

## FEATURES

- **Sample Rate: 400ksps**
- **Power Dissipation: 70mW**
- **Guaranteed  $\pm 1.5\text{LSB DNL}$ ,  $\pm 2\text{LSB INL (Max)}$**
- **80.5dB S/(N + D) and 93dB THD at 100kHz**
- **80dB S/(N + D) and 90dB THD at Nyquist**
- Nap and Sleep Shutdown Modes
- Operates with Internal or External Reference
- True Differential Inputs Reject Common Mode Noise
- 15MHz Full Power Bandwidth Sampling
- $\pm 2.5\text{V}$  Bipolar Input Range
- 28-Pin SSOP Package

## APPLICATIONS

- Telecommunications
- Digital Signal Processing
- Multiplexed Data Acquisition Systems
- High Speed Data Acquisition
- Spectrum Analysis
- Imaging Systems

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## DESCRIPTION

The LTC<sup>®</sup>1416 is a 2.2 $\mu\text{s}$ , 400ksps, 14-bit sampling A/D converter that draws only 70mW from  $\pm 5\text{V}$  supplies. This easy-to-use device includes a high dynamic range sample-and-hold and a precision reference. Two digitally selectable power shutdown modes provide flexibility for low power systems.

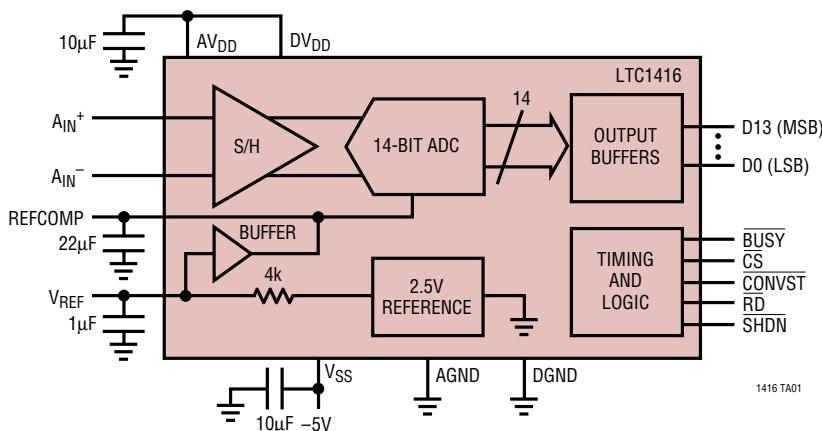
The LTC1416's full-scale input range is  $\pm 2.5\text{V}$ . Maximum DC specifications include  $\pm 2\text{LSB INL}$ ,  $\pm 1.5\text{LSB DNL}$  over temperature. Outstanding AC performance includes 80.5dB S/(N + D) and 93dB THD with a 100kHz input, and 80dB S/(N + D) and 90dB THD at the Nyquist input frequency of 200kHz.

The unique differential input sample-and-hold can acquire single-ended or differential input signals up to its 15MHz bandwidth. The 60dB common mode rejection allows users to eliminate ground loops and common mode noise by measuring signals differentially from the source.

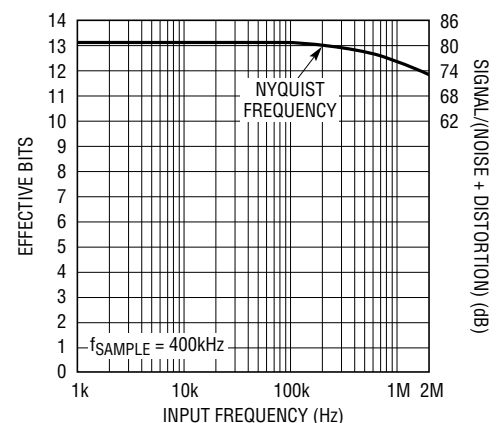
The ADC has a  $\mu\text{P}$  compatible, 14-bit parallel output port. There is no pipeline delay in the conversion results. A separate convert start input and a data ready signal ( $\overline{\text{BUSY}}$ ) ease connections to FIFOs, DSPs and microprocessors.

## TYPICAL APPLICATION

Complete, 70mW, 14-Bit ADC with 80.5dB S/(N + D)



Effective Bits and  
 Signal-to-(Noise + Distortion)  
 vs Input Frequency

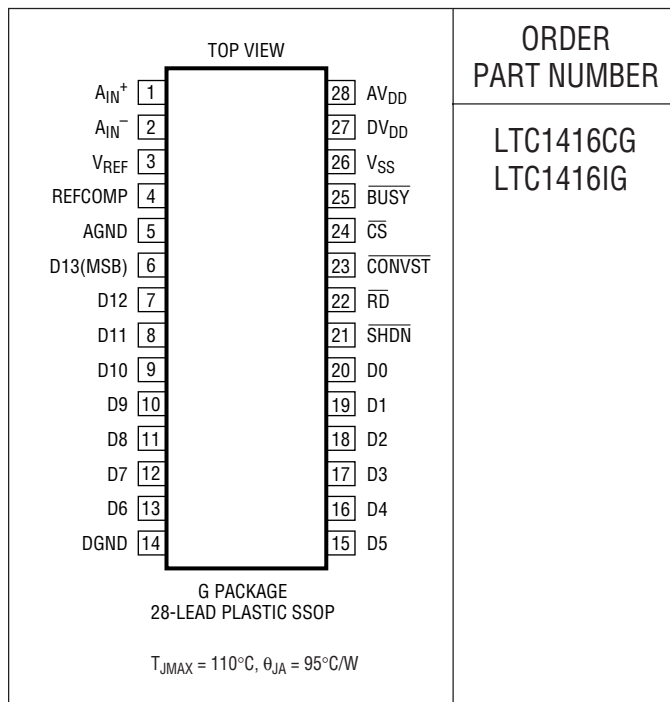


## ABSOLUTE MAXIMUM RATINGS

$AV_{DD} = DV_{DD} = V_{DD}$  (Notes 1, 2)

|   |  |
|---|--|
| Supply Voltage ( $V_{DD}$ ) .....                   | 6V   |
| Negative Supply Voltage ( $V_{SS}$ ) .....          | -6V  |
| Total Supply Voltage ( $V_{DD}$ to $V_{SS}$ ) ..... | 12V  |
| Analog Input Voltage                                |  |
| (Note 3) .....                                      | ( $V_{SS} - 0.3V$ ) to ( $V_{DD} + 0.3V$ ) |
| Digital Input Voltage (Note 4) .....                | ( $V_{SS} - 0.3V$ ) to 10V                 |
| Digital Output Voltage .....                        | ( $V_{SS} - 0.3V$ ) to ( $V_{DD} + 0.3V$ ) |
| Power Dissipation .....                             | 500mW                                      |
| Operating Temperature Range                         |  |
| Commercial .....                                    | 0°C to 70°C                                |
| Industrial .....                                    | -40°C to 85°C                              |
| Storage Temperature Range .....                     | -65°C to 150°C                             |
| Lead Temperature (Soldering, 10 sec) .....          | 300°C                                      |

## PACKAGE/ORDER INFORMATION



ORDER  
PART NUMBER

LTC1416CG  
LTC1416IG

Consult factory for Military grade parts and for A grade parts.

## CONVERTER CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . With Internal Reference (Notes 5, 6)

| PARAMETER                     | CONDITIONS                | MIN | TYP  | MAX  | UNITS  |
|-------------------------------|---------------------------|-----|------|------|--------|
| Resolution (No Missing Codes) |                           | ●   | 13   |      | Bits   |
| Integral Linearity Error      | (Note 7)                  | ●   | ±0.8 | ±2   | LSB    |
| Differential Linearity Error  |                           | ●   | ±0.7 | ±1.5 | LSB    |
| Offset Error                  | (Note 8)                  | ●   | ±5   | ±20  | LSB    |
| Full-Scale Error              | Internal Reference        |     | ±20  | ±60  | LSB    |
|                               | External Reference = 2.5V |     | ±10  | ±40  | LSB    |
| Full-Scale Tempco             | $I_{OUT(REF)} = 0$        |     | ±15  |      | ppm/°C |

## ANALOG INPUT

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 5)

| SYMBOL       | PARAMETER                                  | CONDITIONS   | MIN | TYP  | MAX | UNITS |
|--------------|--|--|-----|------|-----|-------|
| $V_{IN}$     | Analog Input Range (Note 9)                | $4.75V \leq V_{DD} \leq 5.25V, -5.25V \leq V_{SS} \leq -4.75V$ | ●   | ±2.5 |     | V     |
| $I_{IN}$     | Analog Input Leakage Current               | $\overline{CS} = \text{High}$                                  | ●   |      | ±1  | μA    |
| $C_{IN}$     | Analog Input Capacitance                   | Between Conversions  |     | 15   |     | pF    |
|              |  | During Conversions   |     | 5    |     | pF    |
| $t_{ACQ}$    | Sample-and-Hold Acquisition Time           | (Note 9)   | ●   | 100  | 400 | ns    |
| $t_{AP}$     | Sample-and-Hold Aperture Delay Time        |  |     | -1.5 |     | ns    |
| $t_{jitter}$ | Sample-and-Hold Aperture Delay Time Jitter |  |     | 2    |     | pSRMS |
| CMRR         | Analog Input Common Mode Rejection Ratio   | $-2.5V < (A_{IN}^- = A_{IN}^+) < 2.5V$                         |     | 60   |     | dB    |

## DYNAMIC ACCURACY

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 5)

| SYMBOL    | PARAMETER                            | CONDITIONS   | MIN | TYP        | MAX | UNITS    |
|-----------|--------------------------------------|--|-----|------------|-----|----------|
| S/(N + D) | Signal-to-(Noise + Distortion) Ratio | 100kHz Input Signal<br>200kHz Input Signal                                       | 77  | 80.5<br>80 |     | dB<br>dB |
| THD       | Total Harmonic Distortion            | 100kHz Input Signal, First 5 Harmonics<br>200kHz Input Signal, First 5 Harmonics |     | -93<br>-90 | -86 | dB<br>dB |
| SFDR      | Spurious-Free Dynamic Range          | 100kHz Input Signal  |     | -95        | -86 | dB       |
| IMD       | Intermodulation Distortion           | $f_{IN1} = 87.01172\text{kHz}$ , $f_{IN2} = 113.18359\text{kHz}$                 |     | -90        |     | dB       |
|           | Full Power Bandwidth                 |  |     | 15         |     | MHz      |
|           | Full Linear Bandwidth                | $S/(N + D) \geq 77\text{dB}$   |     | 0.8        |     | MHz      |

## INTERNAL REFERENCE CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 5)

| PARAMETER                   | CONDITIONS   | MIN   | TYP          | MAX   | UNITS                 |
|-----------------------------|--|-------|--------------|-------|-----------------------|
| $V_{REF}$ Output Voltage    | $I_{OUT} = 0$  | 2.480 | 2.500        | 2.520 | V                     |
| $V_{REF}$ Output Tempco     | $I_{OUT} = 0$  |       | $\pm 15$     |       | ppm/ $^\circ\text{C}$ |
| $V_{REF}$ Line Regulation   | $4.75\text{V} \leq V_{DD} \leq 5.25\text{V}$<br>$-5.25\text{V} \leq V_{SS} \leq -4.75\text{V}$ |       | 0.05<br>0.05 |       | LSB/V<br>LSB/V        |
| $V_{REF}$ Output Resistance | $-0.1\text{mA} \leq  I_{OUT}  \leq 0.1\text{mA}$   |       | 4            |       | $\text{k}\Omega$      |
| COMP Output Voltage         | $I_{OUT} = 0$  |       | 4.06         |       | V                     |

## DIGITAL INPUTS AND DIGITAL OUTPUTS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 5)

| SYMBOL       | PARAMETER                         | CONDITIONS   | MIN | TYP          | MAX      | UNITS         |
|--------------|-----------------------------------|--|-----|--------------|----------|---------------|
| $V_{IH}$     | High Level Input Voltage          | $V_{DD} = 5.25\text{V}$  | 2.4 |              |          | V             |
| $V_{IL}$     | Low Level Input Voltage           | $V_{DD} = 4.75\text{V}$  |     |              | 0.8      | V             |
| $I_{IN}$     | Digital Input Current             | $V_{IN} = 0\text{V}$ to $V_{DD}$   |     |              | $\pm 10$ | $\mu\text{A}$ |
| $C_{IN}$     | Digital Input Capacitance         |  |     | 5            |          | pF            |
| $V_{OH}$     | High Level Output Voltage         | $V_{DD} = 4.75\text{V}$<br>$I_{OUT} = -10\mu\text{A}$<br>$I_{OUT} = -200\mu\text{A}$ | 4.0 | 4.5          |          | V<br>V        |
| $V_{OL}$     | Low Level Output Voltage          | $V_{DD} = 4.75\text{V}$<br>$I_{OUT} = 160\mu\text{A}$<br>$I_{OUT} = 1.6\text{mA}$    |     | 0.05<br>0.10 | 0.4      | V<br>V        |
| $I_{OZ}$     | Hi-Z Output Leakage D13 to D0     | $V_{OUT} = 0\text{V}$ to $V_{DD}$ , $\overline{\text{CS}}$ High                      |     |              | $\pm 10$ | $\mu\text{A}$ |
| $C_{OZ}$     | Hi-Z Output Capacitance D13 to D0 | $\overline{\text{CS}}$ High (Note 9)   |     |              | 15       | pF            |
| $I_{SOURCE}$ | Output Source Current             | $V_{OUT} = 0\text{V}$  |     | -10          |          | mA            |
| $I_{SINK}$   | Output Sink Current               | $V_{OUT} = V_{DD}$   |     | 10           |          | mA            |

## POWER REQUIREMENTS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 5)

| SYMBOL   | PARAMETER               | CONDITIONS  | MIN   | TYP | MAX   | UNITS         |
|----------|-------------------------|---|-------|-----|-------|---------------|
| $V_{DD}$ | Positive Supply Voltage | (Note 10)   | 4.75  |     | 5.25  | V             |
| $V_{SS}$ | Negative Supply Voltage | (Note 10)   | -4.75 |     | -5.25 | V             |
| $I_{DD}$ | Positive Supply Current |   |       | 7   | 10    | mA            |
|          | Nap Mode                | $\overline{\text{SHDN}} = 0\text{V}$ , $\overline{\text{CS}} = 0\text{V}$ |       | 1   | 1.6   | mA            |
|          | Sleep Mode              | $\overline{\text{SHDN}} = 0\text{V}$ , $\overline{\text{CS}} = 5\text{V}$ |       | 1   |       | $\mu\text{A}$ |

## POWER REQUIREMENTS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 5)

| SYMBOL     | PARAMETER                     | CONDITIONS  | MIN | TYP | MAX | UNITS         |
|------------|-------------------------------|---|-----|-----|-----|---------------|
| $I_{SS}$   | Negative Supply Current       |   |     | 7   | 10  | mA            |
|            | Nap Mode                      | $\overline{\text{SHDN}} = 0\text{V}$ , $\overline{\text{CS}} = 0\text{V}$ |     | 20  |     | $\mu\text{A}$ |
|            | Sleep Mode                    | $\overline{\text{SHDN}} = 0\text{V}$ , $\overline{\text{CS}} = 5\text{V}$ |     | 15  |     | $\mu\text{A}$ |
| $P_{DISS}$ | Power Dissipation             |   |     | 70  | 100 | mW            |
|            | Power Dissipation, Nap Mode   | $\overline{\text{SHDN}} = 0\text{V}$ , $\overline{\text{CS}} = 0\text{V}$ |     | 4   | 6   | mW            |
|            | Power Dissipation, Sleep Mode | $\overline{\text{SHDN}} = 0\text{V}$ , $\overline{\text{CS}} = 5\text{V}$ |     | 0.1 |     | mW            |

## TIMING CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 5, see Figures 15 to 21)

| SYMBOL                   | PARAMETER   | CONDITIONS   | MIN | TYP      | MAX | UNITS |               |
|--------------------------|---|--|-----|----------|-----|-------|---------------|
| $f_{\text{SAMPLE(MAX)}}$ | Maximum Sampling Frequency  |  | ●   | 400      |     | kHz   |               |
| $t_{\text{CONV}}$        | Conversion Time   |  | ●   | 1.5      | 1.9 | 2.2   | $\mu\text{s}$ |
| $t_{\text{ACQ}}$         | Acquisition Time  | (Note 9)   | ●   |          | 100 | 400   | ns            |
| $t_{\text{ACQ+CONV}}$    | Acquisition + Conversion Time   |  | ●   |          | 2   | 2.5   | $\mu\text{s}$ |
| $t_1$                    | $\overline{\text{CS}}$ to $\overline{\text{RD}}$ Setup Time                           | (Notes 9, 10)  | ●   | 0        |     |       | ns            |
| $t_2$                    | $\overline{\text{CS}}\downarrow$ to $\overline{\text{CONVST}}\downarrow$ Setup Time   | (Notes 9, 10)  | ●   | 10       |     |       | ns            |
| $t_3$                    | $\overline{\text{CS}}\downarrow$ to $\overline{\text{SHDN}}\downarrow$ Setup Time     | (Notes 9, 10)  | ●   | 10       |     |       | ns            |
| $t_4$                    | $\overline{\text{SHDN}}\uparrow$ to $\overline{\text{CONVST}}\downarrow$ Wake-Up Time | $\overline{\text{CS}} = 0\text{V}$ (Note 10)   |     |          | 400 |       | ns            |
| $t_5$                    | $\overline{\text{CONVST}}$ Low Time   | (Notes 10, 11)   | ●   | 40       |     |       | ns            |
| $t_6$                    | $\overline{\text{CONVST}}$ to $\overline{\text{BUSY}}$ Delay                          | $C_L = 25\text{pF}$  | ●   |          | 25  |       | ns            |
|                          |   |  |     |          |     | 50    | ns            |
| $t_7$                    | Data Ready Before $\overline{\text{BUSY}}\uparrow$                                    | (Note 9)   | ●   | 75       | 100 |       | ns            |
|                          |   |  |     | 50       |     |       | ns            |
| $t_8$                    | Delay Between Conversions   | (Note 10)  | ●   | 40       |     |       | ns            |
| $t_9$                    | Wait Time $\overline{\text{RD}}\downarrow$ After $\overline{\text{BUSY}}\uparrow$     |  | ●   | -5       |     |       | ns            |
| $t_{10}$                 | Data Access Time After $\overline{\text{RD}}\downarrow$                               | $C_L = 25\text{pF}$  | ●   |          | 15  | 25    | ns            |
|                          |   |  |     |          |     | 35    | ns            |
|                          |   |  | ●   |          | 20  | 35    | ns            |
| $t_{11}$                 | Bus Relinquish Time   | $0^\circ\text{C} \leq T_A \leq 70^\circ\text{C}$<br>$-40^\circ\text{C} \leq T_A \leq 85^\circ\text{C}$ | ●   |          | 8   | 20    | ns            |
|                          |   |  | ●   |          |     | 25    | ns            |
|                          |   |  | ●   |          |     | 30    | ns            |
| $t_{12}$                 | $\overline{\text{RD}}$ Low Time   |  | ●   | $t_{10}$ |     |       | ns            |
| $t_{13}$                 | $\overline{\text{CONVST}}$ High Time  |  | ●   | 40       |     |       | ns            |

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

**Note 2:** All voltage values are with respect to ground with DGND and AGND wired together unless otherwise noted.

**Note 3:** When these pin voltages are taken below  $V_{SS}$  or above  $V_{DD}$ , they will be clamped by internal diodes. This product can handle input currents greater than 100mA below  $V_{SS}$  or above  $V_{DD}$  without latching.

**Note 4:** When these pin voltages are taken below  $V_{SS}$ , they will be clamped by internal diodes. This product can handle input currents greater than 100mA below  $V_{SS}$  without latching. These pins are not clamped to  $V_{DD}$ .

**Note 5:**  $V_{DD} = 5\text{V}$ ,  $V_{SS} = -5\text{V}$ ,  $f_{\text{SAMPLE}} = 400\text{kHz}$ ,  $t_r = t_f = 5\text{ns}$  unless otherwise specified.

**Note 6:** Linearity, offset and full-scale specifications apply for a single-ended  $A_{IN}^+$  input with  $A_{IN}^-$  grounded.

**Note 7:** Integral nonlinearity is defined as the deviation of a code from a straight line passing through the actual endpoints of the transfer curve. The deviation is measured from the center of the quantization band.

**Note 8:** Bipolar offset is the offset voltage measured from  $-0.5\text{LSB}$  when the output code flickers between 0000 0000 0000 00 and 1111 1111 1111 11.

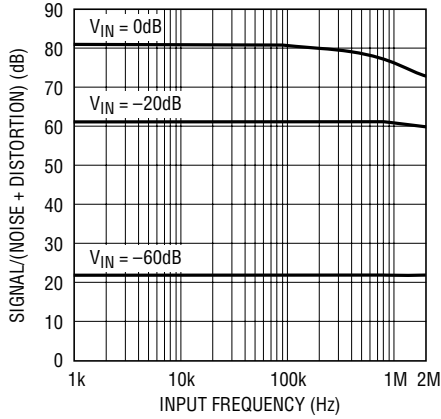
**Note 9:** Guaranteed by design, not subject to test.

**Note 10:** Recommended operating conditions.

**Note 11:** The falling  $\overline{\text{CONVST}}$  edge starts a conversion. If  $\overline{\text{CONVST}}$  returns high at a critical point during the conversion it can create small errors. For best results ensure that  $\overline{\text{CONVST}}$  returns high either within 900ns after the start of the conversion or after  $\overline{\text{BUSY}}$  rises.

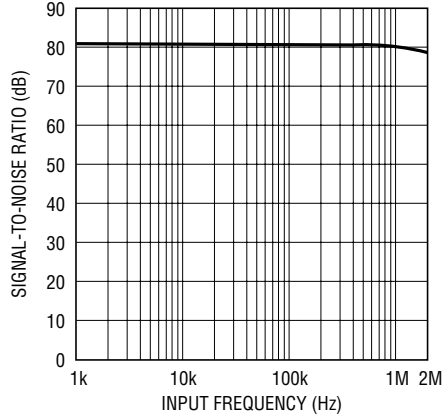
# TYPICAL PERFORMANCE CHARACTERISTICS

**S/(N + D) vs Input Frequency and Amplitude**



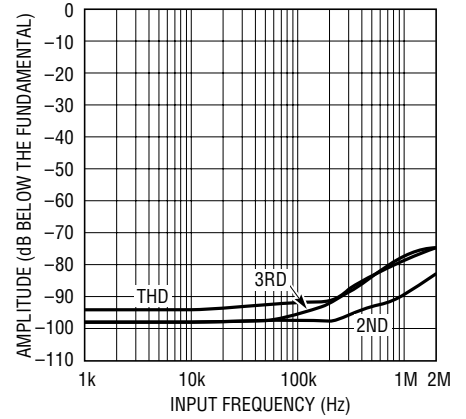
1416 G01

**Signal-to-Noise Ratio vs Input Frequency**



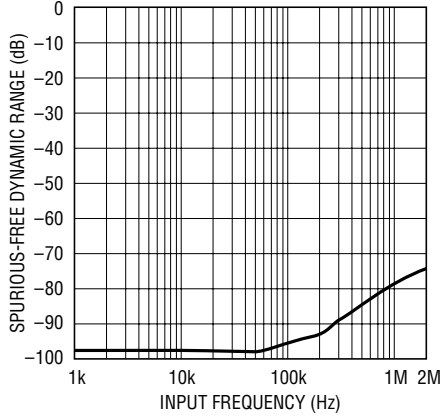
1416 G02

**Distortion vs Input Frequency**



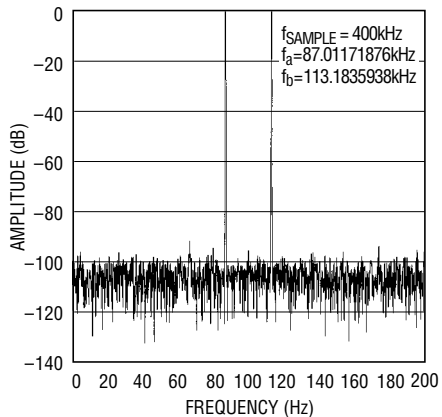
1416 G03

**Spurious-Free Dynamic Range vs Input Frequency**



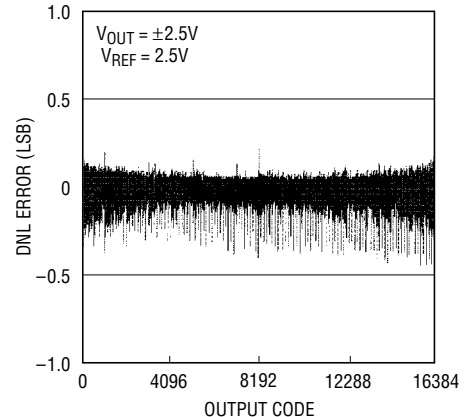
1416 G04

**Intermodulation Distortion Plot**



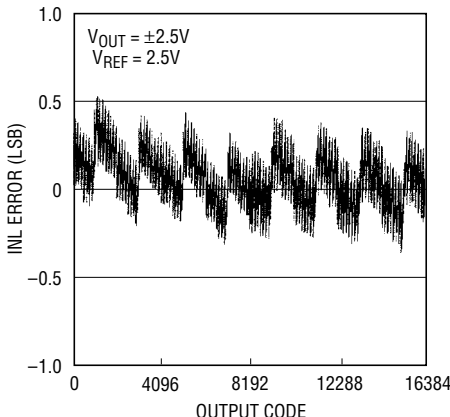
1416 G05

**Differential Nonlinearity vs Output Code**



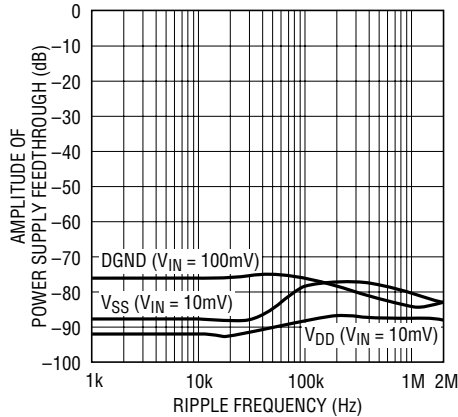
1416 G06

**Integral Nonlinearity vs Output Code**



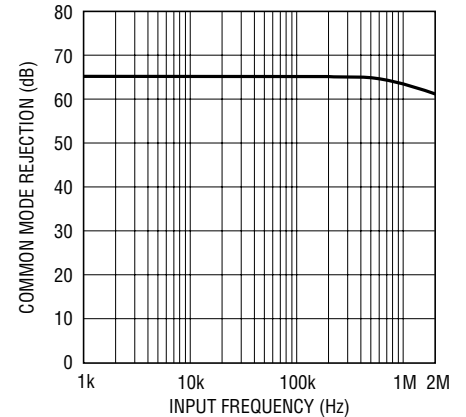
1416 G07

**Power Supply Feedthrough vs Ripple Frequency**



1416 G08

**Input Common Mode Rejection vs Input Frequency**



1416 G09

## PIN FUNCTIONS

**$A_{IN}^+$  (Pin 1):**  $\pm 2.5V$  Positive Analog Input.

**$A_{IN}^-$  (Pin 2):**  $\pm 2.5V$  Negative Analog Input.

**$V_{REF}$  (Pin 3):** 2.5V Reference Output. Bypass to AGND with  $1\mu F$ .

**REFCOMP (Pin 4):** 4.06V Reference Output. Bypass to AGND with  $22\mu F$  tantalum in parallel with  $0.1\mu F$  ceramic, or  $22\mu F$  ceramic.

**AGND (Pin 5):** Analog Ground.

**D13 to D6 (Pins 6 to 13):** Three-State Data Outputs.

**DGND (Pin 14):** Digital Ground for Internal Logic. Tie to AGND.

**D5 to D0 (Pins 15 to 20):** Three-State Data Outputs.

**SHDN (Pin 21):** Power Shutdown Input. Low selects shutdown. Shutdown mode selected by  $\overline{CS}$ .  $\overline{CS} = 0$  for nap mode and  $\overline{CS} = 1$  for sleep mode.

**RD (Pin 22):** Read Input. This enables the output drivers when  $\overline{CS}$  is low.

**CONVST (Pin 23):** Conversion Start Signal. This active low signal starts a conversion on its falling edge.

**CS (Pin 24):** The Chip Select input must be low for the ADC to recognize  $\overline{CONVST}$  and  $\overline{RD}$  inputs.  $\overline{CS}$  also sets the shutdown mode when  $\overline{SHDN}$  goes low.  $\overline{CS}$  and  $\overline{SHDN}$  low select the quick wake-up nap mode.  $\overline{CS}$  high and  $\overline{SHDN}$  low select sleep mode.

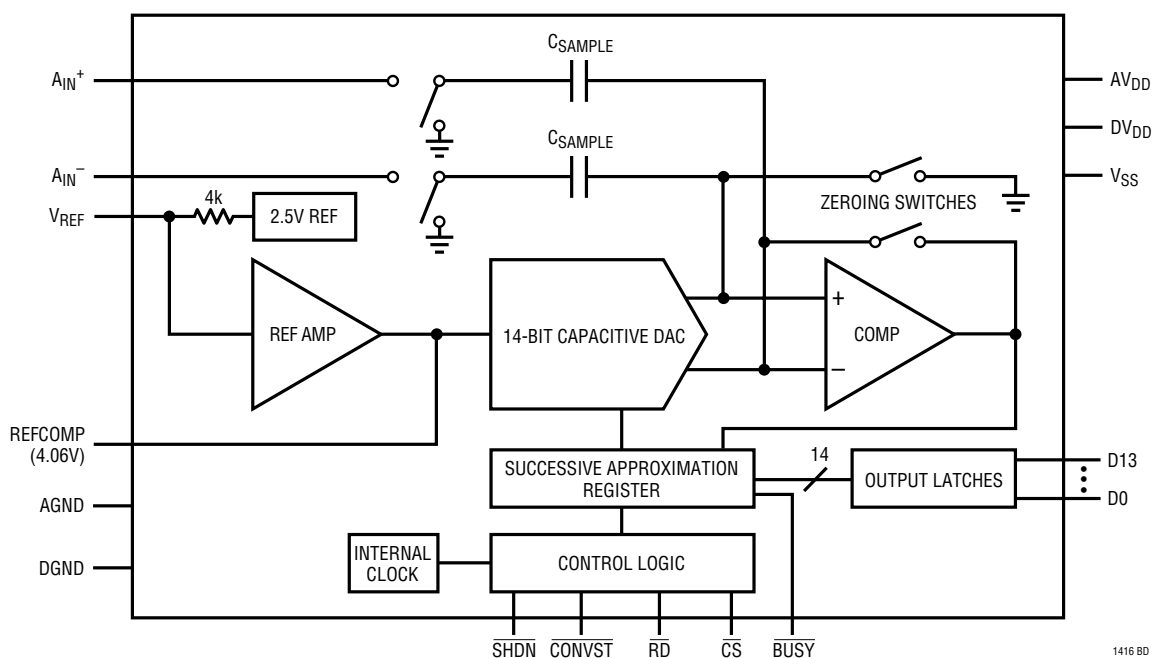
**BUSY (Pin 25):** The  $\overline{BUSY}$  output shows the converter status. It is low when a conversion is in progress. Data is valid on the rising edge of  $\overline{BUSY}$ .

**$V_{SS}$  (Pin 26):**  $-5V$  Negative Supply. Bypass to AGND with  $10\mu F$  tantalum in parallel with  $0.1\mu F$  ceramic, or  $10\mu F$  ceramic.

**DVDD (Pin 27):** 5V Positive Supply. Tie to Pin 28.

**AVDD (Pin 28):** 5V Positive Supply. Bypass to AGND with  $10\mu F$  tantalum in parallel with  $0.1\mu F$  ceramic, or  $10\mu F$  ceramic.

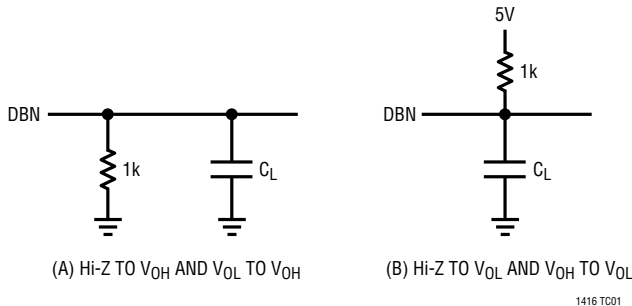
## FUNCTIONAL BLOCK DIAGRAM



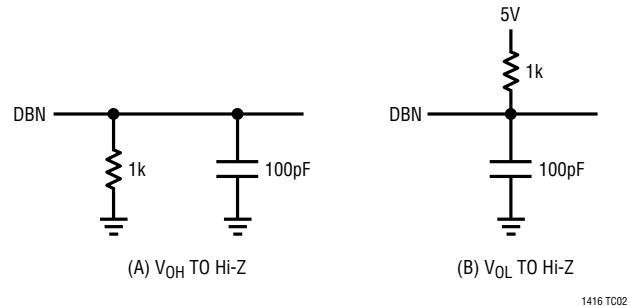
1416 BD

## TEST CIRCUITS

### Load Circuits for Access Timing



### Load Circuits for Output Float Delay



## APPLICATIONS INFORMATION

### CONVERSION DETAILS

The LTC1416 uses a successive approximation algorithm and an internal sample-and-hold circuit to convert an analog signal to a 14-bit parallel output. The ADC is complete with a precision reference and an internal clock. The control logic provides easy interface to microprocessors and DSPs. (Please refer to the Digital Interface section for the data format.)

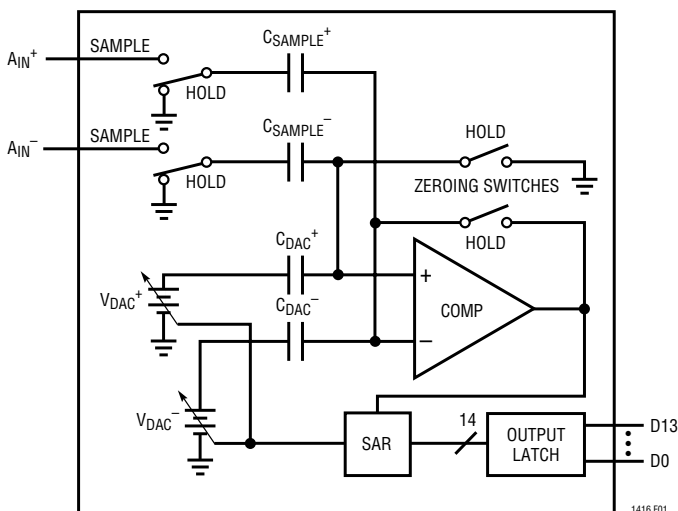


Figure 1. Simplified Block Diagram

Conversion start is controlled by the  $\overline{CS}$  and  $\overline{CONVST}$  inputs. At the start of the conversion, the successive approximation register (SAR) is reset. Once a conversion cycle has begun, it cannot be restarted.

During the conversion, the internal differential 14-bit capacitive DAC output is sequenced by the SAR from the most significant bit (MSB) to the least significant bit (LSB). Referring to Figure 1, the  $A_{IN}^+$  and  $A_{IN}^-$  inputs are connected to the sample-and-hold capacitors ( $C_{SAMPLE}$ ) during the acquire phase and the comparator offset is nulled by the zeroing switches. In this acquire phase, a minimum delay of 400ns will provide enough time for the sample-and-hold capacitors to acquire the analog signal. During the convert phase the comparator zeroing switches open, putting the comparator into compare mode. The input switches connect the  $C_{SAMPLE}$  capacitors to ground, transferring the differential analog input charge onto the summing junction. This input charge is successively compared with the binary-weighted charges supplied by the differential capacitive DAC. Bit decisions are made by the high speed comparator. At the end of a conversion, the differential DAC output balances the  $A_{IN}^+$  and  $A_{IN}^-$  input charges. The SAR contents (a 14-bit data word) which represents the difference of  $A_{IN}^+$  and  $A_{IN}^-$  are loaded into the 14-bit output latches.

# APPLICATIONS INFORMATION

## DYNAMIC PERFORMANCE

The LTC1416 has excellent high speed sampling capability. FFT (Fast Fourier Transform) test techniques are used to test the ADC's frequency response, distortion and noise at the rated throughput. By applying a low distortion sine wave and analyzing the digital output using an FFT algorithm, the ADC's spectral content can be examined for frequencies outside the fundamental. Figure 2 shows a typical LTC1416 FFT plot.

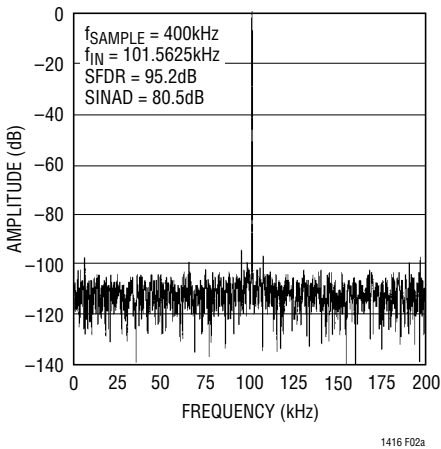


Figure 2a. LTC1416 Nonaveraged, 4096 Point FFT, Input Frequency = 100kHz

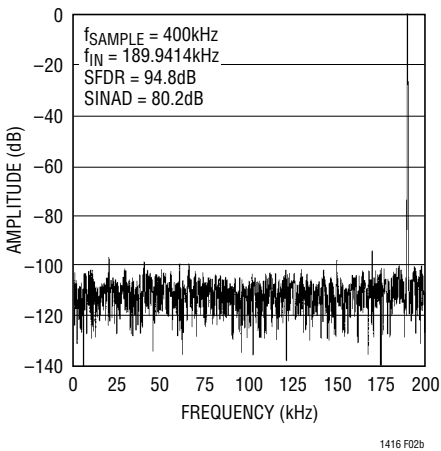


Figure 2b. LTC1416 Nonaveraged, 4096 Point FFT, Input Frequency = 190kHz

## Signal-to-Noise Ratio

The Signal-to-Noise plus Distortion Ratio  $[S/(N + D)]$  is the ratio between the RMS amplitude of the fundamental input frequency to the RMS amplitude of all other frequency components at the A/D output. The output is band limited to frequencies from above DC and below half the sampling frequency. Figure 2a shows a typical spectral content with a 400kHz sampling rate and a 100kHz input. The dynamic performance is excellent for input frequencies up to and beyond the Nyquist limit of 200kHz, Figure 2b.

## Effective Number of Bits

The Effective Number of Bits (ENOBs) is a measurement of the resolution of an ADC and is directly related to the  $S/(N + D)$  by the equation:

$$ENOB = [S/(N + D) - 1.76]/6.02$$

where ENOB is the Effective Number of Bits of resolution and  $S/(N + D)$  is expressed in dB. At the maximum sampling rate of 400kHz, the LTC1416 maintains near ideal ENOBs up to the Nyquist input frequency of 200kHz (refer to Figure 3).

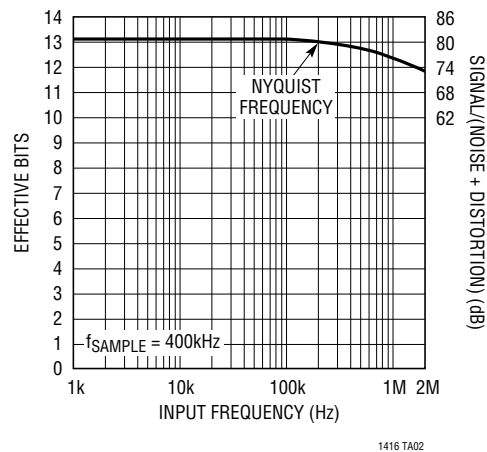


Figure 3. Effective Bits and Signal/(Noise + Distortion) vs Input Frequency



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### Total Harmonic Distortion

Total Harmonic Distortion (THD) is the ratio of the RMS sum of all harmonics of the input signal to the fundamental itself. The out-of-band harmonics alias into the frequency band between DC and half the sampling frequency. THD is expressed as:

$$\text{THD} = 20 \log \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots + V_n^2}}{V_1}$$

where  $V_1$  is the RMS amplitude of the fundamental frequency and  $V_2$  through  $V_n$  are the amplitudes of the second through  $N$ th harmonics. THD versus input frequency is shown in Figure 4. The LTC1416 has good distortion performance up to the Nyquist frequency and beyond.

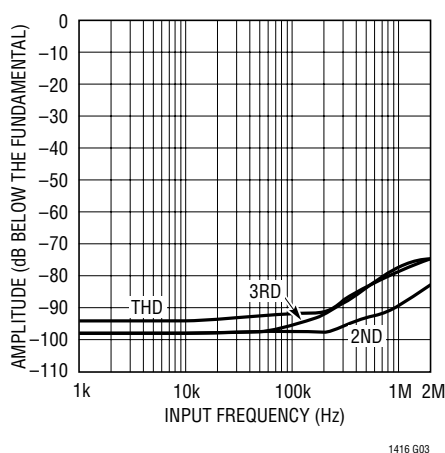


Figure 4. Distortion vs Input Frequency

### Intermodulation Distortion

If the ADC input signal consists of more than one spectral component, the ADC transfer function nonlinearity can produce intermodulation distortion (IMD) in addition to THD. IMD is the change in one sinusoidal input caused by the presence of another sinusoidal input at a different frequency.

If two pure sine waves of frequencies  $f_a$  and  $f_b$  are applied to the ADC input, nonlinearities in the ADC transfer function can create distortion products at the sum and

difference frequencies of  $m f_a \pm n f_b$ , where  $m$  and  $n = 0, 1, 2, 3$ , etc. For example, the 2nd order IMD terms include  $(f_a + f_b)$ . If the two input sine waves are equal in magnitude, the value (in decibels) of the 2nd order IMD products can be expressed by the following formula:

$$\text{IMD}(f_a + f_b) = 20 \log \frac{\text{Amplitude at } (f_a + f_b)}{\text{Amplitude at } f_a}$$

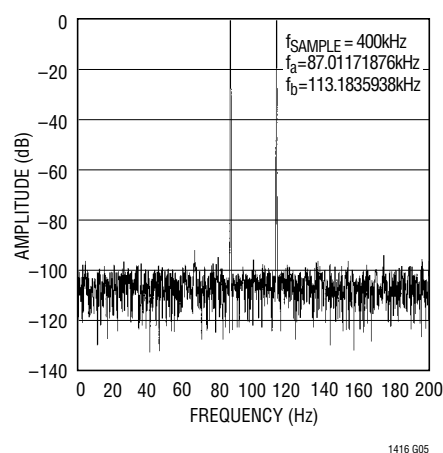


Figure 5. Intermodulation Distortion Plot

### Peak Harmonic or Spurious Noise

The peak harmonic or spurious noise is the largest spectral component excluding the input signal and DC. This value is expressed in decibels relative to the RMS value of a full-scale input signal.

### Full-Power and Full-Linear Bandwidth

The full-power bandwidth is that input frequency at which the amplitude of the reconstructed fundamental is reduced by 3dB for a full-scale input signal. The full-linear bandwidth is the input frequency at which the  $S/(N + D)$  has dropped to 77dB (12.5 effective bits). The LTC1416 has been designed to optimize input bandwidth, allowing the ADC to undersample input signals with frequencies above the converter's Nyquist frequency. The noise floor stays very low at high frequencies;  $S/(N + D)$  becomes dominated by distortion at frequencies far beyond Nyquist.

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### Driving the Analog Input

The differential analog inputs of the LTC1416 are easy to drive. The inputs may be driven differentially or as a single-ended input (i.e., the  $A_{IN}^-$  input is grounded). The  $A_{IN}^+$  and  $A_{IN}^-$  inputs are sampled at the same instant. Any unwanted signal that is common mode to both inputs will be reduced by the common mode rejection of the sample-and-hold circuit. The inputs draw only one small current spike while charging the sample-and-hold capacitors at the end of conversion. During conversion, the analog inputs draw only a small leakage current. If the source impedance of the driving circuit is low, then the LTC1416 inputs can be driven directly. As source impedance increases so will acquisition time (see Figure 6). For minimum acquisition time, with high source impedance, a buffer amplifier should be used. The only requirement is that the amplifier driving the analog input(s) must settle after the small current spike before the next conversion starts (settling time must be 400ns for full throughput rate).

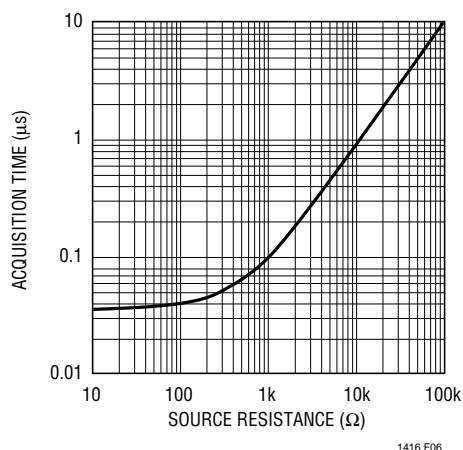


Figure 6. Acquisition Time vs Source Resistance

### Choosing an Input Amplifier

Choosing an input amplifier is easy if a few requirements are taken into consideration. First, to limit the magnitude of the voltage spike seen by the amplifier from charging the sampling capacitor, choose an amplifier that has a low output impedance ( $<100\Omega$ ) at the closed-loop bandwidth

frequency. For example, if an amplifier is used in a gain of 1 and has a unity-gain bandwidth of 50MHz, then the output impedance at 50MHz should be less than  $100\Omega$ . The second requirement is that the closed-loop bandwidth must be greater than 10MHz to ensure adequate small-signal settling for full throughput rate. If slower op amps are used, more settling time can be provided by increasing the time between conversions.

The best choice for an op amp to drive LTC1416 will depend on the application. Generally, applications fall into two categories: AC applications where dynamic specifications are most critical and time domain applications where DC accuracy and settling time are most critical. The following list is a summary of the op amps that are suitable for driving the LTC1416. More detailed information is available in the Linear Technology Databooks and the LinearView™ CD-ROM.

**LT®1220:** 30MHz unity-gain bandwidth voltage feedback amplifier.  $\pm 5V$  to  $\pm 15V$  supplies, excellent DC specifications.

**LT1223:** 100MHz video current feedback amplifier. 6mA supply current,  $\pm 5V$  to  $\pm 15V$  supplies, low distortion at frequencies above 400kHz, low noise, good for AC applications.

**LT1227:** 140MHz video current feedback amplifier. 10mA supply current,  $\pm 5V$  to  $\pm 15V$  supplies, lowest distortion at frequencies above 400kHz, low noise, best for AC applications.

**LT1229/LT1230:** Dual and quad 100MHz current feedback amplifiers.  $\pm 2V$  to  $\pm 15V$  supplies, low noise, good AC specs, 6mA supply current each amplifier.

**LT1360:** 50MHz voltage feedback amplifier. 3.8mA supply current, good AC and DC specs,  $\pm 5V$  to  $\pm 15V$  supplies.

**LT1363:** 70MHz, 1000V/ $\mu s$  op amps. 6.3mA supply current, good AC and DC specs.

**LT1364/LT1365:** Dual and quad 70MHz, 100V/ $\mu s$  op amps. 6.3mA supply current per amplifier.

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### Input Filtering

The noise and the distortion of the input amplifier and other circuitry must be considered since they will add to the LTC1416 noise and distortion. The small-signal bandwidth of the sample-and-hold circuit is 15MHz. Any noise or distortion products that are present at the analog inputs will be summed over this entire bandwidth. Noisy input circuitry should be filtered prior to the analog inputs to minimize noise. A simple 1-pole RC filter is sufficient for many applications. For example, Figure 7 shows a 1000pF capacitor from  $A_{IN}^+$  to ground and a 200 $\Omega$  source resistor to limit the input bandwidth to 800kHz. The 1000pF capacitor also acts as a charge reservoir for the input sample-and-hold and isolates the ADC input from sampling glitch sensitive circuitry. High quality capacitors and resistors should be used since these components can add distortion. NPO and silver mica type dielectric capacitors have excellent linearity. Carbon surface mount resistors can also generate distortion from self-heating and from damage that may occur during soldering. Metal film surface mount resistors are much less susceptible to both problems.

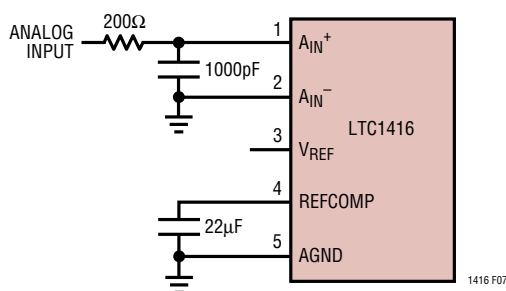


Figure 7. RC Input Filter

### Input Range

The  $\pm 2.5V$  input range of the LTC1416 is optimized for low noise and low distortion. Most op amps also perform best over this same range, allowing direct coupling to the analog inputs and eliminating the need for special translation circuitry.

Some applications may require other input ranges. The LTC1416 differential inputs and reference circuitry can

accommodate other input ranges often with little or no additional circuitry. The following sections describe the reference and input circuitry and how they affect the input range.

### Internal Reference

The LTC1416 has an on-chip, temperature compensated, curvature corrected, bandgap reference that is factory trimmed to 2.500V. It is connected internally to a reference amplifier and is available at  $V_{REF}$  (Pin 3). See Figure 8a. A 4k resistor is in series with the output so that it can be easily overdriven by an external reference or other circuitry (see Figure 8b). The reference amplifier gains the voltage at the  $V_{REF}$  pin by 1.625 to create the required internal reference voltage. This provides buffering between the  $V_{REF}$  pin and the high speed capacitive DAC. The

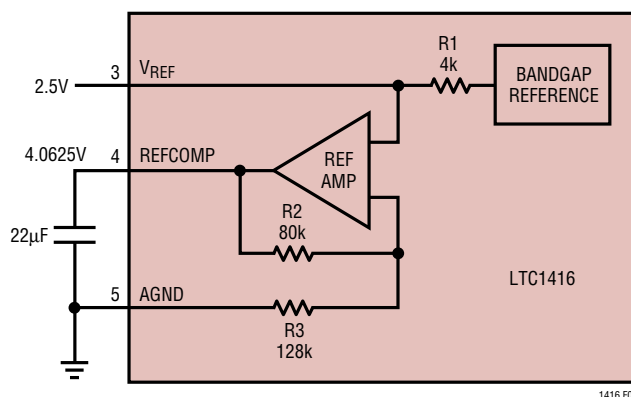


Figure 8a. LTC1416 Reference Circuit

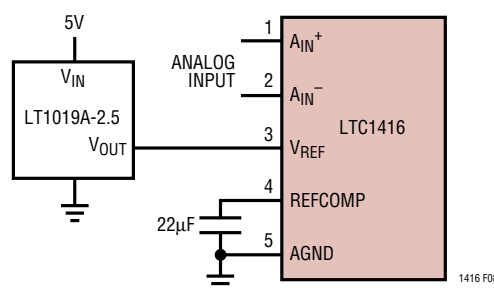


Figure 8b. Using the LT1019-2.5 as an External Reference

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reference amplifier compensation pin, REFCOMP (Pin 4), must be bypassed with a capacitor to ground. The reference amplifier is stable with capacitors of  $1\mu\text{F}$  or greater. For the best noise performance, a  $22\mu\text{F}$  ceramic or  $22\mu\text{F}$  tantalum in parallel with a  $0.1\mu\text{F}$  ceramic is recommended.

The  $V_{\text{REF}}$  pin can be driven with a DAC or other means shown in Figure 9. This is useful in applications where the peak input signal amplitude may vary. The input span of the ADC can then be adjusted to match the peak input signal, maximizing the signal-to-noise ratio. The filtering of the internal LTC1416 reference amplifier will limit the bandwidth and settling time of this circuit. A settling time of 5ms should be allowed for after a reference adjustment.

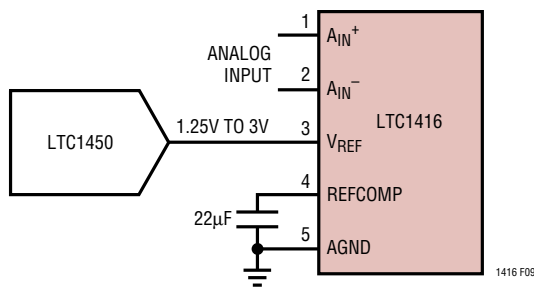


Figure 9. Driving  $V_{\text{REF}}$  with a DAC

### Differential Inputs

The LTC1416 has a unique differential sample-and-hold circuit that allows rail-to-rail inputs. The ADC will always convert the difference of  $A_{\text{IN}^+} - A_{\text{IN}^-}$  independent of the common mode voltage. The common mode rejection holds up to extremely high frequencies (see Figure 10a). The only requirement is that both inputs cannot exceed the  $AV_{\text{DD}}$  or  $AV_{\text{SS}}$  power supply voltages. Integral nonlinearity errors (INL) and differential nonlinearity errors (DNL) are independent of the common mode voltage, however, the bipolar zero error (BZE) will vary. The change in BZE is typically less than 0.1% of the common mode voltage. Dynamic performance is also affected by the common mode voltage. THD will degrade as the inputs approach either power supply rail, from 90dB with a common mode of 0V to 79dB with a common mode of 2.5V or  $-2.5\text{V}$ .

Differential inputs allow greater flexibility for accepting different input ranges. Figure 10b shows a circuit that

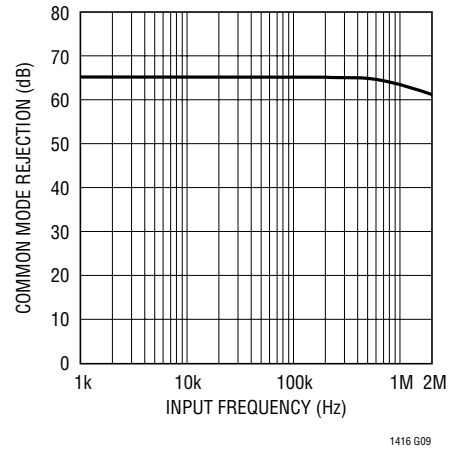


Figure 10a. CMRR vs Input Frequency

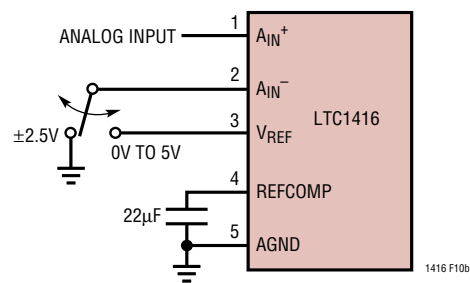


Figure 10b. Selectable 0V to 5V or  $\pm 2.5\text{V}$  Input Range

converts a 0V to 5V analog input signal with no additional translation circuitry.

### Full-Scale and Offset Adjustment

Figure 11a shows the ideal input/output characteristics for the LTC1416. The code transitions occur midway between successive integer LSB values (i.e.,  $-FS + 0.5\text{LSB}$ ,  $-FS + 1.5\text{LSB}$ ,  $-FS + 2.5\text{LSB}$ , ...  $FS - 1.5\text{LSB}$ ,  $FS - 0.5\text{LSB}$ ). The output is two's complement binary with  $1\text{LSB} = \text{FS} - (-\text{FS})/16384 = 5\text{V}/16384 = 305.2\mu\text{V}$ .

In applications where absolute accuracy is important, offset and full-scale errors can be adjusted to zero. Offset error must be adjusted before full-scale error. Figure 11b shows the extra components required for full-scale error adjustment. Zero offset is achieved by adjusting the offset applied to the  $A_{\text{IN}^-}$  input. For zero offset error, apply  $-152\mu\text{V}$  (i.e.,  $-0.5\text{LSB}$ ) at  $A_{\text{IN}^+}$  and adjust the offset at the  $A_{\text{IN}^-}$  input until the output code flickers between 0000

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0000 0000 00 and 1111 1111 1111 11. For full-scale adjustment, an input voltage of  $2.499544V$  ( $FS/2 - 1.5LSB$ ) is applied to  $A_{IN}$  and  $R2$  is adjusted until the output code flickers between 0111 1111 1111 10 and 0111 1111 1111 11.

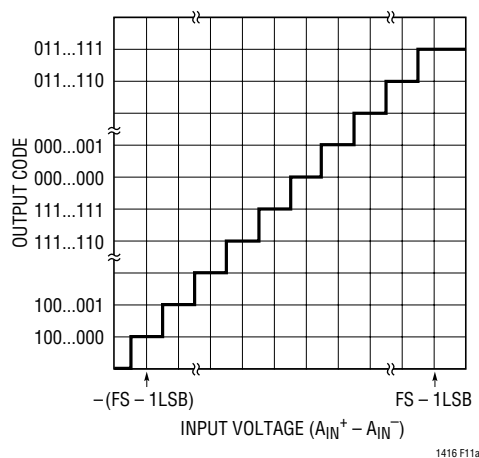


Figure 11a. LTC1416 Transfer Characteristics

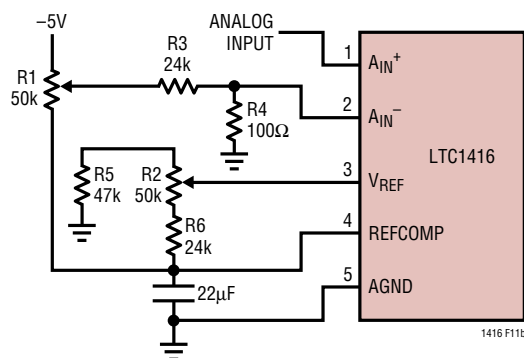


Figure 11b. Offset and Full-Scale Adjust Circuit

### Generating a $-5V$ Supply

There are several advantages to using  $\pm 5V$  supplies rather than a single  $5V$  supply. A larger signal magnitude is possible which increases the dynamic range and improves the signal-to-noise ratio. Operating on  $\pm 5V$  supplies also offers increased headroom which eases the requirements for signal conditioning circuitry, avoids the limitations of rail-to-rail operation and widens the selection of high performance operational amplifiers. Some

applications, however, do not have a  $-5V$  supply readily available and most ADCs have inadequate PSRR to sufficiently attenuate the noise created by a switching or charge pump supply. The LTC1416's excellent PSRR makes it possible to achieve good performance, even at 14 bits, using a switch based regulator for a  $-5V$  supply. Figure 12a shows a circuit using an LT1373 configured as a Cuk converter creating  $-5V$  from a  $5V$  supply. The circuit shown in Figure 12b uses an LT1054 regulated charge pump to provide  $-5V$ . This circuit has the advantage of reduced board space and fewer passive components. (For further details refer to *Linear Technology Magazine*, June 1997, Page 29.)

### BOARD LAYOUT AND BYPASSING

Wire wrap boards are not recommended for high resolution or high speed A/D converters. To obtain the best performance from the LTC1416, a printed circuit board with ground plane is required. Layout for the printed circuit board should ensure that digital and analog signal lines are separated as much as possible. In particular, care should be taken not to run any digital track alongside an analog signal track or underneath the ADC. The analog input should be screened by AGND.

An analog ground plane separate from the logic system ground should be established under and around the ADC (see Figure 13). Pin 5 (AGND), Pins 14 and 19 (ADC's DGND) and all other analog grounds should be connected to this single analog ground point. The REFCOMP bypass capacitor and the  $DV_{DD}$  bypass capacitor should also be connected to this analog ground plane. No other digital grounds should be connected to this analog ground plane. Low impedance analog and digital power supply common returns are essential to low noise operation of the ADC and the foil width for these tracks should be as wide as possible. In applications where the ADC data outputs and control signals are connected to a continuously active microprocessor bus, it is possible to get errors in the conversion results. These errors are due to feedthrough from the microprocessor to the successive approximation comparator. The problem can be eliminated by forcing the microprocessor into a Wait state during conversion or by using three-state buffers to isolate the ADC data bus. The

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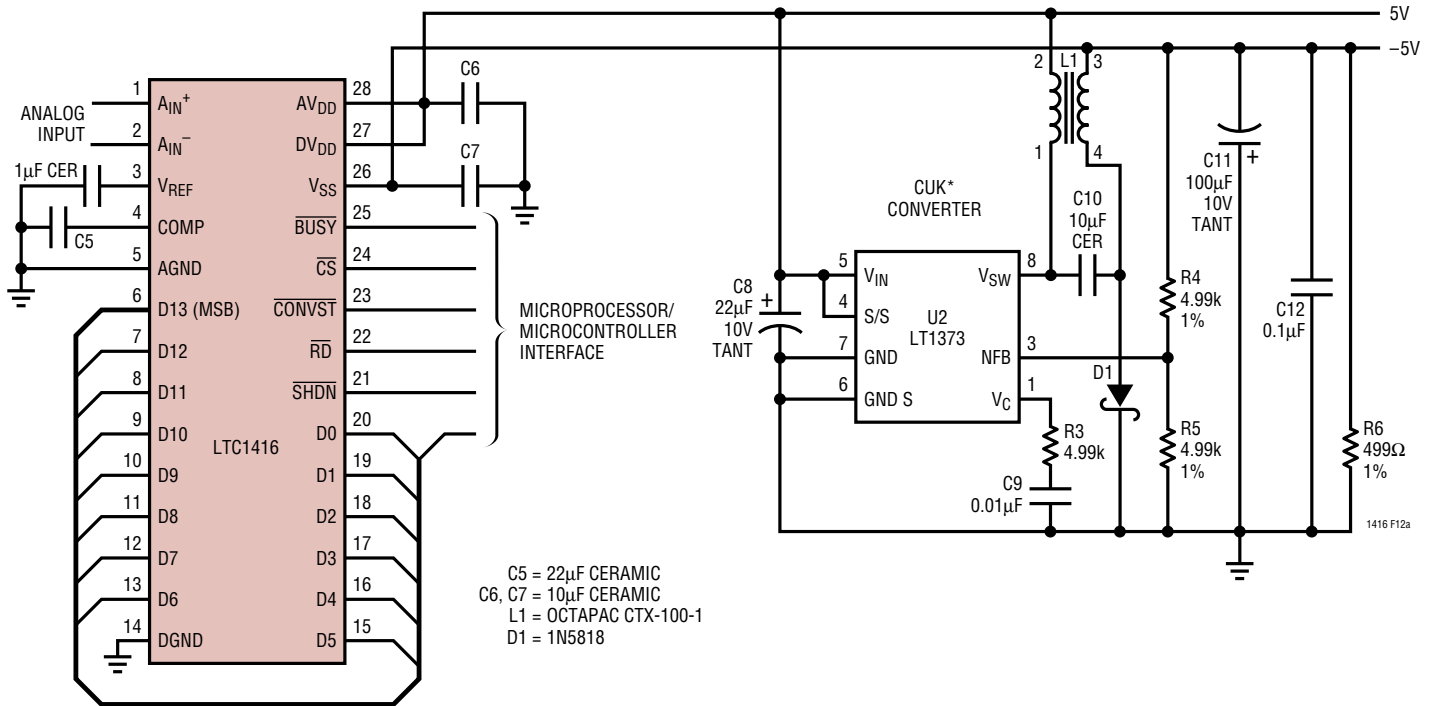


Figure 12a. Using the LT1373 to Generate a -5V Supply

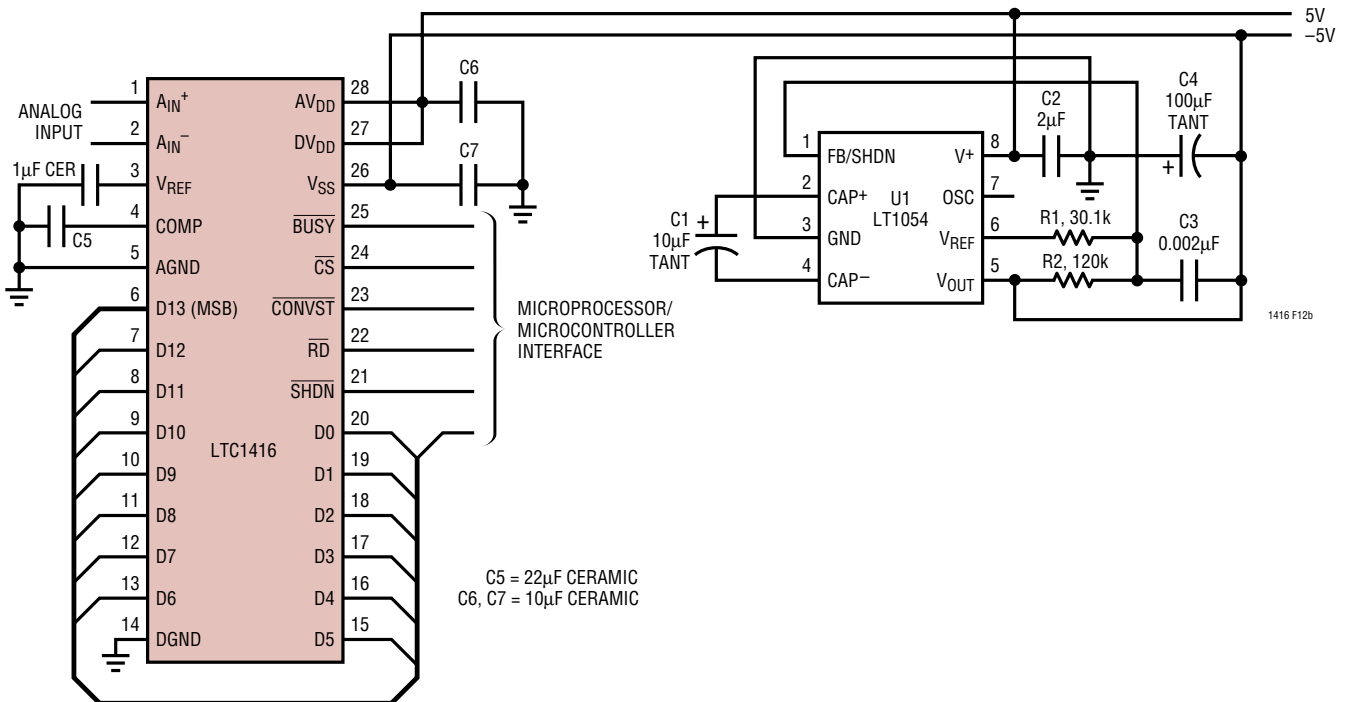


Figure 12b. Using the LT1054 to Generate a -5V Supply

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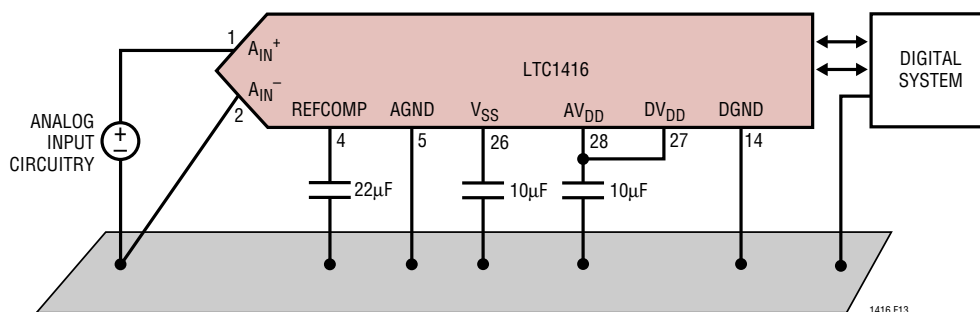


Figure 13. Power Supply Grounding Practice.

traces connecting the pins and bypass capacitors must be kept short and should be made as wide as possible.

The LTC1416 has differential inputs to minimize noise coupling. Common mode noise on the  $A_{IN}^+$  and  $A_{IN}^-$  leads will be rejected by the input CMRR. The  $A_{IN}^-$  input can be used as a ground sense for the  $A_{IN}^+$  input; the LTC1416 will hold and convert the difference voltage between  $A_{IN}^+$  and  $A_{IN}^-$ . The leads to  $A_{IN}^+$  (Pin 1) and  $A_{IN}^-$  (Pin 2) should be kept as short as possible. In applications where this is not possible, the  $A_{IN}^+$  and  $A_{IN}^-$  traces should be run side by side to equalize coupling.

### Supply Bypassing

High quality, low series resistance ceramic, bypass capacitors should be used at the  $V_{DD}$  (10 $\mu$ F) and REFCOMP (22 $\mu$ F) pins as shown in the Typical Application on the first page of this data sheet. Surface mount ceramic capacitors such as Murata GRM235Y5V106Z016 provide excellent bypassing in a small board space. Alternatively tantalum capacitors in parallel with 0.1 $\mu$ F ceramic capacitors can be used. Bypass capacitors must be located as close to the pins as possible. The traces connecting the pins and the bypass capacitors must be kept short and should be made as wide as possible.

### Example Layout

Figures 14a, 14b, 14c and 14d show the schematic and layout of an evaluation board. The layout demonstrates the proper use of decoupling capacitors and ground plane with a 2-layer printed circuit board.

### DIGITAL INTERFACE

The A/D converter is designed to interface with microprocessors as a memory mapped device. The  $\overline{CS}$  and  $\overline{RD}$  control inputs are common to all peripheral memory interfacing. A separate  $\overline{CONVST}$  is used to initiate a conversion.

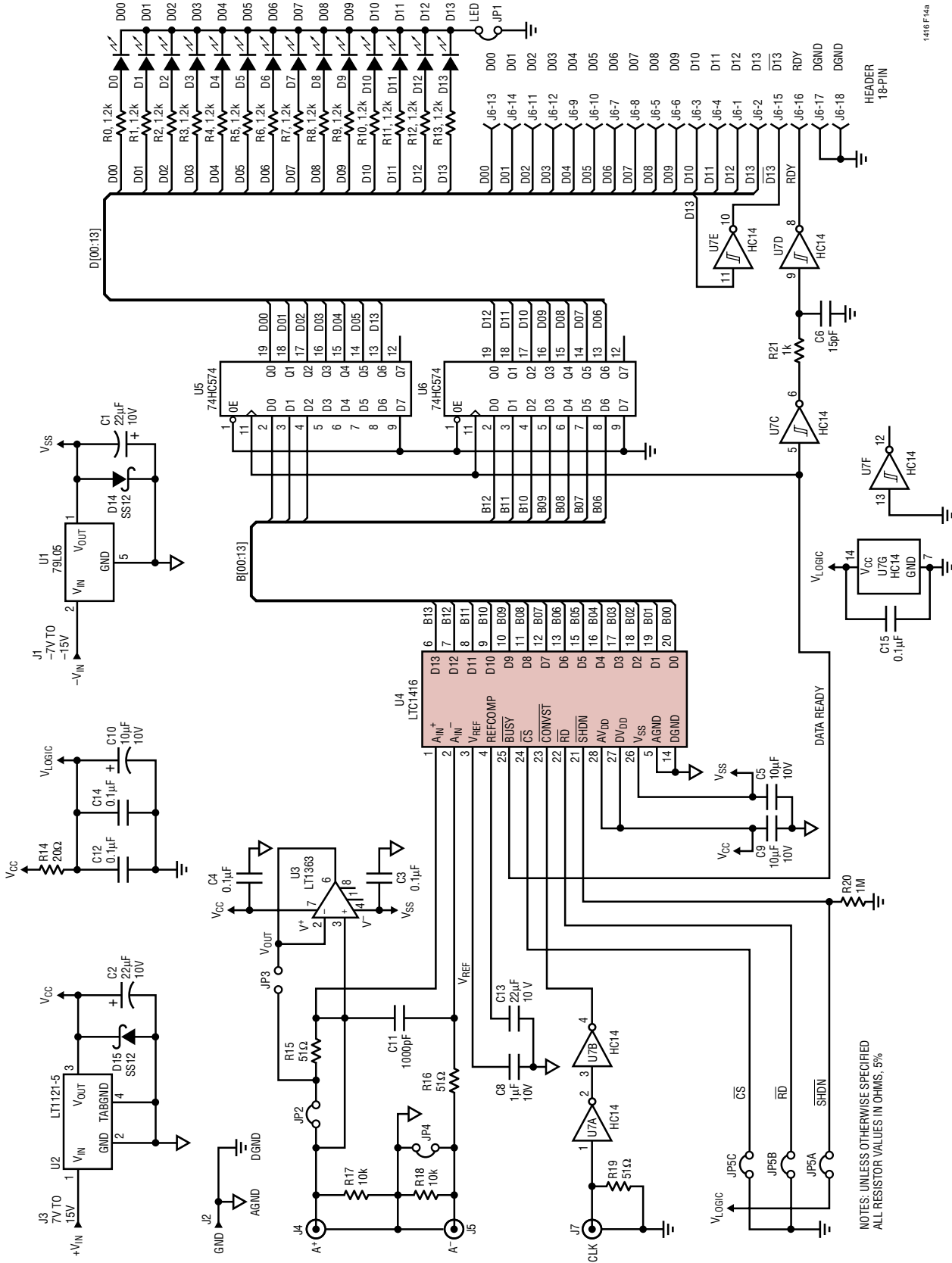
### Internal Clock

The A/D converter has an internal clock that eliminates the need for synchronization between the external clock and the  $\overline{CS}$  and  $\overline{RD}$  signals found in other ADCs. The internal clock is factory trimmed to achieve a typical conversion time of 1.8 $\mu$ s, and a maximum conversion time over the full operating temperature range of 2.2 $\mu$ s. No external adjustments are required. The guaranteed maximum acquisition time is 400ns. In addition, a throughput time of 2.5 $\mu$ s and a minimum sampling rate of 400ksps is guaranteed.

### Power Shutdown

The LTC1416 provides two power shutdown modes—nap mode and sleep mode to save power during inactive periods. The nap mode reduces the power by 95% and leaves only the digital logic and reference powered up. The wake-up time from nap to active is 400ns. In sleep mode, the reference is shut down and only a small current of 120 $\mu$ A remains. Wake-up time from sleep mode is much slower since the reference circuit must power up and settle to 0.005% for full 14-bit accuracy. Sleep mode wake-up time is dependent on the value of the capacitor connected to the REFCOMP (Pin 4). The wake-up time is 20ms with the recommended 22 $\mu$ F capacitor.

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1416 F.14a

Figure 14a. Suggested Evaluation Circuit Schematic

NOTES: UNLESS OTHERWISE SPECIFIED  
ALL RESISTOR VALUES IN OHMS, 5%



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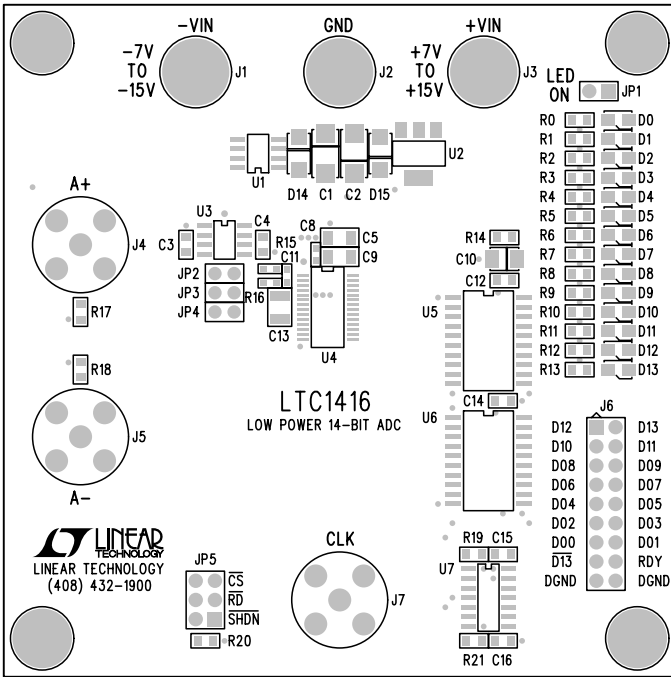


Figure 14b. Suggested Evaluation Circuit Board—Component Side Silkscreen

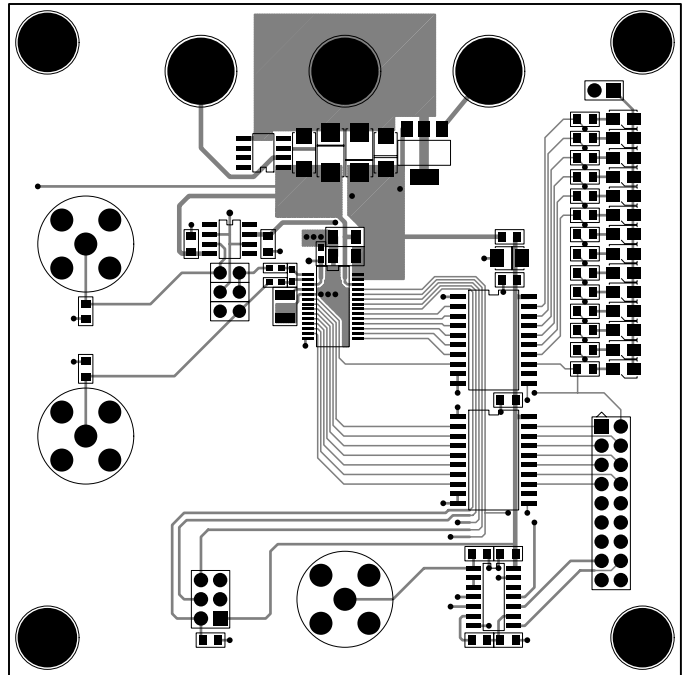


Figure 14c. Suggested Evaluation Circuit Board—Component Side Layout

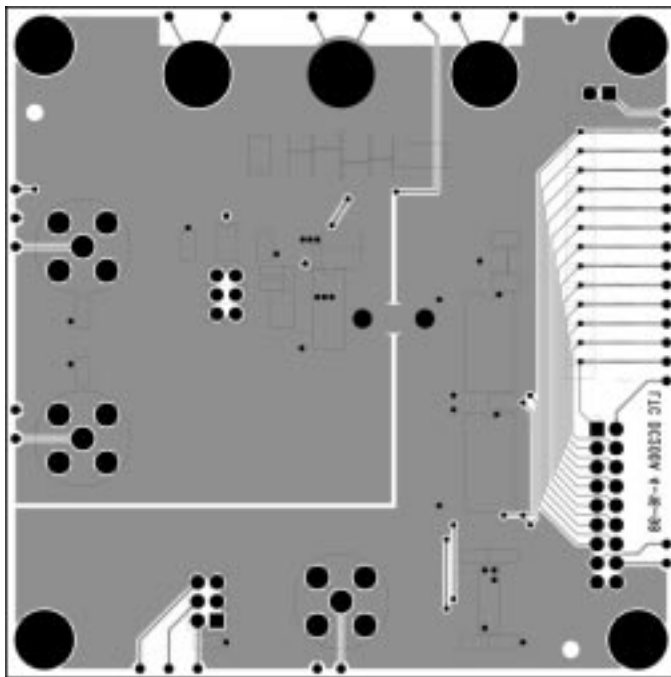


Figure 14d. Suggested Evaluation Circuit Board—Solder Side Layout

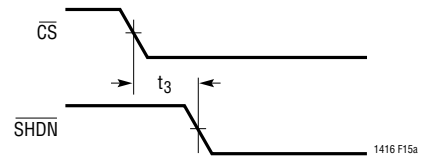


Figure 15a.  $\overline{CS}$  to  $\overline{SHDN}$  Timing

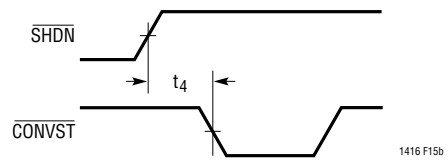


Figure 15b.  $\overline{SHDN}$  to  $\overline{CONVST}$  Wake-Up Timing

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Shutdown is controlled by Pin 21 ( $\overline{\text{SHDN}}$ ), the ADC is in shutdown when it is low. The shutdown mode is selected with Pin 20 ( $\overline{\text{CS}}$ ), low selects nap.

### Timing and Control

Conversion start and data read operations are controlled by three digital inputs:  $\overline{\text{CONVST}}$ ,  $\overline{\text{CS}}$  and  $\overline{\text{RD}}$ . A logic “0” applied to the  $\overline{\text{CONVST}}$  pin will start a conversion after the ADC has been selected (i.e.,  $\overline{\text{CS}}$  is low). Once initiated, it cannot be restarted until the conversion is complete. Converter status is indicated by the  $\overline{\text{BUSY}}$  output.  $\overline{\text{BUSY}}$  is low during a conversion.

Figures 16 through 21 show several different modes of operation. In modes 1a and 1b (Figures 17 and 18),  $\overline{\text{CS}}$  and  $\overline{\text{RD}}$  are both tied low. The falling edge of  $\overline{\text{CONVST}}$  starts the conversion. The data outputs are always enabled and data can be latched with the  $\overline{\text{BUSY}}$  rising edge. Mode 1a shows operation with a narrow logic low  $\overline{\text{CONVST}}$  pulse. Mode 1b shows a narrow logic high  $\overline{\text{CONVST}}$  pulse.

In mode 2 (Figure 19),  $\overline{\text{CS}}$  is tied low. The falling edge of  $\overline{\text{CONVST}}$  signal again starts the conversion. Data outputs are in three-state until read by the MPU with the  $\overline{\text{RD}}$  signal. Mode 2 can be used for operation with a shared MPU data bus.

In slow memory and ROM modes (Figures 20 and 21),  $\overline{\text{CS}}$  is tied low and  $\overline{\text{CONVST}}$  and  $\overline{\text{RD}}$  are tied together. The MPU

starts the conversion and reads the output with the  $\overline{\text{RD}}$  signal. Conversions are started by the MPU or DSP (no external sample clock).

In slow memory mode, the processor applies a logic low to  $\overline{\text{RD}}$  ( $=\overline{\text{CONVST}}$ ), starting the conversion.  $\overline{\text{BUSY}}$  goes low, forcing the processor into a Wait state. The previous conversion result appears on the data outputs. When the conversion is complete, the new conversion results appear on the data outputs;  $\overline{\text{BUSY}}$  goes high releasing the processor, and the processor takes  $\overline{\text{RD}}$  ( $=\overline{\text{CONVST}}$ ) back high and reads the new conversion data.

In ROM mode, the processor takes  $\overline{\text{RD}}$  ( $=\overline{\text{CONVST}}$ ) low, starting a conversion and reading the previous conversion result. After the conversion is complete, the processor can read the new result and initiate another conversion.

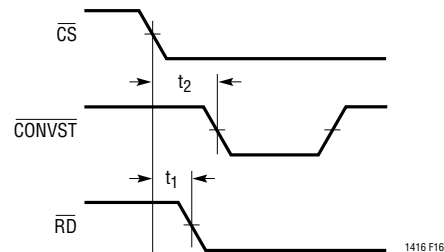


Figure 16.  $\overline{\text{CS}}$  to  $\overline{\text{CONVST}}$  Setup Timing

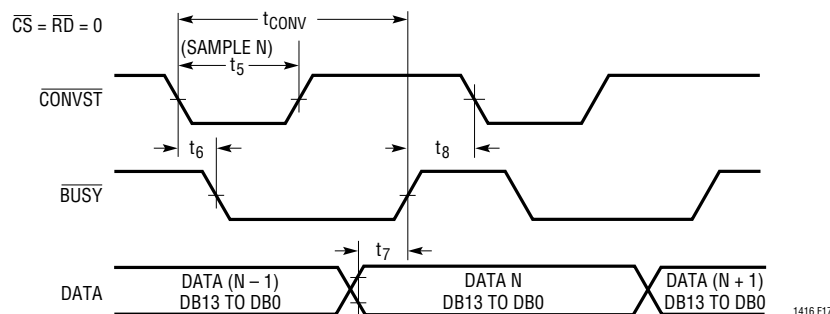


Figure 17. Mode 1a.  $\overline{\text{CONVST}}$  Starts a Conversion. Data Outputs Always Enabled ( $\overline{\text{CONVST}} = \text{[pulse]}$ )

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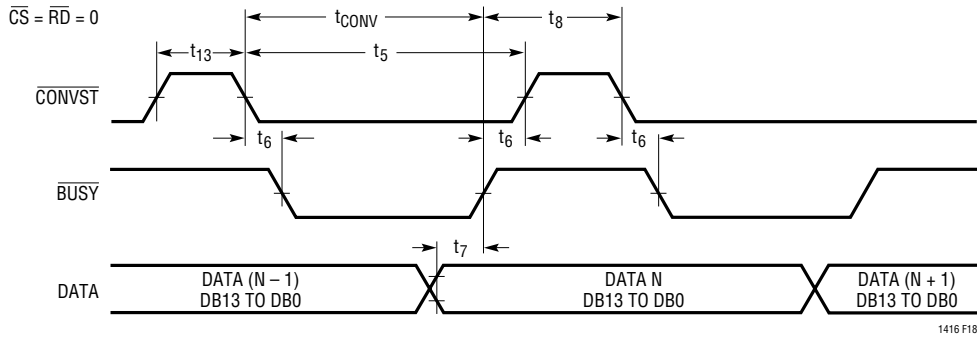


Figure 18. Mode 1b.  $\overline{CONVST}$  Starts a Conversion. Data Outputs Always Enabled ( $\overline{CONVST} = \square$ )

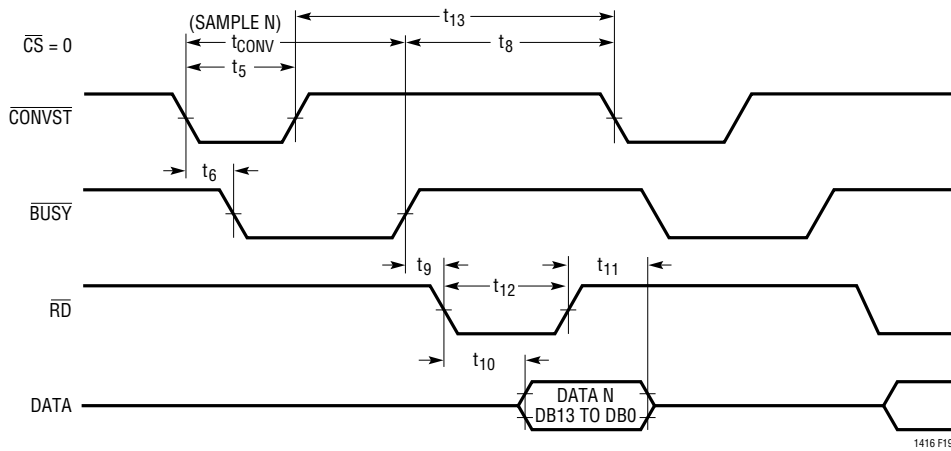


Figure 19. Mode 2.  $\overline{CONVST}$  Starts a Conversion. Data Is Read by  $\overline{RD}$

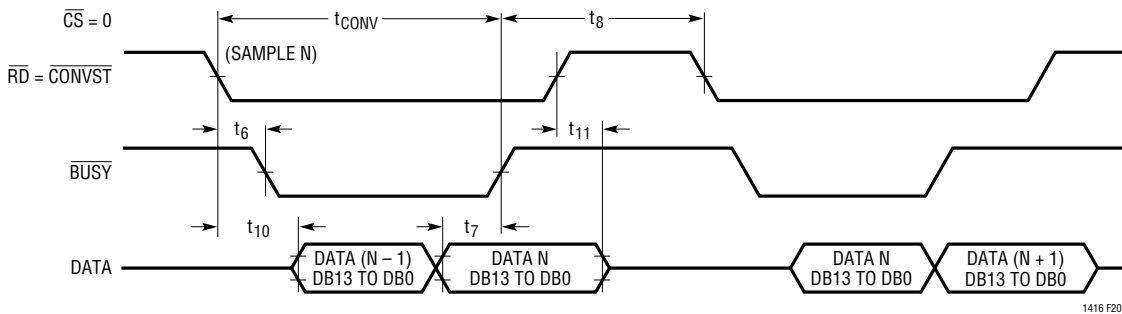


Figure 20. Slow Memory Mode Timing

## APPLICATIONS INFORMATION

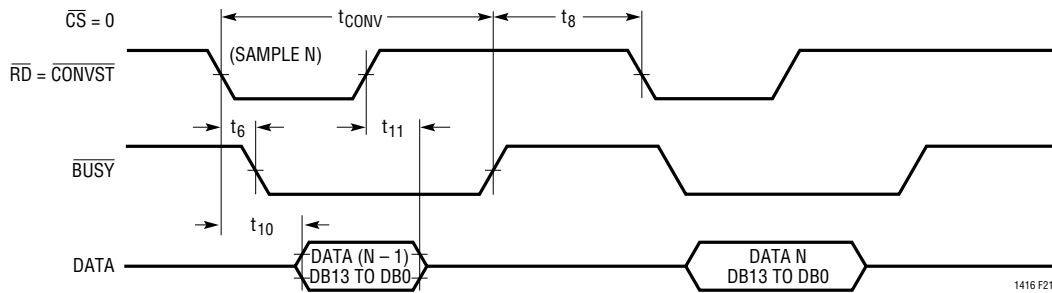
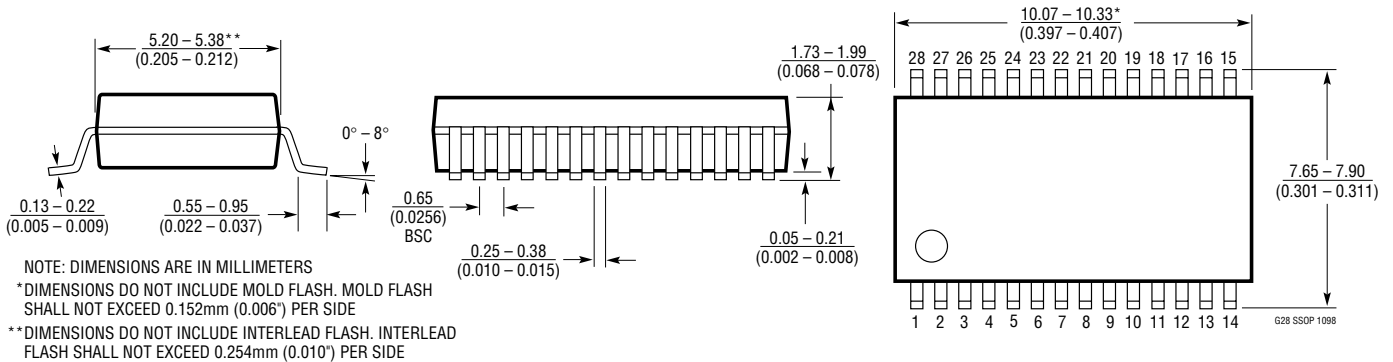


Figure 21. ROM Mode Timing

## PACKAGE DESCRIPTION Dimensions in inches (millimeters) unless otherwise noted.

**G Package**  
**28-Lead Plastic SSOP (0.209)**  
 (LTC DWG # 05-08-1640)



## RELATED PARTS

| PART NUMBER     | DESCRIPTION  | COMMENTS   |
|-----------------|--|--|
| LTC1278/LTC1279 | Single Supply, 12-Bit, 500ksps/600ksps ADCs          | Low Power, 5V or ±5V Supply  |
| LTC1400         | High Speed Serial 12-Bit ADC                         | 400ksps, Complete with V <sub>REF</sub> , CLK, Sample-and-Hold in SO-8 |
| LTC1409/LTC1410 | 12-Bit, 800ksps/1.25Msps Sampling ADCs with Shutdown | Best Dynamic Performance, THD = 84dB and SINAD = 71dB at Nyquist       |
| LTC1412         | 12-Bit, 3Msps Sampling ADC                           | Best Dynamic Performance, SINAD = 72dB at Nyquist                      |
| LTC1415         | Single 5V, 12-Bit, 1.25Msps ADC                      | Single Supply, 55mW Dissipation  |
| LTC1418         | 14-Bit, 200ksps Sampling ADC                         | 16mW Dissipation, Serial and Parallel Outputs                          |
| LTC1419         | 14-Bit, 800ksps Sampling ADC with Shutdown           | 81.5dB SINAD, 150mW from ±5V Supplies                                  |
| LTC1604         | 16-Bit, 333ksps Sampling ADC                         | ±2.5V Input, SINAD = 90dB, THD = 100dB                                 |
| LTC1605         | Single 5V, 16-Bit, 100ksps ADC                       | Low Power, ±10V Inputs   |
| LTC1606         | 16-Bit, 250ksps ADC                                  | ±10V Inputs, Pin Compatible with the LTC1605                           |
| LTC1608         | 16-Bit, 500ksps ADC                                  | 16-Bit, No Missing Codes, Pin Compatible with the LTC1604              |