

### FEATURES

- 16-bit resolution AD5545**
- 14-bit resolution AD5555**
- ±1 LSB DNL monotonic**
- ±2 LSB INL AD5545**
- 2 mA full-scale current ±20%, with  $V_{REF} = 10\text{ V}$**
- 0.5  $\mu\text{s}$  settling time**
- 2Q multiplying reference-input 4 MHz BW**
- Zero or midscale power-up preset**
- Zero or midscale dynamic reset**
- 3-wire interface**
- Compact TSSOP-16 package**

### APPLICATIONS

- Automatic test equipment**
- Instrumentation**
- Digitally controlled calibration**
- Industrial control PLCs**
- Programmable attenuator**

### PRODUCT OVERVIEW

The AD5545/AD5555 are 16-bit/14-bit, current-output, digital-to-analog converters designed to operate from a single 5 V supply with bipolar output up to  $\pm 15\text{ V}$  capability.

An external reference is needed to establish the full-scale output-current. An internal feedback resistor ( $R_{FB}$ ) enhances the resistance and temperature tracking when combined with an external op amp to complete the I-to-V conversion.

A serial data interface offers high speed, 3-wire microcontroller compatible inputs using serial data in (SDI), clock (CLK), and chip select ( $\overline{CS}$ ). Additional  $\overline{LDAC}$  function allows simultaneous update operation. The internal reset logic allows power-on preset and dynamic reset at either zero or midscale, depending on the state of the MSB pin.

The AD5545/AD5555 are packaged in the compact TSSOP-16 package and can be operated from  $-40^\circ\text{C}$  to  $+85^\circ\text{C}$ .

### FUNCTIONAL BLOCK DIAGRAM

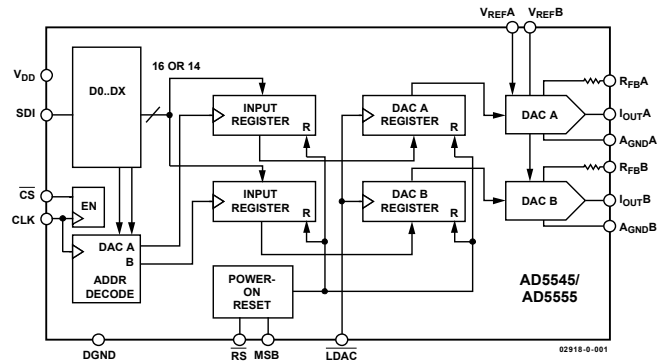


Figure 1.

### Rev. 0

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## REVISION HISTORY

Revision 0: Initial Version

## AD5545/AD5555—ELECTRICAL CHARACTERISTICS

Table 1.  $V_{DD} = 5\text{ V} \pm 10\%$ ,  $I_{OUT} = \text{Virtual GND}$ ,  $GND = 0\text{ V}$ ,  $V_{REF} = 10\text{ V}$ ,  $T_A = \text{Full Operating Temperature Range}$ , unless otherwise noted.

Parameter	Symbol	Conditions	5 V $\pm$ 10%	Units
<b>STATIC PERFORMANCE<sup>1</sup></b>				
Resolution	N	AD5545, 1 LSB = $V_{REF}/2^{16} = 153\ \mu\text{V}$ when $V_{REF} = 10\text{ V}$	16	Bits
Resolution	N	AD5555, 1 LSB = $V_{REF}/2^{14} = 610\ \mu\text{V}$ when $V_{REF} = 10\text{ V}$	14	Bits
Relative Accuracy	INL	AD5545	$\pm 2$	LSB max
Relative Accuracy	INL	AD5555	$\pm 1$	LSB max
Differential Nonlinearity	DNL	Monotonic	$\pm 1$	LSB max
Output Leakage Current	$I_{OUT}$	Data = 0x0000, $T_A = 25^\circ\text{C}$	10	nA max
Output Leakage Current	$I_{OUT}$	Data = 0x0000, $T_A = T_A \text{ Max}$	20	nA max
Full-Scale Gain Error	$G_{FSE}$	Data = Full Scale	$\pm 1/\pm 4$	mV typ/max
Full-Scale Temperature Coefficient <sup>2</sup>	$TCV_{FS}$		1	ppm/ $^\circ\text{C}$ typ
<b>REFERENCE INPUT</b>				
$V_{REF}$ Range	$V_{REF}$		-12/+12	V min/V max
Input Resistance	$R_{REF}$		5	k $\Omega$ typ <sup>3</sup>
Input Capacitance <sup>2</sup>	$C_{REF}$		5	pF typ
<b>ANALOG OUTPUT</b>				
Output Current	$I_{OUT}$	Data = Full Scale	2	mA typ
Output Capacitance <sup>2</sup>	$C_{OUT}$	Code Dependent	200	pF typ
<b>LOGIC INPUTS AND OUTPUT</b>				
Logic Input Low Voltage	$V_{IL}$		0.8	V max
Logic Input High Voltage	$V_{IH}$		2.4	V min
Input Leakage Current	$I_{IL}$		10	$\mu\text{A}$ max
Input Capacitance <sup>2</sup>	$C_{IL}$		10	pF max
<b>INTERFACE TIMING<sup>2,4</sup></b>				
Clock Input Frequency	$f_{CLK}$		50	MHz
Clock Width High	$t_{CH}$		10	ns min
Clock Width Low	$t_{CL}$		10	ns min
$\overline{\text{CS}}$ to Clock Setup	$t_{CSS}$		0	ns min
Clock to $\overline{\text{CS}}$ Hold	$t_{CSH}$		10	ns min
Data Setup	$t_{DS}$		5	ns min
Data Hold	$t_{DH}$		10	ns min
$\overline{\text{LDAC}}$ Setup	$t_{LDS}$		5	ns min
Hold	$t_{LDH}$		10	ns min
$\overline{\text{LDAC}}$ Width	$t_{LDAC}$		10	ns min
<b>SUPPLY CHARACTERISTICS</b>				
Power Supply Range	$V_{DD}$ Range		4.5/5.5	V min/V max
Positive Supply Current	$I_{DD}$	Logic Inputs = 0 V	10	$\mu\text{A}$ max
Power Dissipation	$P_{DISS}$	Logic Inputs = 0 V	0.055	mW max
Power Supply Sensitivity	PSS	$\Delta V_{DD} = \pm 5\%$	0.006	%/% max

<sup>1</sup> All static performance tests (except  $I_{OUT}$ ) are performed in a closed-loop system using an external precision OP1177 I-to-V converter amplifier. The AD5545  $R_{FB}$  terminal is tied to the amplifier output. Typical values represent average readings measured at  $25^\circ\text{C}$ .

<sup>2</sup> These parameters are guaranteed by design and not subject to production testing.

<sup>3</sup> All ac characteristic tests are performed in a closed-loop system using an O42 I-to-V converter amplifier.

<sup>4</sup> All input control signals are specified with  $t_R = t_F = 2.5\text{ ns}$  (10% to 90% of 3 V) and timed from a voltage level of 1.5 V.

# AD5545/AD5555

Parameter	Symbol	Conditions	5 V ± 10%	Units
AC CHARACTERISTICS				
Output Voltage Setting Time	$t_s$	To ±0.1% Full Scale, Data = Zero Scale to Full Scale to Zero Scale	0.5	μs typ
Reference Multiplying BW	BW	$V_{REF} = 5$ V p-p, Data = Full Scale	4	MHz typ
DAC Glitch Impulse	Q	$V_{REF} = 0$ V, Data = Zero Scale to Midscale to Zero Scale	7	nV-s typ
Feedthrough Error	$V_{OUT}/V_{REF}$	Data = Zero Scale, $V_{REF} = 100$ mV rms, $f = 1$ kHz, Same Channel	-65	dB
Digital Feedthrough	Q	$\overline{CS} =$ Logic High and $f_{CLK} = 1$ MHz	7	nV-s typ
Total Harmonic Distortion	THD	$V_{REF} = 5$ V p-p, Data = Full Scale, $f = 1$ kHz to 10 kHz	-85	dB typ
Analog Crosstalk	$C_{TA}$	$V_{REFB} = 0$ V, Measure $V_{OUTB}$ with $V_{REFA} = 5$ V p-p Sine Wave, Data = Full Scale, $f = 1$ kHz to 10 kHz	-95	dB typ
Output Spot Noise Voltage	$e_N$	$f = 1$ kHz, BW = 1 Hz	12	nV/√Hz

## ABSOLUTE MAXIMUM RATINGS

Table 2. AD5545/AD5555 Absolute Maximum Ratings

Parameter	Rating
V <sub>DD</sub> to GND	-0.3 V, +8 V
V <sub>REF</sub> to GND	-18 V, +18 V
Logic Inputs to GND	-0.3 V, +8 V
V(I <sub>OUT</sub> ) to GND	-0.3 V, V <sub>DD</sub> + 0.3 V
Input Current to Any Pin except Supplies	±50 mA
Package Power Dissipation	(T <sub>J max</sub> - T <sub>A</sub> )/θ <sub>JA</sub>
Thermal Resistance θ <sub>JA</sub>	
16-Lead TSSOP	150°C/W
Maximum Junction Temperature (T <sub>J max</sub> )	150°C
Operating Temperature Range	-40°C to +85°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature	
RU-16 (Vapor Phase, 60 sec)	215°C
RU-16 (Infrared, 15 sec)	220°C

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## PIN CONFIGURATION AND FUNCTIONAL DESCRIPTIONS

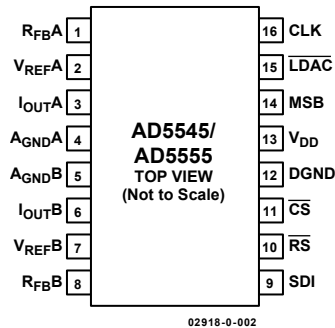


Figure 2. 16-Lead TSSOP

Table 3. Pin Function Descriptions—16-Lead TSSOP

Pin No.	Mnemonic	Function
1	R <sub>FBA</sub>	Establish voltage output for DAC A by connecting to external amplifier output.
2	V <sub>REF A</sub>	DAC A Reference Voltage Input Terminal. Establishes DAC A full-scale output voltage. Pin can be tied to V <sub>DD</sub> pin.
3	I <sub>OUT A</sub>	DAC A Current Output.
4	A <sub>GND A</sub>	DAC A Analog Ground.
5	A <sub>GND B</sub>	DAC B Analog Ground.
6	I <sub>OUT B</sub>	DAC B Current Output.
7	V <sub>REF B</sub>	DAC B Reference Voltage Input Terminal. Establishes DAC B full-scale output voltage. Pin can be tied to V <sub>DD</sub> pin.
8	R <sub>F B</sub>	Establish voltage output for DAC B by connecting to external amplifier output.
9	SDI	Serial Data Input. Input data loads directly into the shift register.
10	$\overline{\text{RS}}$	RESET Pin, Active Low Input. Input registers and DAC registers are set to all 0s or midscale. Register Data = 0x0000 when MSB = 0. Register Data = 0x8000 for AD5545 and 0x2000 for AD5555 when MSB = 1.
11	$\overline{\text{CS}}$	Chip Select, Active Low Input. Disables shift register loading when high. Transfers <u>serial</u> register data to the input register when $\overline{\text{CS}}/\overline{\text{LDAC}}$ returns high. This does not affect <u>LDAC</u> operation.
12	DGND	Digital Ground Pin.
13	V <sub>DD</sub>	Positive Power Supply Input. Specified range of operation 5 V ± 10% or 3 V ± 10%.
14	MSB	MSB bit sets output to either 0 or midscale during a RESET pulse ( $\overline{\text{RS}}$ ) or at system power-on. Output equals zero scale when MSB = 0 and midscale when MSB = 1. MSB pin can also be tied permanently to ground or V <sub>DD</sub> .
15	$\overline{\text{LDAC}}$	Load DAC Register Strobe, Level Sensitive Active Low. Transfers all input register data to DAC registers. Asynchronous active low input. See Table 4 and Table 5 for operation.
16	CLK	Clock Input. Positive edge clocks data into shift register.

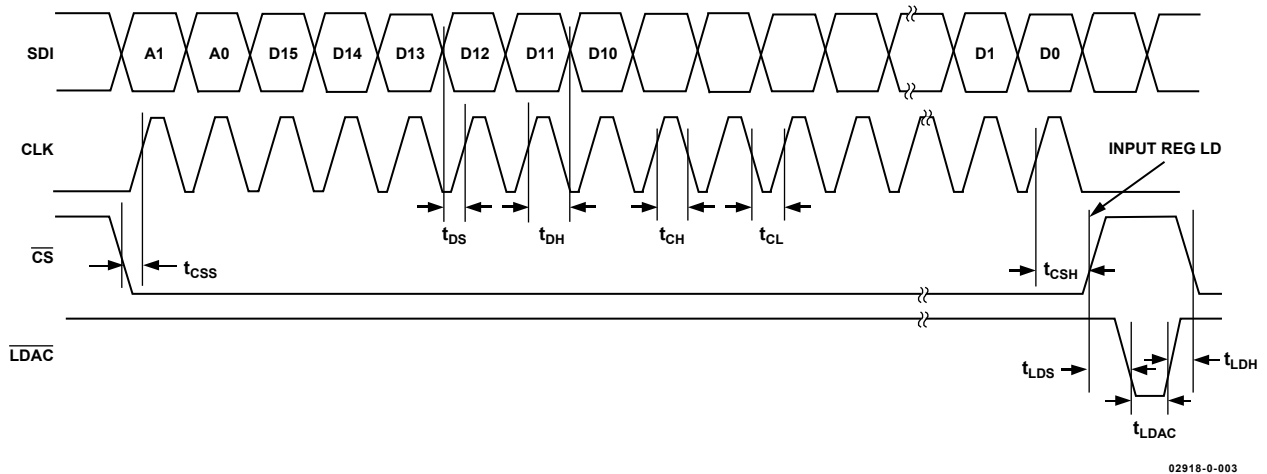


Figure 3. AD5545 18-Bit Data Word Timing Diagram

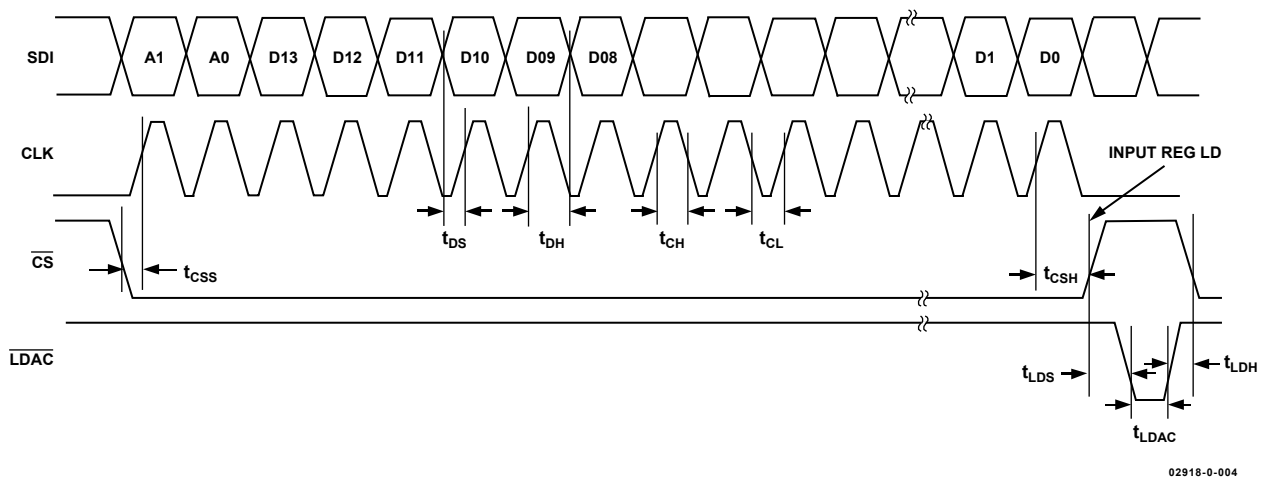


Figure 4. AD5555 16-Bit Data Word Timing Diagram

Table 4. AD5545 Control Logic Truth Table

CS	CLK	LDAC	RS	MSB	Serial Shift Register Function	Input Register Function	DAC Register
H	X	H	H	X	No Effect	Latched	Latched
L	L	H	H	X	No Effect	Latched	Latched
L	↑+	H	H	X	Shift Register Data Advanced One Bit	Latched	Latched
L	H	H	H	X	No Effect	Latched	Latched
↑+	L	H	H	X	No Effect	Selected DAC Updated with Current SR Current	Latched
H	X	L	H	X	No Effect	Latched	Transparent
H	X	H	H	X	No Effect	Latched	Latched
H	X	↑+	H	X	No Effect	Latched	Latched
H	X	H	L	0	No Effect	Latched Data = 0x0000	Latched Data = 0x0000
H	X	H	L	H	No Effect	Latched Data = 0x8000	Latched Data = 0x8000

NOTES

1. SR = Shift Register, ↑+ = Positive Logic Transition, and X = Don't Care.
2. At power-on, both the input register and the DAC register are loaded with all 0s.

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**Table 5. AD5555 Control Logic Truth Table**

CS	CLK	LDAC	RS	MSB	Serial Shift Register Function	Input Register Function	DAC Register
H	X	H	H	X	No Effect	Latched	Latched
L	L	H	H	X	No Effect	Latched	Latched
L	↑+	H	H	X	Shift Register Data Advanced One Bit	Latched	Latched
L	H	H	H	X	No Effect	Latched	Latched
↑+	L	H	H	X	No Effect	Selected DAC Updated with Current SR Current	Latched
H	X	L	H	X	No Effect	Latched	Transparent
H	X	H	H	X	No Effect	Latched	Latched
H	X	↑+	H	X	No Effect	Latched	Latched
H	X	H	L	0	No Effect	Latched Data = 0x0000	Latched Data = 0x0000
H	X	H	L	H	No Effect	Latched Data = 0x2000	Latched Data = 0x2000

**NOTES**

1. SR = Shift Register, ↑+ = Positive Logic Transition, and X = Don't Care.
2. At power-on, both the input register and the DAC register are loaded with all 0s.

**Table 6. AD5545 Serial Input Register Data Format, Data Is Loaded in the MSB-First Format**

	MSB																	LSB
Bit Position	B17	B16	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
Data Word	A1	A0	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0

Note that only the last 18 bits of data clocked into the serial register (Address + Data) are inspected when the  $\overline{CS}$  line's positive edge returns to logic high. At this point, an internally generated load strobe transfers the serial register data contents (Bits D15–D0) to the decoded DAC input register address determined by Bits A1 and A0. Any extra bits clocked into the AD5545 shift register are ignored; only the last 18 bits clocked in are used. If double-buffered data is not needed, the  $\overline{LDAC}$  pin can be tied logic low to disable the DAC registers.

**Table 7. AD5555 Serial Input Register Data Format, Data Is Loaded in the MSB-First Format**

	MSB																	LSB
Bit Position	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0		
Data Word	A1	A0	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0		

Note that only the last 16 bits of data clocked into the serial register (Address + Data) are inspected when the  $\overline{CS}$  line's positive edge returns to logic high. At this point, an internally generated load strobe transfers the serial register data contents (Bits D13–D0) to the decoded DAC input register address determined by Bits A1 and A0. Any extra bits clocked into the AD5555 shift register are ignored; only the last 16 bits clocked in are used. If double-buffered data is not needed, the  $\overline{LDAC}$  pin can be tied logic low to disable the DAC registers.

**Table 8. Address Decode**

A1	A0	DAC Decoded
0	0	None
0	1	DAC A
1	0	DAC B
1	1	DAC A and DAC B



# TYPICAL PERFORMANCE CHARACTERISTICS

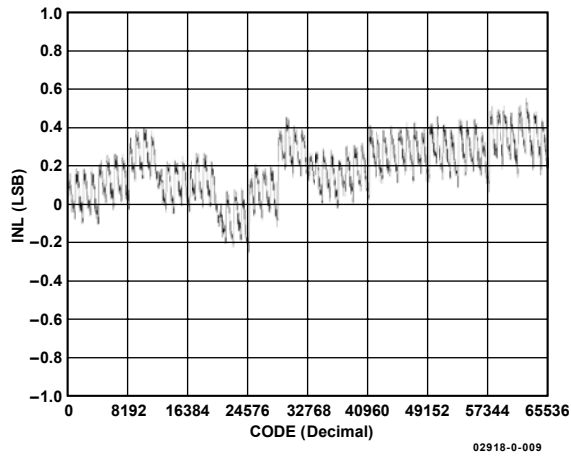


Figure 5. AD5545 Integral Nonlinearity Error

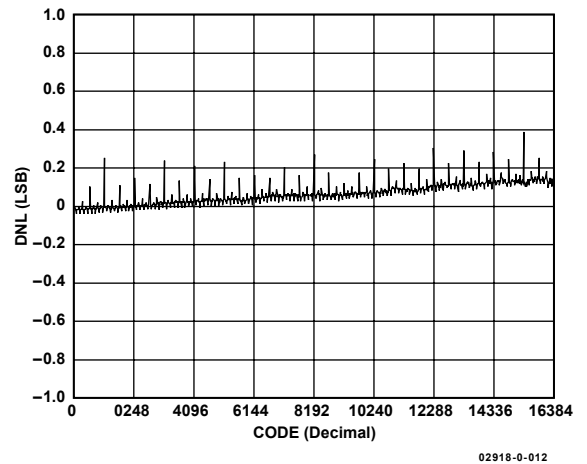


Figure 8. AD5555 Differential Nonlinearity Error

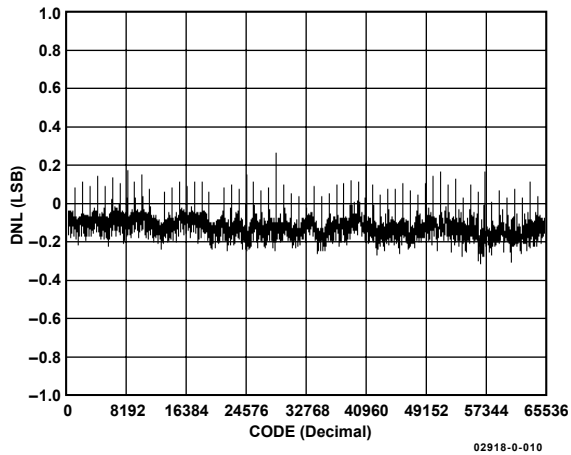


Figure 6. AD5545 Differential Nonlinearity Error

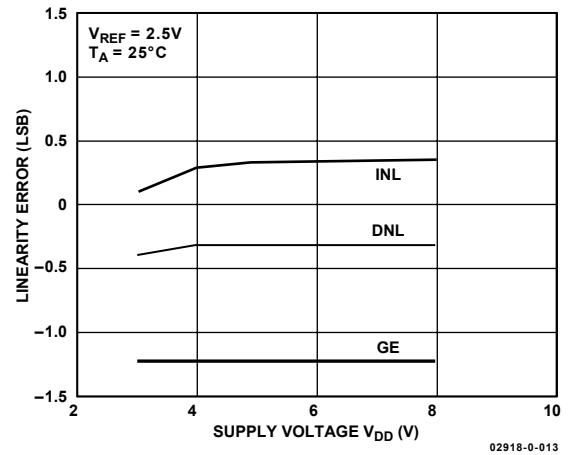


Figure 9. Linearity Errors vs.  $V_{DD}$

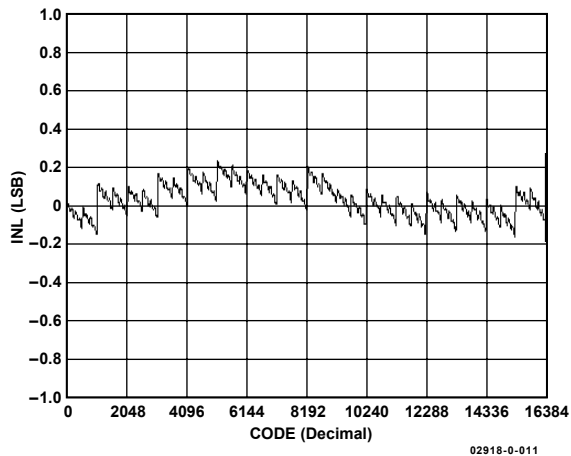


Figure 7. AD5555 Integral Nonlinearity Error

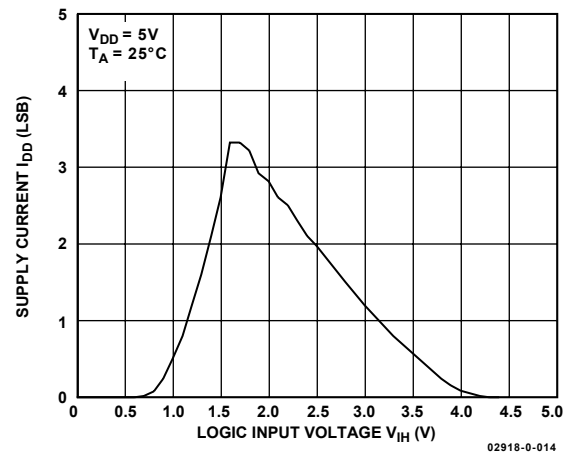


Figure 10. Supply Current vs. Logic Input Voltage

# AD5545/AD5555

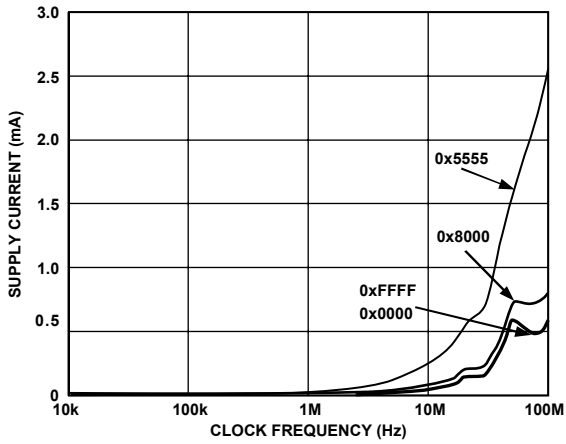


Figure 11. Supply Current vs. Clock Frequency

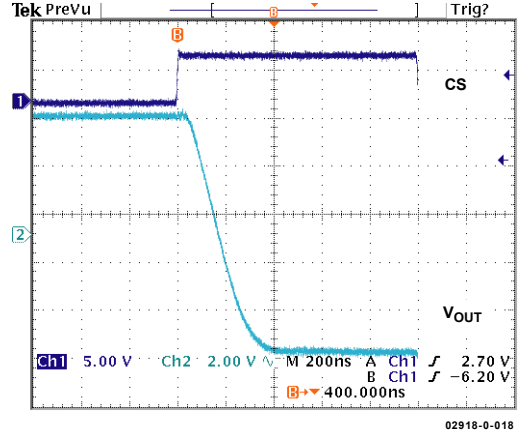


Figure 14. Settling Time

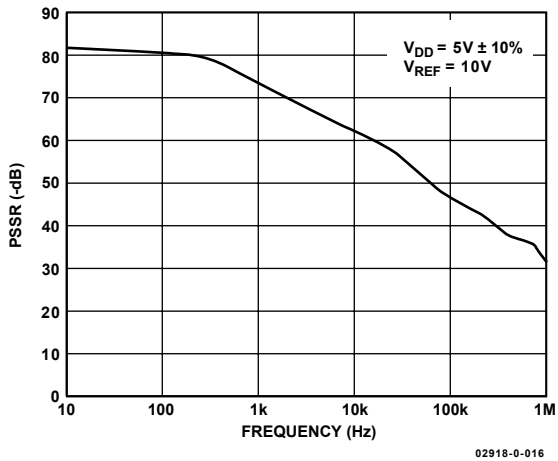


Figure 12. Power Supply Rejection Ration vs. Frequency

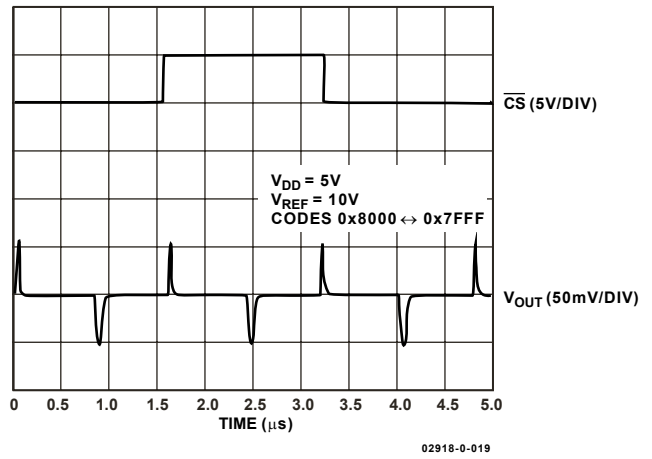


Figure 15. Midscale Transition and Digital Feedthrough

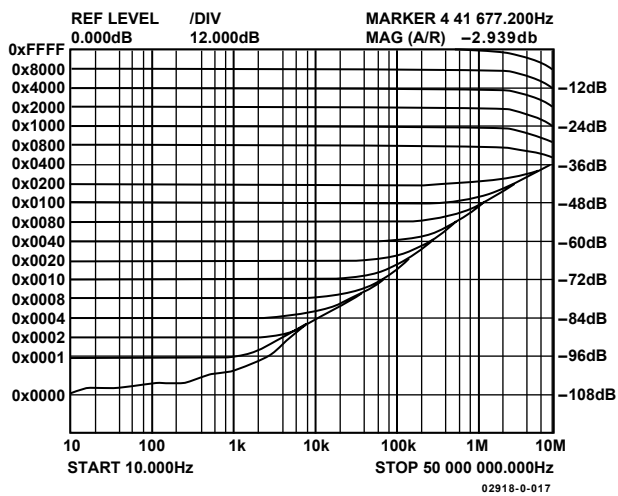


Figure 13. Reference Multiplying Bandwidth

## CIRCUIT OPERATION

The AD5545/AD5555 contain a 16-/14-bit, current-output, digital-to-analog converter, a serial-input register, and a DAC register. Both parts require a minimum of a 3-wire serial data interface with additional LDAC for dual channel simultaneous update.

### D/A CONVERTER SECTION

The DAC architecture uses a current-steering R-2R ladder design. Figure 16 shows the typical equivalent DAC. The DAC contains a matching feedback resistor for use with an external I-to-V converter amplifier. The R<sub>FB</sub> pin is connected to the output of the external amplifier. The I<sub>OUT</sub> terminal is connected to the inverting input of the external amplifier. These DACs are designed to operate with both negative or positive reference voltages. The V<sub>DD</sub> power pin is used only by the logic to drive the DAC switches ON and OFF. Note that a matching switch is used in series with the internal 5 kΩ feedback resistor. If users attempt to measure the R<sub>FB</sub> value, power must be applied to V<sub>DD</sub> to achieve continuity. The V<sub>REF</sub> input voltage and the digital data (D) loaded into the corresponding DAC register, according to Equation 1 and Equation 2, determine the DAC output voltage.

$$V_{OUT} = -V_{REF} \times D / 65,536 \quad (1)$$

$$V_{OUT} = -V_{REF} \times D / 16,384 \quad (2)$$

Note that the output full-scale polarity is the opposite of the V<sub>REF</sub> polarity for dc reference voltages.

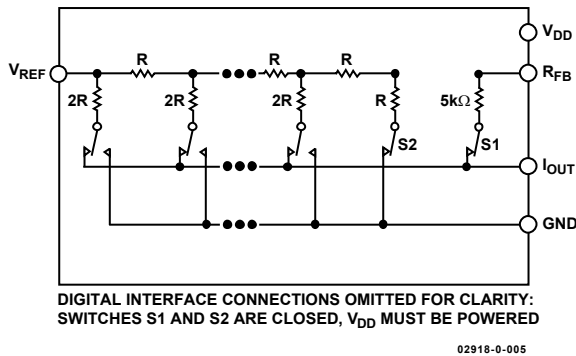


Figure 16. Equivalent R-2R DAC Circuit

These DACs are also designed to accommodate ac reference input signals. The AD5545/AD5555 will accommodate input reference voltages in the range of -12 V to +12 V. The reference voltage inputs exhibit a constant nominal input-resistance value of 5 kΩ, ±30%. The DAC output (I<sub>OUT</sub>) is code dependent, producing various output resistances and capacitances. When choosing an external amplifier, the user should take into account the variation in impedance generated by the AD5545/AD5555 on the amplifiers inverting input node. The feedback resistance in parallel with the DAC ladder resistance dominates output voltage noise.

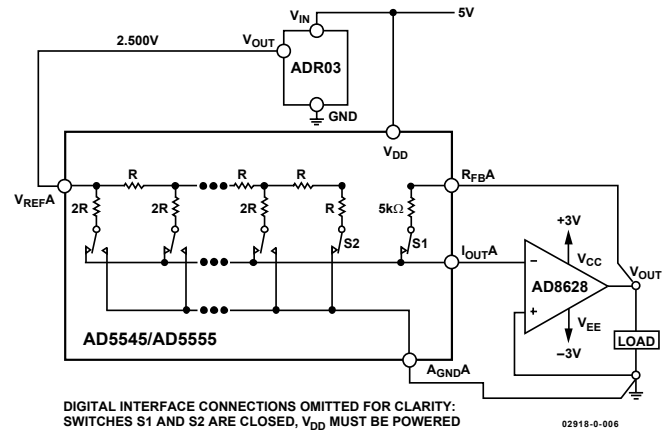


Figure 17. Recommended System Connections

### SERIAL DATA INTERFACE

The AD5545/AD5555 use a minimum 3-wire ( $\overline{CS}$ , SDI, CLK) serial data interface for single channel update operation. With Table 4 as an example (AD5545), users can tie LDAC low and  $\overline{RS}$  high, then pull  $\overline{CS}$  low for an 18-bit duration. New serial data is then clocked into the serial-input register in an 18-bit data-word format with the MSB bit loaded first. Table 5 defines the truth table for the AD5555. Data is placed on the SDI pin and clocked into the register on the positive clock edge of CLK. For the AD5545, only the last 18-bits clocked into the serial register will be interrogated when the  $\overline{CS}$  pin is strobed high, transferring the serial register data to the DAC register and updating the output. If the applied microcontroller outputs serial data in different lengths than the AD5545, such as 8-bit bytes, three right justified data bytes can be written to the AD5545. The AD5545 will ignore the six MSB and recognize the 18 LSB as valid data. After loading the serial register, the rising edge of  $\overline{CS}$  transfers the serial register data to the DAC register and updates the output; during the  $\overline{CS}$  strobe, the CLK should not be toggled.

If users want to program each channel separately but update them simultaneously, they need to program LDAC and  $\overline{RS}$  high initially, then pull  $\overline{CS}$  low for an 18-bit duration and program DAC A with the proper address and data bits.  $\overline{CS}$  is then pulled high to latch data to the DAC A register. At this time, the output is not updated. To load DAC B data, pull  $\overline{CS}$  low for an 18-bit duration and program DAC B with the proper address and data, then pull  $\overline{CS}$  high to latch data to the DAC B register. Finally, pull LDAC low and then high to update both the DAC A and DAC B outputs simultaneously.

# AD5545/AD5555

Table 8 shows that each DAC A and DAC B can be individually loaded with a new data value. In addition, a common new data value can be loaded into both DACs simultaneously by setting Bit A1 = A0 = high. This command enables the parallel combination of both DACs, with I<sub>OUTA</sub> and I<sub>OUTB</sub> tied together, to act as one DAC with significant improved noise performance.

## ESD Protection Circuits

All logic input pins contain back-biased ESD protection Zeners connected to digital ground (DGND) and V<sub>DD</sub> as shown in Figure 18.

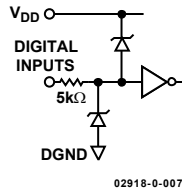


Figure 18. Equivalent ESD Protection Circuits

## POWER-UP SEQUENCE

It is recommended to power-up V<sub>DD</sub> and ground prior to any reference voltages. The ideal power-up sequence is A<sub>GNDX</sub>, DGND, V<sub>DD</sub>, V<sub>REFX</sub>, and digital inputs. A noncompliance power-up sequence can elevate reference current, but the device will resume normal operation once V<sub>DD</sub> is powered.

## LAYOUT AND POWER SUPPLY BYPASSING

It is a good practice to employ compact, minimum lead length layout design. The input leads should be as direct as possible with a minimum conductor length. Ground paths should have low resistance and low inductance.

Similarly, it is also good practice to bypass the power supplies with quality capacitors for optimum stability. Supply leads to the device should be bypassed with 0.01 μF to 0.1 μF disc or chip ceramic capacitors. Low ESR 1 μF to 10 μF tantalum or electrolytic capacitors should also be applied at V<sub>DD</sub> to minimize any transient disturbance and to filter any low frequency ripple (see Figure 19). Users should not apply switching regulators for V<sub>DD</sub> due to the power supply rejection ratio degradation over frequency.

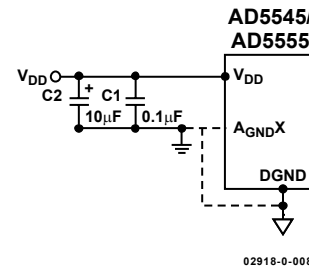


Figure 19. Power Supply Bypassing and Grounding Connection

## GROUNDING

The DGND and A<sub>GNDX</sub> pins of the AD5545/AD5555 refer to the digital and analog ground references. To minimize the digital ground bounce, the DGND terminal should be joined remotely at a single point to the analog ground plane (see Figure 19).

## APPLICATIONS

### STABILITY

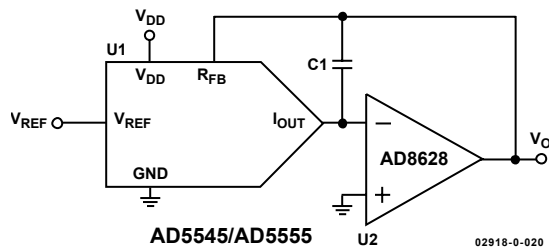


Figure 20. Operational Compensation Capacitor for Gain Peaking Prevention

In the I-to-V configuration, the  $I_{OUT}$  of the DAC and the inverting node of the op amp must be connected as close as possible, and proper PCB layout techniques must be employed. Since every code change corresponds to a step function, gain peaking may occur if the op amp has limited GBP, and if there is excessive parasitic capacitance at the inverting node.

An optional compensation capacitor, C1, can be added for stability as shown in Figure 20. C1 should be found empirically, but 20 pF is generally more than adequate for the compensation.

### POSITIVE VOLTAGE OUTPUT

To achieve the positive voltage output, an applied negative reference to the input of the DAC is preferred over the output inversion through an inverting amplifier because of the resistors' tolerance errors. To generate a negative reference, the reference can be level shifted by an op amp such that the  $V_{OUT}$  and GND pins of the reference become the virtual ground and  $-2.5$  V, respectively (see Figure 21).

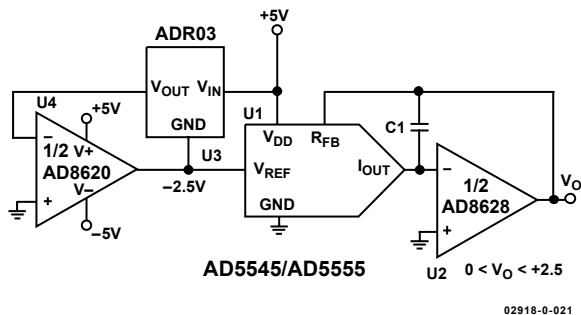


Figure 21. Positive Voltage Output Configuration

### BIPOLAR OUTPUT

The AD5545/AD5555 is inherently a 2-quadrant multiplying D/A converter. It can easily be set up for unipolar output operation. The full-scale output polarity is the inverse of the reference input voltage.

In some applications, it may be necessary to generate the full 4-quadrant multiplying capability or a bipolar output swing. This is easily accomplished by using an additional external amplifier, U4, configured as a summing amplifier (see Figure 22). In this

circuit, the second amplifier, U4, provides a gain of +2, which increases the output span magnitude to 5 V. Biasing the external amplifier with a 2.5 V offset from the reference voltage results in a full 4-quadrant multiplying circuit. The transfer equation of this circuit shows that both negative and positive output voltages are created because the input data ( $D$ ) is incremented from code zero ( $V_{OUT} = -2.5$  V) to midscale ( $V_{OUT} = 0$  V) to full scale ( $V_{OUT} = +2.5$  V).

$$V_{OUT} = (D/32,768 - 1) \times V_{REF} \quad (AD5545) \quad (3)$$

$$V_{OUT} = (D/16,384 - 1) \times V_{REF} \quad (AD5555) \quad (4)$$

For the AD5545, the external resistance tolerance becomes the dominant error that users should be aware of.

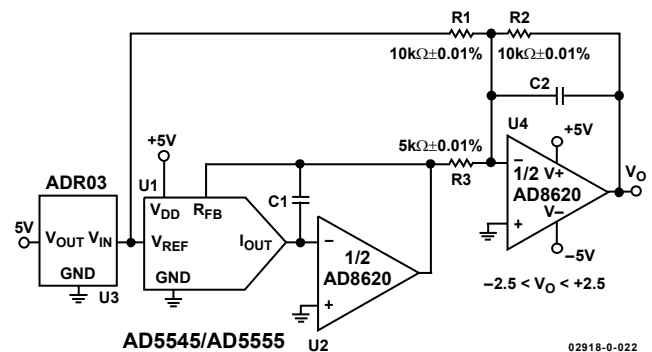


Figure 22. Four-Quadrant Multiplying Application Circuit

### PROGRAMMABLE CURRENT SOURCE

Figure 23 shows a versatile V-to-I conversion circuit using improved Howland Current Pump. In addition to the precision current conversion it provides, this circuit enables a bidirectional current flow and high voltage compliance. This circuit can be used in a 4 mA to 20 mA current transmitter with up to a 500  $\Omega$  of load. In Figure 23, it shows that if the resistor network is matched, the load current is

$$I_L = \frac{(R_2 + R_3)}{R_3} \times V_{REF} \times D \quad (5)$$

$R_3$ , in theory, can be made small to achieve the current needed within the U3 output current driving capability. This circuit is versatile such that the AD8510 can deliver  $\pm 20$  mA in both directions, and the voltage compliance approaches 15 V, which is mainly limited by the supply voltages of U3. However, users must pay attention to the compensation. Without C1, it can be shown that the output impedance becomes

$$Z_O = \frac{R_1' R_3 (R_1 + R_2)}{R_1 (R_2' + R_3') - R_1' (R_2 + R_3)} \quad (6)$$

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If the resistors are perfectly matched,  $Z_o$  is infinite, which is desirable, and the resistors behave as an ideal current source. On the other hand, if they are not matched,  $Z_o$  can be either positive or negative. The latter can cause oscillation. As a result, C1 is needed to prevent the oscillation. For critical applications, C1 could be found empirically but typically falls in the range of a few pF.

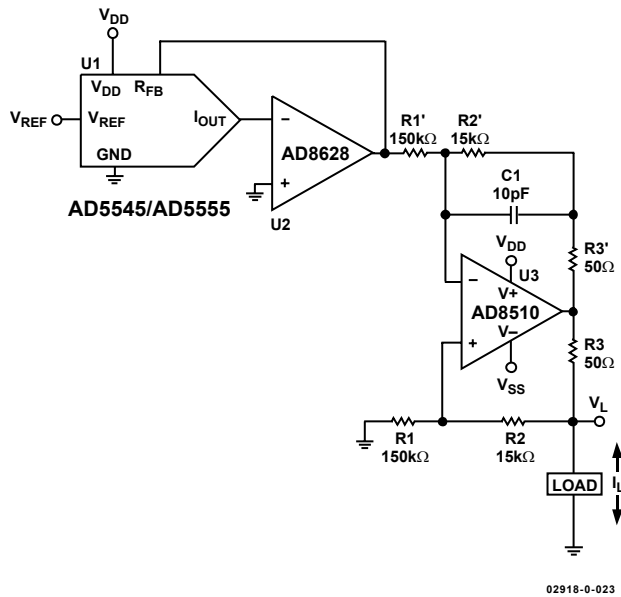


Figure 23. Programmable Current Source with Bidirectional Current Control and High Voltage Compliance Capabilities

## DAC WITH PROGRAMMABLE INPUT REFERENCE RANGE

Since high voltage references can be costly, users may consider using one of the DACs, a digital potentiometer, and a low voltage reference to form a single-channel DAC with a programmable input reference range. This approach optimizes the programmable range as well as facilitates future system upgrades with just software changes. Figure 24 shows this implementation.  $V_{REFAB}$  is in the feedback network, therefore,

$$V_{REFAB} = V_{REF} \times \left( 1 + \frac{R_{WB}}{R_{WA}} \right) - \left( -V_{REF\_AB} \times \frac{D_A}{2^N} \times \frac{R_{WB}}{R_{WA}} \right) \quad (7)$$

where:

$V_{REFAB}$  = Reference Voltage of  $V_{REFA}$  and  $V_{REFB}$

$V_{REF}$  = External Reference Voltage

$D_A$  = DAC A Digital Code in Decimal

$N$  = Number of Bits of DAC

$R_{WB}$  and  $R_{WA}$  are digital potentiometer 128-step programmable resistances and are given by

$$R_{WB} \approx \frac{D_C}{128} R_{AB} \quad (8)$$

$$R_{WA} \approx \frac{128 - D_C}{128} R_{AB} \quad (9)$$

$$\frac{R_{WB}}{R_{WA}} \approx \frac{D_C}{128 - D_C} \quad (10)$$

where  $D_C$  = Digital Potentiometer Digital Code in Decimal ( $0 \leq D_C \leq 127$ ).

By putting Equations 7 through 10 together, the following results:

$$V_{REFAB} = V_{REF} \times \frac{\left( 1 + \frac{D_C}{128 - D_C} \right)}{1 - \frac{D_A}{2^N} \times \frac{D_C}{128 - D_C}} \quad (11)$$

Table 9 shows a few examples of  $V_{REFAB}$  of the 14-bit AD5555.

Table 9.  $V_{REFAB}$  vs.  $D_B$  and  $D_C$  of the AD5555

$D_C$	$D_A$	$V_{REFAB}$
0	X	$V_{REF}$
32	0	$1.33 V_{REF}$
32	8192	$1.6 V_{REF}$
64	0	$2 V_{REF}$
64	8192	$4 V_{REF}$
96	0	$4 V_{REF}$
96	8192	$-8 V_{REF}$

The output of DAC B is, therefore,

$$V_{OB} = -V_{REFAB} \frac{D_B}{2^N} \quad (12)$$

where  $D_B$  is the DAC B digital code in decimal.

The accuracy of  $V_{REFAB}$  will be affected by the matching of the input and feedback resistors and, therefore, a digital potentiometer is used for U4 because of its inherent resistance matching. The AD7376 is a 30 V or  $\pm 15$  V, 128-step digital potentiometer. If 15 V or  $\pm 7.5$  V is adequate for the application, a 256-step AD5260 digital potentiometer can be used instead.

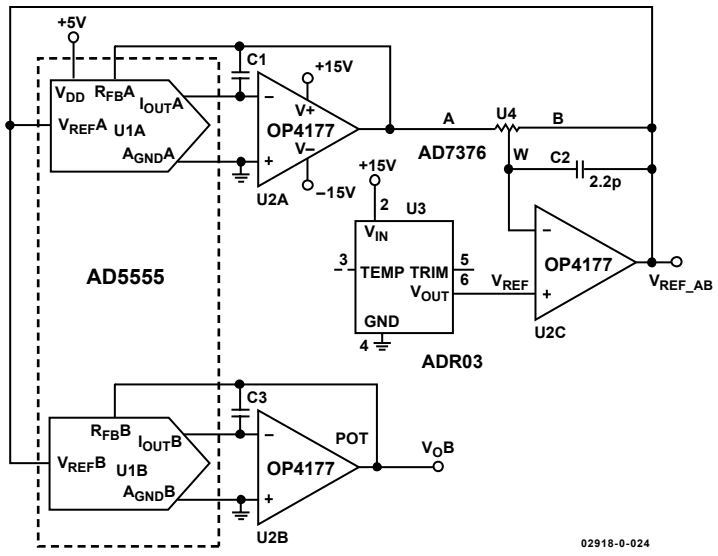
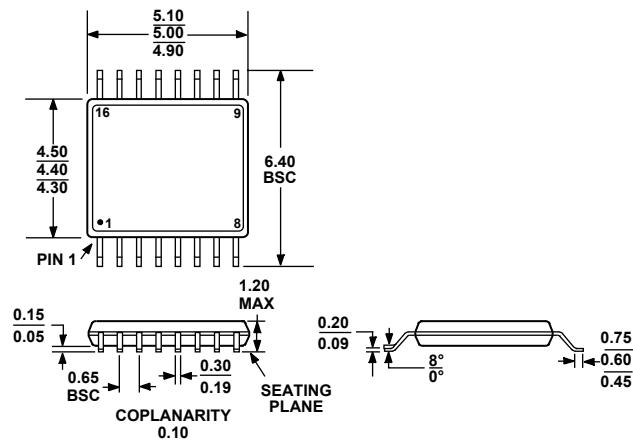


Figure 24. DAC with Programmable Input Reference Range

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## OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MO-153AB

Figure 25. 16-Lead Thin Shrink Small Outline Package [TSSOP] (RU-16)—Dimensions shown in millimeters

### ESD CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



### ORDERING GUIDE

AD5545/AD5555 Products	INL LSB	DNL LSB	RES (Bits)	Temperature Range	Package Description	Package Outline	Qty
AD5545BRU*	±2	±1	16	−40°C to +85°C	TSSOP-16	RU-16	96
AD5545BRU-REEL7	±2	±1	16	−40°C to +85°C	TSSOP-16	RU-16	1000
AD5555CRU	±1	±1	14	−40°C to +85°C	TSSOP-16	RU-16	96
AD5555CRU-REEL7	±1	±1	14	−40°C to +85°C	TSSOP-16	RU-16	1000

\*The AD5545/AD5555 contain 3131 transistors. The die size measures 71 mil. × 96 mil., 6816 sq. mil.