

# CMOS 8-Bit DAC with Output Amplifier

## General Description

The MX7224 is a precision voltage-output CMOS digital-to-analog converter (DAC) which includes an output amplifier on chip. Only an external reference source is required for operation and the fully specified accuracy is achieved with no external trims.

Double buffered interface logic is included to allow simultaneous updating in systems which have several DAC channels in operation. Control is provided by CS, WR, and LDAC (Load DAC) inputs. A RESET input is provided which acts as a zero override. All logic inputs are compatible with TTL and 5V CMOS logic levels.

Specified Performance is guaranteed for reference inputs ranging from +2V to +12.5V when using dual supplies. With a +10V reference the performance is also specified for single supply operation. The DAC output can drive +10V into a 2k $\Omega$  load.

## Applications

Automatic Calibration  
Motion Control  
Digital Attenuators  
Function Generators

## Functional Diagram



## Features

- ◆ Voltage Output
- ◆ Complete DAC with Output Amplifier
- ◆ Single or Dual Supply Operation
- ◆ 1 LSB Unadjusted Error
- ◆ Double Buffered Logic Inputs

## Ordering Information

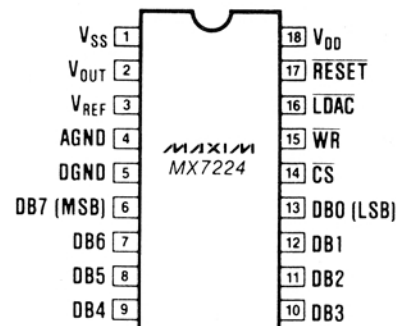
PART	TEMP. RANGE	PACKAGE*	ERROR
MX7224KN	0°C to +70°C	Plastic DIP	$\pm 2$ LSB
MX7224LN	0°C to +70°C	Plastic DIP	$\pm 1$ LSB
MX7224K/D	0°C to +70°C	Dice	$\pm 2$ LSB
MX7224KCWN	0°C to +70°C	Wide S.O.	$\pm 2$ LSB
MX7224LCWN	0°C to +70°C	Wide S.O.	$\pm 1$ LSB
MX7224BQ	-25°C to +85°C	CERDIP**	$\pm 2$ LSB
MX7224CQ	-25°C to +85°C	CERDIP**	$\pm 1$ LSB
MX7224TD	-55°C to +125°C	Ceramic	$\pm 2$ LSB
MX7224UD	-55°C to +125°C	Ceramic	$\pm 1$ LSB
MX7224TQ	-55°C to +125°C	CERDIP**	$\pm 2$ LSB
MX7224UQ	-55°C to +125°C	CERDIP**	$\pm 1$ LSB

\* All devices—18 lead packages

\*\* Maxim reserves the right to ship Ceramic packages in lieu of CERDIP packages.

## Pin Configuration

Top View



# CMOS 8-Bit DAC with Output Amplifier

## ABSOLUTE MAXIMUM RATINGS

$V_{DD}$ to AGND	-0.3V, +17V	Power Dissipation (Any Package) to +75°C	450mW
$V_{DD}$ to DGND	-0.3V, +17V	Derating above +75°C	6mW/°C
AGND to DGND	-0.3V, $V_{DD}$	Operating Temperature	
$V_{SS}$ to DGND	-7V, $V_{DD} + 0.3V$	MX7224K/L	0°C to +70°C
$V_{DD}$ to $V_{SS}$	-0.3V, +24V	MX7224A/B	-25°C to +85°C
Digital Input Voltage to DGND	-0.3V, $V_{DD}$	MX7224T/U	-55°C to +125°C
$V_{REF}$ to AGND	-0.3V, $V_{DD}$	Storage Temperature	-65°C to +160°C
$V_{OUT}$ to DGND	$V_{SS}$ , $V_{DD}$	Lead Temperature (Soldering 10 secs)	+300°C

The output may be shorted to AGND provided that the power dissipation of the package is not exceeded. Typical short circuit current to AGND is 25mA.

Stresses above 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 above those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum ratings conditions for extended periods may affect device reliability.

## ELECTRICAL CHARACTERISTICS—MX7224, Dual Supply Operation

( $V_{DD} = +11.4V$  to  $+16.5V$ ,  $V_{SS} = -5V \pm 10\%$ , AGND = DGND = 0V,  $V_{REF} = +2V$  to ( $V_{DD} - 4V$ ) (Note 1), Over Temperature unless otherwise noted.)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
<b>STATIC PERFORMANCE</b>						
Resolution			8			Bits
Total Unadjusted Error		$V_{REF} = +10V$ $V_{DD} = +15V \pm 5\%$			$\pm 1$ $\pm 2$	LSB
Relative Accuracy		MX7224L/C/U MX7224K/B/T			$\pm 1/2$ $\pm 1$	LSB
Differential Nonlinearity		Guaranteed Monotonic			$\pm 1$	LSB
Full Scale Error		MX7224L/C/U MX7224K/B/T			$\pm 1$ $\pm 1/2$	LSB
Full Scale Temperature Coefficient		$V_{REF} = +10V$		$\pm 5$		ppm/°C
Zero Code Error		MX7224L/C/U MX7224K/B/T			$\pm 20$ $\pm 30$	mV
Zero Code Temperature Coefficient		MX7224L/C/U MX7224K/B/T		$\pm 30$ $\pm 50$		$\mu V/^\circ C$
<b>REFERENCE INPUT</b>						
Reference Input Voltage Range	$V_{REF}$		2		$V_{DD} - 4$	V
Reference Input Resistance	$V_{REF}$		8			k $\Omega$
Reference Input Capacitance (Code Dependent, Note 2)	$C_{REF}$	DAC at full scale code.			100	pF
<b>DIGITAL INPUTS</b>						
Digital Input High Voltage	$V_{INH}$		2.4			V
Digital Input Low Voltage	$V_{INL}$				0.8	V
Digital Input Leakage Current		$V_{IN} = 0V$ or $V_{DD}$			$\pm 1$	$\mu A$
Digital Input Capacitance (Note 2)					8	pF

# CMOS 8-Bit DAC with Output Amplifier

MX7224

## ELECTRICAL CHARACTERISTICS—MX7224, Dual Supply Operation (Continued)

( $V_{DD} = +11.4V$  to  $+16.5V$ ,  $V_{SS} = -5V \pm 10\%$ ,  $AGND = DGND = 0V$ ,  $V_{REF} = +2V$  to  $(V_{DD} - 4V)$  (Note 1), Over Temperature unless otherwise noted.)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
<b>DYNAMIC PERFORMANCE</b>						
Voltage Output Slew Rate (Note 2)			2.5	10		V/ $\mu$ s
Voltage Output Settling Time (Note 5)		To 1/2 LSB, $V_{REF} = +10V$		2	5	$\mu$ s
Digital Feedthrough (Notes 3, 4)		All 0's to all 1's code change, $V_{REF} = 0V$		50		nV-s
Output Load Resistance		$V_{OUT} = +10V$	2			k $\Omega$
<b>POWER SUPPLIES</b>						
$V_{DD}$ Range		For Specified Performance	+11.4		+16.5	V
$V_{SS}$ Range		For Specified Performance	-4.5		-5.5	V
Positive Supply Current	$I_{DD}$	Outputs unloaded, $T_A = 25^\circ C$ at $V_{INL}/V_{INH}$ Over Temp			4 6	mA
Negative Supply Current	$I_{SS}$	Outputs unloaded, $T_A = 25^\circ C$ at $V_{INL}/V_{INH}$ Over Temp			3 5	mA
<b>SWITCHING CHARACTERISTICS (Note 2)</b>						
Chip Select to Write Setup Time	$t_{CS}$		0			ns
Load DAC to Write Setup Time	$t_{LS}$		0			ns
Chip select to Write Hold Time	$t_{CH}$		0			ns
Load DAC to Write Setup Time	$t_{LH}$		0			ns
Data Valid to Write Setup Time	$t_{DS}$	$T_A = 25^\circ C$ Over Temp	90 100			ns
Data Valid to Write Hold Time	$t_{DH}$		10			ns
Write Pulse Width	$t_{WR}$	$T_A = 25^\circ C$ Over Temp	150 200			ns
Chip Select Pulse Width	$t_{CW}$	$T_A = 25^\circ C$ Over Temp	150 200			ns
Reset Pulse Width	$t_{RS}$	$T_A = 25^\circ C$ Over Temp	150 200			ns
Load DAC (LDAC) Pulse Width	$t_{LD}$	$T_A = 25^\circ C$ Over Temp	150 200			ns

**Note 1:** Maximum possible reference voltage.

**Note 2:** Sample tested at  $25^\circ C$  to ensure compliance.

**Note 3:** Guaranteed, but not 100% production tested.

**Note 4:** Feedthrough is reduced by connecting the metal lid on the ceramic package (suffix D) to DGND.

**Note 5:** Positive or negative full scale change.

# CMOS 8-Bit DAC with Output Amplifier

## ELECTRICAL CHARACTERISTICS—MX7224, Single Supply Operation

( $V_{DD} = +15V \pm 5\%$ ,  $V_{SS} = AGND = DGND = 0V$ ,  $V_{REF} = +10V$  (Note 1), Over Temperature unless otherwise stated.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
<b>STATIC PERFORMANCE</b>							
Resolution				8			Bits
Total Unadjusted Error						$\pm 2$	LSB
Differential Nonlinearity		Guaranteed Monotonic				$\pm 1$	LSB
<b>REFERENCE INPUT</b>							
Reference Input Resistance	$R_{REF}$			8			k $\Omega$
Reference Input Capacitance (Code Dependent)(Note 2)	$C_{REF}$	DAC at full scale code				100	pF
<b>DIGITAL INPUTS</b>							
Digital Input High Voltage	$V_{INH}$			2.4			V
Digital Input Low Voltage	$V_{INL}$					0.8	V
Digital Input Leakage Current		$V_{IN} = 0V$ to $V_{DD}$				$\pm 1$	$\mu A$
Digital Input Capacitance (Note 2)						8	pF
<b>DYNAMIC PERFORMANCE</b>							
Voltage Output Slew Rate (Note 2)				2.5	10		V/ $\mu s$
Output Settling Time (Note 2)		To 1/2 LSB,	Positive FS Chg Negative FS Chg		2 3	5 8	$\mu s$
Digital Feedthrough (Notes 3, 4)		All 0's to all 1's code change $V_{REF} = 0V$			50		nV-s
Output Load Resistance		$V_{OUT} = +10V$		2			k $\Omega$
<b>POWER SUPPLIES</b>							
$V_{DD}$ Range		For Specified Performance		+14.25		+15.75	V
Positive Supply Current	$I_{DD}$	Outputs unloaded, at $V_{INL}/V_{INH}$	$T_A = 25^\circ C$ Over Temp			4 6	mA
<b>SWITCHING CHARACTERISTICS</b> (Note 2)							
Chip Select to Write Setup Time	$t_{CS}$			0			ns
Load DAC to Write Setup Time	$t_{LS}$			0			ns
Chip select to Write Hold Time	$t_{CH}$			0			ns
Load DAC to Write Setup Time	$t_{LH}$			0			ns
Data Valid to Write Setup Time	$t_{DS}$	$T_A = 25^\circ C$ Over Temp		90 100			ns
Data Valid to Write Hold Time	$t_{DH}$			10			ns
Write Pulse Width	$t_{WR}$	$T_A = 25^\circ C$ Over Temp		150 200			ns
Chip Select Pulse Width	$t_{CW}$	$T_A = 25^\circ C$ Over Temp		150 200			ns
Reset Pulse Width	$t_{RS}$	$T_A = 25^\circ C$ Over Temp		150 200			ns
Load DAC ( $\overline{LDAC}$ ) Pulse Width	$t_{LD}$	$T_A = 25^\circ C$ Over Temp		150 200			ns

**Note 1:** Maximum possible reference voltage.

**Note 2:** Sample tested at 25°C to ensure compliance.

**Note 3:** Guaranteed, but not 100% production tested.

**Note 4:** Feedthrough is reduced by connecting the metal lid on the ceramic package (suffix D) to DGND.

# CMOS 8-Bit DAC with Output Amplifier

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## Typical Operating Characteristics

## Detailed Description D/A Section

The MX7224 contains an 8-bit digital-to-analog converter that operates in the voltage output mode. The output voltage is of the same polarity as the external reference voltage thus allowing single supply operation. A DAC switch pair arrangement on the MX7224 allows a reference voltage range from +2V to +12.5V.

The DAC consists of a stable thin-film resistor R-2R ladder and eight NMOS single pole, double-throw switches. A simplified circuit diagram is shown in Figure 1.

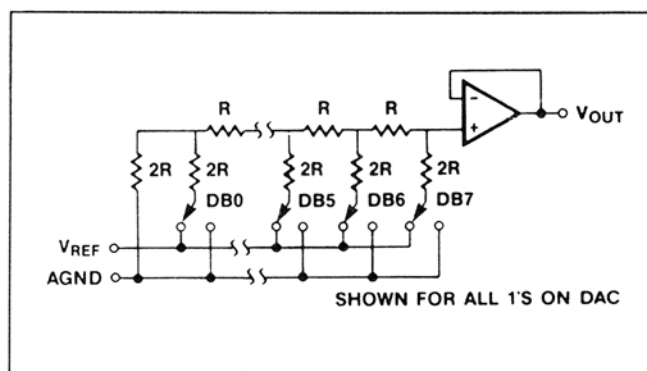
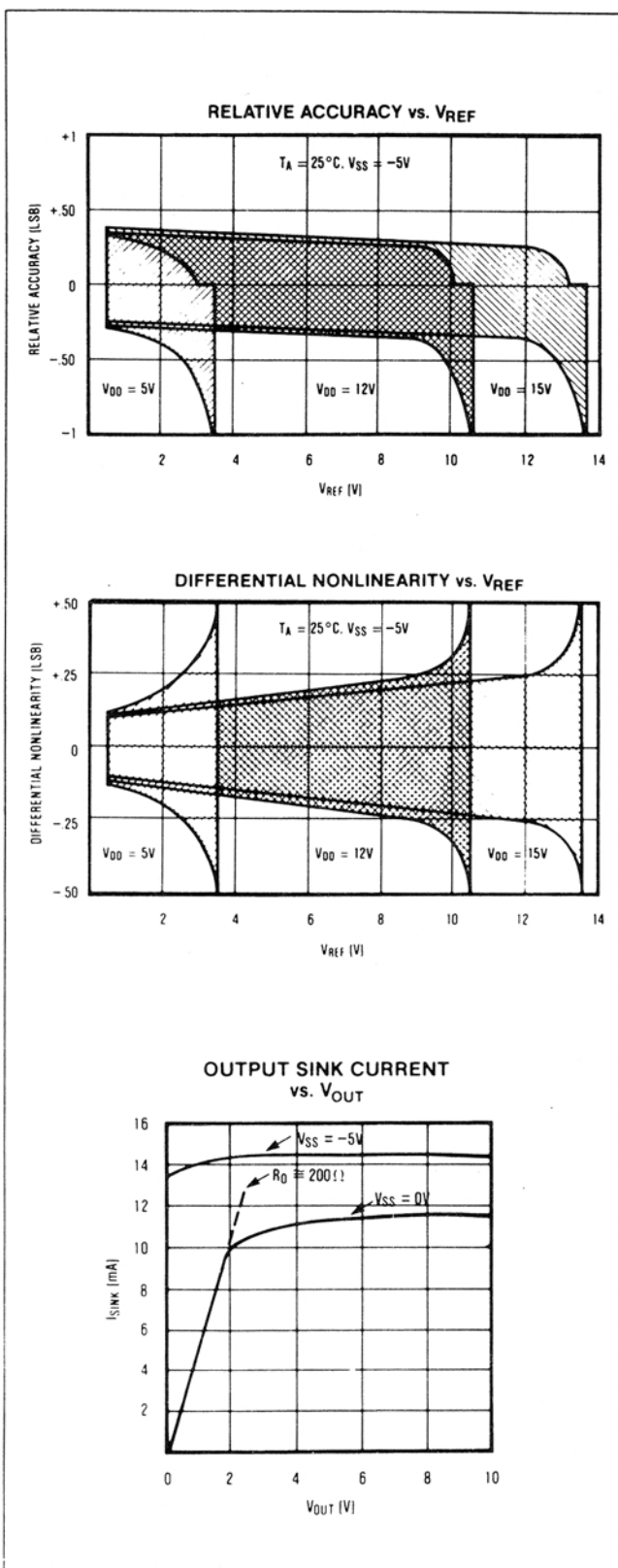


Figure 1. D/A Simplified Circuit Diagram

The input impedance at the  $V_{REF}$  pin is code dependent and varies from  $8\text{k}\Omega$  minimum to infinity. The lowest input impedance occurs when the DAC is loaded with the digital code 01010101. Therefore, it is important that the reference presents a low impedance under changing load conditions. Capacitance at the reference terminal is also code dependent and typically varies from  $25\text{pF}$  to  $50\text{pF}$ .

The  $V_{OUT}$  pin can be considered as a digitally-programmable voltage source with the output defined by:

$$V_{OUT} = D \cdot V_{REF}$$

where D is a fractional representation of the digital input code and can vary from 0 to  $255/256$ .

### Output Buffer Amplifier

The DAC's voltage output is buffered by a unity-gain CMOS voltage follower that slews at greater than  $2.5\text{V}/\mu\text{s}$ . This amplifier is capable of driving a  $2\text{k}\Omega$  load to  $+10\text{V}$ . When driving a  $2\text{k}\Omega$  load in parallel with  $100\text{pF}$  with full-scale transitions ( $0\text{V}$  to  $+10\text{V}$  or  $+10\text{V}$  to  $0\text{V}$ ), the output settles to  $1/2\text{LSB}$  in less than  $5\mu\text{s}$ . Typical dynamic response and settling performance of the MX7224 is shown in Figures 2 through 7.

The MX7224 can be operated single or dual supply. In single supply operation, Maxim's MX7224 can sink and source up to  $5\text{mA}$ .



# CMOS 8-Bit DAC with Output Amplifier

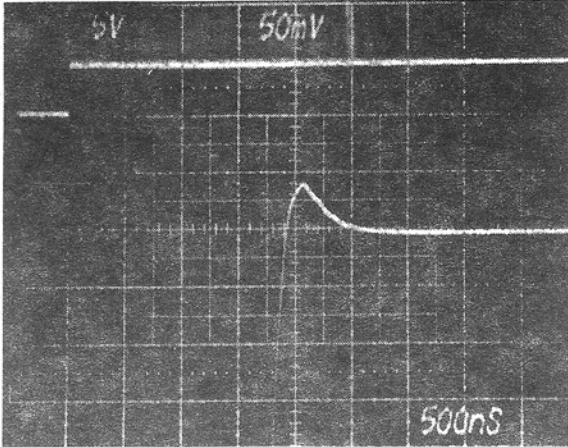


Figure 2. Positive Settling Time with  $V_{DD} = +15V$ ,  $V_{SS} = -5V$ .

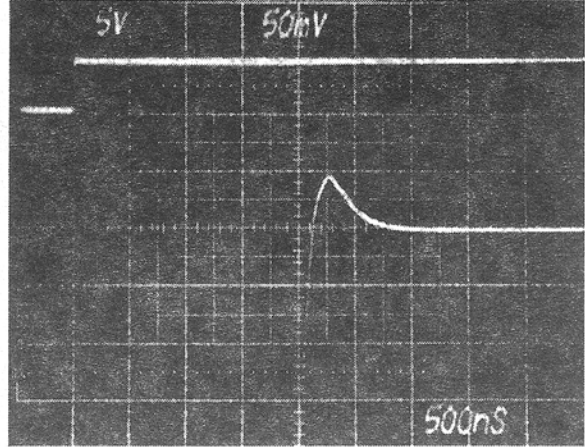


Figure 3. Positive Settling Time with  $V_{DD} = +15V$ ,  $V_{SS} = 0V$ .

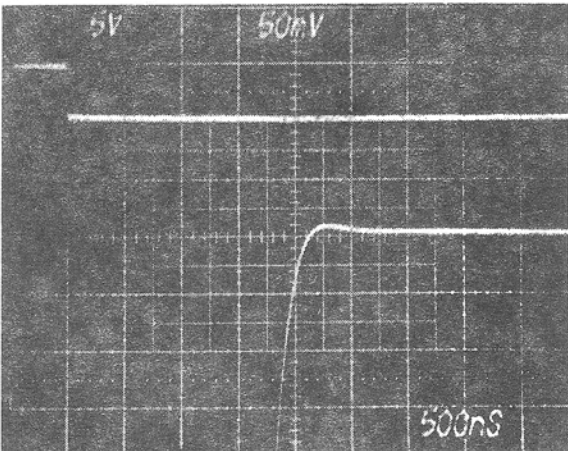


Figure 4. Negative Settling Time with  $V_{DD} = +15V$ ,  $V_{SS} = -5V$ .

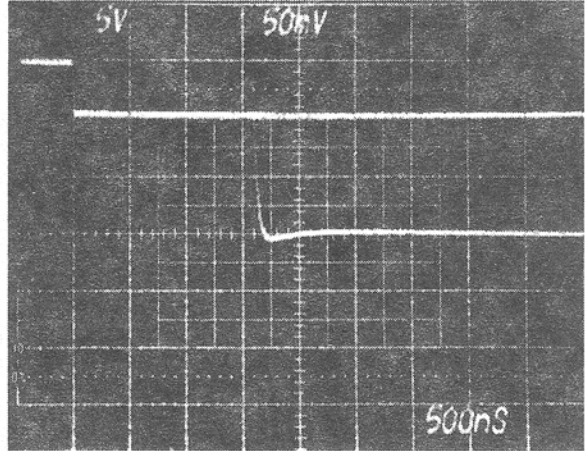


Figure 5. Negative Settling Time with  $V_{DD} = +15V$ ,  $V_{SS} = 0V$ .

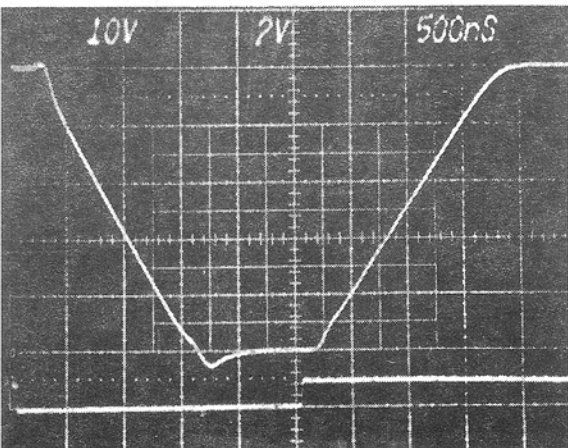


Figure 6. Dynamic Response with  $V_{DD} = +15V$ ,  $V_{SS} = -5V$ .

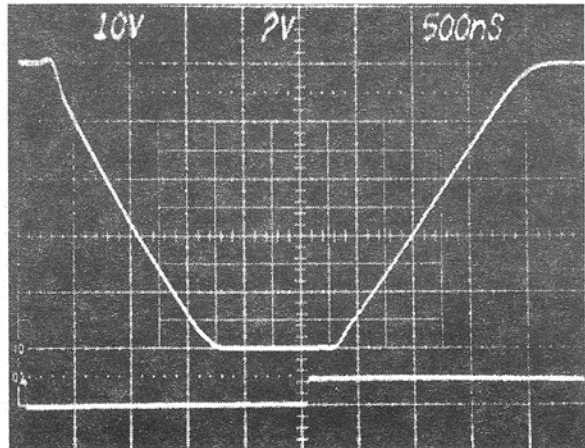


Figure 7. Dynamic Response with  $V_{DD} = +15V$ ,  $V_{SS} = 0V$ .

# CMOS 8-Bit DAC with Output Amplifier

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A simplified circuit diagram of the output buffer is shown in Figure 8. Input common-mode range to  $V_{SS}$  is provided by a PMOS input structure. The improved output circuitry incorporates a Maxim proprietary pull-down circuit to actively drive  $V_{OUT}$  to within typically +15mV of the negative supply ( $V_{SS}$ ). Maxim's improved buffer circuitry allows the output to sink and source up to 5mA. This is especially important in single supply applications, where  $V_{SS}$  is connected to GND, so that zero error is kept at or under 1/2LSB ( $V_{REF} = +10V$ ). A plot of output sink current versus output voltage is shown in the Typical Operating Characteristics section.

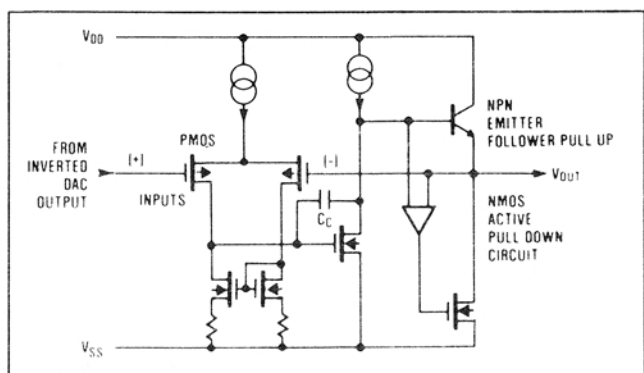


Figure 8. Simplified Output Buffer Circuit

## Digital Inputs and Interface Logic

The digital inputs are compatible with both TTL and 5V CMOS logic. Power supply current,  $I_{DD}$  and  $I_{SS}$ , are specified for TTL input levels. The supply currents are somewhat dependent on input logic level and are highest when the MX7224 is driven from TTL, however, they can be significantly reduced if the inputs are driven as close to +5V as possible.

Table 1 shows the truth table for MX7224 operation. The part contains two registers, an input register and a DAC register. CS and WR control the loading of the input register while LDAC and WR control the transfer of information from the input to the DAC register. Only the data held in the DAC register will determine the converter's analog output.

All control signals are level-triggered and therefore either or both registers may be made transparent; the input register by keeping CS and WR "LOW," the DAC register by keeping LDAC and WR "LOW." The rising edge of the WR input latches input data.

The contents of both registers are reset by a low level on the RESET line. With both registers transparent, the RESET line overrides input data for the duration of the RESET pulse. If both registers are latched, a "LOW" pulse on the RESET will latch all 0's into the registers, with the output remaining at 0V after the reset pulse has been removed. The RESET line can be used to force 0V on the output at power-up, and is also useful as a zero override in system calibration cycles. Figure 9 shows the input control logic for the MX7224.

Table 1. MX7224 Truth Table

RESET	LDAC	WR	CS	Function
H	L	L	L	Both Registers are Transparent
H	X	H	X	Both Registers are Latched
H	H	X	H	Both Registers are Latched
H	H	L	L	Input Register Transparent
H	H		L	Input Register Latched
H	L	L	H	DAC Register Transparent
H	L		H	DAC Register Latched
L	X	X	X	Both Registers Loaded with all Zeros
	H	H	H	Both Registers Latched with all Zeros and Output Remains at Zero
	L	L	L	Both Registers are Transparent and Output Follows Input Data

H = High State, L = Low State, X = Don't Care

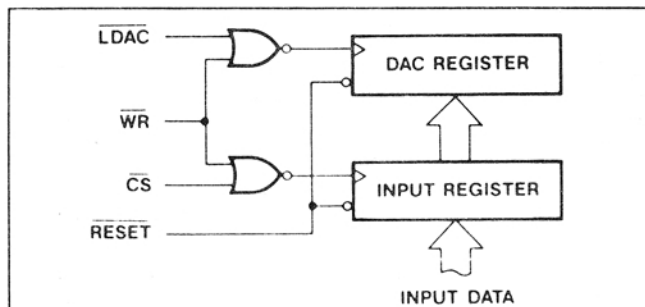


Figure 9. Input Control Logic

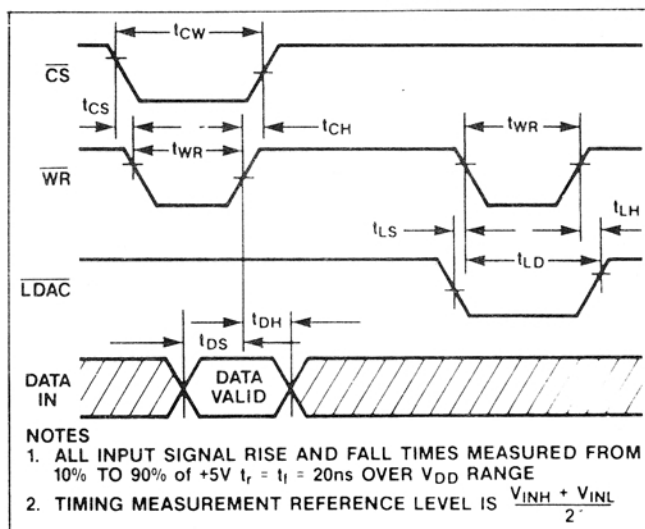


Figure 10. Write Cycle Timing Diagram

# CMOS 8-Bit DAC with Output Amplifier

## Applications Information

### Power Supply and Reference Operating Ranges

The MX7224 is fully specified to operate with  $V_{DD}$  between  $+12V \pm 5\%$  and  $+15V \pm 10\%$  ( $+11.4V$  to  $+16.5V$ ), and with  $V_{SS}$  from  $0V$  to  $-5.5V$ . Eight bit performance is also guaranteed for single supply operation ( $V_{SS} = 0V$ ), however zero code error is reduced when  $V_{SS}$  is  $-5V$  (see Output Buffer Amplifier section).

For adequate DAC and buffer operating range, the  $V_{REF}$  voltage must always be at least  $4V$  below  $V_{DD}$ . The MX7224 is specified to operate with a reference input range of  $+2V$  to  $V_{DD} - 4V$ .

### Ground Management

Digital or AC transient signals between AGND and DGND will create noise at the analog outputs. It is recommended that AGND and DGND be tied together at the DAC and that this point be tied to the highest quality ground that is available. If separate ground busses are used, then two clamp diodes (1N914 or equivalent) should be connected between AGND and DGND to keep the two ground busses within one diode drop of each other. To avoid parasitic device turn-on, AGND must not be allowed to be more negative than DGND. DGND should be used as supply ground for bypassing purposes.

Careful PCB ground layout techniques should be used to minimize crosstalk between the DAC output, the reference input, and the digital inputs. This is particularly important if the reference is driven from an AC source.

### Unipolar Output

In unipolar operation, the output voltage and the reference input are the same polarity. The unipolar circuit configuration is shown in Figure 11. A slight increase in zero error occurs when the MX7224 is operated from a single supply (see Output Buffer Amplifier section). To avoid parasitic device turn-on, the voltage at  $V_{REF}$  must always be positive with respect to DGND. The unipolar code table is given in Table 2.

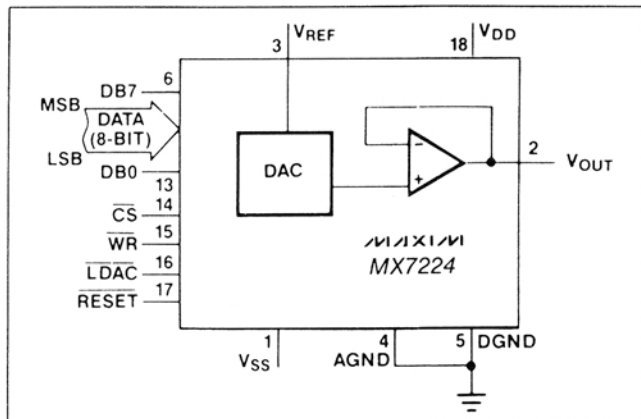


Figure 11. Unipolar Output Circuit

Table 2. Unipolar Code Table

DAC CONTENTS		ANALOG OUTPUT
MSB	LSB	
1 1 1 1	1 1 1 1	$+V_{REF} \left( \frac{255}{256} \right)$
1 0 0 0	0 0 0 1	$+V_{REF} \left( \frac{129}{256} \right)$
1 0 0 0	0 0 0 0	$+V_{REF} \left( \frac{128}{256} \right) = + \frac{V_{REF}}{2}$
0 1 1 1	1 1 1 1	$+V_{REF} \left( \frac{127}{256} \right)$
0 0 0 0	0 0 0 1	$+V_{REF} \left( \frac{1}{256} \right)$
0 0 0 0	0 0 0 0	0V

Note:  $1\text{LSB} = (V_{REF})(2^{-8}) = +V_{REF} \left( \frac{1}{256} \right)$

### Bipolar Output

The DAC output may be configured for bipolar operation using the circuit in Figure 12. Only one op-amp and two resistors are required. With  $R1 = R2$ :

$$V_{OUT} = V_{REF} \cdot (2D - 1)$$

where  $D$  is a fractional representation of the digital word in the DAC register.

Table 3 shows the digital code versus output voltage for the circuit in Figure 12.

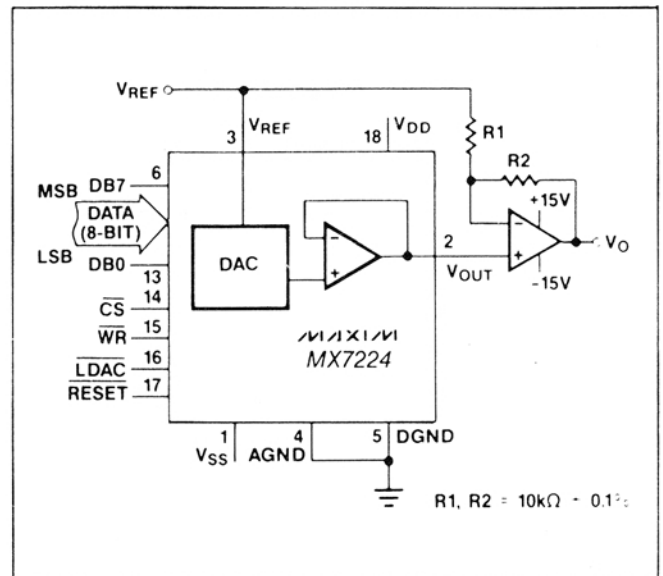


Figure 12. Bipolar Output Circuit



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Table 3. Bipolar (Offset Binary) Code Table

DAC CONTENTS		ANALOG OUTPUT
MSB	LSB	
1 1 1 1	1 1 1 1	$+V_{REF} \left( \frac{127}{128} \right)$
1 0 0 0	0 0 0 1	$+V_{REF} \left( \frac{1}{128} \right)$
1 0 0 0	0 0 0 0	0V
0 1 1 1	1 1 1 1	$-V_{REF} \left( \frac{1}{128} \right)$
0 0 0 0	0 0 0 1	$-V_{REF} \left( \frac{127}{128} \right)$
0 0 0 0	0 0 0 0	$-V_{REF} \left( \frac{128}{128} \right) = -V_{REF}$

### Offsetting AGND

AGND can be biased above DGND to provide an arbitrary non-zero output voltage for a "zero" input code. This is shown in Figure 13. The output voltage at  $V_{OUT}$  is:

$$V_{OUT} = V_{BIAS} + (D \cdot V_{IN})$$

where D is a fractional representation of the digital input word and can vary from 0 to 255/256. For a given  $V_{IN}$ , increasing AGND above system GND will reduce the effective  $V_{DD}-V_{REF}$  which must be at least 4V to ensure specified operation. Note that  $V_{DD}$  and  $V_{SS}$  for the MX7224 must be referenced to DGND.

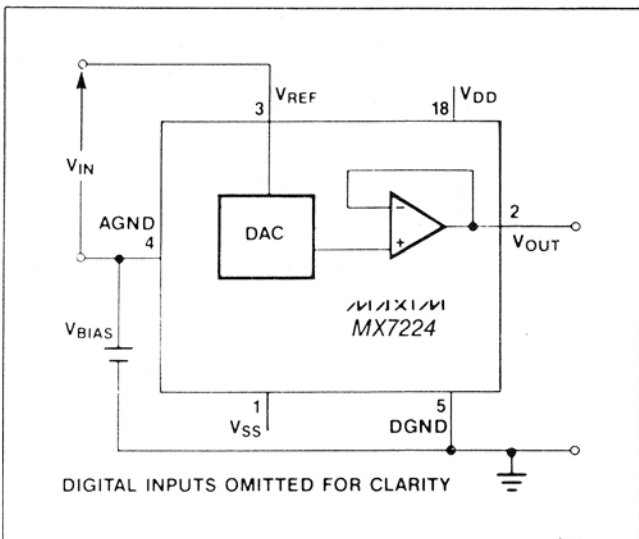


Figure 13. AGND Bias Circuit

### Using an AC Reference

In applications where  $V_{REF}$  has AC signal components, the MX7224 has multiplying capability within the limits of the  $V_{REF}$  input range specifications. Figure 14 shows a technique for applying a sinewave signal to the reference input where the AC signal is biased up before being applied to  $V_{REF}$ . Output distortion is typically less than 0.1% with input frequencies up to 50kHz, and the typical -3dB frequency is 700kHz. Note that  $V_{REF}$  must never be more negative than AGND.

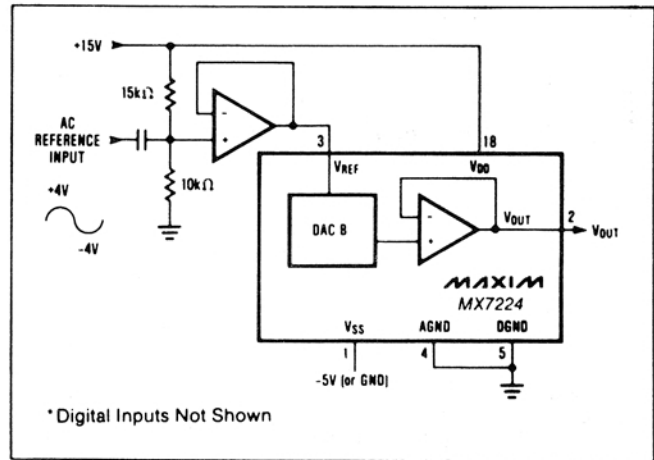


Figure 14. AC Reference Input Circuit

### Generating $V_{SS}$

The performance of the MX7224 is specified for both dual and single supply ( $V_{SS} = 0V$ ) operation. When the improved performance of dual supply operation is desired, but only a single supply is available, a -5V  $V_{SS}$  supply can be generated using an ICL7660 in one of the circuits of Figure 15.

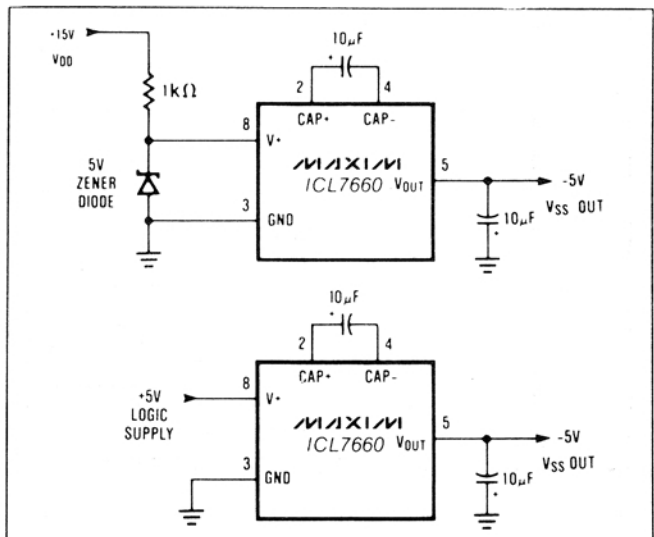


Figure 15. Generating -5V for  $V_{SS}$

# CMOS 8-Bit DAC with Output Amplifier

## Microprocessor Interfacing



Figure 16. MX7224 to 8085A/8088 Interface



Figure 19. MX7224 to 68008 Interface

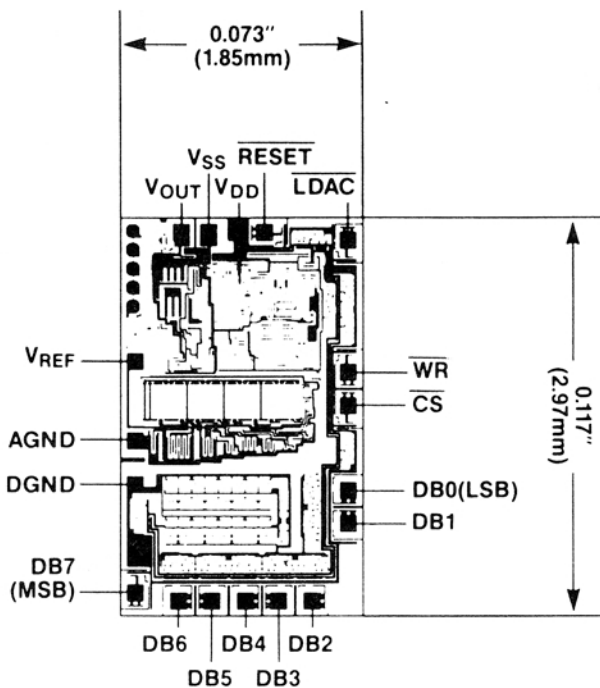


Figure 17. MX7224 to 6809/6502 Interface



Figure 18. MX7224 to Z-80 Interface

## Chip Topography



# **CMOS 8-Bit DAC with Output Amplifier**

**MX7224**

# **CMOS 8-Bit DAC with Output Amplifier**

**MX7224**

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