



# AD766—SPECIFICATIONS ( $T_{MIN}$ to $T_{MAX}$ , $\pm 5$ V supplies, $F_S = 500$ kSPS unless otherwise noted. No deglitchers or MSB trimming is used.)

Parameter	AD766J			AD766A			Units
	Min	Typ	Max	Min	Typ	Max	
RESOLUTION			16			16	Bits
DIGITAL INPUTS							
$V_{IH}$	2.0		$+V_L$	2.0		$+V_L$	V
$V_{IL}$			0.8			0.8	V
$I_{IH}$ , $V_{IH} = V_L$			1.0			1.0	$\mu$ A
$I_{IL}$ , $V_{IL} = 0.4$			-10			-10	$\mu$ A
SERIAL PORT TIMING							
Serial Clock Period ( $t_{CLK}$ )	95			115			ns
Serial Clock HI ( $t_{HI}$ )	30			30			ns
Serial Clock LO ( $t_{LO}$ )	30			70			ns
Data Valid ( $t_{DATA}$ )	40			40			ns
Data Setup ( $t_S$ )	15			20			ns
Data Hold ( $t_H$ )	15			20			ns
Clock-to-Latch-Enable ( $t_{CTLE}$ )	80			100			ns
Latch-Enable-to-Clock ( $t_{LETC}$ )	15			15			ns
Latch Enable HI ( $t_{LEHI}$ )	40			40			ns
Latch Enable LO ( $t_{LELO}$ )	40			80			ns
ACCURACY <sup>1</sup>							
Gain Error		$\pm 2.0$			$\pm 2.0$		% of FSR
Gain Drift		$\pm 25$			$\pm 25$		ppm of FSR/ $^{\circ}$ C
Midscale Output Voltage Error		$\pm 30$			$\pm 30$		mV
Bipolar Zero Drift		$\pm 4$			$\pm 4$		ppm of FSR/ $^{\circ}$ C
Differential Linearity Error		$\pm 0.001$			$\pm 0.001$		% of FSR
Monotonicity		15			15		Bits
TOTAL HARMONIC DISTORTION							
$F_{OUT} = 1037$ Hz <sup>1</sup>							
0 dB		-88	-81		-88	-81	dB
-20 dB		-75	-65		-75	-65	dB
-60 dB		-37	-27		-37	-27	dB
$F_{OUT} = 49.07$ kHz <sup>2</sup>							
0 dB		-77	-72		-77	-72	dB
-20 dB		-69	-66		-69	-66	dB
-60 dB		-25	-21		-25	-21	dB
SIGNAL-TO-NOISE RATIO <sup>3</sup>							
20 Hz to 20 kHz ( $F_{OUT} = 1037$ Hz) <sup>1</sup>	94	102		94	102		dB
20 kHz to 250 kHz ( $F_{OUT} = 49.07$ kHz) <sup>2</sup>	79	83		79	83		dB
SETTLING TIME (to $\pm 0.0015\%$ of FSR)							
Voltage Output <sup>1</sup>							
6 V Step		1.5			1.5		$\mu$ s
1 LSB Step		1.0			1.0		$\mu$ s
Slew Rate		9			9		V/ $\mu$ s
Current Output							
1 mA Step 10 $\Omega$ to 100 $\Omega$ Load		350			350		ns
1 k $\Omega$ Load		350			350		ns
OUTPUT							
Voltage Output Configuration <sup>1</sup>							
Bipolar Range	$\pm 2.88$	$\pm 3.0$	$\pm 3.12$	$\pm 2.88$	$\pm 3.0$	$\pm 3.12$	V
Output Current		$\pm 8.0$			$\pm 8.0$		mA
Output Impedance		0.1			0.1		$\Omega$
Short Circuit Duration		Indefinite to Common			Indefinite to Common		
Current Output Configuration							
Bipolar Range	$\pm 0.7$	$\pm 1.0$	$\pm 1.3$	$\pm 0.7$	$\pm 1.0$	$\pm 1.3$	mA
Output Impedance ( $\pm 30\%$ )		1.7			1.7		k $\Omega$
POWER SUPPLY							
Voltage: $+V_L$ and $+V_S$	4.75		13.2	4.75		13.2	V
$-V_L$ and $-V_S$	-13.2		-4.75	-13.2		-4.75	V
Current Case 1 <sup>1</sup> : $V_S$ and $V_L = +5$ V		12.0	15.0		12.0	15.0	mA
$-V_S$ and $-V_L = -5$ V		-12.0	-15.0		-12.0	-15.0	mA
Case 2: $V_S$ and $V_L = +12$ V		10.5			10.5		mA
$-V_S$ and $-V_L = -12$ V		-14			-14		mA
Case 3 <sup>4</sup> : $V_S$ and $V_L = +5$ V		12			12		mA
$-V_S$ and $-V_L = -12$ V		-14			-14		mA
Power Dissipation: $V_S$ and $V_L = \pm 5$ V <sup>1</sup>		120	150		120	150	mW
$V_S$ and $V_L = \pm 12$ V		300			300		mW
$V_S$ and $V_L = +5$ V, $-V_S$ and $-V_L = -12$ V <sup>4</sup>		225			225		mW



# AD766—Definition of Specifications

## TOTAL HARMONIC DISTORTION

Total Harmonic Distortion (THD) is defined as the ratio of the square root of the sum of the squares of the values of the harmonics to the value of the fundamental input frequency. It is expressed in percent (%) or decibels (dB).

THD is a measure of the magnitude and distribution of integral linearity error and differential linearity error. The distribution of these errors may be different, depending on the amplitude of the output signal. Therefore, to be most useful, THD should be specified for both large and small signal amplitudes.

## SETTLING TIME

Settling Time is the time required for the output to reach and remain within a specified error band about its final value, measured from the digital input transition. It is the primary measure of dynamic performance.

## BIPOLAR ZERO ERROR

Bipolar Zero Error or midscale error is the deviation of the actual analog output from the ideal output (0 V) when the 2s complement input code representing half scale (all 0s) is loaded in the input register.

## DIFFERENTIAL LINEARITY ERROR

Differential Linearity Error is the measure of the variation in analog value, normalized to full scale, associated with a 1 LSB change in the digital input. Monotonic behavior requires that the differential linearity error not exceed 1 LSB in the negative direction.

## MONOTONICITY

A D/A converter is monotonic if the output either increases or remains constant as the digital input increases.

## SIGNAL-TO-NOISE RATIO

SNR is defined as the ratio of the fundamental to the square root of the sum of the squares for the values of all the nonfundamental, nonharmonic signals for a specified bandwidth. SNR is tested at full-scale input. The AD766 specifies SNR for 20 kHz and 250 kHz bandwidths.

## FUNCTIONAL DESCRIPTION

Serial input data is clocked into the AD766's shift register by the falling edge of  $\overline{\text{CLK}}$ . Data is presumed to be in two's complement format with MSB (i.e., the sign bit) clocked in first. The shift register converts the most recently clocked-in 16 bits to a parallel word. The falling edge of the latch enable (LE) signal causes the most recent parallel word to be transferred to the internal DAC input latch. See Figure 2 for detailed serial port timing requirements.

The contents of the DAC input latch cause the 16-bit DAC to generate a corresponding current. This  $\pm 1$  mA current is available directly on the  $I_{\text{OUT}}$  pin.

To use the internal op amp, connect  $I_{\text{OUT}}$  (Pin 13) directly to the summing junction pin, SJ (Pin 11) and connect the feedback resistor pin,  $R_F$  (Pin 10) to  $V_{\text{OUT}}$  (Pin 9). Note that the internal op amp is in the inverting configuration. Using the internal 3 k $\Omega$  feedback resistor, this op amp will produce  $\pm 3$  V outputs.

One advantage of external pins at each end of the feedback resistor is that it allows the user to implement a single pole active low-pass filter simply by adding a capacitor across these pins (Pins 10 and 13). The circuit can best be understood redrawn as shown in Figure 1.

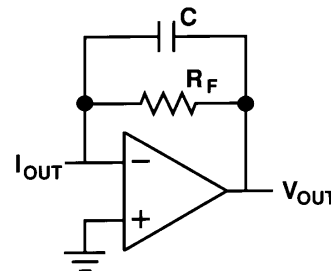


Figure 1. Low-Pass Filter Using External Capacitor

The frequency response from this filter will be

$$\frac{V_{\text{OUT}}(s)}{I_{\text{OUT}}} = \frac{-R_F}{R_F \cdot C \cdot s + 1}$$

where  $R_F$  is 3 k $\Omega$  ( $\pm 20\%$ ).

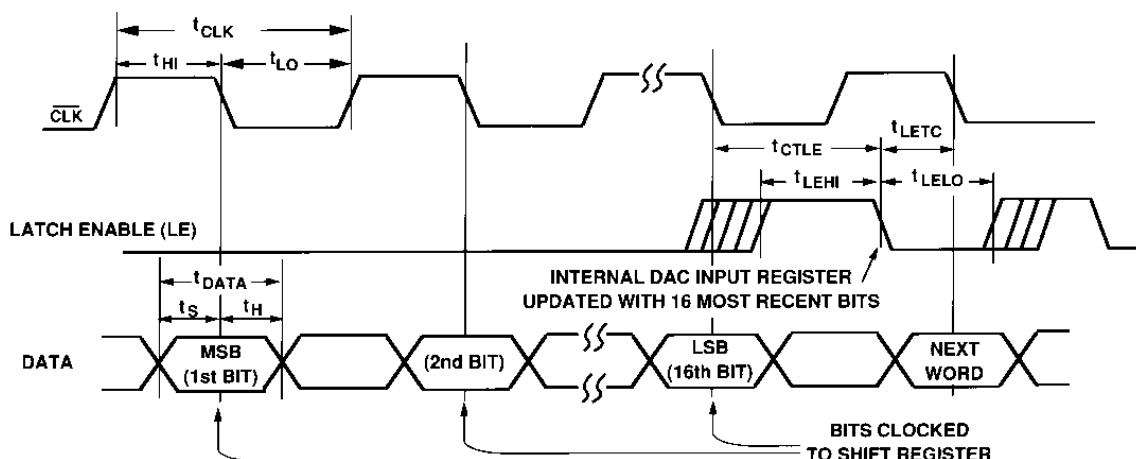


Figure 2. AD766 Serial Input Timing

# Analog Circuit Considerations—AD766

For applications requiring broader bandwidths and/or even lower noise than that afforded by the AD766's internal op amp, an external op amp can easily be used in its place.  $I_{OUT}$  (Pin 13) drives the negative (inverting) input terminal of the external op amp, and its external voltage output is connected to the feedback resistor pin,  $R_F$  (Pin 10). To insure that the AD766's unused internal op amp remains in a closed-loop configuration,  $V_{OUT}$  (Pin 9) should be tied to the summing junction pin, SJ (Pin 11).

As an example, Figure 3 shows the AD766 using the AD744 op amp as an external current-to-voltage converter. In this inverting configuration, the AD744 will provide the same  $\pm 3$  V output as the internal op amp would have. Other recommended amplifiers include the AD845 and AD846. Note that a single pole of low-pass filtering could also be attained with this circuit simply by adding a capacitor in parallel with the feedback resistor as just shown in Figure 1.

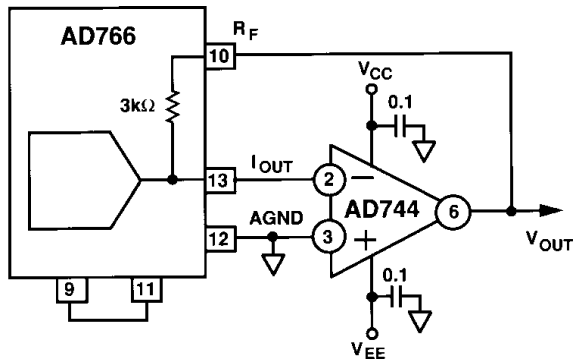


Figure 3. External Op Amp Connections

Residual DAC differential linearity error around midscale can be externally trimmed out, improving THD beyond the AD766's guaranteed tested specifications. This error is most significant with low-amplitude signals because the ratio of the midscale linearity error to the signal amplitude is greatest in this case, thereby increasing THD. The MSB adjust circuitry shown in Figure 4 can be used for improving THD with low-level signals. Otherwise, the AD766 will operate to its specifications with MSB ADJ (Pin 14) and TRIM (Pin 15) unconnected.

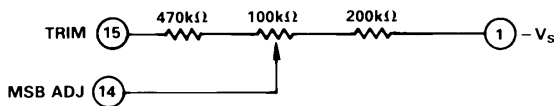


Figure 4. Optional MSB Adjustment Circuit

## ANALOG CIRCUIT CONSIDERATIONS GROUNDING RECOMMENDATIONS

The AD766 has two ground pins, designated AGND (analog ground) and DGND (digital ground). The analog ground pin is the "high-quality" ground reference point for the device. The analog ground pin should be connected to the analog common point in the system. The output load should also be connected to that same point.

The digital ground pin returns ground current from the digital logic portions of the AD766 circuitry. This pin should be connected to the digital common point in the system.

As illustrated in Figure 5, the analog and digital grounds should be connected together at one point in the system.

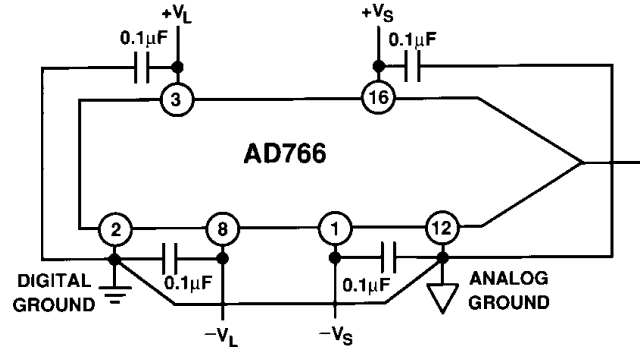


Figure 5. Recommended Circuit Schematic

## POWER SUPPLIES AND DECOUPLING

The AD766 has four power supply input pins.  $\pm V_S$  provide the supply voltages to operate the linear portions of the DAC including the voltage reference, output amplifier and control amplifier. The  $\pm V_S$  supplies are designed to operate from  $\pm 5$  V to  $\pm 12$  V.

The  $\pm V_L$  supplies operate the digital portions of the chip, including the input shift register and the input latching circuitry. The  $\pm V_L$  supplies are also designed to operate from  $\pm 5$  V to  $\pm 12$  V. To assure freedom from latch-up,  $-V_L$  should never go more negative than  $-V_S$ .

Special restrictions on power supplies apply to extended temperature range versions of the AD766 that do not apply to the commercial AD766J. First, supplies must be symmetric. That is,  $+V_S = |-V_S|$  and  $+V_L = |-V_L|$ . Each supply must independently meet this equality within  $\pm 5\%$ . Since we require that  $-V_S \leq -V_L$  to guarantee latch-up immunity, this symmetry principle implies that the positive analog supply must be greater than or equal to the positive digital supply, i.e.,  $V_S \geq -V_L$  for extended-temperature range parts. In other words, the digital supply range must be inside the analog supply range. Second, the internal op amp's performance in generating voltage outputs is only guaranteed if  $+V_S \geq 7$  V (and  $-V_S \leq -7$  V, by the symmetry principle). These constraints do not apply to the AD766J.

Decoupling capacitors should be used on all power supply pins. Furthermore, good engineering practice suggests that these capacitors be placed as close as possible to the package pins as well as the common points. The logic supplies,  $\pm V_L$ , should be decoupled to digital common; and the analog supplies,  $\pm V_S$ , should be decoupled to analog common.

The use of four separate power supplies will reduce feedthrough from the digital portion of the system to the linear portions of the system, thus contributing to the performance as tested. However, four separate voltage supplies are not necessary for good circuit performance. For example, Figure 6 illustrates a

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system where only a single positive and a single negative supply are available. In this case, the positive logic and positive analog supplies may both be connected to the single positive supply. The negative logic and negative analog supplies may both be connected to the single negative supply. Performance would benefit from a measure of isolation between the supplies introduced by using simple low-pass filters in the individual power supply leads.

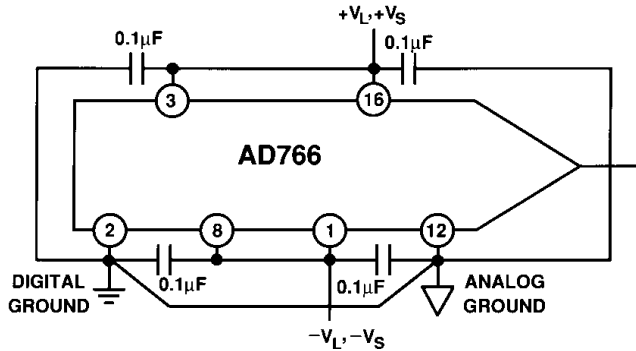


Figure 6. Alternate Recommended Schematic

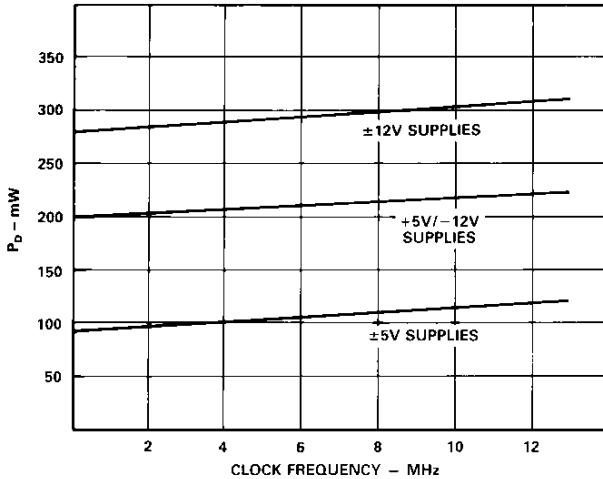


Figure 7. Power Dissipation vs. Clock Frequency

As with most linear circuits, changes in the power supplies will affect the output of the DAC. Analog Devices recommends that well regulated power supplies with less than 1% ripple be incorporated into the design of any system using these device.

## MEASUREMENT OF TOTAL HARMONIC DISTORTION

The THD specification of a DSP DAC represents the amount of undesirable signal produced during reconstruction of a digital waveform. To account for the variety of operating conditions

in signal processing applications, the DAC is tested at two output frequencies and at three signal levels over the full operating temperature ranges.

A block diagram of the test setup is shown in Figure 8. In this test setup, a digital data stream, representing a 0 dB, -20 dB or -60 dB sine wave is sent to the device under test. The frequencies used are 1037 Hz and 49.07 kHz. Input data is latched into the AD766 at 500 kSPS. The AD766 under test produces an analog output signal using the on-board op amp for 1 kHz and an external op amp for 50 kHz.

The automatic test equipment digitizes the output test waveform, and then an FFT to 250 kHz is performed on the results of the test. Based on the first 9 harmonics of the fundamental 1037 Hz and the first 3 harmonics of the 49.07 kHz output waves, the total harmonic distortion of the device is calculated. Neither a deglitcher nor an MSB trim is used during the THD test.

The circuit design, layout and manufacturing techniques employed in the production of the AD766 result in excellent THD performance. Figure 9 shows the typical unadjusted THD performance of the AD766 for various amplitudes of 1 kHz and 50 kHz sine waves. As can be seen, the AD766 offers excellent performance even at amplitudes as low as 60 dB. Figure 10 illustrates the typical THD versus frequency performance from the internal amplifier for a filtered AD766 output. At frequencies greater than approximately 30 kHz, depending on the low-pass filter used, an improvement in THD of 3-4 dB over the performance shown in the figure can be achieved. Figure 11 illustrates the consistent THD performance of the AD766 over temperature.

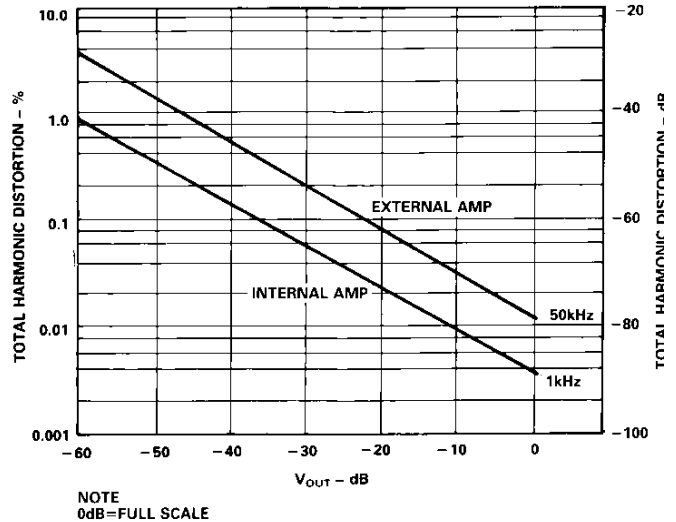


Figure 9. Typical Unadjusted THD

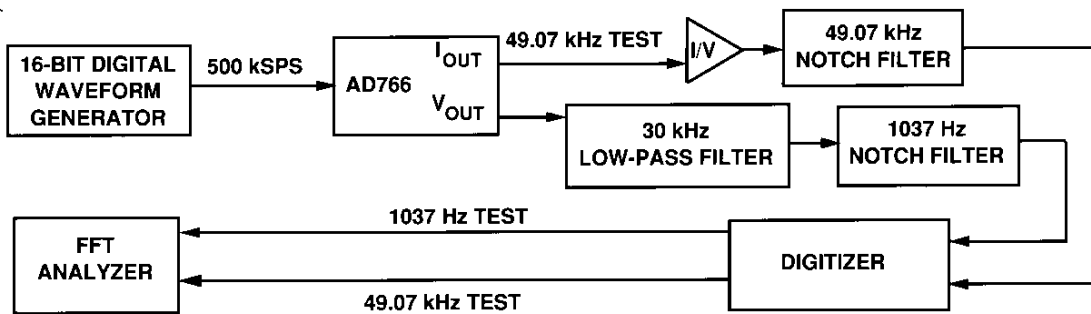


Figure 8. Distortion Test Circuit

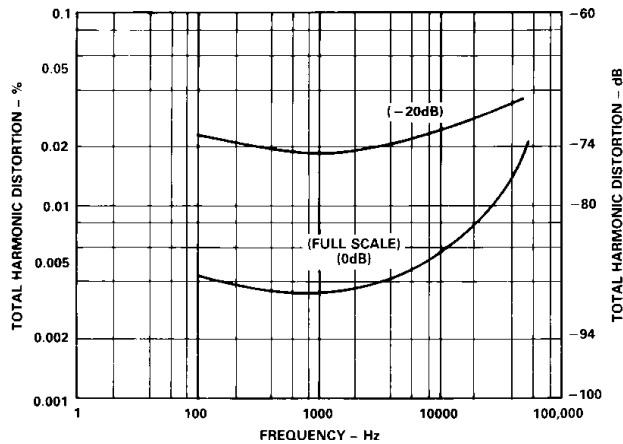


Figure 10. Typical THD vs. Frequency

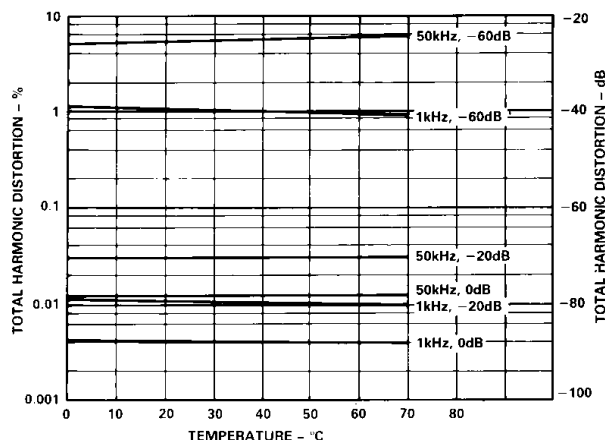


Figure 11. THD vs. Temperature

## INTERFACING THE AD766 TO DIGITAL SIGNAL PROCESSORS

The AD766 is specifically designed to easily interface to several popular digital signal processors (DSP) without any additional logic. Such an interface reduces the possibility of interface problems and improves system reliability by minimizing component count.

### AD766 TO ADSP-2101

The ADSP-2101 incorporates two complete serial ports which can be directly interfaced to the AD766 as shown in Figure 12. The SCLK, TFS and DT outputs of the ADSP-2101 are connected directly to the  $\overline{\text{CLK}}$ , LE and DATA inputs of the AD766, respectively. SCLK is internally generated and can be programmed to operate from 94 Hz to 6.25 MHz. Data (DT) is valid on the falling edge of SCLK. After 16 bits have been transmitted, the falling edge of TFS updates the AD766's data latch. Using both serial ports of the ADSP-2101, two AD766's can be directly interfaced with no additional hardware.

### AD766 TO TMS320C25

Figure 13 shows the zero-chip interface to the TMS320C25. The interface to other TMS320C2X processors is similar. Note that the C25 should be run in continuous mode. The C25's frame synch signal (FSX) will be asserted at the beginning of each 16-bit word but will actually latch in the previous word.

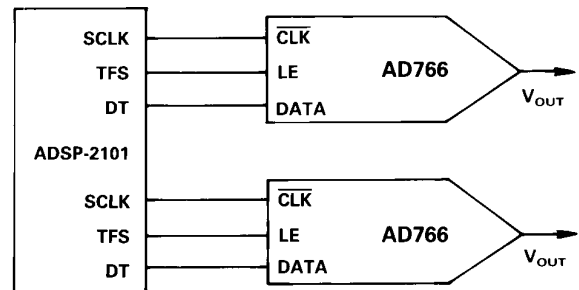


Figure 12. AD766 to ADSP-2101/ADSP-2102/ADSP-2105/ADSP-2111

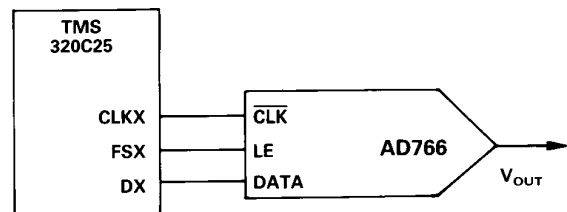


Figure 13. AD766 to TMS320C25

The CLKX, FSX and DX outputs of the TMS320C25 are connected to the CLK, LE and DATA inputs of the AD766, respectively. Data (DX) is valid on the falling edge of CLKX. The maximum serial clock rate of the TMS320C25 is 5 MHz.

### AD766 TO DSP56000/56001

Figure 14 shows the zero-chip interface to the DSP56000/56001. The SSI of the 56000/56001 allows serial clock rates up to  $f_{osc}/4$ . SCK, SC2 and STD can be directly connected to the  $\overline{\text{CLK}}$ , LE and DATA inputs of the AD766. The CRA control register of the 56000 allows SCK to be internally generated and software configurable to various divisions of the master clock frequency. The data (STD) is valid on the falling edge of SCK.

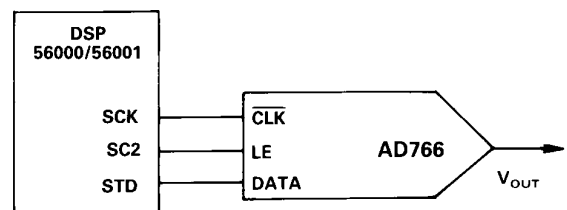
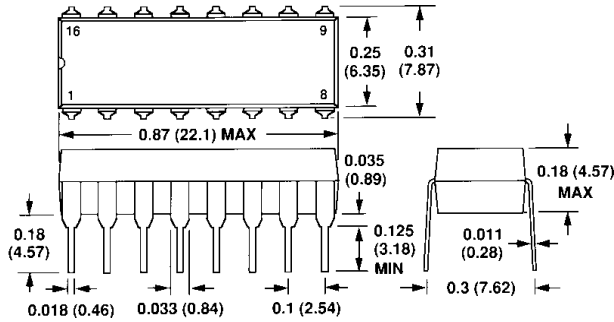


Figure 14. AD766 to DSP56000/DSP56001

**OUTLINE DIMENSIONS**

Dimensions shown in inches and (mm).

**16-Pin Plastic DIP (N-16)**



**D-16  
16-Lead Side Brazed Ceramic DIP**

