8-Bit, High Bandwidth Multiplying DAC with Serial Interface

AD5425*

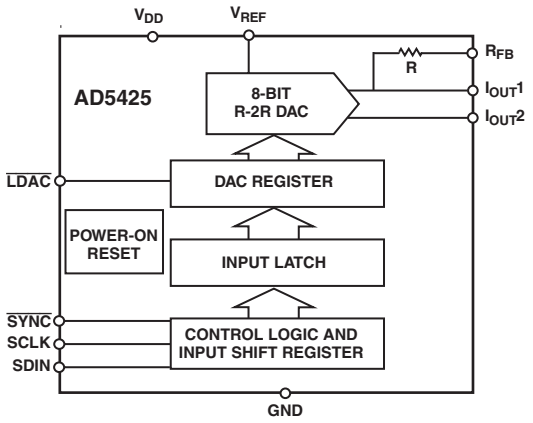
FEATURES

- 2.5 V to 5.5 V Supply Operation
- 50 MHz Serial Interface
  - 8-Bit (Byte Load) Serial Interface, 6 MHz Update Rate
- 10 MHz Multiplying Bandwidth
- ±10 V Reference Input
- Low Glitch Energy < 2 nV-s
- Extended Temperature Range –40°C to +125°C
- 10-Lead MSOP Package
- Guaranteed Monotonic
- 4-Quadrant Multiplication
- Power On Reset with Brownout Detection
- $\overline{\text{LDAC}}$ Function
- 0.4 μA Typical Power Consumption

APPLICATIONS

- Portable Battery-Powered Applications
- Waveform Generators
- Analog Processing
- Instrumentation Applications
- Programmable Amplifiers and Attenuators
- Digitally-Controlled Calibration
- Programmable Filters and Oscillators
- Composite Video
- Ultrasound
- Gain, Offset, and Voltage Trimming

FUNCTIONAL BLOCK DIAGRAM



GENERAL DESCRIPTION

The AD5425 is a CMOS 8-bit current output digital-to-analog converter that operates from a 2.5 V to 5.5 V power supply, making it suited to battery-powered applications and many other applications.

This DAC utilizes a double buffered 3-wire serial interface that is compatible with SPI®, QSPI™, MICROWIRE™, and most DSP interface standards. In addition, an $\overline{\text{LDAC}}$ pin is provided, which allows simultaneous update in a multi-DAC configuration. On power-up, the internal shift register and latches are filled with 0s and the DAC outputs are at 0 V.

As a result of processing on a CMOS submicron process, this DAC offers excellent 4-quadrant multiplication characteristics, with large signal multiplying bandwidths of 10 MHz.

The applied external reference input voltage (V_{REF}) determines the full-scale output current. An integrated feedback resistor (R_{FB}) provides temperature tracking and full-scale voltage output when combined with an external I-to-V precision amplifier.

The AD5425 DAC is available in a small 10-lead MSOP package.

*Protected by U.S. Patent No. 5,969,657; other patents pending.

REV. 0

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AD5425–SPECIFICATIONS[1]

(V_{DD} = 2.5 V to 5.5 V, V_{REF} = 10 V, I_{OUT}x = 0 V. All specifications T_{MIN} to T_{MAX}, unless otherwise noted. DC performance measured with OP177, AC performance with AD8038, unless otherwise noted.)

Parameter	Min	Typ	Max	Unit	Conditions
STATIC PERFORMANCE					
Resolution			8	Bits	
Relative Accuracy			0.25	LSB	
Differential Nonlinearity			0.5	LSB	Guaranteed monotonic
Gain Error			±10	mV	
Gain Error Temperature Coefficient[2]		±5		ppm FSR/°C	
Output Leakage Current			±5	nA	Data = 0x0000, T_A = 25°C, I_{OUT}
			±25	nA	Data = 0x0000, I_{OUT}
REFERENCE INPUT[2]					
Reference Input Range		±10		V	
V_{REF} Input Resistance	8	10	12	kΩ	Input resistance TC = –50 ppm/°C
R_{FB} Resistance	8	10	12	kΩ	Input resistance TC = –50 ppm/°C
Input Capacitance					
Code Zero Scale		3	6	pF	
Code Full Scale		5	8	pF	
DIGITAL INPUTS					
Input High Voltage, V_{IH}	1.7			V	
Input Low Voltage, V_{IL}			0.6	V	
Input Leakage Current, I_{IL}			2	μA	
Input Capacitance		4	10	pF	
DYNAMIC PERFORMANCE[2]					
Reference Multiplying Bandwidth		10		MHz	V_{REF} = ±3.5 V; DAC loaded all 1s
Output Voltage Settling Time		50	100	ns	Measured to ±16 mV. R_{LOAD} = 100 Ω, C_{LOAD} = 15 pF DAC latch alternately loaded with 0s and 1s
Digital Delay		40	75	ns	
10% to 90% Settling Time		15	30	ns	Rise and Fall time, V_{REF} = 10 V, R_{LOAD} = 100 Ω
Digital-to-Analog Glitch Impulse		2		nV-s	1 LSB change around major carry V_{REF} = 0 V
Multiplying Feedthrough Error		70		dB	DAC latch loaded with all 0s. V_{REF} = ±3.5 V, 1 MHz
		48		dB	10 MHz
Output Capacitance					
$I_{OUT}2$		22	25	pF	All 0s loaded
		10	12	pF	All 1s loaded
$I_{OUT}1$		12	17	pF	All 0s loaded
		25	30	pF	All 1s loaded
Digital Feedthrough		0.1		nV-s	Feedthrough to DAC output with $\overline{SYNC}$ high and alternate loading of all 0s and all 1s
Total Harmonic Distortion		–81		dB	V_{REF} = 3.5 V pk-pk; all 1s loaded, f = 1 kHz
Digital THD Clock = 1 MHz					
50 kHz f_{OUT}		70		dB	8k Codes
Output Noise Spectral Density		25		nV√Hz	@ 1 kHz
SFDR Performance (Wide Band)					8k Codes, V_{REF} = 3.5 V
Clock = 2 MHz					
50 kHz f_{OUT}		55		dB	
20 kHz f_{OUT}		63		dB	
SFDR Performance (Narrow Band)					
Clock = 2 MHz					
50 kHz f_{OUT}		73		dB	
20 kHz f_{OUT}		80		dB	
Intermodulation Distortion					8k codes, V_{REF} = 3.5 V
Clock = 2 MHz					
f_1 = 20 kHz, f_2 = 25 kHz		79		dB	

Parameter	Min	Typ	Max	Unit	Conditions
POWER REQUIREMENTS					
Power Supply Range	2.5		5.5	V	
I_{DD}		0.4	5	μA	Logic inputs = 0 V or V_{DD}
			0.6	μA	T_A = 25°C, Logic inputs = 0 V or V_{DD}

NOTES
[1]Temperature range is as follows: Y version: –40°C to +125°C.
[2]Guaranteed by design, not subject to production test.

Specifications subject to change without notice.

TIMING CHARACTERISTICS[1, 2]

(V_{DD} = 2.5 V to 5.5 V, V_{REF} = 10 V, $I_{OUT}2$ = 0 V. All specifications T_{MIN} to T_{MAX}, unless otherwise noted.)

Parameter	Limit at T_{MIN}, T_{MAX}	Unit	Conditions/Comments
f_{SCLK}	50	MHz max	Max clock frequency
t_1	20	ns min	SCLK cycle time
t_2	8	ns min	SCLK high time
t_3	8	ns min	SCLK low time
t_4	13	ns min	$\overline{SYNC}$ falling edge to SCLK falling edge setup time
t_5	5	ns min	Data setup time
t_6	3	ns min	Data hold time
t_7	5	ns min	$\overline{SYNC}$ rising edge to SCLK falling edge
t_8	30	ns min	Minimum $\overline{SYNC}$ high time
t_9	0	ns min	SCLK falling edge to $\overline{LDAC}$ falling edge
t_{10}	12	ns min	$\overline{LDAC}$ pulse width
t_{11}	10	ns min	SCLK falling edge to $\overline{LDAC}$ rising edge

NOTES
[1]See Figure 1. Temperature range is as follows: Y version: –40°C to +125°C. Guaranteed by design and characterization, not subject to production test.
[2]All input signals are specified with tr = tf = 1 ns (10% to 90% of V_{DD}) and timed from a voltage level of (V_{IL} + V_{IH})/2.

Specifications subject to change without notice.

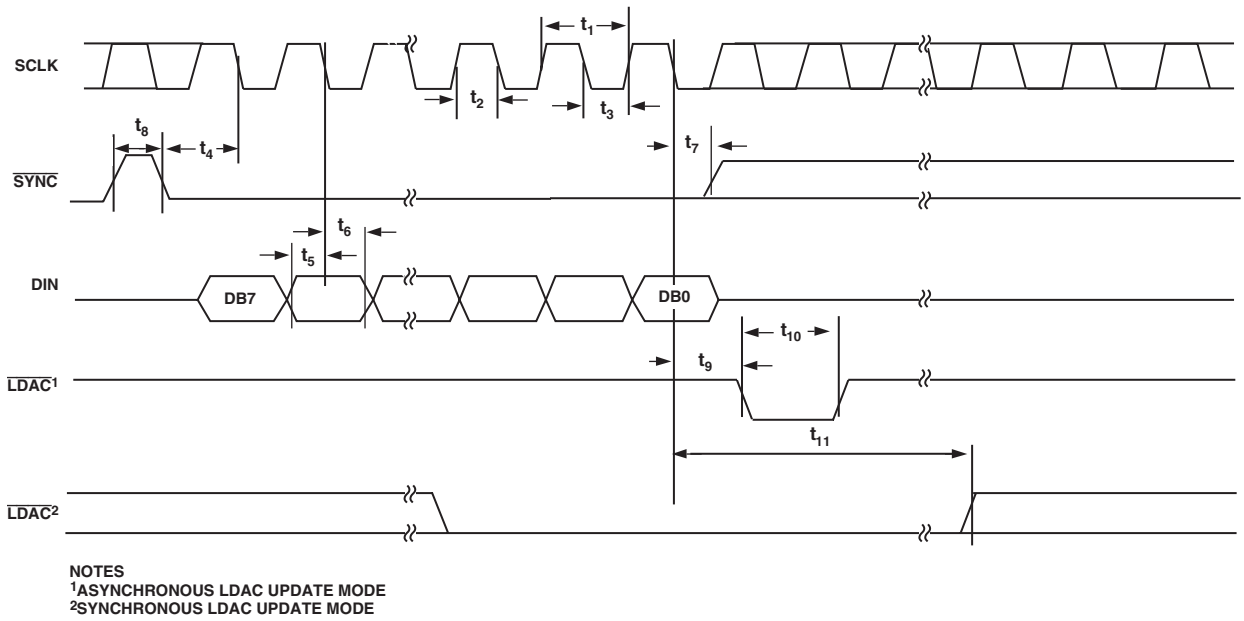


Figure 1. Timing Diagram

ABSOLUTE MAXIMUM RATINGS[1]

(T_A = 25°C, unless otherwise noted.)

V_{DD} to GND . . . . . –0.3 V to +7 V
V_{REF}, R_{FB} to GND . . . . . –12 V to +12 V
$I_{OUT}1$, $I_{OUT}2$ to GND . . . . . –0.3 V to +7 V
Logic Inputs and Output[2] . . . . . –0.3 V to V_{DD} + 0.3 V
Operating Temperature Range
  Extended Industrial (Y Version) . . . . . –40°C to +125°C
Storage Temperature Range . . . . . –65°C to +150°C
Junction Temperature . . . . . 150°C
10-lead MSOP θ_{JA} Thermal Impedance . . . . . 206°C/W
Lead Temperature, Soldering (10 seconds) . . . . . 300°C
IR Reflow, Peak Temperature (<20 seconds) . . . . . 235°C

NOTES

[1] 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 listed in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. Only one absolute maximum rating may be applied at any one time.

[2] Overvoltages at SCLK, $\overline{\text{SYNC}}$, DIN, and $\overline{\text{LDAC}}$ will be clamped by internal diodes.

ORDERING GUIDE

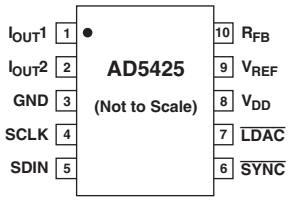
Model	Resolution (Bits)	INL (LSBs)	Temperature Range	Package Description	Branding	Package Option
AD5425YRM	8	±0.25	–40°C to +125°C	MSOP	D1P	RM-10
AD5425YRM-REEL	8	±0.25	–40°C to +125°C	MSOP	D1P	RM-10
AD5425YRM-REEL7	8	±0.25	–40°C to +125°C	MSOP	D1P	RM-10
EVAL-AD5425EB				Evaluation Kit		

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 the AD5425 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.

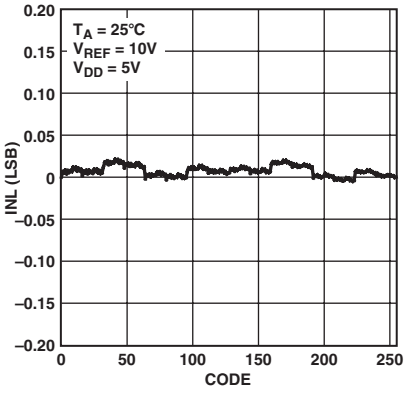


PIN CONFIGURATION

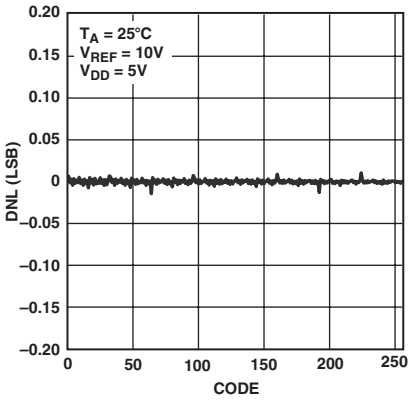


PIN FUNCTION DESCRIPTIONS

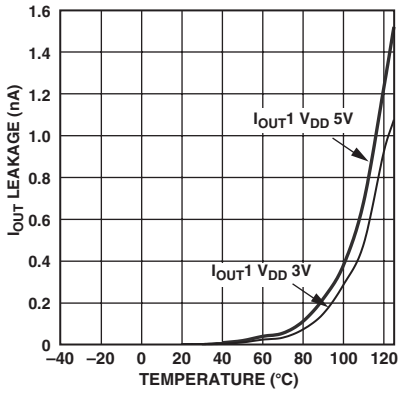
Pin No.	Mnemonic	Function
1	$I_{OUT}1$	DAC Current Output.
2	$I_{OUT}2$	DAC Analog Ground. This pin should normally be tied to the analog ground of the system.
3	GND	Digital Ground Pin.
4	SCLK	Serial Clock Input. Data is clocked into the input shift register on each falling edge of the serial clock input. This device can accommodate clock rates of up to 50 MHz.
5	SDIN	Serial Data Input. Data is clocked into the 8-bit input register on each falling edge of the serial clock input.
6	$\overline{SYNC}$	Active Low Control Input. This is the frame synchronization signal for the input data. When $\overline{SYNC}$ goes low, it powers on the SCLK and DIN buffers and the input shift register is enabled. Data is transferred on each falling edge of the following 8 clocks.
7	$\overline{LDAC}$	Load DAC Input. Updates the DAC output. The DAC is updated when this signal goes low or alternatively, if this line is held permanently low, an automatic update mode is selected whereby the DAC is updated after 8 SCLK falling edges with $\overline{SYNC}$ low.
8	V_{DD}	Positive Power Supply Input. This part can be operated from a supply of 2.5 V to 5.5 V.
9	V_{REF}	DAC Reference Voltage Input Terminal.
10	R_{FB}	DAC Feedback Resistor Pin. Establishes voltage output for the DAC by connecting to external amplifier output.



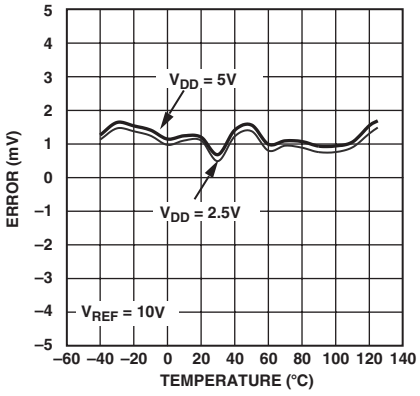
TPC 1. INL vs. Code (8-Bit DAC)



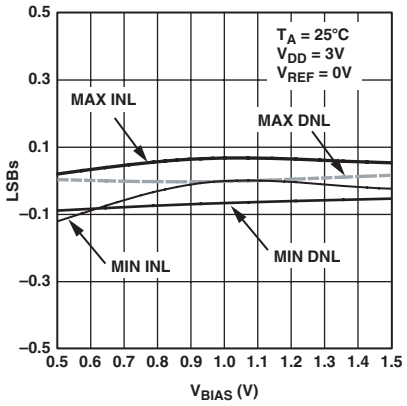
TPC 2. DNL vs. Code (8-Bit DAC)



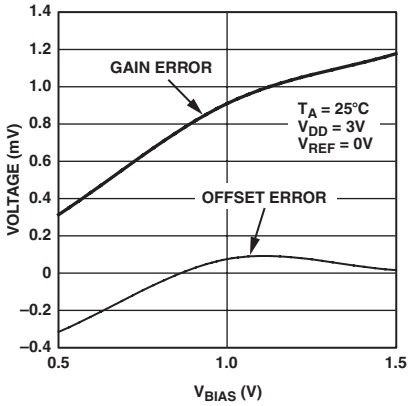
TPC 3. $I_{OUT}1$ Leakage Current vs. Temperature



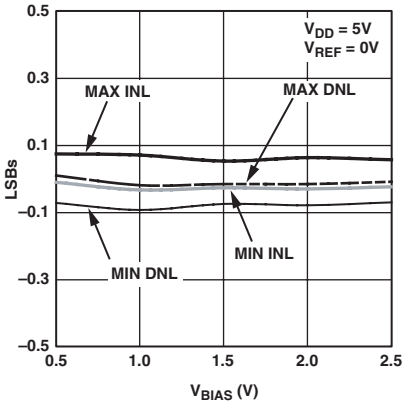
TPC 4. Gain Error vs. Temperature



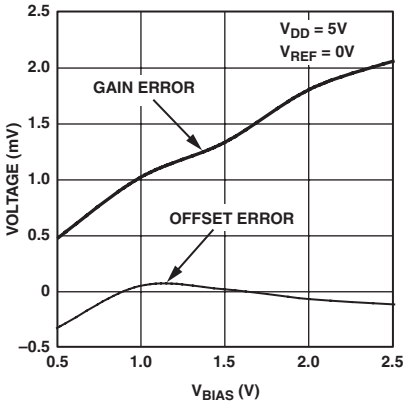
TPC 5. Linearity vs. V_{BIAS} Voltage Applied to $I_{OUT}2$



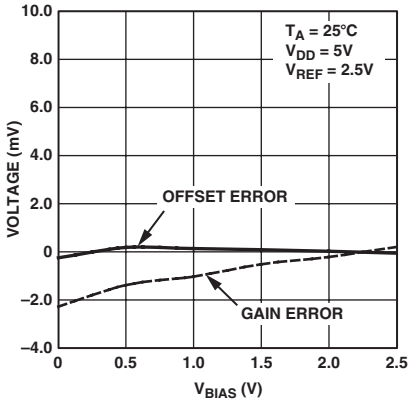
TPC 6. Gain and Offset Errors vs. V_{BIAS} Voltage Applied to $I_{OUT}2$



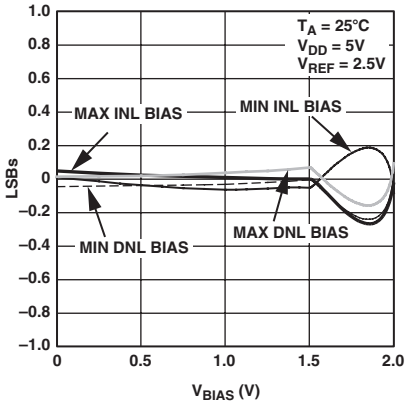
TPC 7. Linearity vs. V_{BIAS} Voltage Applied to $I_{OUT}2$



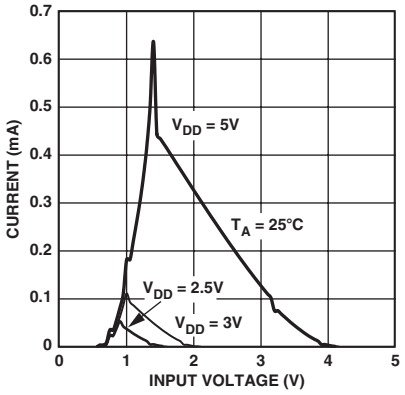
TPC 8. Gain and Offset Errors vs. Voltage Applied to $I_{OUT}2$



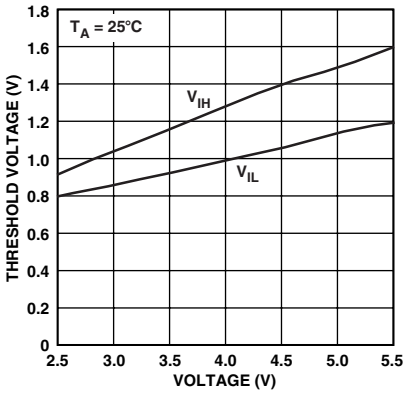
TPC 9. Gain and Offset Errors vs. V_{BIAS} Voltage Applied to $I_{OUT}2$



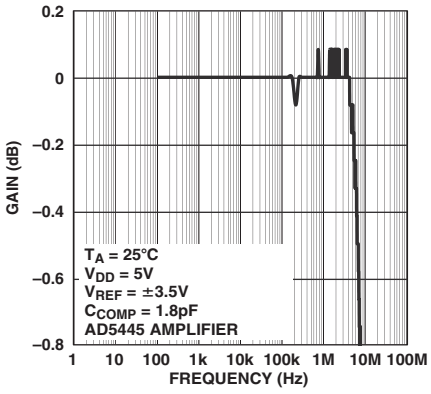
TPC 10. Linearity vs. V_{BIAS} Voltage Applied to $I_{OUT}2$



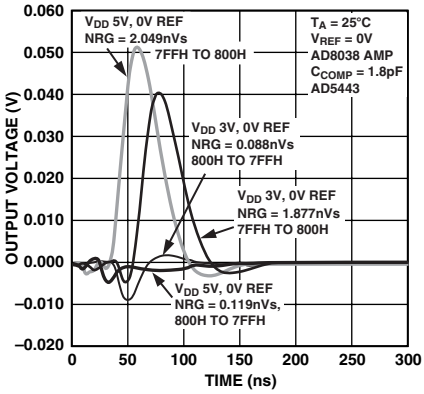
TPC 11. Supply Current vs. Input Voltage



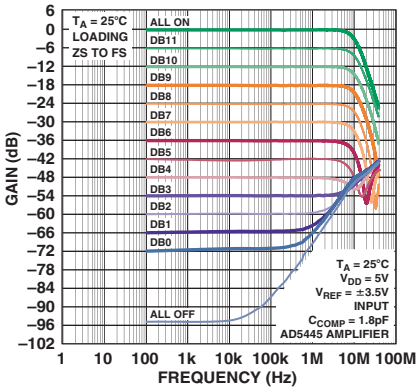
TPC 12. Threshold Voltages vs. Supply Voltage



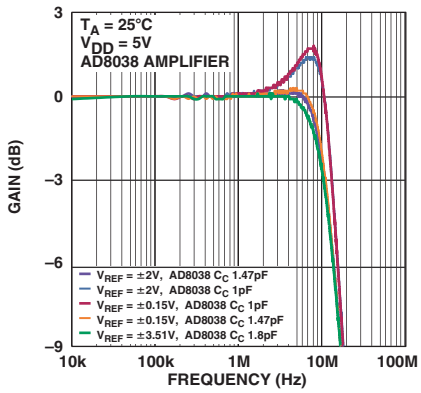
TPC 13. Reference Multiplying Bandwidth—All 1s Loaded



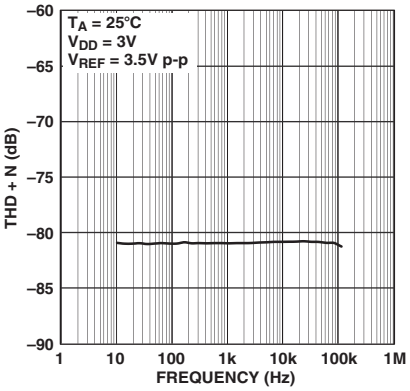
TPC 14. Midscale Transition, V_{REF} = 3.5 V



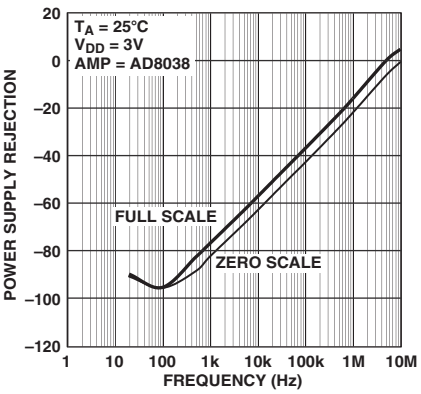
TPC 15. Reference Multiplying Bandwidth vs. Frequency and Code



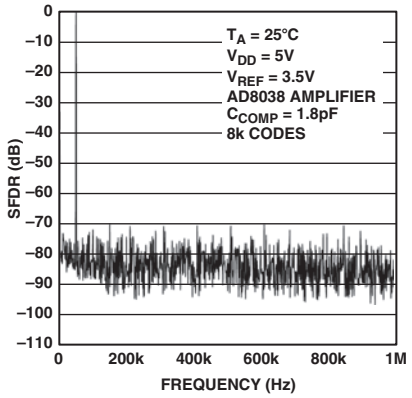
TPC 16. Reference Multiplying Bandwidth vs. Frequency and Compensation Capacitor



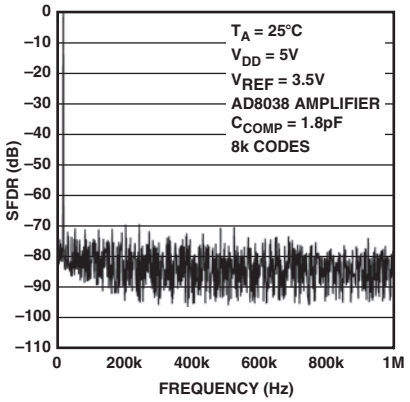
TPC 17. THD and Noise vs. Frequency



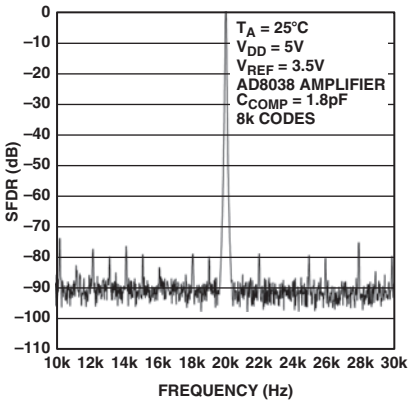
TPC 18. Power Supply Rejection vs. Frequency



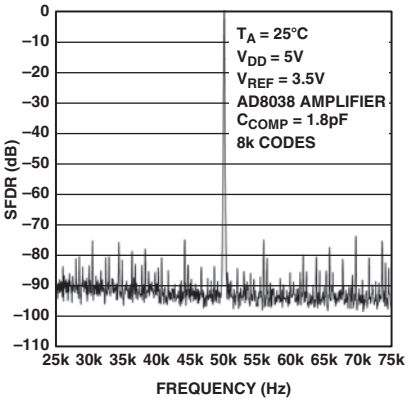
TPC 19. Wideband SFDR, Clock = 2 MHz, f_{OUT} = 50 kHz



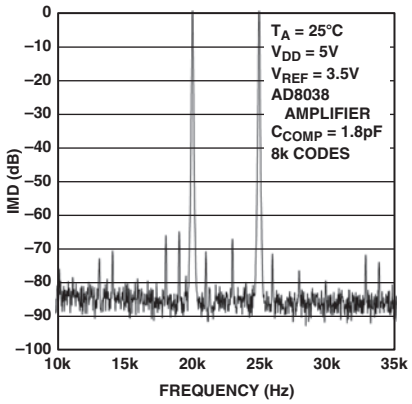
TPC 20. Wideband SFDR, Clock = 2 MHz, f_{OUT} = 20 kHz



TPC 21. Narrowband SFDR, Clock = 2 MHz, f_{OUT} = 20 kHz



TPC 22. Narrowband SFDR, Clock = 2 MHz, f_{OUT} = 50 kHz



TPC 23. Narrowband IMD (±50%) Clock = 2 MHz, $f_{OUT}1$ = 20 kHz, $f_{OUT}2$ = 25 kHz

TERMINOLOGY

Relative Accuracy
Relative accuracy or endpoint nonlinearity is a measure of the maximum deviation from a straight line passing through the endpoints of the DAC transfer function. It is measured after adjusting for zero and full scale and is normally expressed in LSBs or as a percentage of full-scale reading.

Differential Nonlinearity
Differential nonlinearity is the difference between the measured change and the ideal 1 LSB change between any two adjacent codes. A specified differential nonlinearity of –1 LSB max over the operating temperature range ensures monotonicity.

Gain Error
Gain error or full-scale error is a measure of the output error between an ideal DAC and the actual device output. For these DACs, ideal maximum output is V_{REF} – 1 LSB. Gain error of the DACs is adjustable to 0 with external resistance.

Output Leakage Current
Output leakage current is current that flows in the DAC ladder switches when these are turned off. For the $I_{OUT}1$ terminal, it can be measured by loading all 0s to the DAC and measuring the $I_{OUT}1$ current. Minimum current will flow in the $I_{OUT}2$ line when the DAC is loaded with all 1s.

Output Capacitance
Capacitance from $I_{OUT}1$ or $I_{OUT}2$ to AGND.

Output Current Settling Time
This is the amount of time it takes for the output to settle to a specified level for a full-scale input change. For these devices, it is specified with a 100 Ω resistor to ground. The settling time specification includes the digital delay from $\overline{SYNC}$ rising edge of the full scale output charge.

Digital-to-Analog Glitch lmpulse
The amount of charge injected from the digital inputs to the analog output when the inputs change state. This is normally specified as the area of the glitch in either pA-secs or nV-secs depending upon whether the glitch is measured as a current or voltage signal.

Digital Feedthrough
When the device is not selected, high frequency logic activity on the device digital inputs is capacitively coupled through the device to show up as noise on the I_{OUT} pins and subsequently into the following circuitry. This noise is digital feedthrough.

Multiplying Feedthrough Error
This is the error due to capacitive feedthrough from the DAC reference input to the DAC $I_{OUT}1$ terminal, when all 0s are loaded to the DAC.

Total Harmonic Distortion (THD)
The DAC is driven by an ac reference. The ratio of the rms sum of the harmonics of the DAC output to the fundamental value is the THD. Usually only the lower order harmonices are included, such as second to fifth.

$$THD = 20\log\frac{\sqrt{\left(V_2^2 + V_3^2 + V_4^2 + V_5^2\right)}}{V_1}$$

Spurious-Free Dynamic Range (SFDR)
It is the usable dynamic range of a DAC before spurious noise interferes or distorts the fundamental signal. SFDR is the measure of difference in amplitude between the fundamental and the largest harmonically or nonharmonically related spur from dc to full Nyquist bandwidth (half the DAC sampling rate, or fs/2). Narrow band SFDR is a measure of SFDR over an arbitrary window size, in this case 50% of the fundamental. Digital SFDR is a measure of the usable dynamic range of the DAC when the signal is digitally generated sine wave.

DAC SECTION

The AD5425 is an 8-bit current output DAC consisting of a standard inverting R-2R ladder configuration. A simplified diagram is shown in Figure 2. The feedback resistor R_{FB} has a value of R. The value of R is typically 10 kΩ (minimum 8 kΩ and maximum 12 kΩ). If $I_{OUT}1$ and $I_{OUT}2$ are kept at the same potential, a constant current flows in each ladder leg, regardless of digital input code. Therefore, the input resistance presented at V_{REF} is always constant and nominally of value R. The DAC output (I_{OUT}) is code-dependent, producing various resistances and capacitances. External amplifier choice should take into account the variation in impedance generated by the DAC on the amplifiers inverting input node.

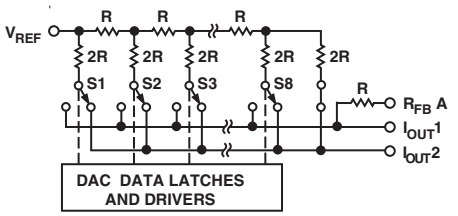


Figure 2. Simplified Ladder

Access is provided to the V_{REF}, R_{FB}, $I_{OUT}1$ and $I_{OUT}2$ terminals of the DAC, making the device extremely versatile and allowing it to be configured in several different operating modes, for example, to provide a unipolar output, bipolar output, or in single-supply modes of operation in unipolar mode or 4-quadrant multiplication in bipolar mode. Note that a matching switch is used in series with the internal R_{FB} feedback resistor. If users attempt to measure R_{FB}, power must be applied to V_{DD} to achieve continuity.

SERIAL INTERFACE

The AD5425 has a simple 3-wire interface which is compatible with SPI/QSPI/MICROWIRE and DSP interface standards. Data is written to the device in 8 bit words. This 8-bit word consists of 8 data bits as shown in Figure 3.

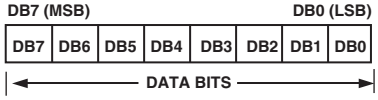


Figure 3. 8-Bit Input Shift Register Contents

$\overline{SYNC}$ is an edge-triggered input that acts as a frame synchronization signal and chip enable. Data can be transferred into the device only while $\overline{SYNC}$ is low. To start the serial data transfer, $\overline{SYNC}$ should be taken low, observing the minimum $\overline{SYNC}$ falling to SCLK falling edge setup time, t_4.

After loading eight data bits to the shift register, the $\overline{SYNC}$ line is brought high. The contents of the DAC register and the output will be updated by bringing $\overline{LDAC}$ low any time after the 8-bit data transfer is complete as seen in the timing diagram of Figure 1. $\overline{LDAC}$ may be tied permanently low if required. For another serial transfer to take place, the interface must be enabled by another falling edge of $\overline{SYNC}$.

Low Power Serial Interface

To minimize the power consumption of the device, the interface powers up fully only when the device is being written to, i.e., on the falling edge of $\overline{SYNC}$. The SCLK and SDIN input buffers are powered down on the rising edge of $\overline{SYNC}$.

CIRCUIT OPERATION

Unipolar Mode

Using a single op amp, this device can easily be configured to provide 2-quadrant multiplying operation or a unipolar output voltage swing as shown in Figure 4.

When an output amplifier is connected in unipolar mode, the output voltage is given by:

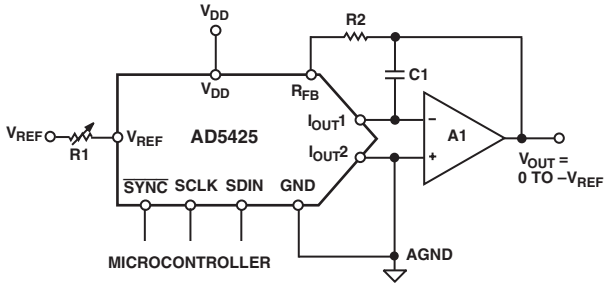
$$V_{OUT} = -V_{REF} \times \frac{D}{2^n}$$

where *D* is the fractional representation of the digital word loaded to the DAC, in this case 0 to 255, and *n* is the number of bits.

Note that the output voltage polarity is opposite to the V_{REF} polarity for dc reference voltages.

This DAC is designed to operate with either negative or positive reference voltages. The V_{DD} power pin is used by only the internal digital logic to drive the DAC switches' on and off states.

This DAC is also designed to accommodate ac reference input signals in the range of –10 V to +10 V.



NOTES
1. R1 AND R2 USED ONLY IF GAIN ADJUSTMENT IS REQUIRED.
2. C1 PHASE COMPENSATION (1pF – 2pF) MAY BE REQUIRED IF A1 IS A HIGH SPEED AMPLIFIER.

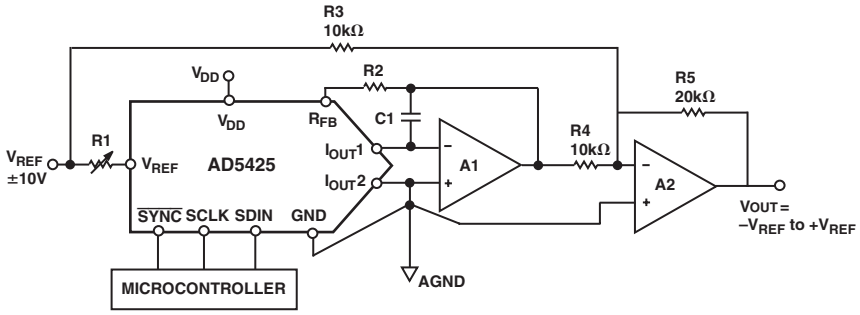
Figure 4. Unipolar Operation

With a fixed 10 V reference, the circuit shown in Figure 4 will give an unipolar 0 V to –10 V output voltage swing. When V_{IN} is an ac signal, the circuit performs 2-quadrant multiplication.

Table I shows the relationship between digital code and the expected output voltage for unipolar operation.

Table I. Unipolar Code Table

Digital Input	Analog Output (V)
1111 1111	$-V_{REF}$ (255/256)
1000 0000	$-V_{REF}$ (128/256) = $-V_{REF}/2$
0000 0001	$-V_{REF}$ (1/256)
0000 0000	$-V_{REF}$ (0/256) = 0



NOTES
1. R1 AND R2 ARE USED ONLY IF GAIN ADJUSTMENT IS REQUIRED. ADJUST R1 FOR V_{OUT} = 0 V WITH CODE 10000000 LOADED TO DAC.
2. MATCHING AND TRACKING IS ESSENTIAL FOR RESISTOR PAIRS R3 AND R4.
3. C1 PHASE COMPENSATION (1pF–2pF) MAY BE REQUIRED IF A1/A2 IS A HIGH SPEED AMPLIFIER.

Figure 5. Bipolar Operation (4-Quadrant Multiplication)

Bipolar Operation

In some applications, it may be necessary to generate full 4-quadrant multiplying operation or a bipolar output swing. This can be easily accomplished by using another external amplifier and some external resistors as shown in Figure 5. In this circuit, the second amplifier A2 provides a gain of 2. Biasing the external amplifier with an offset from the reference voltage results in full 4-quadrant multiplying operation. The transfer function of this circuit shows that both negative and positive output voltages are created as the input data (D) is incremented from code zero ($V_{OUT} = -V_{REF}$) to midscale (V_{OUT} = 0 V) to full scale ($V_{OUT} = + V_{REF}$).

$$V_{OUT} = \left(V_{REF} \times D / 2^{n-1}\right) - V_{REF}$$

Where *D* is the fractional representation of the digital word loaded to the DAC and *n* is the resolution of the DAC.

When V_{IN} is an ac signal, the circuit performs 4-quadrant multiplication.

Table II shows the relationship between digital code and the expected output voltage for bipolar operation.

Table II. Bipolar Code Table

Digital Input	Analog Output (V)
1111 1111	$+V_{REF}$ (127/128)
1000 0000	0
0000 0001	$-V_{REF}$ (127/128)
0000 0000	$-V_{REF}$ (128/128)

Stability

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 there is excessive parasitic capacitance at the inverting node. This parasitic capacitance introduces a pole into the open-loop response, which can cause ringing or instability in closed-loop applications.

An optional compensation capacitor, C1 can be added in parallel with R_{FB} for stability as shown in Figures 6 and 7. Too small a value of C1 can produce ringing at the output, while too large a value can adversely affect the settling time. C1 should be found empirically but 1 pF–2 pF is generally adequate for compensation.

SINGLE-SUPPLY APPLICATIONS

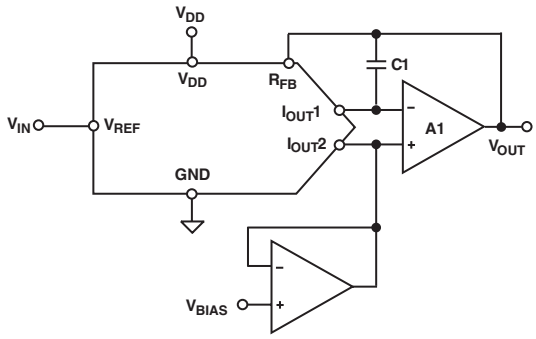
Current Mode Operation

Figure 6 shows a typical circuit for operation with a single 2.5 V to 5 V supply. In the current mode circuit of Figure 6, $I_{OUT}2$ and hence $I_{OUT}1$ is biased positive by an amount applied to V_{BIAS}. In this configuration, the output voltage is given by

$$V_{OUT} = \left\{D \times \left(R_{FB}/R_{DAC}\right) \times \left(V_{BIAS} - V_{IN}\right)\right\} + V_{BIAS}$$

As D varies from 0 to 255, the output voltage varies from

$$V_{OUT} = V_{BIAS}\ to\ V_{OUT} = 2V_{BIAS} - V_{IN}$$



NOTES
1. ADDITIONAL PINS OMITTED FOR CLARITY
2. C1 PHASE COMPENSATION (1pF–2pF) MAY BE REQUIRED IF A1 IS A HIGH SPEED AMPLIFIER.

Figure 6. Single-Supply Current Mode Operation

V_{BIAS} should be a low impedance source capable of sinking and sourcing all possible variations in current at the $I_{OUT}2$ terminal without any problems.

It is important to note that V_{IN} is limited to low voltages because the switches in the DAC ladder no longer have the same source-drain drive voltage. As a result their on resistance differs and this degrades the linearity of the DAC.

Voltage Switching Mode of Operation

Figure 7 shows this DAC operating in the voltage switching mode. The reference voltage, V_{IN} is applied to the $I_{OUT}1$ pin, $I_{OUT}2$ is connected to AGND and the output voltage is available at the V_{REF} terminal. In this configuration, a positive reference voltage results in a positive output voltage making single-supply operation possible. The output from the DAC is voltage at a constant impedance (the DAC ladder resistance), thus an op amp is necessary to buffer the output voltage. The reference input no longer sees a constant input impedance, but one that varies with code. So, the voltage input should be driven from a low impedance source.

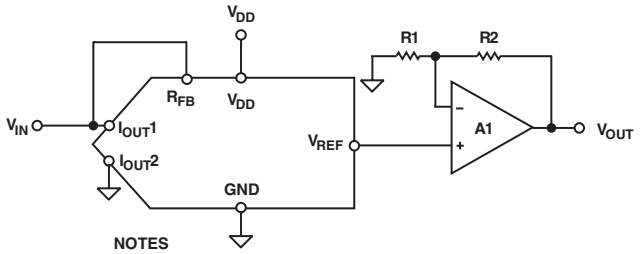


Figure 7. Single-Supply Voltage Switching Mode Operation

It is important to note that V_{IN} is limited to low voltage because the switches in the DAC ladder no longer have the same source-drain drive voltage. As a result, their on resistance differs, which degrades the linearity of the DAC.

Also, V_{IN} must not go negative by more than 0.3 V or an internal diode will turn on, exceeding the max ratings of the device. In this type of application, the full range of multiplying capability of the DAC is lost.

POSITIVE OUTPUT VOLTAGE

Note that the output voltage polarity is opposite to the V_{REF} polarity for dc reference voltages. To achieve a 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 resistor 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, as shown in Figure 8.

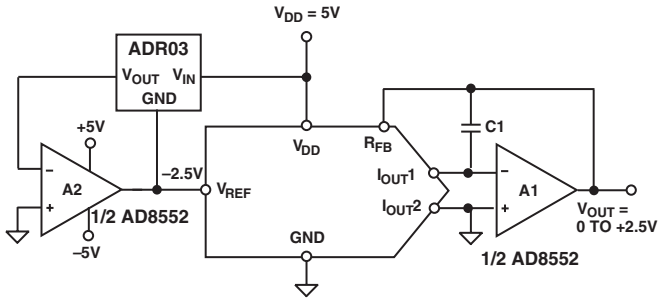


Figure 8. Positive Voltage Output with Minimum of Components

ADDING GAIN

In applications where the output voltage is required to be greater than V_{IN}, gain can be added with an additional external amplifier or it can also be achieved in a single stage. It is important to take into consideration the effect of temperature coefficients of the thin film resistors of the DAC. Simply placing a resistor in series with the R_{FB} resistor will causing mismatches in the temperature coefficients resulting in larger gain temperature coefficient errors. Instead, the circuit of Figure 9 is a recommended method of increasing the gain of the circuit. R1, R2, and R3 should all have similar temperature coefficients, but they need not match the temperature coefficients of the DAC. This approach is recommended in circuits where gains of greater than 1 are required.

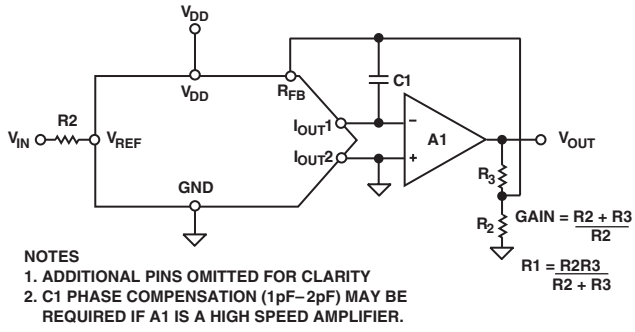


Figure 9. Increasing Gain of Current Output DAC

USED AS A DIVIDER OR PROGRAMMABLE GAIN ELEMENT

Current steering DACs are very flexible and lend themselves to many different applications. If this type of DAC is connected as the feedback element of an op amp and R_{FB} is used as the input resistor as shown in Figure 10, then the output voltage is inversely proportional to the digital input fraction D. For D = 1 – 2n the output voltage is

$$V_{OUT} = -V_{IN}/D = -V_{IN}/\left(1-2^{-n}\right)$$

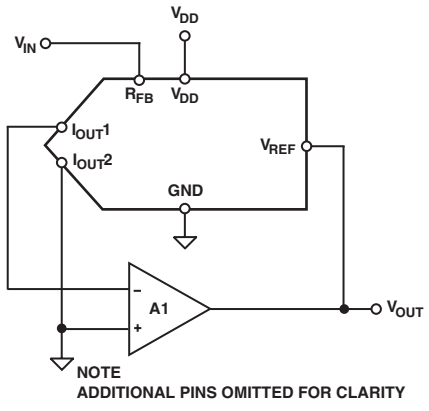


Figure 10. Current Steering DAC Used as a Divider or Programmable Gain Element

As D is reduced, the output voltage increases. For small values of the digital fraction D, it is important to ensure that the amplifier does not saturate and also that the required accuracy is met. For example, an eight bit DAC driven with the binary code $0_{x/0}$ (00010000), i.e., 16 decimal, in the circuit of Figure 10 should

cause the output voltage to be 16× V_{IN}. However, if the DAC has a linearity specification of ± 0.5 LSB, then D can in fact have the weight anywhere in the range 15.5/256 to 16.5/256 so that the possible output voltage will be in the range 15.5 V_{IN} to 16.5 V_{IN}—an error of +3% even though the DAC itself has a maximum error of 0.2%.

DAC leakage current is also a potential error source in divider circuits. The leakage current must be counterbalanced by an opposite current supplied from the op amp through the DAC. Since only a fraction D of the current into the V_{REF} terminal is routed to the $I_{OUT}1$ terminal, the output voltage has to change as follows:

$$Output\ Error\ Voltage\ Due\ to\ DAC\ Leakage = (Leakage \times R)/D$$

where *R* is the DAC resistance at the V_{REF} terminal. For a DAC leakage current of 10 nA, R = 10 kΩ and a gain (i.e., 1/D) of 16 the error voltage is 1.6 mV.

REFERENCE SELECTION

When selecting a reference for use with the AD5425 series of current output DACs, pay attention to the reference's output voltage temperature coefficient specification. This parameter not only affects the full-scale error, but can also affect the linearity (INL and DNL) performance. The reference temperature coefficient should be consistent with the system accuracy specifications. For example, an 8-bit system required to hold its overall specification to within 1 LSB over the temperature range 0°C to 50°C dictates that the maximum system drift with temperature should be less than 78 ppm/°C. A 12-bit system with the same temperature range to overall specification within 2 LSB requires a maximum drift of 10 ppm/°C. By choosing a precision reference with low output temperature coefficient, this error source can be minimized. Table III suggests some of the suitable references available from Analog Devices that are suitable for use with this range of current output DACs.

AMPLIFIER SELECTION

The primary requirement for the current-steering mode is an amplifier with low input bias currents and low input offset voltage. The input offset voltage of an op amp is multiplied by the variable gain (due to the code dependent output resistance of the DAC) of the circuit. A change in this noise gain between two adjacent digital fractions produces a step change in the output voltage due to the amplifier's input offset voltage. This output voltage change is superimposed on the desired change in output between the two codes and gives rise to a differential linearity error, which if large enough, could cause the DAC to be nonmonotonic. In general, the input offset voltage should be a fraction (~<1/4) of an LSB to ensure monotonic behavior when stepping through codes.

The input bias current of an op amp also generates an offset at the voltage output as a result of the bias current flowing in the feedback resistor R_{FB}. Most op amps have input bias currents low enough to prevent any significant errors.

Common-mode rejection of the op amp is important in voltage switching circuits, since it produces a code dependent error at the voltage output of the circuit. Most op amps have adequate common-mode rejection for use at 8-bit resolution.

Provided the DAC switches are driven from true wideband low impedance sources (V_{IN} and AGND), they settle quickly. Consequently, the slew rate and settling time of a voltage switching DAC circuit is determined largely by the output op amp. To obtain minimum settling time in this configuration, it is important to minimize capacitance at the V_{REF} node (voltage output node in this application) of the DAC. This is done by using low inputs capacitance buffer amplifiers and careful board design.

Most single-supply circuits include ground as part of the analog signal range, which in turns requires an amplifier that can handle rail-to-rail signals. There is a large range of single-supply amplifiers available from Analog Devices.

Table III. Suitable ADI Precision Voltage References Recommended for Use with AD5425 DACs

Part No.	Output Voltage	Initial Tolerance	Temperature Drift	0.1 Hz to 10 Hz Noise	Package
ADR01	10 V	0.1%	3 ppm/°C	20 μV p-p	SC70, TSOT, SOIC
ADR02	5 V	0.1%	3 ppm/°C	10 μV p-p	SC70, TSOT, SOIC
ADR03	2.5 V	0.2%	3 ppm/°C	10 μV p-p	SC70, TSOT, SOIC
ADR425	5 V	0.04%	3 ppm/°C	3.4 μV p-p	MSOP, SOIC

Table IV. Some Precision ADI Op Amps Suitable for Use with AD5425 DACs

Part No.	Max Supply Voltage (V)	V_{OS}(max) (μV)	I_B(max) (nA)	GBP (MHz)	Slew Rate (V/μs)
OP97	±20	25	0.1	0.9	0.2
OP1177	±18	60	2	1.3	0.7
AD8551	+6	5	0.05	1.5	0.4

Table V. Some High Speed ADI Op Amps Suitable for Use with AD5425 DACs

Part No.	Max Supply Voltage (V)	BW @ A_{CL} (MHz)	Slew Rate (V/μs)	V_{OS}(max) (μV)	I_B(max) (nA)
AD8065	±12	145	180	1500	0.01
AD8021	±12	200	100	1000	1000
AD8038	±5	350	425	3000	0.75
AD9631	±5	320	1300	10000	7000

MICROPROCESSOR INTERFACING

Microprocessor interfacing to this DAC is via a serial bus that uses standard protocol compatible with microcontrollers and DSP processors. The communications channel is a 3-wire interface consisting of a clock signal, a data signal, and a synchronization signal. An $\overline{LDAC}$ pin is also included. The AD5425 requires an 8-bit word with the default being data valid on the falling edge of SCLK, but this is changeable via the control bits in the data-word.

ADSP-21xx to AD5425 Interface

The ADSP-21xx family of DSPs are easily interfaced to this family of DACs without extra glue logic. Figure 11 shows an example of an SPI interface between the DAC and the ADSP-2191. SCK of the DSP drives the serial data line, DIN. SYNC is driven from one of the port lines, in this case SPIxSEL.

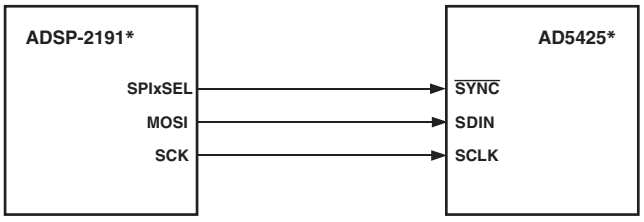


Figure 11. ADSP-2191 SPI to AD5425 Interface

A serial interface between the DAC and DSP SPORT is shown in Figure 12. In this interface example, SPORT0 is used to transfer data to the DAC shift register. Transmission is initiated by writing a word to the Tx register after the SPORT has been enabled. In a write sequence, data is clocked out on each rising edge of the DSPs serial clock and clocked into the DAC input shift register on the falling edge of its SCLK. The update of the DAC output takes place on the rising edge of the $\overline{SYNC}$ signal.

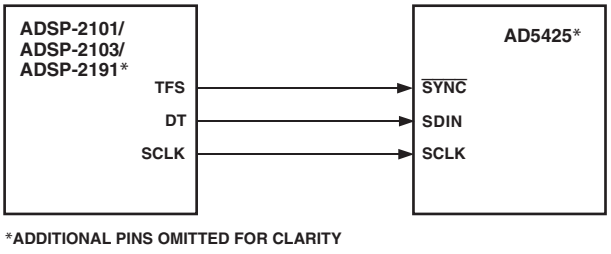


Figure 12. ADSP-2101/ADSP-2103/ADSP-2191 SPORT to AD5425 Interface

Communication between two devices at a given clock speed is possible when the following specifications are compatible: frame sync delay and frame sync setup and hold, data delay and data setup and hold, and SCLK width. The DAC interface expects a t_4 (SYNC falling edge to SCLK falling edge setup time) of 13 ns minimum. Consult the ADSP-21xx User Manual for information on clock and frame sync frequencies for the SPORT register.

The SPORT Control Register should be set up as follows:

TFSW = 1, Alternate Framing

INVTFS = 1, Active Low Frame Signal

DTYPE = 00, Right Justify Data

ISCLK = 1, Internal Serial Clock

TFSR = 1, Frame Every Word

ITFS = 1, Internal Framing Signal

SLEN = 0111, 8-Bit Data-Word

80C51/80L51 to AD5425 Interface

A serial interface between the DAC and the 8051 is shown in Figure 13. TxD of the 8051 drives SCLK of the DAC serial interface, while RxD drives the serial data line, D_{IN}. P3.3 is a bit-programmable pin on the serial port and is used to drive $\overline{SYNC}$. When data is to be transmitted to the switch, P3.3 is taken low. The 80C51/80L51 transmits data in 8-bit bytes which is perfect for the AD5425 as it only requires an 8-bit word. Data on RxD is clocked out of the microcontroller on the rising edge of TxD and is valid on the falling edge. As a result, no glue logic is required between the DAC and microcontroller interface. P3.3 is taken high following the completion of this cycle. The 8051 provides the LSB of its SBUF register as the first bit in the data stream. The DAC input register requires its data with the MSB as the first bit received. The transmit routine should take this into account.

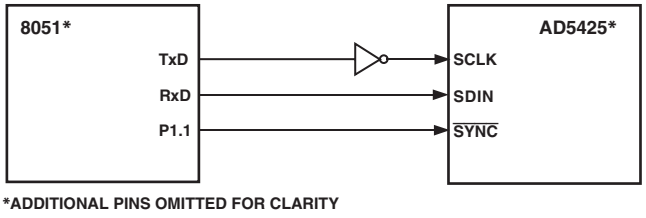


Figure 13. 80C51/80L51 to AD5425 Interface

MC68HC11 Interface to AD5425 Interface

Figure 14 shows an example of a serial interface between the DAC and the MC68HC11 microcontroller. The serial peripheral interface (SPI) on the MC68HC11 is configured for master mode (MSTR = 1), clock polarity bit (CPOL) = 0, and the clock phase bit (CPHA) = 1. The SPI is configured by writing to the SPI control register (SPCR)—see the 68HC11 User Manual. SCK of the 68HC11 drives the SCLK of the DAC interface, the MOSI output drives the serial data line (D_{IN}) of the AD5516. The $\overline{SYNC}$ signal is derived from a port line (PC7). When data is being transmitted to the AD5516, the $\overline{SYNC}$ line is taken low (PC7). Data appearing on the MOSI output is valid on the falling edge of SCK. Serial data from the 68HC11 is transmitted in 8-bit bytes with only eight falling clock edges occurring in the transmit cycle. Data is transmitted MSB first. PC7 is taken high at the end of the write.

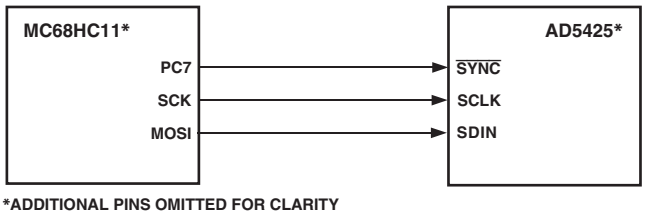


Figure 14. 68HC11/68L11 to AD5425 Interface

MICROWIRE to AD5425 Interface

Figure 15 shows an interface between the DAC and any MICROWIRE compatible device. Serial data is shifted out on the falling edge of the serial clock, SK, and is clocked into the DAC input shift register on the rising edge of SK, which corresponds to the falling edge of the DAC's SCLK.

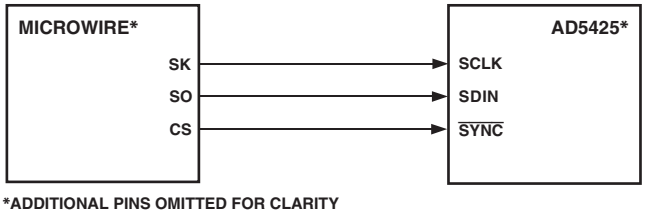


Figure 15. MICROWIRE to AD5425 Interface

PIC16C6x/7x to AD5425

The PIC16C6x/7x synchronous serial port (SSP) is configured as an SPI master with the clock polarity bit (CKP) = 0. This is done by writing to the synchronous serial port control register (SSPCON). See the PIC16/17 Microcontroller User Manual. In this example, I/O port RA1 is being used to provide a $\overline{SYNC}$ signal and enable the serial port of the DAC. This microcontroller transfers eight bits of data during each serial transfer operation. Figure 16 shows the connection diagram.

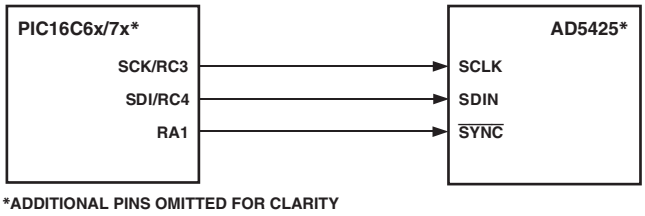


Figure 16. PIC16C6x/7x to AD5425 Interface

PCB LAYOUT AND POWER SUPPLY DECOUPLING

In any circuit where accuracy is important, careful consideration of the power supply and ground return layout helps to ensure the rated performance. The printed circuit board on which the AD5425 is mounted should be designed so that the analog and digital sections are separated and confined to certain areas of the board. If the DAC is in a system where multiple devices require an AGND-to-DGND connection, the connection should be made at one point only. The star ground point should be established as close as possible to the device.

These DACs should have ample supply bypassing of 10 µF in parallel with 0.1 µF on the supply located as close to the package as possible, ideally right up against the device. The 0.1 µF capacitor should have low effective series resistance (ESR) and effective series inductance (ESI), such as the common ceramic types that provide a low impedance path to ground at high frequencies, to handle transient currents due to internal logic switching. Low ESR 1 µF to 10 µF tantalum or electrolytic capacitors should also be applied at the supplies to minimize transient disturbance and to filter out low frequency ripple.

Fast switching signals such as clocks should be shielded with digital ground to avoid radiating noise to other parts of the board, and should never be run near the reference inputs.

Avoid crossover of digital and analog signals. Traces on opposite sides of the board should run at right angles to each other. This reduces the effects of feedthrough through the board. A microstrip technique is by far the best, but not always possible with a double-sided board. In this technique, the component side of the board is dedicated to ground plane while signal traces are placed on the solder side.

It is good practice to employ compact, minimum lead length PCB layout design. Leads to the input should be as short as possible to minimize IR drops and stray inductance.

The PCB metal traces between V_{REF} and R_{FB} should also be matched to minimize gain error. To maximize on high frequency performance, the I-to-V amplifier should be located as close to the device as possible.

EVALUATION BOARD FOR THE AD5425 DAC

The board consists of an 8-bit AD5425 and a current to voltage amplifier AD8065. Included on the evaluation board is a 10 V reference ADR01. An external reference may also be applied via an SMB input.

The evaluation kit consists of a CD-ROM with self-installing PC software to control the DAC. The software simply allows the user to write a code to the device.

OPERATING THE EVALUATION BOARD

Power Supplies

The board requires ±12 V, and +5 V supplies. The +12 V V_{DD} and V_{SS} are used to power the output amplifier, while the +5 V is used to power the DAC (V_{DD1}) and transceivers (V_{CC}).

Both supplies are decoupled to their respective ground plane with 10 µF tantalum and 0.1 µF ceramic capacitors.

Link1 (LK1) is provided to allow selection between the on-board reference (ADR01) or an external reference applied through J2. Link2 should be connected to $\overline{LDAC}$ position.

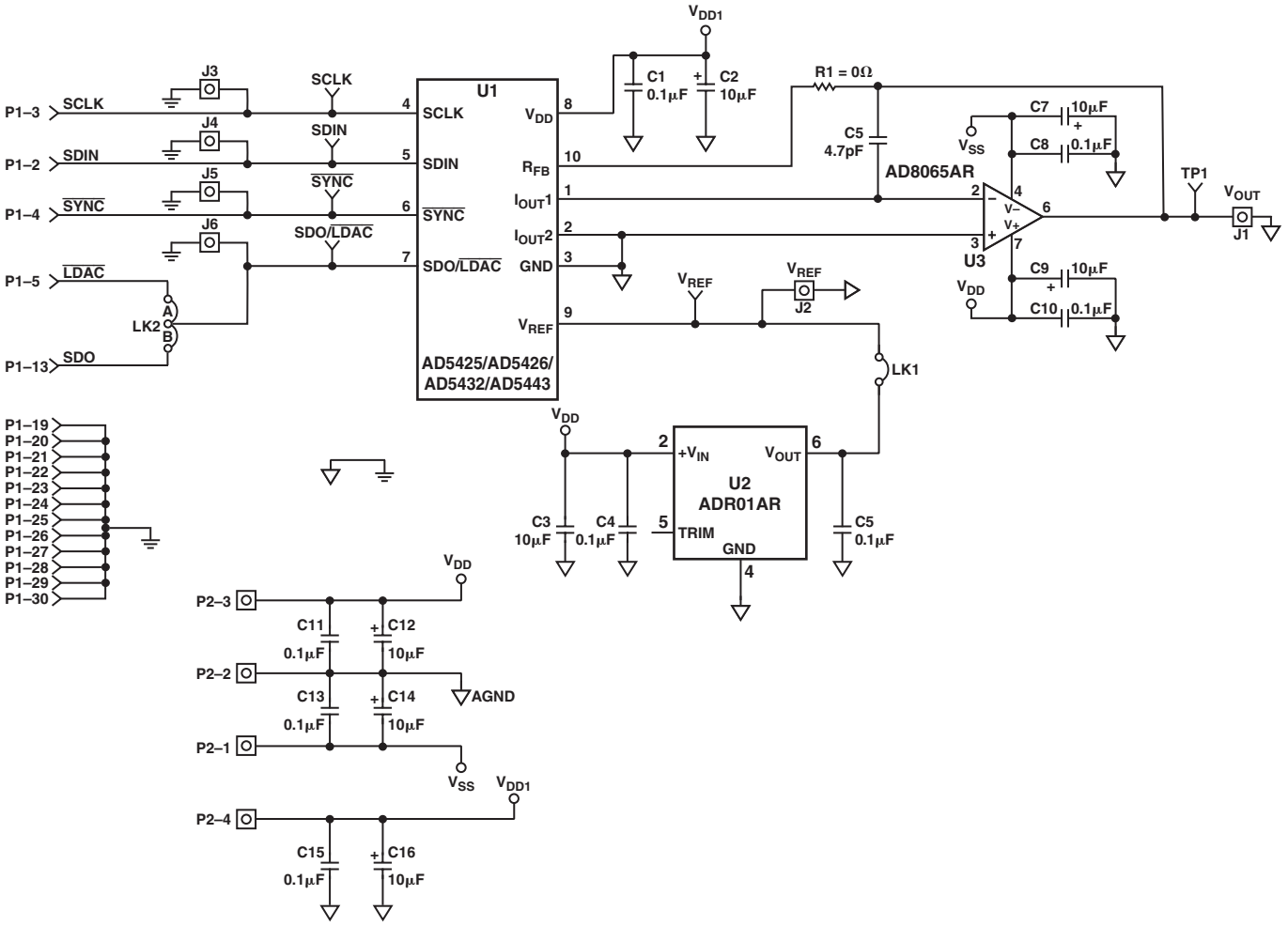


Figure 17. Schematic of the AD5425 Evaluation Board

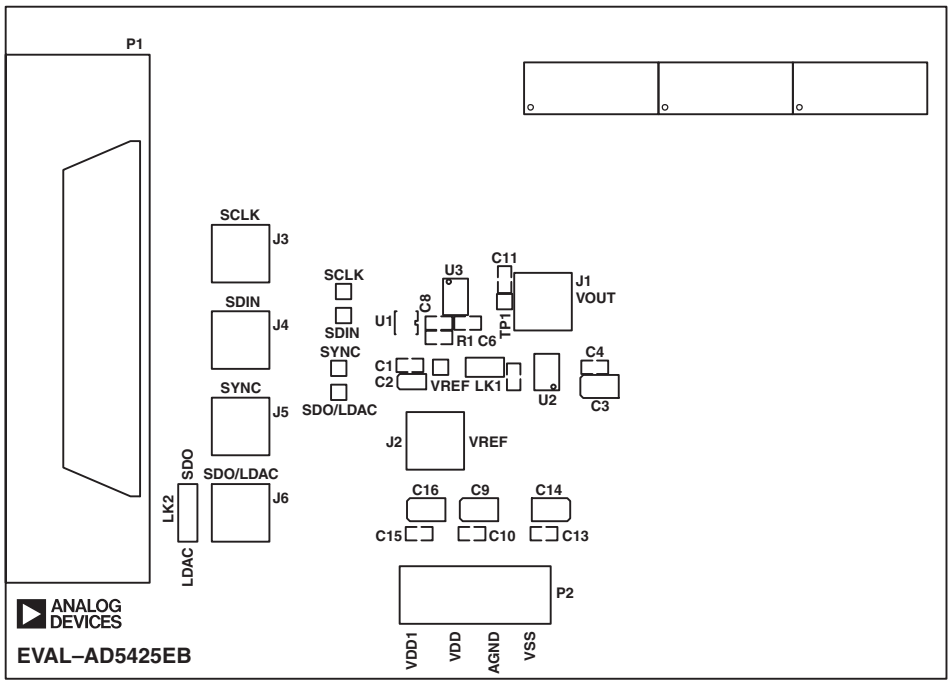


Figure 18. Silkscreen—Component Side View (Top Layer)

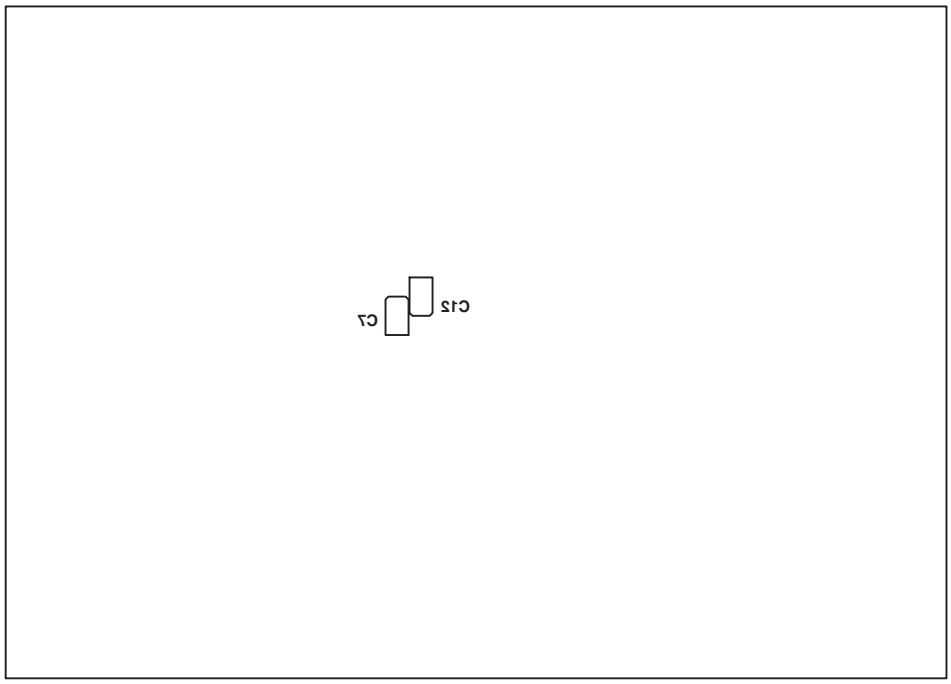


Figure 19. Silkscreen—Component Side View (Bottom Layer)

Overview of AD54xx Devices

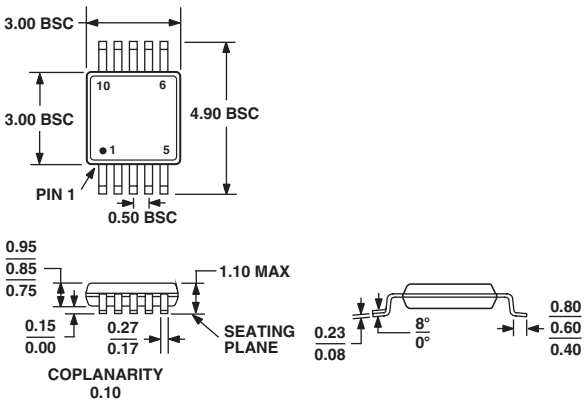
Part No.	Resolution	No. DACs	INL	t_S max	Interface	Package	Features
AD5403*	8	2	±0.25	60 ns	Parallel	CP-40	10 MHz Bandwidth, 10 ns $\overline{CS}$ Pulse Width, 4-Quadrant Multiplying Resistors
AD5410*	8	1	±0.25	100 ns	Serial	RU-16	10 MHz Bandwidth, 50 MHz Serial, 4-Quadrant Multiplying Resistors
AD5413*	8	2	±0.25	100 ns	Serial	RU-24	10 MHz Bandwidth, 50 MHz Serial, 4-Quadrant Multiplying Resistors
AD5424	8	1	±0.25	60 ns	Parallel	RU-16, CP-20	10 MHz Bandwidth, 17 ns $\overline{CS}$ Pulse Width
AD5425	8	1	±0.25	100 ns	Serial	RM-10	Byte Load, 10 MHz Bandwidth, 50 MHz Serial
AD5426	8	1	±0.25	100 ns	Serial	RM-10	10 MHz Bandwidth, 50 MHz Serial
AD5428	8	2	±0.25	60 ns	Parallel	RU-20	10 MHz Bandwidth, 17 ns $\overline{CS}$ Pulse Width
AD5429	8	2	±0.25	100 ns	Serial	RU-10	10 MHz Bandwidth, 50 MHz Serial
AD5450	8	1	±0.25	100 ns	Serial	RJ-8	10 MHz Bandwidth, 50 MHz Serial
AD5404*	10	2	±0.5	70 ns	Parallel	CP-40	10 MHz Bandwidth, 17 ns $\overline{CS}$ Pulse Width, 4-Quadrant Multiplying Resistors
AD5411*	10	1	±0.5	110 ns	Serial	RU-16	10 MHz Bandwidth, 50 MHz Serial, 4-Quadrant Multiplying Resistors
AD5414*	10	2	±0.5	110 ns	Serial	RU-24	10 MHz Bandwidth, 50 MHz Serial, 4-Quadrant Multiplying Resistors
AD5432	10	1	±0.5	110 ns	Serial	RM-10	10 MHz Bandwidth, 50 MHz Serial
AD5433	10	1	±0.5	70 ns	Parallel	RU-20, CP-20	10 MHz Bandwidth, 17 ns $\overline{CS}$ Pulse Width
AD5439	10	2	±0.5	110 ns	Serial	RU-16	10 MHz Bandwidth, 50 MHz Serial
AD5440	10	2	±0.5	70 ns	Parallel	RU-24	10 MHz Bandwidth, 17 ns $\overline{CS}$ Pulse Width
AD5451	10	1	±0.25	110 ns	Serial	RJ-8	10 MHz Bandwidth, 50 MHz Serial
AD5405	12	2	±1	120 ns	Parallel	CP-40	10 MHz Bandwidth, 17 ns $\overline{CS}$ Pulse Width, 4-Quadrant Multiplying Resistors
AD5412*	12	1	±1	160 ns	Serial	RU-16	10 MHz Bandwidth, 50 MHz Serial, 4-Quadrant Multiplying Resistors
AD5415	12	2	±1	160 ns	Serial	RU-24	10 MHz Bandwidth, 50 MHz Serial, 4-Quadrant Multiplying Resistors
AD5443	12	1	±1	160 ns	Serial	RM-10	10 MHz Bandwidth, 50 MHz Serial
AD5444	12	1	±0.5	160 ns	Serial	RM-10	10 MHz Bandwidth, 50 MHz Serial
AD5445	12	1	±1	120 ns	Parallel	RU-20, CP-20	10 MHz Bandwidth, 17 ns $\overline{CS}$ Pulse Width
AD5446	14	1	±2	180 ns	Serial	RM-10	10 MHz Bandwidth, 50 MHz Serial
AD5447	12	2	±1	120 ns	Parallel	RU-24	10 MHz Bandwidth, 17 ns $\overline{CS}$ Pulse Width
AD5449	12	2	±1	160 ns	Serial	RU-16	10 MHz Bandwidth, 17 ns $\overline{CS}$ Pulse Width
AD5452	12	1	±0.5	160 ns	Serial	RJ-8, RM-8	10 MHz Bandwidth, 50 MHz Serial
AD5453	14	1	±2	180 ns	Serial	RJ-8, RM-8	10 MHz Bandwidth, 50 MHz Serial

*Future parts, contact factory for availability

OUTLINE DIMENSIONS

10-Lead Mini Small Outline Package [MSOP]
(RM-10)

Dimensions shown in millimeters



COMPLIANT TO JEDEC STANDARDS MO-187BA

D03161–0–1/04(0)