

# ISL6377

Multiphase PWM Regulator for AMD Fusion Desktop CPUs Using SVI 2.0

FN8336  
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The [ISL6377](#) is fully compliant with AMD Fusion™ SVI 2.0 and provides a complete solution for microprocessor and graphics processor core power. The ISL6377 controller supports two Voltage Regulators (VRs) with three integrated gate drivers and three optional external drivers for maximum flexibility. The Core VR can be configured for 4-, 3-, 2-, or 1-phase operation while the Northbridge VR supports 2- or 1-phase configurations. The two VRs share a serial control bus to communicate with the AMD CPU and achieve lower cost and smaller board area compared with two-chip solutions.

The PWM modulator is based on Intersil's Robust Ripple Regulator R3™ technology. Compared to traditional modulators, the R3 modulator can automatically change switching frequency for faster transient settling time during load transients and improved light-load efficiency.

The ISL6377 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 utilize remote voltage sense, adjustable switching frequency, OC protection and power-good.

## Applications

- AMD fusion CPU/GPU core power
- Desktop computers

## Features

- Supports AMD SVI 2.0 serial data bus interface
  - Serial VID clock frequency range 100kHz to 25MHz
- Dual output controller with integrated drivers
  - Two dedicated core drivers
  - One programmable driver for either core or Northbridge
- Precision voltage regulation
  - 0.5% system accuracy over-temperature
  - 0.5V to 1.55V in 6.25mV steps
  - Enhanced load line accuracy
- Supports multiple current sensing methods
  - Lossless inductor DCR current sensing
  - Precision resistor current sensing
- Programmable 1-, 2-, 3- or 4-phase for the core output and 1- or 2-phase for the Northbridge output
- Adaptive body diode conduction time reduction
- Superior noise immunity and transient response
- Output current and voltage telemetry
- Differential remote voltage sensing
- High efficiency across entire load range
- Programmable slew rate
- Programmable VID offset and droop on both outputs
- Programmable switching frequency for both outputs
- Excellent dynamic current balance between phases
- Protection: OCP/WOC, OVP, PG00D and thermal monitor
- Small footprint 48 Ld 6x6 QFN package
  - Pb-free (RoHS compliant)

## Core Performance

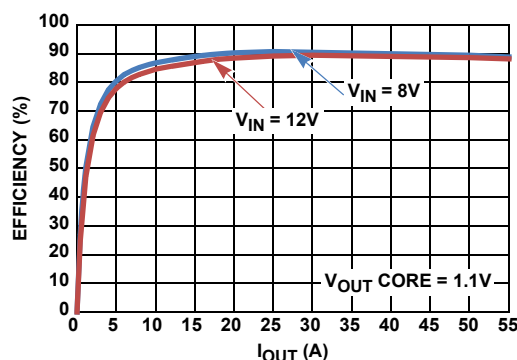


FIGURE 1. EFFICIENCY vs LOAD

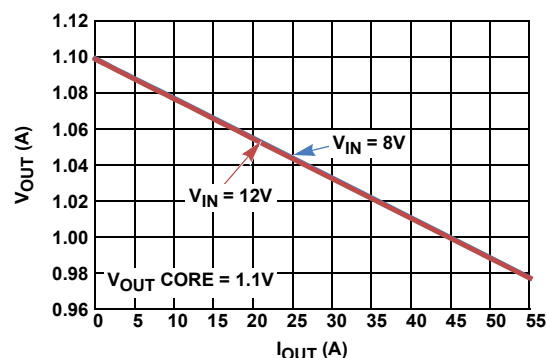


FIGURE 2. VOUT vs LOAD

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## Simplified Application Circuit for High Power CPU Core

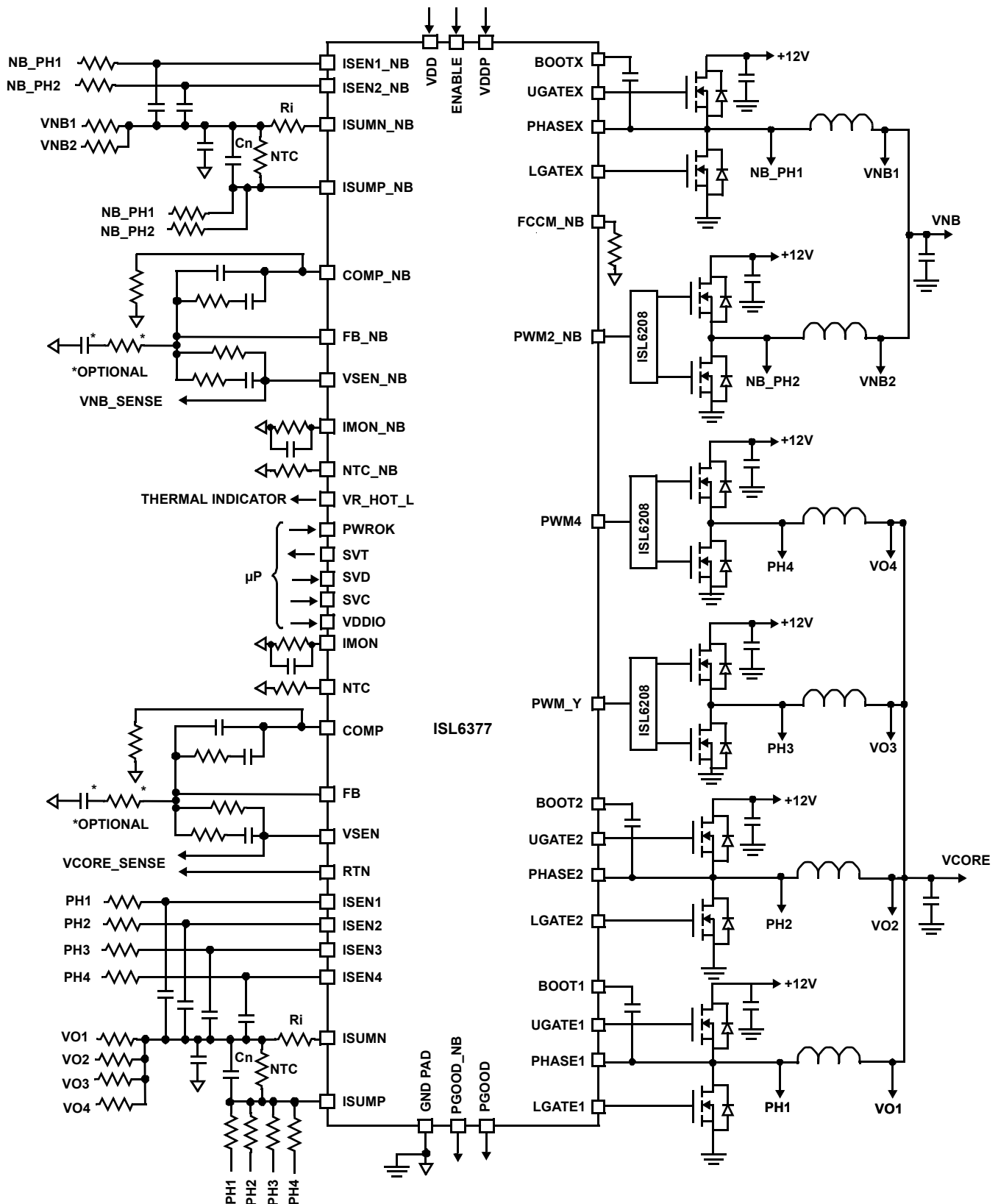


FIGURE 3. TYPICAL APPLICATION CIRCUIT USING INDUCTOR DCR SENSING

## Simplified Application Circuit with 3 Internal Drivers Used for Core

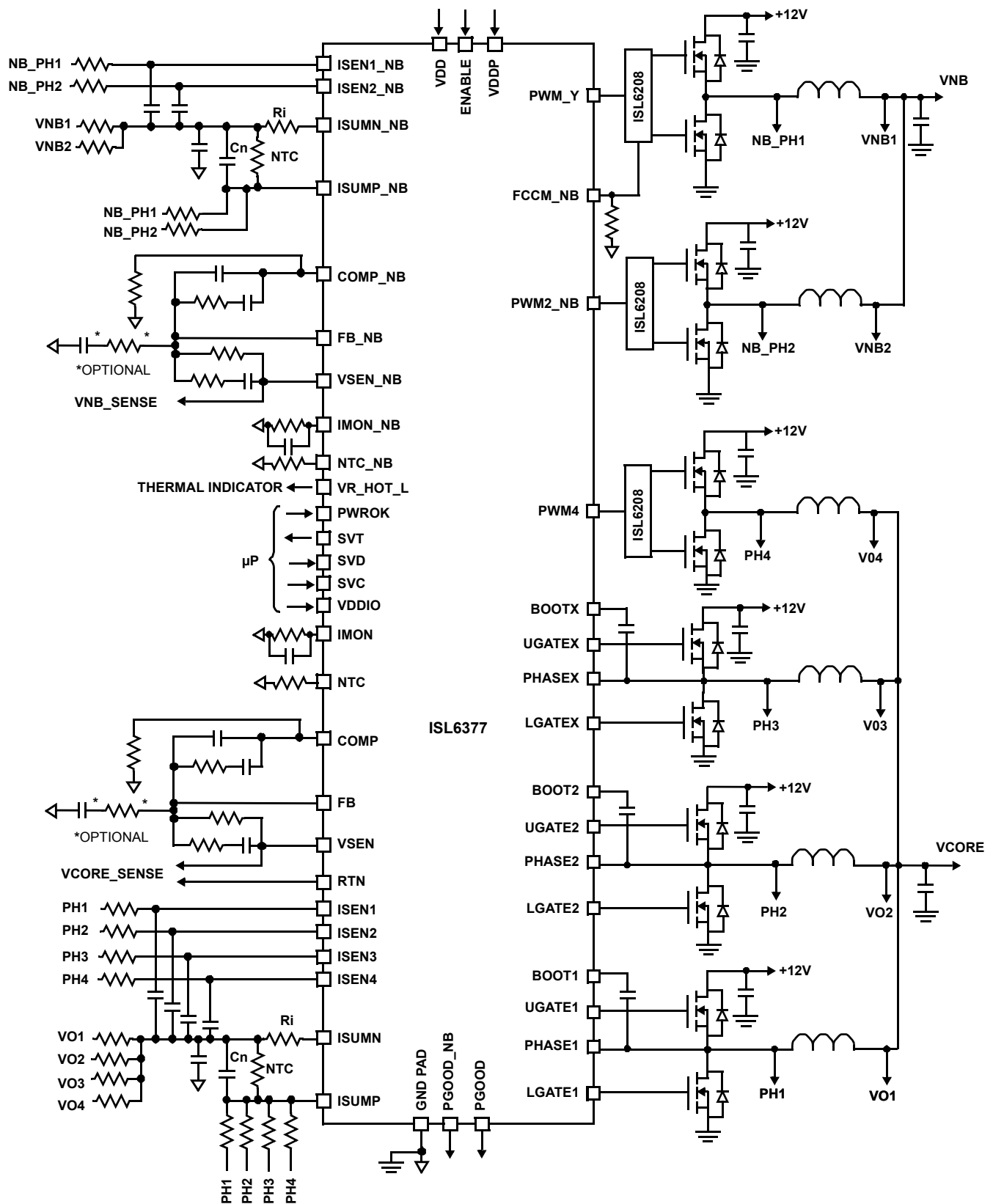


FIGURE 4. TYPICAL APPLICATION CIRCUIT USING INDUCTOR DCR SENSING

## Simplified Application Circuit for Mid-Power CPUs [3+1 Configuration]

\* Resistor required or ISEN1\_NB will pull HIGH if left open and disable Channel 1.

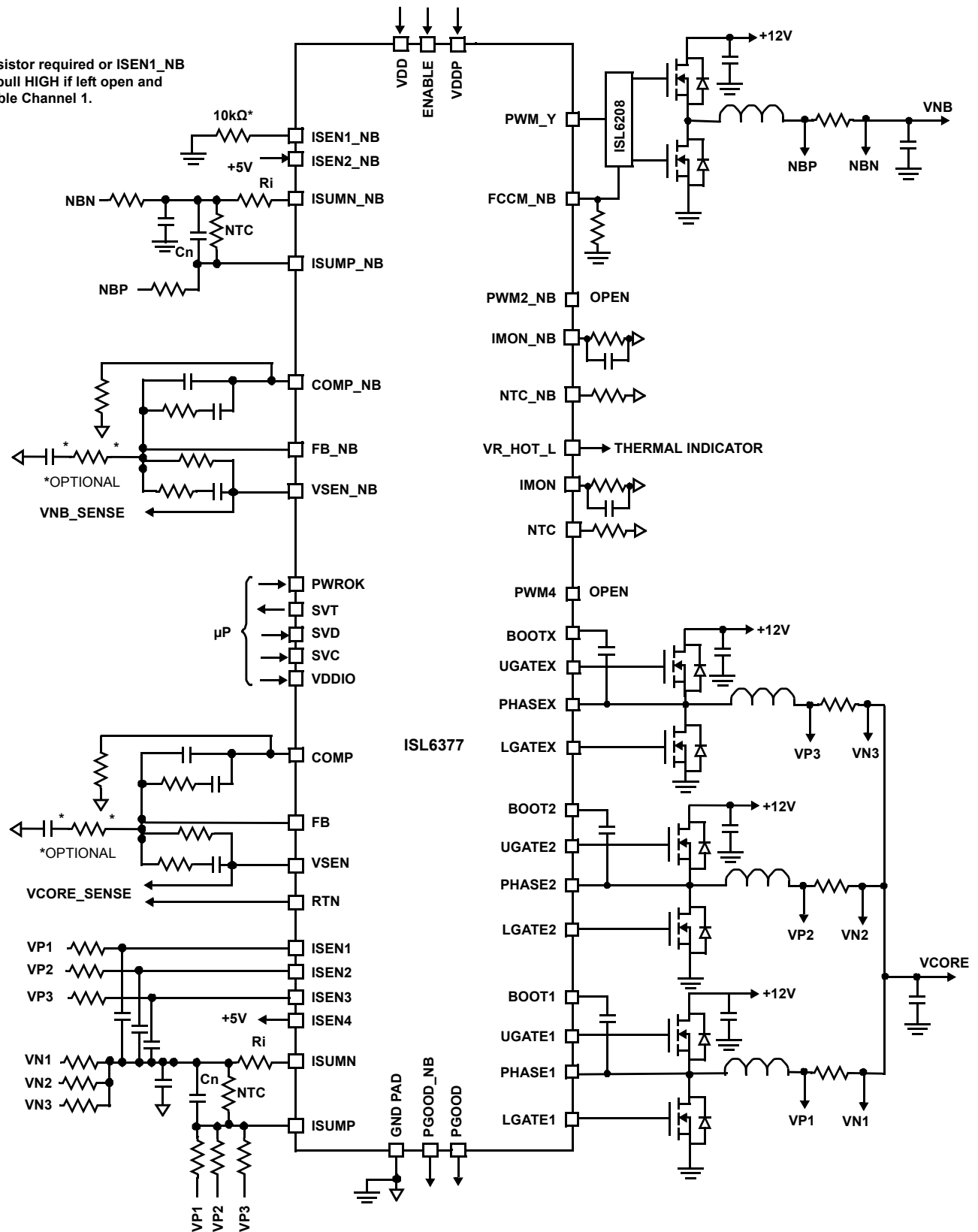


FIGURE 5. TYPICAL APPLICATION CIRCUIT USING RESISTOR SENSING

## Block Diagram

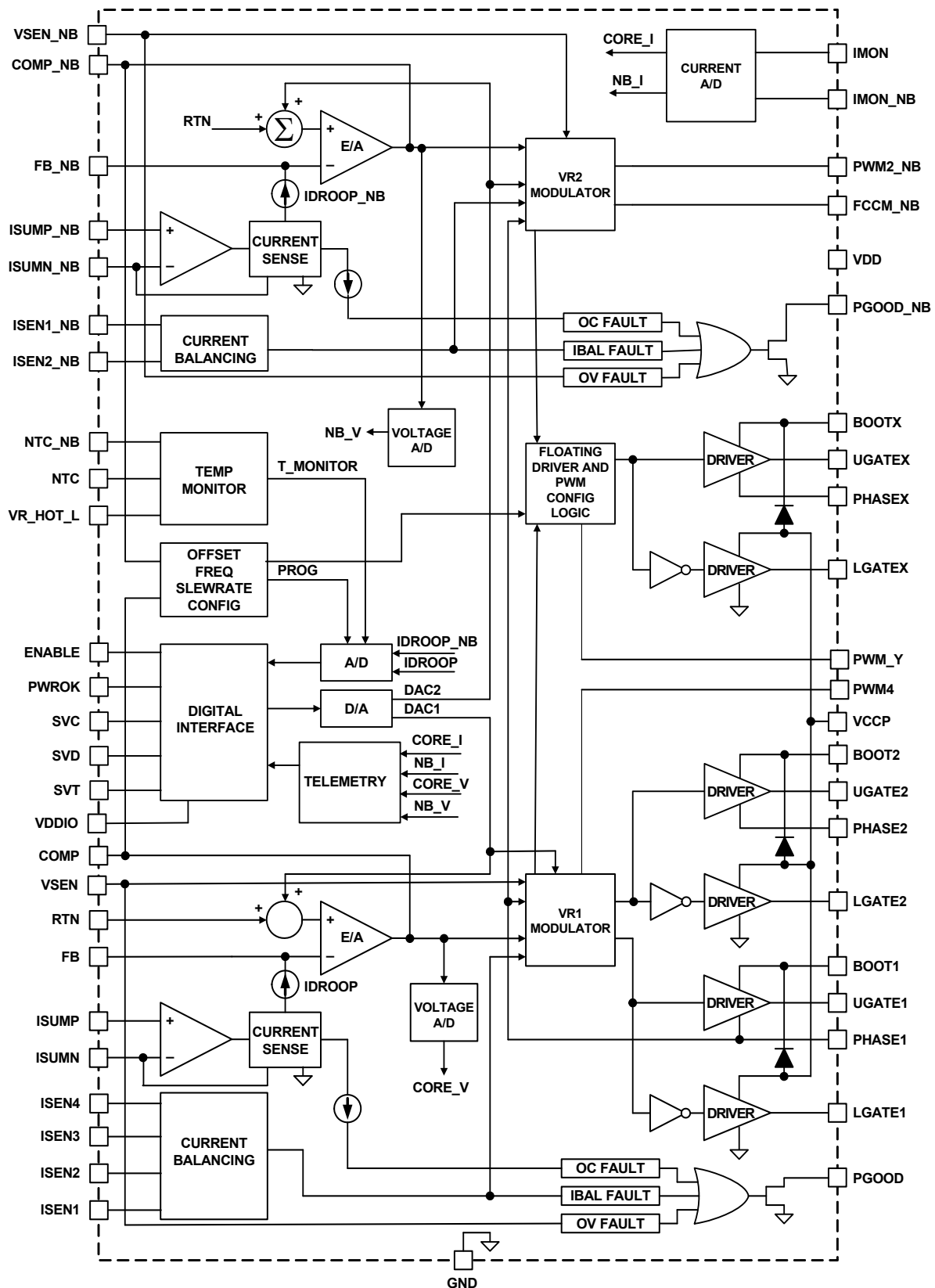
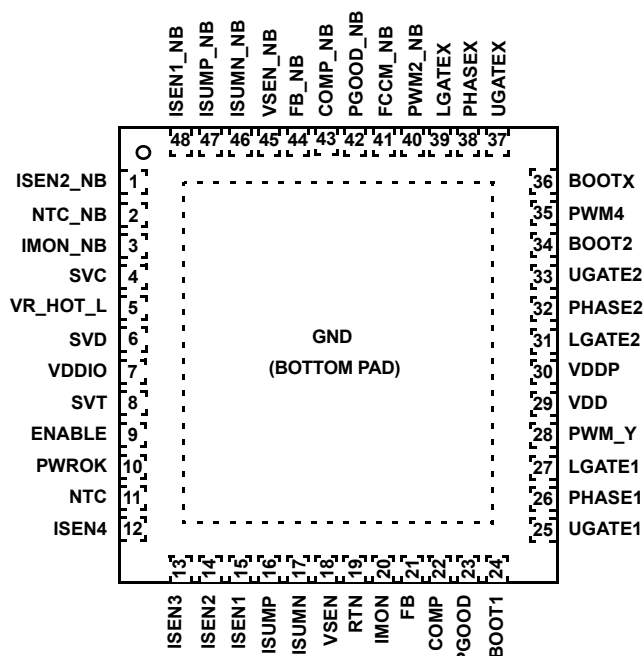


FIGURE 6. BLOCK DIAGRAM

## Pin Configuration

ISL6377  
(48 LD QFN)  
TOP VIEW



## Pin Descriptions

| PIN NUMBER | SYMBOL   | DESCRIPTION                                                                                                                                                                                                                                                                                                                     |
|------------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1          | ISEN2_NB | Individual current sensing for Channel 2 of the Northbridge VR. When ISEN2_NB is pulled to +5V, the controller will disable Channel 2 and the Northbridge VR will run single-phase.                                                                                                                                             |
| 2          | NTC_NB   | Thermistor input to VR_HOT_L circuit to monitor Northbridge VR temperature.                                                                                                                                                                                                                                                     |
| 3          | IMON_NB  | Northbridge output current monitor. A current proportional to the Northbridge VR output current is sourced from this pin.                                                                                                                                                                                                       |
| 4          | SVC      | Serial VID clock input from the CPU processor master device.                                                                                                                                                                                                                                                                    |
| 5          | VR_HOT_L | Thermal indicator signal to AMD CPU. Thermal overload open-drain output indicator active LOW.                                                                                                                                                                                                                                   |
| 6          | SVD      | Serial VID data bidirectional signal from the CPU processor master device to the VR.                                                                                                                                                                                                                                            |
| 7          | VDDIO    | VDDIO is the processor memory interface power rail and this pin serves as the reference to the controller IC for this processor I/O signal level.                                                                                                                                                                               |
| 8          | SVT      | Serial VID Telemetry (SVT) data line input to the CPU from the controller IC. Telemetry and VID-on-the-fly complete signal provided from this pin.                                                                                                                                                                              |
| 9          | ENABLE   | Enable input. A high level logic on this pin enables both VRs.                                                                                                                                                                                                                                                                  |
| 10         | PWROK    | System power-good input. When this pin is high, the SVI 2 interface is active and the I <sup>2</sup> C protocol is running. While this pin is low, the SVC and SVD input states determine the pre-PWROK metal VID. This pin must be low prior to the ISL6377 PGOOD output going high per the AMD SVI 2.0 Controller Guidelines. |
| 11         | NTC      | Thermistor input to VR_HOT_L circuit to monitor Core VR temperature.                                                                                                                                                                                                                                                            |
| 12         | ISEN4    | ISEN4 is the individual current sensing for Channel 4. When ISEN4 is pulled to +5V, the controller disables Channel 4 and the Core VR runs in three-phase mode.                                                                                                                                                                 |
| 13         | ISEN3    | ISEN3 is the individual current sensing for Channel 3. When ISEN3 is pulled to +5V, the controller disables Channel 3 and the Core VR runs in two-phase mode.                                                                                                                                                                   |

## Pin Descriptions (Continued)

| PIN NUMBER | SYMBOL | DESCRIPTION                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 14         | ISEN2  | Individual current sensing for Channel 2 of the Core VR. When ISEN2 is pulled to +5V, the controller disables Channel 2 and the Core VR runs in single-phase mode.                                                                                                                                                                                                                                                                                                                  |
| 15         | ISEN1  | Individual current sensing for Channel 1 of the Core VR. If ISEN2 is tied to +5V, this pin cannot be left open and must be tied to GND with a 10kΩ resistor. If ISEN1 is tied to +5V, the Core portion of the IC is shut down.                                                                                                                                                                                                                                                      |
| 16         | ISUMP  | Noninverting input of the transconductance amplifier for current monitor and load line of Core output.                                                                                                                                                                                                                                                                                                                                                                              |
| 17         | ISUMN  | Inverting input of the transconductance amplifier for current monitor and load line of Core output.                                                                                                                                                                                                                                                                                                                                                                                 |
| 18         | VSEN   | Output voltage sense pin for the Core controller. Connect to the +sense pin of the microprocessor die.                                                                                                                                                                                                                                                                                                                                                                              |
| 19         | RTN    | Output voltage sense return pin for both Core VR and Northbridge VR. Connect to the -sense pin of the microprocessor die.                                                                                                                                                                                                                                                                                                                                                           |
| 20         | IMON   | Core output current monitor. A current proportional to the Core VR output current is sourced from this pin.                                                                                                                                                                                                                                                                                                                                                                         |
| 21         | FB     | Output voltage feedback to the inverting input of the Core controller error amplifier.                                                                                                                                                                                                                                                                                                                                                                                              |
| 22         | COMP   | Core controller error amplifier output. A resistor from COMP to GND sets the Core VR offset voltage.                                                                                                                                                                                                                                                                                                                                                                                |
| 23         | PGOOD  | Open-drain output to indicate the Core portion of the IC is ready to supply regulated voltage. Pull-up externally to VDD or 3.3V through a resistor.                                                                                                                                                                                                                                                                                                                                |
| 24         | 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 VDDP pin to the BOOT1 pin, each time the PHASE1 pin drops below VDDP minus the voltage dropped across the internal boot diode.                                                                                                                                                                                                     |
| 25         | UGATE1 | Output of the Phase 1 high-side MOSFET gate driver of the Core VR. Connect the UGATE1 pin to the gate of the Phase 1 high-side MOSFET(s).                                                                                                                                                                                                                                                                                                                                           |
| 26         | PHASE1 | Current return path for the Phase 1 high-side MOSFET gate driver of VR1. Connect the PHASE1 pin to the node consisting of the high-side MOSFET source, the low-side MOSFET drain and the output inductor of Phase 1.                                                                                                                                                                                                                                                                |
| 27         | LGATE1 | Output of the Phase 1 low-side MOSFET gate driver of the Core VR. Connect the LGATE1 pin to the gate of the Phase 1 low-side MOSFET(s).                                                                                                                                                                                                                                                                                                                                             |
| 28         | PWM_Y  | Floating PWM output used for either Channel 3 of the Core VR or Channel 1 of the Northbridge VR depending on the FCCM_NB resistor connected between FCCM_NB and GND.                                                                                                                                                                                                                                                                                                                |
| 29         | VDD    | 5V bias power. A resistor [2Ω] and a decoupling capacitor should be used from the +5V supply. A high quality, X7R dielectric MLCC capacitor is recommended.                                                                                                                                                                                                                                                                                                                         |
| 30         | VDDP   | Input voltage bias for the internal gate drivers. Connect +5V to the VDDP pin. Decouple with at least 1μF of capacitance to GND. A high quality, X7R dielectric MLCC capacitor is recommended.                                                                                                                                                                                                                                                                                      |
| 31         | LGATE2 | Output of the Phase 2 low-side MOSFET gate driver of the Core VR. Connect the LGATE2 pin to the gate of the Phase 2 low-side MOSFET(s).                                                                                                                                                                                                                                                                                                                                             |
| 32         | PHASE2 | Current return path for the Phase 2 high-side MOSFET gate driver of the Core VR. Connect the PHASE2 pin to the node consisting of the high-side MOSFET source, the low-side MOSFET drain and the output inductor of Phase 2.                                                                                                                                                                                                                                                        |
| 33         | UGATE2 | Output of the Phase 2 high-side MOSFET gate driver of the Core VR. Connect the UGATE2 pin to the gate of the Phase 2 high-side MOSFET(s).                                                                                                                                                                                                                                                                                                                                           |
| 34         | BOOT2  | Connect an MLCC capacitor across the BOOT2 and PHASE2 pins. The boot capacitor is charged, through an internal boot diode connected from the VDDP pin to the BOOT2 pin, each time the PHASE2 pin drops below VDDP minus the voltage dropped across the internal boot diode.                                                                                                                                                                                                         |
| 35         | PWM4   | PWM output of Channel 4 of the Core VR. Disabled if ISEN4 is tied to +5V.                                                                                                                                                                                                                                                                                                                                                                                                           |
| 36         | BOOTX  | Boot connection of the programmable internal driver used for either Channel 3 of the Core VR or Channel 1 of the Northbridge VR based on the configuration state selected by the FCCM_NB resistor. Connect an MLCC capacitor across the BOOT1X and the PHASEX pins. The boot capacitor is charged, through an internal boot diode connected from the VDDP pin to the BOOTX pin, each time the PHASEX pin drops below VDDP minus the voltage dropped across the internal boot diode. |



## Pin Descriptions (Continued)

| PIN NUMBER | SYMBOL           | DESCRIPTION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------------|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 37         | UGATEX           | High-side MOSFET gate driver portion of the programmable internal driver used for either Channel 3 of the Core VR or Channel 1 of the Northbridge VR based on the configuration state selected by the FCCM_NB resistor. Connect the UGATEX pin to the gate of the high-side MOSFET(s) for either Phase 3 of the Core VR or Phase 1 of the Northbridge VR based on the configuration state selected.                                                                                                                                        |
| 38         | PHASEX           | Phase connection of the programmable internal driver used for either Channel 3 of the Core VR or Channel 1 of the Northbridge VR based on the configuration state selected by the FCCM_NB resistor. Current return path for the high-side MOSFET gate driver of the floating internal driver. Connect the PHASEX pin to the node consisting of the high-side MOSFET source, the low-side MOSFET drain and the output inductor of either Phase 3 of the Core VR or Phase 1 of the Northbridge VR based on the configuration state selected. |
| 39         | LGATEX           | Low-side MOSFET gate driver portion of floating internal driver used for either Channel 3 of the Core VR or Channel 1 of the Northbridge VR based on the configuration state selected by the FCCM_NB resistor. Connect the LGATEX pin to the gate of the low-side MOSFET(s) for either Phase 3 of the Core VR or Phase 1 of the Northbridge VR based on the configuration state selected.                                                                                                                                                  |
| 40         | PWM2_NB          | PWM output for Channel 2 of the Northbridge VR. Disabled when ISEN2_NB is tied to +5V.                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 41         | FCCM_NB          | Diode emulation control signal for Intersil MOSFET Drivers. When FCCM_NB is LOW, diode emulation at the driver this pin connects to is allowed. A resistor from FCCM_NB pin to GND configures the PWM_Y and floating internal gate driver [BOOTX, UGATEX, PHASEX, LGATEX pins] to support Phase 3 of the Core VR and Phase 1 of the Northbridge VR. The FCCM_NB resistor value also is used to set the slew rate for the Core VR and Northbridge VR.                                                                                       |
| 42         | PGOOD_NB         | Open-drain output to indicate the Northbridge portion of the IC is ready to supply regulated voltage. Pull up externally to VDDP or 3.3V through a resistor.                                                                                                                                                                                                                                                                                                                                                                               |
| 43         | COMP_NB          | Northbridge VR error amplifier output. A resistor from COMP_NB to GND sets the Northbridge VR offset voltage and is used to set the switching frequency for the Core VR and Northbridge VR.                                                                                                                                                                                                                                                                                                                                                |
| 44         | FB_NB            | Output voltage feedback to the inverting input of the Northbridge controller error amplifier.                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 45         | VSEN_NB          | Output voltage sense pin for the Northbridge controller. Connect to the +sense pin of the microprocessor die.                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 46         | ISUMN_NB         | Inverting input of the transconductance amplifier for current monitor and load line of the Northbridge VR.                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 47         | ISUMP_NB         | Noninverting input of the transconductance amplifier for current monitor and load line of the Northbridge VR.                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 48         | ISEN1_NB         | Individual current sensing for Channel 1 of the Northbridge VR. If ISEN2_NB is tied to +5V, this pin cannot be left open and must be tied to GND with a 10kΩ resistor. If ISEN1_NB is tied to +5V, the Northbridge portion of the IC is shutdown.                                                                                                                                                                                                                                                                                          |
|            | GND (Bottom Pad) | Signal common of the IC. Unless otherwise stated, signals are referenced to the GND pin.                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

## Ordering Information

| PART NUMBER<br>(Notes 1, 2, 3) | PART<br>MARKING | TEMP.<br>RANGE (°C) | PACKAGE<br>(RoHS Compliant) | PKG.<br>DWG. # |
|--------------------------------|-----------------|---------------------|-----------------------------|----------------|
| ISL6377HRZ                     | ISL6377 HRZ     | -10 to +100         | 48 Ld 6x6 QFN               | L48.6x6B       |
| ISL6377IRZ                     | ISL6377 IRZ     | -40 to +85          | 48 Ld 6x6 QFN               | L48.6x6B       |

### NOTES:

1. Add "-T" suffix for tape and reel. Please refer to [TB347](#) for details on reel specifications.
2. Intersil Pb-free plus anneal products employ special Pb-free material sets; molding compounds/die attach materials and 100% matte tin plate termination finish, which are 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 [ISL6377](#). For more information on MSL please see tech brief [TB363](#).

## Absolute Maximum Ratings

|                                                     |                                                       |
|-----------------------------------------------------|-------------------------------------------------------|
| Supply Voltage, $V_{DD}$ , $V_{DDP}$ .....          | -0.3V to +7V                                          |
| Boot Voltage (BOOT) .....                           | -0.3V to +33V                                         |
| Boot to Phase Voltage (BOOT-PHASE) .....            | -0.3V to +7V(DC)                                      |
|                                                     | -0.3V to +9V (<10ns)                                  |
| Phase Voltage (PHASE) .....                         | -7V (<20ns Pulse Width, 10 $\mu$ J)                   |
| UGATE Voltage (UGATE) .....                         | PHASE - 0.3V (DC) to BOOTPHASE - 5V                   |
|                                                     | (<20ns Pulse Width, 10 $\mu$ J) to BOOT LGATE Voltage |
|                                                     | -2.5V (<20ns Pulse Width, 5 $\mu$ J) to VDD + 0.3V    |
| All Other Pins .....                                | -0.3V to (VDD + 0.3V)                                 |
| Open-Drain Outputs, PGOOD, PGOOD_NB, VR_HOT_L ..... | -0.3V to +7V                                          |

## Thermal Information

|                                                      |                           |                      |
|------------------------------------------------------|---------------------------|----------------------|
| Thermal Resistance (Typical)                         | $\theta_{JA}$ (°C/W)      | $\theta_{JC}$ (°C/W) |
| 48 Ld QFN Package (Notes 4, 5) .....                 | 29                        | 3.5                  |
| 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 <a href="#">TB493</a> |                      |

## Recommended Operating Conditions

|                                      |                 |
|--------------------------------------|-----------------|
| Supply Voltage, $V_{DD}$ .....       | +5V $\pm$ 5%    |
| Input Supply Voltage, $V_{IN}$ ..... | 10V to 12.6V    |
| Ambient Temperature                  |                 |
| HRZ .....                            | -10°C to +100°C |
| IRZ .....                            | -40°C to +85°C  |
| Junction Temperature .....           | -10°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:  $V_{DD} = 5V$ ,  $T_A = -10^\circ\text{C}$  to  $+100^\circ\text{C}$  (HRZ),  $T_A = -40^\circ\text{C}$  to  $+85^\circ\text{C}$  (IRZ),  $f_{SW} = 300\text{kHz}$ , unless otherwise noted. **Boldface limits apply across the operating temperature range,  $-40^\circ\text{C}$  to  $+100^\circ\text{C}$ .**

| PARAMETER                            | SYMBOL                            | TEST CONDITIONS                                                  | MIN<br>(Note 6) | TYP  | MAX<br>(Note 6) | UNIT |
|--------------------------------------|-----------------------------------|------------------------------------------------------------------|-----------------|------|-----------------|------|
| INPUT POWER SUPPLY                   |                                   |                                                                  |                 |      |                 |      |
| +5V Supply Current                   | I <sub>VDD</sub>                  | ENABLE = 1V                                                      |                 | 8    | 11              | mA   |
|                                      |                                   | ENABLE = 0V                                                      |                 |      | 1               | μA   |
| POWER-ON-RESET THRESHOLDS            |                                   |                                                                  |                 |      |                 |      |
| VDD POR Threshold                    | VDD_POR <sub>r</sub>              | V <sub>DD</sub> rising                                           |                 | 4.35 | 4.5             | V    |
|                                      | VDD_POR <sub>f</sub>              | V <sub>DD</sub> falling                                          | 4               | 4.15 |                 | V    |
| SYSTEM AND REFERENCES                |                                   |                                                                  |                 |      |                 |      |
| System Accuracy                      | HRZ<br>%Error (V <sub>OUT</sub> ) | No load; closed loop, active mode range,<br>VID = 0.75V to 1.55V | -0.5            |      | +0.5            | %    |
|                                      |                                   | VID = 0.25V to 0.74375V                                          | -10             |      | +10             | mV   |
|                                      | IRZ<br>%Error (V <sub>OUT</sub> ) | No load; closed loop, active mode range,<br>VID = 0.75V to 1.55V | -0.8            |      | +0.8            | %    |
|                                      |                                   | VID = 0.25V to 0.74375V                                          | -12             |      | +12             | mV   |
| Maximum Output Voltage               | V <sub>OUT(max)</sub>             | VID = [00000000]                                                 |                 | 1.55 |                 | V    |
| Minimum Output Voltage               | V <sub>OUT(min)</sub>             | VID = [11111111]                                                 |                 | 0.0  |                 | V    |
| CHANNEL FREQUENCY                    |                                   |                                                                  |                 |      |                 |      |
| Nominal Channel Frequency            | f <sub>SW(nom)</sub>              |                                                                  | 280             | 300  | 320             | kHz  |
| Adjustment Range                     |                                   |                                                                  | 300             |      | 450             | kHz  |
| AMPLIFIERS                           |                                   |                                                                  |                 |      |                 |      |
| Current-Sense Amplifier Input Offset | HRZ                               | I <sub>FB</sub> = 0A                                             | -0.15           |      | +0.15           | mV   |
|                                      | IRZ                               | I <sub>FB</sub> = 0A                                             | -0.20           |      | +0.20           | mV   |
| Error Amp DC Gain                    | A <sub>v0</sub>                   |                                                                  |                 | 119  |                 | dB   |
| Error Amp Gain-Bandwidth Product     | GBW                               | C <sub>L</sub> = 20pF                                            |                 | 17   |                 | MHz  |
| ISEN                                 |                                   |                                                                  |                 |      |                 |      |
| Input Bias Current                   |                                   |                                                                  |                 | 20   |                 | nA   |

**Electrical Specifications** Operating Conditions:  $V_{DD} = 5V$ ,  $T_A = -10^\circ C$  to  $+100^\circ C$  (HRZ),  $T_A = -40^\circ C$  to  $+85^\circ C$  (IRZ),  $f_{SW} = 300kHz$ , unless otherwise noted. **Boldface limits apply across the operating temperature range,  $-40^\circ C$  to  $+100^\circ C$ .** (Continued)

| PARAMETER                                                         | SYMBOL                 | TEST CONDITIONS                                                                                   | MIN<br>( <a href="#">Note 6</a> ) | TYP  | MAX<br>( <a href="#">Note 6</a> ) | UNIT |
|-------------------------------------------------------------------|------------------------|---------------------------------------------------------------------------------------------------|-----------------------------------|------|-----------------------------------|------|
| POWER-GOOD (PGOOD AND PGOOD_NB) AND PROTECTION MONITORS           |                        |                                                                                                   |                                   |      |                                   |      |
| PGOOD Low Voltage                                                 | V <sub>OL</sub>        | I <sub>PGOOD</sub> = 4mA                                                                          |                                   |      | <b>0.4</b>                        | V    |
| PGOOD Leakage Current                                             | I <sub>OH</sub>        | PGOOD = 3.3V                                                                                      | <b>-1</b>                         |      | <b>1</b>                          | μA   |
| PWROK High Threshold                                              |                        |                                                                                                   |                                   | 750  |                                   | mV   |
| VR_HOT_L Pull-Down                                                |                        |                                                                                                   |                                   | 11   |                                   | Ω    |
| PWROK Leakage Current                                             |                        |                                                                                                   |                                   |      | <b>1</b>                          | μA   |
| VR_HOT_L Leakage Current                                          |                        |                                                                                                   |                                   |      | <b>1</b>                          | μA   |
| GATE DRIVER                                                       |                        |                                                                                                   |                                   |      |                                   |      |
| UGATE Pull-Up Resistance                                          | R <sub>UGPU</sub>      | 200mA Source Current                                                                              |                                   | 1    | <b>1.5</b>                        | Ω    |
| UGATE Source Current                                              | I <sub>UGSRC</sub>     | UGATE - PHASE = 2.5V                                                                              |                                   | 2    |                                   | A    |
| UGATE Sink Resistance                                             | R <sub>UGPD</sub>      | 250mA Sink Current                                                                                |                                   | 1    | <b>1.5</b>                        | Ω    |
| UGATE Sink Current                                                | I <sub>UGSNK</sub>     | UGATE - PHASE = 2.5V                                                                              |                                   | 2    |                                   | A    |
| LGATE Pull-Up Resistance                                          | R <sub>LGPU</sub>      | 250mA Source Current                                                                              |                                   | 1    | <b>1.5</b>                        | Ω    |
| LGATE Source Current                                              | I <sub>LGSRC</sub>     | LGATE - VSSP = 2.5V                                                                               |                                   | 2    |                                   | 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    |                                   | A    |
| UGATE to LGATE Dead Time                                          | t <sub>UGFLGR</sub>    | UGATE falling to LGATE rising, no load                                                            |                                   | 23   |                                   | ns   |
| LGATE to UGATE Dead Time                                          | t <sub>LGFUGR</sub>    | LGATE falling to UGATE rising, no load                                                            |                                   | 28   |                                   | ns   |
| PROTECTION                                                        |                        |                                                                                                   |                                   |      |                                   |      |
| Overvoltage Threshold                                             | OV <sub>H</sub>        | VSEN rising above setpoint for >1μs                                                               | <b>275</b>                        | 325  | <b>375</b>                        | mV   |
| Undervoltage Threshold                                            | OV <sub>H</sub>        | VSEN falls below setpoint for >1μs                                                                | <b>275</b>                        | 325  | <b>375</b>                        | mV   |
| Current Imbalance Threshold                                       |                        | One ISEN above another ISEN for >1.2ms                                                            |                                   | 9    |                                   | mV   |
| Way Overcurrent Trip Threshold<br>[IMONx Current Based Detection] | IMONx <sub>WOC</sub>   | All states, I <sub>DR00P</sub> = 60μA, R <sub>IMON</sub> = 135kΩ                                  |                                   | 15   |                                   | μA   |
| Overcurrent Trip Threshold<br>[IMONx Voltage Based Detection]     | V <sub>IMONx_OCP</sub> | All states, I <sub>DR00P</sub> = 45μA,<br>I <sub>IMONx</sub> = 11.25μA, R <sub>IMON</sub> = 135kΩ | <b>1.485</b>                      | 1.51 | <b>1.535</b>                      | V    |
| LOGIC THRESHOLDS                                                  |                        |                                                                                                   |                                   |      |                                   |      |
| ENABLE Input Low                                                  | V <sub>IL</sub>        |                                                                                                   |                                   |      | <b>1</b>                          | V    |
| ENABLE Input High                                                 | V <sub>IH</sub>        | HRZ                                                                                               | 1.6                               |      |                                   | V    |
|                                                                   | V <sub>IH</sub>        | IRZ                                                                                               | 1.65                              |      |                                   | V    |
| ENABLE Leakage Current                                            | I <sub>ENABLE</sub>    | ENABLE = 0V                                                                                       | <b>-1</b>                         | 0    | <b>1</b>                          | μA   |
|                                                                   |                        | ENABLE = 1V                                                                                       |                                   | 18   | <b>35</b>                         | μA   |
| SVT Impedance                                                     |                        |                                                                                                   |                                   | 50   |                                   | Ω    |
| SVC, SVD Input Low                                                | V <sub>IL</sub>        | % of VDDIO                                                                                        |                                   |      | <b>30</b>                         | %    |
| SVC, SVD Input High                                               | V <sub>IH</sub>        | % of VDDIO                                                                                        | 70                                |      |                                   | %    |
| SVC, SVD Leakage                                                  |                        | ENABLE = 0V, SVC, SVD = 0V and 1V                                                                 | <b>-1</b>                         |      | <b>1</b>                          | μA   |
|                                                                   |                        | ENABLE = 1V, SVC, SVD = 1V                                                                        | <b>-5</b>                         |      | <b>1</b>                          | μA   |
|                                                                   |                        | ENABLE = 1V, SVC, SVD = 0V                                                                        | <b>-35</b>                        | -20  | <b>-5</b>                         | μA   |
| PWM                                                               |                        |                                                                                                   |                                   |      |                                   |      |
| 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>                        |      |                                   | V    |
| PWM Tri-State Leakage                                             |                        | PWM = 2.5V                                                                                        |                                   |      | <b>0.5</b>                        | μA   |
| THERMAL MONITOR                                                   |                        |                                                                                                   |                                   |      |                                   |      |
| NTC Source Current                                                |                        | NTC = 0.6V                                                                                        | <b>27</b>                         | 30   | <b>33</b>                         | μA   |
| NTC Thermal Warning Voltage                                       |                        |                                                                                                   | <b>600</b>                        | 640  | <b>680</b>                        | mV   |

**Electrical Specifications**    Operating Conditions:  $V_{DD} = 5V$ ,  $T_A = -10^{\circ}C$  to  $+100^{\circ}C$  (HRZ),  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$  (IRZ),  $f_{SW} = 300kHz$ , unless otherwise noted. **Boldface limits apply across the operating temperature range,  $-40^{\circ}C$  to  $+100^{\circ}C$ .** (Continued)

| PARAMETER                              | SYMBOL | TEST CONDITIONS    | MIN<br>( <a href="#">Note 6</a> ) | TYP | MAX<br>( <a href="#">Note 6</a> ) | UNIT        |
|----------------------------------------|--------|--------------------|-----------------------------------|-----|-----------------------------------|-------------|
| NTC Thermal Warning Voltage Hysteresis |        |                    |                                   | 20  |                                   | mV          |
| NTC Thermal Shutdown Voltage           |        |                    | <b>530</b>                        | 580 | <b>630</b>                        | mV          |
| <b>SLEW RATE</b>                       |        |                    |                                   |     |                                   |             |
| VID-on-the-Fly Slew Rate               |        | Maximum Programmed | <b>16</b>                         | 20  | <b>24</b>                         | mV/ $\mu s$ |
|                                        |        | Minimum Programmed | <b>8</b>                          | 10  | <b>12</b>                         | mV/ $\mu s$ |

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

## Gate Driver Timing Diagram

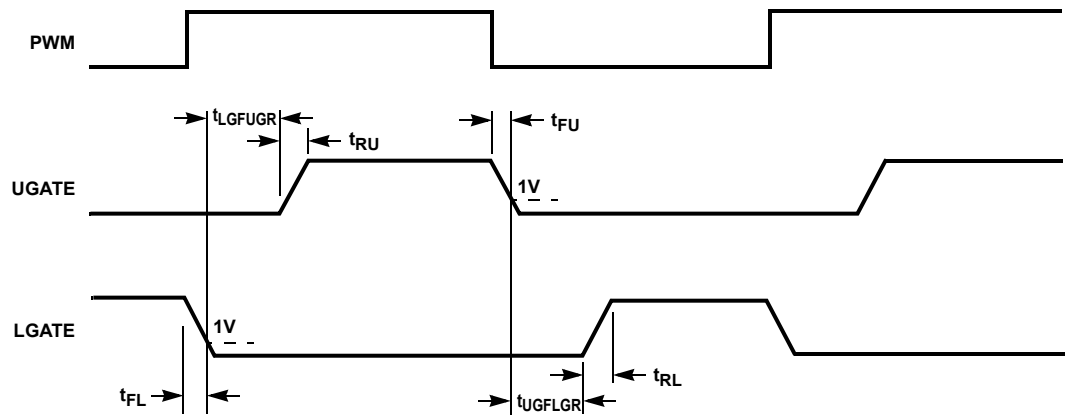


FIGURE 7. GATE DRIVER TIMING DIAGRAM

## Theory of Operation

### Multiphase R3™ Modulator

The ISL6377 is a multiphase regulator implementing two voltage regulators, CORE VR and Northbridge (NB) VR, on one chip controlled by AMD's™ SVI2™ protocol. The CORE VR can be programmed for 1-, 2-, 3- or 4-phase operation. The Northbridge VR can be configured for 1- or 2-phase operation. Both regulators use the Intersil patented R3™ (Robust Ripple Regulator) modulator. The R3™ modulator combines the best features of fixed frequency PWM and hysteretic PWM while eliminating many of their shortcomings. Figure 8 conceptually shows the multiphase R3™ modulator circuit and Figure 9 shows the operation principles.

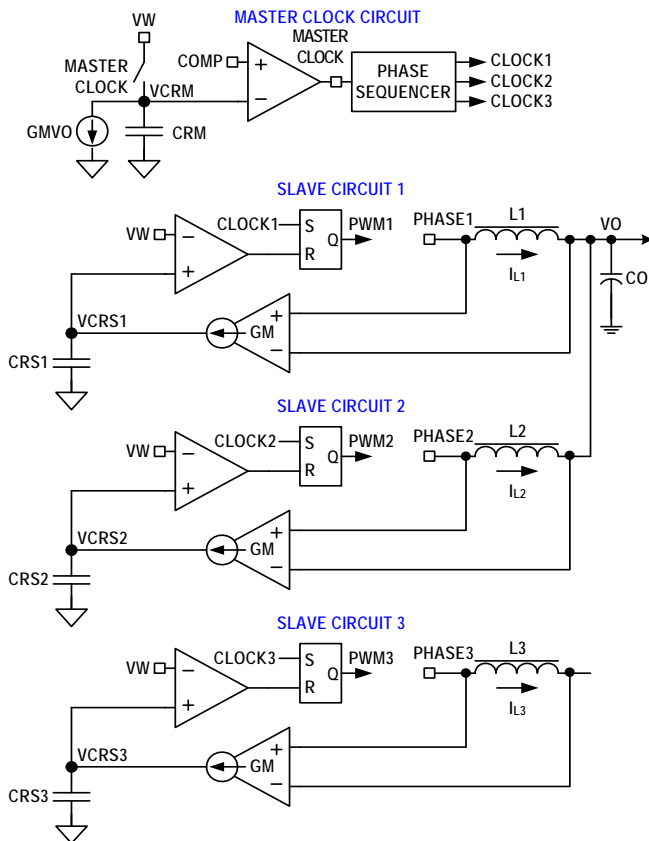


FIGURE 8. R3™ MODULATOR CIRCUIT

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 the CORE VR is in 3-phase mode, the master clock signal is distributed to the three phases and the Clock 1~3 signals will be 120° out-of-phase. If the Core VR is in 2-phase mode, the master clock signal is distributed to Phases 1 and 2 and the Clock1 and Clock2 signals will be 180° out-of-phase. If the Core VR is in 1-phase mode, the

master clock signal will be distributed to Phase 1 only and be the Clock1 signal.

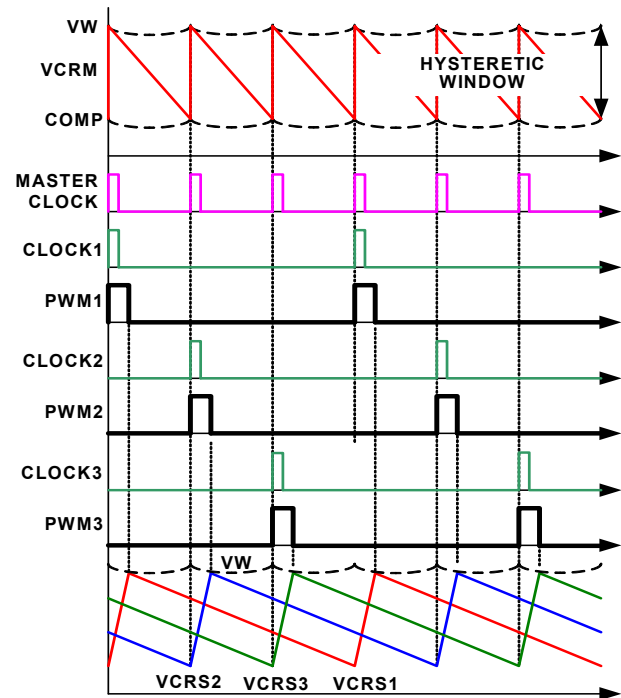


FIGURE 9. R3™ MODULATOR OPERATION PRINCIPLES IN STEADY STATE

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 error amplifier allows the ISL6377 to maintain a 0.5% output voltage accuracy.

Figure 10 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. This 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 ISL6377 excellent response speed.

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

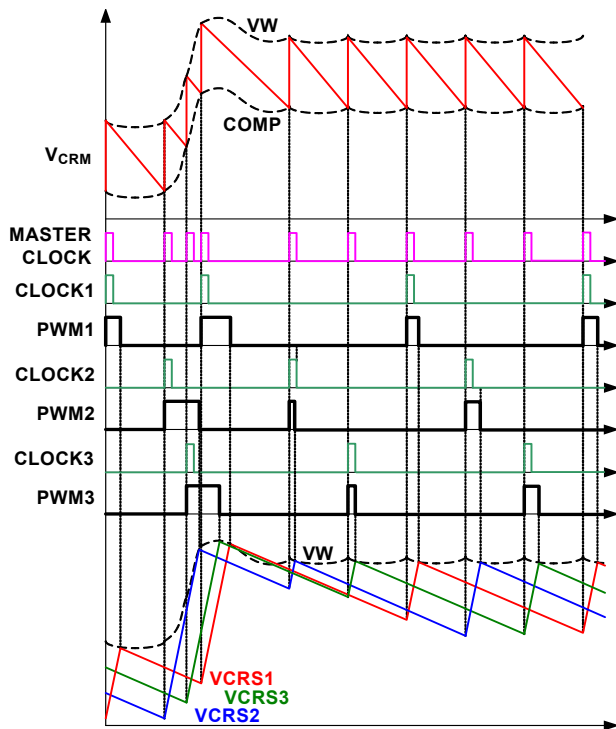


FIGURE 10. R3™ MODULATOR OPERATION PRINCIPLES IN LOAD INSERTION RESPONSE

## Diode Emulation and Period Stretching

The ISL6377 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 does not allow reverse current, thus emulating a diode. As [Figure 11](#) 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 ISL6377 monitors the current by 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.

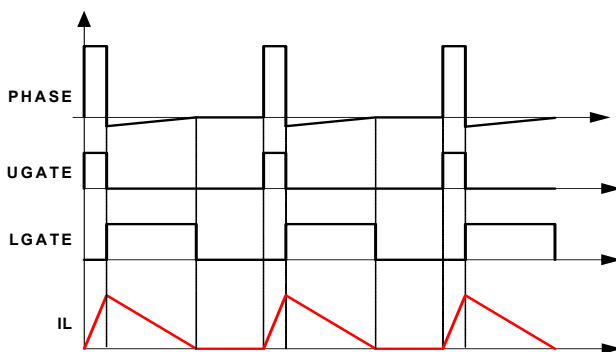


FIGURE 11. DIODE EMULATION

If the load current is light enough, as [Figure 11](#) shows, the inductor current reaches and stays 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 12](#) 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 and therefore is the same, making the inductor current triangle the same in the three cases. The ISL6377 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 farther apart, such that the inductor current average value is equal to the load current. The reduced switching frequency helps increase light-load efficiency.

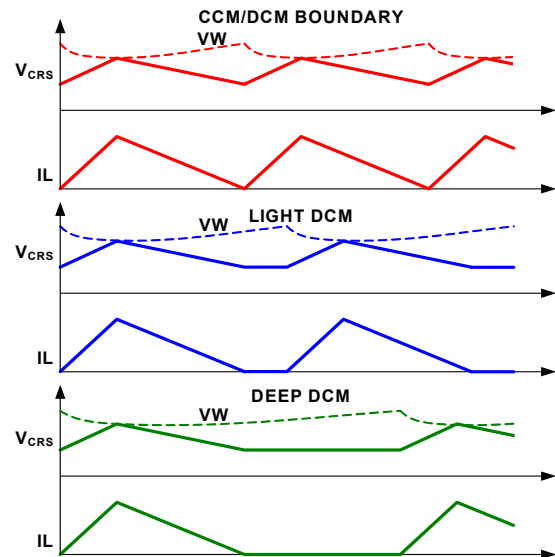


FIGURE 12. PERIOD STRETCHING

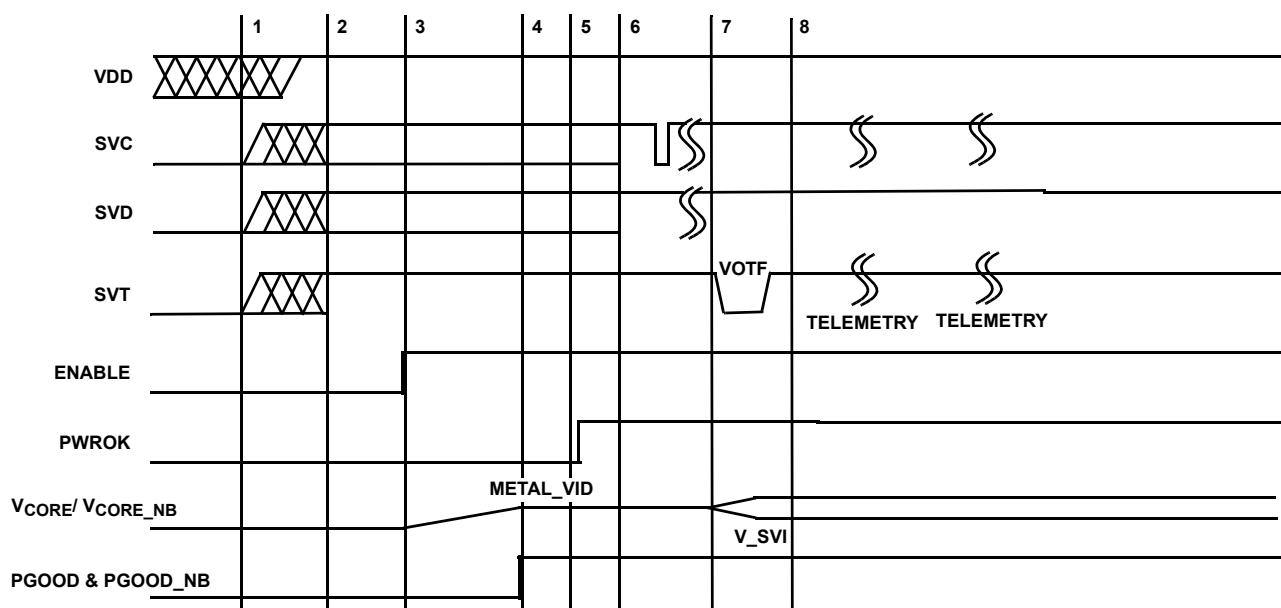
## Channel Configuration

Individual PWM channels of either VR can be disabled by connecting the ISENx pin of the channel not required to +5V. For example, placing the controller in a 3+1 configuration, as shown in [Figure 5](#), requires ISEN4 of the Core VR and ISEN2 of the Northbridge VR to be tied to +5V. This disables Channel 4 of the Core VR and Channel 2 of the Northbridge VR. ISEN1\_NB must be tied through a 10kΩ resistor to GND to prevent this pin from pulling high and disabling the channel.

Connecting ISEN1 or ISEN1\_NB to +5V will disable the corresponding VR output. This feature allows debug of individual VR outputs.

## Power-On Reset

Before the controller has sufficient bias to guarantee proper operation, the ISL6377 requires a +5V input supply tied to VDD and VDDP to exceed the VDD rising Power-On Reset (POR) threshold. Once this threshold is reached or exceeded, the ISL6377 has enough bias to check the state of the SVI inputs once ENABLE is taken high. Hysteresis between the rising and the falling thresholds assure the ISL6377 does not inadvertently turn off unless the bias voltage drops substantially (see "Electrical Specifications" on [page 10](#)). Note that VIN must be present for the controller to drive the output voltage.



Interval 1 to 2: ISL6377 waits to POR.

Interval 2 to 3: SVC and SVD are externally set to pre-Metal VID code.

Interval 3 to 4: ENABLE locks pre-Metal VID code. Both outputs soft-start to this level.

Interval 4 to 5: PGOOD signal goes HIGH, indicating proper operation.

Interval 5 to 6: PGOOD and PGOOD\_NB high is detected and PWROK is taken high. The ISL6377 is prepared for SVI commands.

Interval 6 to 7: SVC and SVD data lines communicate change in VID code.

Interval 7 to 8: ISL6377 responds to VID-ON-THE-FLY code change and issues a VOTF for positive VID changes.

Post 8: Telemetry is clocked out of the ISL6377.

FIGURE 13. SVI INTERFACE TIMING DIAGRAM: TYPICAL PRE-PWROK METAL VID START-UP

## Start-Up Timing

With VDD above the POR threshold, the controller start-up sequence begins when ENABLE exceeds the logic high threshold. [Figure 14](#) shows the typical soft-start timing of the Core and Northbridge VRs. Once the controller registers ENABLE as a high, the controller checks that state of a few programming pins during the typical 8ms delay prior to beginning soft-starting the Core and Northbridge outputs. The pre-PWROK Metal VID is read from the state of the SVC and SVD pins and programs the DAC, the programming resistors on COMP, COMP\_NB and FCCM\_NB are read to configure internal drivers, switching frequency, slew rate, output offsets. These programming resistors are discussed in subsequent sections. The ISL6377 use a digital soft-start to ramp up the DAC to the Metal VID level programmed. The soft-start slew rate is programmed by the FCCM\_NB resistor, which is used to set the VID-on-the-fly slew rate as well. See [“VID-on-the-Fly Slew Rate Selection” on page 20](#) for more details on selecting the FCCM\_NB resistor. PGOOD is asserted high at the end of the soft-start ramp.

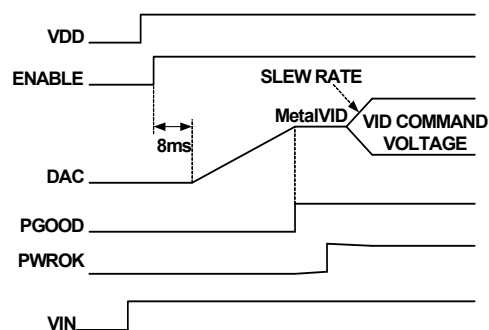


FIGURE 14. TYPICAL SOFT-START WAVEFORMS

## Voltage Regulation and Load Line Implementation

After the soft-start sequence, the ISL6377 regulates the output voltages to the pre-PWROK metal VID programmed, see [Table 6](#). The ISL6377 controls the no load output voltage to an accuracy of  $\pm 0.5\%$  over the range of 0.75V to 1.55V. A differential amplifier allows voltage sensing for precise voltage regulation at the microprocessor die.



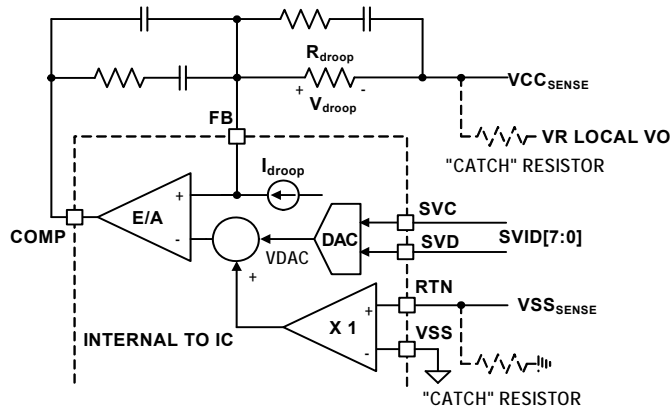


FIGURE 15. DIFFERENTIAL SENSING AND LOAD LINE IMPLEMENTATION

As the load current increases from zero, the output voltage droops from the VID programmed value by an amount proportional to the load current, to achieve the load line. The ISL6377 can sense the inductor current through the intrinsic DC Resistance (DCR) of the inductors, as shown in Figures 3 and 4, or through resistors in series with the inductors as shown in Figure 5. In both methods, capacitor  $C_n$  voltage represents the total inductor current. An internal amplifier converts  $C_n$  voltage into an internal current source,  $I_{sum}$ , with the gain set by resistor  $R_i$ , see Equation 1.

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

The  $I_{sum}$  current is used for load line implementation, current monitoring on the IMON pins and overcurrent protection.

Figure 15 shows the load line implementation. The ISL6377 drives a current source ( $I_{droop}$ ) out of the FB pin, which is a ratio of the  $I_{sum}$  current as described by Equation 2.

$$I_{droop} = \frac{5}{4} \times I_{sum} = \frac{5}{4} \times \frac{V_{Cn}}{R_i} \quad (\text{EQ. 2})$$

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 3.

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

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

## Differential Sensing

Figure 15 also shows the differential voltage sensing scheme.  $V_{CC\_SENSE}$  and  $V_{SS\_SENSE}$  are the remote voltage sensing signals from the processor die. A unity gain differential amplifier senses the  $V_{SS\_SENSE}$  voltage and adds it to the DAC output. The error

amplifier regulates the inverting and non-inverting input voltages to be equal as shown in Equation 4:

$$V_{CC\_SENSE} + V_{droop} = V_{DAC} + V_{SS\_SENSE} \quad (\text{EQ. 4})$$

Rewriting Equation 4 and substituting Equation 3 gives Equation 5 the exact equation required for load line implementation.

$$V_{CC\_SENSE} - V_{SS\_SENSE} = V_{DAC} - R_{droop} \times I_{droop} \quad (\text{EQ. 5})$$

The  $V_{CC\_SENSE}$  and  $V_{SS\_SENSE}$  signals come from the processor die. The feedback is open circuit in the absence of the processor. As Figure 15 shows, it is recommended to add a "catch" resistor to feed the VR local output voltage back to the compensator and to add another "catch" resistor to connect the VR local output ground to the RTN pin. These resistors, typically 10Ω~100Ω, provide voltage feedback if the system is powered up without a processor installed.

## Phase Current Balancing

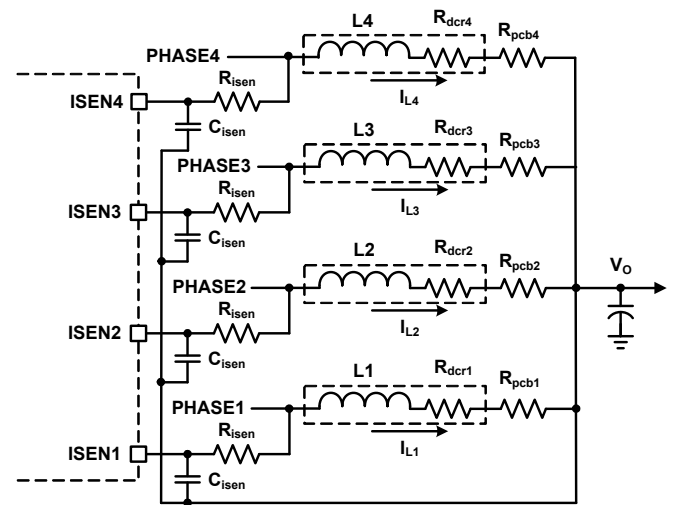


FIGURE 16. CURRENT BALANCING CIRCUIT

The ISL6377 monitors individual phase average current by monitoring the ISEN1, ISEN2, ISEN3 and ISEN4 voltages. Figure 16 shows the recommended current balancing circuit for DCR sensing. Each phase node voltage is averaged by a low-pass filter consisting of  $R_{isen}$  and  $C_{isen}$  and is presented to the corresponding ISEN pin.  $R_{isen}$  should be routed to the inductor phase-node pad in order to eliminate the effect of phase node parasitic PCB DCR. Equations 6 through 9 give the ISEN pin voltages:

$$V_{ISEN1} = (R_{dcr1} + R_{pcb1}) \times I_{L1} \quad (\text{EQ. 6})$$

$$V_{ISEN2} = (R_{dcr2} + R_{pcb2}) \times I_{L2} \quad (\text{EQ. 7})$$

$$V_{ISEN3} = (R_{dcr3} + R_{pcb3}) \times I_{L3} \quad (\text{EQ. 8})$$

$$V_{ISEN4} = (R_{dcr4} + R_{pcb4}) \times I_{L4} \quad (\text{EQ. 9})$$

Where  $R_{dcr1}$ ,  $R_{dcr2}$ ,  $R_{dcr3}$  and  $R_{dcr4}$  are inductor DCR;  $R_{pcb1}$ ,  $R_{pcb2}$ ,  $R_{pcb3}$  and  $R_{pcb4}$  are parasitic PCB DCR between the inductor output side pad and the output voltage rail; and  $I_{L1}$ ,  $I_{L2}$ ,  $I_{L3}$  and  $I_{L4}$  are inductor average currents.



The ISL6377 will adjust the phase pulse-width relative to the other phases to make  $V_{ISEN1} = V_{ISEN2} = V_{ISEN3} = V_{ISEN4}$ , thus to achieve  $I_{L1} = I_{L2} = I_{L3} = I_{L4}$ , when  $R_{dcr1} = R_{dcr2} = R_{dcr3} = R_{dcr4}$  and  $R_{pcb1} = R_{pcb2} = R_{pcb3} = R_{pcb4}$ .

Using the same components for L1, L2, L3 and L4 provides a good match of  $R_{dcr1}$ ,  $R_{dcr2}$ ,  $R_{dcr3}$  and  $R_{dcr4}$ . Board layout determines  $R_{pcb1}$ ,  $R_{pcb2}$ ,  $R_{pcb3}$  and  $R_{pcb4}$ . It is recommended to have a symmetrical layout for the power delivery path between each inductor and the output voltage rail, such that  $R_{pcb1} = R_{pcb2} = R_{pcb3} = R_{pcb4}$ .

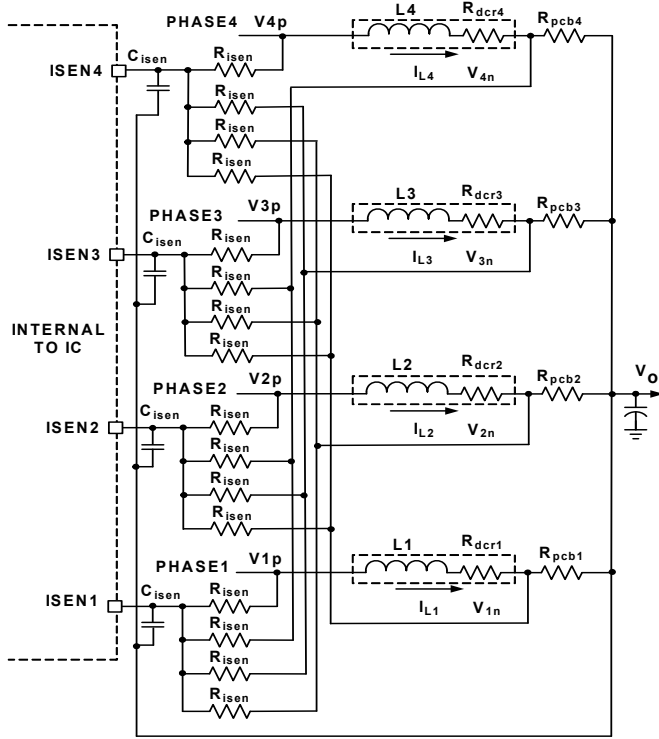


FIGURE 17. DIFFERENTIAL-SENSING CURRENT BALANCING CIRCUIT

Sometimes, it is difficult to implement symmetrical layout. For the circuit shown in Figure 16, asymmetric layout causes different  $R_{pcb1}$ ,  $R_{pcb2}$ ,  $R_{pcb3}$  and  $R_{pcb4}$  values, thus creating a current imbalance. Figure 17 shows a differential sensing current balancing circuit recommended for ISL6377. 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 phase inductor output side pads. Equations 10 through 13 give the ISEN pin voltages:

$$V_{ISEN1} = V_{1p} + V_{2n} + V_{3n} + V_{4n} \quad (\text{EQ. 10})$$

$$V_{ISEN2} = V_{1n} + V_{2p} + V_{3n} + V_{4n} \quad (\text{EQ. 11})$$

$$V_{ISEN3} = V_{1n} + V_{2n} + V_{3p} + V_{4n} \quad (\text{EQ. 12})$$

$$V_{ISEN4} = V_{1n} + V_{2n} + V_{3n} + V_{4p} \quad (\text{EQ. 13})$$

The ISL6377 will make  $V_{ISEN1} = V_{ISEN2} = V_{ISEN3} = V_{ISEN4}$  as shown in Equations 14 and 16:

$$V_{1p} + V_{2n} + V_{3n} + V_{4n} = V_{1n} + V_{2p} + V_{3n} + V_{4n} \quad (\text{EQ. 14})$$

$$V_{1n} + V_{2p} + V_{3n} + V_{4n} = V_{1n} + V_{2n} + V_{3p} + V_{4n} \quad (\text{EQ. 15})$$

$$V_{1n} + V_{2n} + V_{3p} + V_{4n} = V_{1n} + V_{2n} + V_{3n} + V_{4p} \quad (\text{EQ. 16})$$

Rewriting Equation 14 gives Equation 17:

$$V_{1p} - V_{1n} = V_{2p} - V_{2n} \quad (\text{EQ. 17})$$

Rewriting Equation 15 gives Equation 18:

$$V_{2p} - V_{2n} = V_{3p} - V_{3n} \quad (\text{EQ. 18})$$

Rewriting Equation 16 gives Equation 19:

$$V_{3p} - V_{3n} = V_{4p} - V_{4n} \quad (\text{EQ. 19})$$

Combining Equations 17 through 19 gives:

$$V_{1p} - V_{1n} = V_{2p} - V_{2n} = V_{3p} - V_{3n} = V_{4p} - V_{4n} \quad (\text{EQ. 20})$$

Therefore:

$$R_{dcr1} \times I_{L1} = R_{dcr2} \times I_{L2} = R_{dcr3} \times I_{L3} = R_{dcr4} \times I_{L4} \quad (\text{EQ. 21})$$

Current balancing ( $I_{L1} = I_{L2} = I_{L3} = I_{L4}$ ) is achieved when  $R_{dcr1} = R_{dcr2} = R_{dcr3} = R_{dcr4}$ .  $R_{pcb1}$ ,  $R_{pcb2}$ ,  $R_{pcb3}$  and  $R_{pcb4}$  do not have any effect.

Since the slave ripple capacitor voltages mimic the inductor currents, the R3™ modulator can naturally achieve excellent current balancing during steady state and dynamic operations. Figure 18 shows the current balancing performance of a three phase 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 a low repetition rate, but cannot keep up when the repetition rate gets into the hundred-kHz range, where it is out of the control loop bandwidth. The controller achieves excellent current balancing in all cases installed.

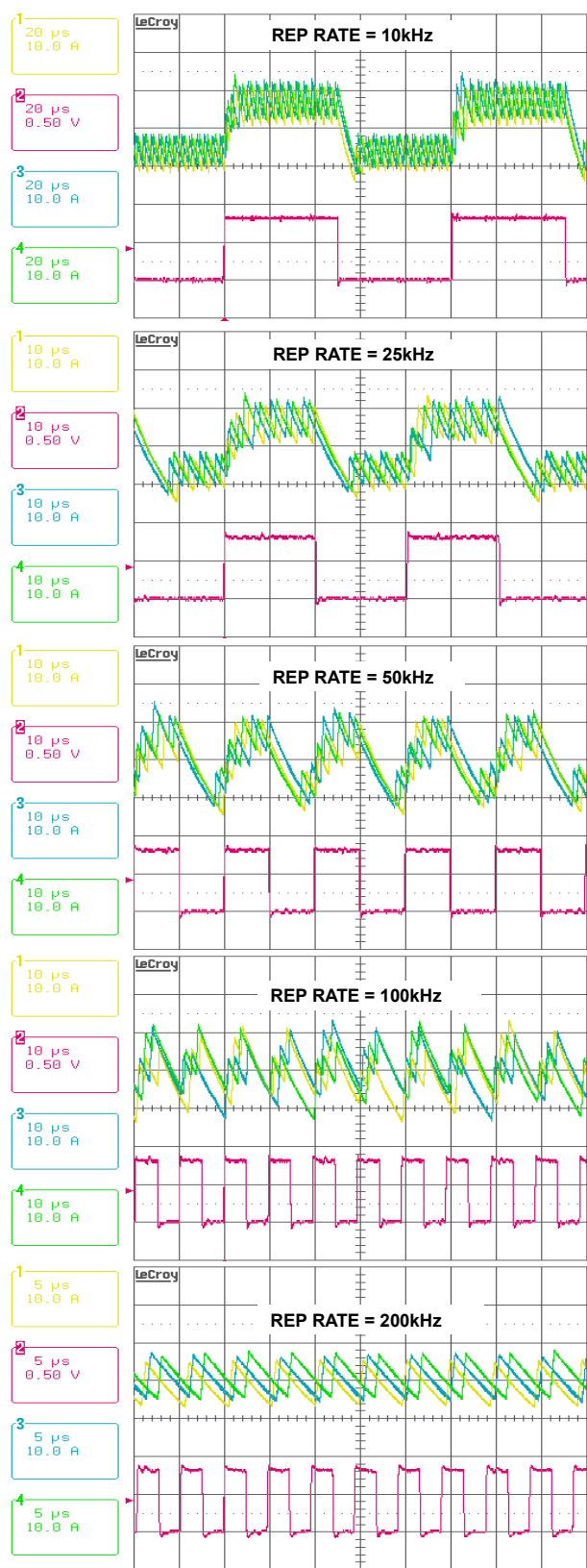


FIGURE 18. CURRENT BALANCING DURING DYNAMIC OPERATION.  
CH1: I<sub>L1</sub>, CH2: I<sub>LOAD</sub>, CH3: I<sub>L2</sub>, CH4: I<sub>L3</sub>

## Modes of Operation

TABLE 1. CORE VR MODES OF OPERATION

| CONFIG.                 | ISEN4          | ISEN3          | ISEN2          | PSIO_L AND PSI1_L | MODE        |
|-------------------------|----------------|----------------|----------------|-------------------|-------------|
| 4-phase Core VR Config. | To Power Stage | To Power Stage | To Power Stage | 11                | 4-phase CCM |
|                         |                |                |                | 01                | 2-phase CCM |
|                         |                |                |                | 00                | 1-phase DE  |
| 3-phase Core VR Config. | Tied to 5V     | To Power Stage | To Power Stage | 11                | 3-phase CCM |
|                         |                |                |                | 01                | 2-phase CCM |
|                         |                |                |                | 00                | 1-phase DE  |
| 2-phase Core VR Config. | Tied to 5V     | Tied to 5V     | To Power Stage | 11                | 2-phase CCM |
|                         |                |                |                | 01                | 1-phase CCM |
|                         |                |                |                | 00                | 1-phase DE  |
| 1-phase Core VR Config. | Tied to 5V     | Tied to 5V     | Tied to 5V     | 11                | 1-phase CCM |
|                         |                |                |                | 01                | 1-phase CCM |
|                         |                |                |                | 00                | 1-phase DE  |

The Core VR can be configured for 4-, 3-, 2- or 1-phase operation. [Table 1](#) shows Core VR configurations and operational modes, programmed by the ISEN4, ISEN3 and ISEN2 pin status and the PSIO\_L and PSI1\_L commands via the SVI 2 interface. The SVI 2 interface description of these bits is outlined in [Table 9 on page 24](#).

The ISENx pins disable the channel which they are related. For example, to setup a 3-phase configuration the ISEN4 pin is tied to 5V. This disables Channel 4 of the controller on the Core side.

In a 3-phase configuration, the Core VR operates in 3-phase CCM, with PSIO\_L and PSI\_L both high. If PSIO\_L is taken low via the SVI 2 interface, the Core VR sheds Phase 3. The Core VR then operates 2-phase and remains in CCM. When both PSIO\_L and PSI1\_L are taken low, the Core VR sheds Phase 2 and the Core VR enters 1-phase Diode Emulation (DE) mode.

For 2-phase configurations, the Core VR operates in 2-phase CCM with PSIO\_L and PSI\_L both high. If PSIO\_L is taken low via the SVI 2 interface, the Core VR sheds Phase 2 and the Core VR operates in 1-phase and remains in CCM. When both PSIO\_L and PSI1\_L are taken low, the Core VR operates in 1-phase DE mode.

In a 1-phase configuration, the Core VR operates in 1-phase CCM and remains in this mode when PSIO\_L is taken low. When both PSIO\_L and PSI1\_L are taken low, the controller enters DE mode.

The Core VR can be disabled completely by connecting ISEN1 to +5V.

The ISL6377 Northbridge VR can be configured for 2- or 1-phase operation. [Table 2](#) shows the Northbridge VR configurations and operational modes, which are programmed by the ISEN2\_NB pin status and the PSIO\_L and PSI1\_L bits of the SVI 2 command.

**TABLE 2. NORTHBRIDGE VR MODES OF OPERATION**

| CONFIG.               | ISEN2_NB       | PSIO_L AND PSI1_L | MODE        |
|-----------------------|----------------|-------------------|-------------|
| 2-phase NB VR Config. | To Power Stage | 11                | 2-phase CCM |
|                       |                | 01                | 1-phase CCM |
|                       |                | 00                | 1-phase DE  |
| 1-phase NB VR Config. | Tied to 5V     | 11                | 1-phase CCM |
|                       |                | 01                | 1-phase CCM |
|                       |                | 00                | 1-phase DE  |

In a 1-phase configuration, the ISEN2\_NB pin is tied to +5V. The Northbridge VR operates in 1-phase CCM when both PSIO\_L and PSI1\_L are high and continues in this mode when PSIO\_L is taken low. The controller enters 1-phase DE mode when both PSIO\_L and PSI1\_L are low.

The Northbridge VR can be disabled completely by tying ISEN1\_NB to 5V.

## Dynamic Operation

Core and Northbridge VRs behave the same during dynamic operation. The controller responds to VID-on-the-fly changes by slewing to the new voltage at the slew rate programmed, see [Table 4](#). During negative VID transitions, the output voltage decays to the lower VID value at the slew rate determined by the load.

The R3™ modulator intrinsically has voltage feed-forward. The output voltage is insensitive to a fast slew rate input voltage change.

## 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  $r_{DS(ON)}$  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 will 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 will 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. To minimize the body diode-related loss, the controller also adjusts the phase comparator threshold voltage accordingly in iterative steps such that the low-side MOSFET body diode conducts for approximately 40ns.

## Resistor Configuration Options

The ISL6377 uses the COMP, COMP\_NB and FCCM\_NB pins to configure some functionality within the IC. Resistors from these pins to GND are read during the first portion of the soft-start

sequence. The following sections outline how to select the resistor values for each of these pins to correctly program the output voltage offset of each output, the configuration of the floating DriverX and PWM\_Y output, VID-on-the-fly slew rate and switching frequency used for both VRs.

## VR Offset Programming

A positive or negative offset is programmed for the Core VR using a resistor to ground from the COMP pin and the Northbridge in a similar manner from the COMP\_NB pin. [Table 3](#) provides the resistor value to select the desired output voltage offset. The 1% tolerance resistor value shown in the table must be used to program the corresponding Core or NB output voltage offset. The MIN and MAX tolerance values provide margin to insure the 1% tolerance resistor will be read correctly.

**TABLE 3. COMP AND COMP\_NB OUTPUT VOLTAGE OFFSET SELECTION**

| RESISTOR VALUE [kΩ] |                       |                  | COMP<br>V <sub>CORE</sub> OFFSET<br>[mV] | COMP_NB<br>OFFSET<br>[mV] |
|---------------------|-----------------------|------------------|------------------------------------------|---------------------------|
| MIN<br>TOLERANCE    | 1% TOLERANCE<br>VALUE | MAX<br>TOLERANCE |                                          |                           |
| 5.54                | 5.62                  | 5.70             | -43.75                                   | 18.75                     |
| 7.76                | 7.87                  | 7.98             | -37.5                                    | 31.25                     |
| 11.33               | 11.5                  | 11.67            | -31.25                                   | 43.76                     |
| 16.65               | 16.9                  | 17.15            | -25                                      | 50                        |
| 19.3                | 19.6                  | 19.89            | -18.75                                   | 37.5                      |
| 24.53               | 24.9                  | 25.27            | -12.5                                    | 25                        |
| 33.49               | 34.0                  | 34.51            | -6.25                                    | 12.5                      |
| 40.58               | 41.2                  | 41.81            | 6.25                                     | 0                         |
| 51.52               | 52.3                  | 53.08            | 18.75                                    | 18.75                     |
| 72.10               | 73.2                  | 74.29            | 31.25                                    | 31.25                     |
| 93.87               | 95.3                  | 96.72            | 43.76                                    | 43.76                     |
| 119.19              | 121                   | 112.81           | 50                                       | 50                        |
| 151.69              | 154                   | 156.31           | 37.5                                     | 37.5                      |
| 179.27              | 182                   | 184.73           | 25                                       | 25                        |
| 206.85              | 210                   | 213.15           | 12.5                                     | 12.5                      |
|                     | OPEN                  |                  | 0                                        | 0                         |

## Floating DriverX and PWM\_Y Configuration

The ISL6377 allows for one internal driver and one PWM output to be configured to opposite VRs depending on the desired configuration of the Northbridge VR. Internal DriverX can be used as Channel 1 of the Northbridge VR with PWM\_Y used for Channel 3 of the Core VR. Using this partitioning, a 2+1 or 1+1 configured ISL6377 would not require an external driver.

If routing of the driver signals would be a cause of concern due to having an internal driver on the Northbridge VR, then the ISL6377 can be configured to use PWM\_Y as Channel 1 on the Northbridge VR. DriverX would then be used as Channel 3 of the Core VR. This allows the placement of the external drivers for the Northbridge VR to be closer to the output stage(s) depending on

the number of active Phases, providing placement and layout flexibility to the Northbridge VR.

The floating internal driver and PWM output are configured based on the programming resistor from FCCM\_NB to GND. The FCCM\_NB programming resistor value also sets the slew rate and switching frequency of the Core and Northbridge VRs. These features are outlined in the following sections. [Table 4](#) shows which resistor values sets the configuration and slew rate for the ISL6377. The resistor value shown in the table must be used and the resistor tolerance must be 1%. The MIN and MAX tolerance around each resistor value is the same as [Table 3](#) and provides margin to insure the 1% tolerance resistor will be read correctly.

**TABLE 4. FCCM\_NB RESISTOR SELECTION**

| RESISTOR VALUE [kΩ] | SLEW RATE FOR CORE AND NORTHBRIDGE [mV/μs] | DriverX              | PWM_Y                |
|---------------------|--------------------------------------------|----------------------|----------------------|
| 5.62                | 20                                         | Core VR<br>Channel 3 | NB VR<br>Channel 1   |
| 7.87                | 15                                         |                      |                      |
| 11.5                | 12.5                                       |                      |                      |
| 16.9                | 10                                         |                      |                      |
| 19.6                | 20                                         |                      |                      |
| 24.9                | 15                                         |                      |                      |
| 34.0                | 12.5                                       |                      |                      |
| 41.2                | 10                                         |                      |                      |
| 52.3                | 20                                         | NB VR<br>Channel 1   | Core VR<br>Channel 3 |
| 73.2                | 15                                         |                      |                      |
| 95.3                | 12.5                                       |                      |                      |
| 121                 | 10                                         |                      |                      |
| 154                 | 20                                         |                      |                      |
| 182                 | 15                                         |                      |                      |
| 210                 | 12.5                                       |                      |                      |
| OPEN                | 10                                         |                      |                      |

## VID-on-the-Fly Slew Rate Selection

The FCCM\_NB resistor is also used to select the slew rate for VID changes commanded by the processor. Once selected, the slew rate is locked in during soft-start and is not adjustable during operation. The lowest slew rate which can be selected is 10mV/μs, which is above the minimum of 7.5mV/μs required by the SVI2 specification. The slew rate selected sets the slew rate for both Core and Northbridge VRs. The controller does not allow for independent selection of slew rate.

## CCM Switching Frequency

The Core and Northbridge VR switching frequency is set by the programming resistors on COMP\_NB and FCCM\_NC. When the ISL6377 is in Continuous Conduction Mode (CCM), the switching frequency is not absolutely constant due to the nature of the R3™ modulator. As explained in [“Multiphase R3™ Modulator” on page 13](#), the effective switching frequency increases during load insertion and decreases during load release to achieve fast

response. Thus, 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 10% and does not have any significant effect on output voltage ripple magnitude. [Table 5](#) defines the switching frequency based on the resistor values used to program the COMP\_NB and FCCM\_NB pins. Use the previous tables related to COMP\_NB and FCCM\_NB to determine the correct resistor value in these ranges to program the desired output offset, slew rate and DriverX/PWM\_Y configuration.

**TABLE 5. SWITCHING FREQUENCY SELECTION**

| FREQUENCY [kHz] | COMP_NB RANGE [kΩ] | FCCM_NB RANGE [kΩ]                |
|-----------------|--------------------|-----------------------------------|
| 300             | 57.6 to OPEN       | 19.1 to 41.2<br>or<br>154 to OPEN |
| 350             | 5.62 to 41.2       | 19.1 to 41.2<br>or<br>154 to OPEN |
| 400             | 57.6 to OPEN       | 5.62 to 16.9<br>or<br>57.6 to 121 |
| 450             | 5.62 to 41.2       | 5.62 to 16.9<br>or<br>57.6 to 121 |

The controller monitors SVI commands to determine when to enter power-saving mode, implement dynamic VID changes and shut down individual outputs.

## AMD Serial VID Interface 2.0

The on-board Serial VID Interface 2.0 (SVI 2) circuitry allows the AMD processor to directly control the Core and Northbridge voltage reference levels within the ISL6377. Once the PWROK signal goes high, the IC begins monitoring the SVC and SVD pins for instructions. The ISL6377 uses a digital-to-analog converter (DAC) to generate a reference voltage based on the decoded SVI value. See [Figure 13 on page 15](#) for a simple SVI interface timing diagram.

## Pre-PWROK Metal VID

Typical motherboard start-up begins with the controller decoding the SVC and SVD inputs to determine the pre-PWROK Metal VID setting (see [Table 6](#)). Once the ENABLE input exceeds the rising threshold, the ISL6377 decodes and locks the decoded value into an on-board hold register.

**TABLE 6. PRE-PWROK METAL VID CODES**

| SVC | SVD | OUTPUT VOLTAGE (V) |
|-----|-----|--------------------|
| 0   | 0   | 1.1                |
| 0   | 1   | 1.0                |
| 1   | 0   | 0.9                |
| 1   | 1   | 0.8                |

Once the programming pins are read, the internal DAC circuitry begins to ramp Core and Northbridge VRs to the decoded pre-PWROK Metal VID output level. The digital soft-start circuitry

ramps the internal reference to the target gradually at a fixed rate of approximately 5mV/μs until the output voltage reaches ~250mV and then at the programmed slew rate. The controlled ramp of all output voltage planes reduces inrush current during the soft-start interval. At the end of the soft-start interval, the PGOOD and PGOOD\_NB outputs transition high, indicating both output planes are within regulation limits.

If the ENABLE input falls below the enable falling threshold, the ISL6377 tri-states both outputs. PGOOD and PGOOD\_NB are pulled low with the loss of ENABLE. The Core and Northbridge VR output voltages decay, based on output capacitance and load leakage resistance. If bias to VDD falls below the POR level, the ISL6377 responds in the manner previously described. Once VDD and ENABLE rise above their respective rising thresholds, the internal DAC circuitry reacquires a pre-PWROK metal VID code and the controller soft-starts.

## SVI Interface Active

Once the Core and Northbridge VRs have successfully soft-started and PGOOD and PGOOD\_NB signals transition high, PWROK can be asserted externally to the ISL6377. Once PWROK is asserted to the IC, SVI instructions can begin as the controller actively monitors the SVI interface. Details of the SVI Bus protocol are provided in the “AMD Serial VID Interface 2.0 (SVI2) Specification”. See AMD publication #48022.

Once a VID change command is received, the ISL6377 decodes the information to determine which VR is affected and the VID target is determined by the byte combinations in [Table 7](#). The internal DAC circuitry steps the output voltage of the VR commanded to the new VID level. During this time, one or more of the VR outputs could be targeted. In the event either VR is commanded to power-off by serial VID commands, the PGOOD signal remains asserted.

If the PWROK input is deasserted, then the controller steps both the Core and the Northbridge VRs back to the stored pre-PWROK metal VID level in the holding register from initial soft-start. No attempt is made to read the SVC and SVD inputs during this time. If PWROK is reasserted, then the ISL6377 SVI interface waits for instructions.

If ENABLE goes low during normal operation, all external MOSFETs are tri-stated and both PGOOD and PGOOD\_NB are pulled low. This event clears the pre-PWROK metal VID code and forces the controller to check SVC and SVD upon restart, storing the pre-PWROK metal VID code found on restart.

A POR event on VCC during normal operation shuts down both regulators and both PGOOD outputs are pulled low. The pre-PWROK metal VID code is not retained. Loss of VIN during operation will typically cause the controller to enter a fault condition on one or both outputs as the output voltage collapses. The controller will shutdown both Core and Northbridge VRs and latch off. The pre-PWROK metal VID code is not retained during the process of cycling ENABLE to reset the fault latch and restart the controller.

## VID-on-the-Fly Transition

Once PWROK is high, the ISL6377 detects this flag and begins monitoring the SVC and SVD pins for SVI instructions. The microprocessor follows the protocol outlined in the following sections to send instructions for VID-on-the-fly transitions. The ISL6377 decodes the instruction and acknowledges the new VID code. For VID codes higher than the current VID level, the ISL6377 begins stepping the commanded VR outputs to the new VID target at the fixed slew rate of 10mV/μs. Once the DAC ramps to the new VID code, a VID-On-The-Fly Complete (VOTFC) request is sent on the SVI lines.

When the VID codes are lower than the current VID level, the ISL6377 checks the state of power state bits in the SVI command. If power state bits are not active, the controller begins stepping the regulator output to the new VID target. If the power state bits are active, the controller allows the output voltage to decay and slowly steps the DAC down with the natural decay of the output. This allows the controller to quickly recover and move to a high VID code if commanded. The controller issues a VOTFC request on the SVI lines once the SVI command is decoded and prior to reaching the final output voltage.

VOTFC requests do not take priority over telemetry per the AMD SVI 2 specification.

## SVI Data Communication Protocol

The SVI WIRE protocol is based on the I<sup>2</sup>C bus concept. Two wires [serial clock (SVC) and serial data (SVD)], carry information between the AMD processor (master) and VR controller (slave) on the bus. The master initiates and terminates SVI transactions and drives the clock, SVC, during a transaction. The AMD processor is always the master and the voltage regulators are the slaves. The slave receives the SVI transactions and acts accordingly. Mobile SVI WIRE protocol timing is based on high-speed mode I<sup>2</sup>C. See AMD publication #48022 for additional details.



TABLE 7. SERIAL VID CODES

| SVID[7:0] | VOLTAGE (V) | SVID[6:0] | VOLTAGE (V) | SVID[6:0] | VOLTAGE (V) | SVID[6:0] | VOLTAGE (V) |
|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|
| 0000_0000 | 1.55000     | 0010_0000 | 1.35000     | 0100_0000 | 1.15000     | 0110_0000 | 0.95000     |
| 0000_0001 | 1.54375     | 0010_0001 | 1.34375     | 0100_0001 | 1.14375     | 0110_0001 | 0.94375     |
| 0000_0010 | 1.53750     | 0010_0010 | 1.33750     | 0100_0010 | 1.13750     | 0110_0010 | 0.93750     |
| 0000_0011 | 1.53125     | 0010_0011 | 1.33125     | 0100_0011 | 1.13125     | 0110_0011 | 0.93125     |
| 0000_0100 | 1.52500     | 0010_0100 | 1.32500     | 0100_0100 | 1.12500     | 0110_0100 | 0.92500     |
| 0000_0101 | 1.51875     | 0010_0101 | 1.31875     | 0100_0101 | 1.11875     | 0110_0101 | 0.91875     |
| 0000_0110 | 1.51250     | 0010_0110 | 1.31250     | 0100_0110 | 1.11250     | 0110_0110 | 0.91250     |
| 0000_0111 | 1.50625     | 0010_0111 | 1.30625     | 0100_0111 | 1.10625     | 0110_0111 | 0.90625     |
| 0000_1000 | 1.50000     | 0010_1000 | 1.30000     | 0100_1000 | 1.10000     | 0110_1000 | 0.90000     |
| 0000_1001 | 1.49375     | 0010_1001 | 1.29375     | 0100_1001 | 1.09375     | 0110_1001 | 0.89375     |
| 0000_1010 | 1.48750     | 0010_1010 | 1.28750     | 0100_1010 | 1.08750     | 0110_1010 | 0.88750     |
| 0000_1011 | 1.48125     | 0010_1011 | 1.28125     | 0100_1011 | 1.08125     | 0110_1011 | 0.88125     |
| 0000_1100 | 1.47500     | 0010_1100 | 1.27500     | 0100_1100 | 1.07500     | 0110_1100 | 0.87500     |
| 0000_1101 | 1.46875     | 0010_1101 | 1.26875     | 0100_1101 | 1.06875     | 0110_1101 | 0.86875     |
| 0000_1110 | 1.46250     | 0010_1110 | 1.26250     | 0100_1110 | 1.06250     | 0110_1110 | 0.86250     |
| 0000_1111 | 1.45625     | 0010_1111 | 1.25625     | 0100_1111 | 1.05625     | 0110_1111 | 0.85625     |
| 0001_0000 | 1.45000     | 0011_0000 | 1.25000     | 0101_0000 | 1.05000     | 0111_0000 | 0.85000     |
| 0001_0001 | 1.44375     | 0011_0001 | 1.24375     | 0101_0001 | 1.04375     | 0111_0001 | 0.84375     |
| 0001_0010 | 1.43750     | 0011_0010 | 1.23750     | 0101_0010 | 1.03750     | 0111_0010 | 0.83750     |
| 0001_0011 | 1.43125     | 0011_0011 | 1.23125     | 0101_0011 | 1.03125     | 0111_0011 | 0.83125     |
| 0001_0100 | 1.42500     | 0011_0100 | 1.22500     | 0101_0100 | 1.02500     | 0111_0100 | 0.82500     |
| 0001_0101 | 1.41875     | 0011_0101 | 1.21875     | 0101_0101 | 1.01875     | 0111_0101 | 0.81875     |
| 0001_0110 | 1.41250     | 0011_0110 | 1.21250     | 0101_0110 | 1.01250     | 0111_0110 | 0.81250     |
| 0001_0111 | 1.40625     | 0011_0111 | 1.20625     | 0101_0111 | 1.00625     | 0111_0111 | 0.80625     |
| 0001_1000 | 1.40000     | 0011_1000 | 1.20000     | 0101_1000 | 1.00000     | 0111_1000 | 0.80000     |
| 0001_1001 | 1.39375     | 0011_1001 | 1.19375     | 0101_1001 | 0.99375     | 0111_1001 | 0.79375     |
| 0001_1010 | 1.38750     | 0011_1010 | 1.18750     | 0101_1010 | 0.98750     | 0111_1010 | 0.78750     |
| 0001_1011 | 1.38125     | 0011_1011 | 1.18125     | 0101_1011 | 0.98125     | 0111_1011 | 0.78125     |
| 0001_1100 | 1.37500     | 0011_1100 | 1.17500     | 0101_1100 | 0.97500     | 0111_1100 | 0.77500     |
| 0001_1101 | 1.36875     | 0011_1101 | 1.16875     | 0101_1101 | 0.96875     | 0111_1101 | 0.76875     |
| 0001_1110 | 1.36250     | 0011_1110 | 1.16250     | 0101_1110 | 0.96250     | 0111_1110 | 0.76250     |
| 0001_1111 | 1.35625     | 0011_1111 | 1.15625     | 0101_1111 | 0.95625     | 0111_1111 | 0.75625     |
| 1000_0000 | 0.75000     | 1010_0000 | 0.55000*    | 1100_0000 | 0.35000*    | 1110_0000 | 0.15000*    |
| 1000_0001 | 0.74375     | 1010_0001 | 0.54375*    | 1100_0001 | 0.34375*    | 1110_0001 | 0.14375*    |
| 1000_0010 | 0.73750     | 1010_0010 | 0.53750*    | 1100_0010 | 0.33750*    | 1110_0010 | 0.13750*    |
| 1000_0011 | 0.73125     | 1010_0011 | 0.53125*    | 1100_0011 | 0.33125*    | 1110_0011 | 0.13125*    |
| 1000_0100 | 0.72500     | 1010_0100 | 0.52500*    | 1100_0100 | 0.32500*    | 1110_0100 | 0.12500*    |
| 1000_0101 | 0.71875     | 1010_0101 | 0.51875*    | 1100_0101 | 0.31875*    | 1110_0101 | 0.11875*    |
| 1000_0110 | 0.71250     | 1010_0110 | 0.51250*    | 1100_0110 | 0.31250*    | 1110_0110 | 0.11250*    |
| 1000_0111 | 0.70625     | 1010_0111 | 0.50625*    | 1100_0111 | 0.30625*    | 1110_0111 | 0.10625*    |

TABLE 7. SERIAL VID CODES (Continued)

| SVID[7:0] | VOLTAGE (V) | SVID[6:0] | VOLTAGE (V) | SVID[6:0]  | VOLTAGE (V) | SVID[6:0] | VOLTAGE (V) |
|-----------|-------------|-----------|-------------|------------|-------------|-----------|-------------|
| 1000_1000 | 0.70000     | 1010_1000 | 0.50000*    | 1100_1000  | 0.30000*    | 1110_1000 | 0.10000*    |
| 1000_1001 | 0.69375     | 1010_1001 | 0.49375*    | 1100_1001  | 0.29375*    | 1110_1001 | 0.09375*    |
| 1000_1010 | 0.68750     | 1010_1010 | 0.48750*    | 1100_1010  | 0.28750*    | 1110_1010 | 0.08750*    |
| 1000_1011 | 0.68125     | 1010_1011 | 0.48125*    | 1100_1011  | 0.28125*    | 1110_1011 | 0.08125*    |
| 1000_1100 | 0.67500     | 1010_1100 | 0.47500*    | 1100_1100  | 0.27500*    | 1110_1100 | 0.07500*    |
| 1000_1101 | 0.66875     | 1010_1101 | 0.46875*    | 1100_1101  | 0.26875*    | 1110_1101 | 0.06875*    |
| 1000_1110 | 0.66250     | 1010_1110 | 0.46250*    | 1100_1110  | 0.26250*    | 1110_1110 | 0.06250*    |
| 1000_1111 | 0.65625     | 1010_1111 | 0.45625*    | 1100_1111  | 0.25625*    | 1110_1111 | 0.05625*    |
| 1001_0000 | 0.65000     | 1011_0000 | 0.45000*    | 1101_0000  | 0.25000*    | 1111_0000 | 0.05000*    |
| 1001_0001 | 0.64375     | 1011_0001 | 0.44375*    | 1101_0001  | 0.24375*    | 1111_0001 | 0.04375*    |
| 1001_0010 | 0.63750     | 1011_0010 | 0.43750*    | 1101_0010  | 0.23750*    | 1111_0010 | 0.03750*    |
| 1001_0011 | 0.63125     | 1011_0011 | 0.43125*    | 1101_0011  | 0.23125*    | 1111_0011 | 0.03125*    |
| 1001_0100 | 0.62500     | 1011_0100 | 0.42500*    | 1101_0100  | 0.22500*    | 1111_0100 | 0.02500*    |
| 1001_0101 | 0.61875     | 1011_0101 | 0.41875*    | 1101_0101  | 0.21875*    | 1111_0101 | 0.01875*    |
| 1001_0110 | 0.61250     | 1011_0110 | 0.41250*    | 1101_0110  | 0.21250*    | 1111_0110 | 0.01250*    |
| 1001_0111 | 0.60625     | 1011_0111 | 0.40625*    | 1101_0111* | 0.20625*    | 1111_0111 | 0.00625*    |
| 1001_1000 | 0.60000*    | 1011_1000 | 0.40000*    | 1101_1000  | 0.20000*    | 1111_1000 | OFF*        |
| 1001_1001 | 0.59375*    | 1011_1001 | 0.39375*    | 1101_1001  | 0.19375*    | 1111_1001 | OFF*        |
| 1001_1010 | 0.58750*    | 1011_1010 | 0.38750*    | 1101_1010  | 0.18750*    | 1111_1010 | OFF*        |
| 1001_1011 | 0.58125*    | 1011_1011 | 0.38125*    | 1101_1011  | 0.18125*    | 1111_1011 | OFF*        |
| 1001_1100 | 0.57500*    | 1011_1100 | 0.37500*    | 1101_1100  | 0.17500*    | 1111_1100 | OFF*        |
| 1001_1101 | 0.56875*    | 1011_1101 | 0.36875*    | 1101_1101  | 0.16875*    | 1111_1101 | OFF*        |
| 1001_1110 | 0.56250*    | 1011_1110 | 0.36250*    | 1101_1110  | 0.16250*    | 1111_1110 | OFF*        |
| 1001_1111 | 0.55625*    | 1011_1111 | 0.35625*    | 1101_1111  | 0.15625*    | 1111_1111 | OFF*        |

NOTE: \*Indicates a VID not required for AMD Family 10h processors. Loosened AMD requirements at these levels.

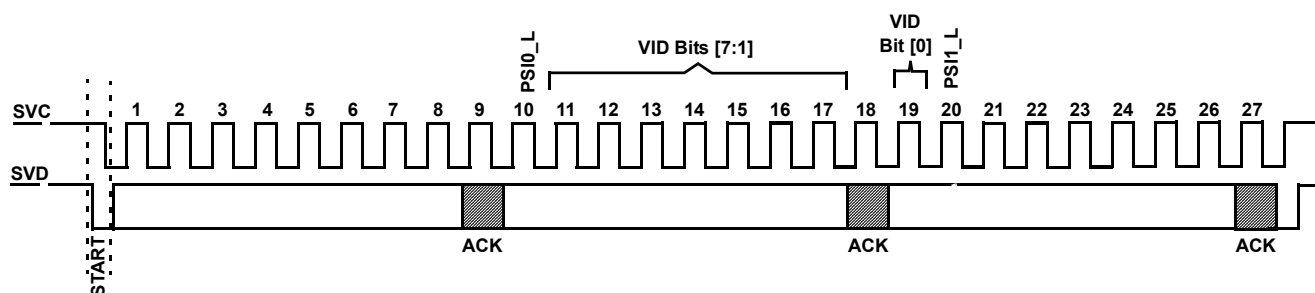


FIGURE 19. SVD PACKET STRUCTURE

## SVI Bus Protocol

The AMD processor bus protocol is similar to SMBus send byte protocol for VID transactions. The AMD SVD packet structure is shown in [Figure 19](#). The description of each bit of the three bytes that make up the SVI command are shown in [Table 8](#). During a transaction, the processor sends the start sequence followed by each of the three bytes which end with an optional acknowledge bit. The ISL6377 does not drive the SVD line during the ACK bit. Finally, the processor sends the stop sequence. After the ISL6377 has detected the stop, it can then proceed with the commanded action from the transaction.

TABLE 8. SVD DATA PACKET

| BITS  | DESCRIPTION                                                                                                                                                                    |
|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1:5   | Always 11000b                                                                                                                                                                  |
| 6     | Core domain selector bit, if set then the following data byte contains VID, power state, telemetry control, load line trim and offset trim apply to the Core VR.               |
| 7     | Northbridge domain selector bit, if set then the following data byte contains VID, power state, telemetry control, load line trim and offset trim apply to the Northbridge VR. |
| 8     | Always 0b                                                                                                                                                                      |
| 9     | Acknowledge bit                                                                                                                                                                |
| 10    | PSIO_L                                                                                                                                                                         |
| 11:17 | VID code bits [7:1]                                                                                                                                                            |
| 18    | Acknowledge bit                                                                                                                                                                |
| 19    | VID code bit [0]                                                                                                                                                               |
| 20    | PSI1_L                                                                                                                                                                         |
| 21    | TFN (Telemetry Functionality)                                                                                                                                                  |
| 22:24 | Load line slope trim                                                                                                                                                           |
| 25:26 | Offset trim [1:0]                                                                                                                                                              |
| 27    | Acknowledge bit                                                                                                                                                                |

## Power States

SVI2 defines two power state indicator levels, see [Table 9](#). As processor current consumption is reduced, the power state indicator level changes to improve VR efficiency under low power conditions.

For the Core VR operating in 4-phase mode, when PSIO\_L is asserted Channels 3 and 4 are tri-stated. The controller continues to operate in 2-phase CCM. The shedding of phases improves the efficiency of the VR at the light to moderate load levels of the CPU in this power state. When PSI1\_L is asserted the Core VR sheds Channel 2 and Channel 1 enters diode emulation mode to further boost light-load efficiency in this power state.

For the Northbridge VR operating in 2-phase mode, when PSIO\_L is asserted Channel 2 is tri-stated and Channel 1 enters diode emulation mode to boost efficiency. When PSI1\_L is asserted the Core VR continues to operate in this fashion.

It is possible for the processor to assert or deassert PSIO\_L and PSI1\_L out of order. PSIO\_L takes priority over PSI1\_L. If PSIO\_L is deasserted while PSI1\_L is still asserted, the ISL6377 will return the selected VR back full channel CCM operation. For example, if the Core VR is configured for 4-phase operation and both PSIO\_L and PSI1\_L are asserted low during a command, the VR will shed three phases and operate in 1-phase DE mode. If an SVI command follows which takes PSIO\_L high, but leaves PSI1\_L low, the VR will exit power savings mode and being operation in 4-phase CCM mode.

TABLE 9. PSIO\_L, PSI1\_L AND TFN DEFINITION

| FUNCTION | BIT | DESCRIPTION                                                                                                                                                                                                         |
|----------|-----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PSIO_L   | 10  | Power State Indicate level 0. When this signal is asserted (active Low) the processor is in a low enough power state for the ISL6377 to take action to boost efficiency by dropping phases and entering 1-phase DE. |
| PSI1_L   | 20  | Power State Indicate level 1. When this signal is asserted (active Low) the processor is in a low enough power state for the ISL6377 to take action to boost efficiency by dropping phases and entering 1-phase DE. |



## Dynamic Load Line Slope Trim

The ISL6377 supports the SVI2 ability for the processor to manipulate the load line slope of the Core and Northbridge VRs independently using the serial VID interface. The slope manipulation applies to the initial load line slope. A load line slope trim will typically coincide with a VOTF change. See [Table 10](#) for more information about the load line slope trim feature of the ISL6377. The Disable LL selection is not recommended unless operation without a LL is required and considered during the compensation of the VR.

TABLE 10. LOAD LINE SLOPE TRIM DEFINITION

| LOAD LINE SLOPE TRIM [2:0] | DESCRIPTION    |
|----------------------------|----------------|
| 000                        | Disable LL     |
| 001                        | -40% mΩ Change |
| 010                        | -20% mΩ Change |
| 011                        | No Change      |
| 100                        | +20% mΩ Change |
| 101                        | +40% mΩ Change |
| 110                        | +60% mΩ Change |
| 111                        | +80% mΩ Change |

## Dynamic Offset Trim

The ISL6377 supports the SVI2 ability for the processor to manipulate the output voltage offset of the Core and Northbridge VRs. This offset is in addition to any output voltage offset set via the COMP resistor reader. The dynamic offset trim can disable the COMP resistor programmed offset of either output when 'Disable All Offset' is selected.

TABLE 11. OFFSET TRIM DEFINITION

| OFFSET TRIM [1:0] | DESCRIPTION        |
|-------------------|--------------------|
| 00                | Disable All Offset |
| 01                | -25mV Change       |
| 10                | 0mV Change         |
| 11                | +25mV Change       |

## Telemetry

The ISL6377 can provide voltage and current information to the AMD CPU through the telemetry system outlined by the AMD SVI2 specification. The telemetry data is transmitted through the SVC and SVT lines of the SVI2 interface.

Current telemetry is based on a voltage generated across a 133kΩ resistor placed from the IMON pin to GND. The current flowing out of the IMON pin is proportional to the load current in the VR. The  $I_{sum}$  current defined in ["Voltage Regulation and Load Line Implementation" on page 15](#), provides the base conversion from the load current to the internal amplifier created  $I_{sum}$  current. The  $I_{sum}$  current is then divided down by a factor of 4 to create the IMON current which flows out of the IMON pin. The  $I_{sum}$  current will measure 36μA when the load current is at full load based on a droop current designed for 45μA at the same load current. The difference between the  $I_{sum}$  current and the

droop current is provided in [Equation 2](#). The IMON current will measure 11.25μA at full load current for the VR and the IMON voltage will be 1.2V. The load percentage, which is reported by the IC is based on the this voltage. When the load is 25% of the full load, the voltage on the IMON pin will be 25% of 1.2V or 0.3V.

The SVI interface allows the selection of no telemetry, voltage only, or voltage and current telemetry on either or both of the VR outputs. The TFN bit along with the Core and Northbridge domain selector bits are used by the processor to change the functionality of telemetry, see [Table 12](#) for more information.

TABLE 12. TFN TRUTH TABLE

| TFN, CORE, NB BITS [21, 6, 7] | DESCRIPTION                                                                                                                    |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| 1,0,1                         | Telemetry is in voltage and current mode. Therefore, voltage and current are sent for VDD and VDDNB domains by the controller. |
| 1,0,0                         | Telemetry is in voltage mode only. Only the voltage of VDD and VDDNB domains is sent by the controller.                        |
| 1,1,0                         | Telemetry is disabled.                                                                                                         |
| 1,1,1                         | Reserved                                                                                                                       |

## Protection Features

Core VR and Northbridge VR both provide overcurrent, current-balance, undervoltage and overvoltage fault protections. The controller also provides over-temperature protection. The following discussion is based on Core VR and also applies to the Northbridge VR.

### Overcurrent

The IMON voltage provides a means of determining the load current at any moment in time. The Overcurrent Protection (OCP) circuitry monitors the IMON voltage to determine when a fault occurs. Based on the previous description in ["Voltage Regulation and Load Line Implementation" on page 15](#), the current which flows out of the IMON pin is proportional to the  $I_{sum}$  current. The  $I_{sum}$  current is created from the sensed voltage across  $C_n$ , which is a measure of the load current based upon the sensing element selected. The IMON current is generated internally and is 1/4 of the  $I_{sum}$  current. The EDC or IDDspike current value for the AMD CPU load is used to set the maximum current level for droop and the IMON voltage of 1.2V which indicates 100% loading for telemetry. The  $I_{sum}$  current level at maximum load, or IDDspike, is 36μA and this translates to an IMON current level of 9μA. The IMON resistor is 133kΩ and the 9μA flowing through the IMON resistor results in a 1.2V level at maximum loading of the VR.

The overcurrent threshold is 1.5V on the IMON pin. Based on a 1.2V IMON voltage equating to 100% loading, the additional 0.3V provided above this level equates to a 25% increase in load current before an OCP fault is detected. The EDC or IDDspike current is used to set the 1.2V on IMON for full load current. So the OCP level is 1.25 times the EDC or IDDspike current level. This additional margin above the EDC or IDDspike current allows the AMD CPU to enter and exit the IDDspike performance mode without issue unless the load current is out of line with the IDDspike expectation, thus the need for overcurrent protection.

When the voltage on the IMON pin meets the overcurrent threshold of 1.5V, this triggers an OCP event. Within 2 $\mu$ s of detecting an OCP event, the controller asserts VR\_HOT\_L low to communicate to the AMD CPU to throttle back. A fault timer begins counting while IMON is at or above the 1.5V threshold. The fault timer lasts 7.5 $\mu$ s to 11 $\mu$ s and then the controller takes action by tri-stating the active channels. This provides the CPU time to recover and reduce the load current. If the OCP conditions are relieved, then the fault timer is cleared and VR\_HOT\_L is taken high clearing the fault condition. If the load current is not reduced and the OCP condition is maintained, the output voltage will fall below the undervoltage threshold due to the lack of switching or a way-overcurrent fault could occur. Either of these fault conditions will cause the controller to drop PGOOD of that output. When PGOOD is taken low, a fault flag from this VR is sent to the other VR and it is shutdown within 10 $\mu$ s and PGOOD of the other output is taken low.

The ISL6377 also features a Way-Overcurrent [WOC] feature, which immediately takes the controller into shutdown. This protection is also referred to as fast overcurrent protection for short-circuit protection. If the IMON current reaches 15 $\mu$ A, WOC is triggered. Active channels are tri-stated and the controller is placed in shutdown and PGOOD is pulled low. There is no fault timer on the WOC fault, the controller takes immediate action. The other controller output is also shutdown within 10 $\mu$ s.

## Current Balance

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

## Undervoltage

If the VSEN voltage falls below the output voltage VID value plus any programmed offsets by -325mV, the controller declares an undervoltage fault. The controller deasserts PGOOD and tri-states the power MOSFETs.

## Overvoltage

If the VSEN voltage exceeds the output voltage VID value plus any programmed offsets by +325mV, the controller declares an overvoltage fault. The controller deasserts PGOOD and turns 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. Once the output voltage is below this level, the lower gate is tri-stated. If the output voltage rises above the overvoltage threshold again, the protection process is repeated. When all power MOSFETs are turned off. This behavior provides the maximum amount of protection against shorted high-side power MOSFETs while preventing output ringing below ground.

## Thermal Monitor [NTC, NTC\_NB]

The ISL6377 features two thermal monitors which use an external resistor network which includes an NTC thermistor to monitor motherboard temperature and alert the AMD CPU of a thermal issue. Figure 20 shows the basic thermal monitor circuit on the Core VR NTC pin. The Northbridge VR features the same thermal monitor. The controller drives a 30 $\mu$ A current out of the NTC pin and monitors the voltage at the pin. The current flowing

out of the NTC pin creates a voltage that is compared to a warning threshold of 640mV. When the voltage at the NTC pin falls to this warning threshold or below, the controller asserts VR\_HOT\_L to alert the AMD CPU to throttle back load current to stabilize the motherboard temperature. A thermal fault counter begins counting toward a minimum shutdown time of 100 $\mu$ s. The thermal fault counter is an up/down counter, so if the voltage at the NTC pin rises above the warning threshold, it will count down and extend the time for a thermal fault to occur. The warning threshold does have 20mV of hysteresis.

If the voltage at the NTC pin continues to fall down to the shutdown threshold of 580mV or below, the controller goes into shutdown and triggers a thermal fault. The PGOOD pin is pulled low and tri-states the power MOSFETs. A fault on either side will shutdown both VRs.

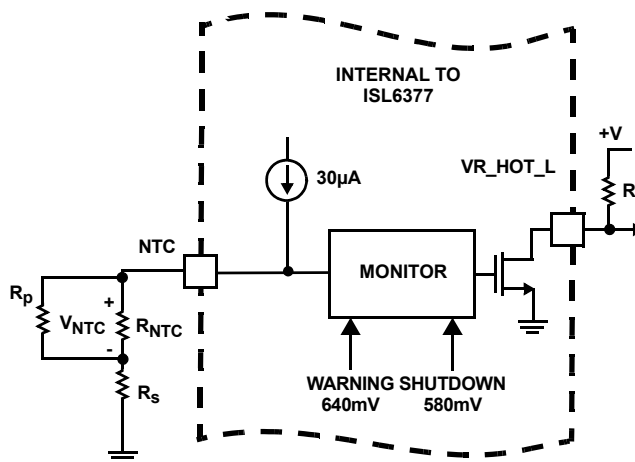


FIGURE 20. CIRCUITRY ASSOCIATED WITH THE THERMAL MONITOR FEATURE OF THE ISL6377

As the board temperature rises, the NTC thermistor resistance decreases and the voltage at the NTC pin drops. When the voltage on the NTC pin drops below the over-temperature trip threshold, then VR\_HOT is pulled low. The VR\_HOT signal is used to change the CPU operation and decrease power consumption. With the reduction in power consumption by the CPU, the board temperature decreases and the NTC thermistor voltage rises. Once the over-temperature threshold is tripped and VR\_HOT is taken low, the over-temperature threshold changes to the reset level. The addition of hysteresis to the over-temperature threshold prevents nuisance trips. Once both pin voltages exceed the over-temperature reset threshold, the pull-down on VR\_HOT is released. The signal changes state and the CPU resumes normal operation. The over-temperature threshold returns to the trip level.

Table 13 summarizes the fault protections.

TABLE 13. FAULT PROTECTION SUMMARY

| FAULT TYPE               | FAULT DURATION BEFORE PROTECTION | PROTECTION ACTION                                                                        | FAULT RESET                 |
|--------------------------|----------------------------------|------------------------------------------------------------------------------------------|-----------------------------|
| Overcurrent              | 7.5μs to 11.5μs                  | PWM tri-state                                                                            | ENABLE toggle or VDD toggle |
| Phase Current Unbalance  | 1ms                              | PWM tri-state, PGOOD latched low                                                         |                             |
| Way-Overcurrent (1.5xOC) | Immediately                      | PGOOD latched low. PWM tri-state.                                                        |                             |
| Undervoltage -325mV      |                                  | PGOOD latched low. PWM tri-state.                                                        |                             |
| Overvoltage +325mV       |                                  | PGOOD latched low. Actively pulls the output voltage to below VID value, then tri-state. |                             |
| NTC Thermal              | 100μs min                        | PGOOD latched low. PWM tri-state.                                                        |                             |

## Fault Recovery

All of the previously described fault conditions can be reset by bringing ENABLE low or by bringing VDD below the POR threshold. When ENABLE and VDD return to their high operating levels, the controller resets the faults and soft-start occurs.

## Interface Pin Protection

The SVC and SVD pins feature protection diodes which must be considered when removing power to VDD and VDDIO, but leaving it applied to these pins. Figure 21 shows the basic protection on the pins. If SVC and/or SVD are powered but VDD is not, leakage current will flow from these pins to VDD.

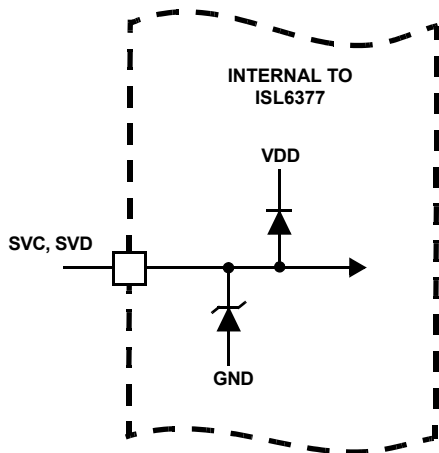


FIGURE 21. PROTECTION DEVICES ON THE SVC AND SVD PINS

## Key Component Selection

### Inductor DCR Current-Sensing Network

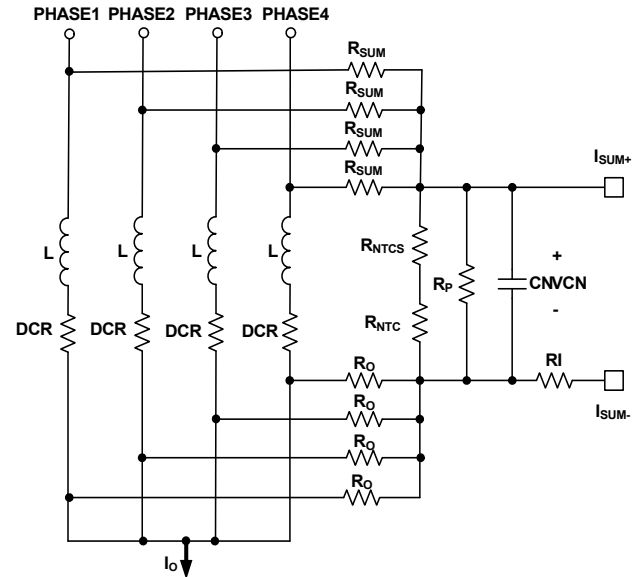


FIGURE 22. DCR CURRENT-SENSING NETWORK

Figure 22 shows the inductor DCR current-sensing network for a 4-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 ignores it.

The summed inductor current information is presented to the capacitor  $C_N$ . Equations 22 through 26 describe the frequency domain relationship between inductor total current  $I_O(s)$  and  $C_N$  voltage  $V_{C_N}(s)$ :

$$V_{C_N}(s) = \left( \frac{R_{ntcnet}}{R_{ntcnet} + \frac{R_{sum}}{N}} \times \frac{DCR}{N} \right) \times I_O(s) \times A_{CS}(s) \quad (EQ. 22)$$

$$R_{ntcnet} = \frac{(R_{ntcs} + R_{ntc}) \times R_P}{R_{ntcs} + R_{ntc} + R_P} \quad (EQ. 23)$$

$$A_{CS}(s) = \frac{1 + \frac{s}{\omega_L}}{1 + \frac{s}{\omega_{SNS}}} \quad (EQ. 24)$$

$$\omega_L = \frac{DCR}{L} \quad (\text{EQ. 25})$$

$$\omega_{sns} = \frac{1}{\frac{R_{ntcnet} \times \frac{R_{sum}}{N}}{R_{ntcnet} + \frac{R_{sum}}{N}} \times C_n} \quad (\text{EQ. 26})$$

Where N is the number of phases.

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  $R_{ntc}$  value decrease as its temperature decreases. Proper selection of  $R_{sum}$ ,  $R_{ntcs}$ ,  $R_p$  and  $R_{ntc}$  parameters ensures that  $V_{cn}$  represents 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 a 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 27](#) gives  $C_n$  value.

$$C_n = \frac{L}{\frac{R_{ntcnet} \times \frac{R_{sum}}{N}}{R_{ntcnet} + \frac{R_{sum}}{N}} \times DCR} \quad (\text{EQ. 27})$$

For example, given  $N = 4$ ,  $R_{sum} = 3.65k\Omega$ ,  $R_p = 11k\Omega$ ,  $R_{ntcs} = 2.61k\Omega$ ,  $R_{ntc} = 10k\Omega$ ,  $DCR = 0.88m\Omega$  and  $L = 0.36\mu H$ , [Equation 27](#) gives  $C_n = 0.518\mu F$ .

Assuming the compensator design is correct, [Figure 23](#) 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,  $V_{cn}(s)$  does not accurately represent real-time  $I_o(s)$  and worsens the transient response. [Figure 24](#) shows the load transient response when  $C_n$  is too small.  $V_{core}$  sags excessively upon load insertion and may create a system failure. [Figure 25](#) shows the transient response when  $C_n$  is too large.  $V_{core}$  is sluggish in drooping to its final value.

There is excessive overshoot if load insertion occurs during this time, which may negatively affect the CPU reliability.

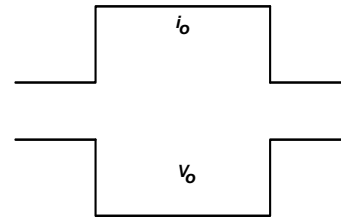


FIGURE 23. DESIRED LOAD TRANSIENT RESPONSE WAVEFORMS

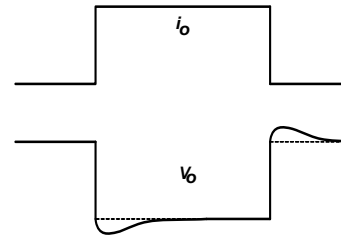


FIGURE 24. LOAD TRANSIENT RESPONSE WHEN  $C_n$  IS TOO SMALL

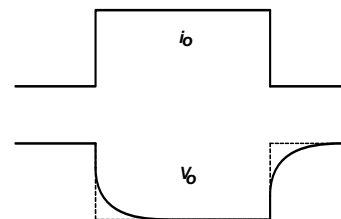


FIGURE 25. LOAD TRANSIENT RESPONSE WHEN  $C_n$  IS TOO LARGE

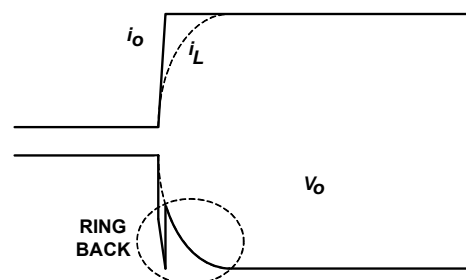


FIGURE 26. OUTPUT VOLTAGE RING BACK PROBLEM

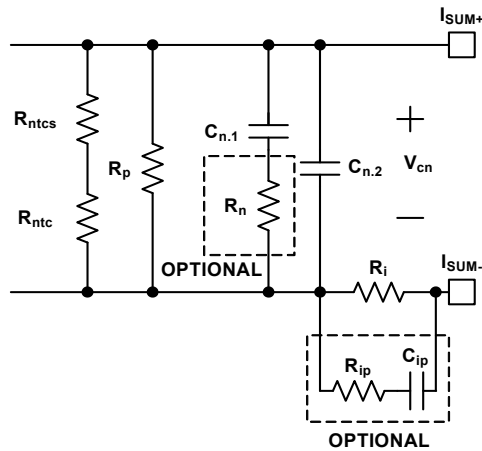


FIGURE 27. OPTIONAL CIRCUITS FOR RINGBACK REDUCTION

Figure 26 shows the output voltage ringback 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 the 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 ringback problem. This phenomenon is not observed when the output capacitor has very low ESR and ESL, as is the case with all ceramic capacitors.

Figure 27 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 27 shows that two capacitors ( $C_{n.1}$  and  $C_{n.2}$ ) are in parallel. Resistor  $R_n$  is an optional component to reduce the  $V_o$  ringback. 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 24 shows,  $V_o$  tends to dip when  $C_n$  is too small and this effect reduces 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

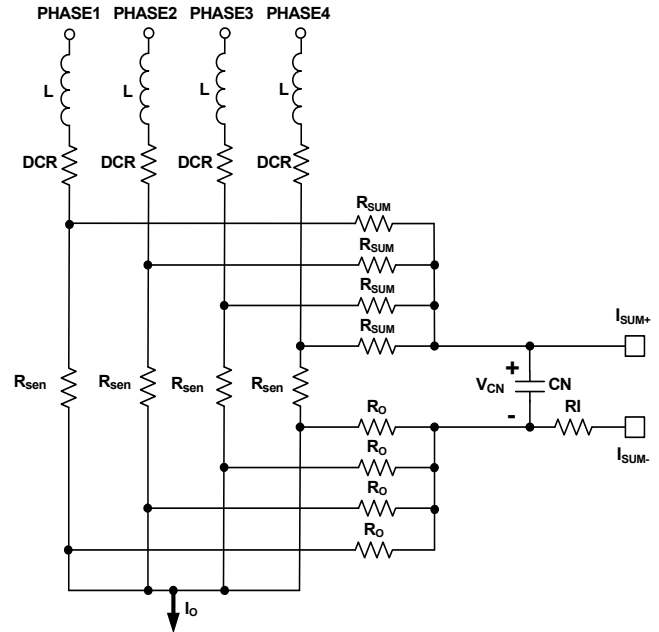


FIGURE 28. RESISTOR CURRENT SENSING NETWORK

Figure 28 shows the resistor current-sensing network for a 4-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 28 through 30 give the  $V_{cn}(s)$  expression.

$$V_{cn}(s) = \frac{R_{sen}}{N} \times I_o(s) \times A_{Rsen}(s) \quad (\text{EQ. 28})$$

$$A_{Rsen}(s) = \frac{1}{1 + \frac{s}{\omega_{sns}}} \quad (\text{EQ. 29})$$

$$\omega_{Rsen} = \frac{1}{\frac{R_{sum}}{N} \times C_n} \quad (\text{EQ. 30})$$

Transfer function  $A_{Rsen}(s)$  always has unity gain at DC. Current-sensing resistor  $R_{sen}$  value does 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 2 on page 16 and Figures 22, 26 and 28; resistor  $R_i$  sets the  $I_{sum}$  current which is proportional to droop current and IMON current. Tables 1 and 2 show the internal OCP threshold based on the IMON pin voltage. Since the  $R_i$  resistor impacts both the droop current and the IMON current, fine adjustments to  $i_{droop}$  will require changing the  $R_{comp}$  resistor.

For example, the OCP threshold is 1.5V on the IMON pin, which equates to an IMON current of 11.25μA using a 133kΩ IMON resistor. The corresponding  $I_{sum}$  is 45μA, which results in an



$I_{\text{droop}}$  of 56.25 $\mu\text{A}$ . At full load current,  $I_{\text{omax}}$ , the  $I_{\text{sum}}$  current is 36 $\mu\text{A}$  and the resulting  $I_{\text{droop}}$  is 45 $\mu\text{A}$ . The ratio of  $I_{\text{sum}}$  at OCP relative to full load current is 1.25. Therefore, the OCP current trip level is 25% higher than the full load current.

For inductor DCR sensing, Equation 31 gives the DC relationship of  $V_{\text{cn}}(s)$  and  $I_o(s)$ :

$$V_{\text{Cn}} = \left( \frac{R_{\text{ntcnet}}}{R_{\text{ntcnet}} + \frac{R_{\text{sum}}}{N}} \times \frac{\text{DCR}}{N} \right) \times I_o \quad (\text{EQ. 31})$$

Substitution of Equation 31 into Equation 2 gives Equation 32:

$$I_{\text{droop}} = \frac{5}{4} \times \frac{1}{R_i} \times \frac{R_{\text{ntcnet}}}{R_{\text{ntcnet}} + \frac{R_{\text{sum}}}{N}} \times \frac{\text{DCR}}{N} \times I_o \quad (\text{EQ. 32})$$

Therefore:

$$R_i = \frac{5}{4} \times \frac{R_{\text{ntcnet}} \times \text{DCR} \times I_o}{N \times \left( R_{\text{ntcnet}} + \frac{R_{\text{sum}}}{N} \right) \times I_{\text{droop}}} \quad (\text{EQ. 33})$$

Substitution of Equation 23 and application of the OCP condition in Equation 33 gives Equation 34:

$$R_i = \frac{5}{4} \times \frac{\frac{(R_{\text{ntcs}} + R_{\text{ntc}}) \times R_p}{R_{\text{ntcs}} + R_{\text{ntc}} + R_p} \times \text{DCR} \times I_{\text{omax}}}{N \times \left( \frac{(R_{\text{ntcs}} + R_{\text{ntc}}) \times R_p}{R_{\text{ntcs}} + R_{\text{ntc}} + R_p} + \frac{R_{\text{sum}}}{N} \right) \times I_{\text{droopmax}}} \quad (\text{EQ. 34})$$

Where  $I_{\text{omax}}$  is the full load current and  $I_{\text{droopmax}}$  is the corresponding droop current. For example, given  $N = 4$ ,  $R_{\text{sum}} = 3.65\text{k}\Omega$ ,  $R_p = 11\text{k}\Omega$ ,  $R_{\text{ntcs}} = 2.61\text{k}\Omega$ ,  $R_{\text{ntc}} = 10\text{k}\Omega$ ,  $\text{DCR} = 0.88\text{m}\Omega$ ,  $I_{\text{omax}} = 100\text{A}$  and  $I_{\text{droopmax}} = 45\mu\text{A}$ .

Equation 34 gives  $R_i = 529\Omega$ .

For resistor sensing, Equation 35 gives the DC relationship of  $V_{\text{cn}}(s)$  and  $I_o(s)$ .

$$V_{\text{Cn}} = \frac{R_{\text{sen}}}{N} \times I_o \quad (\text{EQ. 35})$$

Substitution of Equation 35 into Equation 2 gives Equation 36:

$$I_{\text{droop}} = \frac{5}{4} \times \frac{1}{R_i} \times \frac{R_{\text{sen}}}{N} \times I_o \quad (\text{EQ. 36})$$

Therefore:

$$R_i = \frac{5}{4} \times \frac{R_{\text{sen}} \times I_o}{N \times I_{\text{droop}}} \quad (\text{EQ. 37})$$

Substitution of Equation 37 and application of the OCP condition in Equation 33 gives Equation 38:

$$R_i = \frac{5}{4} \times \frac{R_{\text{sen}} \times I_{\text{omax}}}{N \times I_{\text{droopmax}}} \quad (\text{EQ. 38})$$

Where  $I_{\text{omax}}$  is the full load current and  $I_{\text{droopmax}}$  is the corresponding droop current. For example, given  $N = 4$ ,  $R_{\text{sen}} = 1\text{m}\Omega$ ,  $I_{\text{omax}} = 100\text{A}$  and  $I_{\text{droopmax}} = 45\mu\text{A}$ , Equation 38 gives  $R_i = 694\Omega$ .

## Load Line Slope

See Figure 15 for load line implementation.

For inductor DCR sensing, substitution of Equation 32 into Equation 3 gives the load line slope expression:

$$\text{LL} = \frac{V_{\text{droop}}}{I_o} = \frac{5}{4} \times \frac{R_{\text{droop}}}{R_i} \times \frac{R_{\text{ntcnet}}}{R_{\text{ntcnet}} + \frac{R_{\text{sum}}}{N}} \times \frac{\text{DCR}}{N} \quad (\text{EQ. 39})$$

For resistor sensing, substitution of Equation 36 into Equation 3 gives the load line slope expression:

$$\text{LL} = \frac{V_{\text{droop}}}{I_o} = \frac{5}{4} \times \frac{R_{\text{sen}} \times R_{\text{droop}}}{N \times R_i} \quad (\text{EQ. 40})$$

Substitution of Equation 33 and rewriting Equation 39, or substitution of Equation 37 and rewriting Equation 40, gives the same result as in Equation 41:

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

One can use the full-load condition to calculate  $R_{\text{droop}}$ . For example, given  $I_{\text{omax}} = 100\text{A}$ ,  $I_{\text{droopmax}} = 45\mu\text{A}$  and  $\text{LL} = 2.1\text{m}\Omega$ , Equation 41 gives  $R_{\text{droop}} = 4.67\text{k}\Omega$ .

It is recommended to start with the  $R_{\text{droop}}$  value calculated by Equation 41 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 23 shows the desired load transient response waveforms. Figure 29 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  $Z_{\text{out}}(s)$ . If  $Z_{\text{out}}(s)$  is equal to the load line slope LL, i.e., a constant output impedance, then in the entire frequency range,  $V_o$  will have a square response when  $I_o$  has a square change.

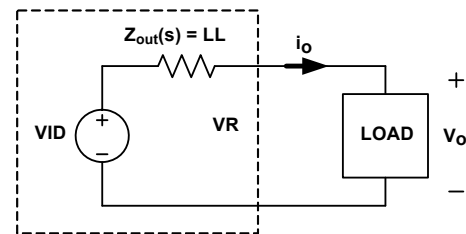


FIGURE 29. VOLTAGE REGULATOR EQUIVALENT CIRCUIT

Intersil provides a Microsoft Excel-based spreadsheet to help design the compensator and the current sensing network so that VR achieves constant output impedance as a stable system.

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 30 conceptually

shows T1(s) measurement set-up and Figure 31 conceptually shows T2(s) measurement set-up. The VR senses the inductor current, multiplies it by a gain of the load line slope, adds it on top of the sensed output voltage and then feeds it to the compensator. T1 is measured after the summing node and T2 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 actually be measured on an ISL6377 regulator.

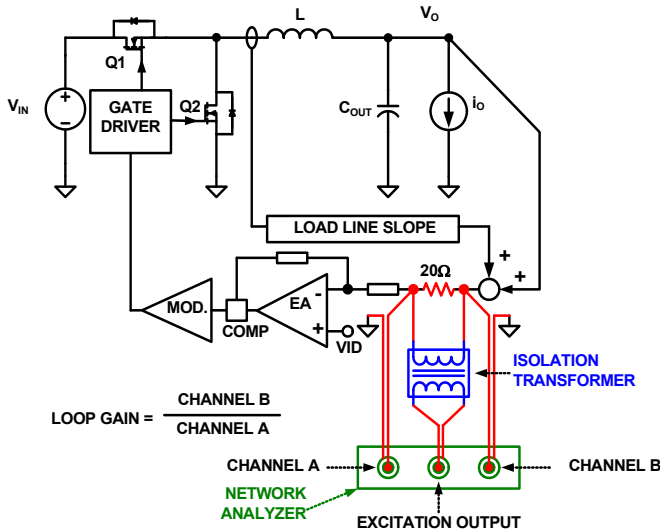


FIGURE 30. LOOP GAIN T1(s) MEASUREMENT SET-UP

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), therefore has a higher impact on system stability.

T2(s) is the voltage loop gain with closed droop loop, thus having a higher impact on output voltage response.

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

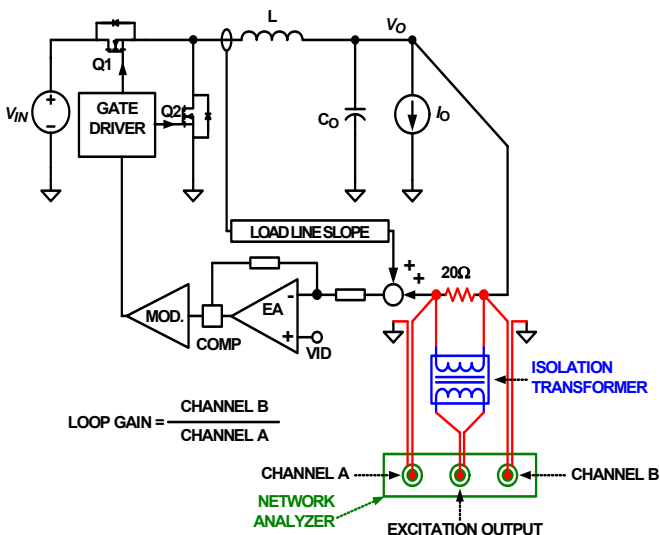


FIGURE 31. LOOP GAIN T2(s) MEASUREMENT SET-UP

## Current Balancing

Refer to Figures 16 through 22 for information on current balancing. The ISL6377 achieves current balancing through matching the ISEN pin voltages.  $R_{isen}$  and  $C_{isen}$  form filters to remove the switching ripple of the phase node voltages. It is recommended to use a rather long  $R_{isen}C_{isen}$  time constant such that the ISEN voltages have minimal ripple and represent the DC current flowing through the inductors. Recommended values are  $R_S = 10k\Omega$  and  $C_S = 0.22\mu F$ .

## Thermal Monitor Component Selection

The ISL6377 features two pins, NTC and NTC\_NB, which are used to monitor motherboard temperature and alert the AMD CPU if a thermal issues arises. The basic function of this circuitry is outlined in the "Thermal Monitor [NTC, NTC\_NB]" on page 26. Figure 32 shows the basic configuration of the NTC resistor,  $R_{NTC}$  and offset resistor,  $R_S$ , used to generate the warning and shutdown voltages at the NTC pin.

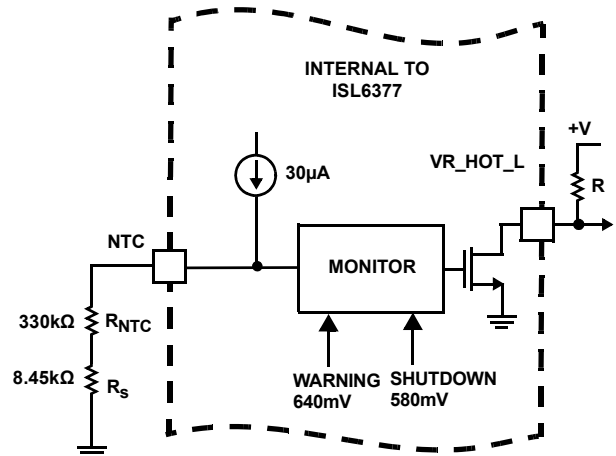


FIGURE 32. THERMAL MONITOR FEATURE OF THE ISL6377

As the board temperature rises, the NTC thermistor resistance decreases and the voltage at the NTC pin drops. When the voltage on the NTC pin drops below the thermal warning threshold of 0.640V, then VR\_HOT\_L is pulled low. When the AMD CPU detects VR\_HOT\_L has gone low, it will begin throttling back load current on both outputs to reduce the board temperature.

If the board temperature continues to rise, the NTC thermistor resistance will drop further and the voltage at the NTC pin could drop below the thermal shutdown threshold of 0.580V. Once this threshold is reached, the ISL6377 shuts down both Core and Northbridge VRs indicating a thermal fault has occurred prior to the thermal fault counter triggering a fault.

Selection of the NTC thermistor can vary depending on how the resistor network is configured. The equivalent resistance at the typical thermal warning threshold voltage of 0.64V is defined in Equation 42.

$$\frac{0.64V}{30\mu A} = 21.3k\Omega \quad (\text{EQ. 42})$$

The equivalent resistance at the typical thermal shutdown threshold voltage of 0.58V required to shutdown both outputs is defined in [Equation 43](#).

$$\frac{0.58\text{V}}{30\mu\text{A}} = 19.3\text{k}\Omega \quad (\text{EQ. 43})$$

The NTC thermistor value correlates to the resistance change between the warning and shutdown thresholds and the required temperature change. If the warning level is designed to occur at a board temperature of +100°C and the thermal shutdown level at a board temperature of +105°C, then the resistance change of the thermistor can be calculated. For example, a Panasonic NTC thermistor with B = 4700 has a resistance ratio of 0.03939 of its nominal value at +100°C and 0.03308 of its nominal value at +105°C. Taking the required resistance change between the thermal warning threshold and the shutdown threshold and dividing it by the change in resistance ratio of the NTC thermistor at the two temperatures of interest, the required resistance of the NTC is defined in [Equation 44](#).

$$\frac{(21.3\text{k}\Omega - 19.3\text{k}\Omega)}{(0.03939 - 0.03308)} = 317\text{k}\Omega \quad (\text{EQ. 44})$$

The closest standard thermistor to the value calculated with B = 4700 is 330kΩ. The NTC thermistor part number is ERTJOEV334J. The actual resistance change of this standard thermistor value between the warning threshold and the shutdown threshold is calculated in [Equation 45](#).

$$(330\text{k}\Omega \cdot 0.03939) - (330\text{k}\Omega \cdot 0.03308) = 2.082\text{k}\Omega \quad (\text{EQ. 45})$$

Since the NTC thermistor resistance at +105°C is less than the required resistance from [Equation 43](#), additional resistance in series with the thermistor is required to make up the difference. A standard resistor, 1% tolerance, added in series with the thermistor will increase the voltage seen at the NTC pin. The additional resistance required is calculated in [Equation 46](#).

$$19.3\text{k}\Omega - 10.916\text{k}\Omega = 8.384\text{k}\Omega \quad (\text{EQ. 46})$$

The closest, standard 1% tolerance resistor is 8.45kΩ.

The NTC thermistor is placed in a hot spot on the board, typically near the upper MOSFET of Channel 1 of the respective output. The standard resistor is placed next to the controller.

## Layout Guidelines

### PCB Layout Considerations

#### POWER AND SIGNAL LAYERS PLACEMENT ON THE PCB

As a general rule, power layers should be close together, either on the top or bottom of the board, with the weak analog or logic signal layers on the opposite side of the board. The ground-plane layer should be adjacent to the signal layer to provide shielding.

### COMPONENT PLACEMENT

There are two sets of critical components in a DC/DC converter; the power components and the small signal components. The power components are the most critical because they switch large amounts of energy. The small signal components connect to sensitive nodes or supply critical bypassing current and signal coupling.

The power components should be placed first and these include MOSFETs, input and output capacitors and the inductor. It is important to have a symmetrical layout for each power train, preferably with the controller located equidistant from each power train. Symmetrical layout allows heat to be dissipated equally across all power trains. Keeping the distance between the power train and the control IC short helps keep the gate drive traces short. These drive signals include the LGATE, UGATE, PGND, PHASE and BOOT.

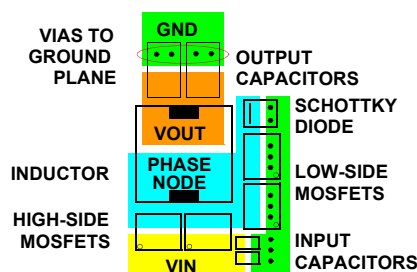


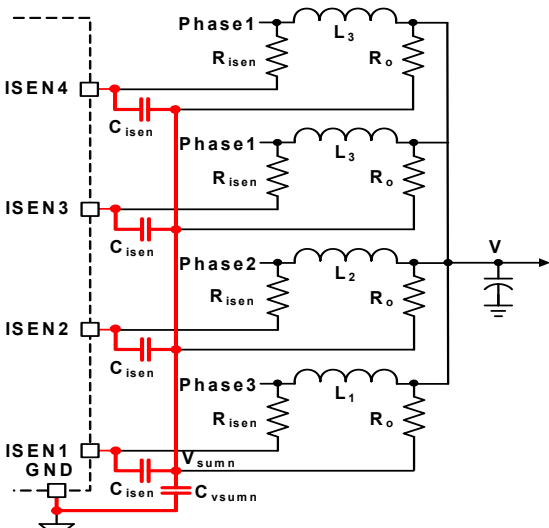
FIGURE 33. TYPICAL POWER COMPONENT PLACEMENT

When placing MOSFETs, try to keep the source of the upper MOSFETs and the drain of the lower MOSFETs as close as thermally possible (see [Figure 33](#)). Input high-frequency capacitors should be placed close to the drain of the upper MOSFETs and the source of the lower MOSFETs. Place the output inductor and output capacitors between the MOSFETs and the load. High-frequency output decoupling capacitors (ceramic) should be placed as close as possible to the decoupling target (microprocessor), making use of the shortest connection paths to any internal planes. Place the components in such a way that the area under the IC has less noise traces with high dV/dt and di/dt, such as gate signals and phase node signals.

[Table 14](#) shows layout considerations for the ISL6377 controller by pin.



TABLE 14. LAYOUT CONSIDERATIONS FOR THE ISL6377 CONTROLLER

| PIN NUMBER | SYMBOL   | LAYOUT GUIDELINES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BOTTOM PAD | GND      | Connect this ground pad to the ground plane through a low impedance path. A minimum of 5 vias are recommended to connect this pad to the internal ground plane layers of the PCB                                                                                                                                                                                                                                                                                                                                                                              |
| 1          | ISEN2_NB | Each ISEN pin has a capacitor ( $C_{isen}$ ) decoupling it to VSUMN_NB, then through another capacitor ( $C_{vsumn\_nb}$ ) to GND. Place $C_{isen}$ capacitors as close as possible to the controller and keep the following loops small:<br>1. ISEN1_NB pin to ISEN2_NB pin<br>2. Any ISENx_NB pin to GND                                                                                                                                                                                                                                                    |
| 2          | NTC_NB   | The NTC thermistor must be placed close to the thermal source that is monitored to determine Northbridge thermal throttling. Placement at the hottest spot of the Northbridge VR is recommended. Additional standard resistors in the resistor network on this pin should be placed near the IC.                                                                                                                                                                                                                                                              |
| 3          | IMON_NB  | Place the IMON_NB resistor close to this pin and make keep a tight GND connection.                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 4          | SVC      | Use good signal integrity practices and follow AMD recommendations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 5          | VR_HOT_L | Follow AMD recommendations. Placement of the pull-up resistor near the IC is recommended.                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 6          | SVD      | Use good signal integrity practices and follow AMD recommendations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 7          | VDDIO    | Use good signal integrity practices and follow AMD recommendations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 8          | SVT      | Use good signal integrity practices and follow AMD recommendations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 9          | ENABLE   | No special considerations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 10         | PWROK    | Use good signal integrity practices and follow AMD recommendations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 11         | NTC      | The NTC thermistor must be placed close to the thermal source that is monitored to determine Core thermal throttling. Placement at the hottest spot of the Core VR is recommended. Additional standard resistors in the resistor network on this pin should be placed near the IC.                                                                                                                                                                                                                                                                            |
| 12         | ISEN4    | <p>Each ISEN pin has a capacitor (<math>C_{isen}</math>) decoupling it to VSUMN and then through another capacitor (<math>C_{vsumn}</math>) to GND. Place <math>C_{isen}</math> 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 to be minimized.</p>  |
| 13         | ISEN3    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 14         | ISEN2    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 15         | ISEN1    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

**TABLE 14. LAYOUT CONSIDERATIONS FOR THE ISL6377 CONTROLLER (Continued)**

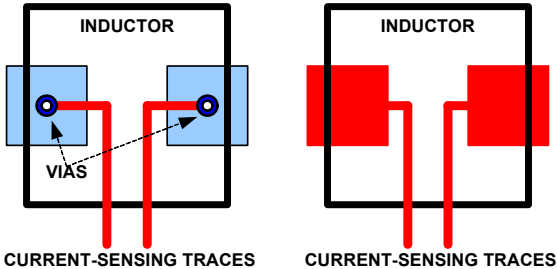
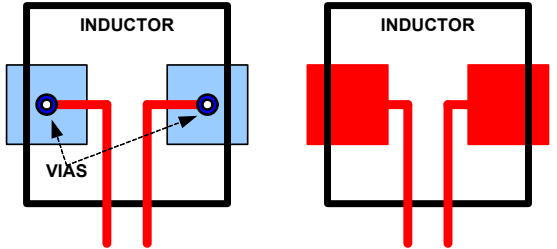
| PIN NUMBER | SYMBOL   | LAYOUT GUIDELINES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|------------|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 16         | ISUMP    | Place the current sensing circuit in general proximity of the controller.<br>Place capacitor Cn very close to the controller.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 17         | ISUMN    | Place the NTC thermistor next to Core VR Channel 1 inductor so it senses the inductor temperature correctly.<br>Each phase of the power stage sends a pair of V <sub>SUMP</sub> and V <sub>SUMN</sub> 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. 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 style="text-align: center;">CURRENT-SENSING TRACES      CURRENT-SENSING TRACES</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 18         | VSEN     | Place the filter on these pins in close proximity to the controller for good coupling.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 19         | RTN      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 20         | IMON     | Place the IMON resistor close to this pin and make keep a tight GND connection.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 21         | FB       | Place the compensation components in general proximity of the controller.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 22         | COMP     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 23         | PGOOD    | No special consideration.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 24         | BOOT1    | Use a wide trace width (>30mil). Avoid routing any sensitive analog signal traces close to or crossing over this trace.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 25         | UGATE1   | These two signals should be routed together in parallel. Each trace should have sufficient width (>30mil). Avoid routing these signals near sensitive analog signal traces or crossing over them. Routing PHASE1 to the Core VR Channel 1 high-side MOSFET source pin instead of a general connection to PHASE1 copper is recommended for better performance.                                                                                                                                                                                                                                                                                                                                                                                                     |
| 26         | PHASE1   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 27         | LGATE1   | Use sufficient trace width (>30mil). Avoid routing this signal near any sensitive analog signal traces or crossing over them.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 28         | PWM_Y    | No special considerations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 29         | VDD      | A high quality, X7R dielectric MLCC capacitor is recommended to decouple this pin to GND. Place the capacitor in close proximity to the pin with the filter resistor nearby the IC.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 30         | VDDP     | A high quality, X7R dielectric MLCC capacitor is recommended to decouple this pin to GND. Place the capacitor in close proximity to the pin.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 31         | LGATE2   | Use sufficient trace width (>30mil). Avoid routing this signal near any sensitive analog signal traces or crossing over them.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 32         | PHASE2   | These two signals should be routed together in parallel. Each trace should have sufficient width (>30mil). Avoid routing these signals near sensitive analog signal traces or crossing over them. Routing PHASE2 to the Core VR Channel 2 high-side MOSFET source pin instead of a general connection to PHASE2 copper is recommended for better performance.                                                                                                                                                                                                                                                                                                                                                                                                     |
| 33         | UGATE2   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 34         | BOOT2    | Use a wide trace width (>30mil). Avoid routing any sensitive analog signal traces close to or crossing over this trace.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 35         | PWM4     | No special considerations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 36         | BOOTX    | Use a wide trace width (>30mil). Avoid routing any sensitive analog signal traces close to or crossing over this trace.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 37         | UGATEX   | These two signals should be routed together in parallel. Each trace should have sufficient width (>30mil). Avoid routing these signals near sensitive analog signal traces or crossing over them. Routing PHASEX to the high-side MOSFET source pin instead of a general connection to the PHASEX copper is recommended for better performance.                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 38         | PHASEX   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 39         | LGATEX   | Use sufficient trace width (>30mil). Avoid routing this signal near any sensitive analog signal traces or crossing over them.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 40         | PWM2_NB  | No special considerations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 41         | FCCM_NB  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 42         | PGOOD_NB |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

TABLE 14. LAYOUT CONSIDERATIONS FOR THE ISL6377 CONTROLLER (Continued)

| PIN NUMBER | SYMBOL   | LAYOUT GUIDELINES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 43         | COMP_NB  | Place the compensation components in general proximity of the controller.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 44         | FB_NB    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 45         | VSEN_NB  | Place the filter on this pin in close proximity to the controller for good coupling.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 46         | ISUMN_NB | Place the current sensing circuit in general proximity of the controller.<br>Place capacitor $C_n$ very close to the controller.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 47         | ISUMP_NB | Place the NTC thermistor next to Core VR Channel 1 inductor so it senses the inductor temperature correctly.<br>Each phase of the power stage sends a pair of $V_{SUMP}$ and $V_{SUMN}$ 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. 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 style="text-align: center;">CURRENT-SENSING TRACES      CURRENT-SENSING TRACES</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 48         | ISEN1_NB | Each ISEN pin has a capacitor ( $C_{isen}$ ) decoupling it to $V_{SUMN\_NB}$ , then through another capacitor ( $C_{vsumn\_nb}$ ) to GND. Place $C_{isen}$ capacitors as close as possible to the controller and keep the following loops small:<br>1. ISEN1_NB pin to ISEN2_NB pin<br>2. Any ISENx_NB pin to GND                                                                                                                                                                                                                                                                                                                                                                                                                                   |

## 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 revision.

| DATE             | REVISION | CHANGE                                                                                                                                                                                               |
|------------------|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| November 2, 2015 | FN8336.1 | On page 1 under Features, added "Serial VID clock frequency range 100kHz to 25MHz" below "Supports AMD SVI 2.0 serial data bus interface".<br>Released Products section with About Intersil section. |
| August 6, 2012   | FN8336.0 | Initial release                                                                                                                                                                                      |

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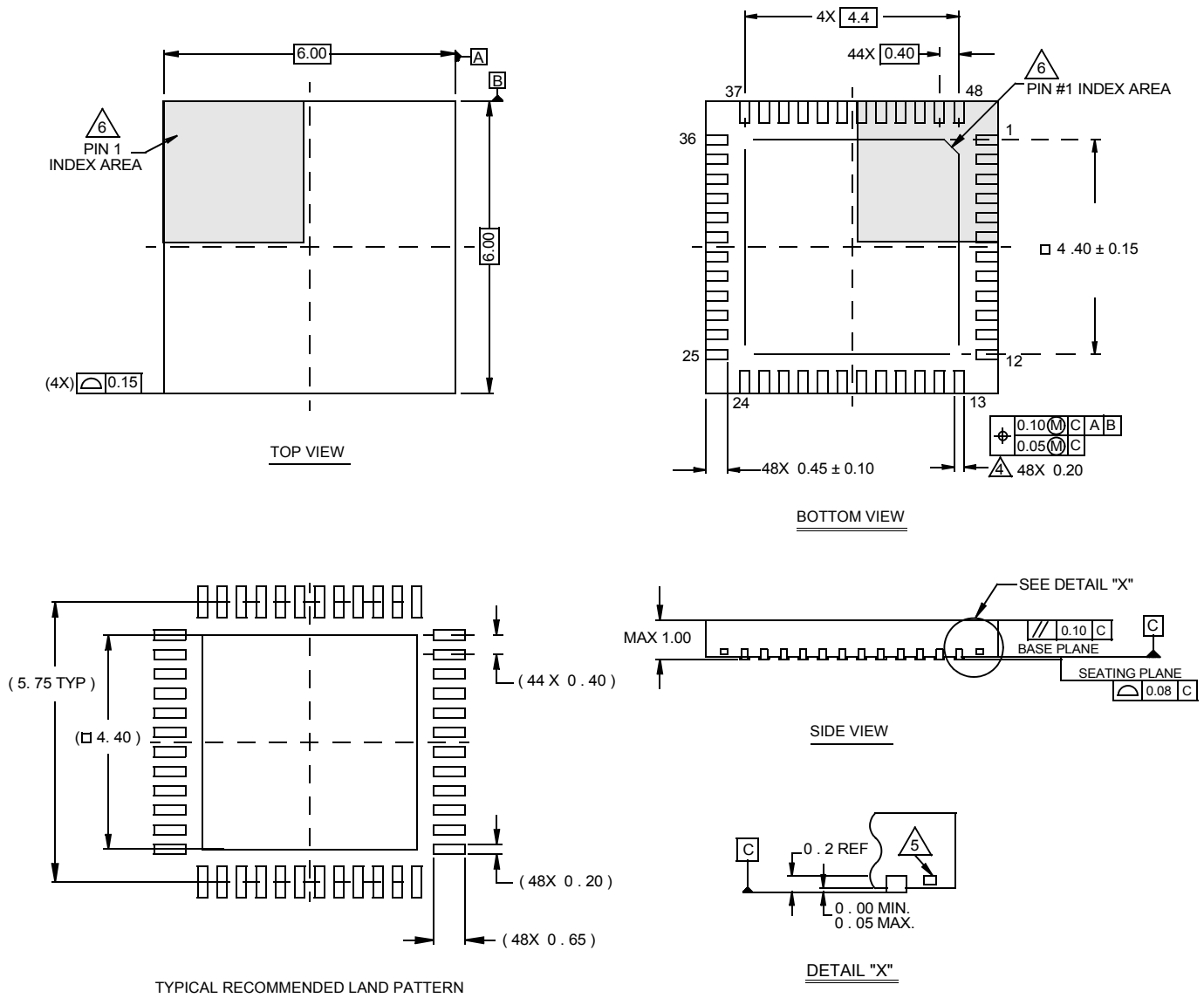
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# Package Outline Drawing

## L48.6x6B

48 LEAD QUAD FLAT NO-LEAD PLASTIC PACKAGE

Rev 0, 9/09



### 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 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.