

### FEATURES

**Dual Independent Digitally Controlled VGAs**

**-4 to 20dB Gain Range**

**1 dB Step Size  $\pm 0.2$  dB**

**Differential input and output**

**150  $\Omega$  Differential Input**

**Open Collector Differential Output**

**8.7 dB noise figure @ maximum gain**

**OIP3 of ~50dBm at 140MHz**

**-3 dB bandwidth of 700 MHz**

**Excellent Channel to Channel Isolation**

**Two Parallel 5-bit Control Interfaces**

**Wide input dynamic range**

**Power-down Control**

**Single 5V Supply Operation**

**32 Lead LFCSP 5 x 5 mm Package**

### APPLICATIONS

**Differential ADC drivers**

**Main and Diversity IF Sampling Receivers**

**High Output Power IF Amplification**

**Multi-channel Receivers**

**Instrumentation**

### GENERAL DESCRIPTION

The AD8376 is a dual channel digitally controlled, variable gain wide bandwidth amplifier that provides precise gain control, high IP3 and low noise figure. The excellent distortion performance and high signal bandwidth makes the AD8376 an excellent gain control device for a variety of receiver applications.

For wide input dynamic range applications, the AD8376 provides a broad 24 dB gain range with 1 dB resolution. The gain of each channel is adjusted through dedicated 5-pin control interfaces and can be driven using standard TTL levels. The open-collector outputs provide a flexible interface, allowing the overall signal gain to be set by the loading resistance. The AD8376 offers a maximum trans-conductance gain of 67 m $\Omega^{-1}$ 's. This results in a signal voltage gain proportional to the load resistance. When driving a 150  $\Omega$  differential load, the maximum signal gain will be 20 dB.

### FUNCTIONAL BLOCK DIAGRAM

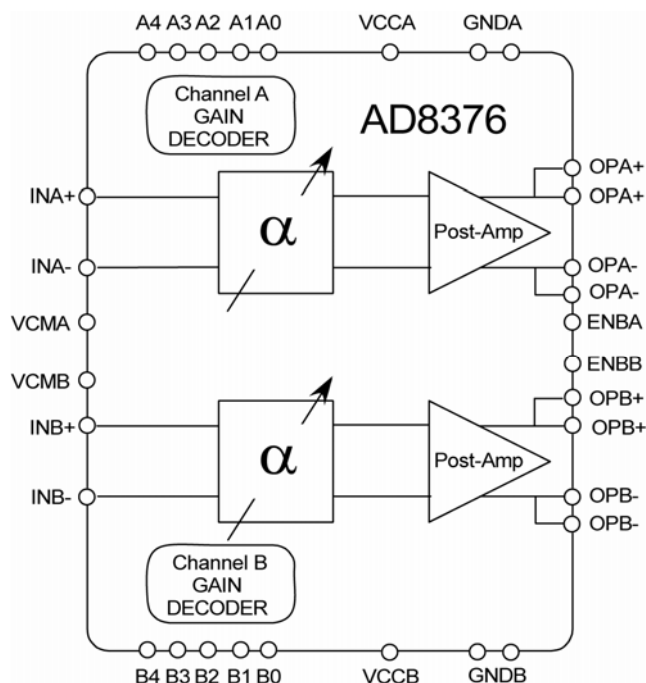


Figure 1.

Using a high speed SiGe process and incorporating proprietary distortion cancellation techniques, the AD8376 achieves 50 dBm output IP3 at 140 MHz.

Each channel of the AD8376 can be individually powered on by applying the appropriate logic level to the ENBA and ENBB power enable pins. The quiescent current of the AD8376 is typically 130 mA per channel. When powered down, the AD8376 consumes less than 5mA and offers excellent input to output isolation, lower than -50 dB at 200 MHz.

Fabricated on an ADI's high speed SiGe process, the AD8376 provides precise gain adjustment capabilities with good distortion performance. The AD8376 amplifier comes in a compact, thermally enhanced 5 x 5mm 32-lead LFCSP package and operates over the temperature range of -40°C to +85°C.

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## SPECIFICATIONS

$V_S = 5\text{ V}$ ,  $T = 25^\circ\text{C}$ ,  $R_S = R_L = 150\Omega$  at 100MHz, 2 V p-p differential output, both channels enabled, unless otherwise noted.

Table 1.

| Parameter                      | Conditions                                                                          | Min   | Typ   | Max   | Unit                  |
|--------------------------------|-------------------------------------------------------------------------------------|-------|-------|-------|-----------------------|
| DYNAMIC PERFORMANCE            |                                                                                     |       |       |       |                       |
| –3 dB Bandwidth                | $V_{OUT} < 2\text{ V p-p}$ (5.2dBm)                                                 |       | 700   |       | MHz                   |
| Slew Rate                      |                                                                                     |       | TBD   |       | V/nsec                |
| INPUT STAGE                    |                                                                                     |       |       |       |                       |
| Maximum Input Swing            | Pins IPA+ and IPA-, IPB+ and IPB-<br>For linear operation ( $A_V = -4\text{ dB}$ )  |       | TBD   | TBD   | V p-p                 |
| Differential Input Resistance  | Differential                                                                        |       | 150   |       | $\Omega$              |
| Common-Mode Input Voltage      |                                                                                     |       | 1.9   |       | V                     |
| CMRR                           | Gain Code = 00000                                                                   |       | TBD   |       | dB                    |
| GAIN                           |                                                                                     |       |       |       |                       |
| Amplifier Transconductance     | Gain Code = 00000                                                                   | 0.058 | 0.067 | 0.076 | $\Omega^{-1}$         |
| Maximum Voltage Gain           | Gain Code = 00000                                                                   |       | 20    |       | dB                    |
| Minimum Voltage Gain           | Gain Code $\geq 11000$                                                              |       | –4    |       | dB                    |
| Gain Step Size                 | From Gain Code 00000 to 11000                                                       | 0.8   | 1.0   | 1.2   | dB                    |
| Gain Flatness                  | Gain Code = 00000 over 20% fractional bandwidth for $f_C < 200\text{MHz}$           |       | TBD   |       | dB                    |
| Gain Temperature Sensitivity   | Gain Code = 00000                                                                   |       | TBD   |       | mdB/ $^\circ\text{C}$ |
| Gain Step Response             | For $V_{IN} = 100\text{mVp-p}$ , Gain Code 10100 to 00000                           |       | TBD   |       | ns                    |
| OUTPUT STAGE                   |                                                                                     |       |       |       |                       |
| Output Voltage Swing           | Pins OPA+ and OPA-, OPB+ and OPB-<br>At P1dB, Gain Code = 00000                     |       | 10    |       | V p-p                 |
| Output impedance               | Differential                                                                        |       | 5k/1  |       | $\Omega/\text{pF}$    |
| Channel Isolation (Worst Case) | Measured at differential output for differential input applied to alternate channel |       | –53   |       | dB                    |
| NOISE/HARMONIC PERFORMANCE     |                                                                                     |       |       |       |                       |
| 46 MHz                         |                                                                                     |       |       |       |                       |
| Noise Figure                   | Gain Code = 00000                                                                   |       | 8.7   |       | dB                    |
| Second Harmonic                | $V_{OUT} = 2\text{ V p-p}$                                                          |       | –94   |       | dBc                   |
| Third Harmonic                 | $V_{OUT} = 2\text{ V p-p}$                                                          |       | –92   |       | dBc                   |
| Output IP3                     | 2 MHz spacing, +3 dBm per tone                                                      |       | 50    |       | dBm                   |
| Output 1 dB Compression Point  |                                                                                     |       | 19    |       | dBm                   |
| 70 MHz                         |                                                                                     |       |       |       |                       |
| Noise Figure                   | Gain Code = 00000                                                                   |       | 8.7   |       | dB                    |
| Second Harmonic                | $V_{OUT} = 2\text{ V p-p}$                                                          |       | –94   |       | dBc                   |
| Third Harmonic                 | $V_{OUT} = 2\text{ V p-p}$                                                          |       | –92   |       | dBc                   |
| Output IP3                     | 2 MHz spacing, +3 dBm per tone                                                      |       | 50    |       | dBm                   |
| Output 1 dB Compression Point  |                                                                                     |       | 19    |       | dBm                   |
| 140 MHz                        |                                                                                     |       |       |       |                       |
| Noise Figure                   | Gain Code = 00000                                                                   |       | 8.7   |       | dB                    |
| Second Harmonic                | $V_{OUT} = 2\text{ V p-p}$                                                          |       | –86   |       | dBc                   |
| Third Harmonic                 | $V_{OUT} = 2\text{ V p-p}$                                                          |       | –91   |       | dBc                   |
| Output IP3                     | 2 MHz spacing, +3 dBm per tone                                                      |       | 50    |       | dBm                   |
| Output 1 dB Compression Point  |                                                                                     |       | 19    |       | dBm                   |

| Parameter                      | Conditions                                                                    | Min | Typ | Max | Unit |
|--------------------------------|-------------------------------------------------------------------------------|-----|-----|-----|------|
| 200 MHz                        | Gain Code = 00000                                                             |     |     |     |      |
| Noise Figure                   |                                                                               |     | 8.7 |     | dB   |
| Second Harmonic                | $V_{OUT} = 2\text{ V p-p}$                                                    |     | -85 |     | dBc  |
| Third Harmonic                 | $V_{OUT} = 2\text{ V p-p}$                                                    |     | -87 |     | dBc  |
| Output IP3                     | 2 MHz spacing, +3 dBm per tone                                                |     | 50  |     | dBm  |
| Output 1 dB Compression Point  |                                                                               |     | 18  |     | dBm  |
| POWER-INTERFACE                |                                                                               |     |     |     |      |
| Supply Voltage                 |                                                                               | 4.5 | 5.0 | 5.5 | V    |
| Quiescent Current Per Channel  | Thermal connection made to exposed paddle under device, both channels enabled | TBD | 130 | 140 | mA   |
| vs. Temperature                | $-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$                       |     |     | 155 | mA   |
| Power Down Current Per Channel | PWUP Low                                                                      |     | 3   |     | mA   |
| vs. Temperature                | $-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$                       |     |     | TBD | mA   |
| POWER-UP/GAIN CONTROL          | Pins A0 – A4, B0 – B4, PUPA, and PUPB                                         |     |     |     |      |
| $V_{IH}$                       | Minimum voltage for a logic high                                              | 1.6 |     |     | V    |
| $V_{IL}$                       | Maximum voltage for a logic low                                               |     |     | 0.8 |      |
| Logic Input Bias Current       |                                                                               |     | 900 |     | nA   |

Table 2. Gain-Code versus Voltage Gain Look-Up Table

| 5-Bit Binary Gain Code | Voltage Gain (dB) | 5-Bit Binary Gain Code | Voltage Gain (dB) |
|------------------------|-------------------|------------------------|-------------------|
| 00000                  | 20                | 01101                  | 7                 |
| 00001                  | 19                | 01110                  | 6                 |
| 00010                  | 18                | 01111                  | 5                 |
| 00011                  | 17                | 10000                  | 4                 |
| 00100                  | 16                | 10001                  | 3                 |
| 00101                  | 15                | 10010                  | 2                 |
| 00110                  | 14                | 10011                  | 1                 |
| 00111                  | 13                | 10100                  | 0                 |
| 01000                  | 12                | 10101                  | -1                |
| 01001                  | 11                | 10110                  | -2                |
| 01010                  | 10                | 10111                  | -3                |
| 01011                  | 9                 | 11000                  | -4                |
| 01100                  | 8                 | >11000                 | -4                |

**ABSOLUTE MAXIMUM RATINGS**

| Parameter                                        | Rating                       |
|--------------------------------------------------|------------------------------|
| Supply Voltage, $V_{POS}$                        | 5.5 V                        |
| ENBA, ENBB, A0-A4, B0-B4                         | -0.6 to ( $V_{POS} + 0.6V$ ) |
| Input Voltage, $V_{IN+}$ , $V_{IN-}$             | -0.6 to +3.1V                |
| Internal Power Dissipation                       | TBD mW                       |
| $\theta_{JA}$ (Exposed paddle soldered down)     | TBD°C/W                      |
| $\theta_{JA}$ (Exposed paddle not soldered down) | TBD°C/W                      |
| $\theta_{JC}$ (At exposed paddle)                | TBD°C/W                      |
| Maximum Junction Temperature                     | TBD°C                        |
| Operating Temperature Range                      | -40°C to +85°C               |
| Storage Temperature Range                        | -65°C to +150°C              |
| Lead Temperature Range<br>(Soldering 60 sec)     | TBD°C                        |

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those listed in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

**ESD CAUTION**

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



## PIN CONFIGURATION AND FUNCTIONAL DESCRIPTIONS

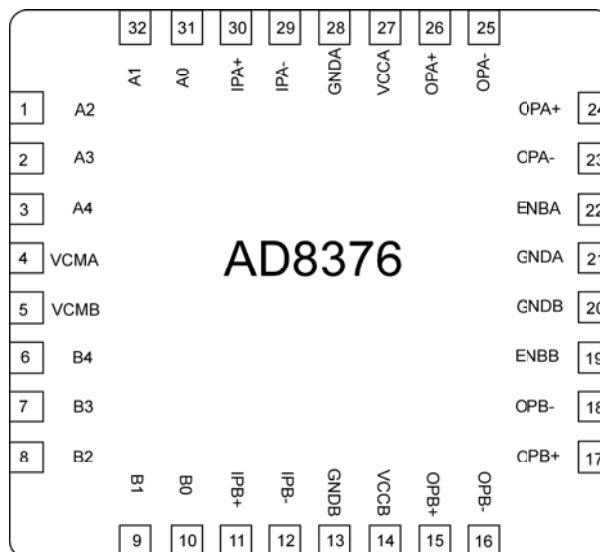


Figure 2. 32 Lead LFCSP

Table 3. Pin Function Descriptions

| Pin No. | Mnemonic | Description                                                                                       |
|---------|----------|---------------------------------------------------------------------------------------------------|
| 1       | A2       | MSB-2 for the Gain Control Interface for Channel A.                                               |
| 2       | A3       | MSB-1 for the Gain Control Interface for Channel A.                                               |
| 3       | A4       | The MSB for the 5-bit Gain Control Interface for Channel A.                                       |
| 4       | VCMA     | Channel A Input Common Mode Voltage. Typically bypassed to ground through capacitor               |
| 5       | VCMB     | Channel B Input Common Mode Voltage. Typically bypassed to ground through capacitor               |
| 6       | B4       | The MSB for the 5-bit Gain Control Interface for Channel B.                                       |
| 7       | B3       | MSB-1 for the Gain Control Interface for Channel B.                                               |
| 8       | B2       | MSB-2 for the Gain Control Interface for Channel B.                                               |
| 9       | B1       | LSB+1 for the Gain Control Interface for Channel B.                                               |
| 10      | B0       | LSB for the Gain Control Interface for Channel B.                                                 |
| 11      | IPB+     | Channel B Positive Input.                                                                         |
| 12      | IPB-     | Channel B Negative Input.                                                                         |
| 13, 20  | GNDB     | Device Common (DC Ground) for Channel B.                                                          |
| 14      | VCCB     | Positive Supply Pin for Channel B. Should be bypassed to Ground using suitable bypass capacitor.  |
| 15, 17  | OPB+     | Positive Ouput Pins (Open Collector) for Channel B. Require DC bias of +5V nominal.               |
| 16, 18  | OPB-     | Negative Ouput Pins (Open Collector) for Channel B. Require DC bias of +5V nominal.               |
| 19      | ENBB     | Power Enable Pin for Channel B.                                                                   |
| 21, 28  | GNDA     | Device Common (DC Ground) for Channel A.                                                          |
| 22      | ENBA     | Power Enable Pin for Channel A.                                                                   |
| 23, 25  | OPA-     | Negative Ouput Pins (Open Collector) for Channel A. Require DC bias of +5V nominal.               |
| 24, 26  | OPA+     | Positive Ouput Pins (Open Collector) for Channel A. Require DC bias of +5V nominal.               |
| 27      | VCCA     | Positive Supply Pins for Channel A. Should be bypassed to Ground using suitable bypass capacitor. |
| 29      | IPA-     | Channel A Negative Input.                                                                         |
| 30      | IPA+     | Channel A Positive Input.                                                                         |
| 31      | A0       | LSB for the Gain Control Interface for Channel A.                                                 |
| 32      | A1       | LSB+1 for the Gain Control Interface for Channel A.                                               |

# TYPICAL PERFORMANCE CHARACTERISTICS

$V_S = 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $R_{\text{Source}} = R_{\text{Load}} = 150\ \Omega$ , both channels enabled, unless otherwise noted.

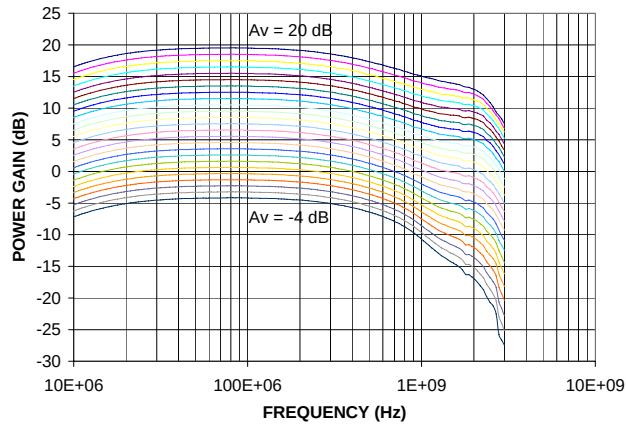


Figure 2. Gain vs. Frequency by Gain Code, (all codes), Differential-in, Differential-out

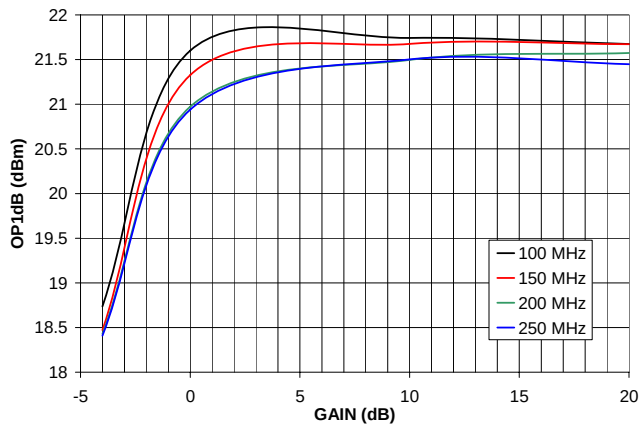


Figure 3. P1dB vs. Gain at Various Frequencies

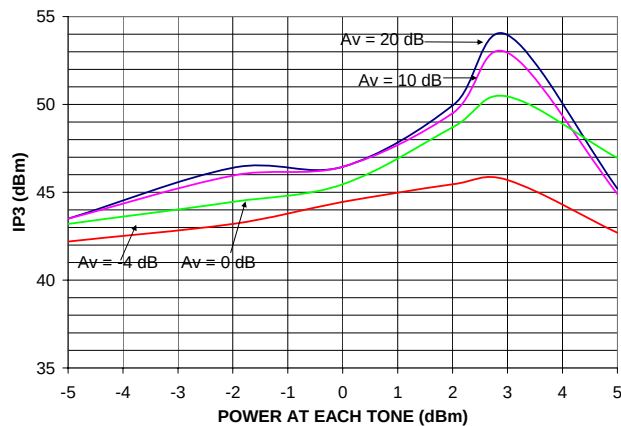


Figure 4. Output IP3 vs. Output Power (20, 10, 0, -4 dB gain codes), Tones at 140 MHz and 142 MHz

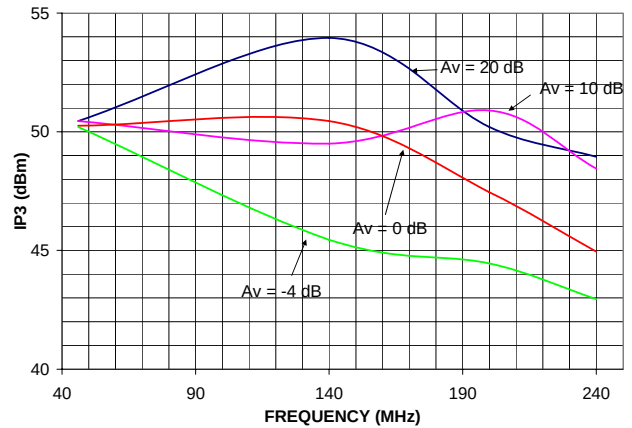


Figure 5. Output IP3 vs. Frequency (20, 10, 0, -4 dB gain codes), 3 dBm tones with 2 MHz spacing

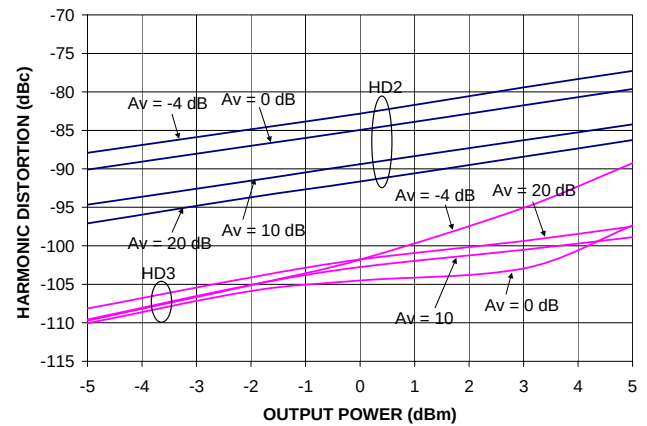


Figure 6. HD2 and HD3 vs. Power Out (20, 10, 0, -4 dB gain codes) at 140 MHz

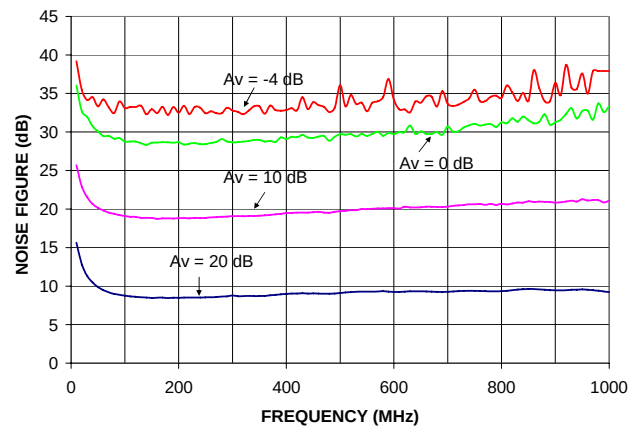


Figure 7. Noise Figure vs. Frequency (20, 10, 0, -4 dB gain codes)

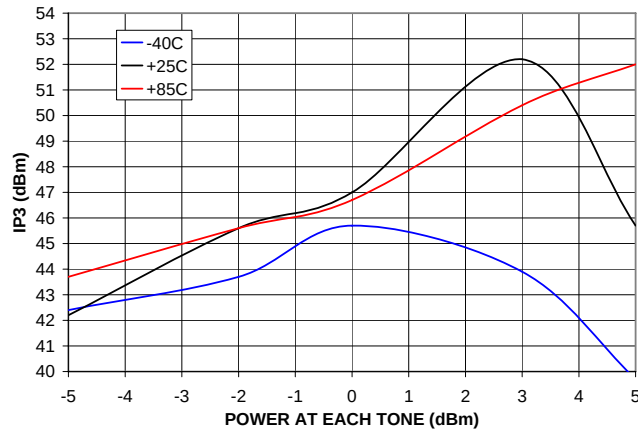


Figure 8. IP3 vs. Power Out over Temperature  
20 dB gain code at 110 MHz, 2 MHz spacing

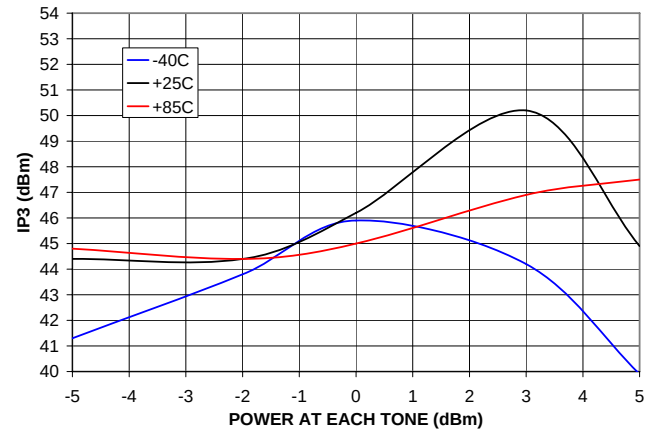


Figure 11. IP3 vs. Power Out over Temperature  
0 dB gain code at 110 MHz, 2 MHz spacing

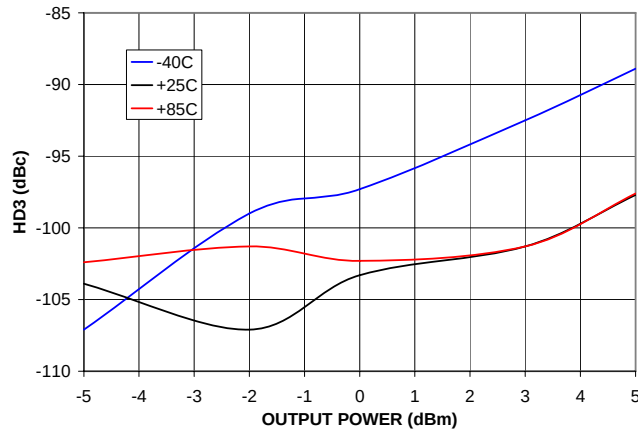


Figure 9. HD3 vs. Power Out over Temperature  
20 dB gain code at 110 MHz

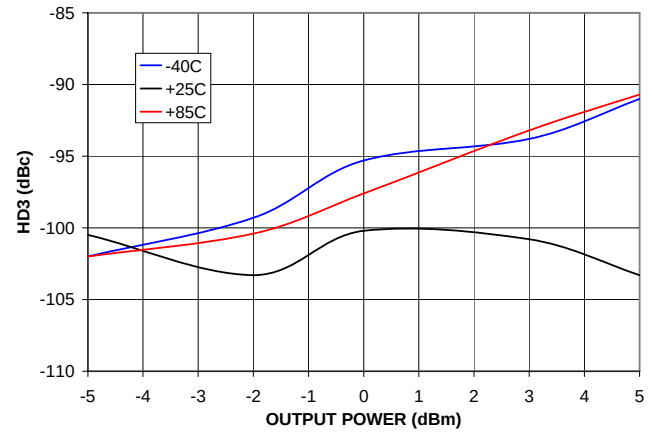


Figure 12. HD3 vs. Power Out over Temperature  
0 dB gain code at 110 MHz

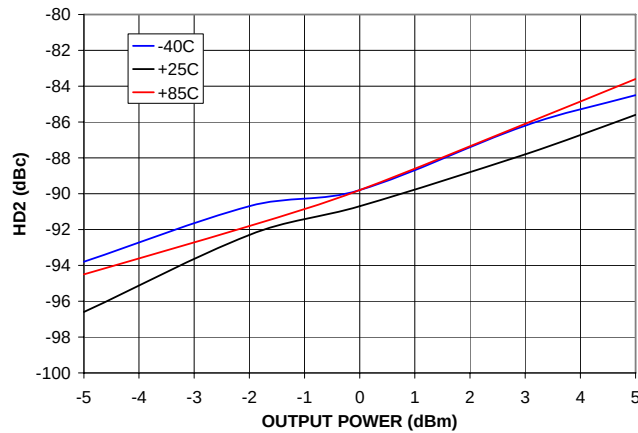


Figure 10. HD2 vs. Power Out over Temperature  
20 dB gain code at 110 MHz

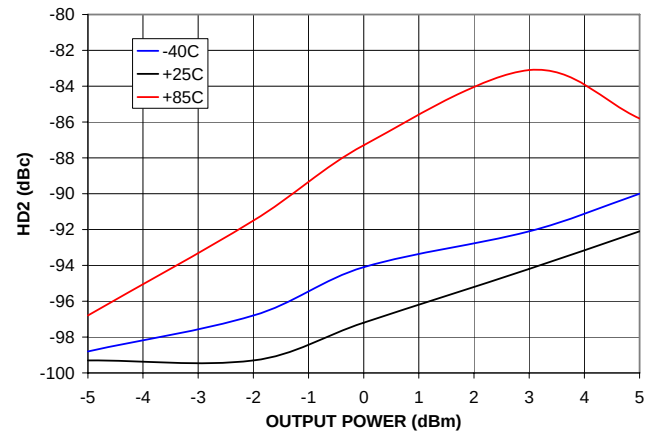


Figure 13. HD2 vs. Power Out over Temperature  
0 dB gain code at 110 MHz

## APPLICATION

### HIGH PERFORMANCE ADC DRIVING

The AD8376 provides the gain, isolation, and balanced low distortion output levels for efficiently driving wideband ADCs such as the AD9445. Figure 9 represents a simplified front end of the AD8376 dual VGA driving two AD9445 14 Bit, 125MSPS A/D converters.

For optimum performance the AD8376 is driven differentially from the input baluns. The input 37.5  $\Omega$  resistors in parallel with the 150  $\Omega$  input impedance of the AD8376 provide a 50  $\Omega$  differential input impedance. The open collector outputs of the AD8376's are biased through the 1  $\mu$ H inductors and are ac coupled from the 75  $\Omega$  load resistors which are required for gain accuracy. The 75  $\Omega$  load resistors are also ac coupled from the AD9445 to negate a DC affect on the input common mode voltage of the AD9445. The series 33  $\Omega$  resistors improve the SNR by providing isolation. The AD9445 represents a 1 k $\Omega$  differential load and requires a 2 V<sub>P-P</sub> differential signal (VREF=1V) between VIN+ and VIN- for a full scale output.

This circuit provides variable gain, isolation and source matching for the AD9445. Using this circuit with the AD8376 in a gain of 20 dB (Max Gain) an SFDR performance of 86 dBc is achieved at 100 MHz (see Figure 8).

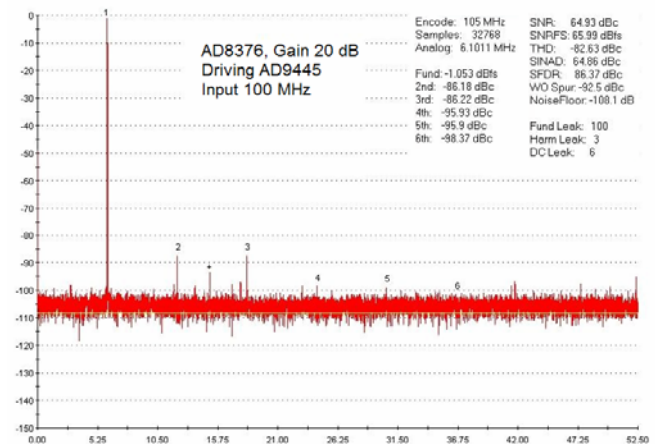


Figure 14. SFDR Performance of the AD8376 Driving the AD9445

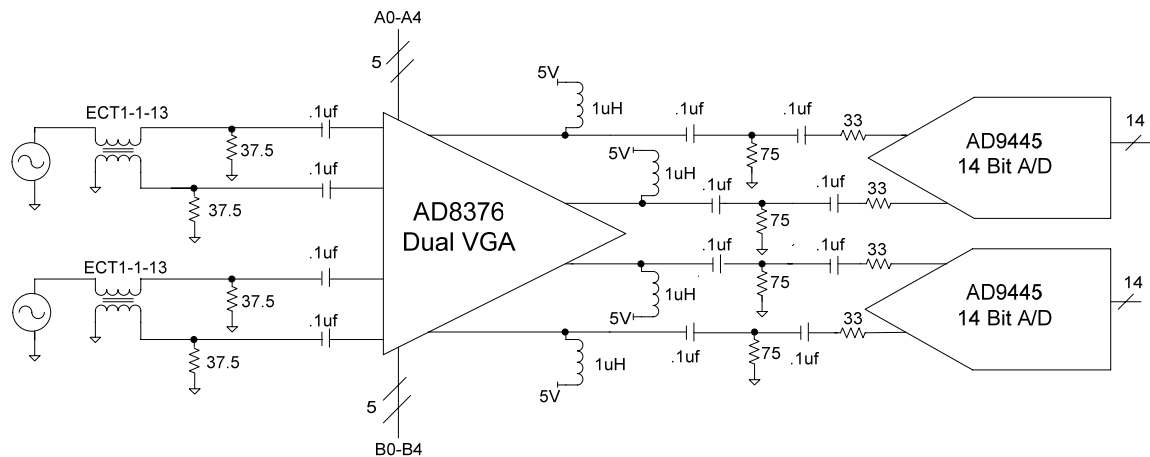


Figure 15. AD8376 Driving the AD9445



## EVALUATION BOARD

Figure 10 shows the schematic of the AD8376 evaluation board. The silkscreen and layout of the component and circuit sides are shown in Figure 11 through Figure 14. The board is powered by a single-supply in the 4.5 V to 5.5 V range. The power supply is decoupled by 10  $\mu$ F and 0.1  $\mu$ F capacitors at each power supply pin. Additional decoupling, in the form of a series resistor or inductor at the supply pins, can also be added. Table 2 details the various configuration options of the evaluation board.

The output pins of the AD8376 require supply biasing with 1  $\mu$ H RF chokes. Both the input and output pins must be ac-coupled. These pins are converted to single-ended with a pair of baluns (Mini-Circuits TC3-1T+ and M/A-COM ETC1-1-13). The baluns at the input, T1 and T2, are used to transform 50  $\Omega$  source impedances to the desired 150  $\Omega$  reference levels. The output baluns, T3 and T4, and the matching components are configured to provide a 150  $\Omega$  to 50  $\Omega$  impedance transformations with insertion losses of about 10 dB.

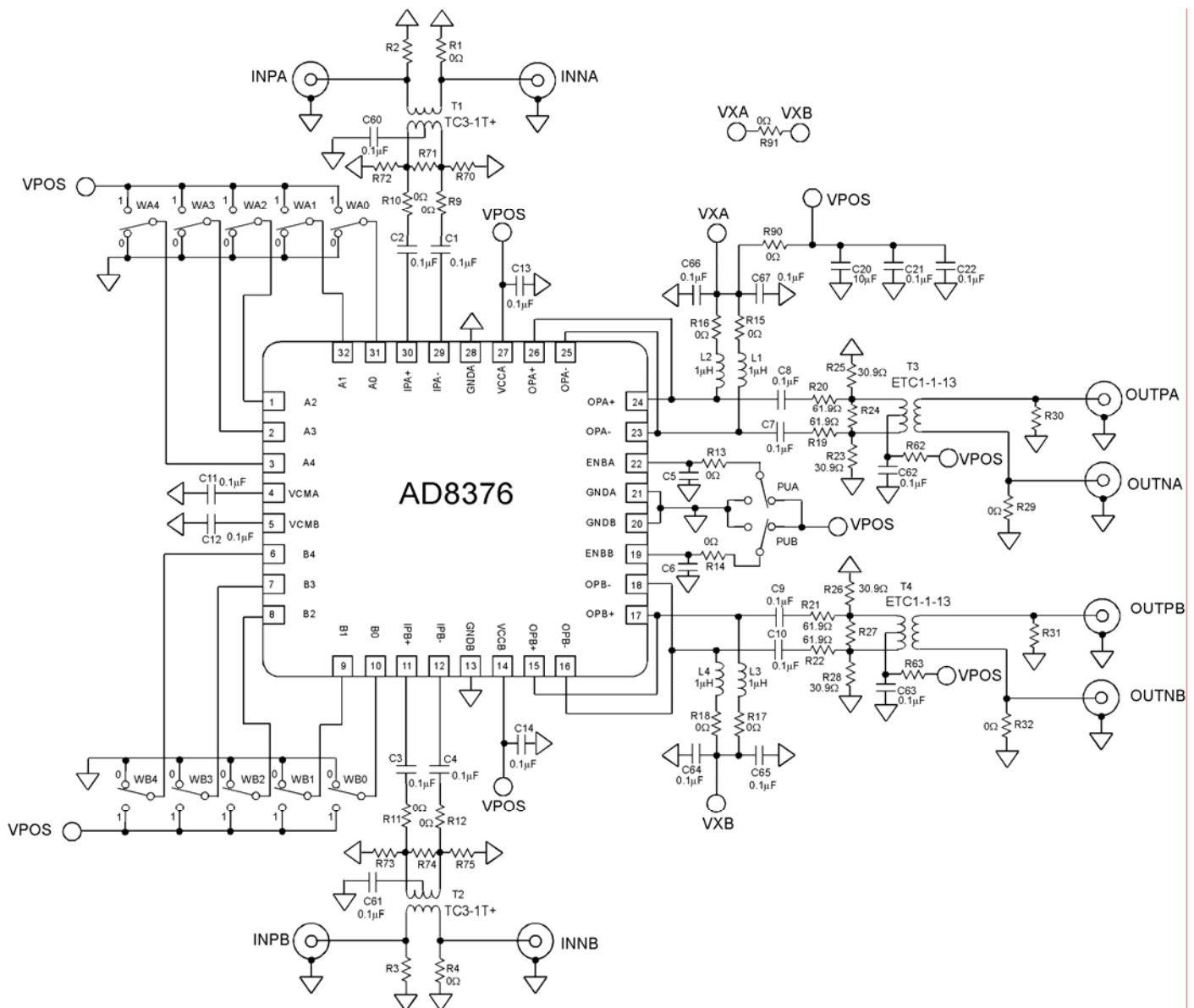
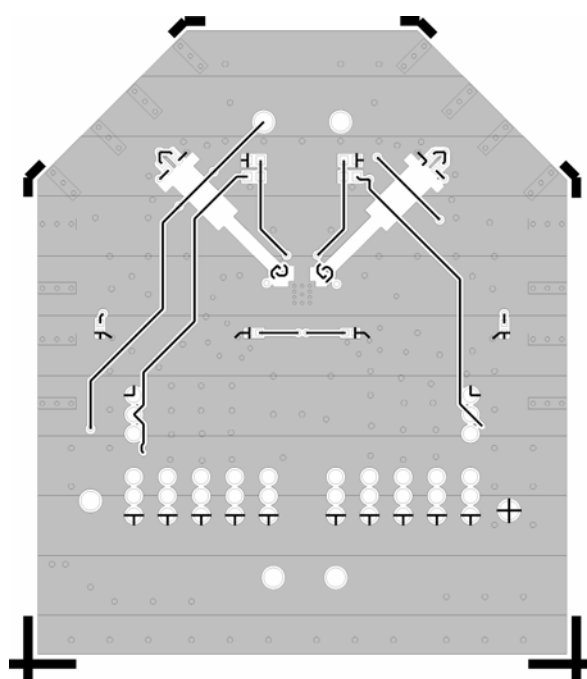
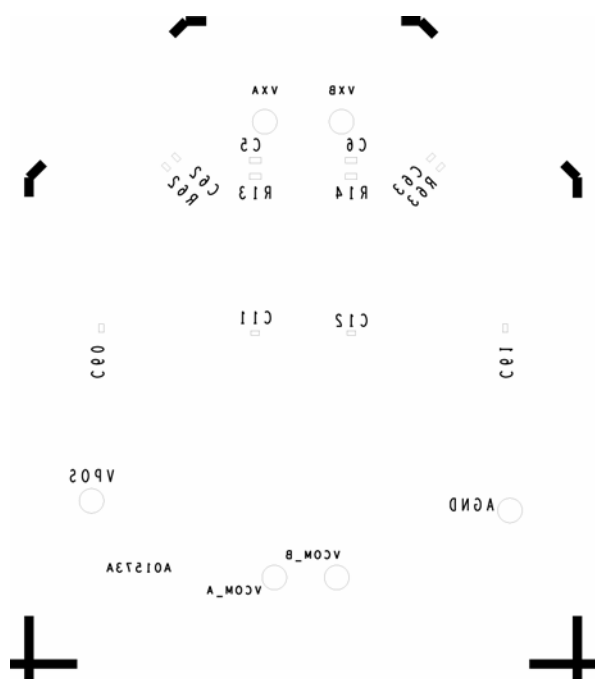
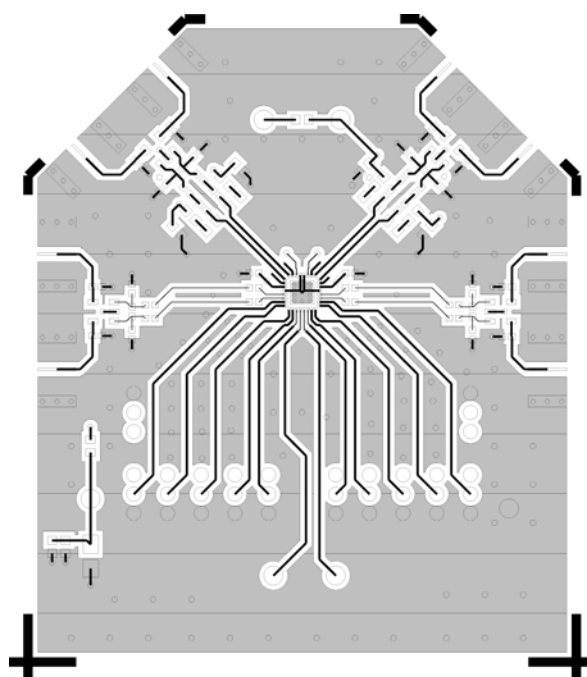
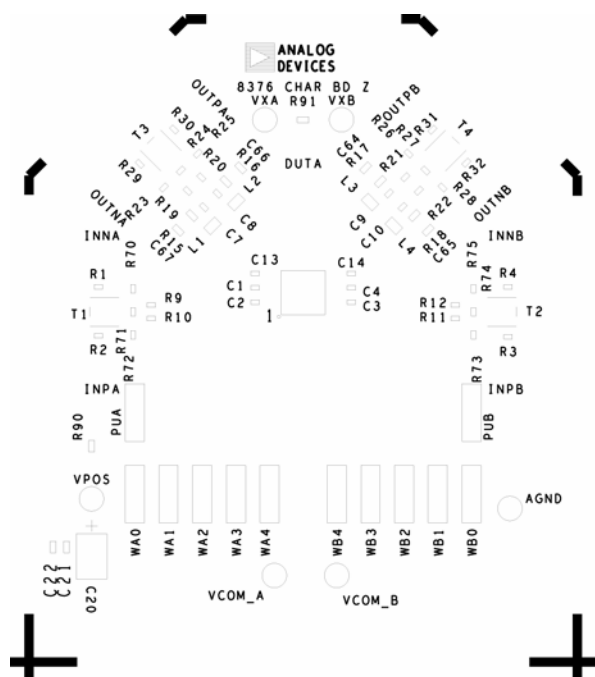


Figure 16. AD8376 Evaluation Board Schematic

Table 2. Evaluation Board Configuration Options

| Components                                                  | Function                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Default Conditions                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| C13, C14, C20 to C22, C64 to C67, R90, R91                  | Power Supply Decoupling. Nominal supply decoupling consists a 10 $\mu$ F capacitor to ground followed by a 0.1 $\mu$ F capacitor to ground positioned as close to the device as possible.                                                                                                                                                                                                                                                                                                                                   | C20 = 10 $\mu$ F (size 3528)<br>C13, C14 = 0.1 $\mu$ F (size 0402)<br>C21, C22, C64 to C67 = 0.1 $\mu$ F (size 0603)<br>R90, R91 = 0 $\Omega$ (size 0603)                                                                                                                                                                                                               |
| T1, T2, C1 to C4, C61, C62, R1 to R4, R9 to R12, R70 to R75 | Input Interface. T1 and T2 are 3-to-1 impedance ratio baluns to transform a 50 $\Omega$ single-ended input into a 150 $\Omega$ balanced differential signal. R1 and R4 ground one side of the differential drive interface for single-ended applications. R9 to R12 and R70 to 75 are provided for generic placement of matching components. C1 to C4 are dc blocks.                                                                                                                                                        | T1, T2 = TC3-1+ (Mini-Circuits)<br>C1 to C4, C60, C61 = 0.1 $\mu$ F (size 0402)<br>R1, R4, R9 to R12 = 0 $\Omega$ (size 0402)<br>R2, R3, R70 to R75 = open (size 0402)                                                                                                                                                                                                  |
| T3, T4, C7 to C10, L1 to L4, R15 to R32, R62, R63, C62, C63 | Output Interface. C7 to C10 are dc blocks. L1 to L4 provide dc biases for the outputs. R19 to R28 are provided for generic placement of matching components. The evaluation board is configured to provide a 150 $\Omega$ to 50 $\Omega$ impedance transformation with an insertion loss of about 10 dB. T3 and T4 are 1-to-1 impedance ratio baluns to transform the balanced differential signal to single-ended signals. R29 and R32 ground one side of the differential output interface for single-ended applications. | C7 to C10 = 0.1 $\mu$ F (size 0402)<br>L1 to L4 = 1 $\mu$ H (size 0805)<br>T3, T4 = ETC1-1-13 (M/A-COM)<br>R19 to R22 = 61.9 $\Omega$ (size 0402)<br>R23, R25, R26, R28 = 30.9 $\Omega$ (size 0402)<br>R15 to 18 = 0 $\Omega$ (size 0603)<br>R29, R32 = 0 $\Omega$ (size 0402)<br>R24, R27, R30, R31, R62, R63 = open (size 0402)<br>C62, C63 = 0.1 $\mu$ F (size 0402) |
| PUA, PUB, R13, R14, C5, C6                                  | Enable Interface. The AD8376 is enabled by applying a logic high voltage to the ENBA pin for channel A or the ENBB pin for channel B. Channel A is enabled when the PUA switch is set in the “up” position, connecting the ENBA pin to VPOS. Likewise, Channel B is enabled when the PUB switch is set in the “up” position, connecting the ENBB pin to VPOS. Both channels are disabled by setting the switches to the “down” position, connecting ENBA and ENBB pins to GND.                                              | PUA, PUB = installed<br>R13, R14 = 0 $\Omega$ (size 0603)<br>C5, C6 = open (size 0603)                                                                                                                                                                                                                                                                                  |
| WA0 to WA4, WB0 to WB4                                      | Parallel Interface Control. Used to hardwire A0 through A4 and B0 through B4 to the desired gain. The bank of switches, WA0 to WA4, set the binary gain code for channel A. The bank of switches, WB0 to WB4, set the binary gain code for channel B. WA0 and WB0 represent the LSB for each of the respective channels.                                                                                                                                                                                                    | WA0 to WA4, WB0 to WB4 = installed                                                                                                                                                                                                                                                                                                                                      |
| C11, C12                                                    | Voltage Reference. Input Common Mode Voltage ac-coupled to ground by 0.1 $\mu$ F capacitors, C11 and C12.                                                                                                                                                                                                                                                                                                                                                                                                                   | C11, C12 = 0.1 $\mu$ F (size 0402)                                                                                                                                                                                                                                                                                                                                      |



## OUTLINE DIMENSIONS

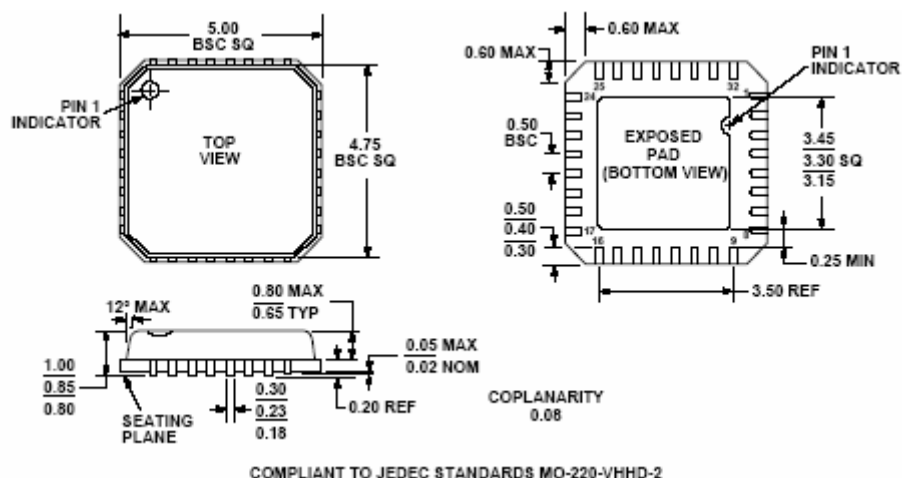


Figure 2. 32-Lead LFCSP

## ORDERING GUIDE

| Model            | Temperature    | Package Description                           | Package Option |
|------------------|----------------|-----------------------------------------------|----------------|
| AD8376ACPZ-WP    | -40°C to +85°C | Waffle Pack, 32 Lead Frame Chip Scale Package | CP-32-3        |
| AD8376ACPZ-REEL7 | -40°C to +85°C | 7" Reel, 32 Lead Frame Chip Scale Package     | CP-32-3        |
| AD8376-EVALZ     |                | Evaluation Board                              |                |