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ANALOG DEVICES

Digital Power Monitor with PMBus Interface

Data Sheet

ADM1293/ADM1294

FEATURES

Monitor current and two voltages
High accuracy current monitoring at low sense voltage
0.33% accurate at ±20 mV sense voltage over temperature
Common-mode sense voltage from 0 V to 20 V (ADM1293)
Support high-side and low-side current sensing
Integrated shunt regulator for wide supply input (ADM1294)
Reports current, voltage, and power
Power accumulation for energy metering
Bidirectional current sensing
Digitally programmable overcurrent alert
Multifunctional pins with user configurable functions
ADC conversion enable input
Multisource alert output
User-controllable GPO
Peak detect registers for current, voltage, and power
PMBus fast mode compliant interface
Separate SDA I/O for easy isolated communication
Two address pins for 16 unique I²C addresses
Available in 4 mm × 4 mm, 16-lead LFCSP and 14-lead TSSOP
Operation temperature range
ADM1293 T_A = −40°C to +105°C
ADM1294 T_J = −40°C to +105°C

APPLICATIONS

Power monitoring/power budgeting
Central office equipment
Telecommunications and data communications equipment
PCs/servers

FUNCTIONAL BLOCK DIAGRAMS

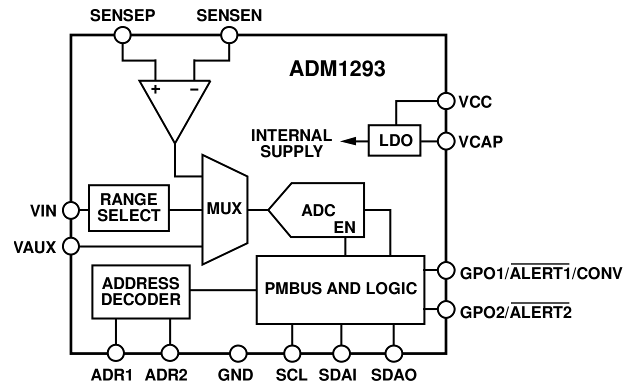

Figure 1. ADM1293 Functional Block Diagram

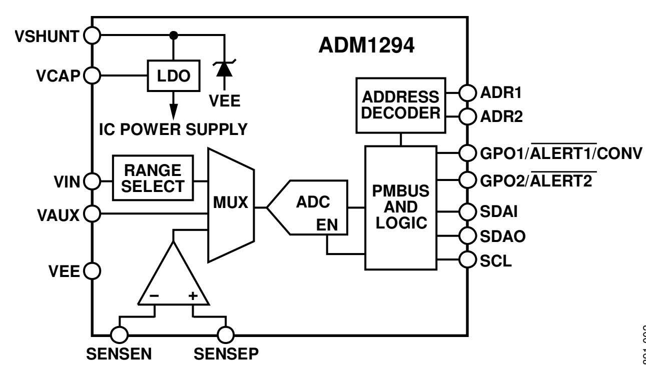

Figure 2. ADM1294 Functional Block Diagram

GENERAL DESCRIPTION

The ADM1293 and ADM1294 are high accuracy integrated digital power monitors that offer digital current, voltage, and power monitoring using an on-chip, 12-bit analog-to-digital converter (ADC), communicated through a PMBus™ compliant I²C interface.

These devices acquire the current by measuring the voltage difference across the external sense resistor. This voltage is amplified and digitized by an internal 12-bit ADC. The same ADC can also sample the primary input voltage and an auxiliary input voltage. The internal digital block can perform multiplication of the current and primary input voltage for power calculation. The ADM1293/ADM1294 also feature a power accumulator for energy metering. An industry-standard PMBus interface allows a master controller to read back these data from the device. The master controller can then combine this information with a known sense resistor value to calculate the current, voltage, power, and energy consumption over time on the monitored rail.

In conditions such as overcurrent, overvoltage, undervoltage, and overpower, the ADM1293/ADM1294 devices can generate an interrupt signal to the microprocessor through the GPOx/$\overline{\text{ALERTx}}$ outputs. The threshold for these conditions is digitally programmed via PMBus.

The ADM1293 is designed for high-side supply monitoring with a voltage monitoring range from 0 V to 20 V. The ADM1294 is designed for low-side supply monitoring. Its integrated shunt regulator allows it to be powered and to monitor supply in wide voltage ranges.

The ADM1293/ADM1294 are available in 4 mm × 4 mm 16-lead LFCSP and 14-lead TSSOP packages with a specified operating ambient temperature range from −40°C to +105°C for the ADM1293 and an operating junction temperature range from −40°C to +105°C for the ADM1294.

Rev. B **Document Feedback**

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One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700

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TABLE OF CONTENTS

REVISION HISTORY

3/15—Rev. A to Rev. B

10/14—Rev. 0 to Rev. A

8/14—Revision 0: Initial Version

SPECIFICATIONS

ELECTRICAL CHARACTERISTICS

For the ADM1293: VCC = 2.95 V to 20 V, V_{SENSEP} = 0 V to 20 V, VCC ≥ V_{SENSEP}, VCC ≥ V_{SENSEN}, T_A = −40°C to +105°C, unless otherwise noted. For the ADM1294: VEE = −48 V, shunt regulation current = 10 mA, V_{SENSEP} = VEE = 0 V, pin voltages are referenced to the VEE pin, T_J = −40°C to +105°C, unless otherwise noted. All minimum/maximum specifications apply over the entire recommended operating range, unless otherwise noted. Typical values are specified at T_A = 25°C.

Table 1.

Parameter	Symbol	Min	Typ	Max	Unit	Test Conditions/Comments
POWER SUPPLY						
ADM1293						
Operating Voltage Range	V_{OP3}	2.95		20	V	
Undervoltage Lockout (UVLO)	V_{UVLO_3}	2.4		2.7	V	VCC rising
UVLO Hysteresis			90	120	mV	
Quiescent Current	I_{CC3}			3.3	mA	
ADM1294						
Typical Operating Voltage	V_{OP4}	2.95		V_{SHUNT}	V	Reference to VEE
Voltage Transient Immunity			200		V	
Shunt Regulation Voltage	V_{SHUNT}	11.5	12.3	13	V	I_{IN} = 3.3 mA to 30 mA, maximum I_{IN} dependent on T_A and θ_{JA} (see the Powering the ADM1294 section)
Undervoltage Lockout	V_{UVLO_4}	2.4		2.7	V	V_{SHUNT} rising
UVLO Hysteresis			90	120	mV	
Quiescent Current	I_{CC4}			3.6	mA	V_{SHUNT} = 13 V
Power Directly Without Shunt	V_{DIR}	2.95		11.5	V	
SENSEP AND SENSEN PINS						
ADM1293						
Input Current	I_{IN_SENSE3}			±25	nA	Per individual pin, V_{SENSEP} = V_{SENSEN} = VCC = 20 V
Input Imbalance	$I_{\Delta SENSE3}$		±5	±25	nA	$I_{\Delta SENSEx}$ = I_{SENSEP} − I_{SENSEN}, V_{SENSE} = ±20 mV, V_{SENSEP} = V_{VSHUNT}
ADM1294						
Input Current	I_{IN_SENSE4}			−1	µA	V_{SENSEP} = V_{SENSEN} ≤ 25 mV, per individual pin, V_{VSHUNT} = 12 V
Input Imbalance	$I_{\Delta SENSE4}$		±0.05	±1	µA	$I_{\Delta SENSEx}$ = I_{SENSEP} − I_{SENSEN}, V_{SENSE} = ±20 mV, V_{SENSEP} = 0 V, V_{VSHUNT} = 12 V
VCAP PIN						
Internally Regulated Voltage	V_{VCAP}	2.66	2.7	2.74	V	0 µA ≤ I_{VCAP} ≤ 100 µA, C_{VCAP} = 1 µF
VIN PIN						
Input Current	I_{VIN}			20	µA	V_{VIN} = 20 V, V_{RANGE} = 0 V to 21 V
				±100	nA	V_{VIN} = 1.2 V, V_{RANGE} = 0 V to 1.2 V
VAUX PIN						
Input Current	I_{VAUX}			±100	nA	V_{VAUX} = 1.2 V, VAUX sampling enabled
GPO1/$\overline{\text{ALERT1}}$/CONV PIN						
Output Low Voltage	V_{OL_GPO1}			0.4	V	I_{GPO1} = 1 mA
				1.5	V	I_{GPO1} = 5 mA
Leakage Current				±100	nA	V_{GPO1} ≤ 2 V, GPO1 output high-Z
				1	µA	V_{GPO1} = 20 V, GPO1 output high-Z
Input High Voltage	V_{IH}	1.1			V	Configured as CONV pin
Input Low Voltage	V_{IL}			0.8	V	Configured as CONV pin
Glitch Filter			1		µs	Configured as CONV pin
GPO2/$\overline{\text{ALERT2}}$ PIN						
Output Low Voltage	V_{OL_GPO2}			0.4	V	I_{GPO2} = 1 mA
				1.5	V	I_{GPO2} = 5 mA
Leakage Current				±100	nA	V_{GPO2} ≤ 2 V, GPO2 output high-Z
				±1	µA	V_{GPO2} = 20 V, GPO2 output high-Z

Parameter	Symbol	Min	Typ	Max	Unit	Test Conditions/Comments
GRADE A DEVICE CURRENT AND VOLTAGE MONITORING						
Current Sense Absolute Error						128 sample averaging, V_{SENSEP} = 0 V to 18 V (unless otherwise noted)
Current Sense Range (CSR) = ±25 mV			0.04	0.33	%	V_{SENSE} = V_{SENSEP} − V_{SENSEN} = ±20 mV, T_A = −40°C to +85°C
				0.38	%	V_{SENSE} = ±20 mV
				0.72	%	V_{SENSE} = ±20 mV, 16 sample averaging
				2.65	%	V_{SENSE} = ±20 mV, one sample averaging
				1	%	V_{SENSE} = ±20 mV, V_{SENSEP} = 18 V to 20 V
				0.35	%	V_{SENSE} = ±25 mV
				0.44	%	V_{SENSE} = ±15 mV
				0.59	%	V_{SENSE} = ±10 mV
				1	%	V_{SENSE} = ±5 mV
				2	%	V_{SENSE} = ±2.5 mV
				5	%	V_{SENSE} = ±1 mV
CSR = ±50 mV				0.26	%	V_{SENSE} = ±40 mV
				0.4	%	V_{SENSE} = ±20 mV
CSR = ±100 mV				0.23	%	V_{SENSE} = ±80 mV
				0.3	%	V_{SENSE} = ±40 mV
CSR = ±200 mV				0.21	%	V_{SENSE} = ±160 mV
				0.27	%	V_{SENSE} = ±80 mV
Voltage Sense Absolute Error						128 sample averaging
VIN				0.35	%	V_{VIN} = 10 V to 20 V, V_{RANGE} = 21 V
				0.26	%	V_{VIN} = 3.6 V to 7.4 V, V_{RANGE} = 7.4 V
				0.2	%	V_{VIN} = 0.6 V to 1.2 V, V_{RANGE} = 1.2 V, T_A = −40°C to +85°C
				0.24	%	V_{VIN} = 0.6 V to 1.2 V, V_{RANGE} = 1.2 V
VAUX				0.2	%	V_{VAUX} = 0.6 V to 1.2 V, T_A = −40°C to +85°C
				0.24	%	V_{VAUX} = 0.6 V to 1.2 V
Power Absolute Error				0.48	%	V_{SENSE} = ±20 mV, SENSEP = VIN = 12 V, V_{RANGE} = 21 V, T_A = −40°C to +85°C
				0.54	%	V_{SENSE} = ±20 mV, SENSEP = VIN = 12 V, V_{RANGE} = 21 V
				0.5	%	V_{SENSE} = ±20 mV, SENSEP = VIN = 3.3 V, V_{RANGE} = 7.4 V, T_A = −40°C to +85°C
				0.54	%	V_{SENSE} = ±20 mV, SENSEP = VIN = 3.3 V, V_{RANGE} = 7.4 V
				0.48	%	V_{SENSE} = ±20 mV, SENSEP = 20 mV, VIN = 0.8 V, V_{RANGE} = 1.2 V, T_A = −40°C to +85°C
				0.53	%	V_{SENSE} = ±20 mV, SENSEP = 20 mV, VIN = 0.8 V, V_{RANGE} = 1.2 V
GRADE B DEVICE CURRENT AND VOLTAGE MONITORING						
Current Sense Absolute Error						128 sample averaging (unless otherwise noted)
CSR = ±25 mV			0.1	0.75	%	V_{SENSE} = V_{SENSEP} − V_{SENSEN} = ±20 mV, T_A = −40°C to +85°C
				0.84	%	V_{SENSE} = ±20 mV
				1.6	%	V_{SENSE} = ±20 mV, 16 sample averaging
				5.8	%	V_{SENSE} = ±20 mV, one sample averaging
				2.2	%	V_{SENSE} = ±20 mV, V_{SENSEP} = 18 V to 20 V
				0.8	%	V_{SENSE} = ±25 mV
				1	%	V_{SENSE} = ±15 mV
				1.3	%	V_{SENSE} = ±10 mV
				4.5	%	V_{SENSE} = ±2.5 mV
				11	%	V_{SENSE} = ±1 mV
CSR = ±50 mV				0.57	%	V_{SENSE} = ±40 mV
				0.9	%	V_{SENSE} = ±20 mV

Parameter	Symbol	Min	Typ	Max	Unit	Test Conditions/Comments
CSR = ±100 mV				0.55	%	V_{SENSE} = ±80 mV
				0.7	%	V_{SENSE} = ±40 mV
CSR = ±200 mV				0.5	%	V_{SENSE} = ±160 mV
				0.6	%	V_{SENSE} = ±80 mV
Voltage Sense Absolute Error						128 sample averaging
VIN				0.8	%	V_{VIN} = 10 V to 20 V, V_{RANGE} = 21 V
				0.6	%	V_{VIN} = 3.6 V to 7.4 V, V_{RANGE} = 7.4 V
				0.45	%	V_{VIN} = 0.6 V to 1.2 V, V_{RANGE} = 1.2 V, T_A = −40°C to +85°C
				0.6	%	V_{VIN} = 0.6 V to 1.2 V, V_{RANGE} = 1.2 V
VAUX				0.45	%	V_{VAUX} = 0.6 V to 1.2 V, T_A = −40°C to +85°C
				0.6	%	V_{VAUX} = 0.6 V to 1.2 V
Power Absolute Error				1.2	%	V_{SENSE} = ±20 mV, SENSEP = VIN = 12 V, V_{RANGE} = 21 V
				1.2	%	V_{SENSE} = ±20 mV, SENSEP = VIN = 3.3 V, V_{RANGE} = 7.4 V
				1.2	%	V_{SENSE} = ±20 mV, SENSEP = 20 mV, VIN = 0.8 V, V_{RANGE} = 1.2 V
ADC CONVERSION TIME						Includes time for power multiplication
			144	165	µs	One sample of IOUT, from command received to valid data in register
			64	73	µs	One sample of VIN, from command received to valid data in register
			64	73	µs	One sample of VAUX, from command received to valid data in register
ADRx PINS						
Address Set to 00		0		0.8	V	Connect to VEE
Input Current for Address 00		−40	−22		µA	V_{ADRx} = 0 V to 0.8 V
Address Set to 01		135	150	165	kΩ	Resistor to VEE
Address Set to 10		−1		+1	µA	No connect state, maximum leakage current allowed
Address Set to 11		2			V	Connect to VCAP
Input Current for Address 11			3	10	µA	V_{ADRx} = 2.0 V to VCAP, must not exceed the maximum allowable current draw from VCAP
SERIAL BUS DIGITAL I/O						SDAI, SDAO, SCL
Input High Voltage	V_{IH}	1.1			V	
Input Low Voltage	V_{IL}			0.8	V	
SDAO Output Low Voltage	V_{OL}			0.4	V	I_{OL} = 4 mA
Input Leakage	I_{LEAK_PIN}	−10		+10	µA	
		−5		+5	µA	Device is not powered
Nominal Bus Voltage	V_{DD}	2.7		5.5	V	3 V to 5 V ± 10%
Capacitance for I/O Pins	C_{PIN}		5		pF	
Input Glitch Filter	t_{SP}	0		50	ns	

SERIAL BUS TIMING CHARACTERISTICS

Table 2.

Parameter	Description	Min	Typ	Max	Unit
f_{SCLK}	Clock frequency			400	kHz
t_{BUF}	Bus free time	1.3			µs
$t_{HD;STA}$	Start hold time	0.6			µs
$t_{SU;STA}$	Start setup time	0.6			µs
$t_{SU;STO}$	Stop setup time	0.6			µs
$t_{HD;DAT}$	SDA hold time	300		900	ns
$t_{SU;DAT}$	SDA setup time	100			ns
t_{LOW}	SCL low time	1.3			µs
t_{HIGH}	SCL high time	0.6			µs
t_R[1]	SCL, SDA rise time	20		300	ns
t_F	SCL, SDA fall time	20		300	ns

[1] $t_R = (V_{IL(MAX)} - 0.15)$ to $(V_{IH3V3} + 0.15)$ and $t_F = 0.9\ V_{DD}$ to $(V_{IL(MAX)} - 0.15)$, where $V_{IH3V3} = 2.1$ V, and $V_{DD} = 3.3$ V.

Serial Bus Timing Diagram

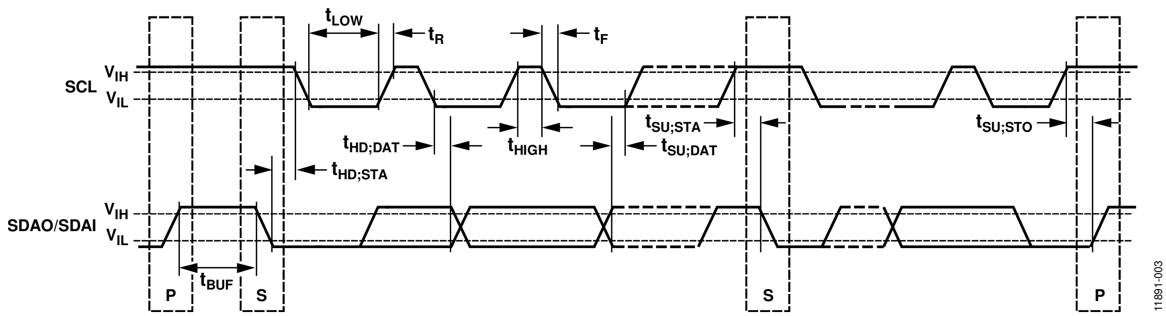

Figure 3. Serial Bus Timing Diagram

ABSOLUTE MAXIMUM RATINGS

Pin voltages on the ADM1293 are referenced to the GND pin and pin voltages on the ADM1294 are referenced to the VEE pin.

Table 3.

Parameter	Rating
VCC Pin	−0.3 V to +25 V
VSHUNT Pin	−0.3 V to +14 V
VCAP Pin	−0.3 V to +4 V
SCL Pin	−0.3 V to +6.5 V
SDAI Pin	−0.3 V to +6.5 V
SDAO Pin	−0.3 V to +6.5 V
ADR1 Pin	−0.3 V to VCAP + 0.3 V
ADR2 Pin	−0.3 V to VCAP + 0.3 V
GPO1/$\overline{\text{ALERT1}}$/CONV Pin	−0.3 V to +25 V
GPO2/$\overline{\text{ALERT2}}$ Pin	−0.3 V to +25 V
VIN Pin	−0.3 V to +25 V
VAUX Pin	−0.3 V to +4 V
SENSEP Pin	−0.3 V to +25 V
SENSEN Pin	−0.3 V to +25 V
Continuous Current into VSHUNT Pin	30 mA
Continuous Current into Any Other Pin	±10 mA
Storage Temperature Range	−65°C to +150°C
Operating Ambient Temperature Range	
ADM1293	−40°C to +105°C
Operating Junction Temperature Range	
ADM1294	−40°C to +105°C
Junction Temperature Range	−40°C to +110°C
Lead Temperature, Soldering (10 sec)	300°C
Junction Temperature	150°C

Stresses at or above those listed under Absolute Maximum Ratings may cause permanent damage to the product. This is a stress rating only; functional operation of the product at these or any other conditions above those indicated in the operational section of this specification is not implied. Operation beyond the maximum operating conditions for extended periods may affect product reliability.

THERMAL CHARACTERISTICS

θ_{JA} is specified for the worst case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 4. Thermal Resistance

Package Type	θ_{JA}	Unit
16-Lead LFCSP	50.58	°C/W
14-Lead TSSOP	122.73	°C/W

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATIONS AND FUNCTION DESCRIPTIONS

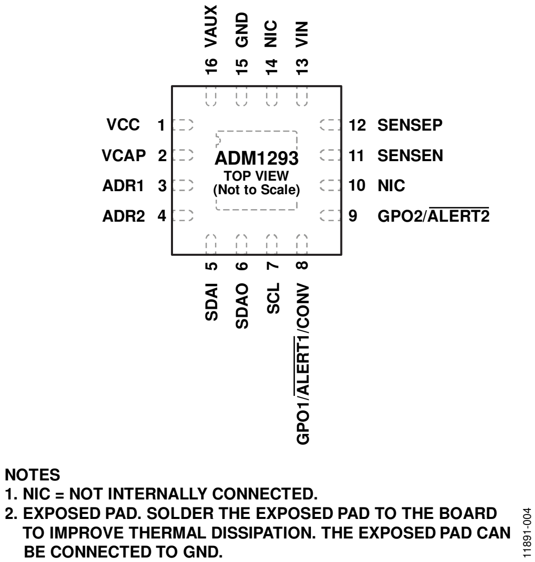

Figure 4. ADM1293 LFCSP Pin Configuration

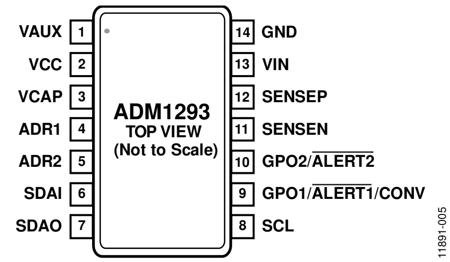

Figure 5. ADM1293 TSSOP Pin Configuration

Table 5. ADM1293 Pin Function Descriptions

Pin No.			
LFCSP	TSSOP[1]	Mnemonic	Description
16	1	VAUX	Auxiliary Voltage Monitoring Input. This pin reads back the auxiliary input voltage using the internal ADC. An external divider is required to monitor voltages higher than 1.2 V.
1	2	VCC	Positive Supply Input. An undervoltage lockout (UVLO) circuit resets the device when a low supply voltage is detected. A 0.1 µF decoupling capacitor must be placed close to the VCC pin.
2	3	VCAP	Internal Regulated Supply. Place a capacitor with a value of 1 µF or greater on this pin to maintain accuracy.
3	4	ADR1	PMBus Address. This pin can be tied low, tied to VCAP, left floating, or tied low through a resistor. Combine with the ADR2 pin to set up to 16 different PMBus addresses.
4	5	ADR2	PMBus Address. This pin can be tied low, tied to VCAP, left floating, or tied low through a resistor. Combine with the ADR1 pin to set up to 16 different PMBus addresses.
5	6	SDAI	PMBus Serial Data Input. This is a split version of the SDA for easy use with optocouplers. Tie this pin directly to the SDAO pin if a bus split is not required.
6	7	SDAO	PMBus Serial Data Output. This is a split version of the SDA for easy use with optocouplers. Tie this pin directly to the SDAI pin if a bus split is not required.
7	8	SCL	PMBus Serial Clock. Open-drain input. Requires an external resistive pull-up.
8	9	GPO1/$\overline{\text{ALERT1}}$/CONV	General-Purpose Digital Output (GPO1). Alert ($\overline{\text{ALERT1}}$). This pin can be configured to generate an alert signal when one or more warning conditions are detected. Conversion (CONV). This pin can be used as an input signal to control when a power monitor ADC sampling cycle begins. This pin defaults to an alert output at power up. There is no internal pull-up on this pin.
9	10	GPO2/$\overline{\text{ALERT2}}$	General-Purpose Digital Output (GPO2). Alert ($\overline{\text{ALERT2}}$). This pin can be configured to generate an alert signal when one or more warning conditions are detected. This pin defaults to an alert output at power up. There is no internal pull-up on this pin.
10	N/A	NIC	Not Internally Connected. This pin is not internally connected.
11	11	SENSEN	Negative Current Sense Input.
12	12	SENSEP	Positive Current Sense Input.
13	13	VIN	Primary Voltage Monitoring Input. This pin reads back the primary input voltage using the internal ADC. The internal divider allows this pin to directly monitor a 20 V supply. An external divider is required to monitor voltages higher than 20 V.
14	N/A	NIC	Not Internally Connected. This pin is not internally connected.
15	14	GND	Chip Ground. This pin must connect to the lowest potential.
EPAD	N/A	EPAD	Exposed Pad. Solder the exposed pad to the board to improve thermal dissipation. Connect the exposed pad to GND.

[1] N/A means not applicable.

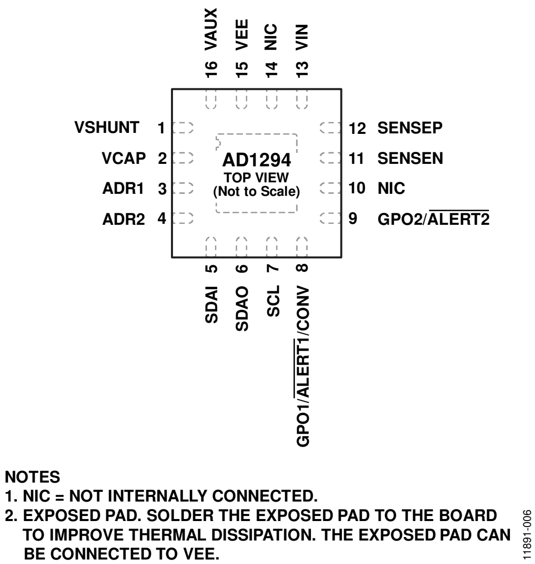

Figure 6. ADM1294 LFCSP Pin Configuration

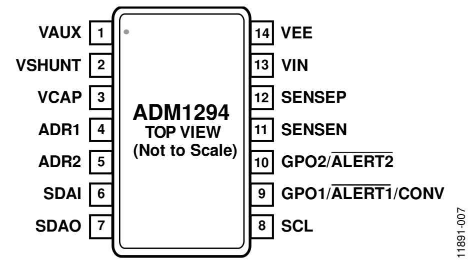

Figure 7. ADM1294 TSSOP Pin Configuration

Table 6. ADM1294 Pin Function Descriptions

Pin No.			
LFCSP	**TSSOP[1]**	**Mnemonic**	**Description**
16	1	VAUX	Auxiliary Voltage Monitoring Input. This pin reads back the auxiliary input voltage using the internal ADC. An external divider is required to monitor voltages higher than 1.2 V.
1	2	VSHUNT	Shunt Regulated Positive Supply to Chip. Connect this pin to the positive supply rail. A shunt resistor in series is required to limit the input current if the supply voltage is higher than the shunt regulation voltage. A 1 μF decoupling capacitor to VEE is recommended on the VSHUNT pin.
2	3	VCAP	Internal Regulated Supply. Place a capacitor with a value of 1 μF or greater on this pin to maintain accuracy.
3	4	ADR1	PMBus Address. This pin can be tied low, tied to VCAP, left floating, or tied low through a resistor. Combine with the ADR2 pin to set up to 16 different PMBus addresses.
4	5	ADR2	PMBus Address. This pin can be tied low, tied to VCAP, left floating, or tied low through a resistor. Combine with the ADR1 pin to set up to 16 different PMBus addresses.
5	6	SDAI	PMBus Serial Data Input. This is a split version of the SDA for easy use with optocouplers. Tie this pin directly to the SDAO pin if a bus split is not required.
6	7	SDAO	PMBus Serial Data Output. This is a split version of the SDA for easy use with optocouplers. Tie this pin directly to the SDAI pin if a bus split is not required.
7	8	SCL	PMBus Serial Clock. Open-drain input. Requires an external resistive pull-up.
8	9	GPO1/$\overline{\text{ALERT1}}$/CONV	General-Purpose Digital Output (GPO1). Alert ($\overline{\text{ALERT1}}$). This pin can be configured to generate an alert signal when one or more warning conditions are detected. Conversion (CONV). This pin can be used as an input signal to control when a power monitor ADC sampling cycle begins. This pin defaults to an alert output at power up. There is no internal pull-up on this pin.
9	10	GPO2/$\overline{\text{ALERT2}}$	General-Purpose Digital Output (GPO2). Alert ($\overline{\text{ALERT2}}$). This pin can be configured to generate an alert signal when one or more warning conditions are detected. This pin defaults to an alert output at power up. There is no internal pull-up on this pin.
10	N/A	NIC	Not Internally Connected. This pin is not internally connected.
11	11	SENSEN	Negative Current Sense Input.
12	12	SENSEP	Positive Current Sense Input.
13	13	VIN	Primary Voltage Monitoring Input. This pin reads back the primary input voltage using the internal ADC. The internal divider allows this pin to directly monitor a 20 V supply. An external divider is required to monitor voltages higher than 20 V.
14	N/A	NIC	Not Internally Connected. This pin is not internally connected.
15	14	VEE	Chip Ground Pin. This pin must connect to the lowest potential.
EPAD	N/A	EPAD	Exposed Pad. Solder the exposed pad to the board to improve thermal dissipation. Connect the exposed pad to VEE.

[1] N/A means not applicable.

TYPICAL PERFORMANCE CHARACTERISTICS

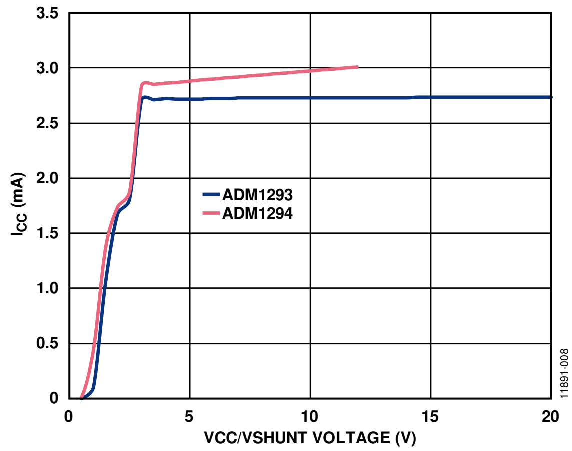

Figure 8. I_{CC} vs. Pin Voltages

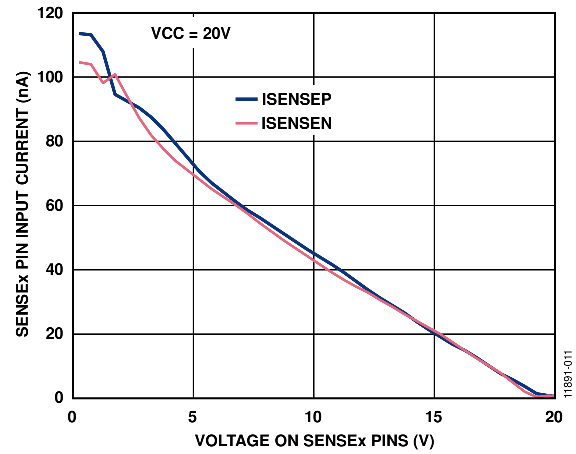

Figure 11. ADM1293 SENSEP/SENSEN Pins Input Current vs. SENSEP and SENSEN Pin Voltage

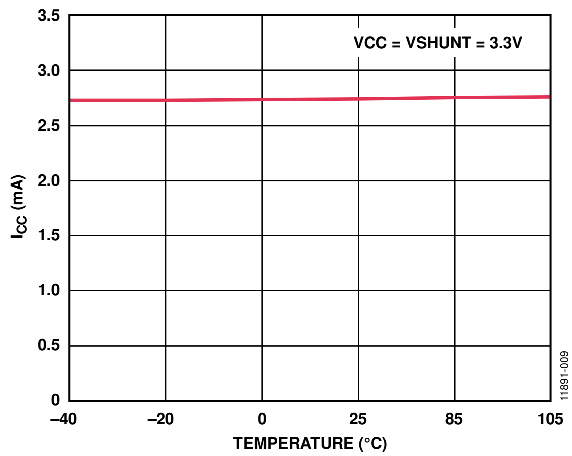

Figure 9. I_{CC} vs. Temperature

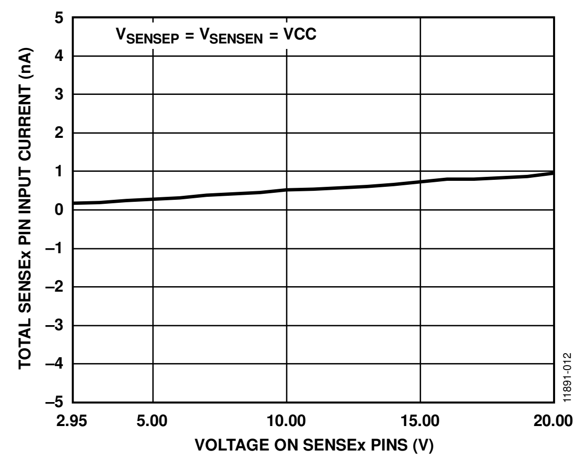

Figure 12. ADM1293 Total SENSEP and SENSEN Pins Input Current vs. SENSEP and SENSEN Pin Voltage

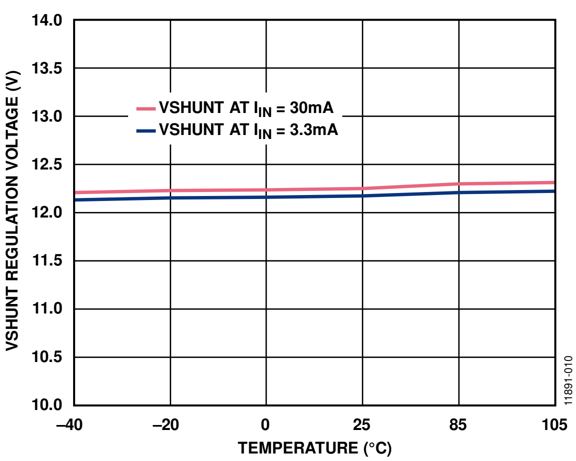

Figure 10. VSHUNT Regulation Voltage vs. Temperature

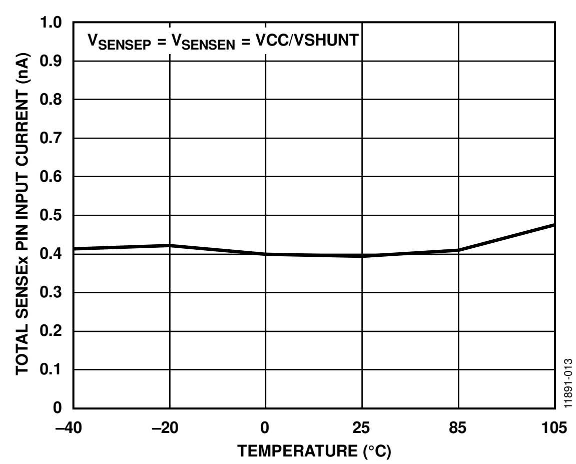

Figure 13. Total SENSEP and SENSEN Input Current vs. Temperature

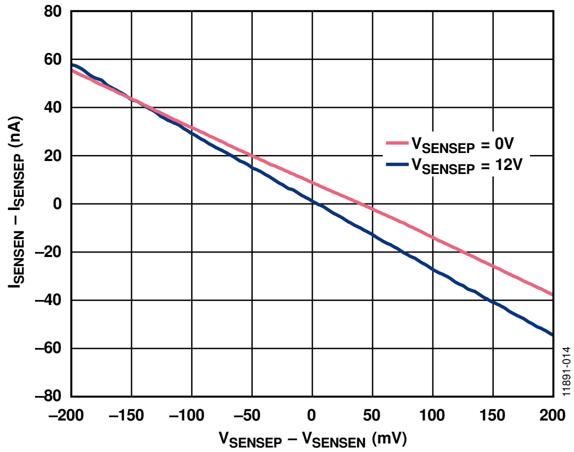

Figure 14. SENSEP and SENSEN Pins Input Current Imbalance vs. SENSEP and SENSEN Pins Differential Voltage

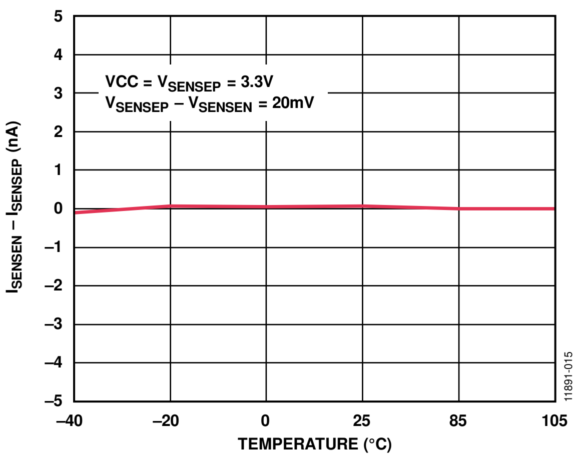

Figure 15. SENSEN and SENSEP Input Current Imbalance vs. Temperature

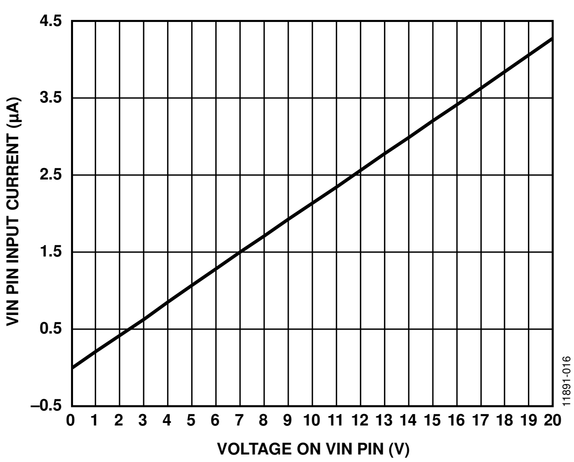

Figure 16. VIN Input Current vs. VIN Pin Voltage, V_{RANGE} = 0 V to 7.4 V or 0 V to 21 V

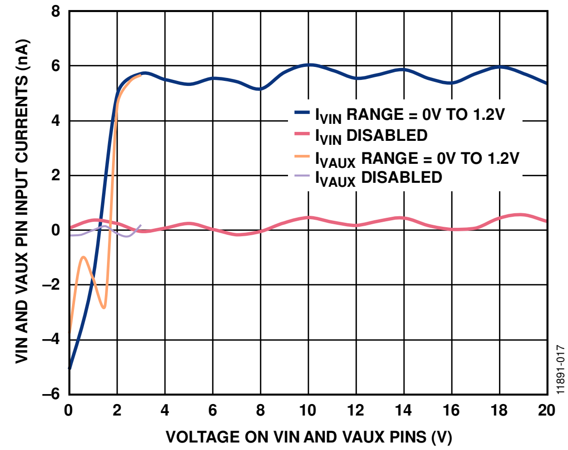

Figure 17. VIN/VAUX Input Currents vs. VIN/VAUX Voltage

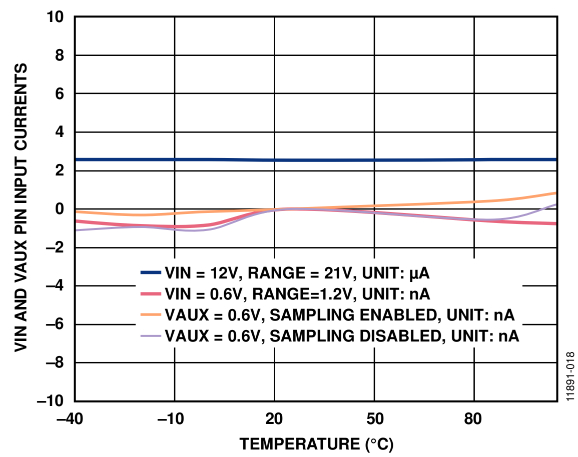

Figure 18. VIN/VAUX Input Currents vs. Temperature

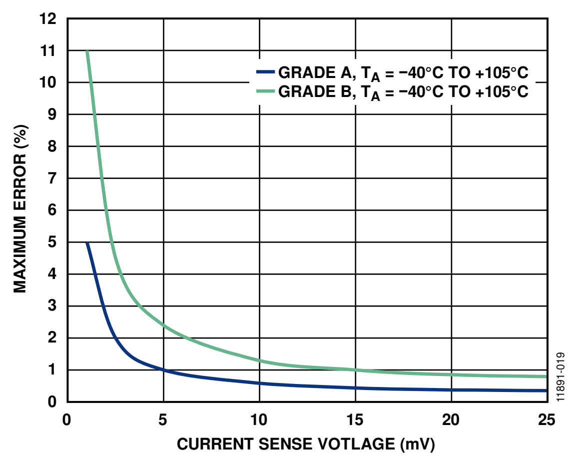

Figure 19. Worst Case Current Sense Error vs. Current Sense Voltage with 128 Sample Averaging, V_{SENSEP} = 0 V to 18 V, over Full Operating Temperature Range

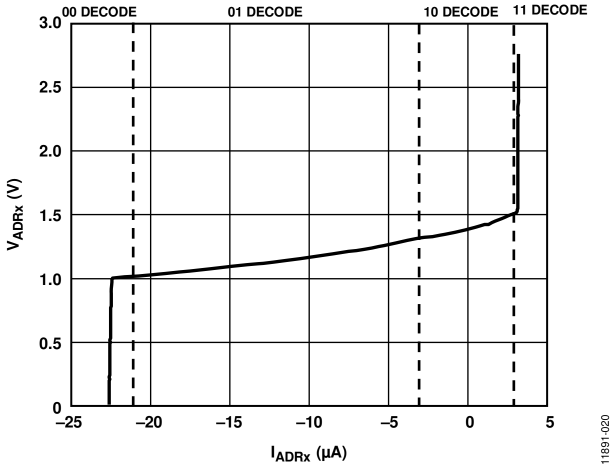

Figure 20. V_{ADRx} vs. I_{ADRx}

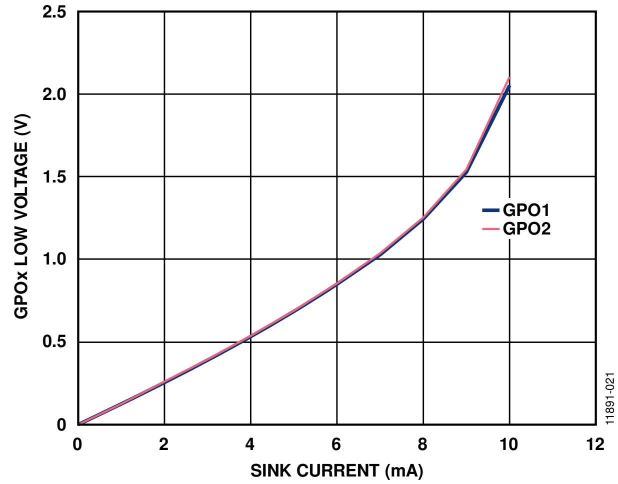

Figure 21. GPOx Output Low Voltage vs. Sink Current

THEORY OF OPERATION

POWERING THE ADM1293

A supply voltage from 2.95 V to 20 V is required to power the ADM1293 via the VCC pin. The VCC pin provides the majority of the bias current for the device.

To ensure correct operation of the ADM1293, the voltage on the VCC pin must be greater than or equal to the voltage on the SENSEP pin. No sequencing of the VCC and SENSEP rails is necessary. The voltage on SENSEP pin can drop to as low as 0 V for normal operation, provided that a voltage of at least 2.95 V is connected to the VCC pin. For a monitoring supply rail above 3 V, connect both the VCC pin and the SENSEP pin to the same voltage rail via separate traces to prevent accuracy loss in the sense voltage measurement (see Figure 22).

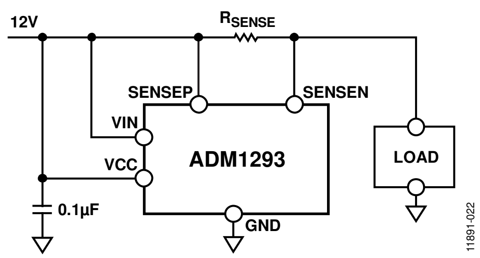

Figure 22. Powering the ADM1293 from a Monitoring Rail

To protect the ADM1293 from unnecessary resets due to transient supply glitches, add an external resistor, as shown in Figure 23. Choose the values of the resistor in conjunction with the decoupling capacitor such that a time constant is provided that can filter any expected glitches. However, use a resistor that is small enough to keep voltage drops due to quiescent current to a minimum.

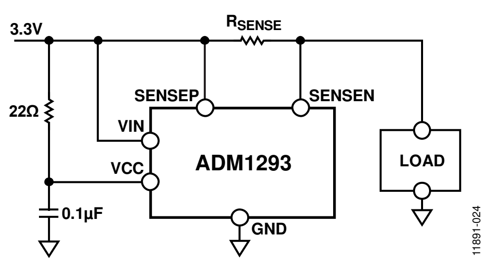

Figure 23. Transient Glitch Protection Using an RC Network

For monitoring rails below 2.95 V to 0 V, a separate supply is required to provide power to the ADM1293, as shown in Figure 24.

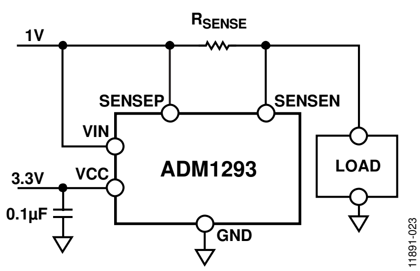

Figure 24. Powering the ADM1293 from a Separate Supply

POWERING THE ADM1294

The internal shunt regulator allows ADM1294 to be powered directly from a high voltage source. The shunt regulator is disabled when the supply voltage on the VSHUNT pin is below shunt regulation voltage level. After the supply rises above the shunt regulation level, the shunt regulator starts to regulate the voltage on the VSHUNT pin to approximately 12 V. An external current limiting resistor is required to limit the current entering the VSHUNT pin, as shown in Figure 25.

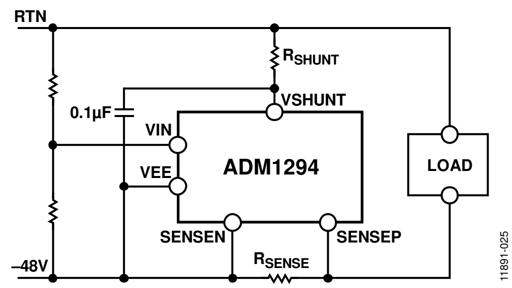

Figure 25. Powering the ADM1294 in a –48 V System

The shunt regulator also maintains a stable supply voltage during transient events on the input supply, protecting the ADM1294 from experiencing overvoltage stress.

Shunt Current Limiting Resistor Selection

The current limiting resistor value must be calculated correctly to provide sufficient current/voltage to power the ADM1294, while keeping the power low enough to prevent the IC from overheating.

Calculate the current limiting resistance upper limit by

$$R_{SHUNT\_MAX} = \frac{V_{INPUT\_MIN} - V_{OP4\_MIN}}{I_{CC4\_MAX}}$$

where:
V_{INPUT_MIN} is the minimum supply input voltage before the current limiting resistor.
V_{OP4_MIN} is the minimum operating voltage of the ADM1294.
I_{CC4_MAX} is the maximum supply current of the ADM1294.

When the ADM1294 is in shunt regulation mode, if the supply voltage decreases to a point where the current flowing through the current limiting resistor is not enough to power the IC, the ADM1294 automatically exits the fixed voltage regulation mode and enters into current regulation mode. In current regulation mode, the device lowers the voltage on the VSHUNT pin to maintain the current required to power itself. The VSHUNT pin voltage can be decreased to the minimum operating voltage of the ADM1294. The smooth transition in and out of shunt regulation mode helps to increase the R_{SHUNT_MAX} value, and as a result, extends the range of the suitable current limiting resistors.

Calculate the current limiting resistance lower limit by

$$R_{SHUNT\_MIN} = \frac{V_{INPUT\_MAX} - V_{SHUNT\_MAX}}{I_{SHUNT\_MAX}}$$

where:
V_{INPUT_MAX} is the maximum supply input voltage before the current limiting resistor.
V_{SHUNT_MAX} is the maximum shunt regulation voltage of the ADM1294.
I_{SHUNT_MAX} is the maximum current allowed into the shunt regulator. It is related to the maximum allowable power dissipation of the device in a given design, which is limited by the maximum junction temperature of the device.

$$I_{SHUNT\_MAX} = \frac{P_{DISS\_MAX}}{V_{SHUNT\_MAX}}$$

and

$$P_{DISS\_MAX} = \frac{T_{J\_MAX} - T_{A\_MAX}}{\theta_{JA}}$$

where:
T_{J_MAX} is the maximum junction temperature of the ADM1294.
T_{A_MAX} is the maximum ambient temperature of the system.
θ_{JA} is the junction to ambient thermal resistance of the ADM1294.

Example 1: A system has a −48 V supply that can vary between −35 V to −75 V. The system maximum ambient temperature is 85°C. An ADM1294 in an LFCSP package monitors the supply. It is soldered on a JEDEC 2S2P board, with a minimal footprint and a 3 × 3 thermal via array.

Note that because the ADM1294 uses low-side sensing, as shown in Figure 25, all of the voltages are expressed by referencing to the negative supply input.

$$R_{SHUNT\_MAX} = \frac{V_{INPUT\_MIN} - V_{OP4\_MIN}}{I_{CC4\_MAX}} = \frac{35\ \text{V} - 2.95\ \text{V}}{3.6\ \text{mA}} = 8.9\ \text{k}\Omega$$

$$P_{DISS\_MAX} = \frac{T_{JMAX} - T_{AMAX}}{\theta_{JA}} = \frac{110°\text{C} - 85°\text{C}}{50.58°\text{C}} = 0.494\ \text{W}$$

$$I_{SHUNT\_MAX} = \frac{P_{DISS\_MAX}}{V_{SHUNT\_MAX}} = \frac{0.494\ \text{W}}{13\ \text{V}} = 38\ \text{mA}$$

$$R_{SHUNT\_MIN} = \frac{V_{INPUT\_MIN} - V_{SHUNT\_MAX}}{I_{SHUNT\_MAX}} = \frac{75\ \text{V} - 13\ \text{V}}{38\ \text{mA}} = 1.63\ \text{k}\Omega$$

The user can select a current limiting resistor with a value between 8.9 kΩ and 1.63 kΩ. It is recommended to select one at the higher end to reduce power dissipation. After a value is chosen, for example, 7.5 kΩ, the user must check its worst-case power dissipation. In this example, the worst case is when the input supply is at its maximum value.

The worst case power dissipation across the current limiting resistor is

$$P_{R\_WORST} = \frac{(V_{INPUT\_MAX} - V_{SHUNT\_MIN})^2}{R_{SHUNT}} = \frac{(75\ \text{V} - 11.5\ \text{V})^2}{7.5\ \text{k}\Omega} = 0.54\ \text{W}$$

The user may need multiple resistors in series or in parallel to meet the power level that is required.

Example 2: A system has a 180 V supply that can vary between −160 V to +200 V. The system maximum ambient temperature is 105°C. An ADM1294 in the LFCSP package monitors the supply. It is soldered on a JEDEC 2S2P board, with a minimal footprint and a 3 × 3 thermal via array.

$$R_{SHUNT\_MAX} = \frac{V_{INPUT\_MIN} - V_{OP4\_MIN}}{I_{CC4\_MAX}} = \frac{160\ \text{V} - 2.95\ \text{V}}{3.6\ \text{mA}} = 43.6\ \text{k}\Omega$$

$$P_{DISS\_MAX} = \frac{T_{JMAX} - T_{AMAX}}{\theta_{JA}} = \frac{110°\text{C} - 105°\text{C}}{50.58°\text{C}} = 0.1\ \text{W}$$

$$I_{SHUNT\_MAX} = \frac{P_{DISS\_MAX}}{V_{SHUNT\_MAX}} = \frac{0.1\ \text{W}}{13\ \text{V}} = 7.7\ \text{mA}$$

$$R_{SHUNT\_MIN} = \frac{V_{INPUT\_MIN} - V_{SHUNT\_MAX}}{I_{SHUNT\_MAX}} = \frac{200\ \text{V} - 13\ \text{V}}{7.7\ \text{mA}} = 24.3\ \text{k}\Omega$$

The user can select a current limiting resistor with a value between 43.6 kΩ and 24.3 kΩ. This example uses a 39 kΩ resistor.

The worst case power dissipation across the current limiting resistor is:

$$P_{R\_WORST} = \frac{(V_{INPUT\_MAX} - V_{SHUNT\_MIN})^2}{R_{SHUNT}} = \frac{(200\ \text{V} - 11.5\ \text{V})^2}{39\ \text{k}\Omega} = 0.91\ \text{W}$$

The user may need multiple resistors in series or in parallel to meet the power level that is required.

Additional Options of Powering the ADM1294

If the supply input range is too wide to choose a suitable current limiting resistor or causing too much power loss, a source follower circuit can be used to generate the supply voltage for the ADM1294, as shown in Figure 26.

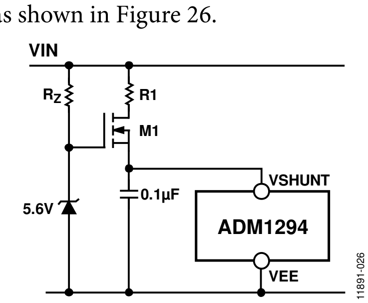

Figure 26. Powering the ADM1294 Through a Source Follower Circuit

In this circuit, R_Z limits the current into the Zener diode, the NMOSFET (or an NPN transistor in the case of an emitter follower) buffers the voltage created by the Zener to supply the ADM1294. The NMOS must be able to withstand the voltage drop of the supply voltage and the worst case power dissipation. The worst case power dissipation is expressed as

$$P_{FET\_WORST} = (V_{INPUT\_MAX} - V_{ZENER} + V_{TH}) \times I_{CC4\_MAX}$$

where:
V_{INPUT_MAX} is the maximum supply input voltage before the current limiting resistor.
V_{ZENER} is the Zener diode reverse breakdown voltage.
V_{TH} is the threshold of the NMOSFET or base to emitter voltage in the case of an NPN emitter follower.
I_{CC4_MAX} is the maximum supply current of the ADM1294.

Another option to supply power to the ADM1294 is to use the ADM3260 I²C and a power isolator, as shown in Figure 27.

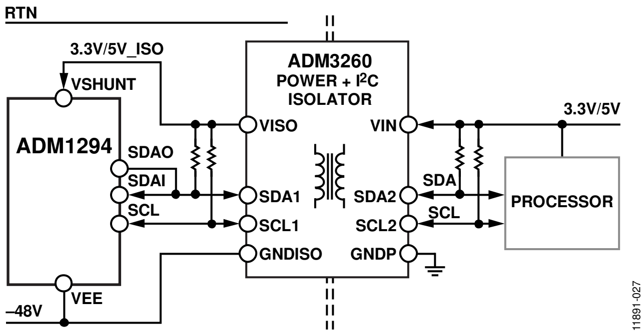

Figure 27. Powering the ADM1294 Using the ADM3260 I²C and Power Isolator

Isolation is usually required in −48 V systems because there can be a large voltage difference between different ground planes in the system. The ADM1294 is referenced to −48 V, whereas the microcontroller unit (MCU) is usually referenced to 0 V. In almost all cases, the I²C signals must be isolated. Any other ADM1294 digital input and output signals that enter or exit the MCU must also be isolated.

The ADM3260 isolator can transfer power and a bidirectional I²C digital signal across an isolation barrier of up to 2.5 kV. The output voltage from the ADM3260 can power the ADM1294 directly as well as providing pull-up resistance for the I²C bus lines. See the ADM3260 data sheet for more information about this device.

OPTIONAL POWER MONITOR INPUTS FILTERING

The internal ADC on both the ADM1293 and ADM1294 uses the current sense input pins, SENSEP and SENSEN, to measure the load current. Additional antialiasing filtering can be placed on the power monitor pins to reduce current monitoring noise. Similarly, RC filters can be used on the voltage sensing inputs, VIN and VAUX, to reduce voltage sensing noise.

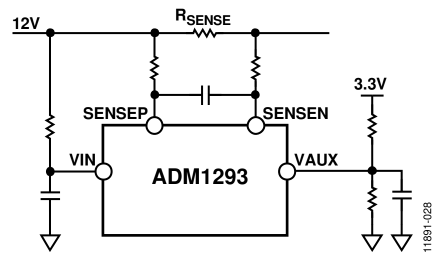

Figure 28. Power Monitor Input Filters for the ADM1293

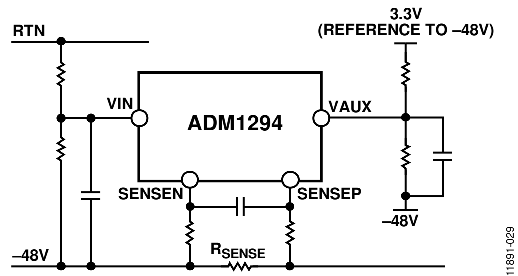

Figure 29. Power Monitor Input Filters for the ADM1294

POWER MONITOR

The ADM1293/ADM1294 feature an integrated ADC that accurately measures the current sense voltage, the input voltage, and optionally, an auxiliary input voltage. The measured input voltage, and current being delivered to the load are multiplied together to give a power value that can be read back. Each power value is also added to an energy accumulator that can be read back to allow an external device to calculate the energy consumption of the load.

The ADM1293/ADM1294 can report the measured current, input voltage, and auxiliary voltage. The PEAK_VIN, PEAK_VAUX, MIN_IOUT, MAX_IOUT, MIN_PIN, and MAX_PIN commands are used to read the peak readings since the value was last cleared.

An averaging function of up to 128× is provided for the voltage, current, and power. This function allows a number of samples to be averaged together by the ADM1293/ADM1294. This function reduces the need for postprocessing of sampled data by the host processor. The number of samples that can be averaged is 2^N, where N is in the range of 0 to 7.

The power averaging is calculated independently of voltage and current averaging value to give the most accurate result. For example, if the two consecutive voltage measurement results are 12.00 V and 12.08 V, and the corresponding current measurement results are 10.0 A and 10.8 A, and the 2× averaging results for voltage and current are 12.04 V and 10.4 A, respectively, then the 2× power averaging result is

$$\frac{12 \times 10 + 12.08 \times 10.8}{2} = 125.232 \text{ W}$$

Not 12.04 × 10.4 = 125.216 W.

The power monitor current sense amplifier is bipolar and can measure both positive and negative currents. The current sense amplifier has four selectable input ranges: ±25 mV, ±50 mV, ±100 mV, and ±200 mV. Operating closer to the full range results in higher current measurement accuracy and higher insertion loss across the sense resistor.

The power monitor voltage sensing input, VIN, has three selectable input ranges: 0 V to 1.2 V, 0 V to 7.6 V, and 0 V to 21 V. Configuring the VIN pin to the 0 V to 1.2 V range gives the pin a direct connection to the internal ADC, and results in minimum leakage current into the pin. It is the recommended configuration for use with external resistor dividers. The VAUX input has a fixed 0 V to 1.2 V voltage monitoring range. Both the current and voltage sensing ranges can be configured using the PMON_CONFIG command.

The two basic modes of operation for the power monitor are single shot and continuous. In single shot mode, the ADC samples the input voltage and current a number of times, depending on the averaging value selected by the user. The ADM1293/ADM1294 return a single value corresponding to the average voltage and current measured. When configured for continuous mode, the power monitor continuously samples the voltage and current, making the most recent sample available to be read.

Single shot mode can be triggered in a number of ways. The simplest is by selecting the single shot mode using the PMON_CONFIG command and writing to the convert bit using the PMON_CONTROL command. The convert bit can also be written as part of a PMBus group command. Using a group command allows multiple devices to be written to as part of the same I^2C bus transaction, with all devices executing the command when the stop condition appears on the bus. In this way, several devices can be triggered to sample at the same time.

When the GPO1/$\overline{\text{ALERT1}}$/CONV pin is set to convert (CONV) mode, an external hardware signal triggers the single shot sampling of one or more parts at the same time.

Each time that current sense and input voltage measurements are taken, a power calculation is performed that multiplies the two measurements together. This can be read from the device using the READ_PIN command, returning the input power.

At the same time, the calculated power value is added to the power accumulator register that may increment a rollover counter if the value exceeds the maximum accumulator value. The power accumulator register also increments a power sample counter.

The power accumulator and power sample counter are read using the same READ_EIN command to ensure that the accumulated value and sample count are from the same point in time. The bus host reading the data assigns a time stamp when the data is read. By calculating the time difference between consecutive uses of READ_EIN and determining the delta in power consumed, it is possible for the host to determine the total energy consumed over that period.

Table 7. ADM1293 and ADM1294 Model Options

Model	Build in Shunt Regulator	Monitoring Accuracy Grade	Energy Meter Implementation
ADM1293-1A	No	A	Custom
ADM1293-1B	No	B	Custom
ADM1294-1A	Yes	A	Custom
ADM1294-1B	Yes	B	Custom
ADM1293-2A	No	A	PMBus Standard
ADM1294-2A	Yes	A	PMBus Standard

PMBus INTERFACE

The I²C bus is a common, simple serial bus used by many devices to communicate. It defines the electrical specifications, the bus timing, the physical layer, and some basic protocol rules.

SMBus is based on I²C and aims to provide a more robust and fault tolerant bus. Functions such as bus timeout and packet error checking are added to help achieve this robustness, along with more specific definitions of the bus messages that read and write data to devices on the bus.

PMBus is layered on top of SMBus and, in turn, on I²C. Using the SMBus defined bus messages, PMBus defines a set of standard commands that control a device that is part of a power chain.

The ADM1293/ADM1294 command set is based upon the *PMBus™ Power System Management Protocol Specification*, Part I and Part II, Revision 1.2. This version of the standard is provides a common set of commands for communicating with dc-to-dc type devices. However, many of the standard PMBus commands can be mapped directly to the functions of a digital power monitor.

Part I and Part II of the PMBus standard describe the basic commands and how they are used in a typical PMBus setup. The following sections describe how the PMBus standard and the ADM1293/ADM1294 specific commands are used.

DEVICE ADDRESSING

The PMBus device address is seven bits in size. There are no default addresses for any of the models; any device can be programmed to any of 16 possible addresses. Two quad level ADRx pins map to the 16 possible device addresses.

Table 8. ADRx Pin Connections

ADRx State	ADRx Pin Connection
Low	Connect to GND
Resistor	150 kΩ resistor to GND
High-Z	No connection (floating)
High	Connect to VCAP

Table 9. Setting I²C Addresses via the ADR1 Pin and the ADR2 Pin

Base Address (Binary)	ADR2 Pin State	ADR1 Pin State	ADR2 Logic State	ADR1 Logic State	Address (Binary)[1]	Address (Hex)
011	Ground	Ground	00	00	0110000X	0x30
	Ground	Resistor to ground	00	01	0110001X	0x31
	Ground	Floating	00	10	0110010X	0x32
	Ground	High	00	11	0110011X	0x33
	Resistor to ground	Ground	01	00	0110100X	0x34
	Resistor to ground	Resistor to ground	01	01	0110101X	0x35
	Resistor to ground	Floating	01	10	0110110X	0x36
	Resistor to ground	High	01	11	0110111X	0x37
	Floating	Ground	10	00	0111000X	0x38
	Floating	Resistor to ground	10	01	0111001X	0x39
	Floating	Floating	10	10	0111010X	0x3A
	Floating	High	10	11	0111011X	0x3B
	High	Ground	11	00	0111100X	0x3C
	High	Resistor to ground	11	01	0111101X	0x3D
	High	Floating	11	10	0111110X	0x3E
	High	High	11	11	0111111X	0x3F

[1] X means don't care.

SMBus PROTOCOL USAGE

All I²C transactions on the ADM1293/ADM1294 are performed using SMBus defined bus protocols. The following SMBus protocols are implemented by the ADM1293/ADM1294:

- Send byte
- Receive byte
- Write byte
- Read byte
- Write word
- Read word
- Block read

PACKET ERROR CHECKING

The ADM1293/ADM1294 PMBus interface supports the use of the packet error checking (PEC) byte, which is defined in the SMBus standard. The PEC byte is transmitted by the ADM1293/ADM1294 during a read transaction or sent by the bus host to the ADM1293/ADM1294 during a write transaction. The ADM1293/ADM1294 support the use of PEC with all the SMBus protocols that it implements.

The use of the PEC byte is optional. The bus host can decide whether to use the PEC byte with the ADM1293/ADM1294 on a message by message basis. There is no need to enable or disable PEC in the ADM1293/ADM1294.

The PEC byte is used by the bus host or the ADM1293/ADM1294 to detect errors during a bus transaction, depending on whether the transaction is a read or a write. If the host determines that the PEC byte read during a read transaction is incorrect, it can decide to repeat the read if necessary. If the ADM1293/ADM1294 determine that the PEC byte sent during a write transaction is incorrect, it ignores the command (does not execute it) and sets a status flag.

Within a group command, the host can choose whether to send a PEC byte as part of the message to the ADM1293/ADM1294.

PARTIAL TRANSACTIONS ON I²C BUS

If there is a partial transaction on the I²C bus, for example, spurious data interpreted as a start command, the ADM1293/ADM1294 I²C bus does not lock up, thinking it is in the middle of an I²C transaction. A new start command is recognized even in the middle of another transaction.

SMBus MESSAGE FORMATS

Figure 30 to Figure 38 show all of the SMBus protocols that are supported by the ADM1293/ADM1294, together with the PEC variant. In these figures, unshaded cells indicate that the bus host is actively driving the bus; shaded cells indicate that the ADM1293/ADM1294 is driving the bus.

Figure 30 to Figure 38 use the following abbreviations:

- S is the start condition.
- Sr is the repeated start condition.
- P is the stop condition.
- R is the read bit.
- $\overline{W}$ is the write bit.
- A is the acknowledge bit (0).
- $\overline{A}$ is the acknowledge bit (1).

A, the acknowledge bit, is typically active low (Logic 0) if the transmitted byte is successfully received by a device. However, when the receiving device is the bus master, the acknowledge bit for the last byte read is a Logic 1, indicated by $\overline{A}$.

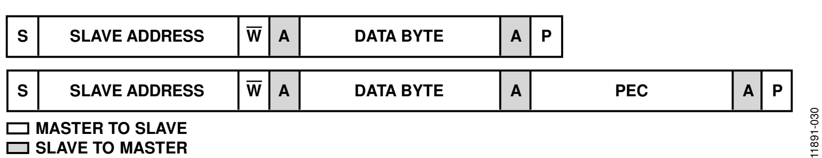

Figure 30. Send Byte and Send Byte with PEC

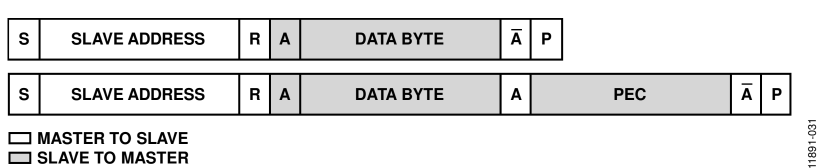

Figure 31. Receive Byte and Receive Byte with PEC

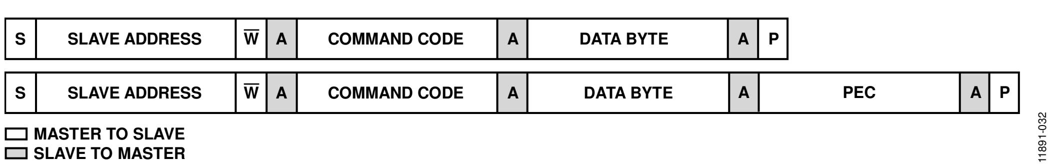

Figure 32. Write Byte and Write Byte with PEC

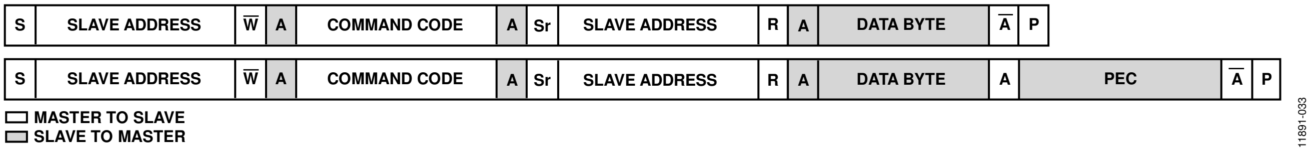

Figure 33. Read Byte and Read Byte with PEC

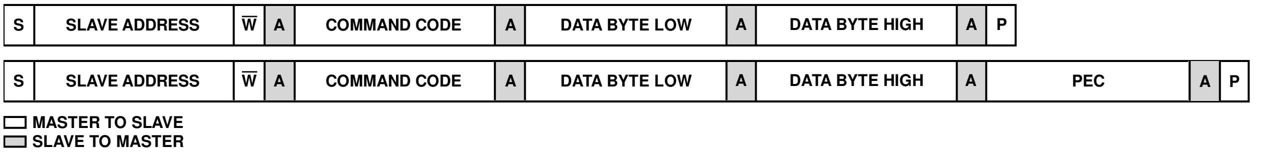

Figure 34. Write Word and Write Word with PEC

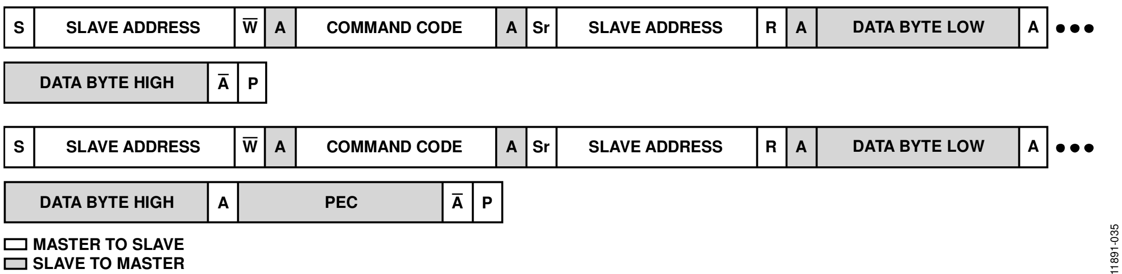

Figure 35. Read Word and Read Word with PEC

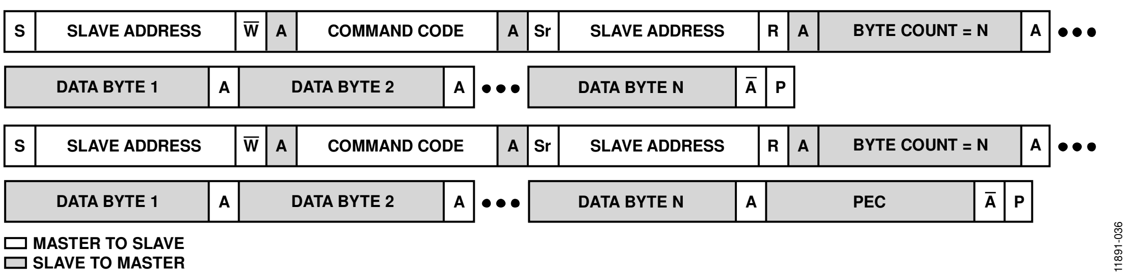

Figure 36. Block Read and Block Read with PEC

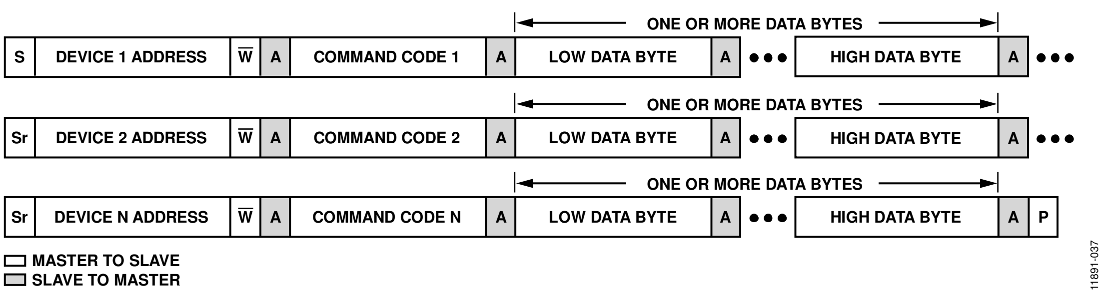

Figure 37. Group Command

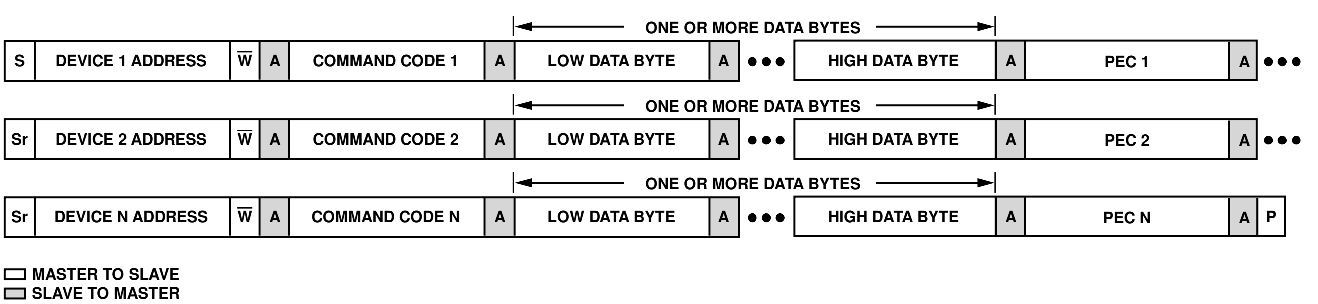

Figure 38. Group Command with PEC

GROUP COMMANDS

The PMBus standard defines what are known as group commands. Group commands are single bus transactions that send commands or data to more than one device at the same time. Each device is addressed separately, using its own address; there is no special group command address. A group command transaction can contain only write commands that send data to a device. It is not possible to use a group command to read data from devices.

From an I²C protocol point of view, a normal write command consists of the following:

- I²C start condition
- Slave address bits and a write bit (followed by an acknowledge from the slave device)
- One or more data bytes (each of which is followed by an acknowledge from the slave device)
- I²C stop condition to end the transaction

A group command differs from a nongroup command in that after the data is written to one slave device, a repeated start condition is placed on the bus, followed by the address of the next slave device and data. This continues until all of the devices have been written to, at which point the stop condition is placed on the bus by the master device.

The format of a group command and a group command with PEC is shown in Figure 37 and Figure 38.

Each device that is written to as part of the group command does not immediately execute the command written. The device must wait until the stop condition appears on the bus. At that point, all devices execute their commands at the same time.

Using a group command, it is possible, for example, to turn multiple PMBus devices on or off simultaneously. In the case of the ADM1293/ADM1294, it is also possible to issue a power monitor command that initiates a conversion, causing multiple ADM1293/ADM1294 devices to sample together at the same time.

INFORMATION COMMANDS

CAPABILITY Command

Host processors can use the CAPABILITY command to determine the I²C bus features that are supported by the ADM1293/ADM1294. The features that can be reported include the maximum bus speed, whether the device supports the PEC byte, and the SMBALERT reporting function.

PMBUS_REVISION Command

The PMBUS_REVISION command reports the version of Part I and Part II of the PMBus standard.

MFR_ID, MFR_MODEL, and MFR_REVISION Commands

The MFR_ID, MFR_MODEL, and MFR_REVISION commands return ASCII strings that facilitate detection and identification of the ADM1293/ADM1294 on the bus.

These commands are read using the SMBus block read message type. This message type requires that the ADM1293/ADM1294 return a byte count corresponding to the length of the string data that is to be read back.

STATUS COMMANDS

The ADM1293/ADM1294 provide a number of status bits that are used to report warnings detected. These status bits are located in four different registers that are arranged in a hierarchy. The STATUS_BYTE and STATUS_WORD commands provide 8 bits and 16 bits of high level information, respectively. The STATUS_BYTE and STATUS_WORD commands contain the most important status bits, as well as pointer bits that indicate whether any of the three other status registers must be read for more detailed status information.

Warnings in the ADM1293/ADM1294 are generated from a digital comparison between the power monitor measurements to the threshold values set by the various limit commands. A warning can be used to control the state of the $\overline{\text{ALERTx}}$ output pins, or to generate a $\overline{\text{SMBALERT}}$ interrupt signal through one of the $\overline{\text{ALERTx}}$ pins.

When a status bit is set, it always means that the status condition is active or was active at some point in the past. When a warning bit is set, it is latched until it is explicitly cleared using the CLEAR_FAULTS command. Some other status bits are live, that is, they always reflect a status condition and are never latched.

STATUS_BYTE and STATUS_WORD Commands

The STATUS_BYTE and STATUS_WORD commands can be used to obtain a snapshot of the overall device status. These commands indicate whether it is necessary to read more detailed information using the other status commands.

The low byte of the word returned by the STATUS_WORD command is the same byte returned by the STATUS_BYTE command. The high byte of the word returned by the STATUS_WORD command provides a number of bits that can be used to determine which of the other status commands must be issued to obtain all active status bits.

STATUS_INPUT Command

The STATUS_INPUT command returns a number of bits relating to voltage warnings on the VIN pin as well as the overpower warning.

STATUS_IOUT Command

The STATUS_IOUT command returns a number of bits relating to current warnings on the monitoring rail.

STATUS_MFR_SPECIFIC Command

The STATUS_MFR_SPECIFIC command is a standard PMBus command, but the contents of the byte returned are specific to the ADM1293/ADM1294. It returns a number of bits relating to voltage warnings on the VAUX pin.

CLEAR_FAULTS Command

The CLEAR_FAULTS command clears warnings bits when they are set. Warning bits are latched when they are set. In this way, a host can read the bits any time after the warning condition occurs and determine which problem actually occurred.

If the CLEAR_FAULTS command is issued and the warning condition is no longer active, the status bit is cleared. If the condition is still active—for example, if the input voltage is below the undervoltage threshold of the VIN pin—the CLEAR_FAULTS command attempts to clear the status bit, but that status bit is immediately set again.

GPOX AND ALERTx PIN SETUP COMMANDS

Two multipurpose pins are provided on the ADM1293/ ADM1294: GPO1/ALERT1/CONV and GPO2/ALERT2.

These pins can be configured over the PMBus in one of three output modes, as follows:

- General-purpose digital output
- Output for generating an SMBALERT when one or more warning status bits become active in the PMBus status registers
- Digital comparator

In digital comparator mode, the current, voltage, and power warning thresholds are compared to the values read or calculated by the ADM1293/ADM1294. The comparison result sets the output high or low according to whether the value is greater or less than the warning threshold that has been set.

For an example of how to configure these pins to generate an SMBALERT and how to respond and clear the condition, see the Example Use of SMBus ARA section.

ALERT1_CONFIG and ALERT2_CONFIG Commands

Using combinations of bit masks, the ALERT1_CONFIG and ALERT2_CONFIG commands select the status bits that, when set, generate an SMBALERT signal to a processor, or control the digital comparator mode. The GPO1/ALERT1/CONV and GPO2/ALERT2 pins must be configured in SMBALERT or digital comparator mode in the DEVICE_CONFIG register.

If configured in GPO mode, the pin is under software control. If this mode is set, the SMBALERT masking bits are ignored.

POWER MONITOR COMMANDS

The ADM1293/ADM1294 provide a high accuracy, 12-bit current, voltage, and power monitor. The power monitor can be configured in a number of different modes of operation and can run in either continuous mode or single shot mode with a number of different sample averaging options.

The power monitor can measure the following quantities:

- Input voltage (VIN)
- Output current (IOUT)
- Auxiliary input voltage (VAUX)

The following quantities are then calculated:

- Input power (PIN)
- Energy flow in forward direction (EIN)
- Energy flow in reverse direction (EOUT)

PMON_CONFIG Command

The power monitor can run in a number of different modes. The PMON_CONFIG command is used to set up the power monitor.

The settings that can be configured are as follows:

- Single shot or continuous sampling
- VIN/VAUX sampling enable/disable
- Current and voltage sample averaging
- Power sample averaging
- Simultaneous sampling enable/disable
- VIN monitoring range selection
- Current monitoring range selection

Modifying the power monitor settings while the power monitor is sampling is not recommended. To ensure correct operation of the device and to avoid any potential spurious data or the generation of status alerts, stop the power monitor before changing any of these settings.

PMON_CONTROL Command

Power monitor sampling can be initiated via hardware or via software using the PMON_CONTROL command. This command can be used with single shot or continuous mode.

READ_VIN, READ_VAUX, and READ_IOUT Commands

The ADM1293/ADM1294 power monitor always measures the voltage developed across the sense resistor to provide a current measurement. ADM1293/ADM1294 supports bidirectional current monitoring and the data returned by the READ_IOUT command is expressed in twos complement format with the MSB indicating the direction of the current flow. A MSB of 0 indicates positive current flow (from the SENSEP pin to the SENSEN pin), and a MSB of 1 indicates reverse current flow (from the SENSEN pin to the SENSEP pin).

The input voltage measurement from the SENSEP pin is also enabled by default. The auxiliary input voltage present on the VAUX pin is available if enabled with the PMON_CONFIG command.

READ_PIN, READ_PIN_EXT, READ_EIN, and READ_EIN_EXT Commands

The 12-bit VIN input voltage and 12-bit IOUT current measurement values are multiplied by the ADM1293/ADM1294 to give the input power value. This is accomplished by using fixed point arithmetic, and produces a 24-bit value. It is assumed that the numbers are in the 12.0 format, meaning that there is no fractional part.

This 24-bit extended precision power value can be read from the ADM1293/ADM1294 using the READ_PIN_EXT command.

The 16 most significant bits of the 24-bit value can be read using the READ_PIN command.

Similar to READ_IOUT, both the READ_PIN and the READ_PIN_EXT commands are expressed in twos complement format with the MSB indicating the direction of the power flow.

READ_EIN, READ_EIN_EXT, READ_EOUT, and READ_EOUT_EXT Commands

There are two sets of power accumulators inside the ADM1293/ADM1294 to support bidirectional energy metering function.

The forward flowing power data (from the SENSEP pin to the SENSEN pin, with an MSB of 0) is accumulated in the READ_EIN register and the negative flowing power data (from the SENSEN pin to the SENSEP pin, with an MSB of 1) is accumulated in the READ_EOUT register.

Each time a power calculation is performed, the 24-bit power value is added to a corresponding unsigned 24-bit energy accumulator register.

Each time this energy accumulator register rolls over from 0xFFFFFF to 0x000000, a 16-bit rollover counter is incremented. The rollover counter is straight binary, with a maximum value of 0xFFFF before it rolls over.

A 24-bit straight binary power sample counter is also incremented by 1 each time a power value is calculated and added to the energy accumulator.

These registers can be read back either in standard data format by the READ_EIN and the READ_EOUT commands, or extended precision data format by the READ_EIN_EXT and the READ_EOUT_EXT commands, depending on the level of accuracy required for the energy accumulator and the desire to limit the frequency of reads from the ADM1293/ADM1294.

A bus host can read these values, and by calculating the delta in the power accumulated, the delta in the number of samples, and the time delta since the last read, the host can calculate the average power since the last read, as well as the energy consumed since the last read.

The time delta is calculated by the bus host based on when it sends its commands to read from the device, and is not provided by the ADM1293/ADM1294.

To avoid data loss, the bus host must read at a rate that ensures the rollover counter does not wrap around more than once, and if the counter does wrap around, that the next value read for P_{IN} is less than the previous one.

The READ_EIN and READ_EOUT commands return the top 16 bits of the energy accumulator, the lower 8 bits of the rollover counter, and the full 24 bits of the sample counter.

The READ_EIN_EXT and READ_EOUT_EXT commands return the full 24 bits of the energy accumulator, the full 16 bits of the rollover counter, and the full 24 bits of the sample counter. The use of the longer rollover counter means that the time interval between reads of the device can be increased from seconds to minutes, without losing any data.

By disabling VIN sampling, a constant value of 1 is assigned to the VIN register. This allows IOUT data to be duplicated in the PIN register, as PIN = IOUT × 1 = IOUT and transforms the power accumulators to current accumulators/coulomb counters.

READ_EIN and READ_EOUT Commands in the PMBus Standard

The definition and implementation of the READ_EIN and READ_EOUT commands on the ADM1293/ADM1294 devices are slightly different from the ones described in the PMBus Standard. Pay special attention to the differences to avoid a calculation error.

In terms of the definition, the READ_EIN and READ_EOUT commands described in the PMBus standard are used to return the accumulated power values entering and then exiting the PMBus device. Together they allow the host to calculate the power and energy consumption of the PMBus device. This is useful for devices with dynamic power loss such as a dc-to-dc converter.

As dedicated power monitors, the power consumption of the ADM1293/ADM1294 devices is fairly constant and generally very small compared to the power they are trying to monitor. Therefore, instead of monitoring their own power consumption, the READ_EIN and READ_EOUT commands on the ADM1293/ADM1294 are designed to return the accumulated bidirectional power data on the monitored supply rail. They allow the user to calculate the energy flow on the rail in both directions.

As for implementation, the power accumulation data described in the PMBus standard are expressed in signed, 16-bit, twos complement format. The rollover counter increases by 1 each time the energy accumulator register rolls over from 0x7FFF to 0x0000.

The power accumulators on the ADM1293/ADM1294 devices are defined to accumulate power in one specific direction. This removes the need for the sign bit and the power accumulation data on the ADM1293/ADM1294 devices is expressed as an unsigned 16-bit value. As a result, the rollover counter increases by 1 each time the energy accumulator register rolls over from 0xFFFF to 0x0000.

PEAK_VIN, PEAK_VAUX, MIN_IOUT, MAX_IOUT, MIN_PIN, and MAX_PIN Commands

In addition to the standard PMBus commands for reading voltage, current, and power, the ADM1293/ADM1294 provide commands that report the maximum peak voltage, the maximum and minimum current, and the power values recorded.

The ADM1293/ADM1294 devices support bidirectional current and power monitoring. Both current and power data are expressed in twos complement format with the MSB being the sign bit indicating the direction of the current/power flow. For current and power, the maximum values are defined as the most positive values recorded (flowing from the SENSEP pin to the SENSEN pin) or least negative values recorded (flowing from the SENSEN pin to the SENSEP pin), and the minimum values are defined as the most negative or least positive values recorded. For example, if the current readback ranges between 3 A and 5 A, the MAX_IOUT command returns 5 A and the MIN_IOUT command returns 3 A. If the current readback ranges between −3 A and −5 A, the MAX_IOUT command returns −3 A and the MIN_IOUT command returns −5 A.

Theses peak values are updated only after the power monitor has sampled and averaged the current and voltage measurements. Individual peak values are cleared by writing a value of 0 with the corresponding command.

WARNING LIMIT SETUP COMMANDS

The ADM1293/ADM1294 power monitor can monitor a number of different warning conditions simultaneously and report any current, voltage, or power values that exceed the user defined thresholds using the status commands.

All comparisons performed by the power monitor require the measured value to be strictly greater or less than the threshold value.

At power-up, all threshold limits are set to either minimum scale (for undervoltage conditions) or to maximum scale (for overvoltage, overcurrent, or overpower conditions). This effectively disables the generation of any status warnings by default; warning bits are not set in the status registers until the user explicitly sets the threshold values.

VIN_OV_WARN_LIMIT and VIN_UV_WARN_LIMIT Commands

The VIN_OV_WARN_LIMIT and VIN_UV_WARN_LIMIT commands set the overvoltage (OV) and undervoltage (UV) thresholds on the input voltage, as measured at the VIN pin.

VAUX_OV_WARN_LIMIT and VAUX_UV_WARN_LIMIT Commands

The VAUX_OV_WARN_LIMIT and VAUX_UV_WARN_LIMIT commands set the OV and UV thresholds on the output voltage, as measured at the VAUX pin.

IOUT_OC_WARN_LIMIT Command

The IOUT_OC_WARN_LIMIT command sets the overcurrent threshold for the current flowing through the sense resistor.

If the threshold is a positive value, a more positive current measurement value is required to trigger the overcurrent warning. If the threshold is a negative value, a more negative current measurement value is required to trigger the overcurrent warning.

PIN_OP_WARN_LIMIT Command

The PIN_OP_WARN_LIMIT command sets the overpower threshold for the power that appears on the rail being monitored.

If the threshold is a positive value, a more positive power measurement value is required to trigger the overpower warning. If the threshold is a negative value, a more negative power measurement value is required to trigger the overpower warning.

PMBus DIRECT FORMAT CONVERSION

The ADM1293/ADM1294 uses the PMBus direct format to represent real-world quantities such as voltage, current, and power values. A direct format number takes the form of a 2-byte, twos complement, binary integer value.

It is possible to convert between direct format value and real-world quantities using the following equations. Equation 1 converts from real-world quantities to PMBus direct values, and Equation 2 converts PMBus direct format values to real-world values.

$$Y = (mX + b) \times 10^{R} \quad (1)$$

$$X = 1/m \times (Y \times 10^{-R} - b) \quad (2)$$

where:
Y is the value in PMBus direct format.
X is the real-world value.
m is the slope coefficient, a 2-byte, twos complement integer.
b is the offset, a 2-byte, twos complement integer.
R is a scaling exponent, a 1-byte, twos complement integer.

The same equations are used for voltage, current, and power conversions (with the exception of accumulated power conversion), the only difference being the values of the m, b, and R coefficients that are used. Table 10 lists all the coefficients required for the ADM1293/ADM1294. The current and power coefficients shown are dependent on the value of the external sense resistor used in a given application. This means that an additional calculation must be performed to take the sense resistor value into account to obtain the coefficients for a specific sense resistor value.

Table 10. PMBus Conversion to Real-World Coefficients

Coefficients	Voltage Range (V)[1]	Current Sense Range (mV)[1]	m[2]	b	R
Voltage (V)	0 to 1.2	N/A	3333	−1	0
	0 to 7.4	N/A	5552	−5	−1
	0 to 21	N/A	19,604	−50	−2
Current (A)	N/A	±25	8000 × R_{SENSE}	−100	−2
	N/A	±50	4000 × R_{SENSE}	−100	−2
	N/A	±100	20,000 × R_{SENSE}	−1000	−3
	N/A	±200	10,000 × R_{SENSE}	−1000	−3
Power (W)	0 to 1.2	±25	10,417 × R_{SENSE}	0	−1
	0 to 1.2	±50	5208 × R_{SENSE}	0	−1
	0 to 1.2	±100	26,042 × R_{SENSE}	0	−2
	0 to 1.2	±200	13,021 × R_{SENSE}	0	−2
	0 to 7.4	±25	17,351 × R_{SENSE}	0	−2
	0 to 7.4	±50	8676 × R_{SENSE}	0	−2
	0 to 7.4	±100	4338 × R_{SENSE}	0	−2
	0 to 7.4	±200	21,689 × R_{SENSE}	0	−3
	0 to 21	±25	6126 × R_{SENSE}	0	−2
	0 to 21	±50	30,631 × R_{SENSE}	0	−3
	0 to 21	±100	15,316 × R_{SENSE}	0	−3
	0 to 21	±200	7658 × R_{SENSE}	0	−3

[1] N/A means not applicable.
[2] The sense resistor value, used in the calculations to obtain the coefficients, is expressed in milliohms.

The sense resistor value used in the calculations to obtain the coefficients is expressed in milliohms. The m coefficients are defined as 2-byte twos complement numbers in the PMBus standard; therefore, the maximum positive value that can be represented is 32,767. If the m value is greater than that, and is to be stored in PMBus standard form, then divide the m coefficients by 10, and increase the R coefficient by a value of 1. For example, if a 10 mΩ sense resistor is used, the m coefficient for power is 6123, and the R coefficient is −1.

Example 1: IOUT_OC_WARN_LIMIT requires a current-limit value expressed in direct format.

Assume the current sense range is 25 mV. If the required current limit is 10 A and the sense resistor is 2 mΩ, the first step is to determine the voltage coefficient. This is m = 8000 × 2, giving 16,000.

Using Equation 1, and expressing X in units of amperes,

$$Y = ((16{,}000 \times 10) - 100) \times 10^{-2}$$

$$Y = 1599$$

Writing a value of 1599 with the IOUT_OC_WARN_LIMIT command sets an overcurrent warning at 10 A.

Example 2: IOUT_OC_WARN_LIMIT requires a current-limit value expressed in direct format.

Assume the current sense range is 25 mV. If the required current limit is −10 A and the sense resistor is 2 mΩ, the first step is to determine the voltage coefficient. This is m = 8000 × 2, giving 16,000.

Using Equation 1, and expressing X in units of amperes,

$$Y = ((16{,}000 \times -10) - 100) \times 10^{-2}$$

$$Y = -1601 = \text{(signed 16 bits) 0xF9BF?} = \text{(unsigned) 63935d}$$

Writing a value of 63935d with the IOUT_OC_WARN_LIMIT command sets an overcurrent warning at −10 A.

Example 3: the READ_IOUT command returns a direct format value of 125, representing the current flowing through a sense resistor of 1 mΩ. The current sense range is 50 mV.

To convert this value to the current flowing, use Equation 2, with m = 4000 × 1.

$$X = 1/4000 \times (125 \times 10^2 + 100)$$

$$X = 3.15 \text{ A}$$

This means that when READ_IOUT returns a value of 125, 3.15 A is flowing in the sense resistor. A positive values means the current is flowing in the forward direction from the SENSEP pin to the SENSEN pin.

Example 4: the READ_PIN command returns a direct format value of 12,635, representing the power measured through a sense resistor of 0.25 mΩ. The voltage range is 0 V to 21 V and the current sense range is 0 mV to 25 mV.

To convert this value to the current flowing, use Equation 2, with m = 6126 × 0.25 = 1531.5

$$X = 1/1531.5 \times (12635 \times 10^2 - 0)$$

$$X = 825 \text{ W}$$

This means that, when READ_PIN returns a value of 12,635, 825 W is being delivered on the rail.