



# LC<sup>2</sup>MOS $\mu$ P Compatible 14-Bit DAC

## AD7535

### FEATURES

All Grades 14-Bit Monotonic over the Full Temperature Range  
Full 4 Quadrant Multiplication  
Microprocessor Compatible with Double Buffered Inputs  
Exceptionally Low Gain Temperature Coefficient, 0.5ppm/°C typ  
Low Output Leakage (<20nA) over the Full Temperature Range

### APPLICATIONS

Microprocessor Based Control Systems  
Digital Audio  
Precision Servo Control  
Control and Measurement in High Temperature Environments

### GENERAL DESCRIPTION

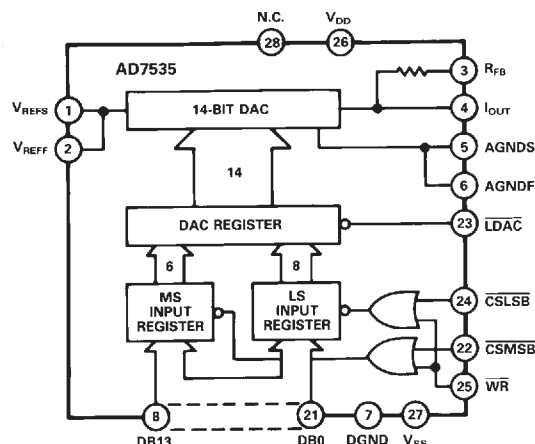
The AD7535 is a 14-bit monolithic CMOS D/A converter which uses laser trimmed thin-film resistors to achieve excellent linearity.

Standard Chip Select and Memory Write logic is used to access the DAC.

A novel low leakage configuration (patent pending) enables the AD7535 to exhibit excellent output leakage current characteristics over the specified temperature range.

The device is fully protected against CMOS "latch up" phenomena and does not require the use of external Schottky diodes or the use of a FET Input op-amp. The AD7535 is manufactured using the Linear Compatible CMOS (LC<sup>2</sup>MOS) process. It is speed compatible with most microprocessors and accepts TTL or CMOS logic level inputs.

### FUNCTIONAL BLOCK DIAGRAM



### PRODUCT HIGHLIGHTS

- Guaranteed Monotonicity**  
The AD7535 is guaranteed monotonic to 14-bits over the full temperature range for all grades.
- Low Output Leakage**  
By tying V<sub>SS</sub> (Pin 27) to a negative voltage, it is possible to achieve a low output leakage current at high temperatures.
- Microprocessor Compatibility**  
High speed input control (TTL/5V CMOS compatible) allows direct interfacing to most of the popular 8-bit and 16-bit microprocessors. When interfacing to 8-bit processors CSMSB and CSLSB are separate and the 8-bit data bus is connected to both the MS Input Register and the LS Input Register. For straight 14-bit parallel loading CSMSB and CSLSB are tied together giving one chip select to load the 14-bit word.

REV. A

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# AD7535—SPECIFICATIONS<sup>1</sup> ( $V_{DD} = +11.4V$ to $+15.75V^2$ , $V_{REF} = +10V$ , $V_{PIN4} = V_{PIN5} = 0V$ , $V_{SS} = -300mV$ All specifications $T_{min}$ to $T_{max}$ unless otherwise stated.)

| Parameter                                                                                   | J, A Versions | K, B Versions | S Version  | T Version  | Units                            | Test Conditions/Comments                                                                                                                    |
|---------------------------------------------------------------------------------------------|---------------|---------------|------------|------------|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| <b>ACCURACY</b>                                                                             |               |               |            |            |                                  |                                                                                                                                             |
| Resolution                                                                                  | 14            | 14            | 14         | 14         | Bits                             | All grades guaranteed monotonic over temperature.<br>Measured using internal $R_{FB}$ and includes effects of leakage current and gain T.C. |
| Relative Accuracy                                                                           | $\pm 2$       | $\pm 1$       | $\pm 2$    | $\pm 1$    | LSB max                          |                                                                                                                                             |
| Differential Nonlinearity                                                                   | $\pm 1$       | $\pm 1$       | $\pm 1$    | $\pm 1$    | LSB max                          |                                                                                                                                             |
| Full Scale Error                                                                            | $\pm 8$       | $\pm 4$       | $\pm 8$    | $\pm 4$    | LSB max                          |                                                                                                                                             |
| Gain Temperature Coefficient <sup>3</sup> ;<br>$\Delta\text{Gain}/\Delta\text{Temperature}$ | $\pm 5$       | $\pm 2.5$     | $\pm 5$    | $\pm 2.5$  | ppm/°C max                       | Typical value is 0.5ppm/°C                                                                                                                  |
| Output Leakage Current $I_{OUT}$ (Pin 4)<br>+ 25°C                                          | $\pm 5$       | $\pm 5$       | $\pm 5$    | $\pm 5$    | nA max                           | All digital inputs 0V<br>$V_{SS} = -300mV$<br>$V_{SS} = 0V$                                                                                 |
| $T_{min}$ to $T_{max}$                                                                      | $\pm 10$      | $\pm 10$      | $\pm 20$   | $\pm 20$   | nA max                           |                                                                                                                                             |
| $T_{min}$ to $T_{max}$                                                                      | $\pm 25$      | $\pm 25$      | $\pm 150$  | $\pm 150$  | nA max                           |                                                                                                                                             |
| <b>REFERENCE INPUT</b>                                                                      |               |               |            |            |                                  |                                                                                                                                             |
| Input resistance, pin 1                                                                     | 3.5<br>10     | 3.5<br>10     | 3.5<br>10  | 3.5<br>10  | k $\Omega$ min<br>k $\Omega$ max | Typical Input Resistance = 6k $\Omega$                                                                                                      |
| <b>DIGITAL INPUTS</b>                                                                       |               |               |            |            |                                  |                                                                                                                                             |
| $V_{IH}$ (Input High Voltage)                                                               | 2.4           | 2.4           | 2.4        | 2.4        | V min                            | $V_{IN} = 0V$ or $V_{DD}$                                                                                                                   |
| $V_{IL}$ (Input Low Voltage)                                                                | 0.8           | 0.8           | 0.8        | 0.8        | V max                            |                                                                                                                                             |
| $I_{IN}$ (Input Current)<br>+ 25°C                                                          | $\pm 1$       | $\pm 1$       | $\pm 1$    | $\pm 1$    | $\mu A$ max                      |                                                                                                                                             |
| $T_{min}$ to $T_{max}$                                                                      | $\pm 10$      | $\pm 10$      | $\pm 10$   | $\pm 10$   | $\mu A$ max                      |                                                                                                                                             |
| $C_{IN}$ (Input Capacitance) <sup>3</sup>                                                   | 7             | 7             | 7          | 7          | pF max                           |                                                                                                                                             |
| <b>POWER SUPPLY</b>                                                                         |               |               |            |            |                                  |                                                                                                                                             |
| $V_{DD}$ Range                                                                              | 11.4/15.75    | 11.4/15.75    | 11.4/15.75 | 11.4/15.75 | $V_{min}/V_{max}$                | Specification guaranteed over this range<br>All digital inputs $V_{IL}$ or $V_{IH}$<br>All digital inputs 0V or $V_{DD}$                    |
| $V_{SS}$ Range                                                                              | -200/-500     | -200/-500     | -200/-500  | -200/-500  | mV min/mV max                    |                                                                                                                                             |
| $I_{DD}$                                                                                    | 4             | 4             | 4          | 4          | mA max                           |                                                                                                                                             |
|                                                                                             | 500           | 500           | 500        | 500        | $\mu A$ max                      |                                                                                                                                             |

These characteristics are included for Design Guidance only and are not subject to test.

## AC PERFORMANCE CHARACTERISTICS ( $V_{DD} = +11.4V$ to $+15.75V$ , $V_{REF} = +10V$ , $V_{PIN4} = V_{PIN5} = 0V$ , $V_{SS} = 0V$ OR $-300mV$ , Output Amplifier is AD544 except where stated.)

| Parameter                                                   | $T_A = 25^\circ C$ $T_A = T_{min}$ , $T_{max}$ |            | Units              | Test Conditions/Comments                                                                                                                                                                             |
|-------------------------------------------------------------|------------------------------------------------|------------|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Output Current Settling Time                                | 1.5                                            | —          | $\mu s$ max        | To 0.003% of full scale range.<br>$I_{OUT}$ load = 100 $\Omega$ ,<br>$C_{EXT} = 13pF$ . DAC register alternately loaded with all 1's and all 0's.<br>Typical value of Settling Time is 0.8 $\mu s$ . |
| Digital to Analog Glitch Impulse                            | 50                                             | —          | nV-sec typ         | Measured with $V_{REF} = 0V$ . $I_{OUT}$ load = 100 $\Omega$ , $C_{EXT} = 13pF$ . DAC register alternately loaded with all 1's and all 0's.                                                          |
| Multiplying Feedthrough Error <sup>4</sup>                  | 3                                              | 5          | mV p-p typ         | $V_{REF} = \pm 10V$ , 10kHz sine wave<br>DAC register loaded with all 0's.                                                                                                                           |
| Power Supply Rejection<br>$\Delta\text{Gain}/\Delta V_{DD}$ | $\pm 0.01$                                     | $\pm 0.02$ | % per % max        | $\Delta V_{DD} = \pm 5\%$                                                                                                                                                                            |
| Output Capacitance<br>$C_{OUT}$ (Pin 4)                     | 260                                            | 260        | pF max             | DAC register loaded with all 1's                                                                                                                                                                     |
| $C_{OUT}$ (Pin 4)                                           | 130                                            | 130        | pF max             | DAC register loaded with all 0's                                                                                                                                                                     |
| Output Noise Voltage Density<br>(10Hz – 100kHz)             | 15                                             | —          | nV $\sqrt{Hz}$ typ | Measured between $R_{FB}$ and $I_{OUT}$                                                                                                                                                              |

### NOTES

<sup>1</sup>Temperature range as follows: J, K Versions: 0 to  $+70^\circ C$   
A, B Versions:  $-25^\circ C$  to  $+85^\circ C$   
S, T Versions:  $-55^\circ C$  to  $+125^\circ C$

<sup>2</sup>Specifications are guaranteed for a  $V_{DD}$  of  $+11.4V$  to  $+15.75V$ . At  $V_{DD} = 5V$ , the device is fully functional with degraded specifications.

<sup>3</sup>Guaranteed by Product Assurance testing.

<sup>4</sup>Feedthrough can be further reduced by connecting the metal lid on the ceramic package to DGND.

Specifications subject to change without notice.

# TIMING CHARACTERISTICS<sup>1</sup> ( $V_{DD} = +11.4V$ to $+15.75V$ , $V_{REF} = +10V$ , $V_{PIN4} = V_{PIN5} = 0V$ , $V_{SS} = 0V$ or $-300mV$ All specifications $T_{min}$ to $T_{max}$ unless otherwise stated. See Figure 1 for Timing Diagram.)

| Parameter | Limit at<br>$T_A = 25^\circ C$ | Limit at<br>$T_A = 0$ to $+70^\circ C$<br>$T_A = -25^\circ C$ to $+85^\circ C$ | Limit at<br>$T_A = -55^\circ C$ to $+125^\circ C$ | Units  | Test Conditions/Comments                                               |
|-----------|--------------------------------|--------------------------------------------------------------------------------|---------------------------------------------------|--------|------------------------------------------------------------------------|
| $t_1$     | 0                              | 0                                                                              | 0                                                 | ns min | $\overline{CSMSB}$ or $\overline{CSLSB}$ to $\overline{WR}$ Setup Time |
| $t_2$     | 0                              | 0                                                                              | 0                                                 | ns min | $\overline{CSMSB}$ or $\overline{CSLSB}$ to $\overline{WR}$ Hold Time  |
| $t_3$     | 170                            | 200                                                                            | 240                                               | ns min | LDAC Pulse Width                                                       |
| $t_4$     | 170                            | 200                                                                            | 240                                               | ns min | Write Pulse Width                                                      |
| $t_5$     | 140                            | 160                                                                            | 180                                               | ns min | Data Setup Time                                                        |
| $t_6$     | 20                             | 20                                                                             | 30                                                | ns min | Data Hold Time                                                         |

## NOTES

<sup>1</sup>Temperature range as follows: JN, KN Versions: 0 to  $+70^\circ C$   
AQ, BQ Versions:  $-25^\circ C$  to  $+85^\circ C$   
SQ, TQ Versions:  $-55^\circ C$  to  $+125^\circ C$

Specifications subject to change without notice.

## ABSOLUTE MAXIMUM RATINGS

( $T_A = 25^\circ C$  unless otherwise stated)

|                                           |                    |
|-------------------------------------------|--------------------|
| $V_{DD}$ (pin 26) to DGND                 | $-0.3V$ , $+17V$   |
| $V_{SS}$ (pin 27) to AGND                 | $-15V$ , $+0.3V$   |
| $V_{REFS}$ (pin 1) to AGND                | $\pm 25V$          |
| $V_{REFF}$ (pin 2) to AGND                | $\pm 25V$          |
| $V_{RFB}$ (pin 3) to AGND                 | $\pm 25V$          |
| Digital Input Voltage (pins 8–25) to DGND | $-0.3V$ , $V_{DD}$ |
| $V_{PIN4}$ to DGND                        | $-0.3V$ , $V_{DD}$ |
| AGND to DGND                              | $-0.3V$ , $V_{DD}$ |
| Power Dissipation (Any Package)           |                    |
| To $+75^\circ C$                          | 1000mW             |
| Derates above $+75^\circ C$               | 10mW/ $^\circ C$   |

## Operating Temperature Range

|                                       |                                 |
|---------------------------------------|---------------------------------|
| Commercial Plastic (J, K Versions)    | 0 to $+70^\circ C$              |
| Industrial Ceramic (A, B Versions)    | $-25^\circ C$ to $+85^\circ C$  |
| Extended Ceramic (S, T Versions)      | $-55^\circ C$ to $+125^\circ C$ |
| Storage Temperature                   | $-65^\circ C$ to $+150^\circ C$ |
| Lead Temperature (Soldering, 10 secs) | $+300^\circ C$                  |

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

## CAUTION

ESD (electrostatic discharge) sensitive device. The digital control inputs are diode protected; however, permanent damage may occur on unconnected devices subject to high energy electrostatic fields. Unused devices must be stored in conductive foam or shunts. The protective foam should be discharged to the destination socket before devices are removed.



## ORDERING GUIDE

| Model    | Temperature Range               | Relative Accuracy | Full-Scale Error | Package Option* |
|----------|---------------------------------|-------------------|------------------|-----------------|
| AD7535JN | $0^\circ C$ to $+70^\circ C$    | $\pm 2LSB$        | $\pm 8LSB$       | N-28            |
| AD7535KN | $0^\circ C$ to $+70^\circ C$    | $\pm 1LSB$        | $\pm 4LSB$       | N-28            |
| AD7535JP | $0^\circ C$ to $+70^\circ C$    | $\pm 2LSB$        | $\pm 8LSB$       | P-28A           |
| AD7535KP | $0^\circ C$ to $+70^\circ C$    | $\pm 1LSB$        | $\pm 4LSB$       | P-28A           |
| AD7535AQ | $-25^\circ C$ to $+85^\circ C$  | $\pm 2LSB$        | $\pm 8LSB$       | Q-28            |
| AD7535BQ | $-25^\circ C$ to $+85^\circ C$  | $\pm 1LSB$        | $\pm 4LSB$       | Q-28            |
| AD7535SQ | $-55^\circ C$ to $+125^\circ C$ | $\pm 2LSB$        | $\pm 8LSB$       | Q-28            |
| AD7535TQ | $-55^\circ C$ to $+125^\circ C$ | $\pm 1LSB$        | $\pm 4LSB$       | Q-28            |
| AD7535SE | $-55^\circ C$ to $+125^\circ C$ | $\pm 2LSB$        | $\pm 8LSB$       | E-28A           |
| AD7535TE | $-55^\circ C$ to $+125^\circ C$ | $\pm 1LSB$        | $\pm 4LSB$       | E-28A           |

\*E = Leadless Ceramic Chip Carrier; N = Plastic DIP; P = Plastic Leaded Chip Carrier; Q = Cerdip.

# AD7535

## TERMINOLOGY

### RELATIVE ACCURACY

Relative accuracy or end-point nonlinearity is a measure of the maximum deviation from a straight line passing through the end-points of the DAC transfer function. It is measured after adjusting for zero error and full scale error and is normally expressed in Least Significant Bits or as a percentage of full scale reading.

### DIFFERENTIAL NONLINEARITY

Differential nonlinearity is the difference between the measured change and the ideal 1LSB change between any two adjacent codes. A specified differential nonlinearity of  $\pm 1$ LSB max over the operating temperature range ensures monotonicity.

### FULL-SCALE ERROR

Full scale error or gain error is a measure of the output error between an ideal DAC and the actual device output. Full scale error is adjustable to zero with an external potentiometer.

### DIGITAL-TO-ANALOG GLITCH IMPULSE

The amount of charge injected from the digital inputs to the analog output when the inputs change state is called Digital-to-Analog Glitch Impulse. This is normally specified as the area of the glitch in either pA-secs or nV-secs depending upon whether the glitch is measured as a current or voltage. It is measured with  $V_{REF} = AGND$ .

### OUTPUT CAPACITANCE

This is the capacitance from  $I_{OUT}$  to AGND.

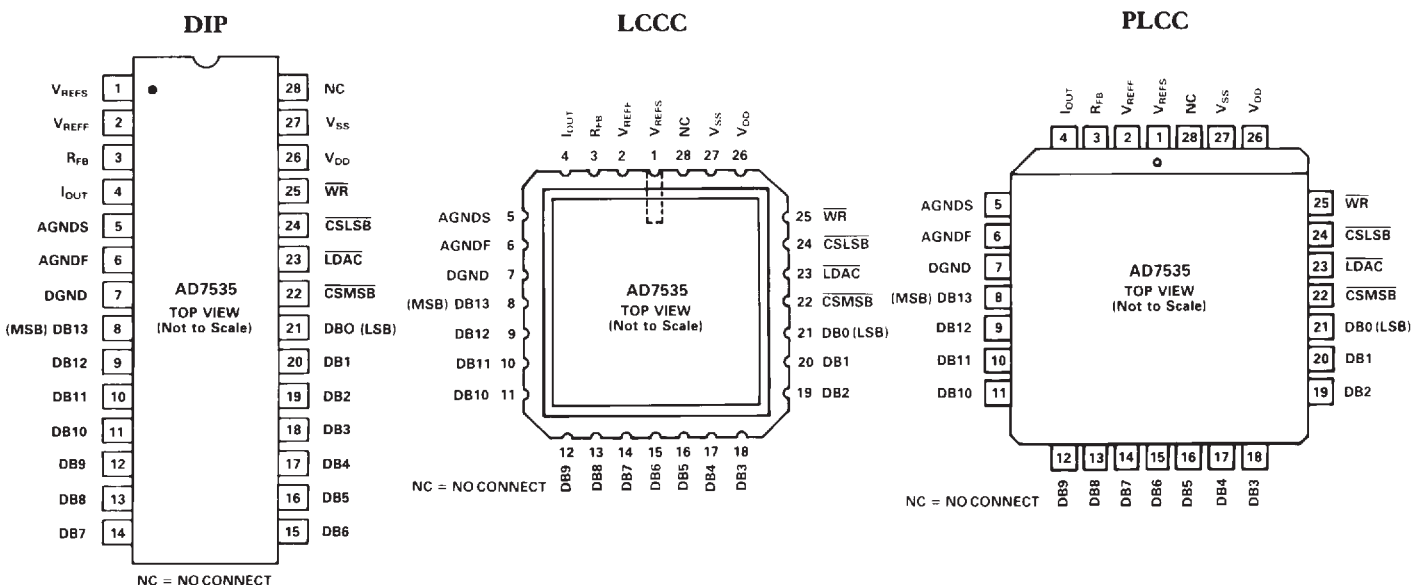
### OUTPUT LEAKAGE CURRENT

Output Leakage Current is current which appears at  $I_{OUT}$  with the DAC register loaded to all 0's.

### MULTIPLYING FEEDTHROUGH ERROR

This is the ac error due to capacitive feedthrough from  $V_{REF}$  terminal to  $I_{OUT}$  with DAC register loaded to all zeros.

## PIN CONFIGURATIONS



# Pin Function Description—AD7535

| Pin | Function          | Description                                                                                                                                                                                                                     |
|-----|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | V <sub>REFS</sub> | Voltage Reference sense pin                                                                                                                                                                                                     |
| 2   | V <sub>REFF</sub> | Voltage Reference force pin. If a remote voltage reference is being used V <sub>REFF</sub> and V <sub>REFS</sub> can be used in a Kelvin configuration to compensate for IR drop along the V <sub>REF</sub> line. See Figure 7. |
| 3   | R <sub>FB</sub>   | Feedback resistor. Used to close the loop around an external op-amp.                                                                                                                                                            |
| 4   | I <sub>OUT</sub>  | Current Output Terminal.                                                                                                                                                                                                        |
| 5   | A <sub>GNDS</sub> | Analog ground sense line. Reference point for external circuitry. This pin should carry minimal current.                                                                                                                        |
| 6   | A <sub>GNDF</sub> | Analog ground force line; carries current from internal analog ground connections. A <sub>GNDF</sub> and A <sub>GNDS</sub> are tied together internally.                                                                        |
| 7   | DGND              | Digital Ground                                                                                                                                                                                                                  |
| 8   | DB13              | Data Bit 13. DAC MSB                                                                                                                                                                                                            |
| 9   | DB12              | Data Bit 12                                                                                                                                                                                                                     |
| 10  | DB11              | Data Bit 11                                                                                                                                                                                                                     |
| 11  | DB10              | Data Bit 10                                                                                                                                                                                                                     |
| 12  | DB9               | Data Bit 9                                                                                                                                                                                                                      |
| 13  | DB8               | Data Bit 8                                                                                                                                                                                                                      |
| 14  | DB7               | Data Bit 7                                                                                                                                                                                                                      |
| 15  | DB6               | Data Bit 6                                                                                                                                                                                                                      |
| 16  | DB5               | Data Bit 5                                                                                                                                                                                                                      |
| 17  | DB4               | Data Bit 4                                                                                                                                                                                                                      |
| 18  | DB3               | Data Bit 3                                                                                                                                                                                                                      |
| 19  | DB2               | Data Bit 2                                                                                                                                                                                                                      |
| 20  | DB1               | Data Bit 1                                                                                                                                                                                                                      |
| 21  | DB0               | Data Bit 0. DAC LSB                                                                                                                                                                                                             |
| 22  | <u>CSMSB</u>      | Chip Select Most Significant (MS) Byte. Active LOW input.                                                                                                                                                                       |
| 23  | <u>LDAC</u>       | Asynchronous Load DAC input. Active LOW.                                                                                                                                                                                        |
| 24  | <u>CSLSB</u>      | Chip Select Least Significant (LS) Byte. Active LOW input.                                                                                                                                                                      |
| 25  | <u>WR</u>         | Write input. Active LOW.                                                                                                                                                                                                        |

| <u>CSMSB</u> | <u>CSLSB</u> | <u>LDAC</u> | <u>WR</u> | Operation                              |
|--------------|--------------|-------------|-----------|----------------------------------------|
| 0            | 1            | 1           | 0         | Load MS Input Register                 |
| 1            | 0            | 1           | 0         | Load LS Input Register                 |
| 0            | 0            | 1           | 0         | Load MS and LS Input Registers         |
| 1            | 1            | 0           | X         | Load DAC Register from Input Registers |
| 0            | 0            | 0           | 0         | All Registers are transparent          |
| 1            | 1            | 1           | X         | No operation                           |
| X            | X            | 1           | 1         | No operation                           |

NOTE X = Don't Care

|    |                 |                                                                                                                                                                                       |
|----|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 26 | V <sub>DD</sub> | +12V to +15V supply input                                                                                                                                                             |
| 27 | V <sub>SS</sub> | Bias pin for High Temperature Low Leakage configuration. To implement low leakage system, the pin should be at a negative voltage. See Figure 4, 5, 6 or 7 for recommended circuitry. |
| 28 | N.C.            | No connection                                                                                                                                                                         |

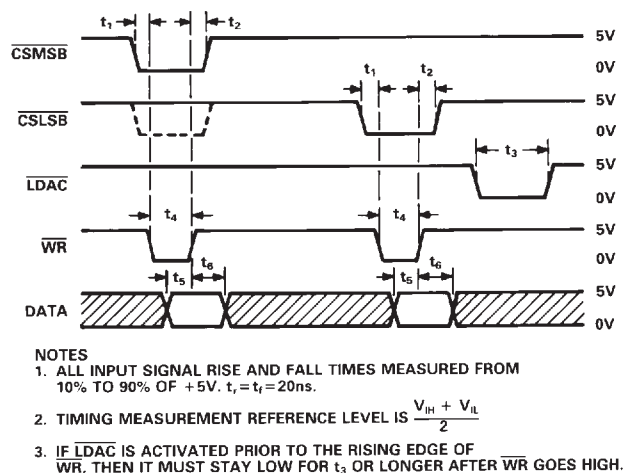


Figure 1. AD7535 Timing Diagram

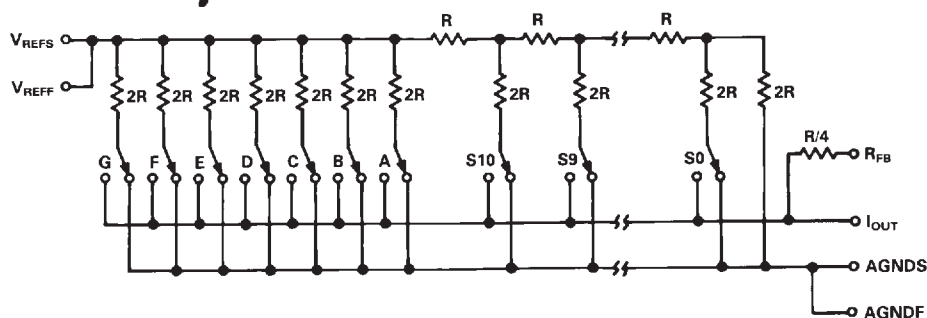


Figure 2. Simplified Circuit Diagram for the AD7535 D/A Section

## CIRCUIT INFORMATION – D/A SECTION

Figure 2 shows a simplified circuit diagram for the AD7535 D/A section. The three MSB's of the 14-bit Data Word are decoded to drive the seven switches A-G. The 11 LSB's of the Data Word consist of an R-2R ladder operated in a current steering configuration.

The R-2R ladder current is 1/8 of the total reference input current. 7/8 I flows in the parallel ladder structure. Switches A-G steer equally weighted currents between  $I_{OUT}$  and  $AGNDF$ .

Since the input resistance at  $V_{REF}$  is constant, it may be driven by a voltage source or a current source of positive or negative polarity.

## EQUIVALENT CIRCUIT ANALYSIS

Figure 3 shows an equivalent circuit for the analog section of the AD7535 D/A converter. The current source  $I_{LEAKAGE}$  is composed of surface and junction leakages. The resistor  $R_O$  denotes the equivalent output resistance of the DAC which varies with input code.  $C_{OUT}$  is the capacitance due to the current steering switches and varies from about 90pF to 180pF (typical values) depending upon the digital input.  $g(V_{REF}, N)$  is the Thevenin equivalent voltage generator due to the reference

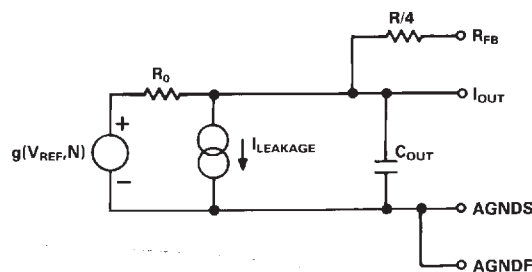


Figure 3. AD7535 Equivalent Analog Output Circuit

input voltage,  $V_{REF}$ , and the transfer function of the DAC ladder,  $N$ .

## CIRCUIT INFORMATION – DIGITAL SECTION

The digital inputs are designed to be both TTL and 5V CMOS compatible. All logic inputs are static protected MOS gates with typical input currents of less than 1nA. Internal input protection is achieved by an on-chip distributed diode from DGND to each MOS gate. To minimize power supply currents, it is recommended that the digital input voltages be driven as close as possible to 0 and 5V logic levels.

## UNIPOLAR BINARY OPERATION (2-QUADRANT MULTIPLICATION)

Figure 4 shows the circuit diagram for unipolar binary operation. With an ac input, the circuit performs 2 quadrant multiplication. The code table for Figure 4 is given in Table I.

Capacitor C1 provides phase compensation and helps prevent overshoot and ringing when high speed op-amps are used.

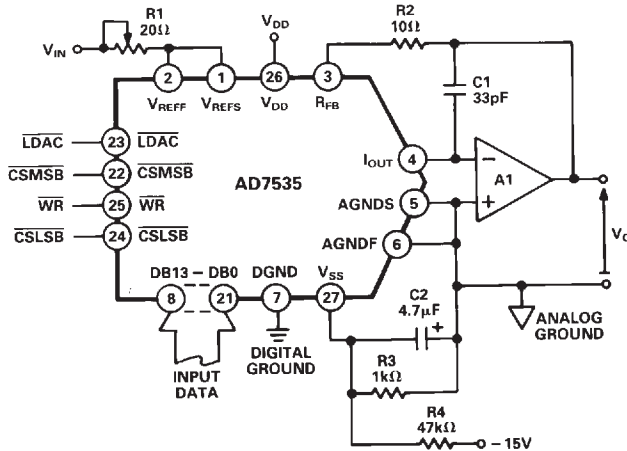


Figure 4. Unipolar Binary Operation

| Binary Number In DAC Register |                | Analog Output, $V_{OUT}$                                  |
|-------------------------------|----------------|-----------------------------------------------------------|
| MSB                           | LSB            |                                                           |
| 11                            | 1111 1111 1111 | $-V_{IN} \left( \frac{16383}{16384} \right)$              |
| 10                            | 0000 0000 0000 | $-V_{IN} \left( \frac{8192}{16384} \right) = -1/2 V_{IN}$ |
| 00                            | 0000 0000 0001 | $-V_{IN} \left( \frac{1}{16384} \right)$                  |
| 00                            | 0000 0000 0000 | 0V                                                        |

Table I. Unipolar Binary Code Table for AD7535

## ZERO OFFSET AND GAIN ADJUSTMENT FOR FIGURE 4.

### Zero Offset Adjustment

1. Load DAC register with all 0's.
2. Adjust offset of amplifier A1 so that  $V_O$  is at a minimum (i.e.  $\leq 30\mu V$ ).

### Gain Adjustment

1. Load DAC register with all 1's.
2. Trim potentiometer R1 so that  $V_O = -V_{IN} \left( \frac{16383}{16384} \right)$

In fixed reference applications, full scale can also be adjusted by omitting R1 and R2 and trimming the reference voltage magnitude.

For high temperature applications resistors and potentiometers should have a low Temperature Coefficient. In many applications, because of the excellent Gain T.C. and Gain Error specifications of the AD7535, Gain Error trimming is not necessary.

## BIPOLAR OPERATION (4-QUADRANT MULTIPLICATION)

The recommended circuit diagram for bipolar operation is shown in Figure 5. Offset binary coding is used.

With the DAC loaded to 10 0000 0000 0000, adjust R1 for  $V_O = 0V$ . Alternatively, one can omit R1 and R2 and adjust the ratio of R5 and R6 for  $V_O = 0V$ . Full scale trimming can be accomplished by adjusting the amplitude of  $V_{IN}$  or by varying the value of R7.

Resistors R5, R6 and R7 should be ratio matched to 0.006%. Mismatch of R5 and R6 causes both offset and full scale error. When operating over a wide temperature range, it is important that the resistors be of the same type so that their temperature coefficients match.

A range of precision voltage dividers, manufactured by Vishay, offers a suitable solution to implementing the bipolar circuit described above. The resistor networks are TCR and Ratio Matched, giving excellent performance over temperature.

The code table for Figure 5 is given in Table II.

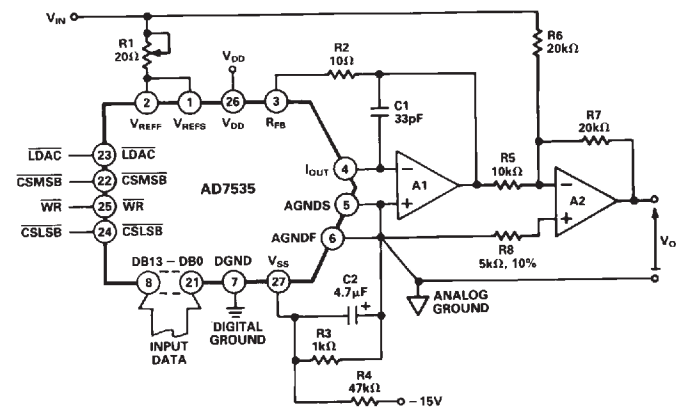


Figure 5. Bipolar Operation

| Binary Number in DAC Register |                | Analog Output $V_{OUT}$                    |
|-------------------------------|----------------|--------------------------------------------|
| MSB                           | LSB            |                                            |
| 11                            | 1111 1111 1111 | $+V_{IN} \left( \frac{8191}{8192} \right)$ |
| 10                            | 0000 0000 0001 | $+V_{IN} \left( \frac{1}{8192} \right)$    |
| 10                            | 0000 0000 0000 | 0V                                         |
| 01                            | 1111 1111 1111 | $-V_{IN} \left( \frac{1}{8192} \right)$    |
| 00                            | 0000 0000 0000 | $-V_{IN} \left( \frac{8192}{8192} \right)$ |

Table II. Bipolar Code Table for Offset Binary Circuit of Figure 5.

# AD7535

## GROUNDING TECHNIQUES

Since the AD7535 is specified for high accuracy it is important to use a proper grounding technique. The two AGND pins (AGNDF and AGNDS) provide flexibility in this respect. In Figure 4, the AD7535 is connected with the signal ground for the load located close to the DAC. There is no possibility of a voltage drop along the signal ground due to track resistance.

If the signal ground for the load is located at a distance from the DAC then the configuration of Figure 6 should be used.  $A_2$  compensates for the error due to IR voltage drop between the DAC's internal Analog ground and the load signal ground.

Figure 7 shows a remote voltage reference driving the AD7535. Op-amps  $A_2$  and  $A_3$  compensate for voltage drops along the reference input line and the analog ground line.

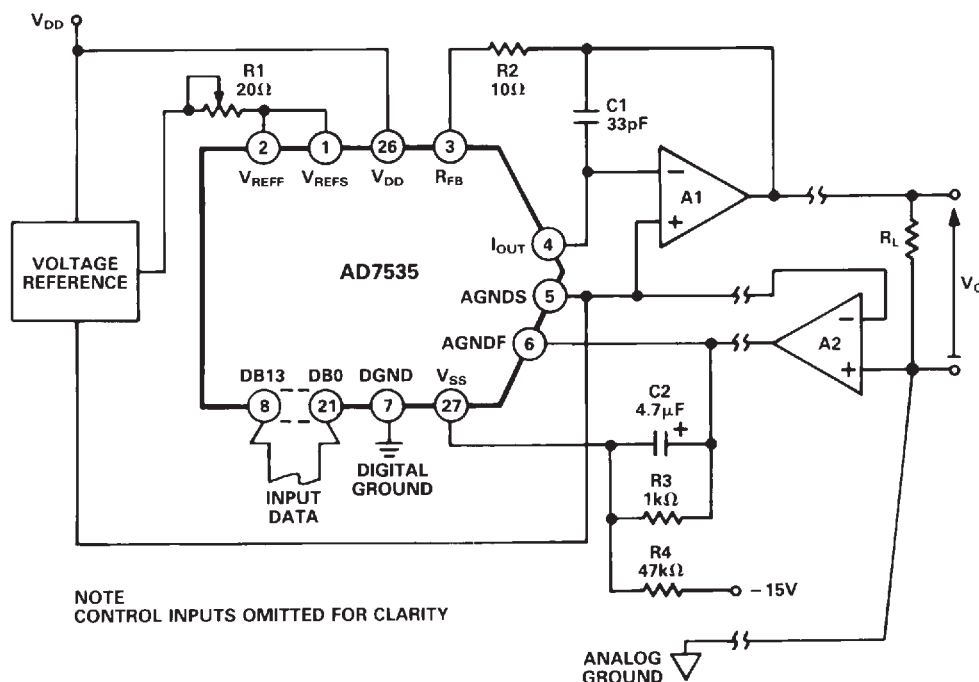


Figure 6. Unipolar Binary Operation with Forced Ground for Remote Load

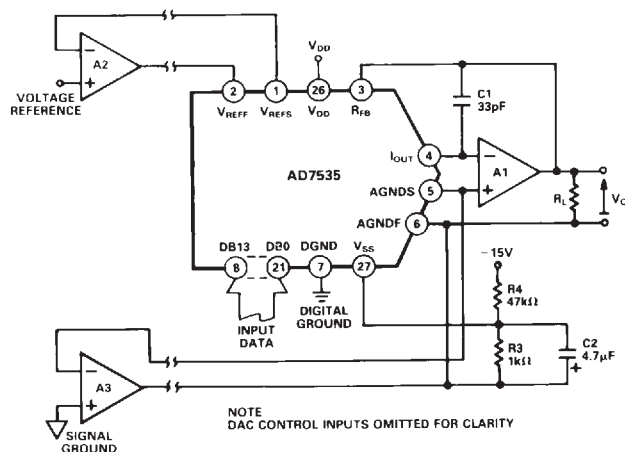


Figure 7. Driving the AD7535 with a Remote Voltage Reference

## ZERO OFFSET AND GAIN ADJUSTMENT FOR FIGURE 6

### Zero Offset Adjustment

1. Load DAC register with all 0's.
2. Adjust offset of amplifier  $A_2$  for a minimum potential at AGNDS. This potential should be  $\leq 30\mu V$  with respect to Signal Ground. Adjust offset of amplifier  $A_1$  so that  $V_O$  is at a minimum (i.e.  $\leq 30\mu V$ ).

### Gain Adjustment

1. Load DAC register with all 1's.
2. Trim potentiometer  $R_1$  so that  $V_O = -V_{IN} \frac{(16383)}{(16384)}$

### LOW LEAKAGE CONFIGURATION

For CMOS Multiplying D/A converters, as the device is operated at higher temperatures the output leakage current increases. For a 14-bit resolution system, this can be a significant source of error. The AD7535 features a leakage reduction configuration (patent pending) to keep the leakage current low over an extended temperature range. One may operate the device with or without this configuration. If  $V_{SS}$  (pin 27) is tied to  $A_{GND}$  then the DAC will exhibit normal output leakage current at high temperatures. To use the low leakage facility,  $V_{SS}$  should be tied to a voltage of approximately  $-0.3V$  as in Figures 4, 5, 6 and 7. A simple resistor divider ( $R_3$ ,  $R_4$ ) produces approximately  $-300mV$  from  $-15V$ . The capacitor  $C_2$  in parallel with  $R_3$  is an integral part of the low leakage configuration and must be  $4.7\mu F$  or greater. Figure 8 is a plot of leakage current versus temperature for both conditions. It clearly shows the improvement gained by using the low leakage configuration.

### OP-AMP SELECTION

In choosing an amplifier to be used with the AD7535, three parameters are of prime importance. These are (1) Input Offset Voltage ( $V_{OS}$ ), (2) Input Bias Current ( $I_B$ ), (3) Offset Voltage

Drift ( $TC V_{OS}$ ). To maintain specified accuracy with  $V_{REF}$  at  $10V$ ,  $V_{OS}$  must be less than  $30\mu V$  while  $I_B$  should be less than  $2nA$ . It is important that the amplifier Open Loop Gain,  $A_{VOL}$ , be sufficiently large to keep  $V_{OS} \leq 30\mu V$  for the full output voltage range. For a maximum output of  $10V$ ,  $A_{VOL}$  must be greater than  $340,000$ .

The AD OP-07 series of op-amps have a very low  $V_{OS}$  ( $25\mu V$ ) and can be used as the output amplifier for the AD7535 without any external adjustment of Offset Voltage. In the Forced Ground configuration of Figure 6, one can use an AD OP-07 for amplifier A2. Settling time to  $0.003\%$  for the AD OP-07 is typically greater than  $50\mu s$ .

For faster settling time, one can use the AD544 series of op amps. Typically this settles to  $0.003\%$  (14-bits) in  $5\mu s$ . Even faster settling time can be achieved using the HA-2620 series of op-amps.

For operation over a wide temperature range Offset Voltage Drift and Bias Current Drift are critical parameters. The OP-27 and OP-37 series of op-amps exhibit extremely low Offset Voltage Drift and the AD544 has very low Bias Current Drift.

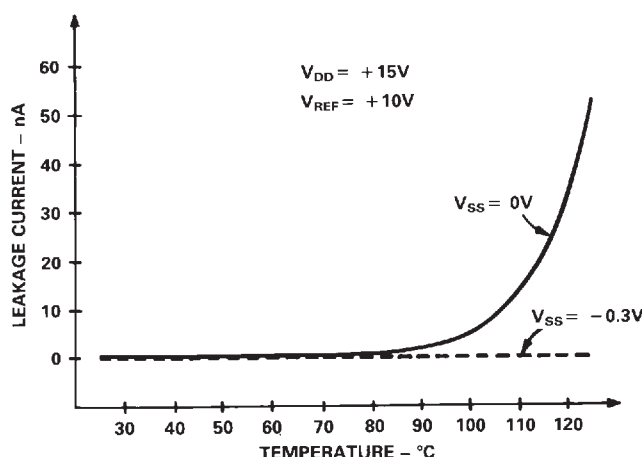


Figure 8. Graph of Typical Leakage Current vs Temperature for AD7535

AD7535

MICROPROCESSOR INTERFACING  
AD7535 – 8086A INTERFACE

The versatility of the AD7535 loading structure allows interfacing to both 8- and 16-bit microprocessor systems. Figure 9 shows the 8086 16-bit processor interfacing to a single device. In this setup the double buffering feature of the DAC is not used. AD0-AD13 of the 16-bit data bus are connected to the DAC data bus (DB0-DB13). The 14-bit word is written to the DAC in one MOV instruction and the analog output responds immediately. In this example the DAC address is D000. A software routine for Figure 9 is given in Table III.

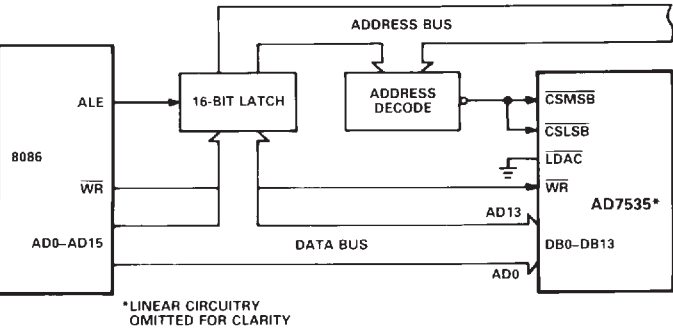


Figure 9. AD7535 – 8086 Interface Circuit

In a multiple DAC system the double buffering of the AD7535 allows the user to simultaneously update all DAC's. In Figure 10, a 14-bit word is loaded to the Input Registers of each of the DACs in sequence. Then, with one instruction to the appropriate address, CS4 (i.e. LDAC) is brought low, updating all the DACs simultaneously.

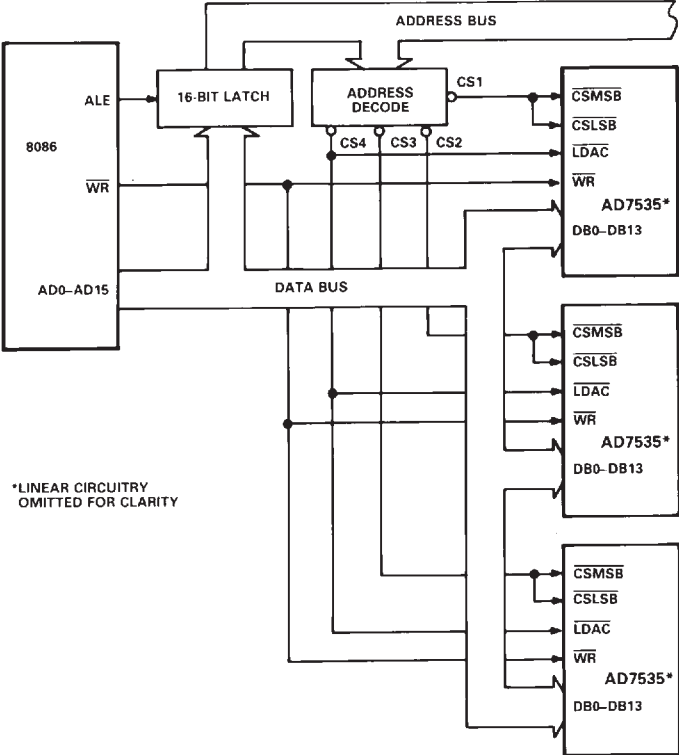


Figure 10. AD7535 – 8086 Interface: Multiple DAC System

ASSUME DS: DACLOAD, CS : DACLOAD  
DACLOAD SEGMENT AT 000

|    |            |                 |                                      |
|----|------------|-----------------|--------------------------------------|
| 00 | 8CC9       | MOV CX,CS       | : DEFINE DATA SEGMENT REGISTER EQUAL |
| 02 | 8ED9       | MOV DS,CX       | : TO CODE SEGMENT REGISTER           |
| 04 | BF00D0     | MOV DI, # D000  | : LOAD DI WITH D000                  |
| 07 | C705"YZWX" | MOV MEM,# YZWX" | : DAC LOADED WITH WXYZ               |
| 0B | EA0000     |                 | : CONTROL IS RETURNED TO THE         |
| 0E | 00FF       |                 | MONITOR PROGRAM                      |

Table III. Sample Program for Loading AD7535 from 8086

### AD7535 – MC68000 INTERFACE

Interfacing between the MC68000 and the AD7535 is accomplished using the circuit of Figure 11. The following routine writes data to the DAC input registers and then outputs the data via the DAC register.

```

01000  MOVE.W    # W, D0      The desired DAC data, W, is loaded into
                                Data Register 0. W may be any value
                                between 0 and 16383 (decimal) or 0
                                and 3FFF (hexadecimal).

                                MOVE.W    D0, $E000      The data W is transferred between D0
                                and the DAC Register.

                                MOVE.B    # 228, D7      Control is returned to the System
                                Monitor Program using these two
                                instructions.

                                TRAP      # 14

```

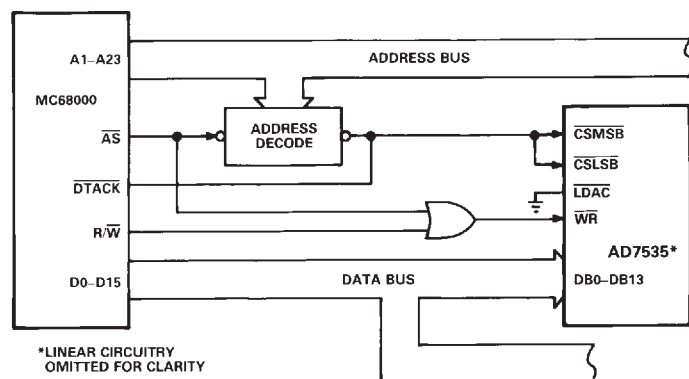


Figure 11. AD7535 – MC68000 Interface

### AD7535 – Z80 INTERFACE

Though the AD7535 is primarily intended for use either with 16-bit microprocessors or in stand alone applications, it can also be interfaced to 8-bit processor systems. Figure 12 is an interface circuit for the Z80 microprocessor.

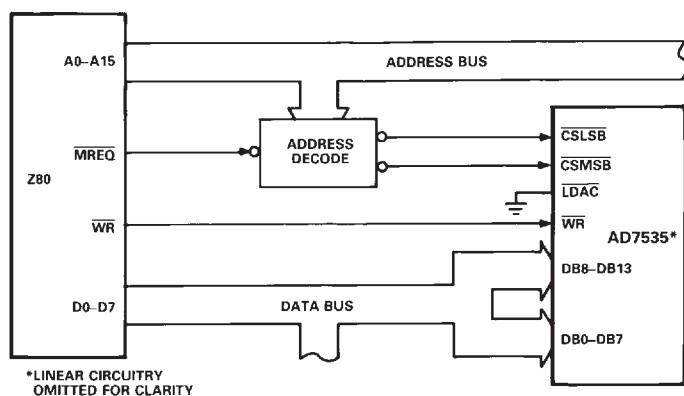


Figure 12. AD7535 – Z80 Interface

### DIGITAL FEEDTHROUGH

In the preceding interface configurations, most digital inputs to the AD7535 are directly connected to the microprocessor bus. Even when the device is not selected, these inputs will be constantly changing. The high frequency logic activity on the bus can feed through the DAC package capacitance to show up as noise on the analog output. To minimize this Digital Feedthrough isolate the DAC from the noise source. Figure 13 shows an interface circuit which physically isolates the DAC from the bus. One may also use other means, such as peripheral interface devices, to reduce the Digital Feedthrough.

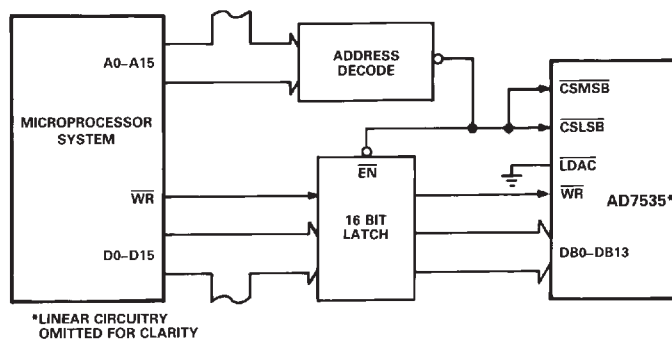


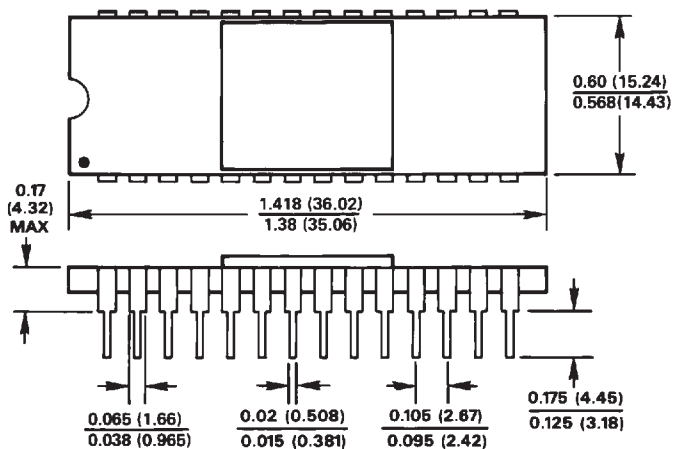
Figure 13. AD7535 Interface Circuit Using Latches to Minimize Digital Feedthrough

# MECHANICAL INFORMATION

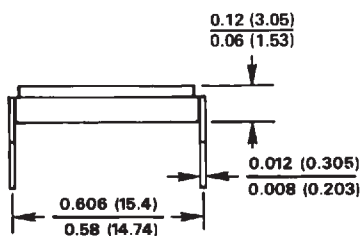
## OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

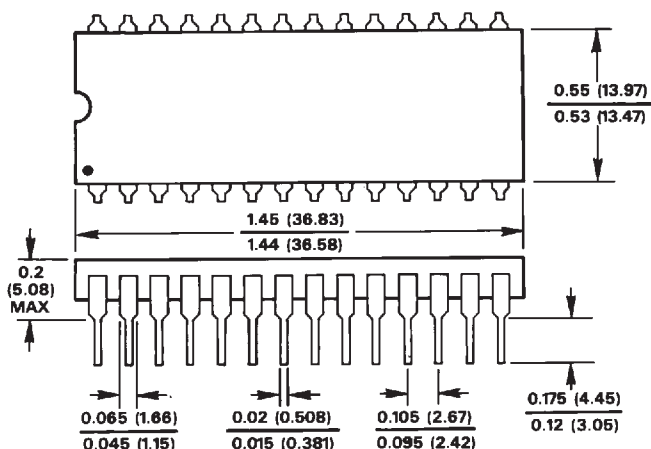
### 28-Pin Ceramic DIP Package (D-28A)



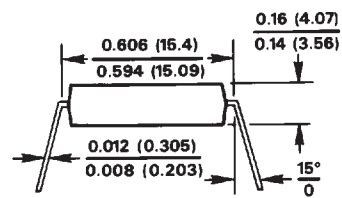
LEAD NO. 1 IDENTIFIED BY DOT OR NOTCH  
LEADS ARE GOLD PLATED (50 MICROINCHES MIN) KOVAR OR ALLOY 42



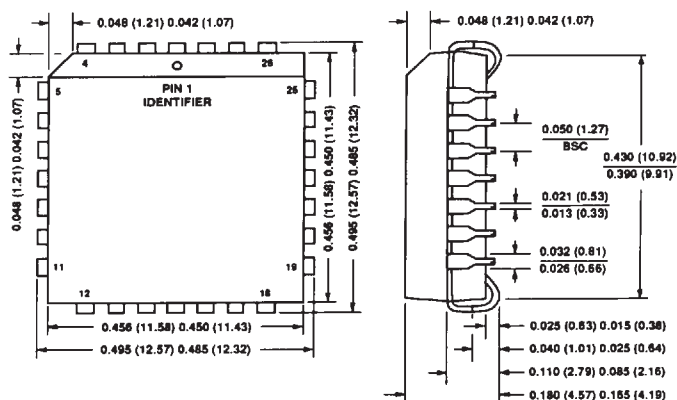
### 28-Pin Plastic DIP (N-28)



LEAD NO. 1 IDENTIFIED BY DOT OR NOTCH  
LEADS ARE SOLDER OR TIN PLATED KOVAR OR ALLOY 42



### P-28A PLCC



### E-28A) LCCC E Package

