19-0240; Rev 2; 7/95

MAXIM

CMOS Serial Input 12-Bit DAC

General Description

The MX7543 is a high precision 12-bit digital-to-analog converter (DAC) which uses a serial rather than parallel input scheme for loading data. Included are a serial-to-parallel shift register, a separate DAC register, and a multiplying DAC.

Serial data is clocked in at the SRI pin on the rising or falling edge (user selected) of the strobe input. When the input register is full, the contents are transferred to the DAC register using the load input. A clear input is provided to initialize the part asynchronously.

The MX7543 features excellent gain stability (5ppm/°C max.) and operates from a single +5V power supply while dissipating about 10mW.

Applications

Remote Analog Systems

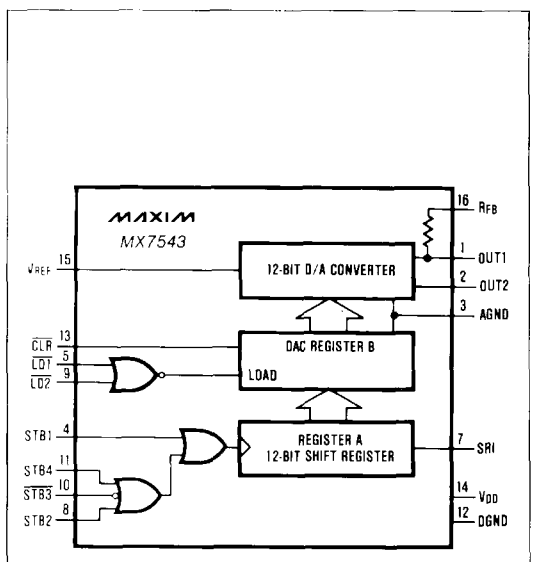
Robotics

Programmable Attenuators

Automatic Test Equipment

Auto-Calibration Systems

Functional Diagram



Features

- **Serial Interface**
- **±½ and ±1 LSB Linearity**
- **CLEAR Input For Initialization**
- **Single +5V Supply Operation**
- **5ppm/°C Gain Stability**
- **1 LSB Max. Feedthrough At 10kHz**
- **Small Size: 16-Lead DIP**

Ordering Information

PART	TEMP. RANGE	PACKAGE*	ERROR
MX7543JN	0°C to +70°C	Plastic DIP	±1 LSB
MX7543KN	0°C to +70°C	Plastic DIP	±½ LSB
MX7543GKN	0°C to +70°C	Plastic DIP	±½ LSB
MX7543JCWE	0°C to +70°C	Small Outline	±1 LSB
MX7543KCWE	0°C to +70°C	Small Outline	±½ LSB
MX7543GKCWE	0°C to +70°C	Small Outline	±½ LSB
MX7543J/D	0°C to +70°C	Dice	±1 LSB
MX7543AD	-25°C to +85°C	Ceramic	±1 LSB
MX7543BD	-25°C to +85°C	Ceramic	±½ LSB
MX7543GBD	-25°C to +85°C	Ceramic	±½ LSB
MX7543AQ	-25°C to +85°C	CERDIP**	±1 LSB
MX7543BQ	-25°C to +85°C	CERDIP**	±½ LSB
MX7543GBQ	-25°C to +85°C	CERDIP**	±½ LSB
MX7543SD	-55°C to +125°C	Ceramic	±1 LSB
MX7543TD	-55°C to +125°C	Ceramic	±½ LSB
MX7543GTD	-55°C to +125°C	Ceramic	±½ LSB
MX7543SQ	-55°C to +125°C	CERDIP**	±1 LSB
MX7543TQ	-55°C to +125°C	CERDIP**	±½ LSB
MX7543GTQ	-55°C to +125°C	CERDIP**	±½ LSB

** All devices—16-pin packages*

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

Pin Configuration

Top View

Call toll free 1-800-998-8800 for free samples or literature.

ABSOLUTE MAXIMUM RATINGS

V_{DD} to AGND ..... -0.3V, +7V
V_{DD} to DGND ..... -0.3V, +7V
AGND to DGND ..... V_{DD}
DGND to AGND ..... V_{DD}
Digital Input Voltage to DGND ..... -0.3V, V_{DD} + 0.3V
(Pins 4-11, 13)
V_{PIN1}, V_{PIN2} to AGND ..... -0.3V, V_{DD} + 0.3V
V_{REF} to AGND ..... +25V
V_{RFB} to AGND ..... ±25V

Power Dissipation 450mW
(derate 6mW/°C above +70°C)
Operating Temperature Range
Commercial MX7543J, K, GK ..... 0°C to +70°C
Industrial MX7543A, B, GB ..... -25°C to +85°C
Military MX7543S, T, GT ..... -55°C to +125°C
Storage Temperature ..... -65°C to +150°C
Lead Temperature (Soldering 10 sec) ..... +300°C

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

(T_A = T_{MIN} to T_{MAX}, V_{DD} = +5V, V_{REF} = +10V, V_{OUT1} = V_{OUT2} = GND, unless otherwise specified)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
DC ACCURACY							
Resolution				12			Bits
Non-Linearity		MX7543J/A/S MX7543K/B/T MX7543GK/GB/GT				±1 ±0.5 ±0.5	LSB
Differential Non-Linearity		MX7543J/A/S (Note 1) MX7543K/B/T (Note 2) MX7543GK/GB/GT (Note 2)				+2 ±1 +1	LSB
Gain Error		MX7543J/K/A/B/S/T MX7543J/K/A/B MX7543S/T	T_A = 25°C T_{MIN} to T_{MAX} T_{MIN} to T_{MAX}			±12.3 ±13.5 ±14.5	LSB
		MX7543GK/GB/GT MX7543GK/GB MX7543GT	T_A = 25°C T_{MIN} to T_{MAX} T_{MIN} to T_{MAX}			±1 ±1 +2	
Gain Temperature Coefficient ΔGain/ΔTemperature (Note 4)					2	5	ppm/°C
Power Supply Rejection	PSRR	V_{DD} = +4.75V to +5.25V	T_A = 25°C T_{MIN} to T_{MAX}			0.005 0.01	%/%V_{DD}
Output Leakage Current I_{OUT1}, I_{OUT2} (Note 3)		MX7543J/K/GK MX7543A/B/GB MX7543S/T/GT	T_A = 25°C T_{MIN} to T_{MAX} T_{MIN} to T_{MAX} T_{MIN} to T_{MAX}			1 10 10 200	nA
DYNAMIC PERFORMANCE (Note 4)							
Output Current Settling Time		To 1/2 LSB, Out1 Load = 100Ω				2	μs
Feedthrough Error		V_{REF} = ±10V 10kHz sine wave				2.5	mVpp
REFERENCE INPUT							
Input Resistance (pin 15)	R_{REF}			8	15	25	kΩ
ANALOG OUTPUT (Note 4)							
Output Capacitance	C_{OUT1} C_{OUT1} C_{OUT2} C_{OUT2}	DAC Register 0000 0000 0000 DAC Register 1111 1111 1111 DAC Register 1111 1111 1111 DAC Register 0000 0000 0000				75 260 75 260	pF

Note 1: Monotonic to 11 bits from T_{MIN} to T_{MAX}
Note 2: Monotonic to 12 bits from T_{MIN} to T_{MAX}
Note 3: I_{OUT1} tested with DAC register loaded to all 0's.
I_{OUT2} tested with DAC register loaded to all 1's.
Note 4: Guaranteed by design but not tested.
Note 5: Sample tested at +25°C to ensure compliance.

ELECTRICAL CHARACTERISTICS (Continued)

(T_A = T_{MIN} to T_{MAX}, V_{DD} = +5V, V_{REF} = +10V, V_{OUT1} = V_{OUT2} = GND, unless otherwise specified)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
LOGIC INPUTS						
Logic HIGH Voltage	V_{INH}		+3.0			V
Logic LOW Voltage	V_{INL}				+0.8	V
Logic Input Current	I_{IN}	V_{IN} = 0V or V_{DD}			1	µA
Input Capacitance (Note 4)	C_{IN}				8	pF
SWITCHING CHARACTERISTICS (see Figure 6) (Note 5)						
Serial Input to Strobe Setup Time	t_{DS1}	T_A = 25°C T_{MIN} to T_{MAX}	50 100			ns
	t_{DS2}	T_A = 25°C T_{MIN} to T_{MAX}	20 40			ns
	t_{DS3}	T_A = 25°C T_{MIN} to T_{MAX}	0 0			ns
	t_{DS4}	T_A = 25°C T_{MIN} to T_{MAX}	0 0			ns
Serial Input to Strobe Hold Time	t_{DH1}	T_A = 25°C T_{MIN} to T_{MAX}	30 60			ns
	t_{DH2}	T_A = 25°C T_{MIN} to T_{MAX}	60 120			ns
	t_{DH3}	T_A = 25°C T_{MIN} to T_{MAX}	80 160			ns
	t_{DH4}	T_A = 25°C T_{MIN} to T_{MAX}	80 160			ns
SRI data pulse width	t_{SRI}	T_A = 25°C T_{MIN} to T_{MAX}	80 160			ns
STB1 pulse width	t_{STB1}	T_A = 25°C T_{MIN} to T_{MAX}	80 160			ns
STB2 pulse width	t_{STB2}	T_A = 25°C T_{MIN} to T_{MAX}	80 160			ns
$\overline{STB3}$ pulse width	t_{STB3}	T_A = 25°C T_{MIN} to T_{MAX}	100 200			ns
STB4 pulse width	t_{STB4}	T_A = 25°C T_{MIN} to T_{MAX}	100 200			ns
Load 1 pulse width	t_{LD1}	T_A = 25°C T_{MIN} to T_{MAX}	150 300			ns
Load 2 pulse width	t_{LD2}	T_A = 25°C T_{MIN} to T_{MAX}	150 300			ns
Time between strobing LSB into Register A and loading Register B	t_{ASB}	T_A = 25°C T_{MIN} to T_{MAX}	0 0			ns
Clear pulse width	t_{CLR}	T_A = 25°C T_{MIN} to T_{MAX}	200 400			ns
POWER SUPPLY						
Supply Voltage	V_{DD}	5V ± 5%	4.75		5.25	V
Supply Current	I_{DD}				2.5	mA

Detailed Description

The basic MX7543 DAC circuit consists of a laser-trimmed, thin-film R-2R resistor array with NMOS current switches as shown in Figure 1. Binarily weighted currents are switched to either OUT1 or OUT2 depending on the status of each input bit. Although the current at OUT1 or OUT2 will depend on the digital input code, the sum of the two output currents is always equal to the input current at V_{REF} minus the termination resistor current (R_T).

Either current output can be converted into a voltage externally by adding an output amplifier (Figure 4). The V_{REF} input accepts a wide range of signals including fixed and time varying voltage or current inputs. If a current source is used for the reference input, then a low temperature coefficient external resistor should be used for R_{FB} to minimize gain variation with temperature.

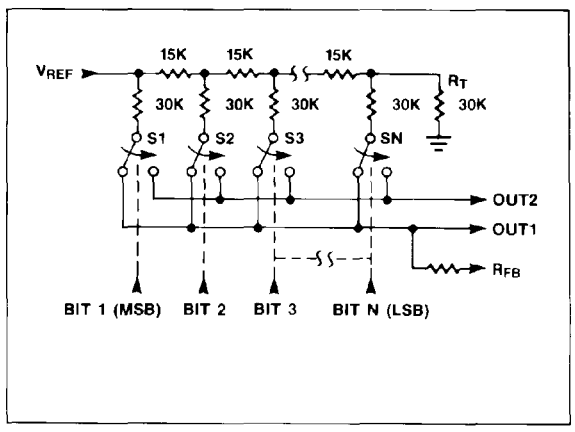


Figure 1. MX7543 Functional Diagram

Equivalent Circuit Analysis

Figures 2 and 3 show the equivalent circuits for the R-2R ladder when all digital inputs are LOW and HIGH respectively. The input resistance at V_{REF} is nominally 15kΩ and does not change with digital input code. The $I_{REF}/4096$ current source, which is actually the ladder termination resistor (R_T, Figure 1), results in an intentional 1-bit current loss to GND. The $I_{LEAKAGE}$ current sources represent junction and surface leakage currents.

Capacitors C_{OUT1} and C_{OUT2} represent the switches ON and OFF capacitances respectively. When all inputs are switched from LOW to HIGH, the capacitance at OUT1 changes from approximately 75pF to 260pF. This capacitance is code-dependent and is a function of the number of ON switches that are connected to a specific output.

Circuit Configurations

Unipolar Operation

The most common configuration for the MX7543 is shown in Figure 4. The circuit is used for unipolar binary operation and/or 2-quadrant multiplication. The code table is given in Table 1. Note that the polarity of the output is the inverse of the reference input.

In many applications, gain adjustment of the MX7543 will not be necessary. In those cases, and also when gain is trimmed but only at the reference source, resistors R1 and R2 in Figure 4 can be omitted. However, if the trims are desired and the DAC is to operate over a wide temperature range, then low tempco (<300ppm/°C) resistors should be used at R1 and R2.

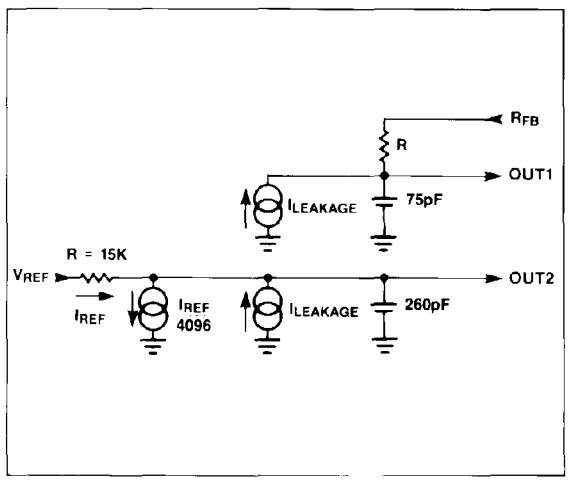


Figure 2. MX7543 DAC Equivalent Circuit, All Digital Inputs LOW

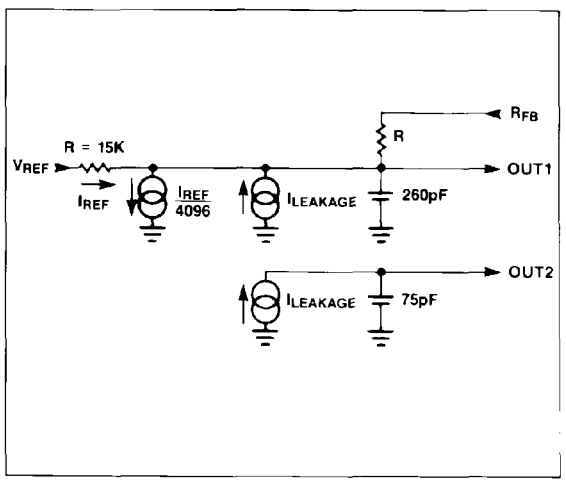
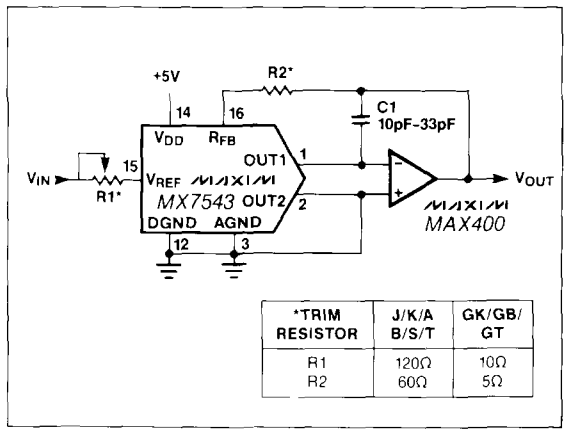


Figure 3. MX7543 DAC Equivalent Circuit, All Digital Inputs HIGH

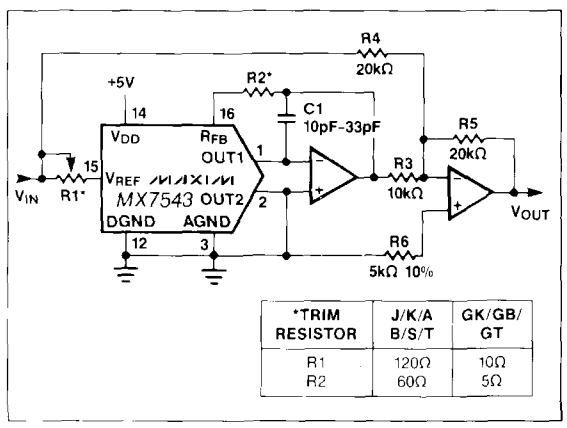


*TRIM RESISTOR	J/K/A B/S/T	GK/GB/ GT
R1	120Ω	10Ω
R2	60Ω	5Ω

Figure 4. Unipolar Binary Operation

Table 1. Code Table—Unipolar Binary

DIGITAL INPUT MSB LSB	ANALOG OUTPUT
1 1 1 1 1 1 1 1 1 1 1 1	$-V_{REF}\left(\frac{4095}{4096}\right)$
1 0 0 0 0 0 0 0 0 0 0 0	$-V_{REF}\left(\frac{2048}{4096}\right) = -\frac{V_{REF}}{2}$
0 0 0 0 0 0 0 0 0 0 0 1	$-V_{REF}\left(\frac{1}{4096}\right)$
0 0 0 0 0 0 0 0 0 0 0 0	0V



*TRIM RESISTOR	J/K/A B/S/T	GK/GB/ GT
R1	120Ω	10Ω
R2	60Ω	5Ω

Figure 5. Bipolar Operation (4-Quadrant Multiplication)

Table 2. Code Table— Bipolar (Offset Binary) Operation

DIGITAL INPUT MSB LSB	ANALOG OUTPUT
1 1 1 1 1 1 1 1 1 1 1 1	$+V_{REF}\left(\frac{2047}{2048}\right)$
1 0 0 0 0 0 0 0 0 0 0 1	$+V_{REF}\left(\frac{1}{2048}\right)$
1 0 0 0 0 0 0 0 0 0 0 0	0V
0 1 1 1 1 1 1 1 1 1 1 1	$-V_{REF}\left(\frac{1}{2048}\right)$
0 0 0 0 0 0 0 0 0 0 0 0	$-V_{REF}\left(\frac{2048}{2048}\right)$

Bipolar Operation

With the circuit configuration in Figure 5, the MX7543 operates in the bipolar, or 4-quadrant multiplying mode. A second amplifier and three matched resistors are required. Matching to 0.01% is recommended for 12 bit performance. The code table for the output, which is "offset binary", is listed in Table 2. In multiplying applications, the MSB determines output polarity while the other 11 bits control amplitude.

To adjust the circuit, load the DAC with a code of 1000 0000 0000 and trim R1 for a 0V output. With R1 and R2 omitted, an alternative zero trim is to adjust the ratio of R3 and R4 for 0V out. Full scale can be trimmed by loading the DAC with all "zeros" or all "ones" and adjusting the amplitude of V_{REF} or varying R5 until the desired positive or negative output is obtained. If gain and offset trims are not required, R1 and R2 in Figure 5 can be omitted.

Interface Logic

Serial data is first loaded into the 12-bit Shift Register A, shown in the MX7543 functional diagram. Each bit of serial data appearing at pin SRI is clocked into Register A MSB first, by any one of the four strobe inputs. STB1, STB2, and STB4 all clock data into Shift Register A on the rising edge of the strobe pulse. $\overline{STB3}$ clocks data into Register A on its falling edge. Table 3 illustrates the logic states for the control inputs. Figure 6 shows the timing diagram for the loading sequence.

Data is then transferred from Shift Register A into Register B by momentarily moving both $\overline{LD1}$ and $\overline{LD2}$, low.

Bringing $\overline{CLR}$ input low asynchronously resets Register B to 0000 0000 0000. This initializes the DAC output voltage to a known condition. With the unipolar circuit of Figure 4, a $\overline{CLR}$ results in a DAC output voltage of 0 volts. Using the bipolar circuit of Figure 5, momentarily bringing $\overline{CLR}$ low sets the DAC output voltage to its lowest value of $-V_{REF}$.

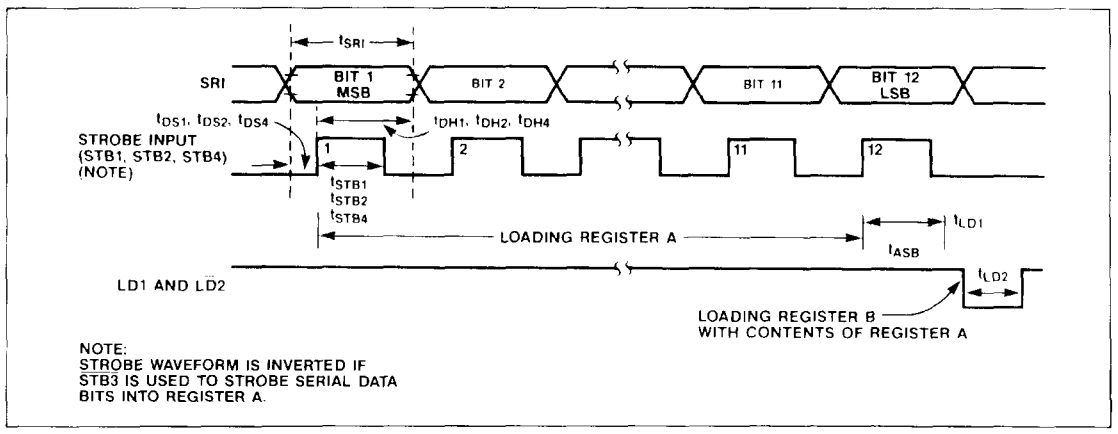


Figure 6. Timing Diagram

Table 3. MX7543 Truth Table

MX7543 Logic Inputs							MX7543 Operation	Notes
Register A Control Inputs				Register B Control Inputs				
STB4	$\overline{STB3}$	STB2	STB1	$\overline{CLR}$	$\overline{LD2}$	$\overline{LD1}$		
0	1	0	↑	X	X	X	Data Appearing At SRI Strobed Into Register A	2, 3
0	1	↑	0	X	X	X	Data Appearing At SRI Strobed Into Register A	2, 3
0	↓	0	0	X	X	X	Data Appearing At SRI Strobed Into Register A	2, 3
↑	1	0	0	X	X	X	Data Appearing At SRI Strobed Into Register A	2, 3
1	X	X	X				No Operation (Register A)	3
X	0	X	X					
X	X	1	X					
X	X	X	1					
				0	X	X	Clear Register B To Code 0000 0000 0000 (Asynchronous Operation)	1, 3
				1	1	X	No Operation (Register B)	3
				1	X	1		
				1	0	0	Load Register B With The Contents Of Register A	3

Notes:
1. CLR 0 Asynchronously resets Register B to 0000 0000 0000, but has no effect on Register A.
2. Serial data is loaded into Register A MSB first, on edges shown ↑ is positive edge ↓ is negative edge.
3. 0 = Logic LOW, 1 = Logic HIGH, X = Don't Care.

Application Information

Output Amplifier Offset

For best linearity, OUT1 and OUT2 should be terminated exactly at 0V. In most applications OUT1 is connected to the summing junction of an inverting op-amp. The amplifier's input offset voltage can degrade the linearity of the DAC by causing OUT1 to be terminated to a non-zero voltage. The resulting error is:

$$\text{Error Voltage} = V_{OS}(1 + R_{FB}/R_O),$$

where V_{OS} is the op-amp's offset voltage and R_O is the output resistance of the DAC. R_O is a function of the digital input code, and varies from approximately 15kΩ to 45kΩ. The error voltage range is then typically $4/3V_{OS}$ to $2V_{OS}$, a change of $2/3V_{OS}$. An amplifier with 3mV of offset will therefore degrade the linearity by 2mV, almost a full LSB with a 10V reference voltage. For best linearity, a low-offset amplifier such as the MAX400 should be used, or the amplifier offset must be trimmed to zero. A good rule of thumb is that V_{OS} should be no more than 1/10 of an LSB's value.

The output amplifier input bias current (I_B) can also limit performance since $I_B \times R_{FB}$ generates an offset error, I_B should therefore be much less than the DAC output current for 1 LSB, typically 250nA with V_{REF} = 10V. One tenth of this value, 25nA, is recommended. Offset and linearity can also be impaired if the output amplifier's noninverting input is grounded through a "bias current compensation resistor". This resistor adds to offset at this pin and should not be used. Best performance is obtained when the noninverting input is directly connected to ground.

Dynamic Considerations

In static or DC applications, the AC characteristics of the output amplifier 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 AC parameters of the output op-amp must be considered.

Another error source in dynamic applications is parasitic coupling of signal from the V_{REF} terminal to OUT1 or OUT2. This is normally a function of board layout and package lead-to-lead capacitance. Signals can also be injected into the DAC outputs when the digital inputs are switched. This digital feedthrough is usually dependent on circuit board layout and on-chip capacitive coupling. Layout induced feedthrough can be minimized with guard traces between digital inputs, V_{REF}, and the DAC outputs.

Compensation

A compensation capacitor, C1, may be needed when the DAC is used with a high speed output amplifier. The purpose of the capacitor is to cancel 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 10 to 33pF. Too small a value causes output ringing while excess capacitance overdamps the output. The size of C1 can be minimized, and output settling performance improved, by keeping the PC board trace and stray capacitance at OUT1 as small as possible.

Grounding and Bypassing

Since OUT1, OUT2 and the output amp's noninverting inputs are sensitive to offset voltages, nodes that are to be grounded should be connected directly to "single point" ground through a separate, very low resistance (less than 0.2Ω) path. The current at OUT1 and OUT2 varies with input code, creating a code dependent error if these terminals are connected to ground (or a virtual ground) through a resistive path.

A 1μF bypass capacitor, in parallel with a 0.01μF ceramic capacitor, should be connected as close to the DAC's V_{DD} and GND pins as possible.

The MX7543 has high-impedance digital inputs. To minimize noise pick-up, they should be tied to either V_{DD} or GND when not used. It is also good practice to connect active inputs to V_{DD} or GND through high valued resistors (1MΩ) to prevent static charge accumulation if these pins are left floating, such as when a circuit card is left unconnected.

Chip Topography