

# NCP5392T

## 2/3/4-Phase Controller with Light Load Power Saving Enhancement for CPU Applications

The NCP5392T provides up to a four-phase buck solution which combines differential voltage sensing, differential phase current sensing, and adaptive voltage positioning to provide accurately regulated power for Intel processors. It also receives power saving command (PSI) from CPU, and operates in a single phase emulation diode mode to obtain a high efficiency at light load. Dual-edge pulse-width modulation (PWM) combined with precise inductor current sensing provides the fastest initial response to dynamic load events both in power saving and normal modes. Dual-edge multiphase modulation reduces the total bulk and ceramic output capacitance required therefore reducing the system cost to meet transient regulation specifications.

A high performance operational error amplifier is provided to simplify compensation of the system. Dynamic Reference Injection further simplifies loop compensation by eliminating the need to compromise between closed-loop transient response and Dynamic VID performance. An enhancement of normal mode and PSI mode operation has been achieved in NCP5392T both under heavy load and light load condition or the load changing.

### Features

- Meets Intel's VR11.1 Specifications
- Enhanced Power Saving Operation (PSI)
- Dual-edge PWM for Fastest Initial Response to Transient Loading
- High Performance Operational Error Amplifier
- Internal Soft Start
- Dynamic Reference Injection®
- DAC Range from 0.375 V to 1.6 V
- DAC Feed Forward Function
- $\pm 0.5\%$  DAC Voltage Accuracy from 1.0 V to 1.6 V
- True Differential Remote Voltage Sensing Amplifier
- Phase-to-Phase Current Balancing
- "Lossless" Differential Inductor Current Sensing
- Accurate Current Monitoring (IMON)
- Differential Current Sense Amplifiers for each Phase
- Adaptive Voltage Positioning (AVP)
- Oscillator Frequency Range of 100 kHz – 1 MHz
- Latched Over Voltage Protection (OVP)
- Guaranteed Startup into Pre-Charged Loads

- Threshold Sensitive Enable Pin for VTT Sensing
- Power Good Output with Internal Delays
- Thermally Compensated Current Monitoring
- This is a Pb-Free Device

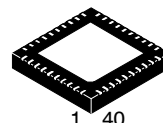
### Applications

- Desktop Processors



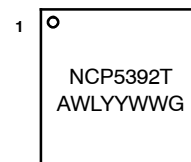
ON Semiconductor®

<http://onsemi.com>



40 PIN QFN, 6x6  
MN SUFFIX  
CASE 488AR

### MARKING DIAGRAM



NCP5392T = Specific Device Code  
A = Assembly Location  
WL = Wafer Lot  
YY = Year  
WW = Work Week  
G = Pb-Free Package

\*Pin 41 is the thermal pad on the bottom of the device.

### ORDERING INFORMATION

| Device         | Package             | Shipping†        |
|----------------|---------------------|------------------|
| NCP5392TMNR2G* | QFN-40<br>(Pb-Free) | 2500/Tape & Reel |

\*Temperature Range: 0°C to 85°C

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specification Brochure, BRD8011/D.

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## PIN CONNECTIONS

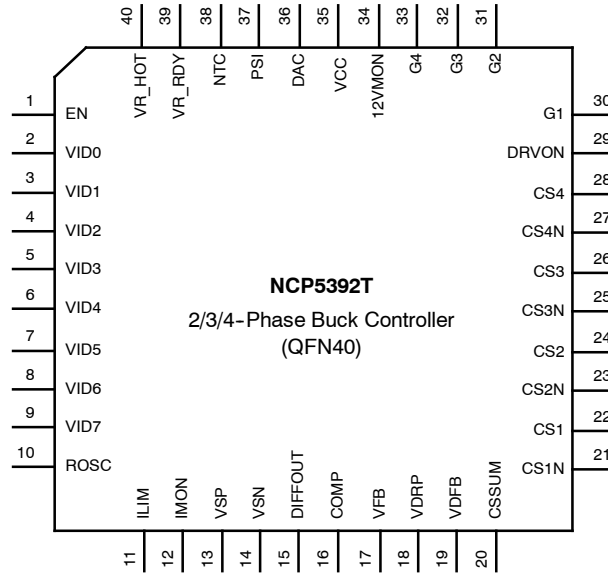


Figure 1. NCP5392T QFN40 Pin Connections (Top View)

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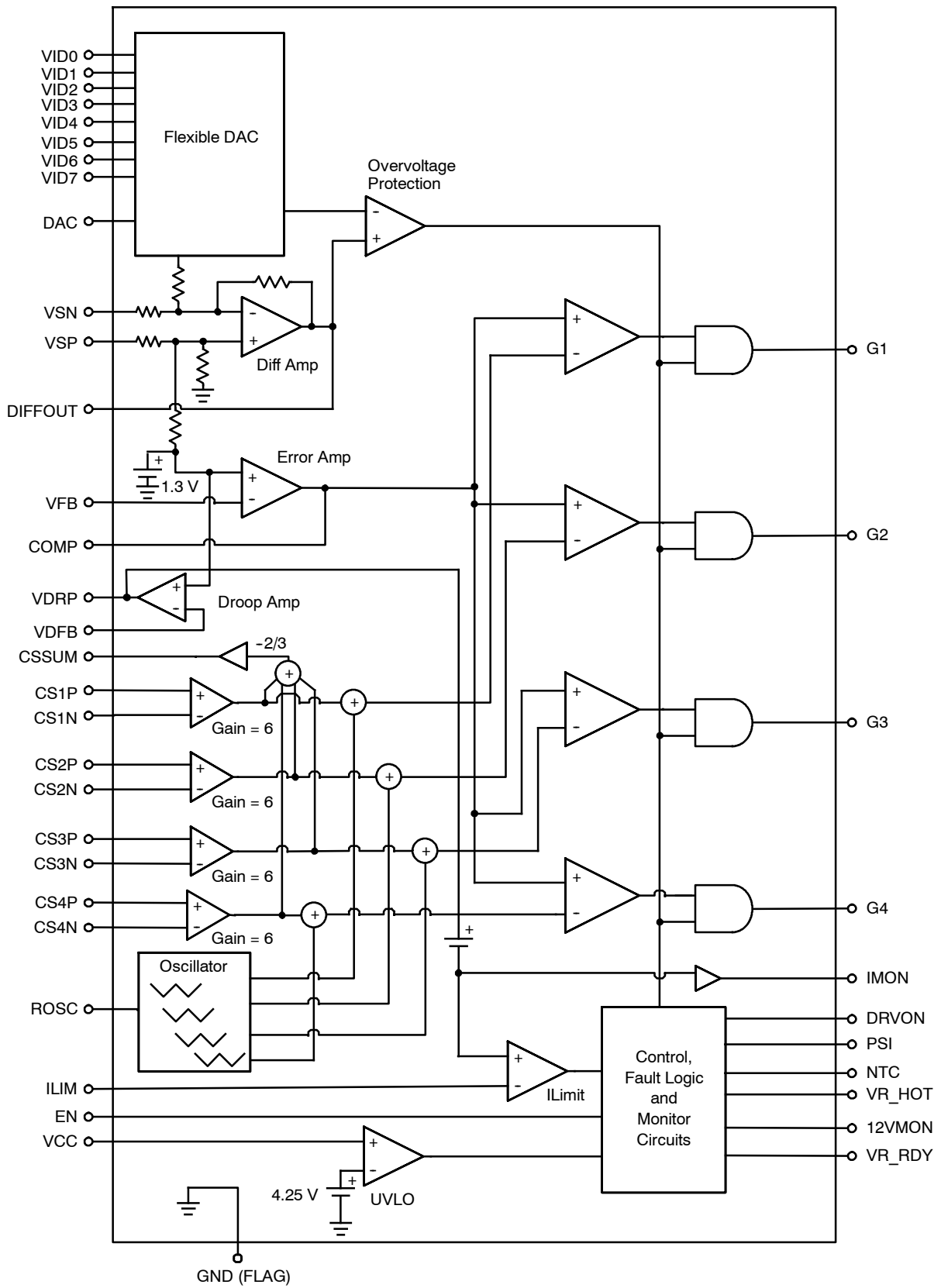


Figure 2. NCP5392T Block Diagram

# NCP5392T

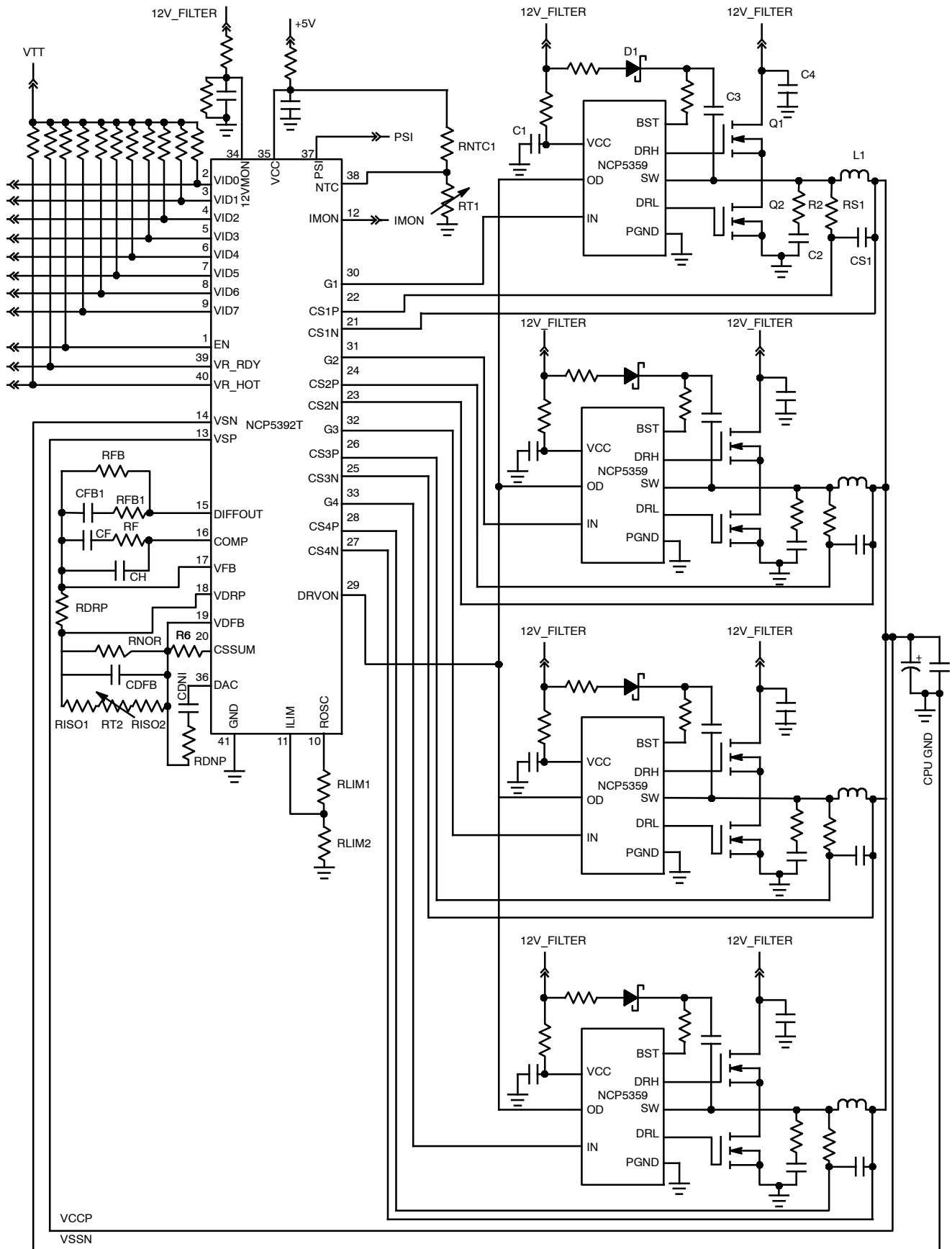
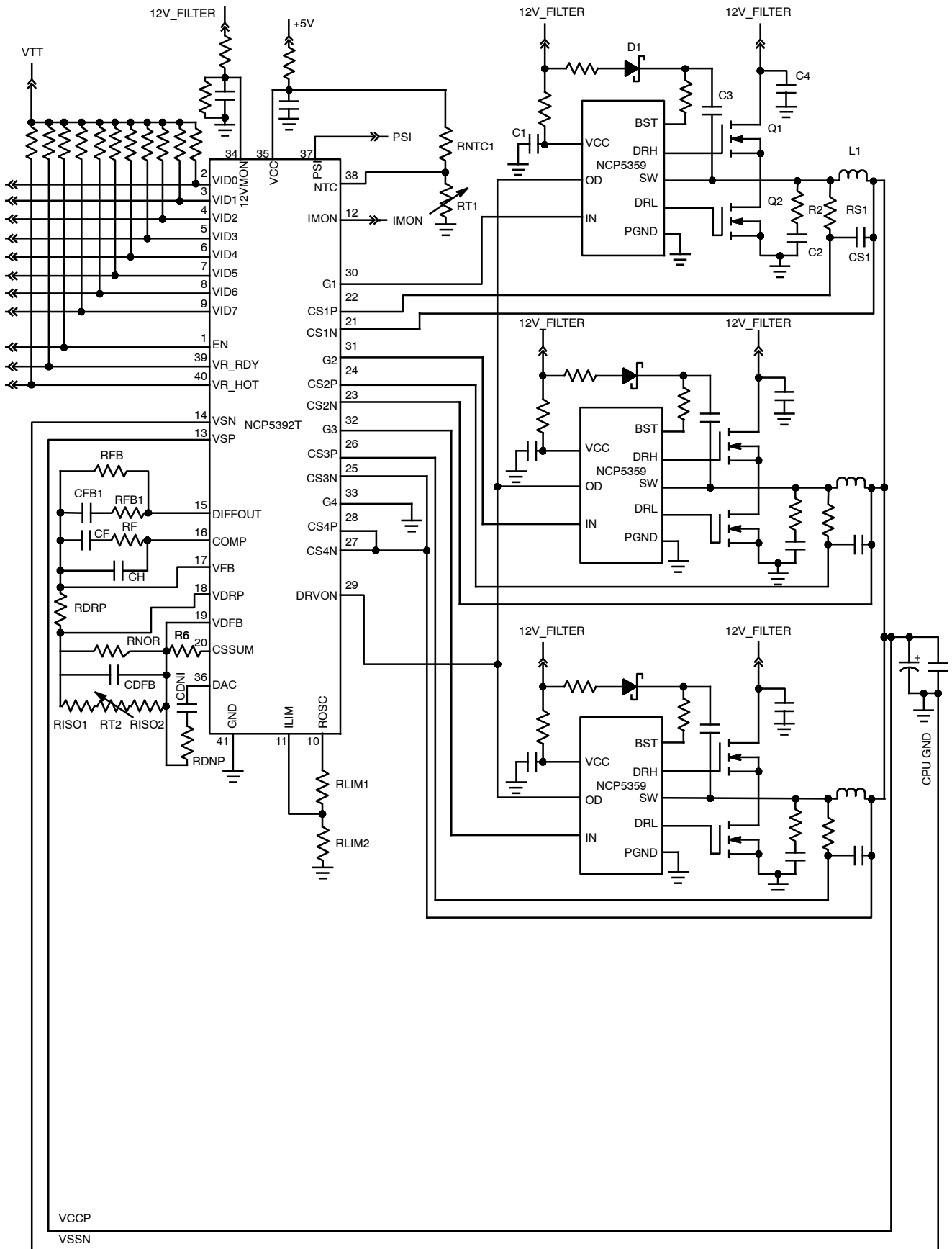


Figure 3. Application Schematic for Four Phases

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### Figure 4. Application Schematic for Three Phases

# NCP5392T

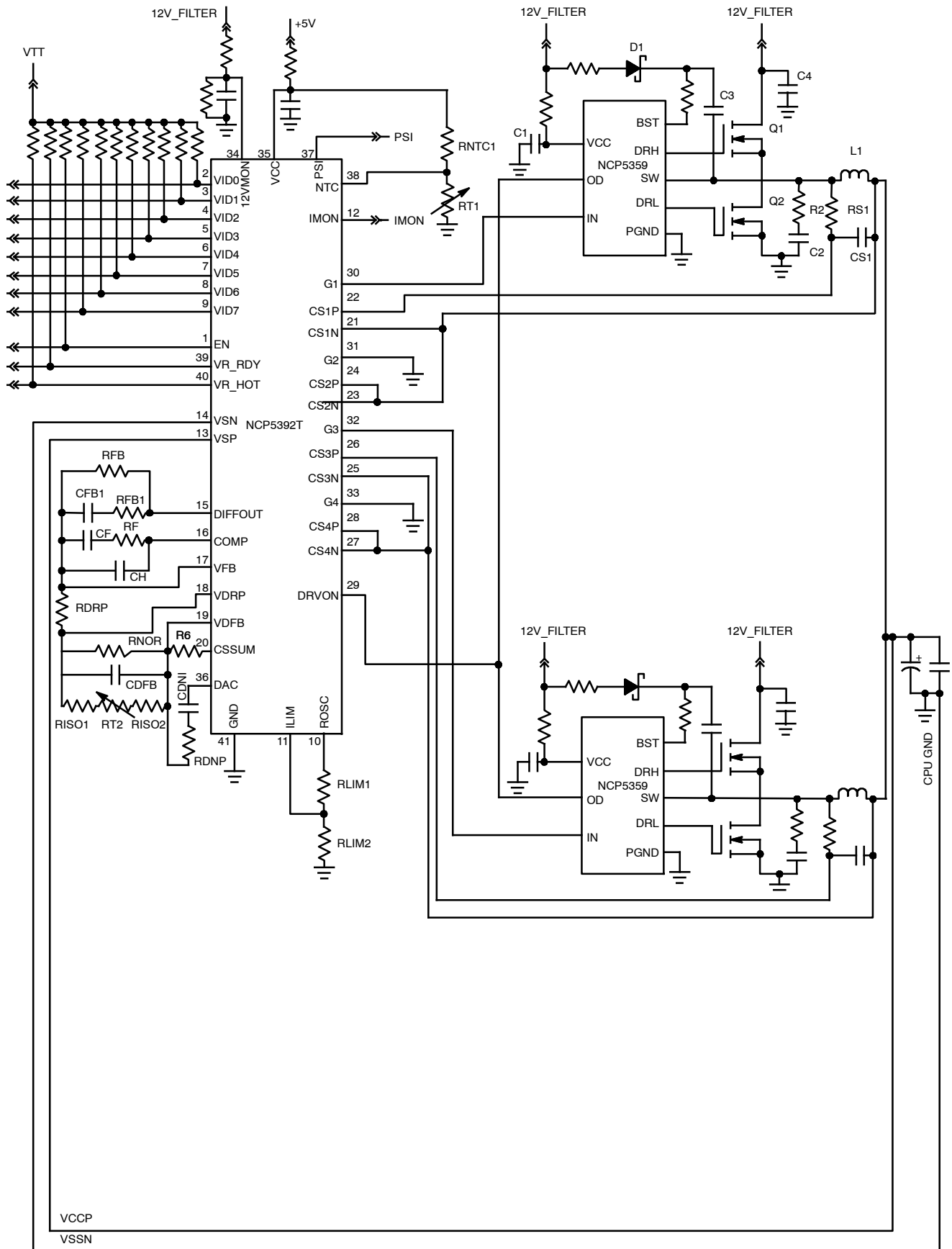


Figure 5. Application Schematic for Two Phases

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## PIN DESCRIPTIONS

| Pin No. | Symbol  | Description                                                                                                                                                                                                                                                                                                                                                                                      |
|---------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1       | EN      | Threshold sensitive input. High = startup, Low = shutdown.                                                                                                                                                                                                                                                                                                                                       |
| 2       | VID0    | Voltage ID DAC input                                                                                                                                                                                                                                                                                                                                                                             |
| 3       | VID1    | Voltage ID DAC input                                                                                                                                                                                                                                                                                                                                                                             |
| 4       | VID2    | Voltage ID DAC input                                                                                                                                                                                                                                                                                                                                                                             |
| 5       | VID3    | Voltage ID DAC input                                                                                                                                                                                                                                                                                                                                                                             |
| 6       | VID4    | Voltage ID DAC input                                                                                                                                                                                                                                                                                                                                                                             |
| 7       | VID5    | Voltage ID DAC input                                                                                                                                                                                                                                                                                                                                                                             |
| 8       | VID6    | Voltage ID DAC input                                                                                                                                                                                                                                                                                                                                                                             |
| 9       | VID7    | Voltage ID DAC input                                                                                                                                                                                                                                                                                                                                                                             |
| 10      | ROSC    | A resistance from this pin to ground programs the oscillator frequency according to $f_{SW}$ . This pin supplies a trimmed output voltage of 2 V.                                                                                                                                                                                                                                                |
| 11      | ILIM    | Overcurrent shutdown threshold setting. Connect this pin to the ROSC pin via a resistor divider as shown in the Application Schematics. To disable the overcurrent feature, connect this pin directly to the ROSC pin. To guarantee correct operation, this pin should only be connected to the voltage generated by the ROSC pin; do not connect this pin to any externally generated voltages. |
| 12      | IMON    | 0 mV to 900 mV analog signal proportional to the output load current. VSN referenced                                                                                                                                                                                                                                                                                                             |
| 13      | VSP     | Non-inverting input to the internal differential remote sense amplifier                                                                                                                                                                                                                                                                                                                          |
| 14      | VSN     | Inverting input to the internal differential remote sense amplifier                                                                                                                                                                                                                                                                                                                              |
| 15      | DIFFOUT | Output of the differential remote sense amplifier                                                                                                                                                                                                                                                                                                                                                |
| 16      | COMP    | Output of the error amplifier                                                                                                                                                                                                                                                                                                                                                                    |
| 17      | VFB     | Compensation Amplifier Voltage feedback                                                                                                                                                                                                                                                                                                                                                          |
| 18      | VDRP    | Voltage output signal proportional to current used for current limit and output voltage droop                                                                                                                                                                                                                                                                                                    |
| 19      | VDFB    | Droop Amplifier Voltage Feedback                                                                                                                                                                                                                                                                                                                                                                 |
| 20      | CSSUM   | Inverted Sum of the Differential Current Sense inputs. $A_v = CSSUM/CSx = -4$                                                                                                                                                                                                                                                                                                                    |
| 21      | CS1N    | Inverting input to current sense amplifier #1                                                                                                                                                                                                                                                                                                                                                    |
| 22      | CS1     | Non-inverting input to current sense amplifier #1                                                                                                                                                                                                                                                                                                                                                |
| 23      | CS2N    | Inverting input to current sense amplifier #2                                                                                                                                                                                                                                                                                                                                                    |
| 24      | CS2     | Non-inverting input to current sense amplifier #2                                                                                                                                                                                                                                                                                                                                                |
| 25      | CS3N    | Inverting input to current sense amplifier #3                                                                                                                                                                                                                                                                                                                                                    |
| 26      | CS3     | Non-inverting input to current sense amplifier #3                                                                                                                                                                                                                                                                                                                                                |
| 27      | CS4N    | Inverting input to current sense amplifier #4                                                                                                                                                                                                                                                                                                                                                    |
| 28      | CS4     | Non-inverting input to current sense amplifier #4                                                                                                                                                                                                                                                                                                                                                |
| 29      | DRVON   | Bidirectional Gate Drive Enable                                                                                                                                                                                                                                                                                                                                                                  |
| 30      | G1      | PWM output pulse to gate driver. 3-level output: Low = LSFET Enabled, Mid = Diode Emulation Enabled, High = HSFET Enabled                                                                                                                                                                                                                                                                        |
| 31      | G2      | PWM output pulse to gate driver. 3-level output (see G1)                                                                                                                                                                                                                                                                                                                                         |
| 32      | G3      | PWM output pulse to gate driver. 3-level output (see G1)                                                                                                                                                                                                                                                                                                                                         |
| 33      | G4      | PWM output pulse to gate driver. 3-level output (see G1)                                                                                                                                                                                                                                                                                                                                         |
| 34      | 12VMON  | Monitor a 12 V input through a resistor divider.                                                                                                                                                                                                                                                                                                                                                 |
| 35      | VCC     | Power for the internal control circuits.                                                                                                                                                                                                                                                                                                                                                         |
| 36      | DAC     | DAC Feed Forward Output                                                                                                                                                                                                                                                                                                                                                                          |
| 37      | PSI     | Power Saving Control. Low = single phase operation, High = normal operation.                                                                                                                                                                                                                                                                                                                     |
| 38      | NTC     | Threshold sensitive input for thermal monitoring                                                                                                                                                                                                                                                                                                                                                 |
| 39      | VR_RDY  | Open collector output. High indicates that the output is regulating                                                                                                                                                                                                                                                                                                                              |
| 40      | VR_HOT  | Open collector output indicates the state of the thermal monitoring input. Low impedance output indicating a normal status when the voltage of NTC pin is above the specified threshold. This pin will transition to high impedance when the voltage of NTC pin decrease (temperature increase) below the specified threshold. This pin requires an external pullup resistor                     |
| FLAG    | GND     | Power supply return (QFN Flag)                                                                                                                                                                                                                                                                                                                                                                   |

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## PIN CONNECTIONS VS. PHASE COUNT

| Number of Phases | G4          | G3          | G2          | G1          | CS4-CS4N         | CS3-CS3N         | CS2-CS2N         | CS1-CS1N         |
|------------------|-------------|-------------|-------------|-------------|------------------|------------------|------------------|------------------|
| 4                | Phase 4 Out | Phase 3 Out | Phase 2 Out | Phase 1 Out | Phase 4 CS input | Phase 3 CS input | Phase 2 CS input | Phase 1 CS input |
| 3                | Tie to GND  | Phase 3 Out | Phase 2 Out | Phase 1 Out | Tie to VCCP      | Phase 3 CS input | Phase 2 CS input | Phase 1 CS input |
| 2                | Tie to GND  | Phase 2 Out | Tie to GND  | Phase 1 Out | Tie to VCCP      | Phase 2 CS input | Tie to VCCP      | Phase 1 CS input |

## MAXIMUM RATINGS

### ELECTRICAL INFORMATION

| Pin Symbol       | V <sub>MAX</sub> | V <sub>MIN</sub> | I <sub>SOURCE</sub> | I <sub>SINK</sub> |
|------------------|------------------|------------------|---------------------|-------------------|
| COMP             | 5.5 V            | -0.3 V           | 10 mA               | 10 mA             |
| V <sub>DRP</sub> | 5.5 V            | -0.3 V           | 5 mA                | 5 mA              |
| V <sub>+</sub>   | 5.5 V            | GND – 300 mV     | 1 mA                | 1 mA              |
| V <sub>-</sub>   | GND + 300 mV     | GND – 300 mV     | 1 mA                | 1 mA              |
| DIFFOUT          | 5.5 V            | -0.3 V           | 20 mA               | 20 mA             |
| VR_RDY           | 5.5 V            | -0.3 V           | N/A                 | 20 mA             |
| VCC              | 7.0 V            | -0.3 V           | N/A                 | 10 mA             |
| ROSC             | 5.5 V            | -0.3 V           | 1 mA                | N/A               |
| IMON Output      | 1.1 V            |                  |                     |                   |
| All Other Pins   | 5.5 V            | -0.3 V           |                     |                   |

\*All signals referenced to AGND unless otherwise noted.

### THERMAL INFORMATION

| Rating                                        | Symbol           | Value       | Unit |
|-----------------------------------------------|------------------|-------------|------|
| Thermal Characteristic, QFN Package (Note 1)  | R <sub>θJA</sub> | 34          | °C/W |
| Operating Junction Temperature Range (Note 2) | T <sub>J</sub>   | 0 to 125    | °C   |
| Operating Ambient Temperature Range           | T <sub>A</sub>   | 0 to +85    | °C   |
| Maximum Storage Temperature Range             | T <sub>STG</sub> | -55 to +150 | °C   |
| Moisture Sensitivity Level, QFN Package       | MSL              | 1           |      |

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

\*The maximum package power dissipation must be observed.

1. JESD 51-5 (1S2P Direct-Attach Method) with 0 LFM.
2. JESD 51-7 (1S2P Direct-Attach Method) with 0 LFM.



# NCP5392T

## ELECTRICAL CHARACTERISTICS

(Unless otherwise stated: 0°C < T<sub>A</sub> < 85°C; 4.75 V < V<sub>CC</sub> < 5.25 V; All DAC Codes; C<sub>VCC</sub> = 0.1 µF)

| Parameter | Test Conditions | Min | Typ | Max | Unit |
|-----------|-----------------|-----|-----|-----|------|
|-----------|-----------------|-----|-----|-----|------|

### ERROR AMPLIFIER

|                                     |                                                                                                                                              |      |     |     |      |
|-------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------|-----|-----|------|
| Input Bias Current (Note 3)         |                                                                                                                                              | -200 |     | 200 | nA   |
| Noninverting Voltage Range (Note 3) |                                                                                                                                              | 0    | 1.3 | 3   | V    |
| Input Offset Voltage (Note 3)       | V <sub>+</sub> = V <sub>-</sub> = 1.1 V                                                                                                      | -1.0 | -   | 1.0 | mV   |
| Open Loop DC Gain                   | C <sub>L</sub> = 60 pF to GND,<br>R <sub>L</sub> = 10 KΩ to GND                                                                              | -    | 100 |     | dB   |
| Open Loop Unity Gain Bandwidth      | C <sub>L</sub> = 60 pF to GND,<br>R <sub>L</sub> = 10 KΩ to GND                                                                              | -    | 10  | -   | MHz  |
| Open Loop Phase Margin              | C <sub>L</sub> = 60 pF to GND,<br>R <sub>L</sub> = 10 KΩ to GND                                                                              | -    | 80  | -   | °    |
| Slew Rate                           | ΔV <sub>in</sub> = 100 mV, G = - 10 V/V,<br>ΔV <sub>out</sub> = 1.5 V – 2.5 V,<br>C <sub>L</sub> = 60 pF to GND,<br>DC Load = ±125 µA to GND | -    | 5   | -   | V/µs |
| Maximum Output Voltage              | I <sub>SOURCE</sub> = 2.0 mA                                                                                                                 | 3.5  | -   | -   | V    |
| Minimum Output Voltage              | I <sub>SINK</sub> = 0.2 mA                                                                                                                   | -    | -   | 50  | mV   |
| Output source current (Note 3)      | V <sub>out</sub> = 3.5 V                                                                                                                     | 2    | -   | -   | mA   |
| Output sink current (Note 3)        | V <sub>out</sub> = 1.0 V                                                                                                                     | 2    | -   | -   | mA   |

### DIFFERENTIAL SUMMING AMPLIFIER

|                                   |                                                                 |      |              |       |     |
|-----------------------------------|-----------------------------------------------------------------|------|--------------|-------|-----|
| VSN Input Bias Current            | VSN Voltage = 0 V                                               |      | 30           |       | µA  |
| VSP Input Resistance              | DRVON = Low<br>DRVON = High                                     |      | 1.5<br>17    |       | kΩ  |
| VSP Input Bias Voltage            | DRVON = Low<br>DRVON = High                                     |      | 0.09<br>0.66 |       | V   |
| Input Voltage Range (Note 3)      |                                                                 | -0.3 | -            | 3.0   | V   |
| -3 dB Bandwidth                   | C <sub>L</sub> = 80 pF to GND,<br>R <sub>L</sub> = 10 KΩ to GND | -    | 10           | -     | MHz |
| Closed Loop DC Gain VS to Diffout | VS <sub>+</sub> to VS <sub>-</sub> = 0.5 to 1.6 V               | 0.98 | 1.0          | 1.025 | V/V |
| Maximum Output Voltage            | I <sub>SOURCE</sub> = 2 mA                                      | 3.0  | -            | -     | V   |
| Minimum Output Voltage            | I <sub>SINK</sub> = 2 mA                                        | -    | -            | 0.5   | V   |
| Output source current (Note 3)    | V <sub>out</sub> = 3 V                                          | 2.0  | -            | -     | mA  |
| Output sink current (Note 3)      | V <sub>out</sub> = 0.5 V                                        | 2.0  | -            | -     | mA  |

### INTERNAL OFFSET VOLTAGE

|                                                                 |  |   |      |   |   |
|-----------------------------------------------------------------|--|---|------|---|---|
| Offset Voltage to the (+) Pin of the Error Amp and the VDRP pin |  | - | 1.30 | - | V |
|-----------------------------------------------------------------|--|---|------|---|---|

### VDROOP AMPLIFIER

|                                      |                                                                              |      |     |     |      |
|--------------------------------------|------------------------------------------------------------------------------|------|-----|-----|------|
| Input Bias Current (Note 3)          |                                                                              | -200 |     | 200 | nA   |
| Non-inverting Voltage Range (Note 3) |                                                                              | 0    | 1.3 | 3   | V    |
| Input Offset Voltage (Note 3)        | V <sub>+</sub> = V <sub>-</sub> = 1.1 V                                      | -4.0 | -   | 4.0 | mV   |
| Open Loop DC Gain                    | C <sub>L</sub> = 20 pF to GND including<br>ESD, R <sub>L</sub> = 1 kΩ to GND | -    | 100 |     | dB   |
| Open Loop Unity Gain Bandwidth       | C <sub>L</sub> = 20 pF to GND including<br>ESD, R <sub>L</sub> = 1 kΩ to GND | -    | 10  | -   | MHz  |
| Slew Rate                            | C <sub>L</sub> = 20 pF to GND including<br>ESD, R <sub>L</sub> = 1 kΩ to GND | -    | 5   | -   | V/µs |
| Maximum Output Voltage               | I <sub>SOURCE</sub> = 4.0 mA                                                 | 3    | -   | -   | V    |
| Minimum Output Voltage               | I <sub>SINK</sub> = 1.0 mA                                                   | -    | -   | 1   | V    |
| Output source current (Note 3)       | V <sub>out</sub> = 3.0 V                                                     | 4    | -   | -   | mA   |
| Output sink current (Note 3)         | V <sub>out</sub> = 1.0 V                                                     | 1    | -   | -   | mA   |

3. Guaranteed by design, not tested in production.

# NCP5392T

## ELECTRICAL CHARACTERISTICS

(Unless otherwise stated: 0°C < T<sub>A</sub> < 85°C; 4.75 V < V<sub>CC</sub> < 5.25 V; All DAC Codes; C<sub>VCC</sub> = 0.1 μF)

| Parameter | Test Conditions | Min | Typ | Max | Unit |
|-----------|-----------------|-----|-----|-----|------|
|-----------|-----------------|-----|-----|-----|------|

### CSSUM AMPLIFIER

|                                               |                                                                              |       |       |       |     |
|-----------------------------------------------|------------------------------------------------------------------------------|-------|-------|-------|-----|
| Current Sense Input to CSSUM Gain             | -60 mV < CS < 60 mV                                                          | -4.00 | -3.88 | -3.76 | V/V |
| Current Sense Input to CSSUM -3 dB Bandwidth  | C <sub>L</sub> = 10 pF to GND,<br>R <sub>L</sub> = 10 kΩ to GND              | -     | 4     | -     | MHz |
| Current Sense Input to CSSUM Output Slew Rate | ΔV <sub>in</sub> = 25 mV, C <sub>L</sub> = 10 pF to GND, Load = 1 k to 1.3 V | -     | 4     | -     | V/s |
| Current Summing Amp Output Offset Voltage     | CSx – CSxN = 0, CSx = 1.1 V                                                  | -15   | -     | +15   | mV  |
| Maximum CSSUM Output Voltage                  | CSx – CSxN = -0.15 V (All Phases) I <sub>SOURCE</sub> = 1 mA                 | 3.0   | -     | -     | V   |
| Minimum CSSUM Output Voltage                  | CSx – CSxN = 0.066 V (All Phases) I <sub>SINK</sub> = 1 mA                   | -     | -     | 0.3   | V   |
| Output source current (Note 3)                | V <sub>out</sub> = 3.0 V                                                     | 1     | -     | -     | mA  |
| Output sink current (Note 3)                  | V <sub>out</sub> = 0.3 V                                                     | 1     | -     | -     | mA  |

### PSI (Power Saving Control, Active Low)

|                                   |                                         |     |     |     |    |
|-----------------------------------|-----------------------------------------|-----|-----|-----|----|
| Enable High Input Leakage Current | External 1 K Pullup to 3.3 V            | -   | -   | 1.0 | μA |
| Upper Threshold                   | V <sub>UPPER</sub>                      | -   | 650 | 770 | mV |
| Lower Threshold                   | V <sub>LOWER</sub>                      | 450 | 550 | -   | mV |
| Hysteresis                        | V <sub>UPPER</sub> - V <sub>LOWER</sub> | -   | 100 | -   | mV |

### DRVON

|                                                 |                                                            |     |     |     |    |
|-------------------------------------------------|------------------------------------------------------------|-----|-----|-----|----|
| Output High Voltage                             | Sourcing 500 μA                                            | 3.0 | -   | -   | V  |
| Sourcing Current for Output High                | V <sub>CC</sub> = 5 V                                      | -   | 2.5 | 4.0 | mA |
| Output Low Voltage                              | Sinking 500 μA                                             | -   | -   | 0.7 | V  |
| Sinking Current for Output Low                  |                                                            | 2.5 | -   | -   | mA |
| Delay Time                                      | Propagation Delay from EN Low to DRVON                     | -   | 10  | -   | ns |
| Rise Time                                       | C <sub>L</sub> (PCB) = 20 pF, ΔV <sub>O</sub> = 10% to 90% | -   | 130 | -   | ns |
| Fall Time                                       | C <sub>L</sub> (PCB) = 20 pF, ΔV <sub>O</sub> = 10% to 90% | -   | 10  | -   | ns |
| Internal Pulldown Resistance                    |                                                            | 35  | 70  | 140 | kΩ |
| V <sub>CC</sub> Voltage when DRVON Output Valid |                                                            | -   | -   | 2.0 | V  |

### CURRENT SENSE AMPLIFIERS

|                                                |                           |      |     |     |     |
|------------------------------------------------|---------------------------|------|-----|-----|-----|
| Input Bias Current (Note 3)                    | CSx = CSxN = 1.4 V        | -    | 0   | -   | nA  |
| Common Mode Input Voltage Range (Note 3)       |                           | -0.3 | -   | 2.0 | V   |
| Differential Mode Input Voltage Range (Note 3) |                           | -120 | -   | 120 | mV  |
| Input Offset Voltage                           | CSx = CSxN = 1.1 V,       | -1.0 | -   | 1.0 | mV  |
| Current Sense Input to PWM Gain (Note 3)       | 0 V < CSx – CSxN < 0.1 V, | 5.7  | 6.0 | 6.3 | V/V |
| Current Sharing Offset CS1 to CSx              | All VID codes             | -2.5 | -   | 2.5 | mV  |

### IMON

|                                          |                                                                  |      |    |      |     |
|------------------------------------------|------------------------------------------------------------------|------|----|------|-----|
| V <sub>DRP</sub> to IMON Gain            | 1.325 V < V <sub>DRP</sub> < 1.8 V                               | 1.98 | 2  | 2.02 | V/V |
| V <sub>DRP</sub> to IMON -3 dB Bandwidth | C <sub>L</sub> = 30 pF to GND,<br>R <sub>L</sub> = 100 kΩ to GND | -    | 4  | -    | MHz |
| Output Referred Offset Voltage           | V <sub>DRP</sub> = 1.6 V, I <sub>SOURCE</sub> = 0 mA             | 8    | 23 | 38   | mV  |
| Minimum Output Voltage                   | V <sub>DRP</sub> = 1.2 V, I <sub>SINK</sub> = 100 μA             | -    | -  | 0.11 | V   |

3. Guaranteed by design, not tested in production.

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## ELECTRICAL CHARACTERISTICS

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| Parameter | Test Conditions | Min | Typ | Max | Unit |
|-----------|-----------------|-----|-----|-----|------|
|-----------|-----------------|-----|-----|-----|------|

### IMON

|                                |                                                              |     |   |      |    |
|--------------------------------|--------------------------------------------------------------|-----|---|------|----|
| Output source current (Note 3) | V <sub>out</sub> = 1 V                                       | 300 | - | -    | μA |
| Output sink current (Note 3)   | V <sub>out</sub> = 0.3 V                                     | 300 | - | -    | μA |
| Maximum Clamp Voltage          | V <sub>DRP</sub> Voltage = 2 V,<br>R <sub>LOAD</sub> = 100 k | -   | - | 1.15 | V  |

### OSCILLATOR

|                                            |                            |      |      |       |     |
|--------------------------------------------|----------------------------|------|------|-------|-----|
| Switching Frequency Range (Note 3)         |                            | 100  | -    | 1000  | kHz |
| Switching Frequency Accuracy 2- or 4-Phase | R <sub>OSC</sub> = 49.9 kΩ | 200  | -    | 224   | kHz |
|                                            | R <sub>OSC</sub> = 24.9 kΩ | 374  | -    | 414   |     |
|                                            | R <sub>OSC</sub> = 10 kΩ   | 800  | -    | 978   |     |
| Switching Frequency Accuracy 3-Phase       | R <sub>OSC</sub> = 49.9 kΩ | 191  | -    | 234   | kHz |
|                                            | R <sub>OSC</sub> = 24.9 kΩ | 354  | -    | 434   |     |
|                                            | R <sub>OSC</sub> = 10 kΩ   | 755  | -    | 1000  |     |
| R <sub>OSC</sub> Output Voltage            |                            | 1.95 | 2.01 | 2.065 | V   |

### MODULATORS (PWM Comparators)

|                                |                                             |    |     |    |    |
|--------------------------------|---------------------------------------------|----|-----|----|----|
| Minimum Pulse Width            | F <sub>SW</sub> = 800 KHz                   | -  | 30  | -  | ns |
| Propagation Delay              | ±20 mV of Overdrive                         | -  | 10  | -  | ns |
| 0% Duty Cycle                  | COMP Voltage when the PWM Outputs Remain LO | -  | 1.3 | -  | V  |
| 100% Duty Cycle                | COMP Voltage when the PWM Outputs Remain HI | -  | 2.3 | -  | V  |
| PWM Ramp Duty Cycle Matching   | Between Any Two Phases                      | -  | 90  | -  | %  |
| PWM Phase Angle Error (Note 3) | Between Adjacent Phases                     | 15 | -   | 15 | °  |

### VR\_RDY (POWER GOOD) OUTPUT

|                                               |                                                                                                                        |     |     |     |              |
|-----------------------------------------------|------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|--------------|
| VR_RDY Output Saturation Voltage              | I <sub>PGD</sub> = 10 mA,                                                                                              | -   | -   | 0.4 | V            |
| VR_RDY Rise Time (Note 3)                     | External Pullup of 1 kΩ to 1.25 V, C <sub>TOT</sub> = 45 pF, ΔV <sub>o</sub> = 10% to 90%                              | -   | 100 | 150 | ns           |
| VR_RDY Output Voltage at Powerup (Note 3)     | VR_RDY Pulled up to 5 V via 2 kΩ, t <sub>R(VCC)</sub> ≤ 3 × t <sub>R(5V)</sub><br>100 μs ≤ t <sub>R(VCC)</sub> ≤ 20 ms | -   | -   | 1.0 | V            |
| VR_RDY High – Output Leakage Current (Note 3) | VR_RDY = 5.5 V via 1 K                                                                                                 | -   | -   | 0.2 | μA           |
| VR_RDY Upper Threshold Voltage                | V <sub>Core</sub> Increasing, DAC = 1.3 V                                                                              | -   | 310 | 270 | mV Below DAC |
| VR_RDY Lower Threshold Voltage                | V <sub>Core</sub> Decreasing<br>DAC = 1.3 V                                                                            | 410 | 370 |     | mV Below DAC |
| VR_RDY Rising Delay                           | V <sub>Core</sub> Increasing                                                                                           | -   | 500 | -   | μs           |
| VR_RDY Falling Delay                          | V <sub>Core</sub> Decreasing                                                                                           | -   | 5   | -   | μs           |

### PWM OUTPUTS

|                            |                                                                           |     |     |     |    |
|----------------------------|---------------------------------------------------------------------------|-----|-----|-----|----|
| Output High Voltage        | Sourcing 500 μA                                                           | 3.0 | -   | -   | V  |
| Mid Output Voltage         |                                                                           | 1.4 | 1.5 | 1.6 | V  |
| Output Low Voltage         | Sinking 500 μA                                                            | -   | -   | 0.7 | V  |
| Delay + Fall Time (Note 3) | C <sub>L</sub> (PCB) = 50 pF,<br>ΔV <sub>o</sub> = V <sub>CC</sub> to GND | -   | 10  | 15  | ns |
| Delay + Rise Time (Note 3) | C <sub>L</sub> (PCB) = 50 pF,<br>ΔV <sub>o</sub> = GND to V <sub>CC</sub> | -   | 10  | 15  | ns |

3. Guaranteed by design, not tested in production.

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## ELECTRICAL CHARACTERISTICS

(Unless otherwise stated: 0°C < T<sub>A</sub> < 85°C; 4.75 V < V<sub>CC</sub> < 5.25 V; All DAC Codes; C<sub>VCC</sub> = 0.1 μF)

| Parameter | Test Conditions | Min | Typ | Max | Unit |
|-----------|-----------------|-----|-----|-----|------|
|-----------|-----------------|-----|-----|-----|------|

### PWM OUTPUTS

|                                   |                                                |   |    |   |   |
|-----------------------------------|------------------------------------------------|---|----|---|---|
| Output Impedance – HI or LO State | Resistance to V <sub>CC</sub> (HI) or GND (LO) | - | 75 | - | Ω |
|-----------------------------------|------------------------------------------------|---|----|---|---|

### 2/3/4-Phase Detection

|                            |  |     |     |     |    |
|----------------------------|--|-----|-----|-----|----|
| Gate Pin Source Current    |  | 60  | 80  | 150 | μA |
| Gate Pin Threshold Voltage |  | 210 | 240 | 265 | mV |
| Phase Detect Timer         |  | 15  | 20  | 27  | μs |

### DIGITAL SOFT-START

|                      |                        |     |     |     |    |
|----------------------|------------------------|-----|-----|-----|----|
| Soft-Start Ramp Time | DAC = 0 to DAC = 1.1 V | 1.0 | -   | 1.5 | ms |
| VR11 Vboot time      |                        | 400 | 500 | 600 | μs |

### VID7/VR11 INPUT

|                                                            |                                                          |     |     |      |    |
|------------------------------------------------------------|----------------------------------------------------------|-----|-----|------|----|
| VID Upper Threshold                                        | V <sub>UPPER</sub>                                       | -   | 650 | 800  | mV |
| VID Lower Threshold                                        | V <sub>LOWER</sub>                                       | 300 | 550 | -    | mV |
| VID Hysteresis                                             | V <sub>UPPER</sub> - V <sub>LOWER</sub>                  | -   | 100 | -    | mV |
| VR11 Input Bias Current (Note 3)                           |                                                          |     |     | 200  | nA |
| Delay before Latching VID Change (VID De-Skewing) (Note 3) | Measured from the edge of the 1 <sup>st</sup> VID change | 200 | -   | 300  | ns |
| VID7 Valid Range                                           |                                                          |     |     | 3.33 | V  |

### ENABLE INPUT

|                                            |                                                                 |     |     |     |    |
|--------------------------------------------|-----------------------------------------------------------------|-----|-----|-----|----|
| Enable High Input Leakage Current (Note 3) | Pullup to 1.3 V                                                 | -   | -   | 200 | nA |
| VR11 Rising Threshold                      |                                                                 | -   | 650 | 770 | mV |
| VR11 Falling Threshold                     |                                                                 | 450 | 550 | -   | mV |
| VR11 Total Hysteresis                      | Rising- Falling Threshold                                       | -   | 100 | -   | mV |
| Enable Delay Time                          | Measure Time from Enable Transitioning HI to when Output Begins | 2.5 |     | 5.0 | ms |

### CURRENT LIMIT

|                                                          |                                                                                                                             |      |      |      |     |
|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|------|------|------|-----|
| I <sub>LIM</sub> to V <sub>DRP</sub> Gain                | Between V <sub>DRP</sub> - V <sub>D<sub>FB</sub></sub> = 450 mV and V <sub>DRP</sub> - V <sub>D<sub>FB</sub></sub> = 650 mV | 0.95 | 1.0  | 1.05 | V/V |
| I <sub>LIM</sub> to V <sub>DRP</sub> Gain in PSI 4 phase | Between V <sub>DRP</sub> - V <sub>D<sub>FB</sub></sub> = 450 mV and V <sub>DRP</sub> - V <sub>D<sub>FB</sub></sub> = 650 mV | -    | 0.25 | -    | V/V |
| I <sub>LIM</sub> to V <sub>DRP</sub> Gain in PSI 3 phase | Between V <sub>DRP</sub> - V <sub>D<sub>FB</sub></sub> = 450 mV and V <sub>DRP</sub> - V <sub>D<sub>FB</sub></sub> = 650 mV | -    | 0.33 | -    | V/V |
| I <sub>LIM</sub> to V <sub>DRP</sub> Gain in PSI 2 phase | Between V <sub>DRP</sub> - V <sub>D<sub>FB</sub></sub> = 450 mV and V <sub>DRP</sub> - V <sub>D<sub>FB</sub></sub> = 650 mV | -    | 0.5  | -    | V/V |
| I <sub>LIM</sub> Offset                                  | V <sub>DRP</sub> - V <sub>D<sub>FB</sub></sub> = 520 mV                                                                     | -50  | 0    | 50   | mV  |
| Delay                                                    |                                                                                                                             | -    | 100  | -    | ns  |

### OVERVOLTAGE PROTECTION

|                                         |  |                  |          |                  |    |
|-----------------------------------------|--|------------------|----------|------------------|----|
| VR11 Overvoltage Threshold              |  | DAC +150         | DAC +185 | DAC +200         | mV |
| VR11 PSI Overvoltage Threshold (Note 3) |  | (1.6 V DAC) +150 |          | (1.6 V DAC) +200 | mV |
| Delay                                   |  |                  | 100      |                  | ns |

### UNDERVOLTAGE PROTECTION

|                          |  |     |      |     |    |
|--------------------------|--|-----|------|-----|----|
| VCC UVLO Start Threshold |  | 4   | 4.25 | 4.5 | V  |
| VCC UVLO Stop Threshold  |  | 3.8 | 4.05 | 4.3 | V  |
| VCC UVLO Hysteresis      |  |     | 200  |     | mV |

3. Guaranteed by design, not tested in production.

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## ELECTRICAL CHARACTERISTICS

(Unless otherwise stated:  $0^{\circ}\text{C} < T_A < 85^{\circ}\text{C}$ ;  $4.75\text{ V} < V_{CC} < 5.25\text{ V}$ ; All DAC Codes;  $C_{VCC} = 0.1\text{ }\mu\text{F}$ )

| Parameter | Test Conditions | Min | Typ | Max | Unit |
|-----------|-----------------|-----|-----|-----|------|
|-----------|-----------------|-----|-----|-----|------|

### VR\_HOT

|                                             |                                                                                                                                                                             |       |       |       |               |
|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-------|-------|---------------|
| VR_HOT Upper Voltage Threshold              | $19.6\text{ k}\Omega\text{ P.U. to }V_{CC}, 68\text{ k}\Omega_{NTC}, \beta = 3740$                                                                                          | 0.257 | 0.268 | 0.280 | $V_{CC}$      |
| VR_HOT Lower Voltage Threshold              | $19.6\text{ k}\Omega\text{ P.U. to }V_{CC}, 68\text{ k}\Omega_{NTC}, \beta = 3740$                                                                                          | 0.316 | 0.329 | 0.343 | $V_{CC}$      |
| VR_HOT Output Voltages at Power-up (Note 3) | External Pull-up resistor of $2\text{ k}\Omega$ to $5\text{ V}$ , $t_{R\_VCC} \leq 3 \times t_{R\_5\text{ V}}$ , $100\text{ }\mu\text{s} \leq t_{R\_VCC} \leq 20\text{ ms}$ | -     | -     | 1.0   | V             |
| VR_HOT Saturation Output Voltage            | $I_{SINK} = 4\text{ mA}$                                                                                                                                                    | -     | -     | 0.3   | V             |
| VR_HOT Output Leakage Current               |                                                                                                                                                                             | -     | -     | 1     | $\mu\text{A}$ |
| NTC Pin Bias Current                        |                                                                                                                                                                             | -     | -     | 1     | $\mu\text{A}$ |

### 12VMON UVLO

|                         |                |      |      |      |   |
|-------------------------|----------------|------|------|------|---|
| 12VMON (High Threshold) | $V_{CC}$ Valid | -    | 0.77 | 0.82 | V |
| 12VMON (Low Threshold)  | $V_{CC}$ Valid | 0.66 | 0.68 | -    | V |

### DAC (FEED FORWARD FUNCTION)

|                             |                            |      |  |     |    |
|-----------------------------|----------------------------|------|--|-----|----|
| Output Source Current       | $V_{OUT} = 3\text{ V}$     | 0.25 |  |     | mA |
| Output Sink Current         | $V_{OUT} = 0.3\text{ V}$   | 1.5  |  |     | mA |
| Max Output Voltage (Note 3) | $I_{source} = 2\text{ mA}$ | 3    |  |     | V  |
| Min Output Voltage (Note 3) | $I_{sink} = 2\text{ mA}$   |      |  | 0.5 | V  |

### VRM 11 DAC

|                                                                                 |                                            |    |   |           |                         |
|---------------------------------------------------------------------------------|--------------------------------------------|----|---|-----------|-------------------------|
| Positive DAC Slew Rate                                                          |                                            | 11 | - | 16.5      | $\text{mV}/\mu\text{s}$ |
| System Voltage Accuracy<br>(DAC Value has a 19 mV Offset Over the Output Value) | $1.0\text{ V} < \text{DAC} < 1.6\text{ V}$ | -  | - | $\pm 0.5$ | %                       |
|                                                                                 | $0.8\text{ V} < \text{DAC} < 1.0\text{ V}$ | -  | - | $\pm 5$   | mV                      |
|                                                                                 | $0.5\text{ V} < \text{DAC} < 0.8\text{ V}$ | -  | - | $\pm 8$   | mV                      |

### V<sub>CC</sub>

|                            |                |   |    |    |    |
|----------------------------|----------------|---|----|----|----|
| $V_{CC}$ Operating Current | EN Low, No PWM | - | 15 | 30 | mA |
|----------------------------|----------------|---|----|----|----|

3. Guaranteed by design, not tested in production.

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Table 1. VRM11 VID Codes

| VID7<br>800 mV | VID6<br>400 mV | VID5<br>200 mV | VID4<br>100 mV | VID3<br>50 mV | VID2<br>25 mV | VID1<br>12.5 mV | VID0<br>6.25 mV | Voltage<br>(V) | HEX |
|----------------|----------------|----------------|----------------|---------------|---------------|-----------------|-----------------|----------------|-----|
| 0              | 0              | 0              | 0              | 0             | 0             | 0               | 0               |                | 00  |
| 0              | 0              | 0              | 0              | 0             | 0             | 0               | 1               |                | 01  |
| 0              | 0              | 0              | 0              | 0             | 0             | 1               | 0               | 1.60000        | 02  |
| 0              | 0              | 0              | 0              | 0             | 0             | 1               | 1               | 1.59375        | 03  |
| 0              | 0              | 0              | 0              | 0             | 1             | 0               | 0               | 1.58750        | 04  |
| 0              | 0              | 0              | 0              | 0             | 1             | 0               | 1               | 1.58125        | 05  |
| 0              | 0              | 0              | 0              | 0             | 1             | 1               | 0               | 1.57500        | 06  |
| 0              | 0              | 0              | 0              | 0             | 1             | 1               | 1               | 1.56875        | 07  |
| 0              | 0              | 0              | 0              | 1             | 0             | 0               | 0               | 1.56250        | 08  |
| 0              | 0              | 0              | 0              | 1             | 0             | 0               | 1               | 1.55625        | 09  |
| 0              | 0              | 0              | 0              | 1             | 0             | 1               | 0               | 1.55000        | 0A  |
| 0              | 0              | 0              | 0              | 1             | 0             | 1               | 1               | 1.54375        | 0B  |
| 0              | 0              | 0              | 0              | 1             | 1             | 0               | 0               | 1.53750        | 0C  |
| 0              | 0              | 0              | 0              | 1             | 1             | 0               | 1               | 1.53125        | 0D  |
| 0              | 0              | 0              | 0              | 1             | 1             | 1               | 0               | 1.52500        | 0E  |
| 0              | 0              | 0              | 0              | 1             | 1             | 1               | 1               | 1.51875        | 0F  |
| 0              | 0              | 0              | 1              | 0             | 0             | 0               | 0               | 1.51250        | 10  |
| 0              | 0              | 0              | 1              | 0             | 0             | 0               | 1               | 1.50625        | 11  |
| 0              | 0              | 0              | 1              | 0             | 0             | 1               | 0               | 1.50000        | 12  |
| 0              | 0              | 0              | 1              | 0             | 0             | 1               | 1               | 1.49375        | 13  |
| 0              | 0              | 0              | 1              | 0             | 1             | 0               | 0               | 1.48750        | 14  |
| 0              | 0              | 0              | 1              | 0             | 1             | 0               | 1               | 1.48125        | 15  |
| 0              | 0              | 0              | 1              | 0             | 1             | 1               | 0               | 1.47500        | 16  |
| 0              | 0              | 0              | 1              | 0             | 1             | 1               | 1               | 1.46875        | 17  |
| 0              | 0              | 0              | 1              | 1             | 0             | 0               | 0               | 1.46250        | 18  |
| 0              | 0              | 0              | 1              | 1             | 0             | 0               | 1               | 1.45625        | 19  |
| 0              | 0              | 0              | 1              | 1             | 0             | 1               | 0               | 1.45000        | 1A  |
| 0              | 0              | 0              | 1              | 1             | 0             | 1               | 1               | 1.44375        | 1B  |
| 0              | 0              | 0              | 1              | 1             | 1             | 0               | 0               | 1.43750        | 1C  |
| 0              | 0              | 0              | 1              | 1             | 1             | 0               | 1               | 1.43125        | 1D  |
| 0              | 0              | 0              | 1              | 1             | 1             | 1               | 0               | 1.42500        | 1E  |
| 0              | 0              | 0              | 1              | 1             | 1             | 1               | 1               | 1.41875        | 1F  |
| 0              | 0              | 1              | 0              | 0             | 0             | 0               | 0               | 1.41250        | 20  |
| 0              | 0              | 1              | 0              | 0             | 0             | 0               | 1               | 1.40625        | 21  |
| 0              | 0              | 1              | 0              | 0             | 0             | 1               | 0               | 1.40000        | 22  |
| 0              | 0              | 1              | 0              | 0             | 0             | 1               | 1               | 1.39375        | 23  |
| 0              | 0              | 1              | 0              | 0             | 1             | 0               | 0               | 1.38750        | 24  |
| 0              | 0              | 1              | 0              | 0             | 1             | 0               | 1               | 1.38125        | 25  |
| 0              | 0              | 1              | 0              | 0             | 1             | 1               | 0               | 1.37500        | 26  |
| 0              | 0              | 1              | 0              | 0             | 1             | 1               | 1               | 1.36875        | 27  |
| 0              | 0              | 1              | 0              | 1             | 0             | 0               | 0               | 1.36250        | 28  |
| 0              | 0              | 1              | 0              | 1             | 0             | 0               | 1               | 1.35625        | 29  |
| 0              | 0              | 1              | 0              | 1             | 0             | 1               | 0               | 1.35000        | 2A  |
| 0              | 0              | 1              | 0              | 1             | 0             | 1               | 1               | 1.34375        | 2B  |
| 0              | 0              | 1              | 0              | 1             | 1             | 0               | 0               | 1.33750        | 2C  |
| 0              | 0              | 1              | 0              | 1             | 1             | 0               | 1               | 1.33125        | 2D  |
| 0              | 0              | 1              | 0              | 1             | 1             | 1               | 0               | 1.32500        | 2E  |
| 0              | 0              | 1              | 0              | 1             | 1             | 1               | 1               | 1.31875        | 2F  |

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Table 1. VRM11 VID Codes

| VID7<br>800 mV | VID6<br>400 mV | VID5<br>200 mV | VID4<br>100 mV | VID3<br>50 mV | VID2<br>25 mV | VID1<br>12.5 mV | VID0<br>6.25 mV | Voltage<br>(V) | HEX |
|----------------|----------------|----------------|----------------|---------------|---------------|-----------------|-----------------|----------------|-----|
| 0              | 0              | 1              | 1              | 0             | 0             | 0               | 0               | 1.31250        | 30  |
| 0              | 0              | 1              | 1              | 0             | 0             | 0               | 1               | 1.30625        | 31  |
| 0              | 0              | 1              | 1              | 0             | 0             | 1               | 0               | 1.30000        | 32  |
| 0              | 0              | 1              | 1              | 0             | 0             | 1               | 1               | 1.29375        | 33  |
| 0              | 0              | 1              | 1              | 0             | 1             | 0               | 0               | 1.28750        | 34  |
| 0              | 0              | 1              | 1              | 0             | 1             | 0               | 1               | 1.28125        | 35  |
| 0              | 0              | 1              | 1              | 0             | 1             | 1               | 0               | 1.27500        | 36  |
| 0              | 0              | 1              | 1              | 0             | 1             | 1               | 1               | 1.26875        | 37  |
| 0              | 0              | 1              | 1              | 1             | 0             | 0               | 0               | 1.26250        | 38  |
| 0              | 0              | 1              | 1              | 1             | 0             | 0               | 1               | 1.25625        | 39  |
| 0              | 0              | 1              | 1              | 1             | 0             | 1               | 0               | 1.25000        | 3A  |
| 0              | 0              | 1              | 1              | 1             | 0             | 1               | 1               | 1.24375        | 3B  |
| 0              | 0              | 1              | 1              | 1             | 1             | 0               | 0               | 1.23750        | 3C  |
| 0              | 0              | 1              | 1              | 1             | 1             | 0               | 1               | 1.23125        | 3D  |
| 0              | 0              | 1              | 1              | 1             | 1             | 1               | 0               | 1.22500        | 3E  |
| 0              | 0              | 1              | 1              | 1             | 1             | 1               | 1               | 1.21875        | 3F  |
| 0              | 1              | 0              | 0              | 0             | 0             | 0               | 0               | 1.21250        | 40  |
| 0              | 1              | 0              | 0              | 0             | 0             | 0               | 1               | 1.20625        | 41  |
| 0              | 1              | 0              | 0              | 0             | 0             | 1               | 0               | 1.20000        | 42  |
| 0              | 1              | 0              | 0              | 0             | 0             | 1               | 1               | 1.19375        | 43  |
| 0              | 1              | 0              | 0              | 0             | 1             | 0               | 0               | 1.18750        | 44  |
| 0              | 1              | 0              | 0              | 0             | 1             | 0               | 1               | 1.18125        | 45  |
| 0              | 1              | 0              | 0              | 0             | 1             | 1               | 0               | 1.17500        | 46  |
| 0              | 1              | 0              | 0              | 0             | 1             | 1               | 1               | 1.16875        | 47  |
| 0              | 1              | 0              | 0              | 1             | 0             | 0               | 0               | 1.16250        | 48  |
| 0              | 1              | 0              | 0              | 1             | 0             | 0               | 1               | 1.15625        | 49  |
| 0              | 1              | 0              | 0              | 1             | 0             | 1               | 0               | 1.15000        | 4A  |
| 0              | 1              | 0              | 0              | 1             | 0             | 1               | 1               | 1.14375        | 4B  |
| 0              | 1              | 0              | 0              | 1             | 1             | 0               | 0               | 1.13750        | 4C  |
| 0              | 1              | 0              | 0              | 1             | 1             | 0               | 1               | 1.13125        | 4D  |
| 0              | 1              | 0              | 0              | 1             | 1             | 1               | 0               | 1.12500        | 4E  |
| 0              | 1              | 0              | 0              | 1             | 1             | 1               | 1               | 1.11875        | 4F  |
| 0              | 1              | 0              | 1              | 0             | 0             | 0               | 0               | 1.11250        | 50  |
| 0              | 1              | 0              | 1              | 0             | 0             | 0               | 1               | 1.10625        | 51  |
| 0              | 1              | 0              | 1              | 0             | 0             | 1               | 0               | 1.10000        | 52  |
| 0              | 1              | 0              | 1              | 0             | 0             | 1               | 1               | 1.09375        | 53  |
| 0              | 1              | 0              | 1              | 0             | 1             | 0               | 0               | 1.08750        | 54  |
| 0              | 1              | 0              | 1              | 0             | 1             | 0               | 1               | 1.08125        | 55  |
| 0              | 1              | 0              | 1              | 0             | 1             | 1               | 0               | 1.07500        | 56  |
| 0              | 1              | 0              | 1              | 0             | 1             | 1               | 1               | 1.06875        | 57  |
| 0              | 1              | 0              | 1              | 1             | 0             | 0               | 0               | 1.06250        | 58  |
| 0              | 1              | 0              | 1              | 1             | 0             | 0               | 1               | 1.05625        | 59  |
| 0              | 1              | 0              | 1              | 1             | 0             | 1               | 0               | 1.05000        | 5A  |
| 0              | 1              | 0              | 1              | 1             | 0             | 1               | 1               | 1.04375        | 5B  |
| 0              | 1              | 0              | 1              | 1             | 1             | 0               | 0               | 1.03750        | 5C  |
| 0              | 1              | 0              | 1              | 1             | 1             | 0               | 1               | 1.03125        | 5D  |
| 0              | 1              | 0              | 1              | 1             | 1             | 1               | 0               | 1.02500        | 5E  |
| 0              | 1              | 0              | 1              | 1             | 1             | 1               | 1               | 1.01875        | 5F  |

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Table 1. VRM11 VID Codes

| VID7<br>800 mV | VID6<br>400 mV | VID5<br>200 mV | VID4<br>100 mV | VID3<br>50 mV | VID2<br>25 mV | VID1<br>12.5 mV | VID0<br>6.25 mV | Voltage<br>(V) | HEX |
|----------------|----------------|----------------|----------------|---------------|---------------|-----------------|-----------------|----------------|-----|
| 0              | 1              | 1              | 0              | 0             | 0             | 0               | 0               | 1.01250        | 60  |
| 0              | 1              | 1              | 0              | 0             | 0             | 0               | 1               | 1.00625        | 61  |
| 0              | 1              | 1              | 0              | 0             | 0             | 1               | 0               | 1.00000        | 62  |
| 0              | 1              | 1              | 0              | 0             | 0             | 1               | 1               | 0.99375        | 63  |
| 0              | 1              | 1              | 0              | 0             | 1             | 0               | 0               | 0.98750        | 64  |
| 0              | 1              | 1              | 0              | 0             | 1             | 0               | 1               | 0.98125        | 65  |
| 0              | 1              | 1              | 0              | 0             | 1             | 1               | 0               | 0.97500        | 66  |
| 0              | 1              | 1              | 0              | 0             | 1             | 1               | 1               | 0.96875        | 67  |
| 0              | 1              | 1              | 0              | 1             | 0             | 0               | 0               | 0.96250        | 68  |
| 0              | 1              | 1              | 0              | 1             | 0             | 0               | 1               | 0.95625        | 69  |
| 0              | 1              | 1              | 0              | 1             | 0             | 1               | 0               | 0.95000        | 6A  |
| 0              | 1              | 1              | 0              | 1             | 0             | 1               | 1               | 0.94375        | 6B  |
| 0              | 1              | 1              | 0              | 1             | 1             | 0               | 0               | 0.93750        | 6C  |
| 0              | 1              | 1              | 0              | 1             | 1             | 0               | 1               | 0.93125        | 6D  |
| 0              | 1              | 1              | 0              | 1             | 1             | 1               | 0               | 0.92500        | 6E  |
| 0              | 1              | 1              | 0              | 1             | 1             | 1               | 1               | 0.91875        | 6F  |
| 0              | 1              | 1              | 1              | 0             | 0             | 0               | 0               | 0.91250        | 70  |
| 0              | 1              | 1              | 1              | 0             | 0             | 0               | 1               | 0.90625        | 71  |
| 0              | 1              | 1              | 1              | 0             | 0             | 1               | 0               | 0.90000        | 72  |
| 0              | 1              | 1              | 1              | 0             | 0             | 1               | 1               | 0.89375        | 73  |
| 0              | 1              | 1              | 1              | 0             | 1             | 0               | 0               | 0.88750        | 74  |
| 0              | 1              | 1              | 1              | 0             | 1             | 0               | 1               | 0.88125        | 75  |
| 0              | 1              | 1              | 1              | 0             | 1             | 1               | 0               | 0.87500        | 76  |
| 0              | 1              | 1              | 1              | 0             | 1             | 1               | 1               | 0.86875        | 77  |
| 0              | 1              | 1              | 1              | 1             | 0             | 0               | 0               | 0.86250        | 78  |
| 0              | 1              | 1              | 1              | 1             | 0             | 0               | 1               | 0.85625        | 79  |
| 0              | 1              | 1              | 1              | 1             | 0             | 1               | 0               | 0.85000        | 7A  |
| 0              | 1              | 1              | 1              | 1             | 0             | 1               | 1               | 0.84375        | 7B  |
| 0              | 1              | 1              | 1              | 1             | 1             | 0               | 0               | 0.83750        | 7C  |
| 0              | 1              | 1              | 1              | 1             | 1             | 0               | 1               | 0.83125        | 7D  |
| 0              | 1              | 1              | 1              | 1             | 1             | 1               | 0               | 0.82500        | 7E  |
| 0              | 1              | 1              | 1              | 1             | 1             | 1               | 1               | 0.81875        | 7F  |
| 1              | 0              | 0              | 0              | 0             | 0             | 0               | 0               | 0.81250        | 80  |
| 1              | 0              | 0              | 0              | 0             | 0             | 0               | 1               | 0.80625        | 81  |
| 1              | 0              | 0              | 0              | 0             | 0             | 1               | 0               | 0.80000        | 82  |
| 1              | 0              | 0              | 0              | 0             | 0             | 1               | 1               | 0.79375        | 83  |
| 1              | 0              | 0              | 0              | 0             | 1             | 0               | 0               | 0.78750        | 84  |
| 1              | 0              | 0              | 0              | 0             | 1             | 0               | 1               | 0.78125        | 85  |
| 1              | 0              | 0              | 0              | 0             | 1             | 1               | 0               | 0.77500        | 86  |
| 1              | 0              | 0              | 0              | 0             | 1             | 1               | 1               | 0.76875        | 87  |
| 1              | 0              | 0              | 0              | 1             | 0             | 0               | 0               | 0.76250        | 88  |
| 1              | 0              | 0              | 0              | 1             | 0             | 0               | 1               | 0.75625        | 89  |
| 1              | 0              | 0              | 0              | 1             | 0             | 1               | 0               | 0.75000        | 8A  |
| 1              | 0              | 0              | 0              | 1             | 0             | 1               | 1               | 0.74375        | 8B  |
| 1              | 0              | 0              | 0              | 1             | 1             | 0               | 0               | 0.73750        | 8C  |
| 1              | 0              | 0              | 0              | 1             | 1             | 0               | 1               | 0.73125        | 8D  |
| 1              | 0              | 0              | 0              | 1             | 1             | 1               | 0               | 0.72500        | 8E  |
| 1              | 0              | 0              | 0              | 1             | 1             | 1               | 1               | 0.71875        | 8F  |



# NCP5392T

Table 1. VRM11 VID Codes

| VID7<br>800 mV | VID6<br>400 mV | VID5<br>200 mV | VID4<br>100 mV | VID3<br>50 mV | VID2<br>25 mV | VID1<br>12.5 mV | VID0<br>6.25 mV | Voltage<br>(V) | HEX |
|----------------|----------------|----------------|----------------|---------------|---------------|-----------------|-----------------|----------------|-----|
| 1              | 0              | 0              | 1              | 0             | 0             | 0               | 0               | 0.71250        | 90  |
| 1              | 0              | 0              | 1              | 0             | 0             | 0               | 1               | 0.70625        | 91  |
| 1              | 0              | 0              | 1              | 0             | 0             | 1               | 0               | 0.70000        | 92  |
| 1              | 0              | 0              | 1              | 0             | 0             | 1               | 1               | 0.69375        | 93  |
| 1              | 0              | 0              | 1              | 0             | 1             | 0               | 0               | 0.68750        | 94  |
| 1              | 0              | 0              | 1              | 0             | 1             | 0               | 1               | 0.68125        | 95  |
| 1              | 0              | 0              | 1              | 0             | 1             | 1               | 0               | 0.67500        | 96  |
| 1              | 0              | 0              | 1              | 0             | 1             | 1               | 1               | 0.66875        | 97  |
| 1              | 0              | 0              | 1              | 1             | 0             | 0               | 0               | 0.66250        | 98  |
| 1              | 0              | 0              | 1              | 1             | 0             | 0               | 1               | 0.65625        | 99  |
| 1              | 0              | 0              | 1              | 1             | 0             | 1               | 0               | 0.65000        | 9A  |
| 1              | 0              | 0              | 1              | 1             | 0             | 1               | 1               | 0.64375        | 9B  |
| 1              | 0              | 0              | 1              | 1             | 1             | 0               | 0               | 0.63750        | 9C  |
| 1              | 0              | 0              | 1              | 1             | 1             | 0               | 1               | 0.63125        | 9D  |
| 1              | 0              | 0              | 1              | 1             | 1             | 1               | 0               | 0.62500        | 9E  |
| 1              | 0              | 0              | 1              | 1             | 1             | 1               | 1               | 0.61875        | 9F  |
| 1              | 0              | 1              | 0              | 0             | 0             | 0               | 0               | 0.61250        | A0  |
| 1              | 0              | 1              | 0              | 0             | 0             | 0               | 1               | 0.60625        | A1  |
| 1              | 0              | 1              | 0              | 0             | 0             | 1               | 0               | 0.60000        | A2  |
| 1              | 0              | 1              | 0              | 0             | 0             | 1               | 1               | 0.59375        | A3  |
| 1              | 0              | 1              | 0              | 0             | 1             | 0               | 0               | 0.58750        | A4  |
| 1              | 0              | 1              | 0              | 0             | 1             | 0               | 1               | 0.58125        | A5  |
| 1              | 0              | 1              | 0              | 0             | 1             | 1               | 0               | 0.57500        | A6  |
| 1              | 0              | 1              | 0              | 0             | 1             | 1               | 1               | 0.56875        | A7  |
| 1              | 0              | 1              | 0              | 1             | 0             | 0               | 0               | 0.56250        | A8  |
| 1              | 0              | 1              | 0              | 1             | 0             | 0               | 1               | 0.55625        | A9  |
| 1              | 0              | 1              | 0              | 1             | 0             | 1               | 0               | 0.55000        | AA  |
| 1              | 0              | 1              | 0              | 1             | 0             | 1               | 1               | 0.54375        | AB  |
| 1              | 0              | 1              | 0              | 1             | 1             | 0               | 0               | 0.53750        | AC  |
| 1              | 0              | 1              | 0              | 1             | 1             | 0               | 1               | 0.53125        | AD  |
| 1              | 0              | 1              | 0              | 1             | 1             | 1               | 0               | 0.52500        | AE  |
| 1              | 0              | 1              | 0              | 1             | 1             | 1               | 1               | 0.51875        | AF  |
| 1              | 0              | 1              | 1              | 0             | 0             | 0               | 0               | 0.51250        | B0  |
| 1              | 0              | 1              | 1              | 0             | 0             | 0               | 1               | 0.50625        | B1  |
| 1              | 0              | 1              | 1              | 0             | 0             | 1               | 0               | 0.50000        | B2  |
| 1              | 1              | 1              | 1              | 1             | 1             | 1               | 0               | OFF            | FE  |
| 1              | 1              | 1              | 1              | 1             | 1             | 1               | 1               | OFF            | FF  |

## FUNCTIONAL DESCRIPTION

**General**

The NCP5392T provides up to four-phase buck solution which combines differential voltage sensing, differential phase current sensing, and adaptive voltage positioning to provide accurately regulated power necessary for both Intel VR11.1 CPU power system. NCP5392T has been designed to work with the NCP5359 driver.

**Remote Output Sensing Amplifier(RSA)**

A true differential amplifier allows the NCP5392T to measure  $V_{core}$  voltage feedback with respect to the  $V_{core}$  ground reference point by connecting the  $V_{core}$  reference point to VSP, and the  $V_{core}$  ground reference point to VSN. This configuration keeps ground potential differences between the local controller ground and the  $V_{core}$  ground reference point from affecting regulation of  $V_{core}$  between  $V_{core}$  and  $V_{core}$  ground reference points. The RSA also subtracts the DAC (minus VID offset) voltage, thereby producing an unamplified output error voltage at the DIFFOUT pin. This output also has a 1.3 V bias voltage as the floating ground to allow both positive and negative error voltages.

**Precision Programmable DAC**

A precision programmable DAC is provided and system trimmed. This DAC has 0.5% accuracy over the entire operating temperature range of the part. The DAC can be programmed to support Intel VR11 VID code specifications.

**High Performance Voltage Error Amplifier**

The error amplifier is designed to provide high slew rate and bandwidth. Although not required when operating as the controller of a voltage regulator, a capacitor from COMP to VFB is required for stable unity gain test configurations.

**Gate Driver Outputs and 2/3/4 Phase Operation**

The part can be configured to run in 2-, 3-, or 4-phase mode. In 2-phase mode, phases 1 and 3 should be used to drive the external gate drivers as shown in the 2-phase Applications Schematic, G2 and G4 must be grounded. In 3-phase mode, gate output G4 must be grounded as shown in the 3-phase Applications Schematic. In 4-phase mode all 4 gate outputs are used as shown in the 4-phase Applications Schematic. The Current Sense inputs of unused channels should be connected to VCCP shown in the Application Schematics. Please refer to table "PIN CONNECTIONS vs. PHASE COUNTS" for details.

**Differential Current Sense Amplifiers and Summing Amplifier**

Four differential amplifiers are provided to sense the output current of each phase. The inputs of each current sense amplifier must be connected across the current sensing element of the phase controlled by the

corresponding gate output (G1, G2, G3, or G4). If a phase is unused, the differential inputs to that phase's current sense amplifier must be shorted together and connected to the output as shown in the 2- and 3-phase Application Schematics.

The current signals sensed from inductor DCR are fed into a summing amplifier to have a summed-up output (CSSUM). Signal of CSSUM combines information of total current of all phases in operation.

The outputs of current sense amplifiers control three functions. First, the summing current signal (CSSUM) of all phases will go through DROOP amplifier and join the voltage feedback loop for output voltage positioning. Second, the output signal from DROOP amplifier also goes to ILIM amplifier to monitor the output current limit. Finally, the individual phase current contributes to the current balance of all phases by offsetting their ramp signals of PWM comparators.

**Thermal Compensation Amplifier with VDRP and VDFB Pins**

Thermal compensation amplifier is an internal amplifier in the path of droop current feedback for additional adjustment of the gain of summing current and temperature compensation. The way thermal compensation is implemented separately ensures minimum interference to the voltage loop compensation network.

**Oscillator and Triangle Wave Generator**

A programmable precision oscillator is provided. The oscillator's frequency is programmed by the resistance connected from the ROSC pin to ground. The user will usually form this resistance from two resistors in order to create a voltage divider that uses the ROSC output voltage as the reference for creating the current limit setpoint voltage. The oscillator frequency range is 100 kHz per phase to 1.0 MHz per phase. The oscillator generates up to 4 symmetrical triangle waveforms with amplitude between 1.3 V and 2.3 V. The triangle waves have a phase delay between them such that for 2-, 3- and 4-phase operation the PWM outputs are separated by 180, 120, and 90 angular degrees, respectively.

**PWM Comparators with Hysteresis**

Four PWM comparators receive an error signal at their noninverting input. Each comparator receives one of the triangle waves at its inverting output. The output of each comparator generates the PWM outputs G1, G2, G3, and G4.

During steady state operation, the duty cycle will center on the valley of the triangle waveform, with steady state duty cycle calculated by  $V_{out}/V_{in}$ . During a transient event, both high and low comparator output transitions shift phase to the points where the error signal intersects the down and up ramp of the triangle wave.

### Power Saving Mode

Upon receiving PSI low command, the NCP5392T enters power saving mode with PWM signals varying between high and mid level to allow diode emulation. The device is also forced into RPM mode.

## PROTECTION FEATURES

### Undervoltage Lockout (VCC) and 12VMON

An undervoltage lockout (UVLO) senses the  $V_{CC}$  input directly. 12 V UVLO senses the 12 V power supply by connecting it to the 12VMON pin through an appropriate resistor divider. During power-up, both the VCC input and 12VMON are monitored, and the PWM outputs and the soft-start circuit are disabled until both input voltages exceed the threshold voltages of their individual UVLO comparators. The UVLO comparators both incorporate hysteresis to avoid chattering. The second function of 12VMON pin is to provide a feed-forward input voltage information when the device works in RPM mode.

### Overcurrent Shutdown

A programmable overcurrent function is incorporated within the IC. A comparator and latch make up this function. The inverting input of the comparator is connected to the ILIM pin. The voltage at this pin sets the maximum output current the converter can produce. The ROSC pin provides a convenient and accurate reference voltage from which a resistor divider can create the overcurrent setpoint voltage. Although not actually disabled, tying the ILIM pin directly to the ROSC pin sets the limit above useful levels - effectively disabling overcurrent shutdown. The comparator noninverting input is the summed current information from the VDRP minus offset voltage. The overcurrent latch is set when the current information exceeds the voltage at the ILIM pin. The outputs are pulled low, and the soft-start is pulled low. The outputs will remain disabled until the  $V_{CC}$  voltage is removed and re-applied, or the ENABLE input is brought low and then high.

### Output Overvoltage and Undervoltage Protection and Power Good Monitor

An output voltage monitor is incorporated. During normal operation, if the output voltage is 180 mV (typical) over the DAC voltage, the VR\_RDY goes low, the DRVON signal remains high, the PWM outputs are set low. The outputs will remain disabled until the  $V_{CC}$  voltage is removed and reapplied. During normal operation, if the output voltage falls more than 350 mV below the DAC setting, the VR\_RDY pin will be set low until the output voltage rises.

### Soft-Start

The VR11 mode ramps  $V_{core}$  to 1.1 V boot voltage at a fixed rate of 0.8 mV/ $\mu$ S, pauses at 1.1 V for around 500  $\mu$ S,

reads the VID pins to determine the DAC setting. Then ramps  $V_{core}$  to the final DAC setting at the Dynamic VID slew rate of up to 12.5 mV/ $\mu$ S. Typical VR11 soft-start sequences are shown in the following graphs (Figure 9 and 10).

## APPLICATION INFORMATION

The NCP5392T demo board for the NCP5392T is available by request. It is configured as a four phase solution with decoupling designed to provide a 1 m $\Omega$  load line under a 100 A step load.

### Startup Procedure

Start by installing the test tool software. It is best to power the test tool from a separate ATX power supply. The test tool should be set to a valid VID code of 0.5 V or above in order for the controller to start. Consult the VTT help manual for more detailed instruction.

### Step Load Testing

The VTT tool is used to generate the  $d_i/d_t$  step load. Select the dynamic loading option in the VTT test tool software. Set the desired step load size, frequency, duty, and slew rate. See Figure 6.

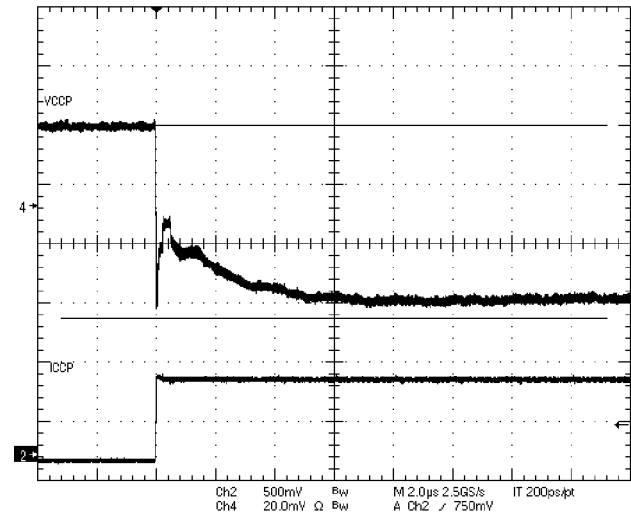


Figure 6. Typical Load Step Response  
(full load, 35 A - 100 A)

### Dynamic VID Testing

The VTT tool provides for VID stepping based on the Intel Requirements. Select the Dynamic VID option. Before enabling the test set the lowest VID to 0.5 V or greater and set the highest VID to a value that is greater than the lowest VID selection, then enable the test. See Figures 7 and 8.

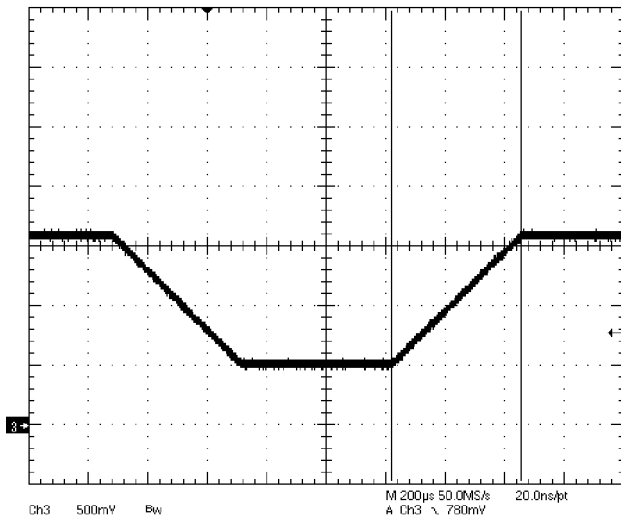


Figure 7. 1.6 V to 0.5 V Dynamic VID response

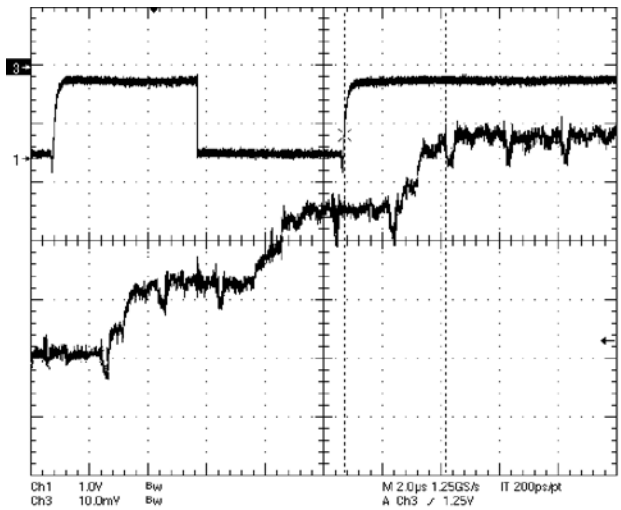


Figure 8. Dynamic VID Settling Time Rising (CH1: VID1, CH2: DAC, CH3:VCCP)

## DESIGN METHODOLOGY

### Decoupling the V<sub>CC</sub> Pin on the IC

An RC input filter is required as shown in the V<sub>CC</sub> pin to minimize supply noise on the IC. The resistor should be sized such that it does not generate a large voltage drop between 5 V supply and the IC.

### Understanding Soft-Start

The controller supports standard VR11 startup routines. The V<sub>core</sub> voltage ramps up to the 1.1 V boot voltage, with a pause to capture the VID code then resume ramping to target value based on internal slew rate limit. The initial ramp rate was set to be 0.8 mV/µS.

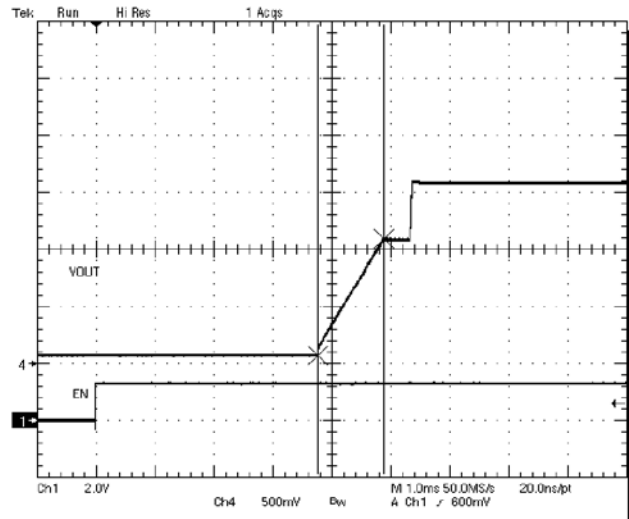


Figure 9. VR11.1 Startup

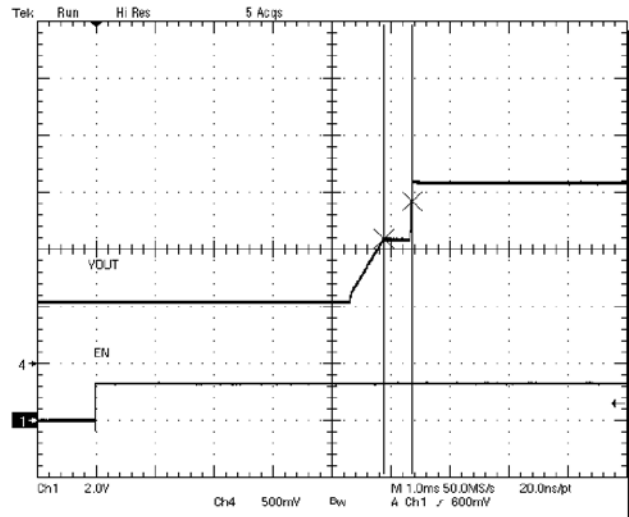


Figure 10. VR11.1 Biased Startup

### Programming the Current Limit and the Oscillator Frequency

The demo board is set for an operating frequency of approximately 330 kHz. The R<sub>OSC</sub> pin provides a 2.0 V reference voltage which is divided down with a resistor divider and fed into the current limit pin ILIM. Then calculate the individual RLIM1 and RLIM2 values for the divider. The series resistors RLIM1 and RLIM2 sink current from the ILIM pin to ground. This current is internally mirrored into a capacitor to create an oscillator. The period is proportional to the resistance and frequency is inversely proportional to the total resistance. The total resistance may be estimated by Equation 1. This equation is valid for the individual phase frequency in both three and four phase mode.

$$R_{OSC} \cong 20947 \times F_{SW}^{-1.1262} \quad (\text{eq. 1})$$

$$30.5 \text{ k}\Omega \cong 20947 \times 330^{-1.1262}$$

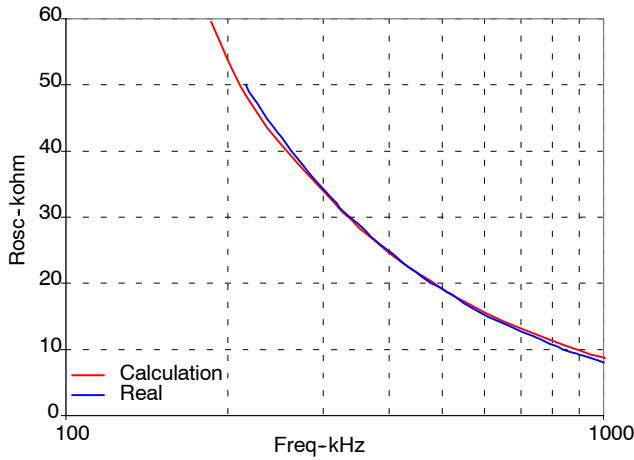


Figure 11. ROSC vs. Frequency

The current limit function is based on the total sensed current of all phases multiplied by a controlled gain ( $A_{CSSUM} \cdot A_{DRP}$ ). DCR sensed inductor current is a function of the winding temperature. The best approach is to set the maximum current limit based on expected average maximum temperature of the inductor windings,

$$DCR_{T_{max}} = DCR_{25C} (1 + 0.00393 \cdot (T_{max} - 25)) \quad (\text{eq. 2})$$

For multiphase controller, the ripple current can be calculated as,

$$I_{pp} = \frac{(V_{in} - N \cdot V_{out}) \cdot V_{out}}{L \cdot F_{SW} \cdot V_{in}} \quad (\text{eq. 3})$$

Therefore calculate the current limit voltage as below,

$$V_{LIMIT} \equiv A_{CSSUM} \cdot A_{DRP} \cdot DCR_{T_{max}} \cdot (I_{MIN\_OCP} + 0.5 \cdot I_{pp}) \quad (\text{eq. 4})$$

$$V_{LIMIT} \equiv A_{CSSUM} \cdot A_{DRP} \cdot DCR_{T_{max}} \cdot \left( I_{MIN\_OCP} + 0.5 \cdot \frac{(V_{in} - N \cdot V_{out}) \cdot V_{out}}{L \cdot F_{SW} \cdot V_{in}} \right)$$

In Equation 4,  $A_{CSSUM}$  and  $A_{DRP}$  are the gain of current summing amplifier and droop amplifier.

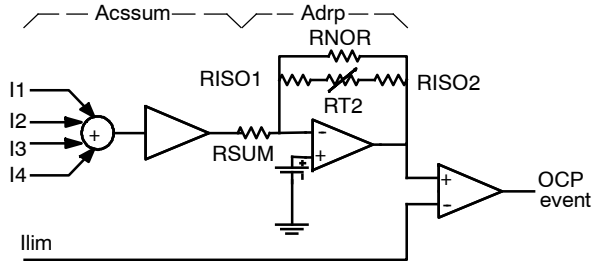


Figure 12. ACSSUM and ADRP

As introduced before,  $V_{LIMIT}$  comes from a resistor divider connected to  $R_{osc}$  pin, thus,

$$V_{LIMIT} = 2V \cdot \frac{R_{LIM2}}{R_{LIM1} + R_{LIM2}} \cdot COEpsi \quad (\text{eq. 5})$$

$$A_{CSSUM} = -4$$

$$A_{DRP} = -\frac{R_{NOR} \cdot (R_{ISO1} + R_{ISO2} + R_{T2})}{(R_{NOR} + R_{ISO1} + R_{ISO2} + R_{T2}) \cdot R_{SUM}} \quad (\text{eq. 6})$$

$R_{ISO1}$  and  $R_{ISO2}$  are in series with  $R_{T2}$ , the NTC temperature sense resistor placed near inductor.  $R_{SUM}$  is the resistor connecting between pin  $V_{DFB}$  and pin  $CSSUM$ . If  $PSI = 1$ ,  $PSI$  function is off, the current limit follows the Equation 7; if  $PSI = 0$ , the power saving mode will be enabled,  $COEpsi$  is a coefficient for the current limiting related with power saving function ( $PSI$ ), the current limit can be calculated from Equation 8.  $COEpsi$  value is one over the original phase count  $N$ . Refer to the  $PSI$  and phase shedding section for more details.

### Final Equations for the Current Limit Threshold

Final equations are described based on two conditions: normal mode and PSI mode.

$$I_{LIMIT}(normal) \cong \frac{\frac{2V \cdot R_{LIM2}}{R_{LIM1} + R_{LIM2}}}{4 \cdot \frac{R_{NOR} \cdot (R_{ISO1} + R_{ISO2} + R_{T2})}{(R_{NOR} + R_{ISO1} + R_{ISO2} + R_{T2}) \cdot R_{SUM}} \cdot DCR_{25C}(1 + 0.00393 \cdot (T_{inductor} - 25))} - 0.5 \cdot \frac{(V_{in} - N \cdot V_{out}) \cdot V_{out}}{L \cdot F_{SW} \cdot V_{in}} \quad (eq. 7)$$

$$I_{LIMIT}(PSI) \cong \frac{\frac{2V \cdot R_{LIM2}}{R_{LIM1} + R_{LIM2}} \cdot COEpsi}{4 \cdot \frac{R_{NOR} \cdot (R_{ISO1} + R_{ISO2} + R_{T2})}{(R_{NOR} + R_{ISO1} + R_{ISO2} + R_{T2}) \cdot R_{SUM}} \cdot DCR_{25C}(1 + 0.00393 \cdot (T_{inductor} - 25))} - 0.5 \cdot \frac{(V_{in} - V_{out}) \cdot V_{out}}{L \cdot F_{SW} \cdot V_{in}} \quad (eq. 8)$$

N is the number of phases involved in the circuit.

The inductors on the demo board have a DCR at 25°C of 0.6 mΩ. Selecting the closest available values of 21.3 kΩ for R<sub>LIM1</sub> and 9.28 kΩ for R<sub>LIM2</sub> yields a nominal operating frequency of 330 kHz. Select R<sub>ISO1</sub> = 1 k, R<sub>ISO2</sub> = 1 k, R<sub>T2</sub> = 10 K (25°C), R<sub>NOR</sub>/R<sub>SUM</sub> = 2, (refer to application diagram). That results to an approximate current limit of 133 A at 100°C for a four phase operation and 131 A at 25°C. The total sensed current can be observed as a scaled voltage at the VDRP with a positive no-load offset of approximately 1.3 V.

### Inductor Selection

When using inductor current sensing it is recommended that the inductor does not saturate by more than 10% at maximum load. The inductor also must not go into hard saturation before current limit trips. The demo board includes a four phase output filter using the T44-8 core from Micrometals with 3 turns and a DCR target of 0.6 mΩ @ 25°C. Smaller DCR values can be used, however, current sharing accuracy and droop accuracy decrease as DCR decreases. Use the NCP5392T design aide for regulation accuracy calculations for specific value of DCR.

### Inductor Current Sensing Compensation

The NCP5392T uses the inductor current sensing method. An RC filter is selected to cancel out the impedance from inductor and recover the current information through the inductor's DCR. This is done by matching the RC time constant of the sensing filter to the L/DCR time constant. The first cut approach is to use a 0.1 μF capacitor for C and then solve for R.

$$R_{sense}(T) = \frac{L}{0.1 \cdot \mu F \cdot DCR_{25C} \cdot (1 + 0.00393(T - 25))} \quad (eq. 9)$$

Because the inductor value is a function of load and inductor temperature final selection of R is best done experimentally on the bench by monitoring the V<sub>droop</sub> pin and performing a step load test on the actual solution.

## Simple Average SPICE Model

A simple state average model shown in Figure 13 can be used to determine a stable solution and provide insight into the control system.

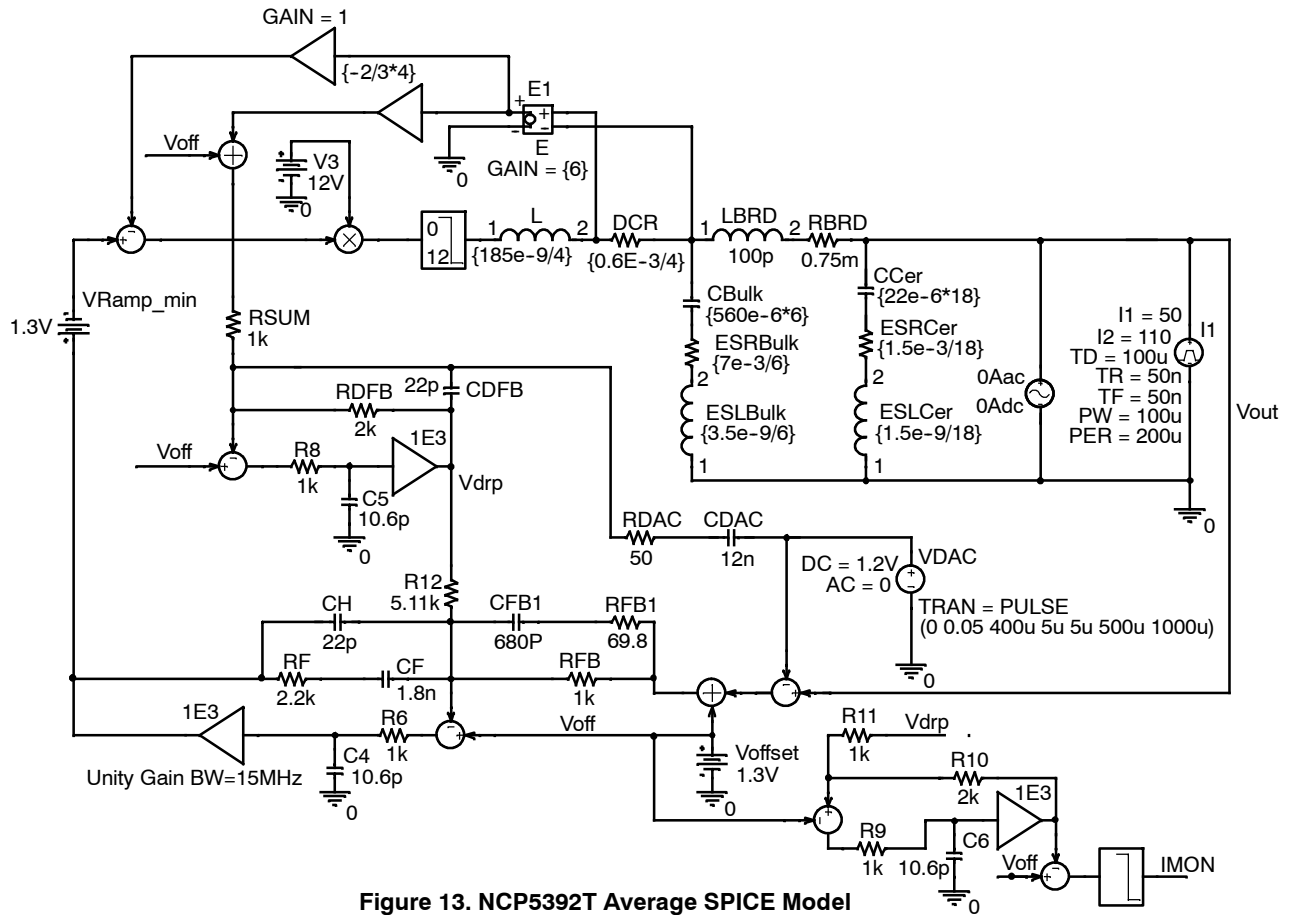


Figure 13. NCP5392T Average SPICE Model

## Compensation and Output Filter Design

If the required output filter and switching frequency are significantly different, it's best to use the available PSPICE models to design the compensation and output filter from scratch.

The design target for this demo board was 1.0 mΩ up to 2.0 MHz. The phase switching frequency is currently set to 330 kHz. It can easily be seen that the board impedance of 0.75 mΩ between the load and the bulk capacitance has a large effect on the output filter. In this case the six 560 μF bulk capacitors have an ESR of 7.0 mΩ. Thus the bulk ESR

plus the board impedance is 1.15 mΩ + 0.75 mΩ or 1.9 mΩ. The actual output filter impedance does not drop to 1.0 mΩ until the ceramic breaks in at over 375 kHz. The controller must provide some loop gain slightly less than one out to a frequency in excess 300 kHz. At frequencies below where the bulk capacitance ESR breaks with the bulk capacitance, the DC-DC converter must have sufficiently high gain to control the output impedance completely. Standard Type-3 compensation works well with the NCP5392T.

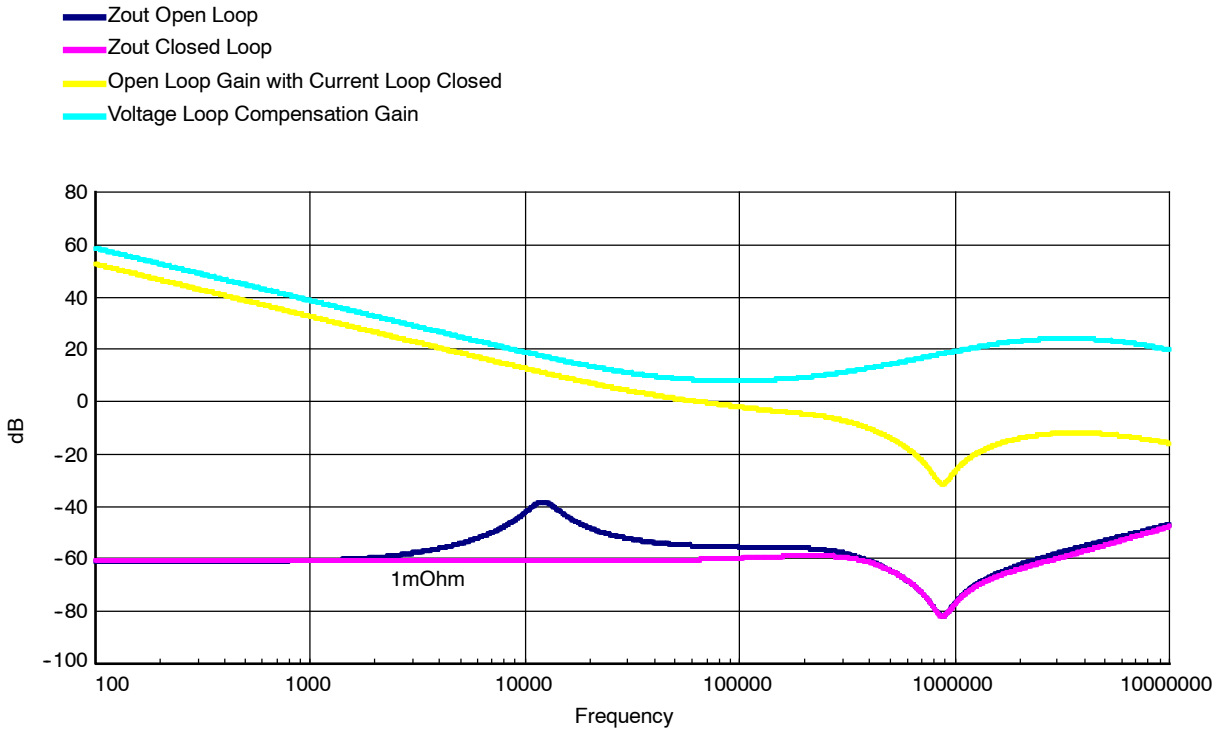


Figure 14. NCP5392T Circuit Frequency Response

The goal is to compensate the system such that the resulting gain generates constant output impedance from DC up to the frequency where the ceramic takes over holding the impedance below 1.0 mΩ. See the example of the locations of the poles and zeros that were set to optimize the model above.

By matching the following equations a good set of starting compensation values can be found for a typical mixed bulk and ceramic capacitor type output filter.

$$\frac{1}{2\pi \cdot CF \cdot RF} = \frac{1}{2\pi \cdot (RBRD + ESR_{Bulk}) \cdot C_{Bulk}} \quad (\text{eq. 10})$$

$$\frac{1}{2\pi \cdot CFB1 \cdot (RFB1 + RFB)} = \frac{1}{2\pi \cdot C_{Cer} \cdot (RBRD + ESR_{Bulk})} \quad (\text{eq. 11})$$

$R_{FB}$  should be set to provide optimal thermal compensation in conjunction with thermistor  $R_{T2}$ ,  $R_{ISO1}$  and  $R_{ISO2}$ . With  $R_{FB}$  set to 1.0 kΩ,  $R_{FB1}$  is usually set to 100 Ω for maximum phase boost, and the value of  $RF$  is typically set to 3.0 kΩ.

#### Droop Injection and Thermal Compensation

The VDRP signal is generated by summing the sensed output currents for each phase. A droop amplifier is added to adjust the total gain to approximately eight. VDRP is externally summed into the feedback network by the resistor  $R_{DRP}$ . This introduces an offset which is proportional to the output current thereby forcing a controlled, resistive output impedance.

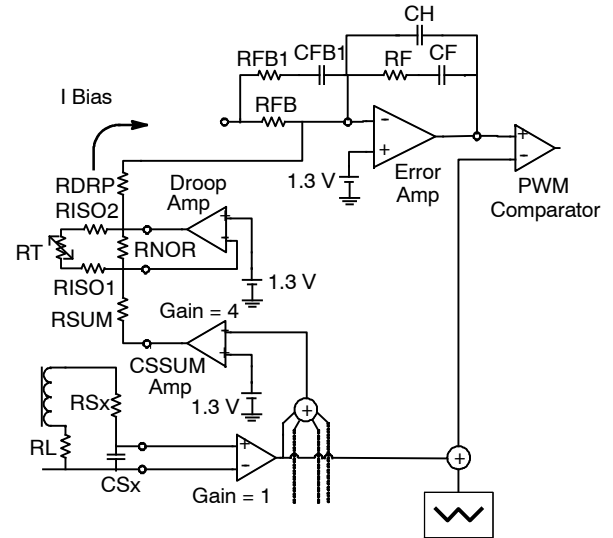


Figure 15. Droop Injection and Thermal Compensation

$R_{DRP}$  determines the target output impedance by the basic equation:

$$\frac{V_{out}}{I_{out}} = Z_{out} = \frac{R_{FB} \cdot DCR \cdot A_{CSSUM} \cdot A_{DRP}}{R_{DRP}} \quad (\text{eq. 12})$$

$$R_{DRP} = \frac{R_{FB} \cdot DCR \cdot A_{CSSUM} \cdot A_{DRP}}{Z_{out}} \quad (\text{eq. 13})$$

The value of the inductor's DCR is a function of temperature according to the Equation 14:

$$DCR(T) = DCR_{25C} \cdot (1 + 0.00393 \cdot (T - 25)) \quad (\text{eq. 14})$$



Actual DCR increases by temperature, the system can be thermally compensated to cancel this effect to a great degree by adding an NTC in parallel with  $R_{NOR}$  to reduce the droop gain as the temperature increases. The NTC device is nonlinear. Putting a resistor in series with the NTC helps make the device appear more linear with

$$Z_{out}(T) = \frac{R_{FB} \cdot DCR_{25C} \cdot (1 + 0.00393 \cdot (T - 25)) \cdot A_{CSSUM} \cdot A_{DRP}}{R_{DRP}} \quad (\text{eq. 15})$$

By including the NTC  $R_{T2}$  and the series isolation resistors the new equation becomes:

$$Z_{out}(T) = \frac{R_{FB} \cdot DCR_{25C} \cdot (1 + 0.00393 \cdot (T - 25)) \cdot A_{CSSUM} \cdot \frac{R_{NOR} \cdot (R_{ISO1} + R_{ISO2} + R_{T2})}{(R_{NOR} + R_{ISO1} + R_{ISO2} + R_{T2}) \cdot R_{SUM}}}{R_{DRP}} \quad (\text{eq. 16})$$

The typical equation of an NTC is based on a curve fit Equation 17

$$RT2(T) = RT2_{25C} \cdot e^{\beta \left[ \left( \frac{1}{273+T} \right) - \left( \frac{1}{298} \right) \right]} \quad (\text{eq. 17})$$

The demo board use a 10 k $\Omega$  NTC with a  $\beta$  value of 3740. Figure 16 shows the comparison of the compensated output impedance and uncompensated output impedance varying with temperature.

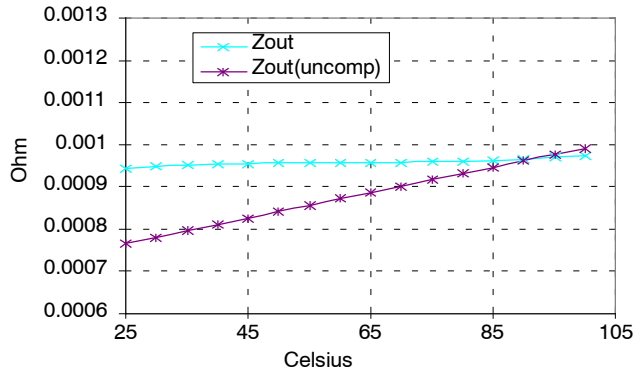


Figure 16.  $Z_{out}$  vs. Temperature

#### IMON for Current Monitor

Since VDRP signal reflects the current information of all phases. It can be fed into the IMON amplifier for current monitoring as shown in Figure 17. IMON amplifier has a fixed gain of 2 with an offset when VDRP is equal to 1.3 V, the internal floating reference voltage. The IMON amplifier will be saturated at an maximum output of 1.09 V therefore the total gain of current should be carefully considered to make the maximum load current indicated by the IMON output. Figure 18 shows a typical of the relation between IMON output and the load current.

temperature. The series resistor is split and inserted on both sides of the NTC to reduce noise injection into the feedback loop. The recommended total value for  $R_{ISO1}$  plus  $R_{ISO2}$  is approximately 1.0 k $\Omega$ .

The output impedance varies with inductor temperature by the equation:

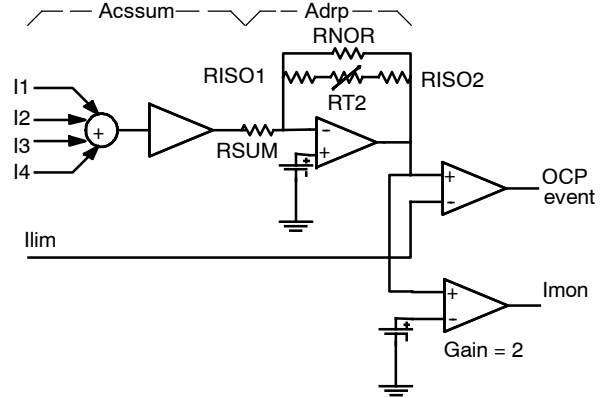


Figure 17. IMON Circuit

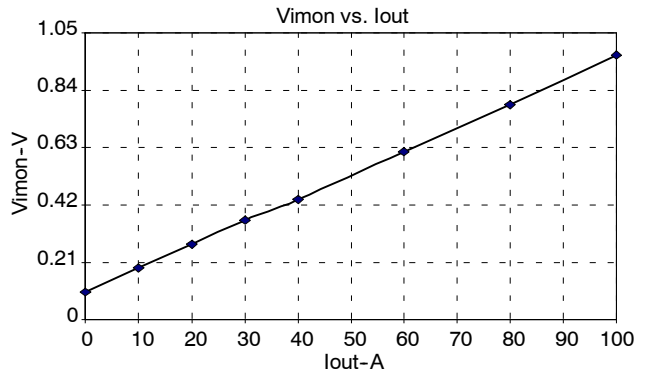


Figure 18. IMON Output vs. Output Current

#### Power Saving Indicator (PSI) and Phase Shedding

VR11.1 requires the processor to provide an output signal to the VR controller to indicate when the processor is in a low power state. NCP5392T use the status of PSI pin to decide if there is a need to change its operating state to maximize efficiency at light loads. When PSI = 0, the PSI function will be enabled, and VR system will be running at a single phase power saving mode.

The PSI signal will de-assert 1  $\mu$ s prior to moving to a normal power state.

At power saving mode, NCP5392T works with the NCP5359 driver to represent diode emulation mode at light load for further power saving.

When system switches on PSI function, an phase shedding will be presented. Only one phase is active in the

emulation mode while other phases are shed. Figure 19 indicates a PSI-on transition from a 3-phase mode to a single phase mode. While staying stable in PSI mode, the PWM signal of phase 1 will vary from a mid-state level (1.5 V typical) to high level while other phases all go to mid-state level. Vice versa, when PSI signal goes high, the system will go back to the original phase mode such as shown in Figure 20.

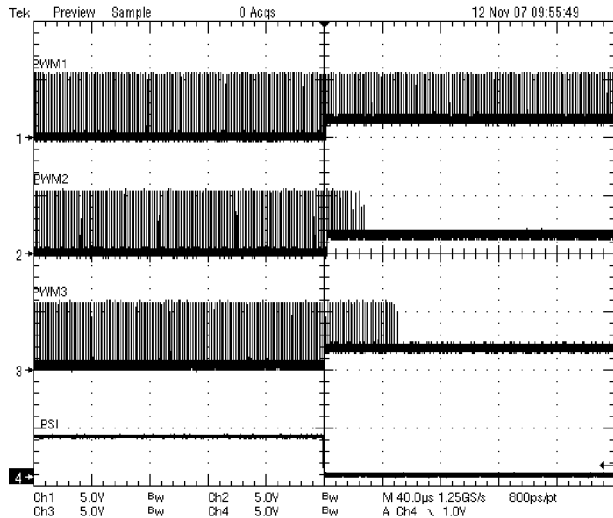


Figure 19. PSI turns on, CH1: PWM1, CH2: PWM2, CH3: PWM3, CH4: PSI

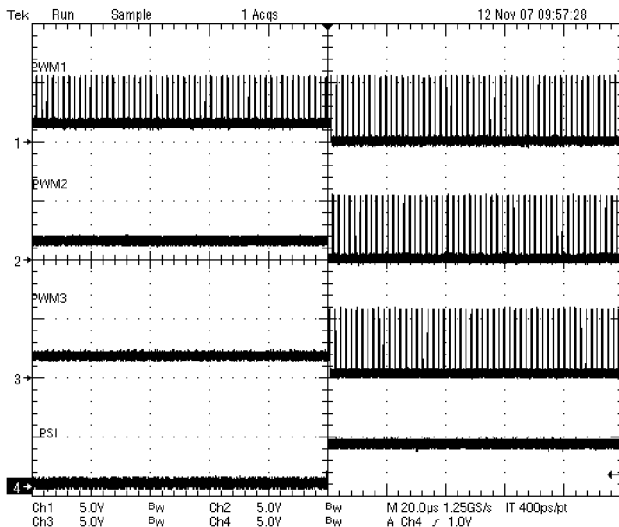


Figure 20. PSI turns off, CH1: PWM1, CH2: PWM2, CH3: PWM3, CH4: PSI

#### VRHOT

Thermal monitoring circuit consists of one sensitive comparator that compares the voltage on the NTC pin with an internal voltage reference. VR\_HOT is an open drain type of output. In normal temperature, the voltage value on NTC pin is higher than the internal reference, VR\_HOT will be low impedance. When the temperature is higher than certain threshold, the VR\_HOT will be high

impedance. The following equations can be used to find the temperature trip points.

$$RT1(T) = RT1_{25C} \cdot e^{\beta \left[ \left( \frac{1}{273+T} \right) - \left( \frac{1}{298} \right) \right]} \quad (\text{eq. 18})$$

With a beta value of 3740, a 68 kΩ NTC resistor is selected for RT1, RNTC1 is populated with 19.6 kΩ. VR\_HOT threshold is carefully selected to make sure when board temperature is less than 92°C.

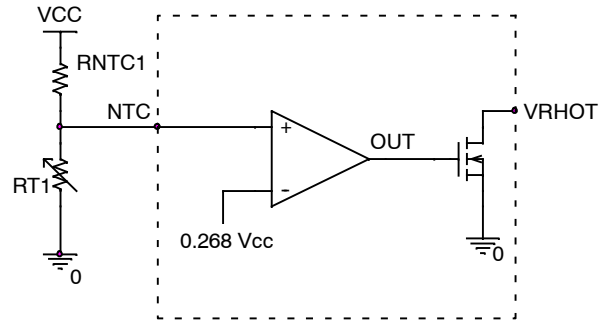


Figure 21. VRHOT Circuit

#### OVP Improved Performance

The overvoltage protection threshold is not adjustable. OVP protection is enabled as soon as soft-start begins and is disabled when part is disabled. When OVP is tripped, the controller commands all four gate drivers to enable their low side MOSFETs and VR\_RDY transitions low. In order to recover from an OVP condition, VCC must fall below the UVLO threshold. See the state diagram for further details. The OVP circuit monitors the output of DIFFOUT. If the DIFFOUT signal reaches 180 mV (typical) above the nominal 1.3 V offset the OVP will trip and VRRDY will be pulled low, after eight consecutive OVP events are detected, all PWMs will be latched. The DIFFOUT signal is the difference between the output voltage and the DAC voltage (minus 19 mV if in VR11.1 modes) plus the 1.3 V internal offset. This results in the OVP tracking on the DAC voltage even during a dynamic change in the VID setting during operation.

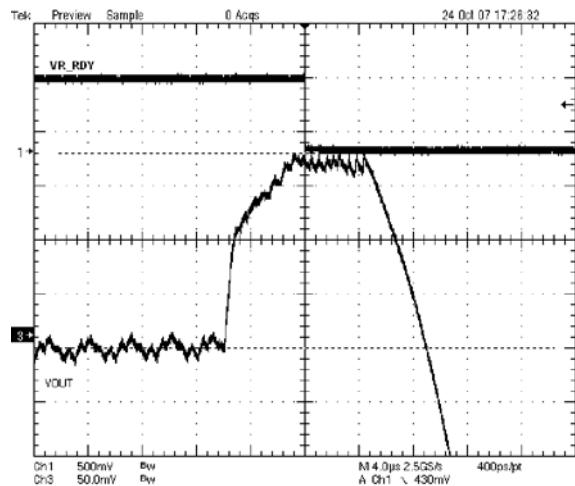


Figure 22. VR11.1, 1.6 V OVP Event

## NCP5392T

### Gate Driver and MOSFET Selection

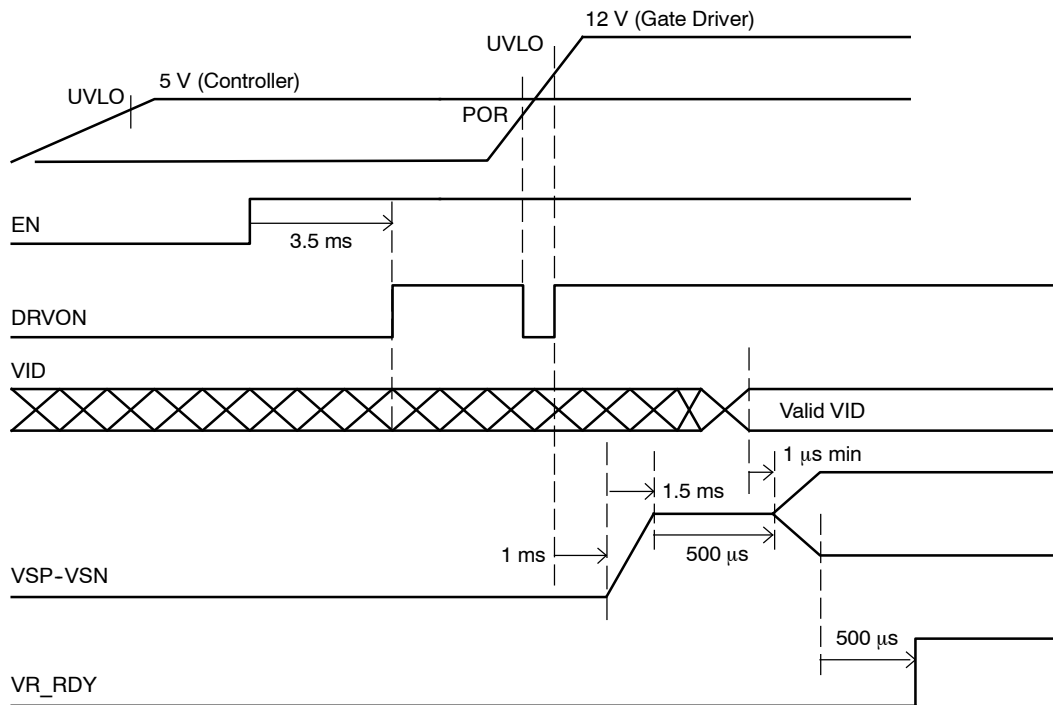
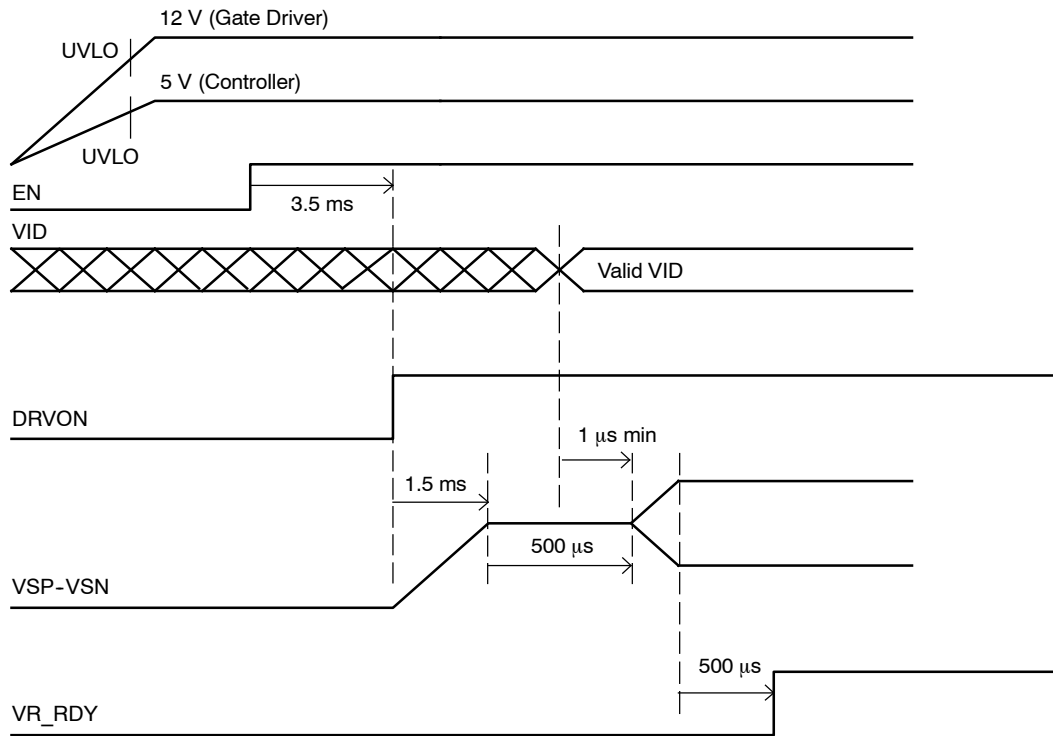
ON Semiconductor provides the NCP5359 as a companion gate driver IC. The NCP5359 driver is optimized to work with a range of MOSFETs commonly used in CPU applications. The NCP5359 provides special functionality including power saving mode operation and is required for high performance dynamic VID operation. Contact your local ON Semiconductor applications engineer for MOSFET recommendations.

### Board Stackup and Board Layout

Close attention should be paid to the routing of the sense traces and control lines that propagate away from the controller IC. Routing should follow the demo board example. For further information or layout review contact ON Semiconductor.

# NCP5392T

## SYSTEM TIMING DIAGRAM



# NCP5392T

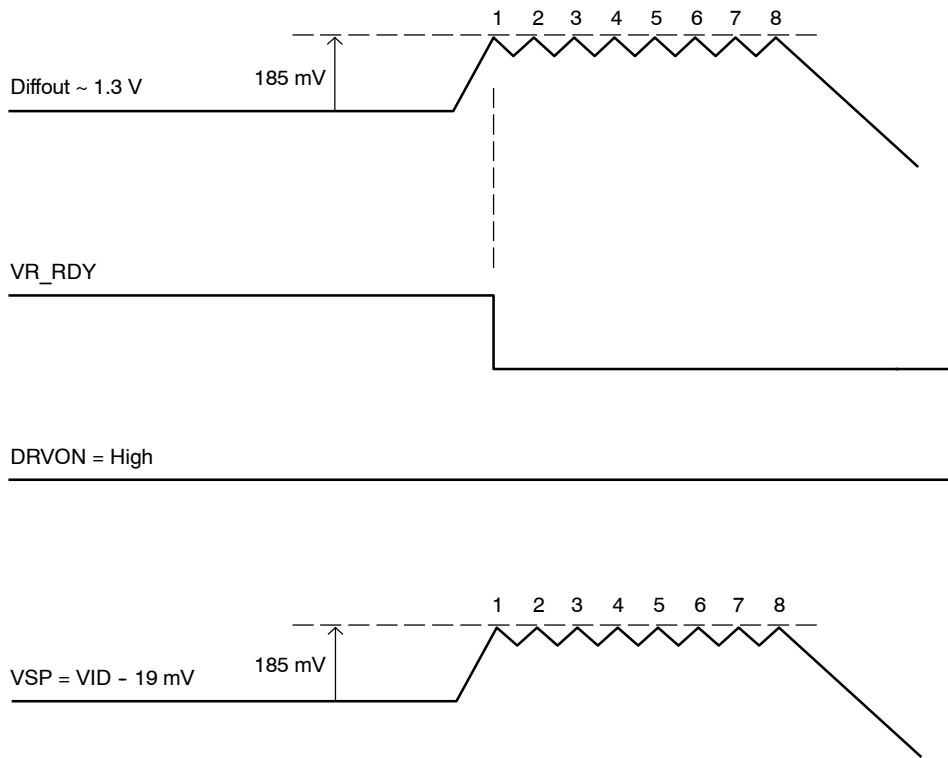


Figure 25. OVP Shutdown

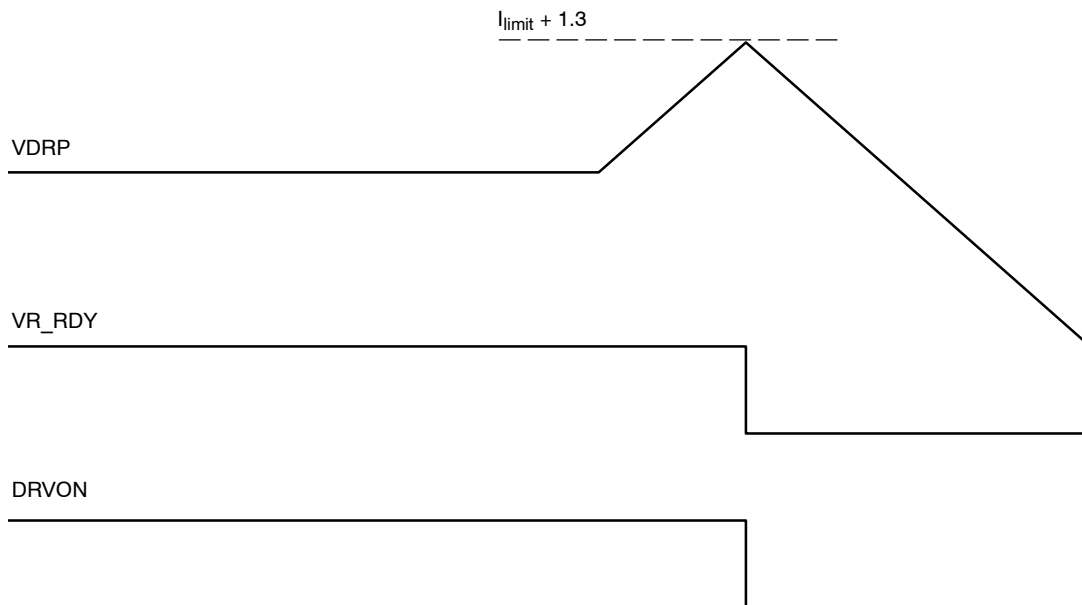
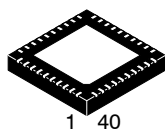


Figure 26. Non-PSI Current Limit

# MECHANICAL CASE OUTLINE

## PACKAGE DIMENSIONS

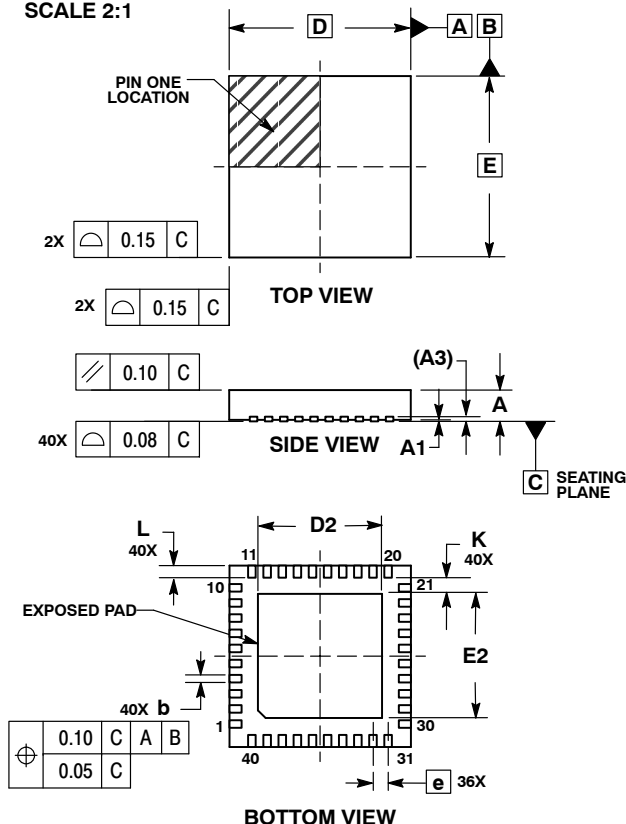
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**QFN40 6x6, 0.5P**  
CASE 488AR-01  
ISSUE A

DATE 18 APR 2007

SCALE 2:1

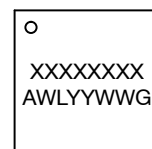


### NOTES:

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSIONS: MILLIMETERS.
3. DIMENSION b APPLIES TO PLATED TERMINAL AND IS MEASURED BETWEEN 0.25 AND 0.30mm FROM TERMINAL
4. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.

| MILLIMETERS |          |      |
|-------------|----------|------|
| DIM         | MIN      | MAX  |
| A           | 0.80     | 1.00 |
| A1          | 0.00     | 0.05 |
| A3          | 0.20 REF |      |
| b           | 0.18     | 0.30 |
| D           | 6.00 BSC |      |
| D2          | 4.00     | 4.20 |
| E           | 6.00 BSC |      |
| E2          | 4.00     | 4.20 |
| e           | 0.50 BSC |      |
| L           | 0.30     | 0.50 |
| K           | 0.20     | ---  |

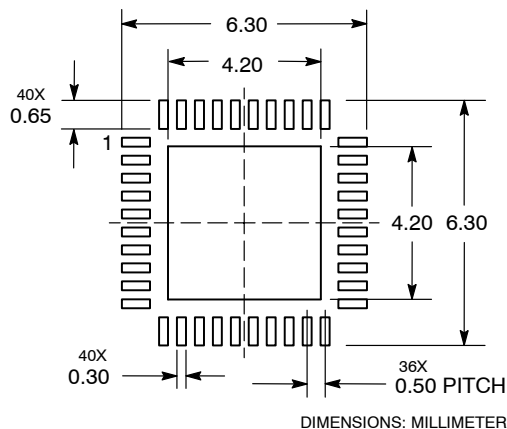
### GENERIC MARKING DIAGRAM\*



XXX = Specific Device Code  
 A = Assembly Location  
 WL = Wafer Lot  
 YY = Year  
 WW = Work Week  
 G = Pb-Free Package

\*This information is generic. Please refer to device data sheet for actual part marking. Pb-Free indicator, "G" or microdot "▪", may or may not be present.

### SOLDERING FOOTPRINT\*



\*For additional information on our Pb-Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

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