

PGA11x Zero-Drift Programmable Gain Amplifier With Mux

1 Features

- Rail-to-Rail Input and Output
- Offset: 25 μV (Typical), 100 μV (Maximum)
- Zero Drift: 0.35 $\mu\text{V}/^\circ\text{C}$ (Typical), 1.2 $\mu\text{V}/^\circ\text{C}$ (Maximum)
- Low Noise: 12 $\text{nV}/\sqrt{\text{Hz}}$
- Input Offset Current: ± 5 nA Maximum (25 $^\circ\text{C}$)
- Gain Error: 0.1% Maximum ($G \leq 32$), 0.3% Maximum ($G > 32$)
- Binary Gains: 1, 2, 4, 8, 16, 32, 64, 128 (PGA112, PGA116)
- Scope Gains: 1, 2, 5, 10, 20, 50, 100, 200 (PGA113, PGA117)
- Gain Switching Time: 200 ns
- 2 Channel MUX: PGA112, PGA113
10 Channel MUX: PGA116, PGA117
- Four Internal Calibration Channels
- Amplifier Optimized for Driving CDAC ADCs
- Output Swing: 50 mV to Supply Rails
- AV_{DD} and DV_{DD} for Mixed Voltage Systems
- $\text{I}_{\text{Q}} = 1.1$ mA (Typical)
- Software and Hardware Shutdown: $\text{I}_{\text{Q}} \leq 4$ μA (Typical)
- Temperature Range: -40°C to 125°C
- SPI™ Interface (10 MHz) With Daisy-Chain Capability

2 Applications

- Remote e-Meter Reading
- Automatic Gain Control
- Portable Data Acquisition
- PC-Based Signal Acquisition Systems
- Test and Measurement
- Programmable Logic Controllers
- Battery-Powered Instruments
- Handheld Test Equipment

3 Description

The PGA112 and PGA113 devices (binary and scope gains) offer two analog inputs, a three-pin SPI interface, and software shutdown in a 10-pin, VSSOP package. The PGA116 and PGA117 (binary and scope gains) offer 10 analog inputs, a SPI interface with daisy-chain capability, and hardware and software shutdown in a 20-pin TSSOP package.

All versions provide internal calibration channels for system-level calibration. The channels are tied to GND, 0.9 V_{CAL} , 0.1 V_{CAL} , and V_{REF} , respectively. V_{CAL} , an external voltage connected to Channel 0, is used as the system calibration reference. Binary gains are: 1, 2, 4, 8, 16, 32, 64, and 128; scope gains are: 1, 2, 5, 10, 20, 50, 100, and 200.

Device Information⁽¹⁾

PART NUMBER	PACKAGE	BODY SIZE (NOM)
PGA112, PGA113	VSSOP (10)	3.00 mm x 3.00 mm
PGA116, PGA117	TSSOP (20)	6.50 mm x 4.40 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Simplified Schematic

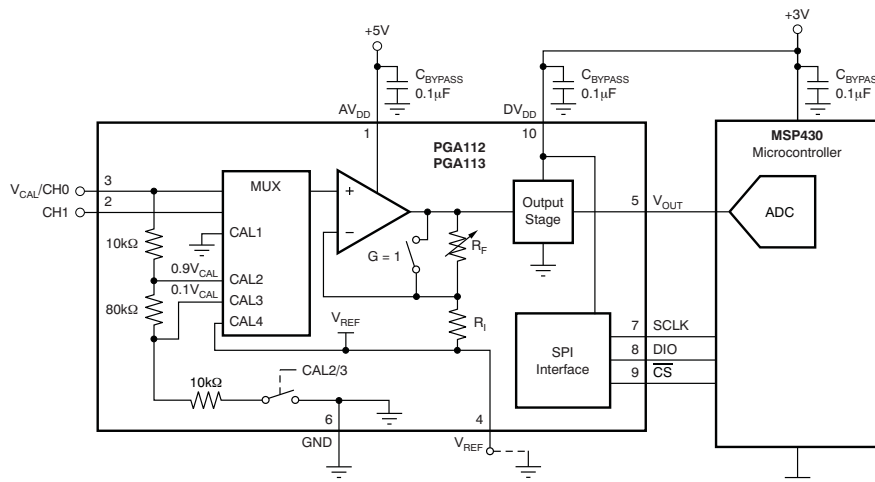


Table of Contents

1 Features	1	8.4 Device Functional Modes	20
2 Applications	1	8.5 Programming	21
3 Description	1	8.6 Serial Interface Information	21
4 Revision History	2	9 Applications and Implementation	31
5 Device Comparison	3	9.1 Application Information	31
6 Pin Configuration and Functions	3	9.2 Typical Applications	43
7 Specifications	5	10 Power Supply Recommendations	46
7.1 Absolute Maximum Ratings	5	11 Layout	47
7.2 ESD Ratings	5	11.1 Layout Guidelines	47
7.3 Recommended Operating Conditions	5	11.2 Layout Example	48
7.4 Thermal Information	5	12 Device and Documentation Support	49
7.5 Electrical Characteristics: $V_S = AV_{DD} = DV_{DD} = 5\text{ V}$..	6	12.1 Documentation Support	49
7.6 SPI Timing: $V_S = AV_{DD} = DV_{DD} = 2.2\text{ V to }5\text{ V}$	9	12.2 Related Links	49
7.7 Typical Characteristics	11	12.3 Community Resources	49
8 Detailed Description	20	12.4 Trademarks	49
8.1 Overview	20	12.5 Electrostatic Discharge Caution	49
8.2 Functional Block Diagram	20	12.6 Glossary	49
8.3 Feature Description	20	13 Mechanical, Packaging, and Orderable Information	49

4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision B (September 2008) to Revision C

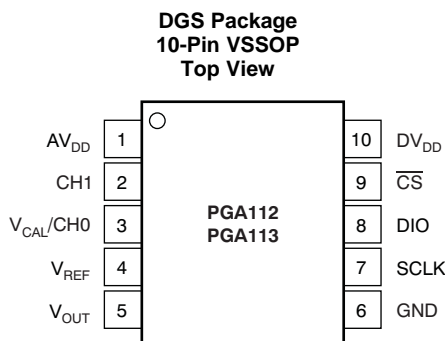
Page

- Added *ESD Ratings* table, *Thermal Information* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section **1**

5 Device Comparison

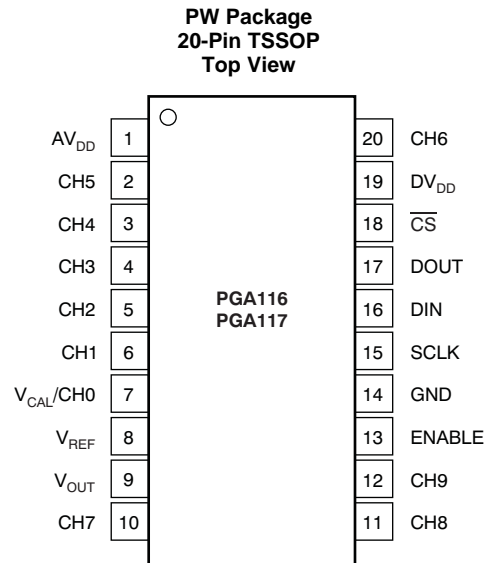
DEVICE	NO. OF MUX INPUTS	GAINS (EIGHT EACH)	SPI DAISY-CHAIN	SHUTDOWN		PACKAGE
				HARDWARE	SOFTWARE	
PGA112	2	Binary	No	No	✓	VSSOP-10
PGA113	2	Scope	No	No	✓	VSSOP-10
PGA116	10	Binary	✓	✓	✓	TSSOP-20
PGA117	10	Scope	✓	✓	✓	TSSOP-20

6 Pin Configuration and Functions



Pin Functions: PGA112, PGA113

PIN		I/O	DESCRIPTION
NO.	NAME		
1	AV _{DD}	I	Analog supply voltage (2.2 V to 5.5 V)
2	CH1	I	Input MUX channel 1
3	V _{CAL} /CH0	I	Input MUX channel 0 and V _{CAL} input. For system calibration purposes, connect this pin to a low-impedance external reference voltage to use internal calibration channels. The four internal calibration channels are connected to GND, 0.9 V _{CAL} , 0.1 V _{CAL} , and V _{REF} , respectively. V _{CAL} is loaded with 100 kΩ (typical) when internal calibration channels CAL2 or CAL3 are selected. Otherwise, V _{CAL} /CH0 appears as high impedance.
4	V _{REF}	I	Reference input pin. Connect external reference for V _{OUT} offset shift or to midsupply for midsupply referenced systems. V _{REF} must be connected to a low-impedance reference capable of sourcing and sinking at least 2 mA or V _{REF} must be connected to GND.
5	V _{OUT}	O	Analog voltage output. When AV _{DD} < DV _{DD} , V _{OUT} is clamped to AV _{DD} + 300 mV.
6	GND	—	Ground pin
7	SCLK	I	Clock input for SPI serial interface
8	DIO	I	Data input/output for SPI serial interface. DIO contains a weak, 10-μA internal pull-down current source.
9	$\overline{\text{CS}}$	I	Chip select line for SPI serial interface
10	DV _{DD}	I	Digital and op amp output stage supply voltage (2.2 V to 5.5 V). Useful in multi-supply systems to prevent overvoltage and lockup condition on an analog-to-digital (ADC) input (for example, a microcontroller with an ADC running on 3 V and the PGA powered from 5 V). Digital I/O levels to be relative to DV _{DD} . DV _{DD} should be bypassed with a 0.1-μF ceramic capacitor, and DV _{DD} must supply the current for the digital portion of the PGA as well as the load current for the op amp output stage.


Pin Functions: PGA116, PGA117

PIN		I/O	DESCRIPTION
NO.	NAME		
1	AV _{DD}	I	Analog supply voltage (2.2 V to 5.5 V)
2	CH5	I	Input MUX channel 5
3	CH4	I	Input MUX channel 4
4	CH3	I	Input MUX channel 3
5	CH2	I	Input MUX channel 2
6	CH1	I	Input MUX channel 1
7	V _{CAL} /CH0	I	Input MUX channel 0 and V _{CAL} input. For system calibration purposes, connect this pin to a low-impedance external reference voltage to use internal calibration channels. The four internal calibration channels are connected to GND, 0.9 V _{CAL} , 0.1 V _{CAL} , and V _{REF} , respectively. V _{CAL} is loaded with 100 kΩ (typical) when internal calibration channels CAL2 or CAL3 are selected. Otherwise, V _{CAL} /CH0 appears as high impedance.
8	V _{REF}	I	Reference input pin. Connect external reference for V _{OUT} offset shift or to midsupply for midsupply referenced systems. V _{REF} must be connected to a low-impedance reference capable of sourcing and sinking at least 2 mA or to GND.
9	V _{OUT}	O	Analog voltage output. When AV _{DD} < DV _{DD} , V _{OUT} is clamped to AV _{DD} + 300 mV.
10	CH7	I	Input MUX channel 7
11	CH8	I	Input MUX channel 8
12	CH9	I	Input MUX channel 9
13	ENABLE	I	Hardware enable pin. Logic low puts the part into Shutdown mode (I _Q < 1 μA).
14	GND	—	Ground pin
15	SCLK	I	Clock input for SPI serial interface
16	DIN	I	Data input for SPI serial interface. DIN contains a weak, 10-μA internal pulldown current source to allow for ease of daisy-chain configurations.
17	DOUT	O	Data output for SPI serial interface. DOUT goes to high-Z state when \overline{CS} goes high for standard SPI interface.
18	\overline{CS}	I	Chip select line for SPI serial interface
19	DV _{DD}	I	Digital and op amp output stage supply voltage (2.2 V to 5.5 V). Useful in multi-supply systems to prevent overvoltage and lockup condition on an ADC input (for example, a microcontroller with an ADC running on 3 V and the PGA powered from 5 V). Digital I/O levels to be relative to DV _{DD} . DV _{DD} should be bypassed with a 0.1-μF ceramic capacitor, and DV _{DD} must supply the current for the digital portion of the PGA as well as the load current for the op amp output stage.
20	CH6	I	Input MUX channel 6

7 Specifications

7.1 Absolute Maximum Ratings

Over operating free-air temperature range, unless otherwise noted.⁽¹⁾

	MIN	MAX	UNIT
Supply voltage		7	V
Signal input terminals, voltage ⁽²⁾	GND – 0.5	AV _{DD} + 0.5	V
Signal input terminals, current ⁽²⁾		±10	mA
Output short circuit	Continuous		
Operating temperature	–40	125	°C
Junction temperature		150	°C
Storage temperature	–65	150	°C

- (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.
- (2) Input terminals are diode-clamped to the power-supply rails. Input signals that can swing more than 0.5 V beyond the supply rails should be current-limited to 10 mA or less.

7.2 ESD Ratings

		VALUE	UNIT
V _(ESD) Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾	±3000	V
	Charged-device model (CDM), per JEDEC specification JESD22-C101 ⁽²⁾	±1000	
	Machine Model (MM)	±300	

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

7.3 Recommended Operating Conditions

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

	MIN	NOM	MAX	UNIT
AV _{DD}	2.2	5	5.5	V
DV _{DD}	2.2	5	5.5	V
Operating temperature	–40	25	125	°C

7.4 Thermal Information

THERMAL METRIC ⁽¹⁾		PGA112, PGA113	PGA116, PGA117	UNIT
		DGS (VSSOP)	PW (TSSOP)	
		10 PINS	20 PINS	
R _{θJA}	Junction-to-ambient thermal resistance	98.3	100.3	°C/W
R _{θJC(top)}	Junction-to-case (top) thermal resistance	57	36.9	°C/W
R _{θJB}	Junction-to-board thermal resistance	51.2	50.6	°C/W
Ψ _{JT}	Junction-to-top characterization parameter	1.3	2.6	°C/W
Ψ _{JB}	Junction-to-board characterization parameter	36.9	50.2	°C/W
R _{θJC(bot)}	Junction-to-case (bottom) thermal resistance	4.8	N/A	°C/W

- (1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).

7.5 Electrical Characteristics: $V_S = AV_{DD} = DV_{DD} = 5\text{ V}$

 at $T_A = 25^\circ\text{C}$, $R_L = 10\text{ k}\Omega/C_L = 100\text{ pF}$ connected to $DV_{DD}/2$, and $V_{REF} = \text{GND}$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OFFSET VOLTAGE						
Input offset voltage	V_{OS}	$AV_{DD} = DV_{DD} = 5\text{ V}$, $V_{REF} = V_{IN} = AV_{DD}/2$, $V_{CM} = 2.5\text{ V}$		± 25	± 100	μV
		$AV_{DD} = DV_{DD} = 5\text{ V}$, $V_{REF} = V_{IN} = AV_{DD}/2$, $V_{CM} = 4.5\text{ V}$		± 75	± 325	μV
vs temperature, -40°C to 125°C	dV_{OS}/dT	$AV_{DD} = DV_{DD} = 5\text{ V}$, $V_{CM} = 2.5\text{ V}$		0.35	1.2	$\mu\text{V}/^\circ\text{C}$
vs temperature, -40°C to 85°C		$AV_{DD} = DV_{DD} = 5\text{ V}$, $V_{CM} = 2.5\text{ V}$		0.15	0.9	$\mu\text{V}/^\circ\text{C}$
vs temperature, -40°C to 125°C		$AV_{DD} = DV_{DD} = 5\text{ V}$, $V_{CM} = 4.5\text{ V}$		0.6	1.8	$\mu\text{V}/^\circ\text{C}$
vs temperature, -40°C to 85°C		$AV_{DD} = DV_{DD} = 5\text{ V}$, $V_{CM} = 4.5\text{ V}$		0.3	1.3	$\mu\text{V}/^\circ\text{C}$
vs power supply	PSRR	$AV_{DD} = DV_{DD} = 2.2\text{ V}$ to 5.5 V , $V_{CM} = 0.5\text{ V}$, $V_{REF} = V_{IN} = AV_{DD}/2$		5	20	$\mu\text{V}/\text{V}$
Over temperature, -40°C to 125°C		$AV_{DD} = DV_{DD} = 2.2\text{ V}$ to 5.5 V , $V_{CM} = 0.5\text{ V}$, $V_{REF} = V_{IN} = AV_{DD}/2$		5	40	$\mu\text{V}/\text{V}$
INPUT ON-CHANNEL CURRENT						
Input on-channel current (Ch0, Ch1)	I_{IN}	$V_{REF} = V_{IN} = AV_{DD}/2$		± 1.5	± 5	nA
Over temperature, -40°C to 125°C		$V_{REF} = V_{IN} = AV_{DD}/2$		See Typical Characteristics		nA
INPUT VOLTAGE RANGE						
Input voltage range ⁽¹⁾	I_{VR}		GND – 0.1		$AV_{DD} + 0.1$	V
Overvoltage input range		No output phase reversal ⁽²⁾	GND – 0.3		$AV_{DD} + 0.3$	V
INPUT IMPEDANCE (Channel On)⁽³⁾						
Channel input capacitance	C_{CH}			2		pF
Channel switch resistance	R_{SW}			150		Ω
Amplifier input capacitance	C_{AMP}			3		pF
Amplifier input resistance	R_{AMP}	Input resistance to GND		10		G Ω
$V_{CAL}/\text{CH0}$	R_{IN}	CAL1 or CAL2 selected		100		k Ω
GAIN SELECTIONS						
Nominal gains		Binary gains: 1, 2, 4, 8, 16, 32, 64, 128		1	128	
		Scope gains: 1, 2, 5, 10, 20, 50, 100, 200		1	200	
DC gain error	$G = 1$	$V_{OUT} = \text{GND} + 85\text{ mV}$ to $DV_{DD} - 85\text{ mV}$		0.006%	0.1%	
	$1 < G \leq 32$	$V_{OUT} = \text{GND} + 85\text{ mV}$ to $DV_{DD} - 85\text{ mV}$			0.1%	
	$G \geq 50$	$V_{OUT} = \text{GND} + 85\text{ mV}$ to $DV_{DD} - 85\text{ mV}$			0.3%	
DC gain drift	$G = 1$	$V_{OUT} = \text{GND} + 85\text{ mV}$ to $DV_{DD} - 85\text{ mV}$	$T_A = -40^\circ\text{C}$ to 125°C	0.5		ppm/ $^\circ\text{C}$
	$1 < G \leq 32$	$V_{OUT} = \text{GND} + 85\text{ mV}$ to $DV_{DD} - 85\text{ mV}$	$T_A = -40^\circ\text{C}$ to 125°C	2		ppm/ $^\circ\text{C}$
	$G \geq 50$	$V_{OUT} = \text{GND} + 85\text{ mV}$ to $DV_{DD} - 85\text{ mV}$	$T_A = -40^\circ\text{C}$ to 125°C	6		ppm/ $^\circ\text{C}$
CAL2 DC gain error ⁽⁴⁾		Op Amp + Input = $0.9 V_{CAL}$, $V_{REF} = V_{CAL} = AV_{DD}/2$, $G = 1$		0.02%		
CAL2 DC gain drift ⁽⁴⁾		Op Amp + Input = $0.9 V_{CAL}$, $V_{REF} = V_{CAL} = AV_{DD}/2$, $G = 1$	$T_A = -40^\circ\text{C}$ to 125°C	2		ppm/ $^\circ\text{C}$
CAL3 DC gain error ⁽⁴⁾		Op Amp + Input = $0.1 V_{CAL}$, $V_{REF} = V_{CAL} = AV_{DD}/2$, $G = 1$		0.02%		
CAL3 DC gain drift ⁽⁴⁾		Op Amp + Input = $0.1 V_{CAL}$, $V_{REF} = V_{CAL} = AV_{DD}/2$, $G = 1$	$T_A = -40^\circ\text{C}$ to 125°C	2		ppm/ $^\circ\text{C}$
INPUT IMPEDANCE (CHANNEL OFF)⁽³⁾						
Input impedance	C_{CH}	See Figure 55		2		pF

- (1) Gain error is a function of the input voltage. Gain error outside of the range ($\text{GND} + 85\text{ mV} \leq V_{OUT} \leq DV_{DD} - 85\text{ mV}$) increases to 0.5% (typical).
- (2) Input voltages beyond this range must be current-limited to $< |10\text{ mA}|$ through the input protection diodes on each channel to prevent permanent destruction of the device.
- (3) See [Figure 55](#).
- (4) Total V_{OUT} error must be computed using input offset voltage error multiplied by gain. Includes op amp $G = 1$ error.

Electrical Characteristics: $V_S = AV_{DD} = DV_{DD} = 5\text{ V}$ (continued)

 at $T_A = 25^\circ\text{C}$, $R_L = 10\text{ k}\Omega/C_L = 100\text{ pF}$ connected to $DV_{DD}/2$, and $V_{REF} = \text{GND}$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT OFF-CHANNEL CURRENT						
Input Off-Channel Current (Ch0, Ch1) ⁽⁵⁾	I_{LKG}	$V_{REF} = \text{GND}$, $V_{OFF-CHANNEL} = AV_{DD}/2$, $V_{ON-CHANNEL} = AV_{DD}/2 - 0.1\text{ V}$		±0.05	±1	nA
Over temperature, -40°C to 125°C		$V_{REF} = \text{GND}$, $V_{OFF-CHANNEL} = AV_{DD}/2$, $V_{ON-CHANNEL} = AV_{DD}/2 - 0.1\text{ V}$	See Typical Characteristics			
Channel-to-Channel Crosstalk				130		dB
OUTPUT						
Voltage output swing from rail		$I_{OUT} = \pm 0.25\text{ mA}$, $AV_{DD} \geq DV_{DD}$ ⁽⁶⁾	GND + 0.05		$DV_{DD} - 0.05$	V
		$I_{OUT} = \pm 5\text{ mA}$, $AV_{DD} \geq DV_{DD}$ ⁽⁶⁾	GND + 0.25		$DV_{DD} - 0.25$	V
DC output nonlinearity		$V_{OUT} = \text{GND} + 85\text{ mV}$ to $DV_{DD} - 85\text{ mV}$ ⁽⁷⁾		0.0015		%FSR
Short circuit current	I_{SC}			-30/+60		mA
Capacitive load drive	C_{LOAD}		See Typical Characteristics			
NOISE						
Input voltage noise density	e_n	$f > 10\text{ kHz}$, $C_L = 100\text{ pF}$, $V_S = 5\text{ V}$		12		$\text{nV}/\sqrt{\text{Hz}}$
		$f > 10\text{ kHz}$, $C_L = 100\text{ pF}$, $V_S = 2.2\text{ V}$		22		$\text{nV}/\sqrt{\text{Hz}}$
Input voltage noise	e_n	$f = 0.1\text{ Hz}$ to 10 Hz , $C_L = 100\text{ pF}$, $V_S = 5\text{ V}$		0.362		μV_{PP}
		$f = 0.1\text{ Hz}$ to 10 Hz , $C_L = 100\text{ pF}$, $V_S = 2.2\text{ V}$		0.736		μV_{PP}
Input current density	i_n	$f = 10\text{ kHz}$, $C_L = 100\text{ pF}$		400		$\text{fA}/\sqrt{\text{Hz}}$
SLEW RATE						
Slew rate	SR		See Table 1			V/ μs
SETTLING TIME						
Settling time	t_s		See Table 1			μs
FREQUENCY RESPONSE						
Frequency response			See Table 1			MHz
THD + NOISE						
		$G = 1$, $f = 1\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.003%		
		$G = 10$, $f = 1\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.005%		
		$G = 50$, $f = 1\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.03%		
		$G = 128$, $f = 1\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.08%		
		$G = 200$, $f = 1\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.1%		
		$G = 1$, $f = 20\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.02%		
		$G = 10$, $f = 20\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.01%		
		$G = 50$, $f = 20\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.03%		
		$G = 128$, $f = 20\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.08%		
		$G = 200$, $f = 20\text{ kHz}$, $V_{OUT} = 4\text{ V}_{PP}$ at $2.5V_{DC}$, $C_L = 100\text{ pF}$		0.11%		
POWER SUPPLY						
Operating voltage range ⁽⁶⁾	AV_{DD}		2.2		5.5	V
	DV_{DD}		2.2		5.5	V
Quiescent current analog	I_{OA}	$I_O = 0$, $G = 1$, $V_{OUT} = V_{REF}$		0.33	0.45	mA
Over temperature, -40°C to 125°C		$T_A = -40^\circ\text{C}$ to 125°C			0.45	mA
Quiescent current digital ⁽⁸⁾⁽⁹⁾⁽¹⁰⁾	I_{OD}	$I_O = 0$, $G = 1$, $V_{OUT} = V_{REF}$, SCLK at 10 MHz, CS = Logic 0, DIO or DIN = Logic 0		0.75	1.2	mA
Over temperature, -40°C to 125°C ⁽⁸⁾⁽⁹⁾⁽¹⁰⁾		$T_A = -40^\circ\text{C}$ to 125°C			1.2	mA
Shutdown current analog + digital ⁽⁸⁾⁽⁹⁾	$I_{SDA} + I_{SDD}$	$I_O = 0$, $V_{OUT} = V_{REF}$, $G = 1$, SCLK Idle		4		μA
		$I_O = 0$, $V_{OUT} = 0$, $G = 1$, SCLK at 10MHz, CS = Logic 0, DIO or DIN = Logic 0		245		μA
POWER-ON RESET (POR)						
POR trip voltage		Digital interface disabled and Command Register set to POR values for $DV_{DD} < \text{POR Trip Voltage}$		1.6		V

(5) Maximum specification limitation limited by final test time and capability.

 (6) When AV_{DD} is less than DV_{DD} , the output is clamped to $AV_{DD} + 300\text{ mV}$.

(7) Measurement limited by noise in test equipment and test time.

 (8) Does not include current into or out of the V_{REF} pin. Internal R_F and R_I are always connected between V_{OUT} and V_{REF} .

 (9) Digital logic levels: DIO or DIN = logic 0. 10- μA internal pulldown current source.

(10) Includes current from op amp output structure.

Electrical Characteristics: $V_S = AV_{DD} = DV_{DD} = 5\text{ V}$ (continued)

 at $T_A = 25^\circ\text{C}$, $R_L = 10\text{k}\Omega/C_L = 100\text{ pF}$ connected to $DV_{DD}/2$, and $V_{REF} = \text{GND}$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
TEMPERATURE RANGE					
Specified range		-40		125	°C
Operating range		-40		125	°C
Thermal resistance	θ_{JA}				
	VSSOP-10		164		°C/W
DIGITAL INPUTS (SCLK, $\overline{\text{CS}}$, DIO, DIN)					
Logic low		0		$0.3DV_{DD}$	V
Input leakage current (SCLK and $\overline{\text{CS}}$ only)		-1		1	μA
Weak pulldown current (DIO, DIN only)			10		μA
Logic high		$0.7DV_{DD}$		DV_{DD}	V
Hysteresis			700		mV
DIGITAL OUTPUT (DIO, DOUT)					
Logic high	$I_{OH} = -3\text{ mA}$ (sourcing)	$DV_{DD} - 0.4$		DV_{DD}	V
Logic low	$I_{OL} = 3\text{ mA}$ (sinking)	GND		$\text{GND} + 0.4$	V
CHANNEL AND GAIN TIMING					
Channel select time			0.2		μs
Gain select time			0.2		μs
SHUTDOWN MODE TIMING					
Enable time			4		μs
Disable time	V_{OUT} goes high-impedance, R_F and R_I remain connected between V_{OUT} and V_{REF}		2		μs
POWER-ON-RESET (POR) TIMING					
POR power-up time	$DV_{DD} \geq 2\text{ V}$		40		μs
POR power-down time	$DV_{DD} \leq 1.5\text{ V}$		5		μs

7.6 SPI Timing: $V_S = AV_{DD} = DV_{DD} = 2.2\text{ V to }5\text{ V}$

At $T_A = +25^\circ\text{C}$, $R_L = 10\text{k}\Omega/C_L = 100\text{pF}$ connected to $DV_{DD}/2$, and $V_{REF} = \text{GND}$, unless otherwise noted.

		MIN	NOM	MAX	UNIT
	Input capacitance (SCLK, $\overline{\text{CS}}$, and DIO pins)		1		pF
t_{RFI}	Input rise and fall time ⁽¹⁾ ($\overline{\text{CS}}$, SCLK, and DIO pins)			2	μs
t_{RFO}	Output rise and fall time (DIO pin) ⁽¹⁾			10	ns
t_{CSH}	$\overline{\text{CS}}$ high time ($\overline{\text{CS}}$ pin) ⁽¹⁾	40			ns
t_{CS0}	SCLK edge to $\overline{\text{CS}}$ fall setup time ⁽¹⁾	10			ns
t_{CSSC}	$\overline{\text{CS}}$ fall to first SCLK edge setup time	10			ns
f_{SCLK}	SCLK Frequency ⁽²⁾			10	MHz
t_{HI}	SCLK high time ⁽³⁾	40			ns
t_{LO}	SCLK low time ⁽³⁾	40			ns
t_{SCCS}	SCLK last edge to $\overline{\text{CS}}$ rise setup time ⁽¹⁾	10			ns
t_{CS1}	$\overline{\text{CS}}$ rise to SCLK edge setup time ⁽¹⁾	10			ns
t_{SU}	DIN setup time	10			ns
t_{HD}	DIN hold time	10			ns
t_{DO}	SCLK to DOUT valid propagation delay ⁽¹⁾			25	ns
t_{SOZ}	$\overline{\text{CS}}$ rise to DOUT forced to Hi-Z ⁽¹⁾			20	ns

(1) Ensured by design; not production tested.

(2) When using devices in daisy-chain mode, the maximum clock frequency for SCLK is limited by SCLK rise and fall time, DIN setup time, and DOUT propagation delay. See Figure 61. Based on this limitation, the maximum SCLK frequency for daisy-chain mode is 9.09 MHz.

(3) t_{HI} and t_{LO} must not be less than $1/\text{SCLK}$ (maximum).

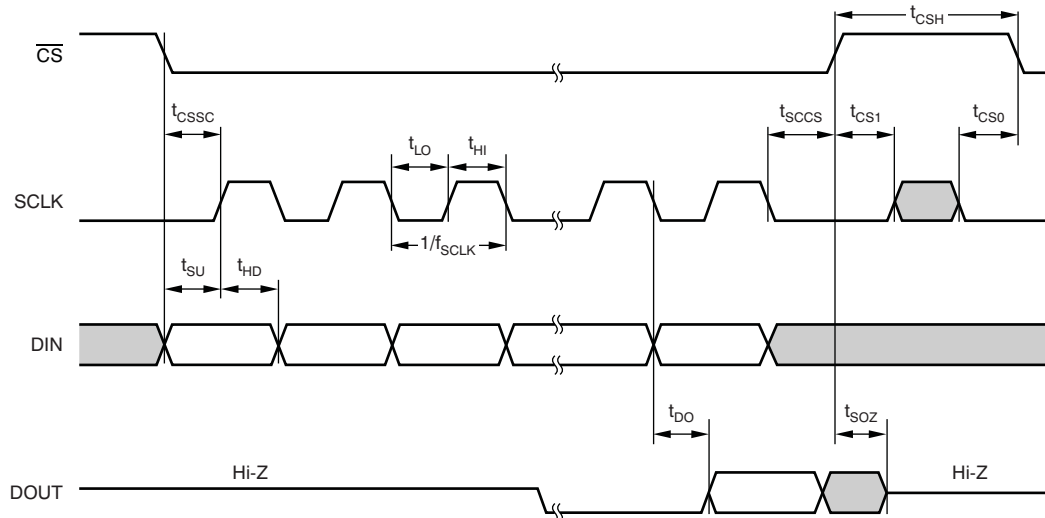
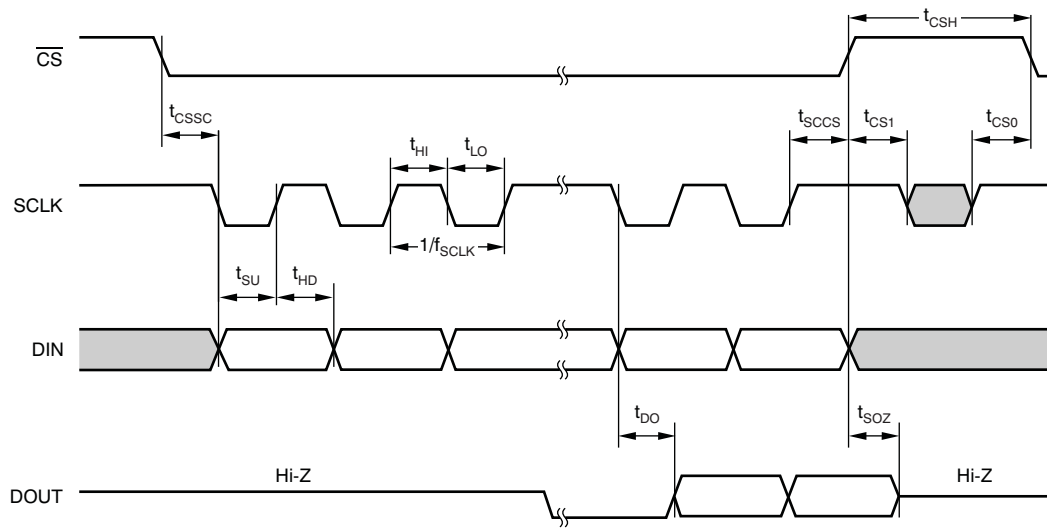


Figure 1. SPI Mode 0, 0


Figure 2. SPI Mode 1, 1

7.7 Typical Characteristics

at $T_A = 25^\circ\text{C}$, $AV_{DD} = DV_{DD} = 5\text{ V}$, $R_L = 10\text{ k}\Omega$ connected to $DV_{DD}/2$, $V_{REF} = \text{GND}$, and $C_L = 100\text{ pF}$, unless otherwise noted.

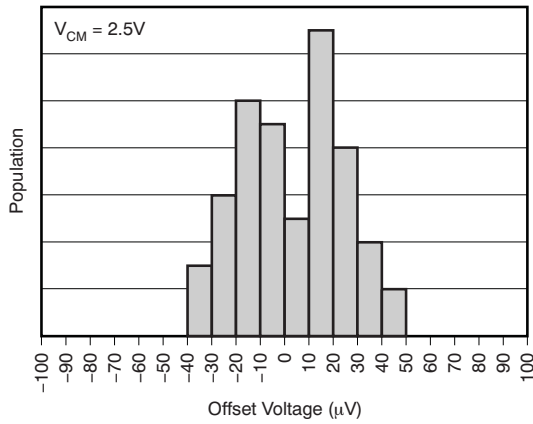


Figure 3. Offset Voltage

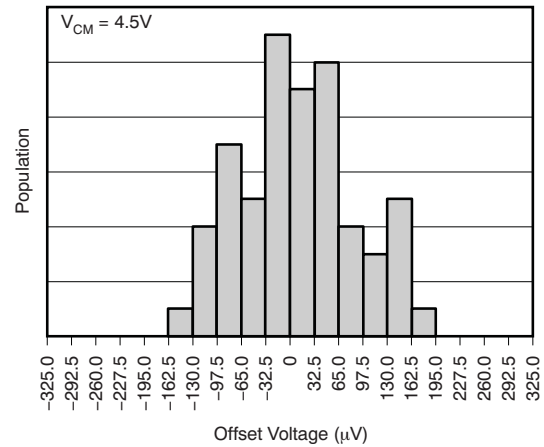


Figure 4. Offset Voltage

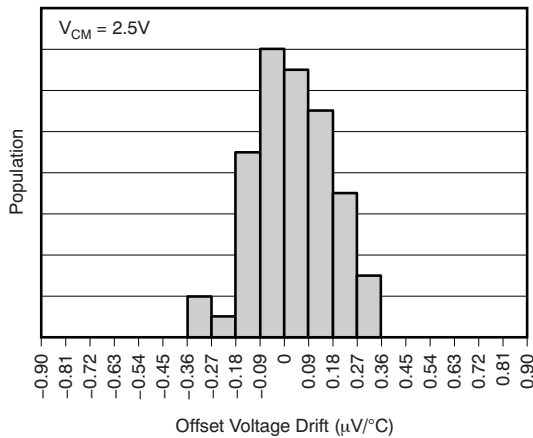


Figure 5. Offset Voltage Drift (–40°C to 85°C)

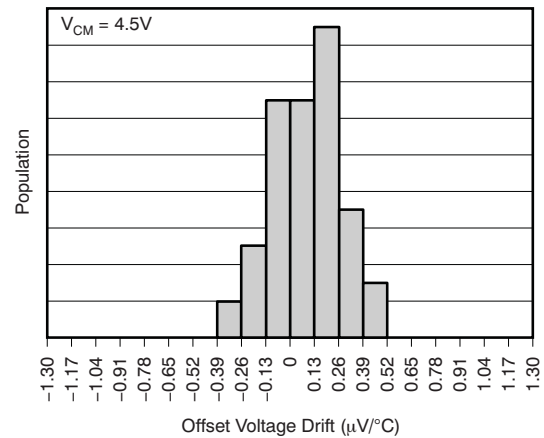


Figure 6. Offset Voltage Drift (–40°C to 85°C)

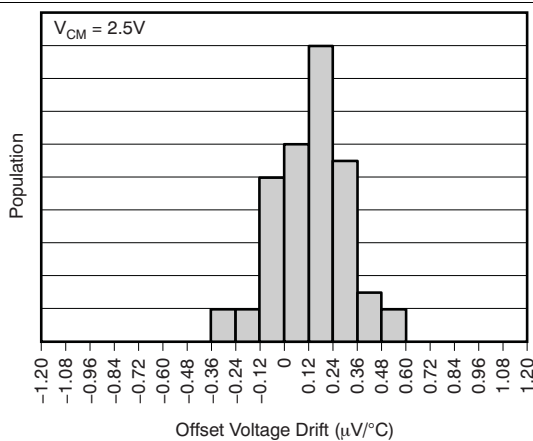


Figure 7. Offset Voltage Drift (–40°C to 125°C)

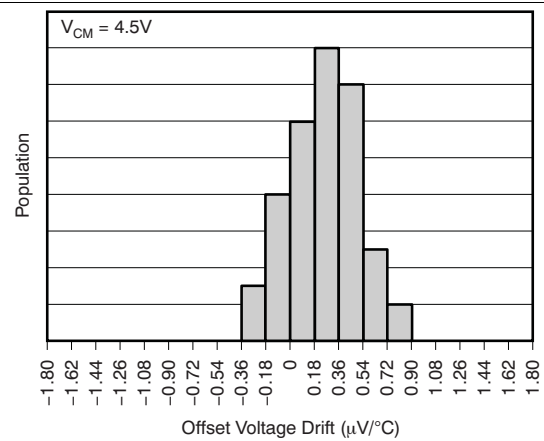


Figure 8. Offset Voltage Drift (–40°C to 125°C)

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $AV_{DD} = DV_{DD} = 5\text{ V}$, $R_L = 10\text{ k}\Omega$ connected to $DV_{DD}/2$, $V_{REF} = \text{GND}$, and $C_L = 100\text{ pF}$, unless otherwise noted.

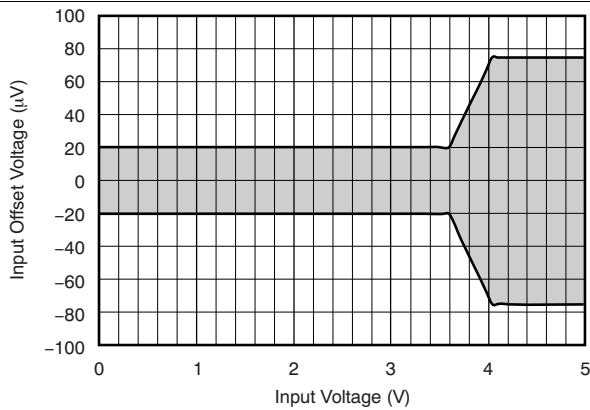


Figure 9. Input Offset Voltage vs Input Voltage

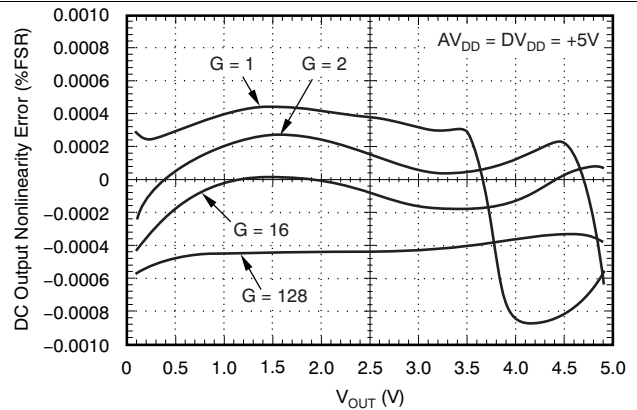


Figure 10. PGA112 and PGA116 Nonlinearity

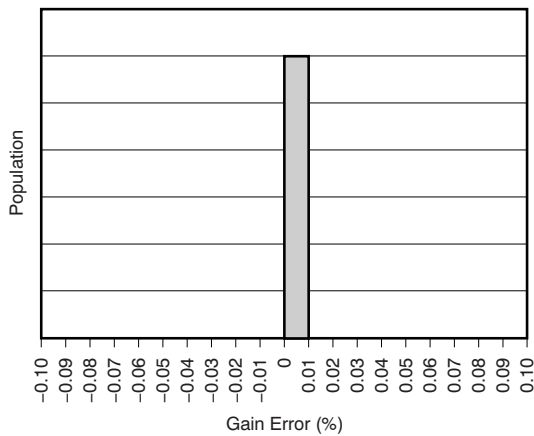


Figure 11. Gain Error ($G = 1$)

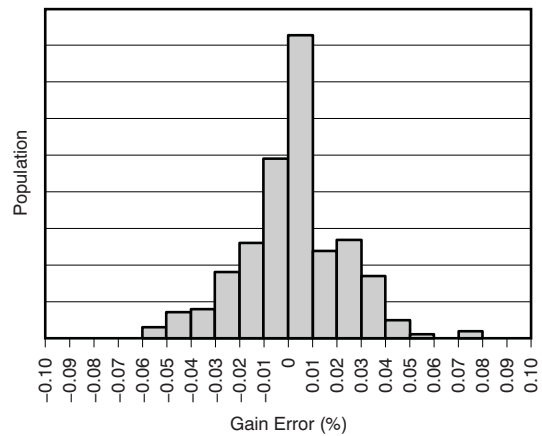


Figure 12. Gain Error ($1 < G \leq 32$)

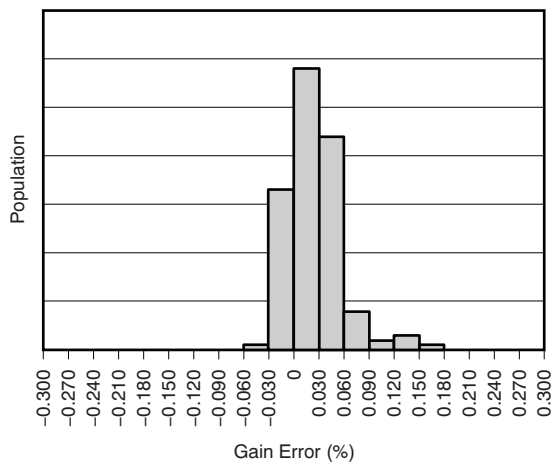


Figure 13. Gain Error ($G \geq 50$)

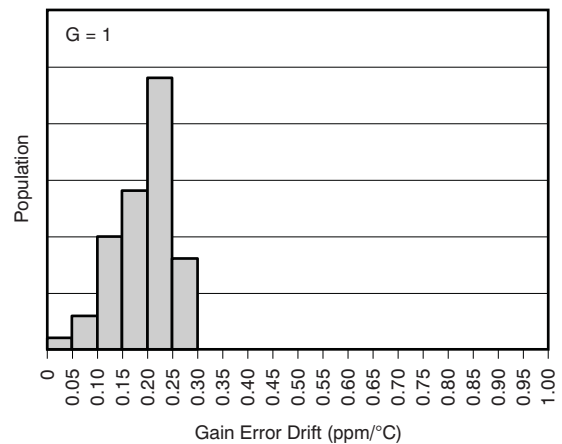


Figure 14. Gain Error Drift (-40°C to 125°C)

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $AV_{DD} = DV_{DD} = 5\text{ V}$, $R_L = 10\text{ k}\Omega$ connected to $DV_{DD}/2$, $V_{REF} = \text{GND}$, and $C_L = 100\text{ pF}$, unless otherwise noted.

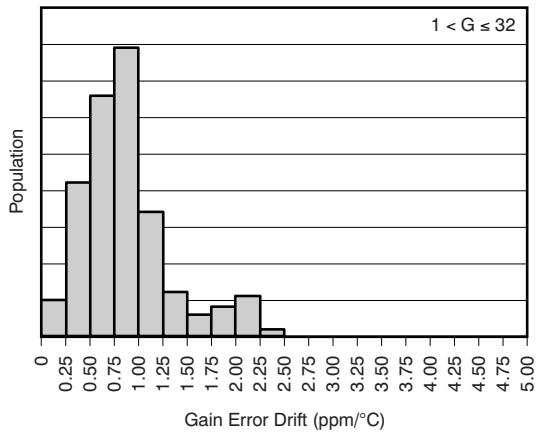


Figure 15. Gain Error Drift (–40°C to 125°C)

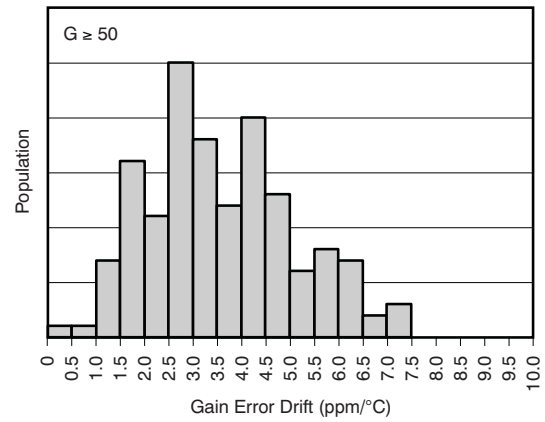


Figure 16. Gain Error Drift (–40°C to 125°C)

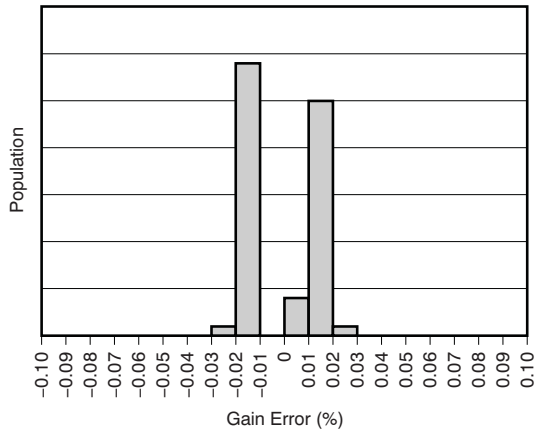


Figure 17. CAL2 Gain Error

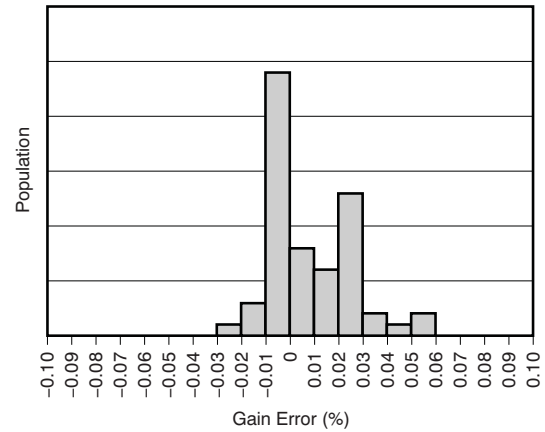


Figure 18. CAL3 Gain Error

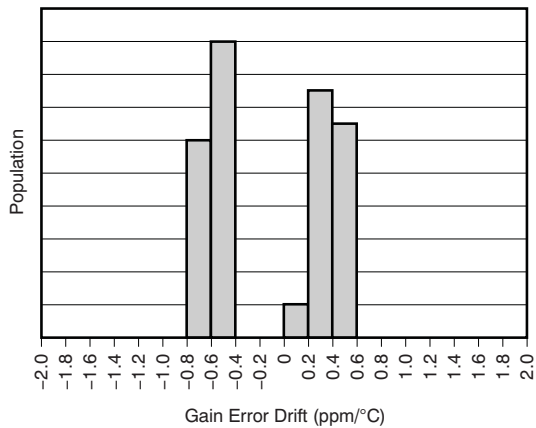


Figure 19. CAL2 Gain Error Drift (–40°C to 125°C)

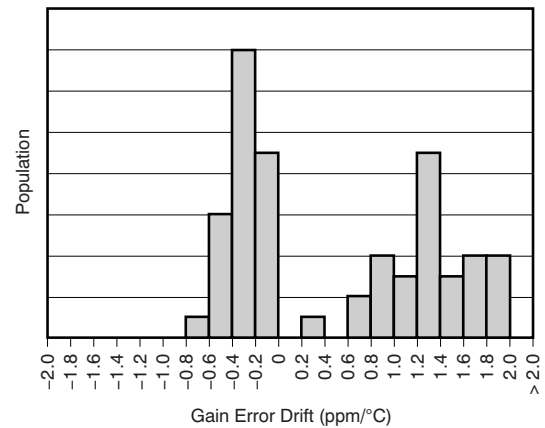


Figure 20. CAL3 Gain Error Drift (–40°C to 125°C)

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $AV_{DD} = DV_{DD} = 5\text{ V}$, $R_L = 10\text{ k}\Omega$ connected to $DV_{DD}/2$, $V_{REF} = \text{GND}$, and $C_L = 100\text{ pF}$, unless otherwise noted.

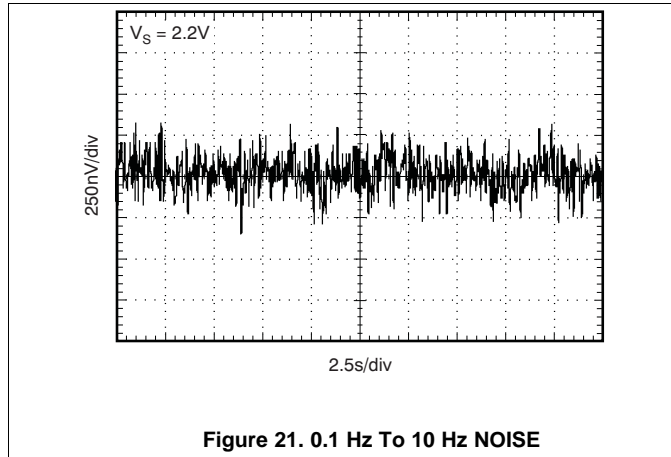


Figure 21. 0.1 Hz To 10 Hz NOISE

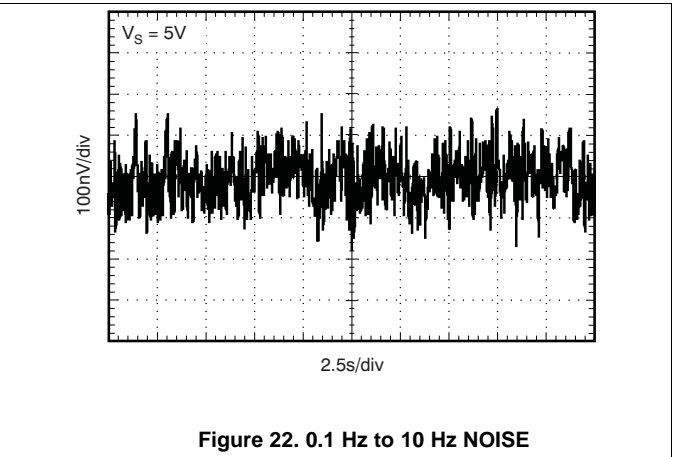


Figure 22. 0.1 Hz to 10 Hz NOISE

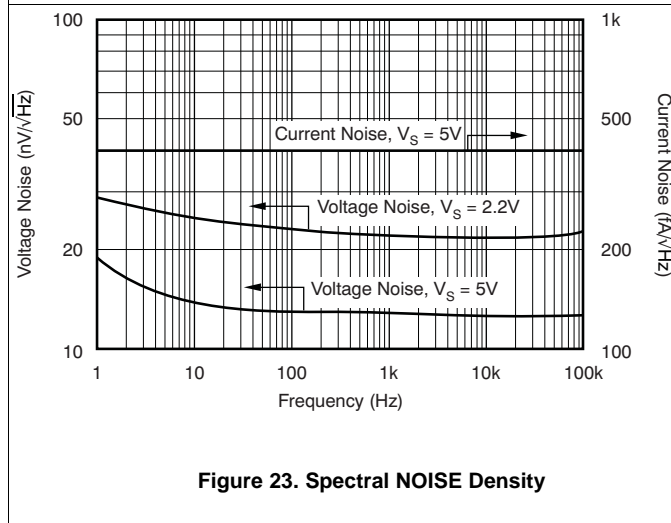


Figure 23. Spectral NOISE Density

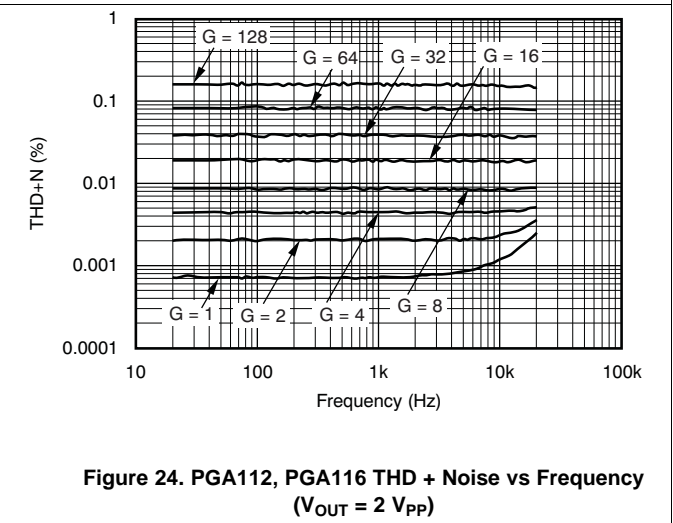


Figure 24. PGA112, PGA116 THD + Noise vs Frequency ($V_{OUT} = 2\text{ V}_{PP}$)

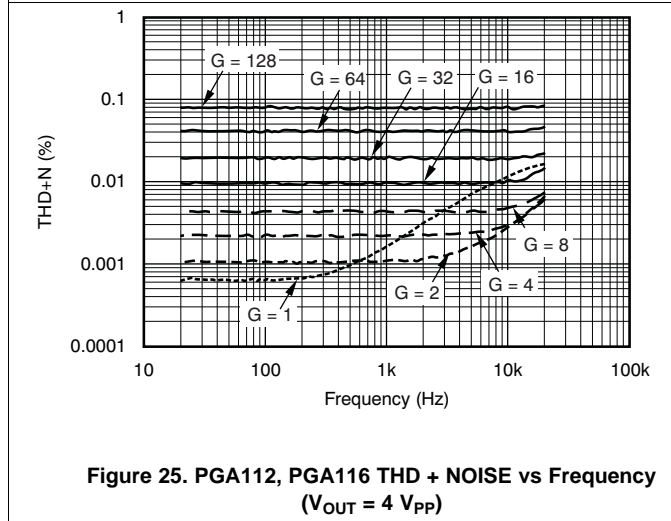


Figure 25. PGA112, PGA116 THD + NOISE vs Frequency ($V_{OUT} = 4\text{ V}_{PP}$)

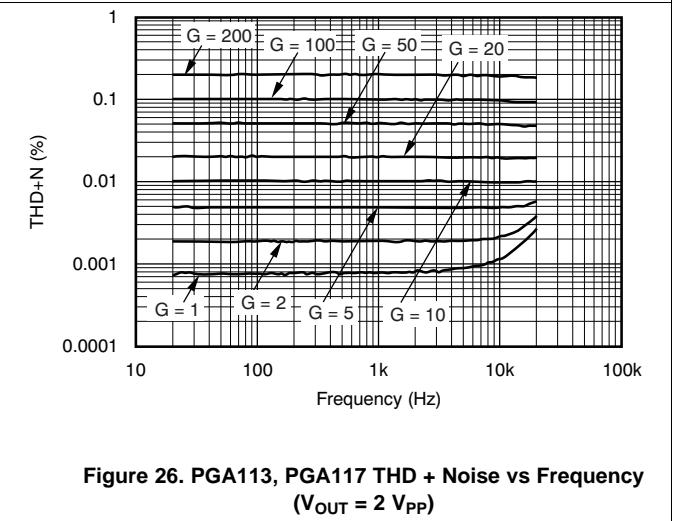


Figure 26. PGA113, PGA117 THD + Noise vs Frequency ($V_{OUT} = 2\text{ V}_{PP}$)

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $AV_{DD} = DV_{DD} = 5\text{ V}$, $R_L = 10\text{ k}\Omega$ connected to $DV_{DD}/2$, $V_{REF} = \text{GND}$, and $C_L = 100\text{ pF}$, unless otherwise noted.

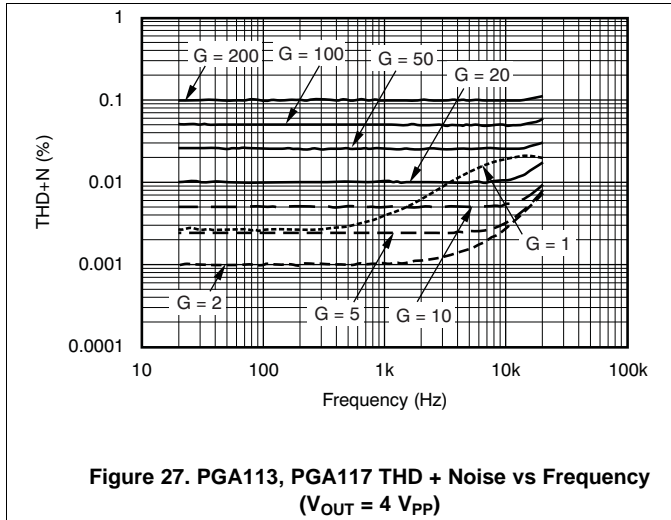


Figure 27. PGA113, PGA117 THD + Noise vs Frequency ($V_{OUT} = 4\text{ V}_{PP}$)

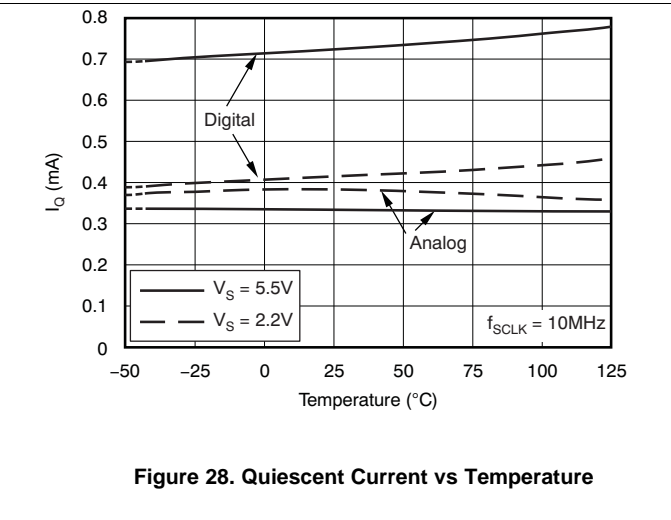


Figure 28. Quiescent Current vs Temperature

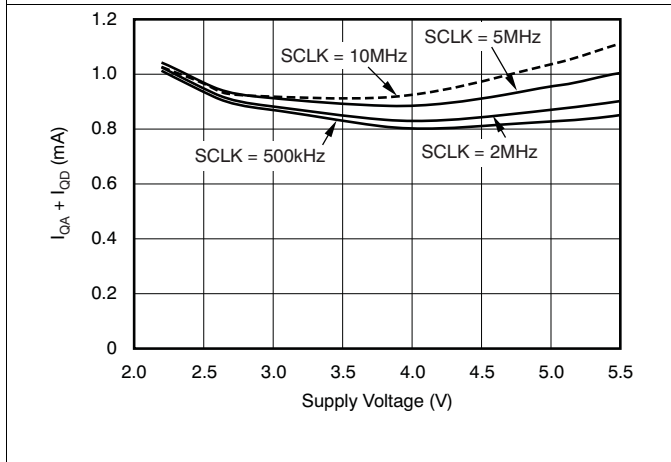


Figure 29. Total Quiescent Current vs Supply Voltage

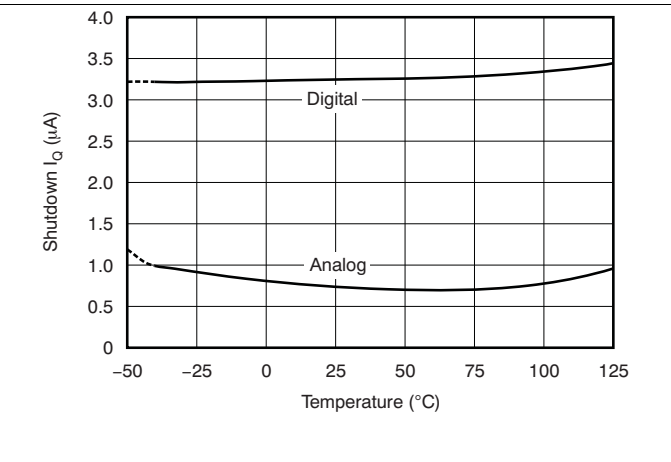


Figure 30. Shutdown Quiescent Current vs Temperature

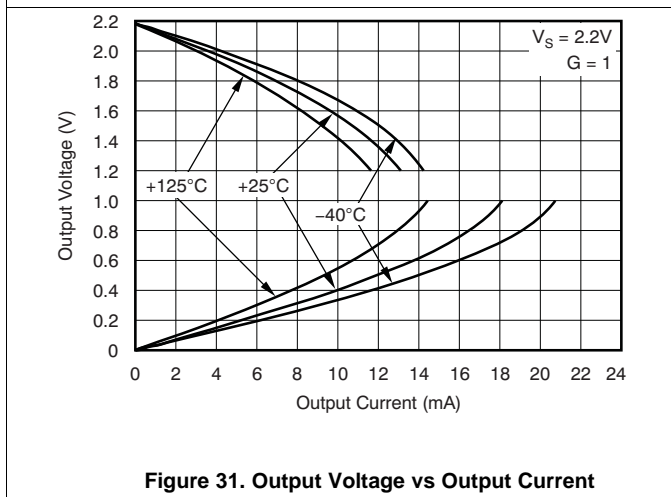


Figure 31. Output Voltage vs Output Current

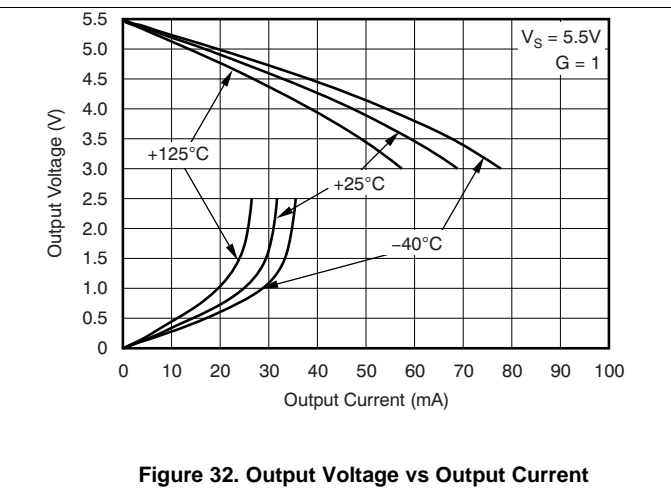


Figure 32. Output Voltage vs Output Current

PGA112, PGA113, PGA116, PGA117

SBOS424C – MARCH 2008 – REVISED NOVEMBER 2015

www.ti.com

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $A_{V_{DD}} = DV_{DD} = 5\text{ V}$, $R_L = 10\text{ k}\Omega$ connected to $DV_{DD}/2$, $V_{REF} = \text{GND}$, and $C_L = 100\text{ pF}$, unless otherwise noted.

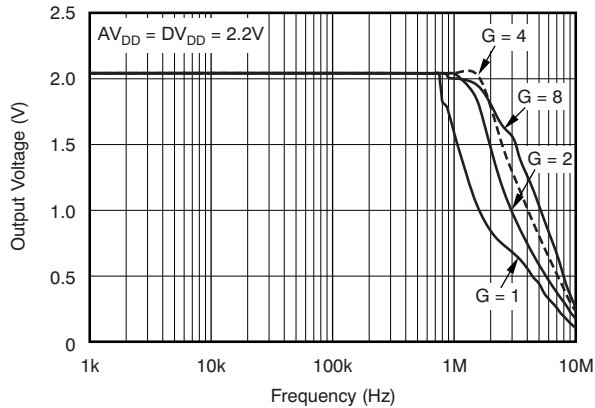


Figure 33. PGA112, PGA116 Output Voltage Swing vs Frequency

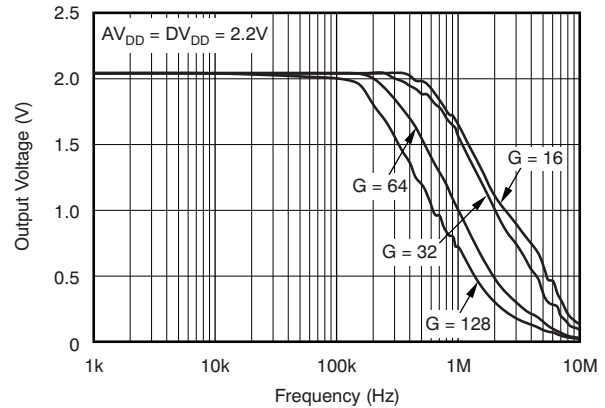


Figure 34. PGA112, PGA116 Output Voltage Swing vs Frequency

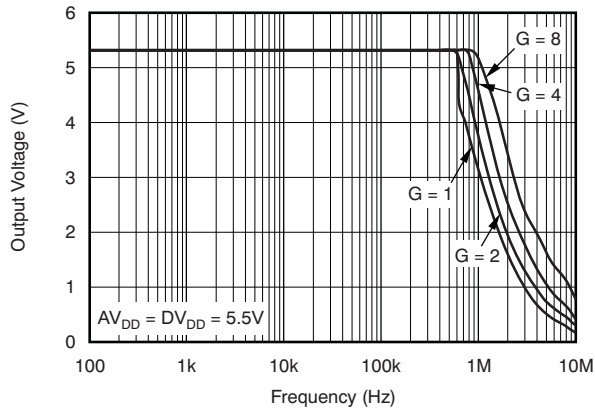


Figure 35. PGA112, PGA116 Output Voltage Swing vs Frequency

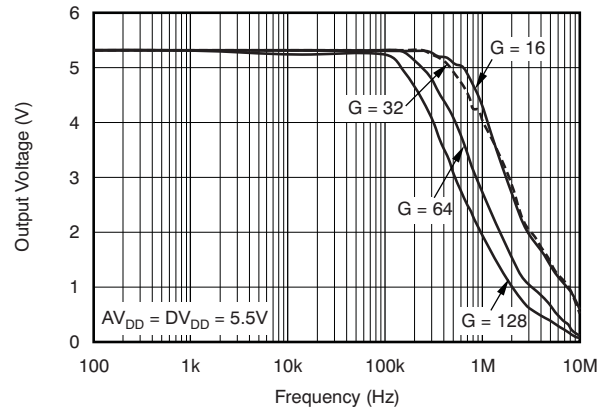


Figure 36. PGA112, PGA116 Output Voltage Swing vs Frequency

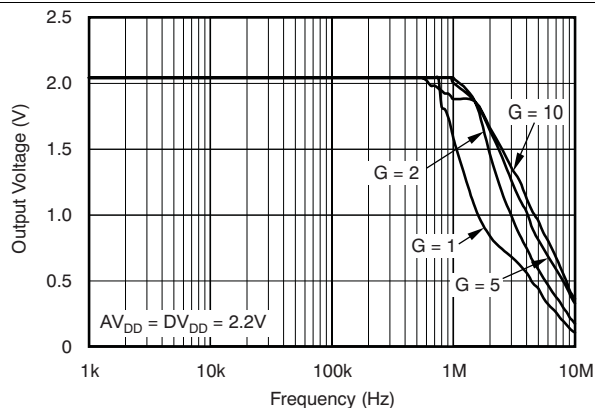


Figure 37. PGA113, PGA117 Output Voltage Swing vs Frequency

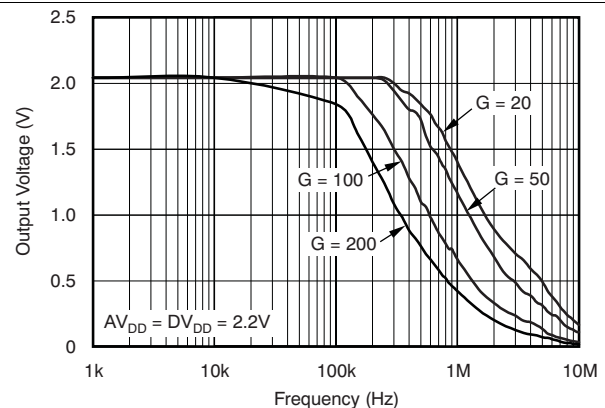


Figure 38. PGA113, PGA117 Output Voltage Swing vs Frequency

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $AV_{DD} = DV_{DD} = 5\text{ V}$, $R_L = 10\text{ k}\Omega$ connected to $DV_{DD}/2$, $V_{REF} = \text{GND}$, and $C_L = 100\text{ pF}$, unless otherwise noted.

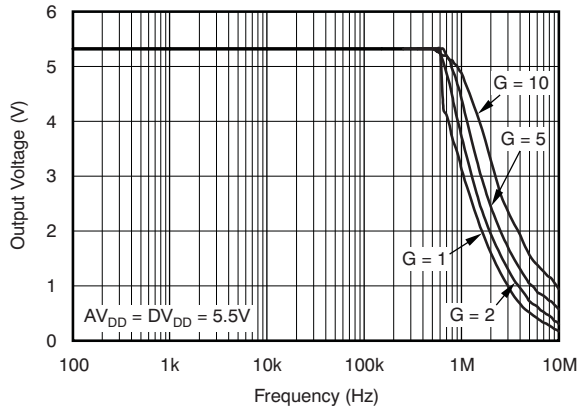


Figure 39. PGA113, PGA117 Output Voltage Swing vs Frequency

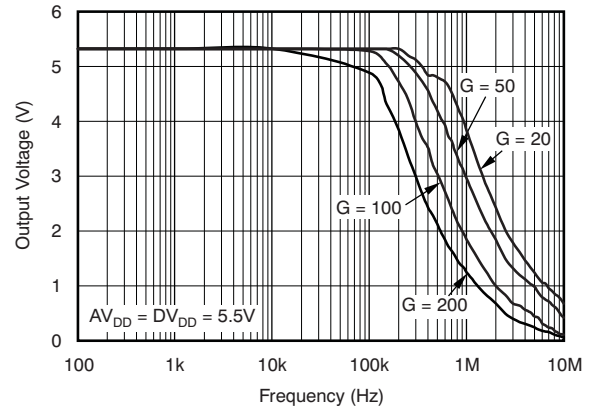


Figure 40. PGA113, PGA117 Output Voltage Swing vs Frequency

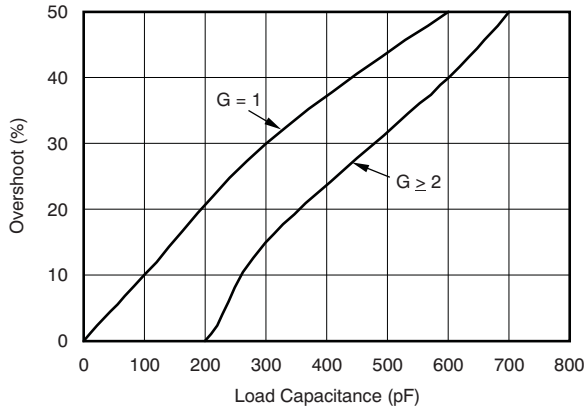


Figure 41. Small-Signal Overshoot vs Load Capacitance

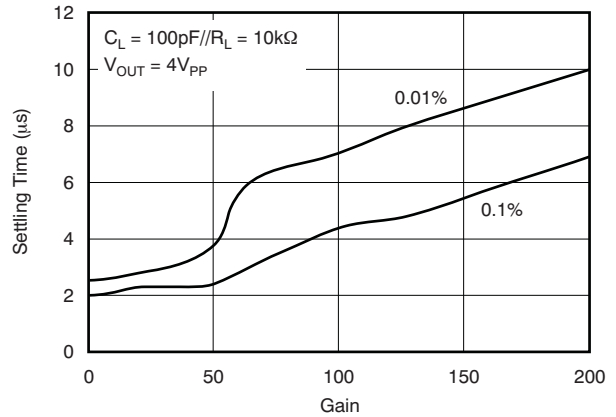


Figure 42. Gain vs Settling Time

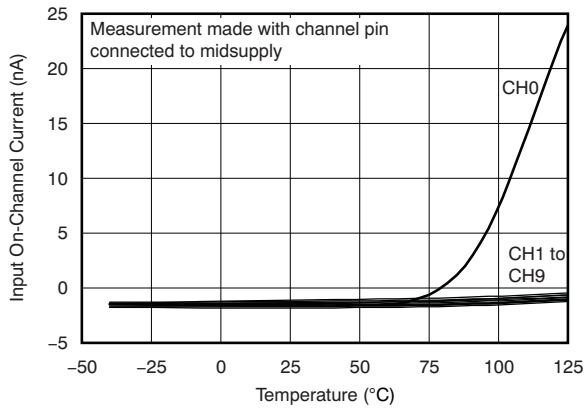


Figure 43. Input ON-Channel Current vs Temperature

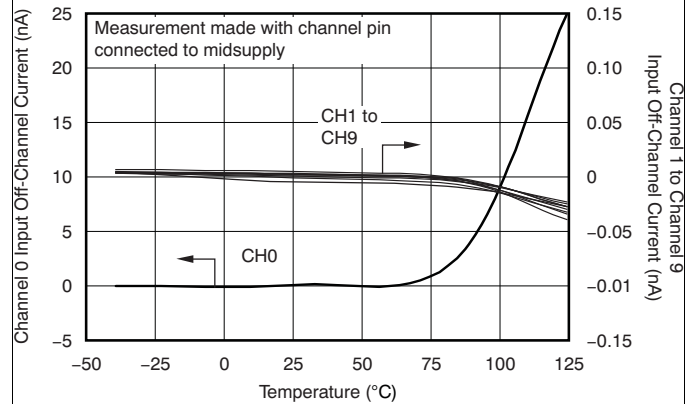


Figure 44. Input OFF-Channel Leakage Current vs Temperature

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_{DD} = DV_{DD} = 5\text{ V}$, $R_L = 10\text{ k}\Omega$ connected to $DV_{DD}/2$, $V_{REF} = \text{GND}$, and $C_L = 100\text{ pF}$, unless otherwise noted.

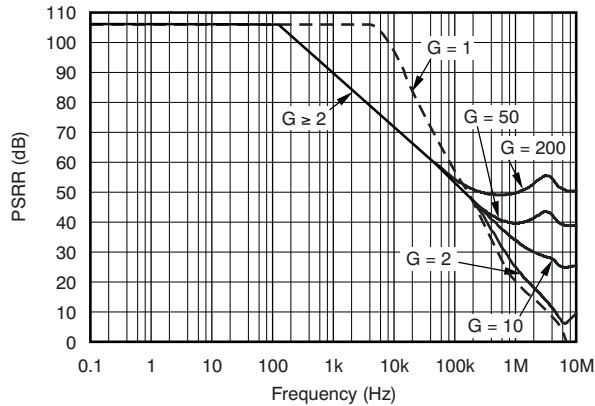


Figure 45. Power-Supply Rejection Ratio vs Frequency

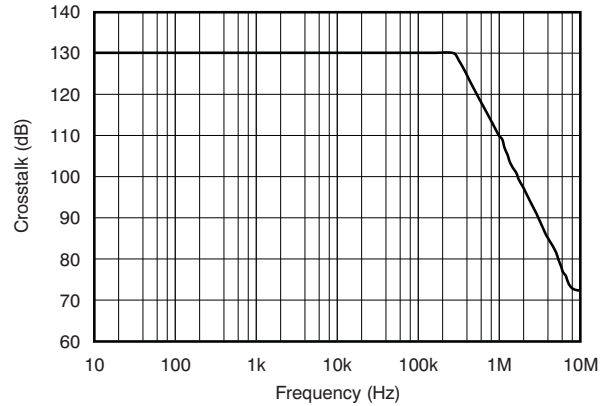


Figure 46. Crosstalk vs Frequency

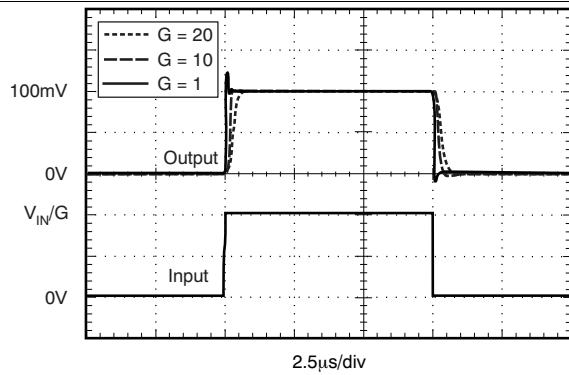


Figure 47. Small-Signal Pulse Response

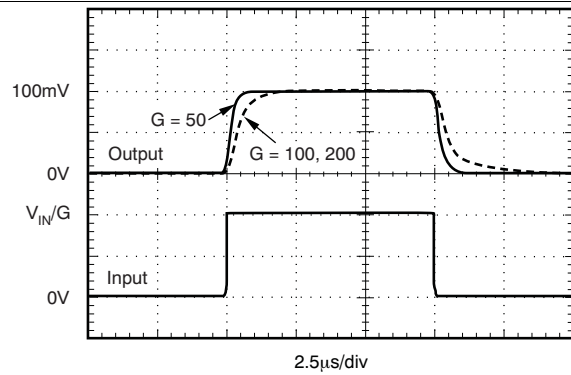


Figure 48. Small-Signal Pulse Response

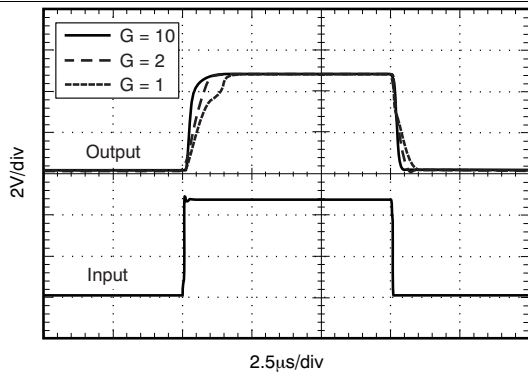


Figure 49. Large-Signal Pulse Response

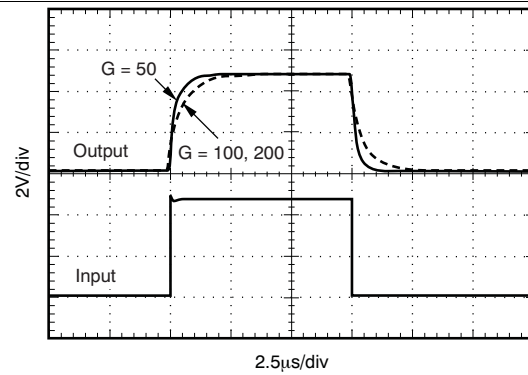
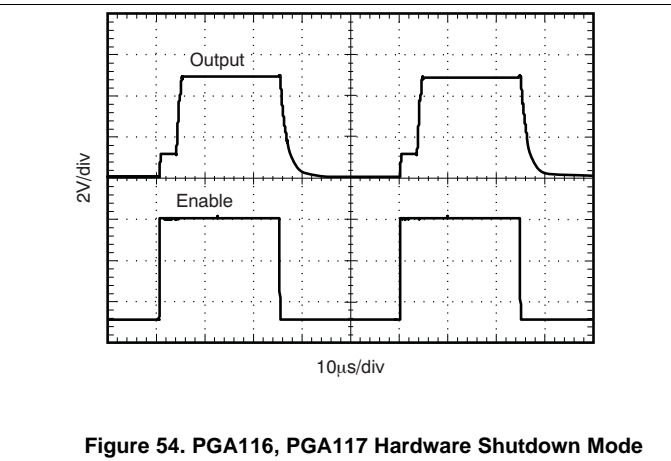
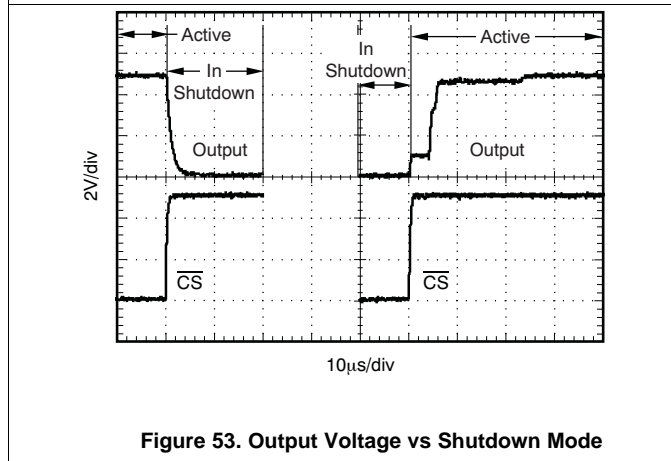
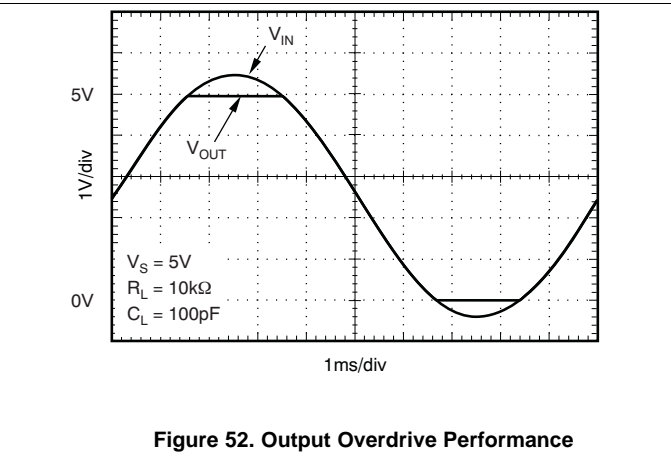
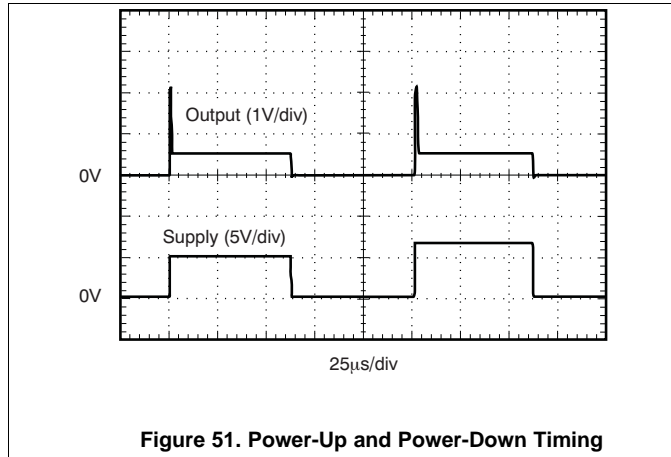


Figure 50. Large-Signal Pulse Response

Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $AV_{DD} = DV_{DD} = 5\text{ V}$, $R_L = 10\text{ k}\Omega$ connected to $DV_{DD}/2$, $V_{REF} = \text{GND}$, and $C_L = 100\text{ pF}$, unless otherwise noted.



8 Detailed Description

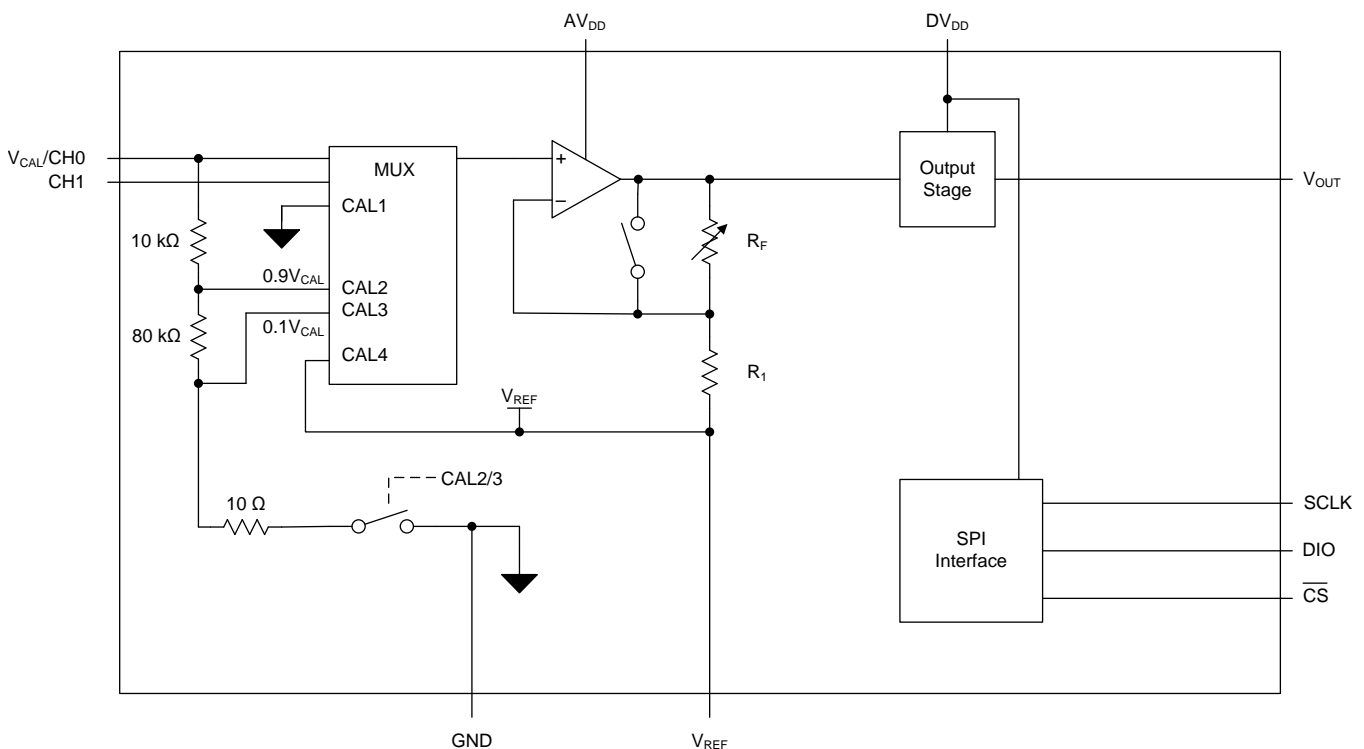
8.1 Overview

The PGA112 and PGA113 devices (binary and scope gains) offer two analog inputs, a three-pin SPI interface, and software shutdown in an 10-pin VSSOP package. The PGA116 and PGA117 (binary and scope gains) offer 10 analog inputs, and hardware and software shutdown in a 20-pin TSSOP package.

All versions provide internal calibration channels for system-level calibration. The channels are tied to GND, $0.9V_{CAL}$, $0.1V_{CAL}$, and V_{REF} , respectively. V_{CAL} , an external voltage connected to Channel 0, is used as the system calibration reference. Binary gains are: 1, 2, 4, 8, 16, 32, 64, and 128; scope gains are: 1, 2, 5, 10, 20, 50, 100, and 200.

The PGA uses a SPI interface with daisy-chain capability, a standard serial peripheral interface (SPI). Both SPI Mode 0,0 and Mode 1,1 are supported, as shown in [Figure 56](#) and described in [Table 2](#).

8.2 Functional Block Diagram



8.3 Feature Description

Featuring low offset, low offset drift and low noise, the PGA11x series provides a flexible analog building block for a variety of applications. The PGA112 and PGA116 offer binary gains of 1, 2, 4, 8, 16, 32, 64, 128 and a 2 channel MUX while the PGA113 and PGA117 offer scope gains of 1, 2, 5, 10, 20, 50, 100, 200 and a 10 channel MUX.

8.4 Device Functional Modes

The PGA112 and PGA113 devices have a software shutdown mode, and the PGA116 and PGA117 devices offer both a hardware and software shutdown mode, see [Shutdown and Power-On-Reset \(POR\)](#) for additional information. The PGA uses a standard serial peripheral interface (SPI). Both SPI Mode 0,0 and Mode 1,1 are supported. More information regarding serial communications, including daisy chaining can be found in [Serial Interface Information](#).

8.5 Programming

Table 1. Frequency Response Versus Gain ($C_L = 100$ pf, $R_L = 10$ kW)

BINARY GAIN (V/V)	TYPICAL -3-dB FREQUENCY (MHz)	SLEW RATE-FALL (V/ μ s)	SLEW RATE-RISE (V/ μ s)	0.1% SETTling TIME: $4 V_{PP}$ (μ s)	0.01% SETTling TIME: $4 V_{PP}$ (μ s)	SCOPE GAIN (V/V)	TYPICAL -3-dB FREQUENCY (MHz)	SLEW RATE-FALL (V/ μ s)	SLEW RATE-RISE (V/ μ s)	0.1% SETTling TIME: $4 V_{PP}$ (μ s)	0.01% SETTling TIME: $4 V_{PP}$ (μ s)
1	10	8	3	2	2.55	1	10	8	3	2	2.55
2	3.8	9	6.4	2	2.6	2	3.8	9	6.4	2	2.6
4	2	12.8	10.6	2	2.6	5	1.8	12.8	10.6	2	2.6
8	1.8	12.8	10.6	2	2.6	10	1.8	12.8	10.6	2.2	2.6
16	1.6	12.8	12.8	2.3	2.6	20	1.3	12.8	9.1	2.3	2.8
32	1.8	12.8	13.3	2.3	3	50	0.9	9.1	7.1	2.4	3.8
64	0.6	4	3.5	3	6	100	0.38	4	3.5	4.4	7
128	0.35	2.5	2.5	4.8	8	200	0.23	2.3	2	6.9	10

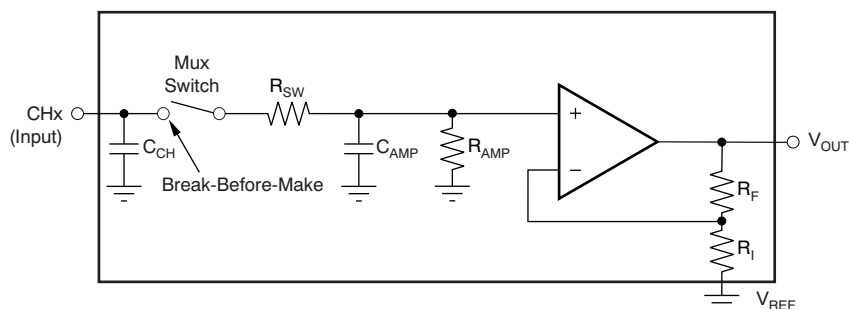


Figure 55. Equivalent Input Circuit

8.6 Serial Interface Information

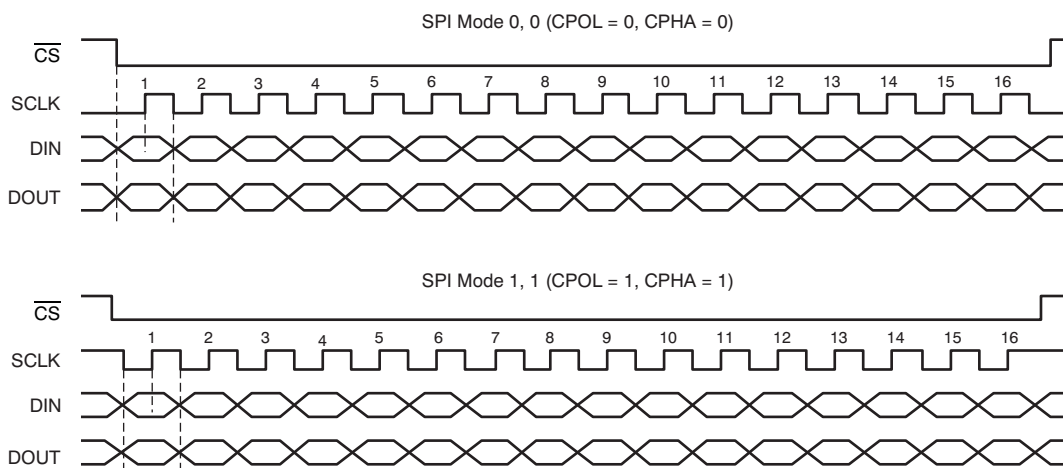


Figure 56. SPI Mode 0,0 And Mode 1,1

Serial Interface Information (continued)

Table 2. SPI Mode Setting Description

MODE	CPOL	CPHA	CPOL DESCRIPTION	CPHA DESCRIPTION
0, 0	0	0 ⁽¹⁾	Clock idles low	Data are read on the rising edge of clock. Data change on the falling edge of clock.
1, 1	1	1 ⁽²⁾	Clock idles high	Data are read on the rising edge of clock. Data change on the falling edge of clock.

- (1) CPHA = 0 means sample on first clock edge (rising or falling) after a valid \overline{CS} .
- (2) CPHA = 1 means sample on second clock edge (rising or falling) after a valid \overline{CS} .

8.6.1 Serial Digital Interface: SPI Modes

The PGA uses a standard serial peripheral interface (SPI). Both SPI Mode 0,0 and Mode 1,1 are supported, as shown in Figure 56 and described in Table 2.

If there are not even-numbered increments of 16 clocks (that is, 16, 32, 64, and so forth) between \overline{CS} going low (falling edge) and \overline{CS} going high (rising edge), the device takes no action. This condition provides reliable serial communication. Furthermore, this condition also provides a way to quickly reset the SPI interface to a known starting condition for data synchronization. Transmitted data are latched internally on the rising edge of \overline{CS} .

On the PGA116 and PGA117 devices, \overline{CS} , DIN, and SCLK are Schmitt-triggered CMOS logic inputs. DIN has a weak internal pulldown to support daisy-chain communications on the PGA116 and PGA117 devices. DOUT is a CMOS logic output. When \overline{CS} is high, the state of DOUT is high-impedance. When \overline{CS} is low, DOUT is driven as illustrated in Figure 57.

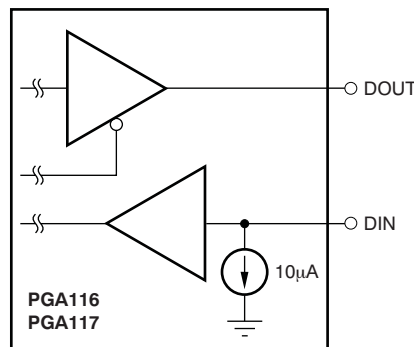


Figure 57. Digital I/O Structure—PGA116 and PGA117

On the PGA112 and PGA113 devices, there are digital output and digital input gates both internally connected to the DIO pin. DIN is an input-only gate and DOUT is a digital output that can give a 3-state output. The DIO pin has a weak 10-µA pulldown current source to prevent the pin from floating in systems with a high-impedance SPI DOUT line. When \overline{CS} is high, the state of the internal DOUT gate is high-impedance. When \overline{CS} is low, the state of DIO depends on the previous valid SPI communication; either DIO becomes an output to clock out data or it remains an input to receive data. This structure is shown in Figure 58.

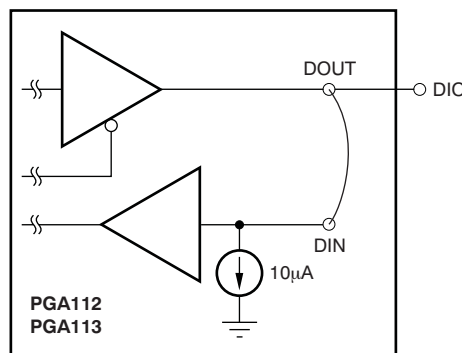


Figure 58. Digital I/O Structure—PGA112 and PGA113

8.6.2 Serial Digital Interface: SPI Daisy-Chain Communications

To reduce the number of I/O port pins used on a microcontroller, the PGA116 and PGA117 support SPI daisy-chain communications with full read and write capability. A two-device daisy-chain configuration is shown in [Figure 59](#), although any number of devices can be daisy-chained. The SPI daisy-chain communication uses a common SCLK and $\overline{\text{CS}}$ line for all devices in the daisy chain, rather than each device requiring a separate $\overline{\text{CS}}$ line. The daisy-chain mode of communication routes data serially through each device in the chain by using its respective DIN and DOUT pins as shown. Special commands are used (see [Table 4](#)) to ensure that data are written or read in the proper sequence. There is a special daisy-chain NOP command (No Operation) which, when presented to the desired device in the daisy-chain, causes no changes in that respective device. Detailed timing diagrams for daisy-chain operation are shown in [Figure 63](#) through [Figure 65](#).

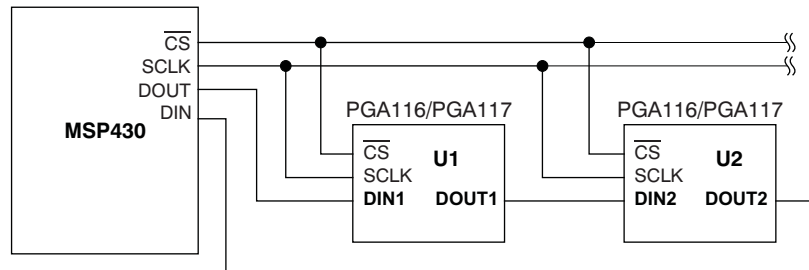


Figure 59. Daisy-Chain Read and Write Configuration

The PGA112 and PGA113 devices can be used as the last device in a daisy-chain as shown in [Figure 60](#) if *write-only* communication is acceptable, because the PGA112 and PGA113 devices have no separate DOUT pin to connect back to the microcontroller DIN pin to read back data in this configuration.

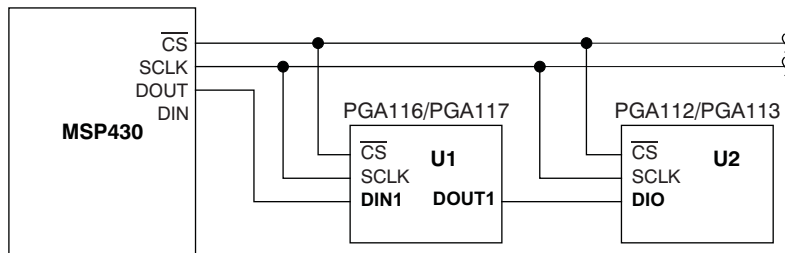


Figure 60. Daisy-Chain Write-Only Configuration

The maximum SCLK frequency that can be used in daisy-chain operation is directly related to SCLK rise and fall times, DIN setup time, and DOUT propagation delay. Any number of two or more devices have the same limitations because it is the timing considerations between adjacent devices that limit the clock speed.

[Figure 61](#) analyzes the maximum SCLK frequency for daisy-chain mode based on the circuit of [Figure 59](#). A clock rise and fall time of 10 ns is assumed to allow for extra bus capacitance that could occur as a result of multiple devices in the daisy-chain.

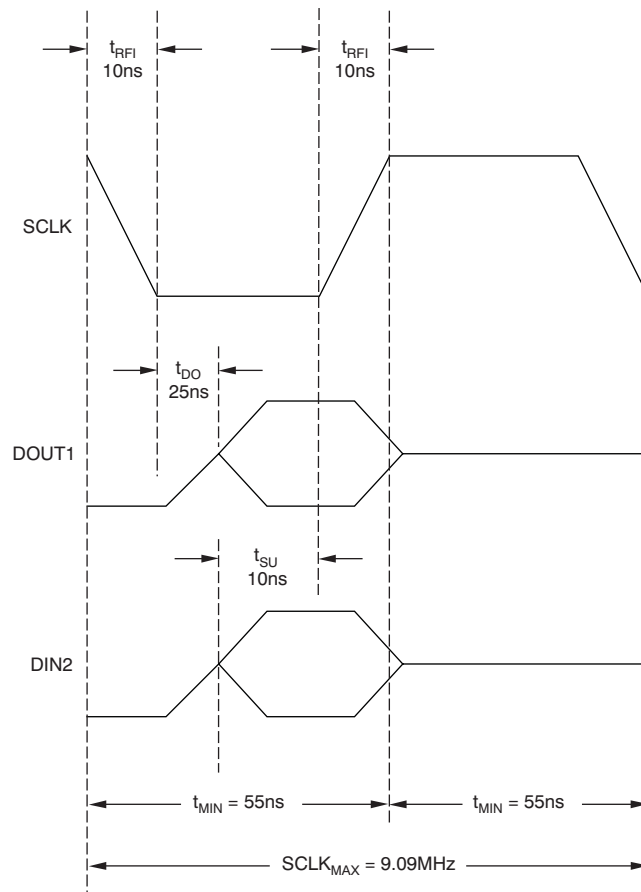


Figure 61. Daisy-Chain Maximum SCLK Frequency

8.6.3 SPI Serial Interface

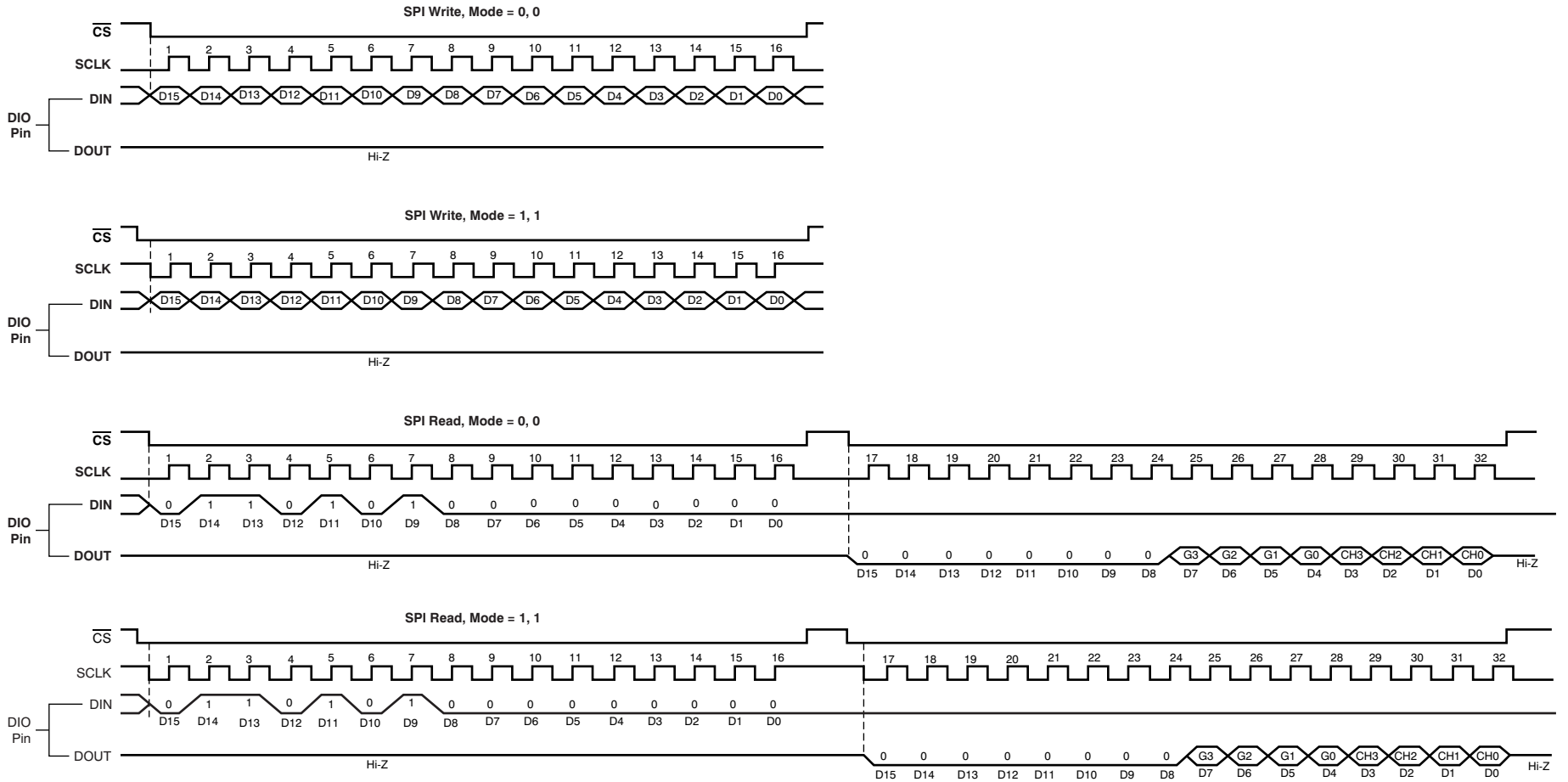


Figure 62. SPI Serial Interface Timing Diagrams

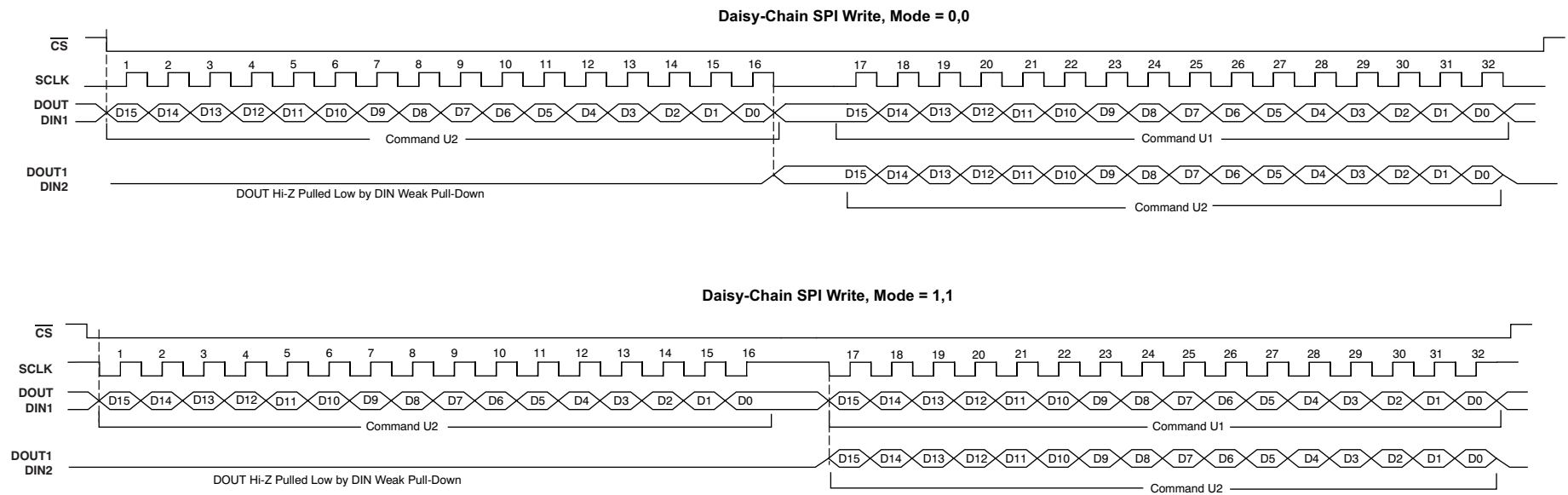
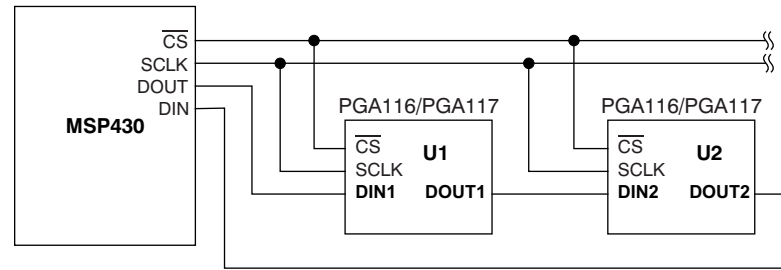


Figure 63. SPI Daisy-Chain Write Timing Diagrams

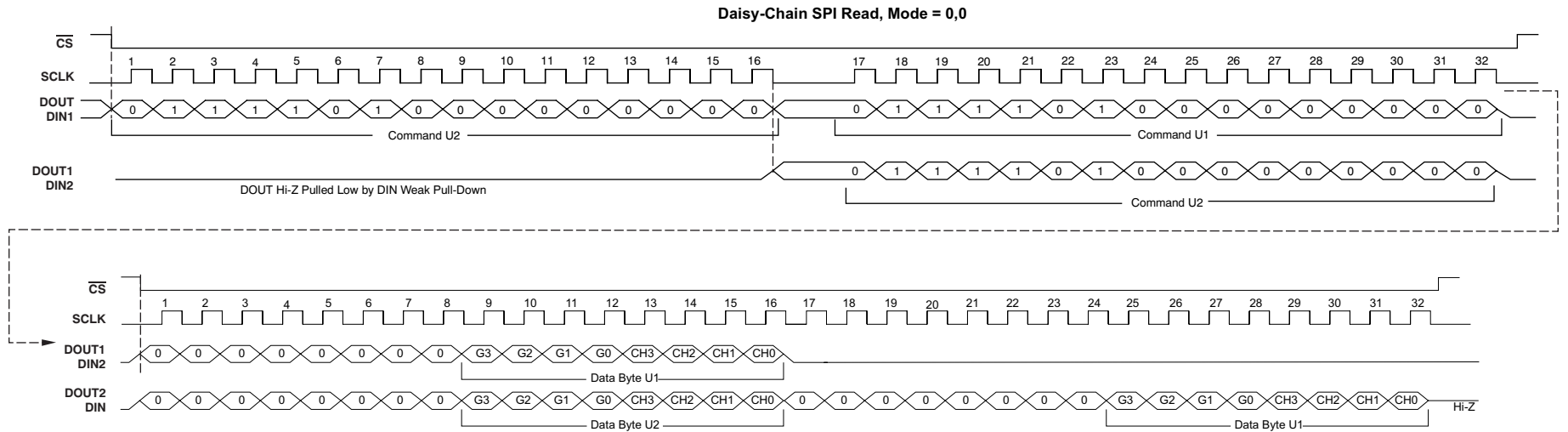
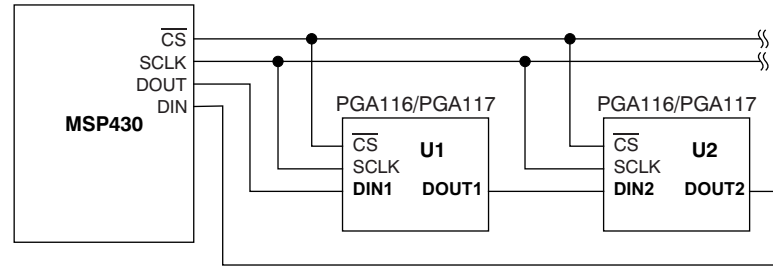


Figure 64. SPI Daisy-Chain Read Timing Diagram (Mode 0,0)

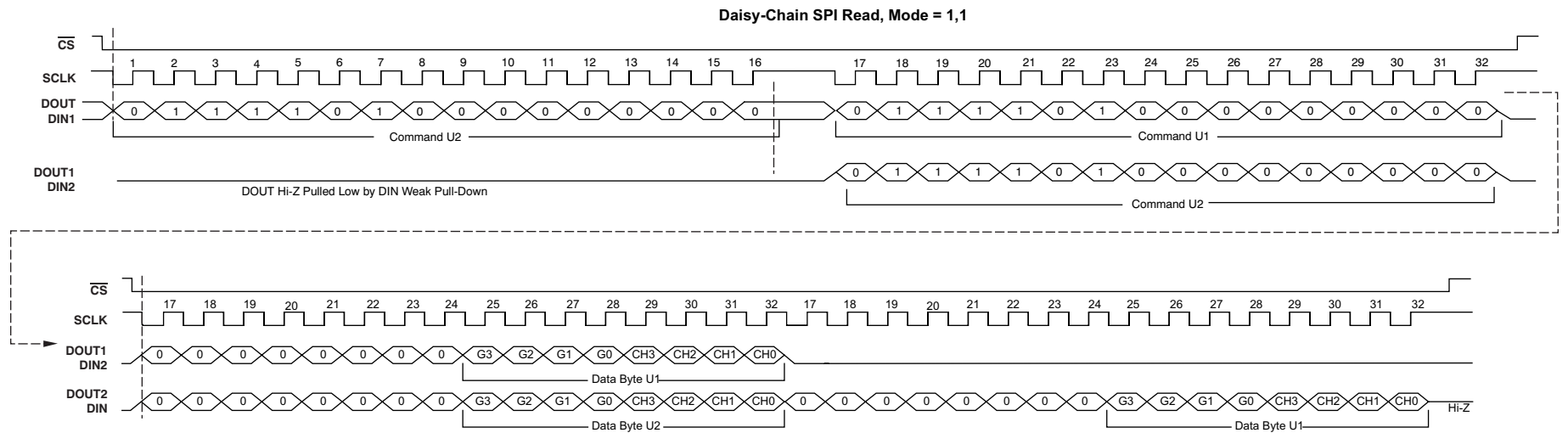
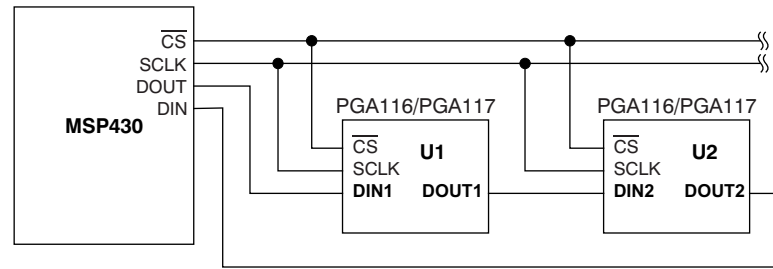


Figure 65. SPI Daisy-Chain Read Timing Diagram (Mode 1,1)

8.6.4 SPI Commands

Table 3. SPI Commands (PGA112 and PGA113)⁽¹⁾⁽²⁾

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	THREE-WIRE SPI COMMAND
0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	READ
0	0	1	0	1	0	1	0	G3	G2	G1	G0	CH3	CH2	CH1	CH0	WRITE
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NOP WRITE
1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	SDN_DIS WRITE
1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	1	SDN_EN WRITE

- (1) SDN = Shutdown mode. Enter Shutdown mode by issuing an SDN_EN command. Shutdown mode is cleared (returned to the last valid write configuration) by a SDN_DIS command or by any valid Write command.
- (2) POR (Power-on-Reset) value of internal Gain/Channel Select Register is all 0s; this value sets Gain = 1, and Channel = V_{CAL}/CH0.

Table 4. SPI Daisy-Chain Commands⁽¹⁾⁽²⁾

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	DAISY-CHAIN COMMAND
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	NOP
1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	SDN_DIS
1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	1	SDN_EN
0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	READ
0	0	1	1	1	0	1	0	G3	G2	G1	G0	CH3	CH2	CH1	CH0	WRITE

- (1) SDN = Shutdown Mode. Shutdown Mode is entered by an SDN_EN command. Shutdown Mode is cleared (returned to the last valid write configuration) by a SDN_DIS command or by any valid Write command.
- (2) POR (Power-on-Reset) value of internal Gain/Channel Register is all 0s; this value sets Gain = 1, V_{CAL}/CH0 selected.

Table 5. Gain Selection Bits (PGA112 and PGA113)

G3	G2	G1	G0	BINARY GAIN	SCOPE GAIN
0	0	0	0	1	1
0	0	0	1	2	2
0	0	1	0	4	5
0	0	1	1	8	10
0	1	0	0	16	20
0	1	0	1	32	50
0	1	1	0	64	100
0	1	1	1	128	200

Table 6. MUX Channel Selection Bits

CH3	CH2	CH1	CH0	PGA112, PGA113	PGA116, PGA117
0	0	0	0	VCAL/CH0	VCAL/CH0
0	0	0	1	CH1	CH1
0	0	1	0	X ⁽¹⁾	CH2
0	0	1	1	X	CH3
0	1	0	0	X	CH4
0	1	0	1	X	CH5
0	1	1	0	X	CH6
0	1	1	1	X	CH7
1	0	0	0	X	CH8
1	0	0	1	X	CH9
1	0	1	0	X	X ⁽¹⁾
1	0	1	1	Factory Reserved	Factory Reserved
1	1	0	0	CAL1 ⁽²⁾	CAL1 ⁽²⁾
1	1	0	1	CAL2 ⁽³⁾	CAL2 ⁽³⁾
1	1	1	0	CAL3 ⁽⁴⁾	CAL3 ⁽⁴⁾
1	1	1	1	CAL4 ⁽⁵⁾	CAL4 ⁽⁵⁾

- (1) X = channel is not used.
 (2) CAL1: connects to GND.
 (3) CAL2: connects to $0.9 V_{CAL}$.
 (4) CAL3: connects to $0.1 V_{CAL}$.
 (5) CAL4: connects to V_{REF} .

9 Applications 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. Customers should validate and test their design implementation to confirm system functionality.

9.1 Application Information

The PGA11x family of devices are single-ended input, single-supply, programmable gain amplifiers (PGAs) with an input multiplexer. Multiplexer channel selection and gain selection are done through a standard SPI interface. The PGA112 and PGA113 have a two-channel input MUX and the PGA116 and PGA117 devices have a 10-channel input MUX. The PGA112 and PGA116 devices provide binary gain selections (1, 2, 4, 8, 16, 32, 64, 128) and the PGA113 and PGA117 devices provide scope gain selections (1, 2, 5, 10, 20, 50, 100, 200). All models use a split-supply architecture with an analog supply, AV_{DD} , and a digital supply, DV_{DD} . This split-supply architecture allows for ease of interface to analog-to-digital converters (ADCs) and microcontrollers in mixed-supply voltage systems, such as where the analog supply is 5 V and the digital supply is 3 V. Four internal calibration channels are provided for system-level calibration. The channels are tied to GND, $0.9 V_{CAL}$, $0.1 V_{CAL}$, and V_{REF} , respectively. V_{CAL} , an external voltage connected to $V_{CAL}/CH0$, acts as the system calibration reference. If V_{CAL} is the system ADC reference, then gain and offset calibration on the ADC are easily accomplished through the PGA11x devices using only one MUX input. If calibration is not used, then $V_{CAL}/CH0$ can be used as a standard MUX input. All four versions provide a V_{REF} pin that can be tied to ground or, for ease of scaling, to midsupply in single-supply systems where midsupply is used as a virtual ground. The PGA112 and PGA113 devices offer a software-controlled shutdown feature for low standby power. The PGA116 and PGA117 devices offer both hardware- and software-controlled shutdown for low standby power. The PGA112 and PGA113 devices have a 3-wire SPI digital interface; the PGA116 and PGA117 devices have a four-wire SPI digital interface. The PGA116 and PGA117 devices also have daisy-chain capability.

9.1.1 Op Amp: Input Stage

The PGA op amp is a rail-to-rail input and output (RRIO) single-supply op amp. The input topology uses two separate input stages in parallel to achieve rail-to-rail input. As [Figure 66](#) shows, there is a PMOS transistor on each input for operation down to ground; there is also an NMOS transistor on each input in parallel for operation to the positive supply rail. When the common-mode input voltage (that is, the single-ended input, because this PGA is configured internally for noninverting gain) crosses a level that is typically about 1.5 V less than the positive supply, there is a transition between the NMOS and PMOS transistors. The result of this transition appears as a small input offset voltage transition that is reflected to the output by the selected PGA gain. This transition may be either increasing or decreasing, and differs from part to part as described in [Figure 67](#) and [Figure 68](#). These figures illustrate possible differences in input offset voltage between two different devices when used with $AV_{DD} = 5$ V. Because the exact transition region varies from device to device, the [Electrical Characteristics: \$V_S = AV_{DD} = DV_{DD} = 5\$ V](#) table specifies an input offset voltage above and below this input transition region.

Application Information (continued)

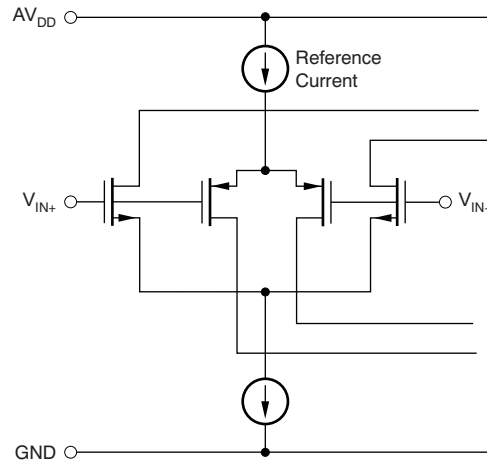


Figure 66. PGA Rail-To-Rail Input Stage

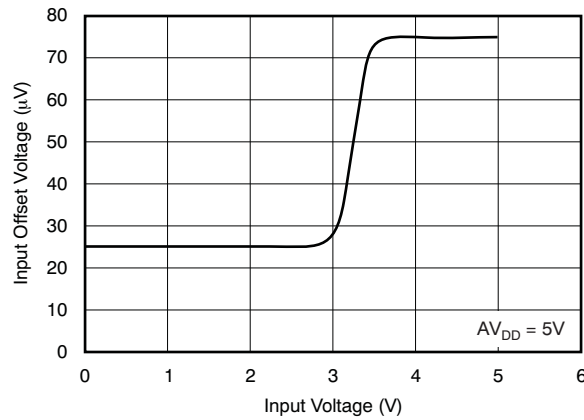


Figure 67. V_{OS} Versus Input Voltage—Case 1

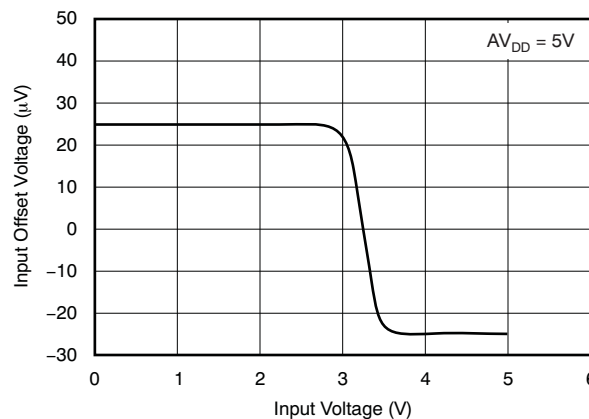


Figure 68. V_{OS} Versus Input Voltage—Case 2

9.1.2 Op Amp: General Gain Equations

Figure 69 shows the basic configuration for using the PGA as a gain block. V_{OUT} / V_{IN} is the selected noninverting gain, depending on the model selected, for either binary or scope gains.

Application Information (continued)

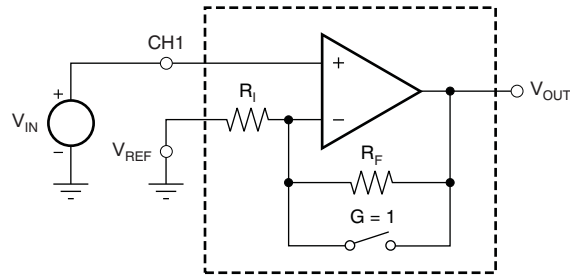


Figure 69. PGA Used as a Gain Block

$$V_{OUT} = G \times V_{IN}$$

where

- G = 1, 2, 4, 8, 16, 32, 64, and 128 (binary gains)
- G = 1, 2, 5, 10, 20, 50, 100, and 200 (scope gains) (1)

Figure 70 shows the PGA configuration and gain equations for $V_{REF} = AV_{DD}/2$. V_{OUT0} is V_{OUT} when CH0 is selected and V_{OUT1} is V_{OUT} when CH1 is selected. Notice the V_{REF} pin has no effect for $G = 1$ because the internal feedback resistor, R_F , is shorted out. This configuration allows for positive and negative voltage excursions around a midsupply virtual ground.

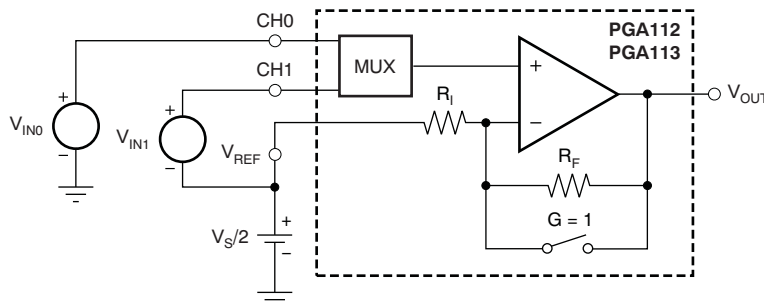


Figure 70. PGA112 and PGA113 Configuration for Positive and Negative Excursions Around Midsupply Virtual Ground

$$V_{OUT0} = G \times V_{IN0} - AV_{DD}/2 \times (G - 1) \quad (2)$$

When: $G = 1$

Then: $V_{OUT0} = G \times V_{IN0}$

$$V_{OUT1} = G \times (V_{IN1} + AV_{DD}/2) - AV_{DD}/2 \times (G - 1)$$

$$V_{OUT1} = G \times V_{IN1} + AV_{DD}/2, \text{ where: } -AV_{DD}/2 < G \times V_{IN1} < +AV_{DD}/2$$

where

- G = 1, 2, 4, 8, 16, 32, 64, and 128 (binary gains)
- G = 1, 2, 5, 10, 20, 50, 100, and 200 (scope gains) (3)

Table 7 details the internal typical values for the op amp internal feedback resistor (R_F) and op amp internal input resistor (R_I) for both binary and scope gains.

Application Information (continued)

Table 7. Typical R_F and R_I Versus Gain

BINARY GAIN (V/V)	R_F (Ω)	R_I (Ω)	SCOPE GAIN (V/V)	R_F (Ω)	R_I (Ω)
1	0	3.25 k	1	0	3.25 k
2	3.25 k	3.25 k	2	3.25 k	3.25 k
4	9.75 k	3.25 k	5	13 k	3.25 k
8	22.75 k	3.25 k	10	29.25 k	3.25 k
16	48.75 k	3.25 k	20	61.75 k	3.25 k
32	100.75 k	3.25 k	50	159.25 k	3.25 k
64	204.75 k	3.25 k	100	321.75 k	3.25 k
128	412.75 k	3.25 k	200	646.75 k	3.25 k

9.1.3 Op Amp: Frequency Response Versus Gain

Table 8 documents how small-signal bandwidth and slew rate change correspond to changes in PGA gain.

Full power bandwidth (that is, the highest frequency that a sine wave can pass through the PGA for a given gain) is related to slew rate by Equation 4:

$$SR (V/\mu s) = 2\pi f \times V_{OP} (1 \times 10^{-6})$$

where

- SR = Slew rate in V/ μ s
- f = Frequency in Hz
- V_{OP} = Output peak voltage in volts

(4)

9.1.3.1 Example:

For $G = 8$, then $SR = 10.6 V/\mu s$ (slew rate rise is minimum slew rate).

For a 5-V system, choose $0.1 V < V_{OUT} < 4.9 V$ or $V_{OUTPP} = 4.8 V$ or $V_{OUTP} = 2.4 V$.

$$SR (V/\mu s) = 2\pi f \times V_{OP} (1 \times 10^{-6}).$$

$$10.6 = 2\pi f (2.4) (1 \times 10^{-6}) \rightarrow f = 702.9 \text{ kHz}$$

This example shows that a $G = 8$ configuration can produce a 4.8- V_{PP} sine wave with frequency up to 702.9 kHz. This computation only shows the theoretical upper limit of frequency for this example, but does not indicate the distortion of the sine wave. The acceptable distortion depends on the specific application. As a general guideline, maintain two to three times the calculated slew rate to minimize distortion on the sine wave. For this example, the application should only use $G = 8$, 4.8 V_{PP} , up to a frequency range of 234 kHz to 351 kHz, depending upon the acceptable distortion. For a given gain and slew rate requirement, check for adequate small-signal bandwidth (typical -3-dB frequency) to assure that the frequency of the signal can be passed without attenuation.

9.1.4 Analog MUX

The analog input MUX provides two input channels for the PGA112 and PGA113 devices and 10 input channels for the PGA116 and PGA117 devices. The MUX switches are designed to be break-before-make and thereby eliminate any concerns about shorting the two input signal sources together.

Four internal MUX CAL channels are included in the analog MUX for ease of system calibration. These CAL channels allow ADC gain and offset errors to be calibrated out. This calibration does not remove the offset and gain errors of the PGA for gains greater than 1, but most systems should see a significant increase in the ADC accuracy. In addition, these CAL channels can be used by the ADC to read the minimum and maximum possible voltages from the PGA. With these minimum and maximum levels known, the system architecture can be designed to indicate an out-of-range condition on the measured analog input signals if these levels are ever measured.

To use the CAL channels, $V_{CAL}/CH0$ must be permanently connected to the system ADC reference. There is a typical 100-k Ω load from $V_{CAL}/CH0$ to ground. Table 9 illustrates how to use the CAL channels with $V_{REF} =$ ground. Table 10 describes how to use the CAL channels with $V_{REF} = AV_{DD}/2$. The V_{REF} pin must be connected to a source that is low-impedance for both DC and AC to maintain gain and nonlinearity accuracy. Worst-case current demand on the V_{REF} pin occurs when $G = 1$ because there is a 3.25-k Ω resistor between V_{OUT} and V_{REF} . For a 5-V system with $AV_{DD}/2 = 2.5$ V, the V_{REF} pin buffer must source and sink 2.5 V/3.25 k $\Omega = 0.7$ mA minimum for a V_{OUT} that can swing from ground to 5 V.

Table 8. Frequency Response versus Gain ($C_L = 100$ pf, $R_L = 10$ k ω)

BINARY GAIN (V/V)	TYPICAL -3dB FREQUENCY (MHz)	SLEW RATE-FALL (V/ μ s)	SLEW RATE-RISE (V/ μ s)	0.1% SETTLE TIME: 4V _{PP} (μ s)	0.01% SETTLE TIME: 4V _{PP} (μ s)	SCOPE GAIN (V/V)	TYPICAL -3dB FREQUENCY (MHz)	SLEW RATE-FALL (V/ μ s)	SLEW RATE-RISE (V/ μ s)	0.1% SETTLE TIME: 4V _{PP} (μ s)	0.01% SETTLE TIME: 4V _{PP} (μ s)
1	10	8	3	2	2.55	1	10	8	3	2	2.55
2	3.8	9	6.4	2	2.6	2	3.8	9	6.4	2	2.6
4	2	12.8	10.6	2	2.6	5	1.8	12.8	10.6	2	2.6
8	1.8	12.8	10.6	2	2.6	10	1.8	12.8	10.6	2.2	2.6
16	1.6	12.8	12.8	2.3	2.6	20	1.3	12.8	9.1	2.3	2.8
32	1.8	12.8	13.3	2.3	3	50	0.9	9.1	7.1	2.4	3.8
64	0.6	4	3.5	3	6	100	0.38	4	3.5	4.4	7
128	0.35	2.5	2.5	4.8	8	200	0.23	2.3	2	6.9	10

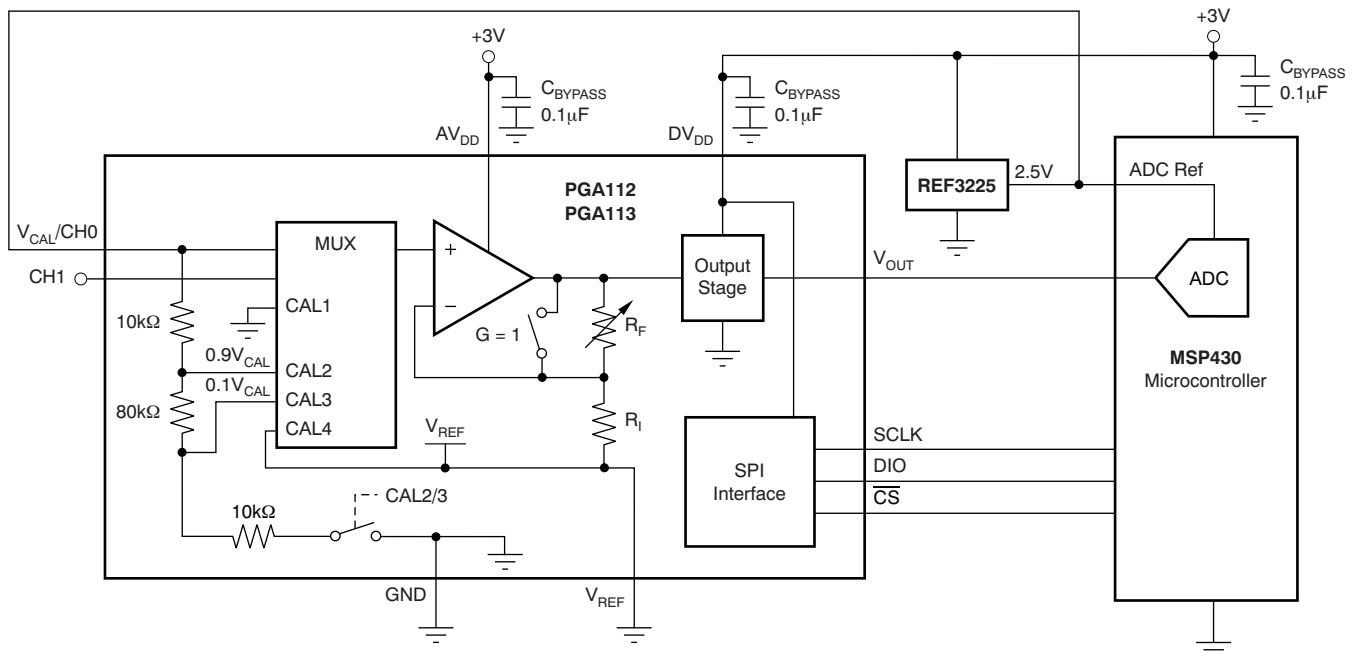
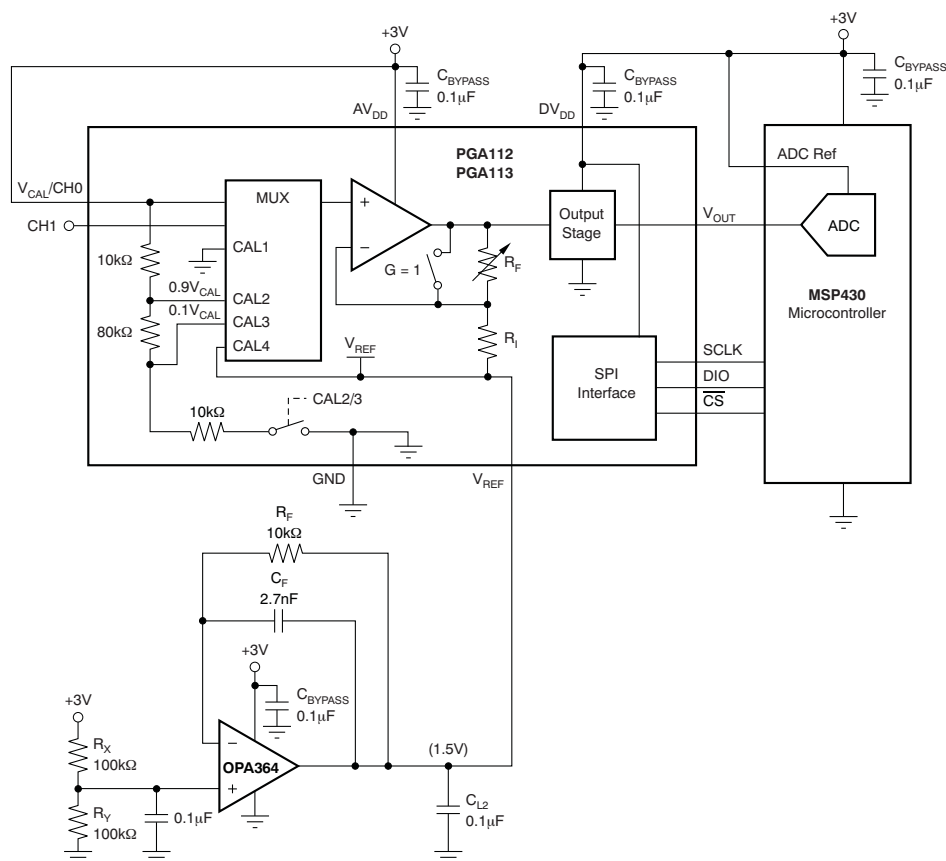


Figure 71. Using CAL Channels With $V_{REF} =$ Ground

**Table 9. Using the MUX CAL Channels With $V_{REF} = GND$
 ($AV_{DD} = 3V$, $DV_{DD} = 3V$, $ADC\ Ref = 2.5V$, and $V_{REF} = GND$)**

FUNCTION	MUX SELECT	GAIN SELECT	MUX INPUT	OP AMP (+In)	OP AMP (V_{OUT})	DESCRIPTION
Minimum Signal	CAL1	1	GND	GND	50 mV	Minimum signal level that the MUX, op amp, and ADC can read. Op amp V_{OUT} is limited by negative saturation.
Gain Calibration	CAL2	1	$0.9 \times (V_{CAL}/CH0)$	2.25 V	2.25 V	90% ADC Ref for system full-scale or gain calibration of the ADC.
Maximum Signal	CAL2	2	$0.9 \times (V_{CAL}/CH0)$	2.25 V	2.95 V	Maximum signal level that the MUX, op amp, and ADC can read. Op amp V_{OUT} is limited by positive saturation. System is limited by ADC max input of 2.5 V (ADC Ref = 2.5 V).
Offset Calibration	CAL3	1	$0.1 \times (V_{CAL}/CH0)$	0.25 V	0.25 V	10% ADC Ref for system offset calibration of the ADC.
Minimum Signal	CAL4	1	V_{REF}	GND	50 mV	Minimum signal level that the MUX, op amp, and ADC can read. Op amp V_{OUT} is limited by negative saturation.

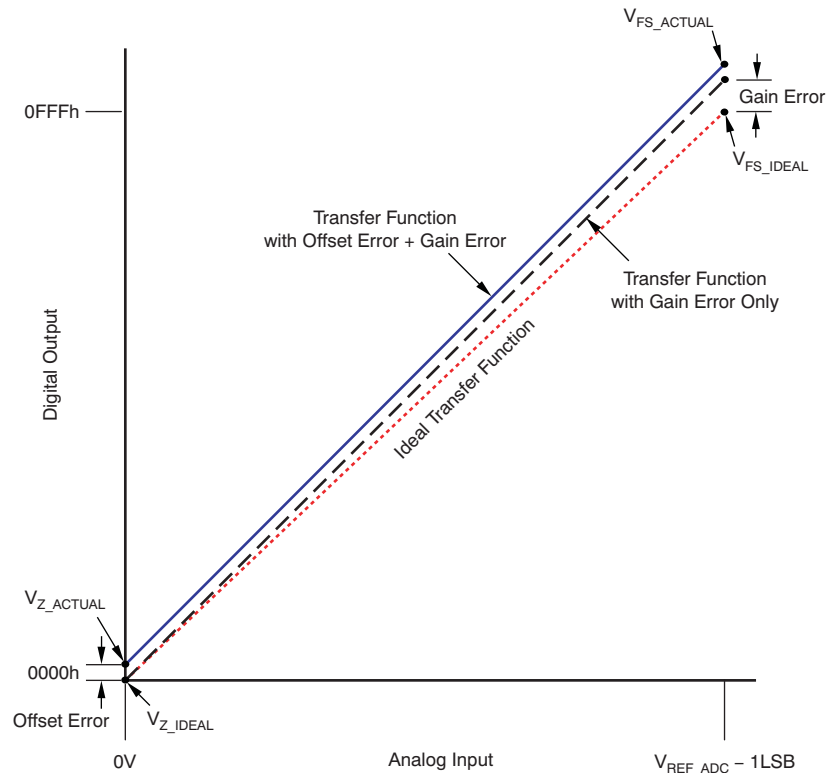

Figure 72. Using CAL Channels With $V_{REF} = AV_{DD}/2$
Table 10. Using the MUX CAL Channels With $V_{REF} = AV_{DD}/2$

**Table 10. Using the MUX CAL Channels With $V_{REF} = AV_{DD}/2$
($AV_{DD} = 3\text{ V}$, $DV_{DD} = 3\text{ V}$, $ADC\text{ Ref} = 3\text{ V}$, and $V_{REF} = 1.5\text{ V}$) (continued)
($AV_{DD} = 3\text{ V}$, $DV_{DD} = 3\text{ V}$, $ADC\text{ Ref} = 3\text{ V}$, and $V_{REF} = 1.5\text{ V}$)**

FUNCTION	MUX SELECT	GAIN SELECT	MUX INPUT	OP AMP (+In)	OP AMP (V _{OUT})	DESCRIPTION
Minimum Signal	CAL1	1	GND	GND	50 mV	Minimum signal level that the MUX, op amp, and ADC can read. Op amp V _{OUT} is limited by negative saturation.
Gain Calibration	CAL2	1	$0.9 \times (V_{CAL}/CHO)$	2.7 V	2.7 V	90% ADC Ref for system full-scale or gain calibration of the ADC.
Maximum Signal	CAL2	4 or 5	$0.9 \times (V_{CAL}/CHO)$	2.25 V	2.95 V	Maximum signal level that the MUX, op amp, and ADC can read. Op amp V _{OUT} is limited by positive saturation.
Offset Calibration	CAL3	1	$0.1 \times (V_{CAL}/CHO)$	0.3 V	0.3 V	10% ADC Ref for system offset calibration of the ADC.
V _{REF} Check	CAL4	1	V _{REF}	1.5 V	1.5 V	Midsupply voltage used as V _{REF} .

9.1.5 System Calibration Using The PGA

Analog-to-digital converters (ADCs) contain two major errors that can be easily removed by calibration at a system level. These errors are gain error and offset error, as shown in [Figure 73](#). [Figure 73](#) shows a typical transfer function for a 12-bit ADC. The analog input is on the x-axis with a range from 0 V to ($V_{REF_ADC} - 1\text{LSB}$), where V_{REF_ADC} is the ADC reference voltage. The y-axis is the hexadecimal equivalent of the digital codes that result from ADC conversions. The dotted red line represents an ideal transfer function with $0000h$ representing 0 V analog input and $0FFFh$ representing an analog input of ($V_{REF_ADC} - 1\text{LSB}$). The solid blue line illustrates the offset error. Although the solid blue line includes both offset error and gain error, at an analog input of 0 V the offset error voltage, V_{Z_ACTUAL} , can be measured. The dashed black line represents the transfer function with gain error. The dashed black line is equivalent to the solid blue line without the offset error, and can be measured and computed using V_{Z_ACTUAL} and V_{Z_IDEAL} . The difference between the dashed black line and the dotted red line is the gain error. Gain and offset error can be computed by taking zero input and full-scale input readings. Using these error calculations, compute a calibrated ADC reading to remove the ADC gain and offset error.


Figure 73. ADC Offset and Gain Error

In practice, the zero input (0 V) or full-scale input ($V_{REF_ADC} - 1LSB$) of ADCs cannot always be measured because of internal offset error and gain error. However, if measurements are made very close to the full-scale input and the zero input, both zero and full-scale can be calibrated very accurately with the assumption of linearity from the calibration points to the desired end points of the ADC ideal transfer function. For the zero calibration, choose $10\%V_{REF_ADC}$; this value should be above the internal offset error and sufficiently out of the noise floor range of the ADC. For the gain calibration, choose $90\%V_{REF_ADC}$; this value should be less than the internal gain error and sufficiently below the tolerance of V_{REF} . These key points can be summarized in this way:

For zero calibration:

- The ADC cannot read the ideal zero because of offset error
- Must be far enough above ground to be above noise floor and ADC offset error
- Therefore, choose $10\%V_{REF_ADC}$ for zero calibration

For gain calibration:

- The ADC cannot read the ideal full-scale because of gain error
- Must be far enough below full-scale to be below the V_{REF} tolerance and ADC gain error
- Therefore, choose $90\%V_{REF_ADC}$ for gain calibration

The 12-bit ADC example in [Figure 74](#) illustrates the technique for calibrating an ADC using a $10\%V_{REF_ADC}$ and $90\%V_{REF_ADC}$ reading where V_{REF_ADC} is the ADC reference voltage. The $10\%V_{REF}$ reading also contains a gain error because it is not a $V_{IN} = 0$ calibration point. First, use the $90\%V_{REF}$ and $10\%V_{REF}$ points to compute the measured gain error. The measured gain error is then used to remove the gain error from the $10\%V_{REF}$ reading, giving a measured $10\%V_{REF}$ number. The measured $10\%V_{REF}$ number is used to compute the measured offset error.

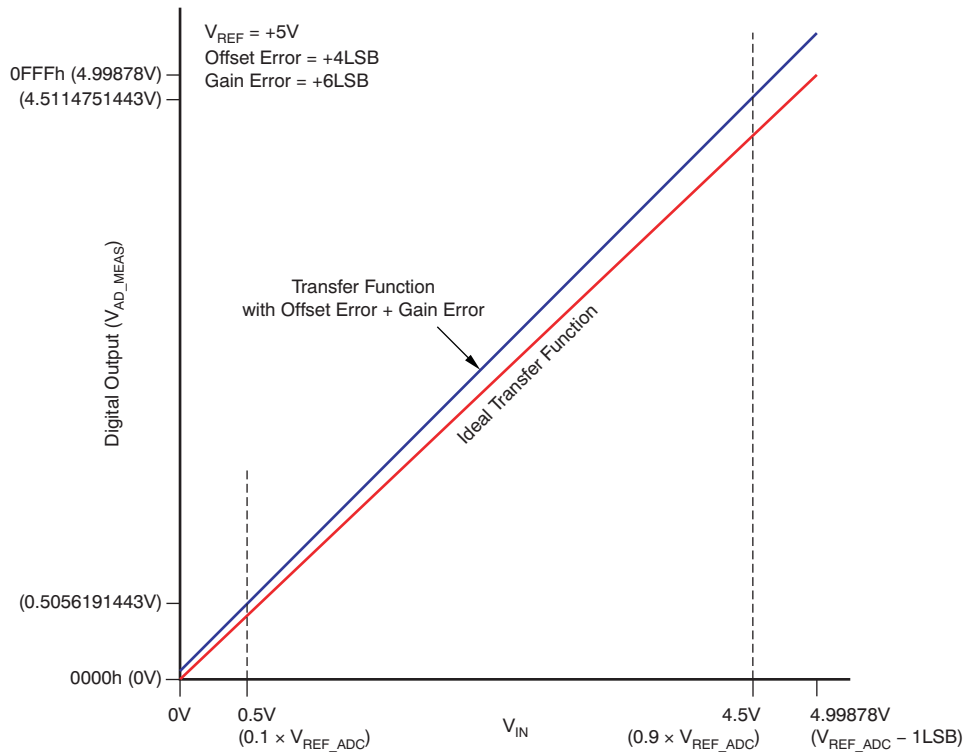


Figure 74. 12-Bit Example of ADC Calibration for Gain and Offset Error

The gain error and offset error in ADC readings can be calibrated by using $10\%V_{REF_ADC}$ and $90\%V_{REF_ADC}$ calibration points. Because the calibration is ratiometric to V_{REF_ADC} , the exact value of V_{REF_ADC} does not need to be known in the end application.

Follow these steps to compute a calibrated ADC reading:

1. Take the ADC reading at $V_{IN} = 90\% \times V_{REF}$ and $V_{IN} = 10\% \times V_{REF}$. The ADC readings for $10\%V_{REF}$ and $90\%V_{REF}$ are taken.

$$V_{REF90} = 0.9(V_{REF_ADC}) \tag{5}$$

$$V_{REF10} = 0.1(V_{REF_ADC}) \tag{6}$$

$$V_{MEAS90} = ADC_{MEASUREMENT} \text{ at } V_{REF90} \tag{7}$$

$$V_{MEAS10} = ADC_{MEASUREMENT} \text{ at } V_{REF10} \tag{8}$$

2. Compute the ADC measured gain. The slope of the curve connecting the measured $10\%V_{REF}$ and measured $90\%V_{REF}$ point is computed and compared to the slope between the ideal $10\%V_{REF}$ and ideal $90\%V_{REF}$. This result is the measured gain.

$$G_{MEAS} = \frac{V_{MEAS90} - V_{MEAS10}}{V_{REF90} - V_{REF10}} \tag{9}$$

3. Compute the ADC measured offset. The measured offset is computed by taking the difference between the measured $10\%V_{REF}$ and the $(\text{ideal } 10\%V_{REF}) \times (\text{measured gain})$.

$$O_{MEAS} = V_{MEAS10} - (V_{REF10} \times G_{MEAS}) \tag{10}$$

4. Compute the calibrated ADC readings.

$$V_{AD_MEAS} = \text{Any } V_{IN} \text{ ADC}_{MEASUREMENT} \tag{11}$$

$$V_{ADC_CAL} = \frac{V_{AD_MEAS} - O_{MEAS}}{G_{MEAS}} \tag{12}$$

Any ADC reading can therefore be calibrated by removing the gain error and offset error. The measured offset is subtracted from the ADC reading and then divided by the measured gain to give a corrected reading. If this calibration is performed on a timed basis, relative to the specific application, gain and offset error over temperature are also removed from the ADC reading by calibration.

For example; given:

- 12-Bit ADC
- ADC Gain Error = 6 LSB
- ADC Offset Error = 4 LSB
- ADC Reference (V_{REF_ADC}) = 5 V
- Temperature = 25°C

Table 11 shows the resulting system accuracy.

Table 11. Bits of System Accuracy⁽¹⁾ (To 0.5 LSB)

V_{IN}	ADC ACCURACY WITHOUT CALIBRATION	ADC ACCURACY WITH PGA112 CALIBRATION
10% V_{REF_ADC}	8.80 Bits	12.80 Bits
90% V_{REF_ADC}	7.77 Bits	11.06 Bits

(1) Difference in maximum input offset voltage for $V_{IN} = 10\%V_{REF_ADC}$ and $V_{IN} = 90\%V_{REF_ADC}$ is the reason for different accuracies.

9.1.6 Driving and Interfacing to ADCs

CDAC SAR ADCs contain an input sampling capacitor, C_{SH} , to sample the input signal during a sample period as shown in Figure 75. After the sample period, C_{SH} is removed from the input signal. Subsequent comparisons of the charge stored on C_{SH} are performed during the ADC conversion process. To achieve optimal op amp stability, input signal settling, and the demands for charge from the input signal conditioning circuitry, most ADC applications are optimized by the use of a resistor (R_{FILT}) and capacitor (C_{FILT}) filter placed between the op amp output and ADC input. For the PGA112 and PGA113 devices, or the PGA116 and PGA117 devices, setting $C_{FILT} = 1\text{ nF}$ and $R_{FILT} = 100\ \Omega$ yields optimum system performance for sampling converters operating at speeds up to 500 kHz, depending upon the application settling time and accuracy requirements.

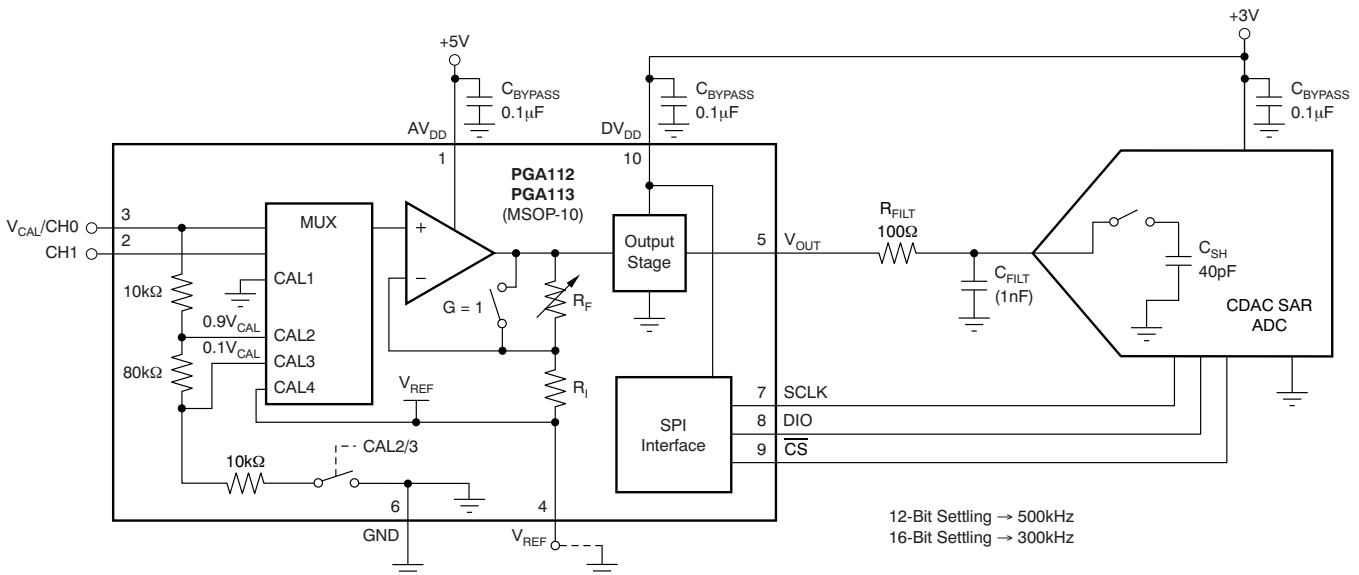


Figure 75. Driving and Interfacing to ADCs

9.1.7 Power Supplies

Figure 76 shows a typical mixed-supply voltage system where the analog supply, AV_{DD} , is 5 V and the digital supply voltage, DV_{DD} , is 3 V. The analog output stage of the PGA and the SPI interface digital circuitry are both powered from DV_{DD} . When considering the power required for DV_{DD} , use the *Electrical Characteristics: $V_S = AV_{DD} = DV_{DD} = 5 V$* table and add any load current anticipated on V_{OUT} ; this load current must be provided by DV_{DD} . This split-supply architecture ensures compatible logic levels with the microcontroller. It also ensures that the PGA output cannot run the input for the onboard ADC into an overvoltage condition; this condition could cause device latch-up and system lock-up, and require power-supply sequencing. Each supply pin should be individually bypassed with a 0.1 μF ceramic capacitor directly at the device to ground. If there is only one power supply in the system, AV_{DD} and DV_{DD} can both be connected to the same supply; however, TI recommends using individual bypass capacitors directly at each respective supply pin to a single point ground. V_{OUT} is diode-clamped to AV_{DD} (as shown in Figure 76); therefore, set DV_{DD} less than or equal to $AV_{DD} + 0.3 V$. DV_{DD} and AV_{DD} must be within the operating voltage range of 2.2 V to 5.5 V.

At initial power-on, the state of the PGA is $G = 1$ and Channel 0 active.

NOTE

For most applications, set $AV_{DD} \geq DV_{DD}$ to prevent V_{OUT} from driving current into AV_{DD} and raising the voltage level of AV_{DD}

9.1.8 Shutdown and Power-On-Reset (POR)

The PGA112 and PGA113 devices have a software shutdown mode, and the PGA116 and PGA117 devices offer both a hardware and software shutdown mode. When the PGA11x is shut down, it goes into a low-power standby mode. The *Electrical Characteristics: $V_S = AV_{DD} = DV_{DD} = 5 V$* table details the current draw in shutdown mode with and without the SPI interface being clocked. In shutdown mode, R_F and R_I remain connected between V_{OUT} and V_{REF} .

When DV_{DD} is less than 1.6 V, the digital interface is disabled and the channel and gain selections are held to the respective POR states of Gain = 1 and Channel = $V_{CAL}/CH0$. When DV_{DD} is above 1.8 V, the digital interface is enabled and the POR gain and channel states remain unchanged until a valid SPI communication is received.

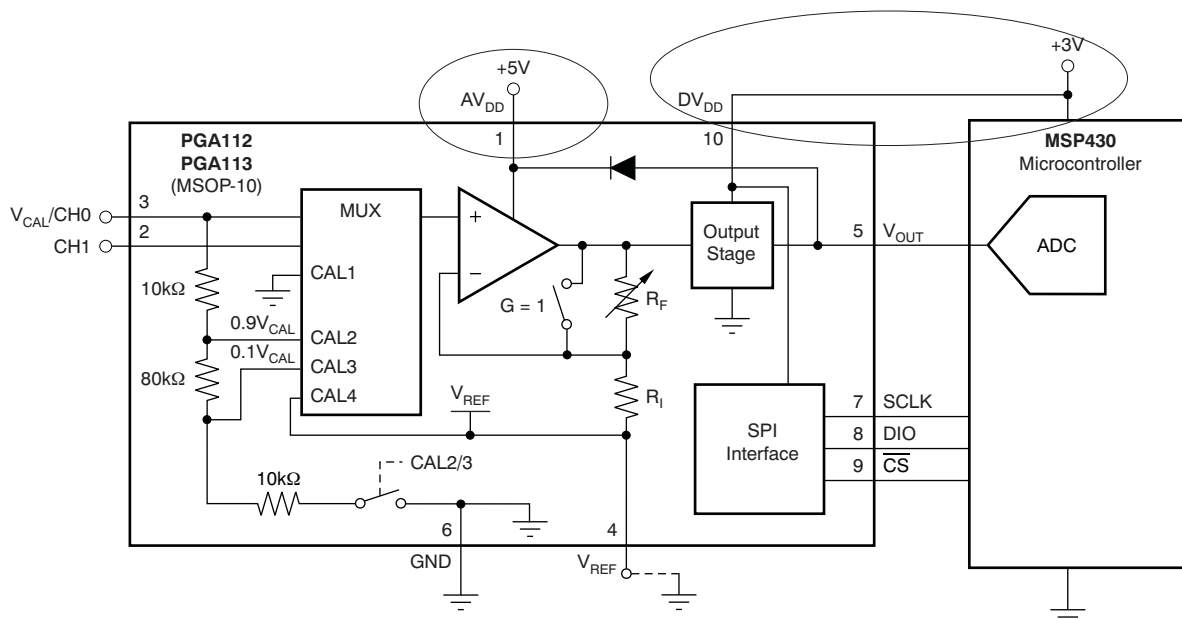


Figure 76. Split Power-Supply Architecture: $AV_{DD} \neq DV_{DD}$

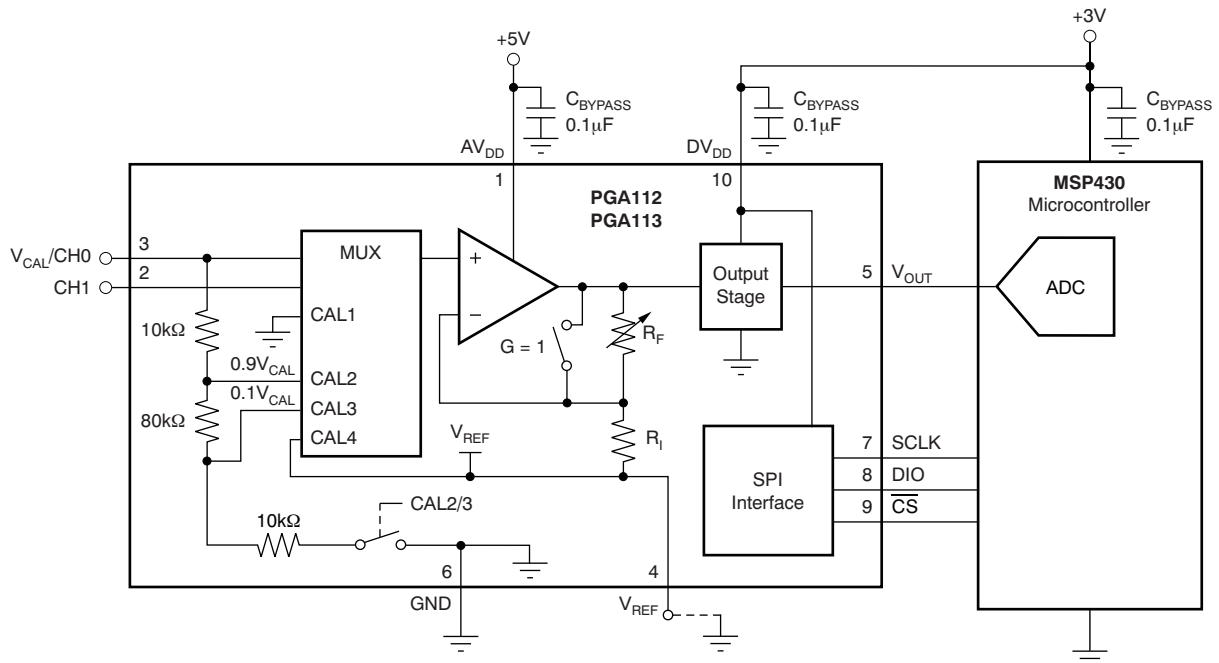


Figure 77. PGA112, PGA113 (VSSOP-10) Typical Application Schematic

9.1.9 Typical Connections: PGA116, PGA117 (TSSOP-20)

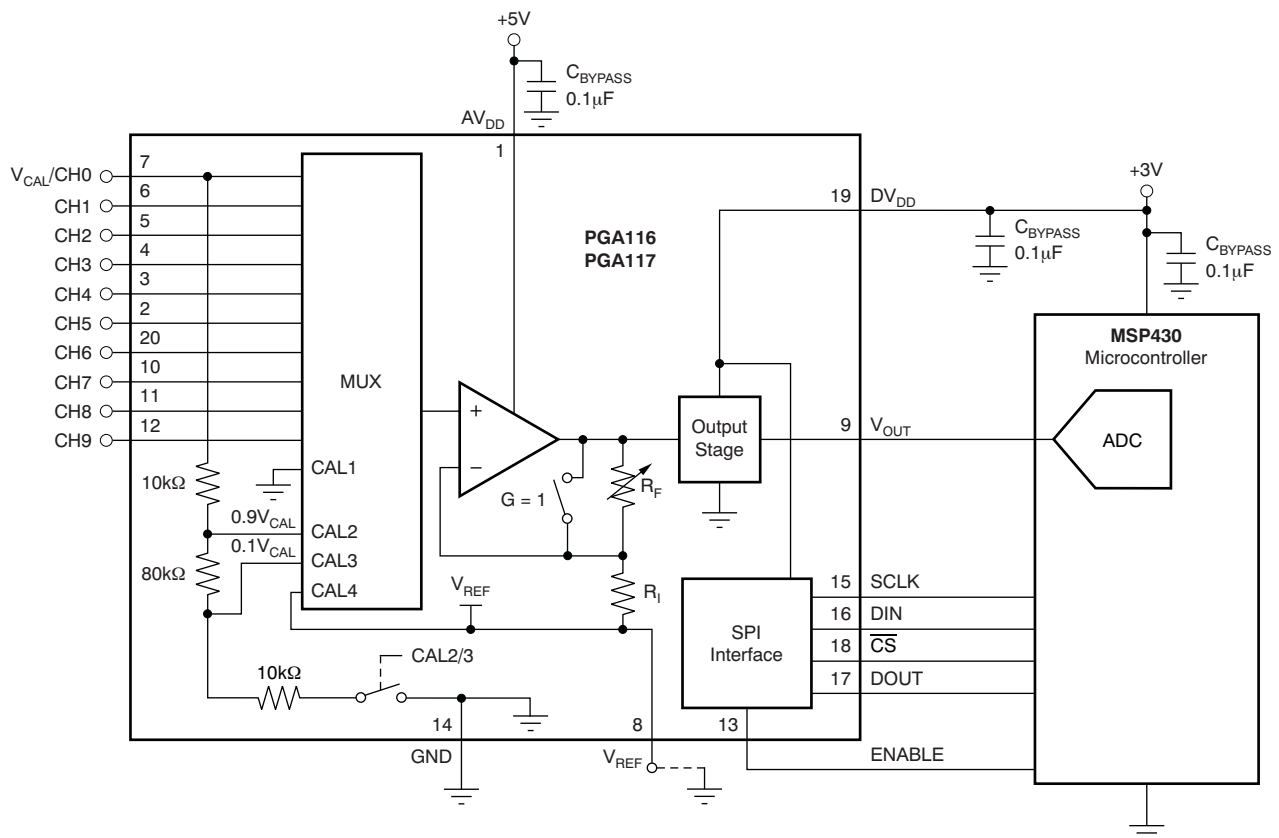


Figure 78. PGA116, PGA117 (TSSOP-20)

9.2 Typical Applications

9.2.1 Bipolar Input to Single-Supply Scaling

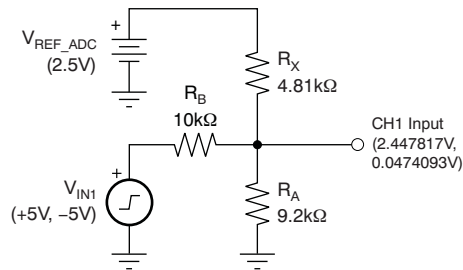


Figure 79. Bipolar to Single-Ended Input Algorithm

9.2.1.1 Design Requirements

Table 12. Bipolar to Single-Ended Input Scaling⁽¹⁾⁽²⁾

V _{REF_ADC} (V)	V _{IN1} (V)	CH1 INPUT	R _A (kΩ)	R _X (Ω)	R _B (kΩ)
2.5	-5	0.047613	9.2	4.81 k	10
	0	1.247613			
	5	2.447613			
2.5	-10	0.050317	3.16	2.4 k	10
	0	1.250317			
	10	2.450317			
3	-5	0.058003	13.5	5.76 k	10
	0	1.498003			
	5	2.938003			
3	-10	0.059303	4.02	2.87 k	10
	0	1.499303			
	10	2.939303			
4.096	-5	0.082224	37	7.87 k	10
	0	2.048304			
	5	4.014384			
4.096	-10	0.086018	6.49	3.92 k	10
	0	2.052098			
	10	4.018178			
5	-5	0.093506	24	965	10
	0	2.493506			
	5	4.893506			
5	-10	0.095227	9.2	4.81 k	10
	0	2.495227			
	10	4.895227			

(1) Scaling is based on 0.02(V_{REF_ADC}) to 0.98(V_{REF_ADC}), using standard 0.1% resistor values.

(2) Assumes symmetrical V_{IN} and symmetrical scaling for CH1 input minimum and maximum.

9.2.1.2 Detailed Design Procedure

This process assumes a symmetrical V_{IN1} and that symmetrical scaling is used for CH1 input minimum and maximum values. The following steps give the algorithm to compute resistor values for references not listed in [Table 12](#).

Step 1: Choose the following:

- $V_{REF_ADC} = 2.5 \text{ V}$ (ADC reference voltage)
- $|V_{IN1}| = 5$
(magnitude of V_{IN} , assuming scaling is for $\pm V_{IN1}$)
- Choose R_B as a standard resistor value. The input on-channel current multiplied by R_B should be less than the input offset voltage, such that R_B is not a major source of inaccuracy.
 $R_B = 10 \text{ k}\Omega$ (select as a starting value for resistors)
- For the most negative V_{IN1} , choose the percentage (in decimal format) of V_{REF_ADC} desired at the ADC input.
 $k_{VO-} = 0.02$
(CH1 input = $k_{VO-} \times V_{REF_ADC}$ when $V_{IN1} = -V_{IN1}$)
- For the most positive V_{IN1} , choose the percentage (in decimal format) of V_{REF_ADC} desired at the ADC input. Because this scaling is based on symmetry, k_{VO+} must be the same percentage away from V_{REF_ADC} at the upper limit as at the lower limit where k_{VO-} is computed.
 $k_{VO+} = 1 - k_{VO-}$
 $k_{VO+} = 1 - 0.02 = 0.98$
(CH1 input = $k_{VO+} \times V_{REF_ADC}$ when $V_{IN1} = +V_{IN1}$)

Step 2: Compute the following:

- To simplify analysis, create one constant called k_{VO} .
 $k_{VO} = k_{VO+} - k_{VO-}$
 $0.96 = 0.98 - 0.02$ (13)
- A constant, g , is created to simplify resistor value computations.

$$g = \frac{k_{VO} \times V_{REF_ADC}}{2 \times |V_{IN1}| - k_{VO} \times V_{REF_ADC}}$$

$$0.315789474 = \frac{0.96 \times 2.5}{2 \times 5 - 0.96 \times 2.5}$$
 (14)

- R_A is now selected from the starting value of R_B and the g constant.

$$R_A = \frac{2 \times R_B \times g}{1 - g}$$

$$9.23077\text{k}\Omega = \frac{2 \times 10\text{k}\Omega \times 0.315789474}{1 - 0.315789474}$$
 (15)

- R_X can now be computed from the starting value of R_B and the computed value for R_A .

$$R_X = \frac{R_B \times R_A}{R_B + R_A}$$

$$4.81\text{k}\Omega = \frac{10\text{k}\Omega \times 9.23077\text{k}\Omega}{10\text{k}\Omega + 9.23077\text{k}\Omega}$$
 (16)

9.2.1.3 Application Curve

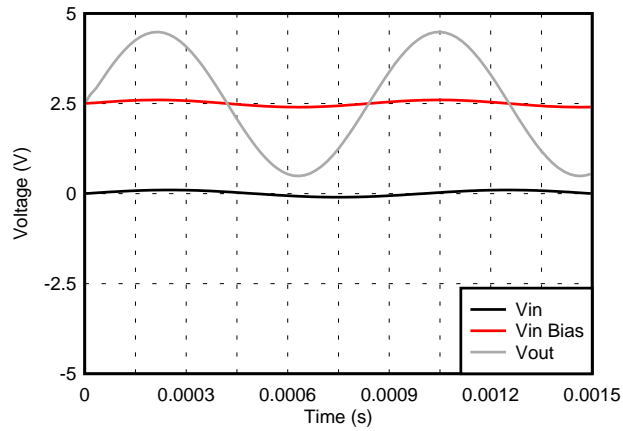


Figure 80. Voltage (V) vs Time (s)

9.2.2 Typical Application: General-Purpose Input Scaling

Figure 81 is an example application that demonstrates the flexibility of the PGA for general-purpose input scaling. V_{IN0} is a $\pm 100\text{-mV}$ input that is ac-coupled into CH0. The PGA112 and PGA113 are powered from a 5-V supply voltage, V_S , and configured with the V_{REF} pin connected to $V_S/2$ (2.5 V). V_{CH0} is the $\pm 100\text{-mV}$ input, level-shifted and centered on $V_S/2$ (2.5 V). A gain of 20 is applied to CH0, and because of the PGA113 configuration, the output voltage at V_{OUT} is ± 2 V centered on $V_S/2$ (2.5 V).

CH1 is set to $G = 1$; through a resistive divider and scalar network, we can read ± 5 V or 0 V. This setting provides bipolar to single-ended input scaling. Table 12 summarizes the scaling resistor values for R_A , R_X , and R_B for different ADC Ref voltages. V_{REF_ADC} is the reference voltage used for the ADC connected to the PGA112 and PGA113 output. It is assumed the ADC input range is 0 V to V_{REF_ADC} . The Table 12 section gives the algorithm to compute resistor values for references not listed in Table 12. As a general guideline, R_B should be chosen such that the input on-channel current multiplied by R_B is less than or equal to the input offset voltage. This value ensures that the scaling network contributes no more error than the input offset voltage. Individual applications may require other design trade-offs.

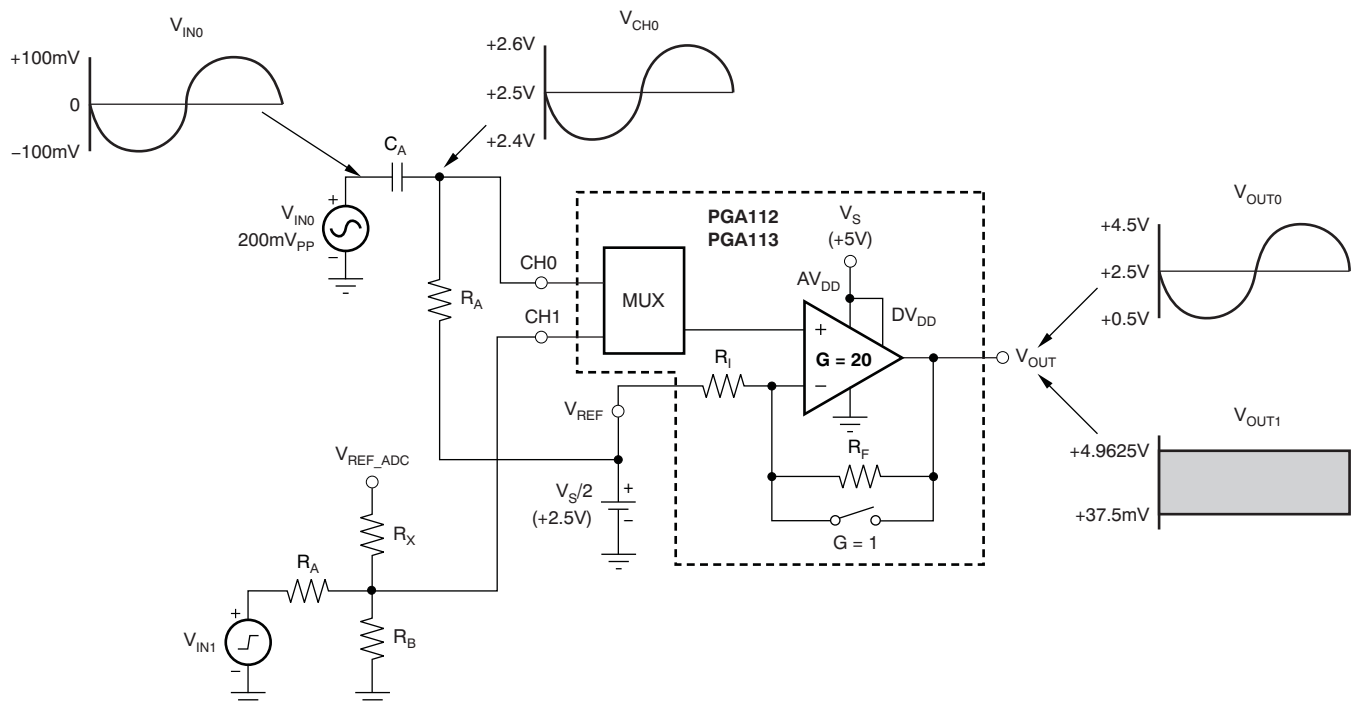


Figure 81. General-Purpose Input Scaling

10 Power Supply Recommendations

Power-supply bypass: Bypass each power-supply pin separately. Use a ceramic capacitor connected directly from the power-supply pin to the ground pin of the IC on the same PCB plane. Vias can then be used to connect to ground and voltage planes. This configuration keeps parasitic inductive paths out of the local bypass for the PGA. Good analog design practice dictates the use of a large value tantalum bypass capacitor on the PCB for each respective voltage.

11 Layout

11.1 Layout Guidelines

11.1.1 High Gain and Wide Bandwidth Considerations

As a result of the combination of wide bandwidth and high gain capability of the PGA112 and PGA113 devices and PGA116 and PGA117 devices, there are several printed-circuit-board (PCB) design and system recommendations to consider for optimum application performance.

1. **Power-supply bypass:** Refer to [Power Supply Recommendations](#).
2. **Signal trace routing:** Keep V_{OUT} and other low impedance traces away from MUX channel inputs that are high impedance. Poor signal routing can cause positive feedback, unwanted oscillations, or excessive overshoot and ringing on step-changing signals. If the input signals are particularly noisy, separate MUX input channels with guard traces on either side of the signal traces. Connect the guard traces to ground near the PGA and at the signal entry point into the PCB. On multilayer PCBs, ensure that there are no parallel traces near MUX input traces on adjacent layers; capacitive coupling from other layers can be a problem. Use ground planes to isolate MUX input signal traces from signal traces on other layers.

Additionally, group and route the digital signals into the PGA as far away as possible from the analog MUX input signals. Most digital signals are fast rise and fall time signals with low-impedance drive capability that can easily couple into the high-impedance inputs of the input MUX channels. This coupling can create unwanted noise that gains up to V_{OUT} .

3. **Input MUX channels and source impedance:** Input MUX channels are high-impedance; when combined with high gain, the channels can pick up unwanted noise. Keep the input signal sources low-impedance ($< 10\text{ k}\Omega$). Also, consider bypassing input MUX channels with a ceramic bypass capacitor directly at the MUX input pin. Bypass capacitors greater than 100 pF are recommended. Lower impedances and a bypass capacitor placed directly at the input MUX channels keep crosstalk between channels to a minimum as a result of parasitic capacitive coupling from adjacent PCB traces and pin-to-pin capacitance.

11.2 Layout Example

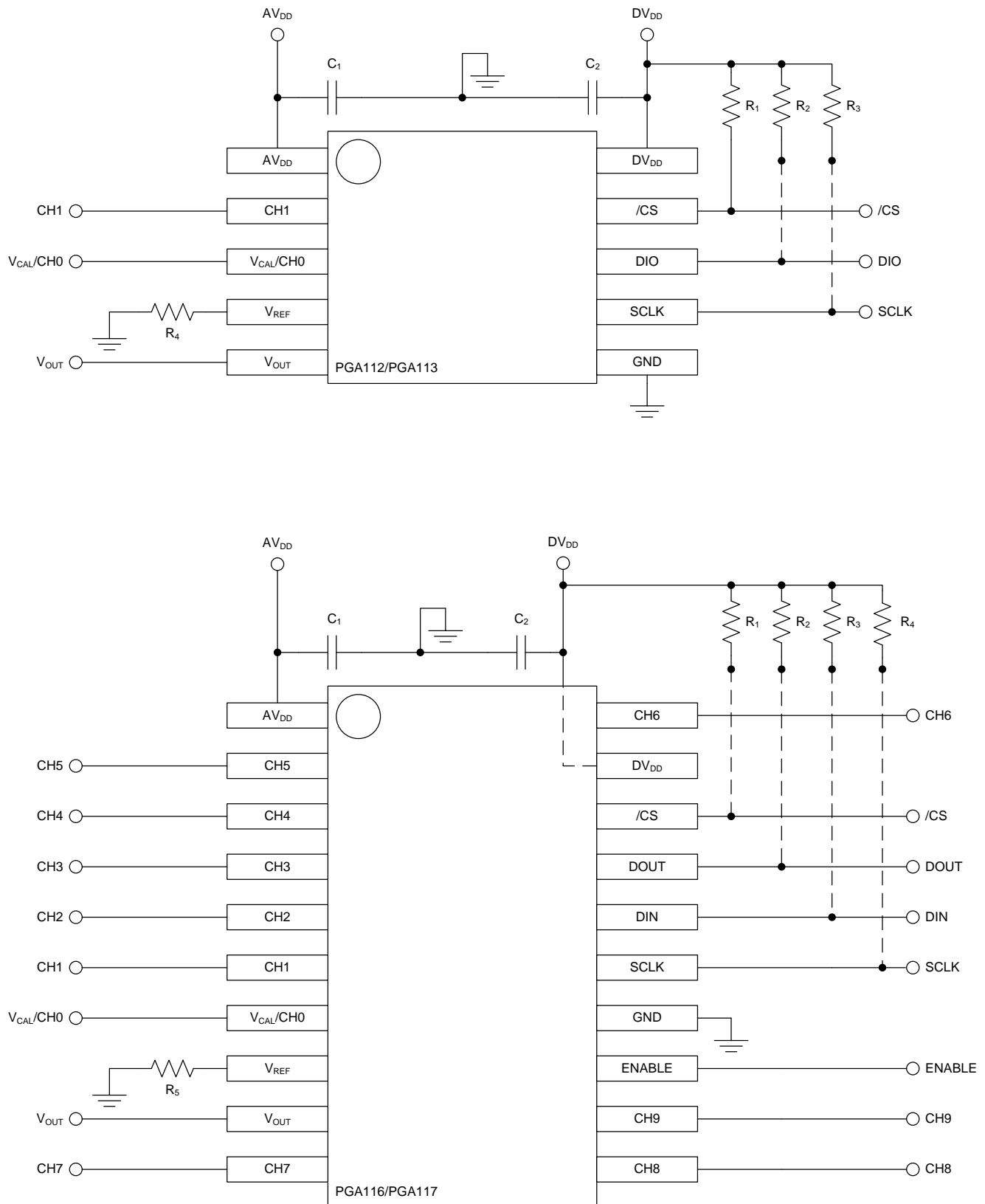


Figure 82. PGA11x Layout Example

12 Device and Documentation Support

12.1 Documentation Support

12.1.1 Related Documentation

For related documentation see the following:

- *Shelf-Life Evaluation of Lead-Free Component Finishes*, [SZZA046](#).
- *PGA112/113EVM Users Guide*, [SBOU073](#).

12.2 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 13. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
PGA112	Click here	Click here	Click here	Click here	Click here
PGA113	Click here	Click here	Click here	Click here	Click here
PGA116	Click here	Click here	Click here	Click here	Click here
PGA117	Click here	Click here	Click here	Click here	Click here

12.3 Community Resources

The following links connect to TI community resources. Linked contents are 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](#).

TI E2E™ Online Community *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

12.4 Trademarks

E2E is a trademark of Texas Instruments.

SPI is a trademark of Motorola.

All other trademarks are the property of their respective owners.

12.5 Electrostatic Discharge Caution



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

12.6 Glossary

[SLYZ022](#) — *TI Glossary*.

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

13 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.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
PGA112AIDGSR	ACTIVE	VSSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU CU NIPDAUAG	Level-2-260C-1 YEAR	-40 to 125	P112	Samples
PGA112AIDGSRG4	ACTIVE	VSSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAUAG	Level-2-260C-1 YEAR	-40 to 125	P112	Samples
PGA112AIDGST	ACTIVE	VSSOP	DGS	10	250	Green (RoHS & no Sb/Br)	CU NIPDAU CU NIPDAUAG	Level-2-260C-1 YEAR	-40 to 125	P112	Samples
PGA112AIDGSTG4	ACTIVE	VSSOP	DGS	10	250	Green (RoHS & no Sb/Br)	CU NIPDAUAG	Level-2-260C-1 YEAR	-40 to 125	P112	Samples
PGA113AIDGSR	ACTIVE	VSSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	P113	Samples
PGA113AIDGSRG4	ACTIVE	VSSOP	DGS	10	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	P113	Samples
PGA113AIDGST	ACTIVE	VSSOP	DGS	10	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	P113	Samples
PGA113AIDGSTG4	ACTIVE	VSSOP	DGS	10	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	P113	Samples
PGA116AIPW	ACTIVE	TSSOP	PW	20	70	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	PGA116	Samples
PGA116AIPWG4	ACTIVE	TSSOP	PW	20	70	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	PGA116	Samples
PGA116AIPWR	ACTIVE	TSSOP	PW	20	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	PGA116	Samples
PGA117AIPW	ACTIVE	TSSOP	PW	20	70	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	PGA117	Samples
PGA117AIPWR	ACTIVE	TSSOP	PW	20	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	PGA117	Samples

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

ACTIVE: Product device recommended for new designs.

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

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

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

OBSOLETE: TI has discontinued the production of the device.

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

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

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

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

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

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

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

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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

TAPE AND REEL INFORMATION

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
PGA112AIDGSR	VSSOP	DGS	10	2500	330.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
PGA112AIDGST	VSSOP	DGS	10	250	180.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
PGA112AIDGST	VSSOP	DGS	10	250	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
PGA113AIDGSR	VSSOP	DGS	10	2500	330.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
PGA113AIDGST	VSSOP	DGS	10	250	180.0	12.4	5.3	3.3	1.3	8.0	12.0	Q1
PGA116AIPWR	TSSOP	PW	20	2000	330.0	16.4	6.95	7.1	1.6	8.0	16.0	Q1
PGA117AIPWR	TSSOP	PW	20	2000	330.0	16.4	6.95	7.1	1.6	8.0	16.0	Q1

TAPE AND REEL BOX DIMENSIONS


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
PGA112AIDGSR	VSSOP	DGS	10	2500	370.0	355.0	55.0
PGA112AIDGST	VSSOP	DGS	10	250	195.0	200.0	45.0
PGA112AIDGST	VSSOP	DGS	10	250	366.0	364.0	50.0
PGA113AIDGSR	VSSOP	DGS	10	2500	370.0	355.0	55.0
PGA113AIDGST	VSSOP	DGS	10	250	195.0	200.0	45.0
PGA116AIPWR	TSSOP	PW	20	2000	367.0	367.0	38.0
PGA117AIPWR	TSSOP	PW	20	2000	367.0	367.0	38.0

DGS (S-PDSO-G10)

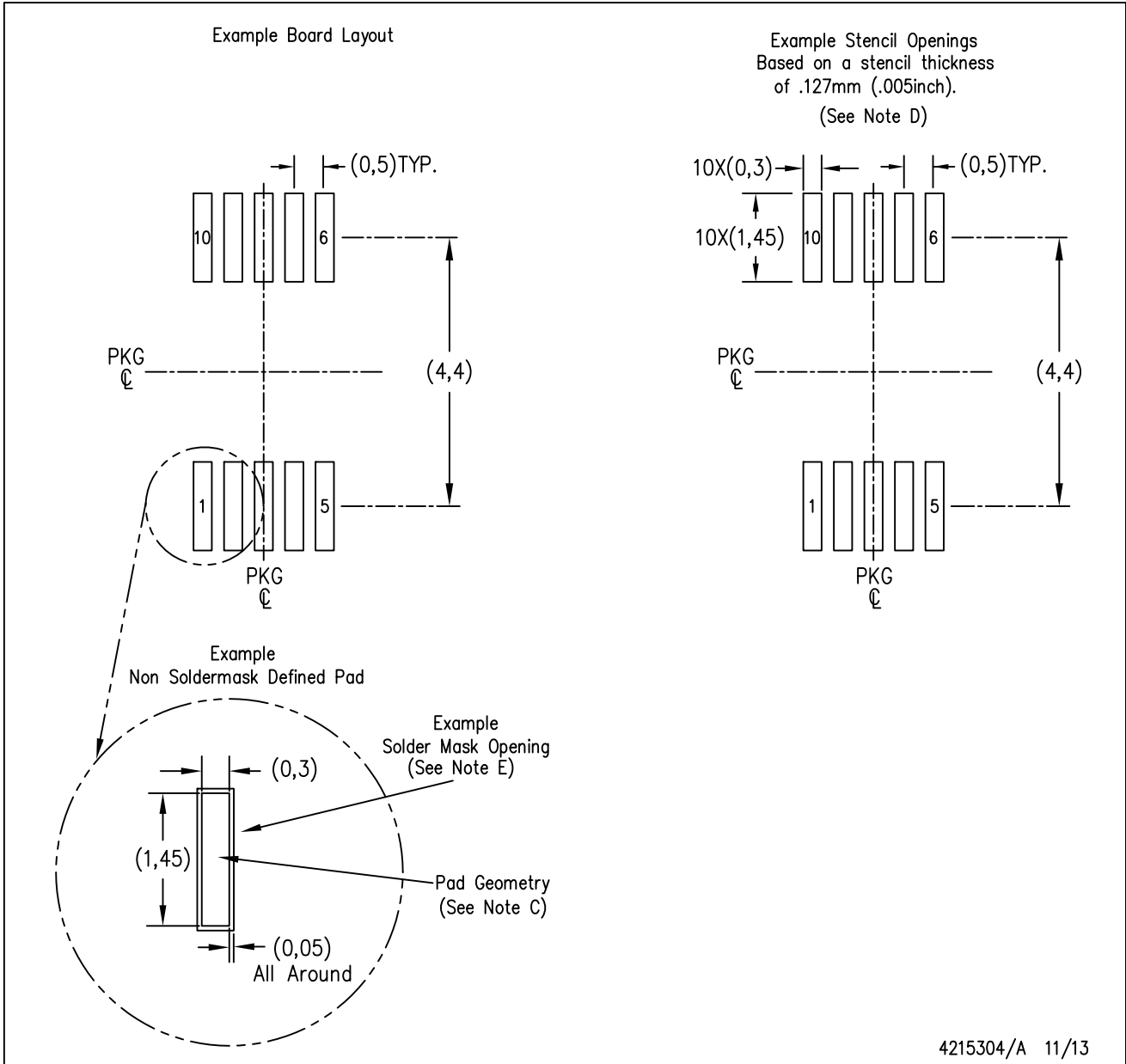
PLASTIC SMALL-OUTLINE PACKAGE



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Body dimensions do not include mold flash or protrusion.
 - D. Falls within JEDEC MO-187 variation BA.

DGS (S-PDSO-G10)

PLASTIC SMALL OUTLINE PACKAGE



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Publication IPC-7351 is recommended for alternate designs.
 - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
 - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

PW (R-PDSO-G20)

PLASTIC SMALL OUTLINE



4040064-5/G 02/11

- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
 - B. This drawing is subject to change without notice.
 - C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0,15 each side.
 - D. Body width does not include interlead flash. Interlead flash shall not exceed 0,25 each side.
 - E. Falls within JEDEC MO-153

PW (R-PDSO-G20)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Publication IPC-7351 is recommended for alternate design.
 - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
 - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

IMPORTANT NOTICE

Texas Instruments Incorporated (TI) reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete.

TI's published terms of sale for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>) apply to the sale of packaged integrated circuit products that TI has qualified and released to market. Additional terms may apply to the use or sale of other types of TI products and services.

Reproduction of significant portions of TI information in TI data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such reproduced documentation. Information of third parties may be subject to additional restrictions. Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyers and others who are developing systems that incorporate TI products (collectively, "Designers") understand and agree that Designers remain responsible for using their independent analysis, evaluation and judgment in designing their applications and that Designers have full and exclusive responsibility to assure the safety of Designers' applications and compliance of their applications (and of all TI products used in or for Designers' applications) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to their applications, Designer has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any applications that include TI products, Designer will thoroughly test such applications and the functionality of such TI products as used in such applications.

TI's provision of technical, application or other design advice, quality characterization, reliability data or other services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using TI Resources in any way, Designer (individually or, if Designer is acting on behalf of a company, Designer's company) agrees to use any particular TI Resource solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

Designer is authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY DESIGNER AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

Unless TI has explicitly designated an individual product as meeting the requirements of a particular industry standard (e.g., ISO/TS 16949 and ISO 26262), TI is not responsible for any failure to meet such industry standard requirements.

Where TI specifically promotes products as facilitating functional safety or as compliant with industry functional safety standards, such products are intended to help enable customers to design and create their own applications that meet applicable functional safety standards and requirements. Using products in an application does not by itself establish any safety features in the application. Designers must ensure compliance with safety-related requirements and standards applicable to their applications. Designer may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

TI may expressly designate certain products as completing a particular qualification (e.g., Q100, Military Grade, or Enhanced Product). Designers agree that it has the necessary expertise to select the product with the appropriate qualification designation for their applications and that proper product selection is at Designers' own risk. Designers are solely responsible for compliance with all legal and regulatory requirements in connection with such selection.

Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer's non-compliance with the terms and provisions of this Notice.