

## FEATURES

- **SO-8 Package (LTC1595)**
- **DNL and INL: 1LSB Max**
- **Low Glitch Impulse: 1nV-s Typ**
- Pin Compatible with Industry Standard 12-Bit DACs: DAC8043 and DAC8143/AD7543
- 4-Quadrant Multiplication
- Low Supply Current: 10 $\mu$ A Max
- Power-On Reset
- 3-Wire SPI and MICROWIRE™ Compatible Serial Interface
- Daisy-Chain Serial Output (LTC1596)
- Asynchronous Clear Input (LTC1596)

## APPLICATIONS

- Process Control and Industrial Automation
- Software Controlled Gain Adjustment
- Digitally Controlled Filter and Power Supplies
- Automatic Test Equipment

## DESCRIPTION

The LTC®1595/LTC1596 are serial input, 16-bit multiplying current output DACs. The LTC1595 is pin and hardware compatible with the 12-bit DAC8043 and comes in 8-pin PDIP and SO packages. The LTC1596 is pin and hardware compatible with the 12-bit DAC8143/AD7543 and comes in 16-pin PDIP and SO wide packages.

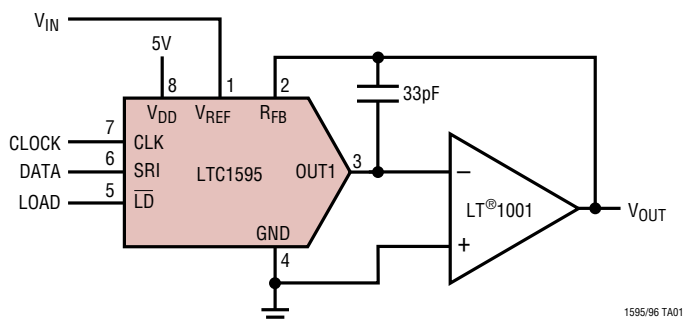
Both are specified over the industrial temperature range. Sensitivity of INL to op amp  $V_{OS}$  is reduced by five times compared to the industry standard 12-bit DACs, so most systems can be easily upgraded to true 16-bit resolution and linearity without requiring more precise op amps.

These DACs include an internal deglitching circuit that reduces the glitch impulse by more than ten times to less than 1nV-s typ.

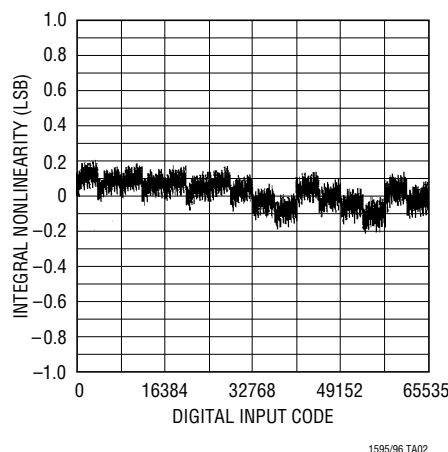
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MICROWIRE is a trademark of National Semiconductor Corporation.

## TYPICAL APPLICATION

**SO-8 Multiplying 16-Bit DAC Has Easy 3-Wire Serial Interface**



**Integral Nonlinearity**

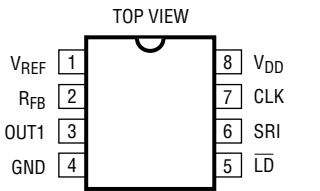
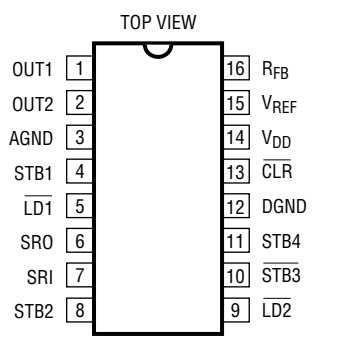


## ABSOLUTE MAXIMUM RATINGS

$V_{DD}$  to AGND .....  $-0.5V$  to  $7V$   
 $V_{DD}$  to DGND .....  $-0.5V$  to  $7V$   
 AGND to DGND .....  $V_{DD} + 0.5V$   
 DGND to AGND .....  $V_{DD} + 0.5V$   
 $V_{REF}$  to AGND, DGND .....  $\pm 25V$   
 $R_{FB}$  to AGND, DGND .....  $\pm 25V$   
 Digital Inputs to DGND .....  $-0.5V$  to  $V_{DD} + 0.5V$

$V_{OUT1}$ ,  $V_{OUT2}$  to AGND .....  $-0.5V$  to  $V_{DD} + 0.5V$   
 Maximum Junction Temperature .....  $150^{\circ}C$   
 Operating Temperature Range  
     LTC1595C/LTC1596C .....  $0^{\circ}C$  to  $70^{\circ}C$   
     LTC1595I/LTC1596I .....  $-40^{\circ}C$  to  $85^{\circ}C$   
 Storage Temperature Range .....  $-65^{\circ}C$  to  $150^{\circ}C$   
 Lead Temperature (Soldering, 10 sec) .....  $300^{\circ}C$

## PACKAGE/ORDER INFORMATION

 <p>             N8 PACKAGE 8-LEAD PDIP  <math>T_{JMAX} = 150^{\circ}C</math>, <math>\theta_{JA} = 130^{\circ}C/W</math> (N)  <math>T_{JMAX} = 150^{\circ}C</math>, <math>\theta_{JA} = 190^{\circ}C/W</math> (S)         </p>	ORDER PART NUMBER	 <p>             N PACKAGE 16-LEAD PDIP  <math>T_{JMAX} = 150^{\circ}C</math>, <math>\theta_{JA} = 100^{\circ}C/W</math> (N)  <math>T_{JMAX} = 150^{\circ}C</math>, <math>\theta_{JA} = 130^{\circ}C/W</math> (SW)         </p>	ORDER PART NUMBER
	LTC1595ACN8 LTC1595ACS8 LTC1595BCN8 LTC1595BCS8 LTC1595CCN8 LTC1595CCS8 LTC1595AIN8 LTC1595AIS8 LTC1595BIN8 LTC1595BIS8 LTC1595CIN8 LTC1595CIS8		LTC1596ACN LTC1596ACSW LTC1596BCN LTC1596BCSW LTC1596CCN LTC1596CCSW LTC1596AIN LTC1596AISW LTC1596BIN LTC1596BISW LTC1596CIN LTC1596CISW
	S8 PART MARKING		
	1595A    1595AI 1595B    1595BI 1595C    1595CI		

Consult factory for Military grade parts.

## ELECTRICAL CHARACTERISTICS

$V_{DD} = 5V \pm 10\%$ ,  $V_{REF} = 10V$ ,  $V_{OUT1} = V_{OUT2} = AGND = 0V$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		LTC1595A/96A			LTC1595B/96B			LTC1595C/96C			UNITS
				MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Accuracy													
	Resolution		●	16			16			16			Bits
	Monotonicity		●	16			16			15			Bits
INL	Integral Nonlinearity	(Note 1) T <sub>A</sub> = 25°C T <sub>MIN</sub> to T <sub>MAX</sub>	●	±0.25 ±1 ±0.35 ±1			±2 ±2			±4 ±4			LSB LSB
DNL	Differential Nonlinearity	T <sub>A</sub> = 25°C T <sub>MIN</sub> to T <sub>MAX</sub>	●	±0.2 ±1 ±0.2 ±1			±1 ±1			±2 ±2			LSB LSB
GE	Gain Error	(Note 2) T <sub>A</sub> = 25°C T <sub>MIN</sub> to T <sub>MAX</sub>	●	2 ±16 3 ±16			±16 ±32			±32 ±32			LSB LSB

## ELECTRICAL CHARACTERISTICS

$V_{DD} = 5V \pm 10\%$ ,  $V_{REF} = 10V$ ,  $V_{OUT1} = V_{OUT2} = AGND = 0V$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
	Gain Temperature Coefficient	(Note 3) $\Delta\text{Gain}/\Delta\text{Temperature}$	●	1	2	ppm/°C
$I_{LEAKAGE}$	OUT1 Leakage Current	(Note 4) $T_A = 25^\circ\text{C}$ $T_{MIN}$ to $T_{MAX}$	●		$\pm 3$ $\pm 15$	nA nA
	Zero-Scale Error	$T_A = 25^\circ\text{C}$ $T_{MIN}$ to $T_{MAX}$	●		$\pm 0.2$ $\pm 1$	LSB LSB
PSRR	Power Supply Rejection	$V_{DD} = 5V \pm 10\%$	●	$\pm 1$	$\pm 2$	LSB/V

### Reference Input

$R_{REF}$	$V_{REF}$ Input Resistance	(Note 5)	●	5	7	10	k $\Omega$
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### AC Performance

	Output Current Settling Time	(Notes 6, 7)		1		$\mu\text{s}$
	Midscale Glitch Impulse	Using LT1122 Op Amp, $C_{FEEDBACK} = 33\text{pF}$		1		nV-s
	Digital-to-Analog Glitch Impulse	Full-Scale Transition, $V_{REF} = 0V$ , Using LT1122 Op Amp, $C_{FEEDBACK} = 33\text{pF}$		2		nV-s
	Multiplying Feedthrough Error	$V_{REF} = \pm 10V$ , 10kHz Sine Wave		1		mV <sub>p-p</sub>
THD	Total Harmonic Distortion	(Note 8)		108		dB
	Equivalent DAC Thermal Noise Voltage Density	(Note 9) $f = 1\text{kHz}$		11		nV/ $\sqrt{\text{Hz}}$

### Analog Outputs (Note 3)

$C_{OUT}$	Output Capacitance (Note 3)	DAC Register Loaded to All 1s $C_{OUT1}$	●	115	130	pF
		DAC Register Loaded to All 0s $C_{OUT1}$	●	70	80	pF

### Digital Inputs

$V_{IH}$	Digital Input High Voltage		●	2.4		V
$V_{IL}$	Digital Input Low Voltage		●		0.8	V
$I_{IN}$	Digital Input Current		●	0.001	$\pm 1$	$\mu\text{A}$
$C_{IN}$	Digital Input Capacitance	(Note 3) $V_{IN} = 0V$	●		8	pF

### Digital Outputs: SRO (LTC1596)

$V_{OH}$	Digital Output High Voltage	$I_{OH} = 200\mu\text{A}$	●	4		V
$V_{OL}$	Digital Output Low Voltage	$I_{OL} = 1.6\text{mA}$	●		0.4	V

$V_{DD} = 5V \pm 10\%$ ,  $V_{REF} = 10V$ ,  $V_{OUT1} = GND = 0V$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
<b>Timing Characteristics (LTC1595)</b>						
$t_{DS}$	Serial Input to CLK Setup Time		●	30	5	ns
$t_{DH}$	Serial Input to CLK Hold Time		●	30	5	ns
$t_{SRI}$	Serial Input Data Pulse Width		●	60		ns
$t_{CH}$	Clock Pulse Width High		●	60		ns
$t_{CL}$	Clock Pulse Width Low		●	60		ns
$t_{LD}$	Load Pulse Width		●	60		ns
$t_{ASB}$	LSB Clocked into Input Register to DAC Register Load Time		●	0		ns

**ELECTRICAL CHARACTERISTICS**

$V_{DD} = 5V \pm 10\%$ ,  $V_{REF} = 10V$ ,  $V_{OUT1} = V_{OUT2} = AGND = 0V$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
<b>Timing Characteristics (LTC1596)</b>							
$t_{DS1}$	Serial Input to Strobe Setup Time	STB1 Used as the Strobe	●	30	5		ns
$t_{DS2}$		STB2 Used as the Strobe	●	20	-5		ns
$t_{DS3}$		STB3 Used as the Strobe	●	25	0		ns
$t_{DS4}$		STB4 Used as the Strobe	●	20	-5		ns
$t_{DH1}$	Serial Input to Strobe Hold Time	STB1 Used as the Strobe	●	30	5		ns
$t_{DH2}$		STB2 Used as the Strobe	●	40	15		ns
$t_{DH3}$		STB3 Used as the Strobe	●	35	10		ns
$t_{DH4}$		STB4 Used as the Strobe	●	40	15		ns
$t_{SRI}$	Serial Input Data Pulse Width		●	60			ns
$t_{STB1}$ to $t_{STB4}$	Strobe Pulse Width	(Note 10)	●	60			ns
$t_{\overline{STB1}}$ to $t_{\overline{STB4}}$	Strobe Pulse Width	(Note 11)	●	60			ns
$t_{LD1}, t_{LD2}$	LD Pulse Width		●	60			ns
$t_{ASB}$	LSB Strobed into Input Register to Load DAC Register Time		●	0			ns
$t_{CLR}$	Clear Pulse Width		●	100			ns
$t_{PD1}$	STB1 to SRO Propagation Delay	$C_L = 50pF$	●	30		150	ns
$t_{PD}$	STB2, STB3, STB4 to SRO Propagation Delay	$C_L = 50pF$	●	30		200	ns
<b>Power Supply</b>							
$V_{DD}$	Supply Voltage		●	4.5	5	5.5	V
$I_{DD}$	Supply Current	Digital Inputs = 0V or $V_{DD}$	●		1.5	10	$\mu A$

The ● denotes specifications which apply over the full operating temperature range.

**Note 1:**  $\pm 1LSB = \pm 0.0015\%$  of full scale =  $\pm 15.3ppm$  of full scale.

**Note 2:** Using internal feedback resistor.

**Note 3:** Guaranteed by design, not subject to test.

**Note 4:**  $I_{OUT1}$  with DAC register loaded with all 0s.

**Note 5:** Typical temperature coefficient is 100ppm/C.

**Note 6:**  $OUT1$  load =  $100\Omega$  in parallel with 13pF.

**Note 7:** To 0.0015% for a full-scale change, measured from the falling edge of LD1, LD2 or LD.

**Note 8:**  $V_{REF} = 6V_{RMS}$  at 1kHz. DAC register loaded with all 1s; op amp = LT1007.

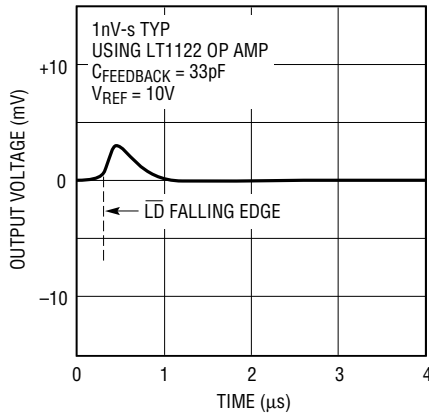
**Note 9:** Calculation from  $e_n = \sqrt{4kTRB}$  where: k = Boltzmann constant (J/°K); R = resistance ( $\Omega$ ); T = temperature (°K); B = bandwidth (Hz).

**Note 10:** Minimum high time for STB1, STB2, STB4. Minimum low time for STB3.

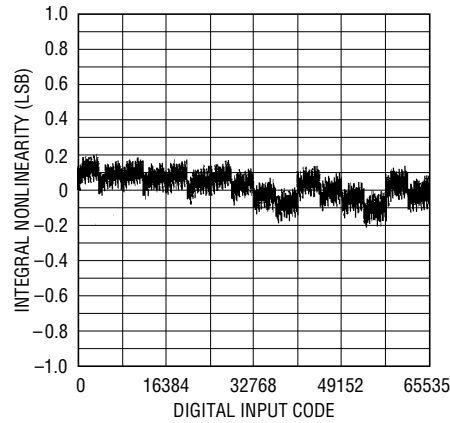
**Note 11:** Minimum low time for STB1, STB2, STB4. Minimum high time for STB3.

# TYPICAL PERFORMANCE CHARACTERISTICS

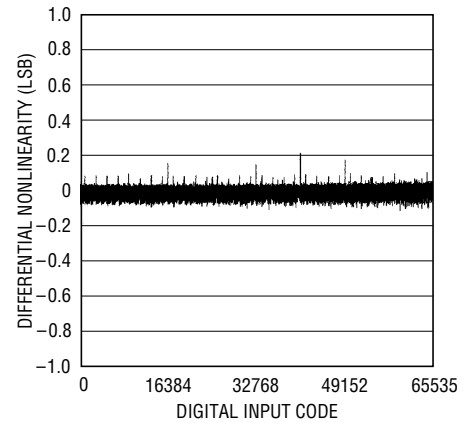
### Midscale Glitch Impulse



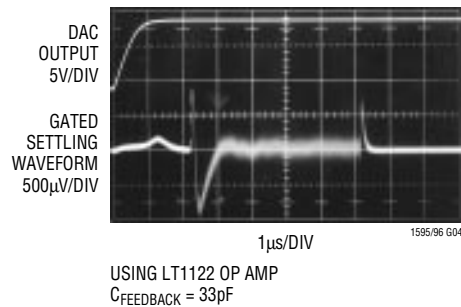
### Integral Nonlinearity (INL)



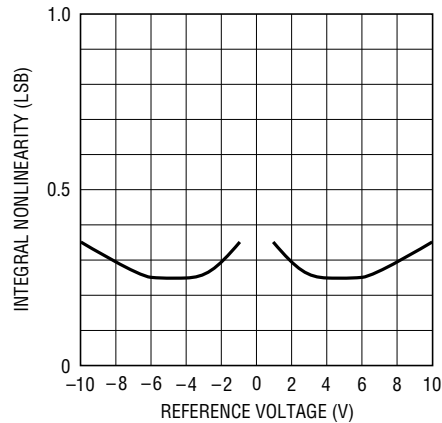
### Differential Nonlinearity (DNL)



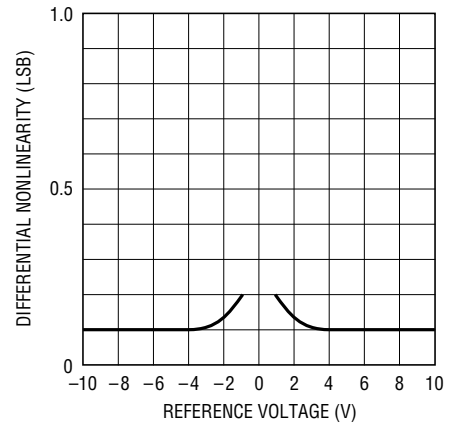
### Full-Scale Settling Waveform



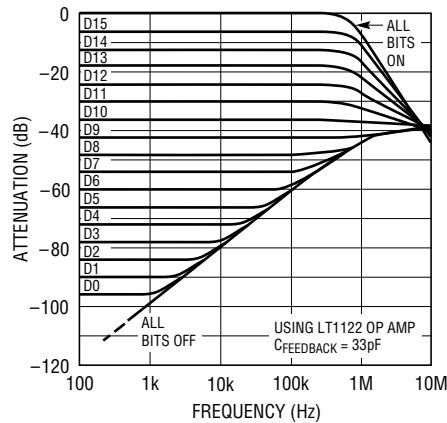
### Integral Nonlinearity vs Reference Voltage



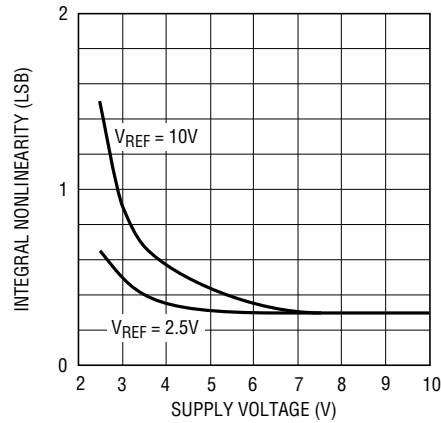
### Differential Nonlinearity vs Reference Voltage



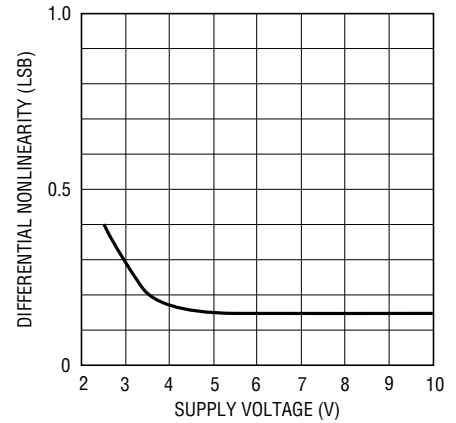
### Multiplying Mode Frequency Response vs Digital Code



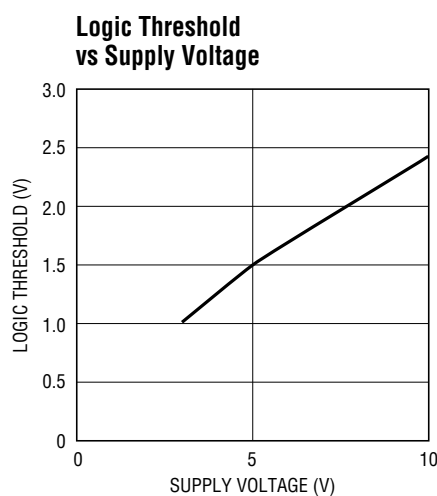
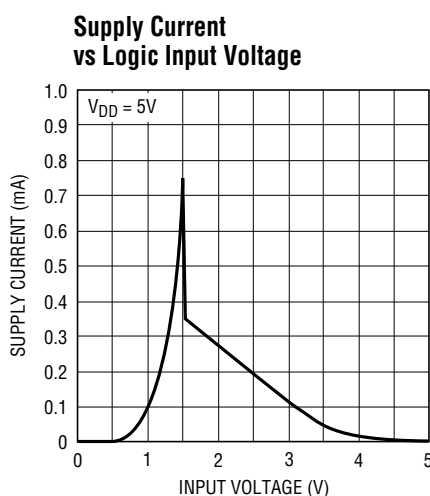
### Integral Nonlinearity vs Supply Voltage



### Differential Nonlinearity vs Supply Voltage



## TYPICAL PERFORMANCE CHARACTERISTICS



## PIN FUNCTIONS

## LTC1595

**V<sub>REF</sub> (Pin 1):** Reference Input.

**R<sub>FB</sub> (Pin 2):** Feedback Resistor. Normally tied to the output of the current to voltage converter op amp.

**OUT1 (Pin 3):** Current Output Pin. Tie to inverting input of current to voltage converter op amp.

**GND (Pin 4):** Ground Pin.

**LD (Pin 5):** The Serial Interface Load Control Input. When LD is pulled low, data is loaded from the shift register into the DAC register, updating the DAC output.

**SRI (Pin 6):** The Serial Data Input. Data on the SRI pin is latched into the shift register on the rising edge of the serial clock. Data is loaded MSB first.

**CLK (Pin 7):** The Serial Interface Clock Input.

**V<sub>DD</sub> (Pin 8):** The Positive Supply Input.  $4.5V \leq V_{DD} \leq 5.5V$ . Requires a bypass capacitor to ground.

## LTC1596

**OUT1 (Pin 1):** True Current Output Pin. Tie to inverting input of current to voltage converter op amp.

**OUT2 (Pin 2):** Complement Current Output Pin. Tie to analog ground.

**AGND (Pin 3):** Analog Ground Pin.

**STB1, STB2, STB3, STB4 (Pins 4, 8, 10, 11):** Serial Interface Clock Inputs. STB1, STB2 and STB4 are rising edge triggered inputs. STB3 is a falling edge triggered input (see Truth Tables).

**LD1, LD2 (Pins 5, 9):** Serial Interface Load Control Inputs. When LD1 and LD2 are pulled low, data is loaded from the shift register into the DAC register, updating the DAC output (see Truth Tables).

**SRO (Pin 6):** The Output of the Shift Register. Becomes valid on the active edge of the serial clock.

**SRI (Pin 7):** The Serial Data Input. Data on the SRI pin is latched into the shift register on the active edge of the serial clock. Data is loaded MSB first.

**DGND (Pin 12):** Digital Ground Pin.

**CLR (Pin 13):** The Clear Pin for the DAC. Clears DAC to zero scale when pulled low. This pin should be tied to V<sub>DD</sub> for normal operation.

**V<sub>DD</sub> (Pin 14):** The Positive Supply Input.  $4.5V \leq V_{DD} \leq 5.5V$ . Requires a bypass capacitor to ground.

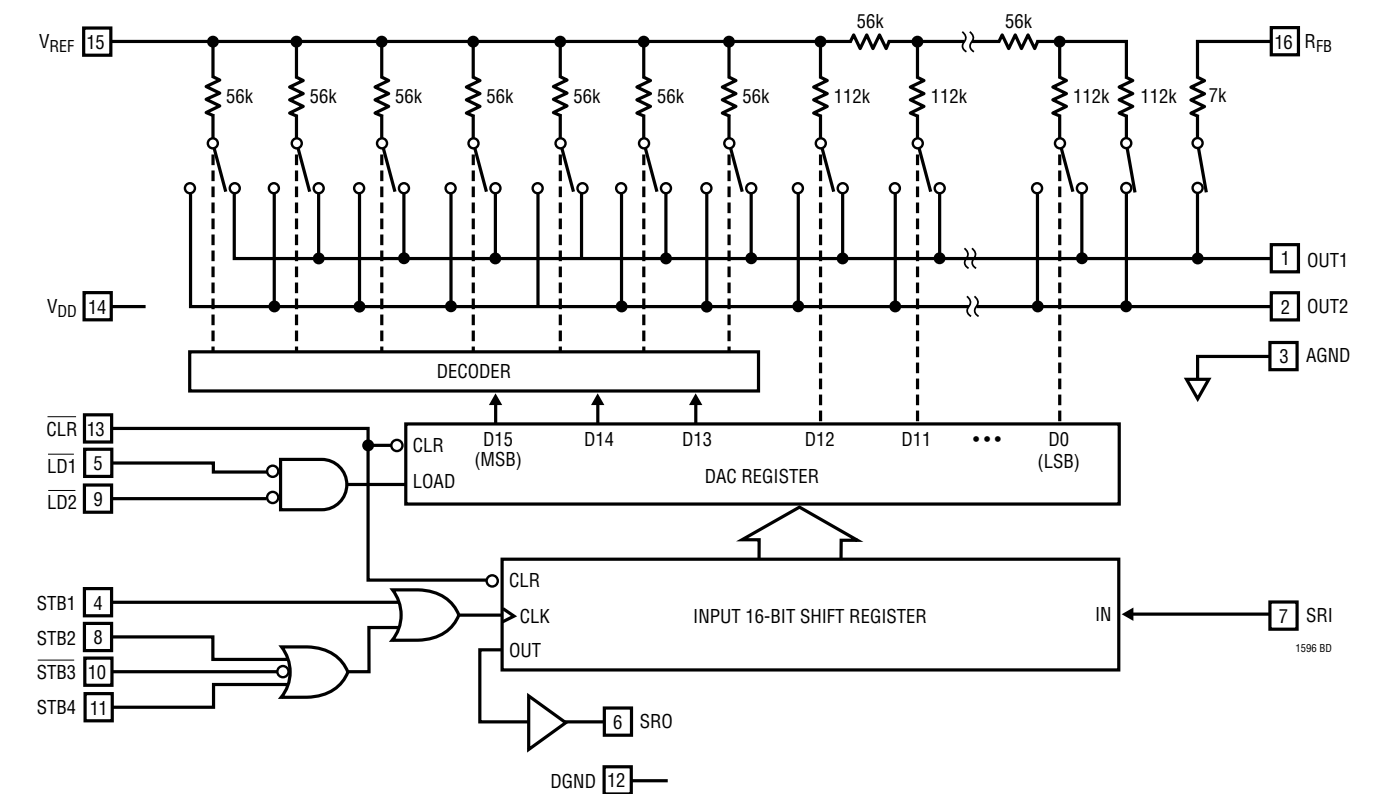
**V<sub>REF</sub> (Pin 15):** Reference Input.

**R<sub>FB</sub> (Pin 16):** Feedback Resistor. Normally tied to the output of the current to voltage converter op amp.

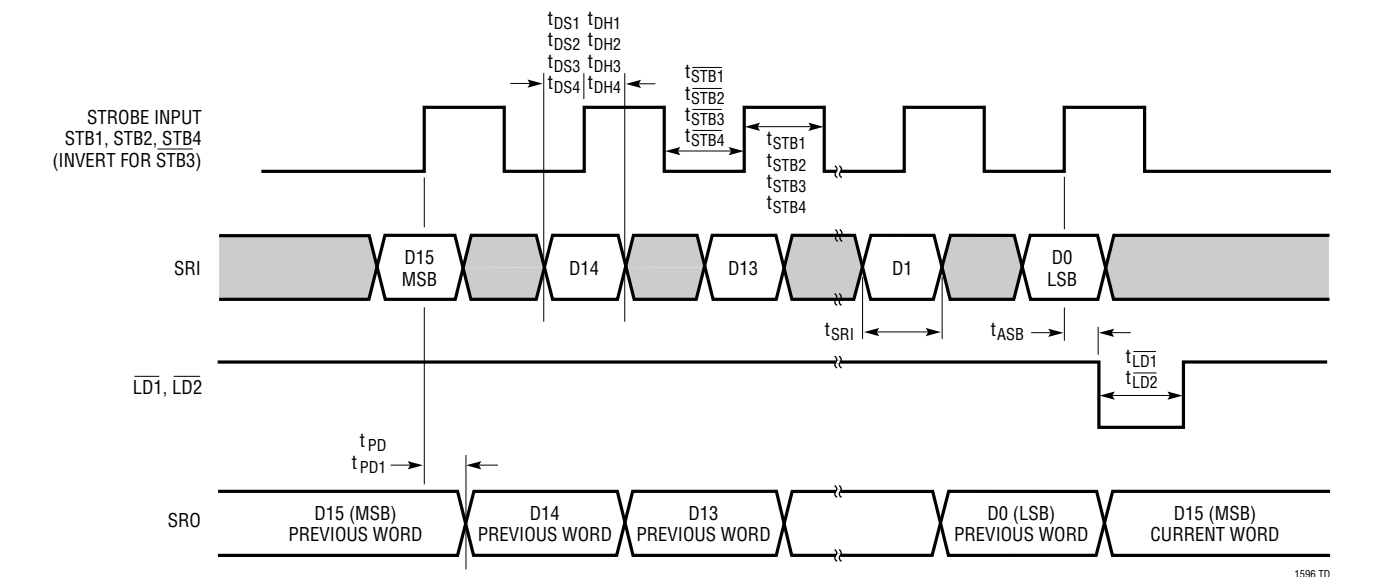


# LTC1595/LTC1596

## BLOCK DIAGRAM (LTC1596)



## TIMING DIAGRAM (LTC1596)





## APPLICATIONS INFORMATION

### Description

The LTC1595/LTC1596 are 16-bit multiplying DACs which have serial inputs and current outputs. They use precision R/2R technology to provide exceptional linearity and stability. The devices operate from a single 5V supply and provide  $\pm 10\text{V}$  reference input and voltage output ranges when used with an external op amp. These devices have a proprietary deglitcher that reduces glitch impulse to 1nV-s over a 0V to 10V output range.

### Serial I/O

The LTC1595/LTC1596 have SPI/MICROWIRE compatible serial ports that accept 16-bit serial words. Data is accepted MSB first and loaded with a load pin.

The 8-pin LTC1595 has a 3-wire interface. Data is shifted into the SRI data input on the rising edge of the CLK pin. At the end of the data transfer, data is loaded into the DAC register by pulling the LD pin low (see LTC1595 Timing Diagram).

The 16-pin LTC1596 can operate in identical fashion to the LTC1595 but offers additional pins for flexibility. Four clock pins are available STB1, STB2, STB3 and STB4. STB1, STB2 and STB4 operate like the CLK pin of the LTC1595, capturing data on their rising edges. STB3 captures data on its falling edge (see Truth Table 1).

The LTC1596 has two load pins,  $\overline{\text{LD1}}$  and  $\overline{\text{LD2}}$ . To load data, both pins must be taken low. If one of the pins is grounded, the other pin will operate identically to LTC1595's  $\overline{\text{LD}}$  pin. An asynchronous clear input ( $\overline{\text{CLR}}$ ) resets the LTC1596 to zero scale when pulled low (see Truth Table 2).

The LTC1596 also has a data output pin SRO that can be connected to the SRI input of another DAC to daisy-chain multiple DACs on one 3-wire interface (see LTC1596 Timing Diagram).

### Unipolar (2-Quadrant Multiplying) Mode ( $V_{\text{OUT}} = 0\text{V}$ to $-V_{\text{REF}}$ )

The LTC1595/LTC1596 can be used with a single op amp to provide 2-quadrant multiplying operation as shown in Figure 1. With a fixed  $-10\text{V}$  reference, the circuits shown give a precision unipolar 0V to 10V output swing.

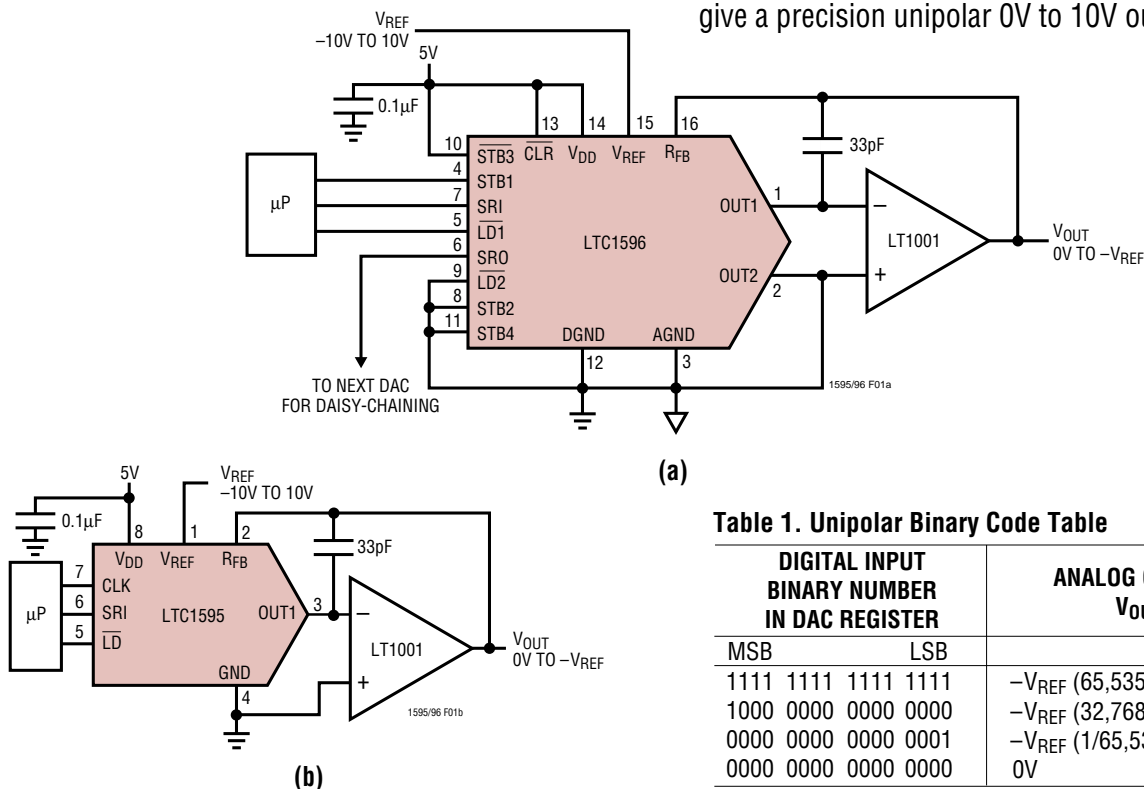


Table 1. Unipolar Binary Code Table

DIGITAL INPUT BINARY NUMBER IN DAC REGISTER				ANALOG OUTPUT $V_{\text{OUT}}$
MSB		LSB		
1111	1111	1111	1111	$-V_{\text{REF}}$ (65,535/65,536)
1000	0000	0000	0000	$-V_{\text{REF}}$ (32,768/65,536) = $-V_{\text{REF}}/2$
0000	0000	0000	0001	$-V_{\text{REF}}$ (1/65,536)
0000	0000	0000	0000	0V

Figure 1. Unipolar Operation (2-Quadrant Multiplication)  $V_{\text{OUT}} = 0\text{V}$  to  $-V_{\text{REF}}$

APPLICATIONS INFORMATION

Bipolar (4-Quadrant Multiplying) Mode  
( $V_{OUT} = -V_{REF}$  to  $V_{REF}$ )

The LTC1595/LTC1596 can be used with a dual op amp and three external resistors to provide 4-quadrant multiplying operation as shown in Figure 2. With a fixed 10V reference, the circuits shown give a precision bipolar  $-10V$  to  $10V$  output swing.

Op Amp Selection

Because of the extremely high accuracy of the 16-bit LTC1595/LTC1596, thought should be given to op amp selection in order to achieve the exceptional performance of which the part is capable. Fortunately, the sensitivity of INL and DNL to op amp offset has been greatly reduced compared to previous generations of multiplying DACs.

Op amp offset will contribute mostly to output offset and gain and will have minimal effect on INL and DNL. For

example, a  $500\mu V$  op amp offset will cause about 0.55LSB INL degradation and 0.15LSB DNL degradation with a 10V full-scale range. The main effects of op amp offset will be a degradation of zero-scale error equal to the op amp offset, and a degradation of full-scale error equal to twice the op amp offset. For example, the same  $500\mu V$  op amp offset will cause a 3.3LSB zero-scale error and a 6.5LSB full-scale error with a 10V full-scale range.

Op amp input bias current ( $I_{BIAS}$ ) contributes only a zero-scale error equal to  $I_{BIAS}(R_{FB}) = I_{BIAS}(R_{REF}) = I_{BIAS}(7k)$ .

Grounding

As with any high resolution converter, clean grounding is important. A low impedance analog ground plane and star grounding should be used.  $I_{OUT2}$  (LTC1596) and GND (LTC1595) must be tied to the star ground with as low a resistance as possible.

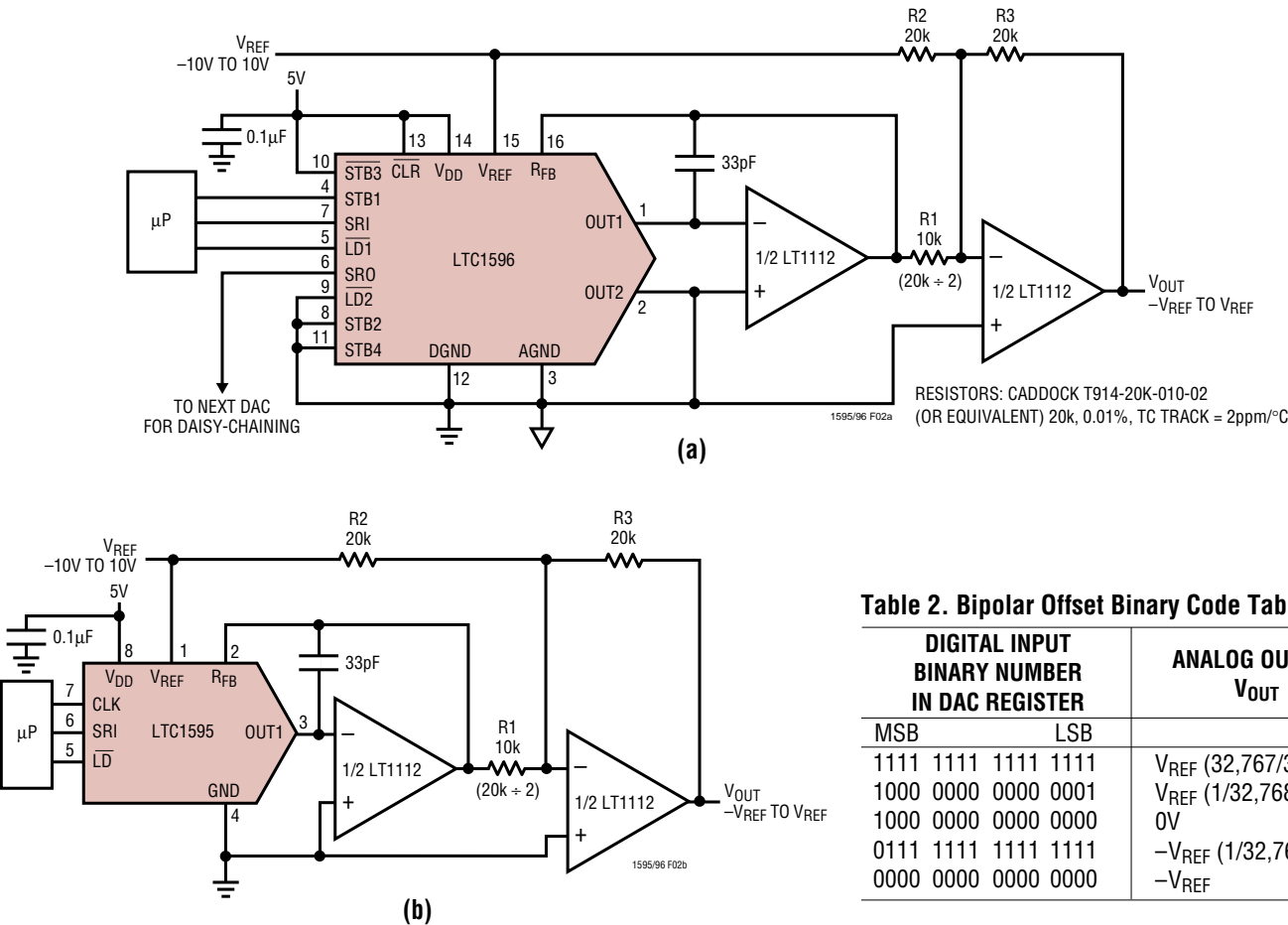
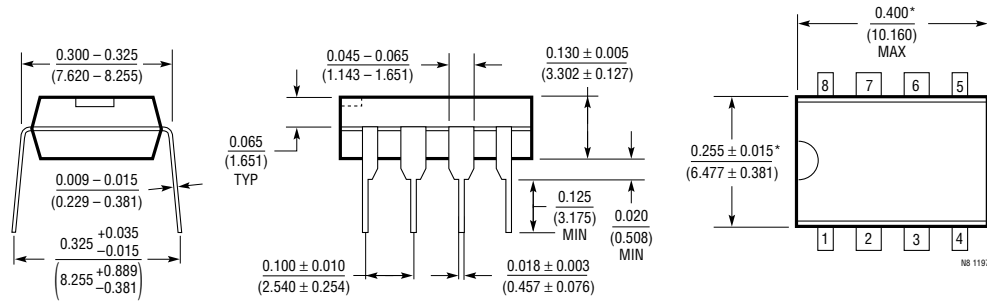


Figure 2. Bipolar Operation (4-Quadrant Multiplication)  $V_{OUT} = -V_{REF}$  to  $V_{REF}$

# PACKAGE DESCRIPTION

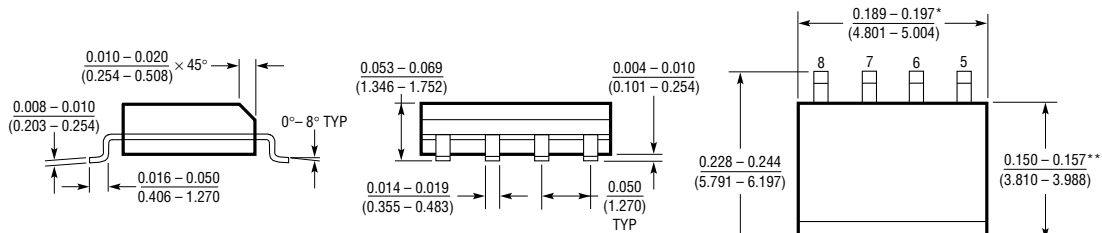
Dimensions in inches (millimeters) unless otherwise noted.

## N8 Package 8-Lead PDIP (Narrow 0.300) (LTC DWG # 05-08-1510)



\*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.  
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 INCH (0.254mm)

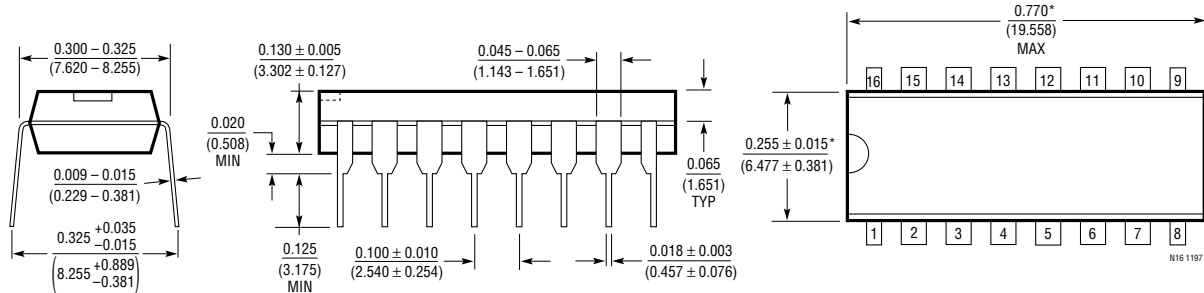
## S8 Package 8-Lead Plastic Small Outline (Narrow 0.150) (LTC DWG # 05-08-1610)



\*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

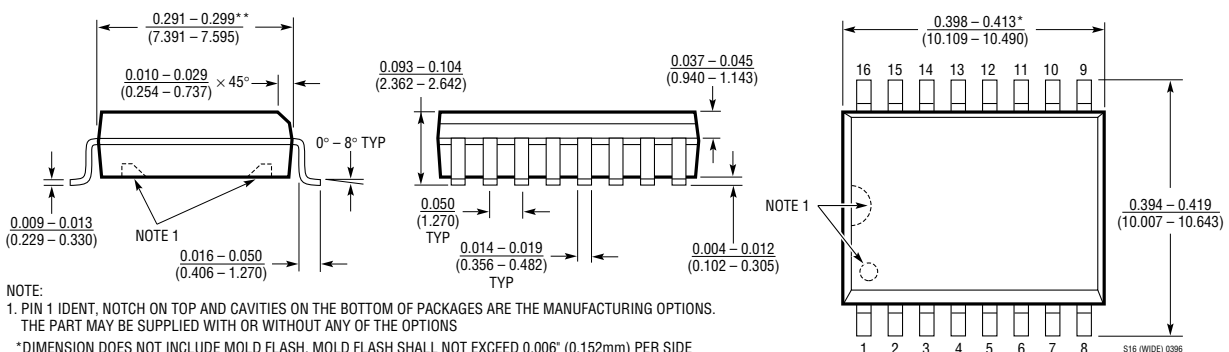
\*\*DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

## N Package 16-Lead PDIP (Narrow 0.300) (LTC DWG # 05-08-1510)



\*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.  
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 INCH (0.254mm)

## SW Package 16-Lead Plastic Small Outline (Wide 0.300) (LTC DWG # 05-08-1620)



NOTE:

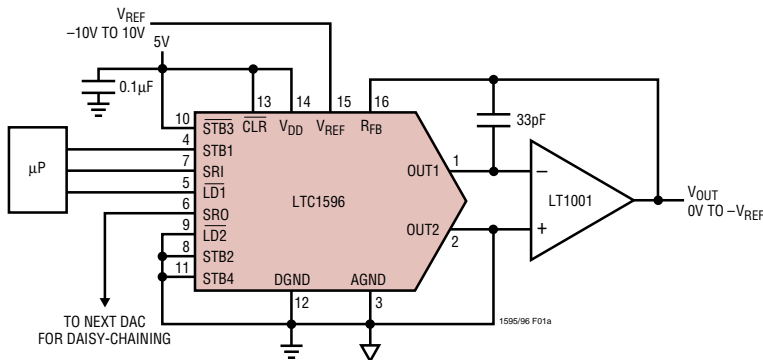
1. PIN 1 IDENT. NOTCH ON TOP AND CAVITIES ON THE BOTTOM OF PACKAGES ARE THE MANUFACTURING OPTIONS. THE PART MAY BE SUPPLIED WITH OR WITHOUT ANY OF THE OPTIONS

\*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

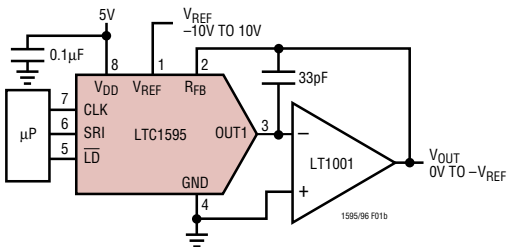
\*\*DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

TYPICAL APPLICATIONS

Unipolar Operation (2-Quadrant Multiplication)  $V_{OUT} = 0V$  to  $-V_{REF}$

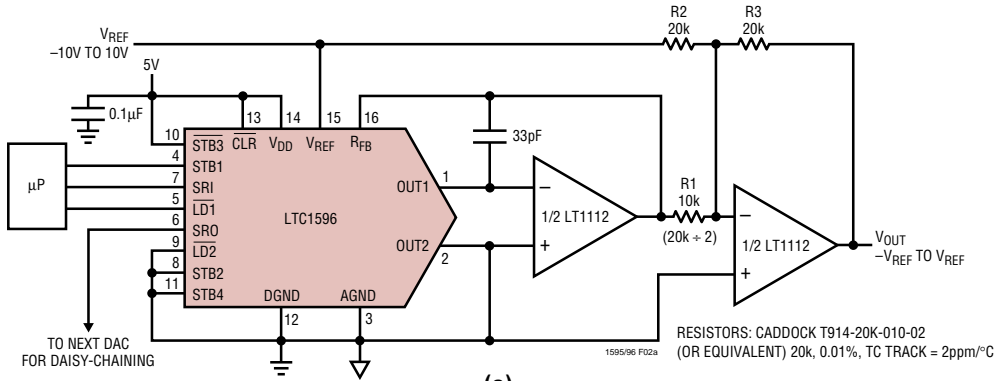


(a)

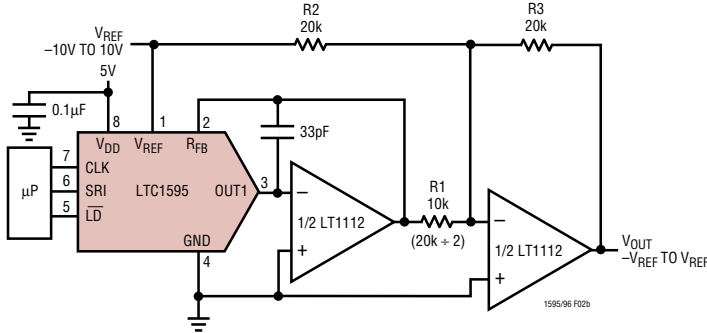


(b)

Bipolar Operation (4-Quadrant Multiplication)  $V_{OUT} = -V_{REF}$  to  $V_{REF}$



(a)



(b)

RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LTC1590	Dual Serial I/O Multiplying $I_{OUT}$ 12-Bit DAC	16-Pin SO and PDIP, SPI Interface
LTC7541A	Parallel I/O Multiplying $I_{OUT}$ 12-Bit DAC	12-Bit Wide Parallel Input
LTC7543/LTC8143	Serial I/O Multiplying $I_{OUT}$ 12-Bit DACs	Clear Pin and Serial Data Output (LTC8143)
LTC7545A	Parallel I/O Multiplying $I_{OUT}$ 12-Bit DAC	12-Bit Wide Latched Parallel Input
LTC8043	Serial I/O Multiplying $I_{OUT}$ 12-Bit DAC	8-Pin SO and PDIP