

January 1995

## DAC0808/DAC0807/DAC0806 8-Bit D/A Converters

### General Description

The DAC0808 series is an 8-bit monolithic digital-to-analog converter (DAC) featuring a full scale output current settling time of 150 ns while dissipating only 33 mW with  $\pm 5V$  supplies. No reference current ( $I_{REF}$ ) trimming is required for most applications since the full scale output current is typically  $\pm 1$  LSB of  $255 I_{REF} / 256$ . Relative accuracies of better than  $\pm 0.19\%$  assure 8-bit monotonicity and linearity while zero level output current of less than  $4 \mu A$  provides 8-bit zero accuracy for  $I_{REF} \geq 2$  mA. The power supply currents of the DAC0808 series are independent of bit codes, and exhibits essentially constant device characteristics over the entire supply voltage range.

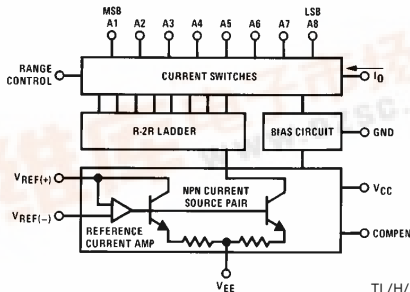
The DAC0808 will interface directly with popular TTL, DTL or CMOS logic levels, and is a direct replacement for the

MC1508/MC1408. For higher speed applications, see DAC0800 data sheet.

### Features

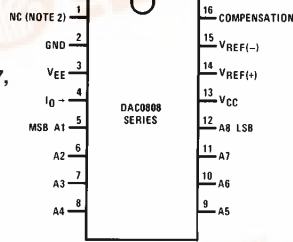
- Relative accuracy:  $\pm 0.19\%$  error maximum (DAC0808)
- Full scale current match:  $\pm 1$  LSB typ
- 7 and 6-bit accuracy available (DAC0807, DAC0806)
- Fast settling time: 150 ns typ
- Noninverting digital inputs are TTL and CMOS compatible
- High speed multiplying input slew rate: 8 mA/ $\mu s$
- Power supply voltage range:  $\pm 4.5V$  to  $\pm 18V$
- Low power consumption: 33 mW @  $\pm 5V$

### Block and Connection Diagrams



Order Number  
DAC0808, DAC0807,  
or DAC0806  
See NS Package  
Number J16A,  
M16A or N16A

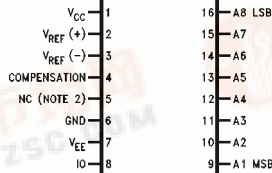
#### Dual-In-Line Package



TL/H/5687-2

TL/H/5687-1

#### Small-Outline Package



TL/H/5687-13

Top View

### Ordering Information

ACCURACY	OPERATING TEMPERATURE RANGE	ORDER NUMBERS				
		J PACKAGE (J16A)*		N PACKAGE (N16A)*		SO PACKAGE (M16A)
7-bit	$0^{\circ}C \leq T_A \leq +75^{\circ}C$	DAC0807LCJ	MC1408L7	DAC0808LCN	MC1408P8	DAC0808LCM
6-bit	$0^{\circ}C \leq T_A \leq +75^{\circ}C$	DAC0806LCJ	MC1408L6	DAC0807LCN	MC1408P7	DAC0807LCM
				DAC0806LCN	MC1408P6	DAC0806LCM

\*Note. Devices may be ordered by using either order number.

DAC0808/DAC0807/DAC0806 8-Bit D/A Converters



## Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Supply Voltage	
$V_{CC}$	+18 $V_{DC}$
$V_{EE}$	-18 $V_{DC}$
Digital Input Voltage, V5-V12	-10 $V_{DC}$ to +18 $V_{DC}$
Applied Output Voltage, $V_O$	-11 $V_{DC}$ to +18 $V_{DC}$
Reference Current, $I_{14}$	5 mA
Reference Amplifier Inputs, V14, V15	$V_{CC}$ , $V_{EE}$
Power Dissipation (Note 3)	1000 mW
ESD Susceptibility (Note 4)	TBD

Storage Temperature Range	-65°C to +150°C
Lead Temp. (Soldering, 10 seconds)	
Dual-In-Line Package (Plastic)	260°C
Dual-In-Line Package (Ceramic)	300°C
Surface Mount Package	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C

## Operating Ratings

Temperature Range	$T_{MIN} \leq T_A \leq T_{MAX}$
DAC0808LC Series	$0 \leq T_A \leq +75^\circ\text{C}$

## Electrical Characteristics

( $V_{CC} = 5V$ ,  $V_{EE} = -15 V_{DC}$ ,  $V_{REF}/R14 = 2 \text{ mA}$ , DAC0808:  $T_A = -55^\circ\text{C}$  to  $+125^\circ\text{C}$ , DAC0808C, DAC0807C, DAC0806C,  $T_A = 0^\circ\text{C}$  to  $+75^\circ\text{C}$ , and all digital inputs at high logic level unless otherwise noted.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
$E_r$	Relative Accuracy (Error Relative to Full Scale $I_O$ )	(Figure 4)				%
	DAC0808LC (LM1408-8)				$\pm 0.19$	%
	DAC0807LC (LM1408-7), (Note 5)				$\pm 0.39$	%
	DAC0806LC (LM1408-6), (Note 5)				$\pm 0.78$	%
	Settling Time to Within $\frac{1}{2}$ LSB (Includes $t_{PLH}$ )	$T_A = 25^\circ\text{C}$ (Note 6), (Figure 5)		150		ns
$t_{PLH}$ , $t_{PHL}$	Propagation Delay Time	$T_A = 25^\circ\text{C}$ , (Figure 5)		30	100	ns
$TC_{IO}$	Output Full Scale Current Drift			$\pm 20$		ppm/ $^\circ\text{C}$
MSB	Digital Input Logic Levels	(Figure 3)				
$V_{IH}$	High Level, Logic "1"		2			$V_{DC}$
$V_{IL}$	Low Level, Logic "0"				0.8	$V_{DC}$
MSB	Digital Input Current	(Figure 3)				
	High Level	$V_{IH} = 5V$		0	0.040	mA
	Low Level	$V_{IL} = 0.8V$		-0.003	-0.8	mA
$I_{15}$	Reference Input Bias Current	(Figure 3)				$\mu\text{A}$
	Output Current Range	(Figure 3)				
		$V_{EE} = -5V$	0	2.0	2.1	mA
		$V_{EE} = -15V$ , $T_A = 25^\circ\text{C}$	0	2.0	4.2	mA
$I_O$	Output Current	$V_{REF} = 2.000V$ , $R14 = 1000\Omega$ , (Figure 3)	1.9	1.99	2.1	mA
	Output Current, All Bits Low	(Figure 3)		0	4	$\mu\text{A}$
	Output Voltage Compliance (Note 2)	$E_r \leq 0.19\%$ , $T_A = 25^\circ\text{C}$				
	$V_{EE} = -5V$ , $I_{REF} = 1 \text{ mA}$				-0.55, +0.4	$V_{DC}$
	$V_{EE}$ Below -10V				-5.0, +0.4	$V_{DC}$

## Electrical Characteristics (Continued)

( $V_{CC} = 5V$ ,  $V_{EE} = -15V_{DC}$ ,  $V_{REF}/R14 = 2\text{ mA}$ , DAC0808:  $T_A = -55^\circ\text{C}$  to  $+125^\circ\text{C}$ , DAC0808C, DAC0807C, DAC0806C,  $T_A = 0^\circ\text{C}$  to  $+75^\circ\text{C}$ , and all digital inputs at high logic level unless otherwise noted.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
$SRI_{REF}$	Reference Current Slew Rate	(Figure 6)	4	8		$\text{mA}/\mu\text{s}$
	Output Current Power Supply Sensitivity	$-5V \leq V_{EE} \leq -16.5V$		0.05	2.7	$\mu\text{A}/V$
$I_{CC}$ $I_{EE}$	Power Supply Current (All Bits Low)	(Figure 3)		2.3 -4.3	22 -13	$\text{mA}$ $\text{mA}$
$V_{CC}$ $V_{EE}$	Power Supply Voltage Range	$T_A = 25^\circ\text{C}$ , (Figure 3)	4.5 -4.5	5.0 -15	5.5 -16.5	$V_{DC}$ $V_{DC}$
	Power Dissipation					
	All Bits Low	$V_{CC} = 5V, V_{EE} = -5V$ $V_{CC} = 5V, V_{EE} = -15V$		33 106	170 305	$\text{mW}$ $\text{mW}$
	All Bits High	$V_{CC} = 15V, V_{EE} = -5V$ $V_{CC} = 15V, V_{EE} = -15V$		90 160		$\text{mW}$ $\text{mW}$

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its specified operating conditions.

**Note 2:** Range control is not required.

**Note 3:** The maximum power dissipation must be derated at elevated temperatures and is dictated by  $T_{JMAX}$ ,  $\theta_{JA}$ , and the ambient temperature,  $T_A$ . The maximum allowable power dissipation at any temperature is  $P_D = (T_{JMAX} - T_A)/\theta_{JA}$  or the number given in the Absolute Maximum Ratings, whichever is lower. For this device,  $T_{JMAX} = 125^\circ\text{C}$ , and the typical junction-to-ambient thermal resistance of the dual-in-line J package when the board mounted is  $100^\circ\text{C}/\text{W}$ . For the dual-in-line N package, this number increases to  $175^\circ\text{C}/\text{W}$  and for the small outline M package this number is  $100^\circ\text{C}/\text{W}$ .

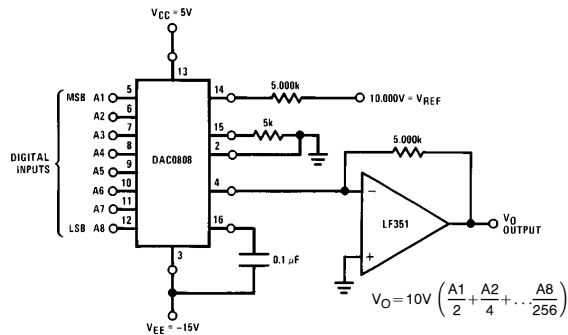
**Note 4:** Human body model, 100 pF discharged through a 1.5 k $\Omega$  resistor.

**Note 5:** All current switches are tested to guarantee at least 50% of rated current.

**Note 6:** All bits switched.

**Note 7:** Pin-out numbers for the DAL080X represent the dual-in-line package. The small outline package pinout differs from the dual-in-line package.

## Typical Application

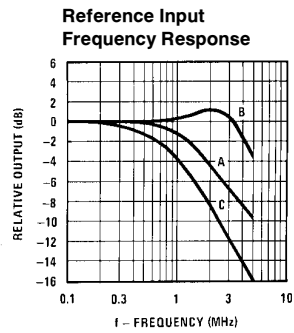
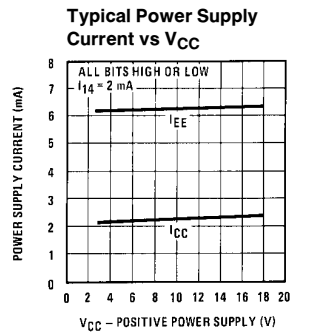
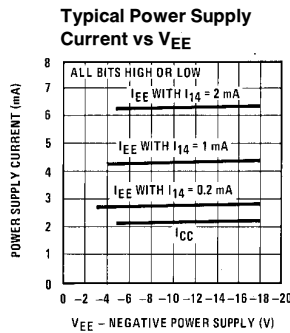
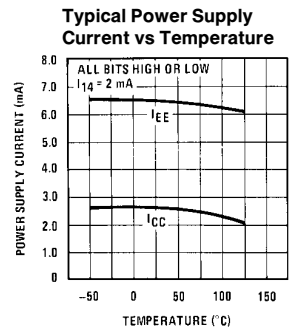
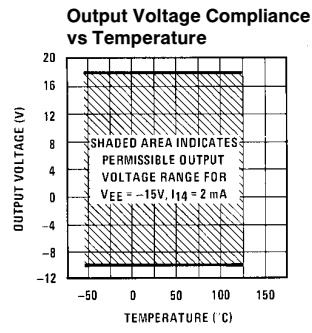
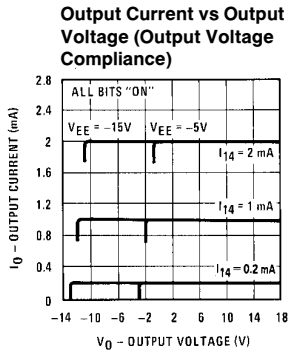
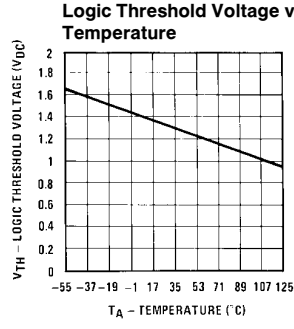
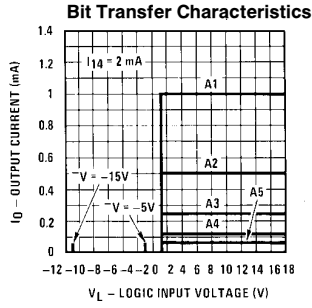
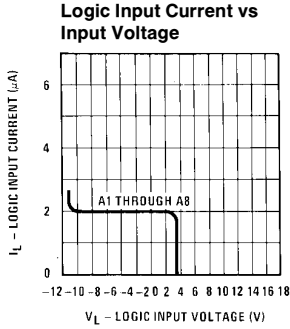


TL/H/5687-3

FIGURE 1. +10V Output Digital to Analog Converter (Note 7)

# Typical Performance Characteristics

$V_{CC} = 5V$ ,  $V_{EE} = -15V$ ,  $T_A = 25^\circ C$ , unless otherwise noted



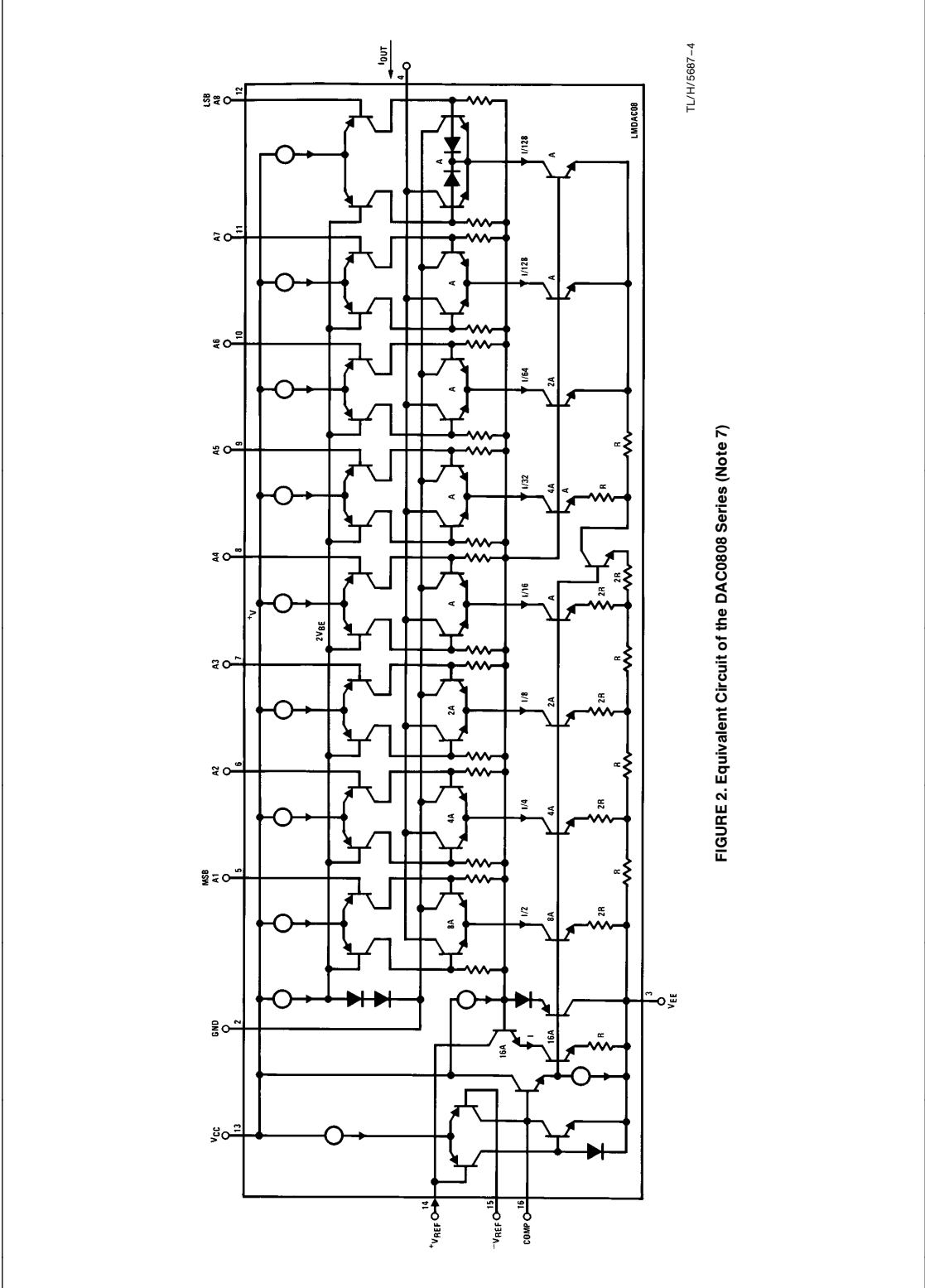
TL/H/5687-5

Unless otherwise specified:  $R_{14} = 15k\Omega$ ,  $C = 15pF$ , pin 16 to  $V_{EE}$ ;  $R_L = 50\Omega$ , pin 4 to ground.

**Curve A:** Large Signal Bandwidth Method of Figure 7,  $V_{REF} = 2V_{p-p}$  offset 1V above ground.

**Curve B:** Small Signal Bandwidth Method of Figure 7,  $R_L = 250\Omega$ ,  $V_{REF} = 50mV_{p-p}$  offset 200mV above ground.

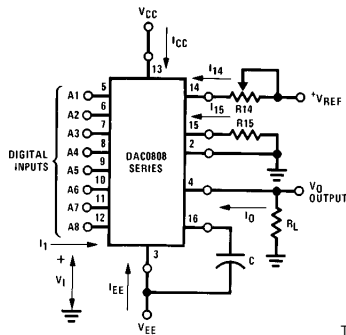
**Curve C:** Large and Small Signal Bandwidth Method of Figure 9 (no op amp,  $R_L = 50\Omega$ ,  $R_S = 50\Omega$ ,  $V_{REF} = 2V$ ,  $V_S = 100mV_{p-p}$  centered at 0V).



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FIGURE 2. Equivalent Circuit of the DAC0808 Series (Note 7)

## Test Circuits



$V_I$  and  $I_1$  apply to inputs A1–A8.

The resistor tied to pin 15 is to temperature compensate the bias current and may not be necessary for all applications.

$$I_O = K \left( \frac{A_1}{2} + \frac{A_2}{4} + \frac{A_3}{8} + \frac{A_4}{16} + \frac{A_5}{32} + \frac{A_6}{64} + \frac{A_7}{128} + \frac{A_8}{256} \right)$$

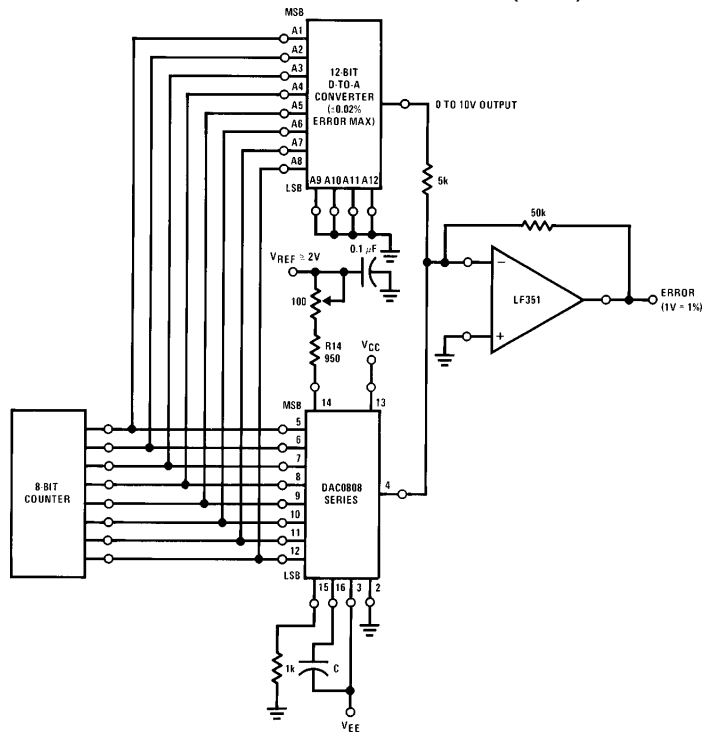
$$\text{where } K \cong \frac{V_{REF}}{R_{14}}$$

and  $A_N = "1"$  if  $A_N$  is at high level

$A_N = "0"$  if  $A_N$  is at low level

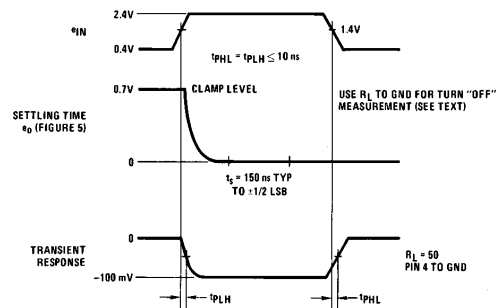
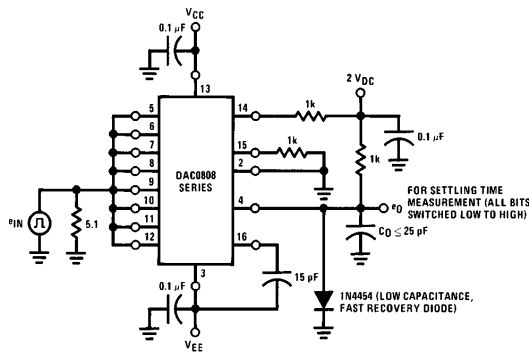
TL/H/5687-6

FIGURE 3. Notation Definitions Test Circuit (Note 7)



TL/H/5687-7

FIGURE 4. Relative Accuracy Test Circuit (Note 7)



TL/H/5687-8

FIGURE 5. Transient Response and Settling Time (Note 7)

## Test Circuits (Continued)

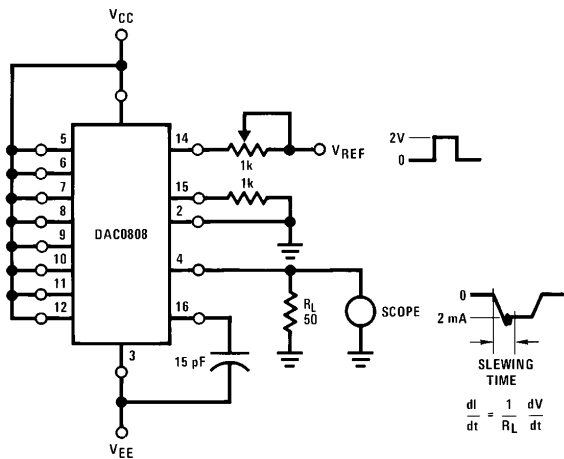


FIGURE 6. Reference Current Slew Rate Measurement (Note 7)

TL/H/5687-9

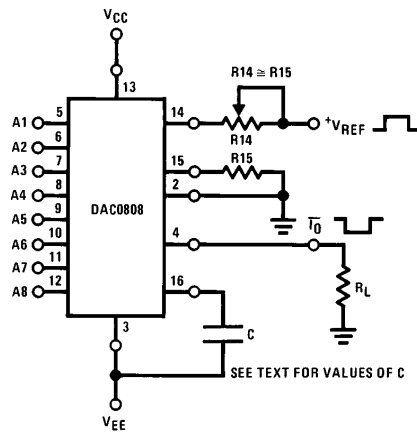


FIGURE 7. Positive  $V_{REF}$  (Note 7)

TL/H/5687-10

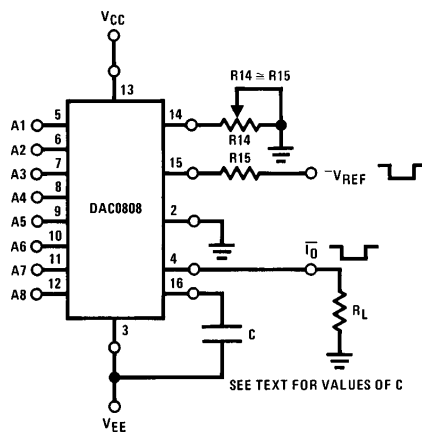


FIGURE 8. Negative  $V_{REF}$  (Note 7)

TL/H/5687-11

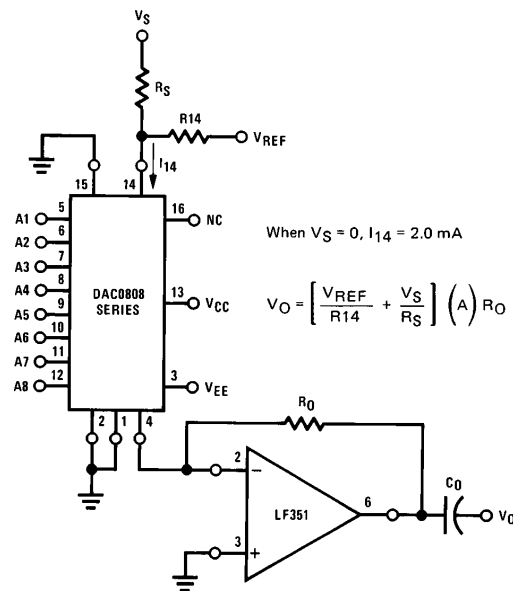


FIGURE 9. Programmable Gain Amplifier or Digital Attenuator Circuit (Note 7)

TL/H/5687-12

## Application Hints

### REFERENCE AMPLIFIER DRIVE AND COMPENSATION

The reference amplifier provides a voltage at pin 14 for converting the reference voltage to a current, and a turn-around circuit or current mirror for feeding the ladder. The reference amplifier input current,  $I_{14}$ , must always flow into pin 14, regardless of the set-up method or reference voltage polarity.

Connections for a positive voltage are shown in Figure 7. The reference voltage source supplies the full current  $I_{14}$ . For bipolar reference signals, as in the multiplying mode,

$R_{15}$  can be tied to a negative voltage corresponding to the minimum input level. It is possible to eliminate  $R_{15}$  with only a small sacrifice in accuracy and temperature drift.

The compensation capacitor value must be increased with increases in  $R_{14}$  to maintain proper phase margin; for  $R_{14}$  values of 1, 2.5 and 5 k $\Omega$ , minimum capacitor values are 15, 37 and 75 pF. The capacitor may be tied to either  $V_{EE}$  or ground, but using  $V_{EE}$  increases negative supply rejection.

## Application Hints (Continued)

A negative reference voltage may be used if R14 is grounded and the reference voltage is applied to R15 as shown in *Figure 8*. A high input impedance is the main advantage of this method. Compensation involves a capacitor to  $V_{EE}$  on pin 16, using the values of the previous paragraph. The negative reference voltage must be at least 4V above the  $V_{EE}$  supply. Bipolar input signals may be handled by connecting R14 to a positive reference voltage equal to the peak positive input level at pin 15.

When a DC reference voltage is used, capacitive bypass to ground is recommended. The 5V logic supply is not recommended as a reference voltage. If a well regulated 5V supply which drives logic is to be used as the reference, R14 should be decoupled by connecting it to 5V through another resistor and bypassing the junction of the 2 resistors with 0.1  $\mu$ F to ground. For reference voltages greater than 5V, a clamp diode is recommended between pin 14 and ground.

If pin 14 is driven by a high impedance such as a transistor current source, none of the above compensation methods apply and the amplifier must be heavily compensated, decreasing the overall bandwidth.

### OUTPUT VOLTAGE RANGE

The voltage on pin 4 is restricted to a range of  $-0.55$  to  $0.4V$  when  $V_{EE} = -5V$  due to the current switching methods employed in the DAC0808.

The negative output voltage compliance of the DAC0808 is extended to  $-5V$  where the negative supply voltage is more negative than  $-10V$ . Using a full-scale current of 1.992 mA and load resistor of 2.5 k $\Omega$  between pin 4 and ground will yield a voltage output of 256 levels between 0 and  $-4.980V$ . Floating pin 1 does not affect the converter speed or power dissipation. However, the value of the load resistor determines the switching time due to increased voltage swing. Values of  $R_L$  up to 500 $\Omega$  do not significantly affect performance, but a 2.5 k $\Omega$  load increases worst-case settling time to 1.2  $\mu$ s (when all bits are switched ON). Refer to the subsequent text section on Settling Time for more details on output loading.

### OUTPUT CURRENT RANGE

The output current maximum rating of 4.2 mA may be used only for negative supply voltages more negative than  $-8V$ , due to the increased voltage drop across the resistors in the reference current amplifier.

### ACCURACY

Absolute accuracy is the measure of each output current level with respect to its intended value, and is dependent upon relative accuracy and full-scale current drift. Relative accuracy is the measure of each output current level as a fraction of the full-scale current. The relative accuracy of the DAC0808 is essentially constant with temperature due to

the excellent temperature tracking of the monolithic resistor ladder. The reference current may drift with temperature, causing a change in the absolute accuracy of output current. However, the DAC0808 has a very low full-scale current drift with temperature.

The DAC0808 series is guaranteed accurate to within  $\pm 1/2$  LSB at a full-scale output current of 1.992 mA. This corresponds to a reference amplifier output current drive to the ladder network of 2 mA, with the loss of 1 LSB (8  $\mu$ A) which is the ladder remainder shunted to ground. The input current to pin 14 has a guaranteed value of between 1.9 and 2.1 mA, allowing some mismatch in the NPN current source pair. The accuracy test circuit is shown in *Figure 4*. The 12-bit converter is calibrated for a full-scale output current of 1.992 mA. This is an optional step since the DAC0808 accuracy is essentially the same between 1.5 and 2.5 mA. Then the DAC0808 circuits' full-scale current is trimmed to the same value with R14 so that a zero value appears at the error amplifier output. The counter is activated and the error band may be displayed on an oscilloscope, detected by comparators, or stored in a peak detector.

Two 8-bit D-to-A converters may not be used to construct a 16-bit accuracy D-to-A converter. 16-bit accuracy implies a total error of  $\pm 1/2$  of one part in 65,536 or  $\pm 0.00076\%$ , which is much more accurate than the  $\pm 0.019\%$  specification provided by the DAC0808.

### MULTIPLYING ACCURACY

The DAC0808 may be used in the multiplying mode with 8-bit accuracy when the reference current is varied over a range of 256:1. If the reference current in the multiplying mode ranges from 16  $\mu$ A to 4 mA, the additional error contributions are less than 1.6  $\mu$ A. This is well within 8-bit accuracy when referred to full-scale.

A monotonic converter is one which supplies an increase in current for each increment in the binary word. Typically, the DAC0808 is monotonic for all values of reference current above 0.5 mA. The recommended range for operation with a DC reference current is 0.5 to 4 mA.

### SETTLING TIME

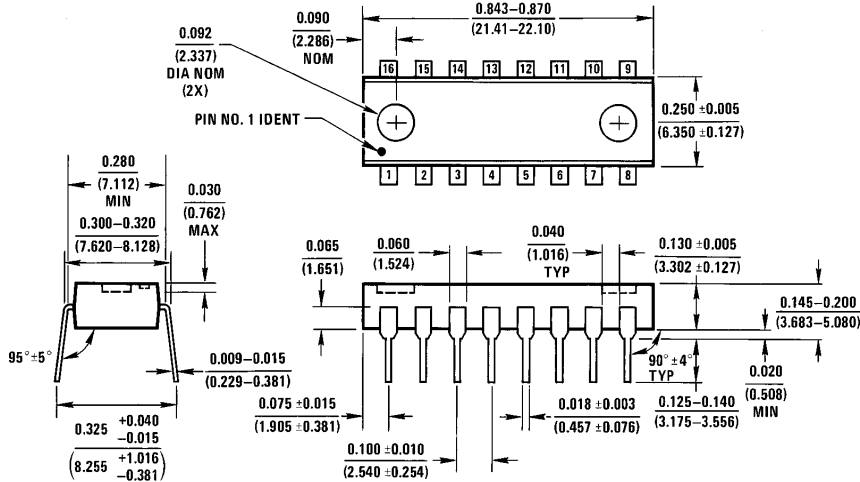
The worst-case switching condition occurs when all bits are switched ON, which corresponds to a low-to-high transition for all bits. This time is typically 150 ns for settling to within  $\pm 1/2$  LSB, for 8-bit accuracy, and 100 ns to  $1/2$  LSB for 7 and 6-bit accuracy. The turn OFF is typically under 100 ns. These times apply when  $R_L \leq 500\Omega$  and  $C_O \leq 25$  pF.

Extra care must be taken in board layout since this is usually the dominant factor in satisfactory test results when measuring settling time. Short leads, 100  $\mu$ F supply bypassing for low frequencies, and minimum scope lead length are all mandatory.





**Physical Dimensions** inches (millimeters) (Continued)



N16A (REV E)

**Dual-In-Line Package**  
**Order Number DAC0808, DAC0807 or DAC0806**  
**NS Package Number N16A**

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**National Semiconductor Corporation**  
 1111 West Bardin Road  
 Arlington, TX 76017  
 Tel: 1(800) 272-9959  
 Fax: 1(800) 737-7018

**National Semiconductor Europe**  
 Fax: (+49) 0-180-530 85 86  
 Email: cnjwge@tevm2.nsc.com  
 Deutsch Tel: (+49) 0-180-530 85 85  
 English Tel: (+49) 0-180-532 78 32  
 Français Tel: (+49) 0-180-532 93 58  
 Italiano Tel: (+49) 0-180-534 16 80

**National Semiconductor Hong Kong Ltd.**  
 13th Floor, Straight Block,  
 Ocean Centre, 5 Canton Rd.  
 Tsimshatsui, Kowloon  
 Hong Kong  
 Tel: (852) 2737-1600  
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 Tel: 81-043-299-2309  
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