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Tel: +86-755-8981 8866 Fax: +86-755-8427 6832
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16-Bit ΔΣ ADC with Easy Drive Input Current Cancellation

FEATURES

- **Extended Temperature Range of –40°C to 125°C**
- **Easy Drive Technology Enables Rail-to-Rail Inputs with Zero Differential Input Current**
- **Directly Digitizes High Impedance Sensors with Full Accuracy**
- **Programmable Gain from 1 to 256**
- **GND to V_{CC} Input/Reference Common Mode Range**
- Programmable 50Hz, 60Hz or Simultaneous 50Hz/60Hz Rejection Mode
- 2ppm (0.25LSB) INL, No Missing Codes
- 1ppm Offset and 15ppm Full-Scale Error
- Selectable 2x Speed Mode (15Hz Using Internal Oscillator)
- No Latency: Digital Filter Settles in a Single Cycle
- Single Supply 2.7V to 5.5V Operation
- Internal Oscillator
- Available in a Tiny (3mm × 3mm) 10-Lead DFN Package and 10-Lead MSOP Package

APPLICATIONS

- Direct Sensor Digitizer
- Weight Scales
- Direct Temperature Measurement
- Strain Gauge Transducers
- Instrumentation
- Industrial Process Control
- DVMs and Meters

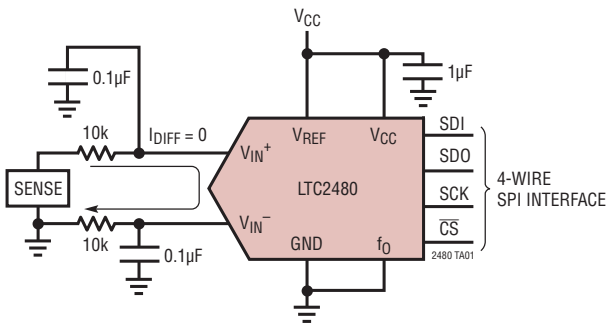
DESCRIPTION

The LTC®2480 combines a 16-bit plus sign No Latency ΔΣ™ analog-to-digital converter with patented Easy Drive™ technology. The patented sampling scheme eliminates dynamic input current errors and the shortcomings of on-chip buffering through automatic cancellation of differential input current. This allows large external source impedances and input signals, with rail-to-rail input range to be directly digitized while maintaining exceptional DC accuracy.

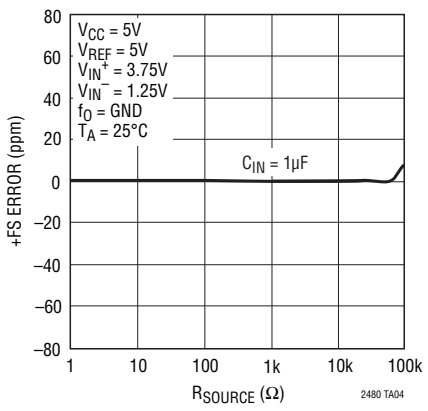
The LTC2480 includes on-chip programmable gain and an oscillator. The LTC2480 can be configured to provide a programmable gain from 1 to 256 in 8 steps, measure an external signal or internal temperature sensor and reject line frequencies. 50Hz, 60Hz or simultaneous 50Hz/60Hz line frequency rejection can be selected as well as a 2x speed-up mode.

The LTC2480 allows a wide common mode input range (0V to V_{CC}) independent of the reference voltage. The reference can be as low as 100mV or can be tied directly to V_{CC}. The LTC2480 includes an on-chip trimmed oscillator eliminating the need for external crystals or oscillators. Absolute accuracy and low drift are automatically maintained through continuous, transparent, offset and full-scale calibration.

TYPICAL APPLICATION



+FS Error vs R_{SOURCE} at IN^+ and IN^-

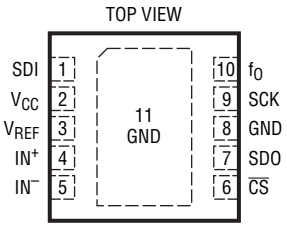


ABSOLUTE MAXIMUM RATINGS (Notes 1, 2)

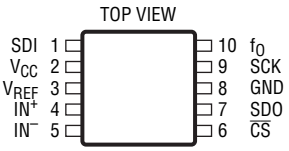
Supply Voltage (V_{CC}) to GND ..... –0.3V to 6V
Analog Input Voltage to GND ..... –0.3V to (V_{CC} + 0.3V)
Reference Input Voltage to GND .. –0.3V to (V_{CC} + 0.3V)
Digital Input Voltage to GND ..... –0.3V to (V_{CC} + 0.3V)
Digital Output Voltage to GND..... –0.3V to (V_{CC} + 0.3V)

Operating Temperature Range
LTC2480C ..... 0°C to 70°C
LTC2480I ..... –40°C to 85°C
LTC2480H ..... –40°C to 125°C
Storage Temperature Range..... –65°C to 125°C

PIN CONFIGURATION



DD PACKAGE
10-LEAD (3mm × 3mm) PLASTIC DFN
T_{JMAX} = 125°C, θ_{JA} = 43°C/W
EXPOSED PAD (PIN 11) IS GND, MUST BE SOLDERED TO PCB



MS PACKAGE
10-LEAD PLASTIC MSOP
T_{JMAX} = 125°C, θ_{JA} = 120°C/W

ORDER INFORMATION

LEAD FREE FINISH	TAPE AND REEL	PART MARKING*	PACKAGE DESCRIPTION	TEMPERATURE RANGE
LTC2480CDD#PBF	LTC2480CDD#TRPBF	LBJY	10-Lead (3mm × 3mm) Plastic DFN	0°C to 70°C
LTC2480IDD#PBF	LTC2480IDD#TRPBF	LBJY	10-Lead (3mm × 3mm) Plastic DFN	–40°C to 85°C
LTC2480CMS#PBF	LTC2480CMS#TRPBF	LTCWB	10-Lead Plastic MSOP	0°C to 70°C
LTC2480IMS#PBF	LTC2480IMS#TRPBF	LTCWB	10-Lead Plastic MSOP	–40°C to 85°C
LTC2480HDD#PBF	LTC2480HDD#TRPBF	LBJY	10-Lead (3mm × 3mm) Plastic DFN	–40°C to 125°C
LTC2480HMS#PBF	LTC2480HMS#TRPBF	LTCWB	10-Lead Plastic MSOP	–40°C to 125°C

Consult LTC Marketing for parts specified with wider operating temperature ranges. *The temperature grade is identified by a label on the shipping container.

For more information on lead free part marking, go to: http://www.linear.com/leadfree/
For more information on tape and reel specifications, go to: http://www.linear.com/tapeandreel/

ELECTRICAL CHARACTERISTICS (NORMAL SPEED)

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Notes 3, 4)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Resolution (No Missing Codes)	0.1 ≤ V_{REF} ≤ V_{CC}, –FS ≤ V_{IN} ≤ +FS (Note 5)	●	16			Bits
Integral Nonlinearity	5V ≤ V_{CC} ≤ 5.5V, V_{REF} = 5V, $V_{IN(CM)}$ = 2.5V (Note 6) 2.7V ≤ V_{CC} ≤ 5.5V, V_{REF} = 2.5V, $V_{IN(CM)}$ = 1.25V (Note 6)	●		2 1	10	ppm of V_{REF} ppm of V_{REF}
Offset Error	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^+ = IN^- ≤ V_{CC} (Note 14)	●		0.5	2.5	µV
Offset Error Drift	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^+ = IN^- ≤ V_{CC}			10		nV/°C
Positive Full-Scale Error	2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF} 2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF} (H-Grade)	● ●			25 40	ppm of V_{REF} ppm of V_{REF}
Positive Full-Scale Error Drift	2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF}			0.1		ppm of V_{REF}/°C
Negative Full-Scale Error	2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF} 2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF} (H-Grade)	● ●			25 40	ppm of V_{REF} ppm of V_{REF}
Negative Full-Scale Error Drift	2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF}			0.1		ppm of V_{REF}/°C
Total Unadjusted Error	5V ≤ V_{CC} ≤ 5.5V, V_{REF} = 2.5V, $V_{IN(CM)}$ = 1.25V 5V ≤ V_{CC} ≤ 5.5V, V_{REF} = 5V, $V_{IN(CM)}$ = 2.5V 2.7V ≤ V_{CC} ≤ 5.5V, V_{REF} = 2.5V, $V_{IN(CM)}$ = 1.25V			15		ppm of V_{REF} ppm of V_{REF} ppm of V_{REF}
Output Noise	5V ≤ V_{CC} ≤ 5.5V, V_{REF} = 5V, GND ≤ IN^- = IN^+ ≤ V_{CC} (Note 13)			0.6		μV_{RMS}
Internal PTAT Signal	T_A = 27°C		390		450	mV
Programmable Gain		●	1		256	

ELECTRICAL CHARACTERISTICS (2X SPEED)

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Notes 3, 4)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Resolution (No Missing Codes)	0.1 ≤ V_{REF} ≤ V_{CC}, –FS ≤ V_{IN} ≤ +FS (Note 5)	●	16			Bits
Integral Nonlinearity	5V ≤ V_{CC} ≤ 5.5V, V_{REF} = 5V, $V_{IN(CM)}$ = 2.5V (Note 6) 2.7V ≤ V_{CC} ≤ 5.5V, V_{REF} = 2.5V, $V_{IN(CM)}$ = 1.25V (Note 6)	●		2 1	10	ppm of V_{REF} ppm of V_{REF}
Offset Error	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^+ = IN^- ≤ V_{CC} (Note 14)	●		0.5	2	mV
Offset Error Drift	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^+ = IN^- ≤ V_{CC}			100		nV/°C
Positive Full-Scale Error	2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF} 2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF} (H-Grade)	● ●			25 40	ppm of V_{REF} ppm of V_{REF}
Positive Full-Scale Error Drift	2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF}			0.1		ppm of V_{REF}/°C
Negative Full-Scale Error	2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF} 2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF} (H-Grade)	● ●			25 40	ppm of V_{REF} ppm of V_{REF}
Negative Full-Scale Error Drift	2.5V ≤ V_{REF} ≤ V_{CC}, IN^+ = 0.75V_{REF}, IN^- = 0.25V_{REF}			0.1		ppm of V_{REF}/°C
Output Noise	5V ≤ V_{CC} ≤ 5.5V, V_{REF} = 5V, GND ≤ IN^- = IN^+ ≤ V_{CC} (Note 13)			0.84		μV_{RMS}
Programmable Gain	(Note 15)	●	1		128	

CONVERTER CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Notes 3, 4)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Input Common Mode Rejection DC	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^- = IN^+ ≤ V_{CC} (Note 5)	●	140			dB
Input Common Mode Rejection 50Hz ±2%	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^- = IN^+ ≤ V_{CC} (Note 5)	●	140			dB
Input Common Mode Rejection 60Hz ±2%	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^- = IN^+ ≤ V_{CC} (Note 5)	●	140			dB
Input Normal Mode Rejection 50Hz ±2%	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^- = IN^+ ≤ V_{CC} (Notes 5, 7) 2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^- = IN^+ ≤ V_{CC} (Notes 5, 7) (H-Grade)	● ●	110 104	120		dB dB
Input Normal Mode Rejection 60Hz ±2%	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^- = IN^+ ≤ V_{CC} (Notes 5, 8) 2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^- = IN^+ ≤ V_{CC} (Notes 5, 8) (H-Grade)	● ●	110 104	120		dB dB
Input Normal Mode Rejection 50Hz/60Hz ±2%	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^- = IN^+ ≤ V_{CC} (Notes 5, 9)	●	87			dB
Reference Common Mode Rejection DC	2.5V ≤ V_{REF} ≤ V_{CC}, GND ≤ IN^- = IN^+ ≤ V_{CC} (Note 5)	●	120	140		dB
Power Supply Rejection DC	V_{REF} = 2.5V, IN^- = IN^+ = GND			120		dB
Power Supply Rejection, 50Hz ±2%	V_{REF} = 2.5V, IN^- = IN^+ = GND (Notes 7, 9)			120		dB
Power Supply Rejection, 60Hz ±2%	V_{REF} = 2.5V, IN^- = IN^+ = GND (Notes 8, 9)			120		dB

ANALOG INPUT AND REFERENCE

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Note 3)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
IN^+	Absolute/Common Mode IN^+ Voltage			GND – 0.3V		V_{CC} + 0.3V	V
IN^-	Absolute/Common Mode IN^- Voltage			GND – 0.3V		V_{CC} + 0.3V	V
FS	Full-Scale of the Differential Input (IN^+ – IN^-)		●	0.5V_{REF}/GAIN			V
LSB	Least Significant Bit of the Output Code		●	FS/2^{16}			
V_{IN}	Input Differential Voltage Range (IN^+ – IN^-)		●	–FS		+FS	V
V_{REF}	Reference Voltage Range		●	0.1		V_{CC}	V
C_S (IN^+)	IN^+ Sampling Capacitance				11		pF
C_S (IN^-)	IN^- Sampling Capacitance				11		pF
C_S (V_{REF})	V_{REF} Sampling Capacitance				11		pF
I_{DC_LEAK} (IN^+)	IN^+ DC Leakage Current	Sleep Mode, IN^+ = GND	●	–10	1	10	nA
I_{DC_LEAK} (IN^-)	IN^- DC Leakage Current	Sleep Mode, IN^- = GND	●	–10	1	10	nA
I_{DC_LEAK} (V_{REF})	V_{REF} DC Leakage Current	Sleep Mode, V_{REF} = V_{CC}	●	–100	1	100	nA

ANALOG INPUTS AND DIGITAL OUTPUTS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Note 3)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{IH}	High Level Input Voltage $\overline{CS}$, f_O, SDI	2.7V ≤ V_{CC} ≤ 5.5V (Note 16)	●	V_{CC} – 0.5			V
V_{IL}	Low Level Input Voltage $\overline{CS}$, f_O, SDI	2.7V ≤ V_{CC} ≤ 5.5V	●			0.5	V
V_{IH}	High Level Input Voltage SCK	2.7V ≤ V_{CC} ≤ 5.5V (Note 10)	●	V_{CC} – 0.5			V
V_{IL}	Low Level Input Voltage SCK	2.7V ≤ V_{CC} ≤ 5.5V (Note 10)	●			0.5	V
I_{IN}	Digital Input Current $\overline{CS}$, f_O, SDI	0V ≤ V_{IN} ≤ V_{CC}	●	–10		10	µA

ANALOG INPUTS AND DIGITAL OUTPUTS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Note 3)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
I_{IN}	Digital Input Current SCK	0V ≤ V_{IN} ≤ V_{CC} (Note 10)	●	–10		10	µA
C_{IN}	Digital Input Capacitance $\overline{CS}$, f_O, SDI				10		pF
C_{IN}	Digital Input Capacitance SCK				10		pF
V_{OH}	High Level Output Voltage SDO	I_O = –800µA	●	V_{CC} – 0.5			V
V_{OL}	Low Level Output Voltage SDO	I_O = 1.6mA	●			0.4	V
V_{OH}	High Level Output Voltage SCK	I_O = –800µA	●	V_{CC} – 0.5			V
V_{OL}	Low Level Output Voltage SCK	I_O = 1.6mA	●			0.4	V
I_{OZ}	Hi-Z Output Leakage SDO		●	–10		10	µA

POWER REQUIREMENTS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Note 3)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{CC}	Supply Voltage		●	2.7		5.5	V
I_{CC}	Supply Current	Conversion Mode (Note 12)	●		160	250	µA
		Sleep Mode (Note 12)	●		1	2	µA
		H-Grade	●			20	µA

TIMING CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Note 3)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
f_{EOSC}	External Oscillator Frequency Range	(Note 15)	●	10		1000	kHz
t_{HEO}	External Oscillator High Period		●	0.125		100	µs
t_{LEO}	External Oscillator Low Period		●	0.125		100	µs
t_{CONV_1}	Conversion Time for 1x Speed Mode	50Hz Mode	●	157.2	160.3	163.5	ms
		50Hz Mode (H-Grade)	●	157.2	160.3	165.1	ms
		60Hz Mode	●	131.0	133.6	136.3	ms
		60Hz Mode (H-Grade)	●	131.0	133.6	137.6	ms
		Simultaneous 50Hz/60Hz Mode	●	144.1	146.9	149.9	ms
		Simultaneous 50Hz/60Hz Mode (H-Grade)	●	144.1	146.9	151.0	ms
		External Oscillator	●		41036/f_{EOSC} (in kHz)		ms
t_{CONV_2}	Conversion Time for 2x Speed Mode	50Hz Mode	●	78.7	80.3	81.9	ms
		50Hz Mode (H-Grade)	●			82.7	ms
		60Hz Mode	●	65.6	66.9	68.2	ms
		60Hz Mode (H-Grade)	●			68.9	ms
		Simultaneous 50Hz/60Hz Mode	●	72.2	73.6	75.1	ms
		Simultaneous 50Hz/60Hz Mode (H-Grade)	●			75.6	ms
		External Oscillator	●		20556/f_{EOSC} (in kHz)		ms
f_{ISCK}	Internal SCK Frequency	Internal Oscillator (Note 10)			38.4		kHz
		External Oscillator (Notes 10, 11)			f_{EOSC}/8		kHz
D_{ISCK}	Internal SCK Duty Cycle	(Note 10)	●	45		55	%
f_{ESCK}	External SCK Frequency Range	(Note 10)	●			4000	kHz

TIMING CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. (Note 3)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
t_{LESCK}	External SCK Low Period	(Note 10)	●	125			ns
t_{HESCK}	External SCK High Period	(Note 10)	●	125			ns
t_{DOUT_ISCK}	Internal SCK 24-Bit Data Output Time	Internal Oscillator (Notes 10, 12) External Oscillator (Notes 10, 11)	● ●	0.61	0.625 192/f_{EOSC} (in kHz)	0.64	ms ms
t_{DOUT_ESCK}	External SCK 24-Bit Data Output Time	(Note 10)	●		24/f_{ESCK} (in kHz)		ms
t_1	$\overline{CS}\downarrow$ to SDO Low		●	0		200	ns
t_2	$\overline{CS}\uparrow$ to SDO High Z		●	0		200	ns
t_3	$\overline{CS}\downarrow$ to SCK↓	Internal SCK Mode	●	0		200	ns
t_4	$\overline{CS}\downarrow$ to SCK↑	External SCK Mode	●	50			ns
t_{KQMAX}	SCK↓ to SDO Valid		●			200	ns
t_{KQMIN}	SDO Hold After SCK↓	(Note 5)	●	15			ns
t_5	SCK Set-Up Before $\overline{CS}\downarrow$		●	50			ns
t_6	SCK Hold After $\overline{CS}\downarrow$		●			50	ns
t_7	SDI Setup Before SCK↑	(Note 5)	●	100			ns
t_8	SDI Hold After SCK↑	(Note 5)	●	100			ns

Note 1: Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

Note 2: All voltage values are with respect to GND.

Note 3: V_{CC} = 2.7V to 5.5V unless otherwise specified.

$V_{REFCM} = V_{REF}/2$, FS = $0.5V_{REF}$/GAIN

$V_{IN} = IN^+ - IN^-$, $V_{IN(CM)} = (IN^+ + IN^-)/2$

Note 4: Use internal conversion clock or external conversion clock source with f_{EOSC} = 307.2kHz unless otherwise specified.

Note 5: Guaranteed by design, not subject to test.

Note 6: Integral nonlinearity is defined as the deviation of a code from a straight line passing through the actual endpoints of the transfer curve. The deviation is measured from the center of the quantization band.

Note 7: 50Hz mode (internal oscillator) or f_{EOSC} = 256kHz ±2% (external oscillator).

Note 8: 60Hz mode (internal oscillator) or f_{EOSC} = 307.2kHz ±2% (external oscillator).

Note 9: Simultaneous 50Hz/60Hz mode (internal oscillator) or f_{EOSC} = 280kHz ±2% (external oscillator).

Note 10: The SCK can be configured in external SCK mode or internal SCK mode. In external SCK mode, the SCK pin is used as digital input and the driving clock is f_{ESCK}. In internal SCK mode, the SCK pin is used as digital output and the output clock signal during the data output is f_{ISCK}.

Note 11: The external oscillator is connected to the f_O pin. The external oscillator frequency, f_{EOSC}, is expressed in kHz.

Note 12: The converter uses the internal oscillator.

Note 13: The output noise includes the contribution of the internal calibration operations.

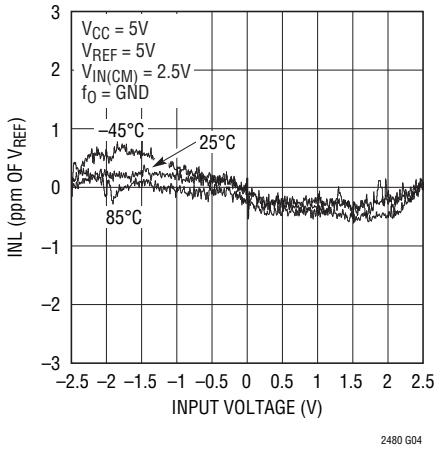
Note 14: Guaranteed by design and test correlation.

Note 15: Refer to Applications Information section for performance vs data rate graphs.

Note 16: For V_{CC} < 3V, V_{IH} is 2.5V for pin f_O.

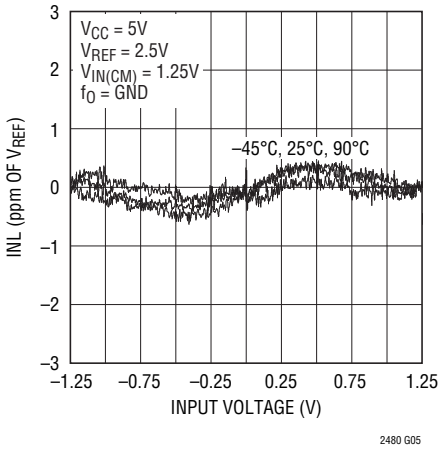
TYPICAL PERFORMANCE CHARACTERISTICS

Integral Nonlinearity (V_{CC} = 5V, V_{REF} = 5V)



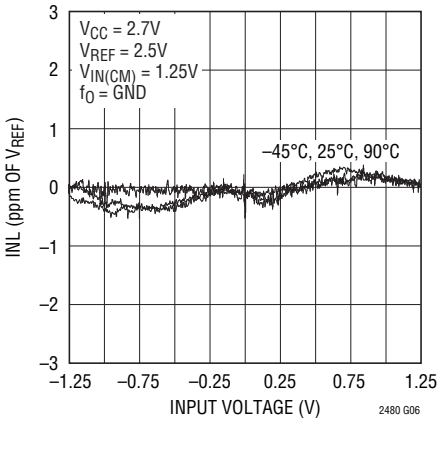
2480 G04

Integral Nonlinearity (V_{CC} = 5V, V_{REF} = 2.5V)



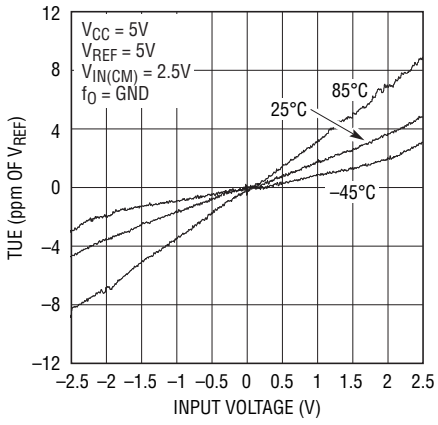
2480 G05

Integral Nonlinearity (V_{CC} = 2.7V, V_{REF} = 2.5V)



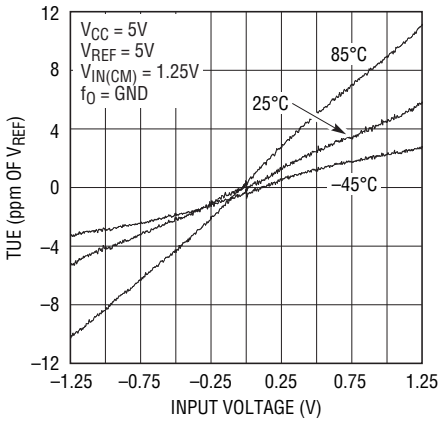
2480 G06

Total Unadjusted Error (V_{CC} = 5V, V_{REF} = 5V)



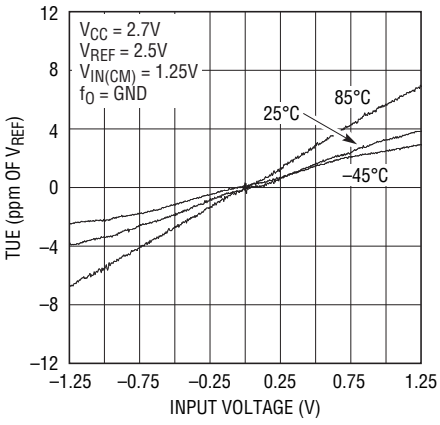
2480 G01

Total Unadjusted Error (V_{CC} = 5V, V_{REF} = 2.5V)



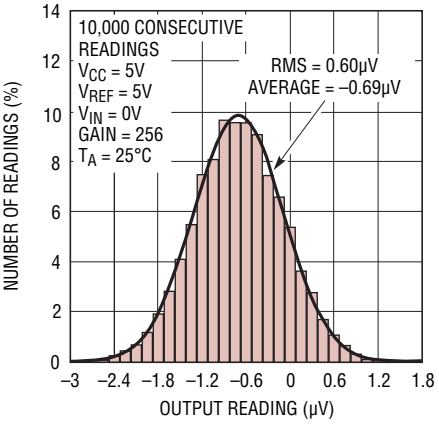
2480 G02

Total Unadjusted Error (V_{CC} = 2.7V, V_{REF} = 2.5V)



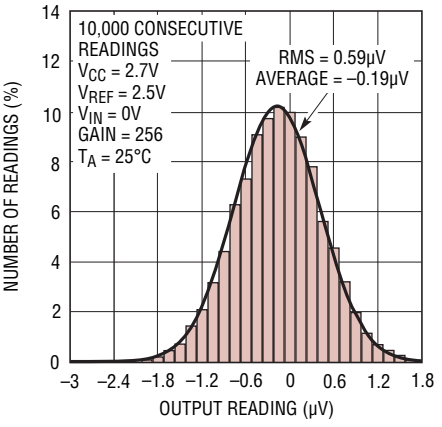
2480 G03

Noise Histogram (6.8sps)



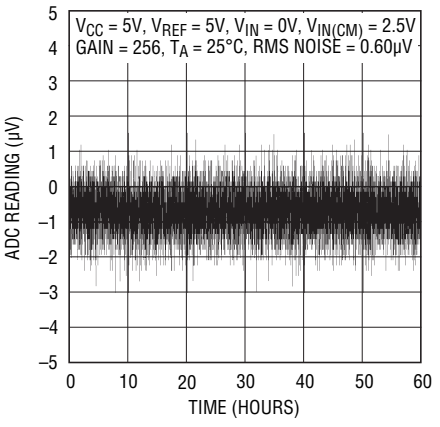
2480 G07

Noise Histogram (7.5sps)



2480 G08

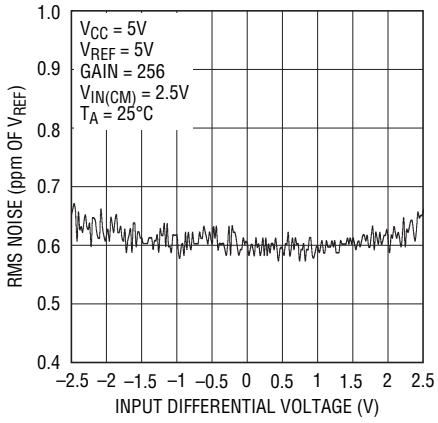
Long-Term ADC Readings



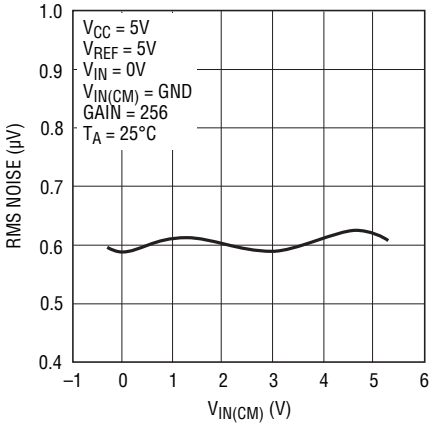
2480 G09

TYPICAL PERFORMANCE CHARACTERISTICS

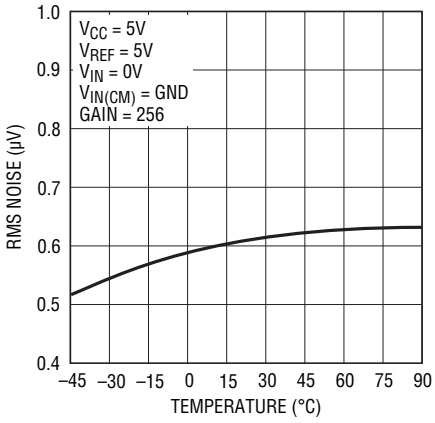
RMS Noise vs Input Differential Voltage



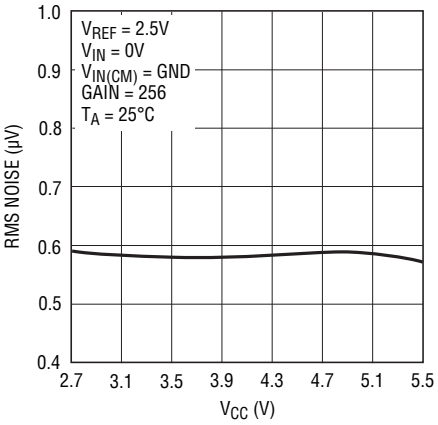
RMS Noise vs $V_{IN(CM)}$



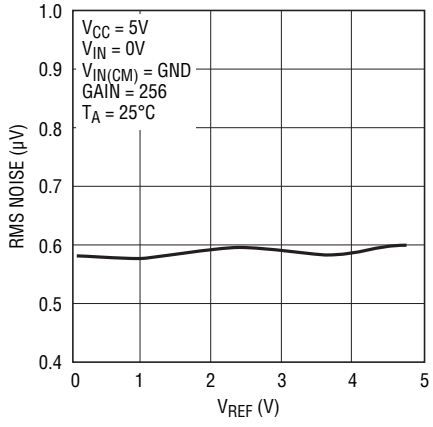
RMS Noise vs Temperature (T_A)



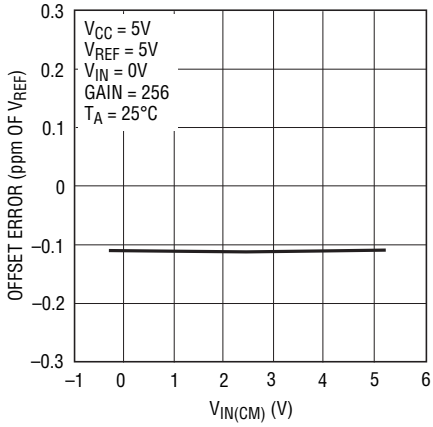
RMS Noise vs V_{CC}



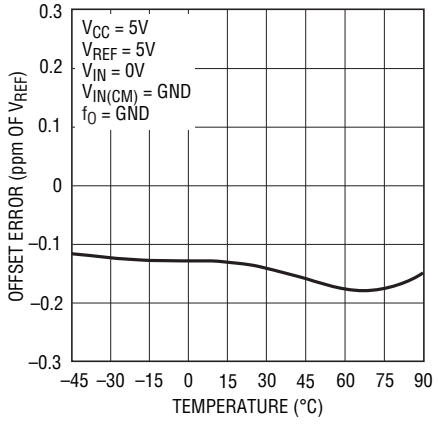
RMS Noise vs V_{REF}



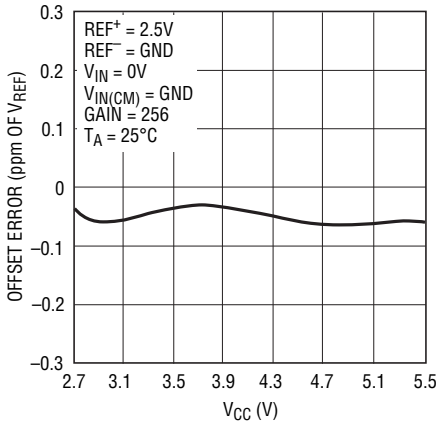
Offset Error vs $V_{IN(CM)}$



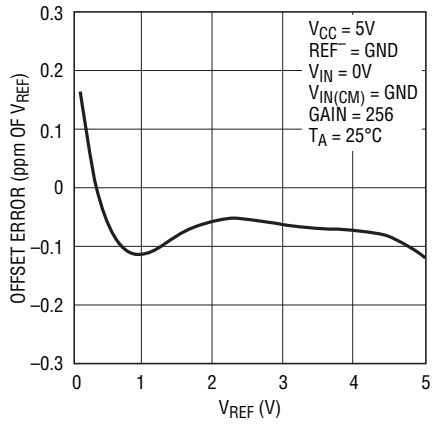
Offset Error vs Temperature



Offset Error vs V_{CC}

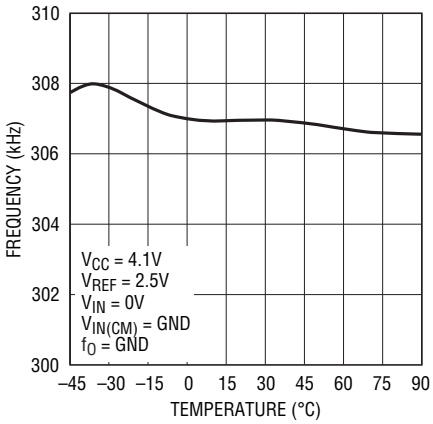


Offset Error vs V_{REF}

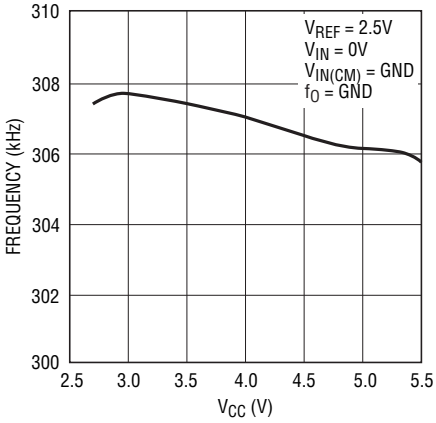


TYPICAL PERFORMANCE CHARACTERISTICS

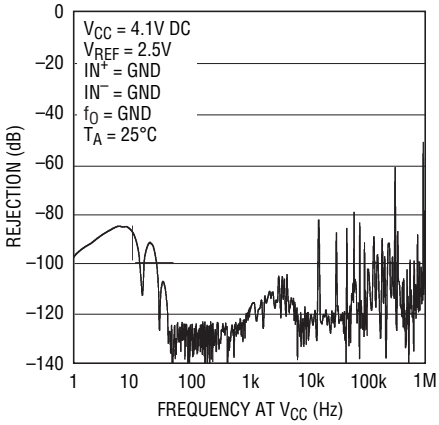
On-Chip Oscillator Frequency vs Temperature



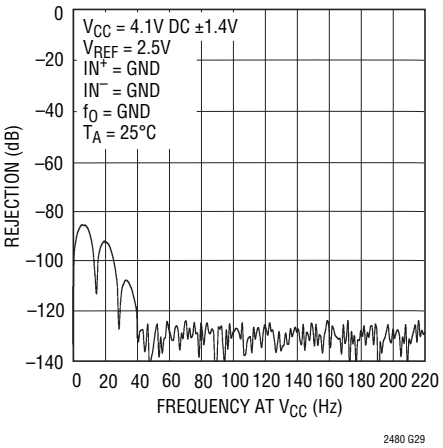
On-Chip Oscillator Frequency vs V_{CC}



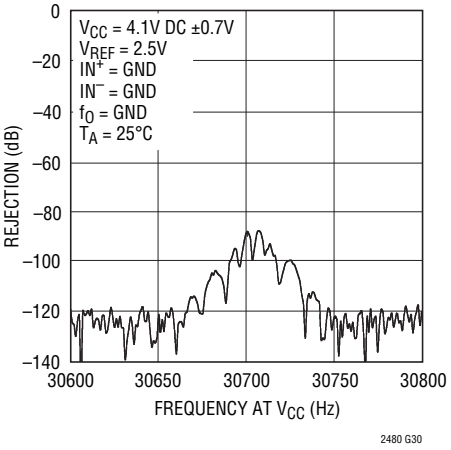
PSRR vs Frequency at V_{CC}



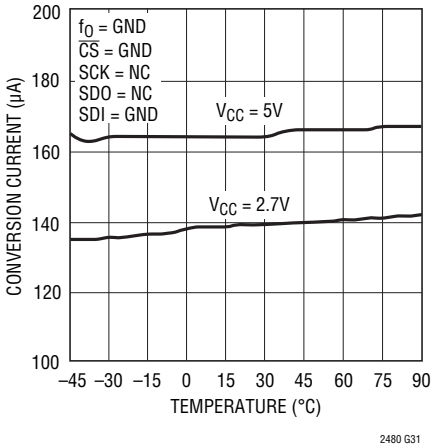
PSRR vs Frequency at V_{CC}



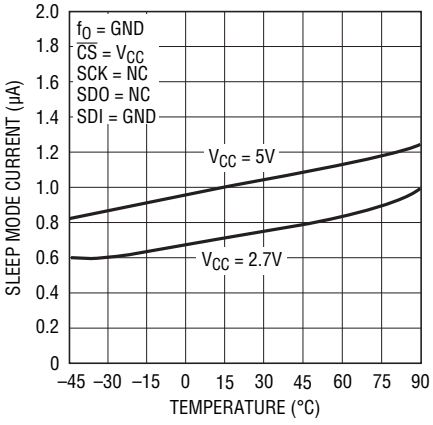
PSRR vs Frequency at V_{CC}



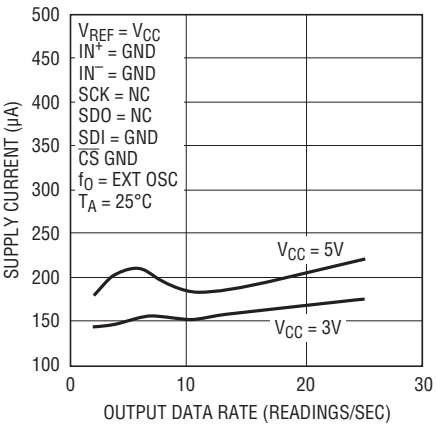
Conversion Current vs Temperature



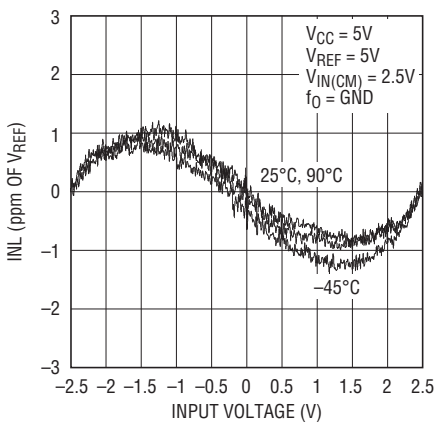
Sleep Mode Current vs Temperature



Conversion Current vs Output Data Rate

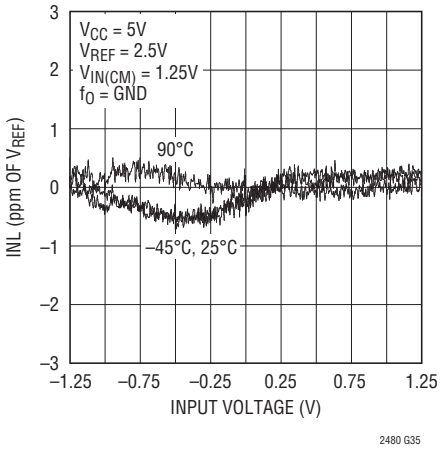


Integral Nonlinearity (2x Speed Mode; V_{CC} = 5V, V_{REF} = 5V)



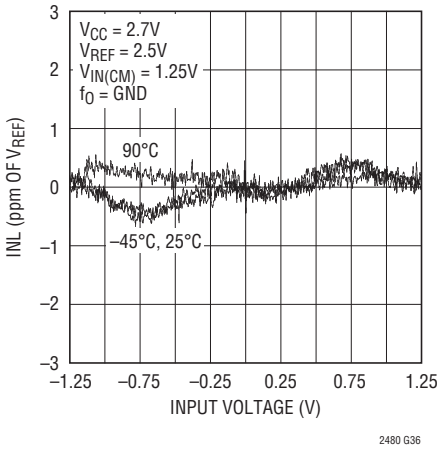
TYPICAL PERFORMANCE CHARACTERISTICS

Integral Nonlinearity (2x Speed Mode; V_{CC} = 5V, V_{REF} = 2.5V)



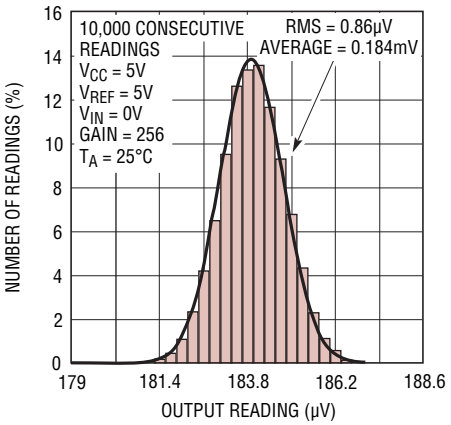
2480 G35

Integral Nonlinearity (2x Speed Mode; V_{CC} = 2.7V, V_{REF} = 2.5V)



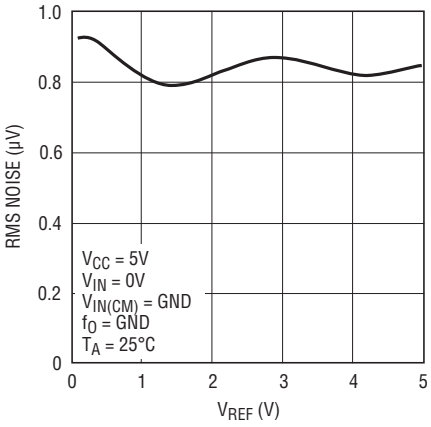
2480 G36

Noise Histogram (2x Speed Mode)



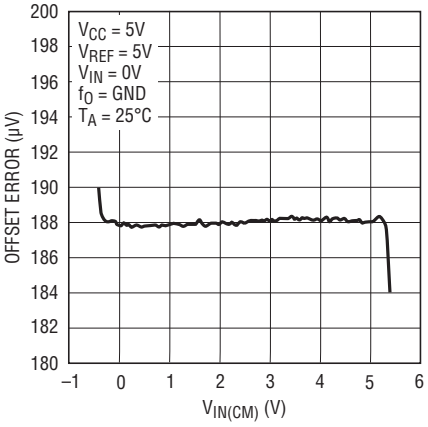
2480 G37

RMS Noise vs V_{REF} (2x Speed Mode)



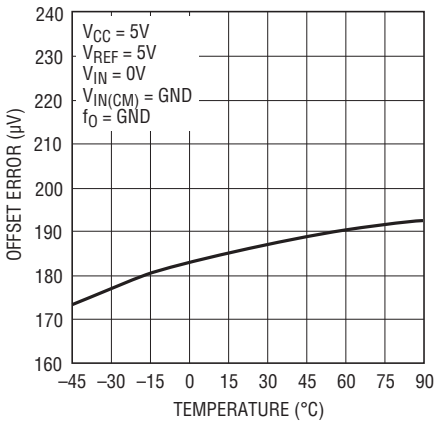
2480 G38

Offset Error vs $V_{IN(CM)}$ (2x Speed Mode)



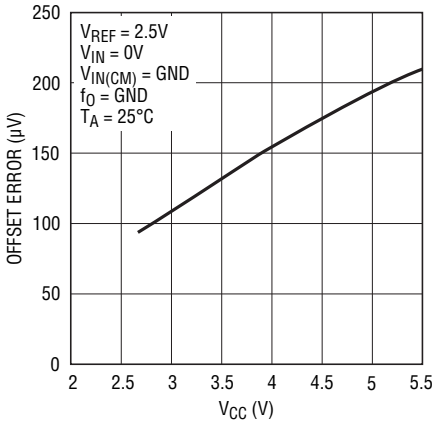
2480 G39

Offset Error vs Temperature (2x Speed Mode)



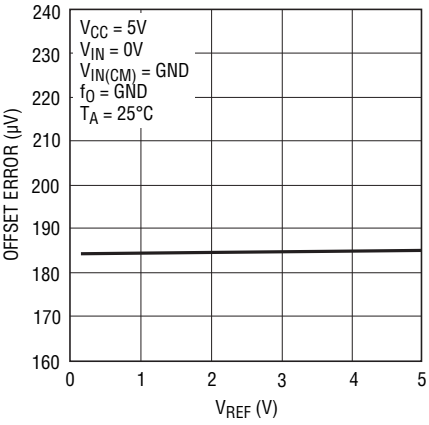
2480 G40

Offset Error vs V_{CC} (2x Speed Mode)



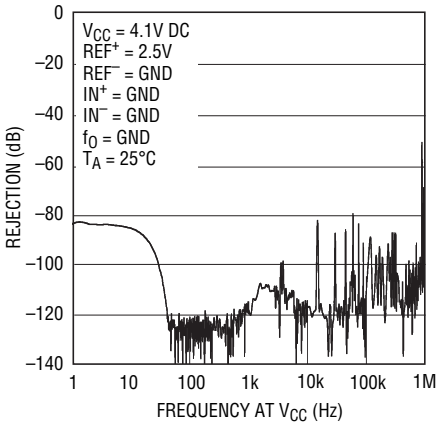
2480 G41

Offset Error vs V_{REF} (2x Speed Mode)



2480 G42

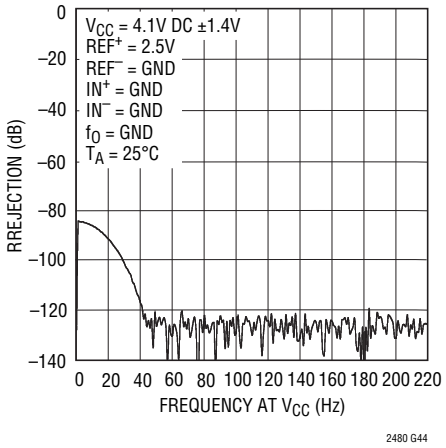
PSRR vs Frequency at V_{CC} (2x Speed Mode)



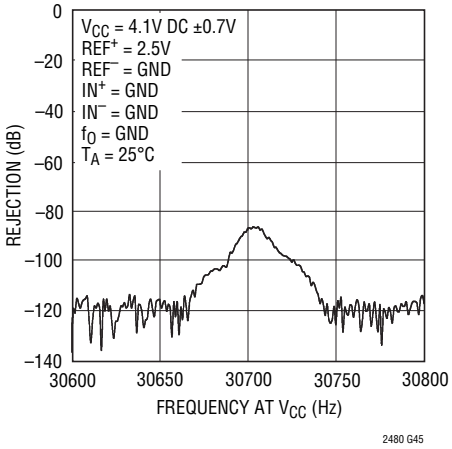
2480 G43

TYPICAL PERFORMANCE CHARACTERISTICS

PSRR vs Frequency at V_{CC} (2x Speed Mode)



PSRR vs Frequency at V_{CC} (2x Speed Mode)



PIN FUNCTIONS

SDI (Pin 1): Serial Data Input. This pin is used to select the GAIN, line frequency rejection, input, temperature sensor and 2x speed mode. Data is shifted into the SDI pin on the rising edge of serial clock (SCK).

V_{CC} (Pin 2): Positive Supply Voltage. Bypass to GND (Pin 8) with a 1µF tantalum capacitor in parallel with 0.1µF ceramic capacitor as close to the part as possible.

V_{REF} (Pin 3): Positive Reference Input. The voltage on this pin can have any value between 0.1V and V_{CC}. The negative reference input is GND (Pin 8).

IN^+ (Pin 4), IN^- (Pin 5): Differential Analog Inputs. The voltage on these pins can have any value between GND – 0.3V and V_{CC} + 0.3V. Within these limits the converter bipolar input range ($V_{IN} = IN^+ – IN^-$) extends from –0.5 • V_{REF}/GAIN to 0.5 • V_{REF}/GAIN. Outside this input range the converter produces unique overrange and underrange output codes.

$\overline{CS}$ (Pin 6): Active LOW Chip Select. A LOW on this pin enables the digital input/output and wakes up the ADC. Following each conversion the ADC automatically enters the sleep mode and remains in this low power state as long as $\overline{CS}$ is HIGH. A LOW-to-HIGH transition on $\overline{CS}$ during the data output transfer aborts the data transfer and starts a new conversion.

SDO (Pin 7): Three-State Digital Output. During the data output period, this pin is used as the serial data output. When the chip select $\overline{CS}$ is HIGH ($\overline{CS} = V_{CC}$), the SDO pin is in a high impedance state. During the conversion and sleep periods, this pin is used as the conversion status output. The conversion status can be observed by pulling $\overline{CS}$ LOW.

GND (Pin 8): Ground. Shared pin for analog ground, digital ground and reference ground. Should be connected directly to a ground plane through a minimum impedance.

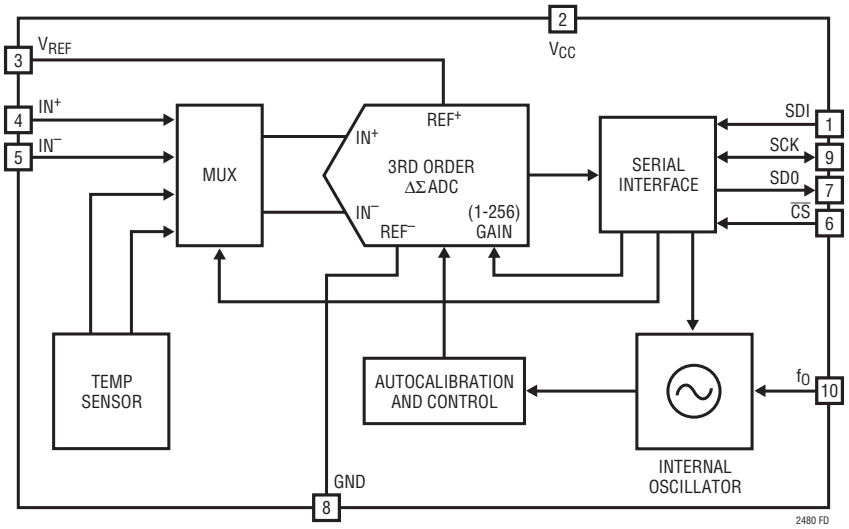
PIN FUNCTIONS

SCK (Pin 9): Bidirectional Digital Clock Pin. In internal serial clock operation mode, SCK is used as the digital output for the internal serial interface clock during the data input/output period. In external serial clock operation mode, SCK is used as the digital input for the external serial interface clock during the data output period. A weak internal pull-up is automatically activated in internal serial clock operation mode. The serial clock operation mode is determined by the logic level applied to the SCK pin at power up or during the most recent falling edge of $\overline{CS}$.

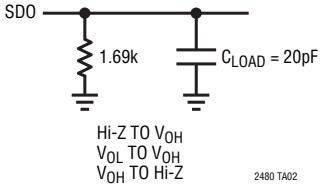
f_O (Pin 10): Frequency Control Pin. Digital input that controls the conversion clock. When f_O is connected to GND the converter uses its internal oscillator running at 307.2kHz. The conversion clock may also be overridden by driving the f_O pin with an external clock in order to change the output rate or the digital filter rejection null.

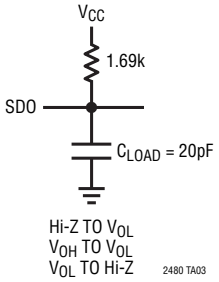
GND (Exposed Pad Pin 11): This pin is ground and should be soldered to the PCB ground plane. For prototyping purposes, this pin may remain floating.

FUNCTIONAL BLOCK DIAGRAM



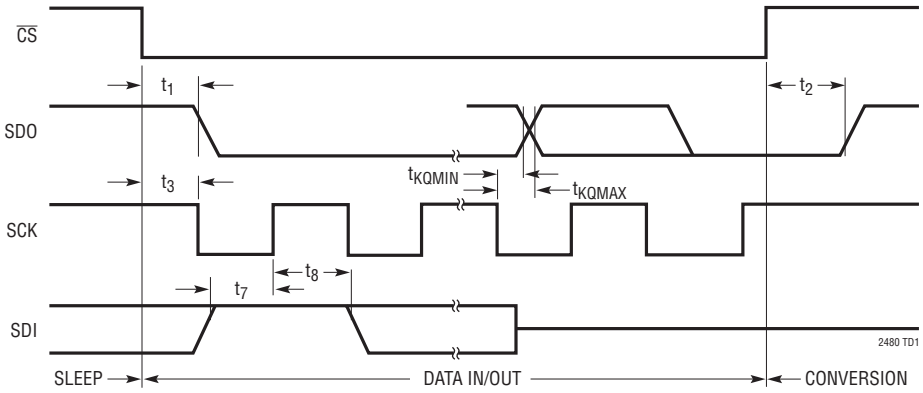
TEST CIRCUITS



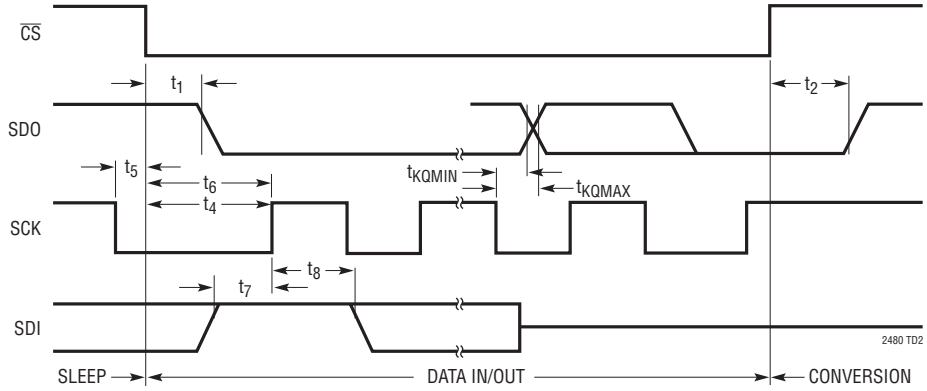


TIMING DIAGRAMS

Timing Diagram Using Internal SCK



Timing Diagram Using External SCK



APPLICATIONS INFORMATION

CONVERTER OPERATION

Converter Operation Cycle

The LTC2480 is a low power, delta-sigma analog-to-digital converter with an easy to use 4-wire serial interface and automatic differential input current cancellation. Its operation is made up of three states. The converter operating cycle begins with the conversion, followed by the low power sleep state and ends with the data output (see Figure 1). The 4-wire interface consists of serial data output (SDO), serial clock (SCK), chip select ($\overline{CS}$) and serial data input (SDI).

Initially, the LTC2480 performs a conversion. Once the conversion is complete, the device enters the sleep state.

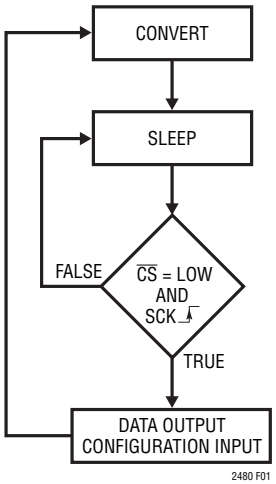


Figure 1. LTC2480 State Transition Diagram

APPLICATIONS INFORMATION

While in this sleep state, power consumption is reduced by two orders of magnitude. The part remains in the sleep state as long as $\overline{CS}$ is HIGH. The conversion result is held indefinitely in a static shift register while the converter is in the sleep state.

Once $\overline{CS}$ is pulled LOW, the device exits the low power mode and enters the data output state. If $\overline{CS}$ is pulled HIGH before the first rising edge of SCK, the device returns to the low power sleep mode and the conversion result is still held in the internal static shift register. If $\overline{CS}$ remains LOW after the first rising edge of SCK, the device begins outputting the conversion result. Taking $\overline{CS}$ high at this point will terminate the data input and output state and start a new conversion. The conversion result is shifted out of the device through the serial data output pin (SDO) on the falling edge of the serial clock (SCK) (see Figure 2). The LTC2480 includes a serial data input pin (SDI) in which data is latched by the device on the rising edge of SCK (Figure 2). The bit stream applied to this pin can be used to select various features of the LTC2480, including an on-chip temperature sensor, programmable GAIN, line frequency rejection and output data rate. Alternatively, this pin may be tied to ground and the part will perform conversions in a default state. In the default state (SDI grounded) the device simply performs conversions on the user applied input with a GAIN of 1 and simultaneous rejection of 50Hz and 60Hz line frequencies.

Through timing control of the $\overline{CS}$ and SCK pins, the LTC2480 offers several flexible modes of operation (internal or external SCK and free-running conversion modes). These various modes do not require programming configuration registers; moreover, they do not disturb the cyclic operation described above. These modes of operation are described in detail in the Serial Interface Timing Modes section.

Easy Drive Input Current Cancellation

The LTC2480 combines a high precision delta-sigma ADC with an automatic differential input current cancellation front end. A proprietary front-end passive sampling network transparently removes the differential input current. This enables external RC networks and high impedance sensors to directly interface to the LTC2480 without external amplifiers. The remaining common mode input current is eliminated by either balancing the differential input impedances or setting the common mode input equal to the common mode reference (see the Automatic Input Current Cancellation section). This unique architecture does not require on-chip buffers enabling input signals to swing all the way to ground and up to V_{CC}. Furthermore, the cancellation does not interfere with the transparent offset and full-scale auto-calibration and the absolute accuracy (full-scale + offset + linearity) is maintained even with external RC networks.

Accessing the Special Features of the LTC2480

The LTC2480 combines a high resolution, low noise $\Delta\Sigma$ analog-to-digital converter with an on-chip selectable temperature sensor, programmable gain, programmable digital filter and output rate control. These special features are selected through a single 8-bit serial input word during the data input/output cycle (see Figure 2).

The LTC2480 powers up in a default mode commonly used for most measurements. The device will remain in this mode as long as the serial data input (SDI) is low. In this default mode, the measured input is external, the GAIN is 1, the digital filter simultaneously rejects 50Hz and 60Hz line frequency noise, and the speed mode is 1x (offset automatically, continuously calibrated).

A simple serial interface grants access to any or all special functions contained within the LTC2480. In order to change the mode of operation, an enable bit (EN) followed by up to 7 bits of data are shifted into the device (see Table 1). The first 3 bits (GS2, GS1, GS0) control the GAIN of the converter from 1 to 256. The 4th bit (IM) is used to select the internal temperature sensor as the conversion input, while the 5th and 6th bits (FA, FB) combine to determine the line frequency rejection mode. The 7th bit (SPD) is used to double the output rate by disabling the offset auto calibration.

APPLICATIONS INFORMATION

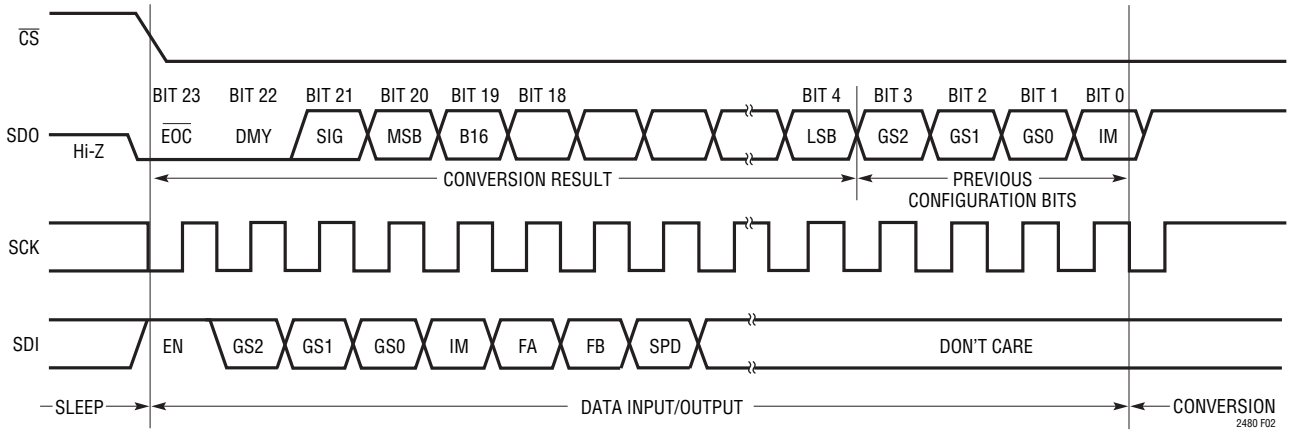


Figure 2. Input/Output Data Timing

Table 1. Selecting Special Modes

	Gain			Rejection Mode				
EN	GS2	GS1	GS0	IM	FA	FB	SPD	Comments
0	X	X	X	X	X	X	X	Keep Previous Mode
1	0	0	0	0	Any Rejection Mode		0	External Input, Gain = 1, Autocalibration
1	0	0	1	0			0	External Input, Gain = 4, Autocalibration
1	0	1	0	0			0	External Input, Gain = 8, Autocalibration
1	0	1	1	0			0	External Input, Gain = 16, Autocalibration
1	1	0	0	0			0	External Input, Gain = 32, Autocalibration
1	1	0	1	0			0	External Input, Gain = 64, Autocalibration
1	1	1	0	0			0	External Input, Gain = 128, Autocalibration
1	1	1	1	0			0	External Input, Gain = 256, Autocalibration
1	0	0	0	0			1	External Input, Gain = 1, 2x Speed
1	0	0	1	0			1	External Input, Gain = 2, 2x Speed
1	0	1	0	0			1	External Input, Gain = 4, 2x Speed
1	0	1	1	0			1	External Input, Gain = 8, 2x Speed
1	1	0	0	0			1	External Input, Gain = 16, 2x Speed
1	1	0	1	0			1	External Input, Gain = 32, 2x Speed
1	1	1	0	0			1	External Input, Gain = 64, 2x Speed
1	1	1	1	0			1	External Input, Gain = 128, 2x Speed
1	Any Gain			0	0	0	Any Speed	External Input, Simultaneous 50Hz/60Hz Rejection
1				0	0	1		External Input, 50Hz Rejection
1				0	1	0		External Input, 60Hz Rejection
1				0	1	1		Reserved, Do Not Use
1	X	X	X	1	0	0	X	Temperature Input, 50Hz/60Hz Rejection, Gain = 1, Autocalibration
1	X	X	X	1	0	1	X	Temperature Input, 50Hz Rejection, Gain = 1, Autocalibration
1	X	X	X	1	1	0	X	Temperature Input, 60Hz Rejection, Gain = 1, Autocalibration
1	X	X	X	1	1	1	X	Reserved, Do Not Use

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Table 2a. The LTC2480 Performance vs GAIN in Normal Speed Mode (V_{CC} = 5V, V_{REF} = 5V)

GAIN	1	4	8	16	32	64	128	256	UNIT
Input Span	±2.5	±0.625	±0.312	±0.156	±78m	±39m	±19.5m	±9.76m	V
LSB	38.1	9.54	4.77	2.38	1.19	0.596	0.298	0.149	µV
Noise Free Resolution*	65536	65536	65536	65536	65536	65536	32768	16384	Counts
Gain Error	5	5	5	5	5	5	5	8	ppm of FS
Offset Error	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	µV

Table 2b. The LTC2480 Performance vs GAIN in 2x Speed Mode (V_{CC} = 5V, V_{REF} = 5V)

GAIN	1	2	4	8	16	32	64	128	UNIT
Input Span	±2.5	±1.25	±0.625	±0.312	±0.156	±78m	±39m	±19.5m	V
LSB	38.1	19.1	9.54	4.77	2.38	1.19	0.596	0.298	µV
Noise Free Resolution*	65536	65536	65536	65536	65536	65536	45875	22937	Counts
Gain Error	5	5	5	5	5	5	5	5	ppm of FS
Offset Error	200	200	200	200	200	200	200	200	µV

*The resolution in counts is calculated as the FS divided by LSB or the RMS noise value, whichever is larger.

GAIN (GS2, GS1, GS0)

The input referred gain of the LTC2480 is adjustable from 1 to 256. With a gain of 1, the differential input range is $\pm V_{REF}/2$ and the common mode input range is rail-to-rail. As the GAIN is increased, the differential input range is reduced to $\pm V_{REF}/2 \bullet GAIN$ but the common mode input range remains rail-to-rail. As the differential gain is increased, low level voltages are digitized with greater resolution. At a gain of 256, the LTC2480 digitizes an input signal range of ±9.76mV with over 16,000 counts.

Temperature Sensor (IM)

The LTC2480 includes an on-chip temperature sensor. The temperature sensor is selected by setting IM = 1 in the serial input data stream. Conversions are performed directly on the temperature sensor by the converter. While operating in this mode, the device behaves as a temperature to bits converter. The digital reading is proportional to the absolute temperature of the device. This feature allows the converter to linearize temperature sensors or continuously remove temperature effects from external sensors. Several applications leveraging this feature are presented in more detail in the applications section. While operating in this mode, the gain is set to 1 and the speed is set to normal independent of the control bits (GS2, GS1, GS0 and SPD).

Rejection Mode (FA, FB)

The LTC2480 includes a high accuracy on-chip oscillator with no required external components. Coupled with a 4th order digital lowpass filter, the LTC2480 rejects line frequency noise. In the default mode, the LTC2480 simultaneously rejects 50Hz and 60Hz by at least 87dB. The LTC2480 can also be configured to selectively reject 50Hz or 60Hz to better than 110dB.

Speed Mode (SPD)

The LTC2480 continuously performs offset calibrations. Every conversion cycle, two conversions are automatically performed (default) and the results combined. This result is free from offset and drift. In applications where the offset is not critical, the autocalibration feature can be disabled with the benefit of twice the output rate.

Linearity, full-scale accuracy and full-scale drift are identical for both 2x and 1x speed modes. In both the 1x and 2x speed there is no latency. This enables input steps or multiplexer channel changes to settle in a single conversion cycle easing system overhead and increasing the effective conversion rate.

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Output Data Format

The LTC2480 serial output data stream is 24 bits long. The first 3 bits represent status information indicating the sign and conversion state. The next 17 bits are the conversion result, MSB first. The remaining 4 bits indicate the configuration state associated with the current conversion result. Bit 20 and bit 21 are also used to indicate an underrange condition (the differential input voltage is below –FS) or an overrange condition (the differential input voltage is above +FS).

In applications where the processor generates 32 clock cycles, or to remain compatible with higher resolution converters, the LTC2480's digital interface will ignore extra clock edges seen during the next conversion period after the 24th and output "1" for the extra clock cycles. Furthermore, $\overline{CS}$ may be pulled high prior to outputting all 24 bits, aborting the data out transfer and initiating a new conversion.

Bit 23 (first output bit) is the end of conversion ($\overline{EOC}$) indicator. This bit is available at the SDO pin during the conversion and sleep states whenever the $\overline{CS}$ pin is LOW. This bit is HIGH during the conversion and goes LOW when the conversion is complete.

Bit 22 (second output bit) is a dummy bit (DMY) and is always LOW.

Bit 21 (third output bit) is the conversion result sign indicator (SIG). If V_{IN} is >0, this bit is HIGH. If V_{IN} is <0, this bit is LOW.

Bit 20 (fourth output bit) is the most significant bit (MSB) of the result. This bit in conjunction with bit 21 also provides the underrange or overrange indication. If both bit 21 and bit 20 are HIGH, the differential input voltage is above +FS. If both bit 21 and bit 20 are LOW, the differential input voltage is below –FS.

The function of these bits is summarized in Table 3.

Table 3. LTC2480 Status Bits

INPUT RANGE	BIT 23 $\overline{EOC}$	BIT 22 DMY	BIT 21 SIG	BIT 20 MSB
$V_{IN} \geq 0.5 \cdot V_{REF}$	0	0	1	1
$0V \leq V_{IN} < 0.5 \cdot V_{REF}$	0	0	1/0	0
$-0.5 \cdot V_{REF} \leq V_{IN} < 0V$	0	0	0	1
$V_{IN} < -0.5 \cdot V_{REF}$	0	0	0	0

Bits 20-4 are the 16-bit plus sign conversion result MSB first.

Bits 3-0 are the corresponding configuration bits for the present conversion result. Bits 3-1 are the gain set bits and bit 0 is IM (see Figure 2).

Data is shifted out of the SDO pin under control of the serial clock (SCK) (see Figure 2). Whenever $\overline{CS}$ is HIGH,

Table 4. LTC2480 Output Data Format

DIFFERENTIAL INPUT VOLTAGE V_{IN}*	BIT 23 $\overline{EOC}$	BIT 22 DMY	BIT 21 SIG	BIT 20 MSB	BIT 19	BIT 18	BIT 17	...	BIT 4
V_{IN}* ≥ FS**	0	0	1	1	0	0	0	...	0
FS** – 1LSB	0	0	1	0	1	1	1	...	1
0.5 • FS**	0	0	1	0	1	0	0	...	0
0.5 • FS** – 1LSB	0	0	1	0	0	1	1	...	1
0	0	0	1/0***	0	0	0	0	...	0
–1LSB	0	0	0	1	1	1	1	...	1
–0.5 • FS**	0	0	0	1	1	0	0	...	0
–0.5 • FS** – 1LSB	0	0	0	1	0	1	1	...	1
–FS**	0	0	0	1	0	0	0	...	0
V_{IN}* < –FS**	0	0	0	0	1	1	1	...	1

* The differential input voltage $V_{IN} = IN^+ – IN^–$.
** The full-scale voltage FS = 0.5 • V_{REF}.
*** The sign bit changes state during the 0 output code when the device is operating in the 2× speed mode.

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SDO remains high impedance and any externally generated SCK clock pulses are ignored by the internal data out shift register.

In order to shift the conversion result out of the device, $\overline{CS}$ must first be driven LOW. $\overline{EOC}$ is seen at the SDO pin of the device once $\overline{CS}$ is pulled LOW. $\overline{EOC}$ changes in real time from HIGH to LOW at the completion of a conversion. This signal may be used as an interrupt for an external microcontroller. Bit 23 ($\overline{EOC}$) can be captured on the first rising edge of SCK. Bit 22 is shifted out of the device on the first falling edge of SCK. The final data bit (bit 0) is shifted out on the falling edge of the 23rd SCK and may be latched on the rising edge of the 24th SCK pulse. On the falling edge of the 24th SCK pulse, SDO goes HIGH indicating the initiation of a new conversion cycle. This bit serves as $\overline{EOC}$ (bit 23) for the next conversion cycle. Table 4 summarizes the output data format.

As long as the voltage on the IN^+ and IN^- pins is maintained within the –0.3V to (V_{CC} + 0.3V) absolute maximum operating range, a conversion result is generated for any differential input voltage V_{IN} from –FS = –0.5 • V_{REF}/GAIN to +FS = 0.5 • V_{REF}/GAIN. For differential input voltages greater than +FS, the conversion result is clamped to the value corresponding to the +FS + 1LSB. For differential input voltages below –FS, the conversion result is clamped to the value corresponding to –FS – 1LSB.

Conversion Clock

A major advantage the delta-sigma converter offers over conventional type converters is an on-chip digital filter (commonly implemented as a SINC or Comb filter). For high resolution, low frequency applications, this filter is typically designed to reject line frequencies of 50Hz or 60Hz plus their harmonics. The filter rejection performance is directly related to the accuracy of the converter system clock. The LTC2480 incorporates a highly accurate on-chip oscillator. This eliminates the need for external frequency setting components such as crystals or oscillators.

Frequency Rejection Selection (f_O)

The LTC2480 internal oscillator provides better than 110dB normal mode rejection at the line frequency and all its harmonics (up to the 255th) for 50Hz ±2% or 60Hz ±2%, or better than 87dB normal mode rejection from 48Hz to 62.4Hz. The rejection mode is selected by writing to the on-chip configuration register and the default mode at POR is simultaneous 50Hz/60Hz rejection.

When a fundamental rejection frequency different from 50Hz or 60Hz is required or when the converter must be synchronized with an outside source, the LTC2480 can operate with an external conversion clock. The converter automatically detects the presence of an external clock signal at the f_O pin and turns off the internal oscillator. The frequency f_{EOSC} of the external signal must be at least 10kHz to be detected. The external clock signal duty cycle is not significant as long as the minimum and maximum specifications for the high and low periods t_{HEO} and t_{LEO} are observed.

While operating with an external conversion clock of a frequency f_{EOSC}, the LTC2480 provides better than 110dB normal mode rejection in a frequency range of f_{EOSC}/5120 ±4% and its harmonics. The normal mode rejection as a function of the input frequency deviation from f_{EOSC}/5120 is shown in Figure 3.

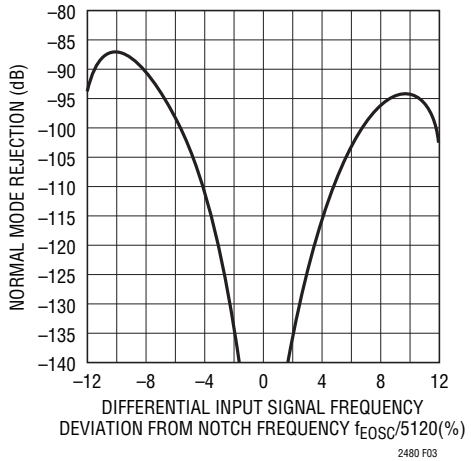

Figure 3. LTC2480 Normal Mode Rejection When Using an External Oscillator

Whenever an external clock is not present at the f_O pin, the converter automatically activates its internal oscillator and enters the internal conversion clock mode. The LTC2480 operation will not be disturbed if the change of conversion clock source occurs during the sleep state or during the data output state while the converter uses

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Table 5. LTC2480 State Duration

STATE	OPERATING MODE		DURATION
CONVERT	Internal Oscillator	60Hz Rejection	133ms, Output Data Rate ≤ 7.5 Readings/s for 1x Speed Mode 67ms, Output Data Rate ≤ 15 Readings/s for 2x Speed Mode
		50Hz Rejection	160ms, Output Data Rate ≤ 6.2 Readings/s for 1x Speed Mode 80ms, Output Data Rate ≤ 12.5 Readings/s for 2x Speed Mode
		50Hz/60Hz Rejection	147ms, Output Data Rate ≤ 6.8 Readings/s for 1x Speed Mode 73.6ms, Output Data Rate ≤ 13.6 Readings/s for 2x Speed Mode
	External Oscillator	f_O = External Oscillator with Frequency f_{EOSC} kHz (f_{EOSC}/5120 Rejection)	$41036/f_{EOSC}$s, Output Data Rate ≤ f_{EOSC}/41036 Readings/s for 1x Speed Mode $20556/f_{EOSC}$s, Output Data Rate ≤ f_{EOSC}/20556 Readings/s for 2x Speed Mode
SLEEP			As Long As $\overline{CS}$ = HIGH, After a Conversion is Complete
DATA OUTPUT	Internal Serial Clock	f_O = LOW/HIGH (Internal Oscillator)	As Long As $\overline{CS}$ = LOW But Not Longer Than 0.62ms (24 SCK Cycles)
		f_O = External Oscillator with Frequency f_{EOSC} kHz	As Long As $\overline{CS}$ = LOW But Not Longer Than $192/f_{EOSC}$ms (24 SCK Cycles)
	External Serial Clock with Frequency f_{SCK} kHz		As Long As $\overline{CS}$ = LOW But Not Longer Than $24/f_{SCK}$ms (24 SCK Cycles)

an external serial clock. If the change occurs during the conversion state, the result of the conversion in progress may be outside specifications but the following conversions will not be affected. If the change occurs during the data output state and the converter is in the Internal SCK mode, the serial clock duty cycle may be affected but the serial data stream will remain valid.

Table 5 summarizes the duration of each state and the achievable output data rate as a function of f_O.

Ease of Use

The LTC2480 data output has no latency, filter settling delay or redundant data associated with the conversion cycle. There is a one-to-one correspondence between the conversion and the output data. Therefore, multiplexing multiple analog voltages is easy.

The LTC2480 performs offset and full-scale calibrations every conversion cycle. This calibration is transparent to the user and has no effect on the cyclic operation described above. The advantage of continuous calibration is extreme stability of offset and full-scale readings with respect to time, supply voltage change and temperature drift.

Power-Up Sequence

The LTC2480 automatically enters an internal reset state when the power supply voltage V_{CC} drops below approximately 2V. This feature guarantees the integrity of the conversion result and of the serial interface mode selection.

When the V_{CC} voltage rises above this critical threshold, the converter creates an internal power-on-reset (POR) signal with a duration of approximately 4ms. The POR signal clears all internal registers. Following the POR signal, the LTC2480 starts a normal conversion cycle and follows the succession of states described in Figure 1. The first conversion result following POR is accurate within the specifications of the device if the power supply voltage is restored within the operating range (2.7V to 5.5V) before the end of the POR time interval.

On-Chip Temperature Sensor

The LTC2480 contains an on-chip PTAT (proportional to absolute temperature) signal that can be used as a temperature sensor. The internal PTAT has a typical value of 420mV at 27°C and is proportional to the absolute temperature

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value with a temperature coefficient of 420/(27 + 273) = 1.40mV/°C (SLOPE), as shown in Figure 4. The internal PTAT signal is used in a single-ended mode referenced to device ground internally. The GAIN is automatically set to one (independent of the values of GS0, GS1, GS2) in order to preserve the PTAT property at the ADC output code and avoid an out of range error. The 1x speed mode with automatic offset calibration is automatically selected for the internal PTAT signal measurement as well.

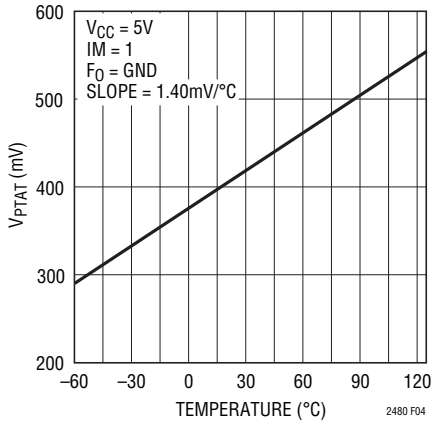

Figure 4. Internal PTAT Signal vs Temperature

When using the internal temperature sensor, if the output code is normalized to $R_{SDO} = V_{PTAT}/V_{REF}$, the temperature is calculated using the following formula:

$$T_K = \frac{R_{SDO} \bullet V_{REF}}{SLOPE} \text{ in Kelvin}$$

and

$$T_C = \frac{R_{SDO} \bullet V_{REF}}{SLOPE} - 273 \text{ in } ^\circ C$$

where SLOPE is nominally 1.4mV/°C.

Since the PTAT signal can have an initial value variation which results in errors in SLOPE, to achieve better temperature measurements, a one-time calibration is needed to adjust the SLOPE value. The converter output of the PTAT signal, $R0_{SDO}$, is measured at a known temperature T0 (in °C) and the SLOPE is calculated as:

$$SLOPE = \frac{R0_{SDO} \bullet V_{REF}}{T0 + 273}$$

This calibrated SLOPE can be used to calculate the temperature.

If the same V_{REF} source is used during calibration and temperature measurement, the actual value of the V_{REF} is not needed to measure the temperature as shown in the calculation below:

$$T_C = \frac{R_{SDO} \bullet V_{REF}}{SLOPE} - 273$$

$$= \frac{R_{SDO}}{R0_{SDO}} \bullet (T0 + 273) - 273$$

Reference Voltage Range

The LTC2480 external reference voltage range is 0.1V to V_{CC}. The converter output noise is determined by the thermal noise of the front-end circuits, and as such, its value in nanovolts is nearly constant with reference voltage. Since the transition noise (600nV) is much less than the quantization noise ($V_{REF}/2^{17}$), a decrease in the reference voltage will increase the converter resolution. A reduced reference voltage will also improve the converter performance when operated with an external conversion clock (external f_O signal) at substantially higher output data rates (see the Output Data Rate section). V_{REF} must be ≥1.1V to use the internal temperature sensor.

The negative reference input to the converter is internally tied to GND. GND (Pin 8) should be connected to a ground plane through as short a trace as possible to minimize voltage drop. The LTC2480 has an average operational current of 160µA and for 0.1Ω parasitic resistance, the voltage drop of 16µV causes a gain error of 3.2ppm for V_{REF} = 5V.

Input Voltage Range

The analog input is truly differential with an absolute/common mode range for the IN^+ and IN^- input pins extending from GND – 0.3V to V_{CC} + 0.3V. Outside these limits, the ESD protection devices begin to turn on and the errors due to input leakage current increase rapidly. Within these limits, the LTC2480 converts the bipolar differential input signal, $V_{IN} = IN^+ – IN^-$, from –FS to +FS where FS = 0.5 • V_{REF}/GAIN. Outside this range, the converter indicates the overrange or the underrange condition using distinct output codes. Since the differential input current cancellation does not rely on an on-chip buffer, current cancellation as well as DC performance is maintained rail-to-rail.

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Input signals applied to IN^+ and IN^- pins may extend by 300mV below ground and above V_{CC}. In order to limit any fault current, resistors of up to 5k may be added in series with the IN^+ and IN^- pins without affecting the performance of the devices. The effect of the series resistance on the converter accuracy can be evaluated from the curves presented in the Input Current/Reference Current sections. In addition, series resistors will introduce a temperature dependent offset error due to the input leakage current. A 1nA input leakage current will develop a 1ppm offset error on a 5k resistor if V_{REF} = 5V. This error has a very strong temperature dependency.

Serial Interface Timing Modes

The LTC2480's 4-wire interface is SPI and MICROWIRE compatible. This interface offers several flexible modes of operation. These include internal/external serial clock, 3- or 4-wire I/O, single cycle or continuous conversion. The following sections describe each of these serial interface timing modes in detail. In all these cases, the converter can use the internal oscillator (f_O = LOW or f_O = HIGH) or an external oscillator connected to the f_O pin. Refer to Table 6 for a summary.

External Serial Clock, Single Cycle Operation (SPI/MICROWIRE Compatible)

This timing mode uses an external serial clock to shift out the conversion result and a $\overline{CS}$ signal to monitor and control the state of the conversion cycle, see Figure 5.

The serial clock mode is selected on the falling edge of $\overline{CS}$. To select the external serial clock mode, the serial clock pin (SCK) must be LOW during each $\overline{CS}$ falling edge.

Table 6. LTC2480 Interface Timing Modes

CONFIGURATION	SCK SOURCE	CONVERSION CYCLE CONTROL	DATA OUTPUT CONTROL	CONNECTION AND WAVEFORMS
External SCK, Single Cycle Conversion	External	$\overline{CS}$ and SCK	$\overline{CS}$ and SCK	Figures 5, 6
External SCK, 3-Wire I/O	External	SCK	SCK	Figure 7
Internal SCK, Single Cycle Conversion	Internal	$\overline{CS}\downarrow$	$\overline{CS}\downarrow$	Figures 8, 9
Internal SCK, 3-Wire I/O, Continuous Conversion	Internal	Continuous	Internal	Figure 10

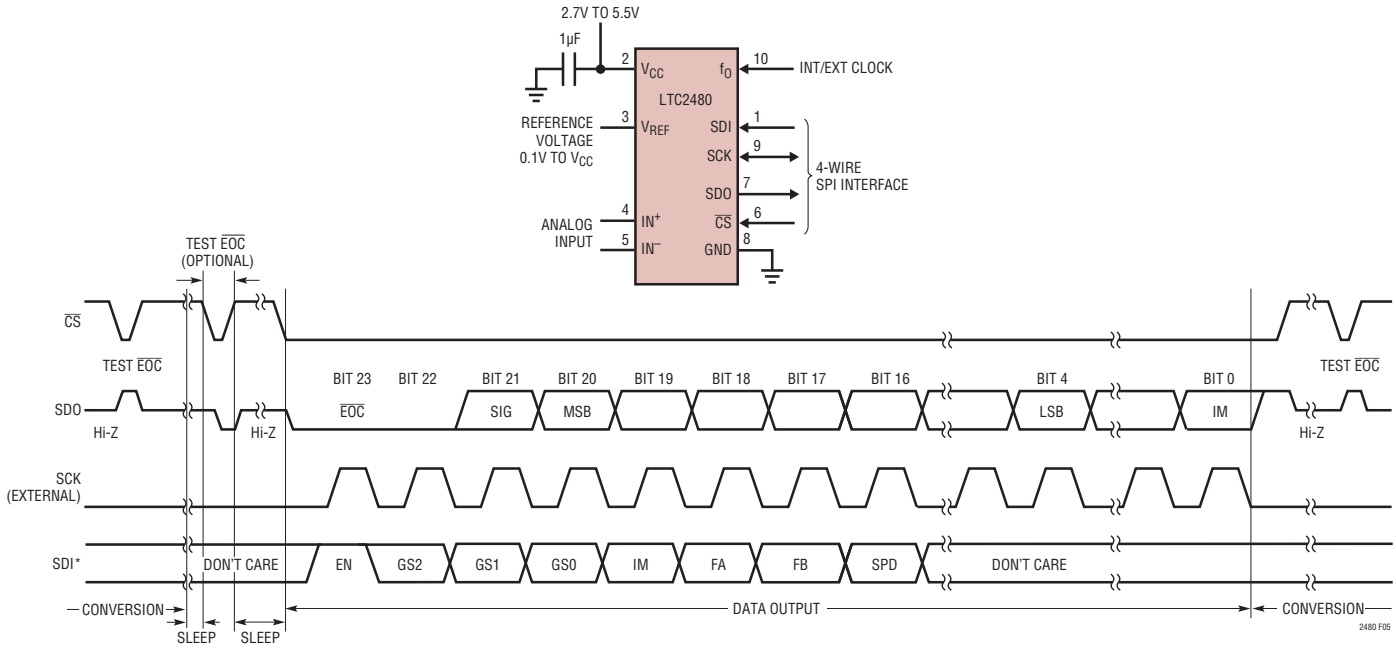

Figure 5. External Serial Clock, Single Cycle Operation

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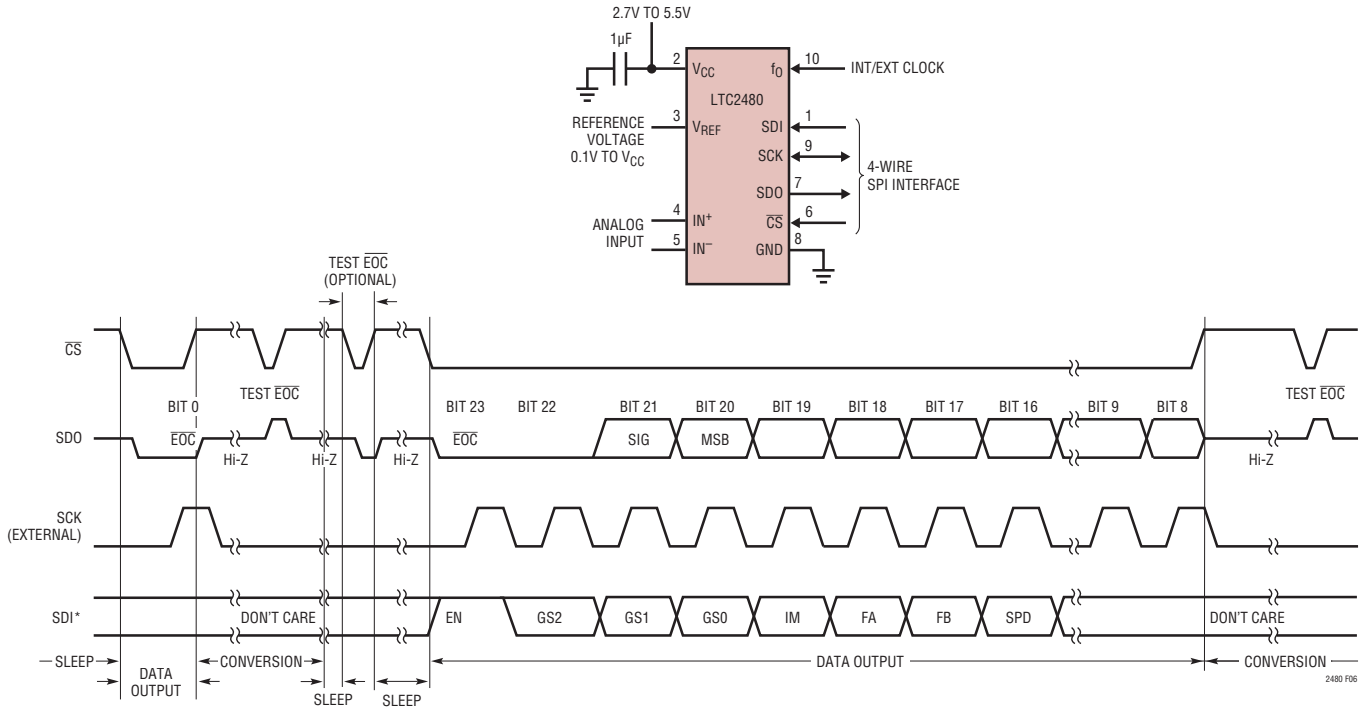

Figure 6. External Serial Clock, Reduced Data Output Length

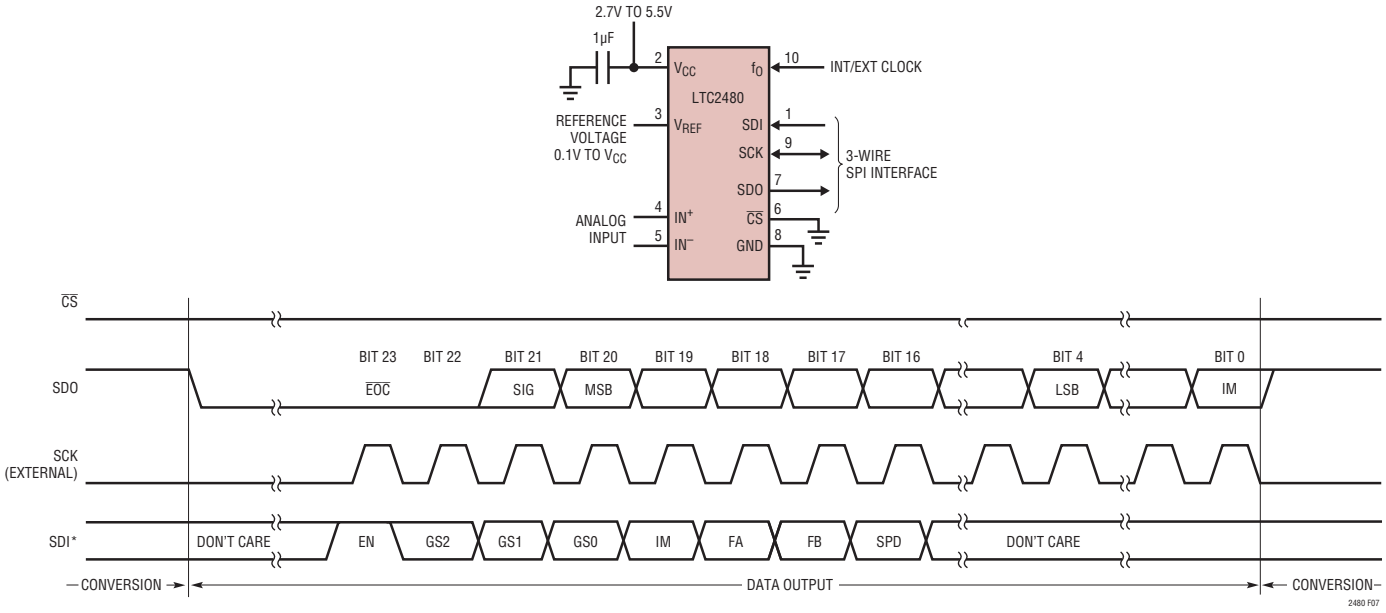

Figure 7. External Serial Clock, $\overline{CS}$ = 0 Operation

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The serial data output pin (SDO) is Hi-Z as long as $\overline{CS}$ is HIGH. At any time during the conversion cycle, $\overline{CS}$ may be pulled LOW in order to monitor the state of the converter. While $\overline{CS}$ is pulled LOW, $\overline{EOC}$ is output to the SDO pin. $\overline{EOC}$ = 1 while a conversion is in progress and $\overline{EOC}$ = 0 if the device is in the sleep state. Independent of $\overline{CS}$, the device automatically enters the low power sleep state once the conversion is complete.

When the device is in the sleep state, its conversion result is held in an internal static shift register. The device remains in the sleep state until the first rising edge of SCK is seen while $\overline{CS}$ is LOW. The input data is then shifted in via the SDI pin on the rising edge of SCK (including the first rising edge) and the output data is shifted out of the SDO pin on each falling edge of SCK. This enables external circuitry to latch the output on the rising edge of SCK. $\overline{EOC}$ can be latched on the first rising edge of SCK and the last bit of the conversion result can be latched on the 24th rising edge of SCK. On the 24th falling edge of SCK, the device begins a new conversion. SDO goes HIGH ($\overline{EOC}$ = 1) indicating a conversion is in progress. In applications where the processor generates 32 clock cycles, or to remain compatible with higher resolution converters, the LTC2480's digital interface will ignore extra clock edges seen during the next conversion period after the 24th and outputs "1" for the extra clock cycles.

At the conclusion of the data cycle, $\overline{CS}$ may remain LOW and $\overline{EOC}$ monitored as an end-of-conversion interrupt. Alternatively, $\overline{CS}$ may be driven HIGH setting SDO to Hi-Z. As described above, $\overline{CS}$ may be pulled LOW at any time in order to monitor the conversion status.

Typically, $\overline{CS}$ remains LOW during the data output state. However, the data output state may be aborted by pulling $\overline{CS}$ HIGH anytime between the first rising edge and the 24th falling edge of SCK (see Figure 6). On the rising edge of $\overline{CS}$, the device aborts the data output state and immediately initiates a new conversion. If the device has not finished loading the last input bit SPD of SDI by the time $\overline{CS}$ is pulled HIGH, the SDI information is discarded and the previous configuration is kept. This is useful for systems not requiring all 24 bits of output data, aborting an invalid conversion cycle or synchronizing the start of a conversion.

External Serial Clock, 3-Wire I/O

This timing mode utilizes a 3-wire serial I/O interface. The conversion result is shifted out of the device by an externally generated serial clock (SCK) signal, see Figure 7. $\overline{CS}$ may be permanently tied to ground, simplifying the user interface or transmission over an isolation barrier.

The external serial clock mode is selected at the end of the power-on reset (POR) cycle. The POR cycle is concluded typically 4ms after V_{CC} exceeds approximately 2V. The level applied to SCK at this time determines if SCK is internal or external. SCK must be driven LOW prior to the end of POR in order to enter the external serial clock timing mode.

Since $\overline{CS}$ is tied LOW, the end-of-conversion ($\overline{EOC}$) can be continuously monitored at the SDO pin during the convert and sleep states. $\overline{EOC}$ may be used as an interrupt to an external controller indicating the conversion result is ready. $\overline{EOC}$ = 1 while the conversion is in progress and $\overline{EOC}$ = 0 once the conversion ends. On the falling edge of $\overline{EOC}$, the conversion result is loaded into an internal static shift register. The input data is then shifted in via the SDI pin on the rising edge of SCK (including the first rising edge) and the output data is shifted out of the SDO pin on each falling edge of SCK. $\overline{EOC}$ can be latched on the first rising edge of SCK. On the 24th falling edge of SCK, SDO goes HIGH ($\overline{EOC}$ = 1) indicating a new conversion has begun. In applications where the processor generates 32 clock cycles, or to remain compatible with higher resolution converters, the LTC2480's digital interface will ignore extra clock edges seen during the next conversion period after the 24th and outputs "1" for the extra clock cycles.

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Internal Serial Clock, Single Cycle Operation

This timing mode uses an internal serial clock to shift out the conversion result and a $\overline{CS}$ signal to monitor and control the state of the conversion cycle, see Figure 8.

In order to select the internal serial clock timing mode, the serial clock pin (SCK) must be floating (Hi-Z) or pulled HIGH prior to the falling edge of $\overline{CS}$. The device will not enter the internal serial clock mode if SCK is driven LOW on the falling edge of $\overline{CS}$. An internal weak pull-up resistor is active on the SCK pin during the falling edge of $\overline{CS}$; therefore, the internal serial clock timing mode is automatically selected if SCK is not externally driven.

The serial data output pin (SDO) is Hi-Z as long as $\overline{CS}$ is HIGH. At any time during the conversion cycle, $\overline{CS}$ may be pulled LOW in order to monitor the state of the converter. Once $\overline{CS}$ is pulled LOW, SCK goes LOW and $\overline{EOC}$ is output to the SDO pin. $\overline{EOC}$ = 1 while a conversion is in progress and $\overline{EOC}$ = 0 if the device is in the sleep state.

When testing $\overline{EOC}$, if the conversion is complete ($\overline{EOC}$ = 0), the device will exit the low power mode during the $\overline{EOC}$ test. In order to allow the device to return to the low power sleep state, $\overline{CS}$ must be pulled HIGH before the first rising edge of SCK. In the internal SCK timing mode, SCK goes HIGH and the device begins outputting data at time $t_{EOCtest}$ after the falling edge of $\overline{CS}$ (if $\overline{EOC}$ = 0) or $t_{EOCtest}$ after $\overline{EOC}$ goes LOW (if $\overline{CS}$ is LOW during the falling edge of $\overline{EOC}$). The value of $t_{EOCtest}$ is 12µs if the device is using its internal oscillator. If f_O is driven by an external oscillator of frequency f_{EOSC}, then $t_{EOCtest}$ is 3.6/f_{EOSC} in seconds. If $\overline{CS}$ is pulled HIGH before time $t_{EOCtest}$, the device returns to the sleep state and the conversion result is held in the internal static shift register.

If $\overline{CS}$ remains LOW longer than $t_{EOCtest}$, the first rising edge of SCK will occur and the conversion result is serially shifted out of the SDO pin. The data I/O cycle concludes after the 24th rising edge. The input data is shifted in via the SDI pin on the rising edge of SCK (including the first rising edge) and the output data is shifted out of the SDO pin on each falling edge of SCK. The internally generated serial clock is output to the SCK pin. This signal may be used to shift the conversion result into external circuitry. $\overline{EOC}$ can be latched on the first rising edge of SCK and the last bit of the conversion result on the 24th rising edge of SCK. After the 24th rising edge, SDO goes HIGH ($\overline{EOC}$ = 1), SCK stays HIGH and a new conversion starts.

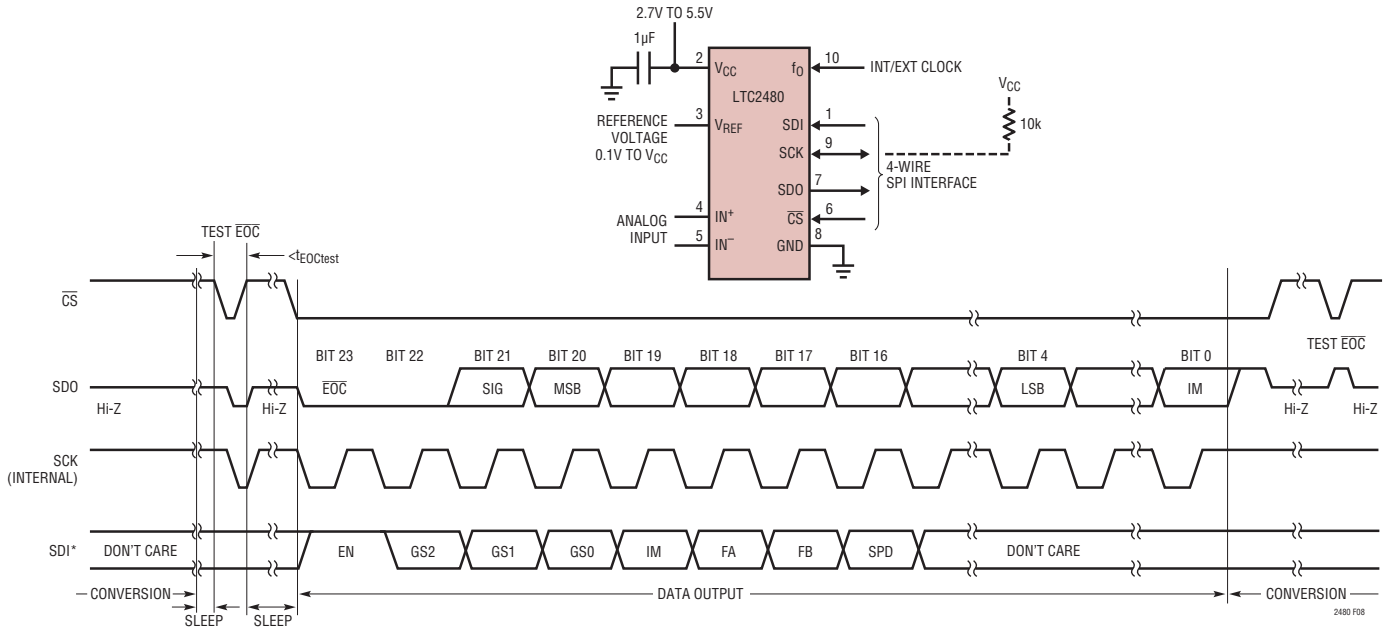

Figure 8. Internal Serial Clock, Single Cycle Operation

APPLICATIONS INFORMATION

$\overline{CS}$ remains LOW during the data output state. However, the data output state may be aborted by pulling $\overline{CS}$ HIGH anytime between the first and 24th rising edge of SCK (see Figure 9). On the rising edge of $\overline{CS}$, the device aborts the data output state and immediately initiates a new conversion. If the device has not finished loading the last input bit SPD of SDI by the time $\overline{CS}$ is pulled HIGH, the SDI information is discarded and the previous configuration is still kept. This is useful for systems not requiring all 24 bits of output data, aborting an invalid conversion cycle, or synchronizing the start of a conversion. If $\overline{CS}$ is pulled HIGH while the converter is driving SCK LOW, the internal pull-up is not available to restore SCK to a logic HIGH state. This will cause the device to exit the internal serial clock mode on the next falling edge of $\overline{CS}$. This can be avoided by adding an external 10k pull-up resistor to the SCK pin or by never pulling $\overline{CS}$ HIGH when SCK is LOW.

Whenever SCK is LOW, the LTC2480's internal pull-up at pin SCK is disabled. Normally, SCK is not externally driven if the device is in the internal SCK timing mode. However, certain applications may require an external driver on SCK. If this driver goes Hi-Z after outputting a LOW signal, the LTC2480's internal pull-up remains disabled. Hence, SCK remains LOW. On the next falling edge of $\overline{CS}$, the device is switched to the external SCK timing mode. By adding an external 10k pull-up resistor to SCK, this pin goes HIGH once the external driver goes Hi-Z. On the next $\overline{CS}$ falling edge, the device will remain in the internal SCK timing mode.

A similar situation may occur during the sleep state when $\overline{CS}$ is pulsed HIGH-LOW-HIGH in order to test the conversion status. If the device is in the sleep state ($\overline{EOC}$ = 0), SCK will go LOW. Once $\overline{CS}$ goes HIGH (within the time period defined above as $t_{EOCtest}$), the internal pull-up is activated. For a heavy capacitive load on the SCK pin, the internal pull-up may not be adequate to return SCK to a HIGH level before $\overline{CS}$ goes low again. This is not a concern under normal conditions where $\overline{CS}$ remains LOW after detecting $\overline{EOC}$ = 0. This situation is easily overcome by adding an external 10k pull-up resistor to the SCK pin.

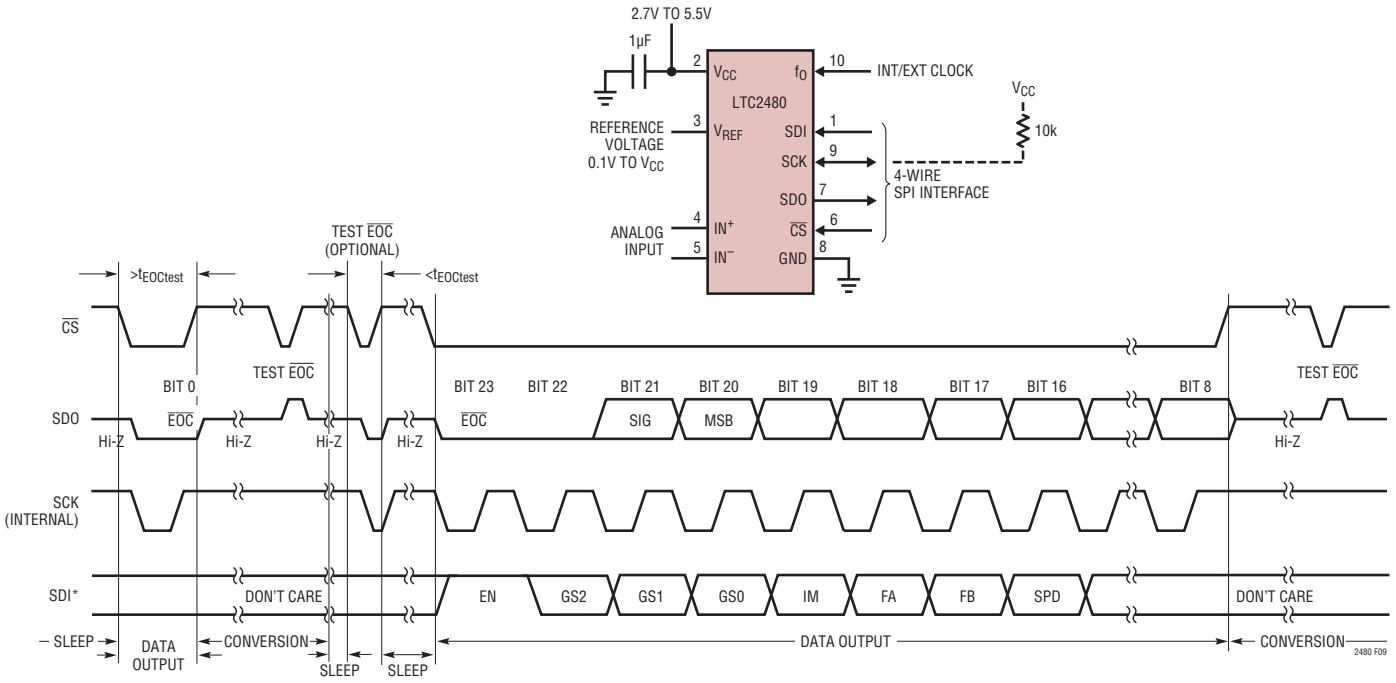

Figure 9. Internal Serial Clock, Reduce Data Output Length