# Digital Dual-Phase Synchronous Buck Controller

## FEATURES

- **Digital Dual-Phase Synchronous Buck PWM Controller with 175ps PWM Resolution**
- **Digital Control with Programmable PID Compensation**
- **Dual-Phase with Current Balancing Capability**
- **$V_{IN}$ from 4.5V to 14.5V (UCD7230)**
- **$V_{OUT}$ from 1% to 99% of $V_{IN}$**
- **Programmable Switching Frequency, Capable of up to 2MHz/Phase**
- **Programmable Soft Start and Soft Stop**
- **Supports Pre-Biased Start-Up**
- **Internally Trimmed 0.5% 800mV Reference**
- **Remote Sensing Differential Amplifier**
- **Power-Supply Monitoring via PMBus**
- **Single Bias Supply (3.3V VDD)**
- **Graphical User Interface Configuration**
- **Internal Thermal Sensor**
- **PMBus Support:**
  - **– Query Voltage, Current, Faults, etc**
  - **– Voltage Setting and Calibration**
  - **– Protection Threshold Adjustment**
- **32-Pin QFN Package**

## APPLICATIONS

- **Networking Equipment**
- **Servers**
- **Storage Systems**
- **Telecommunications Equipment**
- **DC Power Distributed Systems**
- **Industrial / ATE**

## DESCRIPTION

The UCD9112 is dual-phase synchronous buck digital pulse-width modulation (PWM) controller that supports point-of-load (POL) applications. The device is configured through the use of a graphical user interface (GUI). The loop compensator is configurable with the GUI to meet dynamic converter performance, allowing a single hardware design to cover a broad range of POL applications.

In addition to digital control loops, the UCD9112 is able to monitor and manage power supply operating conditions and report the status to the host system through PMBus. The management parameters are configurable through the GUI. The GUI also allows the power supply designer to easily configure the digital control loop characteristics and generate the gain and phase information for analysis using Bode plots.

To ensure balanced outputs on each phase, the UCD9112 incorporates a current balancing scheme. The PWM output of the dual phase controller is capable of operating at a switching frequency of up to 2MHz with a relative phase adjustment of 180°.

The UCD7230 synchronous buck driver has been designed to work with the UCD9112 controller to provide a highly-integrated digital power solution. In addition to 4A output drive capability, the driver integrates current limit, short circuit protection as well as undervoltage lockout protection. The UCD7230 also has a 3.3V, 10mA linear regulator that provides the supply current for the controller.

**PRODUCT PREVIEW**

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

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

### ORDERING INFORMATION(1)

| PACKAGE | TAPE AND REEL QUANTITY | PART NUMBER |
|---|---|---|
| QFN | 250 | UCCD9112RHB |

(1) For the most current package and ordering information, see the Package Option Addendum located at the end of this datasheet or see the TI website at www.ti.com.

## ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range (unless otherwise noted)(1)

| PARAMETER | UCD9112 | UNIT |
|---|---|---|
| VD33 relative to $V_{SS}$ | –0.3 to 3.6 | V |
| IO pin relative to $V_{SS}$ | –0.3 to 3.6 | V |
| Operating junction temperature, $T_J$ | –40 to +125 | °C |
| Storage temperature, $T_{stg}$ | –65 to +150 | °C |
| Lead temperature (soldering, 10 seconds) | 300 | °C |

(1) 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 under recommended operating conditions is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

## RECOMMENDED OPERATING CONDITIONS

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

| | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|
| VD33 relative to $V_{SS}$ | –0.2 | 3.3 | 3.5 | V |
| VEAP relative to VEAN | 0 | | 2.45 | V |
| Operating free-air temperature | –40 | | +85 | °C |

## ELECTROSTATIC DISCHARGE (ESD) PROTECTION

| PARAMETER | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|
| HBM (Human body model) | 2000 | | | V |
| CDM (Charged device model) | 500 | | | V |

PRODUCT PREVIEW

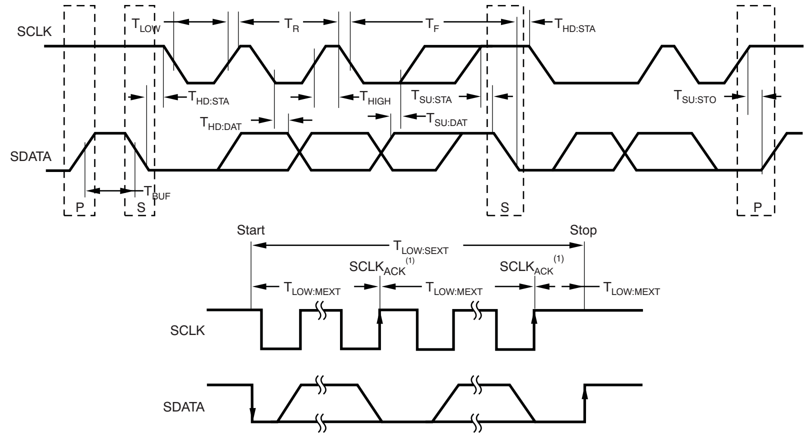
## ELECTRICAL CHARACTERISTICS

VD33 = 3.3V, $T_A$ = –40°C to +85°C(unless otherwise noted).

| PARAMETER | | TEST CONDITIONS | UCD9112 | | | UNIT |
|---|---|---|---|---|---|---|
| | | | MIN | TYP | MAX | |
| **VDD Input Supply** | | | | | | |
| VD33 supply voltage | | | 3.14 | 3.3 | 3.46 | V |
| Supply current | $I_{CC}$ | Normal operation | 4 | 7 | 10 | mA |
| **VD25** | | | | | | |
| Output voltage range | | 1µF ceramic connected, without source current | 2.4 | 2.45 | 2.5 | V |
| Source current(1) | | 5% maximum voltage drop | | | –10 | mA |
| **EAP and EAN** | | | | | | |
| Input differential range | | | –0.2 | | 2.5 | V |
| Input bias current to EAP | | VEAP – VEAN = 2.5V | –10 | | 50 | µA |
| Output source current from EAN | | | | –10 | | µA |
| Bandwidth | | | | 2 | | MHz |
| **PWM OUTPUT** | | | | | | |
| Duty cycle | | | 1 | | 99 | % |
| PWM frequency ($F_{sw}$) | | | 30 | 500 | 2000 | kHz |
| Frequency set point accuracy | | $T_A$ = 25°C | | | 5 | % |
| **$I_{LIM}$** | | | | | | |
| PWM frequency ($F_{il}$) | | | | 50 | | kHz |
| Duty cycle range | | | 0 | | 100 | % |
| **POWER GOOD** | | | | | | |
| PGood assertion delay | | | | ***TBD*** | | µs |
| PGood deassertion delay | | | | ***TBD*** | | µs |
| Low-level output voltage | $V_{OL}$ | $I_{PGOOD}$ = 5 mA | | | 0.4 | V |
| High-level output voltage | $V_{OH}$ | $I_{PGOOD}$ = –5 mA | 2.8 | | | V |
| **PMBus ALERT** | | | | | | |
| PMBus Alert assertion delay | | | | ***TBD*** | | µs |
| PMBus Alert deassertion delay | | | | ***TBD*** | | µs |
| Low-level output voltage | $V_{OL}$ | $I_{ALERT}$ = 5 mA | | | 0.4 | V |
| High-level output voltage | $V_{OH}$ | $I_{ALERT}$ = –5 mA | 2.8 | | | V |
| **THERMAL SHUTDOWN** | | | | | | |
| Shutdown temperature | | Junction temperature | | | ***TBD*** | °C |
| Hysteresis | | | | ***TBD*** | | °C |
| **I/O CHARACTERISTICS** | | | | | | |
| High input voltage | $V_{IH}$ | VD33 = 3.3V | 2 | | 3.45 | V |
| Low input voltage | $V_{IL}$ | VD33 = 3.3V | | | 0.8 | V |
| Input hysteresis voltage | | VD33 = 3.3V | 0.3 | | | V |
| Output voltage high | $V_{OH}$ | VD33 = 3.3V, $I_{OH}$ = –5mA | 2.8 | | | V |
| Output voltage low | $V_{OL}$ | VD33 = 3.3V, $I_{OL}$ = 5mA | | | 0.4 | V |

(1) The UCD9112 times out when any clock low exceeds $t_{(TIMEOUT)}$.

PRODUCT PREVIEW




NOTE: (1) $SCLK_{ACK}$ is the acknowledge-related clock pulse generated by the master.

**Figure 1. PMBus/SMBus/I²C™ Timing Diagram**

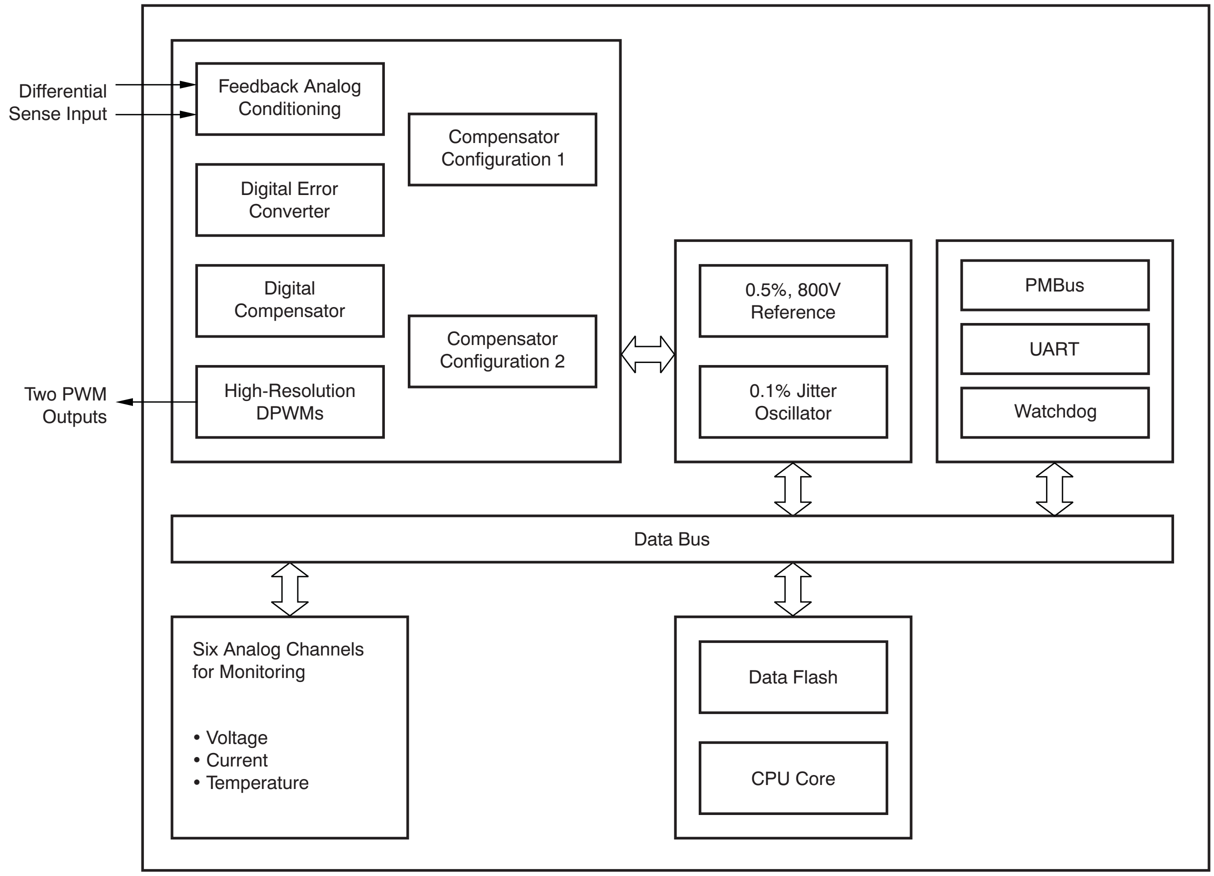
## TIMING REQUIREMENTS

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

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **PWM Output** | | | | | | |
| $t_r$ | Rise time | 1000pF cap load | | 15 | | ns |
| $t_f$ | Fall time | 1000pF cap load | | 15 | | ns |
| $t_{db}$ | Dead band | $F_s$ = 500KHz | 20 | | 512 | ns |
| $t_{dl}$ | Fault shutdown delay | The count of CLF is set at zero | | 20 | | ns |
| **$I_{LIM}$** | | | | | | |
| $t_{f\_il}$ | Fall time | 1000pF cap load | | 15 | | ns |
| $t_{r\_il}$ | Rise time | 1000pF cap load | | 15 | | ns |
| **PMBus/SMBus/I²C** | | | | | | |
| $F_{SMB}$ | PMBus/SMBus operating frequency | Slave mode, SMBC 50% duty cycle | | 100 | | kHz |
| $F_{I2C}$ | I²C operating frequency | Slave mode, SCL 50% duty cycle | | 400 | | kHz |
| $t_{(BUF)}$ | Bus free time between start and stop | | 4.7 | | | µs |
| $t_{(HD:STA)}$ | Hold time after (repeated) start | | 4.0 | | | µs |
| $t_{(SU:STA)}$ | Repeated start setup | | 4.7 | | | µs |
| $t_{(SU:STO)}$ | Repeated start setup | | 4.0 | | | µs |
| $t_{(HD:DAT)}$ | Data hold time | Receive mode | 0 | | | ns |
| | | Transmit mode | 300 | | | |
| $t_{(SU:DAT)}$ | Data setup time | | 250 | | | ns |
| $t_{(TIMEOUT)}$ | Error signal/detect(1) | | 25 | | 35 | ms |
| $t_{(LOW)}$ | Clock low period | | 4.7 | | | µs |
| $t_{(HIGH)}$ | Clock high period(2) | | 4.0 | | 50 | µs |
| $t_{(LOW:SEXT)}$ | Cumulative clock low slave extend time(3) | | | | 25 | ms |
| $t_{(LOW:MEXT)}$ | Cumulative clock low master extend time(4) | | | | 10 | ms |
| $t_f$ | Clock/data fall time(5) | | | | 300 | ns |
| $t_r$ | Clock/data rise time(6) | | | | 1000 | ns |

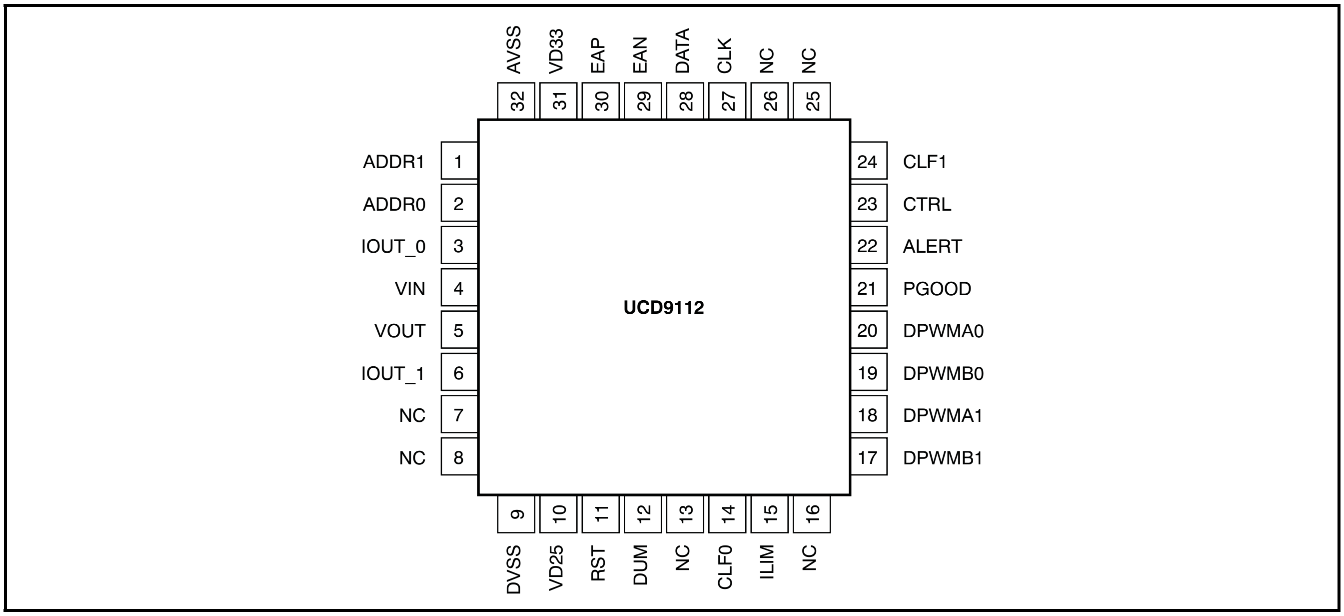
(1) The UCD9112 times out when any clock low exceeds $t_{(TIMEOUT)}$.
(2) $t_{(HIGH), Max}$ is the minimum bus idle time. SMBC = SMBD = 1 for t > 50 ms causes reset of any transaction involving the UCD9110 that is in progress. This specification is valid when the NC_SMB control bit remains in the default cleared state (CLK[0] = 0).
(3) $t_{(LOW:SEXT)}$ is the cumulative time a slave device is allowed to extend the clock cycles in one message from initial start to the stop.
(4) $t_{(LOW:MEXT)}$ is the cumulative time a master device is allowed to extend the clock cycles in one message from initial start to the stop.
(5) Fall time $t_f$ = 0.9VDD to ($V_{ILMAX}$ – 0.15)
(6) Rise time $t_r$ = $V_{ILMAX}$ – 0.15) to ($V_{IHMIN}$ + 0.15)

## DEVICE INFORMATION




PRODUCT PREVIEW

## DEVICE INFORMATION (continued)






### Table 1. TERMINAL FUNCTIONS

| TERMINAL PIN | | | | DESCRIPTION |
|---|---|---|---|---|
| NAME | NO. | I/O | A/D | |
| ADDR1 | 1 | I | A | Addr1 and Addr0 signals are analog voltage that are sampled when UCD9112 is released from reset. The voltage levels set the addresses. See the below section, PMBus Address. |
| ADDR0 | 2 | I | A | |
| IOUT_0 | 3 | I | A | Phase 0 inductor current, the value is amplified in UCD7230 |
| VIN | 4 | I | A | Input DC voltage sensing through resistors. |
| VOUT | 5 | I | A | Output DC voltage sensing through resistors. |
| IOUT_1 | 6 | I | A | Phase 1 inductor curren sensing, the value is amplified in UCD7230. |
| NC | 7 | – | – | Open connection. |
| NC | 8 | – | – | Open connection. |
| DVSS | 9 | – | DP | Digital ground of IC. This ground should be separate from power ground. |
| VD25 | 10 | O | P | Internal 2.5V bypass pin for UCD9112. A 1µF ceramic cap must be connected from VD25 to DVSS. |
| RST | 11 | I | – | Pulling high resets the chip. Need a pull-down resistor and a 0.1µF decoupling capacitor. |
| DUM | 12 | – | – | Connected to analog ground AVSS. |
| NC | 13 | – | – | Open connection. |
| CLF0 | 14 | I | D | Phase 0 over current limit flag from UCD7230. |
| ILIM | 15 | O | D | A PWM ouptut that is used to generate an analog input to the UCD7230 current limit. The ILIM requires an RC filter consisting of 15k and 0.1µF |
| NC | 16 | – | – | Open connection. |
| DPWMB1 | 17 | O | D | Phase 1 DPWM output to the drive UCD7230. |
| DPWMA1 | 18 | O | D | Phase 1 DPWM output to the drive UCD7230. |
| DPWMB0 | 19 | O | D | Phase 0 DPWM output to the drive UCD7230. |
| DPWMA0 | 20 | O | D | Phase 0 DPWM output to the drive UCD7230. |
| PGOOD | 21 | O | D | Power good signal indicating power conversion status. |
| ALERT | 22 | O | D | Alert signal indiating PMBus status. |
| CTRL | 23 | I | D | ON/OFF command to turn on/off power supply output. |
| CLF1 | 24 | I | D | Phase 1 over current flag from UCD7230. |
| NC | 25 | I | D | Open connection. |
| NC | 26 | O | D | Open connection. |
| CLK | 27 | I | D | PMBus/SMBus/I$^2$C clock input. |

## DEVICE INFORMATION (continued)

### Table 1. TERMINAL FUNCTIONS (continued)

| TERMINAL PIN | | | | DESCRIPTION |
|---|---|---|---|---|
| NAME | NO. | I/O | A/D | |
| DATA | 28 | I/O | D | PMBus/SMBus/I$^2$C data (bi-directional). |
| EAN | 29 | I | A | Output voltage remote sense to error amplifier negative input. |
| EAP | 30 | I | A | Output voltage remote sense to error amplifier positive input. |
| VD33 | 31 | I | P | 3.3V VDD bias supply and analog reference. |
| VD33 | 32 | – | P | Analog ground. |
| PAD GND | 33 | – | Pad | Pad analog ground. |

## TYPICAL CHARACTERISTICS

PRODUCT PREVIEW

## APPLICATION INFORMATION

### EXAMPLE DUAL-PHASE IMPLEMENTATION WITH THE UCD7230 DRIVER

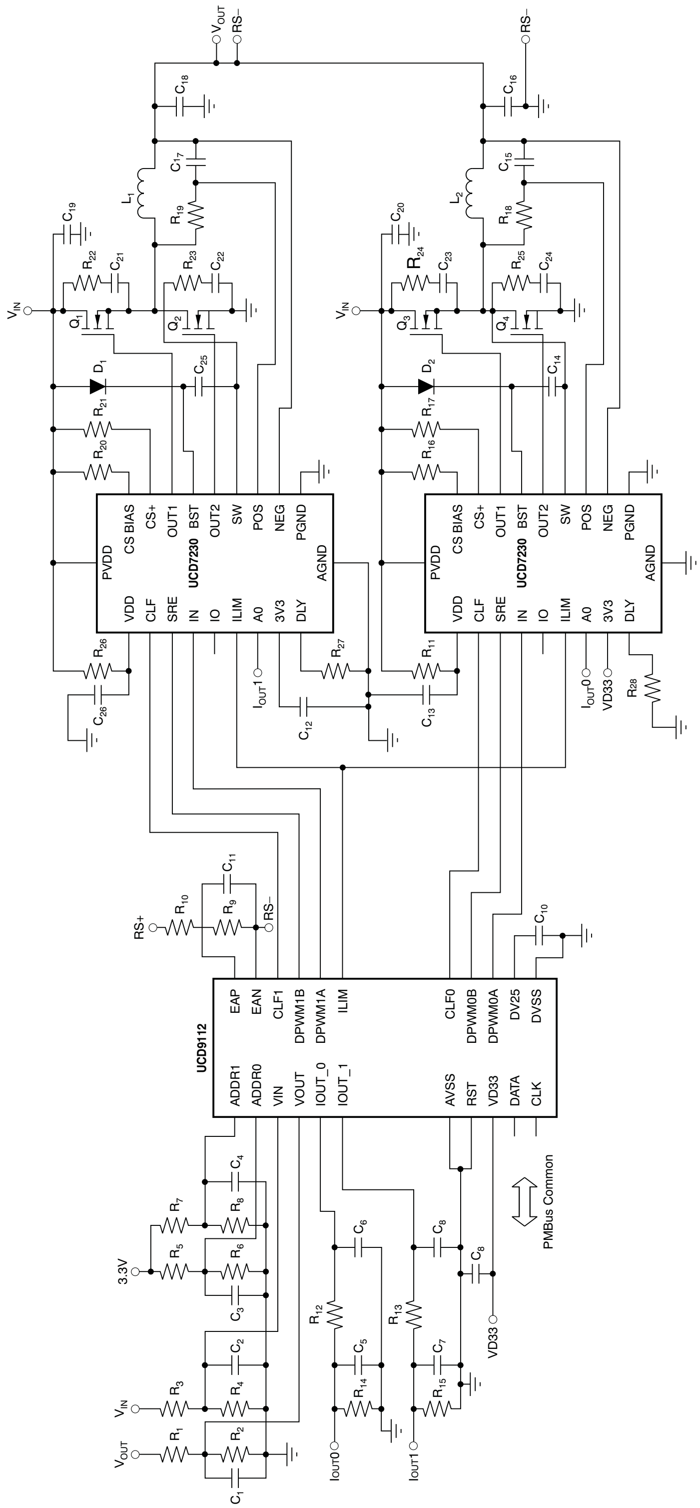



**Figure 2. UCD9112 in a Dual-Phase Configuration**

# FUNCTIONAL OVERVIEW

## Reset

### Power-on Reset

The UCD9112 has an integrated reset block which monitors the supply voltage. At power-up, the POR detects the VD33 rise. When VD33 is greater than a predetermined reference point, VRST, a reset pulse is generated and a startup delay sequence is initiated. At the end of the delay sequence, the system reset signal is deasserted and the device begins normal operation; see Table 2.

In applications with long VD33 rise times, the external reset (RST) should be used to ensure startup occurs when the supply voltage is greater than the minimum operating voltage. At the normal operating condition, this RST pin must be connected to a parallel combination of a 10kΩ resistor and 0.1µF capacitor to AVSS.

### Brown-out Reset

The UCD9112 also has an integrated brown-out reset circuit that is used to generate a reset when the supply voltage falls below a fixed trip reference voltage. The device is held in reset until the supply voltage rises above the minimum voltage threshold, at which time a new reset pulse is generated and the POR circuit restarts the device. (See Table 2.)

### Watchdog Timer

The built-in watchdog timer provides protection from unpredicted operation.

### External Reset

The device can be forced into the reset state by an external circuit connected to the RST pin. A logic high voltage on this pin generates a reset signal. To avoid an erroneous trigger caused by the noise, a pulldown resistor and a decoupling cap are necessary.

**Table 2. Device Reset Voltage Threshold(1)**

| PARAMETER | CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|
| Power-on reset, VRST | | 2.4 | 2.5 | 2.8 | V |
| Brown-out threshold | | | 2.2 | | V |
| RST delay | | | TBD | | ms |
| Hysteresis | | | 0.2 | | V |

(1) VD33= 3.3V, $T_A$= –40°C to +85°C (unless otherwise noted).

## Analog Monitoring

The UCD9112 monitors seven analog signals to determine supply operation. Table 3 shows the analog input pin assignments.

**Table 3. Analog Input Assignment**

| PIN NO. | PIN NAME | FUNCTION/DESCRIPTION |
|---|---|---|
| 1 | ADDR1 | Address 1 voltage conversion |
| 2 | ADDR0 | Address 0 voltage conversion |
| 3 | IOUT_0 | Phase 0 output current conversion |
| 4 | VIN | POL input voltage conversion |
| 5 | VOUT | POL output voltage conversion |
| 6 | IOUT_1 | Phase 1 output current conversion |
| Internal | – | Temperature sensing voltage conversion |

PRODUCT PREVIEW

The UCD9112 takes the proper action based on the information acquired from these analog inputs; for example, turning on the dc output or sending alarm signal to the host system if the output is under voltage. The device temperature is monitored using an internal temperature sensor. The data can be reported to the host after the UCD9112 receives the commands via PMBus. The PMBus commands will be addressed in the PMBus Interface section.

### Resolution

The external analog inputs have 3.22mV resolution based on a 3.3V VD33 input. The maximum input voltage at the analog input should not exceed 3.0V for proper measurement.

In some applications, a voltage divider is used to reduce the voltage level applied to the analog input. The division ratio changes the conversion resolution.

### Input Impedance

The input impedance is typically a 250Ω series input and a 30pF capacitor to ground. The inputs are sampled and require 60ns of settling time. It is desirable to have a 0.1µF input capacitor at each analog input pin.

## PMBus Address

The Digital POL system has the ability to be configured with different PMBus addresses. To configure different addresses, a voltage will be applied to the pins ADDR1 and ADDR0 on the UCD9112.

Figure 3 shows what PMBus addresses are indicated by the applied voltage.

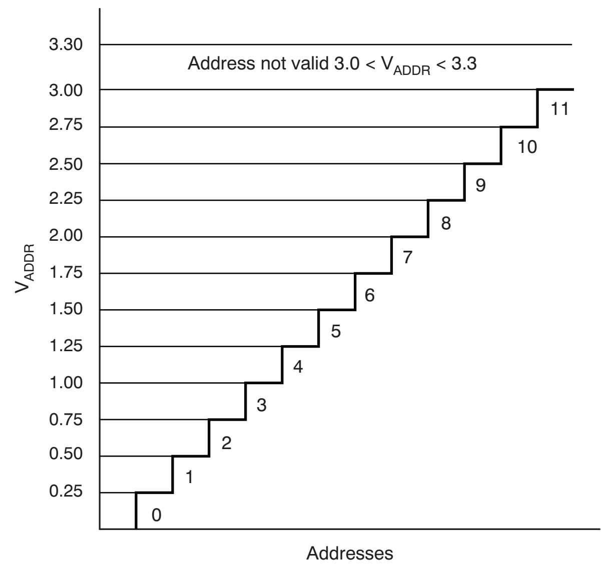



**Figure 3. $V_{ADDR}$ to PMBus Address Translation**

Note that the nominal value for each voltage step (and each PMBus address) is in the center of each band.

The address can be represented by the formula:

```
PMBus_Addr = ADDR0 * 12 + ADDR1
```

PRODUCT PREVIEW

Table 4 lists the examples of the PMBus address for given the voltage level on the pin1 and Pin2.

**Table 4. PMBus Address Configurations**

| PMB_Addr0 | PMB_Addr1 | PMB Address | PMB_Addr0 | PMB_Addr1 | PMB Address |
|---|---|---|---|---|---|
| < 0.25 | < 0.25 | 0x00 | 0.25 – 0.50 | < 0.25 | 0x0C |
| | 0.25 – 0.5 | 0x01 | | 0.25 – 0.5 | 0x0D |
| | 0.5 – 0.75 | 0x02 | | 0.5 – 0.75 | 0x0E |
| | 0.75 – 1.0 | 0x03 | | 0.75 – 1.0 | 0x0F |
| | 1.0 – 1.25 | 0x04 | | 1.0 – 1.25 | 0x10 |
| | 1.25 – 1.50 | 0x05 | | 1.25 – 1.50 | 0x11 |
| | 1.50 – 1.75 | 0x06 | | 1.50 – 1.75 | 0x12 |
| | 1.75 – 2.0 | 0x07 | | 1.75 – 2.0 | 0x13 |
| | 2.0 – 2.25 | 0x08 | | 2.0 – 2.25 | 0x14 |
| | 2.25 – 2.50 | 0x09 | | 2.25 – 2.50 | 0x15 |
| | 2.50 – 2.75 | 0x0A | | 2.50 – 2.75 | 0x16 |
| | 2.75 – 3.0 | 0x0B | | 2.75 – 3.0 | 0x17 |

Other addresses can be figured out by using the above formula. If the voltage placed on the address pins is over 3.0V or below 0V, the value is not valid.

## PID Compensator

The PID compensator allows the output voltage to be regulated at the set point reference level with zero steady state error and simultaneously maintain good dynamic performance. The high dc gain of the control loop maintains the zero steady state error. This high gain is realized by an integrator in the PID compensator. However, the dynamic response may not be ideal if only an integrator exists in the control loop for different applications. To further improve step response and stability, the PID compensator should be designed with properly placed pole and zeroes in order to achieve desired bandwidth and optimum phase margin, and gain margin.

The synchronous buck topology is commonly used for non-isolated dc/dc converters. The placement of the pole and zeroes is determined by the output filter inductor, capacitor and the ESR parasitic. In the traditional power-supply design, an operational error amplifier and external compensation components are used to implement the pole and zeroes. Using the UCD9112, the output voltage is properly scaled and fed to the UCD9112 error converter. The analog-to-digital converter (ADC) output is then fed to the UCD9112 on-chip PID compensator. The compensator is configured using the graphical user interface (during development) and the configuration is stored into the flash memory of the UCD9112.

## Output Voltage Sensing

Figure 4 shows the voltage sensing circuitry in UCD9112. It is part of feedback loop. Two dedicated pins, EAP and EAN, are employed to sense the output voltage differentially. The differential sensing can effectively reduce the noise induced by the switching devices. The maximum voltage for VEAP–VEAN should be less than 2.45V. If output voltage is higher than 2.45V, a voltage divider should be used to decrease the input voltage level below 2.45V.

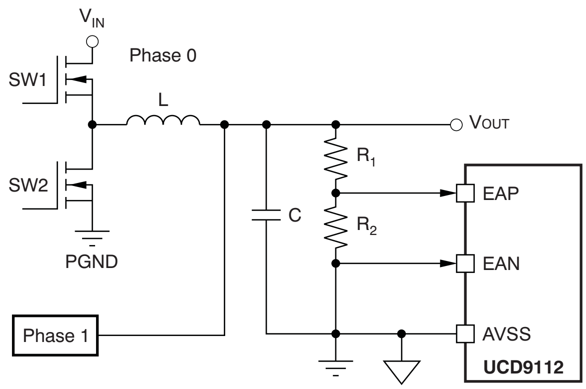



**Figure 4. Output Voltage Sensing Circuitry**

## PMBus INTERFACE

PMBus is an industry-standard specification for power management.. The UCD9112 supports all of the PMBus data commands that are relevant to this application. Most of the functionality in the DPOL application for the UCD9112 uses PMBus commands to support each of the functions. For each PMBus command supported in this specification, all SMBus transaction types associated with that command are also supported. This architecture enables the user to write and read the support parameters through the PMBus commands, and SMBus transactions.

The UCD9112 is PMBus compliant, in accordance with the *Compliance* section of the PMBus specification. The firmware is also compliant with the SMBus 1.1 specification, including support for the SMBus ALERT function.

### PMBus Timing

The timing characteristics and timing diagram for the communications interface that supports $I^2C$, SMBus and PMBus are shown in Figure 1 in the Electrical Characteristics section.

### Output Configuration Commands

#### Remote On/Off

Remote on/off is supported by the software in the UCD9112 controller. This behavior is configurable and is supported by a combination of the PMBus commands below and the PMB_CTL signal that is connected to pin 23.

The PMBus commands that support this functionality are:

- ON_OFF_CONFIG
- OPERATION

The ON_OFF_CONFIG command is used to configure the policy by which the unit is turned on and off, and the OPERATION command is used to turn the unit on and off according to this policy.

Power supply is turned on when PMB_CTL pin is pulled high; it is turned off when the pin is pulled down.

PRODUCT PREVIEW

## PMBus INTERFACE (continued)

### Output Voltage Set Point

The PMBus commands that support this functionality are:

- VOUT_MODE
- VOUT_COMMAND
- VOUT_MAX
- VOLTAGE_SCALE_LOOP
- VOLTAGE_SCALE_MONITOR

VOUT_MODE and VOUT_COMMAND set the new output voltage mode and the VOUT_MAX command sets the maximum output voltage. VOUT_MODE is used for commanding and reading output voltage, and it consists of a 3-bit mode and a 5-bit parameter representing the exponent used in output voltage Read/Write. The voltage set by VOUT_COMMAND is more than VOUT_MAX, the command is ignored.

The VOLTAGE_SCALE_LOOP and VOLTAGE_SCALE_MONITOR commands are used to scale the output voltage.

### Output Voltage Calibration

The UCD9112 supports $V_{OUT}$ output calibration. Output calibration is supported dynamically and can be changed while the supply is operating. The PMBus command that supports this functionality is:

- VOUT_CAL

The VOUT_CAL command supports output voltage calibration by providing a fixed offset voltage to the output voltage command values.

PRODUCT PREVIEW

## PMBus INTERFACE (continued)

### Margin Up/Down

The UCD9112 supports margin up/down linearly through a programmable rate. The PMBus commands to support this functionality are:

- VOUT_MARGIN_HIGH
- VOUT_MARGIN_LOW
- VOUT_TRANSITION_RATE

The VOUT_MARGIN_HIGH command is used to provide the unit with the voltage to which the output is to be changed when the operation is set to *margin high*. The VOUT_MARGIN_LOW command is used to provide the unit with the voltage to which the output is to be changed when the operation is set to *margin low*.

When margining up or down, the rate at which the voltage margining increases or decreases will be specified by the VOUT_TRANSITION_RATE command.

### Output Current Measurement

There are two commands in UCD9112 to measure output current. The output current is measured by sensing the voltage drop across the DCR of each output inductor. The current of each phase is added to provide the IOUT value. The PMBus commands that support this functionality are:

- IOUT_SCALE
- IOUT_CAL_OFFSET

The UCD9112 has two manufacturer-specific commands to report the current on each of the two phases. The IOUT_CAL_OFFSET command support output current calibration by nullifying any offsets in the current sensing circuits. The IOUT_SCALE command is used to set the ratio of the voltage at the current sense pins to the sensed current of each phase.

The output current can be calculated as shown in Equation 1:

$$I_O = \frac{V_{SENSE}}{\text{IOUT\_SCALE}} - \text{IOUT\_CAL\_OFFSET} \quad (1)$$

This can be graphically depicted as shown in Figure 5.

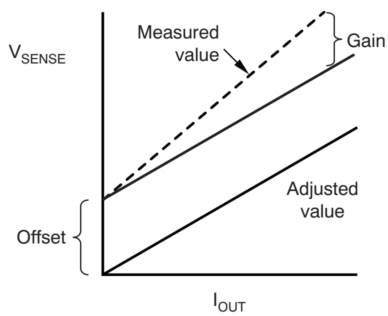



**Figure 5. Current Gain and Offset**

PRODUCT PREVIEW

## PMBus INTERFACE (continued)

### Start Up Into Pre-Bias

The UCD9112 supports starting the power supply when there is an existing output voltage when the system starts. The system will start up with an output voltage higher than the output voltage set point.

The duty cycle is calculated by dividing $V_{OUT}$ by $V_{IN}$ (duty cycle = $V_{OUT}$ / $V_{IN}$). The time constant for this operation is 50ms and regulation will be achieved by this time.

When the PMBus CONTROL line is asserted, the UCD9112 looks at the output voltage to determine if a prebias is present. The algorithm for this determination is:

If $V_{OUT}$ < 300 mV, then startup is executed assuming no pre-bias. Startup proceeds normally through delay and soft start states.

If $V_{OUT}$ > 3.65V, then the device does not attempt startup.

If $V_{OUT}$ > output voltage set point, then disable Overvoltage Protection (OVP), calculate the duty cycle (V\$_{OUT}$ / $V_{IN}$), bypass the soft start state and commence switching. When $V_{OUT}$ < $V_{OUT\_HIGH}$ limit, re-enable OVP. The response time from this action will be less than 10ms.

If $V_{OUT}$ < output voltage set point, then turn off $V_{OUT\_LOW}$ protection, calculate the duty cycle, bypass the soft start state and commence switching. When $V_{OUT}$ > $V_{OUT\_LOW}$, then re-enable $V_{OUT\_LOW}$ protection.

There are no PMBus commands associated with this functionality.

### Output Voltage Sequencing

The UCD9112 supports output voltage sequencing. Output voltage sequencing is started based on receiving an indication from the PMB CONTROL (PMB_CTL) signal from the system host.

The PMBus commands that support this functionality are:

- TON_DELAY
- TOFF_DELAY

TON_DELAY is used to specify the delay from when the PMBus CONTROL line is asserted to when the output voltage starts to rise. TOFF_DELAY is used to specify the delay from when the PMBus CONTROL line is deasserted to when the output voltage starts to fall.

### Output Voltage Soft Start

Soft start timing starts when the PMB_CTL line is asserted (voltage rise). The system configures the delay from the assertion of the PMB_CTL signal to when the output voltage entered the regulation band. The system also configures the maximum time this process can take, without causing an undervoltage fault, and what action to take for an error.

The PMBus commands that support this functionality are:

- TON_RISE
- TON_MAX_FAULT_LIMIT
- TON_MAX_FAULT_RESPONSE

When the voltage is rising, the TON_RISE command specifies the time from when output voltage tracking starts, to when the output voltage enters the regulation band. The TON_MAX_FAULT_LIMIT command specifies the maximum amount of time that this process can take, before an undervoltage fault will occur. The TON_MAX_FAULT_RESPONSE command specifies the action to be taken if the power supply does not reach the regulation band before the maximum time specified by TON_RISE has elapsed.

### Output Voltage Soft Stop

Soft stop timing starts when the PMB_CTL line is deasserted (voltage fall).

The PMBus commands that support this functionality are:

- TOFF_FALL
- TOFF_MAX_FAULT_LIMIT
- TOFF_MAX_FAULT_RESPONSE

PRODUCT PREVIEW

## PMBus INTERFACE (continued)

The TOFF_FALL command specifies the time from when the voltage starts to fall to when it is off. The TOFF_MAX_FAULT_LIMIT command specifies the maximum amount of time that this process can take, before an overvoltage fault will occur. The TOFF_MAX_FAULT_RESPONSE command specifies the action to be taken if the power supply does not reach 0V by the maximum time specifies in TOFF FALL has elapsed.

In the event that the voltage fails to rise or fall according to the criteria above, the STATUS_VOUT command will reflect the failure to meet the configured output voltage tracking.

#### Power Good (PGOOD)

The UCD9112 supports an indication of power good to the host. The UCD9112 will monitor output voltage and will either assert or de-assert the power good signal based on this voltage. The UCD9112 uses the PGOOD (Pin 21) as the power good signal and the polarity of this signal can be configured as active high or active low through PMBus. This signal drives an open collector GPIO pin on the host system.

Power good is asserted when the system is operational and is delivering the configured output voltage. Power good is de-asserted when any condition (fault or otherwise) causes the system to ramp down output voltage. The system asserts (or de-asserts) this signal within 1ms of the event that causes the transition.

The PMBus commands that support this functionality are:

- POWER_GOOD_ON
- POWER_GOOD_OFF
- MFR_SPECIFIC_00

The POWER_GOOD_ON command is used to specify the voltage at which the Power Good signal should be asserted. The POWER_GOOD_OFF command is used to specify the voltage at which the Power Good signal should be de-asserted. The MFR_SPECIFIC_00 command configures the polarity of the Power Good signal. A value of '0' in the least significant byte in this command means that the Power Good signal should be configured to be active low. A value of '1' in the least significant byte in this command means that the Power Good signal should be configured to be active high.

### Protection Commands

The UCD9112 provides many features to monitor input voltage, output voltage, output current, and temperature. The thresholds can be programmable through PMBus, and the status and the faults are sent to the host computer if requested.

#### Input UnderVoltage Protection (VIN_UVP)

Input voltage is sensed on VIN (Pin4) of UCD9112, and the data is processed based on the threshold programmed through PMBus. The PMBus commands that support this functionality are:

- VIN_UV_WARN_LIMIT
- VIN_UV_FAULT_LIMIT
- VIN_UV_FAULT_RESPONSE
- VIN_ON
- VIN_OFF

When the input voltage starts to rise towards the regulation band, the VIN_ON command sets the voltage at which power conversion starts. When the voltage is in the regulation band, the system then observes the input voltage for both input under- and overvoltage warnings and faults. If the voltage falls below the value set by the VIN_OFF command, then power conversion stops.

If the voltage falls below the value set through the VIN_UV_WARN_LIMIT command, then an undervoltage warning occurs.

If the voltage continues to fall and falls below the value set through the VIN_UV_FAULT_LIMIT command, then an undervoltage fault occurs. The action taken in this event is specified by the VIN_UV_FAULT_RESPONSE command.

When an undervoltage fault occurs, the VIN_UV_FAULT_RESPONSE register instructs the system how to react. There are two response bits that instruct the system what to do in the event of these failures.

PRODUCT PREVIEW

## PMBus INTERFACE (continued)

### Input OverVoltage Protection (VIN_OVP)

The UCD9112 supports warnings and faults for input over voltage protection. The latency from when the voltage goes out of range to when power is ramped down is 20ms.

The PMBus commands that support this functionality are:

- VIN_OV_WARN_LIMIT
- VIN_OV_FAULT_LIMIT
- VIN_OV_FAULT_RESPONSE

For input overvoltage *warnings*, the VIN_OV_WARN_LIMIT command is used to set the input voltage at which an overvoltage warning occurs.

### Output OverVoltage Protection (VO_OVP)

UCD9112 monitors output voltage by VOUT (pin 5). In order to compensate for possible transient cases, when the first overvoltage reading happens, the firmware monitors the output voltage more closely. If a second overvoltage reading happens within 100µs, the firmware flags this reading as an overvoltage event and not just as a transient condition.

When an overvoltage fault event occurs, the firmware sends out a short PWM pulse and toggles the SRE signal to latch the sync FET on. This process ensures that the driver will try to pull down the over voltage actively through the sync FET.

The UCD9112 offers programmable output overvoltage protection. The firmware can be configured to monitor (and act upon) OVP faults and warnings independently. If such a condition occurs, the UCD9112 takes the action configured through the PMBus RESPONSE commands shown below.

The PMBus commands that support this functionality are:

- VOUT_OV_WARN_LIMIT
- VOUT_OV_FAULT_LIMIT
- VOUT_OV_FAULT_RESPONSE

For output undervoltage *warnings*, the VOUT_OV_WARN_LIMIT command sets the voltage at which an output under voltage warning occurs.

For output undervoltage faults, the VOUT_UV_FAULT_LIMIT command sets the voltage at which an output under voltage fault occurs. In this event, the VOUT_UV_FAULT_RESPONSE command specifies the action to be taken.

When an OVP fault occurs, the VOUT_OV_FAULT_RESPONSE register instructs the system how to react. There are two response bits that instruct the system what to do in the event of these failures.

### Output UnderVoltage Protection (VO_UVP)

When a fault condition is detected, the PMBus ALERT signal is asserted to the host controller to announce this event. The latency between the undervoltage fault event and the PMBus ALERT to the host is 1ms. After this event has occurred, the system reacts according to the configuration according to the RESPONSE commands below. The latency between the undervoltage fault event happening and the UCD9112 taking the configured action is 10ms.

The output undervoltage warning does not raise the PMBus ALERT signal. The latency between when output under voltage warning threshold being crossed and the UCD9112 taking the configured action is 10ms.

The PMBus commands that support this functionality are:

- VOUT_UV_WARN_LIMIT
- VOUT_UV_FAULT_LIMIT
- VOUT_UV_FAULT_RESPONSE

For output under voltage *warnings*, the VOUT_UV_WARN_LIMIT command specifies the value of the output voltage that will cause an undervoltage warning.

## PMBus INTERFACE (continued)

For output under voltage *faults*, the VOUT_UV_FAULT_LIMIT command specifies the value of the output voltage that will cause an undervoltage fault. The VOUT_UV_FAULT_RESPONSE command specifies the action to be taken should this event occur.

When an output under voltage fault occurs, the VOUT_UV_FAULT_RESPONSE register instructs the system how to react. There are two response bits that instruct the system what to do in the event of these failures.

### Output Over-Current Protection (IO_OCP)

The UCD9112, in conjunction with the UCD7230 drive, monitors the output current and provides output current protection. Current is sensed either by RDSON of the top FET or by DCR of the output inductor. There are two different sensing methods and two different protections.

First, by sensing the current of top MOSFET, the cycle-by-cycle current is obtained on UCD7230. The peak current is compared to the peak current threshold set by external resistors. If the peak current of top FET is higher than the set point, the gate drive pulse is cut off, and the top FET is immediately turned off. In the event the output is short and the current increases extremely fast, this pulse-by-pulse protection can take actions immediately to avoid the damage of the power converter. When over-current happens, the output of CLF is set and kept high until the next switching cycle. The UCD9112 counts the number of CLF low to high transitions. If over-current continues for multiple switching cycles greater than the limit set in the UCD9112, the decision will be made by UCD9112 to shut off the DPWM outputs. The converter is going to enter *hiccup* mode or *latched-off* mode.

Second, the output current is also obtained by measuring the voltage across the DCR of each output inductor. By properly selecting an RC network that is connected in parallel with the output inductor, the output inductor current is sensed and fed to the UCD7230. The UCD9112 provides a current limit ($I_{LIM}$) threshold to the UCD7230 through a filtered PWM output. The sensed voltage across the DCR of each output inductor is compared to $I_{LIM}$ using a high-speed comparator in the UCD7230. If the ICS > $I_{LIM}$, the CLF is set. The UCD9112 counts the number of CLF high to low transitions. The converter enters hiccup or latched-off mode after the number of CLF pulses is more than the limit set in the UCD9112. The current limit threshold $I_{LIM}$ and the number of CLF pulses are programmable through PMBus.

The PMBus commands that support this functionality are:

- IOUT_OC_WARN_LIMIT
- IOUT_OC_FAULT_LIMIT
- IOUT_OC_FAULT_RESPONSE
- MFR_SPECIFIC_01

For over-current warnings, the IOUT_OC_WARN_LIMIT command specifies the current at which the over-current warning occurs.

For over-current faults, the IOUT_OC_FAULT_LIMIT command specifies the current at which the over-current fault occurs. When this event occurs, the IOUT_OC_FAULT_RESPONSE command specifies the action to be taken by the system.

The number of current limit flags to accept before taking action can be configured by using the MFR_SPECIFIC_01 command. The 16b data value from this command represents the number of CLF events.

The inductor current of phase0 and phase1 is amplified in the UCD7230. Then, the current of each phase is input to UCD9112 on the IOUT_0 and IOUT_1. The software monitors the output current and sends a warning signal if the current is over the limit.

### Over-Temperature Protection (OTP)

The UCD9112 supports over-temperature protection (OTP) warnings and faults. There is a temperature sensor in the UCD9112 that senses over-temperature events. The temperature sensor is calibrated according to a calculation based on current output and the power scale using a manufacturer-specific command. The latency between over-temperature events and system reaction time is 20ms.

## PMBus INTERFACE (continued)

The PMBus commands that support this functionality are:

- OT_WARN_LIMIT
- OT_FAULT_LIMIT
- OT_FAULT_RESPONSE
- MFR_SPECIFIC_02

For over-temperature warnings, the OT_WARN_LIMIT command specifies the temperature at which the power supply indicates an over-temperature warning alarm.

For over-temperature faults, the OT_FAULT_LIMIT command specifies the temperature at which the power supply indicates a fault. The OT_FAULT_RESPONSE command specifies the action to be taken in the event of a temperature fault condition in the power supply.

The MFR_SPECIFIC_02 command is used to calibrate the temperature reported by the temperature sensor on the UCD9112.

When an over-temperature fault occurs, the OT_FAULT_RESPONSE register instructs the system how to react. There are two response bits that instruct the system what to do in the event of these failures.

### Status and Fault Reporting Commands

The UCD9112 controller supports status and fault reporting for maintenance of an operating supply. The PMBus commands are listed below:

- STATUS_BYTE
- STATUS_WORD
- STATUS_VOUT
- STATUS_IOUT
- STATUS_INPUT
- STATUS_TEMPERATURE
- STATUS_CML
- CLEAR_FAULTS

The STATUS_BYTE command returns one byte of information with a summary of the most critical faults.

The STATUS_WORD command returns two bytes of information with a summary of the unit fault condition.

The STATUS_VOUT command returns one byte information of output voltage.

The STATUS_IOUT command returns one byte information of output current.

The STATUS_INPUT command returns one byte information of input voltage.

The STATUS_TEMPERATURE command returns one byte information of temperature.

CLEAR_FAULT clears any set faults.

### Non-Volatile Storage Commands

The UCD9112 supports storing configuration valued to its non-volatile memory. The latency for this operation is one second. The PMBus commands that support this functionality are:

- STORE_DEFAULT_ALL
- RESTORE_DEFAULT_ALL
- STORE_DEFAULT_CODE
- RESTORE_DEFAULT_CODE
- STORE_USER_ALL
- RESTORE_USER_ALL
- STORE_USER_CODE
- RESTORE_USER_CODE

## PMBus INTERFACE (continued)

The STORE_DEFAULT_ALL command stores all default values in the system to non-volatile memory. The RESTORE_DEFAULT_ALL command sets all operational values to the values stored in non-volatile memory.

The STORE_DEFAULT_CODE command stores the given value for the given command to non-volatile memory. The RESTORE_DEFAULT_CODE restores the given value for the given command to operational memory from non-volatile memory.

The STORE_USER_ALL command stores all user values in the system to non-volatile memory. The RESTORE_USER_ALL command restores all user values from non-volatile memory to operational memory.

The STORE_USER_CODE command stores the given value for the given user command to non-volatile memory. The RESTORE_USER_CODE restores the given value for the given command from non-volatile memory to operational memory.

### Host Data Storage Commands

The PMBus commands that support this functionality are:

- MFR_ID
- MFR_MODEL
- MFR_REVISION
- MFR_DATE
- MFR_SERIAL

The MFR_ID, MFR_MODEL, MFR_REVISION, MFR_DATE and MFR_SERIAL commands are used by the firmware to store that appropriate data from the release of the UCD9112 and driver, as well as firmware for the application.

## DUAL PHASE CURRENT BALANCING

UCD9112 uses two pins, Iout_0 and Iout_1, to sense the output current of each phase. The current accuracy is important because the current values are used for current balance. DCR of output inductor varies with temperature and is compensated for temperature changes by the UCD9112. An assumption that is made is that the internal temperature of the device is equivalent to the temperature of each inductor. The current balancing is implemented through the software. The current balancing condition is reported to the host. The below requirement of current balancing can be met for UCD9112 dual phase application.

**Table 5. Current Balancing of Two Phases**

| OUTPUT TOTAL CURRENT | TWO PHASE CURRENT DIFFERENCE |
|---|---|
| 0% to 30%, 0A to 12A | TBD |
| 30% to 50%, 12A to 20A | TBD |
| 30% to 50%, 12A to 20A | TBD |

## GRAPHICAL USER INTERFACE

### Overview

The UCD9112 provides GUI (Graphic User Interface) for the user to configure POL operating condition. The functionality of the GUI supporting the UCD9112 is based on compliance with the PMBus specifications. The key functions of GUI are listed below:

- PID coefficients programming
- POL ON/OFF
- $V_{OUT}$ set point
- Converter switching frequency set
- Output voltage soft start and soft stop

PRODUCT PREVIEW

## GRAPHICAL USER INTERFACE (continued)

- Read output voltage
- Read output current
- Read input voltage
- Read temperature
- Fault threshold configuration
- Manufacturing information storage

More information is provided in the *GUI User's Manual*. Figure 6 shows the GUI presented to users.

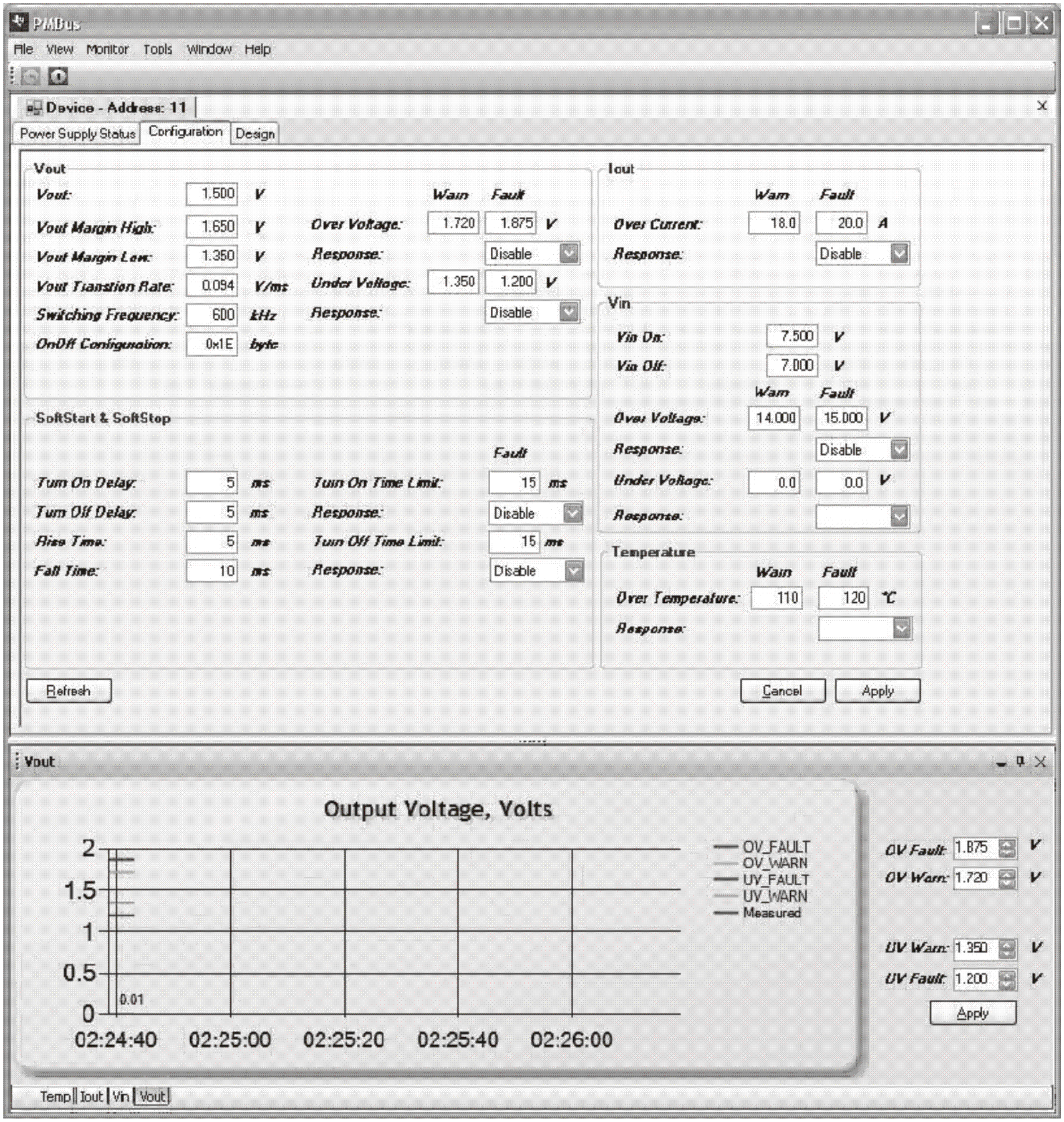



**Figure 6. Example GUI Interface for POL Configuration**

## GRAPHICAL USER INTERFACE (continued)

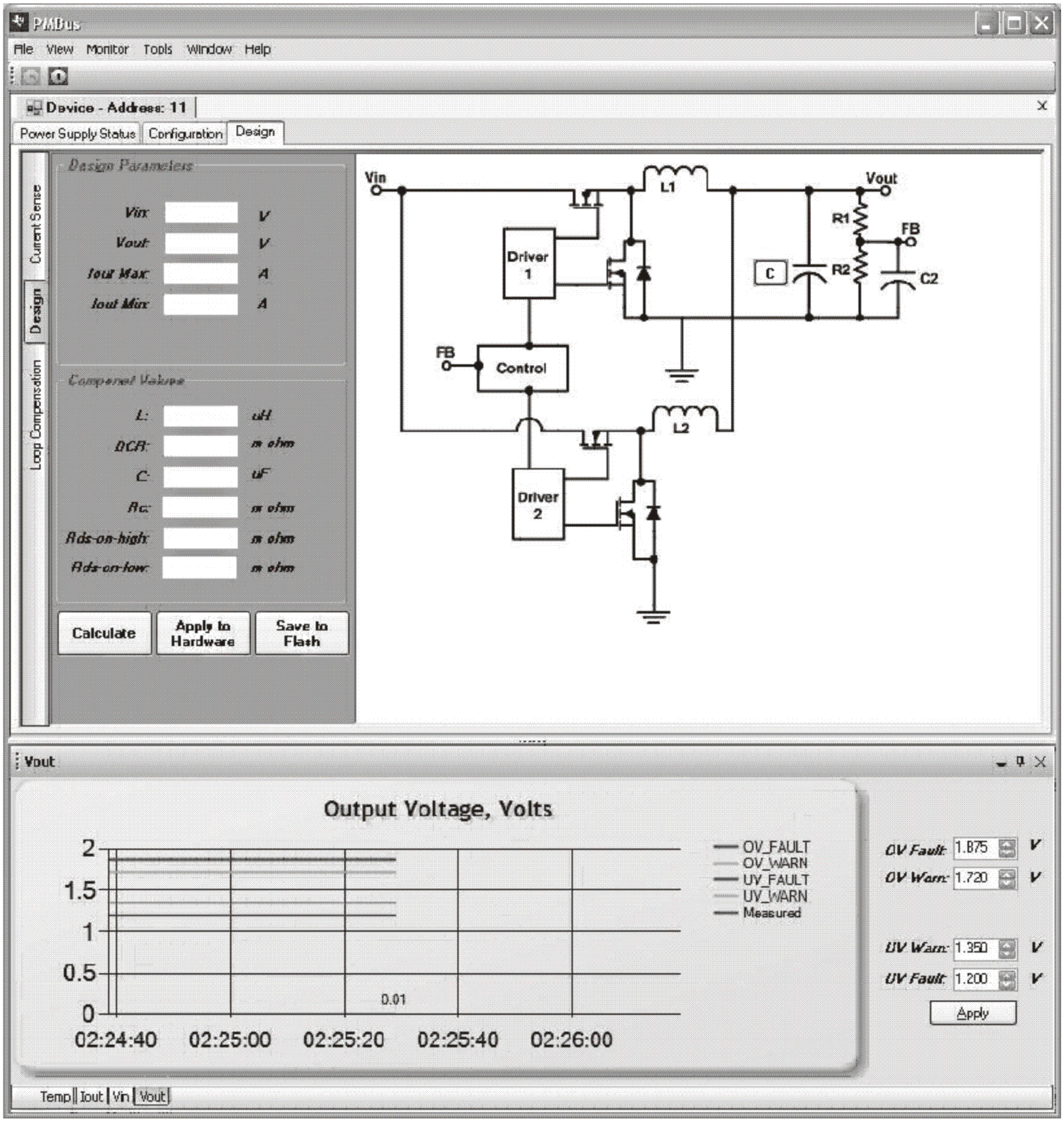


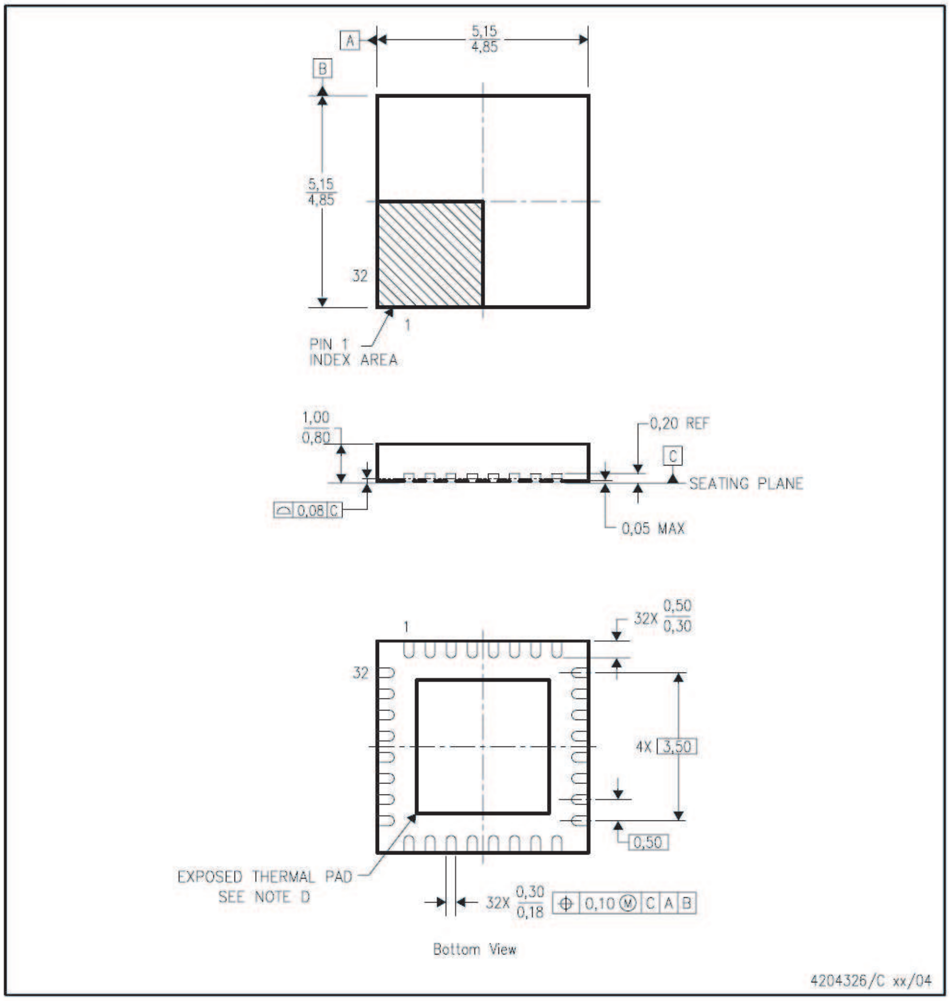

**Figure 7. Example GUI Design Tool**

PRODUCT PREVIEW

## PACKAGE INFORMATION

The UCD9112 is available in Texas Instruments' 32-pin PowerPAD™ plastic quad flatpack package.

RHB (S–PQFP–N32) PLASTIC QUAD FLATPACK




NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. QFN (Quad Flatpack No-Lead) Package configuration.
- D. The Package thermal pad must be soldered to the board for thermal and mechanical performance. See product data sheet for details regarding the exposed thermal pad dimensions.
- E. Falls within JEDEC MO-220.

**Figure 8. 32-Pin PowerPAD QFN Package**

PRODUCT PREVIEW

## PACKAGING INFORMATION

| Orderable Device | Status [1] | Package Type | Package Drawing | Pins | Package Qty | Eco Plan [2] | Lead/Ball Finish | MSL Peak Temp [3] |
|---|---|---|---|---|---|---|---|---|
| UCD9112RHBR | PREVIEW | QFN | RHB | 32 | 3000 | TBD | Call TI | Call TI |
| UCD9112RHBT | PREVIEW | QFN | RHB | 32 | 250 | TBD | Call TI | Call TI |

[1] The marketing status values are defined as follows:
**ACTIVE:** Product device recommended for new designs.
**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.
**OBSOLETE:** TI has discontinued the production of the device.

[2] Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
**TBD:** The Pb-Free/Green conversion plan has not been defined.
**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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