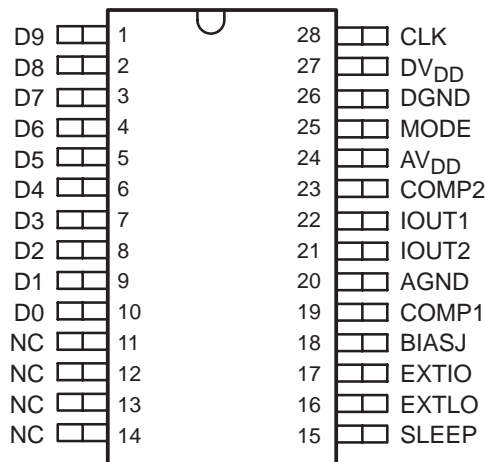


- **Member of the Pin-Compatible CommsDAC™ Product Family**
- **125 MSPS Update Rate**
- **10-Bit Resolution**
- **Superior Spurious Free Dynamic Range Performance (SFDR) to Nyquist at 40 MHz Output: 62 dBc**
- **1 ns Setup/Hold Time**
- **Differential Scalable Current Outputs: 2 mA to 20 mA**
- **On-Chip 1.2-V Reference**
- **3 V and 5 V CMOS-Compatible Digital Interface**
- **Straight Binary or Twos Complement Input**
- **Power Dissipation: 175 mW at 5 V, Sleep Mode: 25 mW at 5 V**
- **Package: 28-Pin SOIC and TSSOP**

**SOIC (DW) OR TSSOP (PW) PACKAGE  
(TOP VIEW)**



NC – No internal connection

## description

The THS5651A is a 10-bit resolution digital-to-analog converter (DAC) specifically optimized for digital data transmission in wired and wireless communication systems. The 10-bit DAC is a member of the CommsDAC series of high-speed, low-power CMOS digital-to-analog converters. The CommsDAC family consists of pin compatible 14-, 12-, 10-, and 8-bit DACs. All devices offer identical interface options, small outline package and pinout. The THS5651A offers superior ac and dc performance while supporting update rates up to 125 MSPS.

The THS5651A operates from an analog supply of 4.5 V to 5.5 V. Its inherent low power dissipation of 175 mW ensures that the device is well suited for portable and low-power applications. Lowering the full-scale current output reduces the power dissipation without significantly degrading performance. The device features a SLEEP mode, which reduces the standby power to approximately 25 mW, thereby optimizing the power consumption for system needs.

The THS5651A is manufactured in Texas Instruments advanced high-speed mixed-signal CMOS process. A current-source-array architecture combined with simultaneous switching shows excellent dynamic performance. On-chip edge-triggered input latches and a 1.2 V temperature compensated bandgap reference provide a complete monolithic DAC solution. The digital supply range of 3 V to 5.5 V supports 3 V and 5 V CMOS logic families. Minimum data input setup and hold times allow for easy interfacing with external logic. The THS5651A supports both a straight binary and twos complement input word format, enabling flexible interfacing with digital signal processors.

The THS5651A provides a nominal full-scale differential output current of 20 mA and >300 kΩ output impedance, supporting both single-ended and differential applications. The output current can be directly fed to the load (e.g., external resistor load or transformer), with no additional external output buffer required. An accurate on-chip reference and control amplifier allows the user to adjust this output current from 20 mA down to 2 mA, with no significant degradation of performance. This reduces power consumption and provides 20 dB gain range control capabilities. Alternatively, an external reference voltage and control amplifier may be applied in applications using a multiplying DAC. The output voltage compliance range is 1.25 V.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

CommsDAC is a trademark of Texas Instruments Incorporated.

**PRODUCTION DATA** information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.



POST OFFICE BOX 655303 • DALLAS, TEXAS 75265

Copyright © 2002, Texas Instruments Incorporated

# THS5651A

## 10-BIT, 125 MSPS, CommsDAC™

### DIGITAL-TO-ANALOG CONVERTER

SLAS260A – FEBRUARY 2000 – REVISED SEPTEMBER 2002

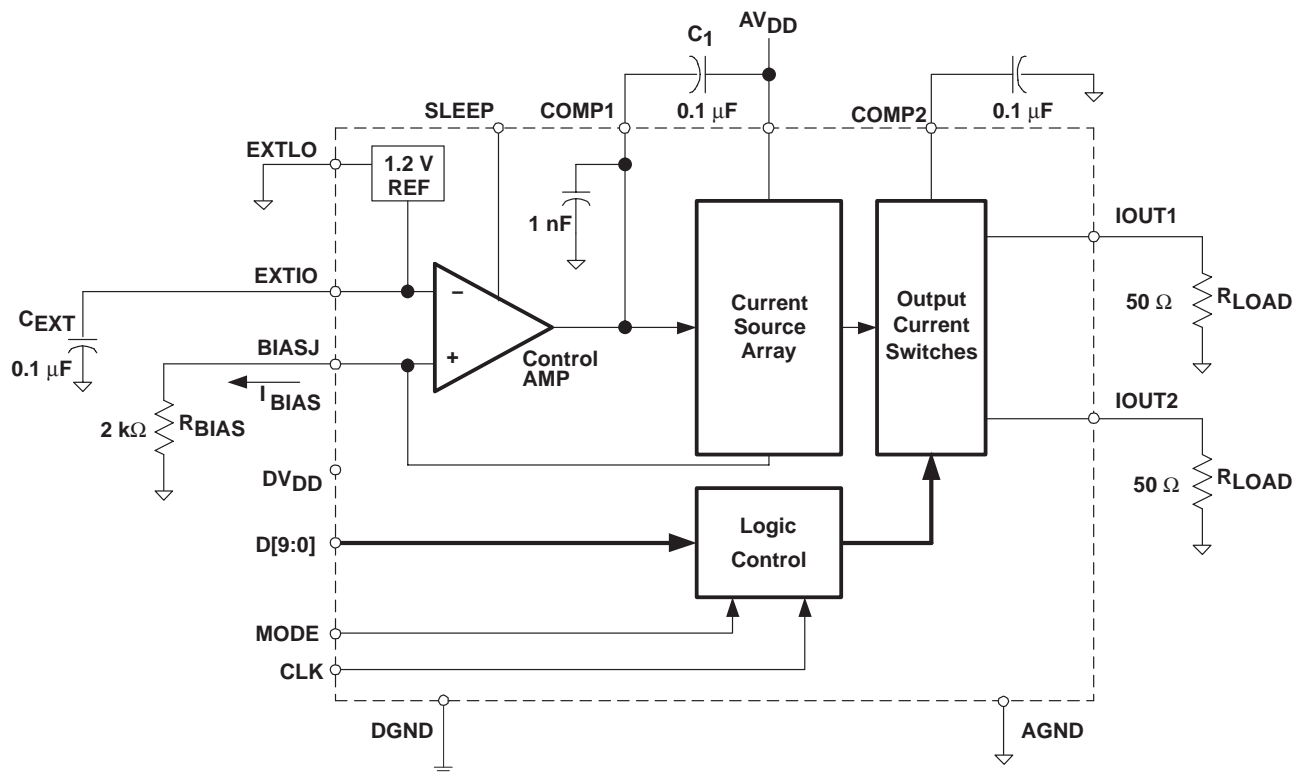
#### description (continued)

The THS5651A is available in both a 28-pin SOIC and TSSOP package. The device is characterized for operation over the industrial temperature range of  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ .

#### AVAILABLE OPTIONS

T <sub>A</sub>	PACKAGE	
	28-TSSOP (PW)	28-SOIC (DW)
$-40^{\circ}\text{C}$ to $85^{\circ}\text{C}$	THS5651AIPW	THS5651AIDW

#### functional block diagram



### Terminal Functions

TERMINAL NAME	NO.	I/O	DESCRIPTION
AGND	20	I	Analog ground return for the internal analog circuitry
AV <sub>DD</sub>	24	I	Positive analog supply voltage (4.5 V to 5.5 V)
BIASJ	18	O	Full-scale output current bias
CLK	28	I	External clock input. Input data latched on rising edge of the clock.
COMP1	19	I	Compensation and decoupling node, requires a 0.1 μF capacitor to AV <sub>DD</sub> .
COMP2	23	I	Internal bias node, requires a 0.1 μF decoupling capacitor to AGND.
D[9:0]	[1:10]	I	Data bits 0 through 9. D9 is most significant data bit (MSB), D0 is least significant data bit (LSB).
DGND	26	I	Digital ground return for the internal digital logic circuitry
DV <sub>DD</sub>	27	I	Positive digital supply voltage (3 V to 5.5 V)
EXTIO	17	I/O	Used as external reference input when internal reference is disabled (i.e., EXTLO = AV <sub>DD</sub> ). Used as internal reference output when EXTLO = AGND, requires a 0.1 μF decoupling capacitor to AGND when used as reference output
EXTLO	16	O	Internal reference ground. Connect to AV <sub>DD</sub> to disable the internal reference source
IOUT1	22	O	DAC current output. Full scale when all input bits are set 1
IOUT2	21	O	Complementary DAC current output. Full scale when all input bits are 0
MODE	25	I	Mode select. Internal pulldown. Mode 0 is selected if this pin is left floating or connected to DGND. See timing diagram.
NC	[11:14]	N	No connection
SLEEP	15	I	Asynchronous hardware power down input. Active High. Internal pulldown. Requires 5 μs to power down but 3 ms to power up.

#### absolute maximum ratings over operating free-air temperature (unless otherwise noted)†

Supply voltage range, AV <sub>DD</sub> (see Note 1)	–0.3 V to 6.5 V
DV <sub>DD</sub> (see Note 2)	–0.3 V to 6.5 V
Voltage between AGND and DGND	–0.3 V to 0.5 V
Supply voltage range, AV <sub>DD</sub> to DV <sub>DD</sub>	–6.5 V to 6.5 V
CLK, SLEEP, MODE (see Note 2)	–0.3 V to DV <sub>DD</sub> + 0.3 V
Digital input D9–D0 (see Note 2)	–0.3 V to DV <sub>DD</sub> + 0.3 V
IOUT1, IOUT2 (see Note 1)	–1 V to AV <sub>DD</sub> + 0.3 V
COMP1, COMP2 (see Note 1)	–0.3 V to AV <sub>DD</sub> + 0.3 V
EXTIO, BIASJ (see Note 1)	–0.3 V to AV <sub>DD</sub> + 0.3 V
EXTLO (see Note 1)	–0.3 V to 0.3 V
Peak input current (any input)	20 mA
Peak total input current (all inputs)	–30 mA
Operating free-air temperature range, T <sub>A</sub> : THS5651AI	–40°C to 85°C
Storage temperature range	–65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from the case for 10 seconds	260°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

- NOTES: 1. Measured with respect to AGND.  
 2. Measured with respect to DGND.

**THS5651A**  
**10-BIT, 125 MSPS, CommsDAC™**  
**DIGITAL-TO-ANALOG CONVERTER**

SLAS260A – FEBRUARY 2000 – REVISED SEPTEMBER 2002

electrical characteristics over recommended operating free-air temperature range,  $AV_{DD} = 5\text{ V}$ ,  $DV_{DD} = 5\text{ V}$ ,  $I_{OUTFS} = 20\text{ mA}$  (unless otherwise noted)

**dc specifications**

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>Resolution</b>			10			Bits
<b>DC accuracy†</b>						
INL	Integral nonlinearity	$T_A = -40^\circ\text{C to } 85^\circ\text{C}$	-1	$\pm 0.5$	1	LSB
DNL	Differential nonlinearity		-0.5	$\pm 0.25$	0.5	LSB
<b>Monotonicity</b>			Monotonic			
<b>Analog output</b>						
Offset error			0.02			%FSR
Gain error	Without internal reference		2.3			%FSR
	With internal reference		1.3			
Full scale output current‡			2		20	mA
Output compliance range		$AV_{DD} = 5\text{ V}, I_{OUTFS} = 20\text{ mA}$	-1		1.25	V
Output resistance			300			k $\Omega$
Output capacitance			5			pF
<b>Reference output</b>						
Reference voltage			1.18	1.22	1.32	V
Reference output current§			100			nA
<b>Reference input</b>						
V <sub>EXTIO</sub>	Input voltage range		0.1		1.25	V
Input resistance			1			M $\Omega$
Small signal bandwidth¶		Without C <sub>COMP1</sub>	1.3			MHz
Input capacitance			100			pF
<b>Temperature coefficients</b>						
Offset drift			0			ppm of FSR/°C
Gain drift	Without internal reference		$\pm 40$			
	With internal reference		$\pm 120$			
Reference voltage drift			$\pm 35$			
<b>Power supply</b>						
AV <sub>DD</sub>	Analog supply voltage		4.5	5	5.5	V
DV <sub>DD</sub>	Digital supply voltage		3		5.5	V
I <sub>AVDD</sub>	Analog supply current		25 30			mA
	Sleep mode supply current	Sleep mode	3 5			mA
I <sub>DVDD</sub>	Digital supply current#		5 6			mA
Power dissipation		$AV_{DD} = 5\text{ V}, DV_{DD} = 5\text{ V}, I_{OUTFS} = 20\text{ mA}$	175			mW
AV <sub>DD</sub>	Power supply rejection ratio		$\pm 0.4$			%FSR/V
DV <sub>DD</sub>			$\pm 0.025$			
Operating range			-40		85	°C

† Measured at IOUT1 in virtual ground configuration.

‡ Nominal full-scale current IOUTFS equals 32X the IBIAS current.

§ Use an external buffer amplifier with high impedance input to drive any external load.

¶ Reference bandwidth is a function of external cap at COMP1 pin and signal level.

# Measured at fCLK = 50 MSPS and fOUT = 1 MHz.

|| Measured for 50  $\Omega$  RLOAD at IOUT1 and IOUT2, fCLK = 50 MSPS and fOUT = 20 MHz.

Specifications subject to change



electrical characteristics over recommended operating free-air temperature range,  $AV_{DD} = 5\text{ V}$ ,  $DV_{DD} = 5\text{ V}$ ,  $I_{OUTFS} = 20\text{ mA}$ , differential transformer coupled output,  $50\ \Omega$  doubly terminated load (unless otherwise noted)

**ac specifications**

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>Analog output</b>						
$f_{CLK}$	Maximum output update rate	$DV_{DD} = 4.5\text{ V to }5.5\text{ V}$	100	125		MSPS
		$DV_{DD} = 3\text{ V to }3.6\text{ V}$	70	100		
$t_s(DAC)$	Output settling time to 0.1%†			35		ns
$t_{pd}$	Output propagation delay			1		ns
GE	Glitch energy‡	Worst case LSB transition (code 511 – code 512)		5		pV–s
$t_r(I_{OUT})$	Output rise time 10% to 90%†			1		ns
$t_f(I_{OUT})$	Output fall time 90% to 10%†			1		ns
Output noise		$I_{OUTFS} = 20\text{ mA}$		15		pA/ $\sqrt{Hz}$
		$I_{OUTFS} = 2\text{ mA}$		10		
<b>AC linearity§</b>						
THD	Total harmonic distortion	$f_{CLK} = 25\text{ MSPS}, f_{OUT} = 1\text{ MHz}, T_A = 25^\circ\text{C}$		-72		dBc
		$f_{CLK} = 50\text{ MSPS}, f_{OUT} = 1\text{ MHz}, T_A = -40^\circ\text{C to }85^\circ\text{C}$		-72	-64	
		$f_{CLK} = 50\text{ MSPS}, f_{OUT} = 2\text{ MHz}, T_A = 25^\circ\text{C}$		-70		
		$f_{CLK} = 100\text{ MSPS}, f_{OUT} = 2\text{ MHz}, T_A = 25^\circ\text{C}$		-70		
SFDR	Spurious free dynamic range to Nyquist	$f_{CLK} = 25\text{ MSPS}, f_{OUT} = 1\text{ MHz}, T_A = 25^\circ\text{C}$		79		dBc
		$f_{CLK} = 50\text{ MSPS}, f_{OUT} = 1\text{ MHz}, T_A = -40^\circ\text{C to }85^\circ\text{C}$		66		
		$f_{CLK} = 50\text{ MSPS}, f_{OUT} = 1\text{ MHz}, T_A = 25^\circ\text{C}$		77		
		$f_{CLK} = 50\text{ MSPS}, f_{OUT} = 2.51\text{ MHz}, T_A = 25^\circ\text{C}$		75		
		$f_{CLK} = 50\text{ MSPS}, f_{OUT} = 5.02\text{ MHz}, T_A = 25^\circ\text{C}$		71		
		$f_{CLK} = 50\text{ MSPS}, f_{OUT} = 20.2\text{ MHz}, T_A = 25^\circ\text{C}$		58		
		$f_{CLK} = 100\text{ MSPS}, f_{OUT} = 5.04\text{ MHz}, T_A = 25^\circ\text{C}$		69		
		$f_{CLK} = 100\text{ MSPS}, f_{OUT} = 20.2\text{ MHz}, T_A = 25^\circ\text{C}$		61		
	Spurious free dynamic range within a window	$f_{CLK} = 100\text{ MSPS}, f_{OUT} = 40.4\text{ MHz}, T_A = 25^\circ\text{C}$		62		
		$f_{CLK} = 50\text{ MSPS}, f_{OUT} = 1\text{ MHz}, T_A = 25^\circ\text{C}, 1\text{ MHz span}$		82		dBc
$f_{CLK} = 50\text{ MSPS}, f_{OUT} = 5.02\text{ MHz}, 2\text{ MHz span}$			81			
$f_{CLK} = 100\text{ MSPS}, f_{OUT} = 5.04\text{ MHz}, 4\text{ MHz span}$		78				

† Measured single ended into  $50\ \Omega$  load at  $I_{OUT1}$ .

‡ Single-ended output  $I_{OUT1}$ ,  $50\ \Omega$  doubly terminated load.

§ Measured with a 50%/50% duty cycle (high/low percentage of the clock). Optimum ac linearity is obtained when limiting the duty cycle to a range from 45%/55% to 55%/45%.

**THS5651A**  
**10-BIT, 125 MSPS, CommsDAC™**  
**DIGITAL-TO-ANALOG CONVERTER**

SLAS260A – FEBRUARY 2000 – REVISED SEPTEMBER 2002

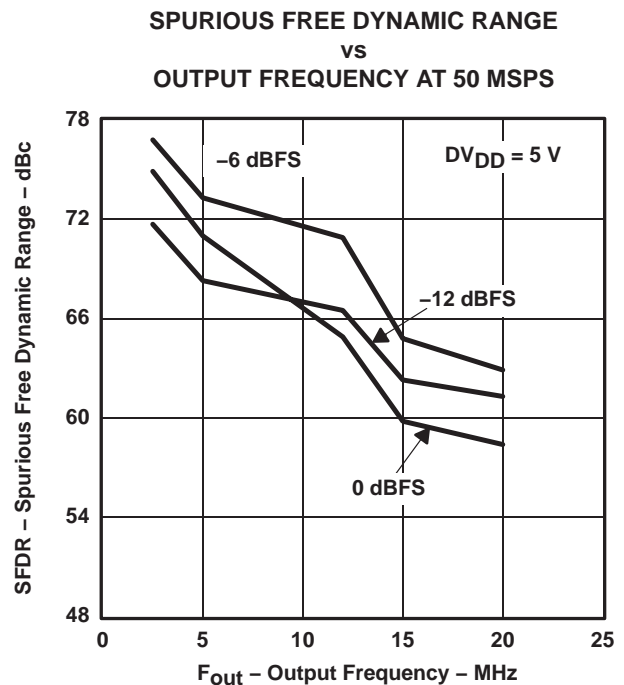
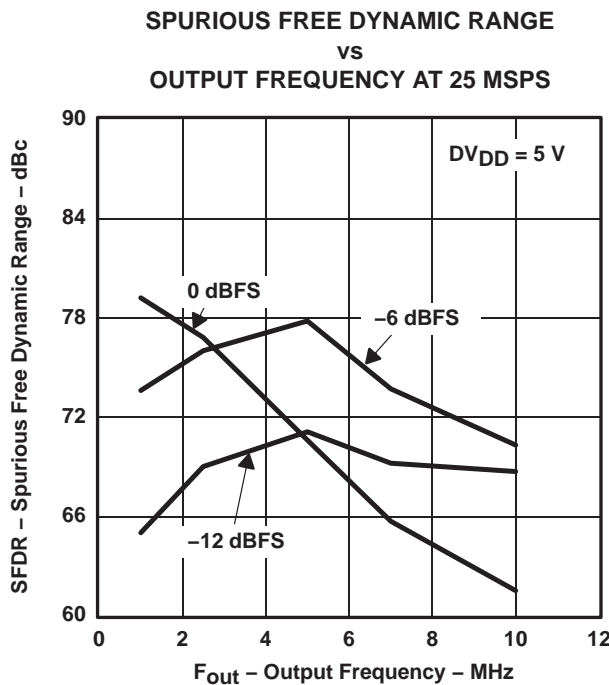
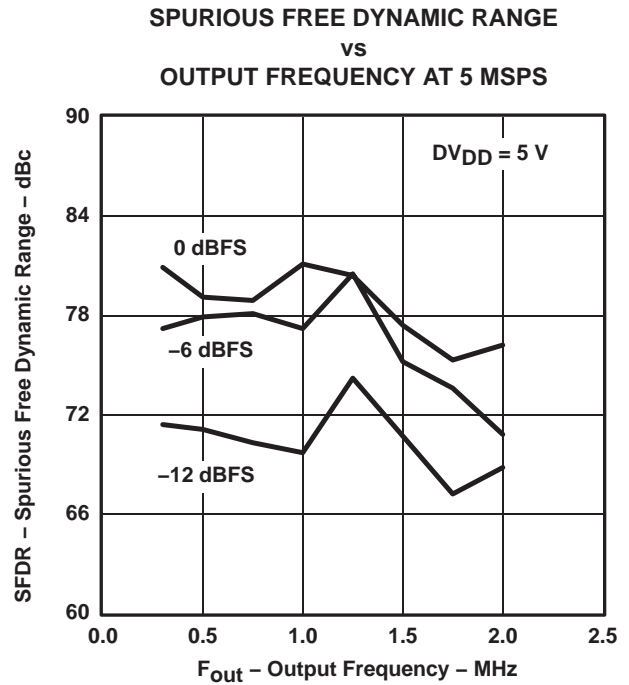
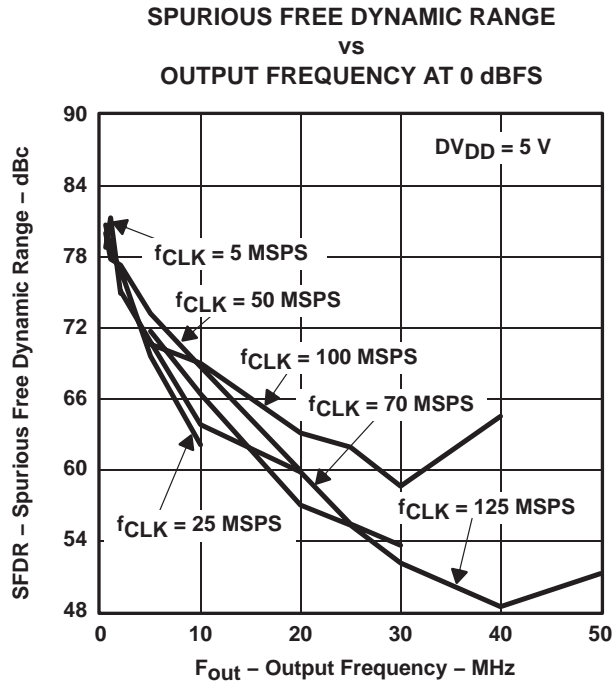
electrical characteristics over recommended operating free-air temperature range,  $AV_{DD} = 5\text{ V}$ ,  $DV_{DD} = 5\text{ V}$ ,  $IOUT_{FS} = 20\text{ mA}$  (unless otherwise noted)

**digital specifications**

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT	
<b>Interface</b>							
$V_{IH}$	High-level input voltage	$DV_{DD} = 5\text{ V}$	3.5	5		V	
		$DV_{DD} = 3.3\text{ V}$	2.1	3.3			
$V_{IL}$	Low-level input voltage	$DV_{DD} = 5\text{ V}$		0	1.3	V	
		$DV_{DD} = 3.3\text{ V}$		0	0.9		
$I_{IH}$	High-level input current	MODE and SLEEP	$DV_{DD} = 3\text{ V to }5.5\text{ V}$		-15	15	$\mu\text{A}$
		All other digital pins	$DV_{DD} = 3\text{ V to }5.5\text{ V}$		-10	10	
$I_{IL}$	Low-level input current	MODE and SLEEP	$DV_{DD} = 3\text{ V to }5.5\text{ V}$		-15	15	$\mu\text{A}$
		All other digital pins	$DV_{DD} = 3\text{ V to }5.5\text{ V}$		-10	10	
$C_I$	Input capacitance		1		5	pF	
<b>Timing</b>							
$t_{su(D)}$	Input setup time		1			ns	
$t_h(D)$	Input hold time		1			ns	
$t_w(LPH)$	Input latch pulse high time		4			ns	
$t_d(D)$	Digital delay time				1	clk	

Specifications subject to change

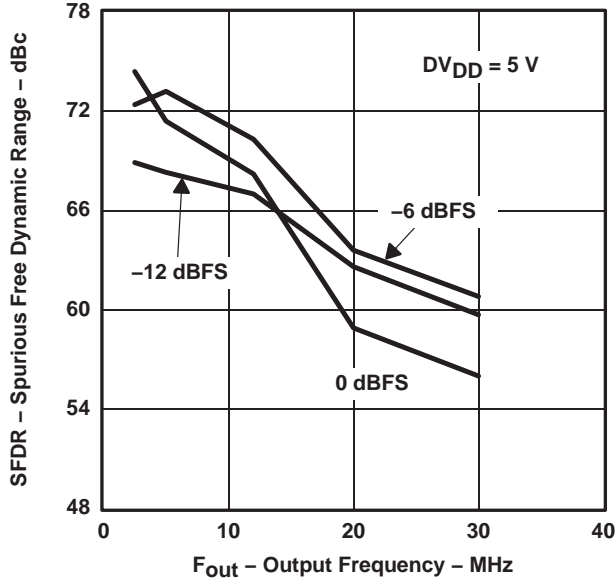
**TYPICAL CHARACTERISTICS†**



†  $A_{V_{DD}} = 5\text{ V}$ ,  $I_{OUTFS} = 20\text{ mA}$ , differential transformer coupled output,  $50\ \Omega$  doubly terminated load,  $T_A = 25^\circ\text{C}$  (unless otherwise noted.)

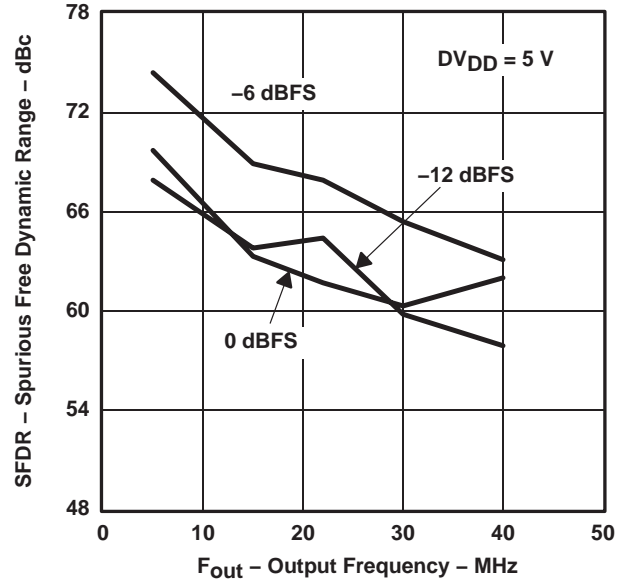
**TYPICAL CHARACTERISTICS†**

**SPURIOUS FREE DYNAMIC RANGE  
 vs  
 OUTPUT FREQUENCY AT 70 MSPS**



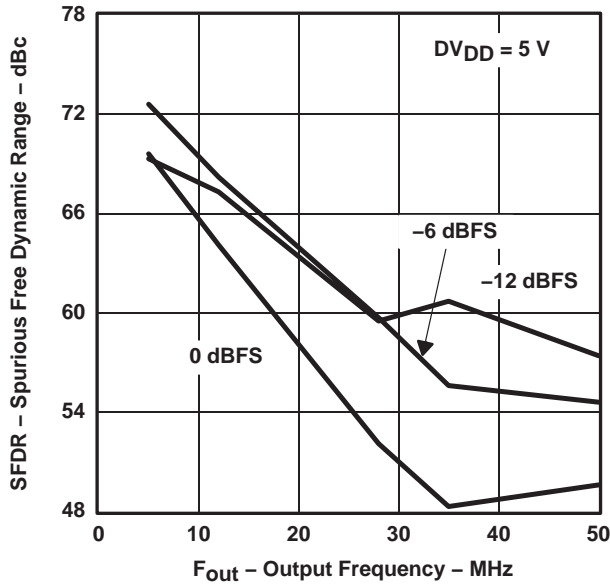
**Figure 5**

**SPURIOUS FREE DYNAMIC RANGE  
 vs  
 OUTPUT FREQUENCY AT 100 MSPS**



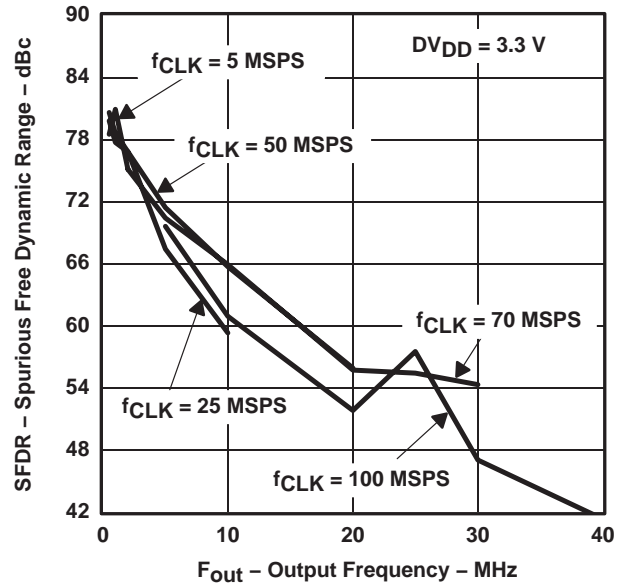
**Figure 6**

**SPURIOUS FREE DYNAMIC RANGE  
 vs  
 OUTPUT FREQUENCY AT 125 MSPS**



**Figure 7**

**SPURIOUS FREE DYNAMIC RANGE  
 vs  
 OUTPUT FREQUENCY AT 0 dBFS**



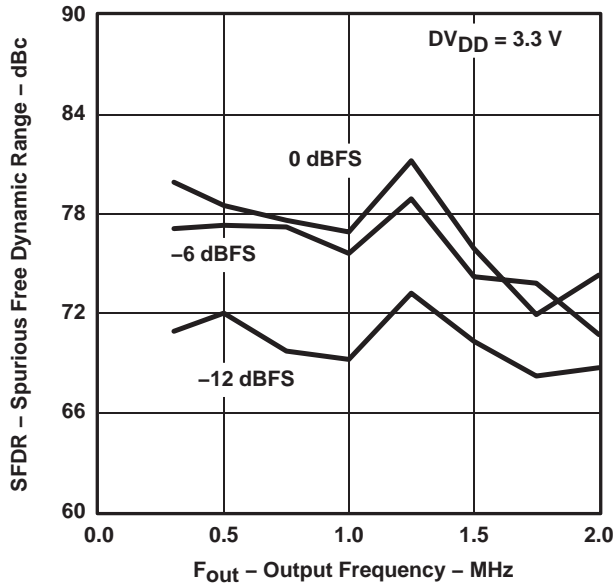
**Figure 8**

†  $AV_{DD} = 5\text{ V}$ ,  $IO_{TFS} = 20\text{ mA}$ , differential transformer coupled output,  $50\ \Omega$  doubly terminated load,  $T_A = 25^\circ\text{C}$  (unless otherwise noted.)



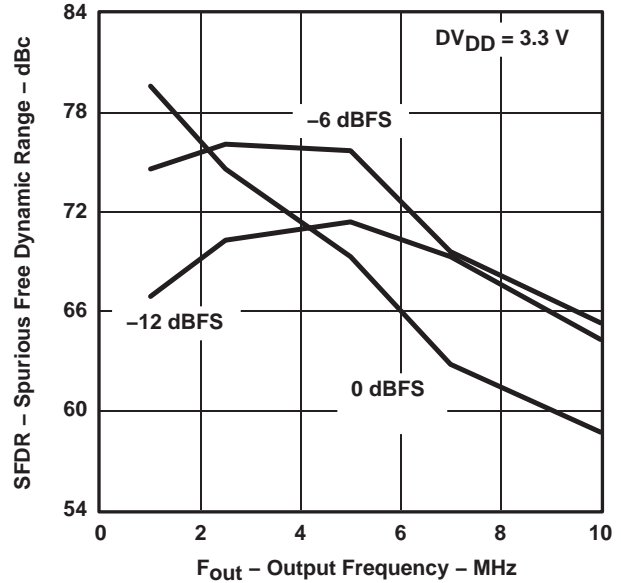
**TYPICAL CHARACTERISTICS†**

**SPURIOUS FREE DYNAMIC RANGE  
vs  
OUTPUT FREQUENCY AT 5 MSPS**



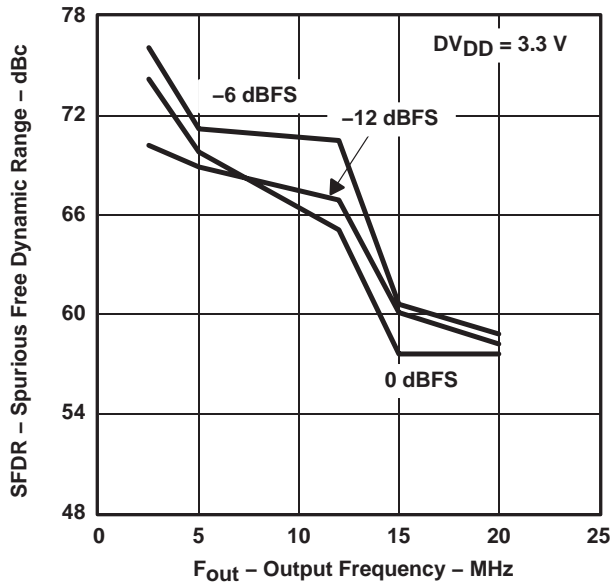
**Figure 9**

**SPURIOUS FREE DYNAMIC RANGE  
vs  
OUTPUT FREQUENCY AT 25 MSPS**



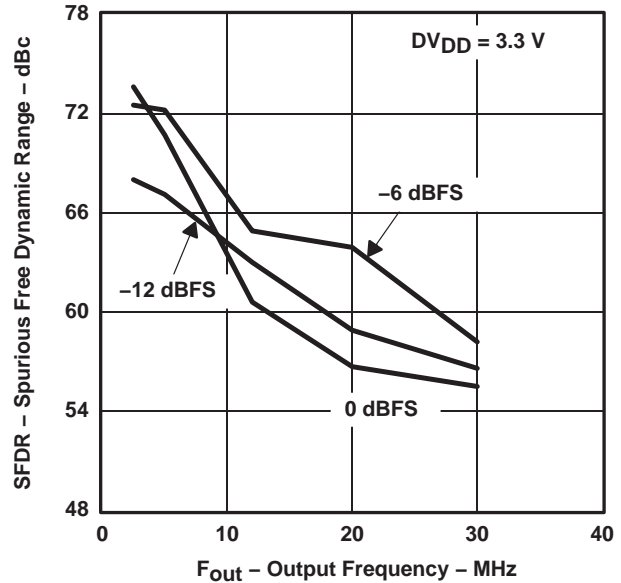
**Figure 10**

**SPURIOUS FREE DYNAMIC RANGE  
vs  
OUTPUT FREQUENCY AT 50 MSPS**



**Figure 11**

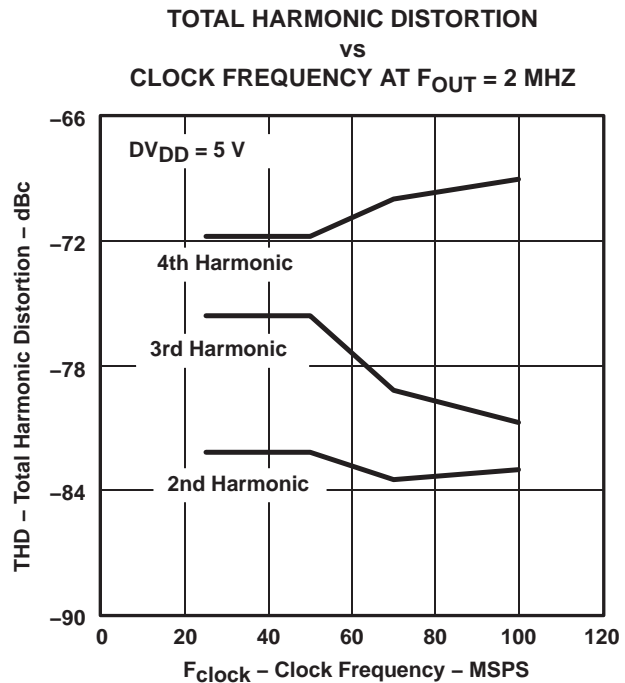
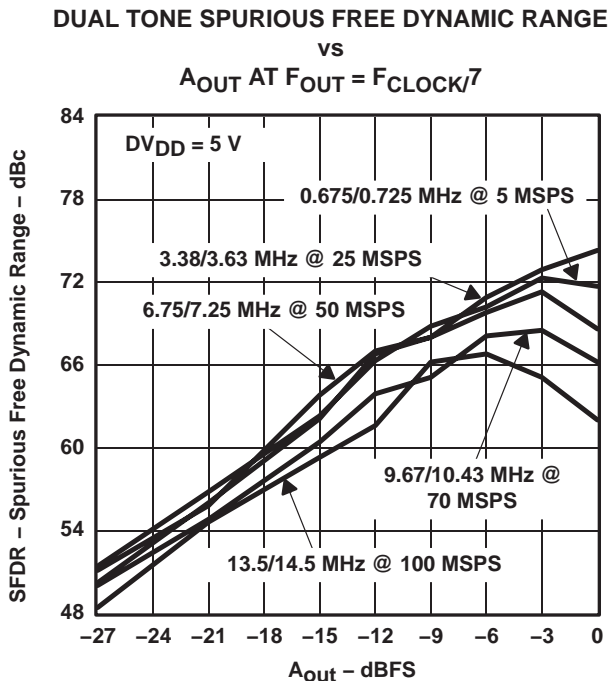
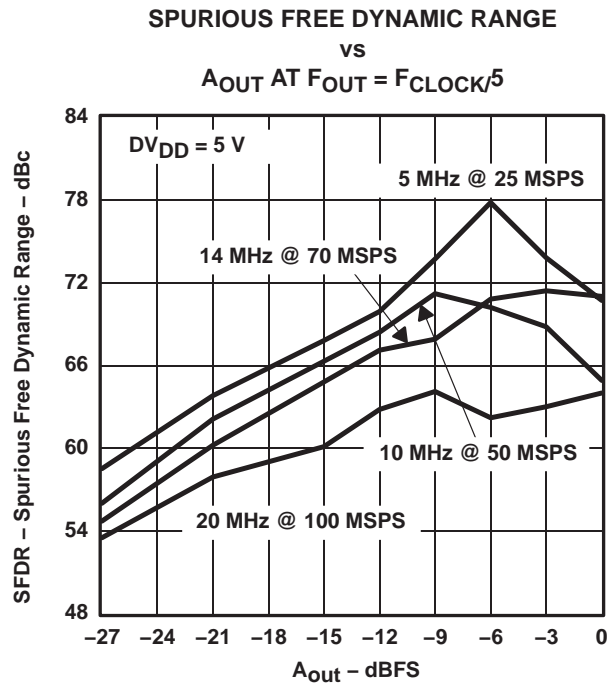
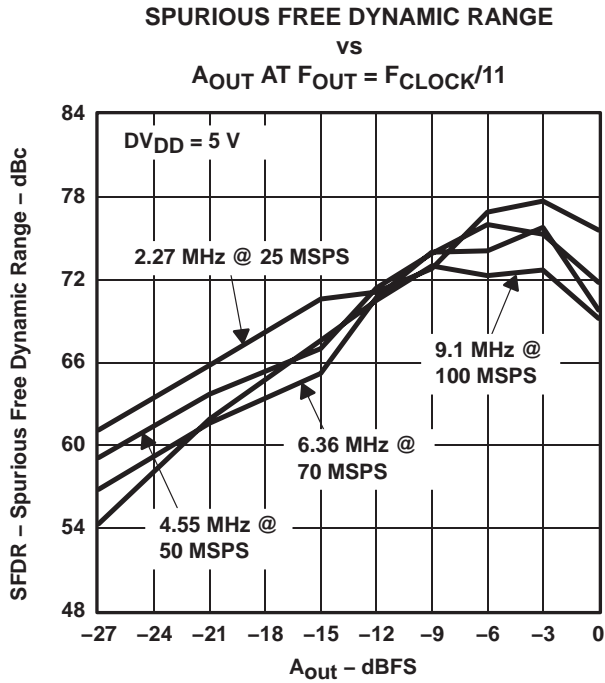
**SPURIOUS FREE DYNAMIC RANGE  
vs  
OUTPUT FREQUENCY AT 70 MSPS**



**Figure 12**

†  $AV_{DD} = 5\text{ V}$ ,  $I_{OUTFS} = 20\text{ mA}$ , differential transformer coupled output,  $50\ \Omega$  doubly terminated load,  $T_A = 25^\circ\text{C}$  (unless otherwise noted.)

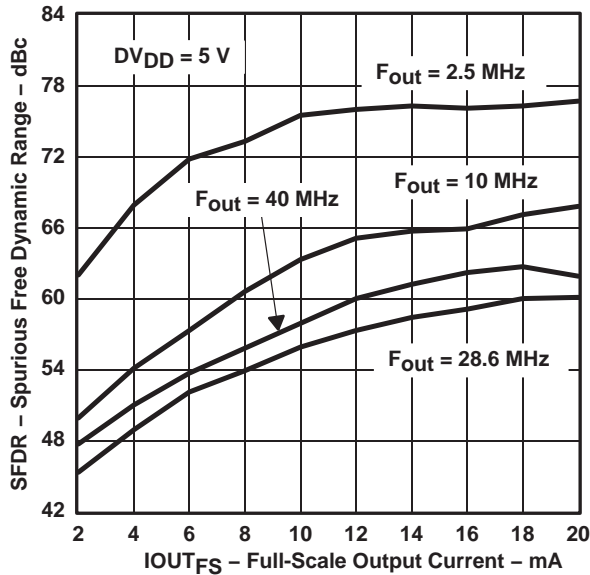
**TYPICAL CHARACTERISTICS†**



†  $V_{DD} = 5\text{ V}$ ,  $I_{OUTFS} = 20\text{ mA}$ , differential transformer coupled output,  $50\ \Omega$  doubly terminated load,  $T_A = 25^\circ\text{C}$  (unless otherwise noted.)

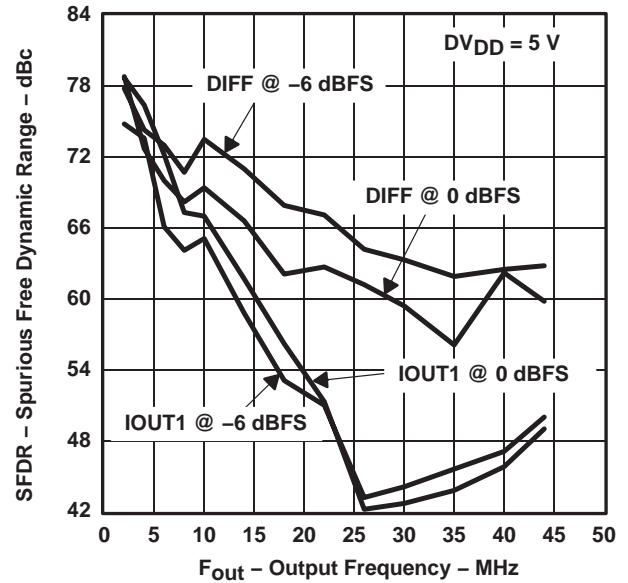
**TYPICAL CHARACTERISTICS†**

**SPURIOUS FREE DYNAMIC RANGE  
vs  
FULL-SCALE OUTPUT CURRENT AT 100 MSPS**



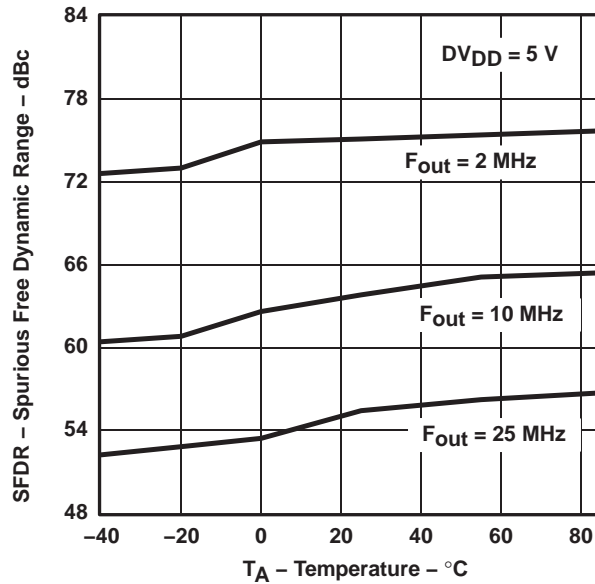
**Figure 17**

**SPURIOUS FREE DYNAMIC RANGE  
vs  
OUTPUT FREQUENCY AT 100 MSPS**



**Figure 18**

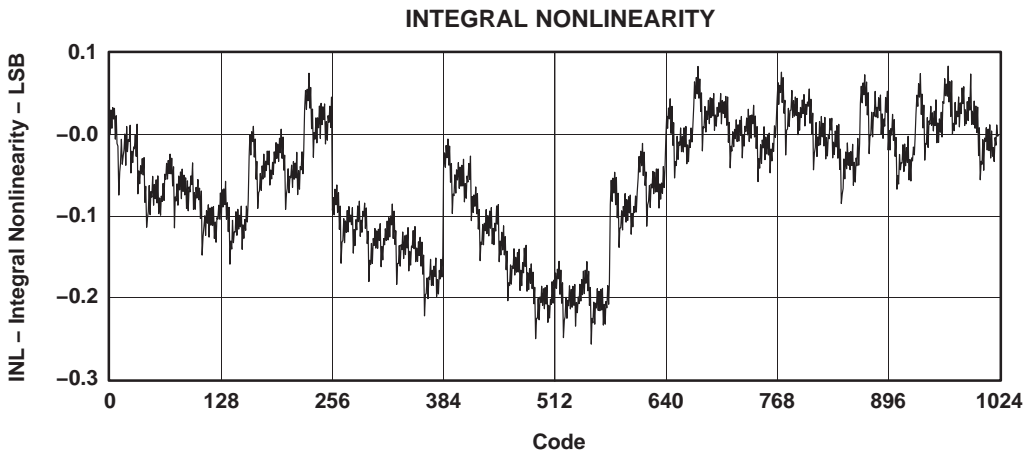
**SPURIOUS FREE DYNAMIC RANGE  
vs  
TEMPERATURE AT 70 MSPS**



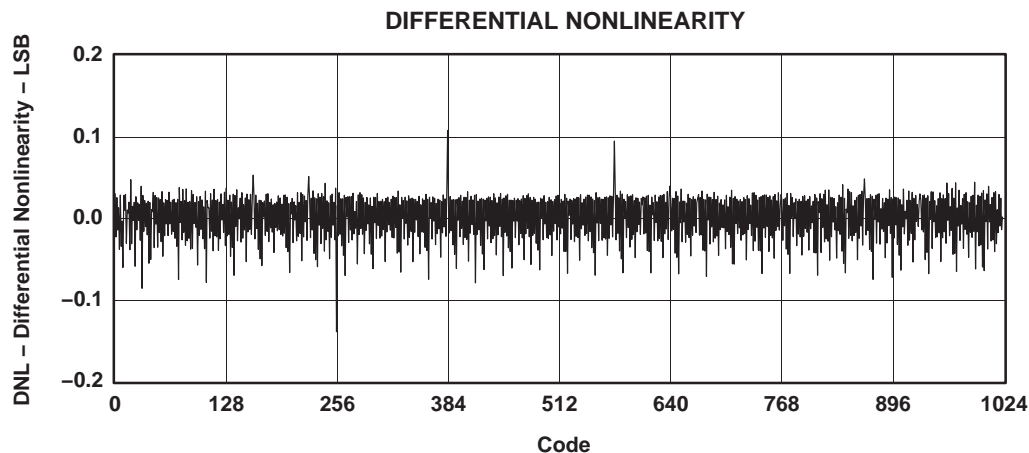
**Figure 19**

†  $A_{V_{DD}} = 5\text{ V}$ ,  $I_{OUT_{FS}} = 20\text{ mA}$ , differential transformer coupled output,  $50\ \Omega$  doubly terminated load,  $T_A = 25^\circ\text{C}$  (unless otherwise noted.)

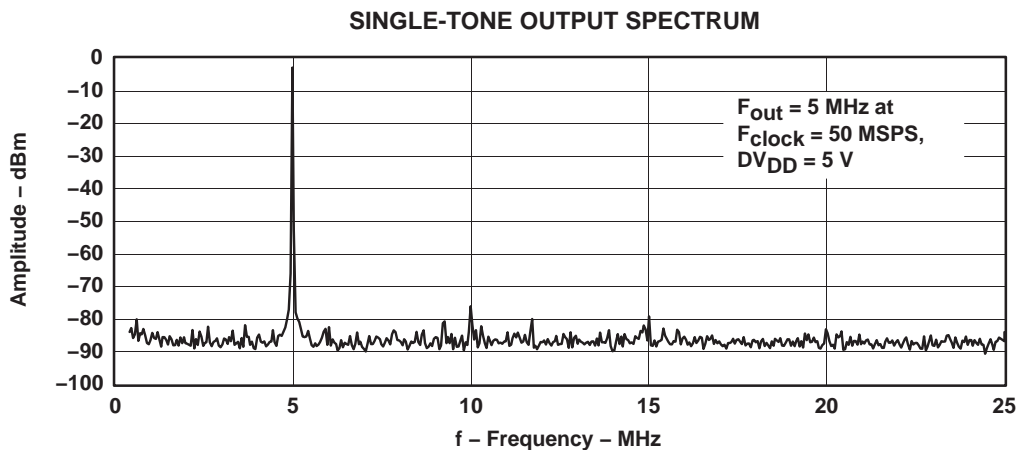
**TYPICAL CHARACTERISTICS†**



**Figure 20**



**Figure 21**



**Figure 22**

†  $V_{DD} = 5\text{ V}$ ,  $I_{OUTFS} = 20\text{ mA}$ , differential transformer coupled output,  $50\ \Omega$  doubly terminated load,  $T_A = 25^\circ\text{C}$  (unless otherwise noted.)

**TYPICAL CHARACTERISTICS†**

**SINGLE-TONE OUTPUT SPECTRUM**

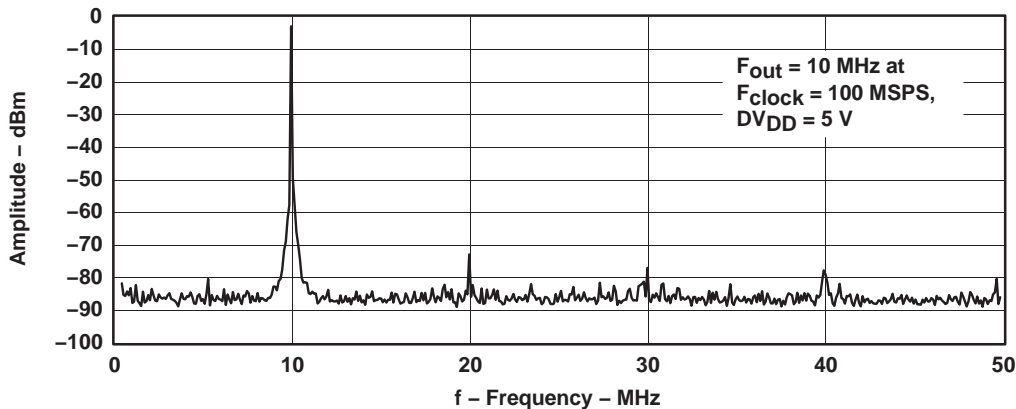


Figure 23

**DUAL-TONE OUTPUT SPECTRUM**

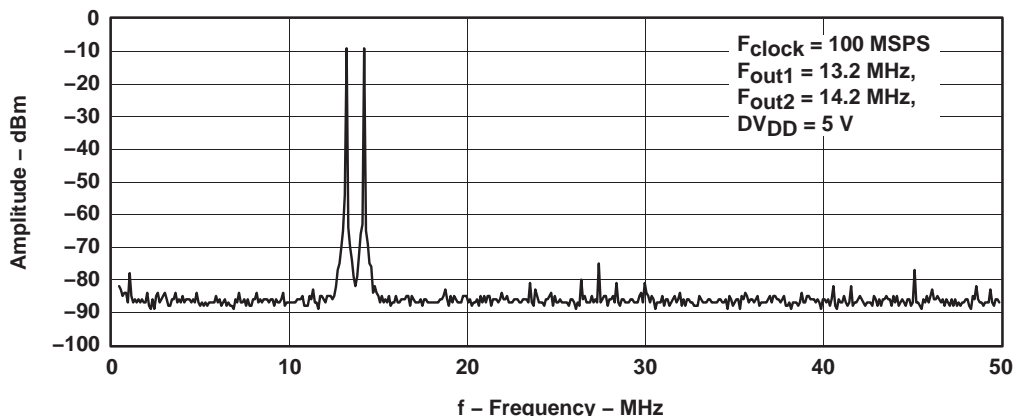


Figure 24

**FOUR-TONE OUTPUT SPECTRUM**

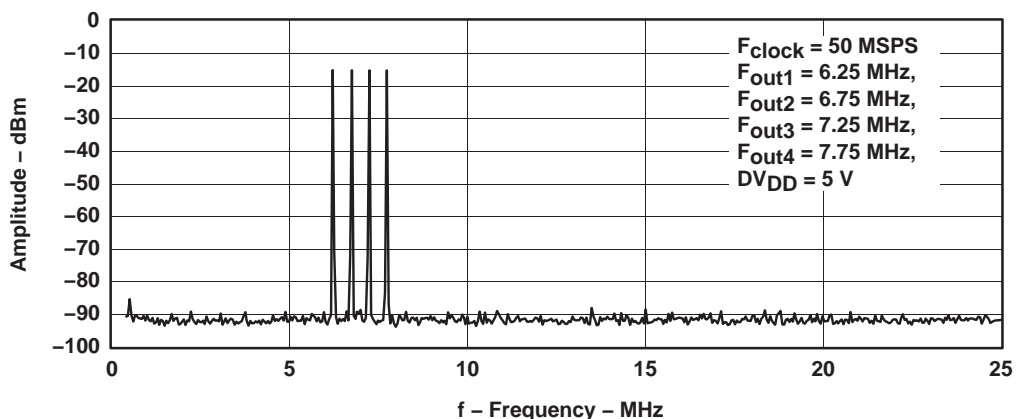
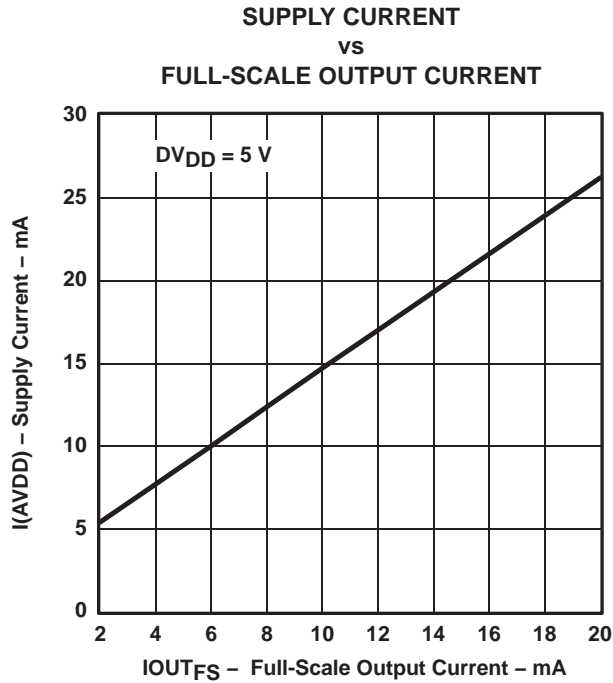


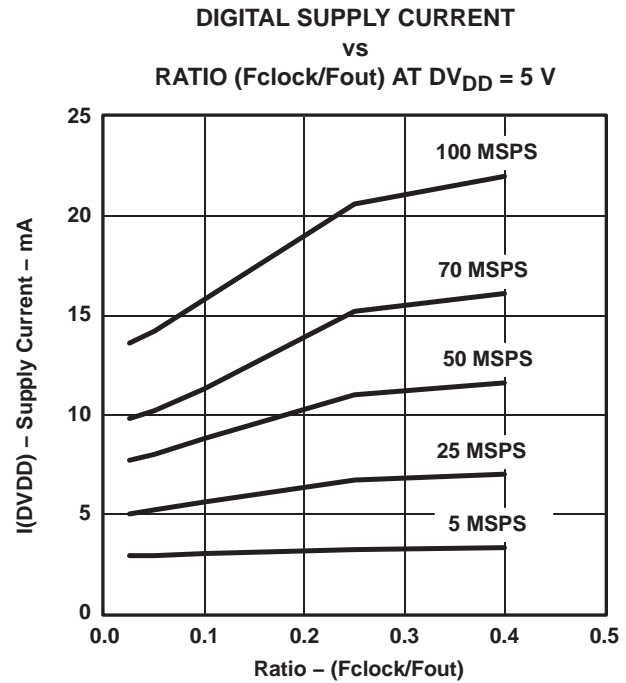
Figure 25

†  $AV_{DD} = 5 \text{ V}$ ,  $I_{OUTFS} = 20 \text{ mA}$ , differential transformer coupled output,  $50 \Omega$  doubly terminated load,  $T_A = 25^\circ\text{C}$  (unless otherwise noted.)

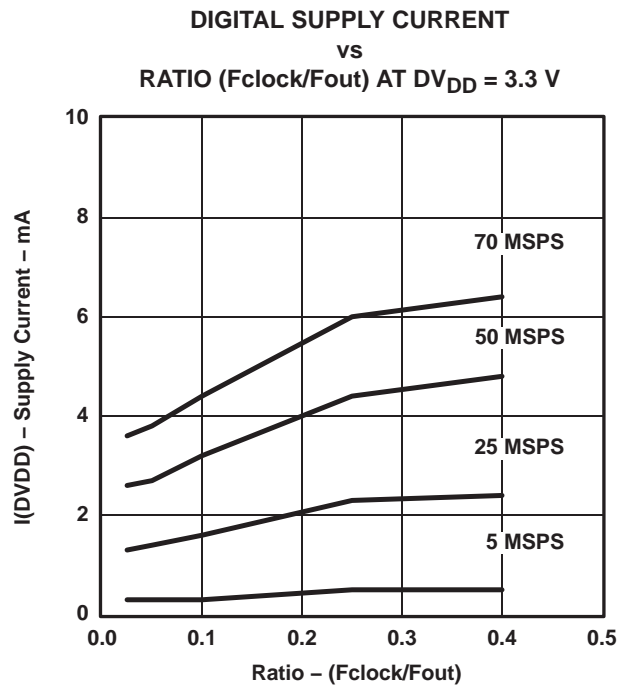
**TYPICAL CHARACTERISTICS†**



**Figure 26**



**Figure 27**



**Figure 28**

## APPLICATION INFORMATION

The THS5651A architecture is based on current steering, combining high update rates with low power consumption. The CMOS device consists of a segmented array of PMOS transistor current sources, which are capable of delivering a full-scale current up to 20 mA. High-speed differential current switches direct the current of each current source to either one of the output nodes, IOUT1 or IOUT2. The complementary output currents thus enable differential operation, canceling out common mode noise sources (on-chip and PCB noise), dc offsets, even order distortion components, and increase signal output power by a factor of two. Major advantages of the segmented architecture are minimum glitch energy, excellent DNL, and very good dynamic performance. The DAC's high output impedance of >300 k $\Omega$  and fast switching result in excellent dynamic linearity (spurious free dynamic range SFDR).

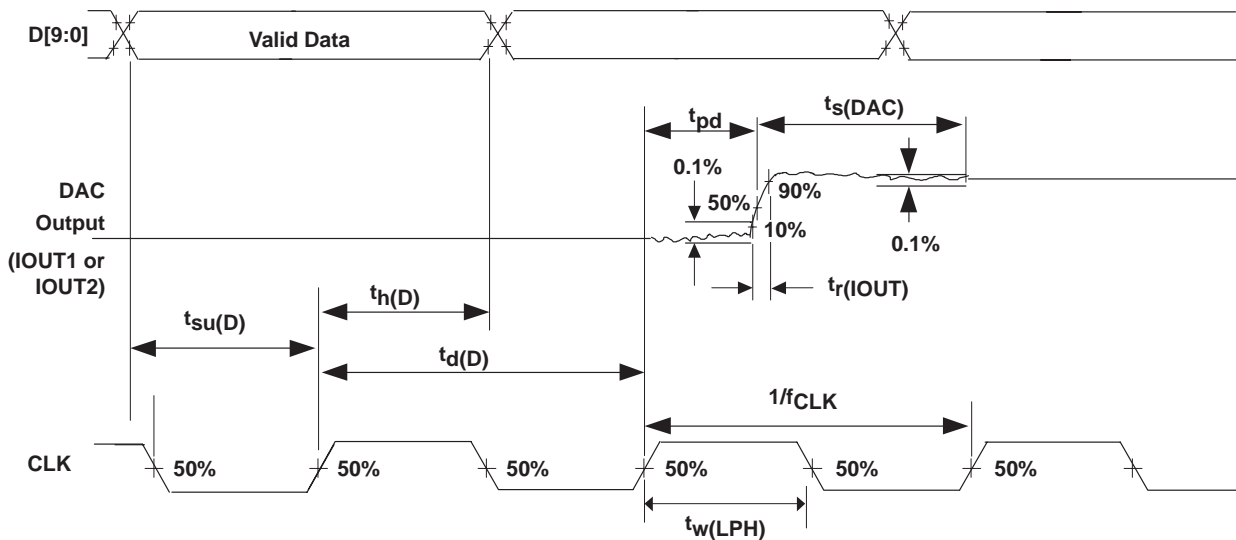
The full-scale output current is set using an external resistor  $R_{BIAS}$  in combination with an on-chip bandgap voltage reference source (1.2 V) and control amplifier. The current  $I_{BIAS}$  through resistor  $R_{BIAS}$  is mirrored internally to provide a full-scale output current equal to 32 times  $I_{BIAS}$ . The full-scale current can be adjusted from 20 mA down to 2 mA.

### data interface and timing

The THS5651A comprises separate analog and digital supplies, i.e.  $AV_{DD}$  and  $DV_{DD}$ . The digital supply voltage can be set from 5.5 V down to 3 V, thus enabling flexible interfacing with external logic. The THS5651A provides two operating modes, as shown in Table 1. Mode 0 (mode pin connected to DGND) supports a straight binary input data word format, whereas mode 1 (mode pin connected to  $DV_{DD}$ ) sets a twos complement input configuration.

Figure 29 shows the timing diagram. Internal edge-triggered flip-flops latch the input word on the rising edge of the input clock. The THS5651A provides for minimum setup and hold times (> 1 ns), allowing for noncritical external interface timing. Conversion latency is one clock cycle for both modes. The clock duty cycle can be chosen arbitrarily under the timing constraints listed in the digital specifications table. However, a 50% duty cycle will give optimum dynamic performance. Figure 30 shows a schematic of the equivalent digital inputs of the THS5651A, valid for pins D9–D0, SLEEP, and CLK. The digital inputs are CMOS-compatible with logic thresholds of  $DV_{DD}/2 \pm 20\%$ . Since the THS5651A is capable of being updated up to 100 MSPS, the quality of the clock and data input signals are important in achieving the optimum performance. The drivers of the digital data interface circuitry should be specified to meet the minimum setup and hold times of the THS5651A, as well as its required min/max input logic level thresholds. Typically, the selection of the slowest logic family that satisfies the above conditions will result in the lowest data feed-through and noise. Additionally, operating the THS5651A with reduced logic swings and a corresponding digital supply ( $DV_{DD}$ ) will reduce data feed-through. Note that the update rate is limited to 70 MSPS for a digital supply voltage  $DV_{DD}$  of 3 V to 3.6 V.

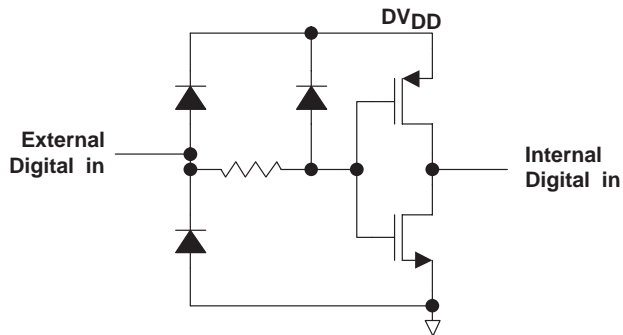
**APPLICATION INFORMATION**



**Figure 29. Timing Diagram**

**Table 1. Input Interface Modes**

FUNCTION/MODE	MODE 0	MODE 1
	MODE PIN CONNECTED TO DGND	MODE PIN CONNECTED TO DVDD
Input code format	Binary	Twos complement



**Figure 30. Digital Equivalent Input**



## APPLICATION INFORMATION

### DAC transfer function

The THS5651A delivers complementary output currents IOUT1 and IOUT2. Output current IOUT1 equals the approximate full-scale output current when all input bits are set high in mode 0 (straight binary input), i.e. the binary input word has the decimal representation 1023. For mode 1, the MSB is inverted (twos complement input format). Full-scale output current will flow through terminal IOUT2 when all input bits are set low (mode 0, straight binary input). The relation between IOUT1 and IOUT2 can thus be expressed as:

$$IOUT1 = IOUT_{FS} - IOUT2$$

where IOUT<sub>FS</sub> is the full-scale output current. The output currents can be expressed as:

$$IOUT1 = IOUT_{FS} \times \frac{CODE}{1024}$$

$$IOUT2 = IOUT_{FS} \times \frac{(1023 - CODE)}{1024}$$

where CODE is the decimal representation of the DAC data input word. Output currents IOUT1 and IOUT2 drive resistor loads R<sub>LOAD</sub> or a transformer with equivalent input load resistance R<sub>LOAD</sub>. This would translate into single-ended voltages VOUT1 and VOUT2 at terminal IOUT1 and IOUT2, respectively, of:

$$VOUT1 = IOUT1 \times R_{LOAD} = \frac{CODE}{1024} \times IOUT_{FS} \times R_{LOAD}$$

$$VOUT2 = IOUT2 \times R_{LOAD} = \frac{(1023 - CODE)}{1024} \times IOUT_{FS} \times R_{LOAD}$$

The differential output voltage VOUT<sub>DIFF</sub> can thus be expressed as:

$$VOUT_{DIFF} = VOUT1 - VOUT2 = \frac{(2CODE - 1023)}{1024} \times IOUT_{FS} \times R_{LOAD}$$

The latter equation shows that applying the differential output will result in doubling of the signal power delivered to the load. Since the output currents of IOUT1 and IOUT2 are complementary, they become additive when processed differentially. Care should be taken not to exceed the compliance voltages at node IOUT1 and IOUT2, which would lead to increased signal distortion.

**APPLICATION INFORMATION**

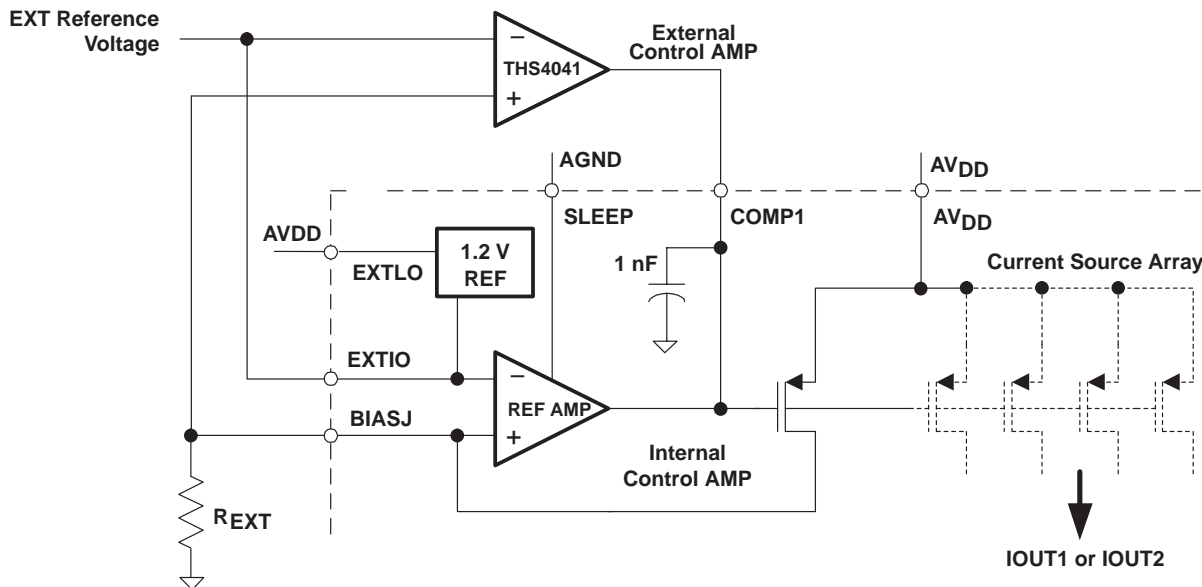
**reference operation**

The THS5651A comprises a bandgap reference and control amplifier for biasing the full-scale output current. The full-scale output current is set by applying an external resistor  $R_{BIAS}$ . The bias current  $I_{BIAS}$  through resistor  $R_{BIAS}$  is defined by the on-chip bandgap reference voltage and control amplifier. The full-scale output current equals 32 times this bias current. The full-scale output current  $I_{OUT_{FS}}$  can thus be expressed as:

$$I_{OUT_{FS}} = 32 \times I_{BIAS} = \frac{32 \times V_{EXTIO}}{R_{BIAS}}$$

where  $V_{EXTIO}$  is the voltage at terminal EXTIO. The bandgap reference voltage delivers an accurate voltage of 1.2 V. This reference is active when terminal EXTLO is connected to AGND. An external decoupling capacitor  $C_{EXT}$  of 0.1  $\mu$ F should be connected externally to terminal EXTIO for compensation. The bandgap reference can additionally be used for external reference operation. In that case, an external buffer with high impedance input should be applied in order to limit the bandgap load current to a maximum of 100 nA. The internal reference can be disabled and overridden by an external reference by connecting EXTLO to AVDD. Capacitor  $C_{EXT}$  may hence be omitted. Terminal EXTIO thus serves as either input or output node.

The full-scale output current can be adjusted from 20 mA down to 2 mA by varying resistor  $R_{BIAS}$  or changing the externally applied reference voltage. The internal control amplifier has a wide input range, supporting the full-scale output current range of 20 dB. The bandwidth of the internal control amplifier is defined by the internal 1 nF compensation capacitor at pin COMP1 and the external compensation capacitor C1. The relatively weak internal control amplifier may be overridden by an externally applied amplifier with sufficient drive for the internal 1 nF load, as shown in Figure 31. This provides the user with more flexibility and higher bandwidths, which are specifically attractive for gain control and multiplying DAC applications. Pin SLEEP should be connected to AGND or left disconnected when an external control amplifier is used.



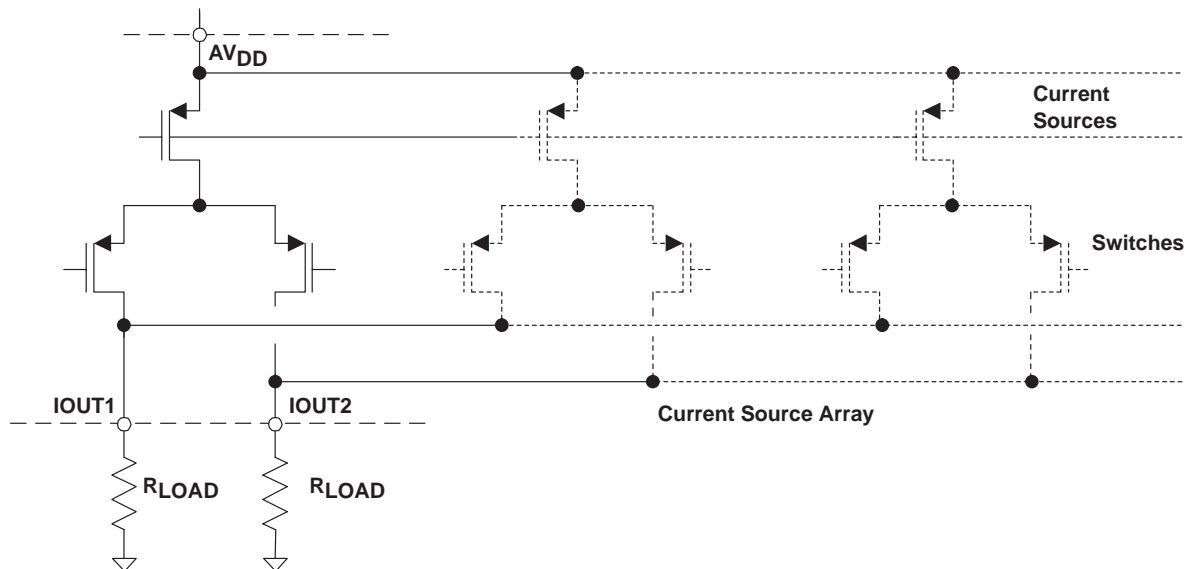
**Figure 31. Bypassing the Internal Reference and Control Amplifier**

## APPLICATION INFORMATION

### analog current outputs

Figure 32 shows a simplified schematic of the current source array output with corresponding switches. Differential PMOS switches direct the current of each individual PMOS current source to either the positive output node IOUT1 or its complementary negative output node IOUT2. The output impedance is determined by the stack of the current sources and differential switches, and is typically >300 kΩ in parallel with an output capacitance of 5 pF.

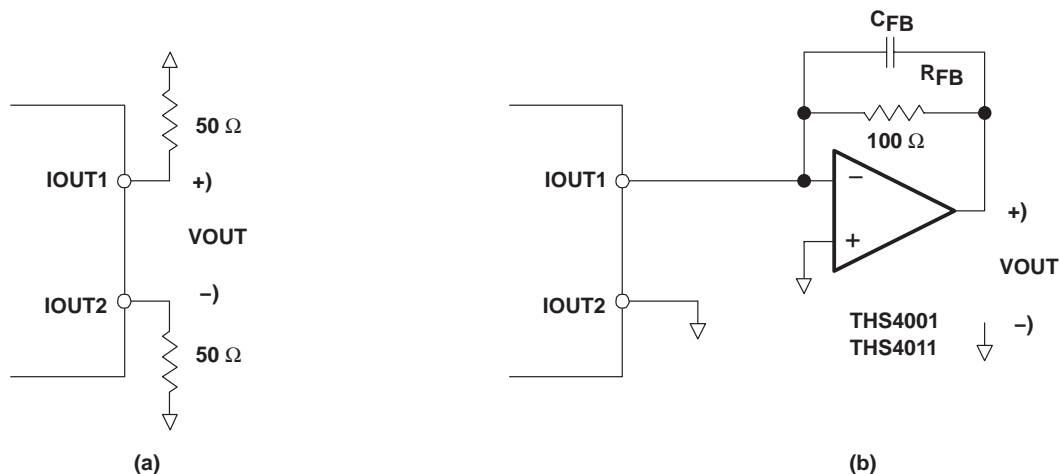
Output nodes IOUT1 and IOUT2 have a negative compliance voltage of  $-1\text{ V}$ , determined by the CMOS process. Beyond this value, transistor breakdown may occur, resulting in reduced reliability of the THS5651A device. The positive output compliance depends on the full-scale output current  $I_{OUTFS}$  and positive supply voltage  $AV_{DD}$ . The positive output compliance equals  $1.25\text{ V}$  for  $AV_{DD} = 5\text{ V}$  and  $I_{OUTFS} = 20\text{ mA}$ . Exceeding the positive compliance voltage adversely affects distortion performance and integral nonlinearity. The optimum distortion performance for a single-ended or differential output is achieved when the maximum full-scale signal at IOUT1 and IOUT2 does not exceed  $0.5\text{ V}$  (e.g. when applying a  $50\text{-}\Omega$  doubly terminated load for  $20\text{ mA}$  full-scale output current). Applications requiring the THS5651A output (i.e., OUT1 and/or OUT2) to extend its output compliance should size  $R_{LOAD}$  accordingly.



**Figure 32. Equivalent Analog Current Output**

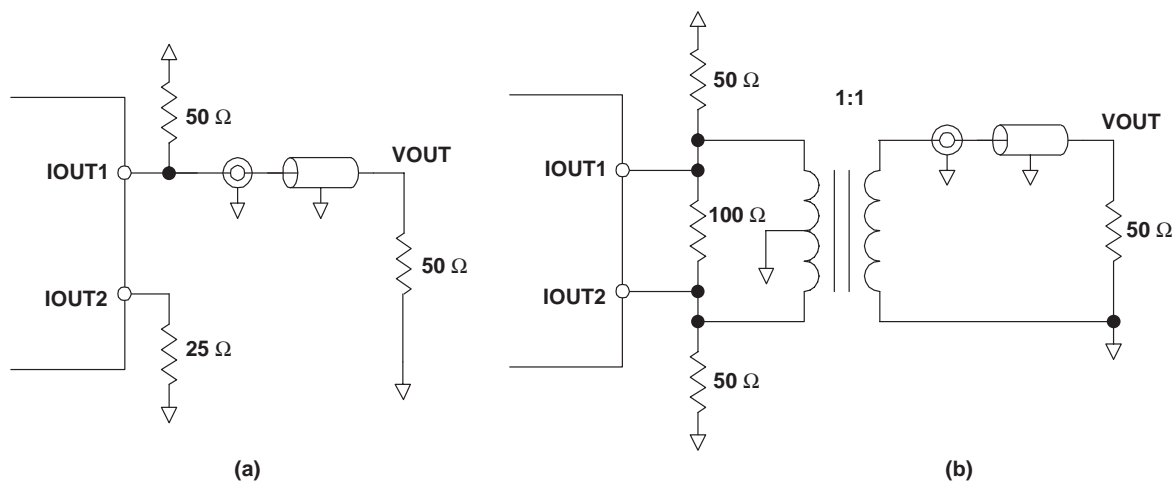
Figure 33(a) shows the typical differential output configuration with two external matched resistor loads. The nominal resistor load of  $50\text{ }\Omega$  will give a differential output swing of  $2\text{ V}_{PP}$  when applying a  $20\text{-mA}$  full-scale output current. The output impedance of the THS5651A depends slightly on the output voltage at nodes IOUT1 and IOUT2. Consequently, for optimum dc integral nonlinearity, the configuration of Figure 33(b) should be chosen. In this I-V configuration, terminal IOUT1 is kept at virtual ground by the inverting operational amplifier. The complementary output should be connected to ground to provide a dc current path for the current sources switched to IOUT2. Note that the INL/DNL specifications for the THS5651A are measured with IOUT1 maintained at virtual ground. The amplifier's maximum output swing and the DAC's full-scale output current determine the value of the feedback resistor  $R_{FB}$ . Capacitor  $C_{FB}$  filters the steep edges of the THS5651A current output, thereby reducing the operational amplifier slew-rate requirements. In this configuration, the op amp should operate on a dual supply voltage due to its positive and negative output swing. Node IOUT1 should be selected if a single-ended unipolar output is desirable.

**APPLICATION INFORMATION**



**Figure 33. Differential and Single-Ended Output Configuration**

The THS5651A can be easily configured to drive a doubly terminated 50-Ω cable. Figure 34(a) shows the single-ended output configuration, where the output current IOUT1 flows into an equivalent load resistance of 25 Ω. Node IOUT2 should be connected to ground or terminated with a resistor of 25 Ω. Differential-to-single conversion (e.g., for measurement purposes) can be performed using a properly selected RF transformer, as shown in Figure 34(b). This configuration provides maximum rejection of common-mode noise sources and even order distortion components, thereby doubling the power to the output. The center tap on the primary side of the transformer is connected to AGND, enabling a dc current flow for both IOUT1 and IOUT2. Note that the ac performance of the THS5651A is optimum and specified using this differential transformer coupled output, limiting the voltage swing at IOUT1 and IOUT2 to ±0.5 V.



**Figure 34. Driving a Doubly Terminated 50 Ω Cable**

## APPLICATION INFORMATION

### sleep mode

The THS5651A features a power-down mode that turns off the output current and reduces the supply current to less than 5 mA over the analog supply range of 4.5 V to 5.5 V and temperature range. The power-down mode is activated by applying a logic level 1 to the SLEEP pin (e.g., by connecting pin SLEEP to AVDD). An internal pulldown circuit at node SLEEP ensures that the THS5651A is enabled if the input is left disconnected. Power-up and power-down activation times depend on the value of external capacitor at node SLEEP. For a nominal capacitor value of 0.1  $\mu$ F power down takes less than 5  $\mu$ s, and approximately 3 ms to power back up. The SLEEP mode should not be used when an external control amplifier is used, as shown in Figure 22.

### definitions of specifications and terminology

#### integral nonlinearity (INL)

The relative accuracy or integral nonlinearity (INL), sometimes referred to as linearity error, is the maximum deviation of the output from the line between zero and full scale excluding the effects of zero code and full-scale errors.

#### differential nonlinearity (DNL)

The differential nonlinearity (DNL), sometimes referred to as differential error, is the difference between the measured and ideal 1 LSB amplitude change of any two adjacent codes. Monotonic means the output voltage changes in the same direction (or remains constant) as a change in the digital input code.

#### offset error

Offset error is defined as the deviation of the output current from the ideal of zero at a digital input value of 0.

#### gain error

Gain error is the error in slope of the DAC transfer function.

#### signal-to-noise ratio + distortion (S/N+D or SINAD)

S/N+D or SINAD is the ratio of the rms value of the output signal to the rms sum of all other spectral components below the Nyquist frequency, including harmonics but excluding dc. The value for S/N+D is expressed in decibels.

#### spurious free dynamic range (SFDR)

SFDR is the difference between the rms value of the output signal and the rms value of the largest spurious signal within a specified bandwidth. The value for SFDR is expressed in decibels.

#### total harmonic distortion (THD)

THD is the ratio of the rms sum of the first six harmonic components to the rms value of the fundamental signal and is expressed in decibels.

#### output compliance range

The maximum and minimum allowable voltage of the output of the DAC, beyond which either saturation of the output stage or breakdown may occur.

#### settling time

The time required for the output to settle within a specified error band.

#### glitch energy

The time integral of the analog value of the glitch transient.

# THS5651A

## 10-BIT, 125 MSPS, CommsDAC™

### DIGITAL-TO-ANALOG CONVERTER

SLAS260A – FEBRUARY 2000 – REVISED SEPTEMBER 2002

---

#### offset drift

The change in offset error versus temperature from the ambient temperature ( $T_A = 25^\circ\text{C}$ ) in ppm of full-scale range per  $^\circ\text{C}$ .

#### gain drift

The change in gain error versus temperature from the ambient temperature ( $T_A = 25^\circ\text{C}$ ) in ppm of full-scale range per  $^\circ\text{C}$ .

#### reference voltage drift

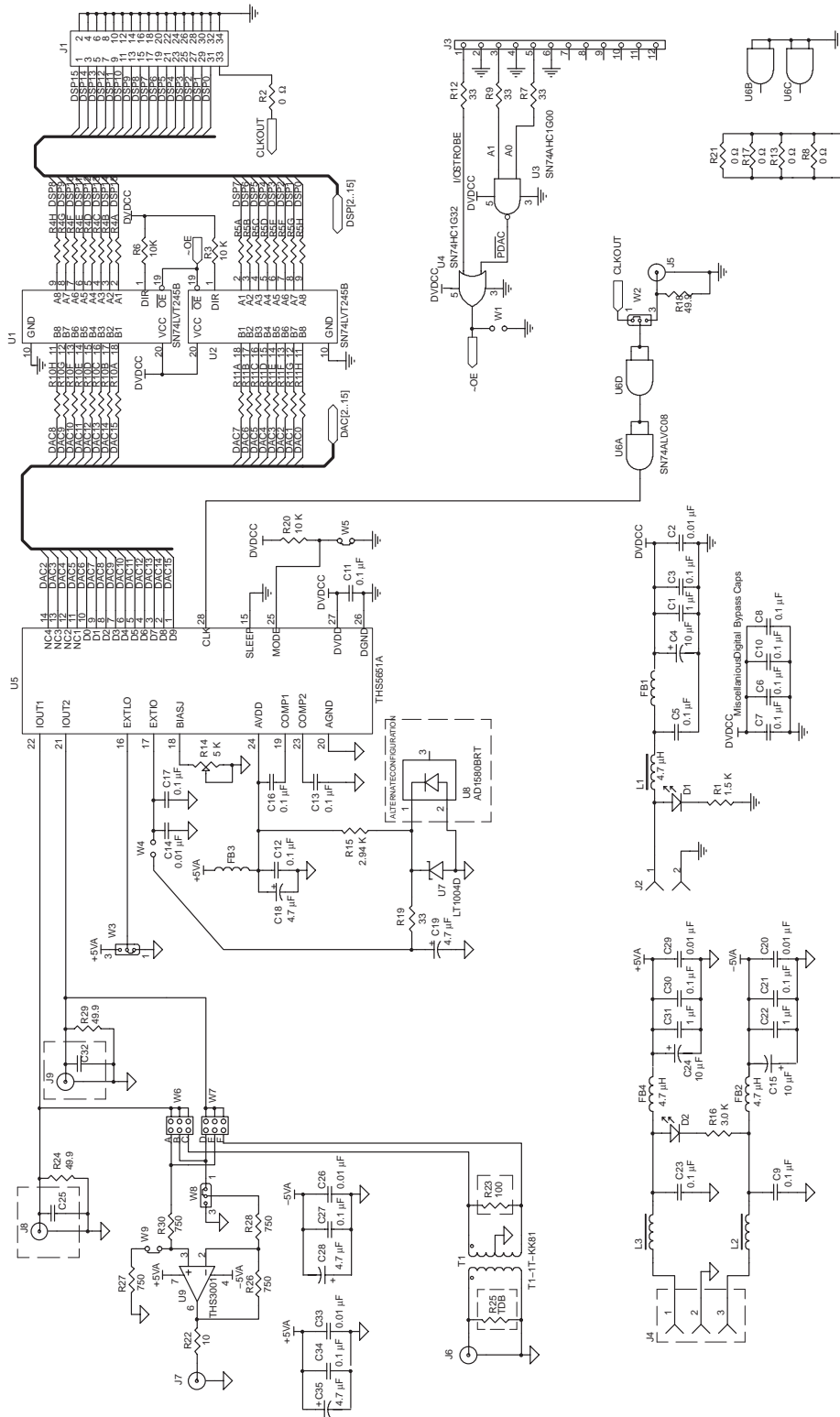
The change in reference voltage error versus temperature from the ambient temperature ( $T_A = 25^\circ\text{C}$ ) in ppm of full-scale range per  $^\circ\text{C}$ .

#### THS5651A evaluation board

An evaluation module (EVM) board for the THS5651A digital-to-analog converter is available for evaluation. This board allows the user the flexibility to operate the THS5651A in various configurations. Possible output configurations include transformer coupled, resistor terminated, and inverting/noninverting amplifier outputs. The digital inputs are designed to interface with the TMS320 C5000 or C6000 family of DSPs or to be driven directly from various pattern generators with the onboard option to add a resistor network for proper load termination.

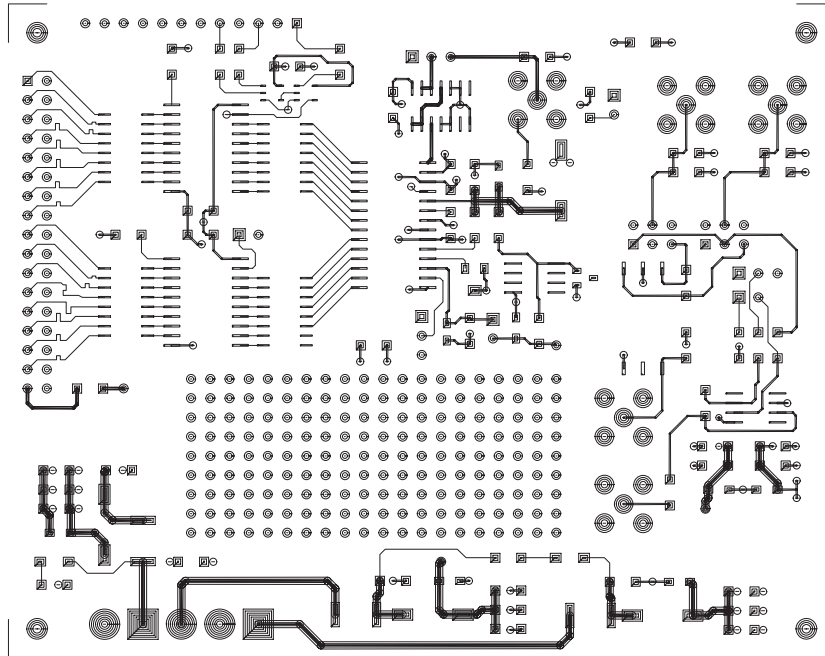
See the *THS56x1 Evaluation Module User's Guide* for more details (SLAU032).

## APPLICATION INFORMATION

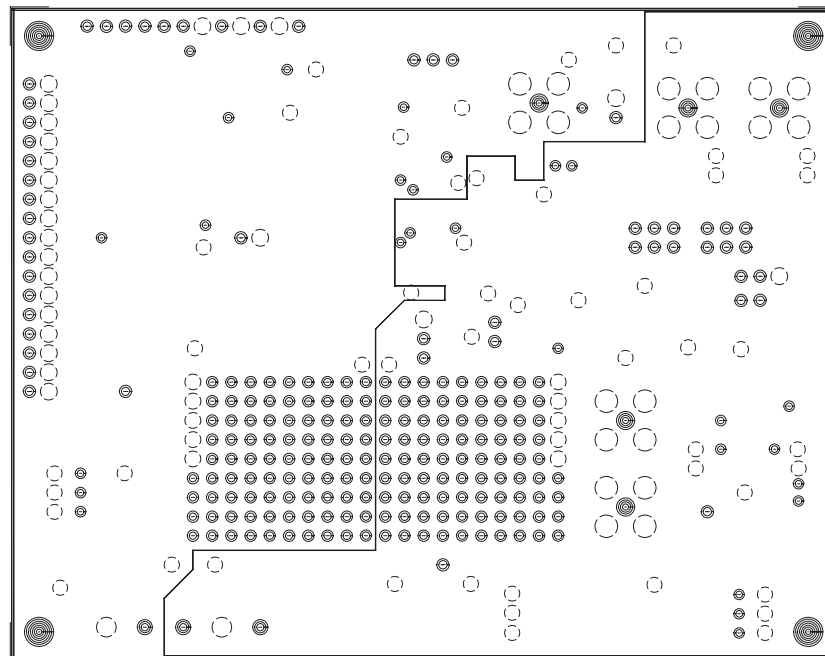


**Figure 35. Schematic**

**APPLICATION INFORMATION**



**Figure 36. Board Layout, Layer 1**



**Figure 37. Board Layout, Layer 2**



APPLICATION INFORMATION

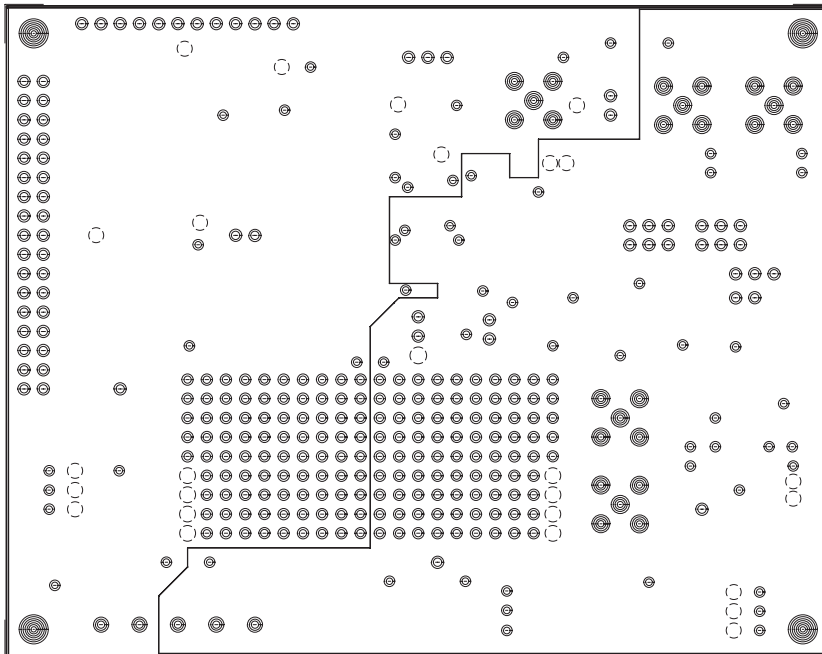


Figure 38. Board Layout, Layer 3

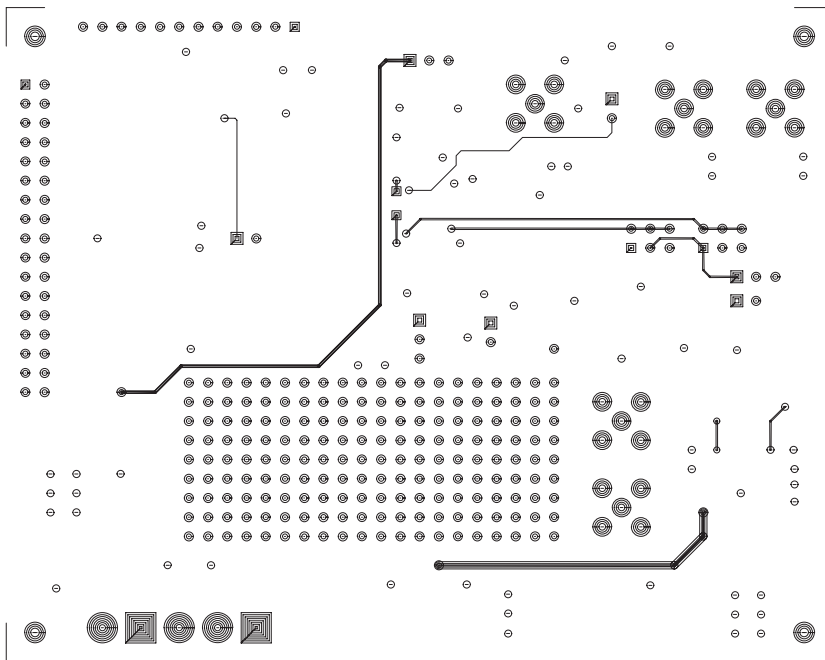
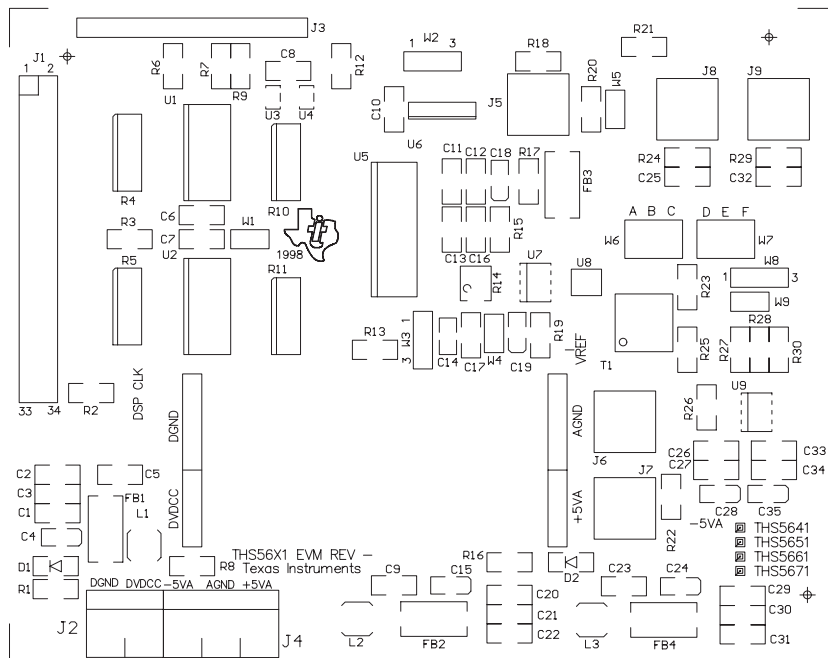


Figure 39. Board Layout, Layer 4

**THS5651A**  
**10-BIT, 125 MSPS, CommsDAC™**  
**DIGITAL-TO-ANALOG CONVERTER**

SLAS260A – FEBRUARY 2000 – REVISED SEPTEMBER 2002

**APPLICATION INFORMATION**



**Figure 40. Board Layout, Layer 5**

**Table 2. Bill of Materials**

QTY	REF. DES	PART NUMBER	DESCRIPTION	MFG.
3	C1, C22, C31	1206ZC105KAT2A	Ceramic, 1 $\mu$ F, 10 V, X7R, 10%	AVX
4	C18, C19, C28, C35	ECSTOJY475	6.3 V, 4.7 $\mu$ F, tantalum	Panasonic
3	C15, C24, C4	ECSTOJY106	6.3 V, 10 $\mu$ F, tantalum	Panasonic
0	C25, C32		Ceramic, not installed, 50 V, X7R, 10%	
6	C14, C2, C20, C26, C29, C33	12065C103KAT2A	Ceramic, 0.01 $\mu$ F, 50 V, X7R, 10%	AVX
17	C10, C11, C12, C13, C16, C17, C21, C23, C27, C3, C30, C34, C5, C6, C7, C8, C9	12065C104KAT2A	Ceramic, 0.1 $\mu$ F, 50 V, X7R, 10%	AVX
2	D1, D2	AND/AND5GA or equivalent	Green LED, 1206 size SM chip LED	
4	FB1, FB2, FB3, FB4	27-43-037447	Fair-Rite SM beads #27-037447	FairRite
1	J1	TSW-117-07-L-D or equivalent	34-Pin header for IDC	Samtec
1	J2	KRMZ2 or equivalent	2 Terminal screw connector, 2TERM_CON	Lumberg
1	J3	TSW-112-07-L-S or equivalent	Single row 12-pin header	Samtec
1	J4	KRMZ3 or equivalent	3 Terminal screw connector	Lumberg
3	J5, J6, J7	142-0701-206 or equivalent	PCB Mount SMA jack, SMA_PCB_MT	Johnson Components
0	J8, J9	142-0701-206 or equivalent	PCB Mount SMA jack, not installed	Johnson Components
3	L1, L2, L3	DO1608C-472	DO1608C-series, DS1608C-472	Coil Craft
1	R1	1206	1206 Chip resistor, 1.5K, 1/4 W, 1%	
4	R10, R11, R4, R5	CTS/CTS766-163-(R)330-G-TR	8 Element isolated resistor pack, 33 $\Omega$	



**APPLICATION INFORMATION**

**Table 2. Bill of Materials (Continued)**

QTY	REF. DES	PART NUMBER	DESCRIPTION	MFG.
4	R12, R19, R7, R9	1206	1206 Chip resistor, 33 Ω, 1/4 W, 1%	
5	R13, R17, R2, R21, R8	1206	1206 Chip resistor, 0 Ω, 1/4 W, 1%	
1	R14	3214W-1-502 E or equivalent	4 mm SM Pot, 5K	Bourns
1	R15	1206	1206 Chip resistor, 2.94K, 1/4 W, 1%	
1	R16	1206	1206 Chip resistor, 3K, 1/4 W, 1%	
3	R18, R24, R29	1206	1206 Chip resistor, 49.94K, 1/4 W, 1%	
3	R20, R3, R6	1206	1206 Chip resistor, 10K, 1/4 W, 1%	
1	R22	1206	1206 Chip resistor, 10K, 1/4 W, 1%	
1	R23	1206	1206 Chip resistor, 100K, 1/4 W, 1%	
1	R25	1206	1206 Chip resistor, TBD, 1/4 W, 1%	
4	R26, R27, R28, R30	1206	1206 Chip resistor, 750K, 1/4 W, 1%	
1	T1	T1-1T-KK81	RF Transformer, T1-1T-KK81	MiniCircuits
2	U1, U2	SN74LVT245BDW	Octal bus transceiver, 3-state, SN74LVT245B	TI
1	U3	SN74AHCT1G00DBVR/ SN74AHC1G00DBVR	Single gate NAND, SN74AHC1G00	TI
1	U4	SN74AHCT1G32DBVR/ SN74AHCC1G32DBVR	Single 2 input positive or gate, SN74AHC1G32	TI
	THS5641A	THS5641AIDW	DAC, 3–5.5 V, 8 Bit, 100 MSPS	TI
	THS5651A	THS5651AIDW	DAC, 3–5.5 V, 10 Bit, 125 MSPS	TI
	THS5661A	THS5661AIDW	DAC, 3–5.5 V, 12 Bit, 125 MSPS	TI
	THS5671A	THS5647AIDW	DAC, 3–5.5 V, 14 Bit, 125 MSPS	TI
1	SN74ALVC08	SN74ALVC08D	Quad AND gate	TI
1	LT1004D	LT1004CD-1-2/LT1004ID-1-2	Precision 1.2 V reference	TI
0	NOT INSTALLED	AD1580BRT	Precision voltage reference, not installed	
1	THS3001	THS3001CD/THS2001ID	THS3001 high-speed op amp	TI
4	W2	TSW-102-07-L-S or equivalent	2 position jumper_.1" spacing, W2	Samtec
3	W3	TSW-102-07-L-S or equivalent	3 position jumper_.1" spacing, W3	Samtec
2	2X3_JUMPER	TSW-102-07-L-S or equivalent	6-Pin header dual row, 0.025×0.1, 2X3_JUMPER	Samtec

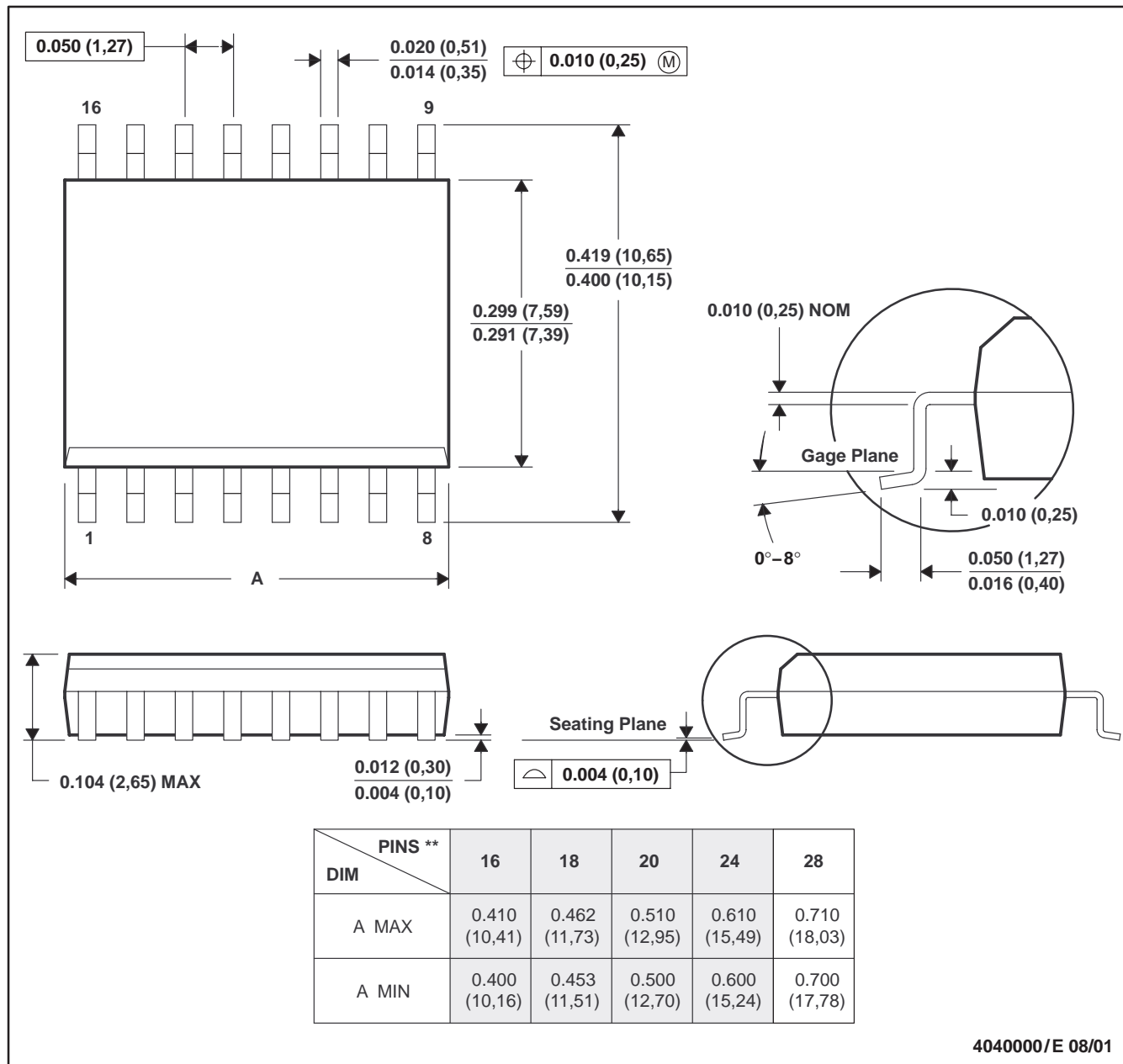
**THS5651A**  
**10-BIT, 125 MSPS, CommsDAC™**  
**DIGITAL-TO-ANALOG CONVERTER**  
 SLAS260A – FEBRUARY 2000 – REVISED SEPTEMBER 2002

**MECHANICAL DATA**

**DW (R-PDSO-G\*\*)**

**PLASTIC SMALL-OUTLINE PACKAGE**

16 PINS SHOWN



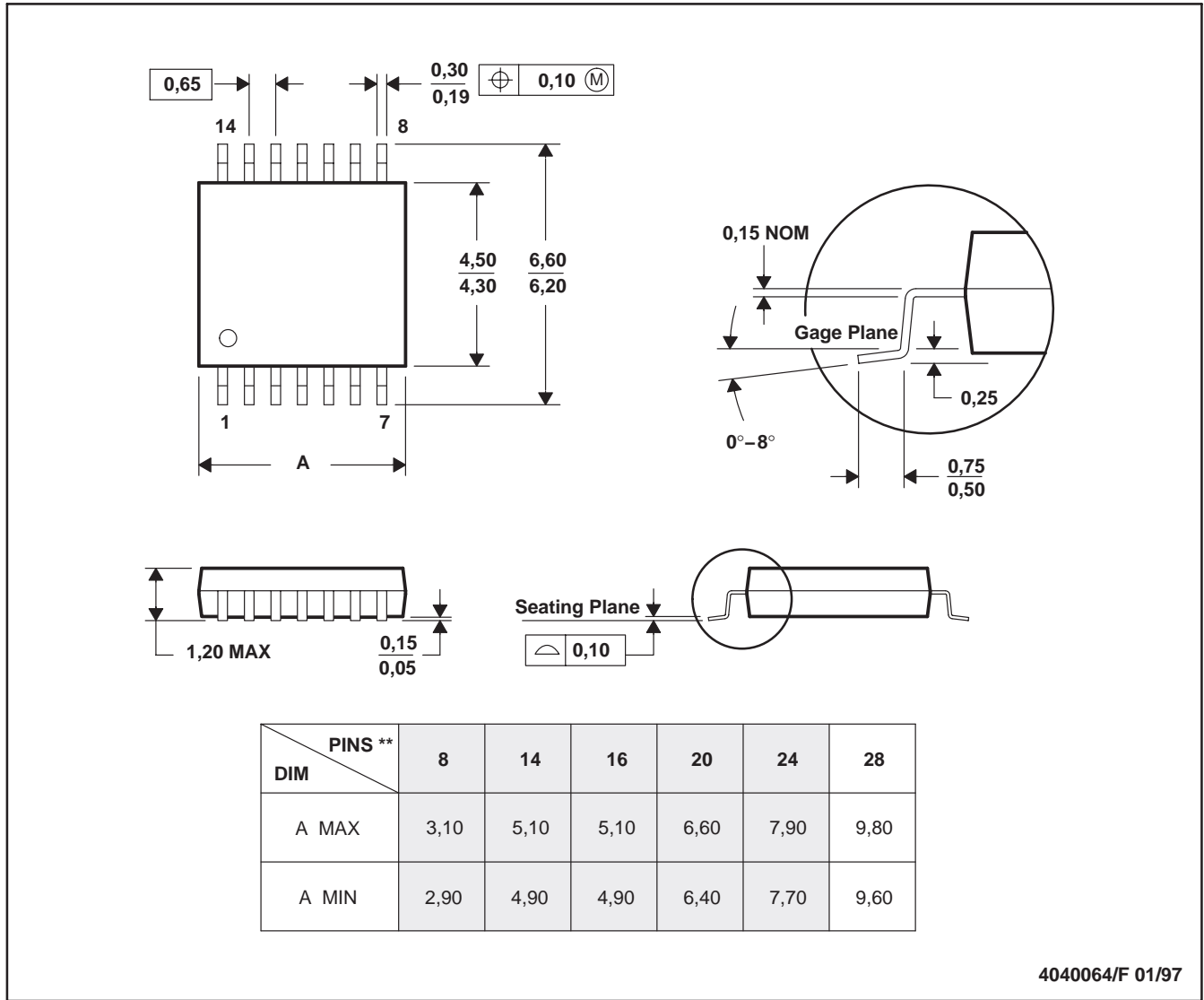
- NOTES: A. All linear dimensions are in inches (millimeters).  
 B. This drawing is subject to change without notice.  
 C. Body dimensions do not include mold flash or protrusion not to exceed 0.006 (0,15).  
 D. Falls within JEDEC MS-013

**MECHANICAL DATA**

**PW (R-PDSO-G\*\*)**

**PLASTIC SMALL-OUTLINE PACKAGE**

**14 PINS SHOWN**



- NOTES: A. All linear dimensions are in millimeters.  
 B. This drawing is subject to change without notice.  
 C. Body dimensions do not include mold flash or protrusion not to exceed 0,15.  
 D. Falls within JEDEC MO-153

**PACKAGING INFORMATION**

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
THS5651AIDW	ACTIVE	SOIC	DW	28	20	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	THS5651AI	<a href="#">Samples</a>
THS5651AIDWR	ACTIVE	SOIC	DW	28	1000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	THS5651AI	<a href="#">Samples</a>
THS5651AIPW	ACTIVE	TSSOP	PW	28	50	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	TJ5651A	<a href="#">Samples</a>
THS5651AIPWR	ACTIVE	TSSOP	PW	28	2000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	TJ5651A	<a href="#">Samples</a>

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSELETE:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) **MSL, Peak Temp.** - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "-" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) **Lead finish/Ball material** - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

**Important Information and Disclaimer:**The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and

continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

**TAPE AND REEL INFORMATION**

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
THS5651AIDWR	SOIC	DW	28	1000	330.0	32.4	11.35	18.67	3.1	16.0	32.0	Q1
THS5651AIPWR	TSSOP	PW	28	2000	330.0	16.4	6.9	10.2	1.8	12.0	16.0	Q1



**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
THS5651AIDWR	SOIC	DW	28	1000	350.0	350.0	66.0
THS5651AIPWR	TSSOP	PW	28	2000	350.0	350.0	43.0

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (<https://www.ti.com/legal/termsofsale.html>) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2021, Texas Instruments Incorporated