

3V 140ksps 12-Bit Sampling A/D Converter with Reference

FEATURES

- **Single Supply 3V or $\pm 3V$ Operation**
- **140kps Throughput Rate**
- **12mW (Typ) Power Dissipation**
- **On-Chip 25ppm/ $^{\circ}C$ Reference**
- **Internal Synchronized Clock; No Clock Required**
- **High Impedance Analog Input**
- **69dB S/(N + D) and 77dB THD at Nyquist**
- **$\pm 1/2$ LSB INL and $\pm 3/4$ LSB DNL Max (A Grade)**
- **2.7V Guaranteed Minimum Supply Voltage**
- **ESD Protected On All Pins**
- **24-Pin Narrow DIP and SOL Packages**
- **0V to 2.5V or $\pm 1.25V$ Input Ranges**

APPLICATIONS

- 3V Powered Systems
- High Speed Data Acquisition
- Digital Signal Processing
- Multiplexed Data Acquisition Systems
- Audio and Telecom Processing
- Spectrum Analysis

DESCRIPTION

The LTC1282 is a 6 μ s, 140ksp/s, sampling 12-bit A/D converter which draws only 12mW from a single 3V or dual \pm 3V supply. This easy-to-use device comes complete with 1.0 μ s sample-and-hold, precision reference and internally trimmed clock. Unipolar and bipolar conversion modes provide flexibility for various applications. They are built with LTBiCMOS™ switched capacitor technology.

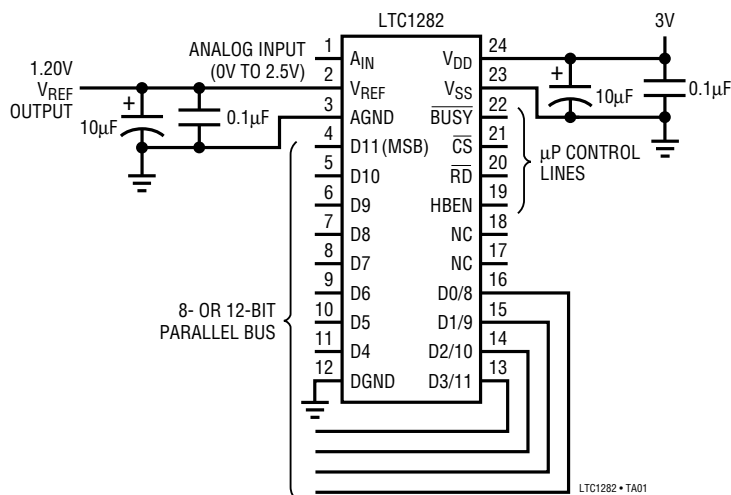
The LTC1282 has a 25ppm/°C (max) internal reference and converts 0V to 2.5V unipolar inputs from a single 3V supply. With $\pm 3V$ supplies its input range is $\pm 1.25V$ with two's complement output format. Maximum DC specifications include $\pm 1/2$ LSB INL, $\pm 3/4$ LSB DNL and 25ppm/°C full scale drift over temperature. Outstanding AC performance includes 69dB S/(N + D) and 77dB THD at the Nyquist input frequency of 70kHz.

The internal clock is trimmed for 6 μ s maximum conversion time. The clock automatically synchronizes to each sample command eliminating problems with asynchronous clock noise found in competitive devices. A high speed parallel interface eases connections to FIFOs, DSPs and microprocessors.

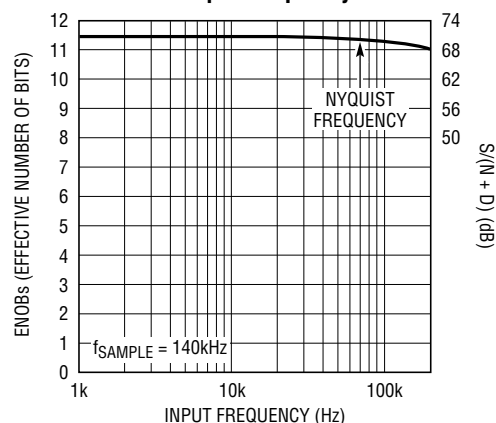
LTBiCMOS™ is a trademark of Linear Technology Corporation

TYPICAL APPLICATION

Single 3V Supply, 140ksps, 12-Bit Sampling A/D Converter



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



LTC1282 • TA02

ABSOLUTE MAXIMUM RATINGS

(Notes 1 and 2)

| | |
|---|------------------------------------|
| Supply Voltage (V_{DD}) | 12V |
| Negative Supply Voltage (V_{SS}) | -6V to GND |
| 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 12V |
| Digital Output Voltage | |
| (Note 3) | $V_{SS} - 0.3V$ to $V_{DD} + 0.3V$ |
| Power Dissipation | 500mW |
| Specified Temperature Range (Note 14) | 0°C to 70°C |
| Operating Temperature Range | |
| LTC1282AC, LTC1282BC | 0°C to 70°C |
| Storage Temperature Range | -65°C to 150°C |
| Lead Temperature (Soldering, 10 sec) | 300°C |

PACKAGE/ORDER INFORMATION

| TOP VIEW | | ORDER PART NUMBER | |
|--|----|--|----------|
| AIN | 1 | 24 | V_{DD} |
| VREF | 2 | 23 | V_{SS} |
| AGND | 3 | 22 | BUSY |
| D11(MSB) | 4 | 21 | CS |
| D10 | 5 | 20 | RD |
| D9 | 6 | 19 | HBEN |
| D8 | 7 | 18 | NC |
| D7 | 8 | 17 | NC |
| D6 | 9 | 16 | D0/8 |
| D5 | 10 | 15 | D1/9 |
| D4 | 11 | 14 | D2/10 |
| DGND | 12 | 13 | D3/11 |
| N PACKAGE | | S PACKAGE | |
| 24-LEAD PLASTIC DIP | | 24-LEAD PLASTIC SOL | |
| $T_{JMAX} = 110^{\circ}C$, $\theta_{JA} = 100^{\circ}C/W$ (N) | | $T_{JMAX} = 110^{\circ}C$, $\theta_{JA} = 130^{\circ}C/W$ (S) | |
| | | LTC1282ACN | |
| | | LTC1282BCN | |
| | | LTC1282ACS | |
| | | LTC1282BCS | |

Consult factory for Industrial and Military grade parts (Note 14).

CONVERTER CHARACTERISTICS With Internal Reference (Notes 5 and 6)

| PARAMETER | CONDITIONS | MIN | LTC1282A TYP | MAX | MIN | LTC1282B TYP | MAX | UNITS |
|-------------------------------|-----------------------------|-----|-----------------|-----------|-----|-----------------|----------|--------|
| Resolution (No Missing Codes) | | ● | 12 | | 12 | | | Bits |
| Integral Linearity Error | (Note 7) | | | $\pm 1/2$ | | | ± 1 | LSB |
| | Commercial | ● | | $\pm 1/2$ | | | ± 1 | LSB |
| | Military | ● | | $\pm 3/4$ | | | ± 1 | LSB |
| Differential Linearity Error | Commercial | ● | | $\pm 3/4$ | | | ± 1 | LSB |
| | Military | ● | | ± 1 | | | ± 1 | LSB |
| Offset Error | (Note 8) | | | ± 3 | | | ± 4 | LSB |
| | | ● | | ± 4 | | | ± 6 | LSB |
| Full Scale Error | | | | ± 10 | | | ± 15 | LSB |
| Full Scale Tempco | $I_{OUT(REF)} = 0$ | ● | ± 5 | ± 25 | | ± 10 | ± 45 | ppm/°C |
| Power Supply Rejection | (Note 9) $V_{DD} \pm 10\%$ | | ± 0.3 | | | ± 0.3 | | LSB |
| | (Note 10) $V_{SS} \pm 10\%$ | | ± 0.1 | | | ± 0.1 | | LSB |

DYNAMIC ACCURACY (Note 5)

| SYMBOL | PARAMETER | CONDITIONS | LTC1282A/LTC1282B MIN TYP MAX | UNITS |
|-----------|--|--|----------------------------------|-------|
| S/(N + D) | Signal-to-Noise Plus Distortion Ratio | 10kHz/70kHz Input Signal | 71/69 | dB |
| THD | Total Harmonic Distortion | 10kHz/70kHz Input Signal, Up to 5th Harmonic | -82/-77 | dB |
| | Peak Harmonic or Spurious Noise | 10kHz/70kHz Input Signal | -82/-77 | dB |
| IMD | Intermodulation Distortion | $f_{IN1} = 19.0kHz$, $f_{IN2} = 20.6kHz$ | -78 | dB |
| | Full Power Bandwidth | | 4 | MHz |
| | Full Linear Bandwidth (S/(N + D) $\geq 68dB$) | | 200 | kHz |

ANALOG INPUT (Note 5)

| SYMBOL | PARAMETER | CONDITIONS | | LTC1282A/LTC1282B | | | UNITS |
|-----------|----------------------------------|---|--------|-------------------|------------------------|--------------|--------------------|
| | | | | MIN | TYP | MAX | |
| V_{IN} | Analog Input Range (Note 11) | $2.7V \leq V_{DD} \leq 3.6V$ (Unipolar Mode) $2.7V \leq V_{DD} \leq 3.6V, -3.3V \leq V_{SS} \leq -2.5V$ (Bipolar Mode) | ● ● | | 0 to 2.5 ± 1.25 | | V V |
| I_{IN} | Analog Input Leakage Current | $\overline{CS} = \text{High}$ | ● | | | ± 1 | μA |
| C_{IN} | Analog Input Capacitance | Between Conversions (Sample Mode) During Conversions (Hold Mode) | | | 63 5 | | pF pF |
| t_{ACQ} | Sample-and-Hold Acquisition Time | Commercial Military | ● ● | | 0.45 | 1.00 1.50 | μs μs |

INTERNAL REFERENCE CHARACTERISTICS (Note 5)

| PARAMETER | CONDITIONS | | LTC1282A | | | LTC1282B | | | UNITS |
|---------------------------|--|---|----------|--------------|----------|----------|--------------|----------|------------------|
| | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| V_{REF} Output Voltage | $I_{OUT} = 0$ | | 1.1900 | 1.200 | 1.210 | 1.190 | 1.200 | 1.210 | V |
| V_{REF} Output Tempco | $I_{OUT} = 0$ | ● | | ± 5 | ± 25 | | ± 10 | ± 45 | ppm/ $^{\circ}C$ |
| V_{REF} Line Regulation | $2.7V \leq V_{DD} \leq 3.6V$ $-3.6V \leq V_{SS} \leq -2.7V$ | | | 0.55 0.02 | | | 0.55 0.02 | | LSB/V LSB/V |
| V_{REF} Load Regulation | $0V \leq I_{OUT} \leq 1mA$ | | | 3 | | | 3 | | LSB/mA |

DIGITAL INPUTS AND DIGITAL OUTPUTS (Note 5)

| SYMBOL | PARAMETER | CONDITIONS | | LTC1282A/LTC1282B | | | UNITS |
|--------------|------------------------------------|--|---|-------------------|--------------|----------|---------|
| | | | | MIN | TYP | MAX | |
| V_{IH} | High Level Input Voltage | $V_{DD} = 3.6V$ | ● | 1.9 | | | V |
| V_{IL} | Low Level Input Voltage | $V_{DD} = 2.7V$ | ● | | | 0.45 | V |
| I_{IN} | Digital Input Current | $V_{IN} = 0V$ to V_{DD} | ● | | | ± 10 | μA |
| C_{IN} | Digital Input Capacitance | | | | 5 | | pF |
| V_{OH} | High Level Output Voltage | $V_{DD} = 2.7V$ $I_O = -10\mu A$ $I_O = -200\mu A$ | ● | 2.3 | 2.6 | | V V |
| V_{OL} | Low Level Output Voltage | $V_{DD} = 2.7V$ $I_O = 160\mu A$ $I_O = 1.6mA$ | ● | | 0.05 0.10 | 0.4 | V V |
| I_{OZ} | High Z Output Leakage D11-D0/8 | $V_{OUT} = 0V$ to V_{DD} , \overline{CS} High | ● | | | ± 10 | μA |
| C_{OZ} | High Z Output Capacitance D11-D0/8 | \overline{CS} High (Note 12) | ● | | | 15 | pF |
| I_{SOURCE} | Output Source Current | $V_{OUT} = 0V$ | | | -4.5 | | mA |
| I_{SINK} | Output Sink Current | $V_{OUT} = V_{DD}$ | | | 4.5 | | mA |

POWER REQUIREMENTS (Note 5)

| SYMBOL | PARAMETER | CONDITIONS | | LTC1282A/LTC1282B | | | UNITS |
|----------|-------------------------|-----------------------------|---|-------------------|------|-------|-------|
| | | | | MIN | TYP | MAX | |
| V_{DD} | Positive Supply Voltage | (Note 13) | | 2.70 | | 3.60 | V |
| V_{SS} | Negative Supply Voltage | Bipolar Operation (Note 13) | | -2.50 | | -3.60 | V |
| I_{DD} | Positive Supply Current | $f_{SAMPLE} = 140ksps$ | ● | | 4 | 7.8 | mA |
| I_{SS} | Negative Supply Current | $f_{SAMPLE} = 140ksps$ | ● | | 0.03 | 0.15 | mA |
| P_D | Power Dissipation | $f_{SAMPLE} = 140ksps$ | ● | | 12 | 24 | mW |

TIMING CHARACTERISTICS (Note 5)

| SYMBOL | PARAMETER | CONDITIONS | | LTC1282A/LTC1282B | | | UNITS |
|--------------------------|--|--|--------|-------------------|-------------------|-------------------|--------------------------------|
| | | | | MIN | TYP | MAX | |
| $f_{\text{SAMPLE(MAX)}}$ | Maximum Sampling Frequency | Commercial (Note 13) Military (Note 13) | ● ● | 140 120 | | | kHz kHz |
| t_{CONV} | Conversion Time | Commercial Military | ● ● | | | 6.0 6.5 | μs μs |
| t_1 | $\overline{\text{CS}}$ to $\overline{\text{RD}}$ Setup Time | | ● | 0 | | | ns |
| t_2 | $\overline{\text{RD}}\downarrow$ to $\overline{\text{BUSY}}\downarrow$ Delay | $C_L = 50\text{pF}$ Commercial Military | ● ● | 140 | 200 230 260 | | ns ns ns |
| t_3 | Data Access Time After $\overline{\text{RD}}\downarrow$ | $C_L = 20\text{pF}$ (Note 13) Commercial | ● | 100 | 180 | | ns |
| | | Military | ● | | 200 | | ns |
| | | | ● | | 220 | | ns |
| | | $C_L = 100\text{pF}$ (Note 13) Commercial Military | ● ● | 110 | 200 240 260 | | ns ns ns |
| t_4 | $\overline{\text{RD}}$ Pulse Width | (Note 13) | ● | t_3 | | | ns |
| t_5 | $\overline{\text{CS}}$ to $\overline{\text{RD}}$ Hold Time | (Note 13) | ● | 0 | | | ns |
| t_6 | Data Setup Time After $\overline{\text{BUSY}}\uparrow$ | (Note 13) Commercial Military | ● ● | 60 | 85 110 120 | | ns ns ns |
| t_7 | Bus Relinquish Time | (Note 13) Commercial Military | ● ● | 40 40 40 | 60 | 120 130 150 | ns ns ns |
| t_8 | HBEN to $\overline{\text{RD}}$ Setup Time | (Note 13) | ● | 0 | | | ns |
| t_9 | HBEN to $\overline{\text{RD}}$ Hold Time | (Note 13) | ● | 0 | | | ns |
| t_{10} | Delay Between $\overline{\text{RD}}$ Operations | | ● | 40 | | | ns |
| t_{11} | Delay Between Conversions | Commercial (Note 13) Military (Note 13) | ● ● | 1000 1500 | 450 | | ns ns |
| t_{12} | Aperture Delay of Sample-and-Hold | | | | 30 | | ns |

The ● indicates specifications which apply over the full operating temperature range; all other limits and typicals $T_A = 25^\circ\text{C}$.

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 60mA below V_{SS} or above V_{DD} without latchup.

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 60mA below V_{SS} without latchup. These pins are not clamped to V_{DD} .

Note 5: $V_{\text{DD}} = 3\text{V}$, $V_{\text{SS}} = 0\text{V}$ for unipolar mode and $V_{\text{SS}} = -3\text{V}$ for bipolar mode, $f_{\text{SAMPLE}} = 140\text{kHz}$, $t_r = t_f = 5\text{ns}$ unless otherwise specified.

Note 6: Linearity, offset and full scale specifications apply for unipolar and bipolar modes.

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 different voltage measured from $-1/2\text{LSB}$ when the output code flickers between 0000 0000 0000 and 1111 1111 1111.

Note 9: Full scale change when $V_{\text{SS}} = 0\text{V}$ (Unipolar Mode) or -3V (Bipolar Mode).

Note 10: Full scale change when $V_{\text{DD}} = 3\text{V}$.

Note 11: The LTC1282 can perform unipolar and bipolar conversions. When V_{SS} is grounded (i.e. $-0.1\text{V} \leq V_{\text{SS}}$), the ADC will convert in unipolar mode with input voltage of 0V to 2.5V. When V_{SS} is taken negative (i.e. $V_{\text{SS}} \leq -2.5\text{V}$), the ADC will convert in bipolar mode with an input voltage of $\pm 1.25\text{V}$. A_{IN} must not exceed V_{DD} or fall below V_{SS} by more than 50mV for specified accuracy.

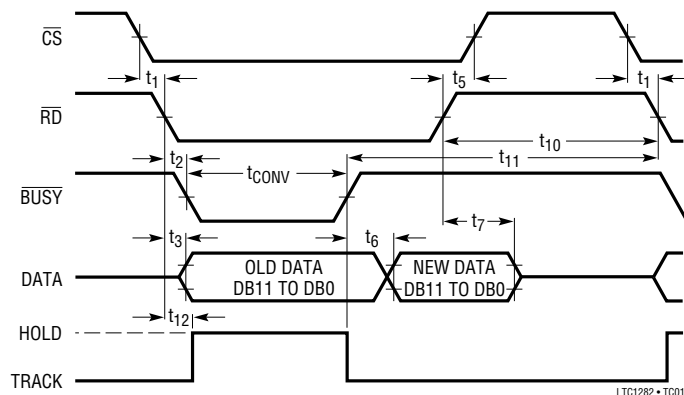
Note 12: Guaranteed by design, not subject to test.

Note 13: Recommended operating conditions.

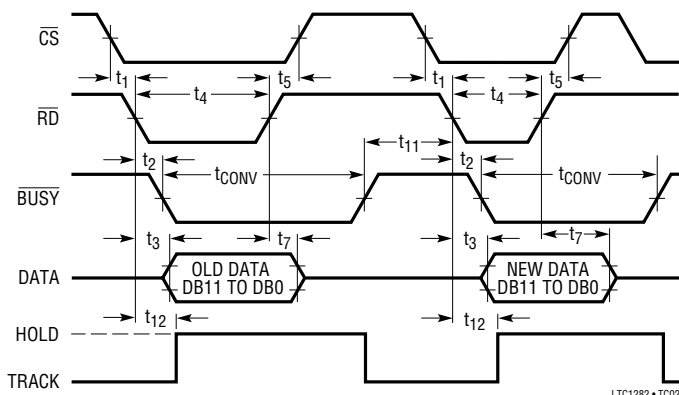
Note 14: Commercial grade parts are designed to operate over the temperature range of -40°C to 85°C but are neither tested nor guaranteed beyond 0°C to 70°C . Industrial grade parts specified and tested over -40°C to 85°C are available on special request. Consult factory.

TIMING CHARACTERISTICS (Note 5)

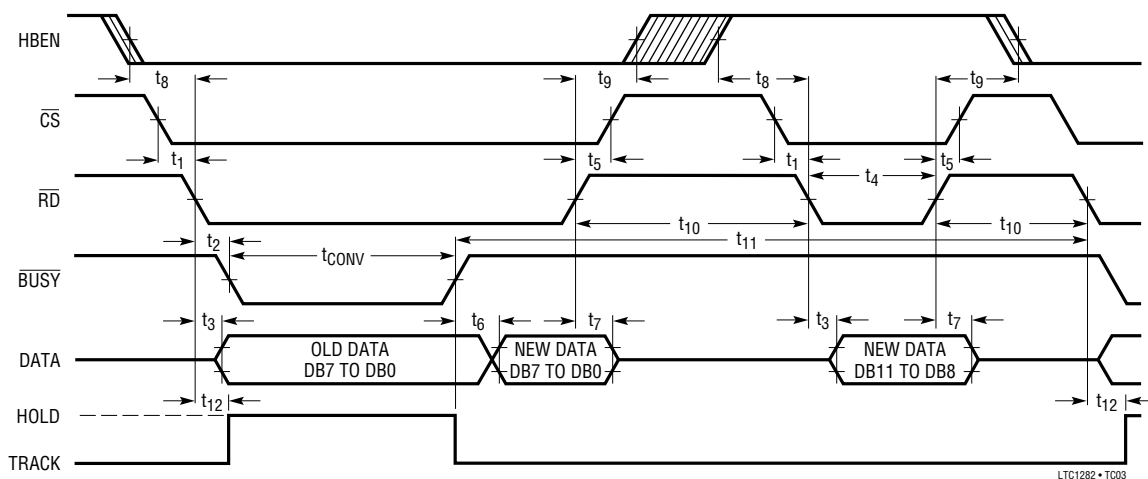
Slow Memory Mode, Parallel Read Timing Diagram



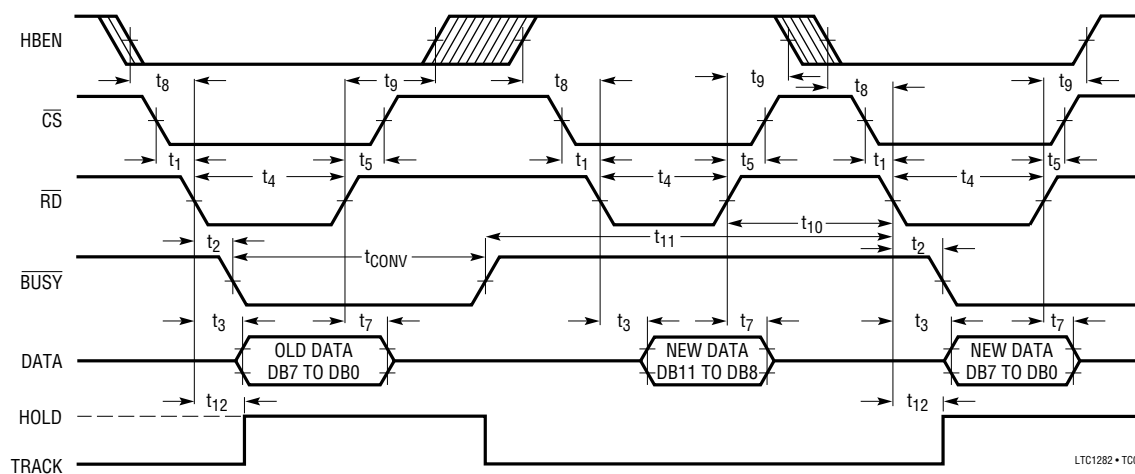
ROM Mode, Parallel Read Timing Diagram



Slow Memory Mode, Two Byte Read Timing Diagram

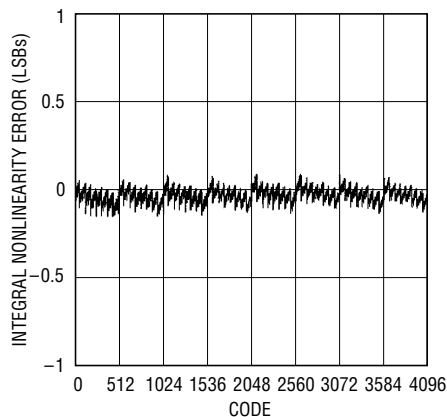


ROM Mode, Two Byte Read Timing Diagram



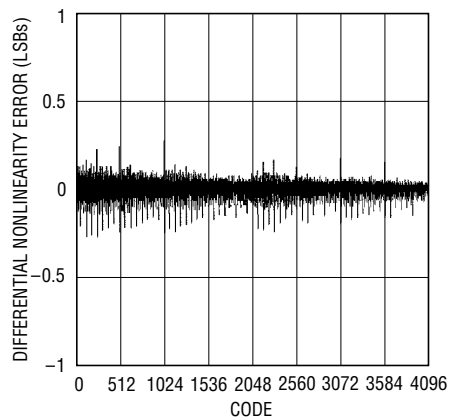
TYPICAL PERFORMANCE CHARACTERISTICS

Integral Nonlinearity

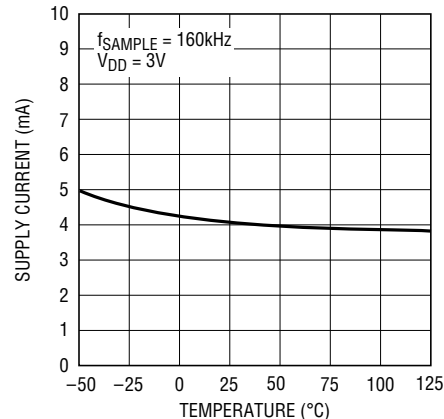


LTC1282 • TPC01

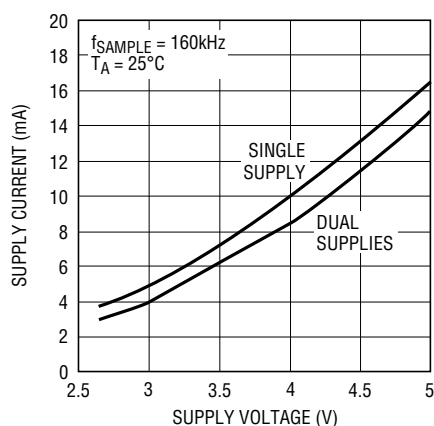
Differential Nonlinearity



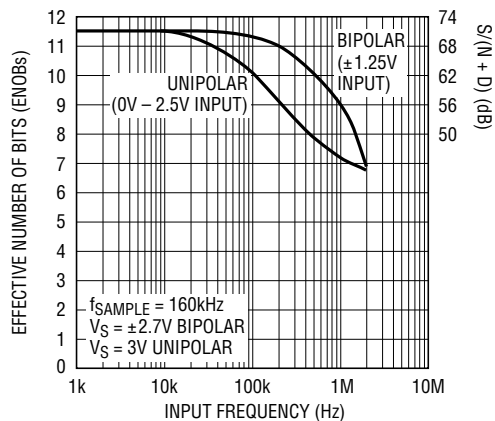
LTC1282 • TPC02

Supply Current (I_{DD}) vs Temperature

LTC1282 • TPC03

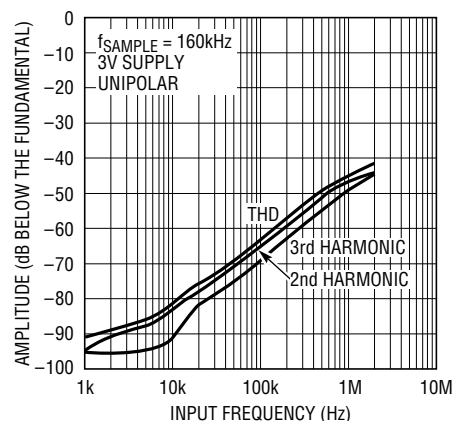
Supply Current (I_{DD}) vs Supply Voltage

LTC1282 • TPC04

ENOBs and $S/(N + D)$ vs Input Frequency

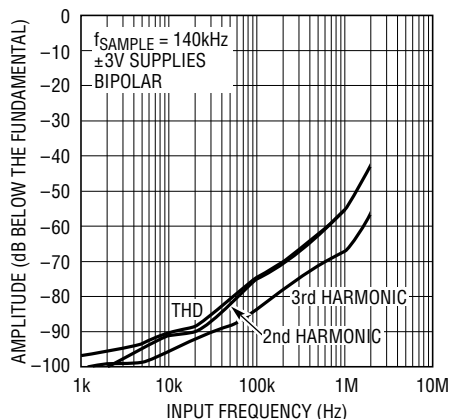
LTC1282 • TPC05

Distortion vs Input Frequency (Unipolar)



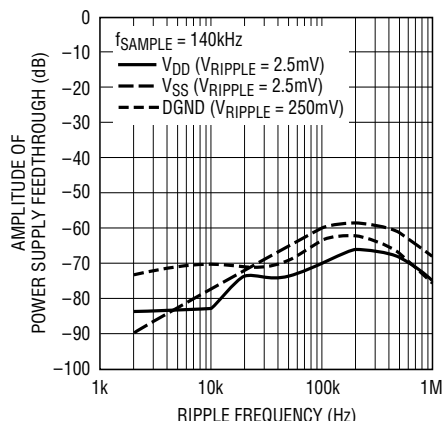
LTC1282 • TPC06

Distortion vs Input Frequency (Bipolar)



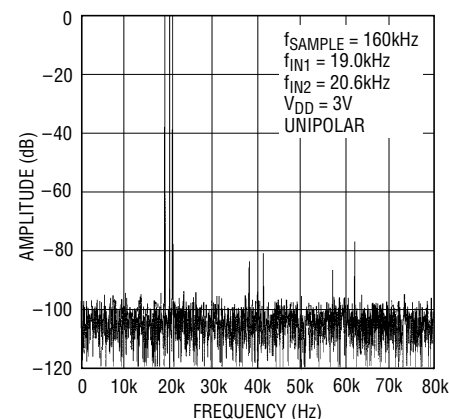
LTC1282 • TPC07

Power Supply Feedthrough vs Ripple Frequency



LTC1282 • TPC08

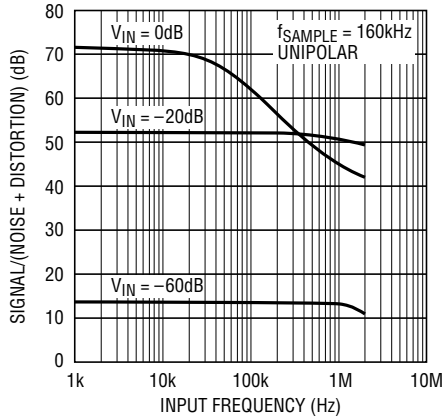
Intermodulation Distortion Plot



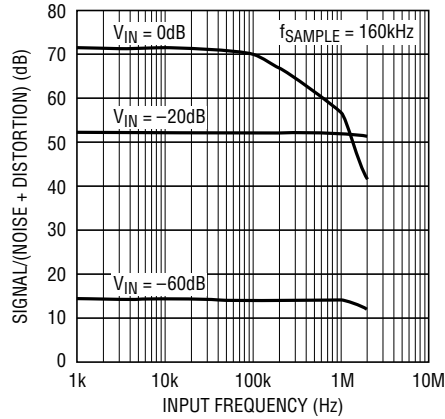
LTC1282 • TPC09

TYPICAL PERFORMANCE CHARACTERISTICS

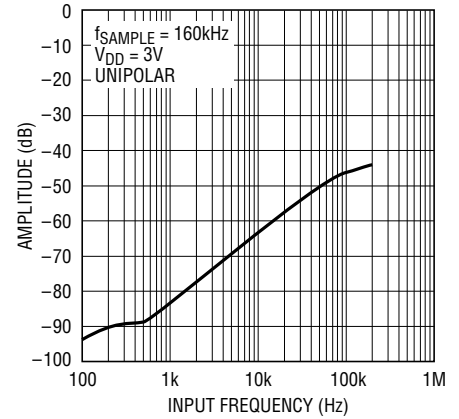
S/(N + D) vs Input Frequency and Amplitude (Unipolar, $V_{DD} = 3V$)



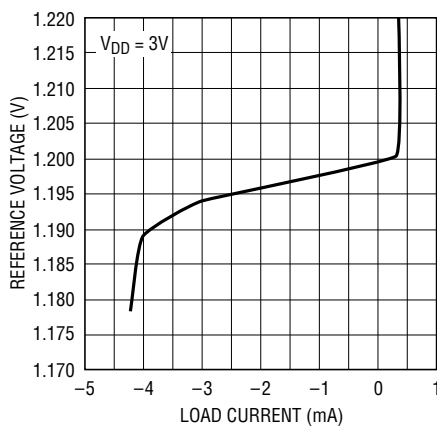
S/(N + D) vs Input Frequency and Amplitude (Bipolar, $\pm 3V$ Supplies)



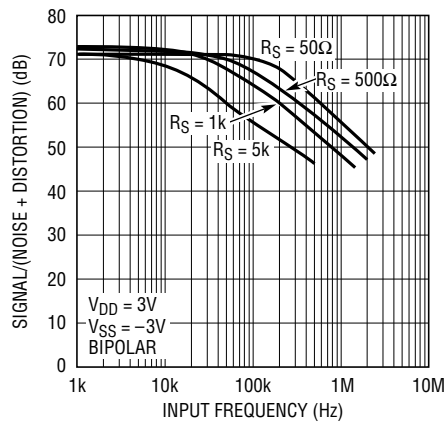
Spurious Free Dynamic Range vs Input Frequency



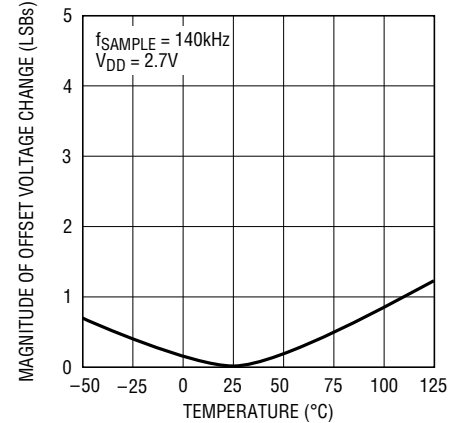
Reference Voltage vs Load Current



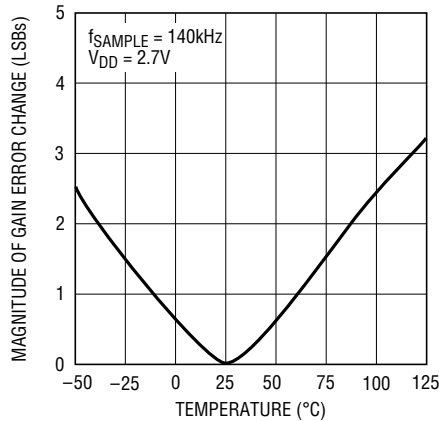
S/(N + D) vs Input Frequency vs Source Resistance (Bipolar)



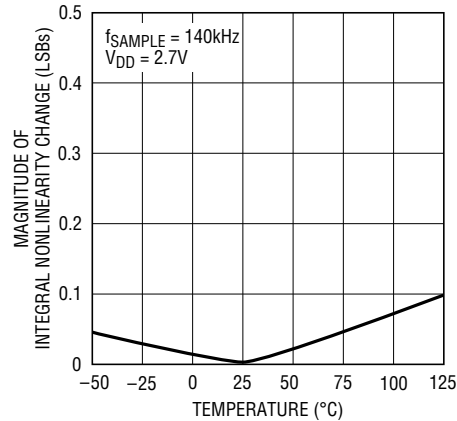
Change in Offset Voltage vs Temperature



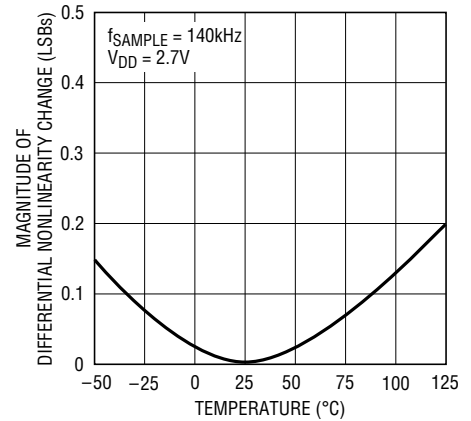
Change in Gain Error vs Temperature



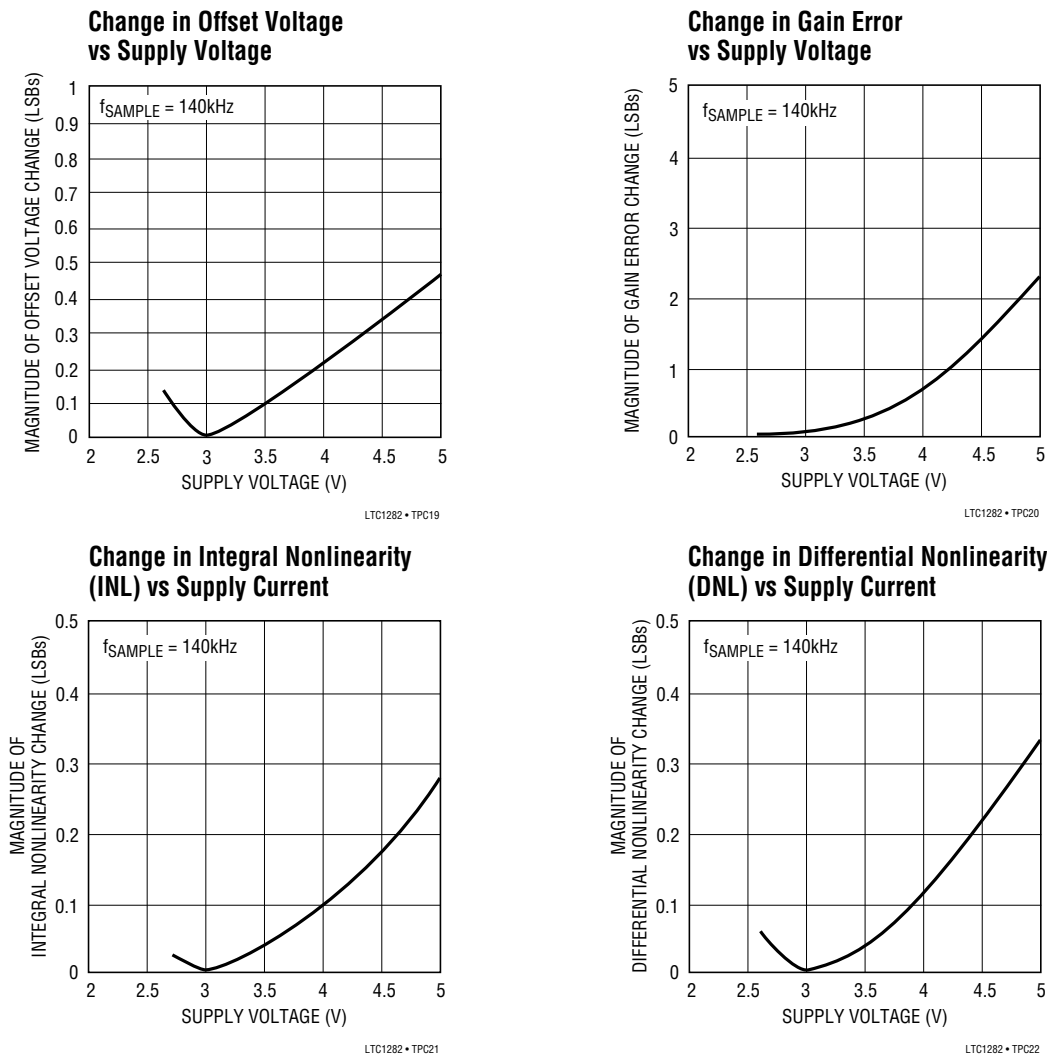
Change in Integral Nonlinearity (INL) vs Temperature



Change in Differential Nonlinearity (DNL) vs Temperature



TYPICAL PERFORMANCE CHARACTERISTICS



PIN FUNCTIONS

A_{IN} (Pin 1): Analog Input. 0V to 2.5V (Unipolar), $\pm 1.25V$ (Bipolar).

V_{REF} (Pin 2): +1.20V Reference Output. Bypass to AGND (10 μ F tantalum in parallel with 0.1 μ F ceramic).

AGND (Pin 3): Analog Ground.

D11-D4 (Pins 4 to 11): Three-State Data Outputs. D11 is the Most Significant Bit.

DGND (Pin 12): Digital Ground.

D3/11-D0/8 (Pins 13 to 16): Three-State Data Outputs.

NC (Pins 17 and 18): No Connection.

HBEN (Pin 19): High Byte Enable Input. This pin is used to multiplex the internal 12-bit conversion result into the lower bit outputs (D7 and D0/8). See Table 1. HBEN also disables conversion start when HIGH.

\overline{RD} (Pin 20): READ Input. This active low signal starts a conversion when \overline{CS} and HBEN are low. \overline{RD} also enables the output drivers when \overline{CS} is low.

\overline{CS} (Pin 21): The CHIP SELECT Input must be low for the ADC to recognize \overline{RD} and HBEN inputs.

\overline{BUSY} (Pin 22): The \overline{BUSY} Output shows the converter status. It is low when a conversion is in progress.

V_{SS} (Pin 23): Bipolar Mode — Negative Supply, $-3V$. Bypass to AGND with 0.1 μ F ceramic.

Unipolar Mode — Tie to DGND.

V_{DD} (Pin 24): Positive Supply, 3V. Bypass to AGND (10 μ F tantalum in parallel with 0.1 μ F ceramic).

Table 1. Data Bus Output, \overline{CS} and \overline{RD} = LOW

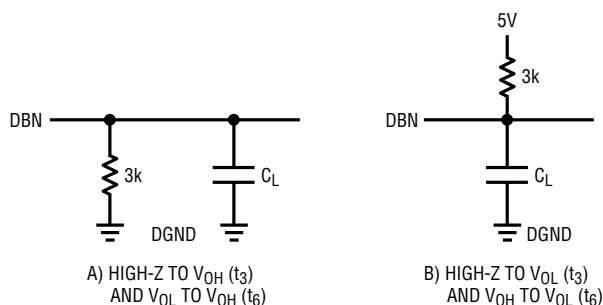
| | Pin 4 | Pin 5 | Pin 6 | Pin 7 | Pin 8 | Pin 9 | Pin 10 | Pin 11 | Pin 13 | Pin 14 | Pin 15 | Pin 16 |
|-------------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|
| MNEMONIC* | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3/11 | D2/10 | D1/9 | D0/8 |
| HBEN = LOW | DB11 | DB10 | DB9 | DB8 | DB7 | DB6 | DB5 | DB4 | DB3 | DB2 | DB1 | DB0 |
| HBEN = HIGH | DB11 | DB10 | DB9 | DB8 | LOW | LOW | LOW | LOW | DB11 | DB10 | DB9 | DB8 |

* D11...D0/8 are the ADC data output pins.

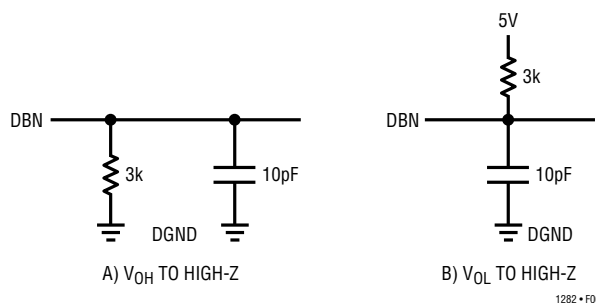
DB11...DB0 are the 12-bit conversion results, DB11 is the MSB.

TEST CIRCUITS

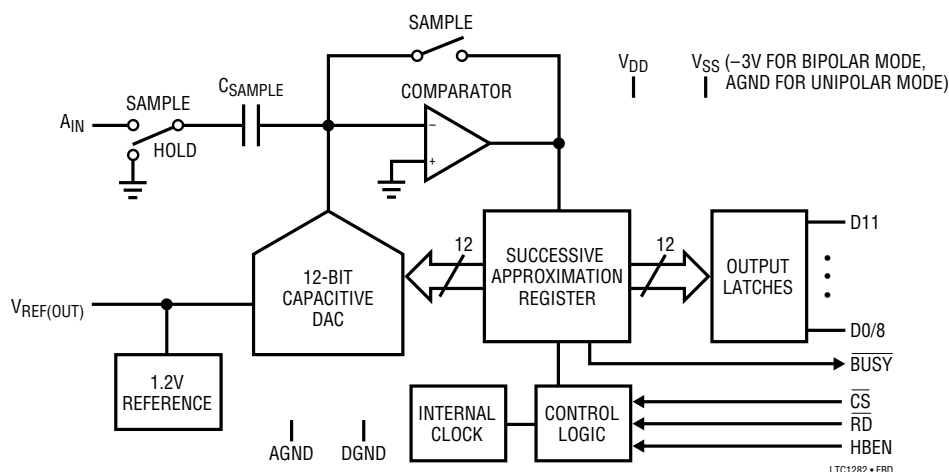
Load Circuits for Access Time



Load Circuits for Output Float Delay



FUNCTIONAL BLOCK DIAGRAM



APPLICATIONS INFORMATION

CONVERSION DETAILS

The LTC1282 uses a successive approximation and an internal sample-and-hold circuitry to convert an analog signal to a 12-bit parallel or 2-byte 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.

Conversion start is controlled by the \overline{CS} , \overline{RD} and HBEN inputs. At the start of conversion the successive approximation register (SAR) is reset and the three-state data outputs are enabled. Once a conversion cycle has begun it cannot be restarted.

During conversion, the internal 12-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} input connects to the sample-and-hold capacitor during the sample phase, and the comparator offset is nulled by the feedback switch. In this sample phase, a minimum delay of $1.0\mu s$ will provide enough time for the sample-and-hold capacitor to acquire the analog signal. During the convert phase, the comparator feed-

back switch opens, putting the comparator into the compare mode. The input switch switches C_{SAMPLE} to ground, injecting the analog input charge to the summing junction. This input charge is successively compared with the binary-weighted charges supplied by the capacitive DAC. Bit decisions are made by the high speed comparator. At the end of a conversion, the DAC output balances the A_{IN} input charge. The SAR contents (a 12-bit data word) which represent the A_{IN} are loaded into the 12-bit latch.

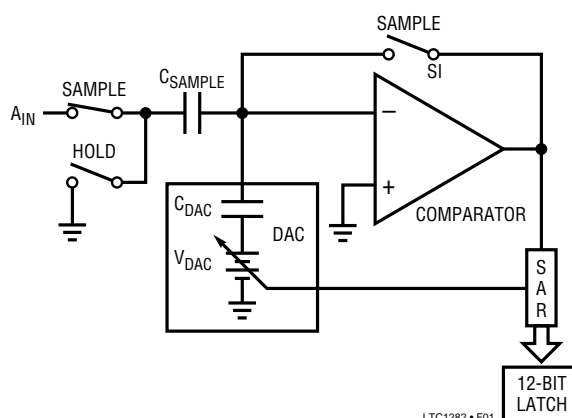


Figure 1. A_{IN} Input

APPLICATIONS INFORMATION

DYNAMIC PERFORMANCE

The LTC1282 has exceptionally high speed sampling capability. FFT (Fast Fourier Transform) test techniques are used to characterize 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 LTC1282 FFT plot.

Signal-to-(Noise + Distortion) 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 2 shows a typical LTC1282 FFT plot.

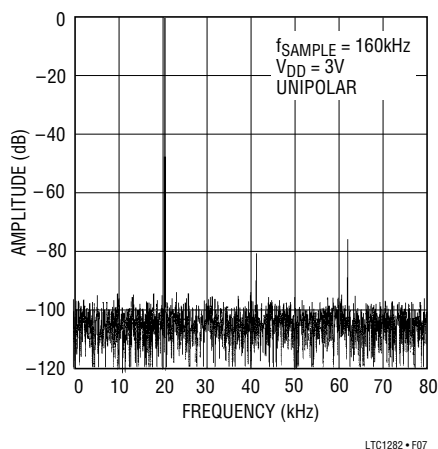


Figure 2. LTC1282 Nonaveraged, 1024 Point FFT Plot

Effective Number of Bits

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

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

where N is the Effective Number of Bits of resolution and $S/(N + D)$ is expressed in dB. At the maximum sampling rate of 140kHz the LTC1282 maintains 11.3 ENOBs at 70kHz input frequency. Refer to Figure 3.

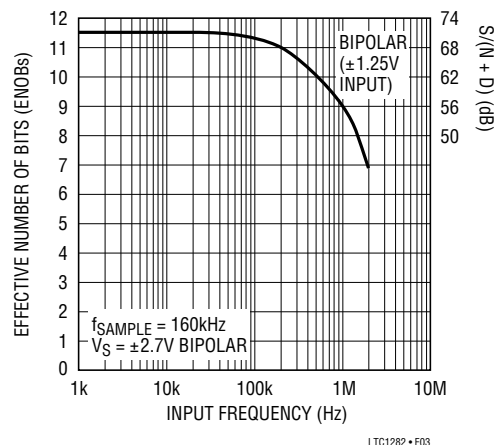


Figure 3. ENOBs and $S/(N + D)$ vs Input Frequency

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:

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

where V_1 is the RMS amplitude of the fundamental frequency and V_2 through V_N are the amplitudes of the second through Nth harmonics. The typical THD specification in the Dynamic Accuracy table includes the 2nd through 5th harmonics. With a 70kHz input signal, the LTC1282 has a typical -82 dB THD as shown in Figure 4.

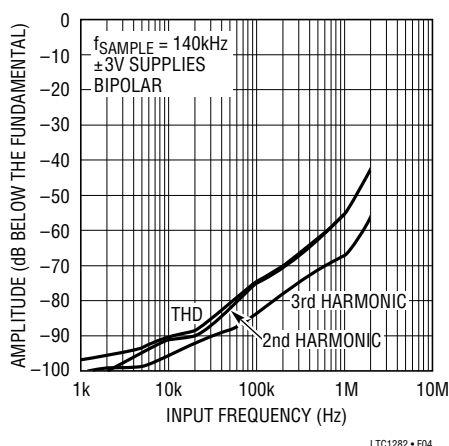


Figure 4. Distortion vs Input Frequency (Bipolar)

APPLICATIONS INFORMATION

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 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 $(f_a + f_b)$ and $(f_a - f_b)$ while the 3rd order IMD terms include $(2f_a + f_b)$, $(2f_a - f_b)$, $(f_a + 2f_b)$, and $(f_a - 2f_b)$ 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:

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

Figure 5 shows the IMD performance at a 20kHz input.

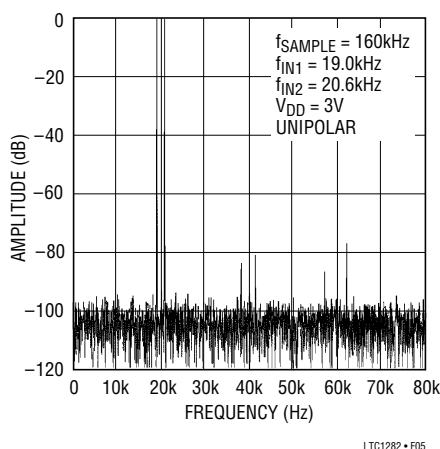


Figure 5. Intermodulation Distortion Plot

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 68dB (11 effective bits). The LTC1282 has been designed to optimize input bandwidth, allowing the ADC to undersample input signals with frequencies above the converter's Nyquist Frequency.

Driving the Analog Input

The analog input of the LTC1282 is easy to drive. It draws only one small current spike while charging the sample-and-hold capacitor at the end of conversion. During conversion the analog input draws no current. The only requirement is that the amplifier driving the analog input must settle after the small current spike before the next conversion starts. Any op amp that settles in 1.0μs to small current transients will allow maximum speed operation. If slower op amps are used, more settling time can be provided by increasing the time between conversions. Suitable devices capable of driving the ADC's A_{IN} input include the LT1190/LT1191, LT1007, LT1220, LT1223 and LT1224 op amps.

The analog input tolerates source resistance very well. Here again, the only requirement is that the analog input must settle before the next conversion starts. For larger source resistance, full accuracy can be obtained if more time is allowed between conversions.

Internal Reference

The LTC1282 has an on-chip, temperature compensated, curvature corrected, bandgap reference which is factory trimmed to 1.20V. It is internally connected to the DAC and is available at pin 2 to provide up to 0.3mA current to an external load.

For minimum code transition noise the reference output should be decoupled with a capacitor to filter wideband noise from the reference (10μF tantalum in parallel with a 0.1μF ceramic).

APPLICATIONS INFORMATION

Overdriving the Internal Reference

The V_{REF} pin can be driven above its normal value with a DAC or other means to provide input span adjustment. Figure 6 shows an LT1006 op amp driving the reference pin. The V_{REF} pin must be driven to at least 1.25V to prevent conflict with the internal reference. The reference should be driven to no more than 1.44V in unipolar mode or 2.88V for bipolar mode to keep the input span within the single 3V or $\pm 3V$ supplies.

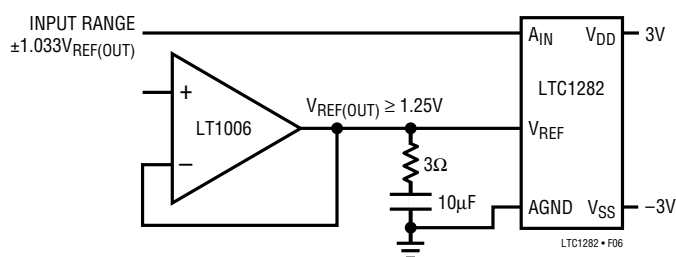


Figure 6. Driving the V_{REF} with the LT1006 Op Amp

Figure 7 shows a typical reference, the LT1019A-2.5 connected to the LTC1282 operating in bipolar mode. This will provide an improved drift (due to the 5ppm/°C of the LT1019A-2.5) and a $\pm 2.604V$ full scale.

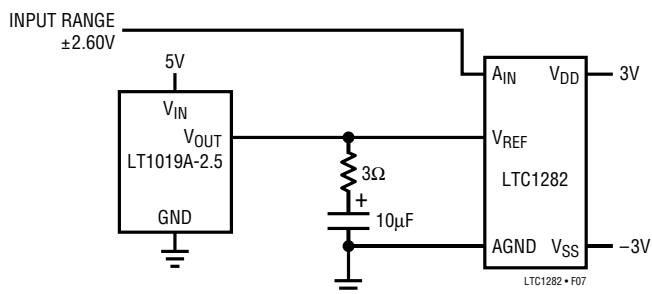


Figure 7. Supplying a 2.5V Reference Voltage to the LTC1282 with the LT1019A-2.5

UNIPOLAR/BIPOLAR OPERATION AND ADJUSTMENT

Figure 8 shows the ideal input/output characteristics for the LTC1282. The code transitions occur midway between successive integer LSB values (i.e., $1/2LSB$, $1\ 1/2LSBs$, $2\ 1/2LSBs$, $FS - 1\ 1/2LSBs$). The output code

is natural binary with $1LSB = FS/4096 = 2.5V/4096 = 0.61mV$. Figure 9 shows the input/output transfer characteristics for the LTC1282 in bipolar operation. The full scale for LTC1282 in bipolar mode is still 2.5V and $1LSB = 0.61mV$.

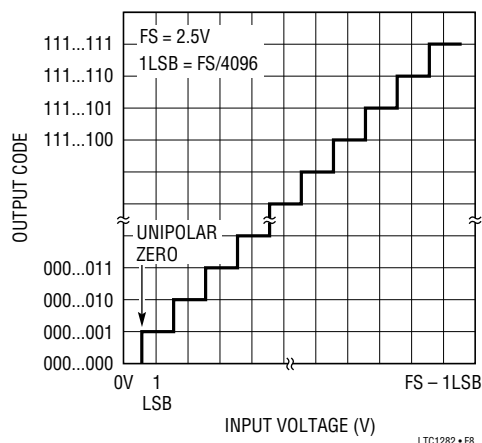


Figure 8. LTC1282 Unipolar Transfer Characteristic

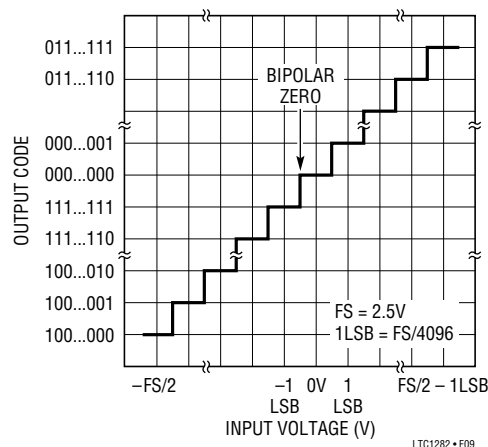


Figure 9. LTC1282 Bipolar Transfer Characteristic

Unipolar Offset and Full Scale Adjustment

In applications where absolute accuracy is important, offset and full scale errors can be adjusted to zero. Figure 10 shows the extra components required for full scale error adjustment. If both offset and full scale adjustments are needed, the circuit in Figure 11 can be used. Offset should be adjusted before full scale. To adjust offset,

APPLICATIONS INFORMATION

apply 0.305mV (i.e., 1/2LSB) at V_I and adjust the op amp offset voltage until the LTC1282 output code flickers between 0000 0000 0000 and 0000 0000 0001. For zero full scale error, apply an analog input of 2.49909V (i.e., FS – 1 1/2LSBs or last code transition) at the input and adjust the full scale trim until the LTC1282 output code flickers between 1111 1111 1110 and 1111 1111 1111.

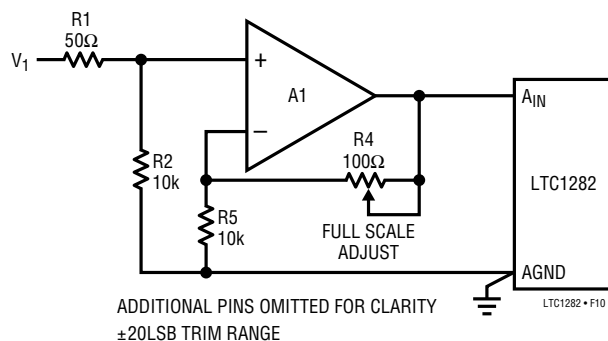


Figure 10. Full Scale Adjust Circuit

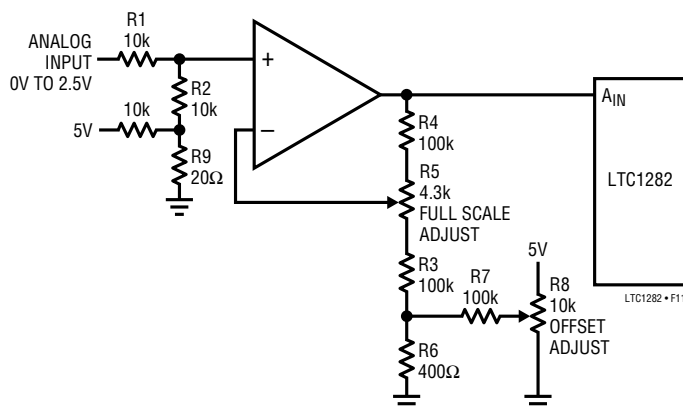


Figure 11. Unipolar Offset and Full Scale Adjust Circuit

Bipolar Offset and Full Scale Adjustment

Bipolar offset and full scale errors are adjusted in a similar fashion to the unipolar case. Figure 10 shows the extra components required for full scale error adjustment. If both offset and full scale adjustments are needed, the circuit in Figure 12 can be used. Again, bipolar offset must be adjusted before full scale error. Bipolar offset error adjustment is

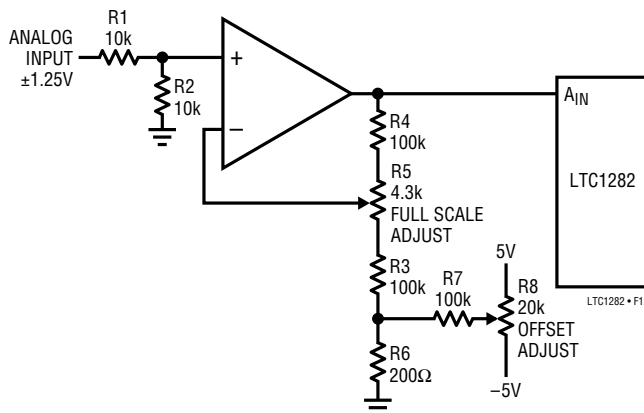


Figure 12. Bipolar Offset and Full Scale Adjust Circuit

achieved by trimming the offset adjustment of Figure 12 while the input voltage is 1/2LSB below ground. This is done by applying an input voltage of –0.305mV (–1/2LSB for LTC1282) to the input in Figure 12 and adjusting R8 until the ADC output code flickers between 0000 0000 0000 and 1111 1111 1111. For full scale adjustment, an input voltage of 1.24909V (FS – 3/2LSBs for LTC1282) is applied to the input and R5 is adjusted until the output code flickers between 0111 1111 1110 and 0111 1111 1111.

BOARD LAYOUT AND BYPASSING

The LTC1282 is easy to use. To obtain the best performance from the device, a printed circuit board is recommended. 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.

High quality tantalum and ceramic bypass capacitors should be used at the V_{DD} and V_{REF} pins as shown in Figure 13. In bipolar mode, a 0.1μF ceramic provides adequate bypassing for the V_{SS} pin. The 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.

APPLICATIONS INFORMATION

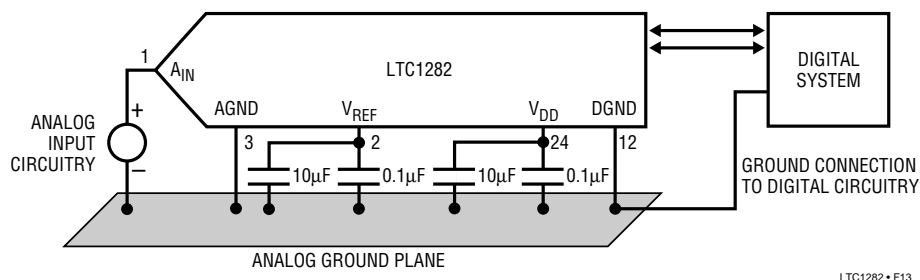


Figure 13. Power Supply Grounding Practice

Noise: Input signal leads to A_{IN} and signal return leads from AGND (Pin 3) should be kept as short as possible to minimize input noise coupling. In applications where this is not possible, a shielded cable between source and ADC is recommended. Also, since any potential difference in grounds between the signal source and ADC appears as an error voltage in series with the input signal, attention should be paid to reducing the ground circuit impedances as much as possible.

A single point analog ground separate from the logic system ground should be established with an analog ground plane at pin 3 (AGND) or as close as possible to the ADC, as shown in Figure 13. Pin 12 (DGND) and all other analog grounds should be connected to this single analog ground point. No other digital grounds should be connected to this analog ground point. 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 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.

DIGITAL INTERFACE

The ADC 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. The HBEN input serves as a data byte select for 8-bit processors and is normally either connected to the microprocessor address bus or grounded.

Connecting to 5V Logic Systems

The LTC1282 interfaces well to 5V logic because the ESD clamps on the inputs do not clamp to the positive supply (see Figure 14). Inputs of 0V to 5V do not bother the ADC at all. In addition, the 0V to 3V outputs of the 3V ADC are more than adequate to meet TTL input levels in the 5V logic. (5V logic with CMOS input levels requires a level shift.)

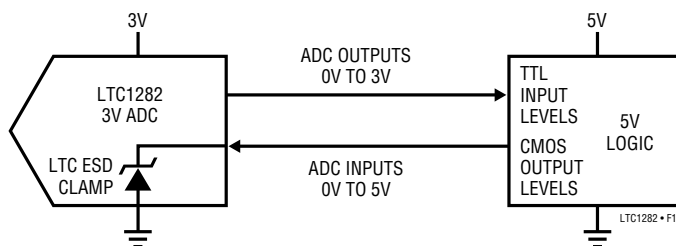


Figure 14. 3V ADC ESD Protection Handles 0V to 5V Swings Easily

APPLICATIONS INFORMATION

Internal Clock

The LTC1282 has an internal clock that eliminates the need for synchronization between the external clock and the $\overline{\text{CS}}$ and $\overline{\text{RD}}$ signals found in other ADCs. The internal clock is factory trimmed to achieve a typical conversion time of $5.5\mu\text{s}$, and a maximum conversion time over the full operating temperature range of $6.0\mu\text{s}$. No external adjustments are required and, with the guaranteed maximum acquisition time of $1.0\mu\text{s}$, throughput performance of 140ksps is assured.

Timing and Control

Conversion start and data read operations are controlled by three digital inputs: HBEN, $\overline{\text{CS}}$ and $\overline{\text{RD}}$. Figure 15 shows the logic structure associated with these inputs. The three signals are internally gated so that a logic "0" is required on all three inputs to initiate a conversion. Once initiated it cannot be restarted until the conversion is complete. Converter status is indicated by the $\overline{\text{BUSY}}$ output, and this is low while conversion is in progress.

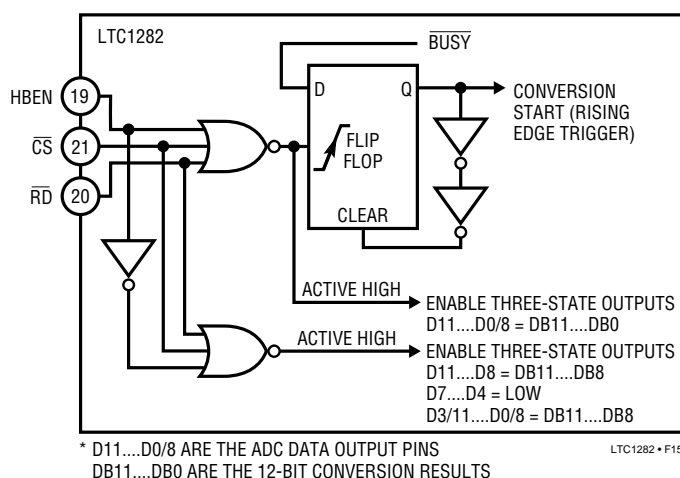


Figure 15. Internal Logic for Control Inputs $\overline{\text{CS}}$, $\overline{\text{RD}}$ and HBEN

There are two modes of operation as outlined by the timing diagrams of Figures 16 to 19. Slow Memory Mode is designed for microprocessors which can be driven into a WAIT state. A READ operation brings $\overline{\text{CS}}$ and $\overline{\text{RD}}$ low which

initiates a conversion and data is read when conversion is complete. The second is the ROM Mode which does not require microprocessor WAIT states. A READ operation brings $\overline{\text{CS}}$ and $\overline{\text{RD}}$ low which initiates a conversion and reads the previous conversion result.

Data Format

The output format can be either a complete parallel load for 16-bit microprocessors or a two byte load for 8-bit microprocessors. Data is always right justified (i.e., LSB is the most right-hand bit in a 16-bit word). For a two byte read, only data outputs D7...D0/8 are used. Byte selection is governed by the HBEN input which controls an internal digital multiplexer. This multiplexes the 12-bits of conversion data onto the lower D7...D0/8 outputs (4MSBs or 8MSBs) where it can be read in two read cycles. The 4MSBs always appear on D11...D8 whenever the three-state output drivers are turned on.

Slow Memory Mode, Parallel Read (HBEN = LOW)

Figure 16 and Table 2 show the timing diagram and data bus status for Slow Memory Mode, Parallel Read. $\overline{\text{CS}}$ and $\overline{\text{RD}}$ going low trigger a conversion and the ADC acknowledges by taking $\overline{\text{BUSY}}$ low. Data from the previous conversion appears on the three-state data outputs. $\overline{\text{BUSY}}$ returns high at the end of conversion when the output latches have been updated and the conversion result is placed on data outputs D11...D0/8.

Slow Memory Mode, Two Byte Read

For a two byte read, only 8 data outputs D7...D0/8 are used. Conversion start procedure and data output status for the first read operation are identical to Slow Memory Mode, Parallel Read. See Figure 17 timing diagram and Table 3 data bus status. At the end of the conversion, the low data byte (D7...D0/8) is read from the ADC. A second READ operation with the HBEN high, places the high byte on data outputs D3/11...D0/8 and disables conversion start. Note the 4MSBs appear on data output D11...D8 during the two READ operations.

APPLICATIONS INFORMATION

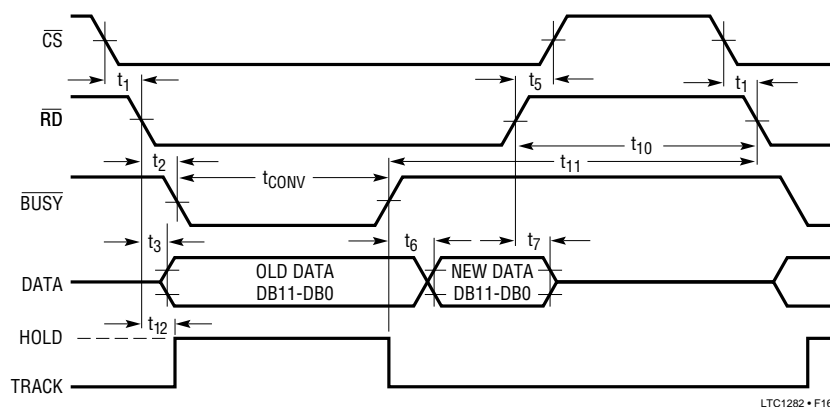


Figure 16. Slow Memory Mode, Parallel Read Timing Diagram

Table 2. Slow Memory Mode, Parallel Read Data Bus Status

| Data Outputs | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3/11 | D2/10 | D1/9 | D0/8 |
|--------------|------|------|-----|-----|-----|-----|-----|-----|-------|-------|------|------|
| Read | DB11 | DB10 | DB9 | DB8 | DB7 | DB6 | DB5 | DB4 | DB3 | DB2 | DB1 | DB0 |

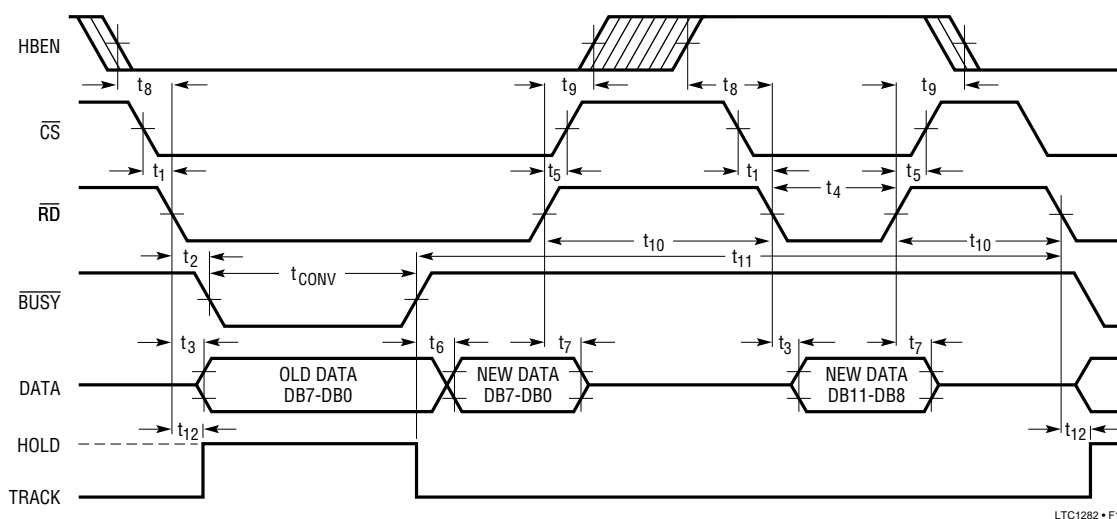


Figure 17. Slow Memory Mode, Two Byte Read Timing Diagram

Table 3. Slow Memory Mode, Two Byte Read Data Bus Status

| Data Outputs | D7 | D6 | D5 | D4 | D3/11 | D2/10 | D1/9 | D0/8 |
|--------------|-----|-----|-----|-----|-------|-------|------|------|
| First Read | DB7 | DB6 | DB5 | DB4 | DB3 | DB2 | DB1 | DB0 |
| Second Read | Low | Low | Low | Low | DB11 | DB10 | DB9 | DB8 |

APPLICATIONS INFORMATION

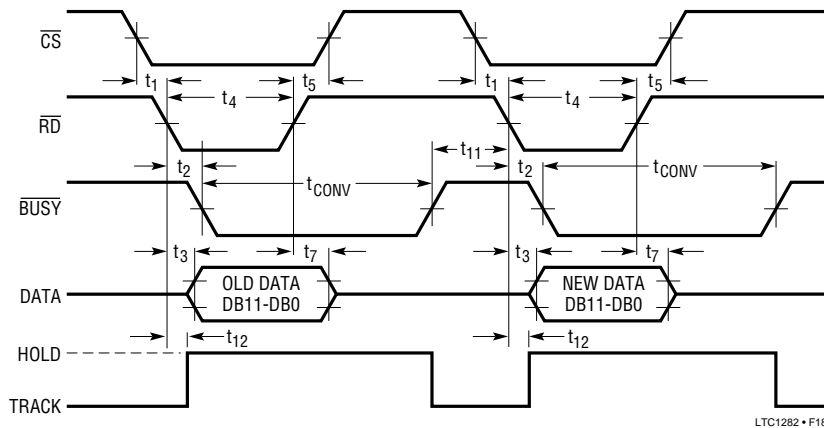


Figure 18. ROM Mode, Parallel Read Timing Diagram (HBEN = LOW)

Table 4. ROM Mode, Parallel Read Data Bus Status

| Data Outputs | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3/11 | D2/10 | D1/9 | D0/8 |
|-----------------------|------|------|-----|-----|-----|-----|-----|-----|-------|-------|------|------|
| First Read (Old Data) | DB11 | DB10 | DB9 | DB8 | DB7 | DB6 | DB5 | DB4 | DB3 | DB2 | DB1 | DB0 |
| Second Read | DB11 | DB10 | DB9 | DB8 | DB7 | DB6 | DB5 | DB4 | DB3 | DB2 | DB1 | DB0 |

ROM Mode, Parallel Read (HBEN = LOW)

The ROM Mode avoids placing a microprocessor into a WAIT state. A conversion is started with a READ operation, and the 12 bits of data from the previous conversion are available on data outputs D11...D0/8 (see Figure 18 and Table 4). This data may be disregarded if not required. A second READ operation reads the new data (DB11...DB0) and starts another conversion. A delay at least as long as the ADC's conversion time plus the 1.0 μ s minimum delay between conversions must be allowed between READ operations.

ROM Mode, Two Byte Read

As previously mentioned for a two byte read, only data outputs D7...D0/8 are used. Conversion is started in the normal way with a READ operation and the data output status is the same as the ROM mode, Parallel Read (see Figure 19 timing diagram and Table 5 data bus status). Two more READ operations are required to access the new conversion result. A delay equal to the ADC's conversion

time must be allowed between conversion start and the second data READ operation. The second READ operation with HBEN high disables conversion start and places the high byte (4MSBs) on data outputs D3/11...D0/8. A third read operation accesses the low data byte (DB7...DB0) and starts another conversion. The 4MSBs appear on data outputs D11...D8 during all three read operations.

MICROPROCESSOR INTERFACING

The LTC1282 allows easy interfacing to digital signal processors as well as modern high speed, 8-bit or 16-bit microprocessors. Here are several examples.

TMS320C25

Figure 20 shows an interface between the LTC1282 and the TMS320C25.

The R/W signal of the DSP initiates a conversion and conversion results are read from the LTC1282 using the following instruction:

IN D, PA

APPLICATIONS INFORMATION

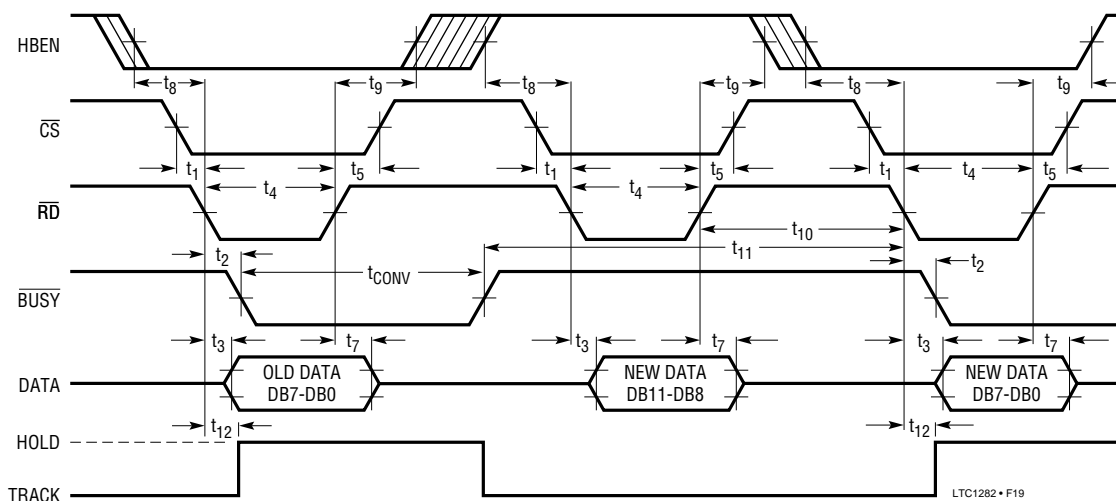


Figure 19. ROM Mode Two Byte Read Timing Diagram

Table 5. ROM Mode, Two Byte Read Data Bus Status

| Data Outputs | D7 | D6 | D5 | D4 | D3/11 | D2/10 | D1/9 | D0/8 |
|------------------------|-----|-----|-----|-----|-------|-------|------|------|
| First Read (Old Data) | DB7 | DB6 | DB5 | DB4 | DB3 | DB2 | DB1 | DB0 |
| Second Read (New Data) | Low | Low | Low | Low | DB11 | DB10 | DB9 | DB8 |
| Third Read (New Data) | DB7 | DB6 | DB5 | DB4 | DB3 | DB2 | DB1 | DB0 |

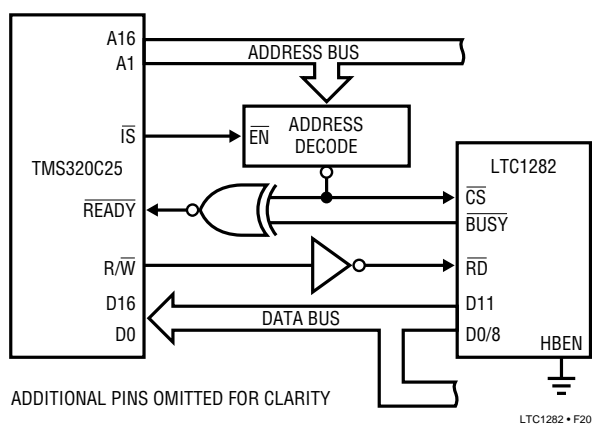


Figure 20. TMS320C25 Interface

where D is Data Memory Address and PA is the PORT ADDRESS.

MC68000 Microprocessor

Figure 21 shows a typical interface for the MC68000. The LTC1282 is operating in the Slow Memory Mode. Assuming the LTC1282 is located at address C000, then the following single 16-bit MOVE instruction both starts a conversion and reads the conversion result:

```
Move.W $C000,D0
```

At the beginning of the instruction cycle when the ADC address is selected, $\overline{\text{BUSY}}$ and $\overline{\text{CS}}$ assert $\overline{\text{DTACK}}$ so that the MC68000 is forced into a WAIT state. At the end of conversion, $\overline{\text{BUSY}}$ returns high and the conversion result is placed in the D0 register of the microprocessor.

APPLICATIONS INFORMATION

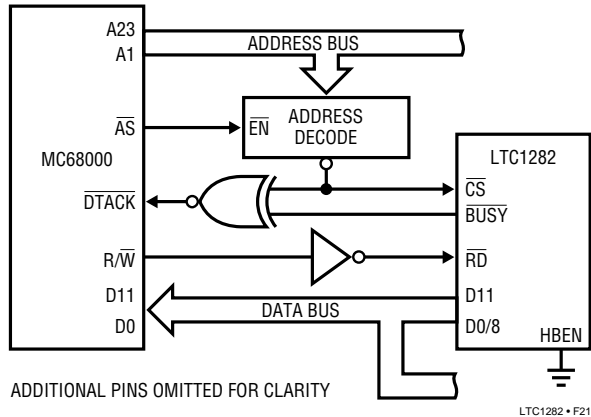


Figure 21. MC68000 Interface

8085A/Z80 Microprocessor

Figure 22 shows an LTC1282 interface for the Z80 and 8085A. The LTC1282 is operating in the Slow Memory Mode and a two byte read is required. Not shown in the figure is the 8-bit latch required to demultiplex the 8085A common address/data bus. A0 is used to assert HBEN so that an even address (HBEN = LOW) to the LTC1282 will start a conversion and read the low data byte. An odd address (HBEN = HIGH) will read the high data byte. This is accomplished with the single 16-bit LOAD instruction below.

For the 8085A LHLD (B000)
For the Z80 LDHL, (B000)

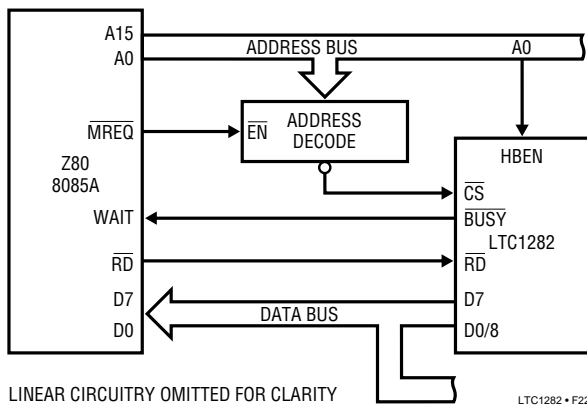


Figure 22. 8085A and Z80 Interface

This is a two byte read instruction which loads the ADC data (address B000) into the HL register pair. During the first read operation, BUSY forces the microprocessor to WAIT for the LTC1282 conversion. No WAIT states are inserted during the second read operation when the microprocessor is reading the high data byte.

TMS32010 Microcomputer

Figure 23 shows an LTC1282/TMS32010 interface. The LTC1282 is operating in the ROM Mode. The interface is designed for a maximum TMS32010 clock frequency of 18MHz but will typically work over the full TMS32010 clock frequency range.

The LTC1282 is mapped at a port address. The following I/O instruction starts a conversion and reads the previous conversion result into data memory.

IN A, PA (PA = PORT ADDRESS)

When conversion is complete, a second I/O instruction reads the up-to-date data into memory and starts another conversion. A delay at least as long as the ADC conversion time must be allowed between I/O instructions.

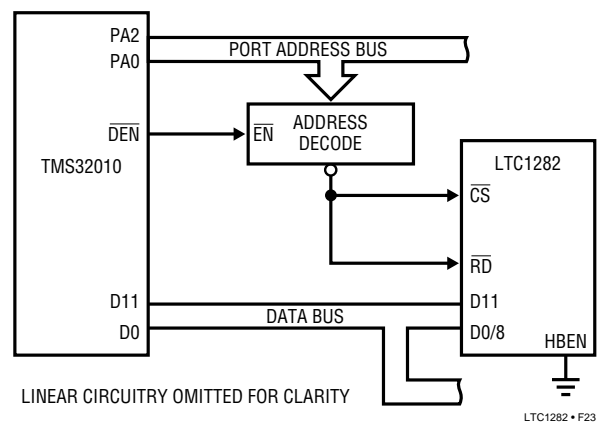


Figure 23. TMS32010 Interface

APPLICATIONS INFORMATION

MUXing with CD4051

The high input impedance of the LTC1282 provides an easy, cheap, fast, and accurate way to multiplex many channels of data through one converter. Figure 24 shows a low cost CD4051, one of the most common multiplexers connected to the LTC1282. The LTC1282's input draws no DC input current so it can be accurately driven by the unbuffered MUX. The CD4520 counter increments the MUX channel after each sample is taken.

100ps Resolution Δ Time Measurement with LTC1282

Figure 25 shows a circuit that precisely measures the difference in time between two events. It has a 400ns full scale and 100ps resolution. The start signal releases the ramp generator made up of the PNP current source and the 500pF capacitor. The circuit ramps until the stop signal shuts off the current source. The final value of the ramp represents the time between the start and stop

events. The LTC1282 digitizes this final value and outputs the digital data.

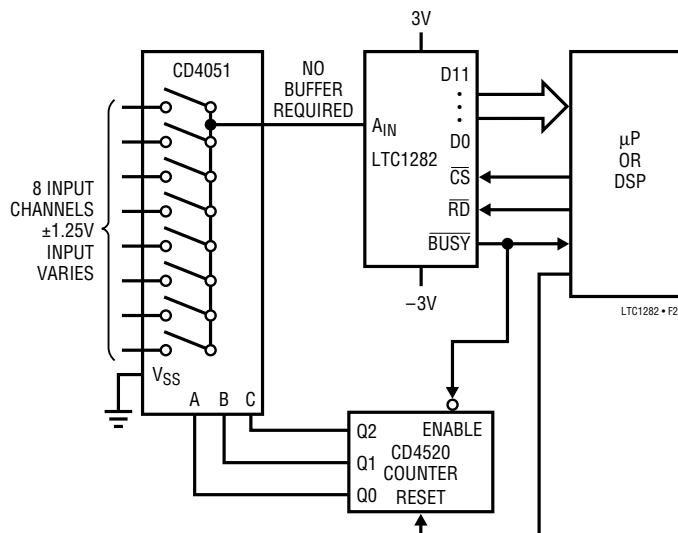


Figure 24. MUXing the LTC1282 with CD4051

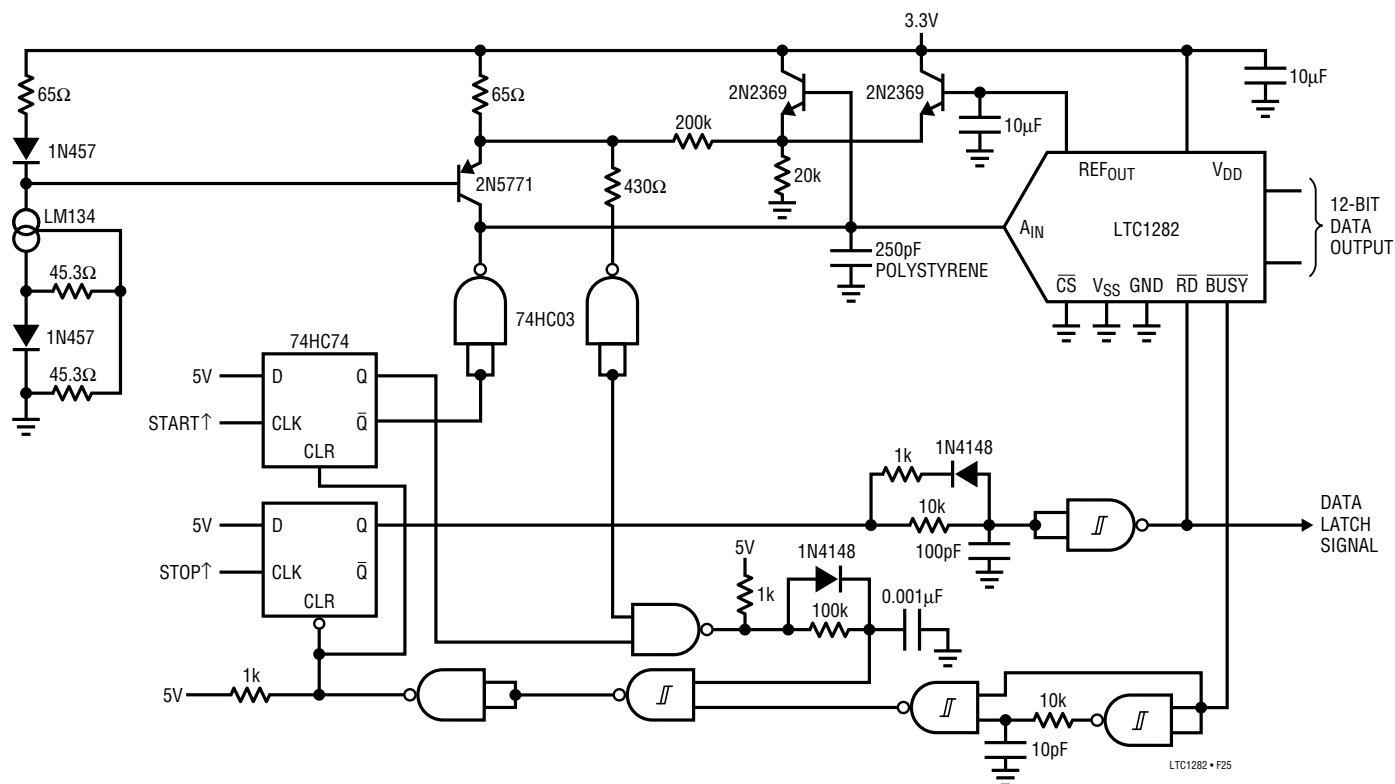


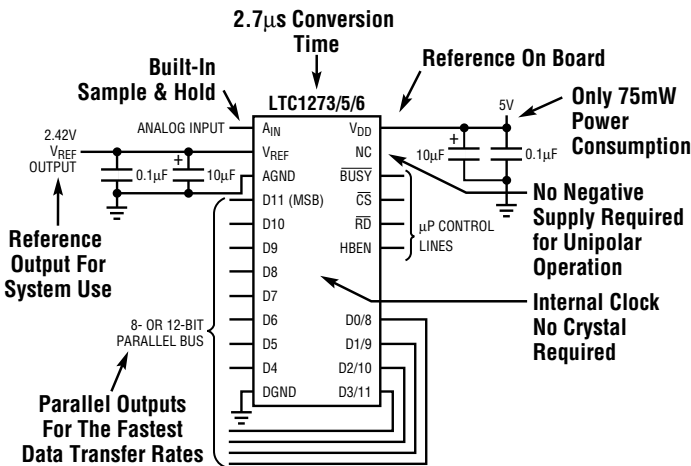
Figure 25. Δ Time Measurement with the LTC1282

APPLICATIONS INFORMATION

Other High Speed A/D Converters

LTC makes a family of high speed sampling ADCs for a variety of applications. Both single 5V and ±5V supply devices are available at high speeds. The high speed 12-bit family is summarized below.

300ksps and 500ksps 12-Bit Sampling A/D Converters



Comparison of Specifications and Features

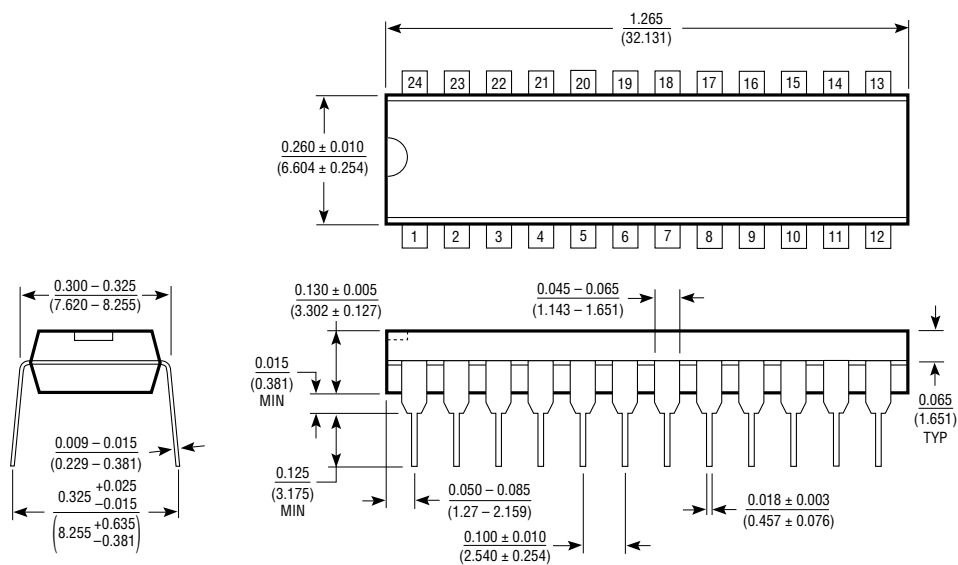
| DEVICE TYPE | SAMPLING FREQ | S/(N + D) @ NYQUIST | INPUT RANGE | POWER SUPPLY | POWER DISSIPATION |
|-------------|---------------|---------------------|-------------------|--------------|-------------------|
| LTC1272 | 250kHz | 65dB | 0V-5V | 5V | 75mW |
| LTC1273 | 300kHz | 70dB | 0V-5V | 5V | 75mW |
| LTC1275 | 300kHz | 70dB | ±2.5V | ±5V | 75mW |
| LTC1276 | 300kHz | 70dB | ±5V | ±5V | 75mW |
| LTC1278 | 520kHz | 70dB | 0V-5V or ±2.5V | 5V or ±5V | 75mW 6mW* |
| LTC1282 | 140kHz | 68dB | 0V-2.5V or ±1.25V | 3V or ±3V | 12mW |

*6mW power shutdown with instant wake up

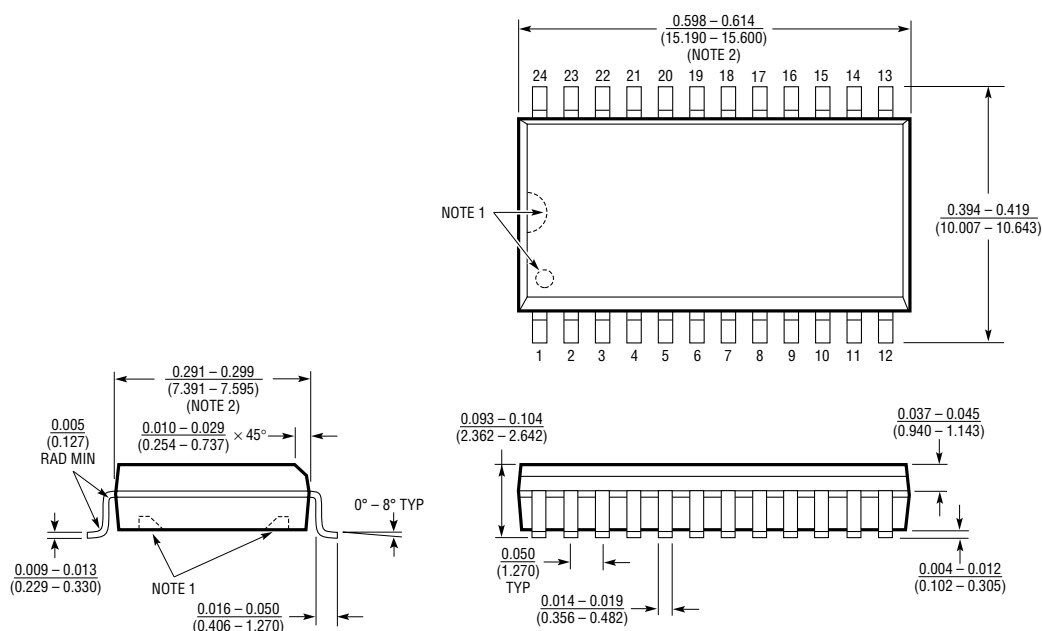
PACKAGE DESCRIPTION

Dimensions in inches (millimeters) unless otherwise noted.

N Package 24-Lead Plastic DIP



S Package 24-Lead Plastic SOL



NOTE:
1. PIN 1 IDENT, NOTCH ON TOP AND CAVITIES ON THE BOTTOM OF PACKAGES ARE THE MANUFACTURING OPTIONS. THE PART MAY BE SUPPLIED WITH OR WITHOUT ANY OF THE OPTIONS.
2. THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.006 INCH (0.15mm).

U.S. Area Sales Offices**NORTHEAST REGION****Linear Technology Corporation**

One Oxford Valley
2300 E. Lincoln Hwy., Suite 306
Langhorne, PA 19047
Phone: (215) 757-8578
FAX: (215) 757-5631

Linear Technology Corporation

266 Lowell St., Suite B-8
Wilmington, MA 01887
Phone: (508) 658-3881
FAX: (508) 658-2701

SOUTHEAST REGION**Linear Technology Corporation**

17060 Dallas Parkway
Suite 208
Dallas, TX 75248
Phone: (214) 733-3071
FAX: (214) 380-5138

CENTRAL REGION**Linear Technology Corporation**

Chesapeake Square
229 Mitchell Court, Suite A-25
Addison, IL 60101
Phone: (708) 620-6910
FAX: (708) 620-6977

SOUTHWEST REGION**Linear Technology Corporation**

22141 Ventura Blvd.
Suite 206
Woodland Hills, CA 91364
Phone: (818) 703-0835
FAX: (818) 703-0517

NORTHWEST REGION**Linear Technology Corporation**

782 Sycamore Dr.
Milpitas, CA 95035
Phone: (408) 428-2050
FAX: (408) 432-6331

International Sales Offices**FRANCE****Linear Technology S.A.R.L.**

Immeuble "Le Quartz"
58 Chemin de la Justice
92290 Chatenay Malabry
France
Phone: 33-1-41079555
FAX: 33-1-46314613

KOREA**Linear Technology Korea Branch**

Namsong Building, #505
Itaewon-Dong 260-199
Yongsan-Ku, Seoul
Korea
Phone: 82-2-792-1617
FAX: 82-2-792-1619

TAIWAN**Linear Technology Corporation**

Rm. 801, No. 46, Sec. 2
Chung Shan N. Rd.
Taipei, Taiwan, R.O.C.
Phone: 886-2-521-7575
FAX: 886-2-562-2285

GERMANY**Linear Technolgy GMBH**

Untere Hauptstr. 9
D-85386 Eching
Germany
Phone: 49-89-3197410
FAX: 49-89-3194821

SINGAPORE**Linear Technology Pte. Ltd.**

101 Boon Keng Road
#02-15 Kallang Ind. Estates
Singapore 1233
Phone: 65-293-5322
FAX: 65-292-0398

UNITED KINGDOM**Linear Technology (UK) Ltd.**

The Coliseum, Riverside Way
Camberley, Surrey GU15 3YL
United Kingdom
Phone: 44-276-677676
FAX: 44-276-64851

JAPAN**Linear Technology KK**

5F YZ Bldg.
4-4-12 Iidabashi, Chiyoda-Ku
Tokyo, 102 Japan
Phone: 81-3-3237-7891
FAX: 81-3-3237-8010

World Headquarters**Linear Technology Corporation**

1630 McCarthy Blvd.
Milpitas, CA 95035-7487
Phone: (408) 432-1900
FAX: (408) 434-0507

08/16/93