

# 3+1 Voltage Regulator for IMVP-7/VR12™ CPUs

## ISL95831

Compliant with IMVP-7/VR12™, the ISL95831 provides a complete solution for microprocessor and graphic processor core power supply. It provides two Voltage Regulators (VRs) with three integrated gate drivers. The first VR can be configured as 3-, 2- or 1-phase VR while the second output is 1-phase VR, providing maximum flexibility. The two VRs share the serial control bus to communicate with the CPU and achieve lower cost and smaller board area compared with the two-chip approach.

Based on Intersil's Robust Ripple Regulator (R3) technology™, the PWM modulator compared to traditional modulators, has faster transient settling time, variable switching frequency during load transients and has improved light load efficiency with its ability to automatically change switching frequency.

The ISL95831 has several other key features. Both outputs support DCR current sensing with single NTC thermistor for DCR temperature compensation or accurate resistor current sensing. Both outputs come with remote voltage sense, programmable  $V_{BOOT}$  voltage, programmable  $I_{MAX}$ ,  $T_{MAX}$ , adjustable switching frequency, OC protection and separate Power-Good.

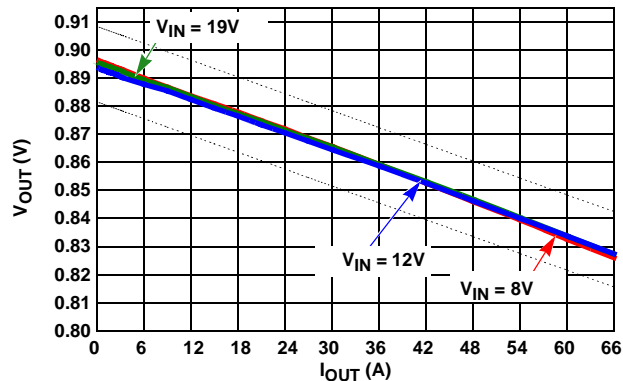
## Features

- Serial Data Bus
- Dual Outputs:
  - Configurable 3-, 2- or 1-phase for the 1st Output using 2 integrated Gate Drivers
  - 1-phase for the 2nd Output using an Integrated Gate Driver
- 0.5% System Accuracy Over-Temperature
- Supports Multiple Current Sensing Methods
  - Lossless Inductor DCR Current Sensing
  - Precision Resistor Current Sensing
- Differential Remote Voltage Sensing
- Programmable  $V_{BOOT}$  Voltage at Start-up
- Resistor Programmable  $I_{MAX}$ ,  $T_{MAX}$  for Both Outputs
- Adaptive Body Diode Conduction Time Reduction

## Applications

- IMVP-7/VR12 Compliant Computers

## Load Line Regulation



## Ordering Information

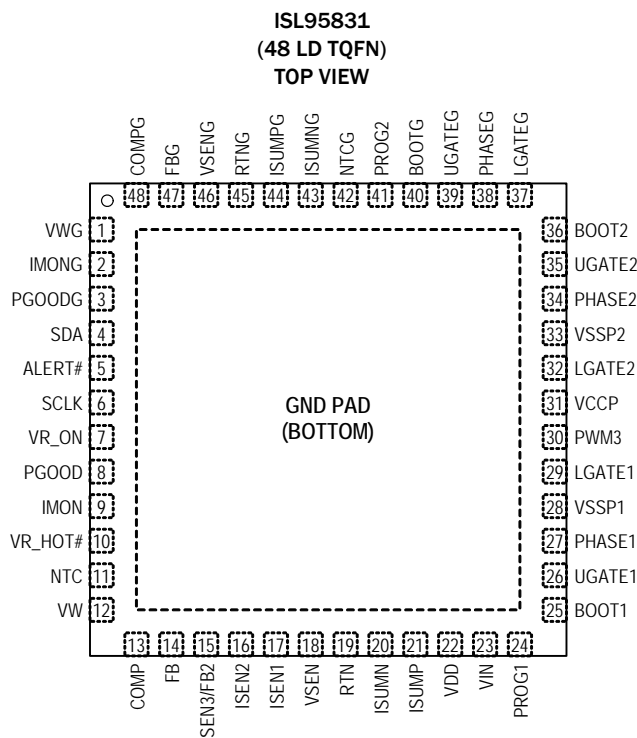
| PART NUMBER<br>(Notes 1, 2, 3) | PART MARKING | TEMP. RANGE<br>(°C) | PACKAGE<br>(Pb-Free) | PKG.<br>DWG. # |
|--------------------------------|--------------|---------------------|----------------------|----------------|
| ISL95831HRTZ                   | 95831 HRTZ   | -10 to +100         | 48 Ld 6x6 TQFN       | L48.6x6        |
| ISL95831IRTZ                   | 95831 IRTZ   | -40 to +100         | 48 Ld 6x6 TQFN       | L48.6x6        |

### NOTES:

1. Add "-T\*" suffix for tape and reel. Please refer to [TB347](#) for details on reel specifications.
2. These Intersil Pb-free plastic packaged products employ special Pb-free material sets, molding compounds/die attach materials, and 100% matte tin plate plus anneal (e3 termination finish, which is RoHS compliant and compatible with both SnPb and Pb-free soldering operations). Intersil Pb-free products are MSL classified at Pb-free peak reflow temperatures that meet or exceed the Pb-free requirements of IPC/JEDEC J STD-020.
3. For Moisture Sensitivity Level (MSL), please see device information page for [ISL95831](#). For more information on MSL please see techbrief [TB363](#).

# ISL95831

## Pin Configuration



## Pin Descriptions

| ISL95831<br>PIN NUMBER | SYMBOL                  | DESCRIPTION  |
|------------------------|-------------------------|--|
| BOTTOM PAD             | GND                     | Signal common of the IC. Unless otherwise stated, signals are referenced to the GND pin. It should also be used as the thermal pad for heat removal.   |
| 1                      | VWG                     | A resistor from this pin to COMPG programs the switching frequency for VR2 (8kΩ gives approximately 300kHz).   |
| 2                      | IMONG                   | An analog output. IMONG outputs a current proportional to VR2 output current.  |
| 3                      | PGOODG                  | Power-Good open-drain output indicating when VR2 is able to supply regulated voltage. Pull up externally with a 680Ω resistor to VCCP or 1.9kΩ to 3.3V.  |
| 4, 5, 6                | SDA,<br>ALERT#,<br>SCLK | Communication bus between the CPU and the VRs.   |
| 7                      | VR_ON                   | Controller enable input. A high level logic signal on this pin enables the controller.   |
| 8                      | PGOOD                   | Power-Good open-drain output indicating when VR1 is able to supply regulated voltage. Pull up externally with a 680Ω resistor to VCCP or 1.9kΩ to 3.3V.  |
| 9                      | IMON                    | An analog output. IMON outputs a current proportional to VR1 output current.   |
| 10                     | VR_HOT#                 | Open drain thermal overload output indicator. Can be considered part of communication bus with CPU.  |
| 11                     | NTC                     | One of the thermistor inputs to VR_HOT# circuit. Use it to monitor VR1 temperature.  |
| 12                     | VW                      | A resistor from this pin to COMP programs the switching frequency for VR1 (8kΩ gives approximately 300kHz).  |
| 13                     | COMP                    | This pin is the output of the error amplifier for VR1.   |
| 14                     | FB                      | This pin is the inverting input of the error amplifier for VR1.  |
| 15                     | ISEN3/FB2               | When the VR1 is configured in 3-phase mode, this pin is ISEN3. ISEN3 is the individual current sensing for VR1 phase 3. When VR1 is configured in 2-phase mode, this pin is FB2. There is a switch between the FB2 pin and the FB pin. The switch is on when VR1 is in 2-phase mode and is off in 1-phase mode. The components connecting to FB2 are used to adjust the compensation in 1-phase mode to achieve optimum performance for VR1. |

## Pin Descriptions (Continued)

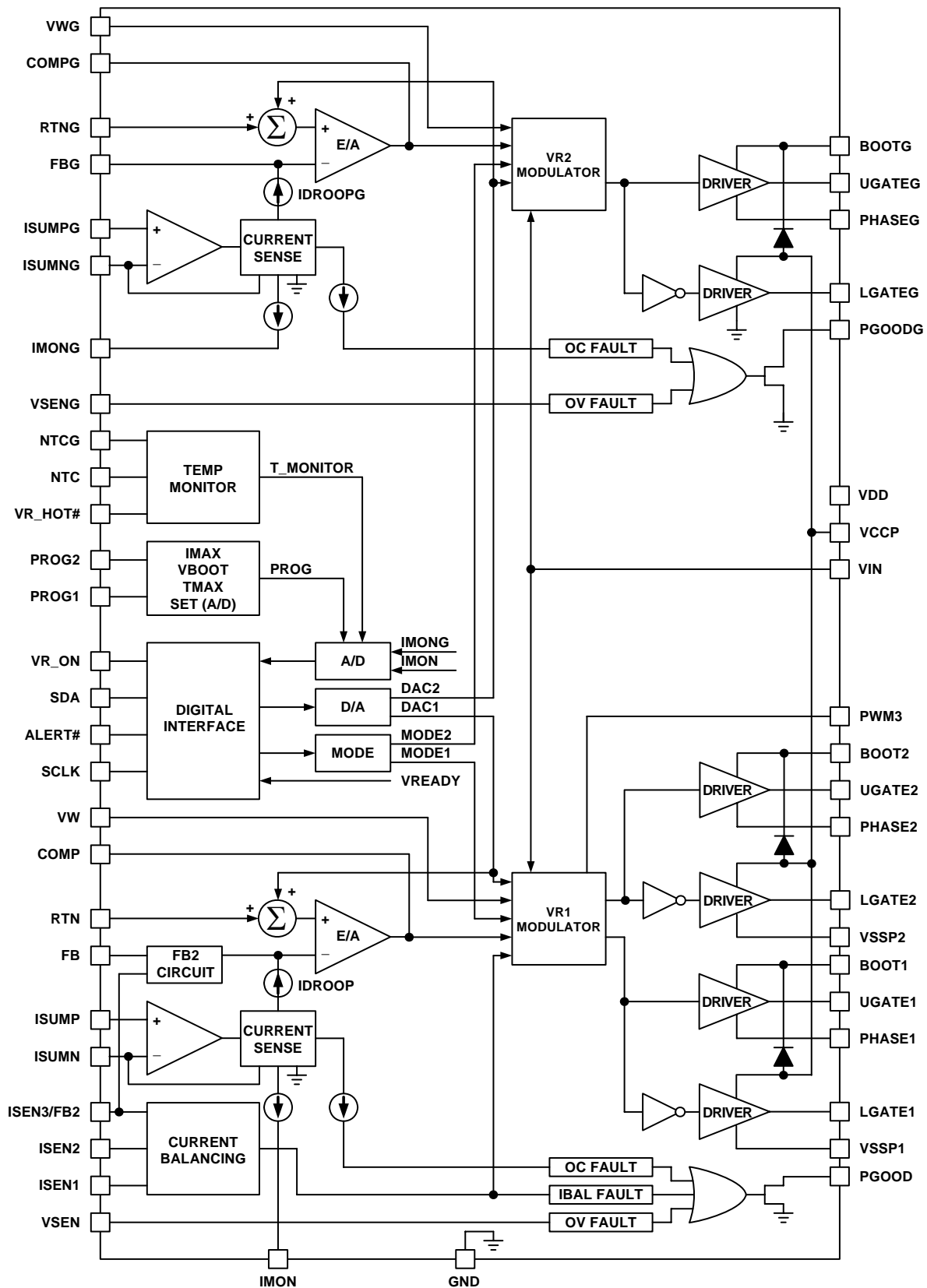
| ISL95831<br>PIN NUMBER | SYMBOL             | DESCRIPTION   |
|------------------------|--------------------|---|
| 16                     | ISEN2              | Individual current sensing for VR1 Phase 2. When ISEN2 and PWM3 are both pulled to 5V VDD, the controller will disable VR1 Phases 3 and 2.  |
| 17                     | ISEN1              | Individual current sensing for VR1 Phase 1.   |
| 18                     | VSEN               | VR1 remote voltage sense input.   |
| 19                     | RTN                | VR1 remote voltage sense return.  |
| 20, 21                 | ISUMN and<br>ISUMP | VR1 droop current sense input.  |
| 22                     | VDD                | 5V bias power.  |
| 23                     | VIN                | This pin is connected to the power stage input voltage and used for feed-forward.   |
| 24                     | PROG1              | A resistor from this pin to GND programs $I_{max}$ for VR1, and $V_{BOOT}$ for both VR1 and VR2.  |
| 25                     | BOOT1              | Connect an MLCC capacitor across the BOOT1 and the PHASE1 pins. The boot capacitor is charged through an internal boot diode connected from the VCCP pin to the BOOT1 pin, each time the PHASE1 pin drops below VCCP minus the voltage dropped across the internal boot diode.  |
| 26                     | UGATE1             | Output of VR1 Phase-1 high-side MOSFET gate driver. Connect the UGATE1 pin to the gate of the Phase-1 high-side MOSFET.   |
| 27                     | PHASE1             | Current return path for the VR1 Phase-1 high-side MOSFET gate driver. Connect the PHASE1 pin to the node consisting of the high-side MOSFET source, the low-side MOSFET drain, and the output inductor of VR1 Phase 1.  |
| 28                     | VSSP1              | Current return path for VR1 Phase-1 low-side MOSFET gate driver. Connect the VSSP1 pin to the source of VR1 Phase-1 low-side MOSFET through a low impedance path, preferably in parallel with the traces connecting the LGATE1 pin to the gates of the Phase-1 low-side MOSFET. |
| 29                     | LGATE1             | Output of VR1 Phase-1 low-side MOSFET gate driver. Connect the LGATE1 pin to the gate of VR1 Phase-1 low-side MOSFET.   |
| 30                     | PWM3               | PWM output for VR1 Phase 3. When PWM3 is pulled to 5V VDD, the controller will disable VR1 Phase 3.   |
| 31                     | VCCP               | Input voltage bias for the internal gate drivers. Connect +5V to the VCCP pin. Decouple with at least 1 $\mu$ F of an MLCC capacitor.   |
| 32                     | LGATE2             | Output of VR1 Phase-2 low-side MOSFET gate driver. Connect the LGATE2 pin to the gate of VR1 Phase-2 low-side MOSFET.   |
| 33                     | VSSP2              | Current return path for VR1 Phase-2 low-side MOSFET gate driver. Connect the VSSP2 pin to the source of VR1 Phase-2 low-side MOSFET through a low impedance path, preferably in parallel with the traces connecting the LGATE2 pin to the gates of the Phase-2 low-side MOSFET. |
| 34                     | PHASE2             | Current return path for VR1 Phase-2 high-side MOSFET gate driver. Connect the PHASE2 pin to the node consisting of the high-side MOSFET source, the low-side MOSFET drain, and the output inductor of VR1 Phase 2.  |
| 35                     | UGATE2             | Output of VR1 Phase-2 high-side MOSFET gate driver. Connect the UGATE2 pin to the gate of VR1 Phase-2 high-side MOSFET.   |
| 36                     | BOOT2              | Connect an MLCC capacitor across the BOOT2 and the PHASE2 pins. The boot capacitor is charged through an internal boot diode connected from the VCCP pin to the BOOT2 pin, each time the PHASE2 pin drops below VCCP minus the voltage dropped across the internal boot diode.  |
| 37                     | LGATEG             | Output of VR2 low-side MOSFET gate driver. Connect the LGATEG pin to the gate of VR2 low-side MOSFET.   |
| 38                     | PHASEG             | Current return path for VR2 high-side MOSFET gate driver. Connect the PHASEG pin to the node consisting of the high-side MOSFET source, the low-side MOSFET drain, and the output inductor of VR2.  |
| 39                     | UGATEG             | Output of VR2 high-side MOSFET gate driver. Connect the UGATEG pin to the gate of VR2 high-side MOSFET.   |
| 40                     | BOOTG              | Connect an MLCC capacitor across the BOOTG and the PHASEG pins. The boot capacitor is charged through an internal boot diode connected from the VCCP pin to the BOOTG pin, each time the PHASEG pin drops below VCCP minus the voltage dropped across the internal boot diode.  |
| 41                     | PROG2              | A resistor from this pin to GND programs $I_{MAX}$ for VR2 and $T_{MAX}$ for both VR1 and VR2.  |
| 42                     | NTCG               | The second thermistor input to VR_HOT# circuit. Use it to monitor VR2 temperature.  |

# ISL95831

## Pin Descriptions (Continued)

| ISL95831<br>PIN NUMBER | SYMBOL               | DESCRIPTION  |
|------------------------|----------------------|--|
| 43, 44                 | ISUMNG and<br>ISUMPG | VR2 droop current sense input. When ISUMNG is pulled to 5V VDD, VR2 is disabled and all communication to VR2 is rejected.          |
| 45                     | RTNG                 | VR2 remote voltage sense return.   |
| 46                     | VSENG                | VR2 remote voltage sense input.  |
| 47                     | FBG                  | This pin is the inverting input of the error amplifier for VR2.  |
| 48                     | COMP                 | This pin is the output of the error amplifier for VR2. Also, a resistor from COMP to GND can program the operational modes of VR2. |

## Block Diagram



## Simplified Application Circuit

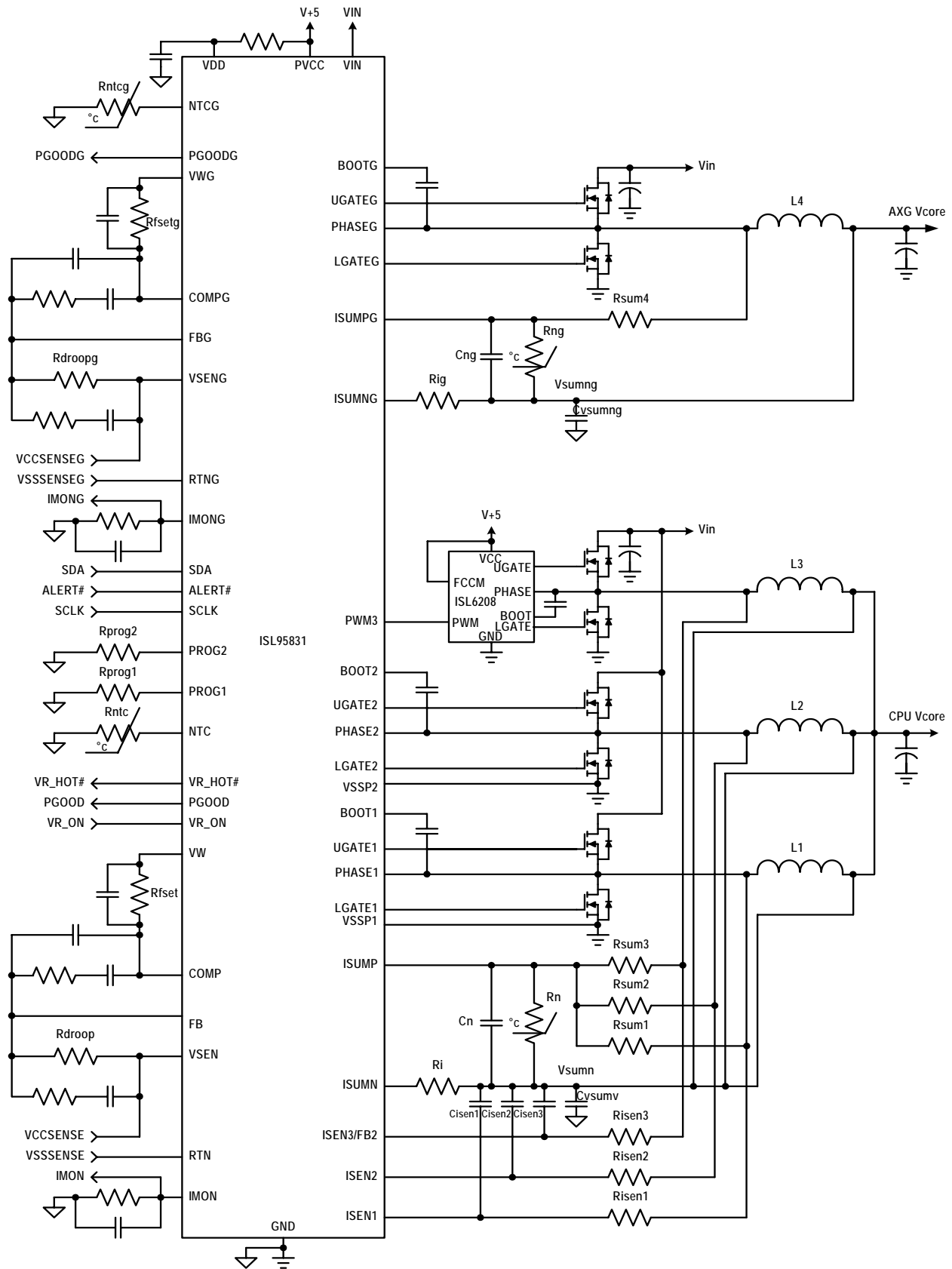


FIGURE 1. TYPICAL ISL95831 APPLICATION CIRCUIT USING INDUCTOR DCR SENSING

# ISL95831

## Simplified Application Circuit

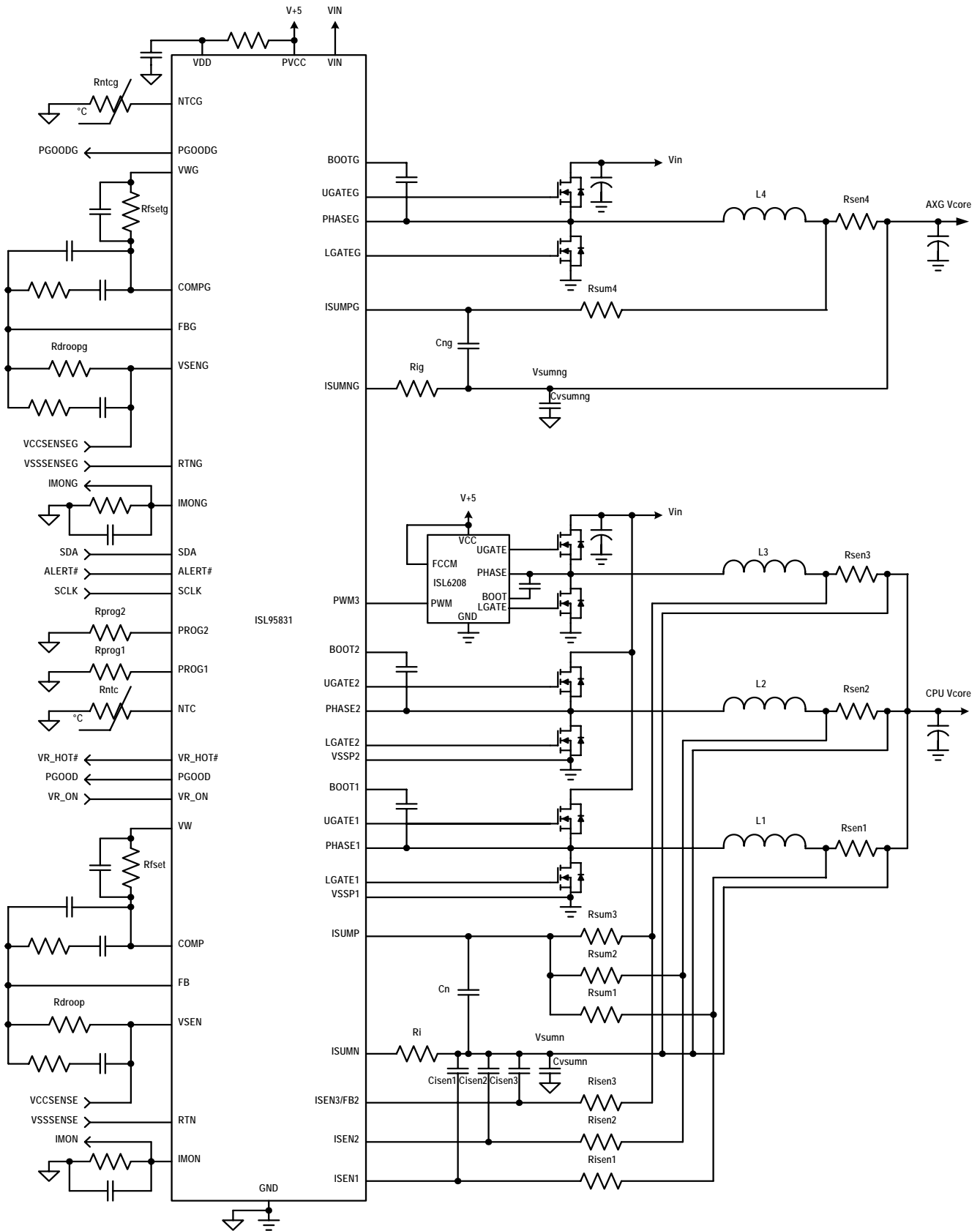


FIGURE 2. TYPICAL ISL95831 APPLICATION CIRCUIT USING RESISTOR SENSING

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## Absolute Maximum Ratings

|  |  |
|--|--|
| Supply Voltage, VDD                                    | -0.3V to +7V                                 |
| Battery Voltage, VIN                                   | +28V   |
| Boot Voltage (BOOT)                                    | -0.3V to +33V                                |
| Boot-to-Phase Voltage<br>(BOOT-PHASE) -0.3V to +7V(DC) | -0.3V to +9V(<10ns)                          |
| Phase Voltage (PHASE)                                  | -7V (<20ns Pulse Width, 10μJ)                |
| UGATE Voltage (UGATE)                                  | PHASE - 0.3V (DC) to BOOT                    |
|  | PHASE - 5V (<20ns Pulse Width, 10μJ) to BOOT |
| LGATE Voltage  | -2.5V (<20ns Pulse Width, 5μJ) to VDD+0.3V   |
| All Other Pins   | -0.3V to (VDD+0.3V)                          |
| Open Drain Outputs, PGOOD, VR_HOT#, ALERT#             | -0.3V to +7V                                 |
| ESD Rating   |  |
| Human Body Model (Tested per JESD22-A114E)             | 2kV  |
| Machine Model (Tested per JESD22-A115-A)               | 200V   |
| Charged Device Model (Tested per JESD22-C101A)         | 1k   |
| Latch Up (Tested per JESD-78B; Class 2, Level A)       | 100mA  |

## Thermal Information

|  |   |                      |
|--|---|----------------------|
| Thermal Resistance (Typical)                   | $\theta_{JA}$ (°C/W)  | $\theta_{JC}$ (°C/W) |
| 48 Ld TQFN Package (Notes 4, 5)                | 29  | 1                    |
| Maximum Junction Temperature                   | +150°C  |                      |
| Maximum Storage Temperature Range              | -65°C to +150°C   |                      |
| Maximum Junction Temperature (Plastic Package) | +150°C  |                      |
| Storage Temperature Range                      | -65°C to +150°C   |                      |
| Pb-Free Reflow Profile                         | see link below  |                      |
|  | <a href="http://www.intersil.com/pbfree/Pb-FreeReflow.asp">http://www.intersil.com/pbfree/Pb-FreeReflow.asp</a> |                      |

## Recommended Operating Conditions

|                      |                 |
|----------------------|-----------------|
| Supply Voltage, VDD  | +5V ±5%         |
| Battery Voltage, VIN | +4.5V to 25V    |
| Ambient Temperature  |                 |
| HRTZ                 | -10°C to +100°C |
| IRTZ                 | -40°C to +100°C |
| Junction Temperature |                 |
| HRTZ                 | -10°C to +125°C |
| IRTZ                 | -40°C to +125°C |

**CAUTION:** Do not operate at or near the maximum ratings listed for extended periods of time. Exposure to such conditions may adversely impact product reliability and result in failures not covered by warranty.

### NOTES:

- $\theta_{JA}$  is measured in free air with the component mounted on a high effective thermal conductivity test board with "direct attach" features. See Tech Brief TB379.
- For  $\theta_{JC}$ , the "case temp" location is the center of the exposed metal pad on the package underside.

**Electrical Specifications** "Operating Conditions: VDD = 5V,  $T_A$  = -40°C to +100°C (ISL95831IRTZ),  $T_A$  = -10°C to +100°C (ISL95831HRTZ), fSW = 300kHz, unless otherwise noted." **Boldface limits apply over the operating temperature ranges, -10°C to +100°C or -40°C to +100°C.**

| PARAMETER                        | SYMBOL                             | TEST CONDITIONS   | MIN (Note 6)  | TYP   | MAX (Note 6)  | UNITS |
|----------------------------------|------------------------------------|---|---------------|-------|---------------|-------|
| <b>INPUT POWER SUPPLY</b>        |                                    |   |               |       |               |       |
| +5V Supply Current               | $I_{VDD}$                          | VR_ON = 1V  |               | 9.2   | <b>10.5</b>   | mA    |
|                                  |                                    | VR_ON = 0V  |               |       | <b>1</b>      | μA    |
| Battery Supply Current           | $I_{VIN}$                          | VR_ON = 0V  |               |       | <b>1</b>      | μA    |
| VIN Input Resistance             | $R_{VIN}$                          | VR_ON = 1V  |               | 550   |               | kΩ    |
| <b>POWER-ON-RESET THRESHOLDS</b> |                                    |   |               |       |               |       |
| VDD Power-On-Reset Threshold     | VDDPOR <sub>r</sub>                | VDD rising  |               | 4.35  | <b>4.5</b>    | V     |
|                                  | VDDPOR <sub>f</sub>                | VDD falling   | <b>4.00</b>   | 4.15  |               | V     |
| VIN Power-On-Reset Threshold     | VINPOR <sub>r</sub>                | VIN rising  |               | 4.00  | <b>4.35</b>   | V     |
|                                  | VINPOR <sub>f</sub>                | VIN falling   | <b>2.8</b>    | 3.3   |               | V     |
| <b>SYSTEM AND REFERENCES</b>     |                                    |   |               |       |               |       |
| System Accuracy                  | HRTZ<br>%Error (V <sub>OUT</sub> ) | No load; closed loop, active mode range,<br>VID = 0.75V to 1.52V, | <b>-0.5</b>   |       | <b>+0.5</b>   | %     |
|                                  |                                    | VID = 0.5V to 0.745V  | <b>-8</b>     |       | <b>+8</b>     | mV    |
|                                  |                                    | VID = 0.25V to 0.495V   | <b>-15</b>    |       | <b>+15</b>    | mV    |
|                                  | IRTZ<br>%Error (V <sub>OUT</sub> ) | No load; closed loop, active mode range,<br>VID = 0.75V to 1.52V  | <b>-0.8</b>   |       | <b>+0.8</b>   | %     |
|                                  |                                    | VID = 0.5V to 0.745V  | <b>-10</b>    |       | <b>+10</b>    | mV    |
|                                  |                                    | VID = 0.25V to 0.495V   | <b>-18</b>    |       | <b>+18</b>    | mV    |
| Internal V <sub>BOOT</sub>       |                                    | HRTZ  | <b>1.0945</b> | 1.100 | <b>1.1055</b> | V     |
|                                  |                                    | IRTZ  | <b>1.0912</b> | 1.100 | <b>1.1088</b> | V     |
| Maximum Output Voltage           | V <sub>OUT(max)</sub>              | VID = [11111111]  |               | 1.52  |               | V     |

# ISL95831

**Electrical Specifications** "Operating Conditions: VDD = 5V, T<sub>A</sub> = -40°C to +100°C (ISL95831IRTZ), T<sub>A</sub> = -10°C to +100°C (ISL95831HRTZ), f<sub>SW</sub> = 300kHz, unless otherwise noted." **Boldface limits apply over the operating temperature ranges, -10°C to +100°C or -40°C to +100°C. (Continued)**

| PARAMETER                                 | SYMBOL                           | TEST CONDITIONS  | MIN<br>(Note 6) | TYP  | MAX<br>(Note 6) | UNITS |
|---|----------------------------------|--|-----------------|------|-----------------|-------|
| Minimum Output Voltage                    | V <sub>OUT(min)</sub>            | VID = [00000001]   |                 | 0.25 |                 | V     |
| <b>CHANNEL FREQUENCY</b>                  |                                  |  |                 |      |                 |       |
| Nominal Channel Frequency-HRTZ            | HRTZ_VR1<br>f <sub>SW(nom)</sub> | R <sub>fset</sub> = 8.66kΩ, 2-channel operation,<br>V <sub>COMP</sub> = 1.1V | <b>285</b>      | 300  | <b>315</b>      | kHz   |
|   | HRTZ_VR2<br>f <sub>SW(nom)</sub> | R <sub>fset</sub> = 9.09kΩ, V <sub>COMP</sub> = 1.1V                         | <b>285</b>      | 300  | <b>315</b>      | kHz   |
| Nominal Channel Frequency-IRTZ            | IRTZ_VR1<br>f <sub>SW(nom)</sub> | R <sub>fset</sub> = 8.66kΩ, 2-channel operation,<br>V <sub>COMP</sub> = 1.1V | <b>280</b>      | 300  | <b>320</b>      | kHz   |
|   | IRTZ_VR2<br>f <sub>SW(nom)</sub> | R <sub>fset</sub> = 9.09kΩ, V <sub>COMP</sub> = 1.1V                         | <b>280</b>      | 300  | <b>320</b>      | kHz   |
| Adjustment Range                          |                                  |  | <b>200</b>      |      | <b>500</b>      | kHz   |
| <b>AMPLIFIERS</b>                         |                                  |  |                 |      |                 |       |
| Current-Sense Amplifier Input Offset      |                                  | I <sub>FB</sub> = 0A   | <b>-0.15</b>    |      | <b>+0.15</b>    | mV    |
| Error Amp DC Gain                         | A <sub>VO</sub>                  |  |                 | 90   |                 | dB    |
| Error Amp Gain-Bandwidth Product          | GBW                              | C <sub>L</sub> = 20pF  |                 | 18   |                 | MHz   |
| <b>ISEN</b>                               |                                  |  |                 |      |                 |       |
| Imbalance Voltage                         |                                  | Maximum of ISENs - Minimum of ISENs  |                 |      | <b>1</b>        | mV    |
| Input Bias Current                        |                                  |  |                 | 20   |                 | nA    |
| <b>POWER-GOOD AND PROTECTION MONITORS</b> |                                  |  |                 |      |                 |       |
| PGOOD Low Voltage                         | V <sub>OL</sub>                  | I <sub>PGOOD</sub> = 4mA   |                 | 0.15 | <b>0.4</b>      | V     |
| PGOOD Leakage Current                     | I <sub>OH</sub>                  | PGOOD = 3.3V   |                 |      | <b>1</b>        | μA    |
| PGOOD Delay                               | tpgd                             |  |                 | 1.2  |                 | ms    |
| ALERT# Low Voltage                        |                                  |  |                 | 7    | <b>12</b>       | Ω     |
| VR_HOT# Low Voltage                       |                                  |  |                 | 7    | <b>12</b>       | Ω     |
| ALERT# Leakage Current                    |                                  |  |                 |      | <b>1</b>        | μA    |
| VR_HOT# Leakage Current                   |                                  |  |                 |      | <b>1</b>        | μA    |
| <b>GATE DRIVER</b>                        |                                  |  |                 |      |                 |       |
| UGATE Pull-Up Resistance                  | R <sub>UGPU</sub>                | 200mA Source Current   |                 | 1.0  | <b>1.5</b>      | Ω     |
| UGATE Source Current                      | I <sub>UGSRC</sub>               | UGATE - PHASE = 2.5V   |                 | 2.0  |                 | A     |
| UGATE Sink Resistance                     | R <sub>UGPD</sub>                | 250mA Sink Current   |                 | 1.0  | <b>1.5</b>      | Ω     |
| UGATE Sink Current                        | I <sub>UGSNK</sub>               | UGATE - PHASE = 2.5V   |                 | 2.0  |                 | A     |
| LGATE Pull-Up Resistance                  | R <sub>LGPU</sub>                | 250mA Source Current   |                 | 1.0  | <b>1.5</b>      | Ω     |
| LGATE Source Current                      | I <sub>LGSR</sub>                | LGATE - VSSP = 2.5V  |                 | 2.0  |                 | A     |
| LGATE Sink Resistance                     | R <sub>LGPD</sub>                | 250mA Sink Current   |                 | 0.5  | <b>0.9</b>      | Ω     |
| LGATE Sink Current                        | I <sub>LGSNK</sub>               | LGATE - VSSP = 2.5V  |                 | 4.0  |                 | A     |
| UGATE to LGATE Deadtime                   | t <sub>UGFLGR</sub>              | UGATE falling to LGATE rising, no load                                       |                 | 23   |                 | ns    |
| LGATE to UGATE Deadtime                   | t <sub>LGFLGR</sub>              | LGATE falling to UGATE rising, no load                                       |                 | 28   |                 | ns    |
| <b>BOOTSTRAP DIODE</b>                    |                                  |  |                 |      |                 |       |
| Forward Voltage                           | V <sub>F</sub>                   | PVCC = 5V, I <sub>F</sub> = 2mA  |                 | 0.58 |                 | V     |
| Reverse Leakage                           | I <sub>R</sub>                   | V <sub>R</sub> = 25V   |                 | 0.2  |                 | μA    |
| <b>PROTECTION</b>                         |                                  |  |                 |      |                 |       |
| Overvoltage Threshold                     | OV <sub>H</sub>                  | VSEN rising above setpoint for >1μs  | <b>120</b>      | 155  | <b>200</b>      | mV    |
| Current Imbalance Threshold               |                                  | One ISEN above another ISEN for >1.2ms                                       |                 | 9    |                 | mV    |

# ISL95831

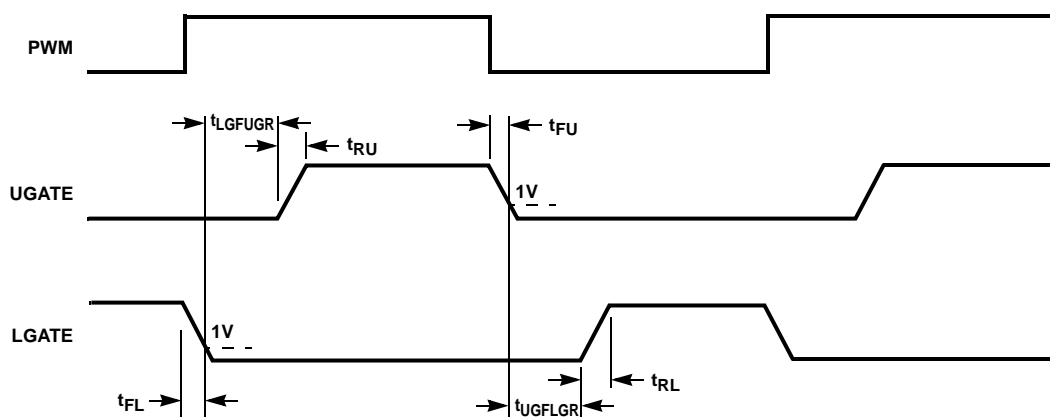
**Electrical Specifications** "Operating Conditions: VDD = 5V, T<sub>A</sub> = -40°C to +100°C (ISL95831IRTZ), T<sub>A</sub> = -10°C to +100°C (ISL95831HRTZ), f<sub>SW</sub> = 300kHz, unless otherwise noted." **Boldface limits apply over the operating temperature ranges, -10°C to +100°C or -40°C to +100°C. (Continued)**

| PARAMETER                                     | SYMBOL             | TEST CONDITIONS                        | MIN<br>(Note 6) | TYP   | MAX<br>(Note 6) | UNITS |
|---|--------------------|--|-----------------|-------|-----------------|-------|
| VR1 Overcurrent Threshold                     |                    | 3-Phase - PS0 and 1-Phase - all states | <b>25.5</b>     | 30.6  | <b>35.5</b>     | μA    |
|   |                    | 3-Phase - PS1, 2-Phase - PS0           | <b>16.75</b>    | 20.6  | <b>24.25</b>    | μA    |
|   |                    | 3-Phase - PS2, 2-Phase - PS1 and PS2   | <b>8.5</b>      | 10.6  | <b>12.75</b>    | μA    |
| VR2 Overcurrent Threshold                     |                    | All states                             | <b>28.5</b>     | 30.6  | <b>33.5</b>     | μA    |
| <b>LOGIC THRESHOLDS</b>                       |                    |  |                 |       |                 |       |
| VR_ON Input Low                               | V <sub>IL</sub>    |  |                 |       | <b>0.3</b>      | V     |
| VR_ON Input High                              | V <sub>IH</sub>    | HRTZ                                   | <b>0.7</b>      |       |                 | V     |
|   | V <sub>IH</sub>    | IRTZ                                   | <b>0.75</b>     |       |                 | V     |
| <b>PWM</b>                                    |                    |  |                 |       |                 |       |
| PWM Output Low                                | V <sub>OL</sub>    | Sinking 5mA                            |                 |       | <b>1.0</b>      | V     |
| PWM Output High                               | V <sub>OH</sub>    | Sourcing 5mA                           | <b>3.5</b>      | 4.2   |                 | V     |
| PWM Tri-State Leakage                         |                    | PWM = 2.5V                             |                 | 2     |                 | μA    |
| <b>THERMAL MONITOR</b>                        |                    |  |                 |       |                 |       |
| NTC Source Current                            |                    | NTC = 1.3V                             | <b>59</b>       | 60    | <b>61</b>       | μA    |
| VR_HOT# Trip Voltage (VR1 and VR2)            |                    | Falling                                | <b>0.86</b>     | 0.873 | <b>0.89</b>     | V     |
| VR_HOT# Reset Voltage (VR1 and VR2)           |                    | Rising                                 | <b>0.905</b>    | 0.929 | <b>0.935</b>    | V     |
| Therm_Alert Trip Voltage (VR1 and VR2)        |                    | Falling                                | <b>0.9</b>      | 0.913 | <b>0.93</b>     | V     |
| Therm_Alert Reset Voltage (VR1 and VR2)       |                    | Rising                                 | <b>0.945</b>    | 0.961 | <b>0.975</b>    | V     |
| <b>CURRENT MONITOR</b>                        |                    |  |                 |       |                 |       |
| IMON Output Current (VR1 and VR2)             |                    | ISUM- pin current = 25μA               | <b>147</b>      | 150   | <b>153</b>      | μA    |
| IMON Current Sinking Capability (VR1 and VR2) |                    |  |                 | 370   |                 | μA    |
| IccMax_Alert Trip Voltage (VR1 and VR2)       |                    | Rising                                 | <b>2.63</b>     | 2.66  | <b>2.69</b>     | V     |
| IccMax_Alert Reset Voltage (VR1 and VR2)      |                    | Falling                                | <b>2.585</b>    | 2.62  | <b>2.655</b>    | V     |
| <b>INPUTS</b>                                 |                    |  |                 |       |                 |       |
| VR_ON Leakage Current                         | I <sub>VR_ON</sub> | VR_ON = 0V                             | <b>-1</b>       | 0     |                 | μA    |
|   |                    | VR_ON = 1V                             |                 | 18    | <b>35</b>       | μA    |
| SCLK, SDA Leakage                             |                    | VR_ON = 0V, SCLK & SDA = 0V & 1V       | <b>-1</b>       |       | <b>1</b>        | μA    |
|   |                    | VR_ON = 1V, SCLK & SDA = 1V            | <b>-5</b>       |       | <b>1</b>        | μA    |
|   |                    | VR_ON = 1V, SCLK & SDA = 0V            | <b>-85</b>      | -60   | <b>-30</b>      | μA    |
| <b>SLEW RATE (For VID Change)</b>             |                    |  |                 |       |                 |       |
| Fast Slew Rate                                |                    |  | <b>10</b>       |       |                 | mV/μs |
| Slow Slew Rate                                |                    |  | <b>2.5</b>      |       |                 | mV/μs |

**NOTES:**

6. Compliance to datasheet limits is assured by one or more methods: production test, characterization and/or design.

## Gate Driver Timing Diagram



## Theory of Operation

### Multiphase R<sup>3</sup>™ Modulator

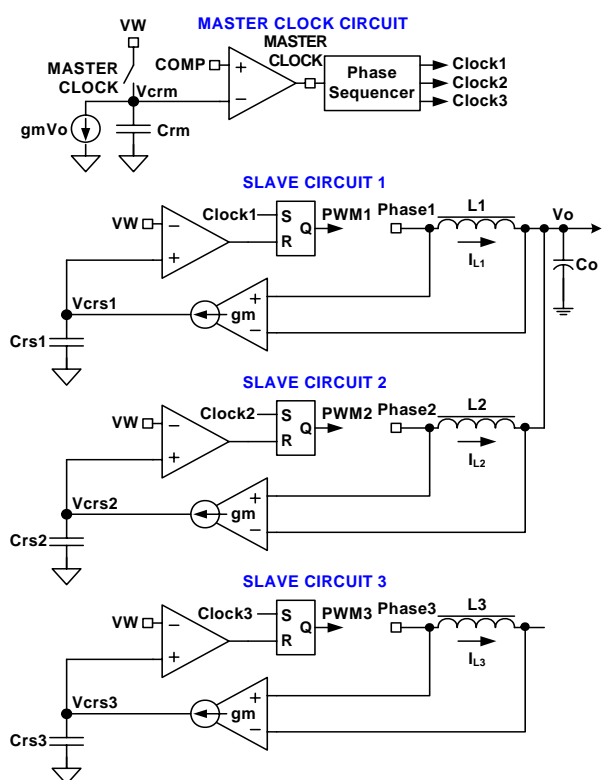


FIGURE 3. R<sup>3</sup>™ MODULATOR CIRCUIT

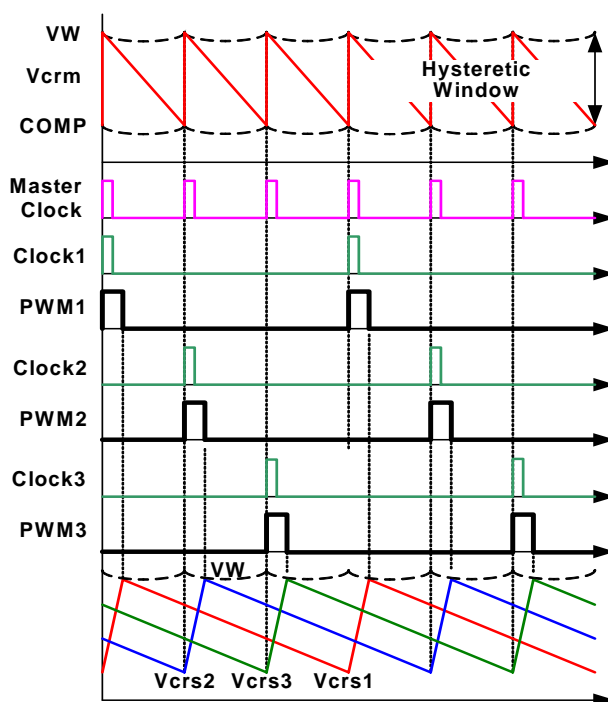


FIGURE 4. R<sup>3</sup>™ MODULATOR OPERATION PRINCIPLES IN STEADY STATE

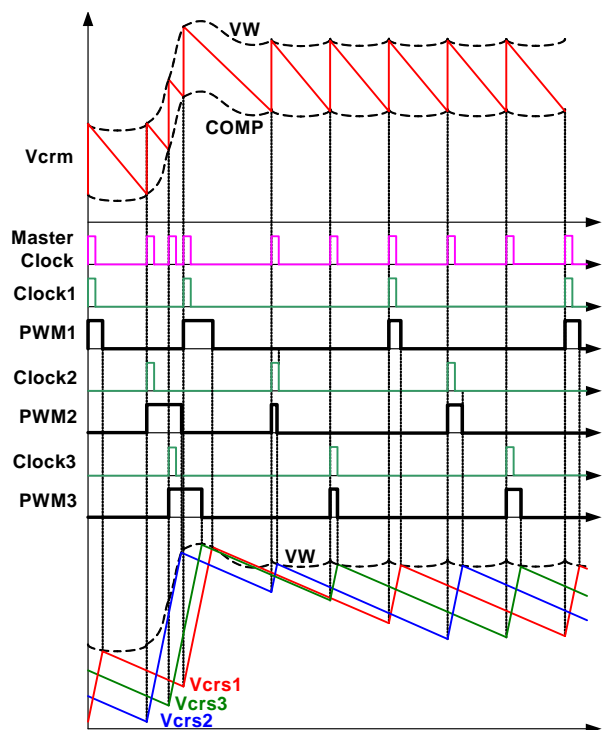


FIGURE 5. R<sup>3</sup>™ MODULATOR OPERATION PRINCIPLES IN LOAD INSERTION RESPONSE

The ISL95831 is a multiphase regulator implementing Intel™ IMVP-7/VR12™ protocol. It has two voltage regulators, VR1 and VR2, on one chip. VR1 can be programmed for 1-, 2- or 3-phase operation, and VR2 is dedicated to 1-phase operation. The following description is based on VR1, but also applies to VR2 because they are based on the same architecture.

The ISL95831 uses Intersil patented R<sup>3</sup>™ (Robust Ripple Regulator™) modulator. The R<sup>3</sup>™ modulator combines the best features of fixed frequency PWM and hysteretic PWM while eliminating many of their shortcomings. Figure 3 conceptually shows the multiphase R<sup>3</sup>™ modulator circuit, and Figure 4 shows the operation principles.

A current source flows from the VW pin to the COMP pin, creating a voltage window set by the resistor between the two pins. This voltage window is called VW window in the following discussion.

Inside the IC, the modulator uses the master clock circuit to generate the clocks for the slave circuits. The modulator discharges the ripple capacitor  $C_{rm}$  with a current source equal to  $g_m V_o$ , where  $g_m$  is a gain factor.  $C_{rm}$  voltage  $V_{crm}$  is a sawtooth waveform traversing between the VW and COMP voltages. It resets to VW when it hits COMP, and generates a one-shot master clock signal. A phase sequencer distributes the master clock signal to the slave circuits. If VR1 is in 3-phase mode, the master clock signal will be distributed to the three phases, and the Clock1~3 signals will be 120° out-of-phase. If VR1 is in 2-phase mode, the master clock signal will be distributed to Phases 1 and 2, and the Clock1 and Clock2 signals will be 180° out-of-phase. If VR1 is in 1-phase mode, the master clock signal will be distributed to Phases 1 only and be the Clock1 signal.

Each slave circuit has its own ripple capacitor  $C_{rs}$ , whose voltage mimics the inductor ripple current. A  $g_m$  amplifier converts the inductor voltage into a current source to charge and discharge  $C_{rs}$ . The slave circuit turns on its PWM pulse upon receiving the clock signal, and the current source charges  $C_{rs}$ . When  $C_{rs}$  voltage  $V_{crs}$  hits VW, the slave circuit turns off the PWM pulse, and the current source discharges  $C_{rs}$ .

Since the controller works with  $V_{crs}$ , which are large-amplitude and noise-free synthesized signals, it achieves lower phase jitter than conventional hysteretic mode and fixed PWM mode controllers. Unlike conventional hysteretic mode converters, the ISL95831 uses an error amplifier that allows the controller to maintain a 0.5% output voltage accuracy.

Figure 5 shows the operation principles during load insertion response. The COMP voltage rises during load insertion, generating the master clock signal more quickly, so the PWM pulses turn on earlier, increasing the effective switching frequency, which allows for higher control loop bandwidth than conventional fixed frequency PWM controllers. The VW voltage rises as the COMP voltage rises, making the PWM pulses wider. During load release response, the COMP voltage falls. It takes the master clock circuit longer to generate the next master clock signal so the PWM pulse is held off until needed. The VW voltage falls as the COMP voltage falls, reducing the current PWM pulse width. This kind of behavior gives the controller excellent response speed.

The fact that all the phases share the same VW window voltage also ensures excellent dynamic current balance among phases.

## Diode Emulation and Period Stretching

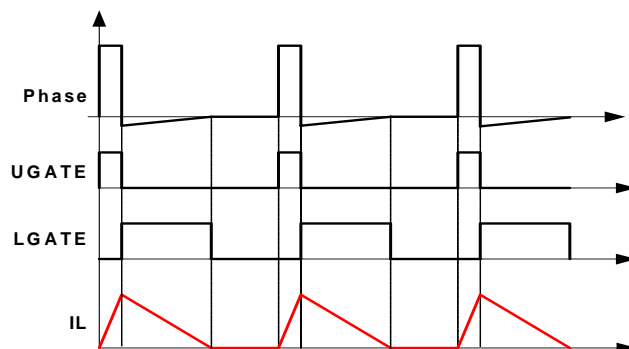


FIGURE 6. DIODE EMULATION

ISL95831 can operate in diode emulation (DE) mode to improve light load efficiency. In DE mode, the low-side MOSFET conducts when the current is flowing from source to drain and doesn't allow reverse current, emulating a diode. As Figure 6 shows, when LGATE is on, the low-side MOSFET carries current, creating negative voltage on the phase node due to the voltage drop across the ON-resistance. The controller monitors the current through monitoring the phase node voltage. It turns off LGATE when the phase node voltage reaches zero to prevent the inductor current from reversing the direction and creating unnecessary power loss.

If the load current is light enough, as Figure 6 shows, the inductor current will reach and stay at zero before the next phase node pulse and the regulator is in discontinuous conduction mode (DCM). If the load current is heavy enough, the inductor current

will never reach 0A, and the regulator is in CCM although the controller is in DE mode.

Figure 7 shows the operation principle in diode emulation mode at light load. The load gets incrementally lighter in the three cases from top to bottom. The PWM on-time is determined by the VW window size, therefore is the same, making the inductor current triangle the same in the three cases. The controller clamps the ripple capacitor voltage  $V_{crs}$  in DE mode to make it mimic the inductor current. It takes the COMP voltage longer to hit  $V_{crs}$ , naturally stretching the switching period. The inductor current triangles move further apart from each other such that the inductor current average value is equal to the load current. The reduced switching frequency helps increase light load efficiency.

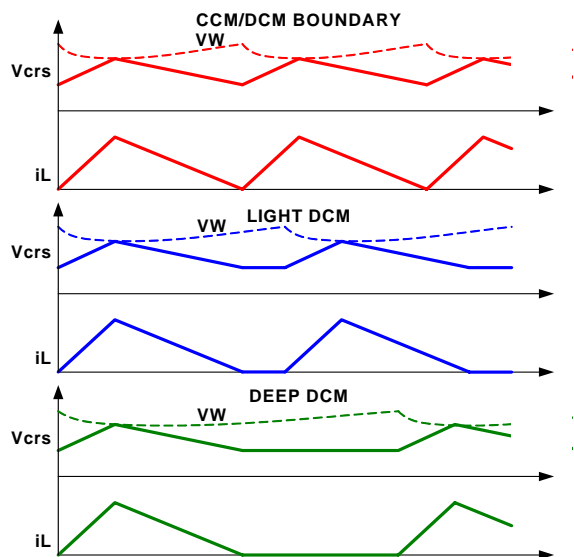


FIGURE 7. PERIOD STRETCHING

## Start-up Timing

With the controller's  $V_{DD}$  voltage above the POR threshold, the start-up sequence begins when  $VR_{ON}$  exceeds the logic high threshold. Figure 8 shows the typical start-up timing of  $VR1$  and  $VR2$ . The controller uses digital soft-start to ramp-up DAC to the voltage programmed by the SetVID command. PGOOD is asserted high and ALERT# is asserted low at the end of the ramp up. Similar results occur if  $VR_{ON}$  is tied to  $V_{DD}$ , with the soft-start sequence starting 800 $\mu$ s after  $V_{DD}$  crosses the POR threshold.

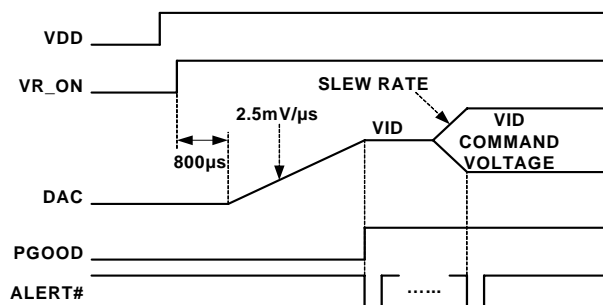


FIGURE 8. VR1 SOFT-START WAVEFORMS

## Voltage Regulation and Load Line Implementation

After the start sequence, the controller regulates the output voltage to the value set by the VID information per Table 1. The controller will control the no-load output voltage to an accuracy of  $\pm 0.5\%$  over the range of 0.75V to 1.52V. A differential amplifier allows voltage sensing for precise voltage regulation at the microprocessor die.

TABLE 1. VID TABLE

| VID |   |   |   |   |   |   |   | Hex | $V_O$ (V) |         |
|-----|---|---|---|---|---|---|---|-----|-----------|---------|
| 7   | 6 | 5 | 4 | 3 | 2 | 1 | 0 |     |           |         |
| 0   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0   | 0         | 0.00000 |
| 0   | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0   | 1         | 0.25000 |
| 0   | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0   | 2         | 0.25500 |
| 0   | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0   | 3         | 0.26000 |
| 0   | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0   | 4         | 0.26500 |
| 0   | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0   | 5         | 0.27000 |
| 0   | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0   | 6         | 0.27500 |
| 0   | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0   | 7         | 0.28000 |
| 0   | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0   | 8         | 0.28500 |
| 0   | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0   | 9         | 0.29000 |
| 0   | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0   | A         | 0.29500 |
| 0   | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0   | B         | 0.30000 |
| 0   | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0   | C         | 0.30500 |
| 0   | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0   | D         | 0.31000 |
| 0   | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0   | E         | 0.31500 |
| 0   | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0   | F         | 0.32000 |
| 0   | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1   | 0         | 0.32500 |
| 0   | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1   | 1         | 0.33000 |
| 0   | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1   | 2         | 0.33500 |
| 0   | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1   | 3         | 0.34000 |
| 0   | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1   | 4         | 0.34500 |
| 0   | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1   | 5         | 0.35000 |
| 0   | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1   | 6         | 0.35500 |
| 0   | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1   | 7         | 0.36000 |
| 0   | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1   | 8         | 0.36500 |
| 0   | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1   | 9         | 0.37000 |
| 0   | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1   | A         | 0.37500 |
| 0   | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1   | B         | 0.38000 |
| 0   | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1   | C         | 0.38500 |
| 0   | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1   | D         | 0.39000 |
| 0   | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1   | E         | 0.39500 |
| 0   | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1   | F         | 0.40000 |

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TABLE 1. VID TABLE (Continued)

| VID |   |   |   |   |   |   |   | Hex | V <sub>O</sub> (V) |
|-----|---|---|---|---|---|---|---|-----|--------------------|
| 7   | 6 | 5 | 4 | 3 | 2 | 1 | 0 |     |                    |
| 0   | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 0 | 0.40500            |
| 0   | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 1 | 0.41000            |
| 0   | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 2 2 | 0.41500            |
| 0   | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 2 3 | 0.42000            |
| 0   | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 4 | 0.42500            |
| 0   | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 2 5 | 0.43000            |
| 0   | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 2 6 | 0.43500            |
| 0   | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 2 7 | 0.44000            |
| 0   | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 2 8 | 0.44500            |
| 0   | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 2 9 | 0.45000            |
| 0   | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 2 A | 0.45500            |
| 0   | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 2 B | 0.46000            |
| 0   | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 2 C | 0.46500            |
| 0   | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 2 D | 0.47000            |
| 0   | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 2 E | 0.47500            |
| 0   | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 2 F | 0.48000            |
| 0   | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 3 0 | 0.48500            |
| 0   | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 3 1 | 0.49000            |
| 0   | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 3 2 | 0.49500            |
| 0   | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 3 3 | 0.50000            |
| 0   | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 3 4 | 0.50500            |
| 0   | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 3 5 | 0.51000            |
| 0   | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 3 6 | 0.51500            |
| 0   | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 3 7 | 0.52000            |
| 0   | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 3 8 | 0.52500            |
| 0   | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 3 9 | 0.53000            |
| 0   | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 3 A | 0.53500            |
| 0   | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 3 B | 0.54000            |
| 0   | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 3 C | 0.54500            |
| 0   | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 3 D | 0.55000            |
| 0   | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 3 E | 0.55500            |
| 0   | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 3 F | 0.56000            |
| 0   | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 4 0 | 0.56500            |
| 0   | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 4 1 | 0.57000            |
| 0   | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 4 2 | 0.57500            |
| 0   | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 4 3 | 0.58000            |
| 0   | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 4 4 | 0.58500            |
| 0   | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 4 5 | 0.59000            |
| 0   | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 4 6 | 0.59500            |

TABLE 1. VID TABLE (Continued)

| VID |   |   |   |   |   |   |   | Hex | V <sub>O</sub> (V) |
|-----|---|---|---|---|---|---|---|-----|--------------------|
| 7   | 6 | 5 | 4 | 3 | 2 | 1 | 0 |     |                    |
| 0   | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 4 7 | 0.60000            |
| 0   | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 4 8 | 0.60500            |
| 0   | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 4 9 | 0.61000            |
| 0   | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 4 A | 0.61500            |
| 0   | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 4 B | 0.62000            |
| 0   | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 4 C | 0.62500            |
| 0   | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 4 D | 0.63000            |
| 0   | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 4 E | 0.63500            |
| 0   | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 4 F | 0.64000            |
| 0   | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 5 0 | 0.64500            |
| 0   | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 5 1 | 0.65000            |
| 0   | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 5 2 | 0.65500            |
| 0   | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 5 3 | 0.66000            |
| 0   | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 5 4 | 0.66500            |
| 0   | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 5 5 | 0.67000            |
| 0   | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 5 6 | 0.67500            |
| 0   | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 5 7 | 0.68000            |
| 0   | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 5 8 | 0.68500            |
| 0   | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 5 9 | 0.69000            |
| 0   | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 5 A | 0.69500            |
| 0   | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 5 B | 0.70000            |
| 0   | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 5 C | 0.70500            |
| 0   | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 5 D | 0.71000            |
| 0   | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 5 E | 0.71500            |
| 0   | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 5 F | 0.72000            |
| 0   | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 6 0 | 0.72500            |
| 0   | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 6 1 | 0.73000            |
| 0   | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 6 2 | 0.73500            |
| 0   | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 6 3 | 0.74000            |
| 0   | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 6 4 | 0.74500            |
| 0   | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 6 5 | 0.75000            |
| 0   | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 6 6 | 0.75500            |
| 0   | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 6 7 | 0.76000            |
| 0   | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 6 8 | 0.76500            |
| 0   | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 6 9 | 0.77000            |
| 0   | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 6 A | 0.77500            |
| 0   | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 6 B | 0.78000            |
| 0   | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 6 C | 0.78500            |
| 0   | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 6 D | 0.79000            |

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TABLE 1. VID TABLE (Continued)

| VID |   |   |   |   |   |   |   | Hex | V <sub>O</sub> (V) |         |
|-----|---|---|---|---|---|---|---|-----|--------------------|---------|
| 7   | 6 | 5 | 4 | 3 | 2 | 1 | 0 |     |                    |         |
| 0   | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 6   | E                  | 0.79500 |
| 0   | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 6   | F                  | 0.80000 |
| 0   | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 7   | 0                  | 0.80500 |
| 0   | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 7   | 1                  | 0.81000 |
| 0   | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 7   | 2                  | 0.81500 |
| 0   | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 7   | 3                  | 0.82000 |
| 0   | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 7   | 4                  | 0.82500 |
| 0   | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 7   | 5                  | 0.83000 |
| 0   | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 7   | 6                  | 0.83500 |
| 0   | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 7   | 7                  | 0.84000 |
| 0   | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 7   | 8                  | 0.84500 |
| 0   | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 7   | 9                  | 0.85000 |
| 0   | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 7   | A                  | 0.85500 |
| 0   | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 7   | B                  | 0.86000 |
| 0   | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 7   | C                  | 0.86500 |
| 0   | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 7   | D                  | 0.87000 |
| 0   | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 7   | E                  | 0.87500 |
| 0   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7   | F                  | 0.88000 |
| 1   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8   | 0                  | 0.88500 |
| 1   | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 8   | 1                  | 0.89000 |
| 1   | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 8   | 2                  | 0.89500 |
| 1   | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 8   | 3                  | 0.90000 |
| 1   | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 8   | 4                  | 0.90500 |
| 1   | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 8   | 5                  | 0.91000 |
| 1   | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 8   | 6                  | 0.91500 |
| 1   | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 8   | 7                  | 0.92000 |
| 1   | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 8   | 8                  | 0.92500 |
| 1   | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 8   | 9                  | 0.93000 |
| 1   | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 8   | A                  | 0.93500 |
| 1   | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 8   | B                  | 0.94000 |
| 1   | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 8   | C                  | 0.94500 |
| 1   | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 8   | D                  | 0.95000 |
| 1   | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 8   | E                  | 0.95500 |
| 1   | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 8   | F                  | 0.96000 |
| 1   | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 9   | 0                  | 0.96500 |
| 1   | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 9   | 1                  | 0.97000 |
| 1   | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 9   | 2                  | 0.97500 |
| 1   | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 9   | 3                  | 0.98000 |
| 1   | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 9   | 4                  | 0.98500 |

TABLE 1. VID TABLE (Continued)

| VID |   |   |   |   |   |   |   | Hex | V <sub>O</sub> (V) |         |
|-----|---|---|---|---|---|---|---|-----|--------------------|---------|
| 7   | 6 | 5 | 4 | 3 | 2 | 1 | 0 |     |                    |         |
| 1   | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 9   | 5                  | 0.99000 |
| 1   | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 9   | 6                  | 0.99500 |
| 1   | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 9   | 7                  | 1.00000 |
| 1   | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 9   | 8                  | 1.00500 |
| 1   | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 9   | 9                  | 1.01000 |
| 1   | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 9   | A                  | 1.01500 |
| 1   | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 9   | B                  | 1.02000 |
| 1   | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 9   | C                  | 1.02500 |
| 1   | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 9   | D                  | 1.03000 |
| 1   | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 9   | E                  | 1.03500 |
| 1   | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 9   | F                  | 1.04000 |
| 1   | 0 | 1 | 0 | 0 | 0 | 0 | 0 | A   | 0                  | 1.04500 |
| 1   | 0 | 1 | 0 | 0 | 0 | 0 | 1 | A   | 1                  | 1.05000 |
| 1   | 0 | 1 | 0 | 0 | 0 | 1 | 0 | A   | 2                  | 1.05500 |
| 1   | 0 | 1 | 0 | 0 | 0 | 1 | 1 | A   | 3                  | 1.06000 |
| 1   | 0 | 1 | 0 | 0 | 1 | 0 | 0 | A   | 4                  | 1.06500 |
| 1   | 0 | 1 | 0 | 0 | 1 | 0 | 1 | A   | 5                  | 1.07000 |
| 1   | 0 | 1 | 0 | 0 | 1 | 1 | 0 | A   | 6                  | 1.07500 |
| 1   | 0 | 1 | 0 | 0 | 1 | 1 | 1 | A   | 7                  | 1.08000 |
| 1   | 0 | 1 | 0 | 1 | 0 | 0 | 0 | A   | 8                  | 1.08500 |
| 1   | 0 | 1 | 0 | 1 | 0 | 0 | 1 | A   | 9                  | 1.09000 |
| 1   | 0 | 1 | 0 | 1 | 0 | 1 | 0 | A   | A                  | 1.09500 |
| 1   | 0 | 1 | 0 | 1 | 0 | 1 | 1 | A   | B                  | 1.10000 |
| 1   | 0 | 1 | 0 | 1 | 1 | 0 | 0 | A   | C                  | 1.10500 |
| 1   | 0 | 1 | 0 | 1 | 1 | 0 | 1 | A   | D                  | 1.11000 |
| 1   | 0 | 1 | 0 | 1 | 1 | 1 | 0 | A   | E                  | 1.11500 |
| 1   | 0 | 1 | 0 | 1 | 1 | 1 | 1 | A   | F                  | 1.12000 |
| 1   | 0 | 1 | 1 | 0 | 0 | 0 | 0 | B   | 0                  | 1.12500 |
| 1   | 0 | 1 | 1 | 0 | 0 | 0 | 1 | B   | 1                  | 1.13000 |
| 1   | 0 | 1 | 1 | 0 | 0 | 1 | 0 | B   | 2                  | 1.13500 |
| 1   | 0 | 1 | 1 | 0 | 0 | 1 | 1 | B   | 3                  | 1.14000 |
| 1   | 0 | 1 | 1 | 0 | 1 | 0 | 0 | B   | 4                  | 1.14500 |
| 1   | 0 | 1 | 1 | 0 | 1 | 0 | 1 | B   | 5                  | 1.15000 |
| 1   | 0 | 1 | 1 | 0 | 1 | 1 | 0 | B   | 6                  | 1.15500 |
| 1   | 0 | 1 | 1 | 0 | 1 | 1 | 1 | B   | 7                  | 1.16000 |
| 1   | 0 | 1 | 1 | 1 | 0 | 0 | 0 | B   | 8                  | 1.16500 |
| 1   | 0 | 1 | 1 | 1 | 0 | 0 | 1 | B   | 9                  | 1.17000 |
| 1   | 0 | 1 | 1 | 1 | 0 | 1 | 0 | B   | A                  | 1.17500 |
| 1   | 0 | 1 | 1 | 1 | 0 | 1 | 1 | B   | B                  | 1.18000 |



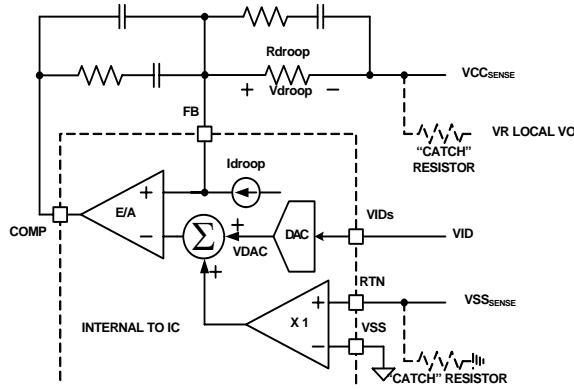
# ISL95831

TABLE 1. VID TABLE (Continued)

| VID |   |   |   |   |   |   |   | Hex |   | V <sub>O</sub> (V) |
|-----|---|---|---|---|---|---|---|-----|---|--------------------|
| 7   | 6 | 5 | 4 | 3 | 2 | 1 | 0 |     |   |                    |
| 1   | 0 | 1 | 1 | 1 | 1 | 0 | 0 | B   | C | 1.18500            |
| 1   | 0 | 1 | 1 | 1 | 1 | 0 | 1 | B   | D | 1.19000            |
| 1   | 0 | 1 | 1 | 1 | 1 | 1 | 0 | B   | E | 1.19500            |
| 1   | 0 | 1 | 1 | 1 | 1 | 1 | 1 | B   | F | 1.20000            |
| 1   | 1 | 0 | 0 | 0 | 0 | 0 | 0 | C   | 0 | 1.20500            |
| 1   | 1 | 0 | 0 | 0 | 0 | 0 | 1 | C   | 1 | 1.21000            |
| 1   | 1 | 0 | 0 | 0 | 0 | 1 | 0 | C   | 2 | 1.21500            |
| 1   | 1 | 0 | 0 | 0 | 0 | 1 | 1 | C   | 3 | 1.22000            |
| 1   | 1 | 0 | 0 | 0 | 1 | 0 | 0 | C   | 4 | 1.22500            |
| 1   | 1 | 0 | 0 | 0 | 1 | 0 | 1 | C   | 5 | 1.23000            |
| 1   | 1 | 0 | 0 | 0 | 1 | 1 | 0 | C   | 6 | 1.23500            |
| 1   | 1 | 0 | 0 | 0 | 1 | 1 | 1 | C   | 7 | 1.24000            |
| 1   | 1 | 0 | 0 | 1 | 0 | 0 | 0 | C   | 8 | 1.24500            |
| 1   | 1 | 0 | 0 | 1 | 0 | 0 | 1 | C   | 9 | 1.25000            |
| 1   | 1 | 0 | 0 | 1 | 0 | 1 | 0 | C   | A | 1.25500            |
| 1   | 1 | 0 | 0 | 1 | 0 | 1 | 1 | C   | B | 1.26000            |
| 1   | 1 | 0 | 0 | 1 | 1 | 0 | 0 | C   | C | 1.26500            |
| 1   | 1 | 0 | 0 | 1 | 1 | 0 | 1 | C   | D | 1.27000            |
| 1   | 1 | 0 | 0 | 1 | 1 | 1 | 0 | C   | E | 1.27500            |
| 1   | 1 | 0 | 0 | 1 | 1 | 1 | 1 | C   | F | 1.28000            |
| 1   | 1 | 0 | 1 | 0 | 0 | 0 | 0 | D   | 0 | 1.28500            |
| 1   | 1 | 0 | 1 | 0 | 0 | 0 | 1 | D   | 1 | 1.29000            |
| 1   | 1 | 0 | 1 | 0 | 0 | 1 | 0 | D   | 2 | 1.29500            |
| 1   | 1 | 0 | 1 | 0 | 0 | 1 | 1 | D   | 3 | 1.30000            |
| 1   | 1 | 0 | 1 | 0 | 1 | 0 | 0 | D   | 4 | 1.30500            |
| 1   | 1 | 0 | 1 | 0 | 1 | 0 | 1 | D   | 5 | 1.31000            |
| 1   | 1 | 0 | 1 | 0 | 1 | 1 | 0 | D   | 6 | 1.31500            |
| 1   | 1 | 0 | 1 | 0 | 1 | 1 | 1 | D   | 7 | 1.32000            |
| 1   | 1 | 0 | 1 | 1 | 0 | 0 | 0 | D   | 8 | 1.32500            |
| 1   | 1 | 0 | 1 | 1 | 0 | 0 | 1 | D   | 9 | 1.33000            |
| 1   | 1 | 0 | 1 | 1 | 0 | 1 | 0 | D   | A | 1.33500            |
| 1   | 1 | 0 | 1 | 1 | 0 | 1 | 1 | D   | B | 1.34000            |
| 1   | 1 | 0 | 1 | 1 | 1 | 0 | 0 | D   | C | 1.34500            |
| 1   | 1 | 0 | 1 | 1 | 1 | 0 | 1 | D   | D | 1.35000            |
| 1   | 1 | 0 | 1 | 1 | 1 | 1 | 0 | D   | E | 1.35500            |
| 1   | 1 | 0 | 1 | 1 | 1 | 1 | 1 | D   | F | 1.36000            |
| 1   | 1 | 1 | 0 | 0 | 0 | 0 | 0 | E   | 0 | 1.36500            |
| 1   | 1 | 1 | 0 | 0 | 0 | 0 | 1 | E   | 1 | 1.37000            |
| 1   | 1 | 1 | 0 | 0 | 0 | 1 | 0 | E   | 2 | 1.37500            |

TABLE 1. VID TABLE (Continued)

| VID |   |   |   |   |   |   |   | Hex |   | V <sub>O</sub> (V) |
|-----|---|---|---|---|---|---|---|-----|---|--------------------|
| 7   | 6 | 5 | 4 | 3 | 2 | 1 | 0 |     |   |                    |
| 1   | 1 | 1 | 0 | 0 | 0 | 1 | 1 | E   | 3 | 1.38000            |
| 1   | 1 | 1 | 0 | 0 | 1 | 0 | 0 | E   | 4 | 1.38500            |
| 1   | 1 | 1 | 0 | 0 | 1 | 0 | 1 | E   | 5 | 1.39000            |
| 1   | 1 | 1 | 0 | 0 | 1 | 1 | 0 | E   | 6 | 1.39500            |
| 1   | 1 | 1 | 0 | 0 | 1 | 1 | 1 | E   | 7 | 1.40000            |
| 1   | 1 | 1 | 0 | 1 | 0 | 0 | 0 | E   | 8 | 1.40500            |
| 1   | 1 | 1 | 0 | 1 | 0 | 0 | 1 | E   | 9 | 1.41000            |
| 1   | 1 | 1 | 0 | 1 | 0 | 1 | 0 | E   | A | 1.41500            |
| 1   | 1 | 1 | 0 | 1 | 0 | 1 | 1 | E   | B | 1.42000            |
| 1   | 1 | 1 | 0 | 1 | 1 | 0 | 0 | E   | C | 1.42500            |
| 1   | 1 | 1 | 0 | 1 | 1 | 0 | 1 | E   | D | 1.43000            |
| 1   | 1 | 1 | 0 | 1 | 1 | 1 | 0 | E   | E | 1.43500            |
| 1   | 1 | 1 | 0 | 1 | 1 | 1 | 1 | E   | F | 1.44000            |
| 1   | 1 | 1 | 1 | 0 | 0 | 0 | 0 | F   | 0 | 1.44500            |
| 1   | 1 | 1 | 1 | 0 | 0 | 0 | 1 | F   | 1 | 1.45000            |
| 1   | 1 | 1 | 1 | 0 | 0 | 1 | 0 | F   | 2 | 1.45500            |
| 1   | 1 | 1 | 1 | 0 | 0 | 1 | 1 | F   | 3 | 1.46000            |
| 1   | 1 | 1 | 1 | 0 | 1 | 0 | 0 | F   | 4 | 1.46500            |
| 1   | 1 | 1 | 1 | 0 | 1 | 0 | 1 | F   | 5 | 1.47000            |
| 1   | 1 | 1 | 1 | 0 | 1 | 1 | 0 | F   | 6 | 1.47500            |
| 1   | 1 | 1 | 1 | 0 | 1 | 1 | 1 | F   | 7 | 1.48000            |
| 1   | 1 | 1 | 1 | 1 | 0 | 0 | 0 | F   | 8 | 1.48500            |
| 1   | 1 | 1 | 1 | 1 | 0 | 0 | 1 | F   | 9 | 1.49000            |
| 1   | 1 | 1 | 1 | 1 | 1 | 0 | 0 | F   | A | 1.49500            |
| 1   | 1 | 1 | 1 | 1 | 1 | 0 | 1 | F   | B | 1.50000            |
| 1   | 1 | 1 | 1 | 1 | 1 | 0 | 0 | F   | C | 1.50500            |
| 1   | 1 | 1 | 1 | 1 | 1 | 0 | 1 | F   | D | 1.51000            |
| 1   | 1 | 1 | 1 | 1 | 1 | 1 | 0 | F   | E | 1.51500            |
| 1   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | F   | F | 1.52000            |



**FIGURE 9. DIFFERENTIAL SENSING AND LOAD LINE IMPLEMENTATION**

As the load current increases from zero, the output voltage will droop from the VID table value by an amount proportional to the load current to achieve the load line. The controller can sense the inductor current through the intrinsic DC Resistance (DCR) of the inductors (as shown in Figure 1) or through resistors in series with the inductors (as shown in Figure 2). In both methods, capacitor  $C_n$  voltage represents the inductor total currents. A droop amplifier converts  $C_n$  voltage into an internal current source with the gain set by resistor  $R_i$ . The current source is used for load line implementation, current monitor and overcurrent protection.

Figure 9 shows the load line implementation. The controller drives a current source  $I_{droop}$  out of the FB pin, described by Equation 1.

$$I_{droop} = \frac{2 \times V_{Cn}}{R_i} \quad (\text{EQ. 1})$$

When using inductor DCR current sensing, a single NTC element is used to compensate the positive temperature coefficient of the copper winding thus sustaining the load line accuracy with reduced cost.

$I_{droop}$  flows through resistor  $R_{droop}$  and creates a voltage drop, as shown in Equation 2.

$$V_{droop} = R_{droop} \times I_{droop} \quad (\text{EQ. 2})$$

$V_{droop}$  is the droop voltage required to implement load line. Changing  $R_{droop}$  or scaling  $I_{droop}$  can both change the load line slope. Since  $I_{droop}$  also sets the overcurrent protection level, it is recommended to first scale  $I_{droop}$  based on OCP requirement, then select an appropriate  $R_{droop}$  value to obtain the desired load line slope.

## Differential Voltage Sensing

Figure 9 also shows the differential voltage sensing scheme.  $V_{CCSENSE}$  and  $V_{SSSENSE}$  are the remote voltage sensing signals from the processor die. A unity gain differential amplifier senses the  $V_{SSSENSE}$  voltage and adds it to the DAC output. The error amplifier regulates the inverting and the non-inverting input voltages to be equal, as shown in Equation 3:

Rewriting Equation 3 and substitution of Equation 2 gives:

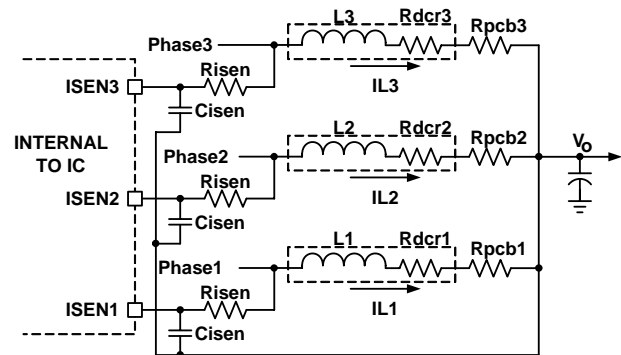
$$V_{CCSENSE} + V_{droop} = V_{DAC} + V_{SSSENSE} \quad (\text{EQ. 3})$$

$$V_{CCSENSE} - V_{SSSENSE} = V_{DAC} - R_{droop} \times I_{droop} \quad (\text{EQ. 4})$$

Equation 4 is the exact equation required for load line implementation.

The  $V_{CCSENSE}$  and  $V_{SSSENSE}$  signals come from the processor die. The feedback will be open circuit in the absence of the processor. As Figure 9 shows, it is recommended to add a “catch” resistor to feed the VR local output voltage back to the compensator, and add another “catch” resistor to connect the VR local output ground to the RTN pin. These resistors, typically  $10\Omega \sim 100\Omega$ , will provide voltage feedback if the system is powered up without a processor installed.

## Phase Current Balancing



**FIGURE 10. CURRENT BALANCING CIRCUIT**

The controller monitors individual phase average current by monitoring the ISEN1, ISEN2, and ISEN3 voltages. Figure 10 shows the recommended current balancing circuit. Each phase node voltage is averaged by a low-pass filter consisting of  $R_{isen}$  and  $C_{isen}$ , and presented to the corresponding ISEN pin.  $R_{isen}$  should be routed to inductor phase-node pad in order to eliminate the effect of phase node parasitic PCB DCR. Equations 5 thru 7 give the ISEN pin voltages:

$$V_{ISEN1} = (R_{dcr1} + R_{pcb1}) \times I_{L1} \quad (\text{EQ. 5})$$

$$V_{ISEN2} = (R_{dcr2} + R_{pcb2}) \times I_{L2} \quad (\text{EQ. 6})$$

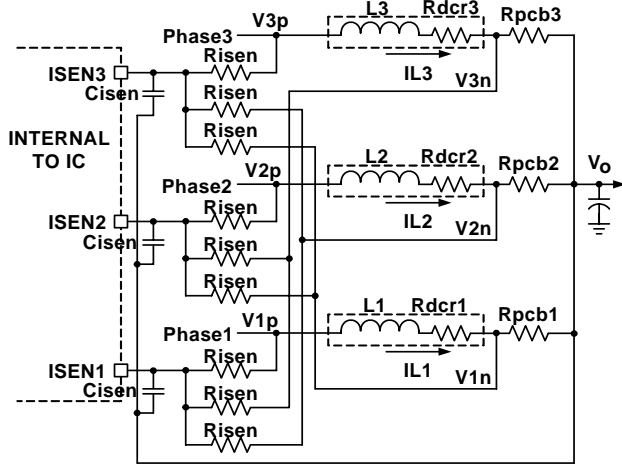
$$V_{ISEN3} = (R_{dcr3} + R_{pcb3}) \times I_{L3} \quad (\text{EQ. 7})$$

where  $R_{dcr1}$ ,  $R_{dcr2}$  and  $R_{dcr3}$  are inductor DCR;  $R_{pcb1}$ ,  $R_{pcb2}$  and  $R_{pcb3}$  are parasitic PCB DCR between the inductor output side pad and the output voltage rail; and  $I_{L1}$ ,  $I_{L2}$  and  $I_{L3}$  are inductor average currents.

The controller will adjust the phase pulse-width relative to the other phases to make  $V_{ISEN1} = V_{ISEN2} = V_{ISEN3}$ , thus to achieve  $I_{L1} = I_{L2} = I_{L3}$ , when there are  $R_{dcr1} = R_{dcr2} = R_{dcr3}$  and  $R_{pcb1} = R_{pcb2} = R_{pcb3}$ .

Using the same components for L1, L2 and L3 will provide a good match of  $R_{dcr1}$ ,  $R_{dcr2}$  and  $R_{dcr3}$ . Board layout will determine

$R_{pcb1}$ ,  $R_{pcb2}$  and  $R_{pcb3}$ . It is recommended to have symmetrical layout for the power delivery path between each inductor and the output voltage rail, such that  $R_{pcb1} = R_{pcb2} = R_{pcb3}$ .



**FIGURE 11. DIFFERENTIAL-SENSING CURRENT BALANCING CIRCUIT**

Sometimes, it is difficult to implement symmetrical layout. For the circuit shown in Figure 10, asymmetric layout causes different  $R_{pcb1}$ ,  $R_{pcb2}$  and  $R_{pcb3}$  thus current imbalance. Figure 11 shows a recommended differential-sensing current balancing circuit. The current sensing traces should be routed to the inductor pads so they only pick up the inductor DCR voltage. Each ISEN pin sees the average voltage of three sources: its own phase inductor phase-node pad, and the other two phases inductor output side pads. Equations 8 thru 10 give the ISEN pin voltages:

$$V_{ISEN1} = V_{1p} + V_{2n} + V_{3n} \quad (\text{EQ. 8})$$

$$V_{ISEN2} = V_{1n} + V_{2p} + V_{3n} \quad (\text{EQ. 9})$$

$$V_{ISEN3} = V_{1n} + V_{2n} + V_{3p} \quad (\text{EQ. 10})$$

The controller will make  $V_{ISEN1} = V_{ISEN2} = V_{ISEN3}$ , as shown in Equations 11 and 12:

$$V_{1p} + V_{2n} + V_{3n} = V_{1n} + V_{2p} + V_{3n} \quad (\text{EQ. 11})$$

$$V_{1n} + V_{2p} + V_{3n} = V_{1n} + V_{2n} + V_{3p} \quad (\text{EQ. 12})$$

Rewriting Equation 11 gives Equation 13:

$$V_{1p} - V_{1n} = V_{2p} - V_{2n} \quad (\text{EQ. 13})$$

and rewriting Equation 12 gives Equation 14:

$$V_{2p} - V_{2n} = V_{3p} - V_{3n} \quad (\text{EQ. 14})$$

Combining Equations 13 and 14 gives:

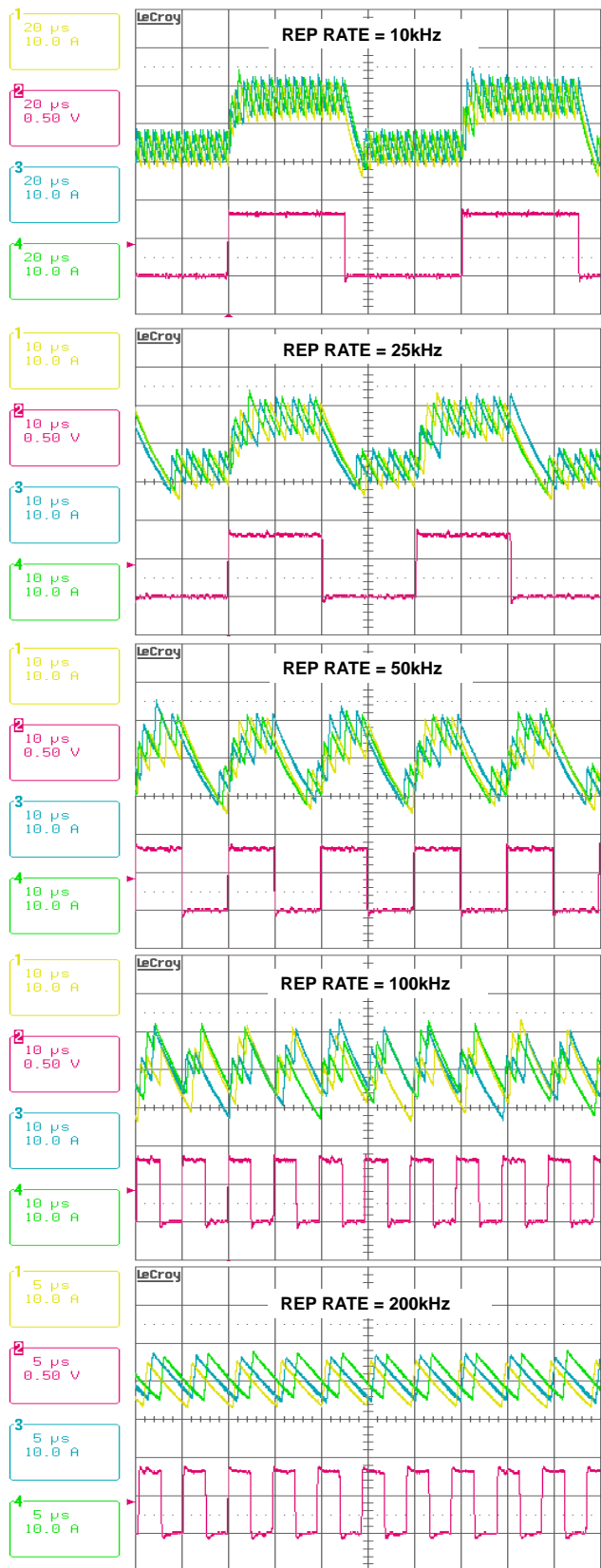
$$V_{1p} - V_{1n} = V_{2p} - V_{2n} = V_{3p} - V_{3n} \quad (\text{EQ. 15})$$

Therefore:

$$R_{dcr1} \times I_{L1} = R_{dcr2} \times I_{L2} = R_{dcr3} \times I_{L3} \quad (\text{EQ. 16})$$

Current balancing ( $I_{L1} = I_{L2} = I_{L3}$ ) will be achieved when there is  $R_{dcr1} = R_{dcr2} = R_{dcr3}$ .  $R_{pcb1}$ ,  $R_{pcb2}$  and  $R_{pcb3}$  will not have any effect.

Since the slave ripple capacitor voltages mimic the inductor currents,  $R^3$ ™ modulator can naturally achieve excellent current balancing during steady state and dynamic operations. Figure 12 shows current balancing performance of the evaluation board with load transient of 12A/51A at different rep rates. The inductor currents follow the load current dynamic change with the output capacitors supplying the difference. The inductor currents can track the load current well at low rep rate, but cannot keep up when the rep rate gets into the hundred-kHz range, where it's out of the control loop bandwidth. The controller achieves excellent current balancing in all cases.



**FIGURE 12. CURRENT BALANCING DURING DYNAMIC OPERATION. CH1: IL1, CH2: I<sub>LOAD</sub>, CH3: IL2, CH4: IL3**

## CCM Switching Frequency

The  $R_{fset}$  resistor between the COMP and the VW pins sets the sets the VW windows size, therefore sets the switching frequency. When the ISL95831 is in continuous conduction mode (CCM), the switching frequency is not absolutely constant due to the nature of the  $R^3$ ™ modulator. As explained in the “Multiphase  $R^3$ ™ Modulator” on page 12, the effective switching frequency will increase during load insertion and will decrease during load release to achieve fast response. On the other hand, the switching frequency is relatively constant at steady state. Variation is expected when the power stage condition, such as input voltage, output voltage, load, etc. changes. The variation is usually less than 15% and doesn't have any significant effect on output voltage ripple magnitude. Equation 17 gives an estimate of the frequency-setting resistor  $R_{fset}$  value.  $8k\Omega$   $R_{fset}$  gives approximately 300kHz switching frequency. Lower resistance gives higher switching frequency.

$$R_{fset}(k\Omega) = (\text{Period}(\mu\text{s}) - 0.29) \times 2.65 \quad (\text{EQ. 17})$$

## Modes of Operation

**TABLE 2. VR1 MODES OF OPERATION**

| PWM3               | ISEN2                  | CONFIG.                | PS | MODE        | OCP Threshold ( $\mu\text{A}$ ) |    |
|--------------------|------------------------|------------------------|----|-------------|---------------------------------|----|
| To External Driver | To Power Stage         | 3-phase CPU VR Config. | 0  | 3-phase CCM | 60                              |    |
|                    |                        |                        | 1  | 2-phase CCM | 40                              |    |
|                    |                        |                        | 2  | 1-phase DE  | 20                              |    |
|                    |                        |                        | 3  |             |                                 |    |
| Tied to 5V         | 2-phase CPU VR Config. |                        | 0  | 2-phase CCM | 40                              |    |
|                    |                        |                        | 1  | 1-phase CCM | 20                              |    |
|                    |                        |                        | 2  | 1-phase DE  |                                 |    |
|                    | Tied to 5V             | 1-phase CPU VR Config. |    | 0           | 1-phase CCM                     | 60 |
|                    |                        |                        |    | 1           |                                 |    |
|                    |                        |                        |    | 2           | 1-phase DE                      |    |
|                    |                        |                        | 3  |             |                                 |    |

VR1 can be configured for 3, 2 or 1-phase operation. Table 2 shows VR1 configurations and operational modes, programmed by the PWM3 pin and the ISEN2 pin status, and the PS command. For 2-phase configuration, tie the PWM3 pin to 5V. In this configuration, phases 1 and 2 are active. For 1-phase configuration, tie the PWM3 pin and the ISEN2 pin to 5V. In this configuration, only phase-1 is active.

In 3-phase configuration, VR1 operates in 3-phase CCM in PS0. It enters 2-phase CCM in PS1 by dropping phase 3 and reducing the overcurrent and the way-overcurrent protection levels to 2/3 of the initial values. It enters 1-phase DE mode in PS2 or PS3 by dropping phases 3 and 2, and reduces the overcurrent and the way-overcurrent protection levels to 1/3 of the initial values.

In 2-phase configuration, VR1 operates in 2-phase CCM in PS0. It enters 1-phase CCM in PS1 and enters 1-phase DE mode in PS2 or PS3 by dropping phase 2, and reducing the overcurrent and the way-overcurrent protection levels to 1/2 of the initial values.

In 1-phase configuration, VR1 operates in 1-phase CCM in PS0 and PS1, and enters 1-phase DE mode in PS2 and PS3.

**TABLE 3. VR2 MODES OF OPERATION**

| Rcomp <sub>g</sub> | PS | MODE        | OCP Threshold (μA) |
|--------------------|----|-------------|--------------------|
| Open Circuit       | 0  | 1-phase CCM | 60                 |
|                    | 1  |             |                    |
|                    | 2  | 1-phase DE  |                    |
|                    | 3  |             |                    |
| 100kΩ              | 0  | 1-phase DE  | 60                 |
|                    | 1  |             |                    |
|                    | 2  |             |                    |
|                    | 3  |             |                    |

Table 3 shows VR2 operational modes, programmed by the PS command and Rcomp<sub>g</sub>. Rcomp<sub>g</sub> is a resistor connected between the COMP<sub>G</sub> pin and GND. If Rcomp<sub>g</sub> is equal to 100kΩ, VR2 operates in DE mode for all PS modes. If Rcomp<sub>g</sub> is open circuit, VR2 operates in 1-phase CCM in PS0 and PS1, and enters 1-phase DE mode in PS2 and PS3.

VR2 can be disabled completely by tying ISUMNG to 5V, and all communication to VR2 will be rejected.

## Dynamic Operation

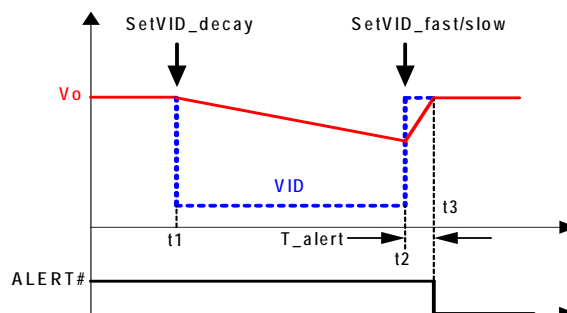
VR1 and VR2 behave the same during dynamic operation. The controller responds to VID changes by slewing to the new voltage at a slew rate indicated in the SetVID command. There are three SetVID slew rates, namely SetVID\_fast, SetVID\_slow and SetVID\_decay.

SetVID\_fast command prompts the controller to enter CCM and to actively drive the output voltage to the new VID value at a minimum 10mV/μs slew rate.

SetVID\_slow command prompts the controller to enter CCM and to actively drive the output voltage to the new VID value at a minimum 2.5mV/μs slew rate.

SetVID\_decay command prompts the controller to enter DE mode. The output voltage will decay down to the new VID value at a slew rate determined by the load. If the voltage decay rate is too fast, the controller will limit the voltage slew rate at SetVID\_slow slew rate.

ALERT# will be asserted low at the end of SetVID\_fast and SetVID\_slow VID transitions.

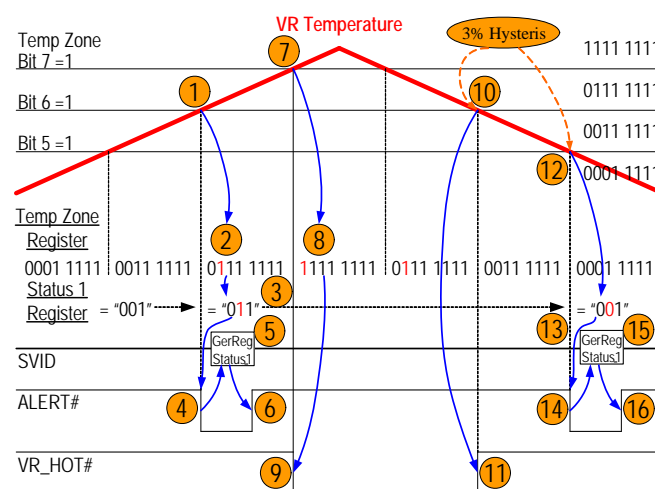


**FIGURE 13. SETVID DECAY PRE-EMPTIVE BEHAVIOR**

Figure 13 shows SetVID Decay Pre-emptive behavior. The controller receives a SetVID\_decay command at t1. The VR enters DE mode and the output voltage Vo decays down slowly. At t2, before Vo reaches the intended VID target of the SetVID\_decay command, the controller receives a SetVID\_fast (or SetVID\_slow) command to go to a voltage higher than the actual Vo. The controller will turn around immediately and slew Vo to the new target voltage at the slew rate specified by the SetVID command. At t3, Vo reaches the new target voltage and the controller asserts the ALERT# signal.

The R<sup>3</sup><sup>TM</sup> modulator intrinsically has voltage feed-forward. The output voltage is insensitive to a fast slew rate input voltage change.

## VR\_HOT#/ALERT# Behavior



**FIGURE 14. VR\_HOT#/ALERT# BEHAVIOR**

The controller drives 60μA current source out of the NTC pin and the NTC<sub>G</sub> pin alternatively at 1kHz frequency with 50% duty cycle. The current source flows through the respective NTC resistor networks on the pins and creates voltages that are monitored by the controller through an A/D converter (ADC) to generate the Tzone value. Table 4 shows the programming table for Tzone. The user needs to scale the NTC and the NTC<sub>G</sub> network resistance such that it generates the NTC (and NTC<sub>G</sub>) pin voltage that corresponds to the left-most column. Do not use any capacitor to filter the voltage.

**TABLE 4. TZONE TABLE**

| VNTC (V) | TMAX (%) | TZONE |
|----------|----------|-------|
| 0.84     | >100     | FFh   |
| 0.88     | 100      | FFh   |
| 0.92     | 97       | 7Fh   |
| 0.96     | 94       | 3Fh   |
| 1.00     | 91       | 1Fh   |
| 1.04     | 88       | 0Fh   |
| 1.08     | 85       | 07h   |
| 1.12     | 82       | 03h   |
| 1.16     | 79       | 01h   |
| 1.2      | 76       | 01h   |
| >1.2     | <76      | 00h   |

Figure 14 shows the how the NTC and the NTCG network should be designed to get correct VR\_HOT#/ALERT# behavior when the system temperature rises and falls, manifested as the NTC and the NTCG pin voltage falls and rises. The series of events are:

1. The temperature rises so the NTC pin (or the NTCG pin) voltage drops. Tzone value changes accordingly.
2. The temperature crosses the threshold where Tzone register Bit 6 changes from 0 to 1.
3. The controller changes Status\_1 register bit 1 from 0 to 1.
4. The controller asserts ALERT#.
5. The CPU reads Status\_1 register value to know that the alert assertion is due to Tzone register bit 6 flipping.
6. The controller clears ALEERT#.
7. The temperature continues rising.
8. The temperature crosses the threshold where Tzone register Bit 7 changes from 0 to 1.
9. The controllers asserts VR\_HOT# signal. The CPU throttles back and the system temperature starts dropping eventually.
10. The temperature crosses the threshold where Tzone register bit 6 changes from 1 to 0. This threshold is 1 ADC step lower than the one when VR\_HOT# gets asserted, to provide 3% hysteresis.
11. The controllers de-asserts VR\_HOT# signal.
12. The temperature crosses the threshold where Tzone register bit 5 changes from 1 to 0. This threshold is 1 ADC step lower than the one when ALERT# gets asserted during the temperature rise to provide 3% hysteresis.
13. The controller changes Status\_1 register bit 1 from 1 to 0.
14. The controller asserts ALERT#.
15. The CPU reads Status\_1 register value to know that the alert assertion is due to Tzone register bit 5 flipping.
16. The controller clears ALERT#.

## Current Monitor

The controller provides the current monitor function for both VRs. The IMON pin reports VR1 inductor current and the IMONG pins reports VR2 inductor current. Since they are designed following

the same principle, the following discussion will be only based on the IMON pin but also applies to the IMONG pin.

The IMON pin outputs a high-speed analog current source that is 3 times of the droop current flowing out of the FB pin. Thus becoming Equation 18:

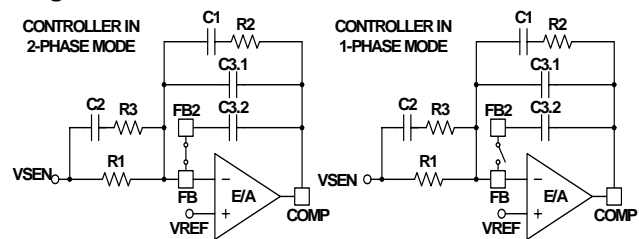
$$I_{\text{IMON}} = 3 \times I_{\text{droop}} \quad (\text{EQ. 18})$$

As Figures 1 and 2 show, a resistor  $R_{\text{imon}}$  is connected to the IMON pin to convert the IMON pin current to voltage. A capacitor should be paralleled with  $R_{\text{imon}}$  to filter the voltage information.

The IMON pin voltage range is 0V to 2.658V. The controller monitors the IMON pin voltage and considers that VR1 has reached ICCMAX when IMON pin voltage is 2.658V.

## FB2 Function

The FB2 function is only available for VR1 in 2-phase configuration.



**FIGURE 15. FB2 FUNCTION**

Figure 15 shows the FB2 function. A switch (called FB2 switch) turns on to short the FB and the FB2 pins when the controller is in 2-phase mode. Capacitors C3.1 and C3.2 are in parallel, serving as part of the compensator. When the controller enters 1-phase mode, the FB2 switch turns off, removing C3.2 and leaving only C3.1 in the compensator. The compensator gain will increase with the removal of C3.2. By properly sizing C3.1 and C3.2, the compensator can be optimal for both 2-phase mode and 1-phase mode.

When the FB2 switch is off, C3.2 is disconnected from the FB pin. However, the controller still actively drives the FB2 pin voltage to follow the FB pin voltage such that C3.2 voltage always follows C3.1 voltage. When the controller turns on the FB2 switch, C3.2 will be reconnected to the compensator smoothly.

The FB2 function ensures excellent transient response in both 2-phase mode and 1-phase mode. If one decides not to use the FB2 function, simply populate C3.1 only.

## Adaptive Body Diode Conduction Time Reduction

In DCM, the controller turns off the low-side MOSFET when the inductor current approaches zero. During on-time of the low-side MOSFET, phase voltage is negative and the amount is the MOSFET  $r_{\text{DS(ON)}}$  voltage drop, which is proportional to the inductor current. A phase comparator inside the controller monitors the phase voltage during on-time of the low-side MOSFET and compares it with a threshold to determine the zero-crossing point of the inductor current. If the inductor current has not reached zero when the low-side MOSFET turns off, it'll flow through the low-side MOSFET body diode, causing the phase



node to have a larger voltage drop until it decays to zero. If the inductor current has crossed zero and reversed the direction when the low-side MOSFET turns off, it'll flow through the high-side MOSFET body diode, causing the phase node to have a spike until it decays to zero. The controller continues monitoring the phase voltage after turning off the low-side MOSFET and adjusts the phase comparator threshold voltage accordingly in iterative steps such that the low-side MOSFET body diode conducts for approximately 40ns to minimize the body diode-related loss.

## Protections

VR1 and VR2 both provide overcurrent, current-balance and overvoltage fault protections. The controller also provides over-temperature protection. The following discussion is based on VR1 and also applies to VR2.

The controller determines overcurrent protection (OCP) by comparing the average value of the droop current  $I_{droop}$  with an internal current source threshold as Table 2 shows. It declares OCP when  $I_{droop}$  is above the threshold for 120 $\mu$ s.

For overcurrent conditions above 1.5x the OCP level, the PWM outputs will immediately shut off and PGOOD will go low to maximize protection. This protection is also referred to as way-overcurrent protection or fast-overcurrent protection, for short-circuit protection.

The controller monitors the ISEN pin voltages to determine current-balance protection. If the ISEN pin voltage difference is greater than 9mV for 1ms, the controller will declare a fault and latch off.

The controller takes the same actions for all of the above fault protections: de-assertion of both PGOODs and turn-off of all the high-side and low-side power MOSFETs. Any residual inductor current will decay through the MOSFET body diodes.

The controller will declare an overvoltage fault and de-assert PGOOD if the output voltage exceeds the VID set value by +200mV. The controller will immediately declare an OV fault, de-assert PGOOD, and turn on the low-side power MOSFETs. The low-side power MOSFETs remain on until the output voltage is pulled down below the VID set value when all power MOSFETs are turned off. If the output voltage rises above the VID set value +200mV again, the protection process is repeated. This behavior provides the maximum amount of protection against shorted high-side power MOSFETs while preventing output ringing below ground.

All the above fault conditions can be reset by bringing VR\_ON low or by bringing  $V_{DD}$  below the POR threshold. When VR\_ON and  $V_{DD}$  return to their high operating levels, a soft-start will occur

Table 5 summarizes the fault protections.

**TABLE 5. FAULT PROTECTION SUMMARY**

| FAULT TYPE               | FAULT DURATION BEFORE PROTECTION | PROTECTION ACTION  | FAULT RESET                |
|--------------------------|----------------------------------|--|----------------------------|
| Overcurrent              | 120 $\mu$ s                      | PWM tri-state, PGOOD latched low   | VR_ON toggle or VDD toggle |
| Phase Current Unbalance  | 1ms                              |  |                            |
| Way-Overcurrent (1.5xOC) | Immediately                      | PGOOD latched low. Actively pulls the output voltage to below VID value, then tri-state. |                            |
| Overvoltage +200mV       |                                  |  |                            |

## Supported Data And Configuration Registers

The controller supports the following data and configuration registers.

**TABLE 6. SUPPORTED DATA AND CONFIGURATION REGISTERS**

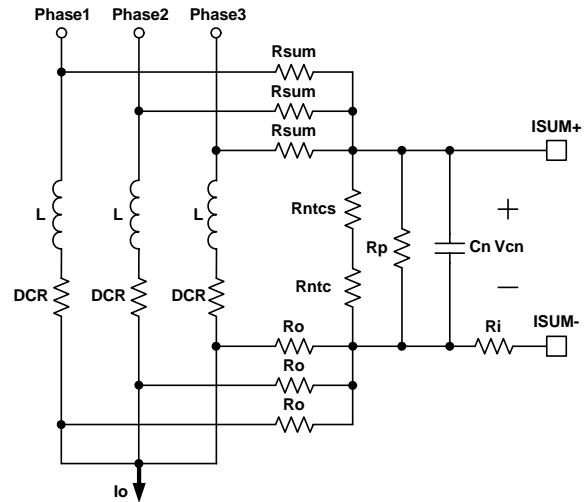
| Index | Register Name     | Description  | Default Value |
|-------|-------------------|--|---------------|
| 00h   | Vendor ID         | Uniquely identifies the VR vendor. Assigned by Intel.  | 12h           |
| 01h   | Product ID        | Uniquely identifies the VR product. Intersil assigns this number.  | 1Fh           |
| 02h   | Product Revision  | Uniquely identifies the revision of the VR control IC. Intersil assigns this data.   |               |
| 05h   | Protocol ID       | Identifies what revision of SVID protocol the controller supports.   | 01h           |
| 06h   | Capability        | Identifies the SVID VR capabilities and which of the optional telemetry registers are supported.                                 | 81h           |
| 10h   | Status_1          | Data register read after ALERT# signal. Indicating if a VR rail has settled, has reached VRHOT condition or has reached ICC max. | 00h           |
| 11h   | Status_2          | Data register showing status_2 communication.  | 00h           |
| 12h   | Temperature Zone  | Data register showing temperature zones that have been entered.  | 00h           |
| 1Ch   | Status_2_LastRead | This register contains a copy of the Status_2 data that was last read with the GetReg (Status_2) command.                        | 00h           |

**TABLE 6. SUPPORTED DATA AND CONFIGURATION REGISTERS (Continued)**

| Index | Register Name   | Description  | Default Value        |
|-------|-----------------|--|----------------------|
| 21h   | ICC max         | Data register containing the ICC max the platform supports, set at start-up by resistors Rprog1 and Rprog2. The platform design engineer programs this value during the design process. Binary format in amps, i.e. 100A = 64h                     | Refer to Table 7     |
| 22h   | Temp max        | Data register containing the temperature max the platform support, set at startup by resistor Rprog2. The platform design engineer programs this value during the design process. Binary format in degree C, i.e. 100C = 64h                       | Refer to Table 8     |
| 24h   | SR-fast         | Slew Rate Normal. The fastest slew rate the platform VR can sustain. Binary format in mV/μs. i.e. 0Ah = 10mV/μs.   | 0Ah                  |
| 25h   | SR-slow         | Is 4x slower than normal. Binary format in mV/μs. i.e. 02h = 2.5mV/μs  | 02h                  |
| 26h   | Vboot           | If programmed by the platform, the VR supports Vboot voltage during start-up ramp. The VR will ramp to V <sub>BOOT</sub> and hold at V <sub>BOOT</sub> until it receives a new SetVID command to move to a different voltage.                      | 00h                  |
| 30h   | Vout max        | This register is programmed by the master and sets the maximum VID the VR will support. If a higher VID code is received, the VR will respond with “not supported” acknowledge.  | FBh                  |
| 31h   | VID Setting     | Data register containing currently programmed VID voltage. VID data format.  | 00h                  |
| 32h   | Power State     | Register containing the current programmed power state.  | 00h                  |
| 33h   | Voltage Offset  | Sets offset in VID steps added to the VID setting for voltage margining. Bit 7 is a sign bit, 0 = positive margin, 1 = negative margin. Remaining 7 bits are # VID steps for the margin. 00h = no margin, 01h = +1 VID step, 02h = +2 VID steps... | 00h                  |
| 34h   | Multi VR Config | Data register that configures multiple VRs behavior on the same SVID bus.  | VR1: 00h<br>VR2: 01h |

## Key Component Selection

### Inductor DCR Current-Sensing Network



**FIGURE 16. DCR CURRENT-SENSING NETWORK**

Figure 16 shows the inductor DCR current-sensing network for a 3-phase solution. An inductor current flows through the DCR and creates a voltage drop. Each inductor has two resistors in  $R_{sum}$  and  $R_o$  connected to the pads to accurately sense the inductor current by sensing the DCR voltage drop. The  $R_{sum}$  and  $R_o$  resistors are connected in a summing network as shown, and feed the total current information to the NTC network (consisting of  $R_{ntcs}$ ,  $R_{ntc}$  and  $R_p$ ) and capacitor  $C_n$ .  $R_{ntc}$  is a negative temperature coefficient (NTC) thermistor, used to temperature-compensate the inductor DCR change.

The inductor output side pads are electrically shorted in the schematic, but have some parasitic impedance in actual board layout, which is why one cannot simply short them together for the current-sensing summing network. It is recommended to use  $1\Omega \sim 10\Omega$   $R_o$  to create quality signals. Since  $R_o$  value is much smaller than the rest of the current sensing circuit, the following analysis will ignore it for simplicity.

The summed inductor current information is presented to the capacitor  $C_n$ . Equations 19 thru 23 describe the frequency-domain relationship between inductor total current  $I_o(s)$  and  $C_n$  voltage  $V_{Cn}(s)$ :

$$V_{Cn}(s) = \left( \frac{R_{ntcnet}}{R_{ntcnet} + \frac{R_{sum}}{N}} \times \frac{DCR}{N} \right) \times I_o(s) \times A_{cs}(s) \quad (EQ. 19)$$

$$R_{ntcnet} = \frac{(R_{ntcs} + R_{ntc}) \times R_p}{R_{ntcs} + R_{ntc} + R_p} \quad (EQ. 20)$$

$$A_{cs}(s) = \frac{1 + \frac{s}{\omega_L}}{1 + \frac{s}{\omega_{sns}}} \quad (EQ. 21)$$

$$\omega_L = \frac{DCR}{L} \quad (EQ. 22)$$

where N is the number of phases.



$$\omega_{sns} = \frac{1}{R_{ntcnet} \times \frac{R_{sum}}{N} \times C_n} \quad (EQ. 23)$$

$$R_{ntcnet} + \frac{R_{sum}}{N}$$

Transfer function  $A_{cs}(s)$  always has unity gain at DC. The inductor DCR value increases as the winding temperature increases, giving higher reading of the inductor DC current. The NTC  $R_{ntc}$  values decrease as its temperature decreases. Proper selections of  $R_{sum}$ ,  $R_{ntcs}$ ,  $R_p$  and  $R_{ntc}$  parameters ensure that  $V_{cn}$  represent the inductor total DC current over the temperature range of interest.

There are many sets of parameters that can properly temperature-compensate the DCR change. Since the NTC network and the  $R_{sum}$  resistors form a voltage divider,  $V_{cn}$  is always a fraction of the inductor DCR voltage. It is recommended to have a higher ratio of  $V_{cn}$  to the inductor DCR voltage, so the droop circuit has higher signal level to work with.

A typical set of parameters that provide good temperature compensation are:  $R_{sum} = 3.65k\Omega$ ,  $R_p = 11k\Omega$ ,  $R_{ntcs} = 2.61k\Omega$  and  $R_{ntc} = 10k\Omega$  (ERT-J1VR103J). The NTC network parameters may need to be fine tuned on actual boards. One can apply full load DC current and record the output voltage reading immediately; then record the output voltage reading again when the board has reached the thermal steady state. A good NTC network can limit the output voltage drift to within 2mV. It is recommended to follow the Intersil evaluation board layout and current-sensing network parameters to minimize engineering time.

$V_{cn}(s)$  also needs to represent real-time  $I_o(s)$  for the controller to achieve good transient response. Transfer function  $A_{cs}(s)$  has a pole  $w_{sns}$  and a zero  $w_L$ . One needs to match  $w_L$  and  $w_{sns}$  so  $A_{cs}(s)$  is unity gain at all frequencies. By forcing  $w_L$  equal to  $w_{sns}$  and solving for the solution, Equation 24 gives  $C_n$  value.

$$C_n = \frac{L}{R_{ntcnet} \times \frac{R_{sum}}{N} \times DCR} \quad (EQ. 24)$$

$$R_{ntcnet} + \frac{R_{sum}}{N}$$

For example, given  $N = 3$ ,  $R_{sum} = 3.65k\Omega$ ,  $R_p = 11k\Omega$ ,  $R_{ntcs} = 2.61k\Omega$ ,  $R_{ntc} = 10k\Omega$ ,  $DCR = 0.9m\Omega$  and  $L = 0.36\mu H$ , Equation 24 gives  $C_n = 0.397\mu F$ .

Assuming the compensator design is correct, Figure 17 shows the expected load transient response waveforms if  $C_n$  is correctly selected. When the load current  $I_{core}$  has a square change, the output voltage  $V_{core}$  also has a square response.

If  $C_n$  value is too large or too small,  $V_{cn}(s)$  will not accurately represent real-time  $I_o(s)$  and will worsen the transient response. Figure 18 shows the load transient response when  $C_n$  is too small.  $V_{core}$  will sag excessively upon load insertion and may create a system failure. Figure 19 shows the transient response when  $C_n$  is too large.  $V_{core}$  is sluggish in drooping to its final value. There will be excessive overshoot if load insertion occurs during this time, which may potentially hurt the CPU reliability.

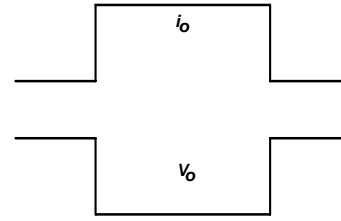


FIGURE 17. DESIRED LOAD TRANSIENT RESPONSE WAVEFORMS

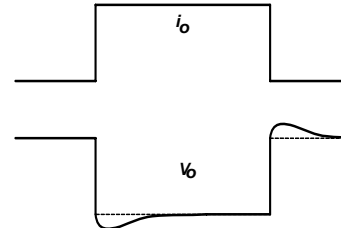


FIGURE 18. LOAD TRANSIENT RESPONSE WHEN  $C_n$  IS TOO SMALL

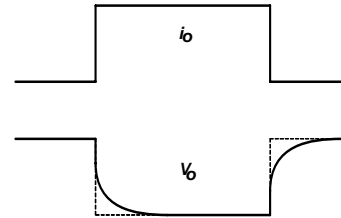


FIGURE 19. LOAD TRANSIENT RESPONSE WHEN  $C_n$  IS TOO LARGE

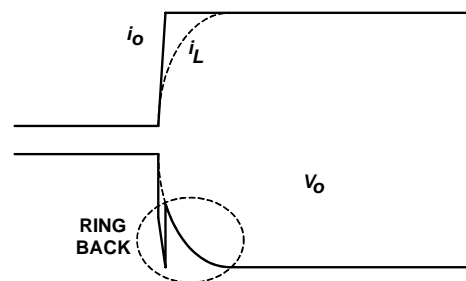
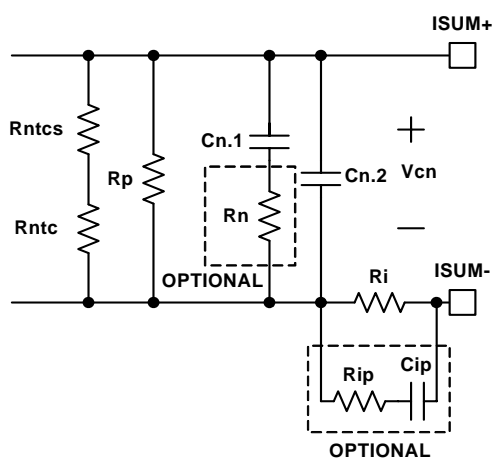


FIGURE 20. OUTPUT VOLTAGE RING BACK PROBLEM



**FIGURE 21. OPTIONAL CIRCUITS FOR RING BACK REDUCTION**

Figure 20 shows the output voltage ring back problem during load transient response. The load current  $i_o$  has a fast step change, but the inductor current  $i_L$  cannot accurately follow. Instead,  $i_L$  responds in first order system fashion due to the nature of current loop. The ESR and ESL effect of the output capacitors makes the output voltage  $V_o$  dip quickly upon load current change. However, the controller regulates  $V_o$  according to the droop current  $i_{droop}$ , which is a real-time representation of  $i_L$ ; therefore it pulls  $V_o$  back to the level dictated by  $i_L$ , causing the ring back problem. This phenomenon is not observed when the output capacitor have very low ESR and ESL, such as all ceramic capacitors.

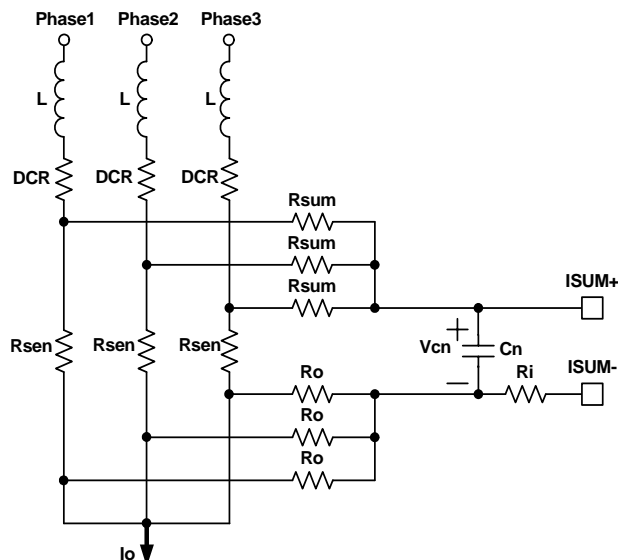
Figure 21 shows two optional circuits for reduction of the ring back.

$C_n$  is the capacitor used to match the inductor time constant. It usually takes the parallel of two (or more) capacitors to get the desired value. Figure 21 shows that two capacitors  $C_{n,1}$  and  $C_{n,2}$  are in parallel. Resistor  $R_n$  is an optional component to reduce the  $V_o$  ring back. At steady state,  $C_{n,1} + C_{n,2}$  provides the desired  $C_n$  capacitance. At the beginning of  $i_o$  change, the effective capacitance is less because  $R_n$  increases the impedance of the  $C_{n,1}$  branch. As Figure 18 explains,  $V_o$  tends to dip when  $C_n$  is too small, and this effect will reduce the  $V_o$  ring back. This effect is more pronounced when  $C_{n,1}$  is much larger than  $C_{n,2}$ . It is also more pronounced when  $R_n$  is bigger. However, the presence of  $R_n$  increases the ripple of the  $V_n$  signal if  $C_{n,2}$  is too small. It is recommended to keep  $C_{n,2}$  greater than 2200pF.  $R_n$  value usually is a few ohms.  $C_{n,1}$ ,  $C_{n,2}$  and  $R_n$  values should be determined through tuning the load transient response waveforms on an actual board.

$R_{ip}$  and  $C_{ip}$  form an R-C branch in parallel with  $R_i$ , providing a lower impedance path than  $R_i$  at the beginning of  $i_o$  change.  $R_{ip}$  and  $C_{ip}$  do not have any effect at steady state. Through proper selection of  $R_{ip}$  and  $C_{ip}$  values,  $i_{droop}$  can resemble  $i_o$  rather than  $i_L$ , and  $V_o$  will not ring back. The recommended value for  $R_{ip}$  is 100Ω.  $C_{ip}$  should be determined through tuning the load transient response waveforms on an actual board. The recommended range for  $C_{ip}$  is 100pF~2000pF. However, it should be noted that the  $R_{ip}$ - $C_{ip}$  branch may distort the  $i_{droop}$  waveform. Instead of being triangular as the real inductor

current,  $i_{droop}$  may have sharp spikes, which may adversely affect  $i_{droop}$  average value detection and therefore may affect OCP accuracy. User discretion is advised.

## Resistor Current-Sensing Network



**FIGURE 22. RESISTOR CURRENT-SENSING NETWORK**

Figure 22 shows the resistor current-sensing network for a 2-phase solution. Each inductor has a series current-sensing resistor  $R_{sen}$ .  $R_{sum}$  and  $R_o$  are connected to the  $R_{sen}$  pads to accurately capture the inductor current information. The  $R_{sum}$  and  $R_o$  resistors are connected to capacitor  $C_n$ .  $R_{sum}$  and  $C_n$  form a filter for noise attenuation. Equations 25 thru 27 give  $V_{Cn}(s)$  expression:

$$V_{Cn}(s) = \frac{R_{sen}}{N} \times I_o(s) \times A_{Rsen}(s) \quad (EQ. 25)$$

$$A_{Rsen}(s) = \frac{1}{1 + \frac{s}{\omega_{Rsen}}} \quad (EQ. 26)$$

$$\omega_{Rsen} = \frac{1}{\frac{R_{sum}}{N} \times C_n} \quad (EQ. 27)$$

Transfer function  $A_{Rsen}(s)$  always has unity gain at DC. Current-sensing resistor  $R_{sen}$  value will not have significant variation over-temperature, so there is no need for the NTC network.

The recommended values are  $R_{sum} = 1k\Omega$  and  $C_n = 5600pF$ .

## Overcurrent Protection

Refer to Equation 1 on page 18 and Figures 16, 20 and 22; resistor  $R_i$  sets the droop current  $I_{droop}$ . Tables 2 and 3 show the internal OCP threshold. It is recommended to design  $I_{droop}$  without using the  $R_{comp}$  resistor.

For example, the OCP threshold is 60μA for 3-phase solution. We will design  $I_{droop}$  to be 40.9μA at full load, so the OCP trip level is 1.5x of the full load current.

For inductor DCR sensing, Equation 28 gives the DC relationship of  $V_{cn}(s)$  and  $I_o(s)$ .

$$V_{Cn} = \left( \frac{R_{ntcnet}}{R_{ntcnet} + \frac{R_{sum}}{N}} \times \frac{DCR}{N} \right) \times I_o \quad (EQ. 28)$$

Substitution of Equation 28 into Equation 1 gives Equation 29:

$$I_{droop} = \frac{2}{R_i} \times \frac{R_{ntcnet}}{R_{ntcnet} + \frac{R_{sum}}{N}} \times \frac{DCR}{N} \times I_o \quad (EQ. 29)$$

Therefore:

$$R_i = \frac{2R_{ntcnet} \times DCR \times I_o}{N \times \left( R_{ntcnet} + \frac{R_{sum}}{N} \right) \times I_{droop}} \quad (EQ. 30)$$

Substitution of Equation 20 and application of the OCP condition in Equation 30 gives Equation 31:

$$R_i = \frac{2 \times \left( \frac{R_{ntcs} + R_{ntc}}{R_{ntcs} + R_{ntc} + R_p} \right) \times R_p \times DCR \times I_{omax}}{N \times \left( \frac{R_{ntcs} + R_{ntc}}{R_{ntcs} + R_{ntc} + R_p} + \frac{R_{sum}}{N} \right) \times I_{droopmax}} \quad (EQ. 31)$$

where  $I_{omax}$  is the full load current,  $I_{droopmax}$  is the corresponding droop current. For example, given  $N = 3$ ,  $R_{sum} = 3.65k\Omega$ ,  $R_p = 11k\Omega$ ,  $R_{ntcs} = 2.61k\Omega$ ,  $R_{ntc} = 10k\Omega$ ,  $DCR = 0.9m\Omega$ ,  $I_{omax} = 94A$  and  $I_{droopmax} = 48\mu A$ , Equation 31 gives  $R_i = 974\Omega$ .

For resistor sensing, Equation 32 gives the DC relationship of  $V_{Cn}(s)$  and  $I_o(s)$ .

$$V_{Cn} = \frac{R_{sen}}{N} \times I_o \quad (EQ. 32)$$

Substitution of Equation 32 into Equation 1 gives Equation 33:

$$I_{droop} = \frac{2}{R_i} \times \frac{R_{sen}}{N} \times I_o \quad (EQ. 33)$$

Therefore:

$$R_i = \frac{2R_{sen} \times I_o}{N \times I_{droop}} \quad (EQ. 34)$$

Substitution of Equation 34 and application of the OCP condition in Equation 30 gives Equation 35:

$$R_i = \frac{2R_{sen} \times I_{omax}}{N \times I_{droopmax}} \quad (EQ. 35)$$

where  $I_{omax}$  is the full load current,  $I_{droopmax}$  is the corresponding droop current. For example, given  $N = 3$ ,  $R_{sen} = 1m\Omega$ ,  $I_{omax} = 94A$  and  $I_{droopmax} = 48\mu A$ , Equation 35 gives  $R_i = 1305\Omega$ .

## Load Line Slope

Refer to Figure 9.

For inductor DCR sensing, substitution of Equation 29 into Equation 2 gives the load line slope expression:

$$LL = \frac{V_{droop}}{I_o} = \frac{2R_{droop}}{R_i} \times \frac{R_{ntcnet}}{R_{ntcnet} + \frac{R_{sum}}{N}} \times \frac{DCR}{N} \quad (EQ. 36)$$

For resistor sensing, substitution of Equation 33 into Equation 2 gives the load line slope expression:

$$LL = \frac{V_{droop}}{I_o} = \frac{2R_{sen} \times R_{droop}}{N \times R_i} \quad (EQ. 37)$$

Substitution of Equation 30 and rewriting Equation 36, or substitution of Equation 34 and rewriting Equation 37 give the same result in Equation 38:

$$R_{droop} = \frac{I_o}{I_{droop}} \times LL \quad (EQ. 38)$$

One can use the full load condition to calculate  $R_{droop}$ . For example, given  $I_{omax} = 94A$ ,  $I_{droopmax} = 48\mu A$  and  $LL = 1.9m\Omega$ , Equation 38 gives  $R_{droop} = 3.72k\Omega$ .

It is recommended to start with the  $R_{droop}$  value calculated by Equation 38, and fine tune it on the actual board to get accurate load line slope. One should record the output voltage readings at no load and at full load for load line slope calculation. Reading the output voltage at lighter load instead of full load will increase the measurement error.

## Compensator

Figure 17 shows the desired load transient response waveforms. Figure 23 shows the equivalent circuit of a voltage regulator (VR) with the droop function. A VR is equivalent to a voltage source (= VID) and output impedance  $Z_{out}(s)$ . If  $Z_{out}(s)$  is equal to the load line slope LL, i.e. constant output impedance, in the entire frequency range,  $V_o$  will have square response when  $I_o$  has a square change.

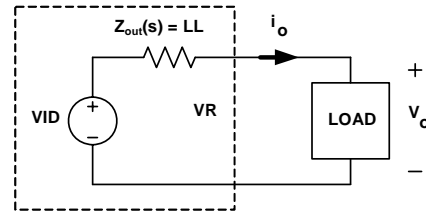


FIGURE 23. VOLTAGE REGULATOR EQUIVALENT CIRCUIT

Intersil provides a Microsoft Excel-based spreadsheet to help design the compensator and the current sensing network, so the VR achieves constant output impedance as a stable system. Please go to [www.intersil.com/design/](http://www.intersil.com/design/) to request spreadsheet. Figure 26 shows a screenshot of the spreadsheet.

A VR with active droop function is a dual-loop system consisting of a voltage loop and a droop loop which is a current loop. However, neither loop alone is sufficient to describe the entire system. The spreadsheet shows two loop gain transfer functions, T1(s) and T2(s), that describe the entire system. Figure 24 conceptually shows T1(s) measurement set-up and Figure 25 conceptually shows T2(s) measurement set-up. The VR senses the inductor current, multiplies it by a gain of the load line slope, then adds it on top of the sensed output voltage and feeds it to the compensator. T(1) is measured after the summing node, and T2(s) is measured in the voltage loop before the summing node. The spreadsheet gives both T1(s) and T2(s) plots. However, only T2(s) can be actually measured on an ISL95831 regulator.

$T1(s)$  is the total loop gain of the voltage loop and the droop loop. It always has a higher crossover frequency than  $T2(s)$  and has more meaning of system stability.

$T2(s)$  is the voltage loop gain with closed droop loop. It has more meaning of output voltage response.

Design the compensator to get stable  $T1(s)$  and  $T2(s)$  with sufficient phase margin, and output impedance equal or smaller than the load line slope.

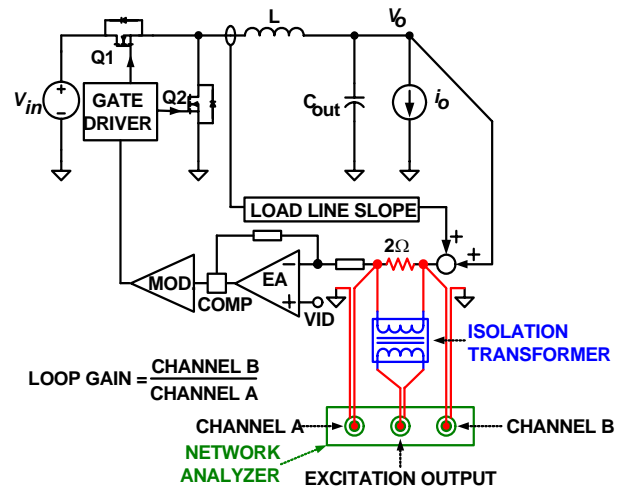


FIGURE 24. LOOP GAIN  $T1(s)$  MEASUREMENT SET-UP

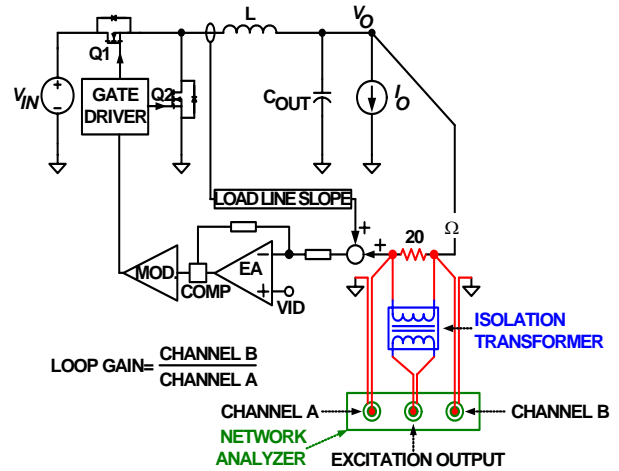


FIGURE 25. LOOP GAIN  $T2(s)$  MEASUREMENT SET-UP



## Programming Resistors

TABLE 7. RPROG1 PROGRAMMING TABLE

| RPROG1 (kohm) |      |            | V <sub>BOOT</sub> (V) | VR1 ICCMAX (A) With POWER-UP CONFIGURATION |      |      |
|---------------|------|------------|-----------------------|--|------|------|
| Min. (-3%)    | Typ. | Max. (+3%) |                       | 3-PH                                       | 2-PH | 1-PH |
|               | 0    |            | 0                     | 99   | 66   | 33   |
| 0.57          | 0.59 | 0.61       | 0                     | 93   | 62   | 31   |
| 1.07          | 1.1  | 1.13       | 0                     | 87   | 58   | 29   |
| 1.64          | 1.69 | 1.74       | 0                     | 81   | 54   | 27   |
| 2.19          | 2.26 | 2.33       | 0                     | 75   | 50   | 25   |
| 3.07          | 3.16 | 3.25       | 0                     | 69   | 46   | 23   |
| 4.19          | 4.32 | 4.45       | 0                     | 63   | 42   | 21   |
| 5.33          | 5.49 | 5.65       | 0                     | 57   | 38   | 19   |
| 6.45          | 6.65 | 6.85       | 1.1                   | 57   | 38   | 19   |
| 7.63          | 7.87 | 8.11       | 1.1                   | 63   | 42   | 21   |
| 9.03          | 9.31 | 9.59       | 1.1                   | 69   | 46   | 23   |
| 11.16         | 11.5 | 11.85      | 1.1                   | 75   | 50   | 25   |
| 13.29         | 13.7 | 14.11      | 1.1                   | 81   | 54   | 27   |
| 15.71         | 16.2 | 16.69      | 1.1                   | 87   | 58   | 29   |
| 18.14         | 18.7 | 19.26      | 1.1                   | 93   | 62   | 31   |
| 24.15         | 24.9 | open       | 1.1                   | 99   | 66   | 33   |

TABLE 8. RPROG2 PROGRAMMING TABLE

| RPROG2 (kΩ) |      |           | T <sub>MAX</sub> (°C) | VR2 ICCMAX (A) |
|-------------|------|-----------|-----------------------|----------------|
| Min.(-3%)   | Typ. | Max.(+3%) |                       |                |
|             | 0    |           | 120                   | 33             |
| 0.57        | 0.59 | 0.61      | 120                   | 29             |
| 1.07        | 1.1  | 1.13      | 120                   | 25             |
| 1.64        | 1.69 | 1.74      | 120                   | 21             |
| 2.19        | 2.26 | 2.33      | 110                   | 21             |
| 3.07        | 3.16 | 3.25      | 110                   | 25             |
| 4.19        | 4.32 | 4.45      | 110                   | 29             |
| 5.33        | 5.49 | 5.65      | 110                   | 33             |
| 6.45        | 6.65 | 6.85      | 105                   | 33             |
| 7.63        | 7.87 | 8.11      | 105                   | 29             |
| 9.03        | 9.31 | 9.59      | 105                   | 25             |
| 11.16       | 11.5 | 11.85     | 105                   | 21             |
| 13.29       | 13.7 | 14.11     | 95                    | 21             |
| 15.71       | 16.2 | 16.69     | 95                    | 25             |
| 18.14       | 18.7 | 19.26     | 95                    | 29             |
| 24.15       | 24.9 | open      | 95                    | 33             |

There are two programming resistors: R<sub>prog1</sub> and R<sub>prog2</sub>. Table 7 shows how to select R<sub>prog1</sub> based on V<sub>BOOT</sub> and VR1 ICCMAX

register settings. VR1 can power to 0V V<sub>BOOT</sub> or an internally-set V<sub>BOOT</sub> based on R<sub>prog1</sub> value. When the controller works with an actual CPU, select R<sub>prog1</sub> such that VR1 powers up to V<sub>BOOT</sub> = 0V as required by the SVID command. In the absence of a CPU, such as testing of the VR alone, select R<sub>prog1</sub> such that VR1 powers up to the internally-set V<sub>BOOT</sub>, which by default is 1.1V. Determine the maximum current VR1 can support and set the VR1 ICCMAX register value accordingly by selecting the appropriate R<sub>prog1</sub> value. The CPU will read the VR1 ICCMAX register value and ensure that the CPU CORE current doesn't exceed the value specified by VR1 ICCMAX.

Table 8 shows how to select R<sub>prog2</sub> based on T<sub>MAX</sub> and VR2 ICCMAX register settings. There are four T<sub>MAX</sub> temperatures to choose from: +120°C, +110°C, +105°C, and +95°C. There are also four VR2 ICCMAX values to choose from:

### Current Monitor

Refer to Equation 18 for the IMON pin current expression.

Referring to Figures 1 and 2 on page 6 and page 7, the IMON pin current flows through R<sub>imon</sub>. The voltage across R<sub>imon</sub> is expressed in Equation 39:

$$V_{R_{imon}} = 3 \times I_{droop} \times R_{imon} \quad (\text{EQ. 39})$$

Rewriting Equation 38 gives Equation 40:

$$I_{droop} = \frac{I_o}{R_{droop}} \times LL \quad (\text{EQ. 40})$$

Substitution of Equation 40 into Equation 39 gives Equation 41:

$$V_{R_{imon}} = \frac{3I_o \times LL}{R_{droop}} \times R_{imon} \quad (\text{EQ. 41})$$

Rewriting Equation 41 and application of full load condition gives Equation 42:

$$R_{imon} = \frac{V_{R_{imon}} \times R_{droop}}{3I_o \times LL} \quad (\text{EQ. 42})$$

For example, given LL = 1.9mΩ, R<sub>droop</sub> = 3.74kΩ, V<sub>Rimon</sub> = 2.658V at I<sub>o</sub>max = 94A, Equation 42 gives R<sub>imon</sub> = 18.6kΩ.

A capacitor C<sub>imon</sub> can be paralleled with R<sub>imon</sub> to filter the IMON pin voltage. The R<sub>imon</sub>C<sub>imon</sub> time constant is the user's choice. It is recommended to have a time constant long enough such that switching frequency ripples are removed.

### Current Balancing

Refer to Figures 1 thru 2. The controller achieves current balancing through matching the ISEN pin voltages. R<sub>isen</sub> and C<sub>isen</sub> form filters to remove the switching ripple of the phase node voltages. It is recommended to use rather long R<sub>isen</sub>C<sub>isen</sub> time constant such that the ISEN voltages have minimal ripple and represent the DC current flowing through the inductors. Recommended values are R<sub>s</sub> = 10kΩ and C<sub>s</sub> = 0.22μF.









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## BOM for 3+1 Reference Design

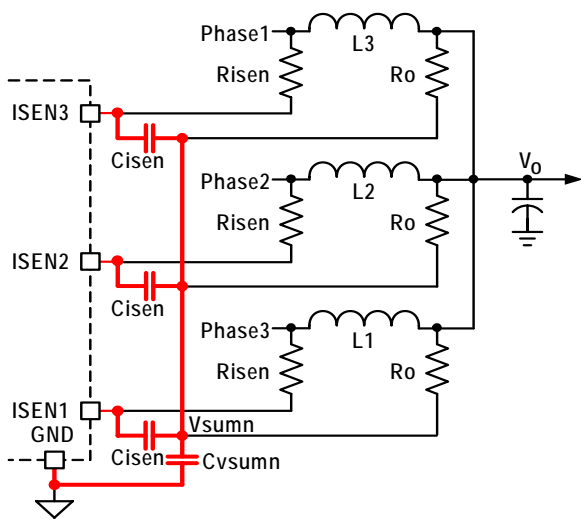
| REFERENCE  | QTY | VALUE  | PART NUMBER          | DESCRIPTION   | PACKAGE   | VENDOR    |
|--|-----|--------|----------------------|---|-----------|-----------|
| C24, C25   | 2   | 56µF   | 25SP56M              | Radial SP Series Cap, 25V, 20%                                | CASE-CC   | SANYO     |
| C27, C28, C29, C33, C34, C35, C110, C112   | 8   | 10µF   | H1065-00106-25V10-T  | Multilayer Cap, 25V, 10%                                      | SM1206    | GENERIC   |
| C30, C31, C32, C111  | 4   | 0.22µF | H1045-00224-16V10-T  | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C39, C44, C52, C57, C113, C117   | 6   | 470µF  | EEFLX0D471R4         | SPCAP, 2V, 4.5mΩ  |           | GENERIC   |
| C40, C41, C42, C43, C45, C46, C47, C48, C49, C50, C54, C55, C56, C59, C75, C76, C240, C241, C242, C243, C247, C248, C249, C250, C254, C255, C256, C259 | 28  | 22µF   | GRM21BR61C226KE15L   | Multilayer CAP, 16V, 10%                                      | SM0805    | GENERIC   |
| C60, C61, C63, C64, C65, C67, C68, C71, C72, C73   | 10  | 10µF   | GRM21BR61C106KE15L   | Multilayer CAP, 16V, 10%                                      | SM0805    | GENERIC   |
| C16, C22, C26, C201  | 4   | 1µF    | H1045-00105-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C20, C97   | 2   | 0.1µF  | H1044-00104-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C96  | 1   | 27nF   | H1045-00273-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C81  | 1   | 2200pF | H1045-00222-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C13, C90   | 2   | 0.01µF | H1045-00103-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C12, C88, C89  | 3   | 330pF  | H1045-00331-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C3, C51  | 2   | 150pF  | H1045-00151-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C130   | 1   | 680pF  | H1045-00681-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C86  | 1   | 39pF   | H1045-00390-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C99  | 1   | 560pF  | H1045-00561-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C4, C85  | 2   | 1000pF | H1045-00102-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C11  | 1   | 390pF  | H1045-00391-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C6   | 1   | 39pF   | H1045-00390-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C7, C9, C10, C17, C18, C82, C95  | 7   | 0.22µF | H1045-00224-16V10    | Multilayer CAP, 16V, 10%                                      | SM0603    | GENERIC   |
| C5, C93  | 2   | DNP    |                      | DNP   | SM0603    | GENERIC   |
| L1, L2, L3, L4   | 4   | 0.36µH | ETQPLR36AFC          | COIL-PWR CHOKE, SMD, 11.5x10, 0.36µH, 20%, 24A, ROHS          | 10mmx10mm | PANASONIC |
| Q4, Q6, Q8, Q2, Q10, Q12   | 6   |        | BSC120N03MS G        | TRANSIST-MOS, N-CHANNEL, SMD, 8P, PG-TDSON-8, 30V, 39A, ROHS  | SuperSO8  | INFINEON  |
| Q5, Q7, Q9, Q3, Q11, Q13   | 6   |        | BSC025N03MS G        | TRANSIST-MOS, N-CHANNEL, SMD, 8P, PG-TDSON-8, 30V, 100A, ROHS | SuperSO8  | INFINEON  |
| Q14, Q18   | 2   |        | BSC090N03MS G        | TRANSIST-MOS, N-CHANNEL, SMD, 8P, PG-TDSON-8, 30V, 48A, ROHS  | SuperSO8  | INFINEON  |
| Q15, Q19   | 2   |        | BSC016N03MS G        | TRANSIST-MOS, N-CHANNEL, SMD, 8P, PG-TDSON-8, 30V, 100A, ROHS | SuperSO8  | INFINEON  |
| R40, R56, R57, R58, R124   | 5   | 0      | H2511-00R00-1/10W1-T | Thick Film Chip Resistor, 1%                                  | SM0603    | GENERIC   |
| R63, R65, R67  | 3   | 3.65k  | H2511-03651-1/10W1-T | Thick Film Chip Resistor, 1%                                  | SM0603    | GENERIC   |

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## BOM for 3+1 Reference Design (Continued)

| REFERENCE                         | QTY | VALUE    | PART NUMBER          | DESCRIPTION                         | PACKAGE      | VENDOR    |
|-----------------------------------|-----|----------|----------------------|-------------------------------------|--------------|-----------|
| R127                              | 1   | 1.87k    | H2511-01871-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R71, R72, R73                     | 3   | 10k      | H2511-01002-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R16, R17, R18, R23, R88, R90, R92 | 7   | 10       | H2511-00100-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R36, R38                          | 2   | 11k      | H2511-01102-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R39                               | 1   | 2.61k    | H2511-02611-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R80, R112                         | 2   | 27.4k    | H2511-02742-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R49, R54                          | 2   | 3.83k    | H2511-03831-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R42, R43                          | 2   | 10k NTC  | ERT-J1VR103J-T       | Thermistor, 10k, NTC                | SM0603       | PANASONIC |
| R20, R8                           | 2   | 470k NTC | NCP18WM474J03RB-T    | Thermistor, 470k, NTC               | SM0603       | MURATA    |
| R31                               | 1   | 887      | H2511-08870-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R24                               | 1   | 422      | H2511-04220-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R25                               | 1   | 2.55k    | H2511-02551-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R9                                | 1   | 475k     | H2511-04753-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R3, R6                            | 2   | 8.06k    | H2511-08061-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R55                               | 1   | 20k      | H2511-02002-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R155                              | 1   | 2k       | H2511-02001-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R7                                | 1   | 267k     | H2511-02673-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R10                               | 1   | 536      | H2511-05360-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R11                               | 1   | 3.74k    | H2511-03741-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R37                               | 1   | 1        | H2511-00010-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R41                               | 1   | 2.61k    | H2511-02611-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R30                               | 1   | 976      | H2511-09760-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R109                              | 1   | 649      | H2511-06490-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R213, R203                        | 2   | 130      | H2511-01300-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R214                              | 1   | 75       | H2511-00750-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R19, R183                         | 2   | 1.91k    | H2511-01911-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R12                               | 1   | 499      | H2511-04990-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R201                              | 1   | 54.9     | H2511-054R9-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R202                              | 1   | 43       | H2511-00430-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R32                               | 1   | DNP      |                      |                                     | SM0603       | GENERIC   |
| U3                                | 1   |          | ISL6208CRZ           | Synchronous Rectified MOSFET DRIVER | SOIC8_150_50 | INTERSIL  |
| R50, R51                          | 2   | 18.2k    | H2511-01822-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R106                              | 1   | 18.7k    | H2511-01872-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R206                              | 1   | 24.9k    | H2511-02492-1/10W1-T | Thick Film Chip Resistor, 1%        | SM0603       | GENERIC   |
| R32                               | 1   | DNP      |                      |                                     | SM0603       | GENERIC   |
| U6                                | 1   |          | ISL95831             | IMVP-7 PWM Controller               | QFN-48       | INTERSIL  |

## Layout Guidelines

| ISL95831<br>PIN NUMBER | SYMBOL                  | LAYOUT GUIDELINES  |
|------------------------|-------------------------|--|
| BOTTOM PAD             | GND                     | Connect this ground pad to the ground plane through low impedance path. Recommend use of at least 5 vias to connect to ground planes in PCB internal layers.   |
| 1                      | VWG                     | Place the capacitor (C4) across VW and COMP in close proximity of the controller.  |
| 2                      | NC                      | No special consideration.  |
| 3                      | PGOODG                  | No special consideration.  |
| 4, 5, 6                | SDA,<br>ALERT#,<br>SCLK | Follow Intel recommendation.   |
| 7                      | VR_ON                   | No special consideration.  |
| 8                      | PGOOD                   | No special consideration.  |
| 9                      | NC                      | No special consideration.  |
| 10                     | VR_HOT#                 | No special consideration.  |
| 11                     | NTC                     | The NTC thermistor (R9) needs to be placed close to the thermal source that is monitored to determine CPU Vcore thermal throttling. Recommend placing it at the hottest spot of the CPU Vcore VR.  |
| 12                     | VW                      | Place the capacitor (C4) across VW and COMP in close proximity of the controller.  |
| 13                     | COMP                    | Place the compensator components (C3, C5, C6 R7, R11, R10 and C11) in general proximity of the controller.   |
| 14                     | FB                      |  |
| 15                     | FB2                     |  |
| 16                     | ISEN3                   | <p>Each ISEN pin has a capacitor (Cisen) decoupling it to VSUMN, then through another capacitor (Cvsumn) to GND. Place Cisen capacitors as close as possible to the controller and keep the following loops small:</p> <ol style="list-style-type: none"> <li>Any ISEN pin to another ISEN pin</li> <li>Any ISEN pin to GND</li> </ol> <p>The red traces in the following drawing show the loops that need to be minimized.</p>  |
| 17                     | ISEN2                   |  |
| 17                     | ISEN1                   |  |
| 18                     | VSEN                    | Place the VSEN/RTN filter (C12, C13) in close proximity of the controller for good decoupling.   |
| 19                     | RTN                     |  |

## Layout Guidelines (Continued)

| ISL95831<br>PIN NUMBER | SYMBOL | LAYOUT GUIDELINES  |
|------------------------|--------|--|
| 20                     | ISUMN  | Place the current sensing circuit in general proximity of the controller.  |
| 21                     | ISUMP  | Place capacitor Cn very close to the controller.<br>Place the NTC thermistor next to VR1 phase-1 inductor (L1) so it senses the inductor temperature correctly.<br>Each phase of the power stage sends a pair of VSUMP and VSUMN signals to the controller. Run these two signals traces in parallel fashion with decent width (>20mil).<br><b>IMPORTANT:</b> Sense the inductor current by routing the sensing circuit to the inductor pads. Route R63 and R71 to VR1 phase-1 side pad of inductor L1. Route R88 to the output side pad of inductor L1. Route R65 and R72 to VR1 phase-2 side pad of inductor L2. Route R90 to the output side pad of inductor L2. If possible, route the traces on a different layer from the inductor pad layer and use vias to connect the traces to the center of the pads. If no via is allowed on the pad, consider routing the traces into the pads from the inside of the inductor. The following drawings show the two preferred ways of routing current sensing traces. |
|                        |        | <p>The diagrams illustrate two preferred methods for routing current sensing traces to inductor pads. The left diagram shows a top-down view of an inductor with two blue pads. Red traces connect to the center of each pad through vias, which are labeled 'Vias'. The right diagram shows a similar view where the red traces connect to the inside of the inductor pads.</p>   |
| 22                     | VDD    | A capacitor (C16) decouples it to GND. Place it in close proximity of the controller.  |
| 23                     | VIN    | A capacitor (C17) decouples it to GND. Place it in close proximity of the controller.  |
| 24                     | PROG1  | No special consideration.  |
| 25                     | BOOT1  | Use decent wide trace (>30mil). Avoid any sensitive analog signal trace from crossing over or getting close.   |
| 26                     | UGATE1 | Run these two traces in parallel fashion with decent width (>30mil). Avoid any sensitive analog signal trace from crossing over or getting close. Recommend routing PHASE1 trace to VR1 phase-1 high-side MOSFET (Q2 and Q8) source pins instead of general copper.  |
| 27                     | PHASE1 |  |
| 28                     | VSSP1  | If available, run VSSP1 trace in parallel with LGATE1 trace. Use decent width (>30mil). Avoid any sensitive analog signal trace from crossing over or getting close.   |
| 29                     | LGATE1 |  |
| 30                     | PWM3   | No special consideration.  |
| 31                     | VCCP   | A capacitor (C22) decouples it to GND. Place it in close proximity of the controller.  |
| 32                     | LGATE2 | If available, run VSSP2 trace in parallel with LGATE2 trace. Use decent width (>30mil). Avoid any sensitive analog signal trace from crossing over or getting close.   |
| 33                     | VSSP2  |  |
| 34                     | PHASE2 | Run these two traces in parallel fashion with decent width (>30mil). Avoid any sensitive analog signal trace from crossing over or getting close. Recommend routing PHASE2 trace to VR1 phase-2 high-side MOSFET (Q4 and Q10) source pins instead of general copper.   |
| 35                     | UGATE2 |  |
| 36                     | BOOT2  | Use decent wide trace (>30mil). Avoid any sensitive analog signal trace from crossing over or getting close.   |
| 37                     | LGATEG | Use decent width (>30mil). Avoid any sensitive analog signal trace from crossing over or getting close.  |
| 38                     | PHASEG | Run these two traces in parallel fashion with decent width (>30mil). Avoid any sensitive analog signal trace from crossing over or getting close. Recommend routing PHASE1G trace to VR2 phase-1 high-side MOSFET source pins instead of general copper.   |
| 39                     | UGATEG |  |
| 40                     | BOOTG  | Use decent wide trace (>30mil). Avoid any sensitive analog signal trace from crossing over or getting close.   |
| 41                     | PROG2  | No special consideration.  |
| 42                     | NTCG   | The NTC thermistor needs to be placed close to the thermal source that is monitored to determine AXG Vcore thermal throttling. Recommend placing it at the hottest spot of the AXG Vcore VR.   |

## Layout Guidelines (Continued)

| ISL95831 PIN NUMBER | SYMBOL | LAYOUT GUIDELINES   |
|---------------------|--------|---|
| 43                  | ISUMNG | Place the current sensing circuit in general proximity of the controller.<br>Place capacitor Cn very close to the controller. |
| 44                  | ISUMPG |   |
| 45                  | RTNG   | Place the VSENG/RTNG filter (C12, C13) in close proximity of the controller for good decoupling.                              |
| 46                  | VSENG  |   |
| 47                  | FBG    | Place the compensator components (C3, C5, C6 R7, R11, R10 and C11) in general proximity of the controller.                    |
| 48                  | COMPG  |   |

## Typical Performance

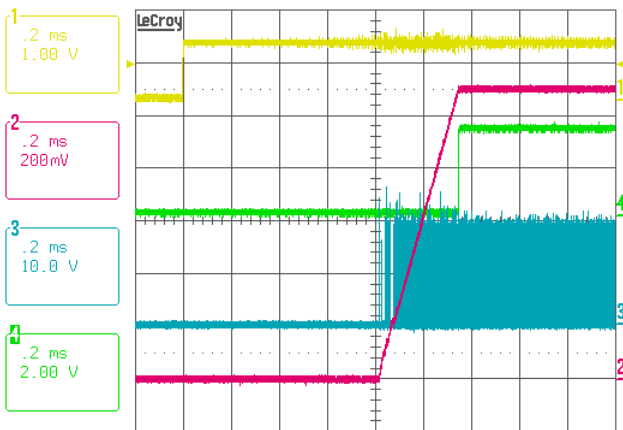


FIGURE 29. VR1 SOFT-START,  $V_{IN} = 19V$ ,  $I_O = 53A$ ,  $V_{ID} = 1.1V$ ,  
Ch1: VR\_ON, Ch2: VR1  $V_O$ , Ch3: PHASE1,  
Ch4: PGOOD

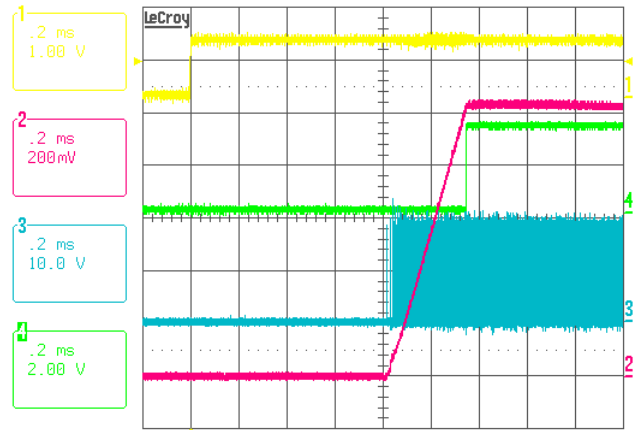


FIGURE 30. VR2 SOFT-START,  $V_{IN} = 19V$ ,  $I_O = 53A$ ,  $V_{ID} = 1.1V$ ,  
Ch1: VR\_ON, Ch2: VR2  $V_O$ , Ch3: PHASE1,  
Ch4: PGOOD

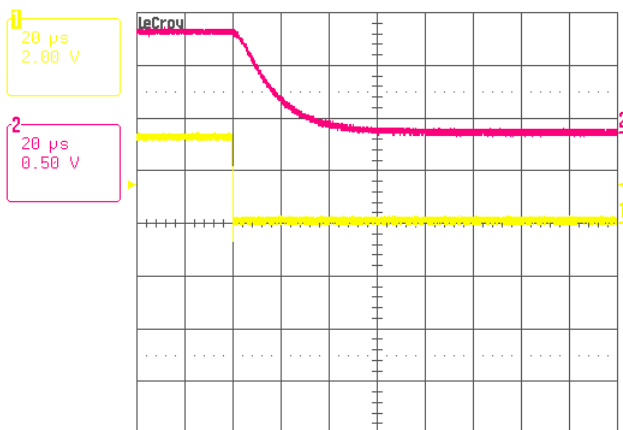


FIGURE 31. VR1 SHUT DOWN,  $V_{IN} = 12V$ ,  $I_O = 94A$ ,  $V_{ID} = 1.1V$ ,  
Ch1: PGOOD, Ch2: VR1  $V_O$

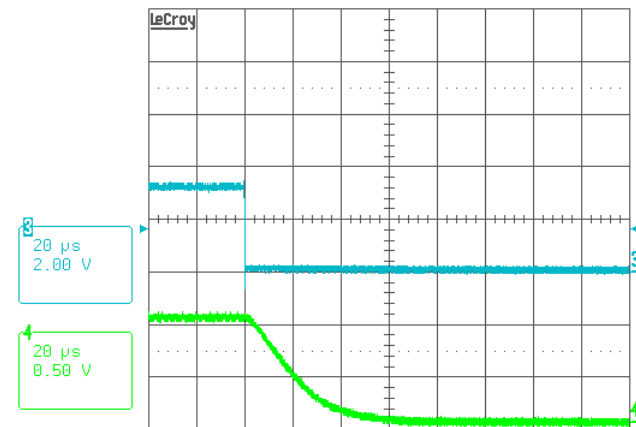
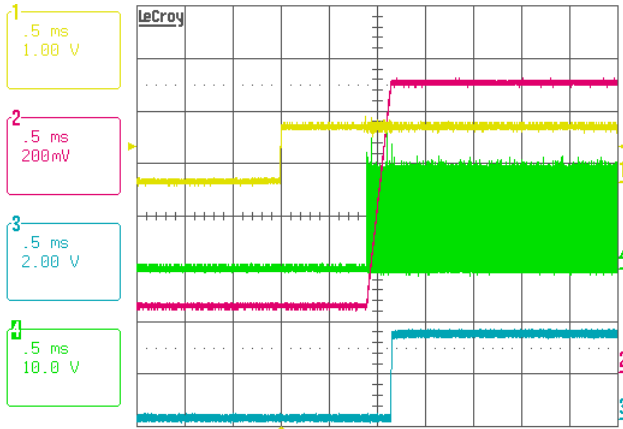
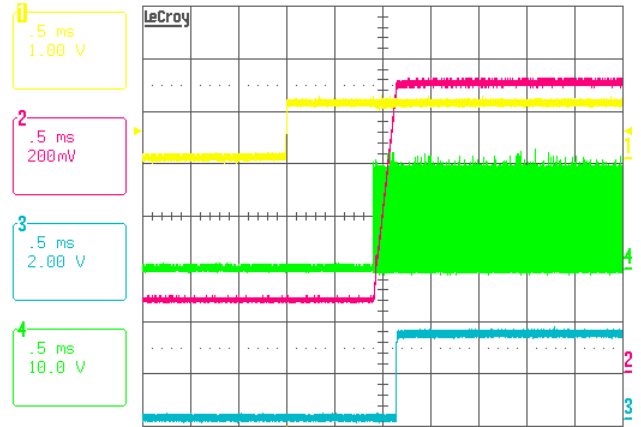


FIGURE 32. VR1 SHUT DOWN,  $V_{IN} = 12V$ ,  $I_O = 33A$ ,  $V_{ID} = 1.1V$ ,  
Ch3: PGOODG, Ch4: VR2  $V_O$

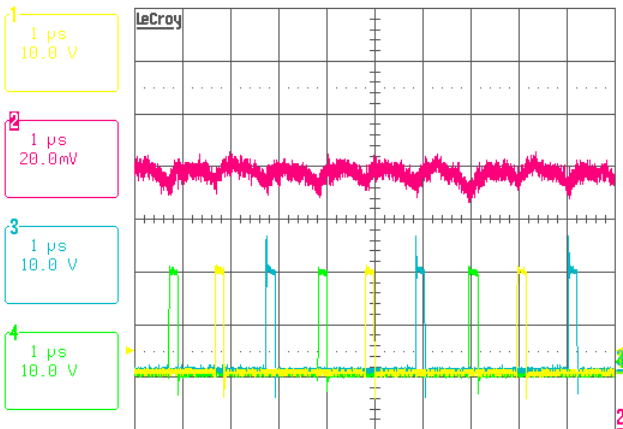
## Typical Performance (Continued)



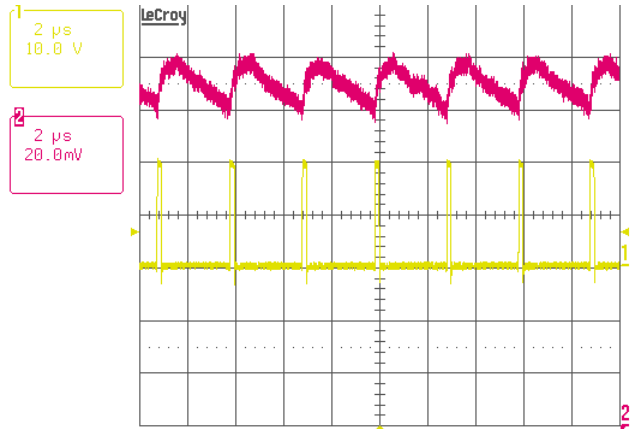
**FIGURE 33. VR1 PRE-CHARGED START UP,  $V_{IN} = 19V$ ,  $VID = 1.1V$ , Ch1: VR\_ON, Ch2: VR1  $V_O$ , Ch3: PGOOD, Ch4: PHASE1**



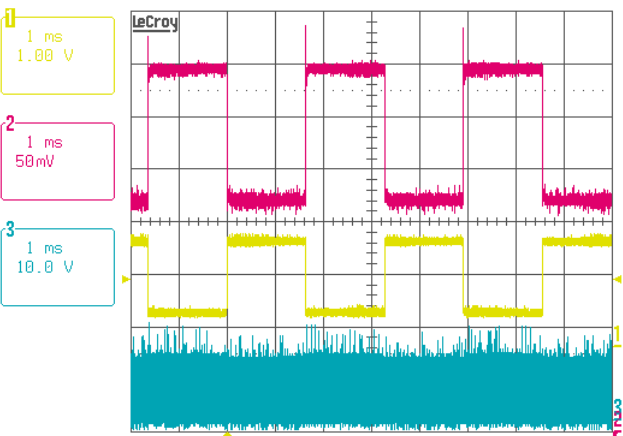
**FIGURE 34. VR2 PRE-CHARGED START UP,  $V_{IN} = 19V$ ,  $VID = 1.1V$ , Ch1: VR\_ON, Ch2: VR2  $V_O$ , Ch3: PGOODG, Ch4: PHASEG**



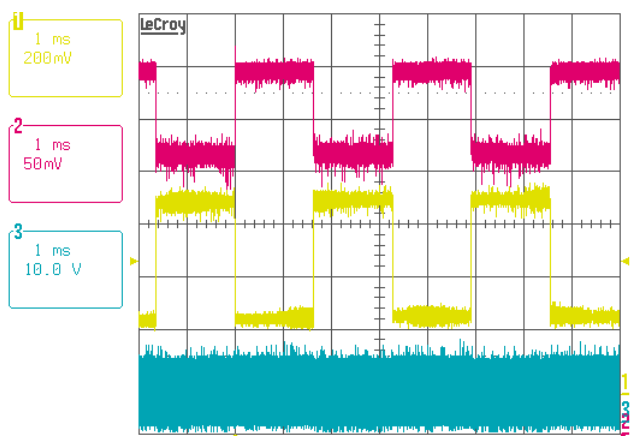
**FIGURE 35. VR1 STEADY STATE,  $V_{IN} = 19V$ ,  $I_O = 94A$ ,  $VID = 1.1V$  Ch1: PHASE1, Ch2: VR1  $V_O$ , Ch3: PHASE2, Ch4: PHASE3**



**FIGURE 36. VR2 STEADY STATE,  $V_{IN} = 19V$ ,  $I_O = 33A$ ,  $VID = 1.1V$  Ch1: PHASEG, Ch2: VR2  $V_O$**

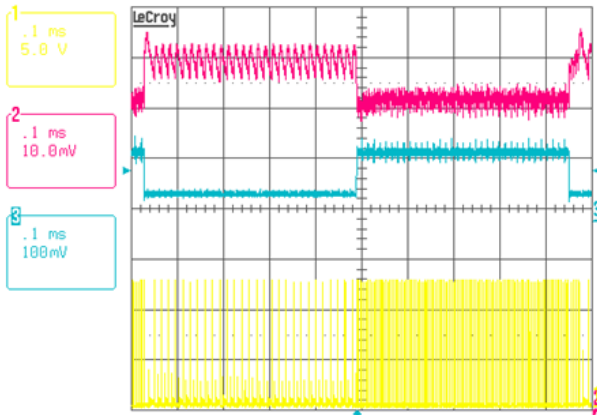


**FIGURE 37. VR1 LOAD TRANSIENT RESPONSE,  $V_{IN} = 19V$ ,  $VID = 1.1V$ ,  $I_O = 28A/94A$ ,  $di/dt = \text{“FASTEST”}$ ,  $LL = 1.9m\Omega$ , Ch1: LOAD CURRENT, Ch2: VR1  $V_O$ , Ch3: PHASE1**

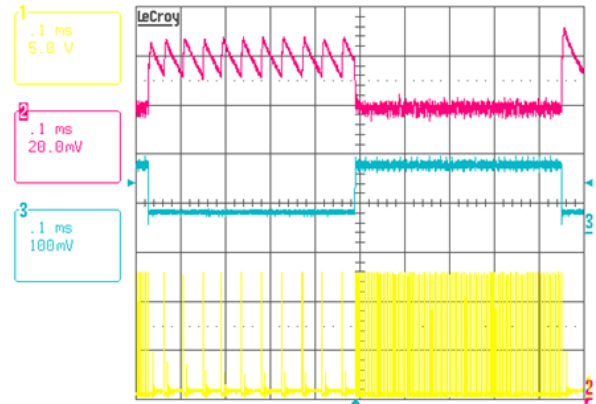


**FIGURE 38. VR2 LOAD TRANSIENT RESPONSE,  $V_{IN} = 12V$ ,  $VID = 1.1V$ ,  $I_O = 13A/33A$ ,  $di/dt = \text{“FASTEST”}$ ,  $LL = 3.9m\Omega$ , Ch1: LOAD CURRENT, Ch2: VR2  $V_O$ , Ch3: PHASEG**

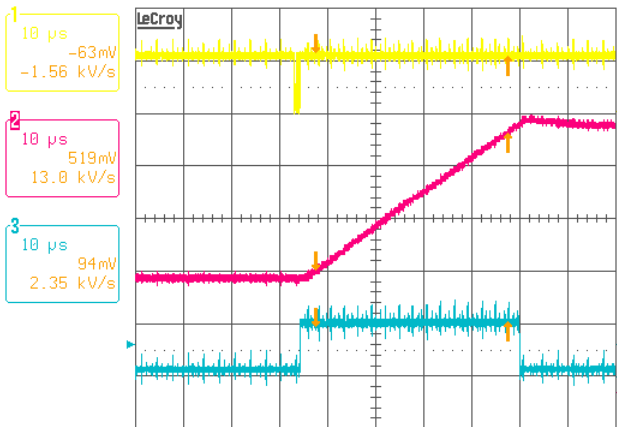
## Typical Performance (Continued)



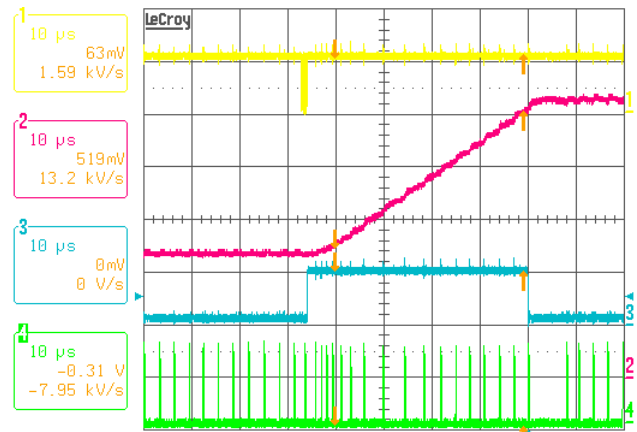
**FIGURE 39. VR1 PS2 LOAD TRANSIENT RESPONSE,  $V_{IN} = 19V$ ,  $VID = 0.3V$ ,  $I_O = 1A/5A$ ,  $di/dt = \text{“FASTEST”}$ ,  $LL = 1.9m\Omega$ , Ch1: PHASE1, Ch2: VR1  $V_O$ , Ch3: LOAD CURRENT**



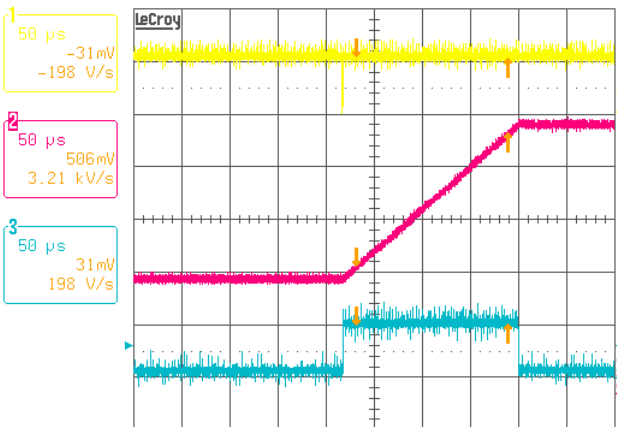
**FIGURE 40. VR2 PS2 LOAD TRANSIENT RESPONSE,  $V_{IN} = 12V$ ,  $VID = 0.3V$ ,  $I_O = 1A/5A$ ,  $di/dt = \text{“FASTEST”}$ ,  $LL = 3.9m\Omega$ , Ch1: PHASEG, Ch2: VR2  $V_O$ , Ch3: LOAD CURRENT**



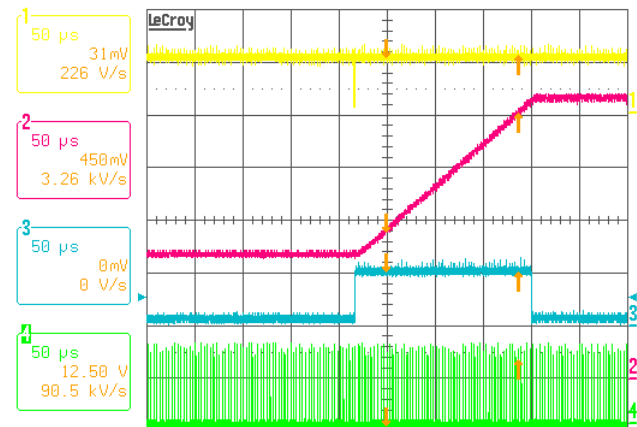
**FIGURE 41. VR1 SETVID-FAST RESPONSE.  $I_O = 50A$ ,  $VID = 0.5V - 1.1V$ , Ch1: SDA, Ch2: VR1  $V_O$ , Ch3: ALERT#**



**FIGURE 42. VR2 SETVID-FAST RESPONSE.  $I_O = 10A$ ,  $VID = 0.5V - 1.1V$ , Ch1: SDA, Ch2: VR2  $V_O$ , Ch3: ALERT#, Ch4: PHASEG**

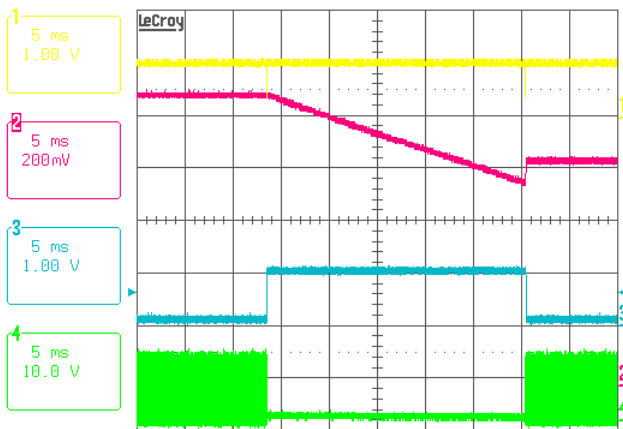


**FIGURE 43. VR1 SETVID-SLOW RESPONSE.  $I_O = 50A$ ,  $VID = 0.5V - 1.1V$ , Ch1: SDA, Ch2: VR1  $V_O$ , Ch3: ALERT#, Ch4:  $V_O$ , Ch5: PHASE3**

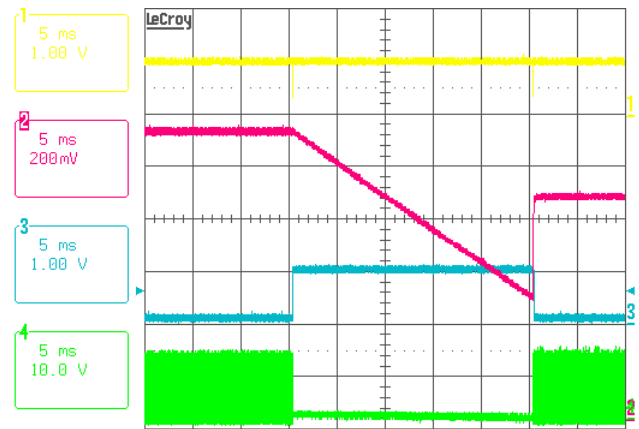


**FIGURE 44. VR2 SETVID-SLOW RESPONSE.  $I_O = 10A$ ,  $VID = 0.5V - 1.1V$ , Ch1: SDA, Ch2: VR2  $V_O$ , Ch3: ALERT#, Ch4: PHASEG**

## Typical Performance (Continued)



**FIGURE 45. VR1 SETVID DECAY PRE\_EMPTIVE BEHAVIOR.**  
 SETVID-FAST 0.85V AFTER SETVID DECAY,  $I_O = 0A$ ,  
 Ch1: SDA, Ch2: VR1  $V_O$ , Ch3: ALERT#,  
 Ch4: PHASE1



**FIGURE 46. VR2 SETVID DECAY PRE\_EMPTIVE BEHAVIOR.**  
 SETVID-FAST 0.85V AFTER SETVID DECAY,  $I_O = 0A$ ,  
 Ch1: SDA, Ch2: VR2  $V_O$ , Ch3: ALERT#,  
 Ch4: PHASE2



## Revision History

The revision history provided is for informational purposes only and is believed to be accurate, but not warranted. Please go to web to make sure you have the latest Rev.

| DATE    | REVISION | CHANGE           |
|---------|----------|------------------|
| 1/21/11 | FN7613.0 | Initial Release. |

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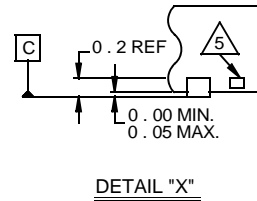
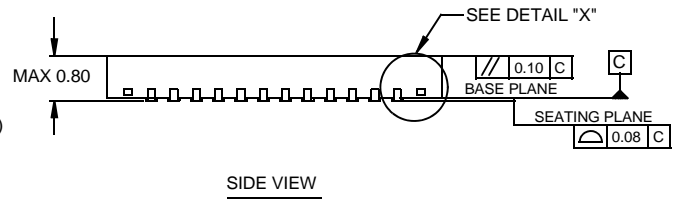
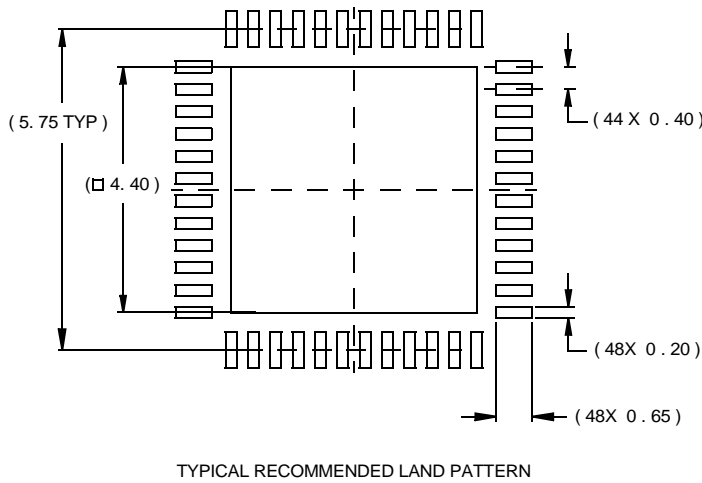
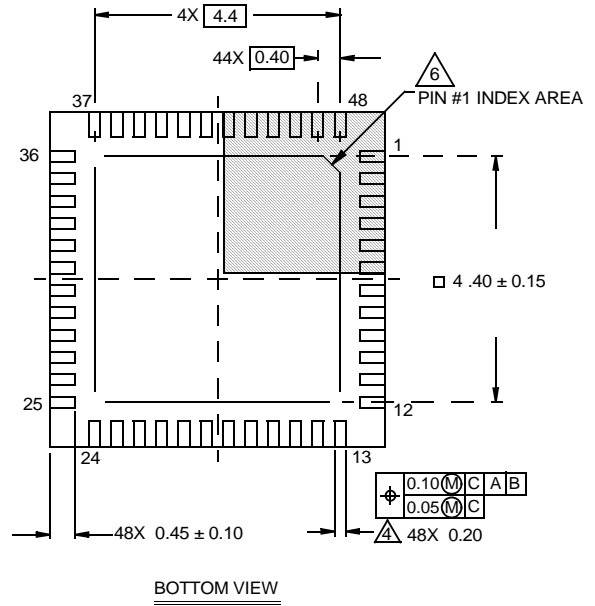
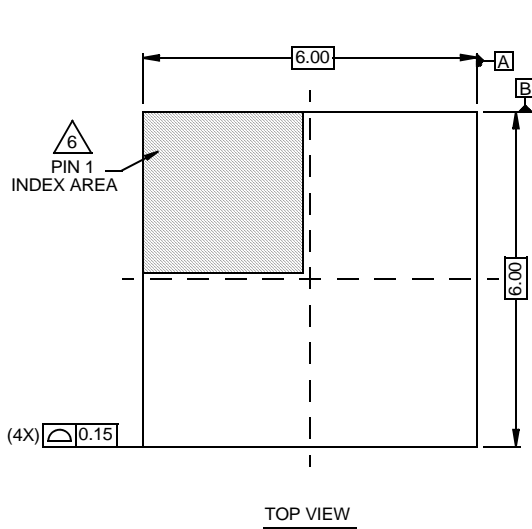
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## Package Outline Drawing

### L48.6x6

#### 48 LEAD THIN QUAD FLAT NO-LEAD PLASTIC PACKAGE

Rev 1, 4/07



#### NOTES:

1. Dimensions are in millimeters.  
Dimensions in ( ) for Reference Only.
2. Dimensioning and tolerancing conform to AMSE Y14.5m-1994.
3. Unless otherwise specified, tolerance : Decimal  $\pm 0.05$
4. Dimension b applies to the metallized terminal and is measured between 0.15mm and 0.30mm from the terminal tip.
5. Tiebar shown (if present) is a non-functional feature.
6. The configuration of the pin #1 identifier is optional, but must be located within the zone indicated. The pin #1 identifier may be either a mold or mark feature.