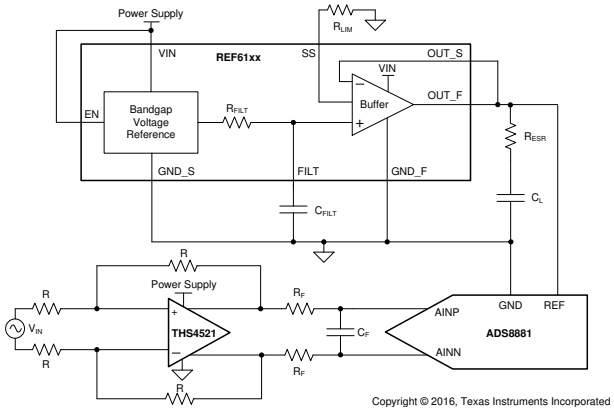
REF61xx High-Precision Voltage Reference With Integrated ADC Drive Buffer

1 Features

- Excellent temperature drift performance
  - 8ppm/°C (maximum) from –40°C to +125°C
- Extremely low noise
  - Total noise: 5μV_{RMS} with 47μF capacitor
  - 1/f noise (0.1Hz to 10Hz): 3μV_{PP}/V
- Integrated ADC drive buffer
  - Low output impedance: < 50mΩ (0kHz to 200kHz)
  - First sample precise to 18 bits with ADS8881
  - Enables burst-mode DAQ systems
- Low supply current: 820μA
- Low shutdown current: 1μA
- High initial accuracy: ±0.05%
- Very-low noise and distortion
  - SNR: 100.5dB, THD: –125dB (ADS8881)
  - SNR: 106dB, THD: –120dB (ADS127L01)
- Output current drive: ±4mA
- Programmable short-circuit current
- Verified to drive REF pin of ADS88xx family of SAR ADCs and ADS127xx family of wideband ΔΣ ADCs

2 Applications

- ATE testers and oscilloscopes
- Test and measurement equipment
- Analog input modules for PLCs
- Medical equipment
- Precision data acquisition systems



Typical Application

3 Description

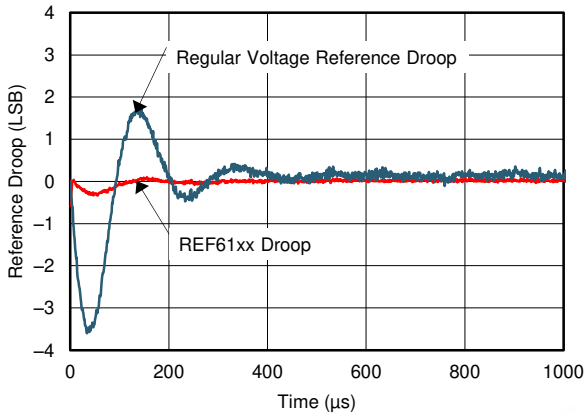
The REF6000 family of voltage references have an integrated low output impedance buffer that enable the user to directly drive the REF pin of precision data converters, while preserving linearity, distortion, and noise performance. Most precision SAR and Delta-Sigma ADCs, switch binary-weighted capacitors onto the REF pin during the conversion process. To support this dynamic load the output of the voltage reference must be buffered with a low-output impedance (high-bandwidth) buffer. The REF6000 family devices are an excellent choice, but not limited, to drive the REF pin of the ADS88xx family of SAR ADCs, and ADS127xx family of delta-sigma ADCs, as well as other digital-to-analog converters (DACs).

The REF6000 family of voltage references are able to maintain an output voltage within 1LSB (18-bit) with minimal droop, even during the first conversion while driving the REF pin of the ADS8881. This feature is useful in burst-mode, event-triggered, equivalent-time sampling, and variable-sampling-rate data-acquisition systems. The REF61xx variants of REF6000 family specify a maximum temperature drift of just 8ppm/°C and initial accuracy of 0.05% for both the voltage reference and the low output impedance buffer combined. For various temperature drift options in REF6000 family, see the *Device Comparison Table*.

Package Information

PART NUMBER	PACKAGE(1)	PACKAGE SIZE(2)
REF61xx	DGK (VSSOP, 8)	3.00mm × 4.90mm

(1) For more information, see Section 12.
(2) The package size (length × width) is a nominal value and includes pins, where applicable.



Reference Droop Comparison (1LSB = 19.07μV, with ADS8881 at 1MSPS)

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4 Device Comparison Table

DEVICE FAMILY	TEMPERATURE DRIFT
REF60xx	5ppm/°C from –40 to 125°C
REF61xx	8ppm/°C from –40 to 125°C
REF62xx	3ppm/°C from 0 to 70°C

5 Pin Configuration and Functions

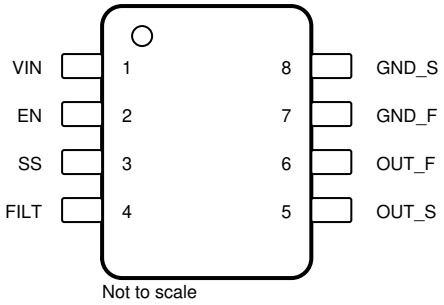


Figure 5-1. DGK Package 8-Pin VSSOP Top View

Table 5-1. Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
EN	2	Input	Enable pin
FILT	4	—	Filter capacitor pin. A capacitor (C_{FILT}) ≥ 1 µF must be connected between the FILT pin and ground for stability.
GND_F	7	Ground	Ground force pin
GND_S	8	Ground	Ground sense pin
OUT_F	6	Output	Output voltage force pin
OUT_S	5	Input	Output voltage sense pin
SS	3	—	Short circuit current limit pin. Connect a resistor to this pin to set the output short-circuit current limit. Connect to VIN pin for highest current limit
VIN	1	Power	Input supply voltage pin

Pin Functions

6 Specifications

6.1 Absolute Maximum Ratings (1)

over operating free-air temperature range (unless otherwise noted)

		MIN	MAX	UNIT
Input voltage	V_{IN}	–0.3	6	V
	V_{EN}	–0.3	V_{IN} + 0.3	V
Operating temperature, T_A		–55	150	°C
Junction temperature, T_j			150	°C
Storage temperature, T_{stg}		–65	150	°C

(1) Operation outside the *Absolute Maximum Ratings* may cause permanent device damage. *Absolute Maximum Ratings* do not imply functional operation of the device at these or any other conditions beyond those listed under *Recommended Operating Conditions*. If used outside the *Recommended Operating Conditions* but within the *Absolute Maximum Ratings*, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	±1000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101(2)	±250	

(1) JEDEC document JEP155 states that 500V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

			MIN	NOM	MAX	UNIT
V_{IN}	Supply input voltage (I_{OUT} = 0mA)	REF6125	3		5.5	V
		REF6130, REF6133, REF6141, REF6145	V_{OUT} + 0.25		5.5	
		REF6150	5.3		5.5	
V_{EN}	Enable voltage		0		V_{IN}	V
I_L	Output current	REF6125, REF6130, REF6133, REF6141	–4		4	mA
		REF6145	–3.5		3.5	
		REF6150	–3		3	
T_A	Operating temperature		–40	25	125	°C

6.4 Thermal Information

THERMAL METRIC(1)		REF61xx DGK (VSSOP) 8 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	158.5	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	51.2	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	79.5	°C/W
ψ_{JT}	Junction-to-top characterization parameter	5.2	°C/W
ψ_{JB}	Junction-to-board characterization parameter	78.0	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.

6.5 Electrical Characteristics

at T_A = 25°C, V_{IN} = 5V for all devices except REF6150, V_{IN} = 5.4V for REF6150, I_L = 0mA, C_L = 22 µF, C_{FILT} = 1 µF, and V_{EN} = 5V (unless otherwise noted)

PARAMETER		TEST CONDITIONS			MIN	TYP	MAX	UNIT
ACCURACY AND DRIFT								
	Output voltage accuracy				-0.05%		0.05%	
	Output voltage temperature coefficient[1]						8	ppm/°C
LINE AND LOAD REGULATION								
$\Delta V_{O(\Delta VI)}$	Line regulation	REF6125	V_{OUT} + 0.5V ≤ V_{IN} ≤ 5.5V	T_A = 25°C		4	20	ppm/V
				T_A = –40°C to +125°C			30	
		REF6130, REF6133, REF6141, REF6145	V_{OUT} + 0.25V ≤ V_{IN} ≤ 5.5V	T_A = 25°C		4	20	
				T_A = –40°C to +125°C			30	
		REF6150	V_{OUT} + 0.3V ≤ V_{IN} ≤ 5.5V	T_A = 25°C		7	60	
				T_A = –40°C to +125°C			120	
$\Delta V_{O(\Delta IL)}$	Load regulation, sourcing and sinking	REF6125, REF6130, REF6133, REF6141	I_L = 0mA to 4mA, V_{IN} = V_{OUT} + 600mV	T_A = 25°C		2	20	ppm/mA
				T_A = –40°C to +125°C			30	
		REF6145	I_L = 0mA to 3.5mA, V_{IN} = V_{OUT} + 600mV	T_A = 25°C		2	20	
				T_A = –40°C to +125°C			30	
		REF6150	I_L = 0mA to 3mA, V_{IN} = V_{OUT} + 400mV	T_A = 25°C		2	20	
				T_A = –40°C to +125°C			50	
I_{SC}	Short-circuit current	SS = open				10.5		mA
NOISE								
	Total integrated noise	C_L = 22 µF				5		μV_{RMS}
		C_L = 47 µF				5		
	Low frequency noise	0.1Hz ≤ f ≤ 10Hz				3		$\mu V_{PP}/V$
OUTPUT IMPEDANCE								
	Output impedance	f = DC to 200kHz, C_L= 47µF				50		mΩ
TURN-ON TIME								
t_{on}	Turn-on time	0.1% settling, C_L = 47 µF, SS = open, REF6125				100		ms
HYSTERESIS AND LONG TERM DRIFT								
	Long term stability	0 to 1000h at 25°C				80		ppm
		1000h to 2000h at 25°C				20		
	Output voltage hysteresis[2]	25°C, –40°C,125°C, 25°C (cycle 1)				33		ppm
		25°C, –40°C,125°C, 25°C (cycle 2)				8		
CAPACITIVE LOAD								
C_L	Stable output capacitor value				10		47	µF

6.5 Electrical Characteristics (continued)

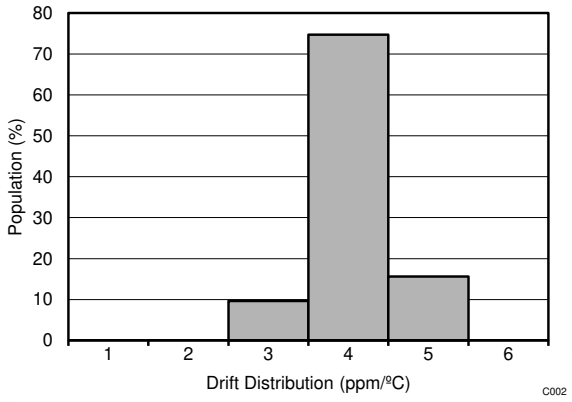
at T_A = 25°C, V_{IN} = 5V for all devices except REF6150, V_{IN} = 5.4V for REF6150, I_L = 0mA, C_L = 22 µF, C_{FILT} = 1 µF, and V_{EN} = 5V (unless otherwise noted)

PARAMETER		TEST CONDITIONS			MIN	TYP	MAX	UNIT
OUTPUT VOLTAGE								
V_{OUT}	Output voltage	REF6125				2.5		V
		REF6130				3		
		REF6133				3.3		
		REF6141				4.096		
		REF6145				4.5		
		REF6150				5		
POWER SUPPLY								
I_{CC}	Supply current	REF6125, REF6130, REF6133, REF6141	Active mode, V_{EN} = 5V	T_A = 25°C		0.82	0.90	mA
				T_A = –40°C to +125°C			1.1	
		REF6145, REF6150	Active mode, V_{EN} = 5V	T_A = 25°C		0.83	0.95	
				T_A = –40°C to +125°C			1.15	
		Shutdown mode, V_{EN} = 0V		T_A = 25°C		1	3	µA
				T_A = –40°C to +125°C			15	
	Enable pin voltage	Voltage reference in active mode (EN = 1)			1.6			V
		Voltage reference in shutdown mode (EN = 0)					0.6	
	Enable pin current	V_{EN} = 5V				100	150	nA
	Dropout voltage	REF6125		I_L = 0mA		500	500	mV
				I_L = 4mA			600	
		REF6130, REF6133, REF6141		I_L = 0mA		50	250	
				I_L = 4mA			600	
		REF6145		I_L = 0mA		50	250	
				I_L = 3.5mA			600	
		REF6150		I_L = 0mA		100	300	
				I_L = 3mA			400	

(1) Temperature drift is specified according to the box method. See Section 8.3 for more details.
(2) See Section 7.2.

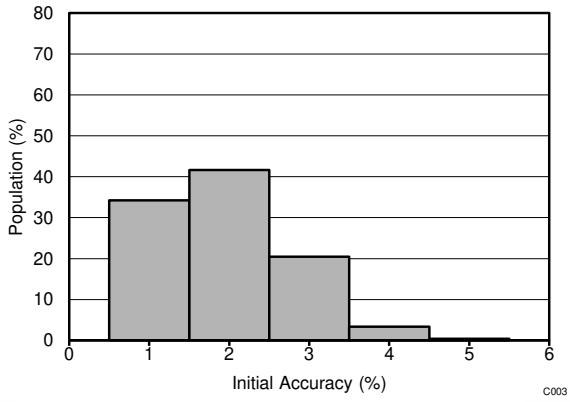
6.6 Typical Characteristics

at T_A = 25°C, I_L = 0mA, and V_{IN} = 5V, using REF6125 (unless otherwise noted)



T_A = –40°C to +125°C

Figure 6-1. Drift Distribution



T_A = –40°C to +85°C

Figure 6-2. Drift Distribution

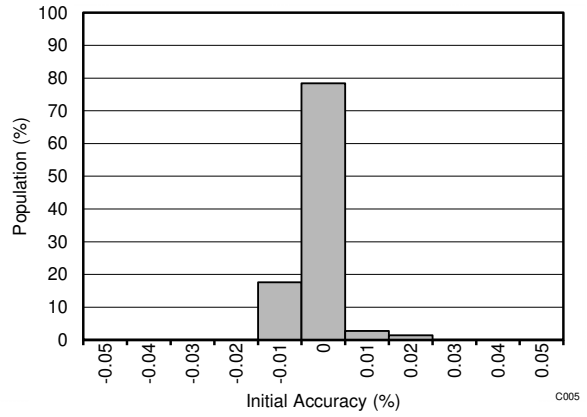


Figure 6-3. Initial Accuracy Distribution

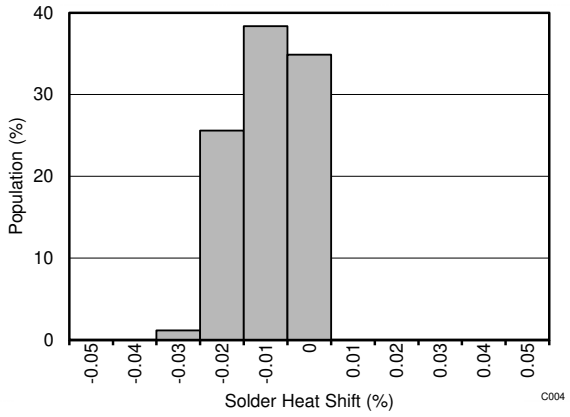


Figure 6-4. Solder-Heat Shift Distribution

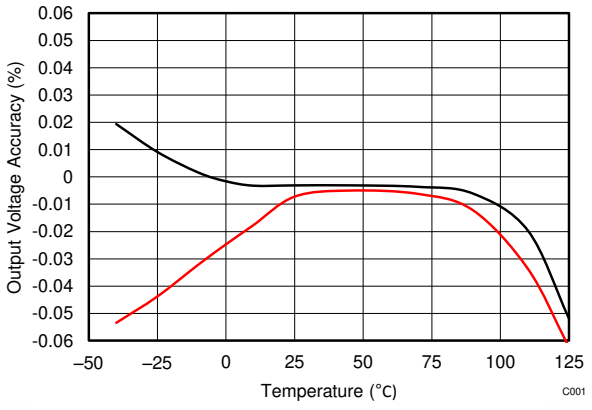


Figure 6-5. Output Voltage Accuracy vs Temperature

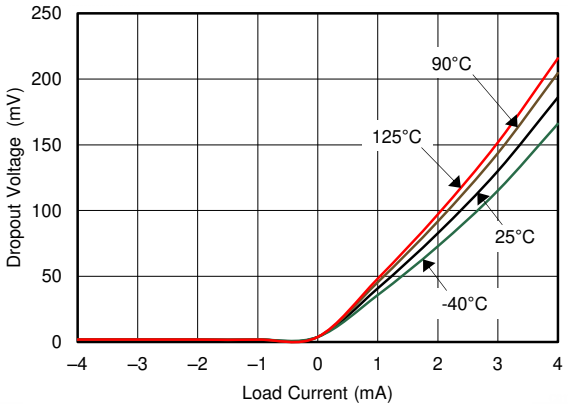
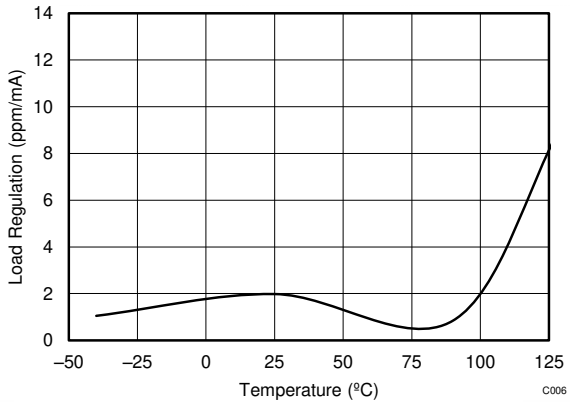


Figure 6-6. Dropout Voltage vs Load Current

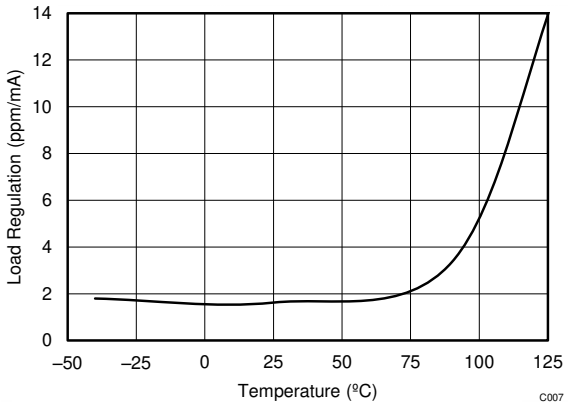
6.6 Typical Characteristics (continued)

at T_A = 25°C, I_L = 0mA, and V_{IN} = 5V, using REF6125 (unless otherwise noted)



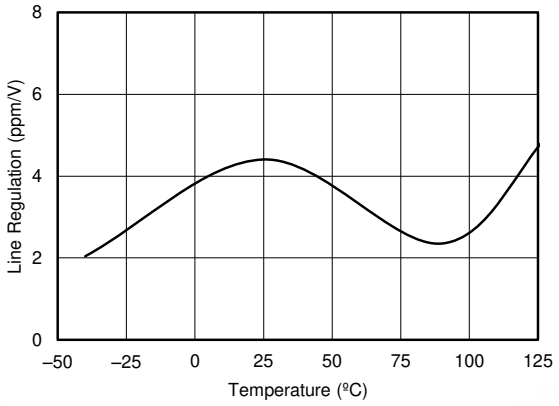
V_{IN} = V_{OUT} + 600mV,
I_L = 0mA to 4mA

Figure 6-7. Load Regulation Sourcing vs Temperature



V_{IN} = V_{OUT} + 600mV,
I_L = 0mA to 4mA

Figure 6-8. Load Regulation Sinking vs Temperature



V_{OUT} + 0.25V ≤ V_{IN} ≤ 5.5V

Figure 6-9. Line Regulation vs Temperature

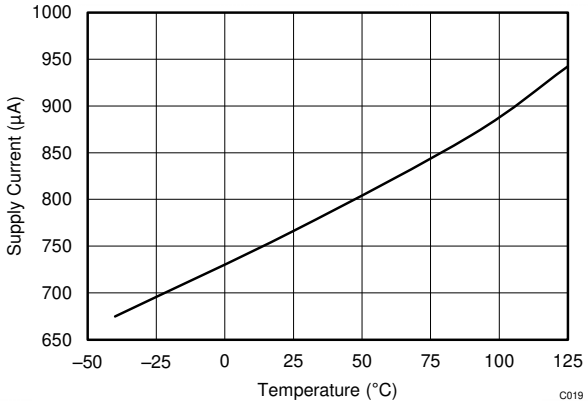


Figure 6-10. Supply Current vs Temperature

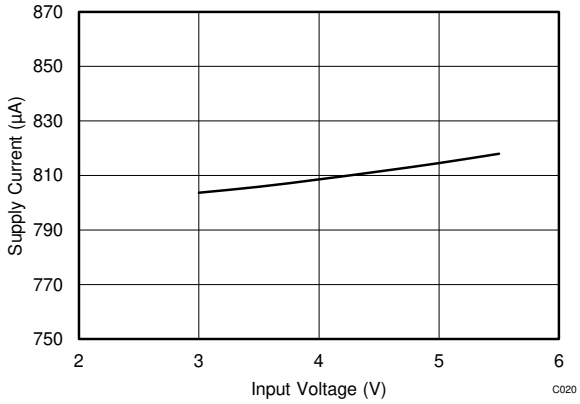


Figure 6-11. Supply Current vs Input Voltage

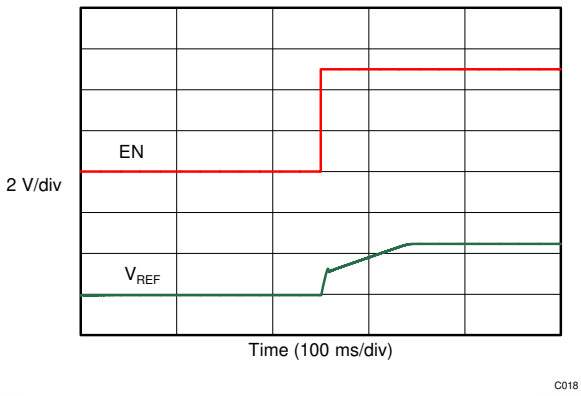


Figure 6-12. Turn-On Settling Time

6.6 Typical Characteristics (continued)

at T_A = 25°C, I_L = 0mA, and V_{IN} = 5V, using REF6125 (unless otherwise noted)

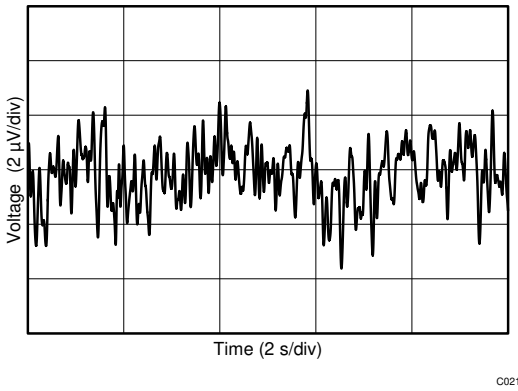


Figure 6-13. 0.1Hz to 10Hz Noise

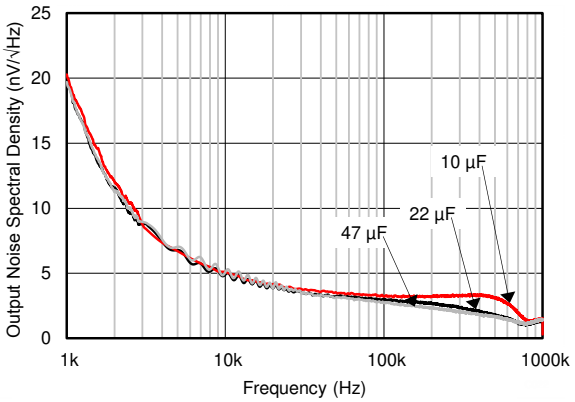


Figure 6-14. Output-Voltage Noise Spectrum

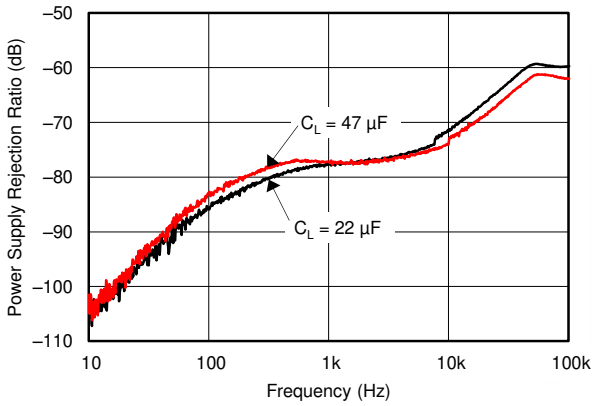
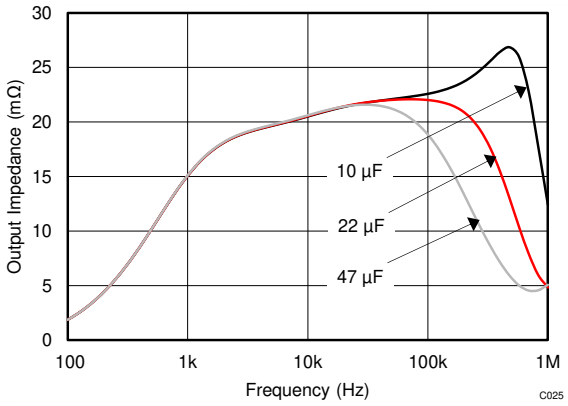
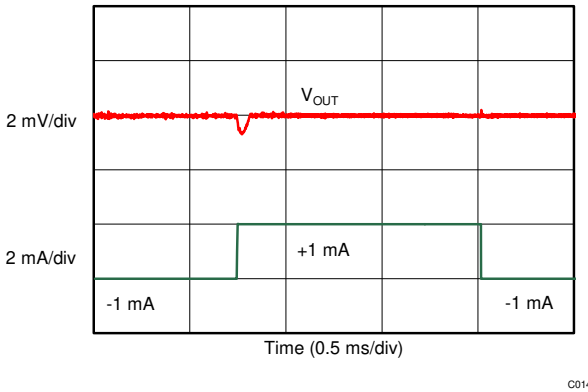


Figure 6-15. PSRR vs Frequency



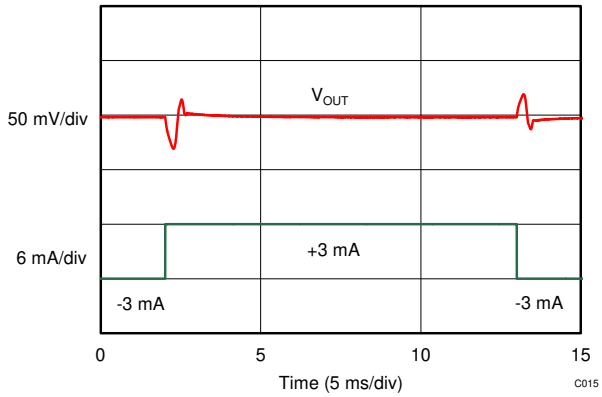
Graph obtained by design simulation

Figure 6-16. Output Impedance vs Frequency



Load current = ±1mA

Figure 6-17. Load Transient Response



Load current = ±3mA

Figure 6-18. Load Transient Response

6.6 Typical Characteristics (continued)

at T_A = 25°C, I_L = 0mA, and V_{IN} = 5V, using REF6125 (unless otherwise noted)

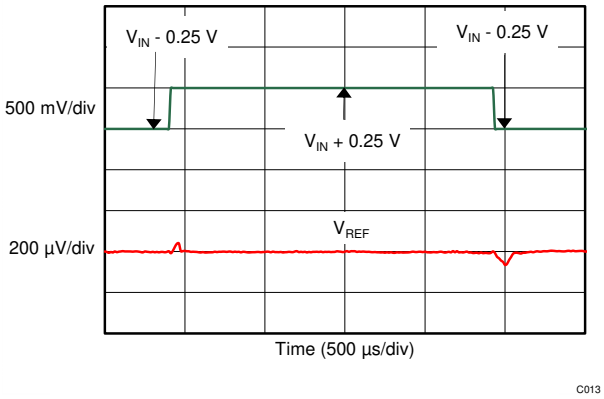


Figure 6-19. Line Transient Response

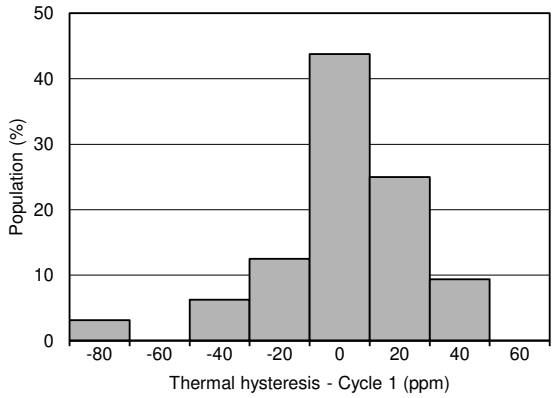


Figure 6-20. Thermal Hysteresis Distribution (Cycle 1)

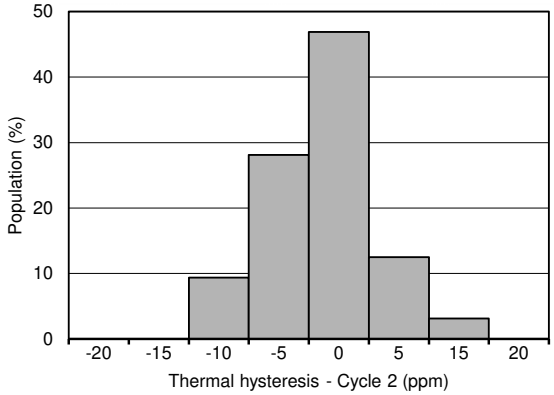


Figure 6-21. Thermal Hysteresis Distribution (Cycle 2)

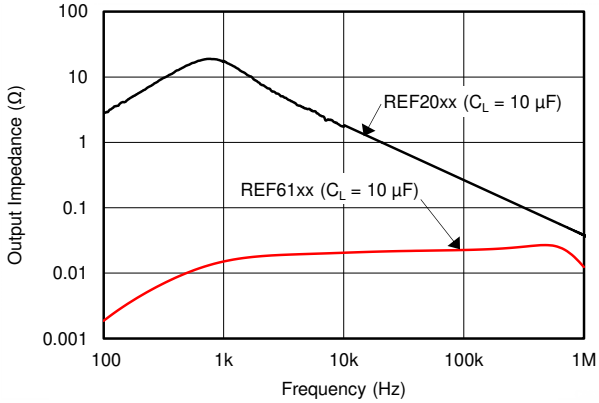
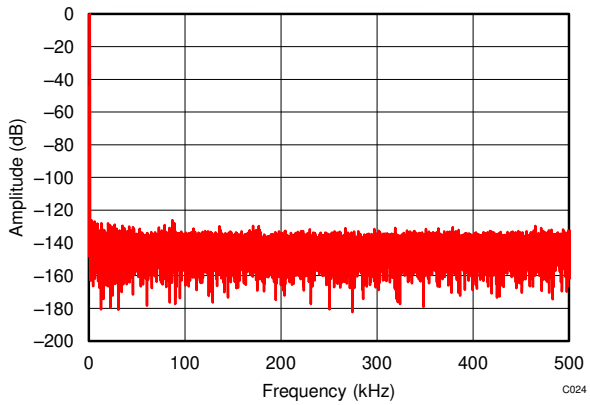
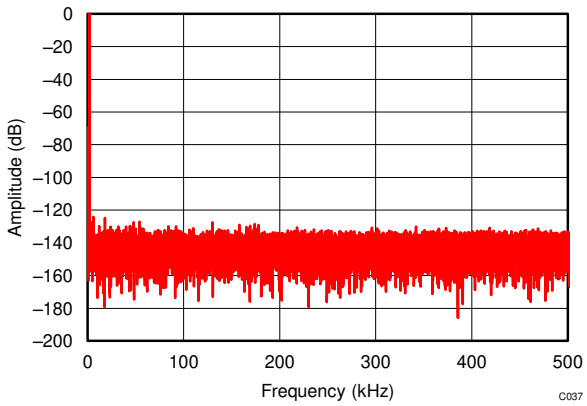


Figure 6-22. Output Impedance Comparison



REF6150 driving REF pin of ADS8881,
f_{IN} = 1kHz, SNR = 100.5dB, THD = –125.9dB

Figure 6-23. Typical FFT Plot

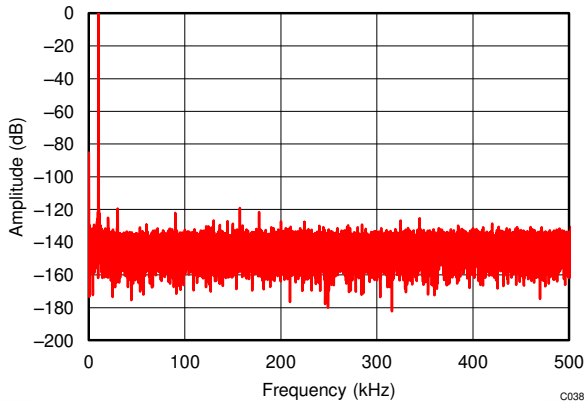


REF6150 driving REF pin of ADS8881,
f_{IN} = 2kHz, SNR = 100.4dB, THD = –123.9dB

Figure 6-24. Typical FFT Plot

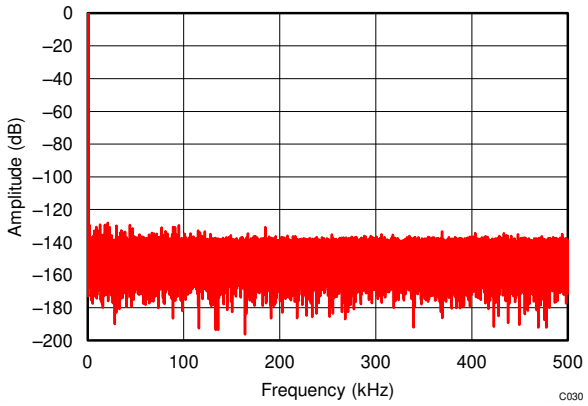
6.6 Typical Characteristics (continued)

at T_A = 25°C, I_L = 0mA, and V_{IN} = 5V, using REF6125 (unless otherwise noted)



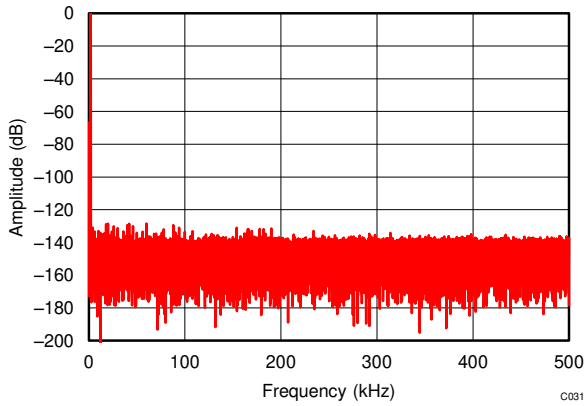
REF6150 driving REF pin of ADS8881,
f_{IN} = 10kHz, SNR = 99.2dB, THD = –119.4dB

Figure 6-25. Typical FFT Plot



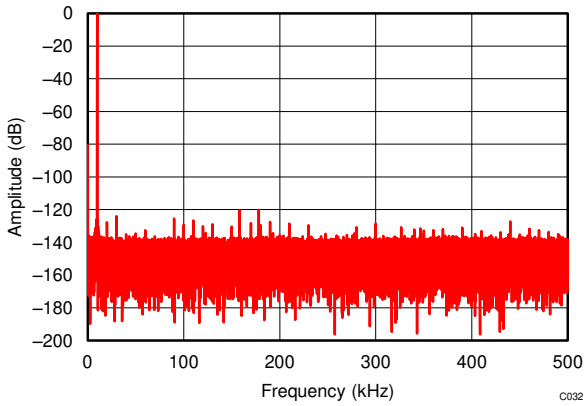
REF6141 driving REF pin of ADS8881,
f_{IN} = 1kHz, SNR = 99dB, THD = –124.4dB

Figure 6-26. Typical FFT Plot



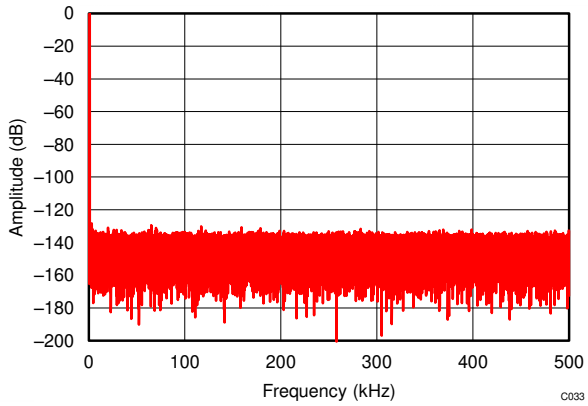
REF6141 driving REF pin of ADS8881,
f_{IN} = 2kHz, SNR = 99dB, THD = –123.6dB

Figure 6-27. Typical FFT Plot



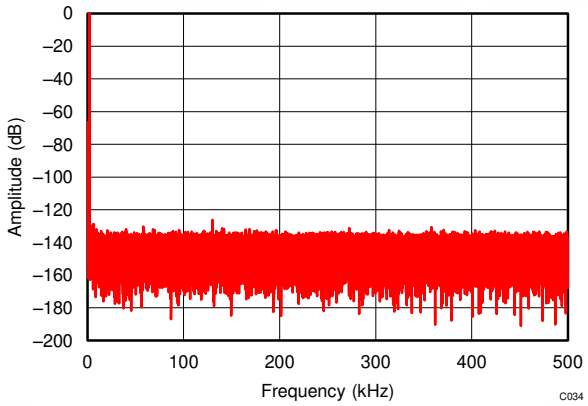
REF6141 driving REF pin of ADS8881,
f_{IN} = 10kHz, SNR = 97.2dB, THD = –119.7dB

Figure 6-28. Typical FFT Plot



REF6125 driving REF pin of ADS8881,
f_{IN} = 1kHz, SNR = 95.4dB, THD = –124dB

Figure 6-29. Typical FFT Plot

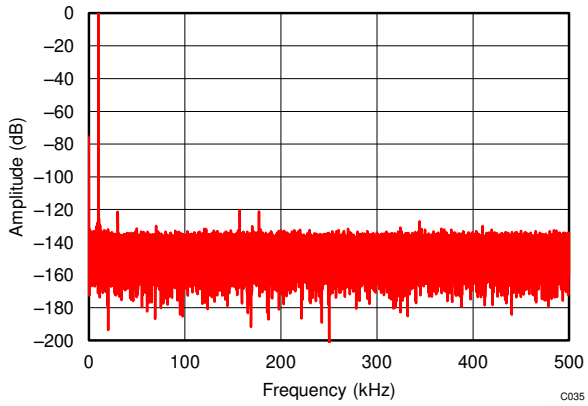


REF6125 driving REF pin of ADS8881,
f_{IN} = 2kHz, SNR = 95.4dB, THD = –123.5dB

Figure 6-30. Typical FFT Plot

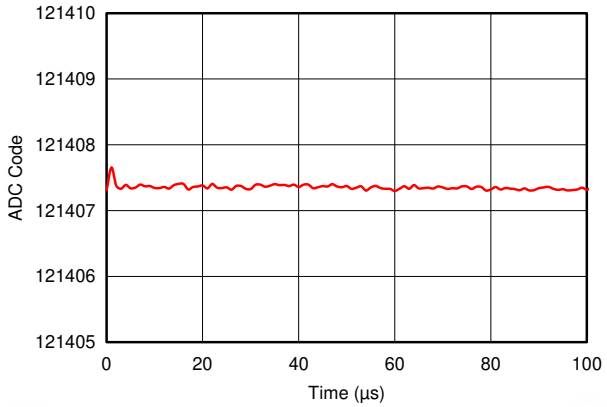
6.6 Typical Characteristics (continued)

at T_A = 25°C, I_L = 0mA, and V_{IN} = 5V, using REF6125 (unless otherwise noted)



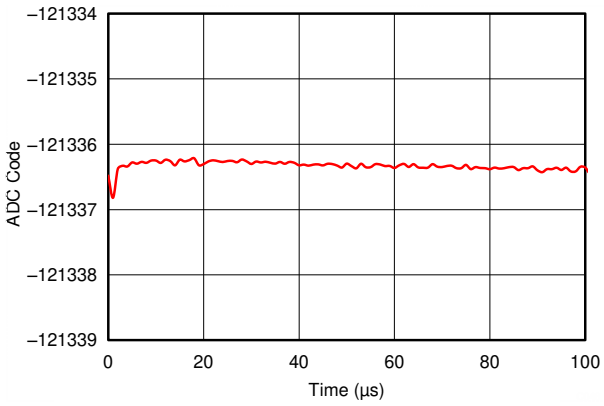
REF6125 driving REF pin of ADS8881,
f_{IN} = 10kHz, SNR = 94.0dB, THD = –119.3dB

Figure 6-31. Typical FFT Plot



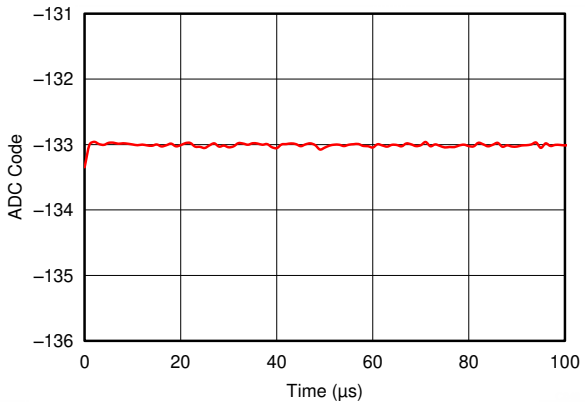
REF6150 driving REF pin of ADS8881 operating at 1MSPS,
positive full-scale input to ADS8881

Figure 6-32. Reference Droop



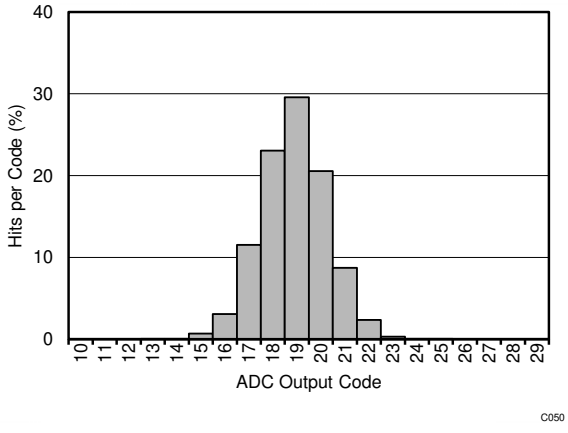
REF6150 driving REF pin of ADS8881 operating at 1MSPS,
negative full-scale input to ADS8881

Figure 6-33. Reference Droop



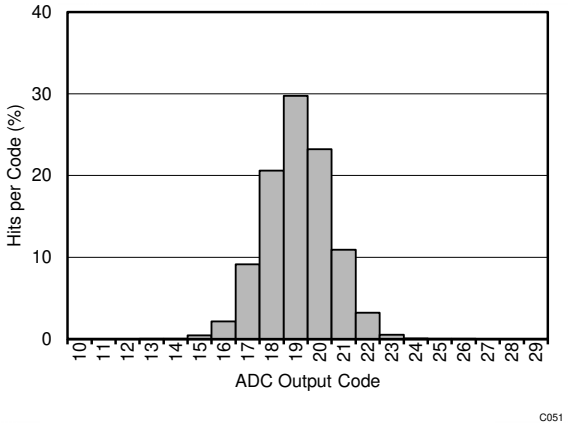
REF6150 driving REF pin of ADS8881 operating at 1MSPS,
AINP = AINN = V_{REF} / 2 for ADS8881

Figure 6-34. Reference Droop



AINP = AINN = V_{REF} / 2 for ADS8881,
sampling rate = 1MSPS

Figure 6-35. DC Input Histogram

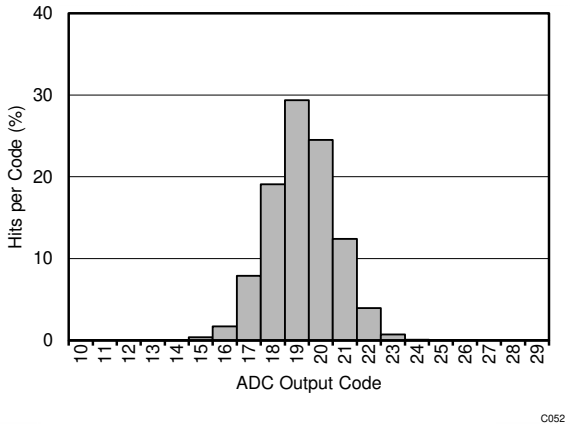


AINP = AINN = V_{REF} / 2 for ADS8881,
sampling rate = 500 kSPS

Figure 6-36. DC Input Histogram

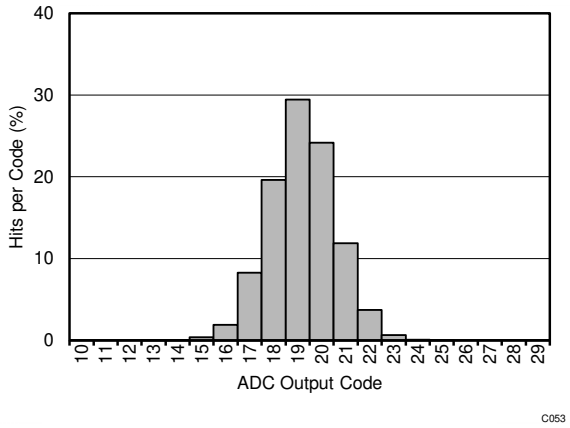
6.6 Typical Characteristics (continued)

at T_A = 25°C, I_L = 0mA, and V_{IN} = 5V, using REF6125 (unless otherwise noted)



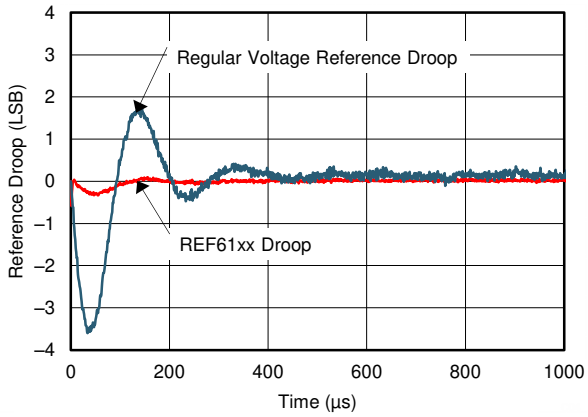
AINP = AINN = V_{REF} / 2 for ADS8881,
sampling rate = 100 kSPS

Figure 6-37. DC Input Histogram



AINP = AINN = V_{REF} / 2 for ADS8881,
sampling rate = 20 kSPS

Figure 6-38. DC Input Histogram



1LSB = 19.07µV, with ADS8881 at 1MSPS

Figure 6-39. Reference Droop Comparison

7 Parameter Measurement Information

7.1 Solder Heat Shift

The materials used in the manufacture of the REF61xx have differing coefficients of thermal expansion, and result in stress on the device die when the part is heated. Mechanical and thermal stress on the device die sometimes causes the output voltages to shift, degrading the initial accuracy specifications of the product. Reflow soldering is a common cause of this error.

In order to illustrate this effect, a total of 128 devices were soldered on eight printed circuit boards (PCBs), with 16 devices on each PCB, using lead-free solder paste, and the manufacturer-suggested reflow profile. The reflow profile is as shown in Figure 7-1. The printed circuit board is comprised of FR4 material. The board thickness is 1.65mm and the area is 101.6mm × 127mm.

The reference output voltage is measured before and after the reflow process; the typical shift is displayed in Figure 7-2. Although all tested units exhibit very low shifts (< 0.03%), higher shifts are also possible depending on the size, thickness, and material of the PCB.

The histogram displays the typical shift for exposure to a single reflow profile. Exposure to multiple reflows, as is common on PCBs with surface-mount components on both sides, causes additional shifts in the output bias voltage. If the PCB is exposed to multiple reflows, solder the device in the final pass to minimize exposure to thermal stress.

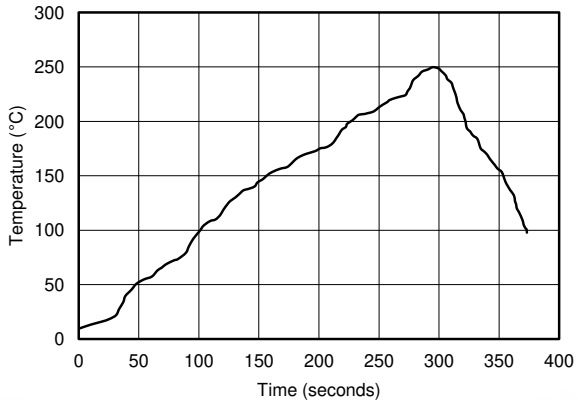


Figure 7-1. Reflow Profile

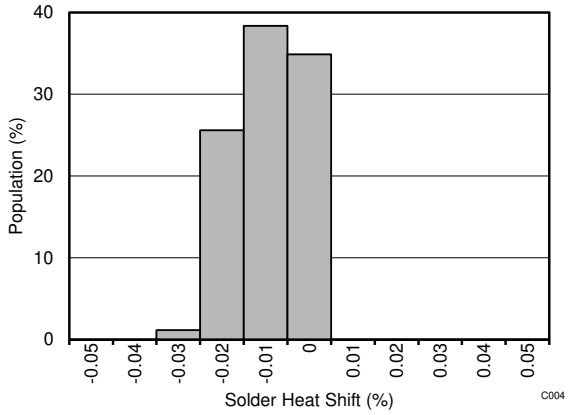


Figure 7-2. Solder Heat Shift Distribution

7.2 Thermal Hysteresis

Thermal hysteresis for the device is defined as the change in output voltage after operating the device at 25°C, cycling the device through the specified temperature range, and returning to 25°C. Thermal hysteresis was measured with the REF61xx soldered to a PCB, similar to a real-world application. The PCB was baked at 150°C for 30 minutes before thermal hysteresis was measured. Thermal hysteresis is expressed as:

$$V_{HYST} = \left(\frac{\left| V_{PRE} - V_{POST} \right|}{V_{NOM}} \right) \bullet 10^6 \quad \text{(ppm)} \tag{1}$$

where

- V_{HYST} = thermal hysteresis (in units of ppm).
- V_{NOM} = the specified output voltage.
- V_{PRE} = output voltage measured at 25°C pretemperature cycling.
- V_{POST} = output voltage measured after the device has cycled from 25°C through the specified temperature range of –40°C to 125°C and returns to 25°C.

Typical thermal hysteresis distribution is shown in Figure 7-3 and Figure 7-4.

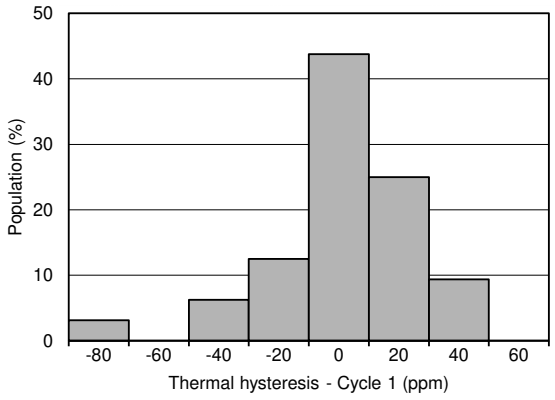


Figure 7-3. Thermal Hysteresis Distribution (Cycle 1)

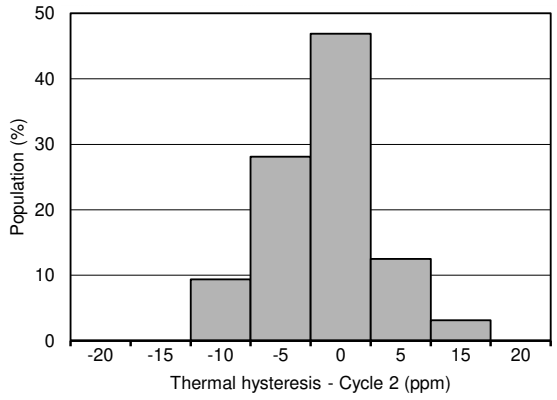
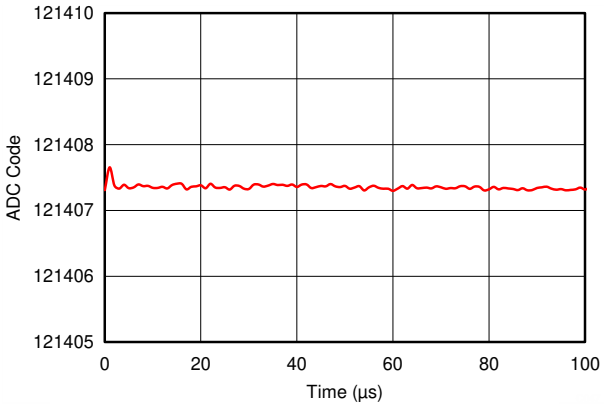


Figure 7-4. Thermal Hysteresis Distribution (Cycle 2)

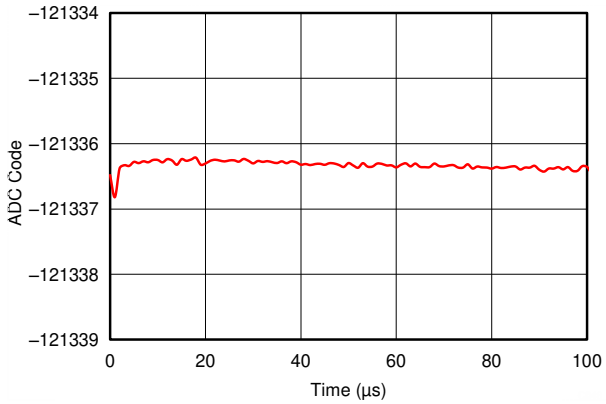
7.3 Reference Droop Measurements

Many applications, such as event-triggered and multiplexed data-acquisition systems, require the very first conversion of the ADC to have 18-bit or greater precision. These types of data-acquisition systems capture data in bursts, and are also called burst-mode, data-acquisition systems. Achieving 18-bit precision for the first sample is a very difficult using a conventional voltage reference because the voltage reference droop limits the accuracy of the first few conversions. The REF61xx have an integrated ADC drive buffer that makes sure the reference droop is less than 1LSB at 18-bit precision when used with the ADS8881, even at full throughput. Figure 7-5 and Figure 7-6 show the REF61xx output voltage droop when driving the REF pin of the ADS8881 at positive and negative full-scale inputs, respectively.



REF6150 driving REF pin of ADS8881 operating at 1MSPS, positive full-scale input to ADS8881

Figure 7-5. Output Voltage Droop



REF6150 driving REF pin of ADS8881 operating at 1MSPS, negative full-scale input to ADS8881

Figure 7-6. Output Voltage Droop

Direct measurement of the reference droop to 18-bit accuracy can be a challenging process. Therefore, the plots in Figure 7-5 and Figure 7-6 were obtained by processing the output code of the ADC. The ADC output code is given by:

$$C = (\text{Input Voltage} / V_{REF}) \times 2^N \quad (2)$$

If the input voltage is kept constant, V_{REF} is computed by monitoring the ADC output code C. The ADC code usually has six to seven LSBs of code spread due to the inherent noise of the ADC. In order to measure reference droop, this noise must be reduced drastically. Noise reduction is done by averaging the output code multiple times, as described in the next paragraph.

Figure 7-7 shows the setup that was used to measure the reference droop. The output ADC code was captured using a field-programmable gate array (FPGA), and post-processing was done on a personal computer. The input to the THS4521, and hence in turn to the ADS8881, is a constant dc voltage (close to positive or negative full-scale because this condition is the worst-case for charge drawn from the REF pin). The dc source must have extremely low noise. After the REF61xx device is powered up and stable, the FPGA sends commands to the ADS8881 to capture data in bursts. The ADS8881 is initially in idle mode for 100ms. The FPGA then sends a command to the ADS8881 to perform 100 conversions at 1MSPS. The ADC code corresponding to these 100 conversions (one burst of data) is stored as the first row in a 1000 × 100 dimensional array. This operation is repeated 1000 times, and the data corresponding to each burst is stored in a new row of the 1000 × 100 dimensional array. Finally, each column in this array is averaged to get a final data-set of 100 elements. This final data-set now has code spread that is much less than 1LSB because most of the noise has now been removed through averaging. This data-set was plotted on a graph with X axis = column number (each column number corresponds to 1µs of time because the sampling rate is 1MSPS), and Y axis = ADC output code to obtain reference-droop measurements.

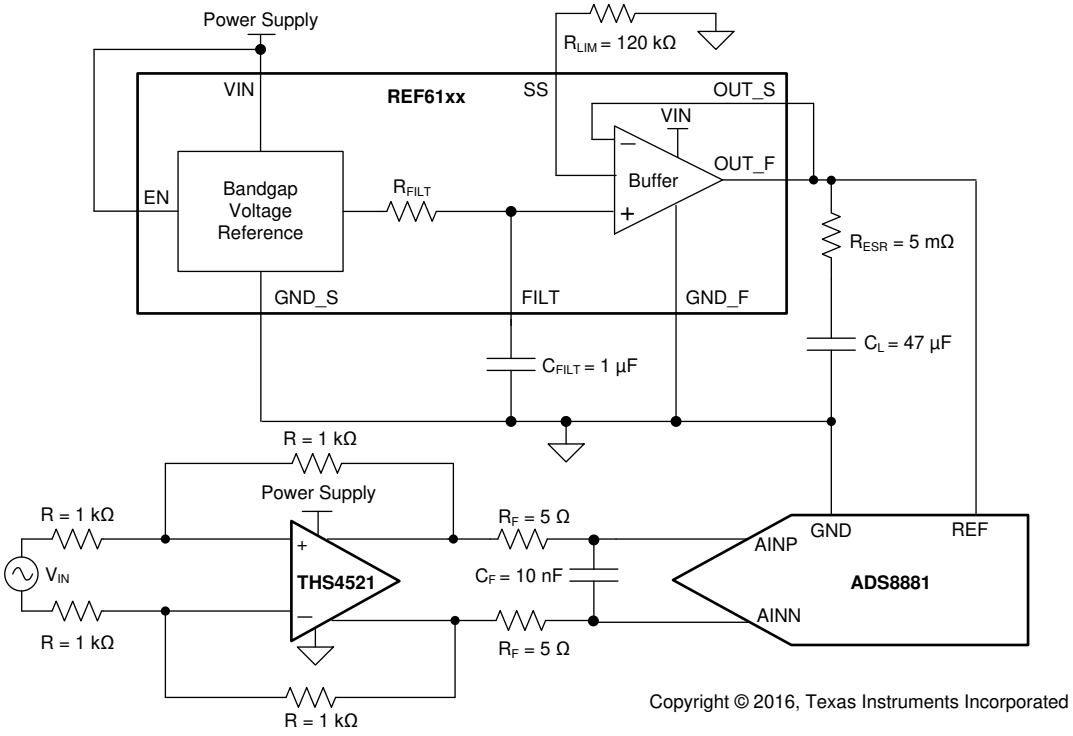


Figure 7-7. Burst-Mode Measurement Setup

7.4 1/f Noise Performance

Typical 0.1Hz to 10Hz voltage noise for the REF6125 is shown in Figure 7-8. The 1/f noise scales with output voltage, but remains 3μV_{PP}/V for all the variants. Peak-to-peak noise measurement setup is shown in Figure 7-9.

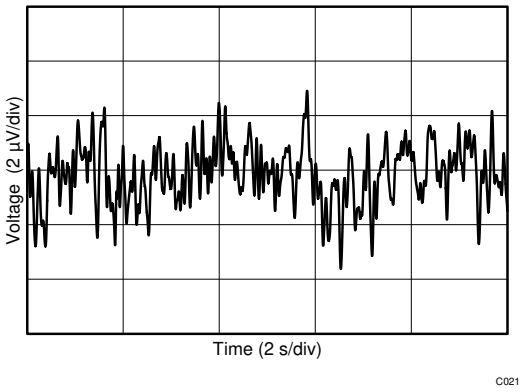


Figure 7-8. 0.1Hz to 10Hz Noise

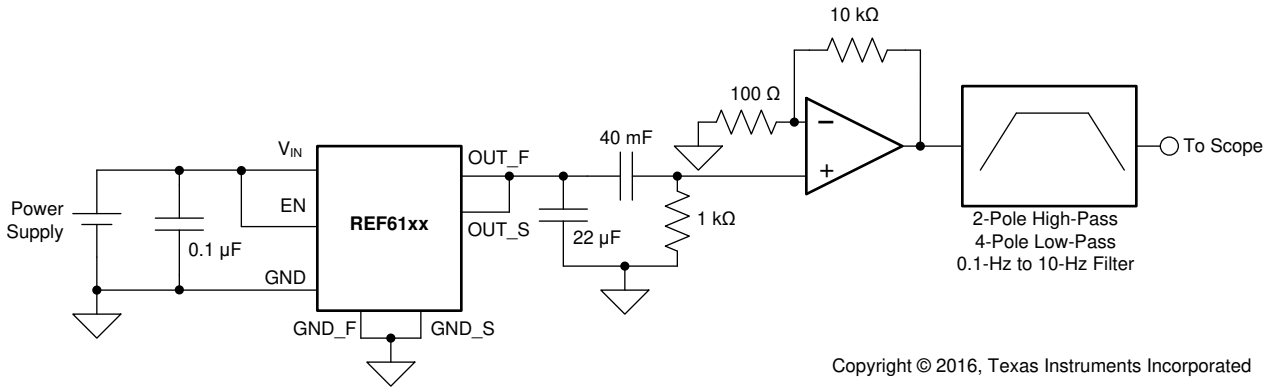


Figure 7-9. 0.1Hz to 10Hz Noise Measurement Setup

8 Detailed Description

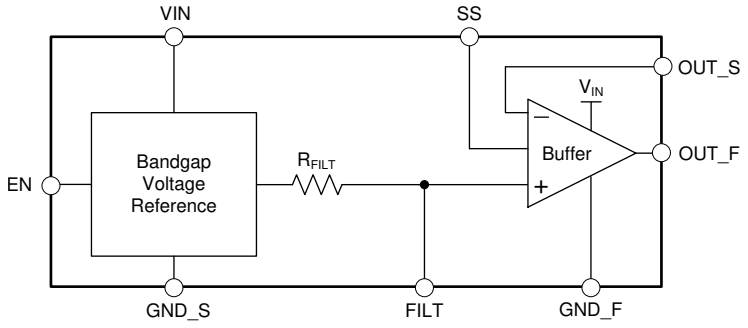
8.1 Overview

Most SAR ADCs, and a few delta-sigma ADCs, switch binary-weighted capacitors onto the REF pin during the conversion process. The magnitude of the capacitance switched onto the REF pin during each conversion depends on the input signal to the ADC. If a voltage reference is directly connected to the REF pin of these ADCs, the reference voltage droops because of the dynamic input signal dependent load of the binary-weighted capacitors. Because the reference voltage droop now has input signal dependance, significant degradation in THD and linearity for the system occurs.

In order to support this dynamic load and preserve the ADC linearity, distortion and noise performance, the output of the voltage reference must be buffered with a low-output impedance (high-bandwidth) buffer. The REF61xx family of voltage references have an integrated low output impedance buffer that enables the user to directly drive the REF pin of a SAR ADC, while preserving ADC linearity and distortion. In addition, the total noise in the full bandwidth of the REF61xx is extremely low, thus preserving the noise performance of the ADC. *Voltage-Reference Impact on Total Harmonic Distortion* (SLYY097) correlates the effect of reference settling to ADC distortion, and how the REF61xx achieves lowest distortion with minimal components and lowest power consumption.

The output voltage of the REF61xx does not droop below 1LSB (18-bit), even during the first conversion while driving the REF pin of the ADS8881. This feature is useful in burst-mode, event-triggered, equivalent-time sampling, and variable-sampling-rate data-acquisition systems. Section 8.2 shows a simplified schematic of the REF61xx.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Integrated ADC Drive Buffer

Many ADC data sheets specify a few microamps of average current draw from the REF pin. Almost all voltage references provide these few microamps of average current; but not all voltage references are practical for driving a high-resolution, high-throughput SAR ADC because the peak current drawn can be very high when the capacitors are switched on the REF pin. The worst-case demand for the voltage reference is during a burst-mode conversion, when the ADC is idle for a very long time, before a conversion is initiated, and the first sample converted is expected to be precise. Usually, a large capacitor is connected between the REF pin and ground pin (or sometimes between the REFP and REFM pins) of the ADC to smooth the current load and reduce the burden on the voltage reference. The voltage reference must then be capable of providing the average current required to completely charge the reference capacitor, but without causing the reference voltage to droop significantly. Most voltage references lack the ability to completely charge the reference capacitor, and settle when the binary-weighted capacitors are being switched onto the REF pin because of the large output impedance. Usually, voltage references have output impedances in the range of 10's of ohms at frequencies higher than 100Hz. The output voltage of the voltage reference must be buffered with a low output impedance (usually high bandwidth) amplifier to achieve excellent linearity and distortion performance.

The key amplifier specifications to be considered when designing a reference buffer for a high-precision ADC are: low offset, low drift, wide bandwidth, and low output impedance. While it is possible to select an amplifier that sufficiently meets all these requirements, the amplifier comes at a cost of excessive power consumption. For example, the OPA350 is a 38MHz bandwidth amplifier with a maximum offset of 0.5mV, and low offset drift of 4µV/°C, but consumes a quiescent current of 5.2mA. This is because (from an amplifier design perspective) offset and drift are dc specifications, whereas bandwidth, low output impedance, and high capacitive drive capability are high-frequency specifications. Therefore, achieving all the performance in one amplifier requires power. However, a more efficient design to meet the low power budget is to use a composite reference buffer, which uses an amplifier with superior high-frequency specifications in the feedback loop of a dc precision amplifier to get the overall performance at much lower power consumption. Figure 8-1 shows such a composite amplifier design with the OPA333 (dc precision amplifier) and THS4281 (high-bandwidth amplifier). This reference buffer design requires three devices, and a large number of external components. This solution still consumes close to 2mA of quiescent current.

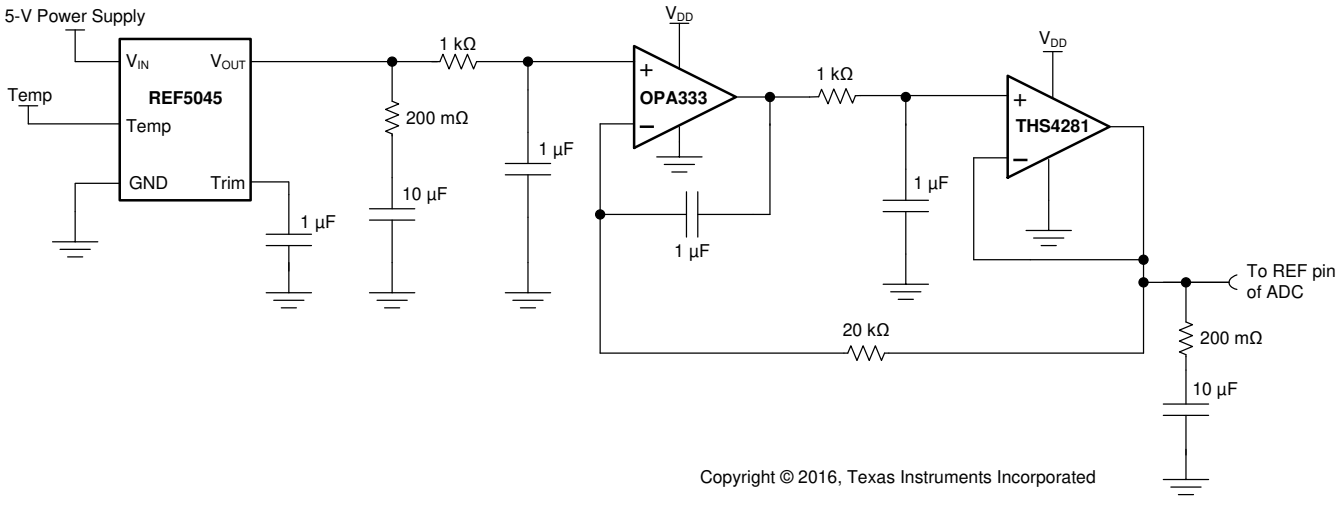


Figure 8-1. Composite Amplifier Reference Buffer

The REF61xx family of voltage references have an integrated low output impedance buffer (ADC drive buffer); therefore, there is no need for an external buffer while driving the REF pin of high-precision, high-throughput SAR ADCs, as shown in Figure 8-2. The ADC drive buffer of the REF61xx is capable of replenishing a charge of 70 pC on a 47-µF capacitor in 1µs, without allowing the voltage on the capacitor to droop more than 1LSB at 18-bit precision. The REF61xx are trimmed at multiple temperatures in production, achieving a max drift of just

8ppm/°C for both the voltage reference and the buffer combined, while operating at a typical quiescent current of 820 µA. Figure 8-3 compares the output impedance of a regular voltage reference (REF20xx) and a voltage reference with integrated ADC drive buffer (REF61xx). Figure 8-4 compares the burst-mode, reference-settling performance of a regular voltage reference and the REF61xx.

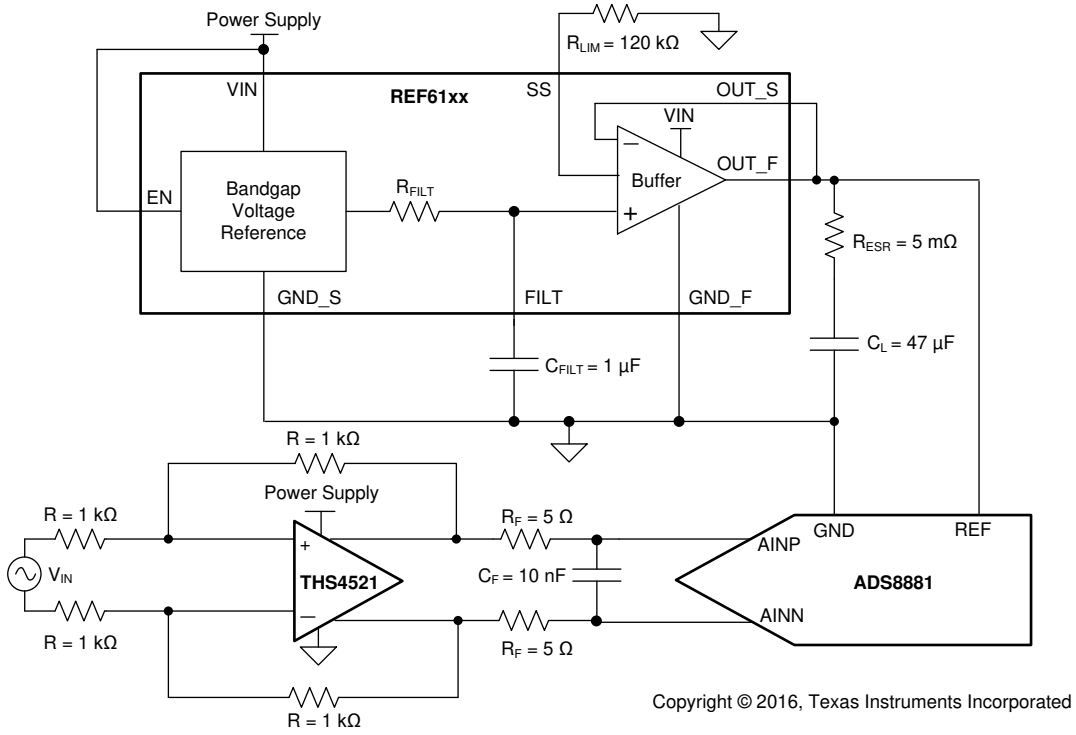


Figure 8-2. REF61xx Driving REF Pin of ADS8881 SAR ADC

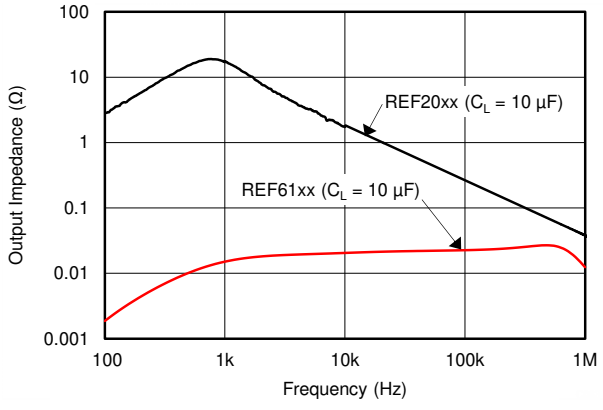
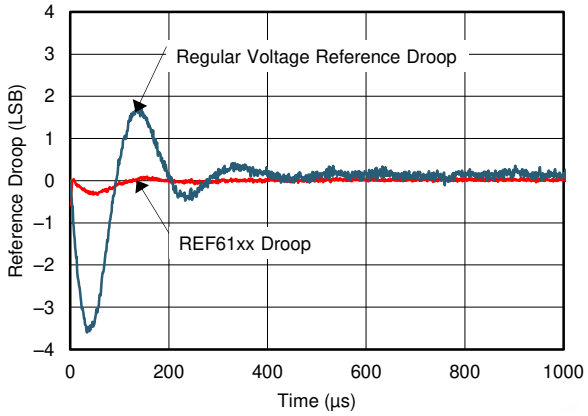


Figure 8-3. Output Impedance Comparison



1LSB = 19.07µV, with ADS8881 at 1MSPS

Figure 8-4. Reference Droop Comparison

8.3.2 Temperature Drift

The REF61xx family is designed for minimal drift error, defined as the change in output voltage over temperature. The drift is calculated using the box method, as described by the following equation:

$$\text{Drift} = \left(\frac{V_{REF(MAX)} - V_{REF(MIN)}}{V_{REF} \bullet \text{Temperature Range}} \right) \bullet 10^{6} \quad \text{(ppm)} \tag{3}$$

8.3.3 Load Current

The REF6125, REF6130, REF6133 and REF6141 are specified to deliver current load of ±4mA. The REF6145 is specified to deliver ±3.5mA, and the REF6150 is specified to deliver ±3mA. The REF61xx are protected from short circuits at the output by limiting the output short-circuit current.

The short-circuit current limit (I_{SC}) of the REF61xx family of devices is adjusted by connecting a resistor (R_{SS}) on the SS pin. The short-circuit current limit when the REF61xx device is sourcing current can be calculated as shown in Equation 4:

$$I_{SC} = (80 * 10^{-9}) * R_{SS} + (3 * 10^{-3}) \tag{4}$$

The short circuit current limit when the REF61xx device is sinking is calculated as shown in Equation 5:

$$I_{SC} = (115 * 10^{-9}) * R_{SS} + (4.6 * 10^{-3}) \tag{5}$$

The recommended output current of the REF61xx also depends on the resistor connected to the SS pin. The recommended output current (sourcing and sinking) for the REF6125, REF6130, REF6133 and REF6141 is given by Equation 6:

$$I_{L} = (31.25 * 10^{-9}) * R_{SS} + (0.25 * 10^{-3}) \tag{6}$$

The recommended output current (sourcing and sinking) for the REF6145 is given by Equation 7:

$$I_{L} = (27.08 * 10^{-9}) * R_{SS} + (0.25 * 10^{-3}) \tag{7}$$

The recommended output current (sourcing and sinking) for the REF6150 is given by Equation 8:

$$I_{L} = (23.75 * 10^{-9}) * R_{SS} + (0.15 * 10^{-3}) \tag{8}$$

The temperature of the device increases according to Equation 9:

$$T_{J} = T_{A} + P_{D} \bullet R_{\theta JA} \tag{9}$$

where:

- T_J = junction temperature (°C).
- T_A = ambient temperature (°C).
- P_D = power dissipated (W).
- $R_{\theta JA}$ = junction-to-ambient thermal resistance (°C/W).

The REF61xx maximum junction temperature must not exceed the absolute maximum rating of 150°C.

8.3.4 Stability

The REF61xx family of voltage references are stable with output capacitor values ranging from 10 µF to 47 µF. At a low output-capacitor value of 10 µF, an effective series resistance (ESR) of 20mΩ to 100mΩ is required for stability; whereas, at a higher value of 47 µF, an ESR of 5mΩ to 100mΩ is required. The shaded region in Figure 8-5 shows the stable region of operation for the REF61xx devices.

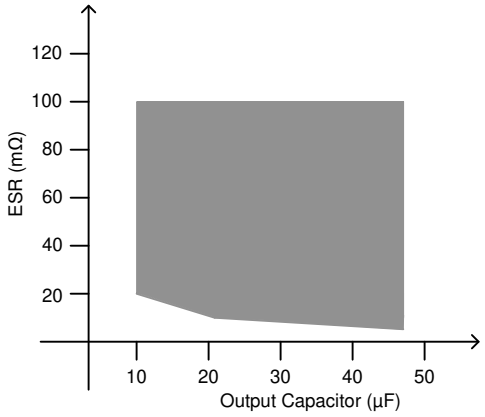


Figure 8-5. Stable Output Capacitor Range

A capacitor of value 1 µF is required at the FILT pin for stability and noise performance. A low ESR (5mΩ to 20mΩ) is easily achieved by increasing the PCB trace length, thus eliminating the need for a discrete resistor. Higher values of ESR (greater than 20mΩ, but lesser than 100mΩ) can be intentionally added to increase the output bandwidth of the REF61xx. This higher ESR improves the transient performance of the REF61xx, but worsens noise performance because of increased bandwidth.

8.4 Device Functional Modes

When the EN pin of the REF61xx is pulled high, the device is in active mode. The device must be in active mode for normal operation.

To place the REF61xx into a shutdown mode, pull the ENABLE pin low. When in shutdown mode, the output of the device becomes high impedance and the quiescent current of the device reduces to 1 µA (typ). See the enable pin voltage parameter in Section 6.5 for logic high and logic low voltage levels.

9 Application and Implementation

Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

9.1 Application Information

Many applications, such as event-triggered and multiplexed data-acquisition systems, require the very first conversion of the ADC to have 18-bit or greater precision. These types of data acquisition systems capture data in bursts, and are also called burst-mode, data-acquisition systems. Achieving 18-bit precision for the first sample is very difficult using a conventional voltage reference because the voltage reference droop limits the accuracy of the first few conversions. Furthermore, variable-sampling-rate systems require that the gain error of the system does not vary with sampling rate. The primary objective of this design example is to demonstrate the lowest distortion and noise, burst-mode data-acquisition block with low power consumption, using an 18-bit SAR ADC operating at a throughput of 1MSPS, for a 1kHz, full-scale, pure sine-wave input.

9.2 Typical Application

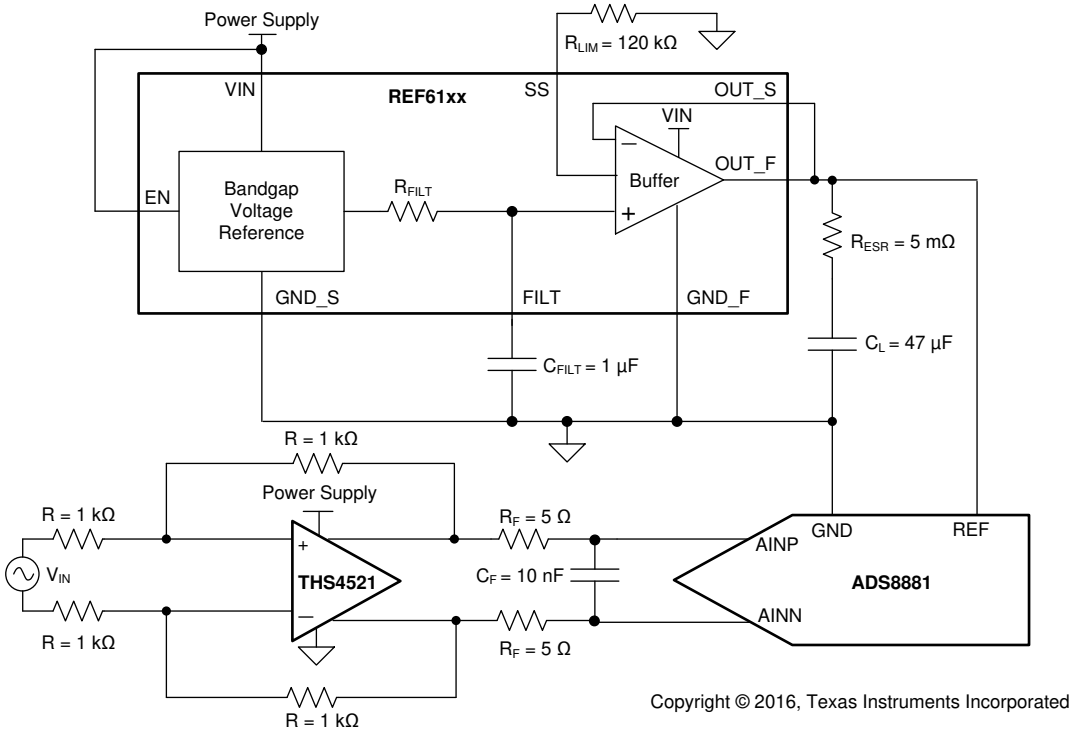


Figure 9-1. 18-bit, 1MSPS, Burst-Mode Data Acquisition system

9.2.1 Design Requirements

1. Burst-mode support (see Section 7.3 for more details)
2. ENOB > 16 bits
3. THD < –120dB
4. Power consumption < 50mW
5. Throughput = 1MSPS

9.2.2 Detailed Design Procedure

The data acquisition system shown in Figure 9-1 has three major contributors to the noise and accuracy in the system: the input driver, the reference with driver, and the data converter. Each analog block is carefully designed so that the data converter specifications limit the system specifications. The THS4551, a fully differential operational amplifier is used to drive the 18-bit ADC (ADS8881). The charge-kickback RC filter at the output of the THS4551 is used to reduce the charge kickback created by the opening and closing of the sampling switch inside the ADC. Design the RC filter so that the voltage at the sampling capacitor settles to 18-bit accuracy within the acquisition time of the ADC.

Data-acquisition systems require stable and accurate voltage references in order to perform the most accurate data conversion. The REF61xx family of voltage references have integrated an ADC drive buffer, and can therefore drive the REF pin of the ADS8881 directly, without the need for an external reference buffer. See Section 8.3.1 for more details about reference-buffer requirements. Correct output capacitor selection for the REF61xx is very important in this design. Section 8.3.4 describes the ESR requirements of the output capacitor for stability and burst-mode requirements. A capacitance of 1µF is connected to the FILT pin to reduce broadband noise of the REF61xx.

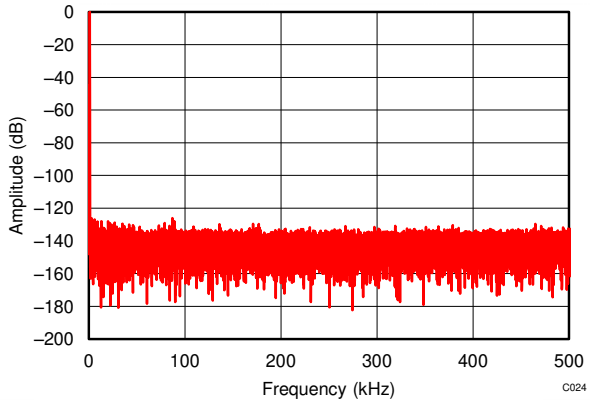
9.2.2.1 Results

Table 9-1 summarizes the measured results.

Table 9-1. Measured Results

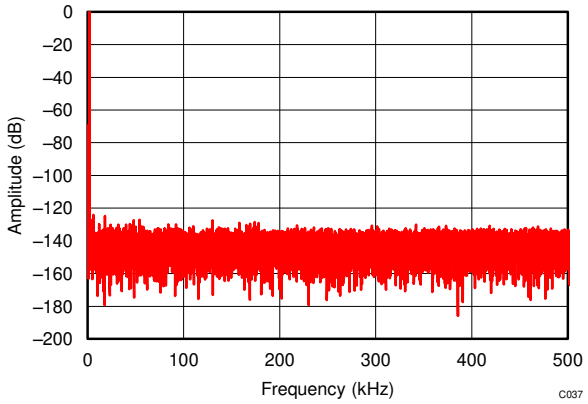
SPECIFICATION	MEASURED RESULT
SNR	100.5dB
ENOB	16.4
THD	–125.9dB
Throughput	1MSPS
Burst mode	First sample > 18-bit precision
Power consumption	40mW

9.2.3 Application Curves



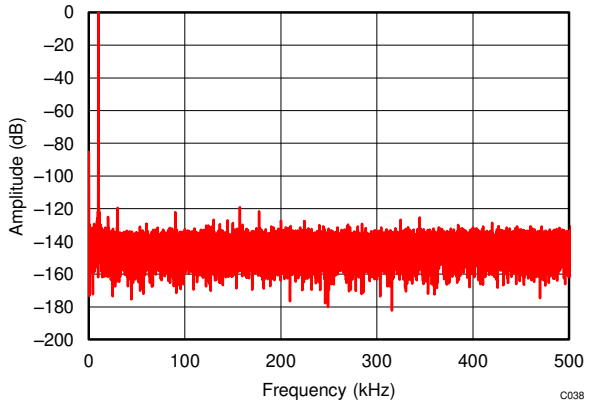
REF6150 driving REF pin of ADS8881,
f_{IN} = 1kHz, SNR = 100.5dB, THD = –125.9dB

Figure 9-2. Typical FFT Plot



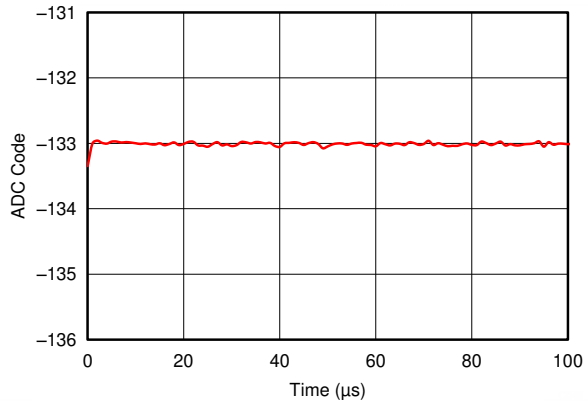
REF6150 driving REF pin of ADS8881,
f_{IN} = 2kHz, SNR = 100.4dB, THD = –123.9dB

Figure 9-3. Typical FFT Plot



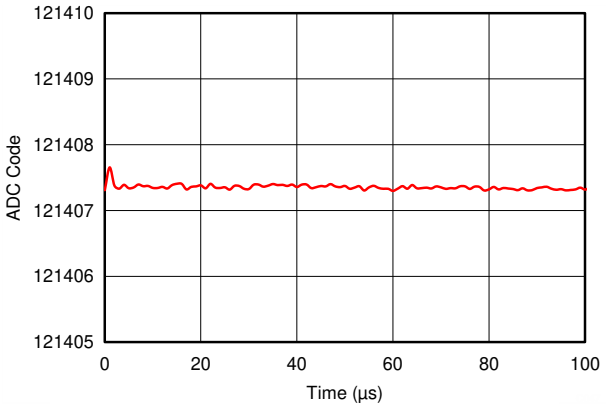
REF6150 driving REF pin of ADS8881,
f_{IN} = 10kHz, SNR = 99.2dB, THD = –119.4dB

Figure 9-4. Typical FFT Plot



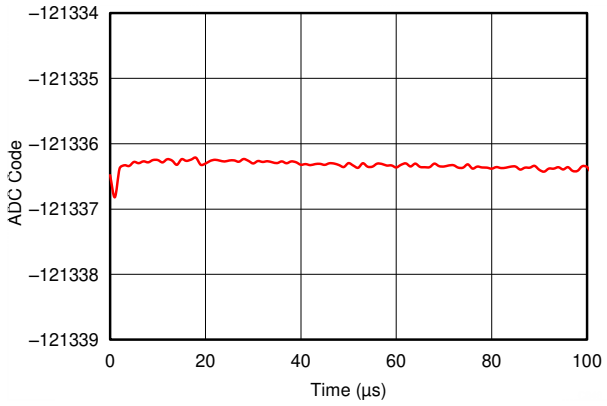
REF6150 driving REF pin of ADS8881 operating at 1MSPS,
AINP = AINN = V_{REF} / 2 for ADS8881

Figure 9-5. Reference Droop



REF6150 driving REF pin of ADS8881 operating at 1MSPS,
positive full-scale input to ADS8881

Figure 9-6. Reference Droop



REF6150 driving REF pin of ADS8881 operating at 1MSPS,
negative full-scale input to ADS8881

Figure 9-7. Reference Droop

9.3 Power Supply Recommendations

The REF61xx family of references have extremely low dropout voltage. The dropout specifications can be found in Section 6.5. A minimum 0.1 µF decoupling capacitor must be connected between the VIN and GND_F pins of the REF61xx. A typical dropout voltage versus load is shown in Figure 9-8.

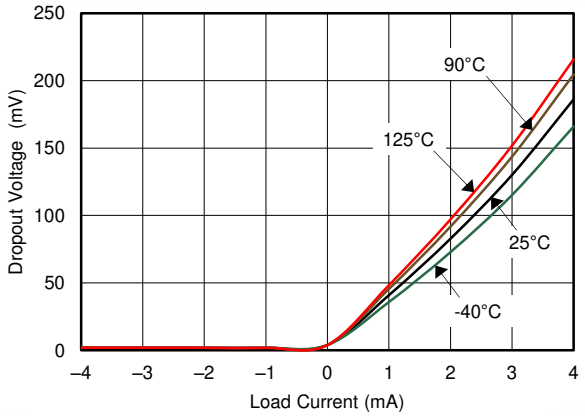


Figure 9-8. Dropout Voltage vs Load Current

9.4 Layout

9.4.1 Layout Guidelines

Figure 9-9 illustrates an example of a PCB layout for a data-acquisition system using the REF61xx. Some key considerations are:

- Connect low-ESR, 0.1µF ceramic bypass capacitors between the VIN pin and ground.
- Place the REF61xx output capacitor (C_L) and the ADC as close to each other as possible.
- Run two separate traces between VOUT_F, VOUT_S and the output capacitor, as shown in Figure 9-9.
- Short the GND_F and GND_S pins with a solid plane, and extend this plane to connect to the output capacitor C_L, as shown in Figure 9-9.
- Use a solid ground plane to help distribute heat and reduces electromagnetic interference (EMI) noise pickup.
- Place the external components as close to the device as possible. This configuration prevents parasitic errors (such as the Seebeck effect) from occurring.
- Do not run sensitive analog traces in parallel with digital traces. Avoid crossing digital and analog traces if possible, and only make perpendicular crossings when absolutely necessary.

9.4.2 Layout Example

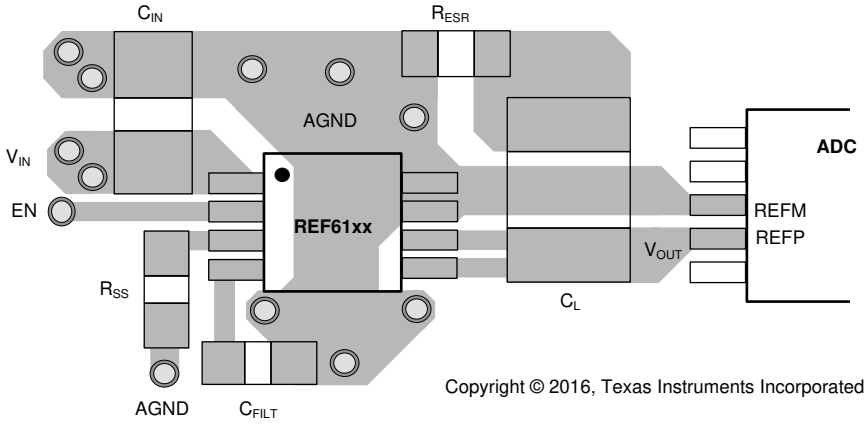


Figure 9-9. Layout Example

10 Device and Documentation Support

10.1 Documentation Support

10.1.1 Related Documentation

For related documentation see the following:

- Texas Instruments, *ADS8881x 18-Bit, 1MSPS, Serial Interface, microPower, Miniature, True-Differential Input, SAR Analog-to-Digital Converter Data Sheet* datasheet
- Texas Instruments, *ADS127L01 24-Bit, High-Speed, Wide-Bandwidth Analog-to-Digital Converter* datasheet
- Texas Instruments, *REF6025EVM-PDK User's Guide*
- Texas Instruments, *Voltage-Reference Impact on Total Harmonic Distortion* marketing white paper

10.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Notifications* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

10.3 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

10.4 Trademarks

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10.5 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

10.6 Glossary

TI Glossary	This glossary lists and explains terms, acronyms, and definitions.

11 Revision History

Changes from Revision B (August 2016) to Revision C (June 2026) **Page**

- Updated the numbering format for tables, figures, and cross-references throughout the document..... 1
- Moved the REF6125, REF6130, REF6133, REF6141, REF6145, REF6150 devices to the REF61 product folder on TI.com and updated the datasheet header.....1

Changes from Revision A (June 2016) to Revision B (August 2016) **Page**

- Changed the *Description* 1
- Changed the *Description* 1
- Changed the *Device Comparison Table* 2
- Changed list of devices for output current in Recommended Operating Conditions 4
- Changed load regulation max value for REF6150 at T_A = –40°C to +125°C from 30 to 50 5
- Changed Figure 1..... 7

- Changed Figure 2 7
- Changed Figure 5 7
- Changed "second pass" to "final pass" in last paragraph of *Solder Heat Shift* section 14
- Added link to SLYY097 in *Overview* section 19

Changes from Revision * (May 2016) to Revision A (June 2016) **Page**

- Changed from product preview to production data 1

12 Mechanical, Packaging, and Orderable Information

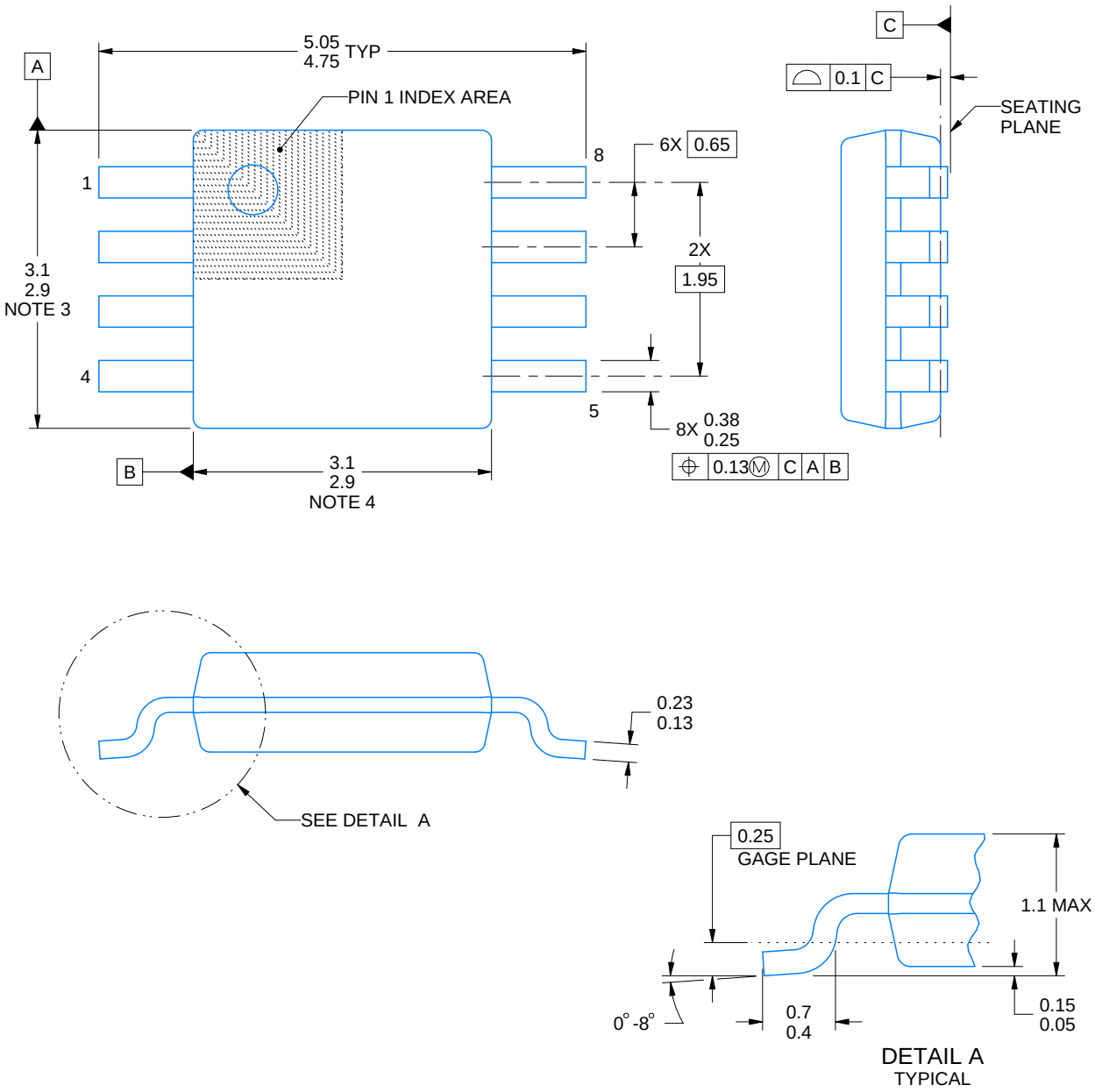
The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGE OUTLINE

DGK0008A

VSSOP - 1.1 mm max height

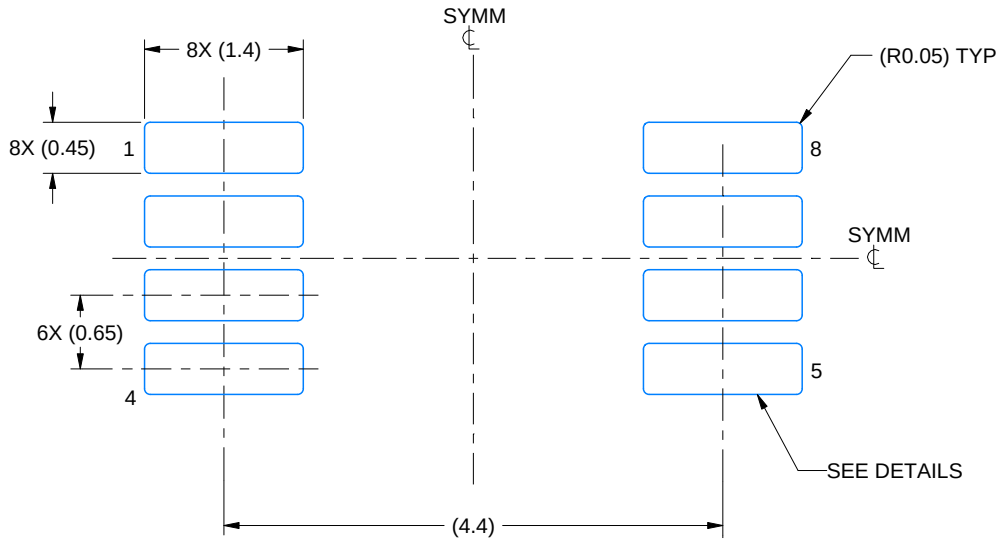
SMALL OUTLINE PACKAGE



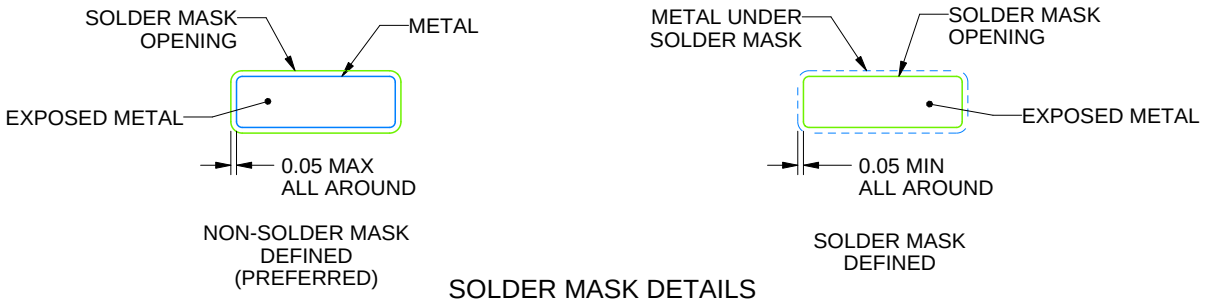
PowerPAD is a trademark of Texas Instruments.

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-187.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 15X

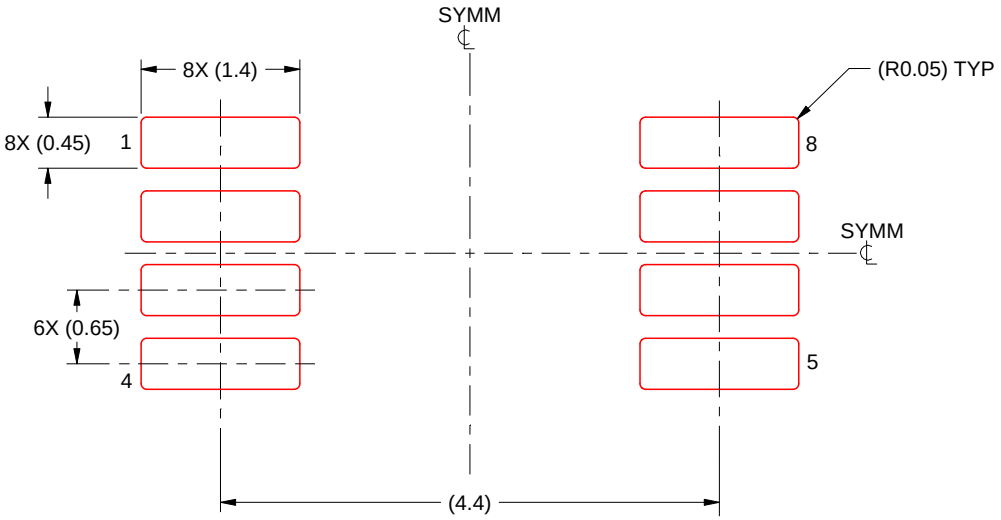


SOLDER MASK DETAILS

4214862/A 04/2023

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
8. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.
9. Size of metal pad may vary due to creepage requirement.



SOLDER PASTE EXAMPLE
SCALE: 15X

4214862/A 04/2023

NOTES: (continued)

11. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
12. Board assembly site may have different recommendations for stencil design.

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Last updated 10/2025