MAXIM

±0.3% Accurate, Quad, Power-Supply Controller with Active-Voltage Output Control and PMBus Interface

MAX16064

General Description

The MAX16064 is a fully integrated 4-channel digital power-supply controller and monitor IC that can be connected up to four power supplies to provide complete digital configurability. By interfacing to the power-supply reference input or feedback node, and the output enable, the MAX16064 takes control of the power supply to provide tracking, soft-start, sequencing, margining, and dynamic adjustment of the output voltage.

Power-supply sequencing can be performed autonomously or controlled over the PMBus™ interface. Sequencing is controlled during power-down as well as power-up. Multiple MAX16064s can be combined to autonomously sequence more supplies. The sequencing order is stored in an external configuration EEPROM so sequence order changes can be reprogrammed without changing the PCB layout.

The MAX16064 features an internal temperature sensor providing an additional level of system monitoring. Other features include a reset output and an SMBus™ alert output.

Each channel of the MAX16064 includes an accurate 12-bit analog-to-digital converter (ADC) input and a differential amplifier for accurately monitoring and reporting the voltage at the load without being influenced by any difference in ground potentials. An integrated 12-bit digital-to-analog converter (DAC) can margin power supplies and dynamically adjust the output voltage using a closed-loop control system to provide an output-voltage accuracy of ±0.3%.

The user-programmable registers provide flexible and accurate control of time events such as delay time and transition period, monitoring for overvoltage and undervoltage, overtemperature fault and warning handling. The closed-loop operation is also programmable to make sure the MAX16064 works with any existing power supply to provide superior regulation accuracy and accurate margining.

The MAX16064 operates using a PMBus-compliant communication protocol. The device can be programmed using this protocol or with a free graphic-user interface (GUI) available from the Maxim website that significantly reduces development time. Once the configuration is complete, the results can be saved into an EEPROM or loaded into the device through PMBus at power-up. This allows remote configuration of any power supply using the MAX16064, replacing expensive recalls or field service. The MAX16064 can be programmed with up to 114 distinct addresses to support large systems. The MAX16064 is offered in a space-saving, 36-pin, lead-free, 6mm x 6mm TQFN package and is fully specified from -40°C to +85°C.

Features

♦ **Accurate Voltage Output Control (AVOC) Controls Output Voltage with ±0.3% Accuracy**

♦ **PMBus Interface for Programming, Monitoring, Sequencing Up and Down, and Margining**

♦ **Output Voltage and Temperature Monitoring with Adjustable Monitor Rate**

♦ **Programmable Soft-Start and Soft-Stop Ramp Rates**

♦ **Power-Supply Control using REFIN or FB Terminals**

♦ **Master-Slave Clocking Option Provides Accurate Timing Reference Across Multiple Devices**

♦ **External EEPROM Interface for Autoboot on Power-Up**

♦ **3.0V to 3.6V Operating Voltage Range**

♦ **6mm x 6mm, 36-Pin TQFN Package**

Applications

Routers

Servers

Storage Systems

Telecom/Networking

DC-DC Modules and Power Supplies

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX16064ETX+	-40°C to +85°C	36 TQFN-EP*

+Denotes a lead(Pb)-free/RoHS-compliant package.
*EP = Exposed pad.

Pin Configuration and Typical Operating Circuit appears at end of data sheet.

PMBus is a trademark of SMIF, Inc.
SMBus is a trademark of Intel Corp.

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ABSOLUTE MAXIMUM RATINGS

AVDD, DVDD to AGND ....-0.3V to +4V
AVDD to DVDD...-0.3V to +0.3V
AGND to DGND...-0.3V to +0.3V
AGND1 to DGND..-0.3V to +0.3V
RS_+, RS_- to AGND...-0.3V to +6V
RS_C, A1/SCLE, A2/SDAE,
    A3/CONTROL to AGND ....-0.3V to (AVDD + 0.3V)
$\overline{RESET}$, $\overline{SMBALERT}$, ENOUT_ to AGND...................-0.3V to +6V
SCL, SDA to DGND ....-0.3V to +4V
DACOUT_, EN, CLKIO, REFO to AGND.....-0.3V to (AVDD + 0.3V)
DACOUT_ Current 10mA
SDA Current ....-1mA to +50mA
Input/Output Current (all other pins) 20mA
Continuous Power Dissipation (T_A = +70°C)
    36-Pin 6mm x 6mm TQFN
    (derate 35.7mW/°C above +70°C)............................2857mW
Thermal Resistance (Note 1)
    θ_{JA}..28°C/W
    θ_{JC}..1°C/W
Operating Temperature Range ....-40°C to +85°C
Junction Temperature...+150°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10s) ....+300°C
Soldering Temperature (reflow) ....+260°C

Note 1: Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to **www.maxim-ic.com/thermal-tutorial**.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{AVDD} = V_{DVDD} = 3.0V to 3.6V, V_{EN} = 2V, V_{RS_+} - V_{RS_-} = 2V, V_{RS_-} = 0V, T_A = T_J = -40°C to +85°C, unless otherwise specified. Typical values are at V_{AVDD} = V_{DVDD} = 3.3V, T_A = +25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
AVDD/DVDD Operating Voltage Range			3.0		3.6	V
AVDD Undervoltage Lockout (AVDD Rising)	V_{UVLO}		2.75	2.8	2.95	V
AVDD Undervoltage Lockout Hysteresis	$V_{UVLO-HYS}$			100		mV
AVDD and DVDD Total Supply Current		V_{RS_+} = V_{RS_-} = 0V		12	18.5	mA
OUTPUT-VOLTAGE SENSING						
Voltage Regulation Accuracy (2V Range)		T_A = +25°C, V_{RS_+} = 1.0V, V_{RS_-} = 0V	-4		+4	mV
		T_A = -40°C to +85°C, V_{RS_+} = 1.0V, V_{RS_-} = 0V	-6		+6	mV
Voltage Regulation Accuracy (5.5V Range)		T_A = +25°C, V_{RS_+} = 2.5V, V_{RS_-} = 0V	-11		+11	mV
		T_A = -40°C to +85°C, V_{RS_+} = 2.5V, V_{RS_-} = 0V	-16.5		+16.5	mV
RS_+, RS_- Differential Mode Range			0		5.5	V
RS_- to AGND Differential Voltage			-250		+250	mV
RS_+ Input Bias Current		2V range, V_{RS_+} = -0.25V to +2V	-20		+20	µA
		5.5V range, V_{RS_+} = -0.25V to +5.5V	-20		+100	
RS_- Input Bias Current		2V or 5.5V range, V_{RS_-} = -0.25V to +0.25V	-20		0	µA

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ELECTRICAL CHARACTERISTICS (continued)

(V$_{AVDD}$ = V$_{DVDD}$ = 3.0V to 3.6V, V$_{EN}$ = 2V, V$_{RS\_+}$ - V$_{RS\_-}$ = 2V, V$_{RS\_-}$ = 0V, T$_A$ = T$_J$ = -40°C to +85°C, unless otherwise specified. Typical values are at V$_{AVDD}$ = V$_{DVDD}$ = 3.3V, T$_A$ = +25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
INTERNAL TEMPERATURE SENSOR						
Temperature Sensing Accuracy		T$_A$ = 0°C to +85°C		±3		°C
INTERNAL OSCILLATOR						
Frequency			7.6	8	8.4	MHz
ADC						
Resolution				12		Bits
INTERNAL REFERENCE						
Reference Voltage	V$_{REF}$	T$_A$ = +25°C		2.048		V
DAC						
Resolution				12		Bits
Differential Nonlinearity	DNL		-2.5		+2.5	LSB
Maximum Output-Voltage Range		No load		V$_{REF}$ - 1 LSB		V
Capacitive Load				200		pF
Output-Voltage Slew Rate				0.35		V/µs
DAC Output Resistance				10		Ω
DAC Driving Capability		DAC output > 100mV; output error < 25mV	-1		+1	mA
DAC Output Leakage Current		DAC output switch open, V$_{DACOUT\_}$ = V$_{REF}$ or 0V	-250		+250	nA
CLKIO						
Input Logic-Low Voltage					0.8	V
Input Logic-High Voltage			2.1			V
Input Bias Current		V$_{CLKIO}$ = 3.6V or 0V	-1		+1	µA
Input Clock Duty Cycle				50		%
Output Low Voltage		CLKIO in output mode, I$_{SINK}$ = 4mA			0.4	V
Output High Leakage		V$_{CLKIO}$ = 3.6V	-1		+1	µA
CLKIO Pullup Voltage					3.6	V
CLKIO Input Frequency Range	f$_{EXT\_CLK}$		100		1000	kHz
CLKIO Output Frequency				1		MHz
ENABLE INPUT (EN)						
EN Falling Threshold Voltage	V$_{EN\_TH}$		1.17	1.21	1.23	V
EN Rising Threshold Voltage			1.175	1.23	1.281	V
EN Input Leakage Current			-0.25		+0.25	µA
OUTPUTS (ENOUT_, $\overline{RESET}$, $\overline{SMBALERT}$)						
Output Low Voltage	V$_{OL}$	I$_{SINK}$ = 10mA			0.4	V
		V$_{AVDD}$ = V$_{DVDD}$ = 1.1V, I$_{SINK}$ = 100µA			0.4	V
Output Leakage		V$_{ENOUT\_}$ = 5V, 0V	-1		+1	µA

ELECTRICAL CHARACTERISTICS (continued)

(V$_{AVDD}$ = V$_{DVDD}$ = 3.0V to 3.6V, V$_{EN}$ = 2V, V$_{RS\_+}$ - V$_{RS\_-}$ = 2V, V$_{RS\_-}$ = 0V, T$_A$ = T$_J$ = -40°C to +85°C, unless otherwise specified. Typical values are at V$_{AVDD}$ = V$_{DVDD}$ = 3.3V, T$_A$ = +25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
ADDRESS PINS (A1/SCLE, A2/SDAE, A3/CONTROL)						
Input Logic-Low Voltage					0.3	V
Input Logic-Low Hysteresis				50		mV
Input Logic-High Voltage			V$_{AVDD}$ - 0.4			V
Input Logic-High Hysteresis				50		mV
Input Leakage Current			-12		+12	µA
SMBus INTERFACE (SCL, SDA) (Note 3)						
SCL, SDA Input Low Voltage	V$_{IL}$	Input voltage falling			0.8	V
SCL, SDA Input High Voltage	V$_{IH}$	Input voltage rising	2.1			V
SCL, SDA Input Leakage Current (Per Pin)		Device powered or unpowered, V$_{AVDD}$ = 0 to 3.6V, V$_{SCL}$ = V$_{SDA}$ = 0V or V$_{AVDD}$	-1		+1	µA
Input Capacitance	C$_{IN}$			10		pF
SCL, SDA Output Low Voltage	V$_{OL}$	I$_{SINK}$ = 3mA			0.4	V
SMBUS TIMING						
Serial-Clock Frequency	f$_{SCL}$		10		100	kHz
Bus Free Time Between STOP and START Condition	t$_{BUF}$		4.7			µs
START Condition Setup Time	t$_{SU:STA}$		4.7			µs
START Condition Hold Time	t$_{HD:STA}$		4.0			µs
STOP Condition Setup Time	t$_{SU:STO}$		4.0			µs
Clock Low Period	t$_{LOW}$		4.7			µs
Clock High Period	t$_{HIGH}$		4.0			µs
Data Setup Time	t$_{SU:DAT}$		250			ns
Output Fall Time	t$_{OF}$	C$_{BUS}$ = 10pF to 400pF			300	ns
Data Hold Time	t$_{HD:DAT}$	From 50% SCL falling to SDA change	300			ns
Pulse Width of Spike Suppressed	t$_{SP}$			30		ns
SMBus Timeout	t$_{TIMEOUT}$	SMBCLK time low for reset	25		55	ms
OTHER TIMING PARAMETERS						
PMBus Command Response Time	t$_{PMB\_RSP}$			300		µs
Fault Response Time	t$_{FAULT\_RSP}$			5		ms
Recovery Time After Device Reset	t$_{RST\_WAIT}$	No external EEPROM		15		ms

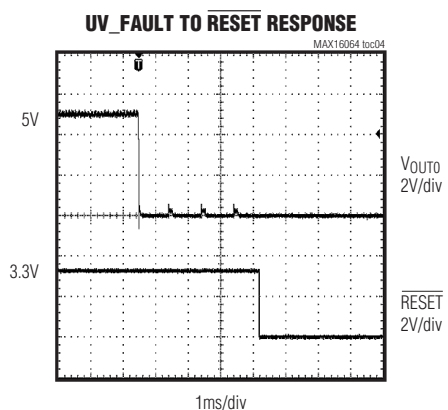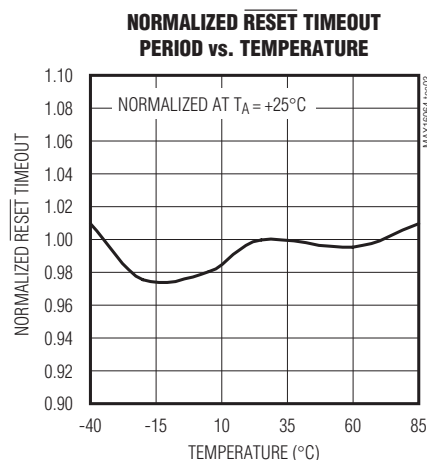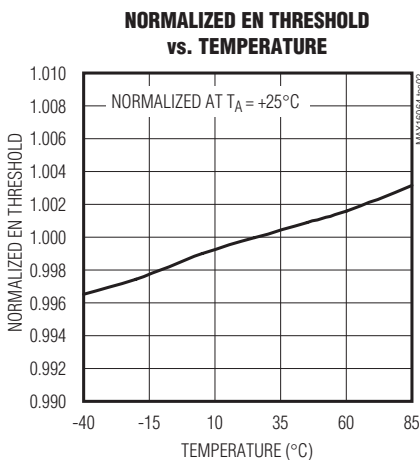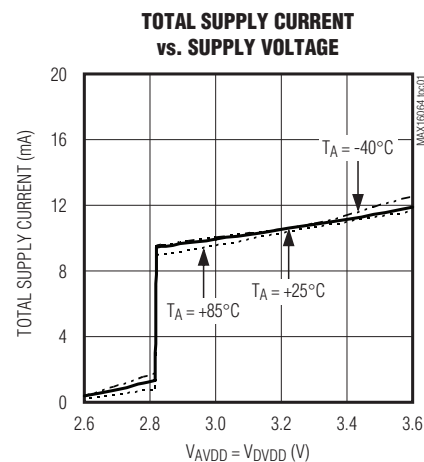**Note 2:** 100% production tested at T$_A$ = +25°C. Limits over temperature are guaranteed by design.
Note 3: The MAX16064 supports SCL clock stretching.

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Typical Operating Characteristics

(V_{AVDD} = V_{DVDD} = 3.3V, T_A = +25°C, unless otherwise noted.)

TOTAL SUPPLY CURRENT vs. SUPPLY VOLTAGE

NORMALIZED EN THRESHOLD vs. TEMPERATURE

NORMALIZED RESET TIMEOUT PERIOD vs. TEMPERATURE

UV_FAULT TO RESET RESPONSE

ENOUT_ OUTPUT LOW VOLTAGE vs. SINK CURRENT

POWER SUPPLIES OUTPUT ACCURACY vs. TEMPERATURE

ENOUT_WITH AVDD = DVDD RISING

ENOUT_ WITH AVDD = DVDD FALLING

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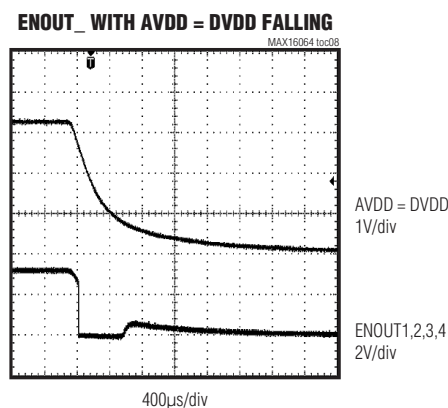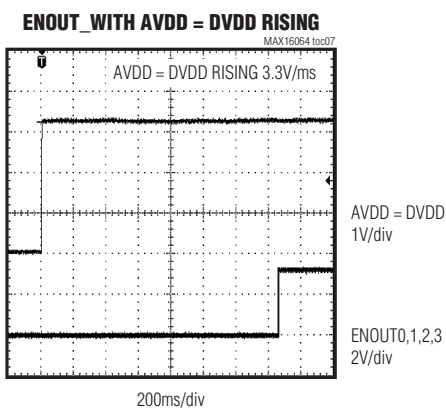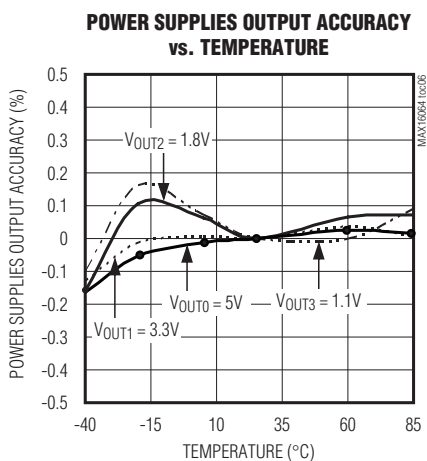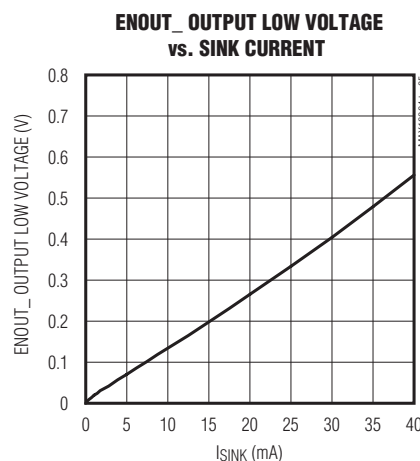
Typical Operating Characteristics (continued)

(V_{AVDD} = V_{DVDD} = 3.3V, T_A = +25°C, unless otherwise noted.)
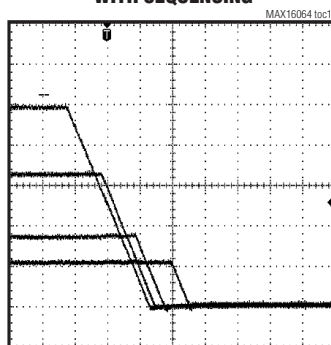
REFIN MODE SOFT-START
WITH SEQUENCING

MAX16064 toc09
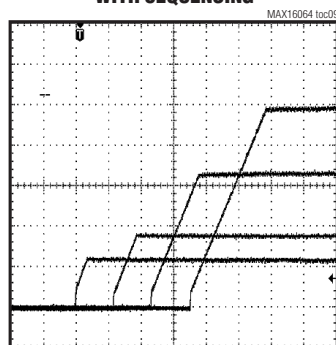
V_{OUT0} = 5V

V_{OUT1} = 3.3V

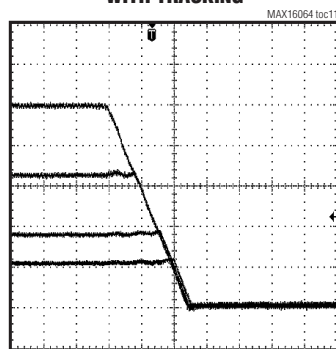V_{OUT2} = 1.8V

V_{OUT3} = 1.1V

2ms/div

REFIN MODE SOFT-STOP
WITH SEQUENCING

MAX16064 toc10

V_{OUT0} = 5V

V_{OUT1} = 3.3V

V_{OUT2} = 1.8V
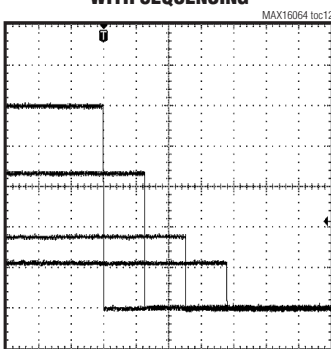V_{OUT3} = 1.1V

2ms/div

REFIN MODE SOFT-STOP
WITH TRACKING

MAX16064 toc11

V_{OUT0} = 5V

V_{OUT1} = 3.3V

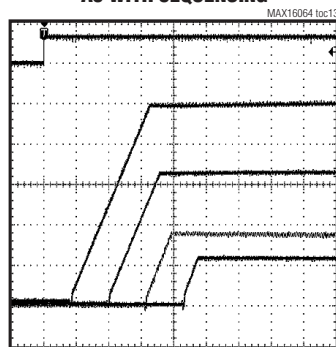V_{OUT2} = 1.8V
V_{OUT3} = 1.1V

2ms/div

REFIN MODE OPERATION OFF
WITH SEQUENCING

MAX16064 toc12

V_{OUT0} = 5V

V_{OUT1} = 3.3V

V_{OUT2} = 1.8V
V_{OUT3} = 1.1V

40ms/div

REFIN MODE SOFT-START FROM
A3 WITH SEQUENCING

MAX16064 toc13

A3/CONTROL
5V/div

V_{OUT0} = 5V

V_{OUT1} = 3.3V

V_{OUT2} = 1.8V
V_{OUT3} = 1.1V
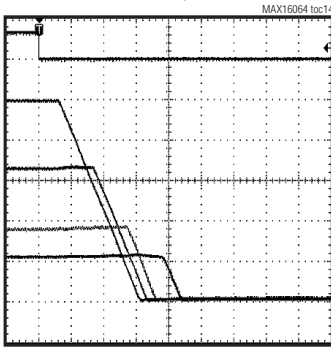
2ms/div

REFIN MODE SOFT-STOP FROM
A3 WITH SEQUENCING

MAX16064 toc14

A3/CONTROL
5V/div

V_{OUT0} = 5V

V_{OUT1} = 3.3V

V_{OUT2} = 1.8V
V_{OUT3} = 1.1V

2ms/div

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_____Typical Operating Characteristics (continued)

(V_{AVDD} = V_{DVDD} = 3.3V, T_A = +25°C, unless otherwise noted.)

REFIN MODE MARGINING
500mV HIGH AT 1mV/µs

MAX16064 toc15

5V
V_{OUT0}
1V/div

0.6V
$V_{DACOUT0}$
200mV/div

400µs/div
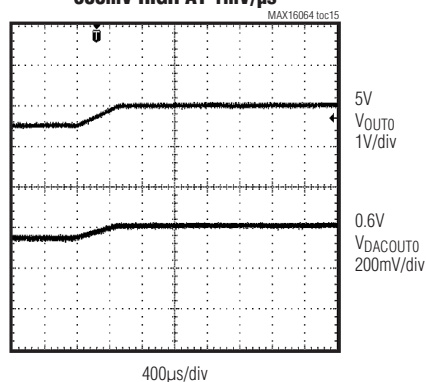
REFIN MODE MARGINING
500mV LOW AT 1mV/µs

MAX16064 toc16

4.5V
V_{OUT0}
1V/div

0.54V
$V_{DACOUT0}$
200mV/div

400µs/div
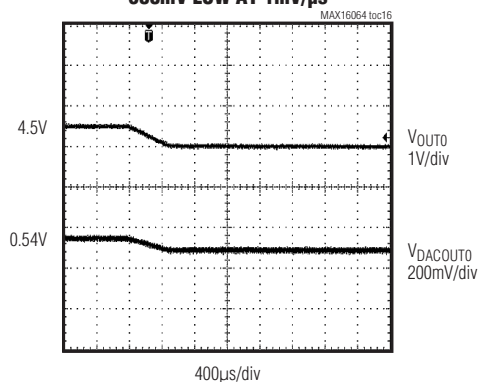
FB MODE MARGINING HIGH
FROM 5V TO 5.5V

MAX16064 toc17

5V
V_{OUT0}
1V/div

0.6V
$V_{DACOUT0}$
200mV/div

400ms/div
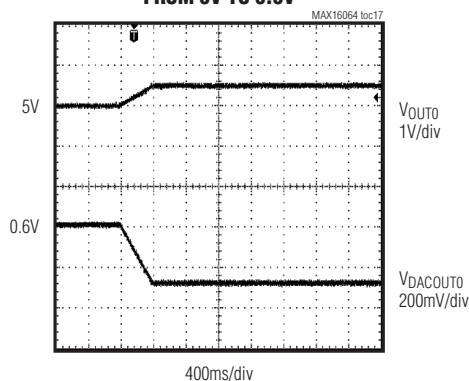
FB MODE MARGINING LOW
FROM 5V TO 4.5V

MAX16064 toc18

5V
V_{OUT0}
1V/div

$V_{DACOUT0}$
200mV/div

0.6V

400ms/div

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PIN	NAME	FUNCTION
1	RS2-	Differential Remote-Sense Input 2 Return of the DC-DC Output Voltage. Connect to the return terminal at the load.
2	RS2+	Differential Remote-Sense Input 2 of DC-DC Output Voltage. Connect to the load terminal where the output must be regulated.
3	RS3+	Differential Remote-Sense Input 3 of DC-DC Output Voltage. Connect to the load terminal where the output must be regulated.
4	RS3-	Differential Remote-Sense Input 3 Return of the DC-DC Output Voltage. Connect to the return terminal at the load.
5	RS3C	Filter Capacitor for V_{SENSE} Amplifier 3. Connect a 1µF capacitor from RS3C to AGND.
6	EN	Enable Input. All ENOUT_ are deasserted when the voltage on EN is below 1.2V (typ). Used to turn on/off the controlled power supplies in conjunction with the PMBus OPERATION command.
7	DACOUT1	Analog Voltage Output of Internal 12-Bit DAC 1. Connect to TRIM, REFIN, or FB of a DC-DC module or an LDO to adjust the power-supply output voltage. High impedance in shutdown.
8	AGND	Analog Ground. Connect AGND to AGND1 and to DGND externally close to the device.
9	ENOUT0	On/Off Signal Output 0. Typically used to turn on/off a power supply. Controlled by the PMBus OPERATION command or the sequencer. Can be configured as either an active-high or an active-low open-drain output. See the *ENOUT_ Operation* section.
10	ENOUT1	On/Off Signal Output 1. Typically used to turn on/off a power supply. Controlled by the PMBus OPERATION command or the sequencer. Can be configured as either an active-high or an active-low open-drain output. See the *ENOUT_ Operation* section.
11	ENOUT2	On/Off Signal Output 2. Typically used to turn on/off a power supply. Controlled by the PMBus OPERATION command or the sequencer. Can be configured as either an active-high or an active-low open-drain output. See the *ENOUT_ Operation* section.
12	ENOUT3	On/Off Signal Output 3. Typically used to turn on/off a power supply. Controlled by the PMBus OPERATION command or the sequencer. Can be configured as either an active-high or an active-low open-drain output. See the *ENOUT_ Operation* section.
13	CLKIO	Clock Input/Output. User-configurable clock input/output signal. The system controller can provide a clock input to synchronize the time bases of multiple MAX16064 devices. Alternatively, a MAX16064 can provide a 1MHz output clock to other MAX16064s for synchronization. See the *MFR_MODE (D1h)* section. When configured as an output, CLKIO is an open-drain output and a pullup resistor is required.
14	A1/SCLE	Dual-Functioned MAX16064 Slave Address Identifier (LSB) and EEPROM I2C Clock Output. See the *MAX16064 Address Assignment* and *External EEPROM Interface* sections.
15	A2/SDAE	Dual-Functioned MAX16064 Slave Address Identifier and EEPROM I2C Data Input/Output. See the *MAX16064 Address Assignment* and *External EEPROM Interface* sections.
16	A3/CONTROL	Dual-Functioned MAX16064 Slave Address Identifier (MSB) and Power-Supply On/Off Control Using the MFR_MODE Command. See the *MAX16064 Address Assignment* and *A3/CONTROL Operation* sections.
17	$\overline{RESET}$	Active-Low, Open-Drain Reset Output

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Pin Description (continued)

PIN	NAME	FUNCTION
18	SMBALERT	Active-Low, Open-Drain Fault-Detection Interrupt Output
19	SCL	SMBus Serial-Clock Input/Output
20	SDA	SMBus Serial-Data Input/Output
21	DGND	Digital Ground. Connect DGND to AGND and AGND1 externally close to the device.
22	DVDD	Digital Power-Supply Input. Connect a 1µF capacitor from DVDD to DGND.
23	RSVD	Reserved. Connect to DVDD externally.
24	DACOUT3	Analog Voltage Output of Internal 12-Bit DAC 3. Connect to TRIM, REFIN, or FB of a DC-DC module or an LDO to adjust the power-supply output voltage. High impedance in shutdown.
25	AGND1	Analog Ground. Connect to AGND and DGND externally close to the device.
26	AVDD	Analog Power-Supply Input. Connect a 1µF capacitor from AVDD to AGND.
27	DACOUT2	Analog Voltage Output of Internal 12-Bit DAC 2. Connect to TRIM, REFIN, or FB of a DC-DC module or an LDO to adjust the power-supply output voltage. High impedance in shutdown.
28	RS1-	Differential Remote-Sense Input 1 Return of the DC-DC Output Voltage. Connect to the return terminal at the load.
29	RS1+	Differential Remote-Sense Input 1 of DC-DC Output Voltage. Connect to the load terminal where the output must be regulated.
30	RS1C	Filter Capacitor for V_{SENSE} Amplifier 1. Connect a 1µF capacitor from RS1C to AGND.
31	REFO	Reference Output. Connect a 1µF capacitor from REFO to AGND.
32	RS0+	Differential Remote-Sense Input 0 of DC-DC Output Voltage. Connect to the load terminal where the output must be regulated.
33	RS0C	Filter Capacitor for V_{SENSE} Amplifier 0. Connect a 1µF capacitor from RS0C to AGND.
34	RS0-	Differential Remote-Sense Input 0 Return of the DC-DC Output Voltage. Connect to the return terminal at the load.
35	DACOUT0	Analog Voltage Output of Internal 12-Bit DAC 0. Connect to TRIM, REFIN, or FB of a DC-DC module or an LDO to adjust the power-supply output voltage. High impedance in shutdown.
36	RS2C	Filter Capacitor for V_{SENSE} Amplifier 2. Connect a 1µF capacitor from RS2C to AGND.
—	EP	Exposed Pad. Internally connected to AGND. Connect EP to the ground plane of the power supplies for best temperature measurement performance.

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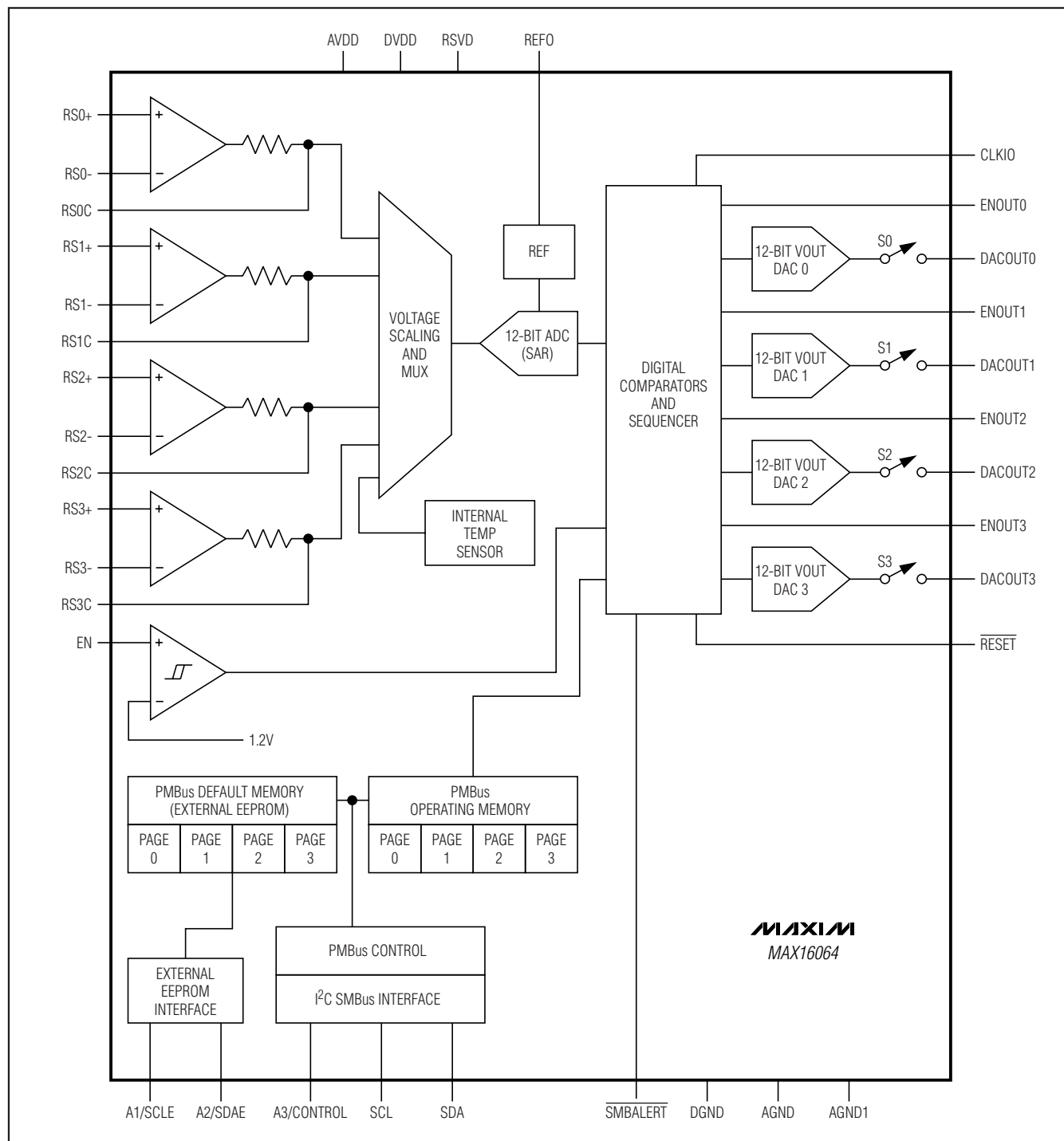Figure 1. MAX16064 Functional Diagram

±0.3% Accurate, Quad, Power-Supply Controller with Active-Voltage Output Control and PMBus Interface

_____Detailed Description

The MAX16064 adds digital control functionality to four power supplies. Using a closed-loop control system, the MAX16064 can continuously adjust the power-supply output voltages to maintain ±0.3% output-voltage accuracy. The MAX16064 can also be programmed to sequence, track, and margin each power supply.

A PMBus-compliant interface bus provides access to configuration parameters of the MAX16064, including monitoring thresholds, sequence delays, soft-start and soft-stop slew rates, output-voltage settings, an on-chip temperature sensor, and more.

Up to 114 MAX16064s can reside on the same PMBus bus, each controlling its own power supplies, under commands from the PMBus system controller, as shown in Figure 2. The MAX16064s can be placed close to the power supplies they control so that all sensitive analog traces are short and less susceptible to noise. The power supplies can also be placed close to the load where they provide the best transient response and lowest losses with short power plane runs.
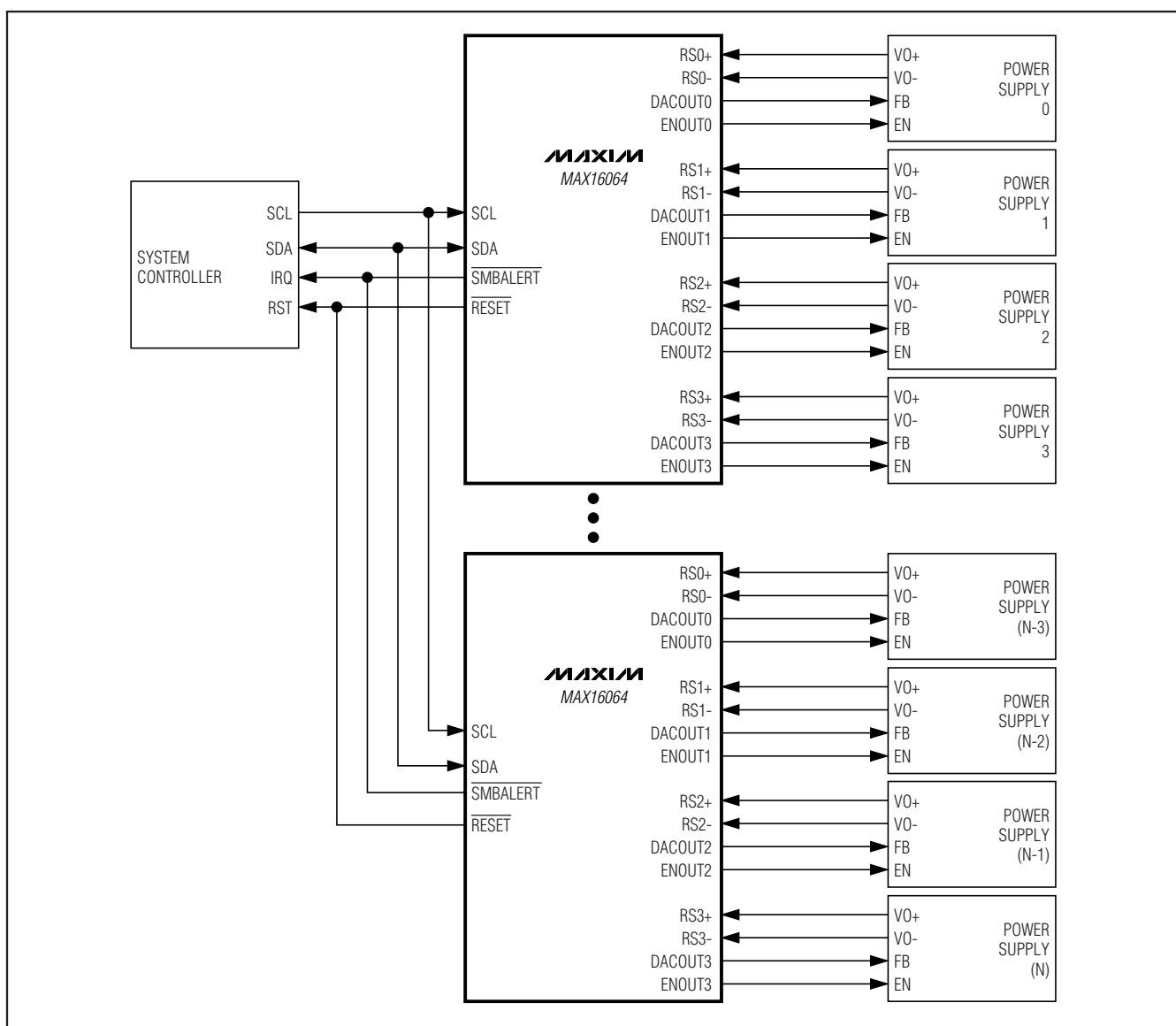

Figure 2. System Application Showing Multiple MAX16064s Controlling Power Supplies

MAX16064 Operating Modes

Reference Input (REFIN) Mode

Figure 3 shows how to connect a MAX16064 to the reference voltage input of a typical power supply, allowing the MAX16064 to fully control the power-supply output voltage. Connect a DACOUT_ of the MAX16064 to the REFIN input of the power supply and connect the output-voltage terminals of the power supply to the RS_+ and RS_- sense inputs of the MAX16064. The sensed voltage on RS_+ and RS_- is filtered by an internal 200Ω resistor and an external capacitor connected to RS_C, and is digitized by a 12-bit ADC that uses an accurate internal reference voltage.

Normal operation begins as follows: upon receiving an OPERATION ON command or a turn-on signal from A3/CONTROL, the MAX16064 waits the programmed t_{ON_DELAY} time, then switches on the associated ENOUT_ output and ramps up the power-supply output voltage to its target VOUT_COMMAND value precisely in the programmed t_{ON_RISE} time. This facilitates easy implementation of tracking of multiple output rails. On reaching the target output voltage, the MAX16064 continuously monitors the power-supply output voltage obtained at the RS_+ and RS_- inputs, and regulates it to within ±0.3% by incrementing or decrementing the DACOUT_ output 1 LSB (0.5mV) at a time. The MAX16064 output-voltage correction rate is controlled by MFR_MODE.1, MFR_VLTO, and MFR_DAC_ACT_CNT, as discussed in the *ADC Conversion, Monitoring, and AVOC Adjustment Rates* section.

Once the requested target power-supply voltage is reached, it can be margined up or down at a slew rate programmed by the VOUT_TRANSITION_RATE parameter. To achieve this, the MAX16064 increments or decrements the DACOUT_ output in a suitable number of steps that depend on the programmed transition rate. The number of steps is calculated from the VOUT_SCALE_LOOP parameter, which must be set to the ratio of the power-supply output voltage to the power-supply reference voltage. This ratio is the same as the voltage-divider ratio implemented on the power supply from its output voltage node to the inverting input of its error amplifier. This allows the MAX16064 to correctly calculate the number of DACOUT_ steps and voltage increments/decrements per step and thus achieve the programmed rise time and transition time.

Since the reference voltage input is provided by the MAX16064, the REFIN mode provides complete control of the power supply in terms of soft-start, soft-stop, and margining transitions.

Upon receiving an OPERATION OFF command or a turn-off signal from A3/CONTROL, the MAX16064 waits the programmed t_{OFF_DELAY} time, ramps the output voltage down to zero in the programmed t_{OFF_FALL} time, then deasserts the ENOUT_ output. Each of the four power-supply converters has its own set of delay parameters, so sequencing is accomplished by loading different delay times for each power supply.

Feedback (FB) Mode

Some power-supply converters do not provide a reference input. In these applications, the feedback node can be used instead. Connect a DACOUT_ output of the MAX16064 to the feedback node (FB) through a resistor R_{FB} as shown in Figure 5. In steady-state operation, the MAX16064 controls the power-supply voltage as measured between RS_+ and RS_- to ±0.3% accuracy by adjusting DACOUT_ 1 LSB at a time (0.5mV), up and down as required. This mode of operation is termed FB mode. Since the MAX16064 does not have control over the power-supply error-amplifier reference voltage, this mode relies on the power-supply soft-start setting to implement the required soft-start time.

Upon receiving an OPERATION ON command or a turn-on signal from A3/CONTROL, the MAX16064 waits the programmed t_{ON_DELAY} time, turns on the ENOUT_ output, causing the power supply to ramp up its output voltage to its target value. The soft-start time taken by the power supply to ramp from zero to its commanded output voltage should be entered into the MAX16064 with the t_{ON_RISE} parameter.

During t_{ON_RISE}, the MAX16064 maintains DACOUT_ in a high-impedance state by keeping the S_ switches open. This allows the voltage at DACOUT_ to equal that of the FB node of the power supply. At the end of the t_{ON_RISE} delay time, the internal DAC output voltage is set to match the external voltage measured on DACOUT_, and then the DACOUT_ switch S_ is closed. The voltages on either side of the resistor R_{FB} should be equal, or very close to equal. Under these conditions, little or no current flows into the FB node from DACOUT_ and no perturbations are introduced to the output voltage. From this point on, the MAX16064 adjusts the voltage at DACOUT_ to provide accurate output-voltage control. In FB mode, the user must supply t_{ON_DELAY} and t_{ON_RISE}. If those parameters are not set (the default values are zero), S_ closes prematurely and causes the supply voltage to overshoot or undershoot.

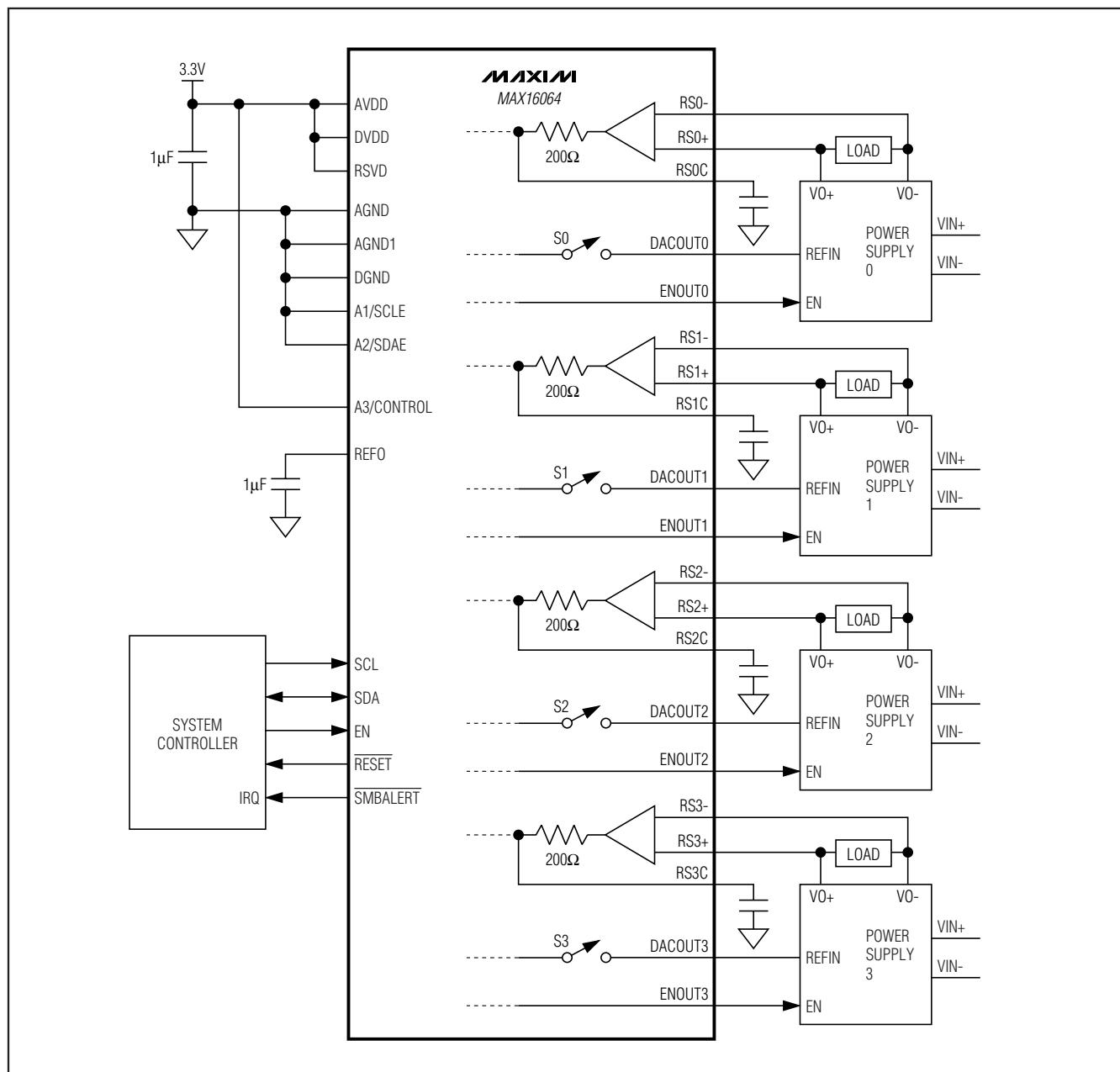# ±0.3% Accurate, Quad, Power-Supply Controller with Active-Voltage Output Control and PMBus Interface

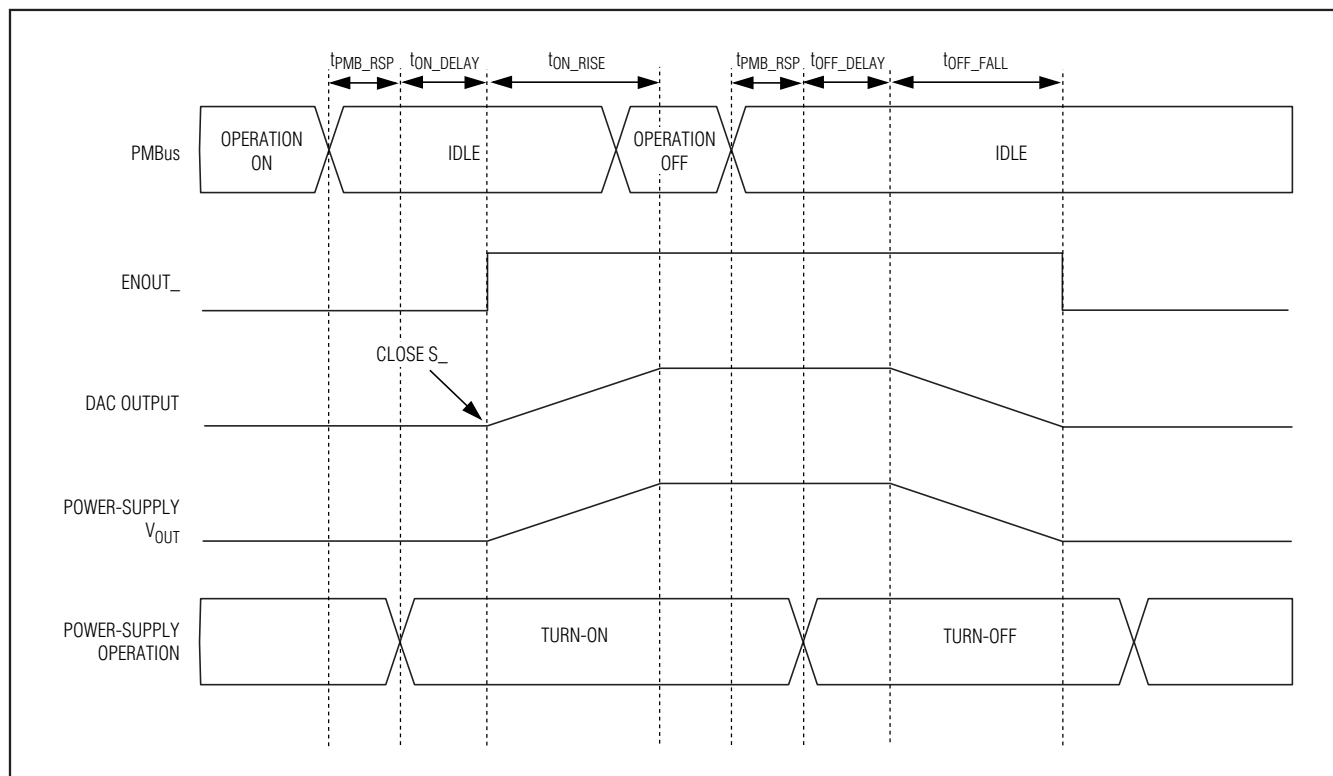Figure 3. Typical System Application—REFIN Mode

MAX16064

Figure 4. REFIN Mode Timing

After receiving an OPERATION OFF command or a turn-off signal from A3/CONTROL, the MAX16064 waits the programmed t_{OFF_DELAY} time, deasserts the ENOUT_ output, and turns off the power supply.

For the FB mode, use the following formula to calculate the value of R_{FB}:

$$R_{FB} = R_1 \times \frac{\Delta V_{DAC}}{\Delta V_O}$$

Where R_1 is the upper feedback divider resistor, ΔV_O is the required change in output voltage, and ΔV_{DAC} is the DACOUT_ output-voltage change that the user allows. The recommended operating range for the DACOUT_ voltage for power-supply output voltage adjustment is between 30mV and 2V. Note that ΔV_{DAC} is the difference between the steady-state power-supply FB node voltage, V_{FB}, and the voltage limits on DACOUT_. This is best illustrated with an example as follows:

Consider an application involving a power supply with $V_{FB} = 0.6V$. Let the desired margining be ±10% for a power-supply output voltage of 1V. For a power supply

with an upper voltage divider resistor $R_1 = 10k\Omega$, R_{FB} is calculated as follows:

$$R_{FB} = 10k\Omega \times \frac{(0.6V - 0.03V)}{0.1V} = 57k\Omega$$

This value of R_{FB} allows the MAX16064 to margin the power-supply output voltage up by 10%. It is useful to check the margin low condition by using the formula:

$$\Delta V_O = R_1 \times \frac{\Delta V_{DAC}}{R_{FB}} = 10k\Omega \times \frac{(2.0V - 0.6V)}{57k\Omega} = 0.245V$$

The effective margining range for the 57kΩ resistor therefore turns out to be between +10% and -24.5%.

Note that the VOUT_TRANSITION_RATE parameter has no effect on FB mode. The transition time for margining in the FB mode of operation is a function of the update rate (f_{AVOC}), see the *MFR_DAC_ACT_CNT (E0h)* section for the calculation of f_{AVOC}. R_{FB} and R_1, and t_{FB} is given by the following formula:

$$t_{FB} = \left(\frac{R_{FB} \times \Delta V_O \times 2000}{f_{AVOC} \times R_1} \right)$$

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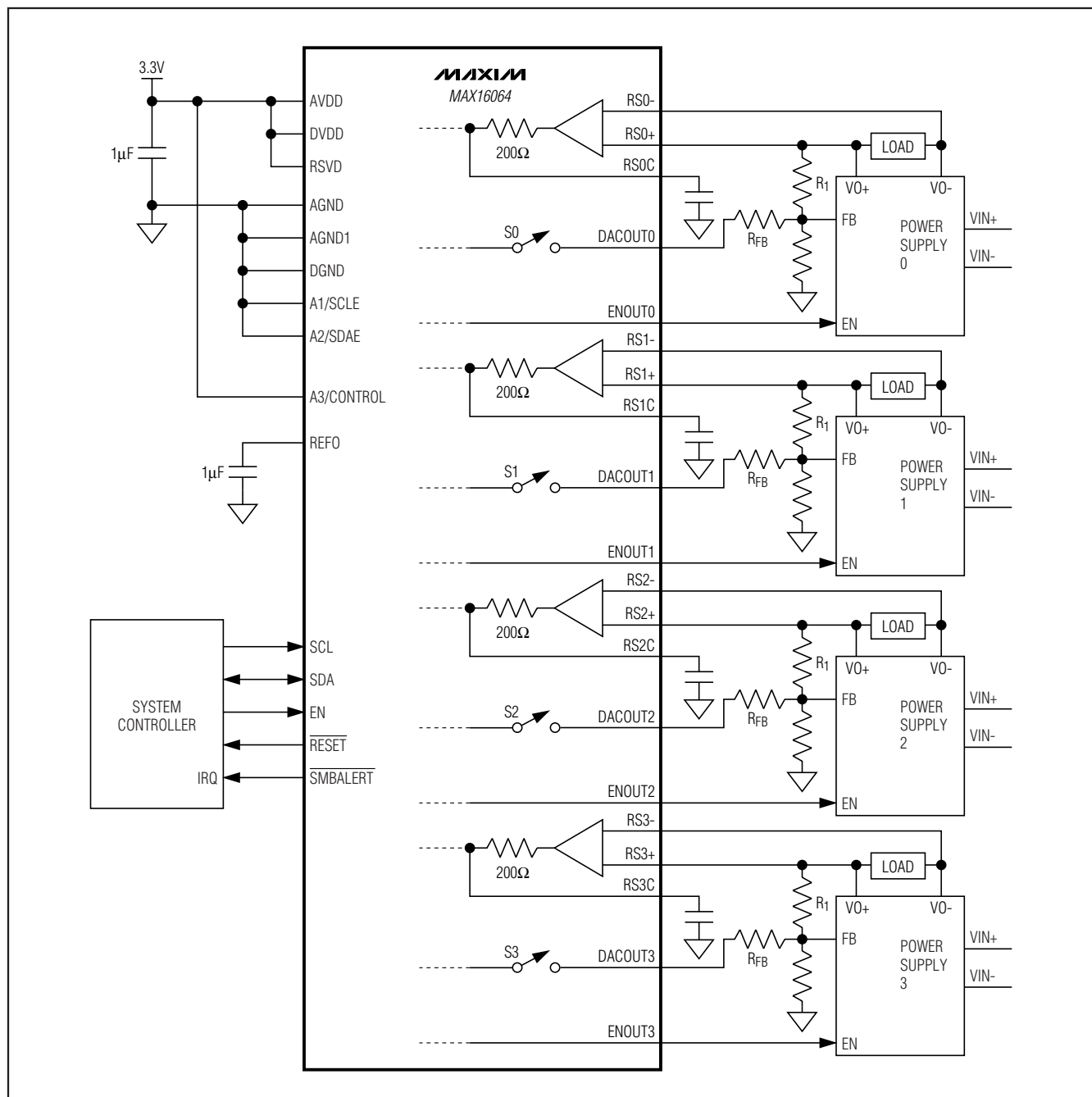
Figure 5. Typical System Application—Feedback Mode
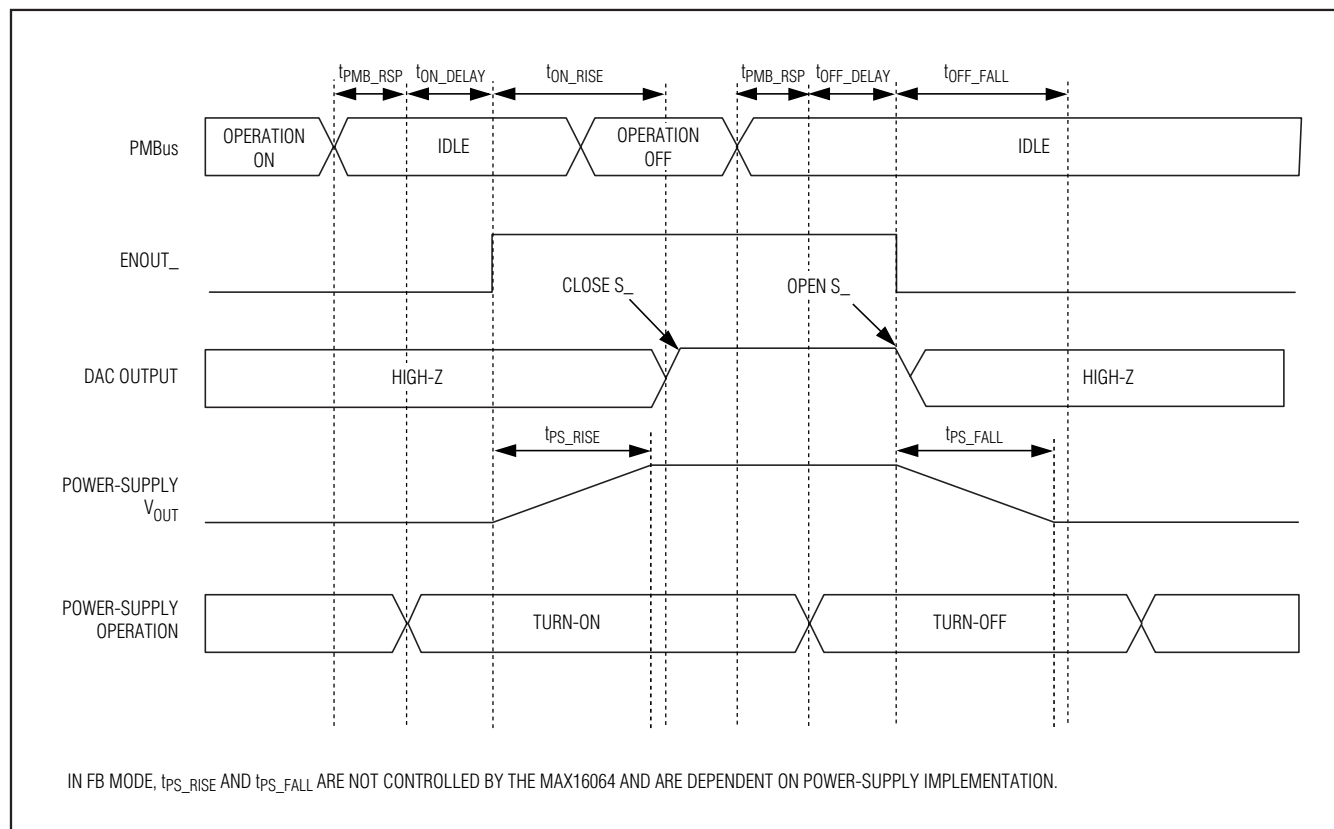
MAX16064

Figure 6. Feedback Mode Timing

Temperature Sensing

To obtain useful temperature readings, place the MAX16064 in close proximity to the power supplies. The on-chip temperature sensor on the MAX16064 senses the temperature of the die, which is related to the exposed pad temperature of the MAX16064 by the junction-to-case thermal resistance. The exposed pad of the MAX16064 can connect to the heat dissipating ground plane of the power supplies, and the power supplies' boards can be characterized to obtain the relationship between the power supplies' temperature and temperature as measured by the MAX16064. This information can be used to set overtemperature fault settings in the MAX16064.

ADC Conversion, Monitoring, and AVOC Adjustment Rates

Several timing parameters control the rate at which the MAX16064 monitors voltages and temperatures and the rate at which the MAX16064 adjusts the power-supply output voltages. Each of the four voltage input channels

and the single temperature channel conversions are performed round-robin fashion. If the input filter is turned on by setting register MFR_MODE.1 to 0, then four conversions are performed for each channel instead of just one. A small programmable delay is inserted in between each conversion, determined by the MFR_VLTO register. This establishes the total conversion rate of the voltages and temperature. Smaller values of MFR_VLTO results in a higher sampling rate, and larger values of MFR_VLTO allow for more ADC settling time.

The ADC conversion result registers are compared to the fault threshold registers at a rate that is independent of the total conversion rate. The value of register MFR_SAMPLE_RATE determines how frequently this comparison occurs. Using higher fault comparison rates increases glitch sensitivity, but slows the response time of the MAX16064 to PMBus commands. Using lower fault comparison rates makes the MAX16064 less sensitive to power-supply output voltage glitches.

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Finally, the AVOC system uses a separate control loop rate that is related to the total ADC conversion rate. The value of register MFR_DAC_ACT_CNT sets the number of total ADC conversion cycles (one cycle is a complete set of ADC conversions for 4 voltages and 1 temperature) that must occur before AVOC changes the DAC output voltage. Smaller values of MFR_DAC_ACT_CNT shorten the adjustment time. Larger values of MFR_DAC_ACT_CNT adjust the output voltage at much slower rates, reducing possible negative effects on the power-supply control loop.

External EEPROM Interface

The MAX16064 can communicate with an EEPROM attached to the A1/SCLE and A2/SDAE. The MAX16064 communicates to the EEPROM with an address byte of 1010 0000 for writing and 1010 0001 for reading. For the data values of 2 bytes, the most significant byte is stored in the lower address of the EEPROM, whereas the least significant byte is stored in the higher address of the EEPROM.

Upon reset, the MAX16064 tests for the presence of a configuration EEPROM. It searches for the SIGNATURE bytes in the attached EEPROM. If the SIGNATURE bytes are present, it concludes that it has a valid configuration EEPROM and starts reading configuration information from the attached EEPROM. If the slave address (MFR_SET_ADDRESS) is a value other than 0xFF, this overrides the slave address information previously set by the address A3:A1 pins.

Table 1b shows the contents and addresses of the configuration information expected by the MAX16064. This information is for reference only. It is recommended to use a properly configured, working MAX16064 to save its state to the EEPROM and limit direct modifications to as few fields as possible (such as the slave address).

Temperature and voltage values are stored in an internal representation, which is not the same as the format used by the corresponding PMBus commands. For details on the EEPROM internal representation, see Conversion Rules (Table 1a).

For example, to store to the EEPROM PAGE 2 VOUT_COMMAND = 3.0V, m = 19995, b = 0, R = -1. First calculate the PMBus command value, which is 5998. If the voltage range is 2V, no conversion is required. Hence write 17h to address 28 and 6Eh to address 29. If the voltage range is 5.5V, the stored EEPROM value = 5998/2.75 = 2181. So write 08h to address 28 and write 85h to address 29.

Note that the conversion is automatically handled by the MAX16064 when it stores and loads configuration information.

Table 1a. Conversion Rules

	READ (INTERNAL TO PMBus)	WRITE (PMBus TO INTERNAL)
TEMPERATURE	Subtract 3010 (decimal) from the PMBus value	Add 3010 (decimal) to the PMBus value
VOLTAGE	No conversion in 2V mode; multiply by 2.75 in 5.5V mode	No conversion in 2V mode; divide by 2.75 in 5.5V mode

Table 1b. 16-Bit Words Stored in EEPROM

EEPROM ADDRESS	NAME	PAGE	PMBus COMMAND	NOTES
0	MFR_FAULT_REASON	—	0E2h	—
2	MFR_MODE	—	0D1h	Must also match MFR_TICK_RELOAD
4	MFR_TEMPERATURE_PEAK	—	0D6h	Internal representation (temperature)
6	MFR_FAULT_TEMP	—	0E4h	Internal representation (temperature)
8	MFR_VOUT_PEAK	0	0D4h	Internal representation (voltage)
10	MFR_VOUT_PEAK	1		
12	MFR_VOUT_PEAK	2		
14	MFR_VOUT_PEAK	3		

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Table 1b. 16-Bit Words Stored in EEPROM (continued)

EEPROM ADDRESS	NAME	PAGE	PMBus COMMAND	NOTES
16	MFR_FAULT_VOUT	0	0E3h	Internal representation (voltage)
18	MFR_FAULT_VOUT	1		
20	MFR_FAULT_VOUT	2		
22	MFR_FAULT_VOUT	3		
24	VOUT_COMMAND	0	21h	Internal representation (voltage)
26	VOUT_COMMAND	1		
28	VOUT_COMMAND	2		
30	VOUT_COMMAND	3		
32	TON_RISE	0	61h	—
34	TON_RISE	1		
36	TON_RISE	2		
38	TON_RISE	3		
40	TON_DELAY	0	60h	—
42	TON_DELAY	1		
44	TON_DELAY	2		
46	TON_DELAY	3		
48	VOUT_MARGIN_HIGH	0	25h	Internal representation (voltage)
50	VOUT_MARGIN_HIGH	1		
52	VOUT_MARGIN_HIGH	2		
54	VOUT_MARGIN_HIGH	3		
56	VOUT_MARGIN_LOW	0	26h	Internal representation (voltage)
58	VOUT_MARGIN_LOW	1		
60	VOUT_MARGIN_LOW	2		
62	VOUT_MARGIN_LOW	3		
64	TOFF_FALL	0	65h	—
66	TOFF_FALL	1		
68	TOFF_FALL	2		
70	TOFF_FALL	3		
72	OT_FAULT_LIMIT	—	4Fh	Internal representation
74	MFR_SAMPLE_RATE	—	0D3h	—
76–87	Reserved (set to 0)	—	—	—
88	MFR_FAULT_RESPONSE	0	0D9h	—
90	MFR_FAULT_RESPONSE	1		
92	MFR_FAULT_RESPONSE	2		
94	MFR_FAULT_RESPONSE	3		
96	MFR_FAULT_RETRY	0	0DAh	—
98	MFR_FAULT_RETRY	1		
100	MFR_FAULT_RETRY	2		
102	MFR_FAULT_RETRY	3		

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Table 1b. 16-Bit Words Stored in EEPROM (continued)

EEPROM ADDRESS	NAME	PAGE	PMBus COMMAND	NOTES
104–115	MFR_DATE	—	9Dh	—
116	MFR_STATUS_WORD	—	0D8h	Set to 0
118	WRITE_PROTECT	—	10h	—
120	ON_OFF_CONFIG	0		—
122	ON_OFF_CONFIG	1	02h	
124	ON_OFF_CONFIG	2		
126	ON_OFF_CONFIG	3		
128	VOUT_SCALE_LOOP	0		—
130	VOUT_SCALE_LOOP	1	29h	
132	VOUT_SCALE_LOOP	2		
134	VOUT_SCALE_LOOP	3		
136	OT_WARN_LIMIT	—	51h	Internal representation (temperature)
138	Reserved (set to 0)	—	—	—
140	MFR_SET_ADDRESS	—	0DBh	Low byte: I^2C address, high byte: reserved
142	Reserved (set to 0)	—	—	—
144	TOFF_DELAY	0		—
146	TOFF_DELAY	1	64h	
148	TOFF_DELAY	2		
150	TOFF_DELAY	3		
152	VOUT_TRANSITION_RATE	0		—
154	VOUT_TRANSITION_RATE	1	27h	
156	VOUT_TRANSITION_RATE	2		
158	VOUT_TRANSITION_RATE	3		
160–175	Reserved (set to 0)	0	—	—
176	MFR_MODE_OUTPUT	0		—
178	MFR_MODE_OUTPUT	1	0DEh	
180	MFR_MODE_OUTPUT	2		
182	MFR_MODE_OUTPUT	3		
184–199	Reserved (set to 0)	—	—	—
200	MFR_RESET_DELAY	—	0DDh	—
202	MFR_RESET_OUTPUT	—	0E1h	—
204	Reserved (set to 0)	—	—	—
206	MFR_TICK_RELOAD	—	0D1h	—
208	MFR_STATUS_WORD	0		
210	MFR_STATUS_WORD	1	0D8h	Set to 0
212	MFR_STATUS_WORD	2		
214	MFR_STATUS_WORD	3		

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Table 1b. 16-Bit Words Stored in EEPROM (continued)

EEPROM ADDRESS	NAME	PAGE	PMBus COMMAND	NOTES
216–237	MFR_LOCATION	—	9Ch	—
238–255	MFR_SERIAL	—	9Eh	—
256–297	MFR_USER_DATA_00	—	0B0h	—
298	VOUT_OV_FAULT_LIMIT	0	40h	Internal representation (voltage)
300	VOUT_UV_FAULT_LIMIT	0	44h	Internal representation (voltage)
302	VOUT_OV_WARN_LIMIT	0	42h	Internal representation (voltage)
304	VOUT_UV_WARN_LIMIT	0	43h	Internal representation (voltage)
306	VOUT_OV_FAULT_LIMIT	1	40h	Internal representation (voltage)
308	VOUT_UV_FAULT_LIMIT	1	44h	Internal representation (voltage)
310	VOUT_OV_WARN_LIMIT	1	42h	Internal representation (voltage)
312	VOUT_UV_WARN_LIMIT	1	43h	Internal representation (voltage)
314	VOUT_OV_FAULT_LIMIT	2	40h	Internal representation (voltage)
316	VOUT_UV_FAULT_LIMIT	2	44h	Internal representation (voltage)
318	VOUT_OV_WARN_LIMIT	2	42h	Internal representation (voltage)
320	VOUT_UV_WARN_LIMIT	2	43h	Internal representation (voltage)
322	VOUT_OV_FAULT_LIMIT	3	40h	Internal representation (voltage)
324	VOUT_UV_FAULT_LIMIT	3	44h	Internal representation (voltage)
326	VOUT_OV_WARN_LIMIT	3	42h	Internal representation (voltage)
328	VOUT_UV_WARN_LIMIT	3	43h	Internal representation (voltage)
330–509	Unused (set to 0)	—	—	—
510	SIGNATURE (set to 4432h)	—	N/A	—

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Figure 7 shows how the MAX16064 interfaces to an external serial EEPROM using the A1/SCLE and A2/SDAE in applications where a master controller does not exist or is not required. Using the GUI, the user can select each MAX16064 device and configure all the required output-voltage settings and sequencing/tracking information. Once the configuration is complete, the results can be saved to the external EEPROM by using the STORE_DEFAULT_ALL command and configuration restored on the MAX16064 power-on reset. The EEPROM can also be preprogrammed prior to board assembly in the manufacturing environment. A3/CONTROL can be used as a control signal to turn on/off the power supply in a similar fashion as the OPERATION command.

Use a serial EEPROM IC with a minimum of 4kb of storage to ensure proper device operation.

MAX16064 Operation

On power-up reset, the MAX16064 goes through an initialization process as shown in Figure 8.

After initialization, the MAX16064 monitors the PMBus and executes the PMBus commands accordingly. In addition, if the power supply has been commanded to turn on, the MAX16064 also monitors the power-supply output voltage and temperature at the MFR_SAMPLE_RATE. The PMBus system controller can monitor the power-supply health by issuing various inquiries and status commands to the MAX16064.

$\overline{RESET}$ Output Operation

$\overline{RESET}$ is an active-low, open-drain output that is low when the device is powering on. $\overline{RESET}$ is assigned to one of the power supplies using the MFR_RESET_OUTPUT command. When that power-supply output is at the target voltage, $\overline{RESET}$ goes high after the reset timeout period (see Figure 9). The reset timeout period (t_{RP}) is set by the MFR_RESET_DELAY command.

The MFR_RESET_OUTPUT value defines which power-supply output affects $\overline{RESET}$. If MFR_RESET_OUTPUT is set to 0, 1, 2, or 3, then $\overline{RESET}$ goes high t_{RP} after that output has reached its target value. If MFR_RESET_OUTPUT is any other value, $\overline{RESET}$ is permanently low.

If the power-supply output selected by MFR_RESET_OUTPUT is later disabled for any reason (either due to a fault condition, or an OPERATION OFF command), then $\overline{RESET}$ goes low immediately. To enable faults on any power supply to cause $\overline{RESET}$ to go low, set the MFR_MODE_OUTPUT.GLOBALFAULTS bit to a 1 for all the supplies.
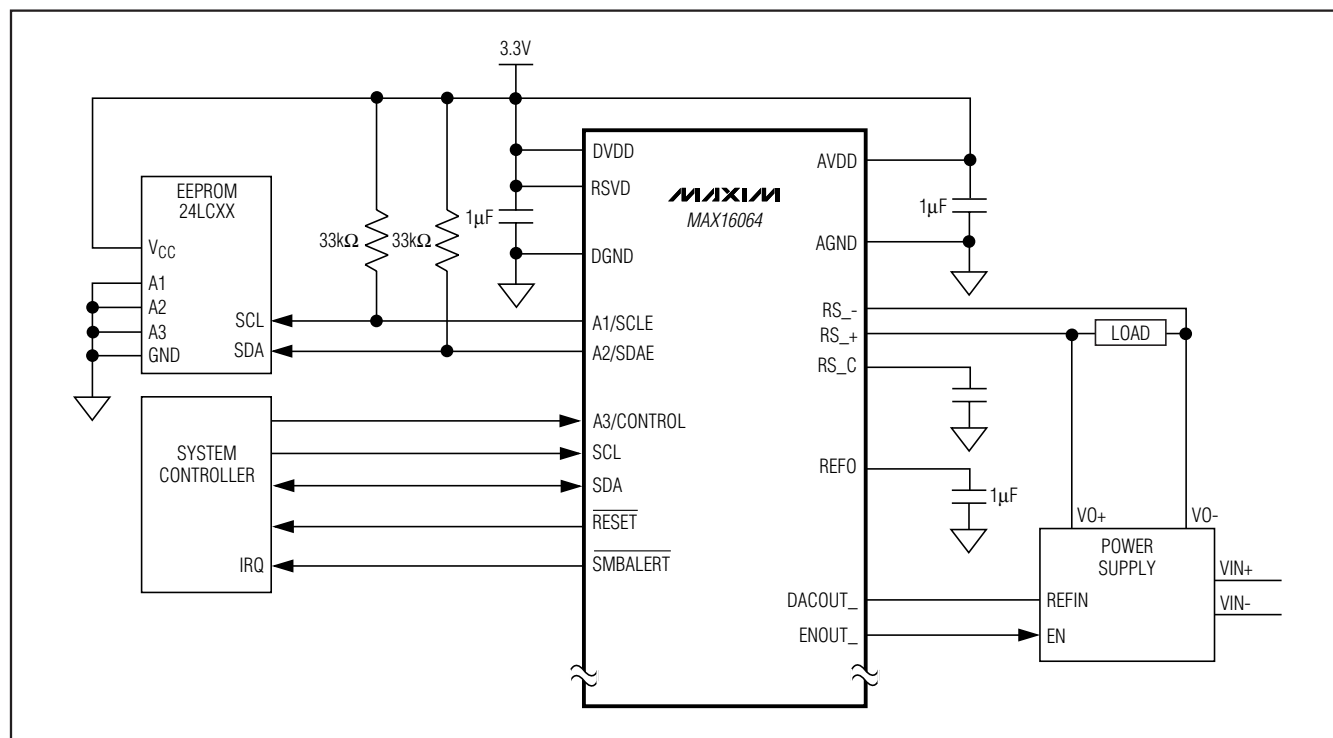
$\overline{RESET}$ requires an external pullup resistor.

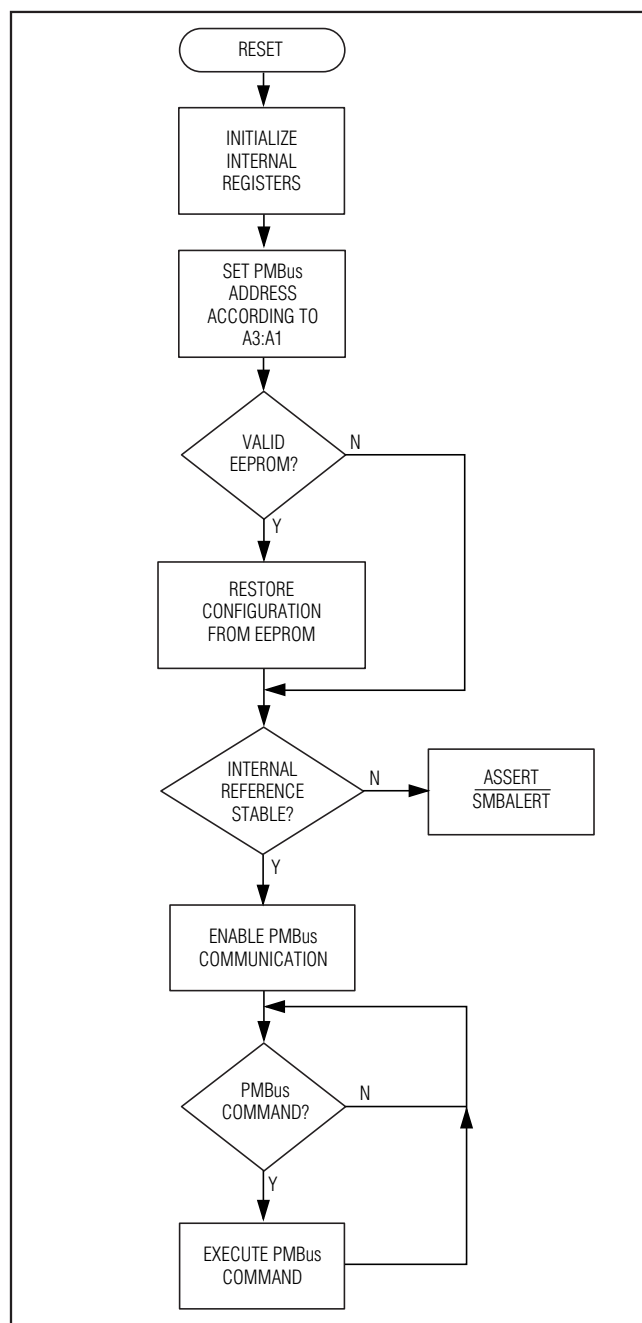Figure 7. Typical System Application with External EEPROM

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Figure 8. MAX16064 Initialization

SMBALERT Output Operation

SMBALERT is an optional interrupt signal defined in Appendix A of the SMBus specification. The MAX16064 provides an output SMBALERT as this interrupt signal. SMBALERT is an active-low, open-drain output and it asserts to signal the PMBus master if any of the voltage or temperature fault has occurred. Typically, SMBALERT is connected to all other SMBALERT open-drain signals in the system, creating a wired-OR function with all SMBALERT outputs. When the master is interrupted by its SMBALERT input, it stops or finishes the current bus transfer and places an alert response address (ARA) on the bus. The slave that pulled the SMBALERT signal low acknowledges the ARA and places its own address on the bus, identifying itself to the master as the slave that caused the interrupt.

SMBALERT deasserts when the MAX16064 responds to the ARA. SMBALERT deasserts when all the fault conditions are removed. SMBALERT is also cleared by the CLEAR_FAULTS command.

ENOUT_ Operation

When power is applied, all ENOUT_ are held low. Upon receiving a command to turn on the power supply, ENOUT_ goes high. The polarity can be changed by the ENOUT_POL bit of the MFR_MODE_OUTPUT command. Setting the bit to a 1 makes the ENOUT_ active low. If the bit in the external EEPROM is set to 1, upon power-up, the ENOUT_ is held low until the bit is copied from the EEPROM to the on-chip register at which time the ENOUT_ goes high. Upon receiving a command to turn on the power supply, ENOUT_ goes low. It takes 1.60ms (typ) to copy the configuration bits from the EEPROM to the on-chip registers.

Table 2. ENOUT_ Active State

ENOUT_ DEFAULT STARTUP STATE	MFR_MODE_OUTPUT. ENOUT_POL	ENOUT_ ACTIVE STATE
Low	0	Active high
Low	1	Active low

EN Operation

The MAX16064 includes an enable input (EN) that controls all ENOUT_ signals in conjunction with the MFR_MODE command. Unless MFR_MODE.IGNORE_EN is set, a below-threshold level on EN prevents any ENOUT_ from turning on. Additionally, if the voltage at EN falls below the 1.2V (typ) threshold during OPERATION ON, the MAX16064 follows the fault action in MFR_FAULT_RESPONSE.EN. Figure 9 shows a typical sequencing with MFR_MODE.IGNORE_EN = 0.

/Λ/ΛXI/Λ
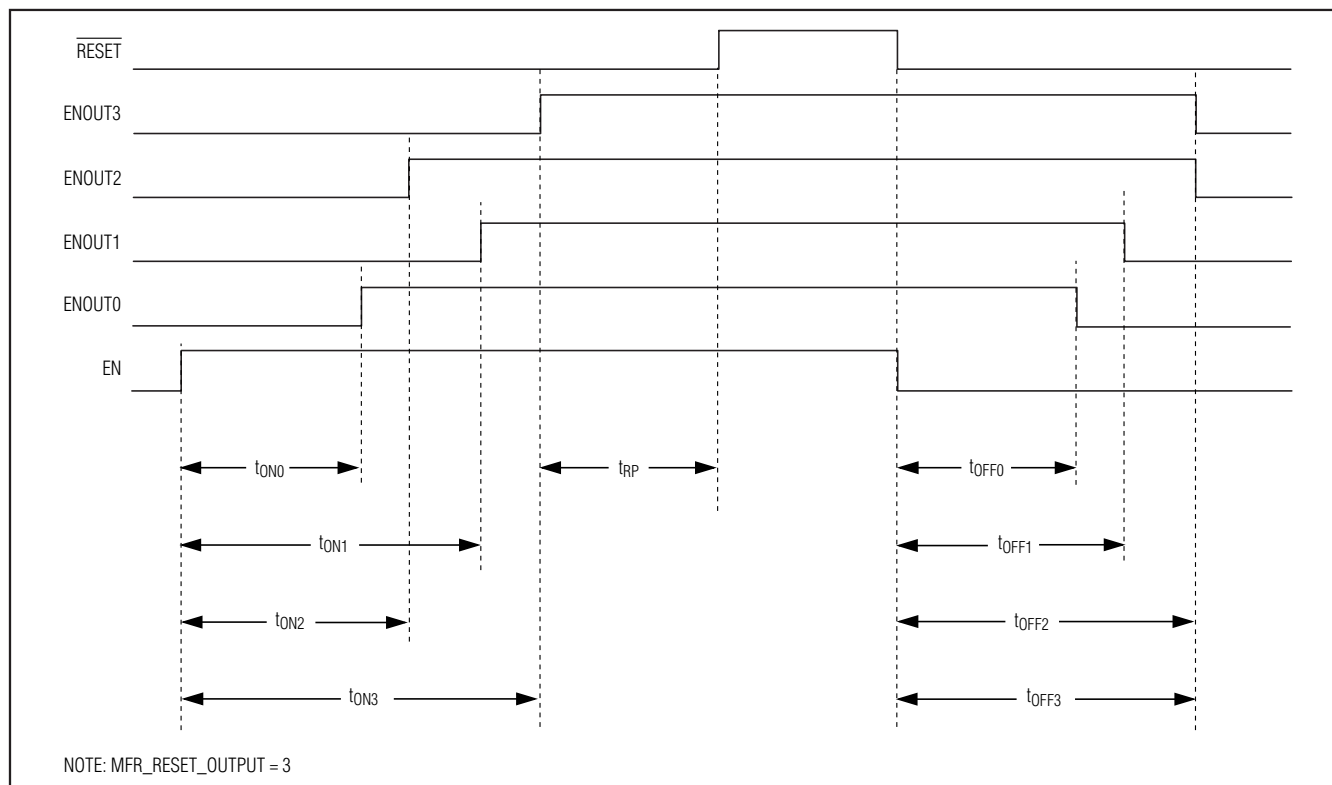
Figure 9. MAX16064 Typical Sequencing Timing

MAX16064 Address Assignment

The MAX16064 picks a slave address in one of the two ways described below:

1) Hardwired by A3:A2:A1.

2) Restored from EEPROM at power-on.

Address assignment order is shown in Figure 10.

The MAX16064 reads A3:A2:A1 address pins upon device reset and determines its address according to Table 3.

Table 3. MAX16064 A3:A1 Slave Address Assignment

A3/CONTROL	A2/SDAE	A1/SCLE	ADDRESS (BITS 7–1)
L	L	L	40h
L	L	Z	01h*
L	Z	L	02h
L	Z	Z	03h
Z	L	L	04h
Z	L	Z	05h
Z	Z	L	06h
Z	Z	Z	07h
L	L	H	09h
L	Z	H	0Bh
Z	L	H	0Dh

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Table 3. MAX16064 A3:A1 Slave Address Assignment (continued)

A3/CONTROL	A2/SDAE	A1/SCLE	ADDRESS (BITS 7–1)
Z	Z	H	0Fh
L	H	L	12h
L	H	Z	13h
Z	H	L	16h
Z	H	Z	17h
L	H	H	1Bh
Z	H	H	1Fh
H	L	L	24h
H	L	Z	25h
H	Z	L	26h
H	Z	Z	27h
H	L	H	2Dh
H	Z	H	2Fh
H	H	L	36h
H	H	Z	37h
H	H	H	3Fh

*The shaded addresses are not available if external EEPROM is attached.

The hardwired address pins give 3^3 = 27 address options. For example, to configure the MAX16064 to have a slave address of 010 0101 (25h), set A3:A2:A1 = H:L:Z. The MAX16064 also responds to the broadcast address (00h).

If an EEPROM with valid SIGNATURE bytes is attached to the MAX16064, the MAX16064 tries to restore its slave address from the EEPROM. This overrides the address set by the address pins. This gives a total of 128 possible slave addresses. Note that there are 14 reserved addresses that are restricted by the PMBus specification and may not be used in PMBus systems. If the address bit 7 from the EEPROM is set to 1, this is an invalid address and the MAX16064 continues using the address set by the address pins. When an EEPROM is attached to A2/SDAE and A1/SCLE, these pins assume either a logic-high or a logic-low level, therefore, the resulting number of possible addresses set by the A3:A2:A1 pins in this scenario is 2^3 = 8.

In addition, for the MAX16064 with an EEPROM attached, the system controller can change the MAX16064 slave address by sending the new address with the MFR_SET_ADDRESS command. However, the new address is not immediately effective. The new address must be stored to the EEPROM first using the STORE_DEFAULT_ALL command. Then, the MAX16064 power must be cycled to start the address assignment procedure and recalls the new address from the EEPROM.

A3/CONTROL Operation

The A3/CONTROL input is utilized in combination with the A2 and A1 inputs to set the PMBus address when power is applied to the device. After the PMBus address detection, the A3/CONTROL input functions as the PMBus CONTROL input.

The ON_OFF_CONFIG command determines whether the A3/CONTROL input affects the on/off behavior of the power supply. When A3/CONTROL is enabled by the ON_OFF_CONFIG command, a transition of A3/CONTROL from low to high turns the power supply on, as if the MAX16064 has received an OPERATION ON command. A transition of A3/CONTROL from high to low initiates a soft-off to the power supply, as if the MAX16064 has received an OPERATION OFF command (soft-off, with sequencing). The MAX16064 still responds to the PMBus OPERATION command while A3/CONTROL is enabled. To detect the A3/CONTROL input, the A3/CONTROL signal pulse width has to satisfy the t_{A3_LOW} and t_{A3_HIGH} requirements to be detected. See the *ON_OFF_CONFIG (02h)* section and Table 6 for more information.

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Figure 10. MAX16064 Address Assignment

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The dual functionality of A3/CONTROL of the MAX16064 requires that the system enable signal be isolated from A3 until the address setting has been read and latched by the MAX16064. Figure 11 shows one implementation for the three possible states of the A3/CONTROL setting. In each case, the system enable signal (MAX16064_EN) is applied to the input of a three-state buffer whose output is kept in the high-impedance state by a control input signal (HIZ_EN) for a time period during which the MAX16064 reads and latches the A3/CONTROL address setting. After this period, the control signal HIZ_EN goes low and allows the system enable signal to be applied to the MAX16064 A3/CONTROL pin. After a t_{A3_LOW}, the MAX16064_EN signal transitions from low to high and causes the MAX16064s to commence power-supply startup operations.

PMBus Digital Interface

From a software perspective, the MAX16064 appears as a PMBus device capable of executing a subset of PMBus commands. A PMBus 1.0-compliant device uses the SMBus version 1.1 for transport protocol and responds to the SMBus slave address. In this data sheet, the term SMBus is used to refer to the electrical characteristics of the PMBus communication using the SMBus physical layer. The term PMBus is used to refer to the PMBus command protocol.

The MAX16064 employs five standard SMBus protocols (Write Word, Read Word, Write Byte, Read Byte, and Send Byte (see Figures 12–15)) to program output voltage and warning/faults thresholds, read monitored data, and provide access to all manufacturer-specific commands.

Figure 11. Application Diagram with A3/CONTROL as Both Address and On/Off Control Signal

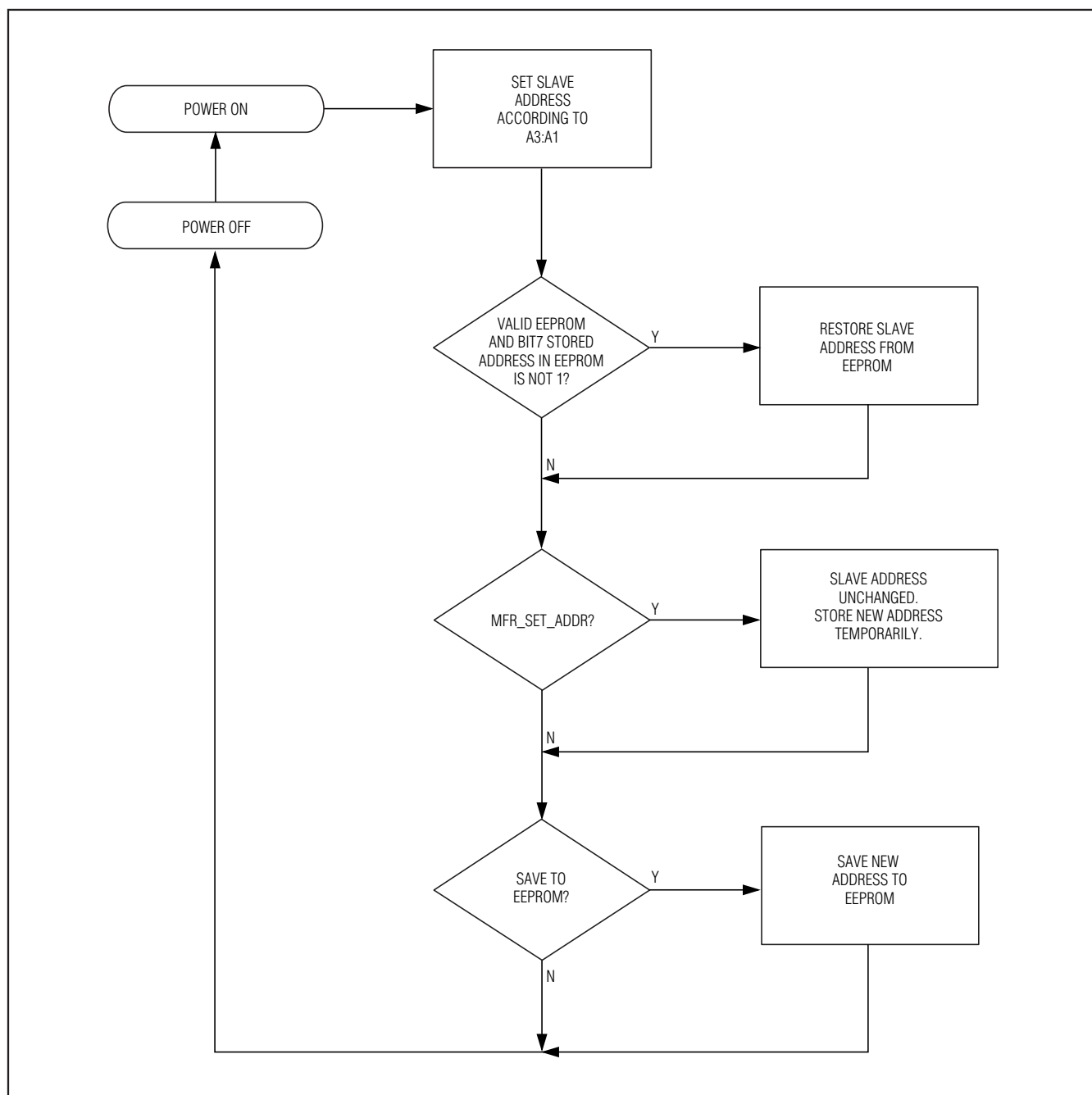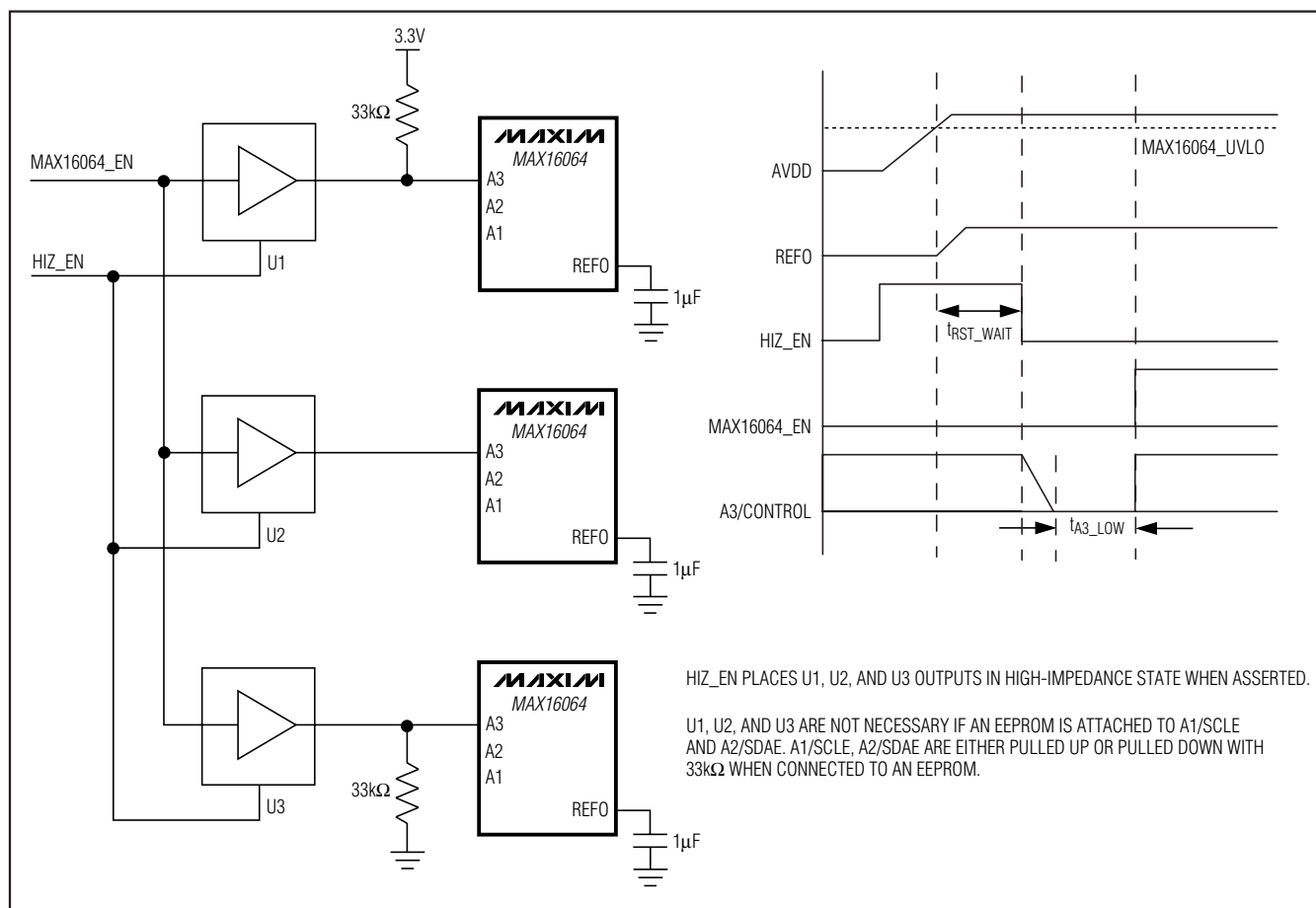**MAXIM**

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The MAX16064 supports the group command. The group command is used to send commands to more than one PMBus device. It is not required that all the devices receive the same command. However, no more than one command can be sent to any one device in one group command packet. The group command must not be used with commands that require receiving devices to respond with data, such as the STATUS_BYTE command. When the MAX16064 receives a command through this protocol, it immediately begins execution of the received command after detecting the STOP condition.

The MAX16064 supports the PAGE command and uses it to select which individual channel to access.

When the data word is transmitted, the lower order byte is sent first and the higher order byte is sent last. Within any byte, the most significant bit (MSB) is sent first and the least significant bit (LSB) is sent last.

The MAX16064 SMBus interface supports Packet Error Checking (PEC). See the *MFR_MODE (D1h)* section.

WRITE BYTE FORMAT

S	ADDR	W	A	COMMAND	A	DATA	A	P
	7 BITS			8 BITS		8 BITS		

SLAVE ADDRESS
COMMAND BYTE: SELECTS TO WHICH COMMAND PARAMETER TO WRITE
DATA BYTE: DATA FOR THE COMMAND SET BY THE COMMAND BYTE

READ BYTE FORMAT

S	ADDR	W	A	COMMAND	A	SR	ADDR	R	A	DATA	NA	P
	7 BITS			8 BITS			7 BITS			8 BITS		

SLAVE ADDRESS
COMMAND BYTE: SELECTS FROM WHICH COMMAND PARAMETER TO READ
SLAVE ADDRESS: REPEATED DUE TO CHANGE IN DATA-FLOW DIRECTION
DATA BYTE: DATA FOR THE COMMAND SET BY THE COMMAND BYTE

WRITE WORD FORMAT

S	ADDR	W	A	COMMAND	A	DATA0	A	DATA1	A	P
	7 BITS			8 BITS		8 BITS		8 BITS		

SLAVE ADDRESS
COMMAND BYTE: SELECTS TO WHICH COMMAND PARAMETER TO WRITE
DATA BYTE: DATA FOR THE COMMAND SET BY THE COMMAND BYTE

READ WORD FORMAT

S	ADDR	W	A	COMMAND	A	SR	ADDR	R	A	DATA0	A	DATA1	NA	P
	7 BITS			8 BITS			7 BITS			8 BITS		8 BITS		

SLAVE ADDRESS
COMMAND BYTE: SELECTS FROM WHICH COMMAND PARAMETER TO READ
SLAVE ADDRESS: REPEATED DUE TO CHANGE IN DATA-FLOW DIRECTION
DATA BYTE: DATA FOR THE COMMAND SET BY THE COMMAND BYTE

SEND BYTE FORMAT

S	ADDR	W	A	COMMAND	A	P
	7 BITS			8 BITS		

SLAVE ADDRESS
COMMAND BYTE: SEND COMMAND WITH NO DATA

S	= START CONDITION
SR	= REPEATED START CONDITION
P	= STOP CONDITION
☐	= SLAVE TRANSMISSION

Figure 12. SMBus Protocols

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S	ADDR1	W	A	CMD1	A	DATA0	A	DATA1	A
	7 BITS			8 BITS		8 BITS		8 BITS	

SLAVE ADDRESS OF DEVICE 1   COMMAND BYTE FOR DEVICE 1   DATA BYTES FOR DEVICE 1   . . .

SR	ADDR2	W	A	CMD2	A	DATA	A
	7 BITS			8 BITS		8 BITS	

SLAVE ADDRESS OF DEVICE 2   COMMAND BYTE FOR DEVICE 2   DATA BYTE FOR DEVICE 2   . . .

SR	ADDR3	W	A	CMD3	A	DATA0	A	DATA1	A
	7 BITS			8 BITS		8 BITS		8 BITS	

SLAVE ADDRESS OF DEVICE 3   COMMAND BYTE FOR DEVICE 3   DATA BYTES FOR DEVICE 3   . . .

SR	ADDRn	W	A	CMDn	A	P
	7 BITS			8 BITS		

SLAVE ADDRESS OF DEVICE n   COMMAND BYTE FOR DEVICE n: NO DATA BYTE
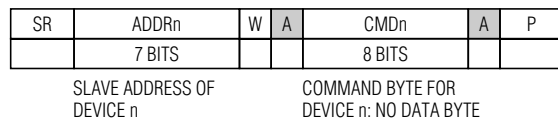
S = START CONDITION
SR = REPEATED START CONDITION
P = STOP CONDITION
☐ = SLAVE TRANSMISSION

Figure 13. SMBus Group Command Protocol

/VI/AXI/VI

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WRITE BYTE FORMAT

S	ADDR	W	A	COMMAND	A	DATA	A	PEC	A	P
	7 BITS			8 BITS		8 BITS		8 BITS		

SLAVE ADDRESS

COMMAND BYTE: SELECTS TO WHICH COMMAND PARAMETER TO WRITE

DATA BYTE: DATA FOR THE COMMAND SET BY THE COMMAND BYTE

READ BYTE FORMAT

S	ADDR	W	A	COMMAND	A	SR	ADDR	R	A	DATA	A	PEC	NA	P
	7 BITS			8 BITS			7 BITS			8 BITS		8 BITS		

SLAVE ADDRESS

COMMAND BYTE: SELECTS FROM WHICH COMMAND PARAMETER TO READ

SLAVE ADDRESS: REPEATED DUE TO CHANGE IN DATA-FLOW DIRECTION

DATA BYTE: DATA FOR THE COMMAND SET BY THE COMMAND BYTE

WRITE WORD FORMAT

S	ADDR	W	A	COMMAND	A	DATA0	A	DATA1	A	PEC	A	P
	7 BITS			8 BITS		8 BITS		8 BITS		8 BITS		

COMMAND BYTE: SELECTS TO WHICH COMMAND PARAMETER TO WRITE

DATA BYTES: DATA FOR THE COMMAND SET BY THE COMMAND BYTE

READ WORD FORMAT

S	ADDR	W	A	COMMAND	A	SR	ADDR	R	A	DATA0	A	DATA1	A	PEC	NA	P
	7 BITS			8 BITS			7 BITS			8 BITS		8 BITS		8 BITS		

SLAVE ADDRESS

COMMAND BYTE: SELECTS FROM WHICH COMMAND PARAMETER TO READ

SLAVE ADDRESS: REPEATED DUE TO CHANGE IN DATA-FLOW DIRECTION

DATA BYTES: DATA FOR THE COMMAND SET BY THE COMMAND BYTE
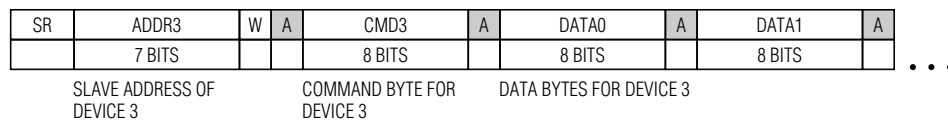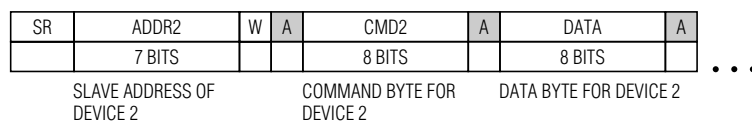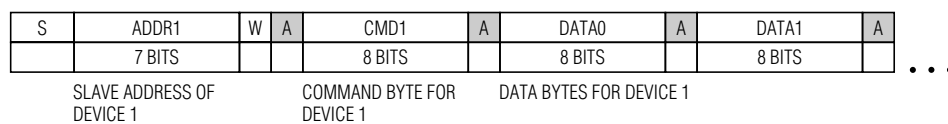
SEND BYTE FORMAT

S	ADDR	W	A	COMMAND	A	PEC	A	P
	7 BITS			8 BITS		8 BITS		

SLAVE ADDRESS

COMMAND BYTE: SEND COMMAND WITH NO DATA

S   = START CONDITION
SR = REPEATED START CONDITION
P   = STOP CONDITION
▨   = SLAVE TRANSMISSION

Figure 14. SMBus Protocols with PEC

MAX16064
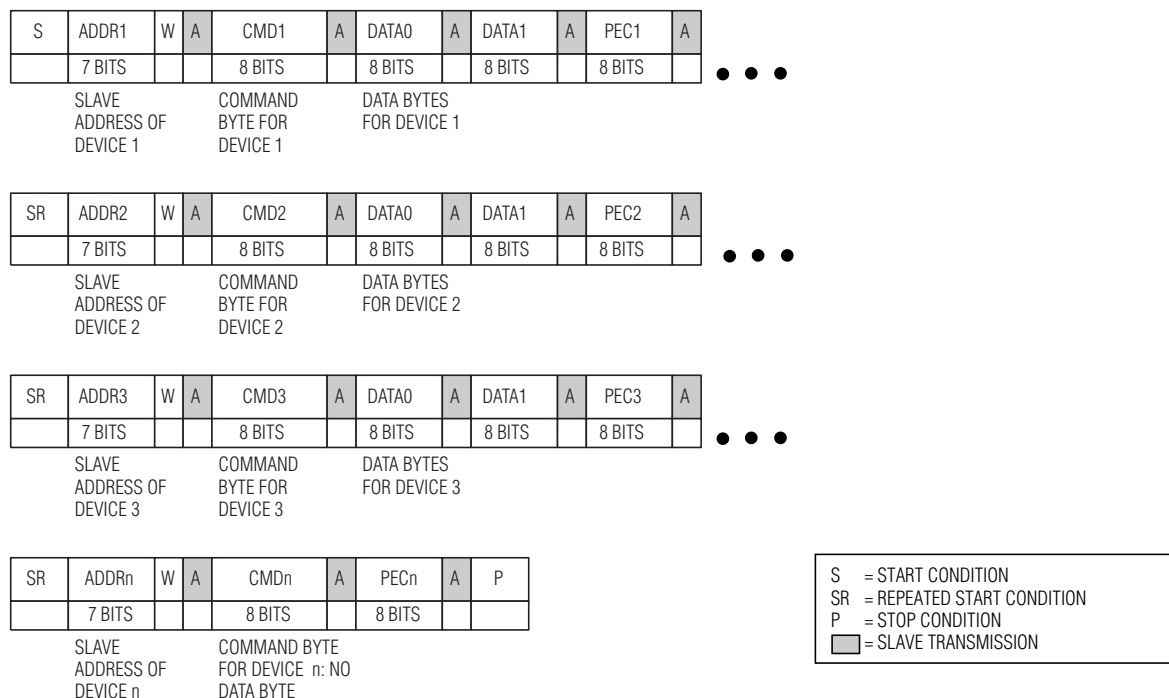
Figure 15. SMBus Group Command Protocol with PEC

A = START CONDITION
B = MSB OF ADDRESS CLOCKED INTO SLAVE
C = LSB OF ADDRESS CLOCKED INTO SLAVE
D = R/W BIT CLOCKED INTO SLAVE
E = SLAVE PULLS SDA LINE LOW

F = ACKNOWLEDGE BIT CLOCKED INTO MASTER
G = MSB OF DATA CLOCKED INTO MASTER
H = LSB OF DATA CLOCKED INTO MASTER
I = MASTER PULLS SDA LINE LOW

J = ACKNOWLEDGE CLOCKED INTO SLAVE
K = ACKNOWLEDGE CLEAR PULSE
L = STOP CONDITION
M = NEW START CONDITION

Figure 16. SMBus Write Timing Diagram

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Figure 17. SMBus Read Timing Diagram

A = START CONDITION
B = MSB OF ADDRESS CLOCKED INTO SLAVE
C = LSB OF ADDRESS CLOCKED INTO SLAVE
D = R/W BIT CLOCKED INTO SLAVE
E = SLAVE PULLS SDA LINE LOW

F = ACKNOWLEDGE BIT CLOCKED INTO MASTER
G = MSB OF DATA CLOCKED INTO SLAVE
H = LSB OF DATA CLOCKED INTO SLAVE
I = SLAVE PULLS SDA LINE LOW

J = ACKNOWLEDGE CLOCKED INTO MASTER
K = ACKNOWLEDGE CLOCK PULSE
L = STOP CONDITION, DATA EXECUTED BY SLAVE
M = NEW START CONDITION

PMBus Protocol Support

The MAX16064 supports a subset of the commands defined in the Power System Management Protocol Specification Part II - Command Language Revision 1.0. For detailed specifications and the complete list of PMBus commands, refer to Part II of the PMBus specification available at **www.PMBus.org**. The supported PMBus commands and the corresponding MAX16064 behavior are described in this document.

All data values are represented in DIRECT format, unless otherwise stated. Whenever the resolution of the data is less than the number of bits required, data are right justified (only the lower bits are significant) and the higher order bits are zero-padded, unless otherwise stated. For example, for a 2-byte value where the MAX16064 only has 12-bit data to return, the MAX16064 returns data in the lower 12 bits and zero-pads the upper 4 bits. Whenever the PMBus specification refers to the PMBus device, it is referring to the MAX16064 operating in conjunction with a power supply. While the command may call for turning on or off the PMBus device, the MAX16064 always remains on to continue communicating with the PMBus master and the MAX16064 transfers the command to the power supply accordingly.

Data Format

Voltage data for commanding or reading the output voltage or related parameters (such as the overvoltage threshold) are presented in DIRECT format. DIRECT format data is a 2-byte, two's complement binary value. DIRECT format data may be used with any command that sends or reads a parametric value. The DIRECT format uses an equation and defined coefficients to calculate the desired values. The coefficients used by the MAX16064 can be found in Table 4.

Interpreting Received DIRECT Format Values

The host system uses the following equation to convert the value received from the PMBus device, in this case the MAX16064, into a reading of volts, degrees Celsius, or other units as appropriate:

$$X = \frac{1}{m}\left(Y \times 10^{-R} - b\right)$$

where X is the calculated, real world value in the appropriate units (V, °C, etc.);

m, the slope coefficient, is a 2-byte, two's complement integer;

Y is a 2-byte, two's complement integer received from the PMBus device;

b, the offset, is a 2-byte, two's complement integer; and

R, the exponent, is a 1-byte, two's complement integer.

Sending a DIRECT Format Value

To send a value, the host must use the equation below to solve for Y:

$$Y = (mX + b) \times 10^R$$

where:

Y is the 2-byte, two's complement integer to be sent to the unit;

m, the slope coefficient, is the 2-byte, two's complement integer;

X is a real world value, in units such as volts, to be converted for transmission;

b is the offset, is the 2-byte, two's complement integer; and

R, the exponent, is the decimal value equivalent to the 1 byte, two's complement integer.

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Table 4. MAX16064 PMBus Command Summary
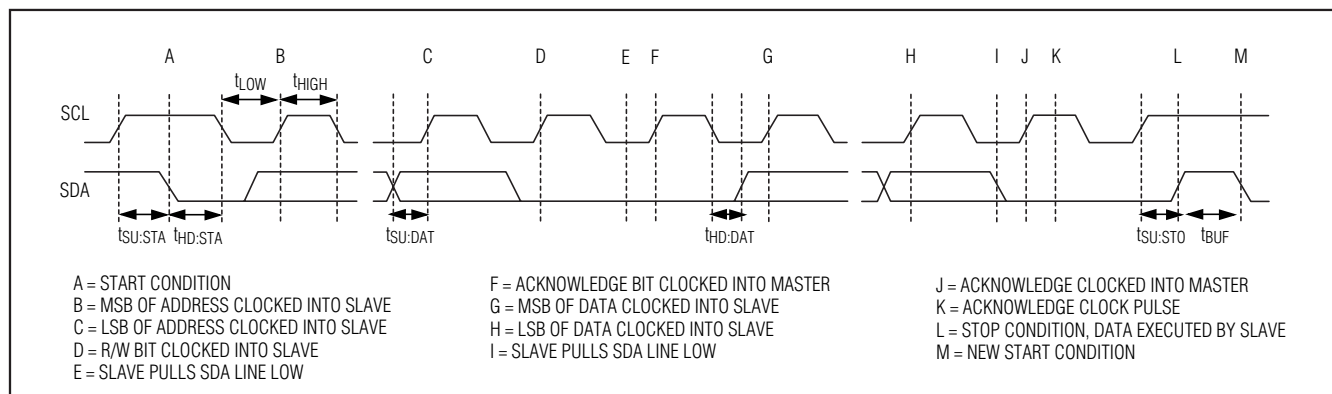**(Global commands are shaded; they are not dependent on the PAGE)**

COMMAND CODE	COMMAND NAME	TRANSACTION TYPE	PAGE 0-3	PAGE 255	NO. OF BYTES	m	b	R
PMBus STANDARD COMMANDS								
00h	PAGE	R/W Byte	R/W		1	—	—	—
01h	OPERATION	Write Byte	W	W	1	—	—	—
02h	ON_OFF_CONFIG	R/W Byte	R/W	W	1	—	—	—
03h	CLEAR_FAULTS	Send Byte	W	W	0	—	—	—
10h	WRITE_PROTECT	R/W Byte	R/W		1	—	—	—
11h	STORE_DEFAULT_ALL	Send Byte	W		0	—	—	—
12h	RESTORE_DEFAULT_ALL	Send Byte	W		0	—	—	—
19h	CAPABILITY	Read Byte	R		1	—	—	—
20h	VOUT_MODE	Read Byte	R		1	—	—	—
21h	VOUT_COMMAND	R/W Word	R/W	W	2	19995	0	-1
25h	VOUT_MARGIN_HIGH	R/W Word	R/W	W	2	19995	0	-1
26h	VOUT_MARGIN_LOW	R/W Word	R/W	W	2	19995	0	-1
27h	VOUT_TRANSITION_RATE	R/W Word	R/W	W	2	256	0	0
29h	VOUT_SCALE_LOOP	R/W Word	R/W	W	2	128	0	0
40h	VOUT_OV_FAULT_LIMIT	R/W Word	R/W	W	2	19995	0	-1
42h	VOUT_OV_WARN_LIMIT	R/W Word	R/W	W	2	19995	0	-1
43h	VOUT_UV_WARN_LIMIT	R/W Word	R/W	W	2	19995	0	-1
44h	VOUT_UV_FAULT_LIMIT	R/W Word	R/W	W	2	19995	0	-1
4Fh	OT_FAULT_LIMIT	R/W Word	R/W		2	-7612	335	-3
51h	OT_WARN_LIMIT	R/W Word	R/W		2	-7612	335	-3
60h	TON_DELAY	R/W Word	R/W	W	2	1	0	1
61h	TON_RISE	R/W Word	R/W	W	2	1	0	3
64h	TOFF_DELAY	R/W Word	R/W	W	2	1	0	1
65h	TOFF_FALL	R/W Word	R/W	W	2	1	0	3
78h	STATUS_BYTE	Read Byte	R	R	1	—	—	—
79h	STATUS_WORD	Read Word	R	R	2	—	—	—
7Ah	STATUS_VOUT	Read Byte	R	R	1	—	—	—
7Dh	STATUS_TEMPERATURE	Read Byte	R		1	—	—	—
7Eh	STATUS_CML	Read Byte	R		1	—	—	—
80h	STATUS_MFR_SPECIFIC	Read Byte	R	R	1	—	—	—
8Bh	READ_VOUT	Read Word	R	R	2	19995	0	-1
8Dh	READ_TEMPERATURE_1	Read Word	R		2	-7612	335	-3
98h	PMBUS_REVISION	Read Byte	R		1	—	—	—
99h	MFR_ID	Block Read	R		2	—	—	—
9Ah	MFR_MODEL	Block Read	R		2	—	—	—
9Bh	MFR_REVISION	Block Read	R		2	—	—	—
9Ch	MFR_LOCATION	Block R/W	R/W		—	—	—	—
9Dh	MFR_DATE	Block R/W	R/W		—	—	—	—
9Eh	MFR_SERIAL	Block R/W	R/W		—	—	—	—
B0h	MFR_USER_DATA_00	Block R/W	R/W		—	—	—	—

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Table 4. MAX16064 PMBus Command Summary (continued)
(Global commands are shaded; they are not dependent on the PAGE)

COMMAND CODE	COMMAND NAME	TRANSACTION TYPE	PAGE 0-3	PAGE 255	NO. OF BYTES	m	b	R
MANUFACTURER-SPECIFIC COMMANDS								
D0h	MFR_SMB_LOOPBACK	R/W Word	R/W		2	—	—	—
D1h	MFR_MODE	R/W Word	R/W		2	—	—	—
D3h	MFR_SAMPLE_RATE	R/W Word	R/W		2	—	—	—
D4h	MFR_VOUT_PEAK	R/W Word	R/W	W	2	19995	0	-1
D6h	MFR_TEMPERATURE_PEAK	Read Word	R/W		2	7612	335	-3
D8h	MFR_STATUS_WORD	Read Word	R	R	2	—	—	—
D9h	MFR_FAULT_RESPONSE	R/W Word	R/W	W	2	—	—	—
DAh	MFR_FAULT_RETRY	R/W Word	R/W	W	2	—	—	—
DBh	MFR_SET_ADDRESS	R/W Byte	R/W		1	—	—	—
DDh	MFR_RESET_DELAY	R/W Word	R/W		2	1	0	1
DEh	MFR_MODE_OUTPUT	R/W Word	R/W	W	2	—	—	—
DFh	MFR_VLTO	R/W Byte	R/W		1	—	—	—
E0h	MFR_DAC_ACT_CNT	R/W Byte	R/W		1	—	—	—
E1h	MFR_RESET_OUTPUT	R/W Byte	R/W		1	—	—	—
E2h	MFR_FAULT_REASON	R/W Word	R/W		2	—	—	—
E3h	MFR_FAULT_VOUT	R/W Word	R/W	W	2	—	—	—
E4h	MFR_FAULT_TEMP	R/W Word	R/W		2	—	—	—

The following example demonstrates how the host can send and retrieve values from the MAX16064.

From Table 4, the coefficients used in the following parameters are:

VOUT_COMMAND: m = 19995, b = 0, R = -1
READ_VOUT: m = 19995, b = 0, R = -1

If a host wants to command the power supply to output a voltage of 3.0V, the corresponding VOUT_COMMAND value is:

$$Y = (mX + b) \times 10^R$$
$$Y = (19995 \times 3.0 + 0) \times 10^{-1} = 5998.5$$
$$(decimal) = 176Eh \text{ (hex)}$$

Conversely, if the host received a value of 176Eh on a READ_VOUT command, this is equivalent to:

$$X = \frac{1}{m}\left(Y \times 10^{-R} - b\right)$$

$$X = \frac{1}{19995}\left(176Eh \times 10^{-(-1)} - 0\right) = 59980/19995 = 2.999750$$

which is within 0.0083% of 3.0V.

Power supplies and power converters generally have no way of knowing how their outputs are connected to ground. Within the power supply, all output voltages are most commonly treated as positive. Accordingly, all output voltages and output voltage-related parameters of PMBus devices are commanded and reported as positive values. It is up to the system to know that a particular output is negative if that is of interest to the system.

All output voltage-related commands use 2 data bytes.

Fault Management and Reporting

For reporting faults/warnings to the host on a real-time basis, the MAX16064 asserts the open-drain $\overline{SMBALERT}$ pin and sets the appropriate bit in the STATUS_BYTE and MFR_STATUS_WORD registers, respectively. On recognition of the $\overline{SMBALERT}$ assertion, the host or system manager is expected to poll the I2C bus to determine the device asserting $\overline{SMBALERT}$. The host sends the SMBus Alert Response Address (0001100). The MAX16064 will ACK the SMBus Alert Response Address, transmit its slave address, and deassert $\overline{SMBALERT}$. The system controller then

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communicates with PMBus commands to retrieve the fault/warning status information from the MAX16064. The following status commands are supported:

STATUS_BYTE

STATUS_WORD

STATUS_VOUT

STATUS_TEMPERATURE

STATUS_CML

STATUS_MFR_SPECIFIC

MFR_STATUS_WORD

MFR_FAULT_REASON

MFR_FAULT_VOUT

MFR_FAULT_TEMP

See the individual command sections for more details.

Faults/warnings are cleared when any one of the following conditions occurs:

- A CLEAR_FAULTS command is received.

- OPERATION commands are received that turn off and on the power supplies or A3/CONTROL is toggled to turn off and then turn on the power supplies.

- Bias power (AVDD, DVDD) to the MAX16064 is removed and then reapplied.

The MAX16064 responds to fault conditions according to the Manufacturer Fault Response command (MFR_FAULT_RESPONSE). This command byte determines how the MAX16064 should respond to each particular fault. In addition, the MAX16064 responds to the following error conditions.

1) If the internal reference fails to operate, $\overline{\text{SMBALERT}}$ is asserted. To clear this fault, the MAX16064 must go through a device reset.

2) The MAX16064 responds to unsupported commands with a NACK.

3) When the host sends insufficient data (too few bytes), the MAX16064 sets the CML bit and asserts $\overline{\text{SMBALERT}}$.

4) When the host sends too much data (too many bytes), the MAX16064 sets the CML bit and asserts $\overline{\text{SMBALERT}}$.

When a read request is issued to a write-only command, the read operation is aborted and no warning is issued.

PMBus Commands

A summary of the PMBus commands supported by the MAX16064 is described in Table 4.

PAGE (00h)

The MAX16064 can control up to four power supplies using one PMBus (I^2C) address. Send the PAGE command with data 0 to 3 to select which power supply is affected by all following commands. Set the PAGE to 255 when it is desired that following commands affect all four power supplies. If, when PAGE = 255, the host sends a command code that is not a global command (any command in Table 4 that is not shaded), the MAX16064 sets the CML, error flag. An example would be to set the PAGE to 255 and then issue an OPERATION command to turn on all the power supplies at one time.

OPERATION (01h)

The OPERATION command is used to turn the power supply on and off in conjunction with ENOUT_ according to the ENOUT_ polarity select setup. The OPERATION command is also used to cause the power supply to set the output voltage to the upper or lower margin voltages. The power supply stays in the commanded operating mode until a subsequent OPERATION command or change in the state of A3/CONTROL (if enabled) instructs the power supply to change to another state.

The valid OPERATION command byte values are shown in Table 5.

The OPERATION command controls how the MAX16064 responds when commanded to change the output. When the command byte is 00h, the MAX16064 immediately turns the power supply off and ignores any programmed turn-off delay and fall time. When the command byte is set to 40h, the MAX16064 powers down according to the programmed turn-off delay and fall time.

In Table 5, Act On Fault means that if an output overvoltage warning or output overvoltage fault is detected when the output is margined high, the MAX16064 treats this as a warning or fault and responds as programmed by the warning limit or fault response command. Similarly, if an output undervoltage warning or output undervoltage fault is detected when the output is margined low, the MAX16064 treats this as a qualified warning/fault event and responds as programmed by the warning/fault limit or fault response command.

Any command value not shown in Table 5 is an invalid command. If the MAX16064 receives a data byte that is not listed in Table 5, then it may treat this as invalid data, declares a communications fault (set CML bit and assert $\overline{\text{SMBALERT}}$), and responds as described in the *Fault Management and Reporting* section.

The default OPERATION value is 00h.

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Table 5. OPERATION Command Byte

COMMAND BYTE	POWER SUPPLY ON OR OFF	MARGIN STATE
00h	Immediate off (no sequencing)	—
40h	Soft-off (with sequencing)	—
80h	On	Margin off (nominal)
94h	On	Margin low (ignore fault)
98h	On	Margin low (act on fault)
A4h	On	Margin high (ignore fault)
A8h	On	Margin high (act on fault)

ON_OFF_CONFIG (02h)

The ON_OFF_CONFIG command configures the combination of A3/CONTROL input and serial bus commands needed to turn the power supply on and off. This indicates how the power supply is commanded when power is applied. The ON_OFF_CONFIG message content is described in Table 6.

CLEAR_FAULTS (03h)

The CLEAR_FAULTS command is used to clear any fault bits that have been set. This command clears all bits in the STATUS_BYTE and MFR_STATUS_WORD registers simultaneously. It also deasserts $\overline{SMBALERT}$.

The CLEAR_FAULTS command does not cause a power supply that has latched off for a fault condition to

Table 6. ON_OFF_CONFIG Message Contents

BIT NUMBER	PURPOSE	MEANING
[7:5]		Reserved. Always returns 000.
4	Sets the default to operate either any time power is present or for the on/off to be controlled by A3/CONTROL input and serial bus commands	0 = Power supply turns on (ENOUT goes high) any time power is present regardless of the state of the A3/CONTROL pin. 1 = Power supply is not turned on until commanded by the A3/CONTROL pin and OPERATION command (as configured in bits [3:0]).
3	Controls how the power supply responds to commands received over the serial bus	0 = Power supply ignores the on/off portion of the OPERATION command received from the serial bus. 1 = An operation command must be received to turn the power supply on. Depending on bit [2], the MAX16064 may require the A3/CONTROL input to be asserted for the power supply to be turned on (ENOUT asserted).
2	Configures how the power supply responds to the A3/CONTROL input	0 = Power supply ignores the A3/CONTROL input. On/off is only controlled by the OPERATION command. 1 = Power supply requires the A3/CONTROL input to be asserted to turn on the power supply. Depending on bit [3], the MAX16064 may require the OPERATION command to be received for the power supply to be turned on (ENOUT asserted).
1	Polarity of the A3/CONTROL input	0 = A3/CONTROL input is active low. Drive low to turn on the power supply. 1 = A3/CONTROL input is active high. Drive high to turn on the power supply.
0	A3/CONTROL input action when commanding the power supply to turn off	0 = Use the configured turn off delay (TOFF_DELAY) and fall time (TOFF_FALL). 1 = Turn off the power supply as quickly as possible (deassert ENOUT).

restart. The status of ENOUT_ under fault conditions is not affected by this command and should change only if commanded through the OPERATION command or A3/CONTROL.

If the fault is still present after the CLEAR_FAULTS command is executed, the fault bit is set again and the host is also notified by asserting SMBALERT.

This command is write-only. There is no data byte for this command.

WRITE_PROTECT (10h)

The WRITE_PROTECT command is used to provide protection against accidental changes to the MAX16064 operating memory. All supported commands may have their parameters read, regardless of the WRITE_PROTECT settings. The WRITE_PROTECT message content is described in Table 7.

STORE_DEFAULT_ALL (11h)

The STORE_DEFAULT_ALL command instructs the MAX16064 to transfer the user memory configuration information to an external I2C EEPROM device (default memory) attached to A1/SCLE and A2/SDAE. If an error occurs during the transfer, SMBALERT asserts and the CML bit is set to 1.

It is permitted to use the STORE_DEFAULT_ALL command while the power supply is operating. However, the MAX16064 is unresponsive to PMBus commands while transferring the configuration. ENOUT_ maintains its state.

This command is write-only. There is no data byte for this command.

For information on EEPROM contents, see the *External EEPROM Interface* section.

RESTORE_DEFAULT_ALL (12h)

The RESTORE_DEFAULT_ALL command transfers the default configuration information from the external I2C EEPROM device attached to A1/SCLE and A2/SDAE to the user memory registers in the device. The RESTORE_DEFAULT_ALL command can only be executed when the power supply is off. Otherwise, a communication fault occurs (CML = 1) and SMBALERT asserts. If an error occurs during data transfer, SMBALERT asserts and the CML bit is set to 1.

The STATUS_BYTE, STATUS_WORD and MFR_STATUS_WORD values are not restored by the RESTORE_DEFAULT_ALL command.

This command is write-only. There is no data byte for this command.

For information on EEPROM contents, see the *External EEPROM Interface* section.

CAPABILITY (19h)

The CAPABILITY command is used to determine some key capabilities of the MAX16064. The CAPABILITY command is read-only. The message content is described in Table 8.

Table 7. WRITE_PROTECT Message Contents

DATA BYTE VALUE	MEANING
1000 0000	Disable all writes except the WRITE_PROTECT command.
0100 0000	Disable all writes except the WRITE_PROTECT, OPERATION, and PAGE commands.
0010 0000	Disable all writes except the WRITE_PROTECT, OPERATION, PAGE, ON_OFF_CONFIG, and VOUT_COMMAND commands.
0000 0000	Enable writes for all commands (default)

Table 8. CAPABILITY Command Message Contents

BIT	DESRIPTION	MEANING
7	Packet error checking	1 = Packet error checking is supported. Always returns a 1.
6:5	Maximum PMBus bus speed	00 = Maximum supported bus speed is 100kHz.
4	SMBALERT#	1 = Device supports an SMBALERT# output and the SMBus ARA protocol.
3:0	Reserved	MAX16064 returns 0000.

VOUT_MODE (20h)

The VOUT_MODE command is used to report the data format of the device. The MAX16064 uses the direct format for all the voltage-related commands. The value returned is 40h, indicating DIRECT data format. This command is read only. See Table 4 for the m, b, and R values for the various commands.

VOUT_COMMAND (21h)

The VOUT_COMMAND command loads the MAX16064 with the voltage to which the power-supply output is to be changed when it is commanded to turn on using the OPERATION command or A3/CONTROL transition when enabled. Once the power supply is turned on, changing the VOUT_COMMAND has no effect on the power-supply output voltage. The MAX16064 only adjusts the power supply to the new VOUT_COMMAND voltage after receiving a new turn-on command.

The two data bytes are in DIRECT format. Valid values are from 0 to 2.0V when the input range is 2.0V, and 0 to 5.5V when the input range is 5.5V. See the *MFR_MODE_OUTPUT (DEh)* section for more information.

The default VOUT_COMMAND value is 00h.

VOUT_MARGIN_HIGH (25h)

The VOUT_MARGIN_HIGH command loads the MAX16064 with the voltage to which the power-supply output is to be changed when the OPERATION command is set to margin high. If the power supply is already operating at margin high, changing VOUT_MARGIN_HIGH has no effect on the output voltage. The MAX16064 only adjusts the power supply to the new VOUT_MARGIN_HIGH voltage after receiving a new margin high OPERATION command.

The two data bytes are in DIRECT format. Valid values are the same as VOUT_COMMAND.

The default VOUT_MARGIN_HIGH value is 00h.

VOUT_MARGIN_LOW (26h)

The VOUT_MARGIN_LOW command loads the MAX16064 with the voltage to which the power-supply output is to be changed when the OPERATION command is set to margin low. If the power supply is already operating at margin low, changing VOUT_MARGIN_LOW has no effect on the output voltage. The MAX16064 only adjusts the power supply to the new VOUT_MARGIN_LOW voltage after receiving a new margin low OPERATION command.

The two data bytes are in DIRECT format. Valid values are the same as VOUT_COMMAND.

The default VOUT_MARGIN_LOW value is 00h.

VOUT_TRANSITION_RATE (27h)

The VOUT_TRANSITION_RATE command sets the rate in mV/µs at which the power-supply output voltage should change when the power supply is commanded to change among the margin high, margin low, and margin off (on) OPERATION mode. This commanded rate of change does not apply when the power supply is commanded to turn on or off. In that case, t_{ON_RISE} and t_{OFF_FALL} apply.

The two data bytes are in DIRECT format. Valid values are from 0 to 128mV/µs (FB mode) or 0.004 to 30mV/µs (REFIN mode).

The default VOUT_TRANSITION_RATE value is 0.

When VOUT_TRANSITION_RATE is cleared to 0, VOUT_TRANSITION_RATE is ignored and the voltage output is not changed even when commanded by the OPERATION command. When VOUT_TRANSITION_RATE is set to 07FFFh, the voltage output is adjusted as quickly as possible. If a VOUT_TRANSITION_RATE parameter results in the DAC outputting an out of range value (valid range 0 to 4090) during transition, the CML flag is set and SMBALERT is asserted to issue a warning.

The VOUT_TRANSITION_RATE command applies to REFIN mode only and is ignored in feedback mode.

VOUT_SCALE_LOOP (29h)

In applications where the V_{OUT} is not equal to the voltage at REFIN, VOUT_SCALE_LOOP is used. For example, if REFIN expects a 0.6V input for a 3.3V output, VOUT_SCALE_LOOP = 0.6V/3.3V = 0.182.

In applications where the power-supply output voltage is greater than the MAX16064 input range, the output voltage of the power supply is sensed through a resistive voltage-divider, as illustrated in Figure 18. The resistive voltage-divider reduces or scales the output voltage, V_{OUT}.

The PMBus commands specify the actual power-supply output voltages and not the input voltage to the control circuit. To allow the MAX16064 to map between the commanded voltage (such as 3.3V), and the voltage at the control circuit input (perhaps 3.3V divided down to match a reference voltage of 2.0V), the VOUT_SCALE_LOOP command is used.

$$VOUT\_SCALE\_LOOP = \frac{R_2}{R_1 + R_2}$$

The two data bytes are in DIRECT format. Valid values are from 0 to 1.0. Note that due to m, b, r representation restriction, the supplied value is rounded off to multiples of 1/128. Therefore, to ensure optimum operation, circuit design should choose a value as close as possible to multiples of 1/128 to avoid rounding errors affect-

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ing the VOUT_TRANSITION_RATE slew rate. Final accuracy of V$_{OUT}$ is assured by the closed-loop voltage control.

This value is dimensionless.

The default VOUT_SCALE_LOOP value is 00h.

The VOUT_SCALE_LOOP command is ignored in feedback mode.

VOUT_OV_FAULT_LIMIT (40h)
The VOUT_OV_FAULT_LIMIT command sets the value of the output voltage measured across RS_+ and RS_-, which causes an output overvoltage fault.

The two data bytes are in DIRECT format. Valid values are the same as VOUT_COMMAND.

The default VOUT_OV_FAULT_LIMIT value is 00h.

In response to the VOUT_OV_FAULT_LIMIT being exceeded, the MAX16064:
1) Sets the VOUT_OV bit in the STATUS_BYTE.
2) Sets the VOUT_OV bit in the STATUS_WORD.
3) Sets bit 5 (low byte) and bit 7 (high byte) of the STATUS_WORD.
4) Sets the VOUT Overvoltage Fault bit in the STATUS_VOUT.
5) Sets the VOUT_OV bit in the MFR_STATUS_WORD register.
6) Responds as specified by VOUT_OV_FAULT_LIMIT_RESPONSE bits in the MFR_FAULT_RESPONSE register.
7) Notifies the host through SMBALERT assertion.

VOUT_OV_WARN_LIMIT (42h)
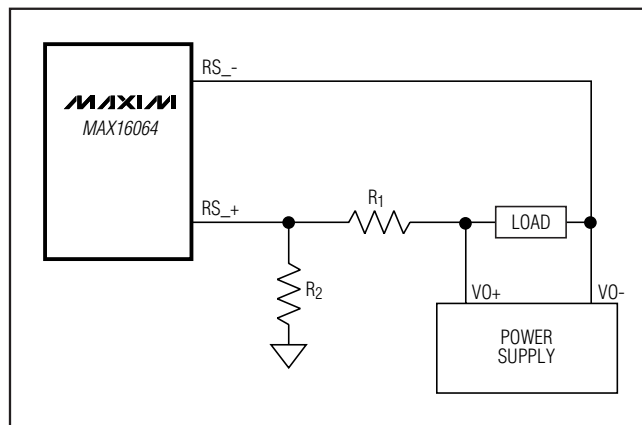The VOUT_OV_WARN_LIMIT command sets the value of the output voltage measured across RS_+ and RS_-,

Figure 18. VOUT_SCALE_LOOP

which causes an output voltage high warning. This value is typically less than the output overvoltage threshold in VOUT_OV_FAULT_LIMIT.

The two data bytes are in DIRECT format. Valid values are the same as the VOUT_COMMAND.

The default VOUT_OV_WARN_LIMIT value is 00h.

In response to the VOUT_OV_WARN_LIMIT being exceeded, the MAX16064:
1) Sets the OTHER bit in the STATUS_BYTE.
2) Sets the OTHER bit in the STATUS_WORD.
3) Sets the VOUT bit in the STATUS_WORD.
4) Sets the VOUT Overvoltage Warning bit in the STATUS_VOUT.
5) Sets the OV_WARN bit in the STATUS_MFR_SPECIFIC register.
6) Sets the OV_WARN bit in the MFR_STATUS_WORD register.
7) Sets the OTHER bit in the MFR_STATUS_WORD.
8) Notifies the host using SMBALERT assertion.

VOUT_UV_WARN_LIMIT (43h)
The VOUT_UV_WARN_LIMIT command sets the value of the output voltage measured across RS_+ and RS_-, which causes an output-voltage low warning. This value is typically greater than the output undervoltage fault threshold in VOUT_UV_FAULT_LIMIT.

This warning is masked until the output voltage reaches the programmed voltage at startup, and also during turn-off when the power supply is disabled.

The two data bytes are in DIRECT format. Valid values are the same as VOUT_COMMAND.

The default VOUT_UV_WARN_LIMIT value is 00h.

In response to violation of the VOUT_UV_WARN_LIMIT, the MAX16064:
1) Sets the OTHER bit in the STATUS_BYTE.
2) Sets the OTHER bit in the STATUS_WORD.
3) Sets the VOUT bit in the STATUS_WORD.
4) Sets the VOUT Undervoltage Warning bit in the STATUS_VOUT register.
5) Sets the UV_WARN bit in the STATUS_MFR_SPECIFIC register.
6) Sets the UV_WARN bit in the MFR_STATUS_WORD register.
7) Sets the OTHER bit in the MFR_STATUS_WORD.
8) Notifies the host using SMBALERT assertion.

VOUT_UV_FAULT_LIMIT (44h)

The VOUT_UV_FAULT_LIMIT command sets the value of the output voltage measured across RS_+ and RS_-, which causes an output undervoltage fault. This fault is masked until the output voltage reaches the pro-grammed voltage at startup, and also during turn-off when the power supply is disabled.

The 2 data bytes are in DIRECT format. Valid values are the same as VOUT_COMMAND.

The default VOUT_UV_FAULT_LIMIT value is 00h.

In response to violation of the VOUT_UV_FAULT_LIMIT, the MAX16064:

1) Sets the OTHER bit in the STATUS_BYTE.

2) Sets the OTHER bit in the STATUS_WORD.

3) Sets the VOUT bit in the STATUS_WORD.

4) Sets the VOUT Undervoltage Fault bit in the STATUS_VOUT register.

5) Sets the UV_FAULT bit in the STATUS_MFR_SPECIFIC register.

6) Sets the UV_FAULT bit in the MFR_STATUS_WORD register.

7) Sets the OTHER bit in the MFR_STATUS_WORD.

8) Responds as specified by VOUT_UV_FAULT_LIMIT_RESPONSE bits in the MFR_FAULT_RESPONSE register.

9) Notifies the host using $\overline{SMBALERT}$ assertion.

OT_FAULT_LIMIT (4Fh)

The OT_FAULT_LIMIT command sets the temperature, in degrees Celsius, of the on-chip temperature sensor at which an overtemperature fault is detected.

The 2 data bytes are in DIRECT format. Valid values are from -142.5°C to +395.4°C.

The default OT_FAULT_LIMIT value is 00h.

In response to the OT_FAULT_LIMIT being exceeded, the MAX16064:

1) Sets the TEMPERATURE bit in the STATUS_BYTE.

2) Sets the TEMPERATURE bit in the STATUS_WORD.

3) Sets the TEMPERATURE bit in the MFR_STATUS_WORD.

4) Sets the Overtemperature Fault bit in the STATUS_TEMPERATURE.

5) Sets the OT_FAULT bit in the MFR_STATUS_WORD register.

6) Responds as specified by OT_FAULT_RESPONSE bits in the MFR_FAULT_RESPONSE register.

7) Notifies the host using $\overline{SMBALERT}$ assertion.

OT_WARN_LIMIT (51h)

The OT_WARN_LIMIT command sets the temperature, in degrees Celsius, of the on-chip temperature sensor at which an overtemperature warning is detected.

The 2 data bytes are in DIRECT format. Valid values are the same as the OT_FAULT_LIMIT.

The default OT_WARN_LIMIT value is 00h.

In response to the OT_WARN_LIMIT being exceeded, the MAX16064:

1) Sets the TEMPERATURE bit in the STATUS_BYTE.

2) Sets the TEMPERATURE bit in the STATUS_WORD.

3) Sets the TEMPERATURE bit in the MFR_STATUS_WORD.

4) Sets the Overtemperature Warning bit in the STATUS_TEMPERATURE.

5) Sets the OT_WARN bit in the MFR_STATUS_WORD register.

6) Notifies the host through $\overline{SMBALERT}$ using asser-tion.

TON_DELAY (60h)

TON_DELAY sets the time, in milliseconds, from when a START condition is received (a valid OPERATION com-mand or through A3/CONTROL when enabled) until the power-supply output voltage starts to rise. During TON_DELAY, the power supply is disabled (ENOUT_deasserted) until TON_DELAY expires. Also, the under-voltage fault and warning are masked off during TON_DELAY.

The 2 data bytes are in DIRECT format. Valid values are from 0 to 3276.7ms.

The default TON_DELAY value is 0.

TON_RISE (61h)

The TON_RISE sets the time, in milliseconds, from when the power-supply output voltage starts to rise until the voltage has entered the regulation band. During TON_RISE, the voltage and temperature-related faults and warnings are masked off. Meanwhile, the MAX16064 still responds to the PMBus command. If a TON_RISE parameter results in the DAC outputting an out-of-range value (valid range 0 to 4090) immediately during TON_RISE, the CML flag is set and $\overline{SMBALERT}$ asserts to issue a warning.

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In feedback mode, the MAX16064 leaves the S_ switch on the DAC open during soft-start. It waits for the TON_RISE time to expire before adjusting the DAC output to equal the DACOUT_ feedback and then closes the S_ switch.

The 2 data bytes are in DIRECT format. In REFIN mode, the TON_RISE parameter is a 16-bit value and the valid values are from 0.01ms to 32.767ms. In FB mode, the TON_RISE is a 14-bit value and the valid values are from 0.01ms to 16.383ms (the upper 2 bits are ignored).

The default TON_RISE value is 0.01ms. Setting any value less than this minimum value defaults to 0.01ms.

TOFF_DELAY (64h)

The TOFF_DELAY sets the time, in milliseconds, from when a STOP condition is received (a soft-off OPERATION command or through A3/CONTROL when enabled) until the power supply stops transferring energy to the output.

When commanded to turn off immediately through the OPERATION command, the TOFF_DELAY value is ignored. When commanded to turn off through A3/CONTROL (when enabled) or EN, the TOFF_DELAY parameter is used.

The 2 data bytes are in DIRECT format. Valid values are from 0 to 3276.7ms.

The default TOFF_DELAY value is 0.

TOFF_FALL (65h)

The TOFF_FALL command sets the time, in milliseconds, from the end of the turn-off delay time until the output voltage is commanded to zero. Note that this command can only be used with a device whose output can sink enough current to cause the output voltage to decrease at a controlled rate.

When commanded to turn off immediately through the OPERATION command, the TOFF_FALL value is ignored. When commanded to turn off through the OPERATION soft-off command or A3/CONTROL (when enabled) or EN, the TOFF_FALL parameter is used. If a TOFF_FALL parameter results in the DAC outputting an out-of-range value (valid range 0 to 4090) immediately during TOFF_FALL, the CML flag is set and SMBALERT asserts to issue a warning.

In feedback mode, this value is not used. The MAX16064 disables ENOUT_ and opens the DAC switch immediately after the TOFF_DELAY.

The 2 data bytes are in DIRECT format. Valid values are from 0.01ms to 32.767ms.

Do not set TOFF_FALL to any value less than 0.1ms.

STATUS_BYTE (78h)

The STATUS_BYTE command returns 1 byte of information with a summary of the most critical faults. A value of 1 indicates that a fault or warning event has occurred and a 0 indicates otherwise. Bits for unsupported features shall be reported as 0.

The STATUS_BYTE cannot be restored by RESTORE_DEFAULT_ALL command. The STATUS_BYTE message content is described in Table 9.

This command is read only.

The default STATUS_BYTE value is 40h (power supply is off).

Table 9. STATUS_BYTE Message Contents

BIT NUMBER	STATUS BIT NAME	MEANING
7	BUSY	A fault was declared because the device was busy and unable to respond. **(The BUSY bit is not supported. This bit always returns 0).**
6	OFF	This bit is asserted if ENOUT is presently disabling the power supply, regardless of the reason, including simply not being enabled.
5	VOUT_OV	An output overvoltage fault has occurred.
4	IOUT_OC	An output overcurrent fault has occurred. **(The IOUT_OC bit is not supported. This bit always returns 0).**
3	VIN_UV	An input undervoltage fault has occurred. **(The VIN_UV bit is not supported. This bit always returns 0).**
2	TEMPERATURE	A temperature fault or warning has occurred.
1	CML	A communication, memory, or logic fault has occurred.
0	OTHER	A fault or warning not listed in bits [7:1] has occurred. See the *MFR_STATUS_WORD (D8h)* section for more information.

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STATUS_WORD (79h)

The STATUS_WORD command returns two bytes of information with a summary of the reason for a fault. The low byte of the STATUS_WORD is the same data as the STATUS_BYTE. The STATUS_WORD message content is described in Table 10.

STATUS_VOUT (7Ah)

The STATUS_VOUT command returns one byte of information with contents as described in Table 11.

Table 10. STATUS_WORD Message Contents

BYTE	BIT NUMBER	STATUS BIT NAME	MEANING
High	7	VOUT	An output-voltage fault or warning has occurred.
	6	IOUT/POUT	The IOUT/POUT bit is not supported. This bit always returns 0.
	5	INPUT	The INPUT bit is not supported. This bit always returns 0.
	4	MFR	A manufacturer-specific fault or warning has occurred.
	3	POWER_GOOD#	The POWER_GOOD# bit is not supported. This bit always returns 0.
	2	FANS	The FANS bit is not supported. This bit always returns 0.
	1	OTHER	Reserved.
	0	UNKNOWN	A fault type not given in bits [15:1] of the STATUS_WORD has been detected.
Low	7	BUSY	A fault was declared because the device was busy and unable to respond. The BUSY bit is not supported. This bit always returns 0.
	6	OFF	This bit is asserted if ENOUT is presently disabling the power supply, regardless of the reason, including simply not being enabled.
	5	VOUT_OV	An output overvoltage fault has occurred.
	4	IOUT_OC	An output overcurrent fault has occurred. The IOUT_OC bit is not supported. This bit always returns 0.
	3	VIN_UV	An input undervoltage fault has occurred. The VIN_UV bit is not supported. This bit always returns 0.
	2	TEMPERATURE	A temperature fault or warning has occurred.
	1	CML	A communication, memory, or logic fault has occurred.
	0	OTHER	A fault or warning not listed in bits [7:1] has occurred. See the *MFR_STATUS_WORD (D8h)* section for more information.

Table 11. STATUS_VOUT Message Contents

BIT NUMBER	MEANING
7	VOUT overvoltage fault
6	VOUT overvoltage warning
5	VOUT undervoltage fault
4	VOUT undervoltage warning
3	VOUT_MAX warning **This bit is not supported. This bit always returns 0.**
2	TON_MAX_FAULT **This bit is not supported. This bit always returns 0.**
1	TOFF_MAX_WARNING **This bit is not supported. This bit always returns 0.**
0	VOUT tracking error **This bit is not supported. This bit always returns 0.**

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STATUS_TEMPERATURE (7Dh)

The STATUS_TEMPERATURE command returns one byte of information with contents as described in Table 12.

STATUS_CML (7Eh)

The STATUS_CML command returns one byte of information with contents as described in Table 13.

STATUS_MFR_SPECIFIC (80h)

The STATUS_MFR_SPECIFIC command returns one byte of information with a summary of the reason for a fault. The STATUS_MFR_SPECIFIC message content is described in Table 14.

Table 12. STATUS_TEMPERATURE Message Contents

BIT NUMBER	MEANING
7	Overtemperature fault
6	Overtemperature warning
5	Undertemperature fault **This bit is not supported. This bit always returns 0.**
4	Undertemperature warning **This bit is not supported. This bit always returns 0.**
3	Reserved
2	Reserved
1	Reserved
0	Reserved

Table 13. STATUS_CML Message Contents

BIT NUMBER	MEANING
7	Invalid or unsupported command received
6	Invalid or unsupported data received
5	Packet error check (PEC) failed
4	Memory fault detected **This bit is not supported. This bit always returns 0.**
3	Processor fault detected **This bit is not supported. This bit always returns 0.**
2	Reserved
1	A communication fault other than the ones listed in this table has occurred. **This bit is not supported. This bit always returns 0.**
0	Other memory of logic fault has occurred. **This bit is not supported. This bit always returns 0.**

Table 14. STATUS_MFR_SPECIFIC Message Contents

BIT NUMBER	STATUS BIT NAME	MEANING
7	EN_FAULT	EN input is below its threshold when OPERATION is on.
6	OT_WARN	Overtemperature warning (same as STATUS_TEMPERATURE bit 6).
5	OT_FAULT	Overtemperature fault (same as STATUS_TEMPERATURE bit 7).
4	ADCERR_FAULT	An ADC conversion fault has occurred.
3	N/A	**This bit is reserved and always returns 0.**
2	UV_WARN	A VOUT undervoltage warning has occurred (same as STATUS_VOUT bit 4).
1	UV_FAULT	A VOUT undervoltage fault has occurred (same as STATUS_VOUT bit 5).
0	OV_WARN	A VOUT overvoltage warning has occurred (same as STATUS_VOUT bit 6).

READ_VOUT (8Bh)

The READ_VOUT command returns the actual measured (not commanded) output voltage across RS_+ and RS_-. If filter mode is enabled, the filtered value is returned.

The 2 data bytes are in DIRECT format. Valid values are the same as VOUT_COMMAND.

The default READ_VOUT value is 00h.

READ_TEMPERATURE_1 (8Dh)

The MAX16064 supports only one temperature reading, READ_TEMPERATURE_1. The MAX16064 returns the actual on-chip measured temperature in degrees Celsius.

The 2 data bytes are in DIRECT format. Valid values are the same as OT_FAULT_LIMIT.

The default READ_TEMPERATURE_1 value is 00h.

PMBUS_REVISION (98h)

The PMBUS_REVISION command returns the revision of the PMBus specification to which the MAX16064 is compliant.

The command has 1 data byte. Bits [7:5] indicate the revision of PMBus specification Part I to which the MAX16064 is compliant. Bits [4:0] indicate the revision of PMBus specification Part II to which the MAX16064 is compliant. The values are shown in Table 15.

This command is read only.

The PMBUS_REVISION value returned is 00h which indicates that the MAX16064 is compliant with Part I Rev 1.0 and Part II Rev 1.0.

Table 15. PMBus Revision Data Byte Contents

BITS [7:5]	PART I REVISION	BITS [4:0]	PART II REVISION
000	1.0	00000	1.0

MFR_ID (99h)

The MFR_ID command returns the MAX16064 manufacturer's identification.

The default MFR_ID value is 4Dh (M).

This command is read only.

MFR_MODEL (9Ah)

The MFR_MODEL command returns the MAX16064 model number.

The default MFR_MODEL value is 43h (C).

This command is read only.

MFR_REVISION (9Bh)

The MFR_REVISION command reads the ASCII characters that contain the MAX16064 revision number with a block read command.

The default MFR_REVISION value is 32h (2).

This command is read only.

MFR_LOCATION (9Ch)

The MFR_LOCATION command loads the device with text (ISO/IEC 8859-1) characters that identify the facility that manufactures the power supply. The maximum number of characters is 20. This can be written to external EEPROM using the STORE_DEFAULT_ALL command. If an external EEPROM is not used, the command returns the text string MXIM.

MFR_DATE (9Dh)

The MFR_DATE command loads the device with text (ISO/IEC 8859-1) characters that identify the date of manufacture of the power supply. The maximum number of characters is 8. This can be written to external EEPROM using the STORE_DEFAULT_ALL command. If an external EEPROM is not used, the command returns the text string 090210.

MFR_SERIAL (9Eh)

The MFR_SERIAL command loads the device with text (ISO/IEC 8859-1) characters that uniquely identify the power supply. The maximum number of characters is 16. This can be written to external EEPROM using the STORE_DEFAULT_ALL command. If an external EEPROM is not used, the command returns the text string 00000000.

USER_DATA_00 (B0h)

The MFR_USER_DATA_00 command loads the device with user data. The maximum number of bytes is 40. This can be written to external EEPROM using the STORE_DEFAULT_ALL command. If an external EEPROM is not used, the command returns 00h for all bytes.

MFR_SMB_LOOPBACK (D0h)

The MFR_SMB_LOOPBACK command returns the data word previously received by the MAX16064. The SMBus master writes a data word to the MAX16064 using this command and then retrieves the data word. A valid communication channel is established if the master reads back the same word.

Note that if another command is sent in between the write MFR_SMB_LOOPBACK command and the read MFR_SMB_LOOPBACK command, the MAX16064 returns whatever last command data word it receives.

MFR_MODE (D1h)

The MFR_MODE command is used to configure the MAX16064 to support manufacturer specific commands. The MFR_MODE command is described in Table 16.

The default MFR_MODE value is 00h.

Table 16. MFR_MODE Bit Definition

BIT	BIT NAME	DESCRIPTION
15:8	Input Clock Time Factor	This is equivalent to the number of external clock cycles provided to CLKIO in 100_S - 2. MFR_MODE[15:8] = f_{EXT_CLK}/10kHz - 2 where f_{EXT_CLK} is the frequency of the external clock. For example, when f_{EXT_CLK} = 1MHz, f_{EXT_CLK}/10kHz = 100, MFR_MODE[15:8] = 100 – 2 = 98. Valid external input clock range is from 100kHz (MFR_MODE[15:8] = 8) to 2.5MHz (MFR_MODE[15:8] = 248). These bits are ignored if internal clock source is selected as the time base (Clock Source Select bit = 0).
7	Clock Out Enable	The Clock Out Enable bit allows the output of a 1MHz reference clock to CLKIO for synchronizing multiple MAX16064s. 1 = Enables the 1MHz output on CLKIO. 0 = Reference clock is not output (default).
6	IGNORE_EN	1 = The EN state is ignored and the MAX16064 is controlled according to ON_OFF_CONFIG. 0 = The MAX16064 turns on the external power supplies when EN exceeds its threshold. If EN goes low after power-up, the MAX16064 turns off a power supply only if MFR_FAULT_RESPONSE[5:4] is configured to do so.
5	EEPROM Lock Enable	The EEPROM Lock Enable bit is used to protect external EEPROM data from being overwritten. 1 = The STORE_DEFAULT_ALL command is ignored. The RESTORE_DEFAULT_ALL command is still valid. 0 = The STORE_DEFAULT_ALL command initiates a store configuration operation to the external EEPROM attached to A1/SCLE and A2/SDAE (default).
4	Correction Bypass Enable	Correction Bypass Enable. 1 = Disables a correction algorithm made to voltage and temperature readings. 0 = Applies a correction algorithm to temperature measurement, thus resulting in high-accuracy readings. For optimal operation, this bit should be cleared to 0 (default).
3	EEPROM Fault Lock	1 = EEPROM fault locations are locked. If a fault occurs, data is not written to the external EEPROM. 0 = EEPROM fault locations are unlocked. If a fault occurs, data is written to the external EEPROM.
2	PEC Enable	1 = PEC enabled for all commands. 0 = PEC is disabled (default).
1	Filter Setting	1 = Disable filtering of the voltage and temperature conversions. 0 = Enable filtering of the voltage and temperature conversions (default).
0	Clock Source Select	The Clock Source Select bit determines the MAX16064 reference clock time source. 1 = An external clock must be supplied to CLKIO and is used as the MAX16064 reference clock. 0 = The internal clock is used.

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MFR_SAMPLE_RATE (D3h)

The MFR_SAMPLE_RATE command sets the frequency (Hz) at which the ADC conversion result registers (representing four voltages and one temperature) are compared with their threshold limits. This parameter does not control the total ADC sampling rate, which is controlled by MFR_VLTO. Also, the output-voltage adjustment rate is not affected by this parameter.

$$\text{Monitor Sample Frequency} = 10\text{kHz}/\text{MFR\_SAMPLE\_RATE}$$

The 2 data bytes are formatted as positive integers. Valid values are from 1 to 65535. Do not set this value to 0.

The default MFR_SAMPLE_RATE value is 50 which is equivalent to a sample frequency of 200Hz.

MFR_VOUT_PEAK (D4h)

The MFR_VOUT_PEAK command returns the maximum actual measured (not commanded) output voltage in volts across RS_+ and RS_-. If the filter mode is enabled, instead of returning the instantaneous value, the filtered output voltage is returned. To reset this value to 0, write to this command with a data value of 0. Any other values written by this command are used as a comparison for future peak updates.

The 2 data bytes are in DIRECT format. Valid values are the same as VOUT_COMMAND.

The default MFR_VOUT_PEAK value is 0.

MFR_TEMPERATURE_PEAK (D6h)

The MFR_TEMPERATURE_PEAK command returns the maximum actual on-chip measured temperature in degrees Celsius. To reset this value to its lowest value, write to this command with a data value of 0FFFFh. Any other values written by this command are used as a comparison for future peak updates.

The 2 data bytes are in DIRECT format. Valid values are the same as OT_FAULT_LIMIT.

The default MFR_TEMPERATURE_PEAK value is 00h.

MFR_STATUS_WORD (D8h)

When a warning or fault condition is detected, the MAX16064 sets the corresponding bit in the MFR_STATUS_WORD register to 1 and notifies the host using SMBALERT assertion. The MFR_STATUS_WORD[7:0] (low byte) bits are the same definition and state as the STATUS_BYTE command.

This register is cleared to 0 together with the STATUS_BYTE register by any of the fault/warning clearing methods mentioned earlier in the CLEAR_FAULTS command.

The MFR_STATUS_WORD command value cannot be restored by the RESTORE_DEFAULT_ALL command.

This command is read only.

Table 17. MFR_STATUS_WORD Bit Definition

BIT NUMBER	STATUS BIT NAME	MEANING
15	EN_FAULT	EN input is below its threshold when OPERATION is on.
14	OT_WARN	Overtemperature warning (Same as STATUS_TEMPERATURE bit 6).
13	OT_FAULT	Overtemperature fault (Same as STATUS_TEMPERATURE bit 7).
12	ADCERR_FAULT	An ADC conversion fault has occurred.
11	N/A	**This bit is reserved and always returns 0.**
10	UV_WARN	A VOUT undervoltage warning has occurred (same as STATUS_VOUT bit 4).
9	UV_FAULT	A VOUT undervoltage fault has occurred (same as STATUS_VOUT bit 5).
8	OV_WARN	A VOUT overvoltage warning has occurred (same as STATUS_VOUT bit 6).
7	BUSY	A fault was declared because the device was busy and unable to respond. **The BUSY bit is not supported. This bit always returns 0.**
6	OFF	This bit is asserted if ENOUT is presently disabling the power supply, regardless of the reason, including simply not being enabled.
5	VOUT_OV	An output overvoltage fault has occurred.
4	IOUT_OC	An output overcurrent fault has occurred. **The IOUT_OC bit is not supported. This bit always returns 0.**
3	VIN_UV	An input undervoltage fault has occurred. **The VIN_UV bit is not supported. This bit always returns 0.**
2	TEMPERATURE	A temperature fault or warning has occurred.
1	CML	A communication, memory, or logic fault has occurred.
0	OTHER	A fault or warning not listed in bits [7:1] has occurred.

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MFR_FAULT_RESPONSE (D9h)

The MFR_FAULT_RESPONSE command specifies the response to each fault condition supported by the MAX16064. Each fault has 2 response bits that describe how the MAX16064 responds to that particular fault. It is also used to record the condition under which a fault occurs.

The STORE_PEAK function is used to store peak values (MFR_VOUT_PEAK and MFR_TEMPERATURE_PEAK) to the EEPROM (if present) on a fault detection regardless of the status of the EEPROM Lock Enable bit. Setting the STORE_PEAK bit to 1 enables the store function.

MFR_FAULT_RETRY (DAh)

The MFR_FAULT_RETRY command sets the time between restarting the power supply if the fault response is to restart the power supply at specified intervals. This command sets the retry time delay in multiples of 100µs. This command value is used for all fault responses that require delay retry.

Delay Retry Time = MFR_FAULT_RETRY[15:0] x 100µs

The 2 data bytes are in DIRECT format. Valid values are from 0 to 3.2768s. When MFR_FAULT_RETRY = 00h, the MAX16064 restarts the power supply at the next available time period.

The default MFR_FAULT_RETRY value is 00h.

Table 18. MFR_FAULT_RESPONSE Bit Definition

BITS	FAULT RESPONSE BIT NAME
15	1 = Save fault data to EEPROM. 0 = Do not save fault data to EEPROM.
14	1 = Lock EEPROM to further fault status writes after saving state (see bit 15). 0 = Do not lock the EEPROM to further fault status writes.
13:8	Reserved
7:6	OT_FAULT_RESPONSE[1:0]
5:4	EN_FAULT_RESPONSE[1:0]
3:2	VOUT_UV_FAULT_LIMIT_RESPONSE[1:0]
1:0	VOUT_OV_FAULT_LIMIT_RESPONSE[1:0]

Table 19. Fault Response Options

RESPONSE[1:0]	FAULT RESPONSE OPTION
11	Set the corresponding fault bit in the fault status register, assert $\overline{SMBALERT}$, save fault state to EEPROM (if enabled by bit 15) and continue operation.
10	Set the corresponding fault bit in the fault status register, assert $\overline{SMBALERT}$, shut down the power supply (deassert ENOUT) and restart the power supply every T (µs), where T is set in the MFR_FAULT_RETRY register.
01	Set the corresponding fault bit in the fault status register, assert $\overline{SMBALERT}$ and shutdown the power supply. Store fault data to EEPROM if enabled by bit 15.
00	Set the corresponding fault bit in the fault status register, assert $\overline{SMBALERT}$ and continue operation without any action.

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MFR_SET_ADDRESS (DBh)

The MFR_SET_ADDRESS command is used to change the MAX16064 slave address. By default the MAX16064 address is set by A3:A1 upon reset according to Table 3. The slave address can be changed by the MFR_SET_ADDRESS command but the change does not take effect until it is written to the external EEPROM using STORE_DEFAULT_ALL and the part is reset (see the *MAX16064 Address Assignment* section).

This command has 1 data byte. The slave address is contained in bits [6:0]. Bit 7 must be 0.

MFR_RESET_DELAY (DDh)

MFR_RESET_DELAY sets the reset timeout, t_{RP}, from when the associated power-supply output voltage reaches regulation and the $\overline{RESET}$ output deasserts (see Figure 9). The reset timeout is also dependent upon MFR_SAMPLE_RATE. The minimum t_{RP} is calculated as follows:

$$t_{RP} = (MFR\_RESET\_DELAY) \times [MFR\_SAMPLE\_RATE \times (100 \times 10^{-6})]$$

For example, if MFR_RESET_DELAY = 20 and MFR_SAMPLE_RATE = 50, then the minimum reset timeout period is t_{RP} = (20) x [50 x (100 x 10^{-6})] = 100ms.

Note that the resolution of t_{RP} is MFR_SAMPLE_RATE x 100µs, so in this example is 50 x 100µs = 5ms.

The 2 data bytes are in DIRECT format. Valid values are from 0 to 3276.7ms.

The default MFR_RESET_DELAY value is 0.

MFR_MODE_OUTPUT (DEh)

The MFR_MODE_OUTPUT command is described in Table 20.

Table 20. MFR_MODE_OUTPUT Bit Definition

BIT	BIT NAME	DESCRIPTION
5	DAC Switch Mode	1 = DAC switch is open when REFIN mode power supply is turned off. 0 = DAC switch remains closed when REFIN mode power supply is turned off.
4	Global Fault Select	1 = Faults on this output causes faults on other outputs as well. 0 = Faults on this output only affects this output (default).
3	Input Range Select	The Input Range Select bit determined the full-scale range of the RS+/RS- voltage conversion. 1 = 5.5V. 0 = 2.0V (default). Prior to sending any voltage-related commands, the user application must first configure the desired input range. All voltage-related commands use the specified input range to convert the commanded value to internal register values. Changing the Input Range Select bit while the power supply is on is not recommended. This may result in unpredictable and possible catastrophic operation since all voltage-related commands continue to refer to the input range that was in effect when the command was received.
2	ENOUT Polarity Select	The ENOUT Polarity bit selects the ENOUT active-on polarity. See the *ENOUT_ Operation* section. 1 = ENOUT asserted on-state is the same as the default startup state (low). 0 = ENOUT asserted on-state is the inverse of the default startup state (high).
1	Feedback Mode Select	The Feedback Mode Select bit selects the closed-loop voltage control operation mode. 1 = Feedback mode. 0 = Refin mode (default).
0	Page 255 Control	1 = Writes when PAGE = 255 does not affect this output. 0 = Writes when PAGE = 255 affects this output (default).

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MFR_VLTO (DFh)

The Voltage Loop Timeout command sets the time between each of the five ADC conversions. The time (VLTO) is calculated as VLTO = N x 250ns, where N is the 16-bit data included in the command. The range of values is 0 to 16.38ms. The default value at power-up is 100, or 25µs. The total ADC acquisition time is:

(1.75µs + 0.25µs x MFR_VLTO) + 4 x (4 x 1.75µs + 0.25µs x MFR_VLTO) (filtering on)

(1.75µs + 0.25µs x MFR_VLTO) + 4 x (1.75µs + 0.25µs x MFR_VLTO) (filtering off)

where 1.75µs represents a single ADC conversion time and MFR_VLTO is the value contained in the register. The internal ADC conversion registers are updated at this rate. However, the voltages and temperatures are monitored at another rate that is controlled by MFR_SAMPLE_RATE.

MFR_DAC_ACT_CNT (E0h)

The MFR_DAC_ACT_CNT command sets the number of ADC samples taken before updating the DAC output voltage during AVOC mode. The resulting adjustment rate is:

$$f_{AVOC} = \frac{1}{\left[MFR\_DAC\_ACT\_CNT \times (29.75 \times 10^{-6} + 1.25 \times 10^{-6} \times MFR\_VLTO) \right]}$$

where f_{AVOC} is the update period, in Hertz. This formula applies only when input filtering is turned on (MFR_MODE.1 = 0). When the filter is turned off, the following formula applies:

$$f_{AVOC} = \frac{1}{\left[MFR\_DAC\_ACT\_CNT \times (8.75 \times 10^{-6} + 1.25 \times 10^{-6} \times MFR\_VLTO) \right]}$$

MFR_RESET_OUTPUT (E1h)

$\overline{RESET}$ is an active-low open-drain output that is low when the device is powering on. $\overline{RESET}$ is assigned to one of the power supplies using the MFR_RESET_OUTPUT command. When that power-supply output is at the target voltage, $\overline{RESET}$ goes high after the reset timeout period (see Figure 9). The reset timeout period is set by the MFR_RESET_DELAY command.

The MFR_RESET_OUTPUT value defines which power-supply output affects $\overline{RESET}$. If MFR_RESET_OUTPUT is set to 0, 1, 2, or 3, then $\overline{RESET}$ goes high MFR_RESET_DELAY after that output has reached its target value. If MFR_RESET_OUTPUT is any other value, $\overline{RESET}$ is permanently low.

If the power-supply output selected by MFR_RESET_OUTPUT is later disabled for any reason (either due to a fault condition, or an OPERATION OFF command), then $\overline{RESET}$ goes low. To enable faults on any power supply to cause $\overline{RESET}$ to go low, set the MFR_MODE_OUTPUT.GLOBALFAULTS bit to a 1 for all the supplies.

MFR_FAULT_REASON (E2h)

The MFR_FAULT_REASON command returns the results of the voltage threshold comparisons for all channels following a fault condition.

Table 21. MFR_FAULT_REASON Bit Definition

BIT	BIT NAME	DESCRIPTION
15	Reserved	Reserved
14	Reserved	Reserved
13	VFMIN3	1 = Voltage at RS3 is less than the VOUT_UV_FAULT_LIMIT. 0 = Voltage at RS3 greater than or equal to VOUT_UV_FAULT_LIMIT.
12	VFMAX3	1 = Voltage at RS3 is greater than the VOUT_OV_FAULT_LIMIT. 0 = Voltage at RS3 less than or equal to VOUT_OV_FAULT_LIMIT.
11	Reserved	Reserved

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Table 21. MFR_FAULT_REASON Bit Definition (continued)

BIT	BIT NAME	DESCRIPTION
10	Reserved	Reserved
9	VFMIN2	1 = Voltage at RS2 is less than the VOUT_UV_FAULT_LIMIT. 0 = Voltage at RS2 greater than or equal to VOUT_UV_FAULT_LIMIT.
8	VFMAX2	1 = Voltage at RS2 is greater than the VOUT_OV_FAULT_LIMIT. 0 = Voltage at RS2 less than or equal to VOUT_OV_FAULT_LIMIT.
7	Reserved	Reserved
6	Reserved	Reserved
5	VFMIN1	1 = Voltage at RS1 is less than the VOUT_UV_FAULT_LIMIT. 0 = Voltage at RS1 greater than or equal to VOUT_UV_FAULT_LIMIT.
4	VFMAX1	1 = Voltage at RS1 is greater than the VOUT_OV_FAULT_LIMIT. 0 = Voltage at RS1 less than or equal to VOUT_OV_FAULT_LIMIT.
3	Reserved	Reserved
2	Reserved	Reserved
1	VFMIN0	1 = Voltage at RS0 is less than the VOUT_UV_FAULT_LIMIT. 0 = Voltage at RS0 greater than or equal to VOUT_UV_FAULT_LIMIT.
0	VFMAX0	1 = Voltage at RS0 is greater than the VOUT_OV_FAULT_LIMIT. 0 = Voltage at RS0 less than or equal to VOUT_OV_FAULT_LIMIT.

MFR_FAULT_VOUT (E3h)

The MFR_FAULT_VOUT command returns V_{OUT} at the time a voltage fault was triggered.

MFR_FAULT_TEMP (E4h)

The MFR_FAULT_TEMP command returns the temperature at the time a temperature fault was triggered.

Applications Information

Performance Consideration

The MAX16064 can be viewed as a task scheduler where it periodically goes through its task list and performs the required tasks. While it may be tempting to monitor the power supplies at the highest supported frequency, MFR_SAMPLE_RATE, it must be noted that doing so takes away resources from other tasks, such as communication with the system controller. Since each application is unique in its own merit, it is impossible to prescribe a solution that suffices in all conditions.

System designers are thus urged to derive optimum configuration based on the particular system needs.

Graphic User Interface (GUI)

The MAX16064 Evaluation Kit comes with a free GUI that eliminates the need for any software development and provides a simple and user-friendly method for configuring large systems in a short time. Once the configuration is complete, the results can be saved to the external EEPROM for MAX16064 configuration on power-up, or loaded at power-up onto the MAX16064 through the PMBus by a master controller. The powerful MAX16064 feature set can be inferred from the GUI screenshot shown in Figure 19, where the programmable parameters are displayed. These parameter values set serve as data bytes for PMBus and manufacturer-specific commands supported by the MAX16064. For details on using the GUI, refer to the MAX16064 Evaluation Kit.
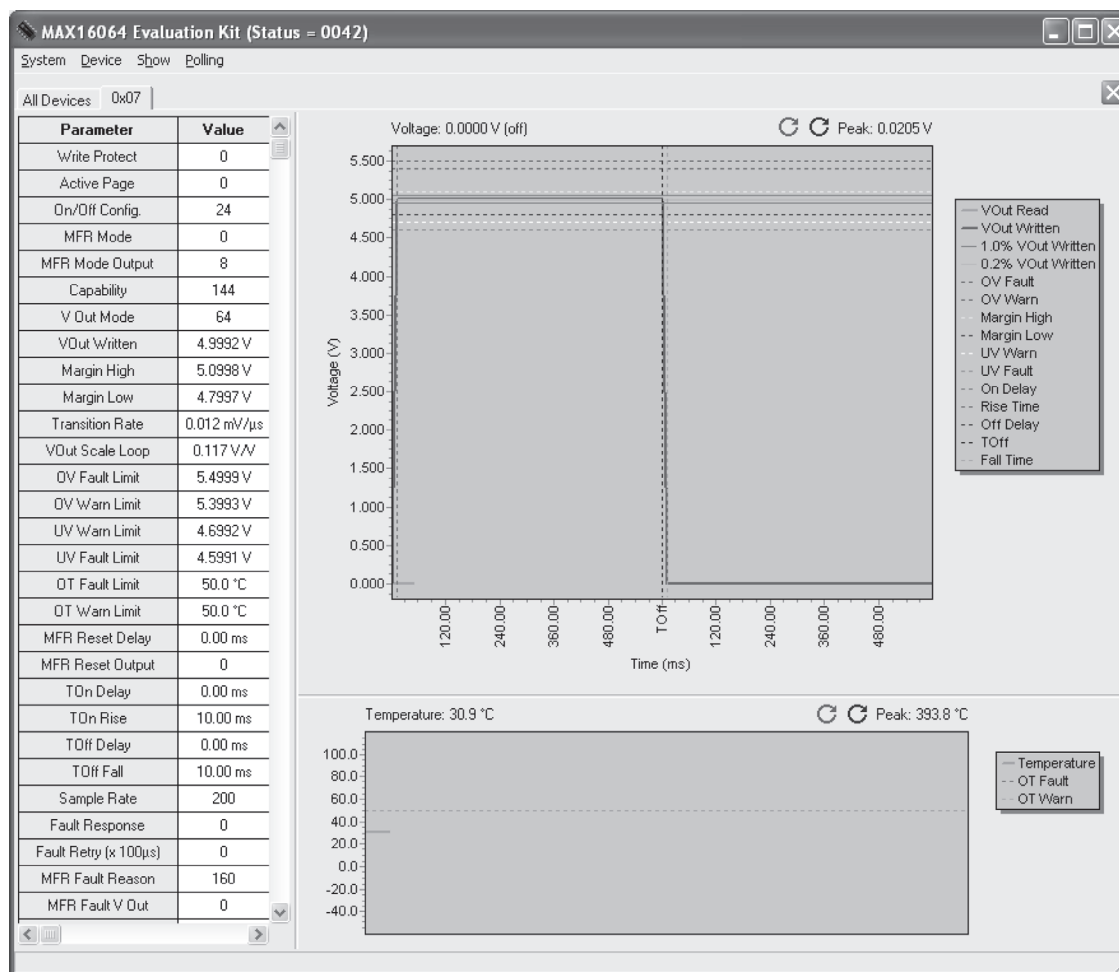
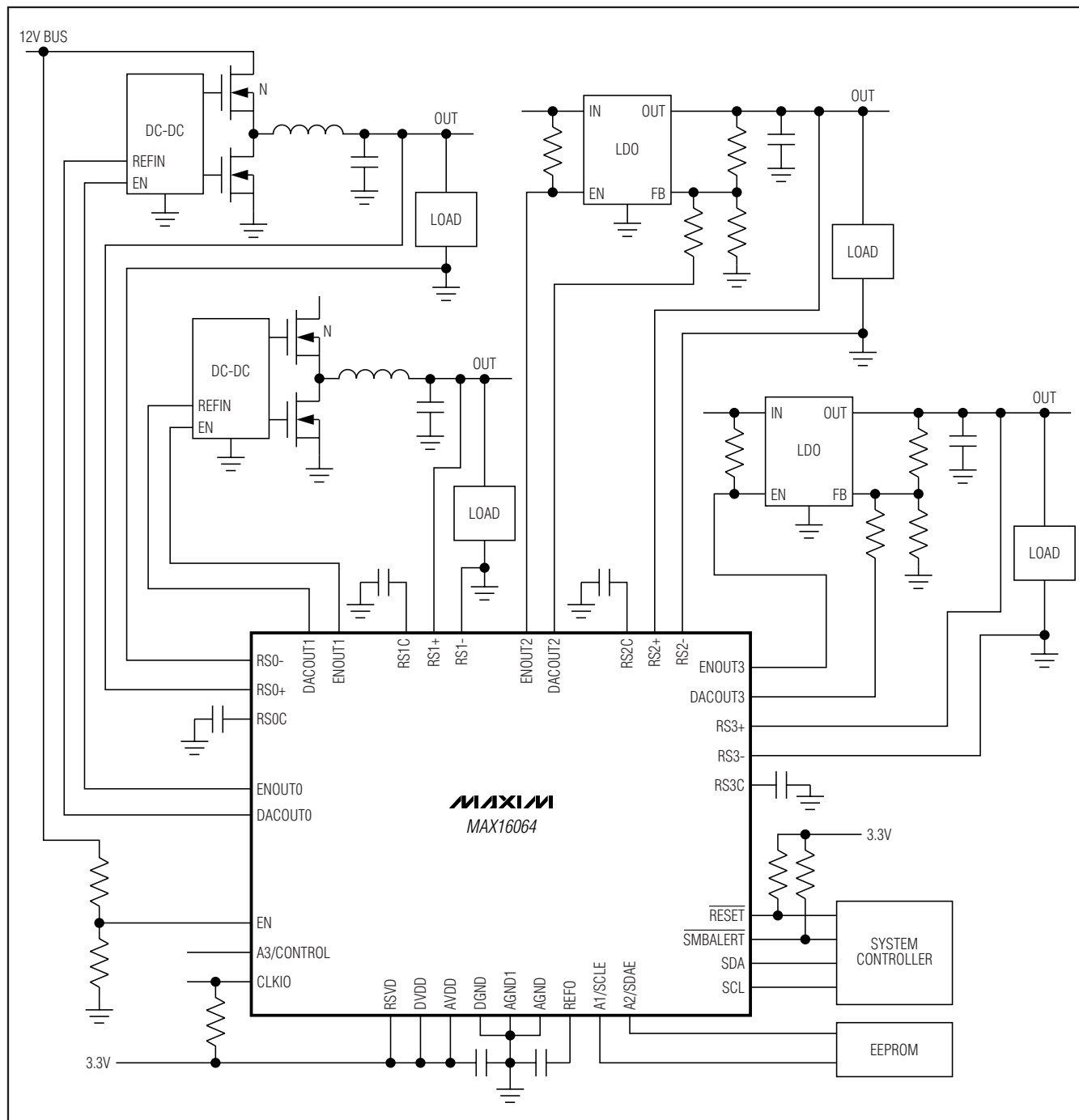Figure 19. MAX16064 Graphic User Interface

PCB Consideration

Accurate voltage measurement and voltage regulation can be achieved by following these guidelines for good PCB layout:

1) Place IC decoupling and filter capacitors for AVDD, DVDD, REFO, and RS_C as close as possible to the IC pins. If using an external EEPROM, place it close to the MAX16064 and use short direct traces for interconnections.

2) Use Kelvin connections for the differential pair traces from the desired remote-sense points on the power-supply output-voltage power plane to RS_+ and RS_- of the MAX16064 for accurate power-supply output-voltage sensing.

3) Connect the analog grounds (AGND, AGND1) and digital ground (DGND) of the MAX16064 to a ground plane right at the IC. Terminate all other ground connections to this ground plane. Connect this ground plane to the quiet analog ground plane of the power supply so that the reference voltage to the power supply is unaffected by switching noise. Use a single-point (star) grounding technique to connect the analog ground plane of the power supply to the heat dissipating power ground plane of the power supply. Place MAX16064 as close as possible to the power supply for best temperature measurement performance.

4) Refer to the MAX16064 Evaluation kit for a sample layout.

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±0.3% Accurate, Quad, Power-Supply Controller with Active-Voltage Output Control and PMBus Interface
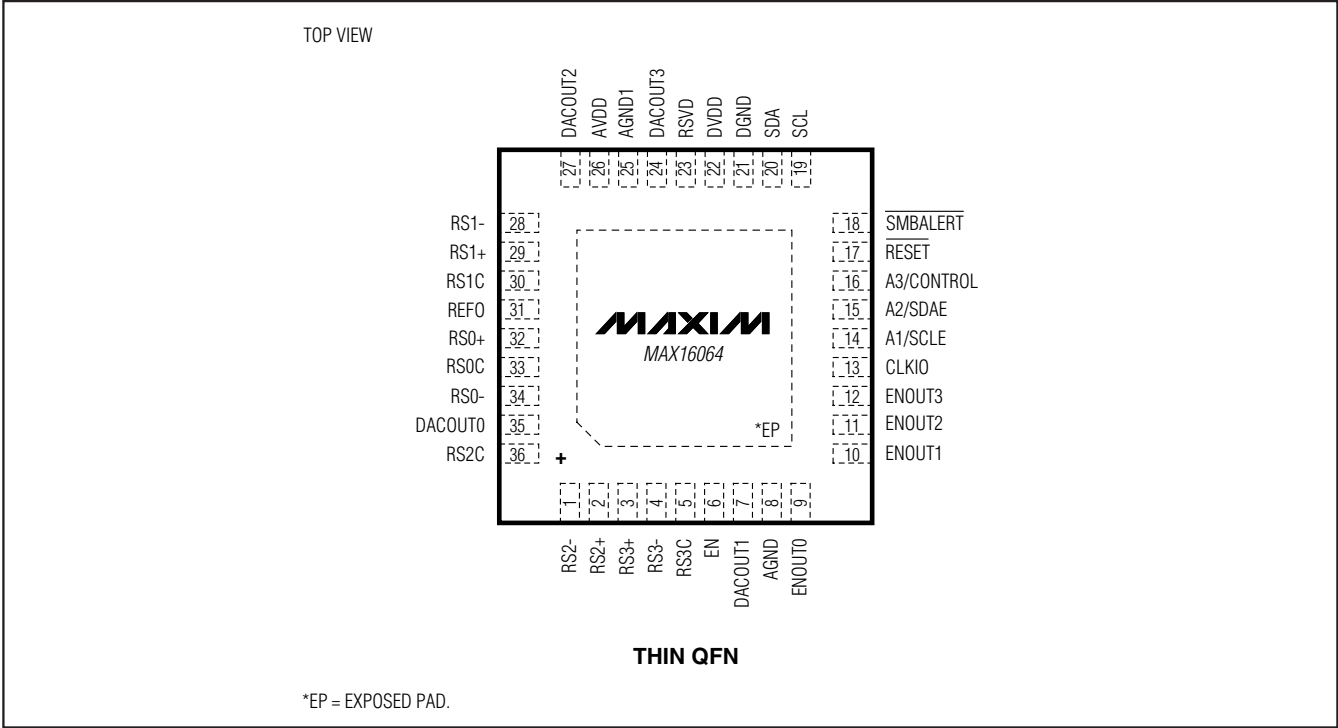
Typical Operating Circuit

MAX16064

Pin Configuration

TOP VIEW

DACOUT2 27
AVDD 26
AGND1 25
DACOUT3 24
RSVD 23
DVDD 22
DGND 21
SDA 20
SCL 19

RS1- 28
RS1+ 29
RS1C 30
REFO 31
RS0+ 32
RS0C 33
RS0- 34
DACOUT0 35
RS2C 36

MAXIM
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*EP

18 SMBALERT
17 RESET
16 A3/CONTROL
15 A2/SDAE
14 A1/SCLE
13 CLKIO
12 ENOUT3
11 ENOUT2
10 ENOUT1

RS2- 1
RS2+ 2
RS3+ 3
RS3- 4
RS3C 5
EN 6
DACOUT1 7
AGND 8
ENOUT0 9

THIN QFN

*EP = EXPOSED PAD.

Chip Information

PROCESS: BiCMOS

Package Information

For the latest package outline information and land patterns, go to **www.maxim-ic.com/packages**. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	DOCUMENT NO.
36 TQFN-EP	T3666-3	**21-0141**

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REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	7/09	Initial release	—
1	2/10	Updated the *Electrical Characteristics*, completed text corrections in *Absolute Maximum Ratings*, Table 4, the *MFR_DATE (9Dh)* and *MFR_SET_ADDRESS (DBh)* sections.	2, 4, 32, 33, 43,47