



## Microprocessor-Compatible, 14-Bit DACs

MX7534/MX7535

### General Description

The MX7534/MX7535 are high-performance, CMOS, monolithic, 14-bit digital-to-analog converters (DACs). Wafer-level, laser-trimmed, thin-film resistors and temperature-compensated NMOS switches assure operation over the full operating temperature range with exceptional linear and gain stability.

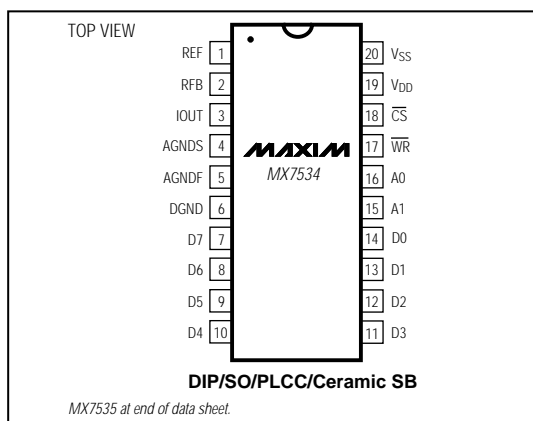
The MX7534 accepts right-justified data in two bytes from an 8-bit bus, while the MX7535 operates with a 14-bit data bus with separate MS-byte and LS-byte select controls. In addition, all digital inputs are compatible with both TTL and 5V CMOS-logic levels. The MX7534/MX7535 are intended for unipolar operation, but may be operated as bipolar DACs with additional external components. Both devices are protected against CMOS latchup, and neither requires the use of external Schottky protection diodes.

The MX7534 is available in 20-pin narrow (0.3") DIP, wide SO, or PLCC packages. The MX7535 is available in 28-pin, 600 mil wide DIP, wide SO, or PLCC packages.

### Applications

Machine and Motion Control Systems  
Automatic Test Equipment  
Digital Audio  
 $\mu$ P-Controlled Calibration Circuitry  
Programmable-Gain Amplifiers  
Digitally Controlled Filters  
Programmable Power Supplies

### Pin Configurations



### Features

- ♦ 14-Bit Monotonic Over Full Temperature Range
- ♦ Full 4-Quadrant Multiplication
- ♦  $\mu$ P-Compatible, Double-Buffered Inputs
- ♦ Exceptionally Low Gain Tempco (2.5ppm/ $^{\circ}$ C)
- ♦ Low Output Leakage (<20nA) Over Temp.
- ♦ Low Power Consumption
- ♦ TTL and CMOS Compatible

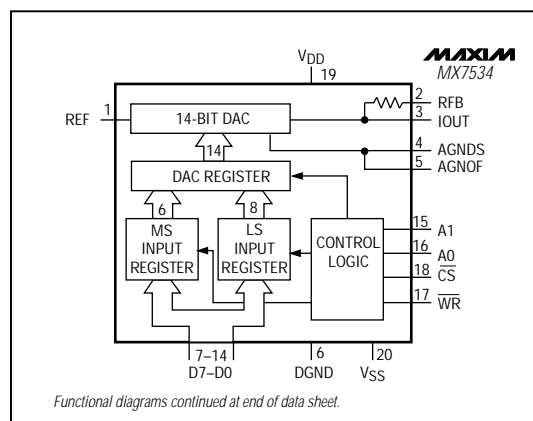
### Ordering Information

| PART       | TEMP. RANGE                           | PIN-PACKAGE    | INL (LSBs) |
|------------|---------------------------------------|----------------|------------|
| MX7534KN   | 0 $^{\circ}$ C to +70 $^{\circ}$ C    | 20 Plastic DIP | $\pm 1$    |
| MX7534JN   | 0 $^{\circ}$ C to +70 $^{\circ}$ C    | 20 Plastic DIP | $\pm 2$    |
| MX7534KCWP | 0 $^{\circ}$ C to +70 $^{\circ}$ C    | 20 SO          | $\pm 1$    |
| MX7534JCWP | 0 $^{\circ}$ C to +70 $^{\circ}$ C    | 20 SO          | $\pm 2$    |
| MX7534KP   | 0 $^{\circ}$ C to +70 $^{\circ}$ C    | 20 PLCC        | $\pm 1$    |
| MX7534JP   | 0 $^{\circ}$ C to +70 $^{\circ}$ C    | 20 PLCC        | $\pm 2$    |
| MX7534J/D  | 0 $^{\circ}$ C to +70 $^{\circ}$ C    | Dice*          | $\pm 2$    |
| MX7534BQ   | -25 $^{\circ}$ C to +85 $^{\circ}$ C  | 20 CERDIP      | $\pm 1$    |
| MX7534AQ   | -25 $^{\circ}$ C to +85 $^{\circ}$ C  | 20 CERDIP      | $\pm 2$    |
| MX7534BD   | -25 $^{\circ}$ C to +85 $^{\circ}$ C  | 20 Ceramic SB  | $\pm 1$    |
| MX7534AD   | -25 $^{\circ}$ C to +85 $^{\circ}$ C  | 20 Ceramic SB  | $\pm 2$    |
| MX7534KEWP | -40 $^{\circ}$ C to +85 $^{\circ}$ C  | 20 SO          | $\pm 1$    |
| MX7534JEWP | -40 $^{\circ}$ C to +85 $^{\circ}$ C  | 20 SO          | $\pm 2$    |
| MX7534TQ   | -55 $^{\circ}$ C to +125 $^{\circ}$ C | 20 CERDIP      | $\pm 1$    |
| MX7534SQ   | -55 $^{\circ}$ C to +125 $^{\circ}$ C | 20 CERDIP      | $\pm 2$    |
| MX7534TD   | -55 $^{\circ}$ C to +125 $^{\circ}$ C | 20 Ceramic SB  | $\pm 1$    |
| MX7534SD   | -55 $^{\circ}$ C to +125 $^{\circ}$ C | 20 Ceramic SB  | $\pm 2$    |

Ordering Information continued at end of data sheet.

\*Dice are tested at +25 $^{\circ}$ C, DC parameters only.

### Functional Diagrams



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## ABSOLUTE MAXIMUM RATINGS

|   |                                    |
|---|------------------------------------|
| V <sub>DD</sub> to DGND                               | .....-0.3V, +17V                   |
| V <sub>SS</sub> to AGND                               | .....-15V, +0.3V                   |
| REF to AGND (MX7534)                                  | .....±25V                          |
| REFS to AGND (MX7535)                                 | .....±25V                          |
| REFF to AGND (MX7535)                                 | .....±25V                          |
| RFB to AGND   | .....±25V                          |
| Digital Input Voltage to DGND                         | .....-0.3V, V <sub>DD</sub> + 0.3V |
| I <sub>OUT</sub> to DGND                              | .....-0.3V, V <sub>DD</sub> + 0.3V |
| AGND to DGND  | .....-0.3V, V <sub>DD</sub> + 0.3V |
| Continuous Power Dissipation (T <sub>A</sub> = +70°C) |                                    |
| 20-Pin Plastic DIP (derate 11.11mW/°C above +70°C)    | .....889mW                         |
| 28-Pin Plastic DIP (derate 14.29mW/°C above +70°C)    | .....1.14W                         |
| 20-Pin SO (derate 10.00mW/°C above +70°C)             | .....800mW                         |
| 28-Pin SO (derate 12.50mW/°C above +70°C)             | .....1W                            |
| 20-Pin PLCC (derate 10.00mW/°C above +70°C)           | .....800mW                         |

|   |                      |
|---|----------------------|
| 28-Pin PLCC (derate 10.53mW/°C above +70°C)   | .....842mW           |
| 20-Pin Cerdip (derate 11.11mW/°C above +70°C) | .....889mW           |
| 28-Pin Cerdip (derate 16.67mW/°C above +70°C) | .....1.33W           |
| 20-Pin Ceramic SB                             |                      |
| (derate 11.76mW/°C above +70°C)               | .....941mW           |
| 28-Pin Ceramic SB                             |                      |
| (derate 20.00mW/°C above +70°C)               | .....1.6W            |
| Operating Temperature Ranges                  |                      |
| MX753_J/K                                     | .....0°C to +70°C    |
| MX753_A/B                                     | .....-25°C to +85°C  |
| MX753_EW                                      | .....-40°C to +85°C  |
| MX753_S/T                                     | .....-55°C to +125°C |
| Storage Temperature Range                     | .....-65°C to +150°C |
| Lead Temperature (soldering, 10sec)           | .....+300°C          |

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## ELECTRICAL CHARACTERISTICS

(V<sub>DD</sub> = +11.4V to +15.75V (Note 1), V<sub>REF</sub> = 10V, V<sub>IOUT</sub> = V<sub>AGND</sub> = V<sub>SS</sub> = 0V, T<sub>A</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted.)

| PARAMETER                                   | SYMBOL           | CONDITIONS   |   |               | MIN  | TYP  | MAX  | UNITS  |
|---|------------------|--|---|---------------|------|------|------|--------|
| DC ACCURACY                                 |                  |  |   |               |      |      |      |        |
| Resolution                                  |                  |  |   |               | 14   |      |      | Bits   |
| Relative Accuracy                           | INL              | MX753_K/B/T  |   |               |      |      | ±1   | LSB    |
|   |                  | MX753_J/A/S  |   |               |      |      | ±2   |        |
| Differential Nonlinearity                   |                  | Guaranteed Monotonic   |   |               |      |      | ±1   | LSB    |
| Full-Scale Error                            |                  | Measured with internal R <sub>FB</sub> , includes effects of leakage current and gain TC | MX753_K/B/T   |               |      |      | ±4   | LSB    |
|   |                  |  | MX753_J/A/S   |               |      |      | ±8   |        |
| Gain Temperature Coefficient (Note 2)       |                  | MX753_K/B/T  |   |               | ±0.5 |      | ±2.5 | ppm/°C |
|   |                  | MX753_J/A/S  |   |               | ±0.5 |      | ±5   |        |
| Output Leakage Current                      | I <sub>OUT</sub> | All digital inputs at 0V   | T <sub>A</sub> = +25°C                                |               |      |      | ±5   | nA     |
|   |                  | All digital inputs at 0V, V <sub>SS</sub> = 0V   | T <sub>A</sub> = T <sub>MIN</sub> to T <sub>MAX</sub> | MX753_J/K/A/B |      | ±25  |      |        |
|   |                  |  |   | MX753_S/T     |      | ±150 |      |        |
| REFERENCE INPUT                             |                  |  |   |               |      |      |      |        |
| Reference Voltage Input Resistance (Note 3) | R <sub>REF</sub> |  |   |               | 3.5  | 6    | 10   | kΩ     |
| DIGITAL INPUTS                              |                  |  |   |               |      |      |      |        |
| Input High Voltage                          | V <sub>INH</sub> |  |   |               | 2.4  |      |      | V      |
| Input Low Voltage                           | V <sub>INL</sub> |  |   |               |      |      | 0.8  | V      |
| Input Leakage Current                       |                  | Digital inputs at 0V or V <sub>DD</sub>  | T <sub>A</sub> = +25°C                                |               |      |      | ±1   | μA     |
|   |                  |  | T <sub>A</sub> = T <sub>MIN</sub> to T <sub>MAX</sub> |               |      |      | ±10  |        |
| Input Capacitance (Note 2)                  | C <sub>IN</sub>  |  |   |               |      |      | 7    | pF     |

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MX7534/MX7535

## ELECTRICAL CHARACTERISTICS (continued)

(V<sub>DD</sub> = +11.4V to +15.75V (Note 1), V<sub>REF</sub> = 10V, V<sub>IOUT</sub> = V<sub>AGNDS</sub> = V<sub>SS</sub> = 0V, T<sub>A</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted.)

| PARAMETER                     | SYMBOL          | CONDITIONS   | MIN    | TYP | MAX   | UNITS |
|-------------------------------|-----------------|--|--------|-----|-------|-------|
| <b>POWER REQUIREMENTS</b>     |                 |  |        |     |       |       |
| Positive Supply-Voltage Range | V <sub>DD</sub> | For specific performance                               | 11.4   |     | 15.75 | V     |
| Negative Supply-Voltage Range | V <sub>SS</sub> | For specific performance                               | -200   |     | -500  | mV    |
| Positive Supply Current       | I <sub>DD</sub> | Digital inputs at V <sub>INH</sub> or V <sub>INL</sub> | MX7534 |     | 3     | mA    |
|                               |                 |  | MX7535 |     | 4     |       |
| Negative Supply Current       | I <sub>SS</sub> | Digital inputs at 0V or V <sub>DD</sub>                |        |     | 500   | μA    |

**Note 1:** Specifications are guaranteed for V<sub>DD</sub> of +11.4V to +15.75V. At V<sub>DD</sub> = +5V, device is still functional with degraded specifications.

**Note 2:** Guaranteed by design, not tested.

**Note 3:** Resistors have a typical -300ppm/°C tempco.

## AC PERFORMANCE CHARACTERISTICS (Note 4)

(V<sub>DD</sub> = +11.4V to +15.75V, V<sub>REF</sub> = 10V, V<sub>IOUT</sub> = V<sub>AGND</sub> (V<sub>AGNDS</sub> for MX7535) = V<sub>SS</sub> = 0V, output amplifier is AD544\*, T<sub>A</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted.)

| PARAMETER                                  | SYMBOL           | CONDITIONS  | MIN   | TYP | MAX   | UNITS  |
|--|------------------|---|---|-----|-------|--------|
| Output Current Setting Time                |                  | T <sub>A</sub> = +25°C, to 0.003% of full-scale range, I <sub>OUT</sub> load = 100Ω    13pF, DAC register alternately loaded with all 1s and all 0s |   | 0.8 | 1.5   | μs     |
| Digital-to-Analog Glitch Impulse           |                  | Measured with V <sub>REF</sub> = 0V, I <sub>OUT</sub> loads = 100Ω    13pF, DAC register alternately loaded with all 1s and all 0s                  |   | 50  |       | nV-sec |
| Multiplying Feedthrough Error (Note 5)     |                  | V <sub>REF</sub> = ±10V, 10kHz sine wave, DAC register loaded with all 0s   | T <sub>A</sub> = +25°C                                |     | 3     | mVp-p  |
|  |                  |   | T <sub>A</sub> = T <sub>MIN</sub> to T <sub>MAX</sub> |     | 5     |        |
| Power-Supply Rejection                     |                  | ΔV <sub>DD</sub> = ±5%  | T <sub>A</sub> = +25°C                                |     | ±0.01 | %/%    |
|  |                  |   | T <sub>A</sub> = T <sub>MIN</sub> to T <sub>MAX</sub> |     | ±0.02 |        |
| Output Capacitance (I <sub>OUT</sub> Pin)  | C <sub>OUT</sub> | DAC register loaded with all 1s   |   |     | 260   | pF     |
|  |                  | DAC register loaded with all 0s   |   |     | 130   |        |
| Output Noise Voltage Density (10Hz–100kHz) |                  | Measured between R <sub>FB</sub> and I <sub>OUT</sub>   |   | 15  |       | nV/Hz  |

**Note 4:** These characteristics are included for design guidance only, and are not subject to test.

**Note 5:** Feedthrough can be further reduced by connecting the metal lid on the ceramic package to DGND.

\* AD544 is an Analog Devices part.

## Microprocessor-Compatible, 14-Bit DACs

### TIMING CHARACTERISTICS (MX7534)

( $V_{DD} = +11.4V$  to  $+15.75V$ ,  $V_{REF} = 10V$ ,  $V_{IOUT} = V_{AGND} = V_{SS} = 0V$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted. See Figure 1a for timing diagram.)

| PARAMETER                         | SYMBOL | CONDITIONS                            | MIN | TYP | MAX | UNITS |
|-----------------------------------|--------|---------------------------------------|-----|-----|-----|-------|
| Address Valid to Write Setup Time | $t_1$  |                                       | 0   |     |     | ns    |
| Address Valid to Write Hold Time  | $t_2$  |                                       | 0   |     |     | ns    |
| Data Setup Time                   | $t_3$  | $T_A = +25^\circ C$                   | 60  |     |     | ns    |
|                                   |        | $T_A = -25^\circ C$ to $+85^\circ C$  | 70  |     |     |       |
|                                   |        | $T_A = -55^\circ C$ to $+125^\circ C$ | 80  |     |     |       |
| Data Hold Time                    | $t_4$  | $T_A = +25^\circ C$                   | 20  |     |     | ns    |
|                                   |        | $T_A = -25^\circ C$ to $+85^\circ C$  | 20  |     |     |       |
|                                   |        | $T_A = -55^\circ C$ to $+125^\circ C$ | 30  |     |     |       |
| Chip-Select to Write-Setup Time   | $t_5$  |                                       | 0   |     |     | ns    |
| Chip-Select to Write-Hold Time    | $t_6$  |                                       | 0   |     |     | ns    |
| Write Pulse Width                 | $t_7$  | $T_A = +25^\circ C$                   | 170 |     |     | ns    |
|                                   |        | $T_A = -25^\circ C$ to $+85^\circ C$  | 200 |     |     |       |
|                                   |        | $T_A = -55^\circ C$ to $+125^\circ C$ | 240 |     |     |       |

### TIMING CHARACTERISTICS (MX7535)

( $V_{DD} = +11.4V$  to  $+15.75V$ ,  $V_{REF} = 10V$ ,  $V_{IOUT} = V_{AGND} = V_{SS} = 0V$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted. See Figure 1b for timing diagram.)

| PARAMETER                                    | SYMBOL | CONDITIONS                            | MIN | TYP | MAX | UNITS |
|--|--------|---------------------------------------|-----|-----|-----|-------|
| CSMSB or CSLSB to $\overline{WR}$ Setup Time | $t_1$  |                                       | 0   |     |     | ns    |
| CSMSB or CSLSB to $\overline{WR}$ Hold Time  | $t_2$  |                                       | 0   |     |     | ns    |
| $\overline{LDAC}$ Pulse Width                | $t_3$  | $T_A = +25^\circ C$                   | 170 |     |     | ns    |
|  |        | $T_A = -25^\circ C$ to $+85^\circ C$  | 200 |     |     |       |
|  |        | $T_A = -55^\circ C$ to $+125^\circ C$ | 240 |     |     |       |
| Write Pulse Width                            | $t_4$  | $T_A = +25^\circ C$                   | 170 |     |     | ns    |
|  |        | $T_A = -25^\circ C$ to $+85^\circ C$  | 200 |     |     |       |
|  |        | $T_A = -55^\circ C$ to $+125^\circ C$ | 240 |     |     |       |
| Data-Setup Time                              | $t_5$  | $T_A = +25^\circ C$                   | 140 |     |     | ns    |
|  |        | $T_A = -25^\circ C$ to $+85^\circ C$  | 160 |     |     |       |
|  |        | $T_A = -55^\circ C$ to $+125^\circ C$ | 180 |     |     |       |
| Data-Hold Time                               | $t_6$  | $T_A = +25^\circ C$                   | 20  |     |     | ns    |
|  |        | $T_A = -25^\circ C$ to $+85^\circ C$  | 20  |     |     |       |
|  |        | $T_A = -55^\circ C$ to $+125^\circ C$ | 30  |     |     |       |

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Pin Description (MX7534)

| PIN | NAME            | FUNCTION  |
|-----|-----------------|---|
| 1   | REF             | Reference Input to DAC  |
| 2   | RFB             | Feedback Resistor. Used to close the loop around an external op amp.  |
| 3   | IOUT            | Current Output  |
| 4   | AGNDS           | Analog Ground Sense. Reference point for external circuitry. AGNDS should carry minimum current.                            |
| 5   | AGNDF           | Analog Ground Force. Carries current from internal analog ground connections. AGNDS and AGNDF are tied together internally. |
| 6   | DGND            | Digital Ground  |
| 7   | D7              | Data Bit 7  |
| 8   | D6              | Data Bit 6  |
| 9   | D5              | Data Bit 5 or Data Bit 13 (MSB)   |
| 10  | D4              | Data Bit 4 or Data Bit 12   |
| 11  | D3              | Data Bit 3 or Data Bit 11   |
| 12  | D2              | Data Bit 2 or Data Bit 10   |
| 13  | D1              | Data Bit 1 or Data Bit 9  |
| 14  | D0              | Data Bit 0 (LSB) or Data Bit 8  |
| 15  | A1              | Address Input 1   |
| 16  | A0              | Address Input 0   |
| 17  | $\overline{WR}$ | Write Input. Active low.  |
| 18  | $\overline{CS}$ | Chip-Select Input. Active low.  |
| 19  | VDD             | +12V to +15V Supply-Voltage Input   |
| 20  | VSS             | Bias pin for high-temperature, low-leakage configuration  |

Pin Description (MX7535)

| PIN | NAME               | FUNCTION  |
|-----|--------------------|---|
| 1   | REFS               | Reference Voltage Sense   |
| 2   | REFF               | Reference Voltage Force   |
| 3   | RFB                | Feedback Resistor. Used to close the loop around an external op amp.  |
| 4   | IOUT               | Current Output  |
| 5   | AGNDS              | Analog Ground Sense. Reference point for external circuitry. This pin should carry minimum current.                         |
| 6   | AGNDF              | Analog Ground Force. Carries current from internal analog ground connections. AGNDS and AGNDF are tied together internally. |
| 7   | DGND               | Digital Ground  |
| 8   | D13                | Data Bit 13 (MSB)   |
| 9   | D12                | Data Bit 12   |
| 10  | D11                | Data Bit 11   |
| 11  | D10                | Data Bit 10   |
| 12  | D9                 | Data Bit 9  |
| 13  | D8                 | Data Bit 8  |
| 14  | D7                 | Data Bit 7  |
| 15  | D6                 | Data Bit 6  |
| 16  | D5                 | Data Bit 5  |
| 17  | D4                 | Data Bit 4  |
| 18  | D3                 | Data Bit 3  |
| 19  | D2                 | Data Bit 2  |
| 20  | D1                 | Data Bit 1  |
| 21  | D0                 | Data Bit 0 (LSB)  |
| 22  | $\overline{CSMSB}$ | Chip-Select Most Significant Byte. Active low.  |
| 23  | $\overline{LDAC}$  | Asynchronous Load DAC Input. Active low.  |
| 24  | $\overline{CSLSB}$ | Chip-Select Least Significant Byte. Active low.   |
| 25  | $\overline{WR}$    | Write Input. Active low.  |
| 26  | VDD                | +12V to +15V Supply-Voltage Input   |
| 27  | VSS                | Bias pin for high-temperature, low-leakage configuration  |
| 28  | N.C.               | No Connection. Not internally connected.  |

MX7534/MX7535

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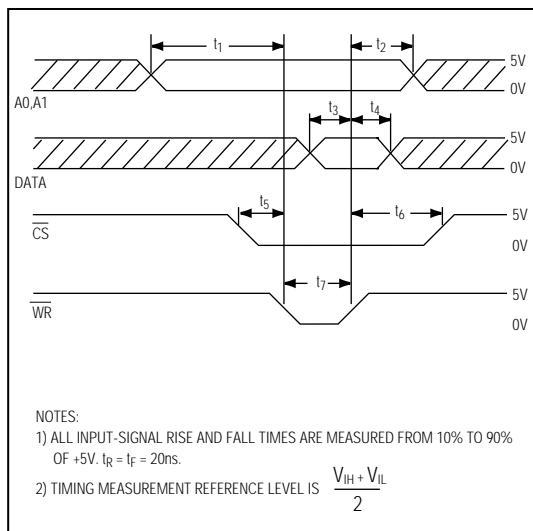


Figure 1a. MX7534 Timing Diagram

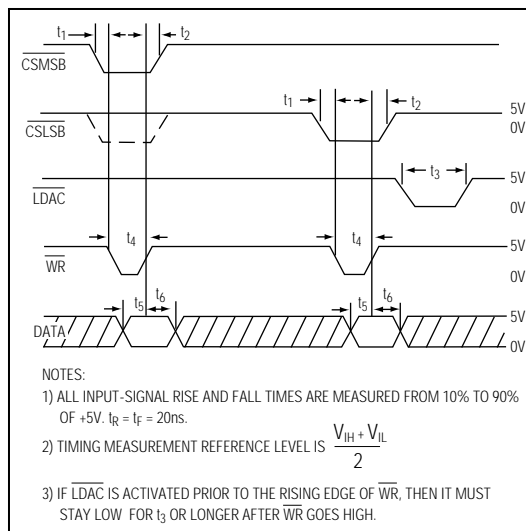


Figure 1b. MX7535 Timing Diagram

### Detailed Description

#### Digital-to-Analog Section

The basic MX7534/MX7535 digital-to-analog converter (DAC) circuit consists of a laser-trimmed, thin-film, 11-bit R-2R resistor array, a 3-bit segmented resistor array, and NMOS current switches, as shown in Figure 2. The three MSBs are decoded to drive switches A–G of the segmented array, and the remaining bits drive switches S0–S10 of the R-2R array.

Binary weighted currents are switched to either AGNDF or IOUT, depending on the status of each input bit. The R-2R ladder current is one-eighth of the total reference input current. The remaining seven-eighths of the current flows in the segmented resistors, dividing equally among these seven resistors. The input resistance at REF is constant; therefore, it can be driven by a voltage or current source of positive or negative polarity.

The MX7534/MX7535 are optimized for unipolar output operation (analog output from 0V to -VREF), although bipolar operation (analog output from +VREF to -VREF) is possible with some added external components.

Figure 3 shows the equivalent circuit for the two DACs. COUT varies from about 90pF to 180pF, depending on the digital code. RO denotes the DAC's equivalent output resistance, which varies with the input code.

$g(V_{REF,N})$  is the Thevenin equivalent voltage generator due to the reference input voltage,  $V_{REF}$ , and the transfer function of the R-2R ladder, N.

#### Digital Section

All digital inputs are both TTL and 5V CMOS logic compatible. The digital inputs are protected from electrostatic discharge (ESD) with typical input currents of less than 1nA. To minimize power-supply currents, keep digital input voltages as close to 0V and 5V logic levels as possible.

### Applications Information

#### Unipolar Operation (2-Quadrant Multiplication)

Figures 4a and 4b show 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 2.

Capacitor C1 provides phase compensation and helps prevent overshoot and ringing when high-speed op amps are used. Note that the output polarity is the inverse of the reference input.

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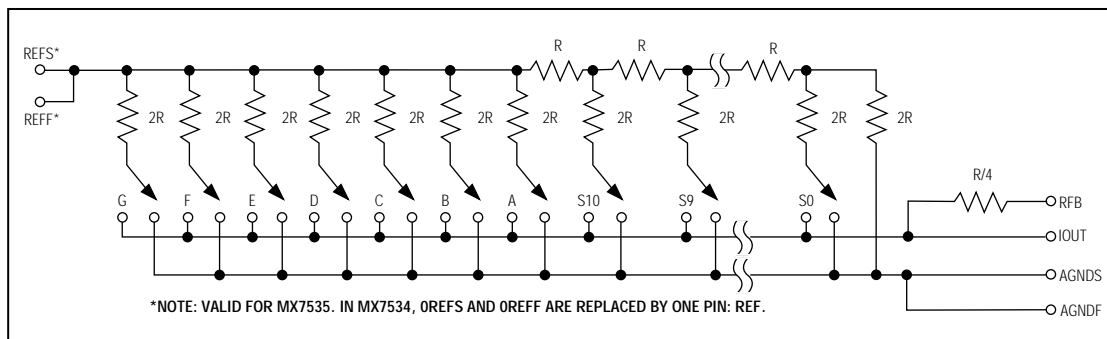


Figure 2. Simplified Circuit Diagram

### Zero-Offset Adjustment (Figures 4a and 4b)

- 1) Load the DAC register with all 0s.
- 2) Adjust the offset of amplifier A1 so that  $V_0$  (see figure) is at a minimum (i.e.,  $\leq 30\mu\text{V}$ ).

### Gain Adjustment (Figures 4a and 4b)

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

In fixed-reference applications, adjust full scale by omitting R1 and R2 and trimming the reference voltage magnitude. In many applications, the excellent Gain Tempco and Gain Error specifications eliminate the need for gain adjustment. However, if trims are required and the DAC is to operate over a wide temperature range, use low-tempco ( $>300\text{ppm}/^\circ\text{C}$ ) resistors.

### Bipolar Operation (4-Quadrant Multiplication)

Bipolar or 4-quadrant operation is shown in Figures 5a and 5b. This configuration provides for offset binary coding. Table 4 shows DAC codes and the corresponding analog outputs for Figures 5a and 5b. With the DAC loaded to 10 0000 0000 0000, either adjust R1 for  $V_{OUT} = 0\text{V}$ , or omit R1 and R2 and adjust the ratio of R5 and R6 for  $V_{OUT} = 0\text{V}$ . Adjust the amplitude of  $V_{IN}$  or vary the value of R7 for full-scale trimming.

Resistors R5, R6, and R7 must be matched to 0.003%. Mismatch of R5 and R6 causes both offset and full-scale errors. For wide temperature range operation, use resistors of the same material so that their temperature coefficients match and track.

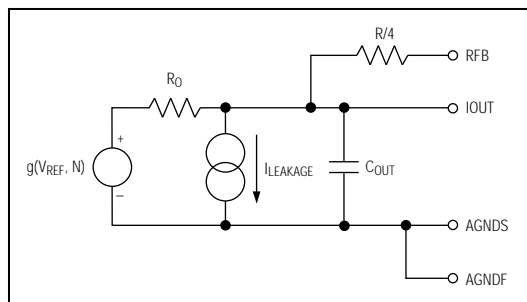


Figure 3. Equivalent Analog Output Circuit

Table 1. MX7534 Logic States

| WR | CS | A1 | A2 | FUNCTION                                   |
|----|----|----|----|--|
| X  | 1  | X  | X  | Device not selected (Note 1)               |
| 1  | X  | X  | X  | No data transfer                           |
| 0  | 0  | 0  | 0  | DAC loaded directly from Data Bus (Note 2) |
| 0  | 0  | 0  | 1  | MS Input Register loaded from Data Bus     |
| 0  | 0  | 1  | 0  | LS Input Register loaded from Data Bus     |
| 0  | 0  | 1  | 1  | DAC Register loaded from Input Registers   |

**Note 1:** X = Don't Care.

**Note 2:** When A1 = 0 and A0 = 0, all DAC registers are transparent. By placing all 0s or all 1s on the data inputs, the user can load the DAC to zero or full-scale output in one write operation. This simplifies system calibration.

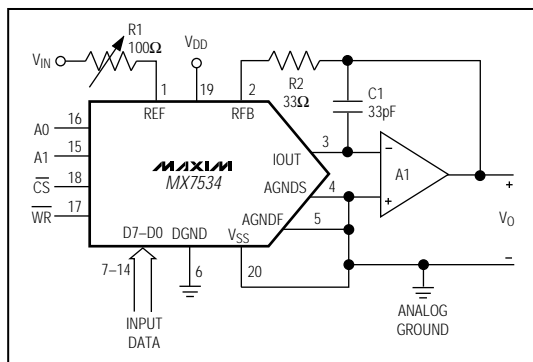


Figure 4a. Unipolar Binary Operation

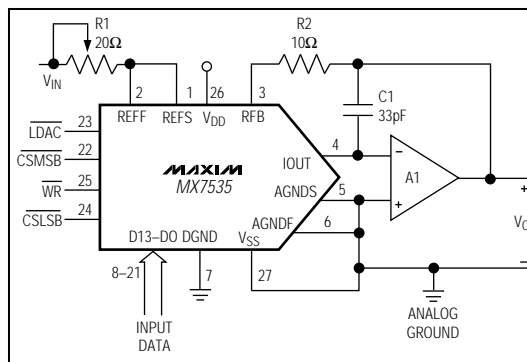


Figure 4b. Unipolar Binary Operation

## Grounding Considerations

Since IOUT and the output amplifier noninverting input are sensitive to offset voltages, connect nodes that must be grounded directly to a single-point ground through a separate, very-low-resistance path. Note that the output currents at IOUT and AGNDF vary with input code and create code-dependent error if these terminals are connected to ground (or a virtual ground) through a resistive path.

To obtain high accuracy, it is important to use a proper grounding technique. The two AGND pins (AGNDF, AGNDS) provide flexibility in this respect. In Figures 4a and 4b, AGNDS and AGNDF are shorted together externally and an extra op amp, A2, is not used. Voltage-drops due to bond-wire resistance are not compensated for in this circuit; this could create a linearity error of approximately 0.1LSB due to bond-wire resistance alone. This can be eliminated by using the circuits shown in Figures 6a and 6b, where A2 maintains AGNDS at signal ground potential. By using force/sense techniques, all switch contacts on the DAC are kept at exactly the same potential, and any error caused by bond-wire resistance is eliminated.

Figure 7 shows a remote voltage reference driving the MX7535. Op amps A2 and A3 compensate for voltage drops along the reference input line and analog ground line.

Figure 8 shows a printed circuit board (PCB) layout with a single output amplifier for the MX7534. The input to REF (Pin 1) is shielded to reduce AC feedthrough, while the digital inputs are shielded to minimize digital

### Table 2. Unipolar Binary Code Table

| BINARY NUMBER IN DAC REGISTER |      |      |             | ANALOG OUTPUT (V <sub>OUT</sub> )                                 |
|-------------------------------|------|------|-------------|---|
| MSB<br>11                     | 1111 | 1111 | LSB<br>1111 | $-V_{IN} \left( \frac{16383}{16384} \right)$                      |
| 10                            | 0000 | 0000 | 0000        | $-V_{IN} \left( \frac{8192}{16384} \right) = -\frac{1}{2} V_{IN}$ |
| 00                            | 0000 | 0000 | 0001        | $-V_{IN} \left( \frac{1}{16384} \right)$                          |
| 00                            | 0000 | 0000 | 0000        | 0V  |

feedthrough. The traces connecting IOUT and AGNDS to the inverting and noninverting op amp inputs are kept as short as possible. Gain trim components, R3 and R4, are omitted.

### Zero-Offset Adjustment (Figures 6a and 6b)

- 1) Load DAC register with all 0s.
- 2) Adjust offset of amplifier A2 for minimum potential at AGNDS. This potential should be  $\leq 30\mu\text{V}$  with respect to signal ground.
- 3) Adjust A1's offset so that  $V_{OUT}$  is at a minimum (i.e.,  $\leq 30\mu\text{V}$ ).



## Microprocessor-Compatible, 14-Bit DACs

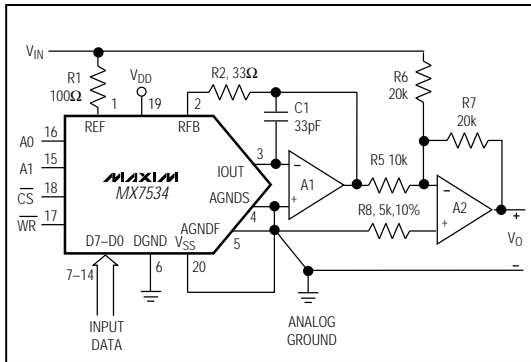


Figure 5a. Bipolar Operation

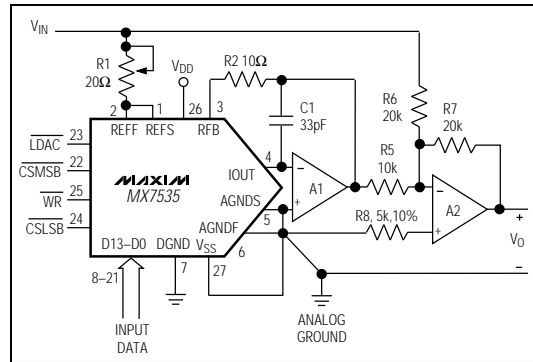


Figure 5b. Bipolar Operation

### Gain Adjustment (Figures 6a and 6b)

- 1) Load DAC register with all 1s.
- 2) Trim potentiometer R3 so that  $V_{OUT} = - \left( \frac{16383}{16384} \right) V_{IN}$

### Low-Leakage Configuration

Leakage current in the DAC flowing into the IOUT line can cause gain, linearity, and offset errors. Leakage is worse at high temperatures.

Negatively bias VSS for a high-temperature, low-leakage configuration.

### Dynamic Considerations

In static or DC applications, the output amplifier's AC characteristics are not critical. In higher-speed applications, where either the reference input is an AC signal or the DAC output must quickly settle to a new programmed value, the output op amp's AC parameters must be considered.

Another error source in dynamic applications is the parasitic signal coupling from the REF terminal to IOUT. This is normally a function of board layout and lead-to-lead package capacitance. Signals can also be injected into the DAC outputs when the digital inputs are switched. This digital feedthrough depends on circuit-board layout and on-chip capacitive coupling. Minimize layout-induced feedthrough with guard traces between digital inputs, REF, and DAC outputs.

Table 3. MX7535 Logic States

| CSMSB | CSLSB | LDAC | WR | FUNCTION                              |
|-------|-------|------|----|---------------------------------------|
| 0     | 1     | 1    | 0  | Load MS Input Register                |
| 1     | 0     | 1    | 0  | Load LS Input Register                |
| 0     | 0     | 1    | 0  | Load LS and MS Input Registers        |
| 1     | 1     | 0    | X  | Load DAC Register from Input Register |
| 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.

Table 4. Offset Binary Bipolar Code Table

| BINARY NUMBER IN DAC REGISTER |      |      |      | Analog Output (Vout)                                 |
|-------------------------------|------|------|------|--|
| MSB                           | 11   | 1111 | 1111 | 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 | 0  |
| 01                            | 1111 | 1111 | 1111 | $-V_{IN} \left( \frac{1}{8192} \right)$              |
| 00                            | 0000 | 0000 | 0000 | $-V_{IN} \left( \frac{8192}{8192} \right) = -V_{IN}$ |



Figure 6a. Unipolar Binary Operation with Forced Ground

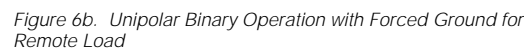


Figure 6b. Unipolar Binary Operation with Forced Ground for Remote Load

### Table 5. Amplifier Performance Comparisons

| OP AMP     | INPUT OFFSET VOLTAGE (V <sub>OS</sub> ) | INPUT BIAS CURRENT (I <sub>B</sub> ) | OFFSET VOLTAGE DRIFT (TC V <sub>OS</sub> ) | SETTLING TO 0.003% FS |
|------------|---|--------------------------------------|--|-----------------------|
| MAX400     | 10μV                                    | 2nA                                  | 0.3μV/°C                                   | 50μs                  |
| Maxim OP07 | 25μV                                    | 2nA                                  | 0.6μV/°C                                   | 50μs                  |
| AD554L*    | 500μV                                   | 25pA                                 | 5μV/°C                                     | 5μs                   |
| HA2620*    | 4mV                                     | 35nA                                 | 20μV/°C                                    | 0.8μs                 |

\* AD544L is an Analog Devices part; HA2620 is a Harris Semiconductor part.

## Compensation

A compensation capacitor, C1, may be needed when the DAC is used with a high-speed output amplifier. The capacitor cancels the pole formed by the DAC's output capacitance and internal feedback resistance. Its value depends on the type of op amp used, but typical values range from 10pF to 33pF. Too small a value causes output ringing, while excess capacitance overdamps the output. Minimize C1's size and improve output settling performance by keeping the PC board trace as short as possible and stray capacitance at IOUT as small as possible.

## Bypassing

Place a 1μF bypass capacitor, in parallel with a 0.01μF ceramic capacitor, as close to the DAC's V<sub>DD</sub> and GND pins as possible. Use a 1μF tantalum bypass capacitor to optimize high-frequency noise rejection. Place a 4.7μF decoupling capacitor at V<sub>SS</sub> to minimize the DAC output leakage current.

The MX7534/MX7535 have high-impedance digital inputs. To minimize noise pickup, connect them to either V<sub>DD</sub> or GND terminals when not in use. Connect active inputs to V<sub>DD</sub> or GND through high-value resistors (1M $\Omega$ ) to prevent static charge accumulation if these pins are left floating, as might be the case when a circuit card is left unconnected.

### Op-Amp Selection

Input offset voltage ( $V_{OS}$ ), input bias current ( $I_B$ ), and offset voltage drift ( $TC\ V_{OS}$ ) are three key parameters in determining the choice of a suitable amplifier. To maintain specified accuracy with  $V_{REF}$  of 10V,  $V_{OS}$  should be less than 30 $\mu$ V and  $I_B$  should be less than 2nA. Open-loop gain should be greater than 340,000. Maxim's MAX400 has low  $V_{OS}$  (10 $\mu$ V max), low  $I_B$  (2nA), and low  $TC\ V_{OS}$  (0.3 $\mu$ V/ $^{\circ}$ C max). This op amp can be used without requiring any adjustments. For

## MX7534/MX7535



## Microprocessor Interfacing

The MX7534/MX7535 interface to both 8-bit and 16-bit processors. Figure 9a shows the 8086 16-bit processor interfacing to a single MX7535. 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 (D0–D13). 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. Table 6a shows a software routine for Figure 9a.

8086 with MX7534

NOTE:  
LAYOUT IS FOR DOUBLE-SIDED  
PCB. BOLD LINE INDICATES  
TRACK ON COMPONENT SIDE.

\*AD544 IS AN ANALOG DEVICES PART.

Figure 8. Suggested Layout for MX7534 Incorporating Output Amplifier

8085A with MX7534

The six MSBs are written into location 3001, and eight LSBs are written to 3002. Then, with a write instruction to 3003, the full 14-bit word is loaded to the DAC register.

## Microprocessor-Compatible, 14-Bit DACs

### MC68000 with MX7535

Figure 11a shows an interface diagram. The following routine writes data to the DAC input registers and then outputs the data via the DAC register:

```
01000  MOVE.W  #W,D0      DAC data, W, loaded
                        into Data Register 0.
MOVE.W      D0,$E000     Data W transferred
                        between D0 and DAC
                        Register.
      MOVE.B  #228,D7     Control returned to the
                        System.
      TRAP    #14         Monitor Program
```

### MC68000 with MX7534

Figure 11b shows the MC68000 interface diagram. The following routine writes data to the DAC input registers and then outputs the data via the DAC register:

```
.A2 E003              Address Register 2
                        loaded with E003.
01000  MOVE.W  #W,D0      DAC data, W, loaded
                        into Data Register 0.
      MOVEP.W D0,$0000(A2) Data W transferred
                        between D0 and the
                        DAC's Input Register.
                        High-ordered byte transferred first. Memory
                        address specified using the address register
                        indirect plus displacement addressing mode.
                        Address used here (E003) is odd, so data is
                        transferred on the low-order half of the data
                        bus (D0-D7).

      MOVE.W  D0,$E006     This instruction provides
                        appropriate signals to
                        transfer data W from
                        the DAC Input Register
                        to the DAC Register,
                        which controls the R-2R
                        ladder switches.

      MOVE.B  #228,D7     Control returned to the
                        System.
      TRAP    #14         Monitor Program
```

Since this interfacing system uses only the lower half of the data bus, it is also suitable for use with the MC68008, which provides the user with an 8-bit data bus instead of the MC68000's 16-bit bus.

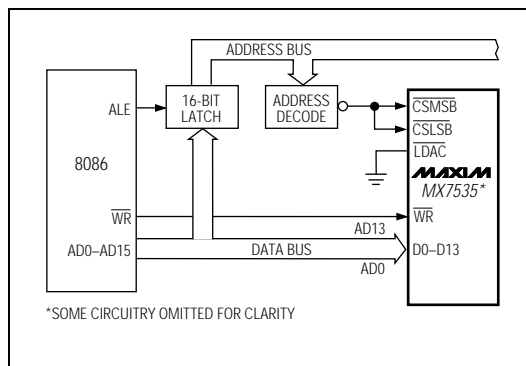


Figure 9a. MX7535—8086 Interface Circuit

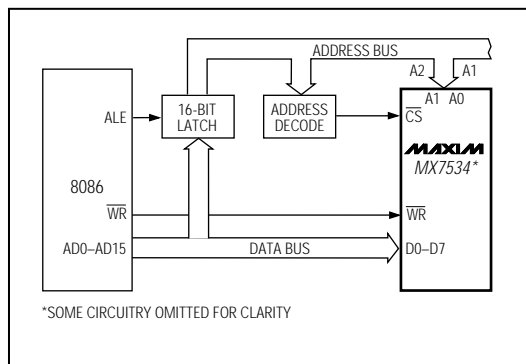


Figure 9b. MX7534—8086 Interface Circuit

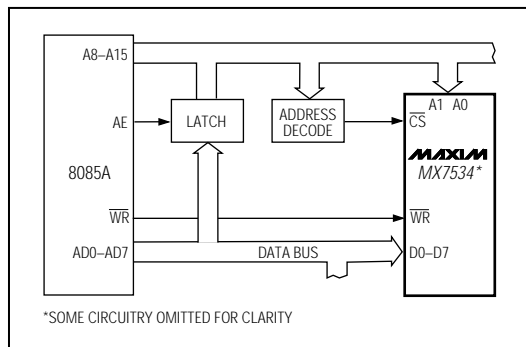


Figure 9c. MX7534—8085A Interface Circuit

# Microprocessor-Compatible, 14-Bit DACs

MX7534/MX7535

**Table 6a. Sample Program for Loading the MX7535**

|    |  |                |   |
|----|--|----------------|---|
|    | ASSUME DS:DACLOAD,CS:DACLOAD<br>DACLOAD SEGMENT AT 000 |                |   |
| 00 | 8CC9   | MOV CX,CS      | :DEFINE DATA SEGMENT REGISTER EQUAL         |
| 02 | 8ED9   | MOVDS,CX       | :TO CODE SEGMENT REGISTER                   |
| 04 | BF00D0   | MOVDI,#D000    | :LOAD DI WITH D000                          |
| 07 | C705"YZWX"   | MOV MEM,"YZWX" | :DAC LOADED WITH WXYZ                       |
| 0B | EA0000   |                | :CONTROL IS RETURNED TO THE MONITOR PROGRAM |
| 0E | 00FF   |                |   |

**Table 6b. Sample Program for Loading the MX7534 from 8086**

|    |  |              |  |
|----|--|--------------|--|
|    | ASSUME DS:DACLOAD,CS:DACLOAD<br>DACLOAD SEGMENT AT 000 |              |  |
| 00 | 8CC9   | MOV CX,CS    | :DEFINE DATA SEGMENT REGISTER EQUAL                        |
| 02 | 8ED9   | MOVDS,CX     | :TO CODE SEGMENT REGISTER                                  |
| 04 | BF02D0   | MOVDI,#D002  | :LOAD DI WITH D002   |
| 07 | C605"MS"   | MOV MEM,"MS" | :DAC LOADED WITH "MS"                                      |
| 0A | 47   | INC DI       |  |
| 0B | 47   | INC DI       |  |
| 0C | C605"LS"   | MOV MEM,"LS" | :LS INPUT REGISTER LOADED WITH "LS"                        |
| 0F | 47   | INC DI       |  |
| 10 | 47   | INC DI       |  |
| 11 | C60500   | MOV MEM,#00  | :CONTENT OF INPUT REGISTERS ARE LOADED TO THE DAC REGISTER |
| 14 | EA0000   | JMP MEM      | :CONTROL IS RETURNED TO THE MONITOR PROGRAM                |

**Table 6c. Sample Program for Loading the MX7534 from 8085A**

|      |      |            |
|------|------|------------|
| 2000 | 26   | MVIH,#30   |
| 01   | 30   |            |
| 02   | 2E   | MVIL,#01   |
| 03   | 01   |            |
| 04   | 3E   | MVIA,"MS"  |
| 05   | "MS" |            |
| 06   | 77   | MOV M,A    |
| 07   | 2C   | INR L      |
| 08   | 3E   | MVI A#"LS" |
| 09   | "LS" |            |
| 0A   | 77   | MOV M,A    |
| 0B   | 2C   | INR L      |
| 0C   | 77   | MOV M,A    |
| 200D | CF   | RST 1      |

## Z80 with MX7534/MX7535

Figure 12a is an interface circuit for the Z80, using the MX7535. This is an example of an 8-bit processor interface for these DACs. Figure 12b shows the schematic for the MX7534.

## MC6809 with MX7534

Figure 13a shows an interface circuit that enables the MX7534 to be programmed using the MC6809 8-bit microprocessor. Use the 16-bit D accumulator to simplify data transfer. The two key processor instructions are:

LDD     Load D accumulator from memory  
STD     Store D accumulator to memory

## MC6502 with MX7534

Figure 13b shows an interface diagram for the MC6502 using the MX7534.

## Digital Feedthrough

In the interface diagrams shown in Figures 9–13, the digital inputs of the DAC are directly connected to the microprocessor bus. Even when the device is not selected, activity on the bus can feed through on the DAC output through package capacitance and appear as noise. To minimize noise, isolate the DACs from the digital bus, as shown in Figures 14a and 14b.

## Microprocessor-Compatible, 14-Bit DACs

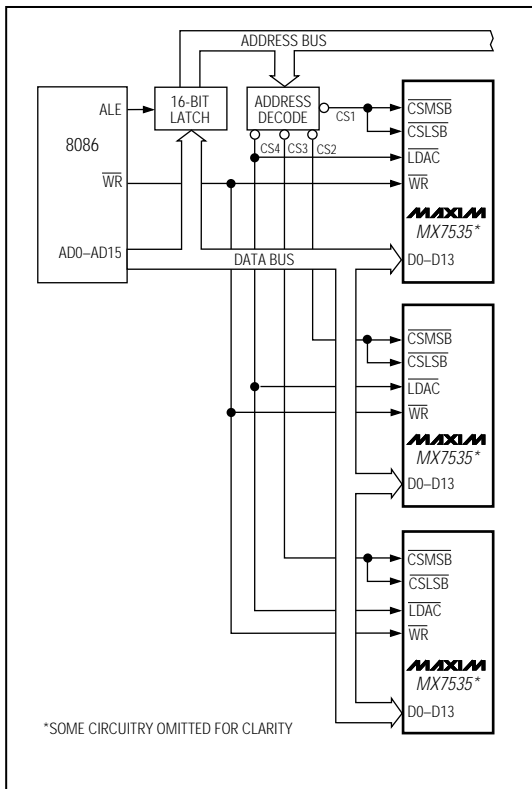


Figure 10. MX7535—8086 Interface: Multiple DAC Systems

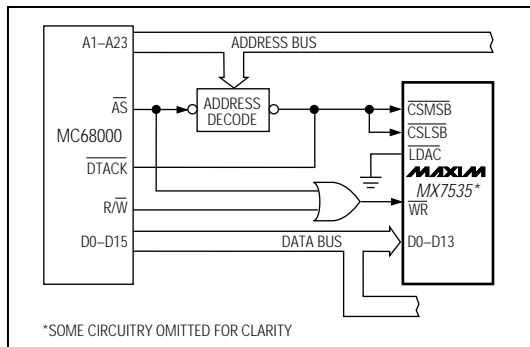


Figure 11a. MX7535—MC68000 Interface

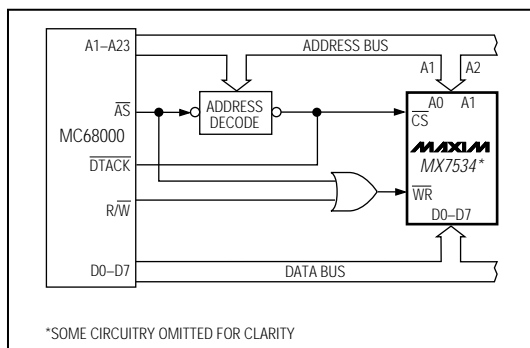


Figure 11b. MX7534—MC68000 Interface

## Microprocessor-Compatible, 14-Bit DACs

MX7534/MX7535

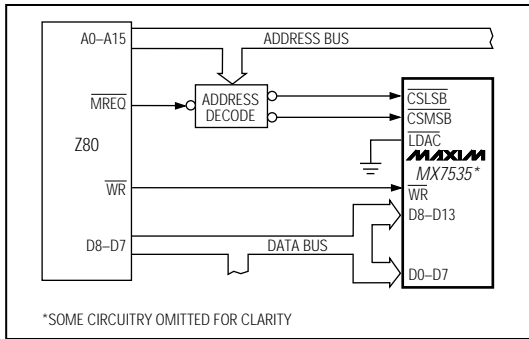


Figure 12a. MX7535—Z80 Interface

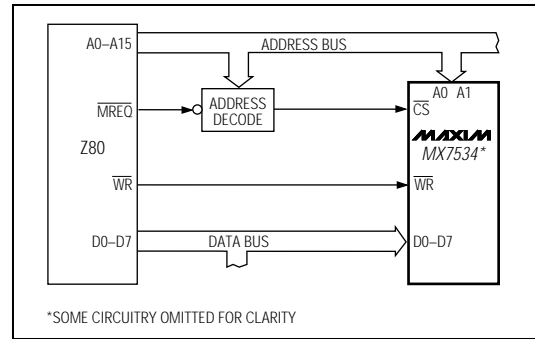


Figure 12b. MX7534—Z80 Interface

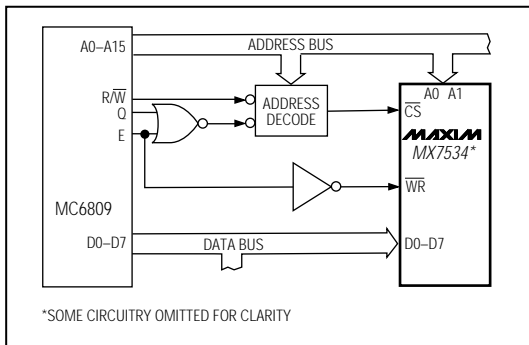


Figure 13a. MX7534—MC6809 Interface Circuit

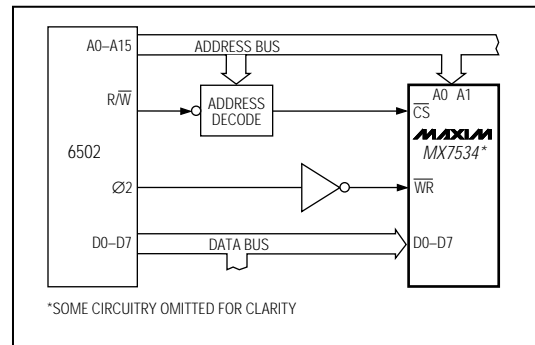


Figure 13b. MX7534—6502 Interface

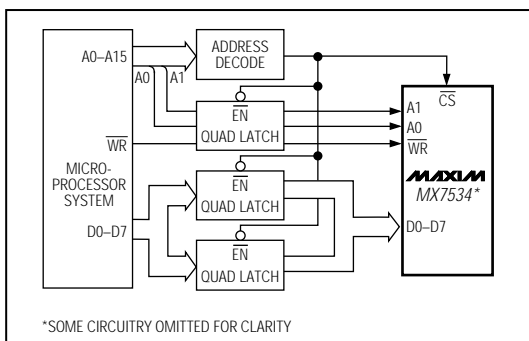


Figure 14a. MX7534—Interface Circuit Using Latches to Minimize Digital Feedthrough

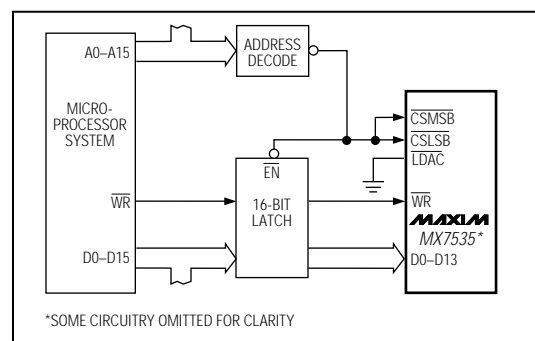
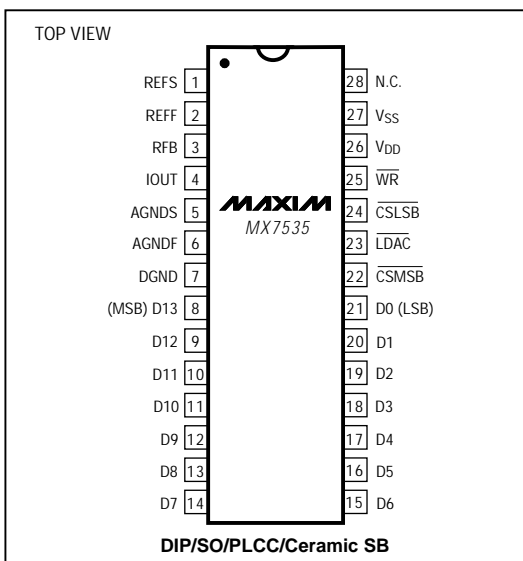


Figure 14b. MX7535—Interface Circuit Using Latches to Minimize Digital Feedthrough

## MX7534/MX7535

\_\_\_\_Pin Configurations (continued)



| PART              | TEMP. RANGE     | PIN PACKAGE    | INL (LSBs) |
|-------------------|-----------------|----------------|------------|
| <b>MX7535KN</b>   | 0°C to +70°C    | 28 Plastic DIP | ±1         |
| <b>MX7535JN</b>   | 0°C to +70°C    | 28 Plastic DIP | ±2         |
| <b>MX7535KCWI</b> | 0°C to +70°C    | 28 Wide SO     | ±1         |
| <b>MX7535JCWI</b> | 0°C to +70°C    | 28 Wide SO     | ±2         |
| <b>MX7535KP</b>   | 0°C to +70°C    | 28 PLCC        | ±1         |
| <b>MX7535JP</b>   | 0°C to +70°C    | 28 PLCC        | ±2         |
| <b>MX7535J/D</b>  | 0°C to +70°C    | Dice*          | ±2         |
| <b>MX7535BQ</b>   | -25°C to +85°C  | 28 CERDIP      | ±1         |
| <b>MX7535AQ</b>   | -25°C to +85°C  | 28 CERDIP      | ±2         |
| <b>MX7535BD</b>   | -25°C to +85°C  | 28 Ceramic SB  | ±1         |
| <b>MX7535AD</b>   | -25°C to +85°C  | 28 Ceramic SB  | ±2         |
| <b>MX7535KEWI</b> | -40°C to +85°C  | 28 Wide SO     | ±1         |
| <b>MX7535JEWI</b> | -40°C to +85°C  | 28 Wide SO     | ±2         |
| <b>MX7535TQ</b>   | -55°C to +125°C | 28 CERDIP      | ±1         |
| <b>MX7535SQ</b>   | -55°C to +125°C | 28 CERDIP      | ±2         |
| <b>MX7535TD</b>   | -55°C to +125°C | 28 Ceramic SB  | ±1         |
| <b>MX7535SD</b>   | -55°C to +125°C | 28 Ceramic SB  | ±2         |

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