $V_{CC} = 2.7V$ to $5.5V$ , Internal Reference, $60\mu A$                                                                         |
| LTC1664          | Quad 10-Bit $V_{OUT}$ DAC in 16-Pin Narrow SSOP                                             | $V_{CC} = 2.7V$ to $5.5V$ , $60\mu A$ per DAC, Rail-to-Rail Output                                                                |
| LTC1665/LTC1660  | Octal 8/10-Bit $V_{OUT}$ DAC in 16-Pin Narrow SSOP                                          | $V_{CC} = 2.7V$ to $5.5V$ , $60\mu A$ per DAC, Rail-to-Rail Output                                                                |
| 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 $2.5V$ |
| 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 $V_{CC}$                             |