

## 16-Bit Multiplying DACs

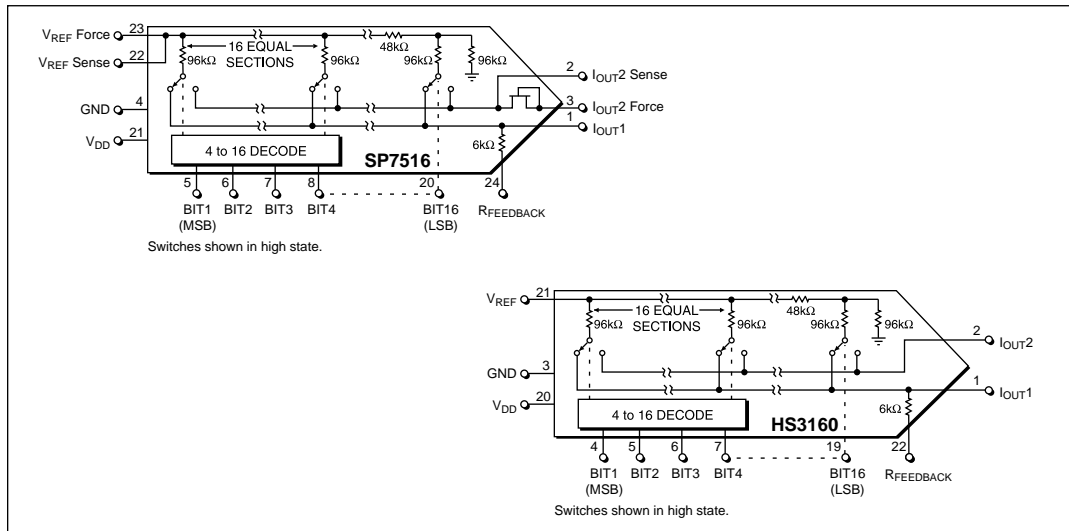
- Monolithic Construction
- 16-Bit Resolution
- 0.003% Non-Linearity
- Four-Quadrant Multiplication
- Latch-up Protected
- Low Power - 30mW
- Single +15V Power Supply

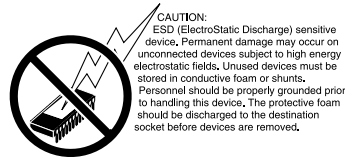


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### DESCRIPTION...

The **SP7516** and **HS3160** are precision 16-bit multiplying DACs, that provide four-quadrant multiplication. Both parts accept both AC and DC reference voltages. The **SP7516** is available for use in commercial and industrial temperature ranges, packaged in a 24-pin SOIC. The **HS3160** is available in commercial and military temperature ranges, packaged in a 22-pin side-brazed DIP.





## SPECIFICATIONS

(Typical @ 25°C, nominal power supply,  $V_{REF} = +10V$ , unipolar unless otherwise noted)

| PARAMETER   | MIN.            | TYP.   | MAX.   | UNITS  | CONDITIONS                                 |
|---|-----------------|--|--|--|--|
| <b>DIGITAL INPUT</b><br>Resolution<br>2–Quad, Unipolar Coding<br>4–Quad, Bipolar Coding<br>Logic Compatibility<br>Input Current   | 16              | Binary<br>Offset Binary<br>CMOS, TTL   | $\pm 1$  | Bits<br><br><br><br>$\mu A$                              | Note 1                                     |
| <b>REFERENCE INPUT</b><br>Voltage Range<br>Input Impedance  | 3.25            |  | $\pm 25$<br>9.75   | V<br>KOhms   | Note 2                                     |
| <b>ANALOG OUTPUT</b><br>Scale Factor<br>Scale Factor Accuracy<br>Output Leakage<br>Output Capacitance<br>$C_{OUT1}$ , all inputs high<br>$C_{OUT1}$ , all inputs low<br>$C_{OUT2}$ , all inputs high<br>$C_{OUT2}$ , all inputs low             | 75              |  | 225<br>$\pm 1$<br>10                                     | $\mu A/V_{REF}$<br>%<br>nA<br>pF<br>pF<br>pF<br>pF       | Note 3<br>Note 4                           |
| <b>STATIC PERFORMANCE</b><br>Integral Linearity<br>SP7516KN/BN, HS3160–4<br>SP7516JN/AN, HS3160–3<br>Differential Linearity<br>SP7516KN/BN, HS3160–4<br>SP7516JN/AN, HS3160–3<br>Monotonicity<br>SP7516KN/BN, HS3160–4<br>SP7516JN/AN, HS3160–3 |                 | $\pm 0.003$<br>$\pm 0.006$<br>$\pm 0.003$<br>$\pm 0.006$<br>Guaranteed to 14 bits<br>Guaranteed to 13 bits | $\pm 0.006$<br>$\pm 0.012$<br>$\pm 0.006$<br>$\pm 0.012$ | % FSR<br>% FSR<br>%FSR<br>% FSR                          | Note 5<br>Note 6                           |
| <b>STABILITY</b><br>Scale Factor<br>Integral Linearity<br>Differential Linearity<br>Monotonicity Temp. Range<br>SP7516JN/KN, HS3160C<br>SP7516AN/BN<br>HS3160B–   | 0<br>–40<br>–55 | 4<br>0.5<br>0.5  | 1.0<br>1.0   | ppm FSR/°C<br>ppm FSR/°C<br>ppm FSR/°C<br>°C<br>°C<br>°C | ( $T_{MIN}$ to $T_{MAX}$ )<br>Note 7 and 8 |
| <b>DYNAMIC PERFORMANCE</b><br>Digital Small Signal Settling<br>Digital Full Scale Settling<br>Reference Feedthrough Error<br>@ 1kHz<br>@ 10kHz<br>Reference Input Bandwidth   |                 | 1.0<br>2.0<br>200<br>2<br>1  |  | $\mu S$<br>$\mu S$<br>$\mu V$<br>mV<br>MHz               | ( $V_{REF} = 20V_{pp}$ )                   |
| <b>POWER SUPPLY (<math>V_{DD}</math>)</b><br>Operating Voltage<br>Voltage Range<br>Current<br>Rejection Ratio   | +8              | +15 $\pm 5\%$<br><br>0.005   | +18<br>2.0   | V<br>V<br>mA<br>%/%                                      | Note 9                                     |

## SPECIFICATIONS (continued)

(Typical @ 25°C, nominal power supply,  $V_{REF} = +10V$ , unipolar unless otherwise noted)

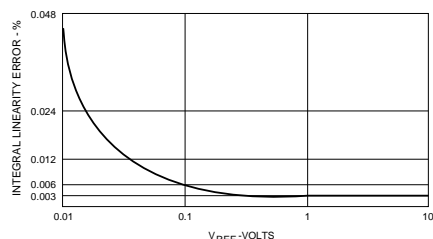
| PARAMETER                           | MIN. | TYP.                   | MAX. | UNITS | CONDITIONS |
|-------------------------------------|------|------------------------|------|-------|------------|
| <b>ENVIRONMENTAL AND MECHANICAL</b> |      |                        |      |       |            |
| Operating Temperature               |      |                        |      |       |            |
| <b>SP7516JN/KN</b>                  | 0    |                        | +70  | °C    |            |
| <b>SP7516AN/BN</b>                  | -40  |                        | +85  | °C    |            |
| <b>HS3160-C</b>                     | 0    |                        | +70  | °C    |            |
| <b>HS3160-B</b>                     | -55  |                        | +125 | °C    |            |
| <b>HS3160-B/883</b>                 | -55  |                        | +125 | °C    |            |
| Storage Temperature                 | -65  |                        | +150 | °C    |            |
| Package                             |      |                        |      |       |            |
| <b>SP7516_N</b>                     |      | 24-pin SOIC            |      |       |            |
| <b>HS3160</b>                       |      | 22-pin Side-Brazed DIP |      |       |            |

### Notes:

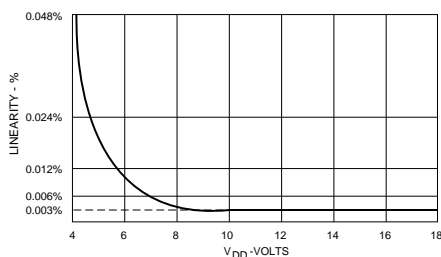
- Digital input voltage must not exceed supply voltage or go below  $-0.5V$ ; "0"  $< 0.8V$ ;  $2.4V < "1" \leq V_{DD}$ .
- AC or DC; use R6758-1 for fixed reference applications
- Using the internal feedback resistor and an external op amp. The Scale Factor can be adjusted externally by variable resistors in series with the reference input and/or in series to the internal feedback resistor. Please refer to the Applications Information section.
- At 25°C; the output leakage current will create an offset voltage at the external op amps output. It doubles every 10°C temperature increase.
- Integral Linearity is measured as the arithmetic mean value of the magnitudes of the greatest positive deviation and the greatest negative deviation from the theoretical value for any given input combination.
- Differential Linearity is the deviation of an output step from the theoretical value of 1LSB for any two adjacent digital input codes.
- At 25°C, the output leakage current will create an offset voltage output. It doubles every 10°C temperature increase.
- Using the internal feedback resistor and an external op amp.
- Use series 470ohm resistor to limit startup current.

## CHARACTERISTIC CURVES

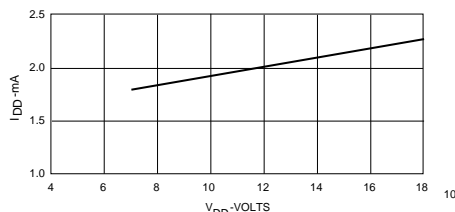
(Typical @ +25°C,  $V_{DD} = +15VDC$ ,  $V_{REF} = +10VDC$ , unless otherwise noted.)



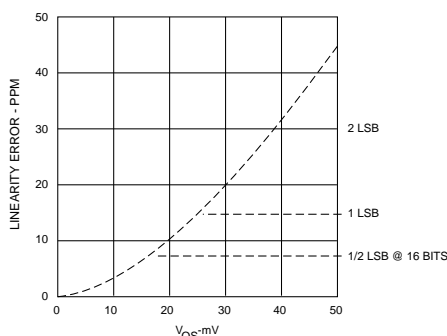
*Integral Linearity Error vs. Reference Voltage*



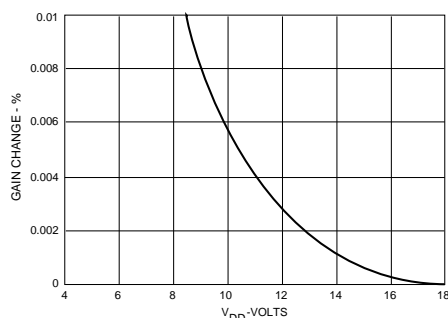
*Linearity vs. Supply Voltage*



*Power Supply Current vs. Voltage*



*Additional Linearity Error vs. Output-Amplifier Offset-Voltage ( $V_{REF} = +10V$ )*



*Gain Change vs. Supply Voltage*

## PIN ASSIGNMENTS

### HS3160 22-PIN

Pin 1 –  $IO_1$  – Current Output 1.  
Pin 2 –  $IO_2$  – Current Output 2.  
Pin 3 – GND – Ground.  
Pin 4 –  $DB_{15}$  – MSB, Data Bit 1.  
Pin 5 –  $DB_{14}$  – Data Bit 2.  
Pin 6 –  $DB_{13}$  – Data Bit 3.  
Pin 7 –  $DB_{12}$  – Data Bit 4.  
Pin 8 –  $DB_{11}$  – Data Bit 5.  
Pin 9 –  $DB_{10}$  – Data Bit 6.  
Pin 10 –  $DB_9$  – Data Bit 7.  
Pin 11 –  $DB_8$  – Data Bit 8.  
Pin 12 –  $DB_7$  – Data Bit 9.  
Pin 13 –  $DB_6$  – Data Bit 10.  
Pin 14 –  $DB_5$  – Data Bit 11.  
Pin 15 –  $DB_4$  – Data Bit 12.  
Pin 16 –  $DB_3$  – Data Bit 13.  
Pin 17 –  $DB_2$  – Data Bit 14.  
Pin 18 –  $DB_1$  – Data Bit 15.  
Pin 19 –  $DB_0$  – LSB, Data Bit 16.  
Pin 20 –  $V_{DD}$  – Positive Supply Voltage.  
Pin 21 –  $V_{REF}$  – Reference Voltage Input.  
Pin 22 –  $R_{FB}$  – Feedback Resistor.

### SP7516 24-PIN

Pin 1 –  $IO_1$  – Current Output 1.  
Pin 2 –  $IO_2$  Sense – Current Output 2.  
Pin 3 –  $IO_3$  Force – Current Output 3.  
Pin 4 – GND – Ground.  
Pin 5 –  $DB_{15}$  – MSB, Data Bit 1.  
Pin 6 –  $DB_{14}$  – Data Bit 2.  
Pin 7 –  $DB_{13}$  – Data Bit 3.  
Pin 8 –  $DB_{12}$  – Data Bit 4.  
Pin 9 –  $DB_{11}$  – Data Bit 5.  
Pin 10 –  $DB_{10}$  – Data Bit 6.  
Pin 11 –  $DB_9$  – Data Bit 7.  
Pin 12 –  $DB_8$  – Data Bit 8.  
Pin 13 –  $DB_7$  – Data Bit 9.  
Pin 14 –  $DB_6$  – Data Bit 10.

Pin 15 –  $DB_5$  – Data Bit 11.

Pin 16 –  $DB_4$  – Data Bit 12.

Pin 17 –  $DB_3$  – Data Bit 13.

Pin 18 –  $DB_2$  – Data Bit 14.

Pin 19 –  $DB_1$  – Data Bit 15.

Pin 20 –  $DB_0$  – LSB, Data Bit 16.

Pin 21 –  $V_{DD}$  – Positive Supply Voltage.

Pin 22 –  $V_{REF}$  Sense – Reference Voltage Input.

Pin 23 –  $V_{REF}$  Force – Reference Voltage Input.

Pin 24 –  $R_{FB}$  – Feedback Resistor.

## FEATURES...

The **SP7516** and **HS3160** are precision 16-bit multiplying DACs. The DACs are implemented as a one-chip CMOS circuit with a resistor ladder network.

Three output lines are provided on the DACs to allow unipolar and bipolar output connection with a minimum of external components. The feedback resistor is internal. The resistor ladder network termination is externally available, thus eliminating an external resistor for the 1 LSB offset in bipolar mode.

The **SP7516** is available for use in commercial and industrial temperature ranges, packaged in a 24-pin SOIC. The **HS3160** is available in commercial and military temperature ranges, packaged in a 24-pin side-brazed DIP. For product processed and screened to the requirements of MIL-M-38510 and MIL-STD-883C, please consult the factory (**HS3160B** only).

## PRINCIPLES OF OPERATION

The **SP7516/HS3160** achieve high accuracy by using a decoded or segmented DAC scheme to implement this function. The following is a brief description of this approach.

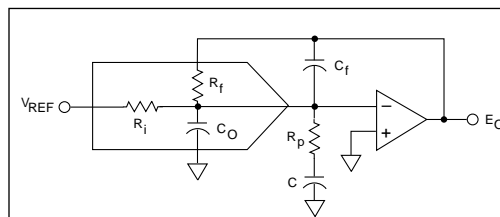


Figure 1. SP7516/HS3160 Equivalent Output Circuit

| $2^{-1}$ (MSB) | $2^{-2}$ | Output         |
|----------------|----------|----------------|
| 0              | 0        | 0              |
| 0              | 1        | 1/4 Full-Scale |
| 1              | 0        | 1/2 Full-Scale |
| 1              | 1        | 3/4 Full-Scale |

Table 1. Contribution of the two MSB's

The most common technique for building a D/A converter of  $n$  bits is to use  $n$  switches to turn  $n$  current or voltage sources on or off. The  $n$  switches and  $n$  sources are designed so that each switch or bit contributes twice as much to the D/A converter's output as the preceding bit. This technique is commonly known as binary weighting and allows an  $n$ -bit converter to generate  $2^n$  output levels by turning on the proper combination of bits.

In such a binary-weighted converter, the switch with the smallest contribution (the LSB) accounts for only  $2^{-n}$  of the converter's full-scale value. Similarly, the switch with the largest contribution (the MSB) accounts for  $2^{-1}$  or half of the converter's full-scale output. Thus it is easy to see that a given percent change in the MSB will have a greater effect on the converter's output than would a similar percent change in the LSB. For example, a 1% change in the LSB of a 10 bit converter would only affect the output by 0.001% of full-scale. A 1% change in the MSB of the same converter would affect the output by 0.5% of FSR.

In order to overcome the problem which results from the large weighting of the MSB, the two MSB's can be decoded to three equally weighted sources. Table 1 shows that all combinations of the two MSB's of a converter result in four output levels. So by replacing the two MSB's with three bits equally weighted at 1/4 full-scale and decoding the two MSB digital inputs into three lines which drive the equally weighted bits,

| TRANSFER FUNCTION (N=16) |                           |                             |
|--------------------------|---------------------------|-----------------------------|
| BINARY INPUT             | UNIPOLAR OUTPUT           | BIPOLAR OUTPUT              |
| 111...111                | $-V_{REF} (1 - 2^{-N})$   | $-V_{REF} (1 - 2^{-(N-1)})$ |
| 100...001                | $-V_{REF} (1/2 + 2^{-N})$ | $-V_{REF} (2^{-(N-1)})$     |
| 100...000                | $-V_{REF} / 2$            | 0                           |
| 011...111                | $-V_{REF} (1/2 - 2^{-N})$ | $V_{REF} (2^{-(N-1)})$      |
| 000...001                | $-V_{REF} (2^{-(N-1)})$   | $V_{REF} (1 - 2^{-(N-1)})$  |
| 000...000                | 0                         | $V_{REF}$                   |

Table 2. Transfer Function

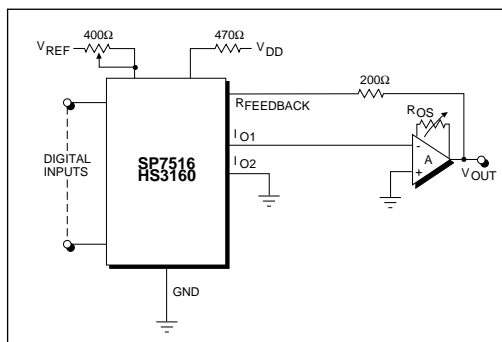


Figure 2. Unipolar Operation

the same functional performance can be obtained. Thus by replacing the two MSB switches of a conventional converter with three switches properly decoded, the contribution of any switch is reduced from 1/2 to 1/4. This reduction in sensitivity also reduces the accuracy required of any switch for a given overall converter accuracy.

With the decoded converter described above, a 1% change in any of the converter's switches will affect the output by no more than 0.25% of full-scale as compared to 0.5% for a conventional converter. In other words the conventional D/A converter can be made less sensitive to the quality of its individual bits by decoding.

In the SP7516/HS3160 the first four MSB's are decoded into 16 levels which drive 15 equally weighted current sources. The sensitivity of each switch on the output is reduced by a factor of 8. Each of the 15 sources contributes 6.25% output change rather than an MSB change of 50% for the common approach.

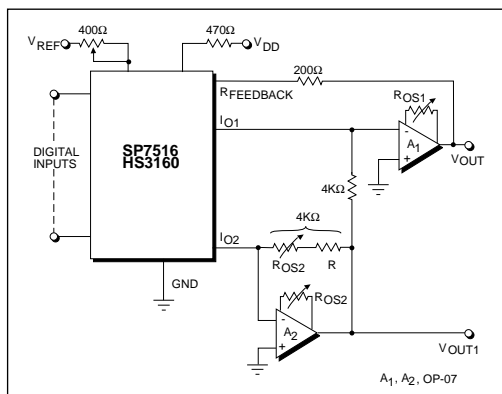


Figure 3. Bipolar Operation

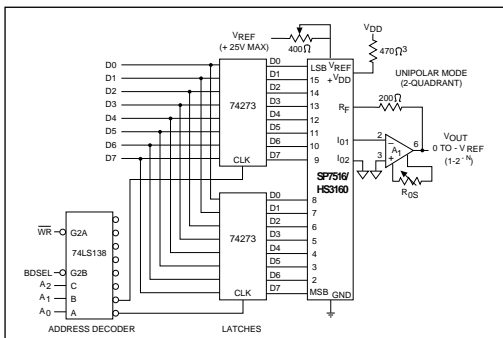


Figure 4. Microprocessor Interface to SP7514

Following the decoded section of the DAC a standard binary weighted R-2R approach is used. This divides each of the 16 levels (or 6.25% of F.S.) into 4096 discrete levels (the 12 LSB's).

### Output Capacitance

The **SP7516/HS3160** have very low output capacitance ( $C_O$ ). This is specified both with all switches ON and all switches OFF. Output capacitance varies from 50pF to 100pF over all input codes. This low capacitance is due in part to the decoding technique used. Smaller switches are used with resulting less capacitance. Three important system characteristics are affected by  $C_O$  and  $\Delta C_O$ ; namely digital feedthrough, settling time, and bandwidth. The DAC output equivalent circuit can be represented as shown in *Figure 1*.

Digital feedthrough is the change in analog output due to the toggling conditions on the converter input data lines when the analog input  $V_{REF}$  is at 0V. The **SP7516/HS3160** very low  $C_O$  and therefore will yield low digital feedthrough. Inputs to the DAC can be buffered. This input latch with microprocessor control is shown in *Figure 4*.

Settling time is directly affected by  $C_O$ . In *Figure 1*,  $C_O$  combines with  $R_f$  to add a pole to the open loop response, reducing bandwidth and causing excessive phase shift - which could result in ringing and/or oscillation. A feedback capacitor,  $C_f$  must be added to restore stability. Even with  $C_f$  there is still a zero-pole mismatch due to  $R_i C_O$  which is code dependent. This code dependent mismatch is minimized when  $C_O R_i = R_f C_f$ . However  $C_f$  must now be made larger to compensate for worst case  $\Delta R_i C_O$  - resulting in reduced bandwidth and increased settling time. With the **SP7516/**

**HS3160**, small values for  $C_f$  must be used. Resistor  $R_p$  can be added, this will parallel  $R_f$  decreasing the effective resistance. If  $C_f$  is reduced the bandwidth will be increased and settling time decreased. However a system penalty for lowering  $C_f$  is to increase noise gain. The tradeoff is noise vs. settling time. If  $R_p$  is added then a large value (1μF or greater) non-polarized capacitor  $C_p$  should be added in series with  $R_p$  to eliminate any DC drifts. If settling time is not important, eliminate  $R_p$  and  $C_p$ , and adjust  $C_f$  to prevent overshoot.

### Output Offset

In most applications, the output of the DAC is fed into an amplifier to convert the DAC's current output to voltage. A little known and not commonly discussed parameter is the linearity error versus offset voltage of the output amplifier. All CMOS DAC's must operate into a virtual ground, i.e., the summing junction of an op amp. Any amplifier's offset from the amplifier will appear as an error at the output (which can be related to LSB's of error).

Most all CMOS DAC's currently available are implemented using an R-2R ladder network. The formula for nonlinearity is typically  $0.67\text{mV/mV}_{OS}$  (not derived here). However the **SP7516** has a coefficient of only  $0.065\text{mV/mV}_{OS}$ . This is due to the decoding technique described earlier. CMOS DAC applications notes (including this one) always show a potentiometer used to null out the amplifier's offset. If an amplifier is chosen having 'pretrimmed' offset it may be possible to eliminate this component. Consider the following calculations:

- Using LF441A amplifier (low power - 741 pinout)
  - Specified offset: 0.5mV max
  - Temperature coefficient of input offset:  $10\mu\text{V}/^\circ\text{C}$  max
- $$V_{OS \text{ max}} (0^\circ\text{C to } 70^\circ\text{C}) = 0.5\text{mV} + (70\mu\text{V})10 = 1.2\text{mV}$$
- $$\text{Add'l nonlinearity (max)} = 1.2\text{mV} \times 0.065\text{mV/mV} = 78\mu\text{V} (1/2 \text{ LSB @ } 16 \text{ Bits!})$$
- Where:  $78\mu\text{V} = 1/2 \text{ LSB @ } 16 \text{ Bits } (10\text{V range})$

Via the above configuration, the **SP7516/HS3160** can be used to divide an analog signal by digital code (i.e. for digitally controlled gain). The transfer function is given in *Table 2*, where the value of each bit is 0 or 1. Division by all "0's is undefined and causes the op amp to saturate.

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## Applications Information

### Unipolar Operation

Figure 2 shows the interconnections for unipolar operation. Connect  $I_{O1}$  and  $FB_1$  as shown in diagram. Tie  $I_{O2}$  (Pin 7),  $FB_3$  (Pin 3), and  $FB_4$  (Pin 1) to Ground (Pin 8). As shown, a series resistor is recommended in the  $V_{DD}$  supply line to limit current during 'turn-on.' To maintain specified linearity, external amplifiers must be zeroed. Apply an ALL "ZEROES" digital input and adjust  $R_{OS}$  for  $V_{OUT} = 0 \pm 1mV$ . The **SP7516** and **HS3160** have been used successfully with OP-07, OP-27 and LF441A. For high speed applications the SP2525 is recommended.

### Bipolar Operation

Figure 3 shows the interconnections for bipolar operation. Connect  $I_{O1}$ ,  $I_{O2}$ ,  $FB_1$ ,  $FB_3$ ,  $FB_4$  as shown in diagram. Tie LDTR to  $I_{O2}$ . As shown, a series resistor is recommended in the  $V_{DD}$  supply line to limit current during 'turn-on. To maintain specified linearity, external amplifiers must be zeroed. This is best done with  $V_{REF}$  set to zero and, the DAC register loaded with 10...0 (MSB = 1). Set  $R_{OS1}$  for  $V_{O1} = 0$ . Set  $R_{OS2}$  for  $V_{OUT} = 0$ . Set  $V_{REF}$  to +10V and adjust  $R_B$  for  $V_{OUT}$  to be 0V.

### Grounding

Connect all GND pins to system analog ground and tie this to digital ground. All unused input pins must be grounded.

## ORDERING INFORMATION

| Model .....            | Monotonicity ..... | Temperature Range ..... | Package .....                |
|------------------------|--------------------|-------------------------|------------------------------|
| 16-Bit Multiplying DAC |                    |                         |                              |
| HS3160C-3Q .....       | 13-Bit .....       | 0°C to +70°C .....      | 22-pin, 0.4" Side-Brazed DIP |
| HS3160B-3Q .....       | 13-Bit .....       | -55°C to +125°C .....   | 22-pin, 0.4" Side-Brazed DIP |
| HS3160B-3/883 .....    | 13-Bit .....       | -55°C to +125°C .....   | 22-pin, 0.4" Side-Brazed DIP |
| HS3160C-4Q .....       | 14-Bit .....       | 0°C to +70°C .....      | 22-pin, 0.4" Side-Brazed DIP |
| HS3160B-4Q .....       | 14-Bit .....       | -55°C to +125°C .....   | 22-pin, 0.4" Side-Brazed DIP |
| HS3160B-4/883 .....    | 14-Bit .....       | -55°C to +125°C .....   | 22-pin, 0.4" Side-Brazed DIP |
| SP7516JN .....         | 13-Bit .....       | 0°C to +70°C .....      | 24-pin, 0.3" SOIC            |
| SP7516KN .....         | 14-Bit .....       | 0°C to +70°C .....      | 24-pin, 0.3" SOIC            |
| SP7516AN .....         | 13-Bit .....       | -40°C to +85°C .....    | 24-pin, 0.3" SOIC            |
| SP7516BN .....         | 14-Bit .....       | -40°C to +85°C .....    | 24-pin, 0.3" SOIC            |