



# SigmaDSP 28-/56-Bit Audio Processor with Two ADCs and Four DACs

Data Sheet

**ADAU1401**

## FEATURES

- 28-/56-bit, 50 MIPS digital audio processor
- 2 ADCs: SNR of 100 dB, THD + N of -83 dB
- 4 DACs: SNR of 104 dB, THD + N of -90 dB
- Complete standalone operation
  - Self-boot from serial EEPROM
  - Auxiliary ADC with 4-input mux for analog control
  - GPIOs for digital controls and outputs
- Fully programmable with SigmaStudio graphical tool
- 28-bit  $\times$  28-bit multiplier with 56-bit accumulator for full double-precision processing
- Clock oscillator for generating master clock from crystal
- PLL for generating master clock from  $64 \times f_s$ ,  $256 \times f_s$ ,  $384 \times f_s$ , or  $512 \times f_s$  clocks
- Flexible serial data input/output ports with I<sup>2</sup>S-compatible, left-justified, right-justified, and TDM modes
- Sampling rates of up to 192 kHz supported
- On-chip voltage regulator for compatibility with 3.3 V systems
- 48-lead, plastic LQFP

## APPLICATIONS

- Multimedia speaker systems
- MP3 player speaker docks
- Automotive head units
- Minicomponent stereos
- Digital televisions
- Studio monitors
- Speaker crossovers
- Musical instrument effects processors
- In-seat sound systems (aircraft/motor coaches)

## GENERAL DESCRIPTION

The ADAU1401 is a complete single-chip audio system with a 28-/56-bit audio DSP, ADCs, DACs, and microcontroller-like control interfaces. Signal processing includes equalization, cross over, bass enhancement, multiband dynamics processing, delay compensation, speaker compensation, and stereo image widening. This processing can be used to compensate for real-world limitations of speakers, amplifiers, and listening environments, providing dramatic improvements in perceived audio quality.

Its signal processing is comparable to that found in high end studio equipment. Most processing is done in full 56-bit, double precision mode, resulting in very good low level signal performance. The ADAU1401 is a fully programmable DSP. The easy to use SigmaStudio™ software allows the user to graphically configure a custom signal processing flow using blocks such as biquad filters, dynamics processors, level controls, and GPIO interface controls.

ADAU1401 programs can be loaded on power-up either from a serial EEPROM through its own self-boot mechanism or from an external microcontroller. On power-down, the current state of the parameters can be written back to the EEPROM from the ADAU1401 to be recalled the next time the program is run.

Two  $\Sigma$ - $\Delta$  ADCs and four  $\Sigma$ - $\Delta$  DACs provide a 98.5 dB analog input to analog output dynamic. Each ADC has a THD + N of -83 dB, and each DAC has a THD + N of -90 dB. Digital input and output ports allow a glueless connection to additional ADCs and DACs. The ADAU1401 communicates through an I<sup>2</sup>C® bus or a 4-wire SPI port.

### Rev. C

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One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.  
Tel: 781.329.4700 [www.analog.com](http://www.analog.com)  
Fax: 781.461.3113 ©2007–2012 Analog Devices, Inc. All rights reserved.

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**REVISION HISTORY**

**1/12—Rev. B to Rev. C**

Changed Pin Number Range from 43 to 46 to Pin Number 43  
Only (Table 11) ..... 14  
Changes to Ordering Guide.....52

**1/11—Rev. A to Rev. B**

Changes to Figure 1.....4  
Changes to Figure 7 and Table 11 .....12  
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**4/08—Rev. 0 to Rev. A**

Changes to Figure 1.....4  
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Replaced Figure 8 to Figure 11 ..... 15  
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**7/07—Revision 0: Initial Version**

FUNCTIONAL BLOCK DIAGRAM

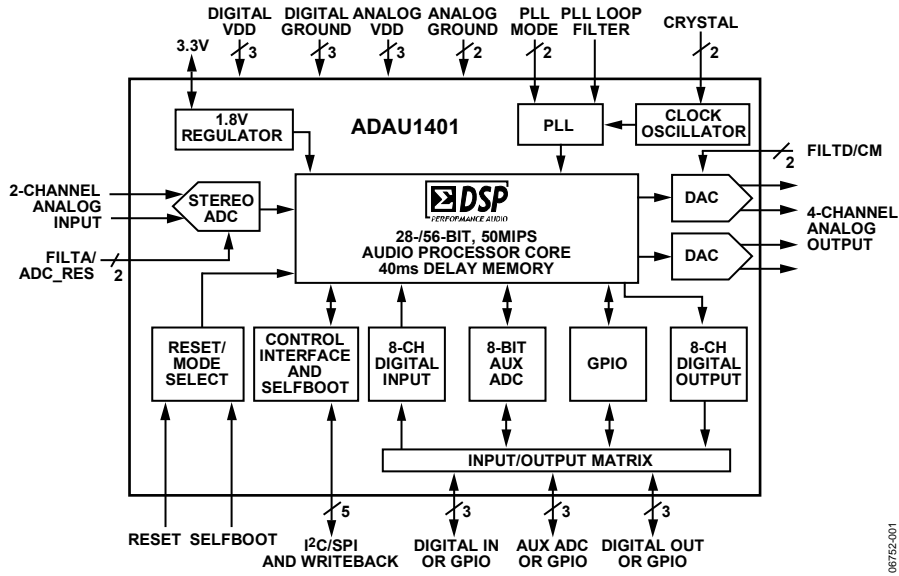


Figure 1.

## SPECIFICATIONS

AVDD = 3.3 V, DVDD = 1.8 V, PVDD = 3.3 V, IOVDD = 3.3 V, master clock input = 12.288 MHz, unless otherwise noted.

### ANALOG PERFORMANCE

Specifications are guaranteed at 25°C (ambient).

Table 1.

| Parameter                         | Min  | Typ       | Max | Unit            | Test Conditions/Comments  |
|-----------------------------------|------|-----------|-----|-----------------|---|
| <b>ADC INPUTS</b>                 |      |           |     |                 |   |
| Number of Channels                |      | 2         |     |                 | Stereo input  |
| Resolution                        |      | 24        |     | Bits            |   |
| Full-Scale Input                  |      | 100 (283) |     | μA rms (μA p-p) | 2 V rms input with 20 kΩ (18 kΩ external + 2 kΩ internal) series resistor |
| Signal-to-Noise Ratio             |      |           |     |                 |   |
| A-Weighted                        |      | 100       |     | dB              |   |
| Dynamic Range                     |      |           |     |                 | –60 dB with respect to full-scale analog input                            |
| A-Weighted                        | 95   | 100       |     | dB              |   |
| Total Harmonic Distortion + Noise |      | –83       |     | dB              | –3 dB with respect to full-scale analog input                             |
| Interchannel Gain Mismatch        |      | 25        | 250 | mdB             |   |
| Crosstalk                         |      | –82       |     | dB              | Analog channel-to-channel crosstalk                                       |
| DC Bias                           | 1.4  | 1.5       | 1.6 | V               |   |
| Gain Error                        | –11  |           | +11 | %               |   |
| <b>DAC OUTPUTS</b>                |      |           |     |                 |   |
| Number of Channels                |      | 4         |     |                 | Two stereo output channels  |
| Resolution                        |      | 24        |     | Bits            |   |
| Full-Scale Analog Output          |      | 0.9 (2.5) |     | V rms (V p-p)   |   |
| Signal-to-Noise Ratio             |      |           |     |                 |   |
| A-Weighted                        |      | 104       |     | dB              |   |
| Dynamic Range                     |      |           |     |                 | –60 dB with respect to full-scale analog output                           |
| A-Weighted                        | 99   | 104       |     | dB              |   |
| Total Harmonic Distortion + Noise |      | –90       |     | dB              | –1 dB with respect to full-scale analog output                            |
| Crosstalk                         |      | –100      |     | dB              | Analog channel-to-channel crosstalk                                       |
| Interchannel Gain Mismatch        |      | 25        | 250 | mdB             |   |
| Gain Error                        | –10  |           | +10 | %               |   |
| DC Bias                           | 1.4  | 1.5       | 1.6 | V               |   |
| <b>VOLTAGE REFERENCE</b>          |      |           |     |                 |   |
| Absolute Voltage (CM)             | 1.4  | 1.5       | 1.6 | V               |   |
| <b>AUXILIARY ADC</b>              |      |           |     |                 |   |
| Full-Scale Analog Input           | 2.8  | 3.0       | 3.1 | V               |   |
| INL                               |      | 0.5       |     | LSB             |   |
| DNL                               |      | 1.0       |     | LSB             |   |
| Offset                            |      | 15        |     | mV              |   |
| Input Impedance                   | 17.8 | 30        | 42  | kΩ              |   |

Specifications are guaranteed at 130°C (ambient).

Table 2.

| Parameter                           | Min  | Typ       | Max | Unit            | Test Conditions/Comments  |
|-------------------------------------|------|-----------|-----|-----------------|---|
| <b>ADC INPUTS</b>                   |      |           |     |                 |   |
| Number of Channels                  |      | 2         |     |                 | Stereo input  |
| Resolution                          |      | 24        |     | Bits            |   |
| Full-Scale Input                    |      | 100 (283) |     | μA rms (μA p-p) | 2 V rms input with 20 kΩ (18 kΩ external + 2 kΩ internal) series resistor |
| Signal-to-Noise Ratio<br>A-Weighted |      | 100       |     | dB              | -60 dB with respect to full-scale analog input                            |
| Dynamic Range<br>A-Weighted         | 92   | 100       |     | dB              |   |
| Total Harmonic Distortion + Noise   |      | -83       |     | dB              | -3 dB with respect to full-scale analog input                             |
| Interchannel Gain Mismatch          |      | 25        | 250 | mdB             | Analog channel-to-channel crosstalk                                       |
| Crosstalk                           |      | -82       |     | dB              |   |
| DC Bias                             | 1.4  | 1.5       | 1.6 | V               |   |
| Gain Error                          | -11  |           | +11 | %               |   |
| <b>DAC OUTPUTS</b>                  |      |           |     |                 |   |
| Number of Channels                  |      | 4         |     |                 | Two stereo output channels  |
| Resolution                          |      | 24        |     | Bits            |   |
| Full-Scale Analog Output            |      | 0.9 (2.5) |     | V rms (V p-p)   |   |
| Signal-to-Noise Ratio<br>A-Weighted |      | 104       |     | dB              | -60 dB with respect to full-scale analog output                           |
| Dynamic Range<br>A-Weighted         | 98   | 104       |     | dB              |   |
| Total Harmonic Distortion + Noise   |      | -90       |     | dB              | -1 dB with respect to full-scale analog output                            |
| Crosstalk                           |      | -100      |     | dB              | Analog channel-to-channel crosstalk                                       |
| Interchannel Gain Mismatch          |      | 25        | 250 | mdB             |   |
| Gain Error                          | -10  |           | +10 | %               |   |
| DC Bias                             | 1.4  | 1.5       | 1.6 | V               |   |
| <b>VOLTAGE REFERENCE</b>            |      |           |     |                 |   |
| Absolute Voltage (CM)               | 1.4  | 1.5       | 1.6 | V               |   |
| <b>AUXILIARY ADC</b>                |      |           |     |                 |   |
| Full-Scale Analog Input             | 2.8  | 3.0       | 3.1 | V               |   |
| INL                                 |      | 0.5       |     | LSB             |   |
| DNL                                 |      | 1.0       |     | LSB             |   |
| Offset                              |      | 15        |     | mV              |   |
| Input Impedance                     | 17.8 | 30        | 42  | kΩ              |   |

**DIGITAL INPUT/OUTPUT**

Table 3.

| Parameter  | Min | Typ | Max <sup>1</sup> | Unit | Comments                               |
|--|-----|-----|------------------|------|--|
| Input Voltage, High (V <sub>IH</sub> )                               | 2.0 |     | IOVDD            | V    |  |
| Input Voltage, Low (V <sub>IL</sub> )                                |     |     | 0.8              | V    |  |
| Input Leakage, High (I <sub>IH</sub> )                               |     |     | 1                | μA   | Excluding MCLKI                        |
| Input Leakage, Low (I <sub>IL</sub> )                                |     |     | 1                | μA   | Excluding MCLKI and bidirectional pins |
| Bidirectional Pin Pull-Up Current, Low                               |     |     | 150              | μA   |  |
| MCLKI Input Leakage, High (I <sub>IH</sub> )                         |     |     | 3                | μA   |  |
| MCLKI Input Leakage, Low (I <sub>IL</sub> )                          |     |     | 3                | μA   |  |
| High Level Output Voltage (V <sub>OH</sub> ), I <sub>OH</sub> = 2 mA | 2.0 |     |                  | V    |  |
| Low Level Output Voltage (V <sub>OL</sub> ), I <sub>OL</sub> = 2 mA  |     |     | 0.8              | V    |  |
| Input Capacitance  |     |     | 5                | pF   |  |
| GPIO Output Drive  |     | 2   |                  | mA   |  |

<sup>1</sup> Maximum specifications are measured across a temperature range of -40°C to +130°C (case), a DVDD range of 1.62 V to 1.98 V, and an AVDD range of 2.97 V to 3.63 V.

**POWER**

Table 4.

| Parameter                                  | Min | Typ   | Max <sup>1</sup> | Unit |
|--|-----|-------|------------------|------|
| <b>SUPPLY VOLTAGE</b>                      |     |       |                  |      |
| Analog Voltage                             |     | 3.3   |                  | V    |
| Digital Voltage                            |     | 1.8   |                  | V    |
| PLL Voltage                                |     | 3.3   |                  | V    |
| IOVDD Voltage                              |     | 3.3   |                  | V    |
| <b>SUPPLY CURRENT</b>                      |     |       |                  |      |
| Analog Current (AVDD and PVDD)             |     | 50    | 85               | mA   |
| Digital Current (DVDD)                     |     | 40    | 60               | mA   |
| Analog Current, Reset                      |     | 35    | 55               | mA   |
| Digital Current, Reset                     |     | 1.5   | 4.5              | mA   |
| <b>DISSIPATION</b>                         |     |       |                  |      |
| Operation (AVDD, DVDD, PVDD) <sup>2</sup>  |     | 286.5 |                  | mW   |
| Reset, All Supplies                        |     | 118   |                  | mW   |
| <b>POWER SUPPLY REJECTION RATIO (PSRR)</b> |     |       |                  |      |
| 1 kHz, 200 mV p-p Signal at AVDD           |     | 50    |                  | dB   |

<sup>1</sup> Maximum specifications are measured across a temperature range of -40°C to +130°C (case), a DVDD range of 1.62 V to 1.98 V, and an AVDD range of 2.97 V to 3.63 V.

<sup>2</sup> Power dissipation does not include IOVDD power because the current drawn from this supply is dependent on the loads at the digital output pins.

**TEMPERATURE RANGE**

Table 5.

| Parameter                | Min | Typ | Max  | Unit       |
|--------------------------|-----|-----|------|------------|
| Functionality Guaranteed | -40 |     | +105 | °C ambient |

**PLL AND OSCILLATOR**Table 6. PLL and Oscillator<sup>1</sup>

| Parameter   | Min            | Typ | Max            | Unit |
|---|----------------|-----|----------------|------|
| PLL Operating Range                                   | MCLK_Nom - 20% |     | MCLK_Nom + 20% | MHz  |
| PLL Lock Time   |                |     | 20             | ms   |
| Crystal Oscillator Transconductance (g <sub>m</sub> ) |                | 78  |                | mmho |

<sup>1</sup> Maximum specifications are measured across a temperature range of -40°C to +130°C (case), a DVDD range of 1.62 V to 1.98 V, and an AVDD range of 2.97 V to 3.63 V.

**REGULATOR**

**Table 7. Regulator<sup>1</sup>**

| Parameter    | Min | Typ | Max  | Unit |
|--------------|-----|-----|------|------|
| DVDD Voltage | 1.7 | 1.8 | 1.84 | V    |

<sup>1</sup> Regulator specifications are calculated using a Zetex Semiconductors FZT953 transistor in the circuit.

**DIGITAL TIMING SPECIFICATIONS**

**Table 8. Digital Timing<sup>1</sup>**

| Parameter                  | Limit            |                  | Unit | Description  |
|----------------------------|------------------|------------------|------|--|
|                            | t <sub>MIN</sub> | t <sub>MAX</sub> |      |  |
| <b>MASTER CLOCK</b>        |                  |                  |      |  |
| t <sub>MP</sub>            | 36               | 244              | ns   | MCLKI period, 512 × f <sub>s</sub> mode                        |
| t <sub>MP</sub>            | 48               | 366              | ns   | MCLKI period, 384 × f <sub>s</sub> mode                        |
| t <sub>MP</sub>            | 73               | 488              | ns   | MCLKI period, 256 × f <sub>s</sub> mode                        |
| t <sub>MP</sub>            | 291              | 1953             | ns   | MCLKI period, 64 × f <sub>s</sub> mode                         |
| <b>SERIAL PORT</b>         |                  |                  |      |  |
| t <sub>BIL</sub>           | 40               |                  | ns   | INPUT_BCLK low pulse width                                     |
| t <sub>BIH</sub>           | 40               |                  | ns   | INPUT_BCLK high pulse width                                    |
| t <sub>LIS</sub>           | 10               |                  | ns   | INPUT_LRCLK setup; time to INPUT_BCLK rising                   |
| t <sub>LIH</sub>           | 10               |                  | ns   | INPUT_LRCLK hold; time from INPUT_BCLK rising                  |
| t <sub>SIS</sub>           | 10               |                  | ns   | SDATA_INx setup; time to INPUT_BCLK rising                     |
| t <sub>SIH</sub>           | 10               |                  | ns   | SDATA_INx hold; time from INPUT_BCLK rising                    |
| t <sub>LOS</sub>           | 10               |                  | ns   | OUTPUT_LRCLK setup in slave mode                               |
| t <sub>LOH</sub>           | 10               |                  | ns   | OUTPUT_LRCLK hold in slave mode                                |
| t <sub>TS</sub>            |                  | 5                | ns   | OUTPUT_BCLK falling to OUTPUT_LRCLK timing skew                |
| t <sub>SODS</sub>          |                  | 40               | ns   | SDATA_OUTx delay in slave mode; time from OUTPUT_BCLK falling  |
| t <sub>SODM</sub>          |                  | 40               | ns   | SDATA_OUTx delay in master mode; time from OUTPUT_BCLK falling |
| <b>SPI PORT</b>            |                  |                  |      |  |
| f <sub>CCLK</sub>          |                  | 6.25             | MHz  | CCLK frequency   |
| t <sub>CCPL</sub>          | 80               |                  | ns   | CCLK pulse width low   |
| t <sub>CCPH</sub>          | 80               |                  | ns   | CCLK pulse width high  |
| t <sub>CLS</sub>           | 0                |                  | ns   | CLATCH setup; time to CCLK rising                              |
| t <sub>CLH</sub>           | 100              |                  | ns   | CLATCH hold; time from CCLK rising                             |
| t <sub>CLPH</sub>          | 80               |                  | ns   | CLATCH pulse width high  |
| t <sub>CDS</sub>           | 0                |                  | ns   | CDATA setup; time to CCLK rising                               |
| t <sub>CDH</sub>           | 80               |                  | ns   | CDATA hold; time from CCLK rising                              |
| t <sub>COD</sub>           |                  | 101              | ns   | COUT delay; time from CCLK falling                             |
| <b>I<sup>2</sup>C PORT</b> |                  |                  |      |  |
| f <sub>SCL</sub>           |                  | 400              | kHz  | SCL frequency  |
| t <sub>SCLH</sub>          | 0.6              |                  | μs   | SCL high   |
| t <sub>SCLL</sub>          | 1.3              |                  | μs   | SCL low  |
| t <sub>SCS</sub>           | 0.6              |                  | μs   | Setup time, relevant for repeated start condition              |
| t <sub>SCH</sub>           | 0.6              |                  | μs   | Hold time; after this period, the first clock is generated     |
| t <sub>DS</sub>            | 100              |                  | ns   | Data setup time  |
| t <sub>SCR</sub>           |                  | 300              | ns   | SCL rise time  |
| t <sub>SCF</sub>           |                  | 300              | ns   | SCL fall time  |
| t <sub>SDR</sub>           |                  | 300              | ns   | SDA rise time  |
| t <sub>SDF</sub>           |                  | 300              | ns   | SDA fall time  |
| t <sub>BFT</sub>           | 0.6              |                  |      | Bus-free time; time between stop and start                     |



| Parameter                   | Limit            |                        | Unit | Description   |
|-----------------------------|------------------|------------------------|------|---|
|                             | t <sub>MIN</sub> | t <sub>MAX</sub>       |      |   |
| MULTIPURPOSE PINS AND RESET |                  |                        |      |   |
| t <sub>GRT</sub>            |                  | 50                     | ns   | GPIO rise time  |
| t <sub>GFT</sub>            |                  | 50                     | ns   | GPIO fall time  |
| t <sub>GIL</sub>            |                  | 1.5 × 1/f <sub>S</sub> | μs   | GPIO input latency; time until high/low value is read by core |
| t <sub>RLPW</sub>           | 20               |                        | ns   | RESET low pulse width   |

<sup>1</sup> All timing specifications are given for the default (I<sup>2</sup>S) states of the serial input port and the serial output port (see Table 66).

**Digital Timing Diagrams**

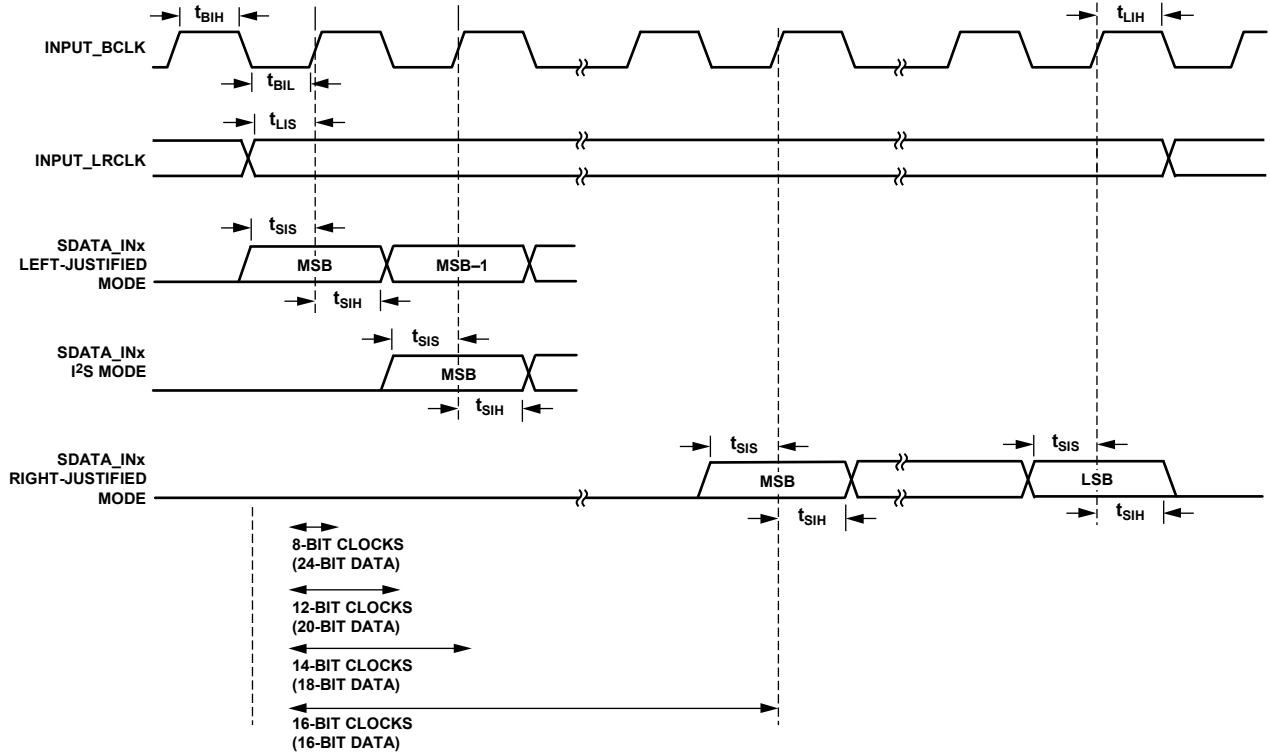


Figure 2. Serial Input Port Timing

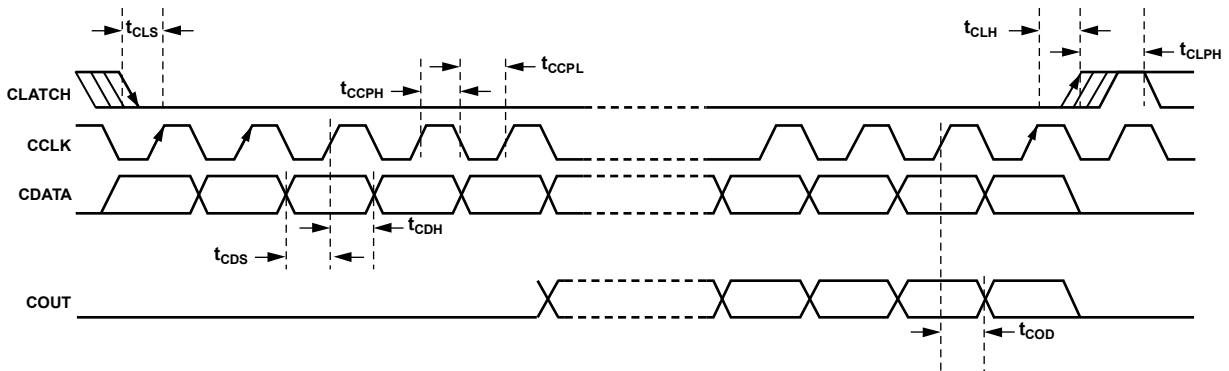


Figure 3. SPI Port Timing

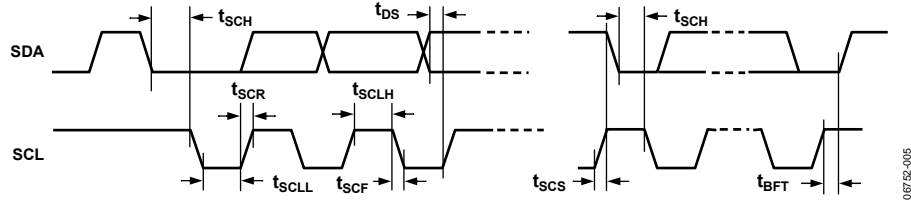


Figure 4. I<sup>2</sup>C Port Timing

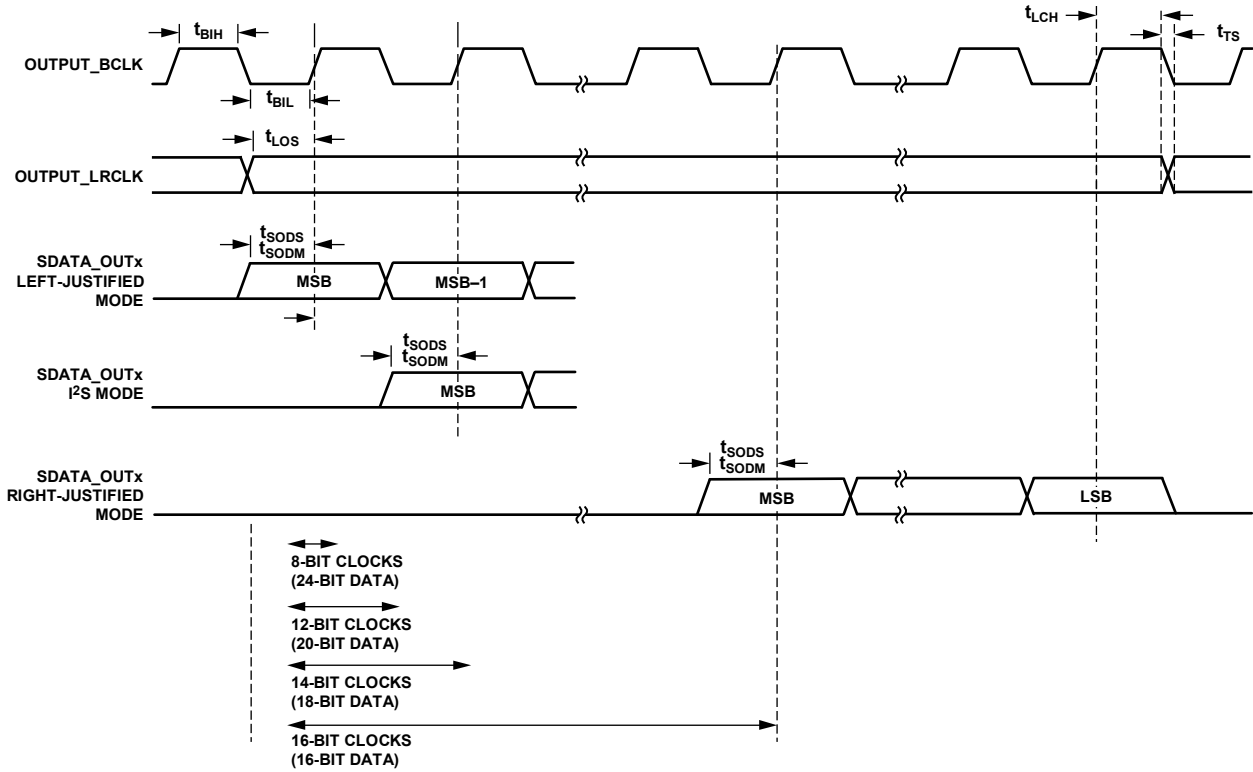


Figure 5. Serial Output Port Timing

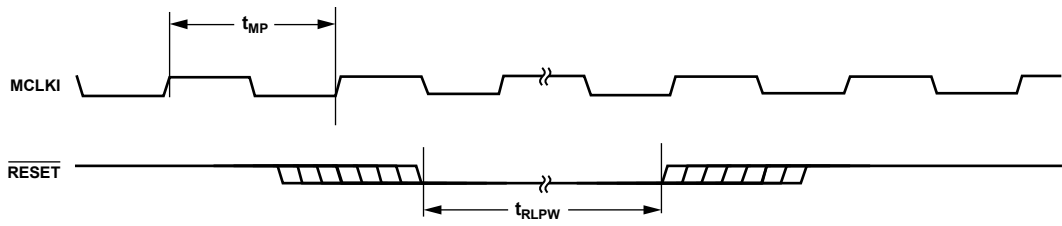


Figure 6. Master Clock and RESET Timing

## ABSOLUTE MAXIMUM RATINGS

Table 9.

| Parameter                    | Rating                      |
|------------------------------|-----------------------------|
| DVDD to GND                  | 0 V to 2.2 V                |
| AVDD to GND                  | 0 V to 4.0 V                |
| IOVDD to GND                 | 0 V to 4.0 V                |
| Digital Inputs               | DGND – 0.3 V, IOVDD + 0.3 V |
| Maximum Junction Temperature | 135°C                       |
| Storage Temperature Range    | –65°C to +150°C             |
| Soldering (10 sec)           | 300°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 indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## THERMAL RESISTANCE

$\theta_{JA}$  is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 10. Thermal Resistance

| Package Type | $\theta_{JA}$ | $\theta_{JC}$ | Unit |
|--------------|---------------|---------------|------|
| 48-Lead LQFP | 72            | 19.5          | °C/W |

## ESD CAUTION



**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

## PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

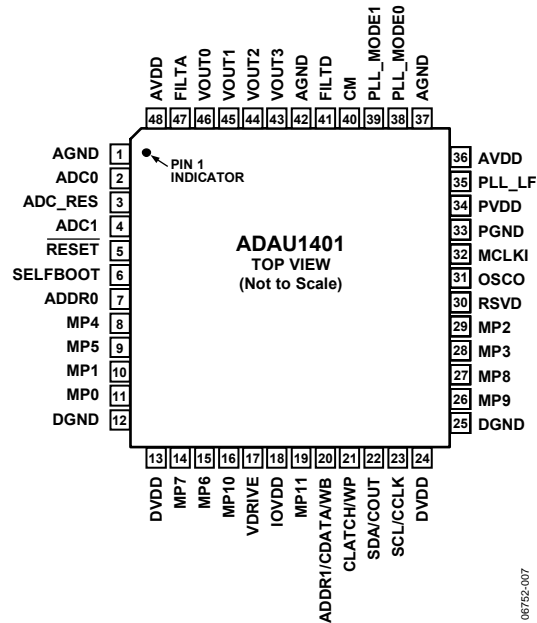


Figure 7. 48-Lead LQFP Pin Configuration

Table 11. Pin Function Descriptions

| Pin No.   | Mnemonic | Type <sup>1</sup> | Description  |
|-----------|----------|-------------------|--|
| 1, 37, 42 | AGND     | PWR               | Analog Ground Pin. The AGND, DGND, and PGND pins can be tied directly together in a common ground plane. AGND should be decoupled to an AVDD pin with a 100 nF capacitor.  |
| 2         | ADC0     | A_IN              | Analog Audio Input 0. Full-scale 100 $\mu$ A rms input. Current input allows input voltage level to be scaled with an external resistor. An 18 k $\Omega$ resistor gives a 2 V rms full-scale input.   |
| 3         | ADC_RES  | A_IN              | ADC Reference Current. The full-scale current of the ADCs can be set with an external 18 k $\Omega$ resistor connected between this pin and ground. See the Audio ADCS section for details.  |
| 4         | ADC1     | A_IN              | Analog Audio Input 1. Full-scale 100 $\mu$ A rms input. Current input allows input voltage level to be scaled with an external resistor. An 18 k $\Omega$ resistor gives a 2 V rms full-scale input. See the Audio ADCS section for details.   |
| 5         | RESET    | D_IN              | Active Low Reset Input. Reset is triggered on a high-to-low edge, and the ADAU1401 exits reset on a low-to-high edge. For more information about initialization, see the Power-Up Sequence section for details.  |
| 6         | SELFBOOT | D_IN              | Enable/Disable Self-Boot. SELFBOOT selects control port (low) or self-boot (high). Setting this pin high initiates a self-boot operation when the ADAU1401 is brought out of a reset. This pin can be tied directly to the control voltage or pulled up/down with a resistor. See the Self-Boot section for details. |
| 7         | ADDR0    | D_IN              | I <sup>2</sup> C and SPI Address 0. In combination with ADDR1, this pin allows up to four ADAU1401s to be used on the same I <sup>2</sup> C bus and up to two ICs to be used with a common SPI CLATCH signal. See the I <sup>2</sup> C Port section for details.   |
| 8         | MP4      | D_IO              | Multipurpose GPIO or Serial Input Port LRCLK (INPUT_LRCLK). See the Multipurpose Pins section for more details.  |
| 9         | MP5      | D_IO              | Multipurpose GPIO or Serial Input Port BCLK (INPUT_BCLK). See the Multipurpose Pins section for more details.  |
| 10        | MP1      | D_IO              | Multipurpose GPIO or Serial Input Port Data 1 (SDATA_IN0). See the Multipurpose Pins section for more details.   |
| 11        | MP0      | D_IO              | Multipurpose GPIO or Serial Input Port Data 0 (SDATA_IN1). See the Multipurpose Pins section for more details.   |
| 12, 25    | DGND     | PWR               | Digital Ground Pin. The AGND, DGND, and PGND pins can be tied directly together in a common ground plane. DGND should be decoupled to a DVDD pin with a 100 nF capacitor.  |

| Pin No. | Mnemonic       | Type <sup>1</sup> | Description   |
|---------|----------------|-------------------|---|
| 13, 24  | DVDD           | PWR               | 1.8 V Digital Supply. This can be supplied either externally or generated from a 3.3 V supply with the on-board 1.8 V regulator. DVDD should be decoupled to DGND with a 100 nF capacitor.  |
| 14      | MP7            | D_IO              | Multipurpose GPIO or Serial Output Port Data 1 (SDATA_OUT1). See the Multipurpose Pins section for more details.  |
| 15      | MP6            | D_IO              | Multipurpose GPIO, Serial Output Port Data 0, or TDM Data Output (SDATA_OUT0). See the Multipurpose Pins section for more details.  |
| 16      | MP10           | D_IO              | Multipurpose GPIO or Serial Output Port LRCLK (OUTPUT_LRCLK). See the Multipurpose Pins section for more details.   |
| 17      | VDRIVE         | A_OUT             | Drive for 1.8 V Regulator. The base of the voltage regulator external PNP transistor is driven from VDRIVE. See the Voltage Regulator section for details.  |
| 18      | IOVDD          | PWR               | Supply for Input and Output Pins. The voltage on this pin sets the highest input voltage that should be seen on the digital input pins. This pin is also the supply for the digital output signals on the control port and MP pins. IOVDD should always be set to 3.3 V. The current draw of this pin is variable because it is dependent on the loads of the digital outputs.  |
| 19      | MP11           | D_IO              | Multipurpose GPIO or Serial Output Port BCLK (OUTPUT_BCLK). See the Multipurpose Pins section for more details.   |
| 20      | ADDR1/CDATA/WB | D_IN              | ADDR1: I <sup>2</sup> C Address 1. In combination with ADDR0, this sets the I <sup>2</sup> C address of the IC so that four ADAU1401s can be used on the same I <sup>2</sup> C bus. See the I <sup>2</sup> C Port section for details.<br>CDATA: SPI Data Input. See the SPI Port section for details.<br>WB: EEPROM Writeback Trigger. A rising (default) or falling (if set in the EEPROM messages) edge on this pin triggers a writeback of the interface registers to the external EEPROM. This function can be used to save parameter data on power-down. See the Self-Boot section for details.       |
| 21      | CLATCH/WP      | D_IO              | CLATCH: SPI Latch Signal. Must go low at the beginning of an SPI transaction and high at the end of a transaction. Each SPI transaction can take a different number of cycles on the CCLK pin to complete, depending on the address and read/write bit that are sent at the beginning of the SPI transaction. See the SPI Port section for details.<br>WP: Self-Boot EEPROM Write Protect. This pin is an open-collector output when in self-boot mode. The ADAU1401 pulls this low to enable writes to an external EEPROM. This pin should be pulled high to 3.3 V. See the Self-Boot section for details. |
| 22      | SDA/COUT       | D_IO              | SDA: I <sup>2</sup> C Data. This pin is a bidirectional open-collector. The line connected to this pin should have a 2.2 k $\Omega$ pull-up resistor. See the I <sup>2</sup> C Port section for details.<br>COUT: This SPI data output is used for reading back registers and memory locations. It is three-stated when an SPI read is not active. See the SPI Port section for details.  |
| 23      | SCL/CCLK       | D_IO              | SCL: I <sup>2</sup> C Clock. This pin is always an open-collector input when in I <sup>2</sup> C control mode. In self-boot mode, this pin is an open-collector output (I <sup>2</sup> C master). The line connected to this pin should have a 2.2 k $\Omega$ pull-up resistor. See the I <sup>2</sup> C Port section for details.<br>CCLK: SPI Clock. This pin can either run continuously or be gated off between SPI transactions. See the SPI Port section for details.   |
| 26      | MP9            | D_IO/A_IO         | Multipurpose GPIO, Serial Output Port Data 3 (SDATA_OUT3), or Auxiliary ADC Input 0. See the Multipurpose Pins section for more details.  |
| 27      | MP8            | D_IO/A_IO         | Multipurpose GPIO, Serial Output Port Data 2 (SDATA_OUT2), or Auxiliary ADC Input 3. See the Multipurpose Pins section for more details.  |
| 28      | MP3            | D_IO/A_IO         | Multipurpose GPIO, Serial Input Port Data 3 (SDATA_IN3), or Auxiliary ADC Input 2. See the Multipurpose Pins section for more details.  |
| 29      | MP2            | D_IO/A_IO         | Multipurpose GPIO, Serial Input Port Data 2 (SDATA_IN2), or Auxiliary ADC Input 1. See the Multipurpose Pins section for more details.  |
| 30      | RSVD           | X                 | Reserved. Tie to ground, either directly or through a pull-down resistor.   |
| 31      | OSCO           | D_OUT             | Crystal Oscillator Circuit Output. A 100 $\Omega$ damping resistor should be connected between this pin and the crystal. This output should not be used to directly drive a clock to another IC. If the crystal oscillator is not used, this pin can be left disconnected. See the Using the Oscillator section for details.  |
| 32      | MCLKI          | D_IN              | Master Clock Input. MCLKI can either be connected to a 3.3 V clock signal or be the input from the crystal oscillator circuit. See the Setting Master Clock/PLL Mode section for details.   |
| 33      | PGND           | PWR               | PLL Ground Pin. The AGND, DGND, and PGND pins can be tied directly together in a common ground plane. PGND should be decoupled to PVDD with a 100 nF capacitor.   |

| Pin No. | Mnemonic                | Type <sup>1</sup> | Description  |
|---------|-------------------------|-------------------|--|
| 34      | PVDD                    | PWR               | 3.3 V Power Supply for the PLL and the Auxiliary ADC Analog Section. This pin should be decoupled to PGND with a 100 nF capacitor.   |
| 35      | PLL_LF                  | A_OUT             | PLL Loop Filter Connection. Two capacitors and a resistor need to be connected to this pin, as shown in Figure 15. See the Setting Master Clock/PLL Mode section for more details.   |
| 36, 48  | AVDD                    | PWR               | 3.3 V Analog Supply. This should be decoupled to AGND with a 100 nF capacitor.   |
| 38, 39  | PLL_MODE0,<br>PLL_MODE1 | D_IN              | PLL Mode Setting. PLL_MODE0 and PLL_MODE1 set the output frequency of the master clock PLL. See the Setting Master Clock/PLL Mode section for more details.  |
| 40      | CM                      | A_OUT             | 1.5 V Common-Mode Reference. A 47 $\mu$ F decoupling capacitor should be connected between this pin and ground to reduce crosstalk between the ADCs and DACs. The material of the capacitors is not critical. This pin can be used to bias external analog circuits, as long as those circuits are not drawing current from the pin (such as when CM is connected to the noninverting input of an op amp). |
| 41      | FILTD                   | A_OUT             | DAC Filter Decoupling Pin. A 10 $\mu$ F capacitor should be connected between this pin and ground. The capacitor material is not critical. The voltage on this pin is 1.5 V.   |
| 43      | VOUT3                   | A_OUT             | VOUT DAC Output. The full-scale output voltage is 0.9 V rms. This output can be used with either an active or passive output reconstruction filter. See the Audio DACS section for details.  |
| 44      | VOUT2                   | A_OUT             | VOUT2 DAC Output. The full-scale output voltage is 0.9 V rms. This output can be used with either an active or passive output reconstruction filter. See the Audio DACS section for details.   |
| 45      | VOUT1                   | A_OUT             | VOUT1 DAC Output. The full-scale output voltage is 0.9 V rms. This output can be used with either an active or passive output reconstruction filter. See the Audio DACS section for details.   |
| 46      | VOUT0                   | A_OUT             | VOUT0 DAC Output. The full-scale output voltage is 0.9 V rms. This output can be used with either an active or passive output reconstruction filter. See the Audio DACS section for details.   |
| 47      | FILTA                   | A_OUT             | ADC Filter Decoupling Pin. A 10 $\mu$ F capacitor should be connected between this pin and ground. The capacitor material is not critical. The voltage on this pin is 1.5 V.   |

<sup>1</sup> PWR = power/ground, A\_IN = analog input, D\_IN = digital input, A\_OUT = analog output, D\_IO = digital input/output, D\_IO/A\_IO = digital input/output or analog input/output.

### TYPICAL PERFORMANCE CHARACTERISTICS

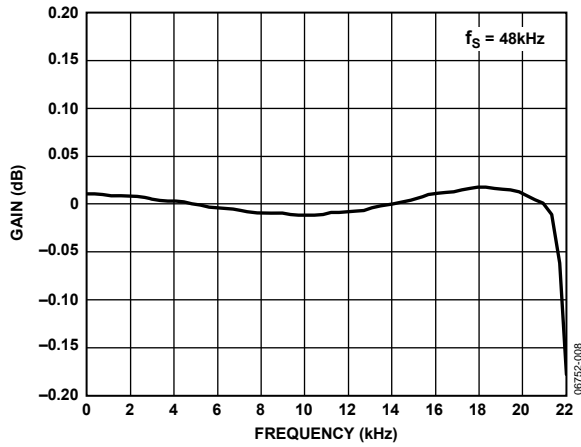


Figure 8. ADC Pass-Band Filter Response

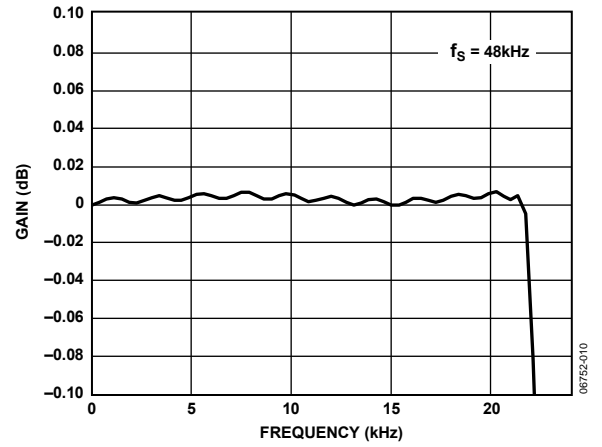


Figure 10. DAC Pass-Band Filter Response

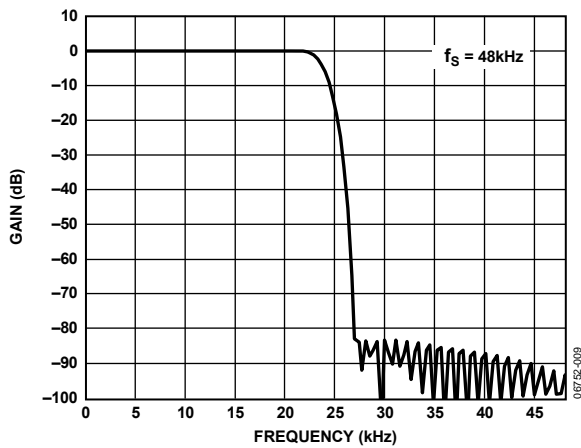


Figure 9. ADC Stop-Band Filter Response

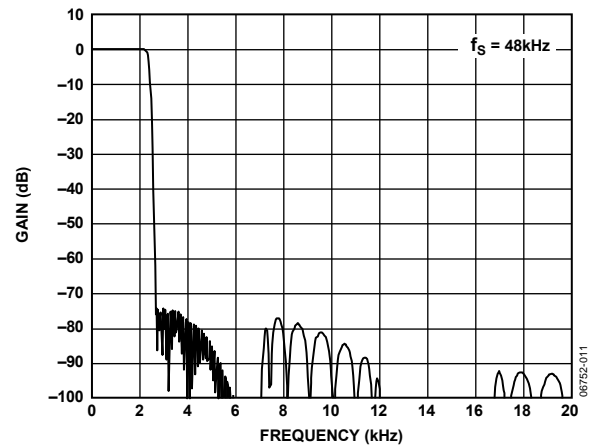


Figure 11. DAC Stop-Band Filter Response

SYSTEM BLOCK DIAGRAM

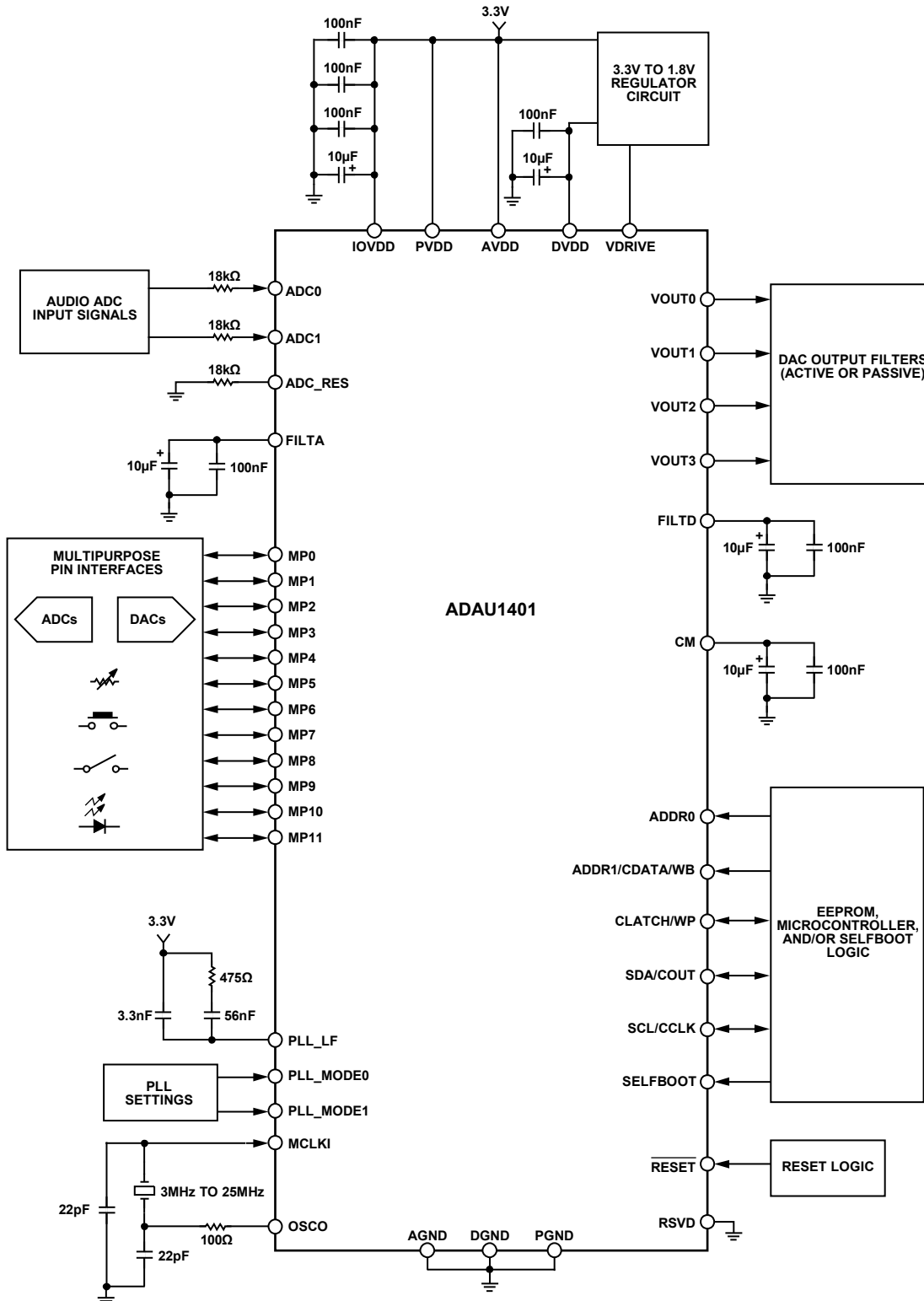


Figure 12. System Block Diagram

06752-012



## THEORY OF OPERATION

The core of the ADAU1401 is a 28-bit DSP (56-bit with double-precision processing) optimized for audio processing. The program and parameter RAMs can be loaded with a custom audio processing signal flow built by using SigmaStudio graphical programming software from Analog Devices, Inc. The values stored in the parameter RAM control individual signal processing blocks, such as equalization filters, dynamics processors, audio delays, and mixer levels. A safeload feature allows for transparent parameter updates and prevents clicks in the output signals.

The program RAM, parameter RAM, and register contents can be saved in an external EEPROM, from which the ADAU1401 can self-boot on startup. In this standalone mode, parameters can be controlled through the on-board multipurpose pins. The ADAU1401 can accept controls from switches, potentiometers, rotary encoders, and IR receivers. Parameters such as volume and tone settings can be saved to the EEPROM on power-down and recalled again on power-up.

The ADAU1401 can operate with digital or analog inputs and outputs, or a mix of both. The stereo ADC and four DACs each have an SNR of at least +100 dB and a THD + N of at least -83 dB. The 8-channel, flexible serial data input/output ports allow glueless interconnection to a variety of ADCs, DACs, general-purpose DSPs, S/PDIF receivers and transmitters, and sample rate converters. The serial ports of the ADAU1401 can be configured in I<sup>2</sup>S, left-justified, right-justified, or TDM serial port compatible modes.

Twelve multipurpose (MP) pins allow the ADAU1401 to receive external control signals as input and to output flags or controls to other devices in the system. The MP pins can be configured as digital I/Os, inputs to the 4-channel auxiliary ADC, or serial data I/O ports. As inputs, they can be connected to buttons, switches, rotary encoders, potentiometers, IR receivers, or other external circuitry to control the internal signal processing program. When configured as outputs, these pins can be used to drive LEDs, control other ICs, or connect to other external circuitry in an application.

The ADAU1401 has a sophisticated control port that supports complete read/write capability of all memory locations. Control registers are provided to offer complete control of the configuration and serial modes of the chip. The ADAU1401 can be configured for either SPI or I<sup>2</sup>C control, or can self-boot from an external EEPROM.

An on-board oscillator can be connected to an external crystal to generate the master clock. In addition, a master clock phase-

locked loop (PLL) allows the ADAU1401 to be clocked from a variety of different clock speeds. The PLL can accept inputs of  $64 \times f_s$ ,  $256 \times f_s$ ,  $384 \times f_s$ , or  $512 \times f_s$  to generate the internal master clock of the core.

The SigmaStudio software is used to program and control the SigmaDSP® through the control port. Along with designing and tuning a signal flow, the tools can be used to configure all of the DSP registers and burn a new program into the external EEPROM. The SigmaStudio graphical interface allows anyone with digital or analog audio processing knowledge to easily design a DSP signal flow and port it to a target application. At the same time, it provides enough flexibility and programmability for an experienced DSP programmer to have in-depth control of the design. In SigmaStudio, the user can connect graphical blocks (such as biquad filters, dynamics processors, mixers, and delays), compile the design, and load the program and parameter files into the ADAU1401 memory through the control port. Signal processing blocks available in the provided libraries include

- Single- and double-precision biquad filters
- Processors with peak or rms detection for monochannel and multichannel dynamics
- Mixers and splitters
- Tone and noise generators
- Fixed and variable gain
- Loudness
- Delay
- Stereo enhancement
- Dynamic bass boost
- Noise and tone sources
- FIR filters
- Level detectors
- GPIO control and conditioning

Additional processing blocks are always being developed. Analog Devices also provides proprietary and third-party algorithms for applications such as matrix decoding, bass enhancement, and surround virtualizers. Contact Analog Devices for information about licensing these algorithms.

The ADAU1401 operates from a 1.8 V digital power supply and a 3.3 V analog supply. An on-board voltage regulator can be used to operate the chip from a single 3.3 V supply. It is fabricated on a single monolithic, integrated circuit and is packaged in a 48-lead LQFP for operation over the -40°C to +105°C temperature range.

## INITIALIZATION

This section details the procedure for properly setting up the ADAU1401. The following five-step sequence provides an overview of how to initialize the IC:

1. Apply power to ADAU1401.
2. Wait for PLL to lock.
3. Load SigmaDSP program and parameters.
4. Set up registers (including multipurpose pins and digital interfaces).
5. Turn off the default muting of the converters, clear the data registers, and initialize the DAC setup register (see the Control Registers Setup section for specific settings).

To only test analog audio pass-through (ADCs to DACs), skip Step 3 and Step 4 and use the default internal program.

## POWER-UP SEQUENCE

The ADAU1401 has a built-in power-up sequence that initializes the contents of all internal RAMs on power-up or when the device is brought out of a reset. On the positive edge of  $\overline{\text{RESET}}$ , the contents of the internal program boot ROM are copied to the internal program RAM memory, the parameter RAM is filled with values (all 0s) from its associated boot ROM, and all registers are initialized to 0s. The default boot ROM program copies audio from the inputs to the outputs without processing it (see Figure 13). In this program, serial digital Input 0 and Input 1 are output on DAC0 and DAC1 and serial digital Output 0 and Output 1. ADC0 and ADC1 are output on DAC2 and DAC3. The data memories are also zeroed at power-up. New values should not be written to the control port until the initialization is complete.

Table 12. Power-Up Time

| MCLKI Input                     | Init. Time | Max Program/Parameter/Register Boot Time (I <sup>2</sup> C) | Total  |
|---------------------------------|------------|---|--------|
| 3.072 MHz ( $64 \times f_s$ )   | 85 ms      | 175 ms  | 260 ms |
| 11.289 MHz ( $256 \times f_s$ ) | 23 ms      | 175 ms  | 198 ms |
| 12.288 MHz ( $256 \times f_s$ ) | 21 ms      | 175 ms  | 196 ms |
| 18.432 MHz ( $384 \times f_s$ ) | 16 ms      | 175 ms  | 191 ms |
| 24.576 MHz ( $512 \times f_s$ ) | 11 ms      | 175 ms  | 186 ms |

The PLL start-up time lasts for  $2^{18}$  cycles of the clock on the MCLKI pin. This time ranges from 10.7 ms for a 24.576 MHz ( $512 \times f_s$ ) input clock to 85.3 ms for a 3.072 MHz ( $64 \times f_s$ ) input clock and is measured from the rising edge of  $\overline{\text{RESET}}$ . Following the PLL startup, the duration of the ADAU1401 boot cycle is about 42  $\mu\text{s}$  for a  $f_s$  of 48 kHz. The user should avoid writing to or reading from the ADAU1401 during this start-up time. For an MCLK input of 12.288 MHz, the full initialization sequence (PLL startup plus boot cycle) is approximately 21 ms. As the device comes out of a reset, the clock mode is immediately set by the PLL\_MODE0 and PLL\_MODE1 pins. The reset is synchronized to the falling edge of the internal clock.

Table 12 lists typical times to boot the ADAU1401 into an operational state of an application, assuming a 400 kHz I<sup>2</sup>C clock loading a full program, parameter set, and all registers (about 8.5 kB). In reality, most applications do not fill the RAMs and therefore boot time (Column 3 of Table 12) is less.

## CONTROL REGISTERS SETUP

The following registers must be set as described in this section to initialize the ADAU1401. These settings are the basic minimum settings needed to operate the IC with an analog input/output of 48 kHz. More registers may need to be set, depending on the application. See the RAMs and Registers section for additional settings.

### DSP Core Control Register (Address 2076)

Set Bits[4:2] (ADM, DAM, and CR) each to 1.

### DAC Setup Register (Address 2087)

Set Bits[0:1] (DS[1:0]) to 01.

## RECOMMENDED PROGRAM/PARAMETER LOADING PROCEDURE

When writing large amounts of data to the program or parameter RAM in direct write mode, the processor core should be disabled to prevent unpleasant noises from appearing in the audio output.

1. Set Bit 3 and Bit 4 (active low) of the core control register to 1 to mute the ADCs and DACs. This begins a volume ramp-down.
2. Set Bit 2 (active low) of the core control register to 1. This zeroes the SigmaDSP accumulators, the data output registers, and the data input registers.
3. Fill the program RAM using burst mode writes.
4. Fill the parameter RAM using burst mode writes.
5. Deassert Bit 2 to Bit 4 of the core control register.

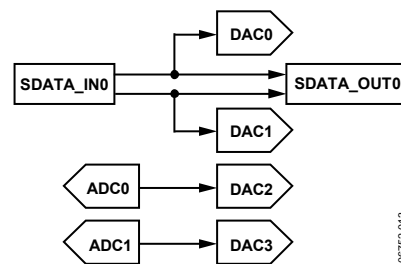


Figure 13. Default Program Signal Flow

## POWER REDUCTION MODES

Sections of the ADAU1401 chip can be turned on and off as needed to reduce power consumption. These include the ADCs, DACs, and voltage reference.

The individual analog sections can be turned off by writing to the auxiliary ADC and power control register. By default, the ADCs, DACs, and reference are enabled (all bits set to 0). Each of these can be turned off by writing a 1 to the appropriate bits

in this register. The ADC power-down mode powers down both ADCs, and each DAC can be powered down individually. The current savings is about 15 mA when the ADCs are powered down and about 4 mA for each DAC that is powered down. The voltage reference, which is supplied to both the ADCs and DACs, should only be powered down if all ADCs and DACs are powered down. The reference is powered down by setting both Bit 6 and Bit 7 of the control register.

## USING THE OSCILLATOR

The ADAU1401 can use an on-board oscillator to generate its master clock. The oscillator is designed to work with a  $256 \times f_s$  master clock, which is 12.288 MHz for a  $f_s$  of 48 kHz and 11.2896 MHz for a  $f_s$  of 44.1 kHz. The crystal in the oscillator circuit should be an AT-cut, parallel resonator operating at its fundamental frequency. Figure 14 shows the external circuit recommended for proper operation.

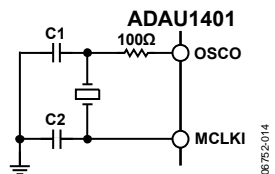


Figure 14. Crystal Oscillator Circuit

The 100 Ω damping resistor on OSCO gives the oscillator a voltage swing of approximately 2.2 V. The crystal shunt capacitance should be 7 pF. Its load capacitance should be about 18 pF, although the circuit supports values of up to 25 pF. The necessary values of the C1 and C2 load capacitors can be calculated from the crystal load capacitance as follows:

$$C_L = \frac{C1 \times C2}{C1 + C2} + C_{stray}$$

where  $C_{stray}$  is the stray capacitance in the circuit and is usually assumed to be approximately 2 pF to 5 pF.

OSCO should not be used to directly drive the crystal signal to another IC. This signal is an analog sine wave, and it is not appropriate to use it to drive a digital input. There are two options for using the ADAU1401 to provide a master clock to other ICs in the system. The first, and less recommended, method is to use a high impedance input digital buffer on the OSCO signal. If this is done, minimize the trace length to the buffer input. The second method is to use a clock from the serial output port. Pin MP11 can be set as an output (master) clock divided down from the internal core clock. If this pin is set to serial output port (OUTPUT\_BCLK) mode in the multipurpose pin configuration register (2081) and the port is set to master in the serial output control register (2078), the desired output frequency can also be set in the serial output control register with Bits[OBF<1:0>] (see Table 49).

If the oscillator is not utilized in the design, it can be powered down to save power. This can be done if a system master clock is already available in the system. By default, the oscillator is powered on. The oscillator powers down when a 1 is written to the OPD bit of the oscillator power-down register (see Table 60).

## SETTING MASTER CLOCK/PLL MODE

The MCLKI input of the ADAU1401 feeds a PLL, which generates the 50 MIPS SigmaDSP core clock. In normal operation, the input to MCLKI must be one of the following:  $64 \times f_s$ ,  $256 \times f_s$ ,  $384 \times f_s$ , or  $512 \times f_s$ , where  $f_s$  is the input sampling rate. The mode is set on PLL\_MODE0 and PLL\_MODE1 as described in Table 13. If the ADAU1401 is set to receive double-rate signals (by reducing the number of program steps per sample by a factor of 2 using the core control register), the master clock frequency must be  $32 \times f_s$ ,  $128 \times f_s$ ,  $192 \times f_s$ , or  $256 \times f_s$ . If the ADAU1401 is set to receive quad-rate signals (by reducing the number of program steps per sample by a factor of 4 using the core control register), the master clock frequency must be  $16 \times f_s$ ,  $64 \times f_s$ ,  $96 \times f_s$ , or  $128 \times f_s$ . On power-up, a clock signal must be present on the MCLKI pin so that the ADAU1401 can complete its initialization routine.

Table 13. PLL Modes

| MCLKI Input      | PLL_MODE0 | PLL_MODE1 |
|------------------|-----------|-----------|
| $64 \times f_s$  | 0         | 0         |
| $256 \times f_s$ | 0         | 1         |
| $384 \times f_s$ | 1         | 0         |
| $512 \times f_s$ | 1         | 1         |

The clock mode should not be changed without also resetting the ADAU1401. If the mode is changed during operation, a click or pop can result in the output signals. The state of the PLL\_MODEx pins should be changed while RESET is held low.

The PLL loop filter should be connected to the PLL\_LF pin. This filter, shown in Figure 15, includes three passive components—two capacitors and a resistor. The values of these components do not need to be exact; the tolerance can be up to 10% for the resistor and up to 20% for the capacitors. The 3.3 V signal shown in Figure 15 can be connected to the AVDD supply of the chip.

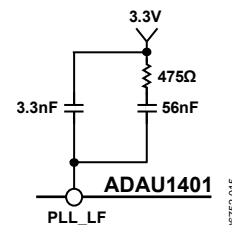


Figure 15. PLL Loop Filter

**VOLTAGE REGULATOR**

The digital voltage of the ADAU1401 must be set to 1.8 V. The chip includes an on-board voltage regulator that allows the device to be used in systems without an available 1.8 V supply but with an available 3.3 V supply. The only external components needed in such instances are a PNP transistor, a resistor, and a few bypass capacitors. Only one pin, VDRIVE, is necessary to support the regulator.

The recommended design for the voltage regulator is shown in Figure 16. The 10 μF and 100 nF capacitors shown in this configuration are recommended for bypassing, but are not necessary for operation. Each DVDD pin should have its own 100 nF bypass capacitor, but only one bulk capacitor (10 μF to 47 μF) is needed for both DVDD pins. With this configuration, 3.3 V is the main system voltage; 1.8 V is generated at the transistor’s collector, which is connected to the DVDD pins. VDRIVE is connected to the base of the PNP transistor. If the regulator is not used in the design, VDRIVE can be tied to ground.

Two specifications must be considered when choosing a regulator transistor: The transistor’s current amplification factor ( $h_{FE}$  or beta) should be at least 100, and the transistor’s collector must be able to dissipate the heat generated when regulating from 3.3 V to 1.8 V. The maximum digital current drawn from the ADAU1401 is 60 mA. The equation to determine the minimum power dissipation of the transistor is as follows:

$$(3.3\text{ V} - 1.8\text{ V}) \times 60\text{ mA} = 90\text{ mW}$$

There are many transistors, such as the FZT953 from Zetex Semiconductors, with these specifications available in small SOT-23 or SOT-223 packages.

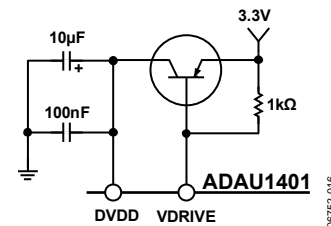


Figure 16. Voltage Regulator Configuration

## AUDIO ADCs

The ADAU1401 has two  $\Sigma$ - $\Delta$  ADCs. The signal-to-noise ratio (SNR) of the ADCs is 100 dB, and the THD + N is  $-83$  dB.

The stereo audio ADCs are current input; therefore, a voltage-to-current resistor is required on the inputs. This means that the voltage level of the input signals to the system can be set to any level; only the input resistors need to be scaled to provide the proper full-scale current input. The ADC0 and ADC1 input pins, as well as ADC\_RES, have an internal  $2\text{ k}\Omega$  resistor for ESD protection. The voltage seen directly on the ADC input pins is the  $1.5\text{ V}$  common mode.

The external resistor connected to ADC\_RES sets the full-scale current input of the ADCs. The full range of the ADC inputs is  $100\text{ }\mu\text{A}$  rms with an external  $18\text{ k}\Omega$  resistor on ADC\_RES ( $20\text{ k}\Omega$  total, because it is in series with the internal  $2\text{ k}\Omega$ ). The only reason to change the ADC\_RES resistor is if a sampling rate other than  $48\text{ kHz}$  is used.

The voltage-to-current resistors connected to ADC0/ADC1 set the full-scale voltage input of the ADCs. With a full-scale current input of  $100\text{ }\mu\text{A}$  rms, a  $2.0\text{ V}$  rms signal with an external  $18\text{ k}\Omega$  resistor (in series with the  $2\text{ k}\Omega$  internal resistor) results in an input using the full range of the ADC. The matching of these resistors to the ADC\_RES resistor is important to the operation of the ADCs. For these three resistors, a  $1\%$  tolerance is recommended.

Either the ADC0 and/or ADC1 input pins can be left unconnected if that channel of the ADC is unused.

These calculations of resistor values assume a  $48\text{ kHz}$  sample rate. The recommended input and current setting resistors scale linearly with the sample rate because the ADCs have a switched-capacitor input. The total value ( $2\text{ k}\Omega$  internal plus external resistor) of the ADC\_RES resistor with sample rate  $f_{S\_NEW}$  can be calculated as follows:

$$R_{total} = 20\text{ k}\Omega \times \frac{48,000}{f_{S\_NEW}}$$

The values of the resistors (internal plus external) in series with the ADC0 and ADC1 pins can be calculated as follows:

$$R_{Input\ Total} = (rms\ Input\ Voltage) \times 10\text{ k}\Omega \times \frac{48,000}{f_{S\_NEW}}$$

Table 14 lists the external and total resistor values for common signal input levels at a  $48\text{ kHz}$  sampling rate. A full-scale rms input voltage of  $0.9\text{ V}$  is shown in the table because a full-scale signal at this input level is equal to a full-scale output on the DACs.

**Table 14. ADC Input Resistor Values**

| Full-Scale RMS Input Voltage (V) | ADC_RES Value (k $\Omega$ ) | ADC0/ADC1 Resistor Value (k $\Omega$ ) | Total ADC0/ADC1 Input Resistance (External + Internal) (k $\Omega$ ) |
|----------------------------------|-----------------------------|--|--|
| 0.9                              | 18                          | 7                                      | 9  |
| 1.0                              | 18                          | 8                                      | 10   |
| 2.0                              | 18                          | 18                                     | 20   |

Figure 17 shows a typical configuration of the ADC inputs for a  $2.0\text{ V}$  rms input signal for a  $f_s$  of  $48\text{ kHz}$ . The  $47\text{ }\mu\text{F}$  capacitors are used to ac-couple the signals so that the inputs are biased at  $1.5\text{ V}$ .

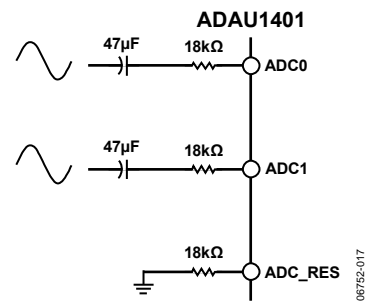


Figure 17. Audio ADC Input Configuration

## AUDIO DACs

The ADAU1401 includes four  $\Sigma$ - $\Delta$  DACs. The SNR of the DAC is 104 dB, and the THD + N is -90 dB. A full-scale output on the DACs is 0.9 V rms (2.5 V p-p).

The DACs are in an inverting configuration. If a signal inversion from input to output is undesirable, it can be reversed either by using an inverting configuration for the output filter or by simply inverting the signal in the SigmaDSP program flow.

The DAC outputs can be filtered with either an active or a passive reconstruction filter. A single-pole, passive, low-pass filter with a 50 kHz corner frequency, as shown in Figure 18, is sufficient to filter the DAC out-of-band noise, although an active filter may provide better audio performance. Figure 19

shows a triple-pole, active, low-pass filter that provides a steeper roll-off and better stop-band attenuation than the passive filter. In this configuration, the V+ and V- pins of the AD8606 op amp are set to VDD and ground, respectively.

To properly initialize the DACs, Bits[DS<1:0>] in the DAC setup register (Address 2087) should be set to 01.

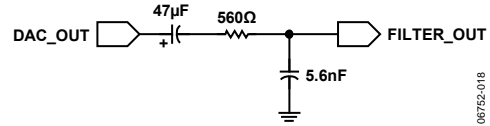


Figure 18. Passive DAC Output Filter

06752-018

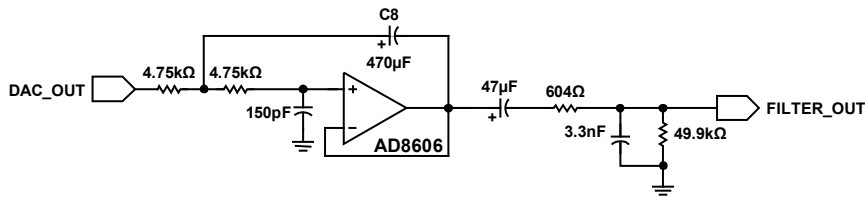


Figure 19. Active DAC Output Filter

06752-019

## CONTROL PORTS

The ADAU1401 can operate in one of three control modes:

- I<sup>2</sup>C control
- SPI control
- Self-boot (no external controller)

The ADAU1401 has both a 4-wire SPI control port and a 2-wire I<sup>2</sup>C bus control port. Each can be used to set the RAMs and registers. When the SELFBOT pin is low at power-up, the part defaults to I<sup>2</sup>C mode but can be put into SPI control mode by pulling the CLATCH/WP pin low three times. When the SELFBOT pin is set high at power-up, the ADAU1401 loads its program, parameters, and register settings from an external EEPROM on startup.

The control port is capable of full read/write operation for all addressable memory and registers. Most signal processing parameters are controlled by writing new values to the parameter RAM using the control port. Other functions, such as mute and input/output mode control, are programmed by writing to the registers.

All addresses can be accessed in a single-address mode or a burst mode. The first byte (Byte 0) of a control port write contains the 7-bit chip address plus the R/W bit. The next two bytes (Byte 1 and Byte 2) together form the subaddress of the memory or register location within the ADAU1401. This subaddress must be two bytes because the memory locations within the ADAU1401 are directly addressable and their sizes

exceed the range of single-byte addressing. All subsequent bytes (starting with Byte 3) contain the data, such as control port data, program data, or parameter data. The number of bytes per word depends on the type of data that is being written. The exact formats for specific types of writes are shown in Table 22 to Table 31.

The ADAU1401 has several mechanisms for updating signal processing parameters in real time without causing pops or clicks. If large blocks of data need to be downloaded, the output of the DSP core can be halted (using the CR bit in the DSP core control register (Address 2076)), new data can be loaded, and then the device can be restarted. This is typically done during the booting sequence at startup or when loading a new program into RAM. In cases where only a few parameters need to be changed, they can be loaded without halting the program. To avoid unwanted side effects while loading parameters on the fly, the SigmaDSP provides the safeload registers. The safeload registers can be used to buffer a full set of parameters (for example, the five coefficients of a biquad) and then transfer these parameters into the active program within one audio frame. The safeload mode uses internal logic to prevent contention between the DSP core and the control port.

The control port pins are multifunctional, depending on the mode in which the part is operating. Table 15 details these multiple functions.

**Table 15. Control Port Pins and SELFBOT Pin Functions**

| Pin            | I <sup>2</sup> C Mode               | SPI Mode     | Self-Boot                                      |
|----------------|-------------------------------------|--------------|--|
| SCL/CCLK       | SCL—input                           | CCLK—input   | SCL—output                                     |
| SDA/COUT       | SDA—open-collector output           | COUT—output  | SDA—open-collector output                      |
| ADDR1/CDATA/WB | ADDR1—input                         | CDATA—input  | WB—writeback trigger                           |
| CLATCH/WP      | Unused input—tie to ground or IOVDD | CLATCH—input | WP—EEPROM write protect, open-collector output |
| ADDR0          | ADDR0—input                         | ADDR0—input  | Unused input—tie to ground or IOVDD            |

**I<sup>2</sup>C PORT**

The ADAU1401 supports a 2-wire serial (I<sup>2</sup>C-compatible) microprocessor bus driving multiple peripherals. Two pins, serial data (SDA) and serial clock (SCL), carry information between the ADAU1401 and the system I<sup>2</sup>C master controller. In I<sup>2</sup>C mode, the ADAU1401 is always a slave on the bus, meaning it cannot initiate a data transfer. Each slave device is recognized by a unique address. The address byte format is shown in Table 16. The ADAU1401 slave addresses are set with the ADDR0 and ADDR1 pins. The address resides in the first seven bits of the I<sup>2</sup>C write. The LSB of this byte sets either a read or write operation. Logic Level 1 corresponds to a read operation, and Logic Level 0 corresponds to a write operation. Bit 5 and Bit 6 of the address are set by tying the ADDR<sub>x</sub> pins of the ADAU1401 to Logic Level 0 or Logic Level 1. The full byte addresses, including the pin settings and read/write (R/W) bit, are shown in Table 17.

Burst mode addressing, where the subaddresses are automatically incremented at word boundaries, can be used for writing large amounts of data to contiguous memory locations. This increment happens automatically after a single-word write unless a stop condition is encountered. The registers and RAMs in the ADAU1401 range in width from one to five bytes, so the auto-increment feature knows the mapping between subaddresses and the word length of the destination register (or memory location). A data transfer is always terminated by a stop condition.

Both SDA and SCL should have 2.2 kΩ pull-up resistors on the lines connected to them. The voltage on these signal lines should not be more than IOVDD (3.3 V).

**Table 16. ADAU1401 I<sup>2</sup>C Address Byte Format**

| Bit 0 | Bit 1 | Bit 2 | Bit 3 | Bit 4 | Bit 5 | Bit 6 | Bit 7 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 0     | 1     | 1     | 0     | 1     | ADDR1 | ADDR0 | R/W   |

**Table 17. ADAU1401 I<sup>2</sup>C Addresses**

| ADDR1 | ADDR0 | R/W | Slave Address |
|-------|-------|-----|---------------|
| 0     | 0     | 0   | 0x68          |
| 0     | 0     | 1   | 0x69          |
| 0     | 1     | 0   | 0x6A          |
| 0     | 1     | 1   | 0x6B          |
| 1     | 0     | 0   | 0x6C          |
| 1     | 0     | 1   | 0x6D          |
| 1     | 1     | 0   | 0x6E          |
| 1     | 1     | 1   | 0x6F          |

**Addressing**

Initially, each device on the I<sup>2</sup>C bus is in an idle state monitoring the SDA and SCL lines for a start condition and the proper address. The I<sup>2</sup>C master initiates a data transfer by establishing a start condition, defined by a high-to-low transition on SDA while SCL remains high. This indicates that an address/data stream follows. All devices on the bus respond to the start condition and shift the next eight bits (the 7-bit address plus the R/W bit) MSB first. The device that recognizes the transmitted address responds by pulling the data line low during the ninth clock pulse. This ninth bit is known as an acknowledge bit. All other devices withdraw from the bus at this point and return to the idle condition. The R/W bit determines the direction of the data. A Logic 0 on the LSB of the first byte means the master writes information to the peripheral, whereas a Logic 1 means the master reads information from the peripheral after writing the subaddress and repeating the start address. A data transfer takes place until a stop condition is encountered. A stop condition occurs when SDA transitions from low to high while SCL is held high. Figure 20 shows the timing of an I<sup>2</sup>C write, and Figure 21 shows an I<sup>2</sup>C read.

Stop and start conditions can be detected at any stage during the data transfer. If these conditions are asserted out of sequence with normal read and write operations, the ADAU1401 immediately jumps to the idle condition. During a given SCL high period, the user should only issue one start condition, one stop condition, or a single stop condition followed by a single start condition. If an invalid subaddress is issued by the user, the ADAU1401 does not issue an acknowledge and returns to the idle condition. If the user exceeds the highest subaddress while in auto-increment mode, one of two actions is taken. In read mode, the ADAU1401 outputs the highest subaddress register contents until the master device issues a no acknowledge, indicating the end of a read. A no-acknowledge condition is where the SDA line is not pulled low on the ninth clock pulse on SCL. On the other hand, if the highest subaddress location is reached while in write mode, the data for the invalid byte is not loaded into any subaddress register, a no acknowledge is issued by the ADAU1401, and the part returns to the idle condition.



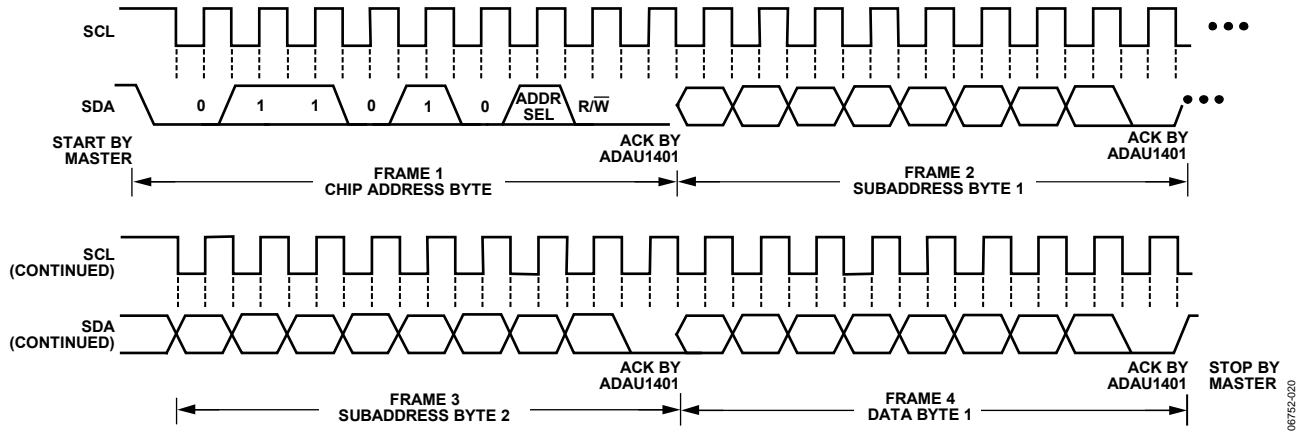


Figure 20. I<sup>2</sup>C Write to ADAU1401 Clcking

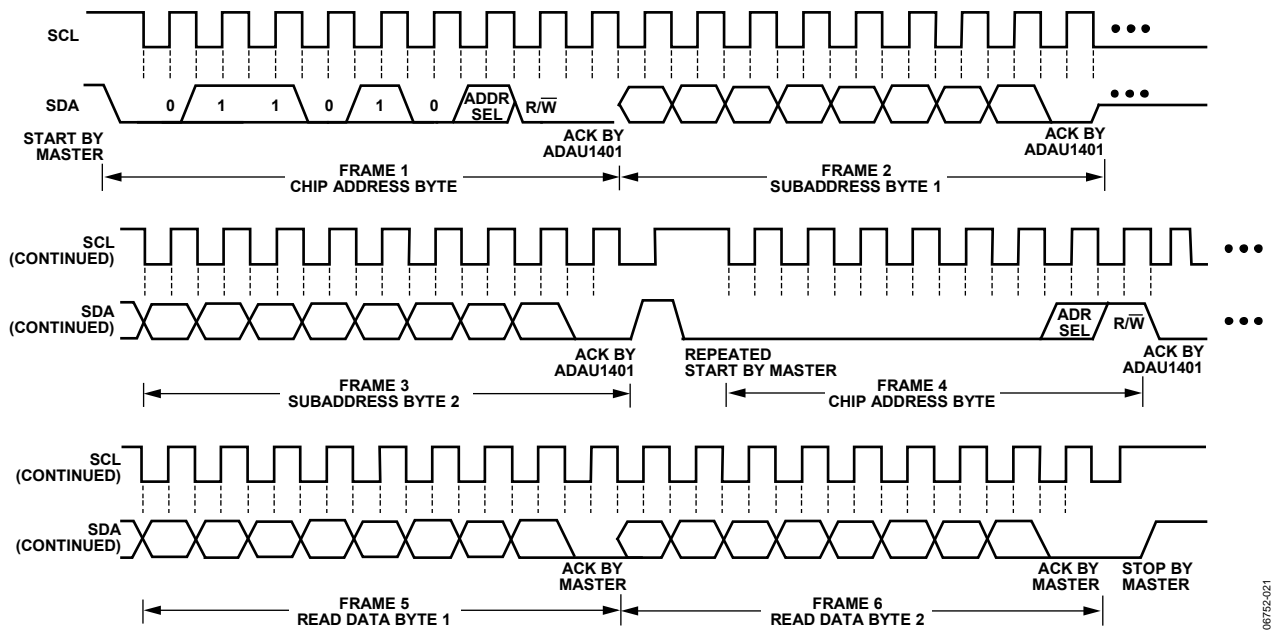


Figure 21. I<sup>2</sup>C Read from ADAU1401 Clcking

**I<sup>2</sup>C Read and Write Operations**

Figure 22 shows the timing of a single-word write operation. Every ninth clock, the ADAU1401 issues an acknowledge by pulling SDA low.

Figure 23 shows the timing of a burst mode write sequence. This figure shows an example where the target destination registers are two bytes. The ADAU1401 knows to increment its subaddress register every two bytes because the requested subaddress corresponds to a register or memory area with a 2-byte word length.

The timing of a single-word read operation is shown in Figure 24. Note that the first R/W bit is 0, indicating a write operation. This is because the subaddress still needs to be written to set up the internal address. After the ADAU1401 acknowledges the receipt of the subaddress, the master must issue a repeated start command followed by the chip address with the R/W set to 1 (read). This causes the ADAU1401 SDA to reverse and begin driving data back to the master. The master then responds every ninth pulse with an acknowledge pulse to the ADAU1401.

Figure 25 shows the timing of a burst mode read sequence. This figure shows an example where the target read registers are two bytes. The ADAU1401 increments its subaddress every two bytes because the requested subaddress corresponds to a register or memory area with word lengths of two bytes. Other addresses may have word lengths ranging from one to five bytes. The ADAU1401 always decodes the subaddress and sets the auto-increment circuit so that the address increments after the appropriate number of bytes.

Figure 22 to Figure 25 use the following abbreviations:

- S = start bit
- P = stop bit
- AM = acknowledge by master
- AS = acknowledge by slave

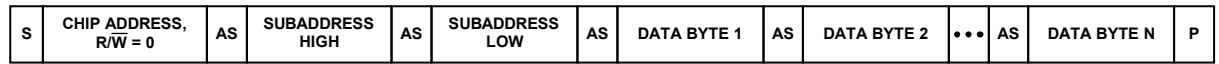


Figure 22. Single Word I<sup>2</sup>C Write Format

06752-024



Figure 23. Burst Mode I<sup>2</sup>C Write Format

06752-023

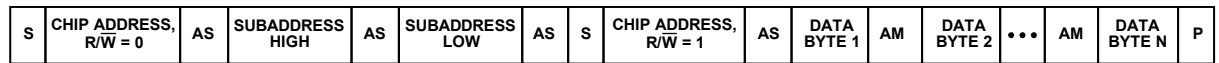


Figure 24. Single-Word I<sup>2</sup>C Read Format

06752-024

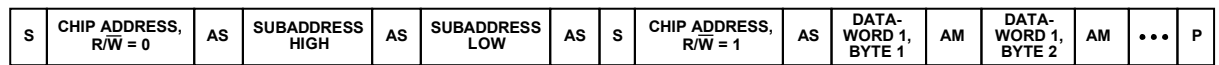


Figure 25. Burst Mode I<sup>2</sup>C Read Format

06752-025

**SPI PORT**

By default, the ADAU1401 is in I<sup>2</sup>C mode, but it can be put into SPI control mode by pulling CLATCH/WP low three times. The SPI port uses a 4-wire interface, consisting of CLATCH, CCLK, CDATA, and COUT signals, and is always a slave port. The CLATCH signal should go low at the beginning of a transaction and high at the end of a transaction. The CCLK signal latches CDATA during a low-to-high transition. COUT data is shifted out of the ADAU1401 on the falling edge of CCLK and should be clocked into a receiving device, such as a microcontroller, on the CCLK rising edge. The CDATA signal carries the serial input data, and the COUT signal is the serial output data. The COUT signal remains three-stated until a read operation is requested. This allows other SPI-compatible peripherals to share the same readback line. All SPI transactions have the same basic format shown in Table 19. A timing diagram is shown in Figure 3. All data should be written MSB first. The ADAU1401 cannot be taken out of SPI mode without a full reset.

**Chip Address R/W**

The first byte of an SPI transaction includes the 7-bit chip address and a R/W bit. The chip address is set by the ADDR0 pin. This allows two ADAU1401s to share a CLATCH signal, yet still operate independently. When ADDR0 is low, the chip address is 0000000; when it is high, the address is 0000001 (see Table 18). The LSB of this first byte determines whether the SPI transaction is a read (Logic Level 1) or a write (Logic Level 0).

**Table 19. Generic Control Word Format**

| Byte 0             | Byte 1             | Byte 2      | Byte 3 | Byte 4 <sup>1</sup> |
|--------------------|--------------------|-------------|--------|---------------------|
| chip_adr[6:0], R/W | 0000, subadr[11:8] | subadr[7:0] | data   | data                |

<sup>1</sup> Continues to end of data.

**Table 18. ADAU1401 SPI Address Byte Format**

| Bit 0 | Bit 1 | Bit 2 | Bit 3 | Bit 4 | Bit 5 | Bit 6 | Bit 7 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 0     | 0     | 0     | 0     | 0     | 0     | ADDR0 | R/W   |

**Subaddress**

The 12-bit subaddress word is decoded into a location in one of the memories or registers. This subaddress is the location of the appropriate RAM location or register. The MSBs of the subaddress are zero-padded to bring the word to a full 2-byte length.

**Data Bytes**

The number of data bytes varies according to the register or memory being accessed. During a burst mode write, an initial subaddress is written followed by a continuous sequence of data for consecutive memory/register locations. The detailed data format for continuous mode operation is shown in Table 23 and Table 25 in the Read/Write Data Formats section.

A sample timing diagram for a single-write SPI operation to the parameter RAM is shown in Figure 26. A sample timing diagram of a single-read SPI operation is shown in Figure 27. The COUT pin goes from three-state to being driven at the beginning of Byte 3. In this example, Byte 0 to Byte 2 contain the addresses and the R/W bit and subsequent bytes carry the data.

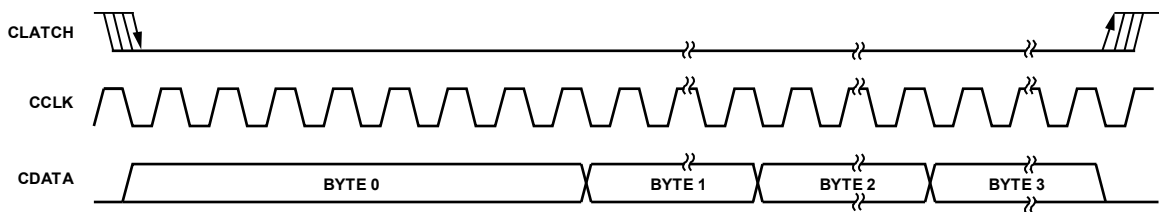


Figure 26. SPI Write to ADAU1401 Clocking (Single-Write Mode)

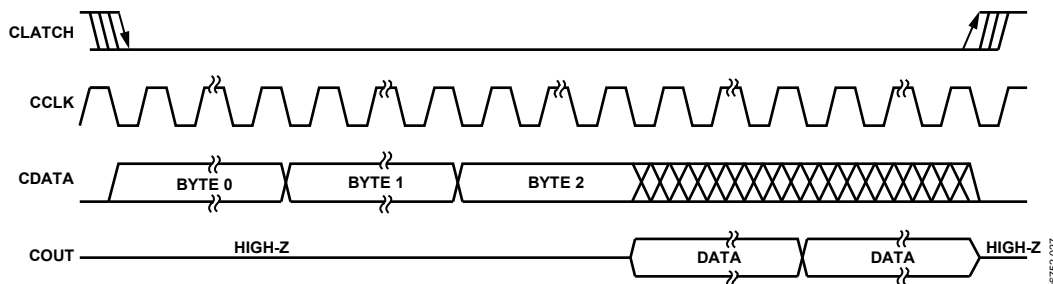


Figure 27. SPI Read from ADAU1401 Clocking (Single-Read Mode)

## SELF-BOOT

On power-up, the ADAU1401 can load a program and a set of parameters that have been saved in an external EEPROM. Combined with the auxiliary ADC and the multipurpose pins, this eliminates the need for a microcontroller in the system. The self-booting is accomplished by the ADAU1401 acting as a master on the I<sup>2</sup>C bus on startup, which occurs when the SELFBOT pin is set high. The ADAU1401 cannot self-boot in SPI mode.

The maximum necessary EEPROM size for program and parameters is 9248 bytes, or just over 8.5 kB. This does not include register settings or overhead bytes, but such factors do not add a significant number of bytes. This much memory is only needed if the program RAM (1024 × five bytes), parameter RAM (1024 × four bytes), and interface registers (8 × four bytes) are completely full. Most applications do not use the full program and parameter RAMs, so an 8 kB EEPROM should be sufficient.

A self-boot operation is triggered on the rising edge of  $\overline{\text{RESET}}$  when the SELFBOT and WP pins are set high. The ADAU1401 reads the program, parameters, and register settings from the EEPROM. After the ADAU1401 finishes self-booting, additional messages can be sent to the ADAU1401 on the I<sup>2</sup>C bus, although this typically is not necessary in a self-booting application. The I<sup>2</sup>C device address is 0x68 for a write and 0x69 for a read in this mode. The ADDR<sub>x</sub> pins have different functions when the chip is in this mode, so the settings on them can be ignored.

The ADAU1401 does not self-boot if WP is set low. Holding this pin low allows the EEPROM to be programmed in-circuit. The WP pin is pulled low (it typically has a resistor pull-up) to enable writes to the EEPROM, but this in turn disables the self-boot function until the WP pin is returned high.

The ADAU1401 is a master on the I<sup>2</sup>C bus during self-boot and writeback. Although it is uncommon for an application using self-boot to also have a microcontroller connected to the control lines, care should be taken that no other device tries to write to the I<sup>2</sup>C bus during self-boot or writeback. The ADAU1401 generates SCL at  $8 \times f_s$ ; therefore, for a  $f_s$  of 48 kHz, SCL runs at 384 kHz. SCL has a duty cycle of 3/8 in accordance with the I<sup>2</sup>C specification.

The ADAU1401 reads from EEPROM Chip Address 0xA1. The LSBs of the addresses of some EEPROMs are pin configurable; in most cases, these pins should be tied low to set this address.

## EEPROM Format

The EEPROM data contains a sequence of messages. Each discrete message is one of the seven types defined in Table 20 and consists of a sequence of one or more bytes. The first byte identifies the message type. Bytes are written MSB first. Most messages are block write (0x01) types, which are used for writing to the ADAU1401 program RAM, parameter RAM, and control registers.

The body of the message following the message type should start with a 0x00 byte; this is the chip address. As with all other control port transactions, following the chip address is a 2-byte register/memory address field.

Figure 28 shows an example of what should be stored in the EEPROM, starting with EEPROM Address 0. In this example, the interface registers are first set to control port write mode (Line 1), which is followed by 18 no operation (no-op) bytes (Line 2 to Line 4) so that the interface register data appears on Page 2 of the EEPROM. Next follows the write header (Line 4), and then 32 bytes of interface register data (Line 5 to Line 8). Finally, the program RAM data, starting at ADAU1401 Address 0x04 0x00 is written (Line 9 to Line 11). In this example, the program length is 70 words, or 350 bytes, so 332 more bytes are included in the EEPROM but are not shown in Figure 28.

## Writeback

A writeback occurs when the WB pin is triggered and data is written to the EEPROM from the ADAU1401. This function is typically used to save the volume setting and other parameter settings to the EEPROM just before power is removed from the system. A rising edge on the WB pin triggers a writeback when the device is in self-boot mode, unless a message to set the WB to the falling edge sensitive (0x05) is contained in the self-boot message sequence. Only one writeback takes place unless a message to set multiple writebacks (0x04) is contained in the self-boot message sequence. The WP pin is pulled low when a writeback is triggered to allow writing to the EEPROM.

The ADAU1401 is only capable of writing back the contents of the interface registers to the EEPROM. These registers are usually set by the DSP program, but can also be written to directly after setting Bit 6 of the core control register. The parameter settings that should be saved are configured in SigmaStudio.

The writeback function writes data from the ADAU1401 interface registers to the second page of the self-boot EEPROM, Address 32 to Address 63. Starting at EEPROM Address 26 (so that the interface register data begins at Address 32), the EEPROM should be programmed with six bytes—the message byte (0x01), two length bytes, the chip address (0x00), and the 2-byte subaddress for the interface registers (0x08 0x00). There must be a message to the DSP core control register to enable writing to the interface registers prior to the interface register data in the EEPROM. This should be stored in EEPROM Address 0. No-op messages (0x03) can be used in between messages to ensure that these conditions are met.

The ADAU1401 writes to EEPROM Chip Address 0xA0. The LSBs of the addresses of some EEPROMs are pin configurable; in most cases, these pins should be tied low to set the address to 0xA0.

The maximum number of bytes that is written back from the ADAU1401 is 35 (eight 4-byte interface registers plus three bytes of EEPROM-addressing overhead). With SCL running at 384 kHz, the writeback operation takes approximately 73 μs to complete after being triggered. Ensure that sufficient power is available to the system to allow enough time for a writeback to complete, especially if the WB signal is triggered from a falling power supply voltage.

Table 20. EEPROM Message Types

| Message ID | Message Type                     | Following Bytes  |
|------------|----------------------------------|--|
| 0x00       | End                              | None   |
| 0x01       | Write                            | Two bytes indicating message length followed by appropriate number of data bytes |
| 0x02       | Delay                            | Two bytes for delay  |
| 0x03       | No operation executed            | None   |
| 0x04       | Set multiple writeback           | None   |
| 0x05       | Set WB to falling edge sensitive | None   |
| 0x06       | End and wait for writeback       | None   |

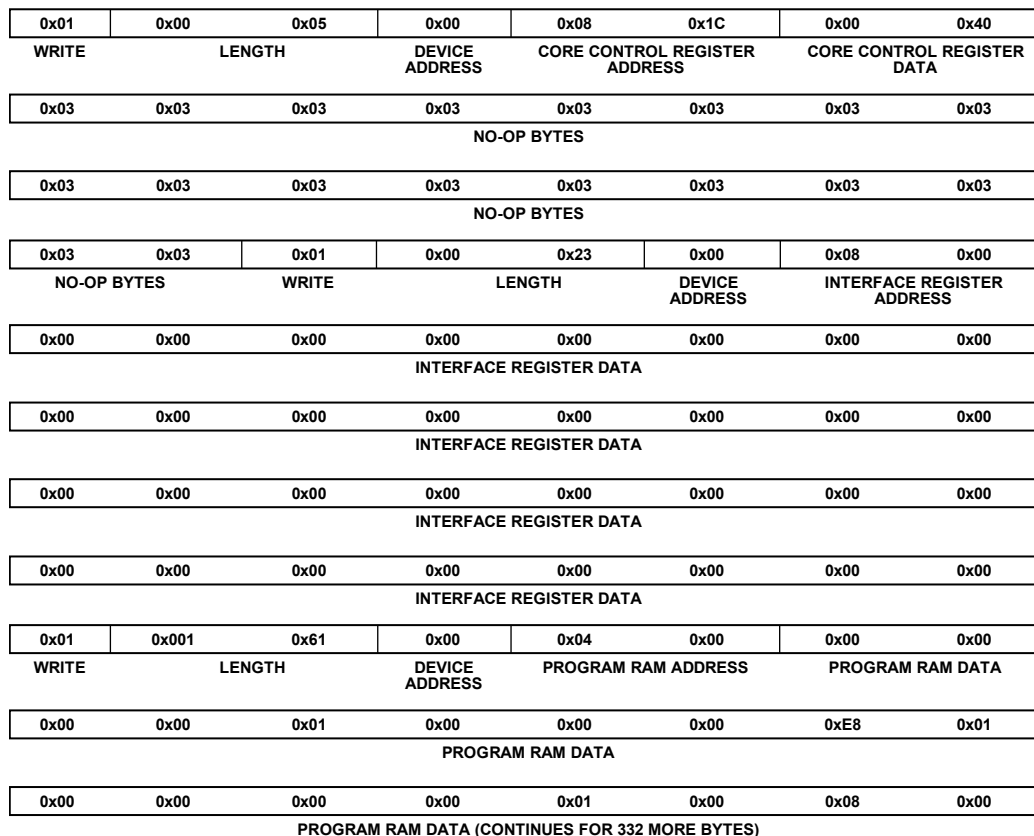


Figure 28. EEPROM Data Example

06752-039

## SIGNAL PROCESSING

The ADAU1401 is designed to provide all audio signal processing functions commonly used in stereo or multichannel playback systems. The signal processing flow is designed using the SigmaStudio software, which allows graphical entry and real-time control of all signal processing functions.

Many of the signal processing functions are coded using full, 56-bit, double-precision arithmetic data. The input and output word lengths of the DSP core are 24 bits. Four extra headroom bits are used in the processor to allow internal gains of up to 24 dB without clipping. Additional gains can be achieved by initially scaling down the input signal in the DSP signal flow.

### NUMERIC FORMATS

DSP systems commonly use a standard numeric format. Fractional number systems are specified by an A.B format, where A is the number of bits to the left of the decimal point and B is the number of bits to the right of the decimal point.

The ADAU1401 uses the same numeric format for both the parameter and data values. The format is as follows.

#### Numerical Format: 5.23

Linear range:  $-16.0$  to  $(+16.0 - 1 \text{ LSB})$

Examples:

- 1000 0000 0000 0000 0000 0000 =  $-16.0$
- 1110 0000 0000 0000 0000 0000 =  $-4.0$
- 1111 1000 0000 0000 0000 0000 =  $-1.0$
- 1111 1110 0000 0000 0000 0000 =  $-0.25$
- 1111 1111 0011 0011 0011 0011 =  $-0.1$
- 1111 1111 1111 1111 1111 1111 = (1 LSB below 0.0)
- 0000 0000 0000 0000 0000 0000 =  $0.0$
- 0000 0000 1100 1100 1100 1101 =  $0.1$
- 0000 0010 0000 0000 0000 0000 =  $0.25$
- 0000 1000 0000 0000 0000 0000 =  $1.0$
- 0010 0000 0000 0000 0000 0000 =  $4.0$
- 0111 1111 1111 1111 1111 1111 =  $(16.0 - 1 \text{ LSB})$ .

The serial port accepts up to 24 bits on the input and is sign-extended to the full 28 bits of the DSP core. This allows internal gains of up to 24 dB without internal clipping.

A digital clipper circuit is used between the output of the DSP core and the DACs or serial port outputs (see Figure 29). This clips the top four bits of the signal to produce a 24-bit output

with a range of 1.0 (minus 1 LSB) to  $-1.0$ . Figure 29 shows the maximum signal levels at each point in the data flow in both binary and decibel levels.

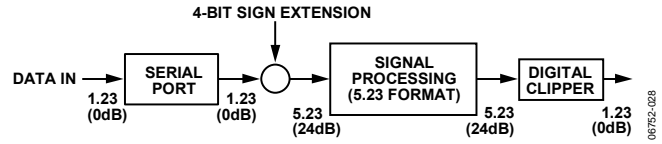


Figure 29. Numeric Precision and Clipping Structure

### PROGRAMMING

On power-up, the ADAU1401 default program passes the unprocessed input signals to the outputs (shown in Figure 13), but the outputs are muted by default (see the Power-Up Sequence section). There are 1024 instruction cycles per audio sample, resulting in about 50 MIPS available. The SigmaDSP runs in a stream-oriented manner, meaning that all 1024 instructions are executed each sample period. The ADAU1401 can also be set up to accept double- or quad-speed inputs by reducing the number of instructions per sample that are set in the core control register.

The part can be easily programmed using SigmaStudio (Figure 30), a graphical tool provided by Analog Devices. No knowledge of writing line-level DSP code is required. More information about SigmaStudio can be found at [www.analog.com](http://www.analog.com).

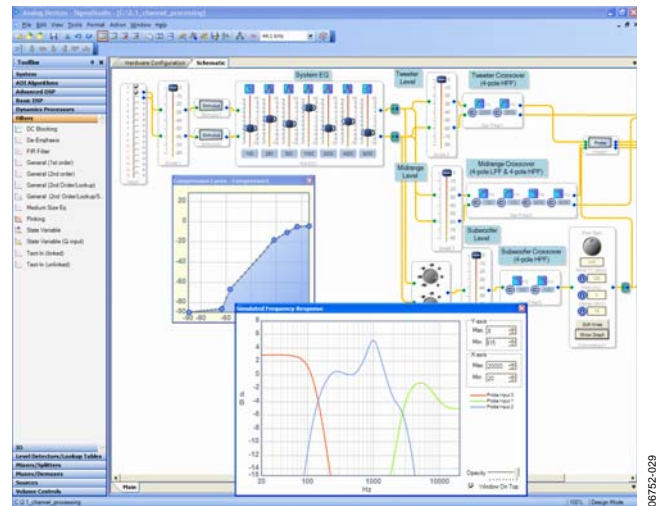


Figure 30. SigmaStudio Screen Shot

## RAMS AND REGISTERS

Table 21. RAM Map and Read/Write Modes

| Memory        | Size      | Address Range                   | Read | Write | Write Modes                              |
|---------------|-----------|---------------------------------|------|-------|--|
| Parameter RAM | 1024 × 32 | 0 to 1023 (0x0000 to 0x03FF)    | Yes  | Yes   | Direct write <sup>1</sup> safeload write |
| Program RAM   | 1024 × 40 | 1024 to 2047 (0x0400 to 0x07FF) | Yes  | Yes   | Direct write <sup>1</sup>                |

<sup>1</sup> Internal registers should be cleared first to avoid clicks/pops.

### ADDRESS MAPS

Table 21 shows the RAM map and Table 32 shows the ADAU1401 register map. The address space encompasses a set of registers and two RAMs: one holds signal processing parameters and one holds the program instructions. The program RAM and parameter RAM are initialized on power-up from on-board boot ROMs (see the Power-Up Sequence section).

All RAMs and registers have a default value of all 0s, except for the program RAM, which is loaded with the default program (see the Initialization section).

### PARAMETER RAM

The parameter RAM is 32 bits wide and occupies Address 0 to Address 1023. Each parameter is padded with four 0s before the MSB to extend the 28-bit word to a full 4-byte width. The parameter RAM is initialized to all 0s on power-up. The data format of the parameter RAM is twos complement, 5.23.

This means that the coefficients can range from +16.0 (minus 1 LSB) to -16.0, with 1.0 represented by the binary word 0000 1000 0000 0000 0000 0000 or by the hexadecimal word 0x00 0x80 0x00 0x00.

The parameter RAM can be written using one of the two following methods: a direct read/write or a safeload write.

#### Direct Read/Write

The direct read/write method allows direct access to the program RAM and parameter RAM. This mode of operation is typically used when loading a new RAM using burst mode addressing. The clear registers bit in the core control register should be set to 0 using this mode to avoid any clicks or pops in the outputs. Note that this mode can be used during live program execution, but because there is no handshaking between the core and the control port, the parameter RAM is unavailable to the DSP core during control writes, resulting in clicks and pops in the audio stream.

#### Safeload Write

Up to five safeload registers can be loaded with the parameter RAM address/data. The data is then transferred to the requested address when the RAM is not busy. This method can be used for dynamic updates while live program material is playing through the ADAU1401. For example, a complete update of one biquad section can occur in one audio frame while the RAM is not busy. This method is not available for writing to the program RAM or control registers.

### DATA RAM

The ADAU1401 data RAM is used to store audio data words for processing. For the most part, this process is transparent to the user. The user cannot address this RAM space, which has a size of 2k words, directly from the control port.

Data RAM utilization should be considered when implementing blocks that require large amounts of data RAM space, such as delays. The SigmaDSP core processes delay times in one-sample increments; therefore, the total pool of delay available to the user equals 2048 multiplied by the sample period. For a  $f_s$  of 48 kHz, the pool of available delay is a maximum of about 43 ms. In practice, this much data memory is not available to the user because every block in a design uses a few data memory locations for its processing. In most DSP programs, this does not significantly impact the total delay time. The SigmaStudio compiler manages the data RAM and indicates if the number of addresses needed in the design exceeds the maximum available.

### READ/WRITE DATA FORMATS

The read/write formats of the control port are designed to be byte oriented. This allows easy programming of common microcontroller chips. To fit into a byte-oriented format, 0s are appended to the data fields before the MSB to extend the data-word to eight bits. For example, 28-bit words written to the parameter RAM are appended with four leading 0s to equal 32 bits (four bytes); 40-bit words written to the program RAM are not appended with 0s because they are already a full five bytes. These zero-padded data fields are appended to a 3-byte field consisting of a 7-bit chip address, a read/write bit, and an 11-bit RAM/register address. The control port knows how many data bytes to expect based on the address given in the first three bytes.

The total number of bytes for a single-location write command can vary from four bytes (for a control register write) to eight bytes (for a program RAM write). Burst mode can be used to fill contiguous register or RAM locations. A burst mode write begins by writing the address and data of the first RAM or register location to be written. Rather than ending the control port transaction (by issuing a stop command in I<sup>2</sup>C mode or by bringing the CLATCH signal high in SPI mode after the data-word), as would be done in a single-address write, the next data-word can be immediately written without specifying its address. The ADAU1401 control port auto-increments the address of each write even across the boundaries of the different RAMs and registers. Table 23 and Table 25 show examples of burst mode writes.

**Table 22. Parameter RAM Read/Write Format (Single Address)**

| Byte 0                          | Byte 1                 | Byte 2         | Byte 3             | Bytes[4:6]  |
|---------------------------------|------------------------|----------------|--------------------|-------------|
| chip_adr[6:0], $\overline{W}/R$ | 000000, param_adr[9:8] | param_adr[7:0] | 0000, param[27:24] | param[23:0] |

**Table 23. Parameter RAM Block Read/Write Format (Burst Mode)**

| Byte 0                          | Byte 1                 | Byte 2         | Byte 3             | Bytes[4:6]    | Bytes[7:10]   | Bytes[11:14] |
|---------------------------------|------------------------|----------------|--------------------|---------------|---------------|--------------|
| chip_adr[6:0], $\overline{W}/R$ | 000000, param_adr[9:8] | param_adr[7:0] | 0000, param[27:24] | param[23:0]   |               |              |
| ←param_adr→                     |                        |                |                    | param_adr + 1 | param_adr + 2 |              |

**Table 24. Program RAM Read/Write Format (Single Address)**

| Byte 0                          | Byte 1                | Byte 2        | Bytes[3:7] |
|---------------------------------|-----------------------|---------------|------------|
| chip_adr[6:0], $\overline{W}/R$ | 00000, prog_adr[10:8] | prog_adr[7:0] | prog[39:0] |

**Table 25. Program RAM Block Read/Write Format (Burst Mode)**

| Byte 0                          | Byte 1                | Byte 2        | Bytes[3:7] | Bytes[8:12]  | Bytes[13:17] |
|---------------------------------|-----------------------|---------------|------------|--------------|--------------|
| chip_adr[6:0], $\overline{W}/R$ | 00000, prog_adr[10:8] | prog_adr[7:0] | prog[39:0] |              |              |
| ←prog_adr→                      |                       |               |            | prog_adr + 1 | prog_adr + 2 |

**Table 26. Control Register Read/Write Format (Core, Serial Out 0, Serial Out 1)**

| Byte 0                          | Byte 1              | Byte 2       | Byte 3     | Byte 4    |
|---------------------------------|---------------------|--------------|------------|-----------|
| chip_adr[6:0], $\overline{W}/R$ | 0000, reg_adr[11:8] | reg_adr[7:0] | data[15:8] | data[7:0] |

**Table 27. Control Register Read/Write Format (RAM Configuration, Serial Input)**

| Byte 0                          | Byte 1              | Byte 2       | Byte 3    |
|---------------------------------|---------------------|--------------|-----------|
| chip_adr[6:0], $\overline{W}/R$ | 0000, reg_adr[11:8] | reg_adr[7:0] | data[7:0] |

**Table 28. Data Capture Register Write Format**

| Byte 0                          | Byte 1                       | Byte 2                | Byte 3                            | Byte 4   |
|---------------------------------|------------------------------|-----------------------|-----------------------------------|--|
| chip_adr[6:0], $\overline{W}/R$ | 0000, data_capture_adr[11:8] | data_capture_adr[7:0] | 000, progCount[10:6] <sup>1</sup> | progCount[5:0] <sup>1</sup> , regSel[1:0] <sup>2</sup> |

<sup>1</sup> progCount[10:0] is the value of the program counter when the data capture occurs (the table of values is generated by the SigmaStudio compiler).

<sup>2</sup> regSel[1:0] selects one of four registers (see the 2074 to 2075 (0x081A to 0x081B)—Data Capture Registers section).

**Table 29. Data Capture (Control Port Readback) Register Read Format**

| Byte 0                          | Byte 1                       | Byte 2                | Bytes[3:5] |
|---------------------------------|------------------------------|-----------------------|------------|
| chip_adr[6:0], $\overline{W}/R$ | 0000, data_capture_adr[11:8] | data_capture_adr[7:0] | data[23:0] |

**Table 30. Safeload Address Register Write Format**

| Byte 0                          | Byte 1                   | Byte 2            | Byte 3                 | Byte 4         |
|---------------------------------|--------------------------|-------------------|------------------------|----------------|
| chip_adr[6:0], $\overline{W}/R$ | 0000, safeload_adr[11:8] | safeload_adr[7:0] | 000000, param_adr[9:8] | param_adr[7:0] |

**Table 31. Safeload Data Register Write Format**

| Byte 0                          | Byte 1                   | Byte 2            | Byte 3   | Byte 4            | Bytes[5:7] |
|---------------------------------|--------------------------|-------------------|----------|-------------------|------------|
| chip_adr[6:0], $\overline{W}/R$ | 0000, safeload_adr[11:8] | safeload_adr[7:0] | 00000000 | 0000, data[27:24] | data[23:0] |



# CONTROL REGISTER MAP

Table 32. Register Map<sup>1</sup>

| Register Address |      | No. of Bytes | Name  | MSB  |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | LSB  |      | Default |      |      |      |      |      |      |      |      |      |      |      |        |        |        |
|------------------|------|--------------|---|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---------|------|------|------|------|------|------|------|------|------|------|------|--------|--------|--------|
| Hex              | Dec  |              |   | D31  | D30  | D29  | D28  | D27  | D26  | D25  | D24  | D23  | D22  | D21  | D20  | D19  | D18  | D17  | D16  | D15  | D14  |         |      |      |      |      |      |      |      |      |      |      |      |        |        |        |
| 0x0800           | 2048 | 4            | Interface 0[31:16]<br>Interface 0[15:0]                                   | 0    | 0    | 0    | 0    | IF27 | IF26 | IF25 | IF24 | IF23 | IF22 | IF21 | IF20 | IF19 | IF18 | IF17 | IF16 | IF15 | IF14 | IF13    | IF12 | IF11 | IF10 | IF09 | IF08 | IF07 | IF06 | IF05 | IF04 | IF03 | IF02 | IF01   | IF00   | 0x0000 |
| 0x0801           | 2049 | 4            | Interface 0[31:16]<br>Interface 0[15:0]                                   | 0    | 0    | 0    | 0    | IF27 | IF26 | IF25 | IF24 | IF23 | IF22 | IF21 | IF20 | IF19 | IF18 | IF17 | IF16 | IF15 | IF14 | IF13    | IF12 | IF11 | IF10 | IF09 | IF08 | IF07 | IF06 | IF05 | IF04 | IF03 | IF02 | IF01   | IF00   | 0x0000 |
| 0x0802           | 2050 | 4            | Interface 0[31:16]<br>Interface 0[15:0]                                   | 0    | 0    | 0    | 0    | IF27 | IF26 | IF25 | IF24 | IF23 | IF22 | IF21 | IF20 | IF19 | IF18 | IF17 | IF16 | IF15 | IF14 | IF13    | IF12 | IF11 | IF10 | IF09 | IF08 | IF07 | IF06 | IF05 | IF04 | IF03 | IF02 | IF01   | IF00   | 0x0000 |
| 0x0803           | 2051 | 4            | Interface 0[31:16]<br>Interface 0[15:0]                                   | 0    | 0    | 0    | 0    | IF27 | IF26 | IF25 | IF24 | IF23 | IF22 | IF21 | IF20 | IF19 | IF18 | IF17 | IF16 | IF15 | IF14 | IF13    | IF12 | IF11 | IF10 | IF09 | IF08 | IF07 | IF06 | IF05 | IF04 | IF03 | IF02 | IF01   | IF00   | 0x0000 |
| 0x0804           | 2052 | 4            | Interface 0[31:16]<br>Interface 0[15:0]                                   | 0    | 0    | 0    | 0    | IF27 | IF26 | IF25 | IF24 | IF23 | IF22 | IF21 | IF20 | IF19 | IF18 | IF17 | IF16 | IF15 | IF14 | IF13    | IF12 | IF11 | IF10 | IF09 | IF08 | IF07 | IF06 | IF05 | IF04 | IF03 | IF02 | IF01   | IF00   | 0x0000 |
| 0x0805           | 2053 | 4            | Interface 0[31:16]<br>Interface 0[15:0]                                   | 0    | 0    | 0    | 0    | IF27 | IF26 | IF25 | IF24 | IF23 | IF22 | IF21 | IF20 | IF19 | IF18 | IF17 | IF16 | IF15 | IF14 | IF13    | IF12 | IF11 | IF10 | IF09 | IF08 | IF07 | IF06 | IF05 | IF04 | IF03 | IF02 | IF01   | IF00   | 0x0000 |
| 0x0806           | 2054 | 4            | Interface 0[31:16]<br>Interface 0[15:0]                                   | 0    | 0    | 0    | 0    | IF27 | IF26 | IF25 | IF24 | IF23 | IF22 | IF21 | IF20 | IF19 | IF18 | IF17 | IF16 | IF15 | IF14 | IF13    | IF12 | IF11 | IF10 | IF09 | IF08 | IF07 | IF06 | IF05 | IF04 | IF03 | IF02 | IF01   | IF00   | 0x0000 |
| 0x0807           | 2055 | 4            | Interface 0[31:16]<br>Interface 0[15:0]                                   | 0    | 0    | 0    | 0    | IF27 | IF26 | IF25 | IF24 | IF23 | IF22 | IF21 | IF20 | IF19 | IF18 | IF17 | IF16 | IF15 | IF14 | IF13    | IF12 | IF11 | IF10 | IF09 | IF08 | IF07 | IF06 | IF05 | IF04 | IF03 | IF02 | IF01   | IF00   | 0x0000 |
| 0x0808           | 2056 | 2            | GPIO pin setting  | 0    | 0    | 0    | 0    | MP11 | MP10 | MP09 | MP08 | MP07 | MP06 | MP05 | MP04 | MP03 | MP02 | MP01 | MP00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x0809           | 2057 | 2            | Auxiliary ADC Data 0  | 0    | 0    | 0    | 0    | AA11 | AA10 | AA09 | AA08 | AA07 | AA06 | AA05 | AA04 | AA03 | AA02 | AA01 | AA00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x080A           | 2058 | 2            | Auxiliary ADC Data 1  | 0    | 0    | 0    | 0    | AA11 | AA10 | AA09 | AA08 | AA07 | AA06 | AA05 | AA04 | AA03 | AA02 | AA01 | AA00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x080B           | 2059 | 2            | Auxiliary ADC Data 2  | 0    | 0    | 0    | 0    | AA11 | AA10 | AA09 | AA08 | AA07 | AA06 | AA05 | AA04 | AA03 | AA02 | AA01 | AA00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x080C           | 2060 | 2            | Auxiliary ADC Data 3  | 0    | 0    | 0    | 0    | AA11 | AA10 | AA09 | AA08 | AA07 | AA06 | AA05 | AA04 | AA03 | AA02 | AA01 | AA00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x080D           | 2061 | 5            | Reserved[39:32]<br>Reserved[31:16]<br>Reserved[15:0]                      | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD    | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD   | 0x0000 |        |
| 0x080E           | 2062 | 5            | Reserved[39:32]<br>Reserved[31:16]<br>Reserved[15:0]                      | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD    | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD   | 0x0000 |        |
| 0x080F           | 2063 | 5            | Reserved[39:32]<br>Reserved[31:16]<br>Reserved[15:0]                      | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD    | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD   | 0x0000 |        |
| 0x0810           | 2064 | 5            | Safeload Data 0[39:32]<br>Safeload Data 0[31:16]<br>Safeload Data 0[15:0] | SD31 | SD30 | SD29 | SD28 | SD27 | SD26 | SD25 | SD24 | SD23 | SD22 | SD21 | SD20 | SD19 | SD18 | SD17 | SD16 | SD15 | SD14 | SD13    | SD12 | SD11 | SD10 | SD09 | SD08 | SD07 | SD06 | SD05 | SD04 | SD03 | SD02 | SD01   | SD00   | 0x0000 |
| 0x0811           | 2065 | 5            | Safeload Data 1[39:32]<br>Safeload Data 1[31:16]<br>Safeload Data 1[15:0] | SD31 | SD30 | SD29 | SD28 | SD27 | SD26 | SD25 | SD24 | SD23 | SD22 | SD21 | SD20 | SD19 | SD18 | SD17 | SD16 | SD15 | SD14 | SD13    | SD12 | SD11 | SD10 | SD09 | SD08 | SD07 | SD06 | SD05 | SD04 | SD03 | SD02 | SD01   | SD00   | 0x0000 |
| 0x0812           | 2066 | 5            | Safeload Data 2[39:32]<br>Safeload Data 2[31:16]<br>Safeload Data 2[15:0] | SD31 | SD30 | SD29 | SD28 | SD27 | SD26 | SD25 | SD24 | SD23 | SD22 | SD21 | SD20 | SD19 | SD18 | SD17 | SD16 | SD15 | SD14 | SD13    | SD12 | SD11 | SD10 | SD09 | SD08 | SD07 | SD06 | SD05 | SD04 | SD03 | SD02 | SD01   | SD00   | 0x0000 |
| 0x0813           | 2067 | 5            | Safeload Data 3[39:32]<br>Safeload Data 3[31:16]<br>Safeload Data 3[15:0] | SD31 | SD30 | SD29 | SD28 | SD27 | SD26 | SD25 | SD24 | SD23 | SD22 | SD21 | SD20 | SD19 | SD18 | SD17 | SD16 | SD15 | SD14 | SD13    | SD12 | SD11 | SD10 | SD09 | SD08 | SD07 | SD06 | SD05 | SD04 | SD03 | SD02 | SD01   | SD00   | 0x0000 |
| 0x0814           | 2068 | 5            | Safeload Data 4[39:32]<br>Safeload Data 4[31:16]<br>Safeload Data 4[15:0] | SD31 | SD30 | SD29 | SD28 | SD27 | SD26 | SD25 | SD24 | SD23 | SD22 | SD21 | SD20 | SD19 | SD18 | SD17 | SD16 | SD15 | SD14 | SD13    | SD12 | SD11 | SD10 | SD09 | SD08 | SD07 | SD06 | SD05 | SD04 | SD03 | SD02 | SD01   | SD00   | 0x0000 |
| 0x0815           | 2069 | 2            | Safeload Address 0  | 0    | 0    | 0    | 0    | SA11 | SA10 | SA09 | SA08 | SA07 | SA06 | SA05 | SA04 | SA03 | SA02 | SA01 | SA00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x0816           | 2070 | 2            | Safeload Address 1  | 0    | 0    | 0    | 0    | SA11 | SA10 | SA09 | SA08 | SA07 | SA06 | SA05 | SA04 | SA03 | SA02 | SA01 | SA00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x0817           | 2071 | 2            | Safeload Address 2  | 0    | 0    | 0    | 0    | SA11 | SA10 | SA09 | SA08 | SA07 | SA06 | SA05 | SA04 | SA03 | SA02 | SA01 | SA00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x0818           | 2072 | 2            | Safeload Address 3  | 0    | 0    | 0    | 0    | SA11 | SA10 | SA09 | SA08 | SA07 | SA06 | SA05 | SA04 | SA03 | SA02 | SA01 | SA00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x0819           | 2073 | 2            | Safeload Address 4  | 0    | 0    | 0    | 0    | SA11 | SA10 | SA09 | SA08 | SA07 | SA06 | SA05 | SA04 | SA03 | SA02 | SA01 | SA00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x081A           | 2074 | 2            | Data Capture 0  | 0    | 0    | 0    | 0    | PC09 | PC08 | PC07 | PC06 | PC05 | PC04 | PC03 | PC02 | PC01 | PC00 | RS01 | RS00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        | 0x0000 |        |
| 0x081B           | 2075 | 2            | Data Capture 1  | 0    | 0    | 0    | 0    | PC09 | PC08 | PC07 | PC06 | PC05 | PC04 | PC03 | PC02 | PC01 | PC00 | RS01 | RS00 |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        |        | 0x0000 |
| 0x081C           | 2076 | 2            | DSP core control  | RSVD | RSVD | GD1  | GD0  | RSVD | RSVD | RSVD | AACW | GPCW | IFCW | IST  | ADM  | DAM  | CR   | SR1  | SR0  |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        | 0x0000 |        |
| 0x081D           | 2077 | 1            | Reserved  | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD |      |      |         |      |      |      |      |      |      |      |      |      |      |      |        | 0x00   |        |
| 0x081E           | 2078 | 2            | Serial output control   | 0    | 0    | OLRP | OBP  | M/S  | OBF1 | OBF0 | OLF1 | OLF0 | FST  | TDM  | MSB2 | MSB1 | MSB0 | OWL1 | OWL0 |      |      |         |      |      |      |      |      |      |      |      |      |      |      | 0x0000 |        |        |
| 0x081F           | 2079 | 1            | Serial input control  |      |      |      |      |      |      |      |      | 0    | 0    | 0    | ILP  | IBP  | M2   | M1   | M0   |      |      |         |      |      |      |      |      |      |      |      |      |      |      | 0x00   |        |        |

| Register Address |      | No. of Bytes | Name                            | MSB  |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       | LSB    |  | Default |
|------------------|------|--------------|---------------------------------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--|---------|
| Hex              | Dec  |              |                                 | D31  | D30  | D29  | D28  | D27  | D26  | D25  | D24  | D39   | D38   | D37   | D36   | D35   | D34   | D33   | D32   |        |  |         |
|                  |      |              |                                 | D15  | D14  | D13  | D12  | D11  | D10  | D9   | D8   | D7    | D6    | D5    | D4    | D3    | D2    | D1    | D0    |        |  |         |
| 0x0820           | 2080 | 3            | MP Pin Config. 0[23:16]         |      |      |      |      |      |      |      |      | MP53  | MP52  | MP51  | MP50  | MP43  | MP42  | MP41  | MP40  | 0x00   |  |         |
|                  |      |              | MP Pin Config. 0[15:0]          | MP33 | MP32 | MP31 | MP30 | MP23 | MP22 | MP21 | MP20 | MP13  | MP12  | MP11  | MP10  | MP03  | MP02  | MP01  | MP00  | 0x0000 |  |         |
| 0x0821           | 2081 | 3            | MP Pin Config. 1[23:16]         |      |      |      |      |      |      |      |      | MP113 | MP112 | MP111 | MP110 | MP103 | MP102 | MP101 | MP100 | 0x00   |  |         |
|                  |      |              | MP Pin Config. 1[15:0]          | MP93 | MP92 | MP91 | MP90 | MP83 | MP82 | MP81 | MP80 | MP73  | MP72  | MP71  | MP70  | MP63  | MP62  | MP61  | MP60  | 0x0000 |  |         |
| 0x0822           | 2082 | 2            | Auxiliary ADC and power control | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | FIL1 | FIL0 | AAPD  | VBPD  | VRPD  | RSVD  | D0PD  | D1PD  | D2PD  | D3PD  | 0x0000 |  |         |
| 0x0823           | 2083 | 2            | Reserved                        | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | 0x0000 |  |         |
| 0x0824           | 2084 | 2            | Auxiliary ADC enable            | AAEN | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | 0x0000 |  |         |
| 0x0825           | 2085 | 2            | Reserved                        | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | 0x0000 |  |         |
| 0x0826           | 2086 | 2            | Oscillator power-down           | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | OPD   | RSVD  | RSVD  | 0x0000 |  |         |
| 0x0827           | 2087 | 2            | DAC setup                       | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | RSVD  | DS1   | DS0   | 0x0000 |  |         |

<sup>1</sup> Shading indicates that registers do not fill these locations, so control bits do not exist in these locations.

## CONTROL REGISTER DETAILS

### 2048 TO 2055 (0x0800 TO 0x0807)—INTERFACE REGISTERS

The interface registers are used in self-boot mode to save parameters that need to be written to the external EEPROM. The ADAU1401 then recalls these parameters from the EEPROM after the next reset or power-up. Therefore, system parameters such as volume and EQ settings can be saved during power-down and recalled the next time the system is turned on.

There are eight 32-bit interface registers, which allow eight 28-bit (plus zero-padding) parameters to be saved. The parameters to

be saved in these registers are selected in the graphical programming tools. These registers are updated with their corresponding parameter RAM data once per sample period.

An edge, which can be set to be either rising or falling, triggers the ADAU1401 to write the current contents of the interface registers to the EEPROM. See the Self-Boot section for details.

The user can write directly to the interface registers after the interface registers control port write mode (IFCW) in the DSP core control register has been set. In this mode, the data in the registers is written from the control port, not from the DSP core.

**Table 33. Interface Register Bit Map**

| D31<br>D15 | D30<br>D14 | D29<br>D13 | D28<br>D12 | D27<br>D11 | D26<br>D10 | D25<br>D9 | D24<br>D8 | D23<br>D7 | D22<br>D6 | D21<br>D5 | D20<br>D4 | D19<br>D3 | D18<br>D2 | D17<br>D1 | D16<br>D0 | Default |
|------------|------------|------------|------------|------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---------|
| 0          | 0          | 0          | 0          | IF27       | IF26       | IF25      | IF24      | IF23      | IF22      | IF21      | IF20      | IF19      | IF18      | IF17      | IF16      | 0x0000  |
| IF15       | IF14       | IF13       | IF12       | IF11       | IF10       | IF09      | IF08      | IF07      | IF06      | IF05      | IF04      | IF03      | IF02      | IF01      | IF00      | 0x0000  |

**Table 34.**

| Bit Name | Description                         |
|----------|-------------------------------------|
| IF[27:0] | Interface register 28-bit parameter |

**2056 (0x808)—GPIO PIN SETTING REGISTER**

This register allows the user to set the GPIO pins through the control port. High or low settings can be directly written to or

read from this register after setting the GPIO pin setting register control port write mode (GPCW) in the core control register. This register is updated once every LRCLK frame ( $1/f_s$ ).

**Table 35. GPIO Pin Setting Register Bit Map**

| D15 | D14 | D13 | D12 | D11  | D10  | D9   | D8   | D7   | D6   | D5   | D4   | D3   | D2   | D1   | D0   | Default |
|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|---------|
| 0   | 0   | 0   | 0   | MP11 | MP10 | MP09 | MP08 | MP07 | MP06 | MP05 | MP04 | MP03 | MP02 | MP01 | MP00 | 0x0000  |

**Table 36.**

| Bit Name | Description   |
|----------|---|
| MP[11:0] | Setting of multipurpose pin when controlled through SPI or I <sup>2</sup> C |

**2057 TO 2060 (0x809 TO 0x80C)—AUXILIARY ADC DATA REGISTERS**

These registers hold the data generated by the 4-channel auxiliary ADC. The ADCs have eight bits of precision and can be extended to 12 bits if filtering is selected via Bits FIL[1:0] of the auxiliary ADC and power control register. The SigmaDSP program reads this data as a 1.11 format data-word with a range of 0 to 1.0. This data-word is mapped to the 5.23 format

parameter word with the four MSBs and 12 LSBs set to 0. A full-scale code of 255 results in a value of 1.0. These registers can be written to directly if the auxiliary ADC data registers control port write mode (AACW) bit is set in the DSP core control register.

**Table 37. Auxiliary ADC Data Register Bit Map**

| D15 | D14 | D13 | D12 | D11  | D10  | D9   | D8   | D7   | D6   | D5   | D4   | D3   | D2   | D1   | D0   | Default |
|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|---------|
| 0   | 0   | 0   | 0   | AA11 | AA10 | AA09 | AA08 | AA07 | AA06 | AA05 | AA04 | AA03 | AA02 | AA01 | AA00 | 0x0000  |

**Table 38.**

| Bit Name | Description                          |
|----------|--------------------------------------|
| AA[11:0] | Auxiliary ADC output data, MSB first |

**2064 TO 2068 (0x0810 TO 0x814)—SAFELOAD DATA REGISTERS**

Many applications require real-time microcontroller control of signal processing parameters, such as filter coefficients, mixer gains, multichannel virtualizing parameters, or dynamics processing curves. When controlling a biquad filter, for example, all of the parameters must be updated at the same time. Doing so prevents the filter from executing with a mix of old and new coefficients for one or two audio frames, thus avoiding temporary instability and transients that may take a long time to decay. To accomplish this, the ADAU1401 uses safeload data registers to simultaneously load a set of five 28-bit values to the desired parameter RAM address. Five registers are used because a biquad filter uses five coefficients and, as previously mentioned, it is desirable to do a complete update in one transaction.

The first step in performing a safeload operation is writing the parameter address to one of the safeload address registers (2069 to 2073). The 10-bit data-word to be written is the address in parameter RAM to which the safeload is being performed. After this address is written, the 28-bit data-word can be written to the corresponding safeload data register (2064 to 2068).

The data formats for these writes are detailed in Table 30 and Table 31. Table 39 shows how each of the five address registers maps to its corresponding data register.

After the address and data registers are loaded, set the initiate safeload transfer bit in the core control register to initiate the loading into RAM. Each of the five safeload registers takes one of the 1024 core instructions to load into the parameter RAM. The total program lengths should, therefore, be limited to 1019 cycles (1024 minus 5) to ensure that the SigmaDSP core always has at least five cycles available. The safeload is guaranteed to occur within one LRCLK period (21 μs for a fs of 48 kHz) of the initiate safeload transfer bit being set.

The safeload logic automatically sends data to be loaded into RAM from only those safeload registers that have been written to since the last safeload operation. For example, if two parameters are to be updated in the RAM, only two of the five safeload registers must be written. When the initiate safeload transfer bit is asserted, only data from those two registers are sent to the RAM; the other three registers are not sent to the RAM and may hold old or invalid data.

**Table 39. Safeload Address and Data Register Mapping**

| Safeload Register | Safeload Address Register | Safeload Data Register |
|-------------------|---------------------------|------------------------|
| 0                 | 2069                      | 2064                   |
| 1                 | 2070                      | 2065                   |
| 2                 | 2071                      | 2066                   |
| 3                 | 2072                      | 2067                   |
| 4                 | 2073                      | 2068                   |

**Table 40. Safeload Registers Bit Map**

| D31<br>D15   | D30<br>D14   | D29<br>D13   | D28<br>D12   | D27<br>D11   | D26<br>D10   | D25<br>D9    | D24<br>D8    | D39<br>D23<br>D7     | D38<br>D22<br>D6     | D37<br>D21<br>D5     | D36<br>D20<br>D4     | D35<br>D19<br>D3     | D34<br>D18<br>D2     | D33<br>D17<br>D1     | D32<br>D16<br>D0     | Default                  |
|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|--------------------------|
| SD31<br>SD15 | SD30<br>SD14 | SD29<br>SD13 | SD28<br>SD12 | SD27<br>SD11 | SD26<br>SD10 | SD25<br>SD09 | SD24<br>SD08 | SD39<br>SD23<br>SD07 | SD38<br>SD22<br>SD06 | SD37<br>SD21<br>SD05 | SD36<br>SD20<br>SD04 | SD35<br>SD19<br>SD03 | SD34<br>SD18<br>SD02 | SD33<br>SD17<br>SD01 | SD32<br>SD16<br>SD00 | 0x00<br>0x0000<br>0x0000 |

**Table 41.**

| Bit Name | Description   |
|----------|---|
| SD[39:0] | Safeload Data. Data (program, parameters, register contents) to be loaded into the RAMs or registers. |

**2069 TO 2073 (0x0815 TO 0x819)—SAFELOAD ADDRESS REGISTERS**

**Table 42. Safeload Address Registers Bit Map**

| D15 | D14 | D13 | D12 | D11  | D10  | D9   | D8   | D7   | D6   | D5   | D4   | D3   | D2   | D1   | D0   | Default |
|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|---------|
| 0   | 0   | 0   | 0   | SA11 | SA10 | SA09 | SA08 | SA07 | SA06 | SA05 | SA04 | SA03 | SA02 | SA01 | SA00 | 0x0000  |

**Table 43.**

| Bit Name | Description  |
|----------|--|
| SA[11:0] | Safeload Address. Address of data that is to be loaded into the RAMs or registers. |

**2074 TO 2075 (0x081A TO 0x081B)—DATA CAPTURE REGISTERS**

The ADAU1401 data capture feature allows the data at any node in the signal processing flow to be sent to one of two readable registers. This feature is useful for monitoring and displaying information about internal signal levels or compressor/limiter activity.

For each of the data capture registers, a capture count and a register select must be set. The capture count is a number between 0 and 1023 that corresponds to the program step number where the capture is to occur. The register select field programs one of four registers in the DSP core that transfers this information to the data capture register when the program counter reaches this step.

The captured data is in 5.19, twos complement data format, which comes from the internal 5.23 data-word with the four LSBs truncated.

The data that must be written to set up the data capture is a concatenation of the 10-bit program count index with the 2-bit register select field. The capture count and register select values that correspond to the desired point to be monitored in the signal processing flow can be found in a file output from the program compiler. The capture registers can be accessed by reading from Location 2074 and Location 2075. The format for writing and reading to the data capture registers is shown in Table 28 and Table 29.

**Table 44. Safeload Data Registers Bit Map**

| D15 | D14 | D13 | D12 | D11  | D10  | D9   | D8   | D7   | D6   | D5   | D4   | D3   | D2   | D1   | D0   | Default |
|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|---------|
| 0   | 0   | 0   | 0   | PC09 | PC08 | PC07 | PC06 | PC05 | PC04 | PC03 | PC02 | PC01 | PC00 | RS01 | RS00 | 0x0000  |

**Table 45.**

| Bit Name | Description  |   |
|----------|--|---|
| PC[9:0]  | 10-bit program counter address                                   |   |
| RS[1:0]  | Select the register to be transferred to the data capture output |   |
|          | <b>RS[1:0]</b>   | <b>Register</b>                         |
|          | 00   | Multiplier X input (Mult_X_input)       |
|          | 01   | Multiplier Y input (Mult_Y_input)       |
|          | 10   | Multiplier-accumulator output (MAC_out) |
| 11       | Accumulator feedback (Accum_fback)                               |   |

**2076 (0x081C)—DSP CORE CONTROL REGISTER**

**Table 46. DSP Core Control Register Bit Map**

| D15  | D14  | D13 | D12 | D11  | D10  | D9   | D8   | D7   | D6   | D5  | D4  | D3  | D2 | D1  | D0  | Default |
|------|------|-----|-----|------|------|------|------|------|------|-----|-----|-----|----|-----|-----|---------|
| RSVD | RSVD | GD1 | GD0 | RSVD | RSVD | RSVD | AACW | GPCW | IFCW | IST | ADM | DAM | CR | SR1 | SR0 | 0x0000  |

**Table 47. DSP Core Control Register**

| Bit Name                         | Description   |
|----------------------------------|---|
| GD[1:0]                          | GPIO Debounce Control. Sets debounce time of multipurpose pins that are set as GPIO inputs.   |
|                                  | <b>GD[1:0]</b> <b>Time (ms)</b>   |
|                                  | 00                      20  |
|                                  | 01                      40  |
|                                  | 10                      10  |
| 11                      5        |   |
| AACW                             | Auxiliary ADC Data Registers Control Port Write Mode. Setting this bit allows data to be written directly to the auxiliary ADC data registers (2057 to 2060) from the control port. When this bit is set, the auxiliary ADC data registers ignore the settings on the multipurpose pins.  |
| GPCW                             | GPIO Pin Setting Register Control Port Write Mode. When this bit is set, the GPIO pin setting register (2056) can be written to directly from the control port and this register ignores the input settings on the multipurpose pins.   |
| IFCW                             | Interface Registers Control Port Write Mode. When this bit is set, data can be written directly to the interface registers (2048 to 2055) from the control port. In that state, the interface registers are not written from the SigmaDSP program.  |
| IST                              | Initiate Safeload Transfer. Setting this bit to 1 initiates a safeload transfer to the parameter RAM. This bit is automatically cleared when the operation is complete. There are five safeload register pairs (address/data); only those registers that have been written since the last safeload event are transferred to the parameter RAM.  |
| ADM                              | Mute ADCs. This bit mutes the output of the ADCs. The bit defaults to 0 and is active low; therefore, it must be set to 1 to transmit audio signals from the ADCs.  |
| DAM                              | Mute DACs. This bit mutes the output of the DACs. The bit defaults to 0 and is active low; therefore, it must be set to 1 to transmit audio signals from the DACs.  |
| CR                               | Clear Internal Registers to 0. This bit defaults to 0 and is active low. It must be set to 1 for a signal to pass through the SigmaDSP core.  |
| SR[1:0]                          | Sample Rate. These bits set the number of DSP instructions for every sample and the sample rate at which the ADAU1401 operates. At the default setting of 1×, there are 1024 instructions per audio sample. This setting should be used with sample rates such as 48 kHz and 44.1 kHz.<br>At the 2× setting, the number of instructions per frame is halved to 512 and the ADCs and DACs nominally run at a 96 kHz sample rate.<br>At the 4× setting, there are 256 instructions per cycle and the converters run at a 192 kHz sample rate. |
|                                  | <b>SR[1:0]</b> <b>Setting</b>   |
|                                  | 00                      1× (1024 instructions)  |
|                                  | 01                      2× (512 instructions)   |
|                                  | 10                      4× (256 instructions)   |
| 11                      Reserved |   |



**2078 (0x081E)—SERIAL OUTPUT CONTROL REGISTER****Table 48. Serial Output Control Register Bit Map**

| D15 | D14 | D13  | D12 | D11 | D10  | D9   | D8   | D7   | D6  | D5  | D4   | D3   | D2   | D1   | D0   | Default |
|-----|-----|------|-----|-----|------|------|------|------|-----|-----|------|------|------|------|------|---------|
| 0   | 0   | OLRP | OBP | M/S | OBF1 | OBF0 | OLF1 | OLF0 | FST | TDM | MSB2 | MSB1 | MSB0 | OWL1 | OWL0 | 0x0000  |

**Table 49.**

| Bit Name | Description  |
|----------|--|
| OLRP     | OUTPUT_LRCLK Polarity. When this bit is set to 0, the left-channel data is clocked when OUTPUT_LRCLK is low and the right-channel data is clocked when OUTPUT_LRCLK is high. When this bit is set to 1, the right-channel data is clocked when OUTPUT_LRCLK is low and the left-channel data is clocked when OUTPUT_LRCLK is high. |
| OBP      | OUTPUT_BCLK Polarity. This bit controls on which edge of the bit clock the output data is clocked. Data changes on the falling edge of OUTPUT_BCLK when this bit is set to 0 and on the rising edge when this bit is set to 1.   |
| M/S      | Master/Slave. This bit sets whether the output port is a clock master or slave. The default setting is slave; on power-up, the OUTPUT_BCLK and OUTPUT_LRCLK pins are set as inputs until this bit is set to 1, at which time they become clock outputs.  |
| OBF[1:0] | OUTPUT_BCLK Frequency (Master Mode Only). When the output port is being used as a clock master, these bits set the frequency of the output bit clock, which is divided down from an internal $1024 \times f_s$ clock (49.152 MHz for a $f_s$ of 48 kHz).   |
|          | <b>OBF[1:0]</b> <b>Setting</b>   |
|          | 00              Internal clock/16  |
|          | 01              Internal clock/8   |
|          | 10              Internal clock/4   |
|          | 11              Internal clock/2   |
| OLF[1:0] | OUTPUT_LRCLK Frequency (Master Mode Only). When the output port is used as a clock master, these bits set the frequency of the output word clock on the OUTPUT_LRCLK pins, which is divided down from an internal $1024 \times f_s$ clock (49.152 MHz for a $f_s$ of 48 kHz).  |
|          | <b>OLF[1:0]</b> <b>Setting</b>   |
|          | 00              Internal clock/1024  |
|          | 01              Internal clock/512   |
|          | 10              Internal clock/256   |
|          | 11              Reserved   |
| FST      | Frame Sync Type. This bit sets the type of signal on the OUTPUT_LRCLK pins. When this bit is set to 0, the signal is a word clock with a 50% duty cycle; when this bit is set to 1, the signal is a pulse with a duration of one bit clock at the beginning of the data frame.   |
| TDM      | TDM Enable. Setting this bit to 1 changes the output port from four serial stereo outputs to a single 8-channel TDM output stream on the SDATA_OUT0 pin (MP6).   |
| MSB[2:0] | MSB Position. These three bits set the position of the MSB of data with respect to the LRCLK edge. The data output of the ADAU1401 is always MSB first.  |
|          | <b>MSB[2:0]</b> <b>Setting</b>   |
|          | 000            Delay by 1  |
|          | 001            Delay by 0  |
|          | 010            Delay by 8  |
|          | 011            Delay by 12   |
|          | 100            Delay by 16   |
|          | 101            Reserved  |
|          | 111            Reserved  |
| OWL[1:0] | Output Word Length. These bits set the word length of the output data-word. All bits following the LSB are set to 0.   |
|          | <b>OWL[1:0]</b> <b>Setting</b>   |
|          | 00            24 bits  |
|          | 01            20 bits  |
|          | 10            16 bits  |
|          | 11            Reserved   |

**2079 (0x081F)—SERIAL INPUT CONTROL REGISTER**

**Table 50. Serial Input Control Register Bit Map**

| D7 | D6 | D5 | D4  | D3  | D2 | D1 | D0 | Default |
|----|----|----|-----|-----|----|----|----|---------|
| 0  | 0  | 0  | ILP | IBP | M2 | M1 | M0 | 0x00    |

**Table 51.**

| Bit Name | Description   |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
|----------|---|--------|---------|-----|------------------|-----|----------------|-----|-----|-----|--------------------------|-----|--------------------------|-----|--------------------------|-----|--------------------------|-----|----------|
| ILP      | INPUT_LRCLK Polarity. When this bit is set to 0, the left-channel data on the SDATA_INx pins is clocked when INPUT_LRCLK is low and the right-channel data is clocked when INPUT_LRCLK is high. When this bit is set to 1, the clocking of these channels is reversed. In TDM mode when this bit is set to 0, data is clocked in, starting with the next appropriate BCLK edge (set in Bit 3 of this register) after a falling edge on the INPUT_LRCLK pin. When this bit is set to 1 and the device is running in TDM mode, the input data is valid on the BCLK edge after a rising edge on the word clock (INPUT_LRCLK). INPUT_LRCLK can also operate with a pulse input, rather than a clock. In this case, the first edge of the pulse is used by the ADAU1401 to start the data frame. When this polarity bit is set to 0, a low pulse should be used; when the bit is set to 1, a high pulse should be used.  |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| IBP      | INPUT_BCLK Polarity. This bit controls on which edge of the bit clock the input data changes and on which edge it is clocked. Data changes on the falling edge of INPUT_BCLK when this bit is set to 0 and on the rising edge when this bit is set at 1.  |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| M[2:0]   | <p>Serial Input Mode. These two bits control the data format that the input port expects to receive. Bit 3 and Bit 4 of this control register override the settings of Bits[2:0]; therefore, all four bits must be changed together for proper operation in some modes. The clock diagrams for these modes are shown in Figure 32, Figure 33, and Figure 34. Note that for left-justified and right-justified modes, the LRCLK polarity is high and then low, which is the opposite of the default setting for ILP.</p> <p>When these bits are set to accept a TDM input, the ADAU1401 data starts after the edge defined by ILP. The ADAU1401 TDM data stream should be input on Pin SDATA_IN0. Figure 35 shows a TDM stream with a high-to-low triggered LRCLK and data changing on the falling edge of the BCLK. The ADAU1401 expects the MSB of each data slot to be delayed by one BCLK from the beginning of the slot, as it would in stereo I<sup>2</sup>S format. In TDM mode, Channel 0 to Channel 3 are in the first half of the frame, and Channel 4 to Channel 7 are in the second half. Figure 36 shows an example of a TDM stream running with a pulse word clock, which is used to interface to ADI codecs in auxiliary mode. To work in this mode with either the input or output serial ports, set the ADAU1401 to begin the frame on the rising edge of LRCLK, to change data on the falling edge of BCLK, and to delay the MSB position from the start of the word clock by one BCLK.</p> <table border="1"> <thead> <tr> <th>M[2:0]</th> <th>Setting</th> </tr> </thead> <tbody> <tr> <td>000</td> <td>I<sup>2</sup>S</td> </tr> <tr> <td>001</td> <td>Left-justified</td> </tr> <tr> <td>010</td> <td>TDM</td> </tr> <tr> <td>011</td> <td>Right-justified, 24 bits</td> </tr> <tr> <td>100</td> <td>Right-justified, 20 bits</td> </tr> <tr> <td>101</td> <td>Right-justified, 18 bits</td> </tr> <tr> <td>110</td> <td>Right-justified, 16 bits</td> </tr> <tr> <td>111</td> <td>Reserved</td> </tr> </tbody> </table> | M[2:0] | Setting | 000 | I <sup>2</sup> S | 001 | Left-justified | 010 | TDM | 011 | Right-justified, 24 bits | 100 | Right-justified, 20 bits | 101 | Right-justified, 18 bits | 110 | Right-justified, 16 bits | 111 | Reserved |
| M[2:0]   | Setting   |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| 000      | I <sup>2</sup> S  |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| 001      | Left-justified  |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| 010      | TDM   |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| 011      | Right-justified, 24 bits  |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| 100      | Right-justified, 20 bits  |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| 101      | Right-justified, 18 bits  |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| 110      | Right-justified, 16 bits  |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |
| 111      | Reserved  |        |         |     |                  |     |                |     |     |     |                          |     |                          |     |                          |     |                          |     |          |

**2080 TO 2081 (0x0820 TO 0x0821)—MULTIPURPOSE PIN CONFIGURATION REGISTERS**

Each multipurpose pin can be set to different functions from these registers (2080 to 2081). The two 3-byte registers are broken up into 12 4-bit (nibble) sections that each control a different MP pin. Table 54 lists the function of each nibble setting within the MP pin configuration registers. The MSB of

each pin's 4-bit configuration inverts the input to or output from the pin. The internal pull-up resistor (approximately 10 kΩ) of each MP pin is enabled when it is set as a digital input (either a GPIO input or a serial data port input).

**Table 52. Register 2080 Bit Map**

| D15  | D14  | D13  | D12  | D11  | D10  | D9   | D8   | D23<br>D7    | D22<br>D6    | D21<br>D5    | D20<br>D4    | D19<br>D3    | D18<br>D2    | D17<br>D1    | D16<br>D0    | Default        |
|------|------|------|------|------|------|------|------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|----------------|
| MP33 | MP32 | MP31 | MP30 | MP23 | MP22 | MP21 | MP20 | MP53<br>MP13 | MP52<br>MP12 | MP51<br>MP11 | MP50<br>MP10 | MP43<br>MP03 | MP42<br>MP02 | MP41<br>MP01 | MP40<br>MP00 | 0x00<br>0x0000 |

**Table 53. Register 2081 Bit Map**

| D15  | D14  | D13  | D12  | D11  | D10  | D9   | D8   | D23<br>D7     | D22<br>D6     | D21<br>D5     | D20<br>D4     | D19<br>D3     | D18<br>D2     | D17<br>D1     | D16<br>D0     | Default        |
|------|------|------|------|------|------|------|------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|----------------|
| MP93 | MP92 | MP91 | MP90 | MP83 | MP82 | MP81 | MP80 | MP113<br>MP73 | MP112<br>MP72 | MP111<br>MP71 | MP110<br>MP70 | MP103<br>MP63 | MP102<br>MP62 | MP101<br>MP61 | MP100<br>MP60 | 0x00<br>0x0000 |

**Table 54.**

| Bit Name | Description   |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
|----------|---|----------|---------|------|------------------------------------|------|----------|------|----------|------|--|------|--------------------------------|------|----------------------|------|----------------------------------|------|--------------------------------|------|-----|------|----------|------|----------|------|---------------------------------|------|-----------------------|------|-------------|------|-------------------------|------|-----------------------|
| MPx[3:0] | Set the function of each multipurpose pin.  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
|          | <table border="1"> <thead> <tr> <th>MPx[3:0]</th> <th>Setting</th> </tr> </thead> <tbody> <tr> <td>1111</td> <td>Auxiliary ADC input (see Table 63)</td> </tr> <tr> <td>1110</td> <td>Reserved</td> </tr> <tr> <td>1101</td> <td>Reserved</td> </tr> <tr> <td>1100</td> <td>Serial data port—inverted (see Table 65)</td> </tr> <tr> <td>1011</td> <td>Open-collector output—inverted</td> </tr> <tr> <td>1010</td> <td>GPIO output—inverted</td> </tr> <tr> <td>1001</td> <td>GPIO input, no debounce—inverted</td> </tr> <tr> <td>1000</td> <td>GPIO input, debounced—inverted</td> </tr> <tr> <td>0111</td> <td>N/A</td> </tr> <tr> <td>0110</td> <td>Reserved</td> </tr> <tr> <td>0101</td> <td>Reserved</td> </tr> <tr> <td>0100</td> <td>Serial data port (see Table 65)</td> </tr> <tr> <td>0011</td> <td>Open-collector output</td> </tr> <tr> <td>0010</td> <td>GPIO output</td> </tr> <tr> <td>0001</td> <td>GPIO input, no debounce</td> </tr> <tr> <td>0000</td> <td>GPIO input, debounced</td> </tr> </tbody> </table> | MPx[3:0] | Setting | 1111 | Auxiliary ADC input (see Table 63) | 1110 | Reserved | 1101 | Reserved | 1100 | Serial data port—inverted (see Table 65) | 1011 | Open-collector output—inverted | 1010 | GPIO output—inverted | 1001 | GPIO input, no debounce—inverted | 1000 | GPIO input, debounced—inverted | 0111 | N/A | 0110 | Reserved | 0101 | Reserved | 0100 | Serial data port (see Table 65) | 0011 | Open-collector output | 0010 | GPIO output | 0001 | GPIO input, no debounce | 0000 | GPIO input, debounced |
| MPx[3:0] | Setting   |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 1111     | Auxiliary ADC input (see Table 63)  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 1110     | Reserved  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 1101     | Reserved  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 1100     | Serial data port—inverted (see Table 65)  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 1011     | Open-collector output—inverted  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 1010     | GPIO output—inverted  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 1001     | GPIO input, no debounce—inverted  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 1000     | GPIO input, debounced—inverted  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 0111     | N/A   |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 0110     | Reserved  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 0101     | Reserved  |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 0100     | Serial data port (see Table 65)   |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 0011     | Open-collector output   |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 0010     | GPIO output   |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 0001     | GPIO input, no debounce   |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |
| 0000     | GPIO input, debounced   |          |         |      |                                    |      |          |      |          |      |  |      |                                |      |                      |      |                                  |      |                                |      |     |      |          |      |          |      |                                 |      |                       |      |             |      |                         |      |                       |

**2082 (0x0822)—AUXILIARY ADC AND POWER CONTROL**

Table 55. Auxiliary ADC and Power Control Bit Map

| D15  | D14  | D13  | D12  | D11  | D10  | D9   | D8   | D7   | D6   | D5   | D4   | D3   | D2   | D1   | D0   | Default |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---------|
| RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | FIL1 | FIL0 | AAPD | VBPD | VRPD | RSVD | D0PD | D1PD | D2PD | D3PD | 0x0000  |

Table 56.

| Bit Name | Description                         |
|----------|-------------------------------------|
| FIL[1:0] | Auxiliary ADC filtering             |
|          | <b>FIL[1:0]</b>                     |
|          | <b>Setting</b>                      |
|          | 00                                  |
|          | 01                                  |
|          | 4-bit hysteresis (12-bit level)     |
|          | 5-bit hysteresis (12-bit level)     |
|          | Filter and hysteresis bypassed      |
|          | Low-pass filter bypassed            |
| AAPD     | ADC power-down (both ADCs)          |
| VBPD     | Voltage reference buffer power-down |
| VRPD     | Voltage reference power-down        |
| D0PD     | DAC0 power-down                     |
| D1PD     | DAC1 power-down                     |
| D2PD     | DAC2 power-down                     |
| D3PD     | DAC3 power-down                     |

**2084 (0x0824)—AUXILIARY ADC ENABLE**

Table 57. Auxiliary ADC Enable Bit Map

| D15  | D14  | D13  | D12  | D11  | D10  | D9   | D8   | D7   | D6   | D5   | D4   | D3   | D2   | D1   | D0   | Default |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---------|
| AAEN | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | 0x0000  |

Table 58.

| Bit Name | Description              |
|----------|--------------------------|
| AAEN     | Enable the auxiliary ADC |

**2086 (0x0826)—OSCILLATOR POWER-DOWN**

Table 59. Oscillator Power-Down Bit Map

| D15  | D14  | D13  | D12  | D11  | D10  | D9   | D8   | D7   | D6   | D5   | D4   | D3   | D2  | D1   | D0   | Default |
|------|------|------|------|------|------|------|------|------|------|------|------|------|-----|------|------|---------|
| RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | OPD | RSVD | RSVD | 0x0000  |

Table 60.

| Bit Name | Description                                       |
|----------|---|
| OPD      | Oscillator Power Down. Power down the oscillator. |

**2087 (0x0827)—DAC SETUP**

To properly initialize the DACs, Bits DS[1:0] in this register should be set to 01.

Table 61. DAC Setup Bit Map

| D15  | D14  | D13  | D12  | D11  | D10  | D9   | D8   | D7   | D6   | D5   | D4   | D3   | D2   | D1  | D0  | Default |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-----|-----|---------|
| RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | RSVD | DS1 | DS0 | 0x0000  |

Table 62.

| Bit Name | Description     |
|----------|-----------------|
| DS[1:0]  | DAC Setup.      |
|          | <b>DS[1:0]</b>  |
|          | <b>Setting</b>  |
|          | 00              |
|          | 01              |
|          | Reserved        |
|          | Initialize DACs |
|          | Reserved        |
|          | Reserved        |

## MULTIPURPOSE PINS

The ADAU1401 has 12 multipurpose (MP) pins that can be individually programmed to be used as serial data inputs, serial data outputs, digital control inputs/outputs to and from the SigmaDSP core, or inputs to the 4-channel auxiliary ADC. These pins allow the ADAU1401 to be used with external ADCs and DACs. They also use analog or digital inputs to control settings such as volume control, or use output digital signals to drive LED indicators. Every MP pin has an internal 15 k $\Omega$  pull-up resistor.

### AUXILIARY ADC

The ADAU1401 has a 4-channel, auxiliary, 8-bit ADC that can be used in conjunction with a potentiometer to control volume, tone, or other parameter settings in the DSP program. Each of the four channels is sampled at the audio sampling frequency ( $f_s$ ). Full-scale input on this ADC is 3.0 V, so the step size is approximately 12 mV (3.0 V/256 steps). The input resistance of the ADC is approximately 30 k $\Omega$ . Table 63 indicates which four MP pins are mapped to the four channels of the auxiliary ADC. The auxiliary ADC is enabled for those pins by writing 1111 to the appropriate portion of the multipurpose pin configuration registers.

The auxiliary ADC is turned on by setting the AAEN bit of the auxiliary ADC enable register (see Table 58).

Noise on the ADC input can cause the digital output to constantly change by a few LSBs. If the auxiliary ADC is used to control volume, this constant change causes small gain fluctuations. To avoid this, add a low-pass filter or hysteresis to the auxiliary ADC signal path by enabling either function in the auxiliary ADC and power control register (2082), as described in Table 56. The filter is enabled by default when the auxiliary ADC is enabled. When data is read from the auxiliary ADC registers, two bytes (12 bits of data, plus zero-padded LSBs) are available because of this filtering.

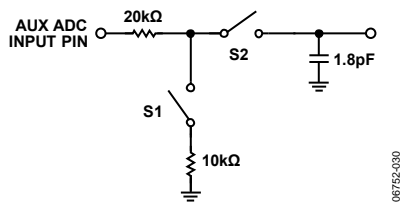


Figure 31. Auxiliary ADC Input Circuit

Figure 31 shows the input circuit for the auxiliary ADC. Switch S1 enables the auxiliary ADC and is set by Bit 15 of the auxiliary ADC enable register. The sampling switch, S2, operates at the audio sampling frequency.

The auxiliary ADC data registers can be written to directly after AACW in the DSP core control register has been set. In this mode, the voltages on the analog inputs are not written into the registers, but rather the data in the registers is written from the control port.

PVDD supplies the 3.3 V power for the auxiliary ADC analog input. The digital core of the auxiliary ADC is powered with the 1.8 V DVDD signal.

Table 63. Multipurpose Pin Auxiliary ADC Mapping

| Multipurpose Pin | Function |
|------------------|----------|
| MP0              | N/A      |
| MP1              | N/A      |
| MP2              | ADC1     |
| MP3              | ADC2     |
| MP4              | N/A      |
| MP5              | N/A      |
| MP6              | N/A      |
| MP7              | N/A      |
| MP8              | ADC3     |
| MP9              | ADC0     |
| MP10             | N/A      |
| MP11             | N/A      |

### GENERAL-PURPOSE INPUT/OUTPUT PINS

The general-purpose input/output (GPIO) pins can be used as either inputs or outputs. These pins are readable and can be set either through the control interface or directly by the SigmaDSP core. When set as inputs, these pins can be used with push-button switches or rotary encoders to control DSP program settings. Digital outputs can be used to drive LEDs or external logic to indicate the status of internal signals and control other devices. Examples of this use include indicating signal overload, signal present, and button press confirmation.

When set as an output, each pin can typically drive 2 mA. This is enough current to directly drive some high efficiency LEDs. Standard LEDs require about 20 mA of current and can be driven from a GPIO output with an external transistor or buffer. Because of issues that could arise from simultaneously driving or sinking a large current on many pins, care should be taken in the application design to avoid connecting high efficiency LEDs directly to many or all of the MPx pins. If many LEDs are required, use an external driver.

When the GPIO pins are set as open-collector outputs, they should be pulled up to a maximum voltage of 3.3 V (the voltage on IOVDD).

### SERIAL DATA INPUT/OUTPUT PORTS

The flexible serial data input and output ports of the ADAU1401 can be set to accept or transmit data in 2-channel format or in an 8-channel TDM stream. Data is processed in twos complement, MSB-first format. The left-channel data field always precedes the right-channel data field in the 2-channel streams. In TDM mode, Slot 0 to Slot 3 are in the first half of the audio frame, and Slot 4 to Slot 7 are in the second half of the frame. TDM mode allows fewer multipurpose pins to be used, freeing more pins for other functions. The serial modes are set in the serial output and serial input control registers.

The serial data clocks need to be synchronous with the ADAU1401 master clock input.

The input control register allows control of clock polarity and data input modes. The valid data formats are I<sup>2</sup>S, left-justified, right-justified (24-/20-/18-/16-bit), and 8-channel TDM. In all modes except for the right-justified modes, the serial port accepts an arbitrary number of bits up to a limit of 24. Extra bits do not cause an error, but they are truncated internally. Proper operation of the right-justified modes requires that there be exactly 64 BCLKs per audio frame. The TDM data is input on SDATA\_IN0. The LRCLK in TDM mode can be input to the ADAU1401 either as a 50/50 duty cycle clock or as a bit-wide pulse.

In TDM mode, the ADAU1401 can be a master for 48 kHz and 96 kHz data, but not for 192 kHz data. Table 64 lists the modes in which the serial output port can function.

**Table 64. Serial Output Port Master/Slave Mode Capabilities**

| f <sub>s</sub> | 2-Channel Modes (I <sup>2</sup> S, Left Justified, Right Justified) | 8-Channel TDM    |
|----------------|---|------------------|
| 48 kHz         | Master and slave  | Master and slave |
| 96 kHz         | Master and slave  | Master and slave |
| 192 kHz        | Master and slave  | Slave only       |

The output control registers allow the user to control clock polarities, clock frequencies, clock types, and data format. In all modes except for the right-justified modes (MSB delayed by 8, 12, or 16 bits), the serial port accepts an arbitrary number of bits up to a limit of 24. Extra bits do not cause an error, but are truncated internally. Proper operation of the right-justified modes requires the LSB to align with the edge of the LRCLK. The default settings of all serial port control registers correspond to 2-channel I<sup>2</sup>S mode. All register settings apply to both master and slave modes unless otherwise noted.

The function of each multipurpose pin in serial data port mode is shown in Table 65. Pin MP0 to Pin MP5 support digital data input to the ADAU1401, and Pin MP6 to Pin MP11 handle digital data output from the DSP. The configuration of the serial data

**Table 66. Data Format Configurations**

| Format                       | LRCLK Polarity               | LRCLK Type | BCLK Polarity                | MSB Position                                  |
|------------------------------|------------------------------|------------|------------------------------|---|
| I <sup>2</sup> S (Figure 32) | Frame begins on falling edge | Clock      | Data changes on falling edge | Delayed from LRCLK edge by 1 BCLK             |
| Left-Justified (Figure 33)   | Frame begins on rising edge  | Clock      | Data changes on falling edge | Aligned with LRCLK edge                       |
| Right-Justified (Figure 34)  | Frame begins on rising edge  | Clock      | Data changes on falling edge | Delayed from LRCLK edge by 8, 12, or 16 BCLKs |
| TDM with Clock (Figure 35)   | Frame begins on falling edge | Clock      | Data changes on falling edge | Delayed from start of word clock by 1 BCLK    |
| TDM with Pulse (Figure 36)   | Frame begins on rising edge  | Pulse      | Data changes on falling edge | Delayed from start of word clock by 1 BCLK    |

input port is set in the serial input control register (Table 51), and the configuration of the corresponding output port is controlled with the serial output control register (Table 49). The clocks of the input port function only as slaves, whereas the output port clocks can be set to function as either masters or slaves. The INPUT\_LRCLK (MP4) and INPUT\_BCLK (MP5) pins are used to clock the SDATA\_INx (MP0 to MP3) signals, and the OUTPUT\_LRCLK (MP10) and OUTPUT\_BCLK (MP11) pins are used to clock the SDATA\_OUTx (MP6 to MP9) signals.

If an external ADC is connected as a slave to the ADAU1401, use both the input and output port clocks. The OUTPUT\_LRCLK (MP10) and OUTPUT\_BCLK (MP11) pins must be set to master mode and connected externally to the INPUT\_LRCLK (MP4) and INPUT\_BCLK (MP5) pins as well as to the external ADC clock input pins. The data is output from the external ADC into the SigmaDSP on one of the four SDATA\_INx pins (MP0 to MP3).

Connections to an external DAC are handled exclusively with the output port pins. The OUTPUT\_LRCLK and OUTPUT\_BCLK pins can be set to function as either masters or slaves, and the SDATA\_OUTx pins are used to output data from the SigmaDSP to the external DAC.

Table 66 describes the proper configurations for standard audio data formats.

**Table 65. Multipurpose Pin Serial Data Port Functions**

| Multipurpose Pin | Function                       |
|------------------|--------------------------------|
| MP0              | SDATA_IN0/TDM_IN               |
| MP1              | SDATA_IN1                      |
| MP2              | SDATA_IN2                      |
| MP3              | SDATA_IN3                      |
| MP4              | INPUT_LRCLK (slave only)       |
| MP5              | INPUT_BCLK (slave only)        |
| MP6              | SDATA_OUT0/TDM_OUT             |
| MP7              | SDATA_OUT1                     |
| MP8              | SDATA_OUT2                     |
| MP9              | SDATA_OUT3                     |
| MP10             | OUTPUT_LRCLK (master or slave) |
| MP11             | OUTPUT_BCLK (master or slave)  |

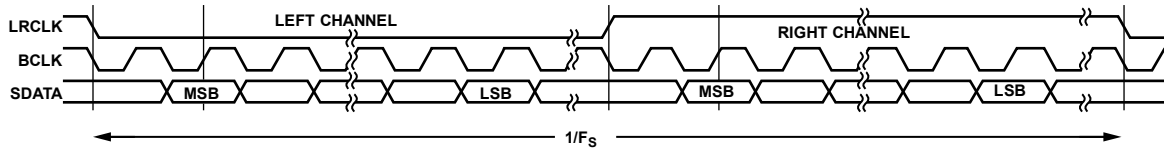


Figure 32. I²S Mode—16 Bits to 24 Bits per Channel

06752-031

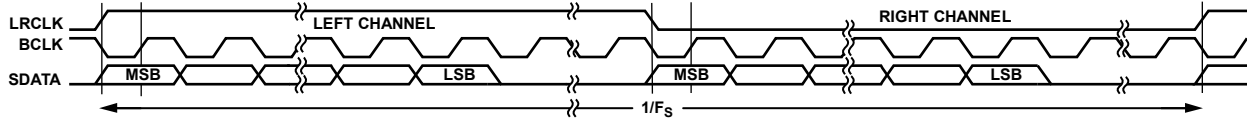


Figure 33. Left-Justified Mode—16 Bits to 24 Bits per Channel

06752-032

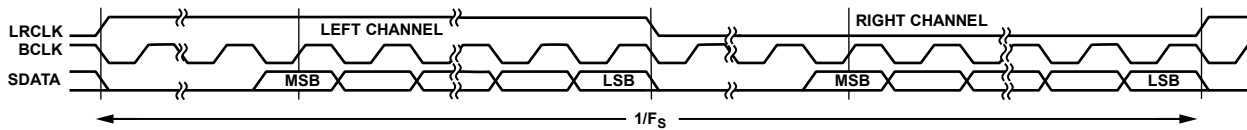


Figure 34. Right-Justified Mode—16 Bits to 24 Bits per Channel

06752-033

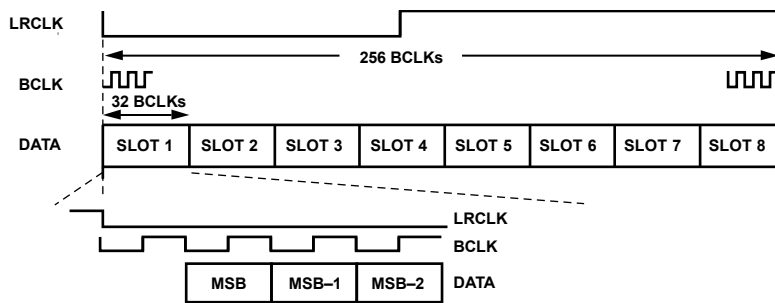


Figure 35. TDM Mode

06752-034

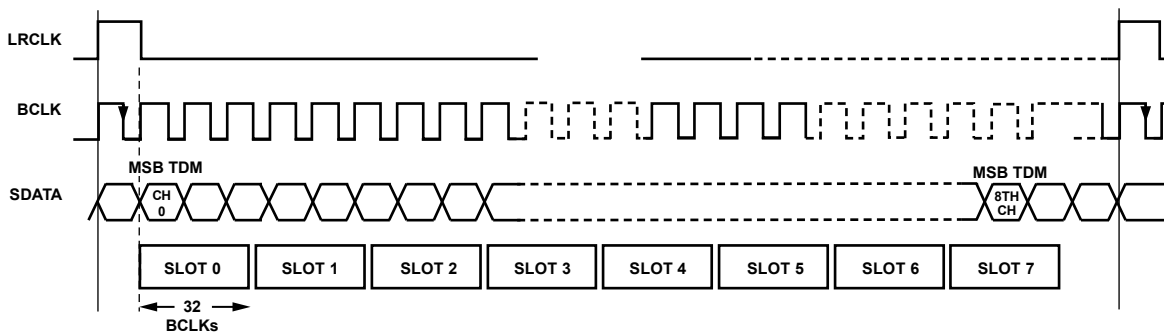


Figure 36. TDM Mode with Pulse Word Clock

06752-035

## LAYOUT RECOMMENDATIONS

### PARTS PLACEMENT

The ADC input voltage-to-current resistors and the ADC current set resistor should be placed as close as possible to the 2, 3, and 4 input pins.

All 100 nF bypass capacitors, which are recommended for every analog, digital, and PLL power/ground pair, should be placed as close as possible to the ADAU1401. The 3.3 V and 1.8 V signals on the board should also each be bypassed with a single bulk capacitor (10  $\mu$ F to 47  $\mu$ F).

All traces in the crystal oscillator circuit (Figure 14) should be kept as short as possible to minimize stray capacitance. In addition, avoid long board traces connected to any of these components because such traces may affect crystal startup and operation.

### GROUNDING

A single ground plane should be used in the application layout. Components in an analog signal path should be placed away from digital signals.



# TYPICAL APPLICATION SCHEMATICS

## SELF-BOOT MODE

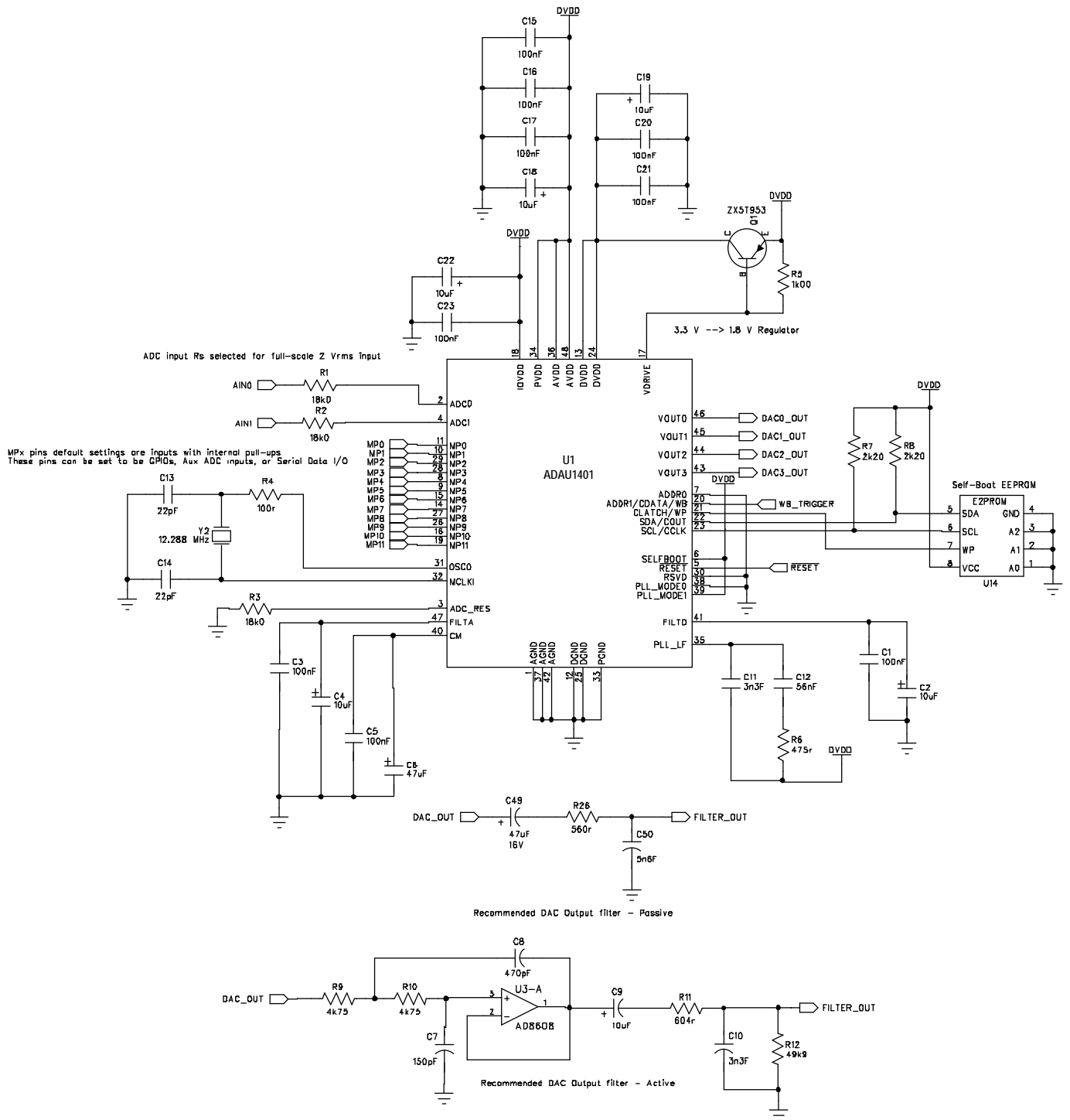


Figure 37. Self-Boot Mode Schematic

06752-036

I<sup>2</sup>C CONTROL

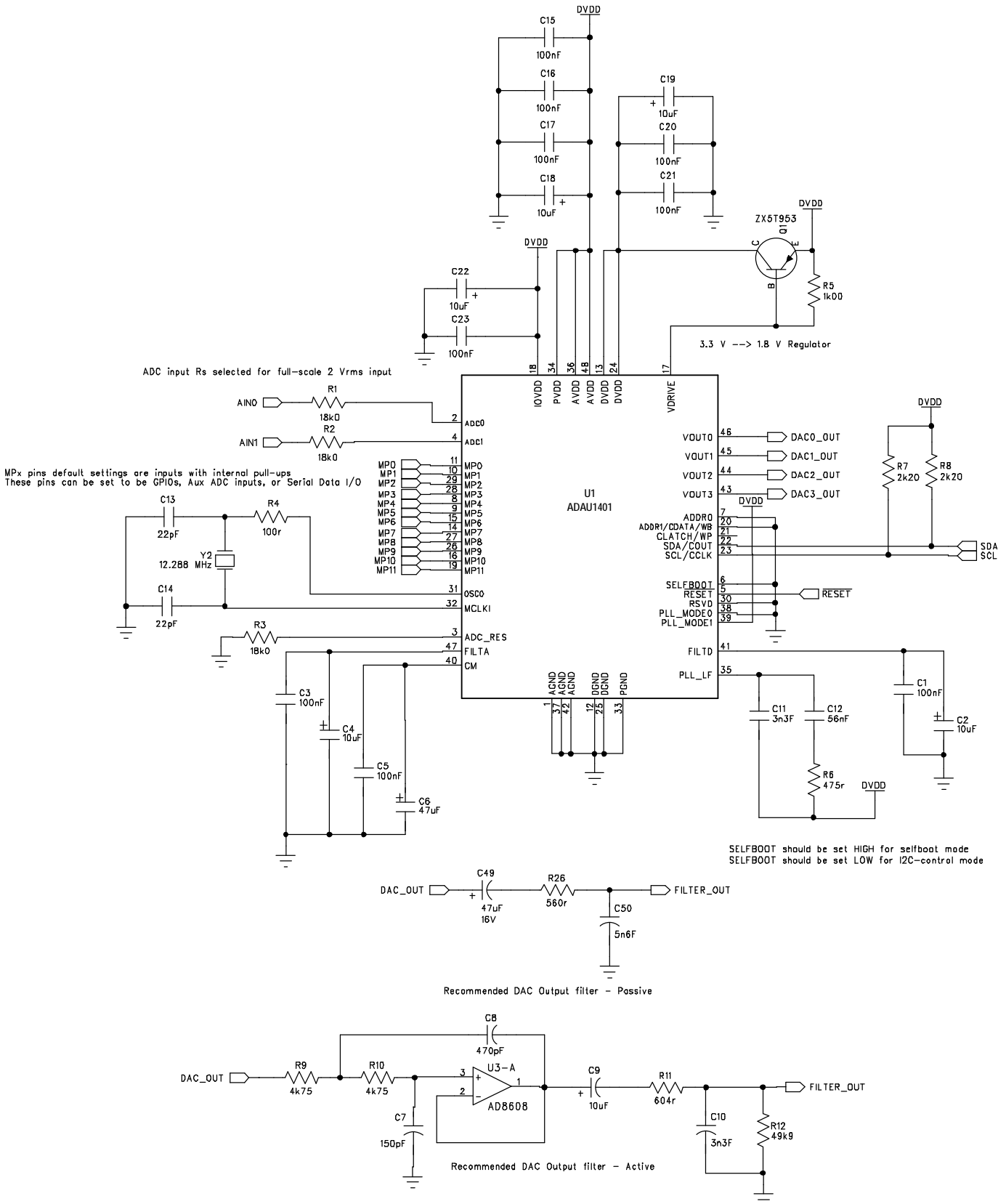


Figure 38. I<sup>2</sup>C Control Schematic

SPI CONTROL

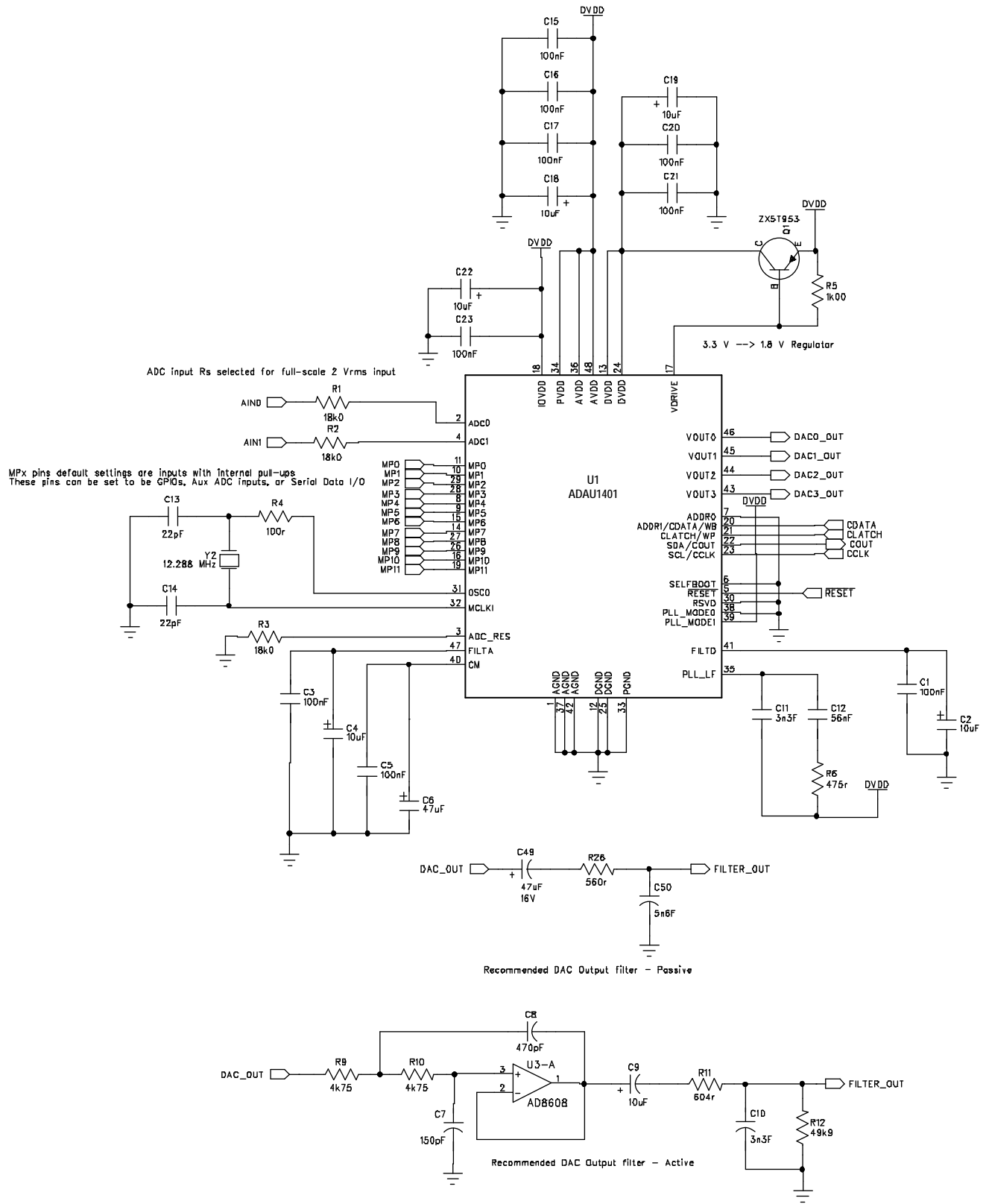
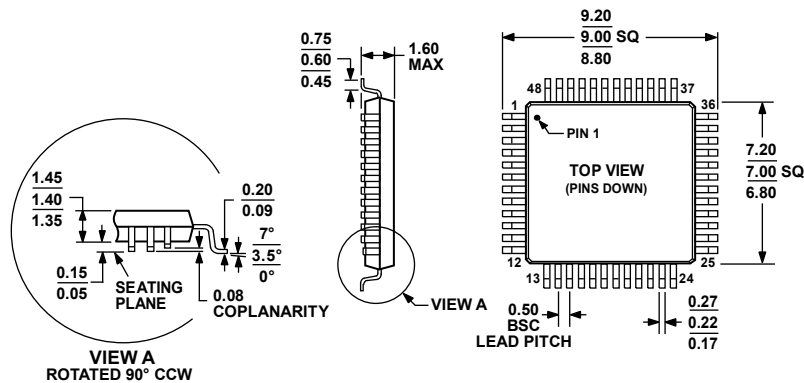


Figure 39. SPI Control Schematic

OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MS-026-BBC  
 Figure 40. 48-Lead Low-Profile Quad Flat Package [LQFP] (ST-48)  
 Dimensions shown in millimeters

ORDERING GUIDE

| Model <sup>1</sup> | Temperature Range | Package Description               | Package Option |
|--------------------|-------------------|-----------------------------------|----------------|
| ADAU1401YSTZ       | -40°C to +105°C   | 48-Lead LQFP                      | ST-48          |
| ADAU1401YSTZ-RL    | -40°C to +105°C   | 48-Lead LQFP in 13" Tape and Reel | ST-48          |

<sup>1</sup> Z = RoHS Compliant Part.