



# CMOS Low Cost 10 Bit Multiplying D/A Converter

## Features

Maxim's MX7533 is pin and functionally compatible with Analog Devices' AD7533 as well as the AD7520. It is packaged in 16-lead DIP and small outline packages.

Machine and Motion Control Systems  
Automatic Test Equipment  
 $\mu$ P Controlled Calibration Circuitry  
Programmable Gain Amplifiers  
Digitally Controlled Filters  
Programmable Power Supplies

The circuit diagram illustrates a Programmable Function Generator implemented using the MAX7533 IC. The IC is configured as follows:

- VREF** (Pin 15) is connected to a square wave output through a  $10k\Omega$  resistor.
- VDD** (Pin 14) is connected to a +15V supply.
- RFB** (Pin 16) is connected to GND (Pin 3).
- DIGITAL INPUT** (Pins 4-13) is connected to pins 4 and 13.
- OUT1** (Pin 1) is connected to a  $1k\Omega$  resistor, which is then connected to the non-inverting input of a buffer amplifier.
- OUT2** (Pin 2) is connected to the inverting input of another buffer amplifier.
- A feedback network consisting of a  $10k\Omega$  resistor and a capacitor  $C1$  is connected between the outputs of the two buffers.
- The final output is labeled **TRIANGLE OUTPUT**, showing a triangular waveform.

- ◆ 10 Bit Resolution
- ◆ 8, 9, and 10 Bit End Point Linearity
- ◆ Low Power Consumption - 20mW
- ◆ Four-Quadrant Multiplication
- ◆ TTL and CMOS Compatible
- ◆ Pin-For-Pin Second Source

| PART       | TEMP RANGE      | PACKAGE*      | ERROR |
|------------|-----------------|---------------|-------|
| MX7533JN   | 0°C to +70°C    | Plastic DIP   | 0.2%  |
| MX7533KN   | 0°C to +70°C    | Plastic DIP   | 0.1%  |
| MX7533LN   | 0°C to +70°C    | Plastic DIP   | 0.05% |
| MX7533JCWE | 0°C to +70°C    | Small Outline | 0.2%  |
| MX7533KCWE | 0°C to +70°C    | Small Outline | 0.1%  |
| MX7533LCWE | 0°C to +70°C    | Small Outline | 0.05% |
| MX7533J/D  | 0°C to +70°C    | Dice          | 0.2%  |
| MX7533AQ   | -25°C to +85°C  | CERDIP**      | 0.2%  |
| MX7533BQ   | -25°C to +85°C  | CERDIP**      | 0.1%  |
| MX7533CQ   | -25°C to +85°C  | CERDIP**      | 0.05% |
| MX7533AD   | -25°C to +85°C  | Ceramic       | 0.2%  |
| MX7533BD   | -25°C to +85°C  | Ceramic       | 0.1%  |
| MX7533CD   | -25°C to +85°C  | Ceramic       | 0.05% |
| MX7533SQ   | -55°C to +125°C | CERDIP**      | 0.2%  |
| MX7533TQ   | -55°C to +125°C | CERDIP**      | 0.1%  |
| MX7533UQ   | -55°C to +125°C | CERDIP**      | 0.05% |
| MX7533SD   | -55°C to +125°C | Ceramic       | 0.2%  |
| MX7533TD   | -55°C to +125°C | Ceramic       | 0.1%  |
| MX7533UD   | -55°C to +125°C | Ceramic       | 0.05% |

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

Top View

Pin 1: OUT1  
Pin 2: OUT2  
Pin 3: GND  
Pin 4: BIT 1 (MSB)  
Pin 5: BIT 2  
Pin 6: BIT 3  
Pin 7: BIT 4  
Pin 8: BIT 5  
Pin 9: BIT 6  
Pin 10: BIT 7  
Pin 11: BIT 8  
Pin 12: BIT 9  
Pin 13: BIT 10 (LSB)  
Pin 14: VDD  
Pin 15: VREF  
Pin 16: RFB

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### ABSOLUTE MAXIMUM RATINGS

|                                                               |                 |
|---------------------------------------------------------------|-----------------|
| $V_{DD}$ to GND                                               | -0.3V, +17V     |
| $V_{REF}$ to GND                                              | $\pm 25V$       |
| $R_{FB}$ to GND                                               | $\pm 25V$       |
| Digital Input Voltage to GND                                  | -0.3V, $V_{DD}$ |
| Output Voltage (OUT1, OUT2) (Note 1)                          | -0.3V, $V_{DD}$ |
| Power Dissipation                                             |                 |
| Plastic DIP (Derate 8.3mW/°C above +70°C)                     | 670mW           |
| Ceramic, CERDIP, Small Outline<br>(Derate 6mW/°C above +75°C) | 450mW           |

|                                      |                 |
|--------------------------------------|-----------------|
| Operating Temperature Range          |                 |
| Commercial J/K/L                     | 0°C to +70°C    |
| Industrial A/B/C                     | -25°C to +85°C  |
| Military S/T/U                       | -55°C to +125°C |
| Storage Temperature                  | -65°C to +150°C |
| Lead Temperature (Soldering 10 secs) | +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 rating conditions for extended periods may affect device reliability.

### ELECTRICAL CHARACTERISTICS

( $T_A = T_{MIN}$  to  $T_{MAX}$ ,  $V_{DD} = +15V$ ,  $V_{REF} = +10V$ ,  $V_{OUT1} = V_{OUT2} = GND$ , unless otherwise specified)

| PARAMETER                                                         | SYMBOL    | CONDITIONS                                                                                                      |                                                | MIN.  | TYP. | MAX.                                 | UNITS            |
|-------------------------------------------------------------------|-----------|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------|-------|------|--------------------------------------|------------------|
| DC ACCURACY                                                       |           |                                                                                                                 |                                                |       |      |                                      |                  |
| Resolution                                                        |           |                                                                                                                 |                                                | 10    |      |                                      | Bits             |
| Relative Accuracy (Note 2)                                        |           | MX7533J/A/S<br>MX7533K/B/T<br>MX7533L/C/U                                                                       |                                                |       |      | $\pm 0.2$<br>$\pm 0.1$<br>$\pm 0.05$ | % FSR            |
| Gain Error (Note 2,3)                                             |           | Digital Inputs = $V_{INH}$                                                                                      | $T_A = +25^{\circ}C$<br>$T_{MIN}$ to $T_{MAX}$ |       |      | $\pm 1.4$<br>$\pm 1.5$               | % FSR            |
| Power Supply Rejection<br>(Note 4) $\Delta$ Gain/ $\Delta V_{DD}$ | PSRR      | $V_{DD} = +14V$ to $+17V$                                                                                       | $T_A = +25^{\circ}C$<br>$T_{MIN}$ to $T_{MAX}$ |       |      | 0.005<br>0.008                       | %/% $V_{DD}$     |
| Output Leakage Current                                            |           | OUT1, Digital Inputs = $V_{INL}$ ,<br>$V_{REF} = \pm 10V$                                                       | $T_A = +25^{\circ}C$<br>$T_{MIN}$ to $T_{MAX}$ |       |      | $\pm 50$<br>$\pm 200$                | nA               |
|                                                                   |           | OUT2, Digital Inputs = $V_{INH}$ ,<br>$V_{REF} = \pm 10V$                                                       | $T_A = +25^{\circ}C$<br>$T_{MIN}$ to $T_{MAX}$ |       |      | $\pm 50$<br>$\pm 200$                |                  |
| $V_{REF}$ Input Resistance                                        | $R_{REF}$ | $T_A = +25^{\circ}C$                                                                                            |                                                | 5     | 10   | 20                                   | k $\Omega$       |
| $V_{REF}$ Resistance Tempco                                       |           |                                                                                                                 |                                                |       | -300 |                                      | ppm/ $^{\circ}C$ |
| DYNAMIC PERFORMANCE                                               |           |                                                                                                                 |                                                |       |      |                                      |                  |
| Output Current<br>Settling Time (Note 5)                          |           | To 0.05% of FSR, $R_L = 100\Omega$ ,<br>Digital Inputs = $V_{INH}$ to<br>$V_{INL}$ and $V_{INL}$ to $V_{INH}$ . | $T_A = +25^{\circ}C$<br>$T_{MIN}$ to $T_{MAX}$ |       |      | 600<br>800                           | ns               |
| Feedthrough Error (Note 4)                                        |           | Digital Inputs = $V_{INL}$ , $V_{REF} = \pm 10V$ ,<br>100KHz Sinewave                                           | $T_A = +25^{\circ}C$<br>$T_{MIN}$ to $T_{MAX}$ |       |      | $\pm 0.05$<br>$\pm 0.1$              | % FSR            |
| Output Capacitance (Note 4)                                       | $C_{OUT}$ | Digital Inputs = $V_{INH}$                                                                                      | OUT1<br>OUT2                                   |       |      | 100<br>35                            | pF               |
|                                                                   |           | Digital Inputs = $V_{INL}$                                                                                      | OUT1<br>OUT2                                   |       |      | 35<br>100                            |                  |
| DIGITAL INPUTS                                                    |           |                                                                                                                 |                                                |       |      |                                      |                  |
| Logic HIGH Threshold                                              | $V_{INH}$ |                                                                                                                 |                                                | +2.4  |      |                                      | V                |
| Logic LOW Threshold                                               | $V_{INL}$ |                                                                                                                 |                                                |       |      | +0.8                                 | V                |
| Input Leakage Current                                             |           | Digital Inputs = 0V or $V_{DD}$                                                                                 |                                                |       |      | $\pm 1$                              | $\mu A$          |
| Input Capacitance (Note 4)                                        |           |                                                                                                                 |                                                |       |      | 5                                    | pF               |
| POWER REQUIREMENTS                                                |           |                                                                                                                 |                                                |       |      |                                      |                  |
| Operating Supply Range                                            | $V_{DD}$  | +15V $\pm 10\%$ for Rated Accuracy                                                                              |                                                | +13.5 |      | +16.5                                | V                |
|                                                                   |           | Accuracy Not Guaranteed (Note 4)                                                                                |                                                | +5    |      | +16.5                                |                  |
| Power Supply Current                                              | $I_{DD}$  | Digital Inputs = $V_{INH}$ or $V_{INL}$                                                                         |                                                |       |      | 2                                    | mA               |

Note 1:  $V_{OUT1,2}$  may exceed the Absolute Maximum voltage rating if the current is limited to 30mA or less.

Note 2: Using internal feedback resistor ( $R_{FB}$ ). Full scale range (FSR) =  $-(V_{REF} - 1LSB)$  in unipolar mode.

Note 3: Maximum gain change from +25°C to  $T_{MIN}$  or  $T_{MAX}$  is  $\pm 0.1\%$  FSR.

Note 4: Guaranteed by design but not 100% tested.

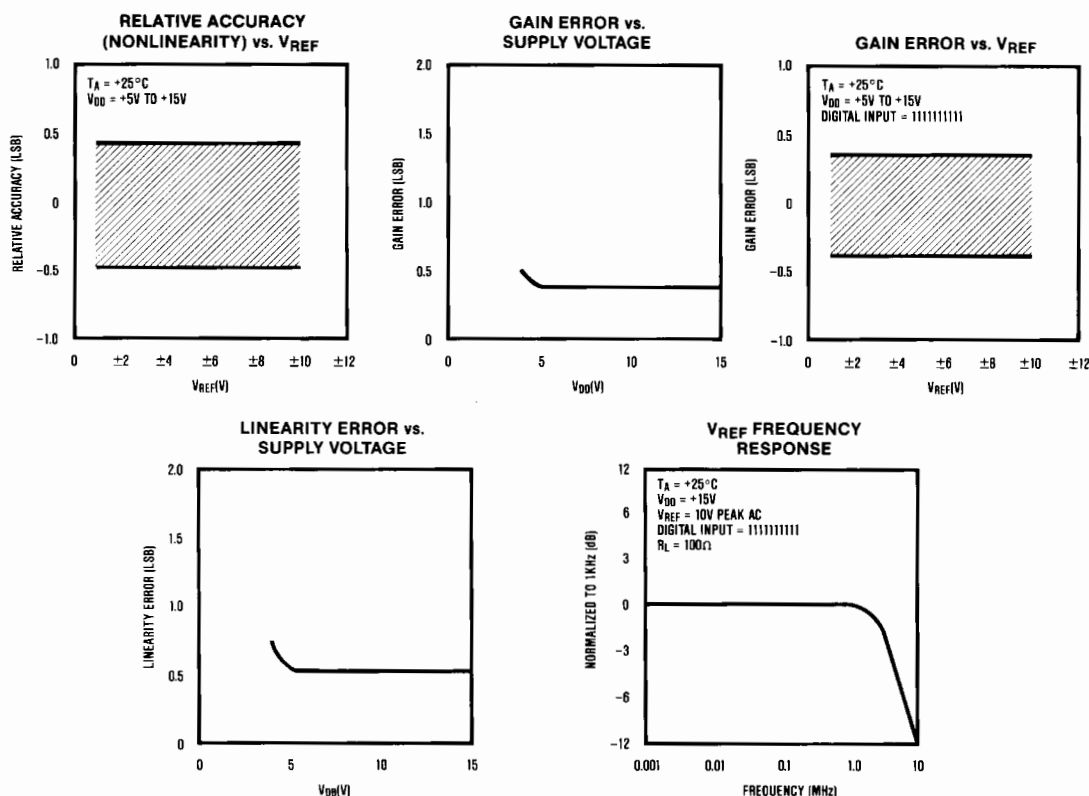
Note 5: Guaranteed by design and sample tested at +25°C to ensure compliance.

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### Typical Operating Characteristics



### Detailed Description

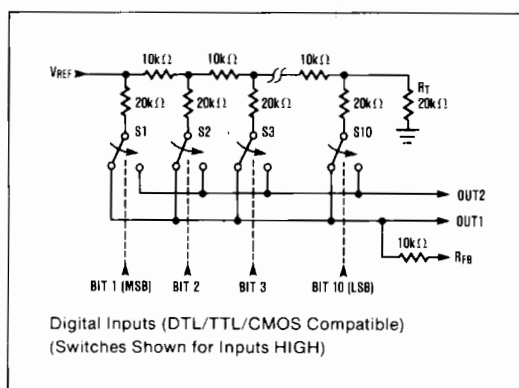


Figure 1. MX7533 Functional Diagram

The basic MX7533 DAC circuit consists of a thin-film R-2R resistor array with CMOS current switches as shown in Figure 1. Binary weighted currents are switched to either OUT1 or OUT2 depending on the status of each input bit. Most applications require only an output op-amp and an external reference. The  $V_{REF}$  input accepts a wide range of reference signals including fixed and time-varying voltage or current inputs.

### 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  $10\text{k}\Omega$  and does not change with digital input code. The  $I_{REF}/1024$  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.

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Capacitors COUT1 and COUT2 represent the switches' ON and OFF capacitances respectively. When all inputs are switched from LOW to HIGH, the capacitance at OUT1 changes from 35pF to 100pF. This capacitance is code-dependent and is a function of the number of ON switches that are connected to a specific output.

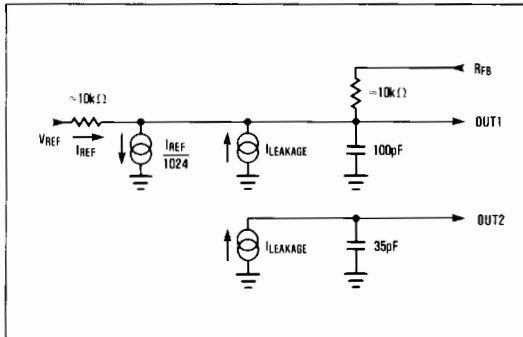


Figure 2. Equivalent DAC Circuit (All digital inputs HIGH)

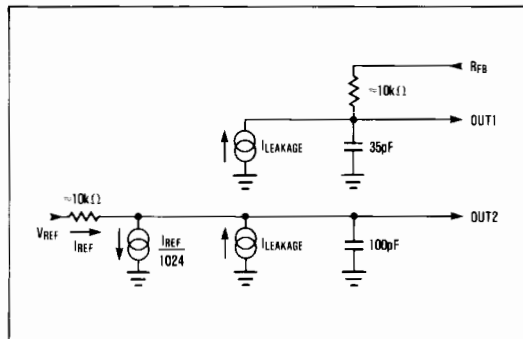


Figure 3. Equivalent DAC Circuit (All digital inputs LOW)

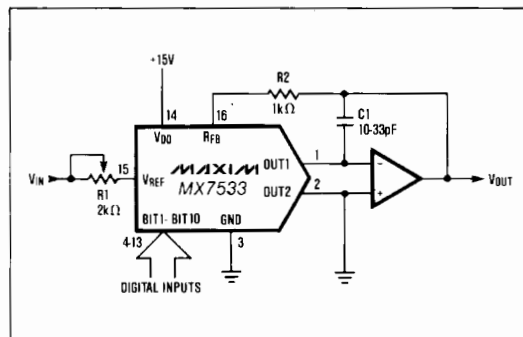


Figure 4. Unipolar Binary Operation (2-Quadrant Multiplication)

#### Application Information

##### Unipolar Operation

The most common configuration for the MX7533 is shown in Figure 4. The circuit is used for unipolar binary operation and/or 2-quadrant multiplication. R1 is used for gain adjustment. If no adjustment is desired, R1 and R2 can be omitted. The code table for unipolar operation is given in Table 1. Note that the output polarity is the inverse of the reference input.

A compensation capacitor, C1, may be needed when the DAC is used with a high speed amplifier. The purpose of the capacitor is to cancel the pole formed by the DAC's output capacitance and internal feedback resistance. The correct compensation value depends on the type of op-amp used but typically ranges from 10 to 33pF.

The output op-amp's offset voltage can degrade DAC linearity by causing OUT1 to be terminated at a non-zero voltage. The resulting linearity error is typically  $2/3V_{OS}$ . For best performance, a low-offset amplifier such as the MAX400 should be used or the amplifier offset must be trimmed to typically more than 1/10 of an LSB's value. The op-amp's input bias current ( $I_B$ ) can also limit performance since  $I_B \times R_{FB}$  generates an offset error as well.  $I_B$  should therefore be much less than the DAC's output current for 1 LSB, which is typically 1μA for the MX7533.

##### Bipolar Operation

Bipolar, or four-quadrant, operation is shown in Figure 5. A second amplifier and three matched resistors are required. R3, R4, and R5 should be matched or trimmed to 0.05% to maintain 10 bit performance. The output vs. code table is listed in Table 2. In multiplying applications, the MSB determines output polarity while the remaining bits control amplitude.

To adjust the circuit, load the DAC with a code of 10000 00000 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. The op-amp recommendations made in the Unipolar Operation section apply for bipolar operation as well.

##### Voltage Mode (Single Supply)

The MX7533 is connected as a voltage output DAC in Figure 6. OUT1 is connected to the external reference and OUT2 is grounded.  $V_{REF}$ , now the DAC output, is a voltage source with a constant output resistance of  $R_{ladder}$  (nominally 10kΩ). In most circuits this output is buffered with an op-amp.

An advantage of voltage mode operation is single supply operation for the complete circuit, i.e. a negative reference is not required for a positive output. It is important to note that the range of the reference is restricted. The reference input (voltage at OUT1) must

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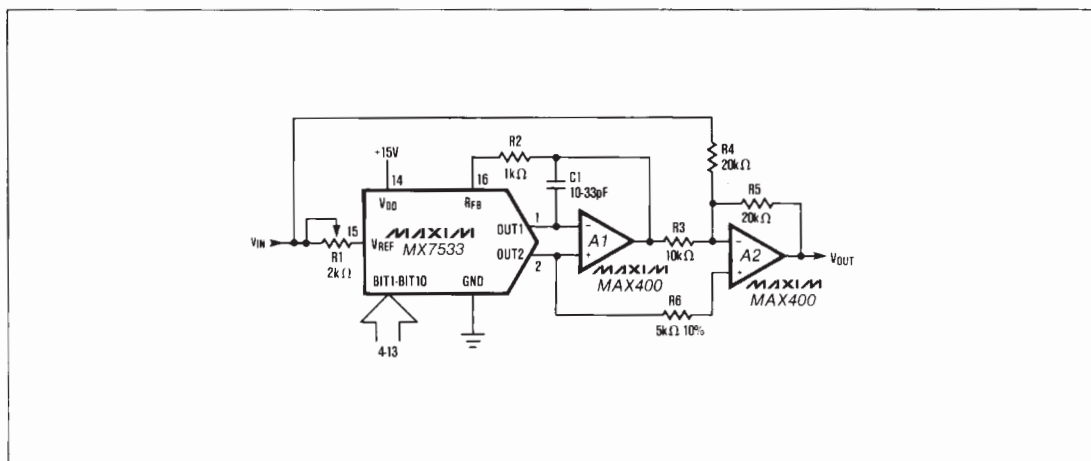


Figure 5. Bipolar Operation (4-Quadrant Multiplication)

always be positive and is limited to no more than 3.5V when  $V_{DD}$  is 15V. If the reference voltage is greater than 3.5V, or  $V_{DD}$  is reduced, linearity is degraded.

### 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 mostly 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.

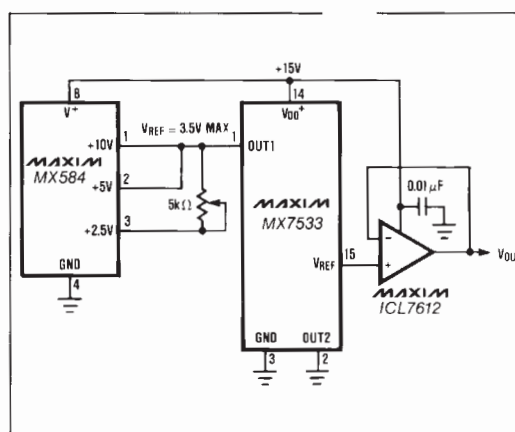


Figure 6. Voltage Mode Operation

Table 1: Code Table —  
Unipolar Binary Operation

| DIGITAL INPUT       | ANALOG OUTPUT                      |
|---------------------|------------------------------------|
| 1 1 1 1 1 1 1 1 1 1 | $-V_{REF} (1 - 2^{-10})$           |
| 1 0 0 0 0 0 0 0 0 1 | $-V_{REF} (\frac{1}{4} + 2^{-10})$ |
| 1 0 0 0 0 0 0 0 0 0 | $-V_{REF}/2$                       |
| 0 1 1 1 1 1 1 1 1 1 | $-V_{REF} (\frac{1}{2} - 2^{-10})$ |
| 0 0 0 0 0 0 0 0 0 1 | $-V_{REF} (2^{-10})$               |
| 0 0 0 0 0 0 0 0 0 0 | 0                                  |

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

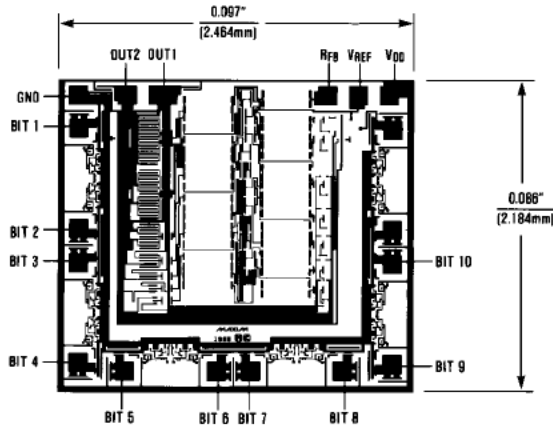
| DIGITAL INPUT       | ANALOG OUTPUT           |
|---------------------|-------------------------|
| 1 1 1 1 1 1 1 1 1 1 | $-V_{REF} (1 - 2^{-9})$ |
| 1 0 0 0 0 0 0 0 0 1 | $-V_{REF} (2^{-9})$     |
| 1 0 0 0 0 0 0 0 0 0 | 0                       |
| 0 1 1 1 1 1 1 1 1 1 | $V_{REF} (2^{-9})$      |
| 0 0 0 0 0 0 0 0 0 1 | $V_{REF} (1 - 2^{-9})$  |
| 0 0 0 0 0 0 0 0 0 0 | $V_{REF}$               |

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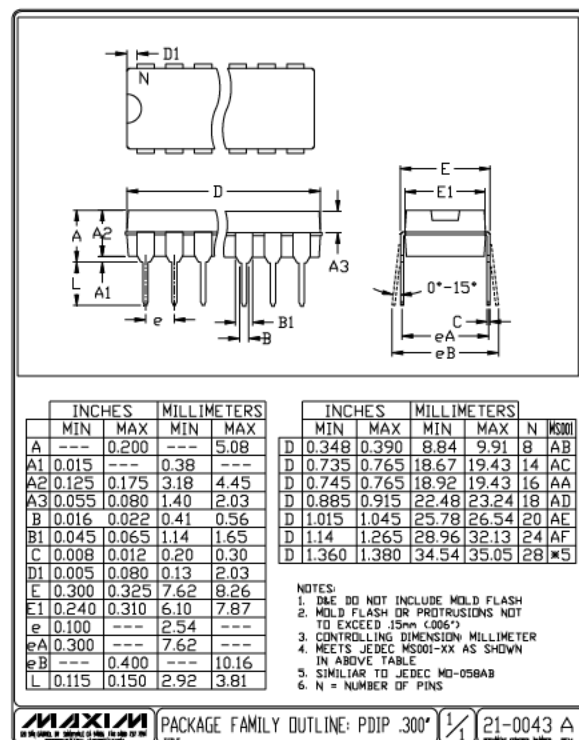
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### Chip Topography



### Package Information

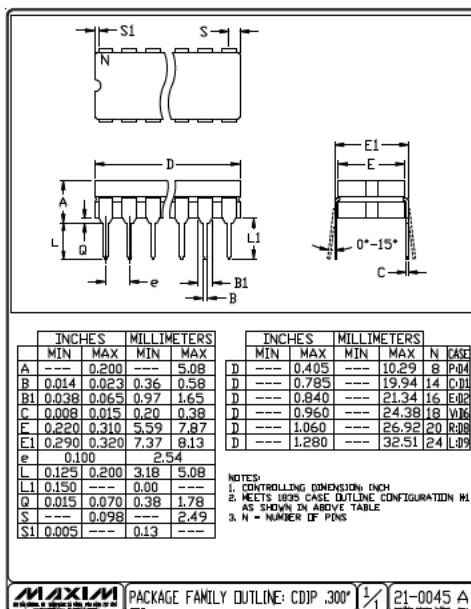
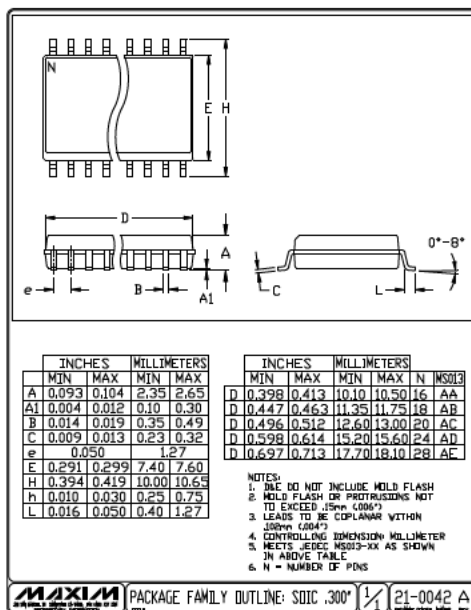


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### Package Information (continued)

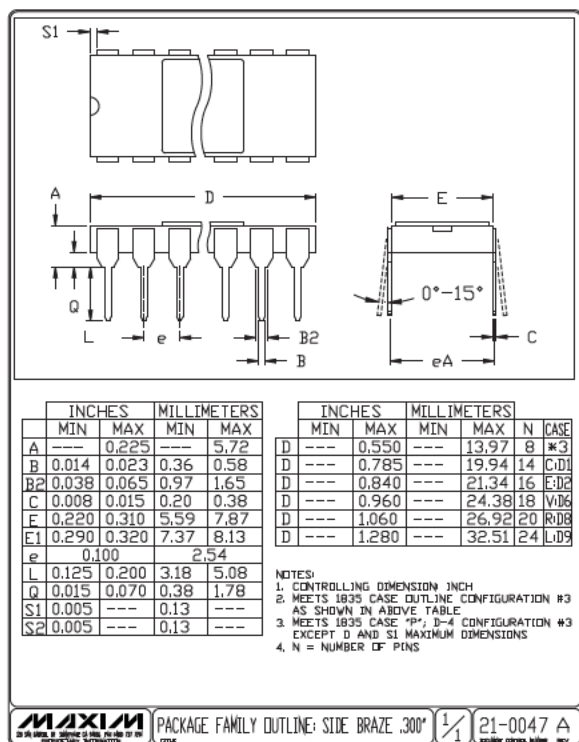


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#### Package Information (continued)



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