

# NCP81141

## Single-Phase Controller with SVID Interface for Desktop and Notebook CPU Applications

The NCP81141 Single-Phase buck solution is optimized for Intel VR12.6 compatible CPUs. The controller combines true differential voltage sensing, differential inductor DCR current sensing, input voltage feed-forward, and adaptive voltage positioning to provide accurately regulated power for both Desktop and Notebook applications. The single phase controller uses DCR current sensing providing the fastest initial response to dynamic load events at reduced system cost.

The NCP81141 incorporates an internal MOSFET driver for improved system efficiency. High performance operational error amplifiers are provided to simplify compensation of the system. Patented Dynamic Reference Injection further simplifies loop compensation by eliminating the need to compromise between closed-loop transient response and Dynamic VID performance. Patented Total Current Summing provides highly accurate digital current monitoring.

### Features

- Meets Intel™ VR12.6 Specifications
- High Performance Operational Error Amplifier
- Digital Soft Start Ramp
- Dynamic Reference Injection
- “Lossless” DCR Current Sensing
- Adaptive Voltage Positioning (AVP)
- Switching Frequency Range of 250 kHz – 1 MHz
- VIN Range 4.5 V – 25 V
- Startup into Pre-Charged Load While Avoiding False OVP
- Vin Feed Forward Ramp Slope
- Over Voltage Protection (OVP) and Under Voltage Protection (UVP)
- Over Current Protection (OCP)
- VR–RDY Output with Internal Delays
- These Devices are Pb–Free and are RoHS Compliant

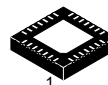
### Applications

- Desktop and Notebook Processors



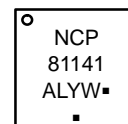
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QFN28  
CASE 485AR

### MARKING DIAGRAM



- A = Assembly Location
- L = Wafer Lot
- Y = Year
- W = Work Week
- = Pb–Free Package

(Note: Microdot may be in either location)

### ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 21 of this data sheet.

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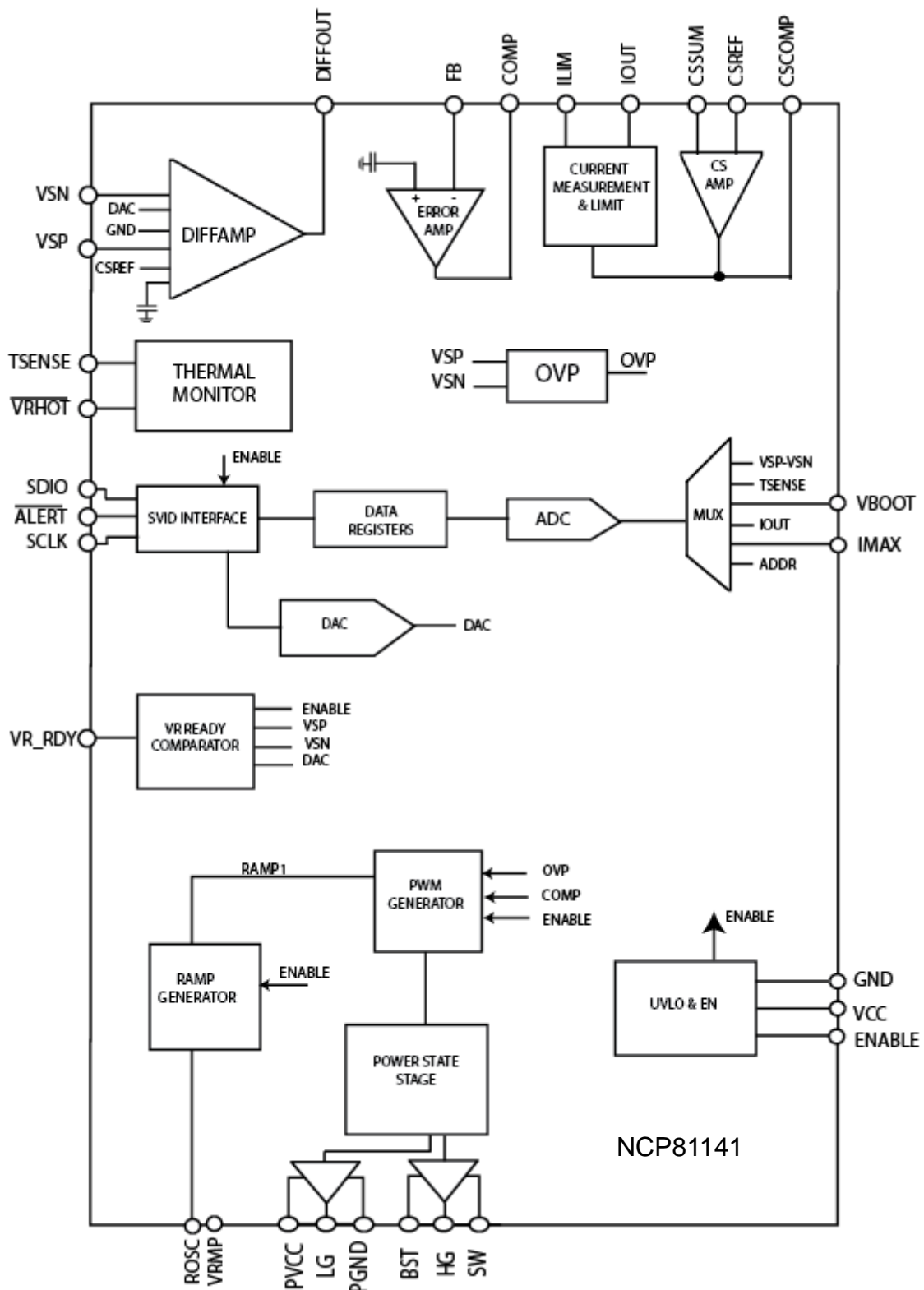


Figure 1. Block Diagram for NCP81141

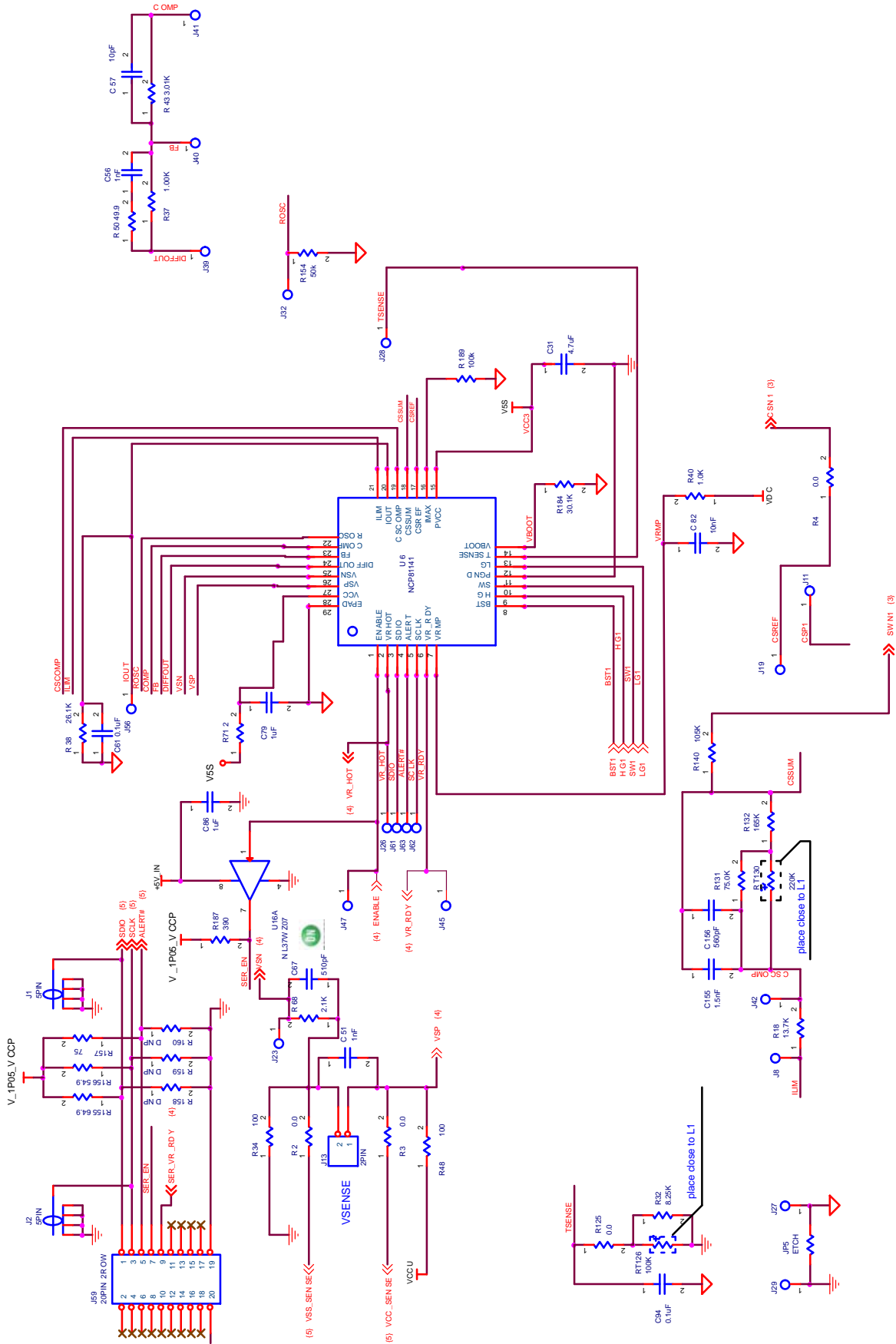


Figure 2. Controller Application Schematic

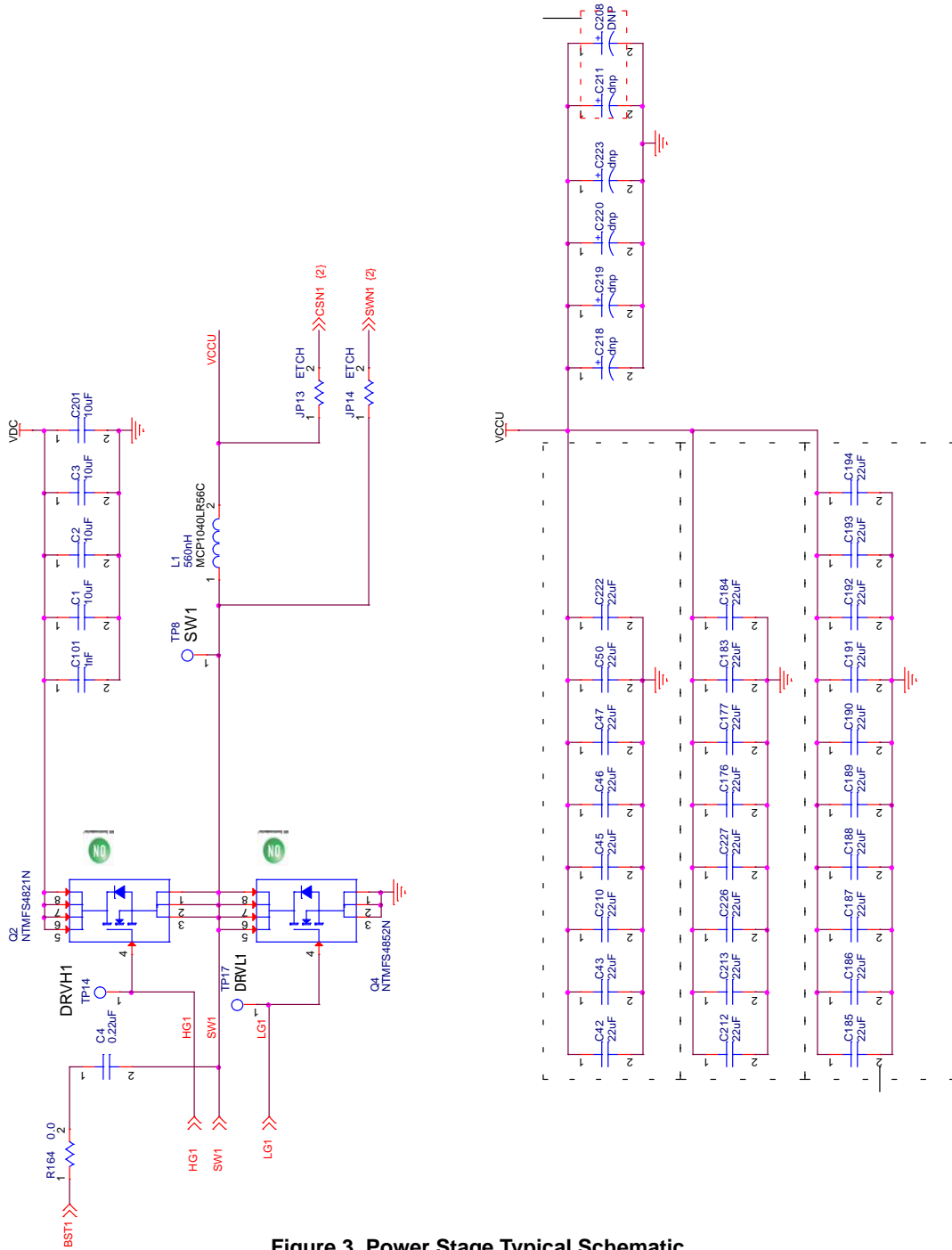


Figure 3. Power Stage Typical Schematic

# NCP81141

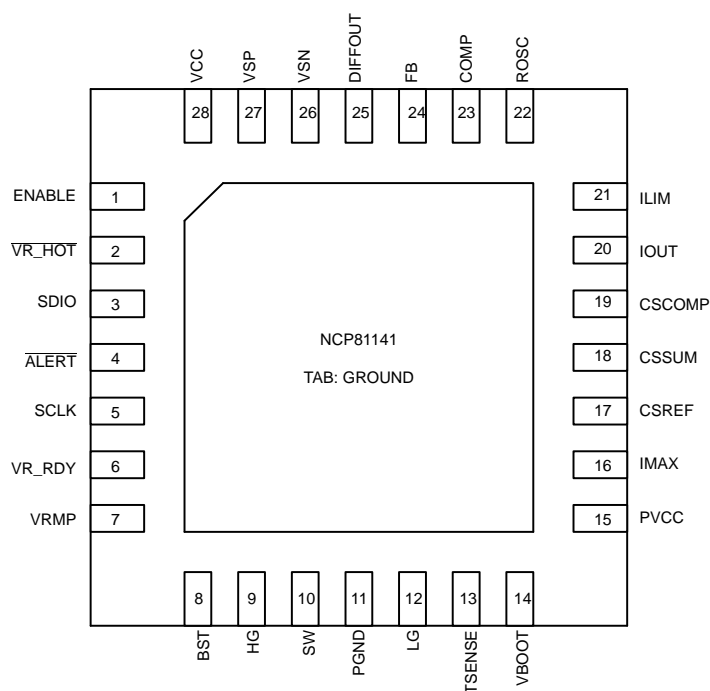


Figure 4. NCP81141 Pin Configurations

## NCP81141 SINGLE ROW PIN DESCRIPTIONS

| Pin No. | Symbol  | Description   |
|---------|---------|---|
| 1       | ENABLE  | Logic input. Logic high enables both outputs and logic low disables both outputs  |
| 2       | VR_HOT# | Thermal logic output for over temperature   |
| 3       | SDIO    | Serial VID data interface   |
| 4       | ALERT#  | Serial VID ALERT#   |
| 5       | SCLK    | Serial VID clock  |
| 6       | VR_RDY  | Open drain output. High indicates that the output is regulating   |
| 7       | VRMP    | Feed-forward input of Vin for the ramp slope compensation. The current fed into this pin is used to control the ramp of PWM slope |
| 8       | BST     | High-Side bootstrap supply for phase 1  |
| 9       | HG      | High side gate driver output for phase 1  |
| 10      | SW      | Current return for high side gate driver 1  |
| 11      | PGND    | Power Ground for gate driver  |
| 12      | LG      | Low-Side gate driver output for phase 1   |
| 13      | TSENSE  | Temp Sense input for the single phase converter   |
| 14      | VBOOT   | An input pin to adjust the boot-up voltage. During start up it is used to program VBOOT with a resistor to ground                 |
| 15      | PVCC    | Power Supply for gate driver, recommended decoupling 2.2 $\mu$ F  |
| 16      | IMAX    | Imax Input Pin. During start up it is used to program IMAX with a resistor to ground  |
| 17      | CSREF   | Total output current sense amplifier reference voltage input  |
| 18      | CSSUM   | Inverting input of total current sense amplifier  |
| 19      | CSCOMP  | Output of total current sense amplifier   |
| 20      | IOUT    | Total output current monitor  |
| 21      | ILIM    | Over current shutdown threshold setting. Resistor to CSCOMP to set threshold  |

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## NCP81141 SINGLE ROW PIN DESCRIPTIONS

| Pin No. | Symbol   | Description  |
|---------|----------|--|
| 22      | ROSC     | A resistance from this pin to ground programs the oscillator frequency                               |
| 23      | COMP     | Output of the error amplifier and the inverting input of the PWM comparator                          |
| 24      | FB       | Error amplifier voltage feedback   |
| 25      | DIFFOUT  | Output of the differential remote sense amplifier  |
| 26      | VSN      | Inverting input to differential remote sense amplifier   |
| 27      | VSP      | Non-inverting input to the differential remote sense amplifier                                       |
| 28      | VCC      | Power for the internal control circuits. A decoupling capacitor is connected from this pin to ground |
| 29      | FLAG/GND |  |

# NCP81141

## ABSOLUTE MAXIMUM RATINGS

### ELECTRICAL INFORMATION

| Pin Symbol     | V <sub>MAX</sub>                                       | V <sub>MIN</sub>                       |
|----------------|--|--|
| COMP           | V <sub>CC</sub> + 0.3 V                                | -0.3 V                                 |
| CSCOMP         | V <sub>CC</sub> + 0.3 V                                | -0.3 V                                 |
| VSN            | GND + 300 mV   | GND - 300 mV                           |
| DIFFOUT        | V <sub>CC</sub> + 0.3 V                                | -0.3 V                                 |
| VR_RDY         | V <sub>CC</sub> + 0.3 V                                | -0.3 V                                 |
| VCC            | 6.5 V  | -0.3 V                                 |
| ROSC           | V <sub>CC</sub> + 0.3 V                                | -0.3 V                                 |
| IOOUT          | 2.0 V  | -0.3 V                                 |
| VRMP           | +25 V  | -0.3 V                                 |
| SW             | 35 V<br>40 V ≤ 50 ns                                   | -5 V<br>-10 V ≤ 200 ns                 |
| BST            | 35 V wrt/ GND 40 V ≤ 50 ns<br>wrt/GND<br>6.5 V wrt/ SW | -0.3 V wrt/SW                          |
| LG             | V <sub>CC</sub> + 0.3 V                                | -0.3 V<br>-5 V ≤ 200 ns                |
| HG             | BST + 0.3 V  | -0.3 V wrt/ SW<br>-2 V ≤ 200 ns wrt/SW |
| All Other Pins | V <sub>CC</sub> + 0.3 V                                | -0.3 V                                 |

\*All signals referenced to GND unless noted otherwise.

### THERMAL INFORMATION

| Description                                    | Symbol           | Typ         | Unit |
|--|------------------|-------------|------|
| Thermal Characteristic<br>QFN Package (Note 1) | R <sub>θJA</sub> | 68          | °C/W |
| Operating Junction Temperature Range (Note 2)  | T <sub>J</sub>   | -40 to +125 | °C   |
| Operating Ambient Temperature Range            |                  | -40 to +100 | °C   |
| Maximum Storage Temperature Range              | T <sub>STG</sub> | -40 to +150 | °C   |
| Moisture Sensitivity Level<br>QFN Package      | MSL              | 1           |      |

\*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

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## ELECTRICAL CHARACTERISTICS

Unless otherwise stated:  $-40^{\circ}\text{C} < T_A < 100^{\circ}\text{C}$ ;  $V_{CC} = 5\text{ V}$ ;  $C_{VCC} = 0.1\ \mu\text{F}$

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

### ERROR AMPLIFIER

|                                |  |     |    |    |                  |
|--------------------------------|--|-----|----|----|------------------|
| Input Bias Current             | @ 1.3 V  | -21 |    | 21 | $\mu\text{A}$    |
| Open Loop DC Gain              | CL = 20 pF to GND,<br>RL = 10 k $\Omega$ to GND  |     | 80 |    | dB               |
| Open Loop Unity Gain Bandwidth | CL = 20 pF to GND,<br>RL = 10 k $\Omega$ to GND  |     | 20 |    | MHz              |
| Slew Rate                      | $\Delta V_{in} = 100\text{ mV}$ , $G = -10\text{ V/V}$ ,<br>$\Delta V_{out} = 1.5\text{ V} - 2.5\text{ V}$ ,<br>CL = 20 pF to GND,<br>DC Load = 10k to GND |     | 25 |    | V/ $\mu\text{s}$ |
| Maximum Output Voltage         | $I_{SOURCE} = 2.0\text{ mA}$   | 3.5 |    |    | V                |
| Minimum Output Voltage         | $I_{SINK} = 2.0\text{ mA}$   |     |    | 1  | V                |

### DIFFERENTIAL SUMMING AMPLIFIER

|                         |  |      |     |     |               |
|-------------------------|--|------|-----|-----|---------------|
| Input Bias Current      | VSP, CSREF = 1.3 V                                   | -12  |     | 12  | $\mu\text{A}$ |
| VSP Input Voltage Range |  | -0.3 |     | 3.0 | V             |
| VSN Input Voltage Range |  | -0.3 |     | 0.3 | V             |
| -3dB Bandwidth          | CL = 20 pF to GND,<br>RL = 10 k $\Omega$ to GND      |      | 10  |     | MHz           |
| Closed Loop DC gain     | $VS+ \text{ to } VS- = 0.5 \text{ to } 1.3\text{ V}$ |      | 1.0 |     | V/V           |

### CURRENT SUMMING AMPLIFIER

|                                    |  |      |    |     |               |
|------------------------------------|--|------|----|-----|---------------|
| Offset Voltage (Vos), (Note 3)     |  | -300 |    | 300 | $\mu\text{V}$ |
| Input Bias Current                 | CSSUM = CSREF = 1 V  | -7.5 |    | 7.5 | nA            |
| Open Loop Gain                     |  |      | 80 |     | dB            |
| Current Sense Unity Gain Bandwidth | $C_L = 20\text{ pF}$ to GND,<br>$R_L = 10\text{ k}\Omega$ to GND |      | 10 |     | MHz           |

### INPUT SUPPLY

|                       |                              |      |     |      |               |
|-----------------------|------------------------------|------|-----|------|---------------|
| Supply Voltage Range  |                              | 4.75 |     | 5.25 | V             |
| VCC Quiescent Current | EN = high, PS0, PS1 Mode     |      | 15  | 18   | mA            |
|                       | EN = high, PS3 Mode          |      | 8.0 | 12   | mA            |
|                       | EN = high, PS4 Mode (@ 25°C) |      |     | 200  | $\mu\text{A}$ |
|                       | EN = low                     |      | 50  |      | $\mu\text{A}$ |
| UVLO Threshold        | VCC rising                   |      |     | 4.5  | V             |
|                       | VCC falling                  | 4.0  |     |      | V             |
| VCC UVLO Hysteresis   |                              |      | 160 |      | mV            |
| UVLO Threshold        | VRMP rising                  |      |     | 4.1  | V             |
|                       | VRMP falling                 | 3.0  |     |      | V             |

### DAC SLEW RATE

|                      |  |  |   |  |                   |
|----------------------|--|--|---|--|-------------------|
| Soft Start Slew Rate |  |  | Fast_SR/4   |  | mV/ $\mu\text{s}$ |
| Slew Rate Slow       |  |  | Fast_SR/2<br>Fast_SR/4<br>Fast_SR/8<br>Fast_SR/16 |  | mV/ $\mu\text{s}$ |
| Slew Rate Fast       |  |  | 48  |  | mV/ $\mu\text{s}$ |

3. Guaranteed by design or characterization data, not in production test.



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## ELECTRICAL CHARACTERISTICS

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

### ENABLE INPUT

|                                   |                                       |     |    |     |               |
|-----------------------------------|---------------------------------------|-----|----|-----|---------------|
| Enable High Input Leakage Current | External 1k pull-up to 3.3 V          |     |    | 1.0 | $\mu\text{A}$ |
| Upper Threshold                   | $V_{\text{UPPER}}$                    | 0.8 |    |     | V             |
| Lower Threshold                   | $V_{\text{LOWER}}$                    |     |    | 0.3 | V             |
| Total Hysteresis                  | $V_{\text{UPPER}} - V_{\text{LOWER}}$ |     | 90 |     | mV            |

### IOU OUTPUT

|                               |  |      |    |       |               |
|-------------------------------|--|------|----|-------|---------------|
| Input Referred Offset Voltage | Ilimit to CSREF  | -5.5 |    | 5.5   | mV            |
| Output Source Current         | Ilimit sink current = 80 $\mu\text{A}$   |      |    | 850   | $\mu\text{A}$ |
| Current Gain                  | $(I_{\text{OUTCURRENT}}) / (I_{\text{LIMITCURRENT}})$ ,<br>$R_{\text{ILIM}} = 20\text{k}$ , $R_{\text{IOUT}} = 5.0\text{k}$ , DAC =<br>0.8 V, 1.25 V, 1.52 V | 9.75 | 10 | 10.25 |               |

### OSCILLATOR

|                           |  |     |  |      |     |
|---------------------------|--|-----|--|------|-----|
| Switching Frequency Range |  | 250 |  | 1200 | kHz |
|---------------------------|--|-----|--|------|-----|

### ZERO CURRENT DETECT (ZCD)

|                              |             |  |      |  |    |
|------------------------------|-------------|--|------|--|----|
| ZCD threshold, DCM detection | SW wrt PGND |  | -0.5 |  | mV |
|------------------------------|-------------|--|------|--|----|

### OUTPUT OVER VOLTAGE & UNDER VOLTAGE PROTECTION (OVP & UVP)

|   |                    |     |     |     |               |
|---|--------------------|-----|-----|-----|---------------|
| Absolute Over Voltage Threshold During Soft Start | CSREF              |     | 2.9 |     | V             |
| Over Voltage Threshold Above DAC                  | VSP rising         | 350 | 400 | 440 | mV            |
| Over Voltage Delay                                | VSP rising         |     | 50  |     | ns            |
| Under Voltage Protection                          | VCC rising         | 250 | 300 | 350 | mV            |
|   | VCC falling        | 255 | 300 | 325 | mV            |
| Under Voltage Delay                               | Ckt in development |     | 5   |     | $\mu\text{s}$ |

### OVERCURRENT PROTECTION

|  |                                      |      |    |      |               |
|--|--------------------------------------|------|----|------|---------------|
| ILIM Threshold Current (OCP shutdown after 50 $\mu\text{s}$ delay) | (PS0) Rlim = 20k                     | 9.0  | 10 | 11.0 | $\mu\text{A}$ |
| ILIM Threshold Current (immediate OCP shutdown)                    | (PS0) Rlim = 20k                     | 13.5 | 15 | 16.5 | $\mu\text{A}$ |
| ILIM Threshold Current (OCP shutdown after 50 $\mu\text{s}$ delay) | (PS1, PS2, PS3) Rlim = 20k           |      | 10 |      | $\mu\text{A}$ |
| ILIM Threshold Current (immediate OCP shutdown)                    | (PS1, PS2, PS3) Rlim = 20k, PS0 mode |      | 15 |      | $\mu\text{A}$ |

### VR\_HOT#

|                        |                                    |      |  |     |               |
|------------------------|------------------------------------|------|--|-----|---------------|
| Output Low Voltage     | $I_{\text{VRHOT}} = -4\ \text{mA}$ |      |  | 0.3 | V             |
| Output Leakage Current | High Impedance State               | -1.0 |  | 1.0 | $\mu\text{A}$ |

### TSENSE

|                            |  |     |     |     |               |
|----------------------------|--|-----|-----|-----|---------------|
| Alert# Assert Threshold    |  |     | 491 |     | mV            |
| Alert# De-assert Threshold |  |     | 513 |     | mV            |
| VRHOT Assert Threshold     |  |     | 472 |     | mV            |
| VRHOT Rising Threshold     |  |     | 494 |     | mV            |
| TSENSE Bias Current        |  | 115 | 120 | 125 | $\mu\text{A}$ |

### ADC

|               |  |   |  |   |   |
|---------------|--|---|--|---|---|
| Voltage Range |  | 0 |  | 2 | V |
|---------------|--|---|--|---|---|

3. Guaranteed by design or characterization data, not in production test.

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## ELECTRICAL CHARACTERISTICS

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

### ADC

|                                 |                         |       |         |      |               |
|---------------------------------|-------------------------|-------|---------|------|---------------|
| Total Unadjusted Error (TUE)    |                         | -1.25 |         | 1.25 | %             |
| Differential Nonlinearity (DNL) | 8-bit, no missing codes |       |         | 1    | LSB           |
| Power Supply Sensitivity        |                         |       | $\pm 1$ |      | %             |
| Conversion Time                 |                         |       | 30      |      | $\mu\text{s}$ |
| Round Robin                     |                         |       | 90      |      | $\mu\text{s}$ |

### VR\_RDY,(Power Good) Output

|                                  |  |      |     |     |               |
|----------------------------------|--|------|-----|-----|---------------|
| Output Low Saturation Voltage    | $I_{VR\_RDY} = 4\text{ mA}$  |      |     | 0.3 | V             |
| Rise Time                        | External pull-up of $1\text{ k}\Omega$ to $3.3\text{ V}$ ,<br>$C_{TOT} = 45\text{ pF}$ , $\Delta V_o = 10\%$ to $90\%$ |      | 100 |     | ns            |
| Fall Time                        | External pull-up of $1\text{ k}\Omega$ to $3.3\text{ V}$ ,<br>$C_{TOT} = 45\text{ pF}$ , $\Delta V_o = 90\%$ to $10\%$ |      | 10  |     | ns            |
| Output Voltage at Power-up       | VR_RDY pulled up to $5\text{ V}$ via $2\text{ k}\Omega$  |      |     | 1.2 | V             |
| Output Leakage Current When High | VR_RDY = $5.0\text{ V}$  | -1.0 |     | 1.0 | $\mu\text{A}$ |
| VR_RDY Delay (rising)            | DAC = TARGET to VR_RDY   |      | 50  |     | $\mu\text{s}$ |
| VR_RDY Delay (falling)           | From OCP or OVP  |      | 5   |     | $\mu\text{s}$ |

### HIGH-SIDE MOSFET DRIVER

|   |   |     |      |     |                  |
|---|---|-----|------|-----|------------------|
| Pull-up Resistance, Sourcing Current          | BST = PVCC  |     | 1.2  | 2.9 | $\Omega$         |
| High Side Driver Sourcing Current             | BST = PVCC  |     | 4.17 |     | A                |
| Pull-down Resistance, Sinking Current         | BST = PVCC  |     | 0.8  | 2.2 | $\Omega$         |
| High Side Driver Sinking Current              | BST = PVCC  |     | 6.25 |     | A                |
| HG Rise Time                                  | $V_{CC} = 5\text{ V}$ , $3\text{ nF}$ load, BST-SW = $5\text{ V}$ | 6.0 | 16   | 30  | ns               |
| HG Fall Time                                  | $V_{CC} = 5\text{ V}$ , $3\text{ nF}$ load, BST-SW = $5\text{ V}$ | 6.0 | 11   | 30  | ns               |
| DRVH Turn-Off Propagation Delay $tpdh_{DRVH}$ | $C_{LOAD} = 3\text{ nF}$  | 4.0 |      | 30  | ns               |
| HG Turn on Propagation Delay $tpdl_{DRVH}$    | $C_{LOAD} = 3\text{ nF}$  | 15  | 30   | 40  | ns               |
| SW Pull-Down Resistance                       | SW to PGND  |     | 1.9  |     | $\text{k}\Omega$ |
| LG Pull-Down Resistance                       | HG to SWBST-SW = $0\text{ V}$                                     |     | 1.9  |     | $\text{k}\Omega$ |

### LOW-SIDE MOSFET DRIVER

|  |   |     |            |     |                  |
|--|---|-----|------------|-----|------------------|
| Pull-up Resistance, Sourcing Current       |   |     | 0.9        | 3.0 | $\Omega$         |
| Low Side Driver Sourcing Current           |   |     | 5.56       |     | A                |
| Pull-down Resistance, Sinking Current      |   |     | 0.8        | 2.0 | $\Omega$         |
| Low Side Driver Sinking Current            |   |     | 12.5       |     | A                |
| LG Rise Time                               | $3\text{ nF}$ load                        | 6.0 | 16         | 30  | ns               |
| LG Fall Time                               | $3\text{ nF}$ load                        | 6.0 | 11         | 30  | ns               |
| LG Turn-On Propagation Delay $tpdh_{DRVH}$ | $C_{LOAD} = 3\text{ nF}$                  |     | 11         | 30  | ns               |
| LG Pull-Down Resistance                    | LG to PGND, $V_{CC} = 5\text{ V}$         |     | 1.9        |     | $\text{k}\Omega$ |
| PVCC Quiescent Current                     | EN = L (Shutdown)<br>EN = H, no switching |     | 1.0<br>490 |     | $\mu\text{A}$    |

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# NCP81141

## ELECTRICAL CHARACTERISTICS

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

### BOOTSTRAP RECTIFIER SWITCH

|               |                              |     |     |    |          |
|---------------|------------------------------|-----|-----|----|----------|
| On Resistance | EN_L or EN = H with DRVL = H | 5.0 | 9.0 | 22 | $\Omega$ |
|---------------|------------------------------|-----|-----|----|----------|

3. Guaranteed by design or characterization data, not in production test.

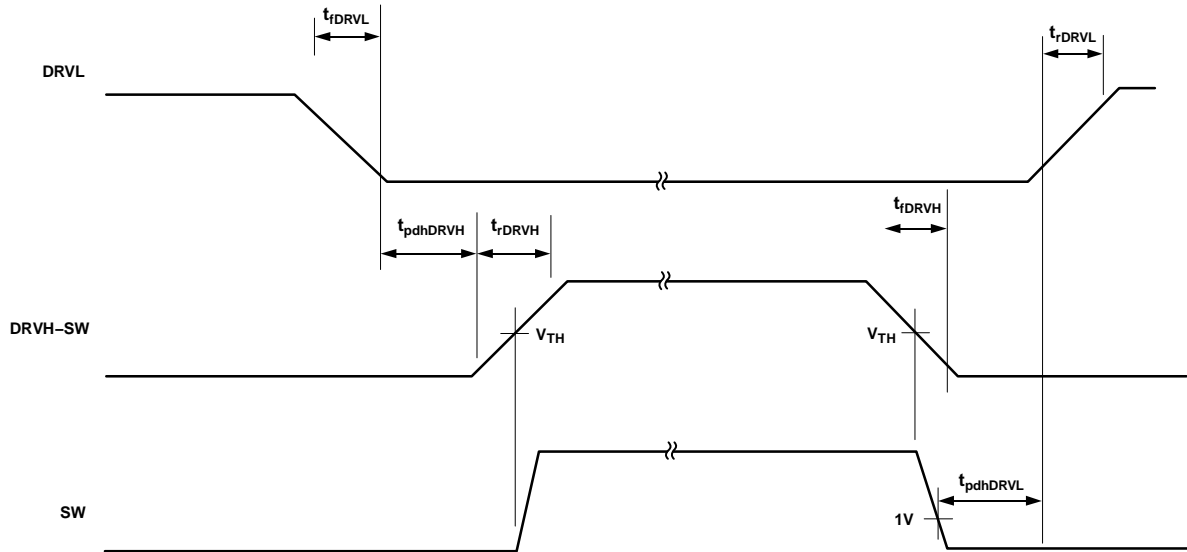


Figure 5. Driver Timing Diagram

NOTE: Timing is referenced to the 90% and the 10% points, unless otherwise stated.

# NCP81141

## STATE TRUTH TABLE

| STATE  | VR_RDY Pin   | Error AMP Comp Pin | OVP & UVP            | Method of Reset |
|--|--|--------------------|----------------------|-----------------|
| POR<br>0 < VCC < UVLO  | N/A  | N/A                | N/A                  |                 |
| Disabled<br>EN < threshold<br>UVLO >threshold                        | Low  | Low                | Disabled             |                 |
| Start up Delay &<br>Calibration<br>EN > threshold<br>UVLO >threshold | Low  | Low                | Disabled             |                 |
| Soft Start<br>EN > threshold<br>UVLO >threshold                      | Low  | Operational        | Active /<br>No latch |                 |
| Normal Operation<br>EN > threshold<br>UVLO >threshold                | High   | Operational        | Active /<br>Latching | N/A             |
| Over Voltage   | Low  | N/A                | DAC + 150 mV         |                 |
| Over Current   | Low  | Operational        | Last DAC Code        |                 |
| V <sub>OUT</sub> = 0 V   | Low: if Reg34h.bit0 = 0;<br>High:if Reg34h.bit0 = 1; | Clamped at 0.9 V   | Disabled             |                 |

### General

The NCP81141 is a single phase PWM controller with integrated driver, designed to meet the Intel VR12.6 specifications with a serial SVID control interface. It is designed to work in notebook and desktop applications.

The NCP81141 has one internal Driver: DRV1. Internally, there is a single PWM signal: PWM1. DRV1 is driven by PWM1.

## Serial VID interface (SVID)

For SVID Interface communication details please contact Intel Inc.

## BOOT VOLTAGE PROGRAMMING

The NCP81141 has a Vboot voltage that can be externally programmed. The Boot voltage for the NCP81141 is set using VBOOT pin on power up. A 10uA current is sourced from the VBoot pin and the resulting voltage is measured. This is compared with the thresholds in table below. This value is programmed on power up and cannot be changed after the initial power up sequence is complete.

**BOOT VOLTAGE TABLE**

| R     | Vboot  |
|-------|--------|
| 30.1k | 0 V    |
| 49.9k | 1.65 V |
| 69.8k | 1.70 V |
| 90.9k | 1.75 V |

## REMOTE SENSE AMPLIFIER

A high performance high input impedance true differential amplifier is provided to accurately sense the output voltage of the regulator. The VSP and VSN inputs should be connected to the regulator's output voltage sense points. The remote sense amplifier takes the difference of the output voltage with the DAC voltage and adds the droop voltage to

$$V_{DIFOUT} = (V_{VSP} - V_{VSN}) + (1.3\text{ V} - V_{DAC}) + (V_{DROOP} - V_{CSREF})$$

This signal then goes through a standard error compensation network and into the inverting input of the error amplifier. The non-inverting input of the error amplifier is connected to the same 1.3 V reference used for the differential sense amplifier output bias.

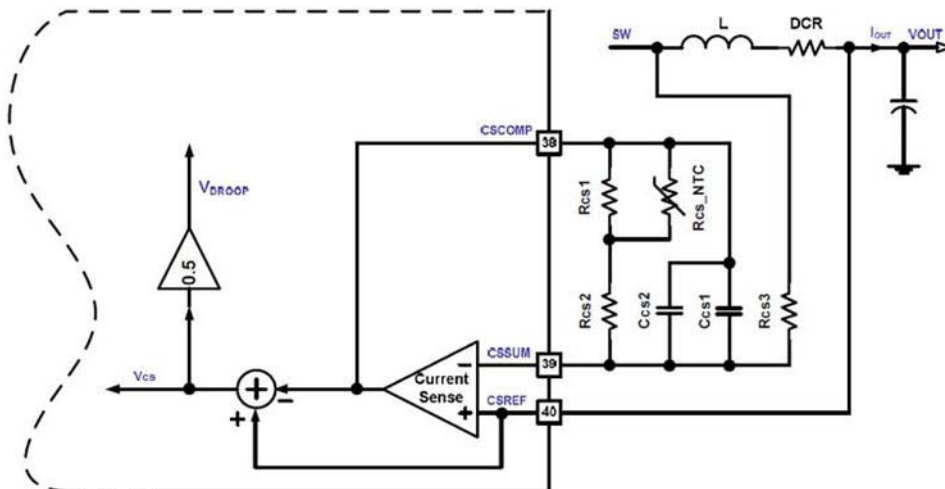
## REMOTE SENSE AMPLIFIER

The differential current-sense circuit diagram is shown in figure below. An internally-used signal Vcs, representing the inductor current level, is the voltage difference between CSREF and CSCOMP. The output side of the inductor is used to create a low impedance virtual ground. The current-sense amplifier actively filters and gains up the voltage applied across the inductor to recover the voltage drop across the inductor's DC resistance(DCR). RCS\_NTC is placed close to the inductor and compensate for the change in the DCR with temperature.

The DC gain in the current sensing loop is

$$GCS = \frac{VCS}{VDCR} = \frac{(VCSREF - VSCOMP)}{(I_{out} \times DCR)} = \frac{RCS}{RCS3}$$

$$RCS = RCS2 + \frac{(RCS1 \times RCS\_NTC)}{(RCS1 + RCS\_NTC)}$$



**Figure 6. Differential Current-Sense Circuit diagram**

## High Performance Voltage Error Amplifier

A high performance error amplifier is provided for high bandwidth transient performance. A standard type 3 compensation circuit is normally used to compensate the system.

## Current Sense Amplifier

The output current signal is floating with respect to CSREF. The current signal is the difference between CSCOMP and CSREF. The output side of the inductor is used to create a low impedance virtual ground. The amplifier actively filters and gains up the voltage applied across the inductor to recover the voltage drop across the inductor series resistance (DCR). Rth is placed near the inductor to sense the temperature of the inductor. This allows the filter time constant and gain to be a function of the Rth NTC resistor and compensate for the change in the DCR with temperature.

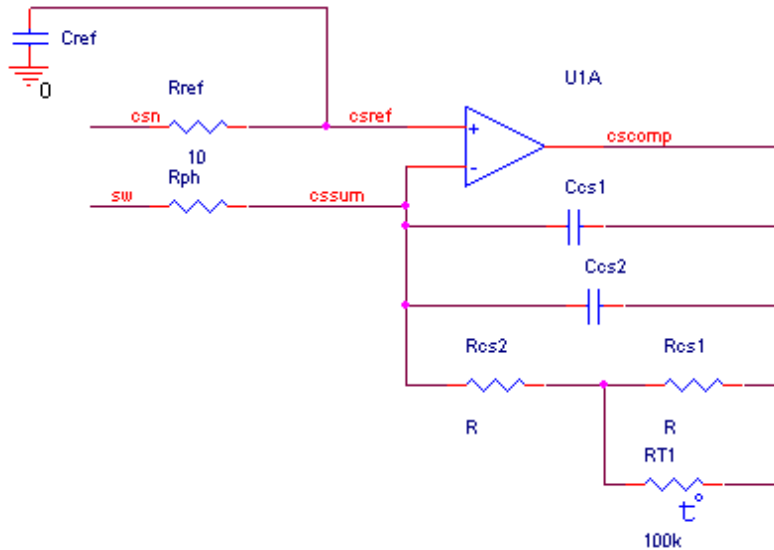


Figure 7. Current Sense Amplifier

The DC gain equation for the current sensing:

$$V_{\text{CSCOMP-CSREF}} = - \frac{R_{\text{cs2}} + \frac{R_{\text{cs1}} \cdot R_{\text{th}}}{R_{\text{cs1}} + R_{\text{th}}}}{R_{\text{ph}}} * (\text{Iout}_{\text{Total}} * \text{DCR})$$

Set the gain by adjusting the value of the Rph resistor. The DC gain should be set to the output voltage droop. If the voltage from CSCOMP to CSREF is less than 100 mV at ICCMAX then it is recommend increasing the gain of the CSCOMP amp. This is required to provide a good current signal to offset voltage ratio for the ILIMIT pin. When no droop is needed, the gain of the amplifier should be set to provide ~100 mV across the current limit programming resistor at full load. The values of Rcs1 and Rcs2 are set based on the 100k NTC and the temperature effect of the inductor and should not need to be changed. The NTC should be placed close to the inductor.

The pole frequency in the CSCOMP filter should be set equal to the zero from the output inductor. This allows the circuit to recover the inductor DCR voltage drop current signal. Ccs1 and Ccs2 are in parallel to allow for fine tuning of the time constant using commonly available values. It is best to fine tune this filter during transient testing.

$$F_z = \frac{\text{DCR}@25^\circ\text{C}}{2 * \text{PI} * L_{\text{Phase}}}$$

## PROGRAMMING CURRENT LIMIT

The current limit thresholds are programmed with a resistor between the ILIMIT and CSCOMP pins. The ILIMIT pin mirrors the voltage at the CSREF pin and mirrors the sink current internally to IOUT (reduced by the IOUT Current Gain) and the current limit comparators. The 100% current limit trips if the ILIMIT sink current exceeds 10 μA for 50 μs. The 150% current limit trips with minimal delay if the ILIMIT sink current exceeds 15 μA. Set the value of the current limit resistor based on the CSCOMP–CSREF voltage as shown below. Note the loadline is set at 50% of cscomp/csref differential.

# NCP81141

$$R_{LIMIT} = \frac{\left( 2 * \frac{R_{cs} + \frac{R_{cs1} * R_{th}}{R_{cs1} + R_{th}}}{R_{ph}} * (I_{out\_LIMIT} * DCR) \right)}{10\mu} \text{ or } R_{LIMIT} = \frac{(2 * V_{CSCOMP-CSREF@ILIMIT})}{10\mu}$$

## PROGRAMMING IOUT

The IOUT pin sources a current in proportion to the ILIMIT sink current. The voltage on the IOUT pin is monitored by the internal A/D converter and should be scaled with an external resistor to ground such that a load equal to ICCMAX generates a 2 V signal on IOUT. A pull-up resistor from 5 V VCC can be used to offset the IOUT signal positive if needed.

$$R_{IOUT} = \frac{2.0 V * R_{LIMIT}}{10 * \left( \frac{R_{cs2} + \frac{R_{cs1} * R_{th}}{R_{cs1} + R_{th}}}{R_{ph}} * (I_{out\_ICC\_MAX} * DCR) * 2 \right)}$$

## PROGRAMMING ICC\_MAX

A resistor to Ground is monitored on startup and this sets the ICC\_MAX value. 10 μA is sourced from these pins to generate a voltage on the program resistor. The resistor value should be no less than 10k.

$$ICC\_MAX = \frac{R * 10 \mu A * 64 A}{2 V}$$

## PROGRAMMING TSENSE

A temperature sense inputs are provided. A precision current is sourced out the output of the TSENSE pin to generate a voltage on the temperature sense network. The voltage on the temperature sense input is sampled by the internal A/D converter. A 100k NTC similar to the VISHAY ERT-J1VS104JA should be used. Rcomp1 is mainly used for noise. See the specification table for the thermal sensing voltage thresholds and source current.

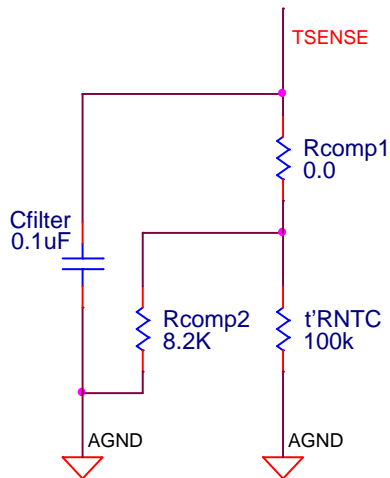
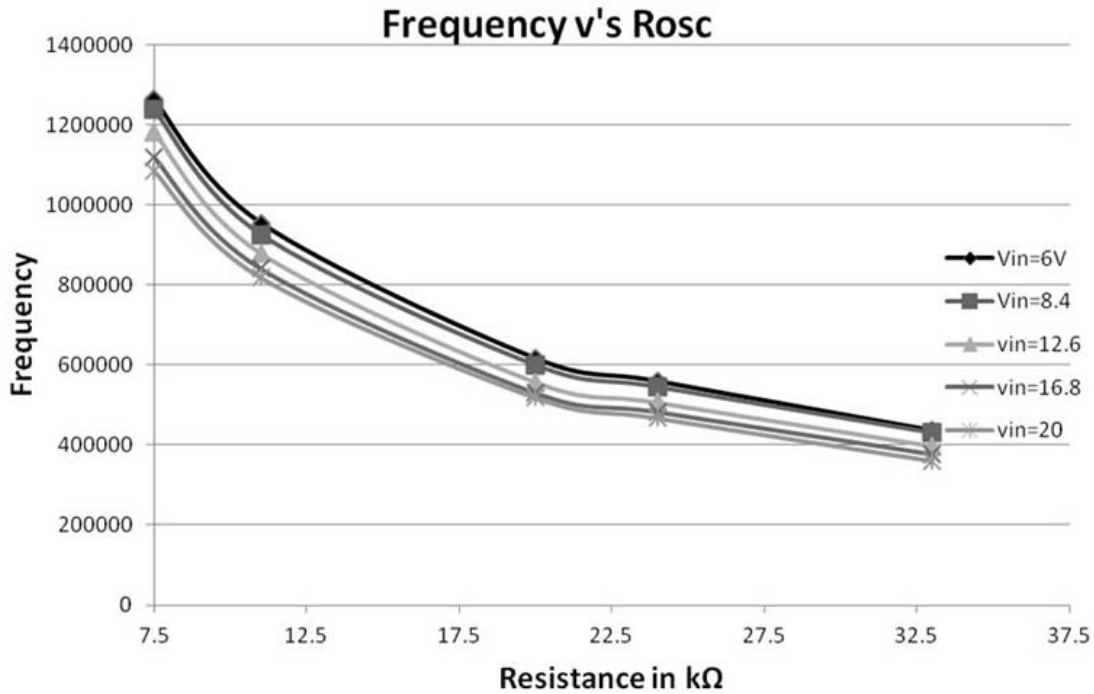


Figure 8. TSENSE Circuit

**PRECISION OSCILLATOR**

Switching frequency is programmed by a resistor  $R_{osc}$  to ground at the  $R_{osc}$  pin. The typical frequency range is from 500 kHz to 1.2 MHz. The  $FREQ$  pin provides approximately 2 V out and the source current is mirrored into the internal ramp generator. The switching frequency can be found in figure below with a given  $R_{osc}$ . The frequency shown in the figure is under condition of 10 A output current at  $VID = 1.8$  V. The frequency has a variation over  $VID$  voltage and loading current, which maintains similar output ripple voltage over different operation condition.



**Figure 9. Operating Frequency vs.  $R_{osc}$**

The oscillator generates a triangular ramp that is 0.5 ~ 2.5 V in amplitude depending on the  $VRMP$  pin voltage to provide input voltage feed forward compensation.



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## Programming the Ramp Feed-Forward Circuit

The ramp generator circuit provides the ramp used by the PWM comparators. The ramp generator provides voltage feed-forward control by varying the ramp magnitude with respect to the VRMP pin voltage. The VRMP pin also has a 3.2 V UVLO function. The VRMP UVLO is only active after the controller is enabled. The VRMP pin is high impedance input when the controller is disabled.

The PWM ramp time is changed according to the following

$$V_{\text{RAMppk}} = \text{pk}_{\text{pp}} = 0.1 \times V_{\text{VRMP}}$$

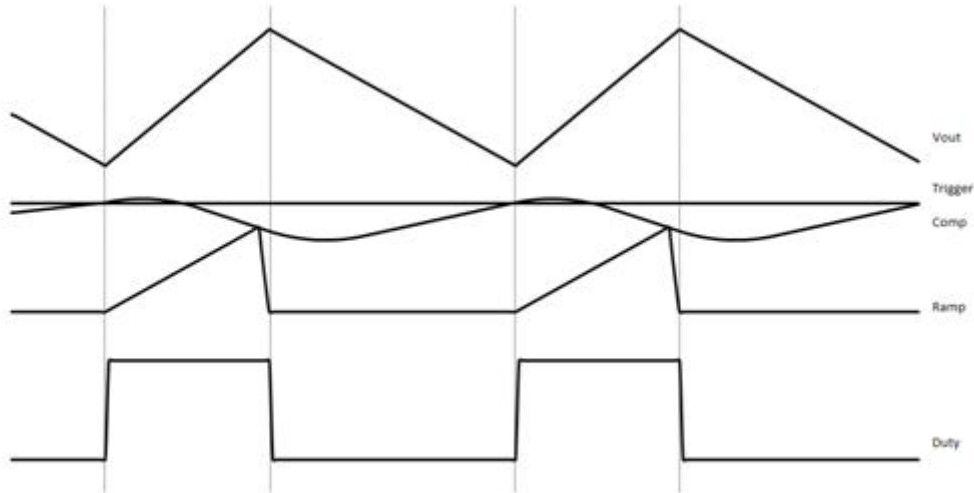


Figure 10. RPM Mode

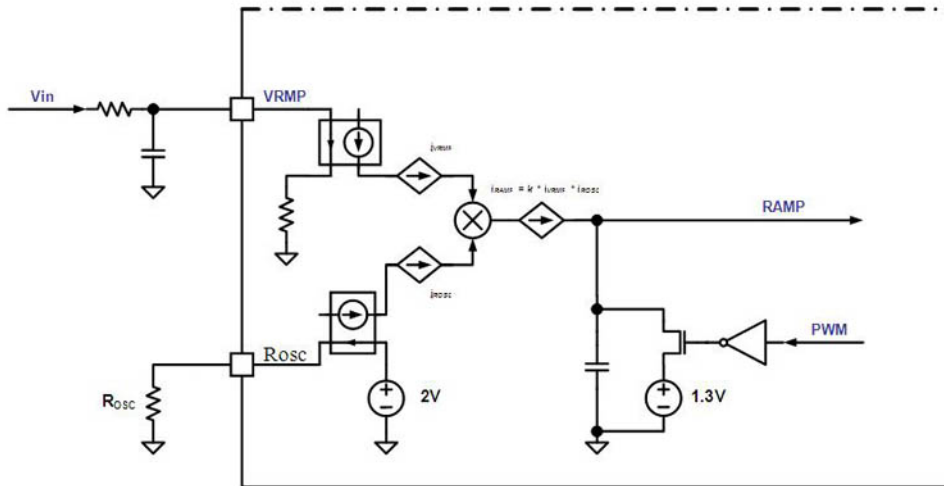
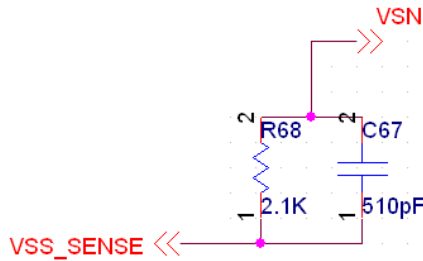


Figure 11. Ramp Feed Forward & ROSC setup

# NCP81141

## Programming DAC Feed-Forward Filter

The DAC feed-forward implementation is realized by having a filter on the VSN pin. Programming Rvsn sets the gain of the DAC feed-forward and Cvsn provides the time constant to cancel the time constant of the system per the following equations. Cout is the total output capacitance and Rout is the output impedance of the system.



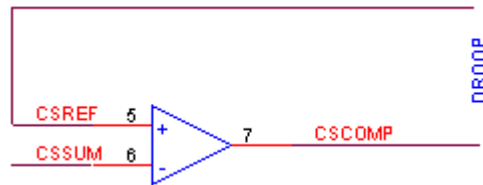
$$R_{vsn} = C_{out} * R_{out} * 453.6 \times 10^6$$

$$C_{vsn} = \frac{R_{out} * C_{out}}{R_{vsn}}$$

Figure 12. DAC Feed-Forward Filter

## Programming DROOP

The signals CSCOMP and CSREF are differentially summed with the output voltage feedback to add precision voltage droop to the output voltage.



$$\text{Droop} = \text{DCR} * \left( \frac{R_{CS}}{R_{ph}} \right)$$

Figure 13. Droop

## Phase COMPARITOR

The noninverting input of the comparator for phase one is connected to the output of the error amplifier (COMP) and the phase current ( $I_L * \text{DCR} * \text{Phase Balance Gain Factor}$ ). The inverting input is connected to the oscillator ramp voltage with a 1.3 V offset. The operating input voltage range of the comparator is from 0 V to 3.0 V and the output of the comparator generates the PWM signal which is applied to the input of the internal driver.

During steady state operation, the duty cycle is centered on the valley of the sawtooth ramp waveform. The steady state duty cycle is still calculated by approximately  $V_{out}/V_{in}$ .

## Protection Features

### UNDERVOLTAGE LOCKOUT

There are several under voltage monitors in the system. Hysteresis is incorporated within the comparators. NCP81141 monitors the VCC Shunt supply. The gate driver monitors both the gate driver  $V_{CC}$  and the BST voltage.

### SOFT START

Soft start is implemented internally. A digital counter steps the DAC up from zero to the target voltage based on the predetermined rate in the spec table.

### OVER CURRENT LATCH-OFF PROTECTION

The NCP81141 compares a programmable current-limit set point to the voltage from the output of the current-summing amplifier. The level of current limit is set with the resistor from the ILIM pin to CSCOMP. The current through the external resistor connected between ILIM and CSCOMP is then compared to the internal current limit current  $I_{CL}$ . If the current generated through this resistor into the ILIM pin (Ilim) exceeds the internal current-limit threshold current (ICL), an internal latch-off counter starts, and the controller shuts down if the fault is not removed after 50  $\mu$ s (shut down immediately for 150% load current) after which the outputs will remain disabled until the  $V_{CC}$  voltage or EN is toggled.

# NCP81141

The voltage swing seen on CSCOMP cannot go below ground. This limits the voltage drop across the DCR. The over-current limit is programmed by a resistor on the ILIM pin. The resistor value can be calculated by the following equation:

$$R_{ILIM} = \frac{(I_{LIM} * DCR * R_{CS} / R_{PH}) * 2}{I_{CL}}$$

Where  $I_{CL} = 10 \mu A$ .

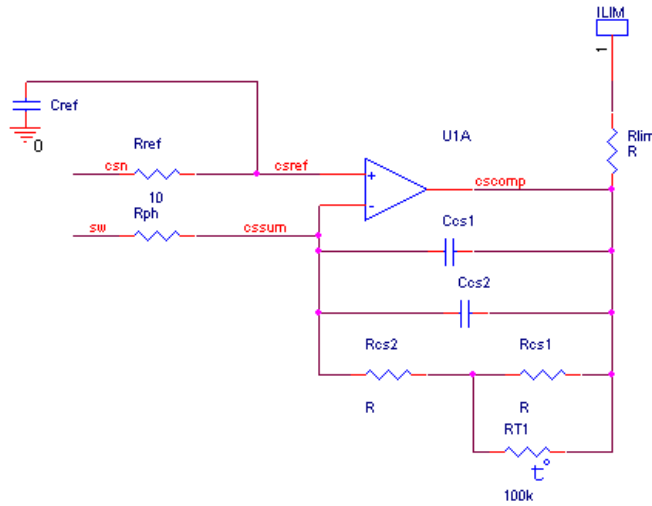


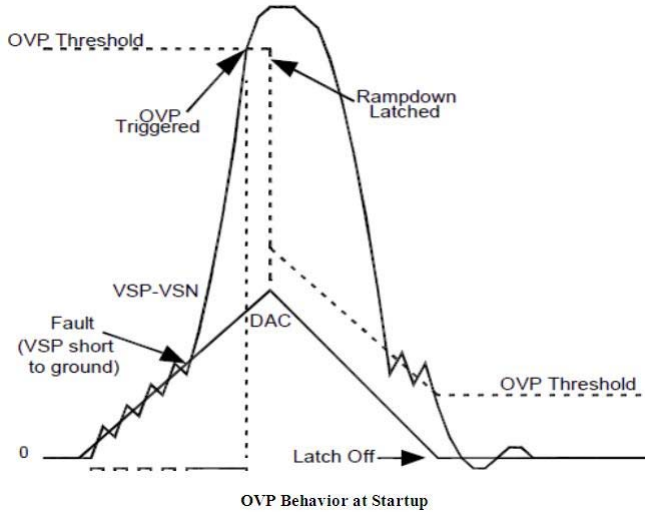
Figure 14. Current Limit

## UNDER VOLTAGE MONITOR

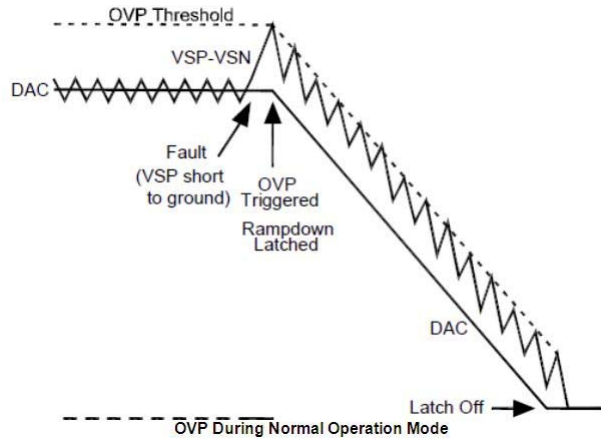
The output voltage is monitored at the output of the differential amplifier for UVLO. If the output falls more than 300 mV below the DAC-DROOP voltage the UVLO comparator will trip sending the VR\_RDY signal low.

**OVER VOLTAGE PROTECTION**

The output voltage is also monitored at the output of the differential amplifier for OVP. During normal operation, if the output voltage exceeds the DAC voltage by 400 mV, the VR\_RDY flag goes low, and the DAC will be ramped down slowly. At the same time, the high side gate driver is turned off and the low side gate driver is turned on until the voltage falls to 100 mV. The part will stay in this mode until the V<sub>CC</sub> voltage or EN is toggled. During start up, the OVP threshold is set to 2.9 V. This allows the controller to start up without false triggering the OVP.



**Figure 15. OVP Behavior at Startup**



**Figure 16. OVP During Normal Operation Mode**

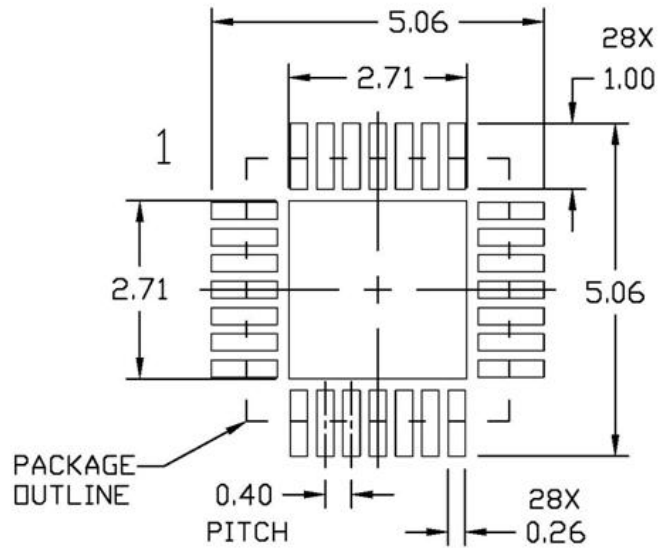
During start up, the OVP threshold is set to 2.2 V. This allows the controller to start up without false triggering the OVP.

# NCP81141

## ORDERING INFORMATION

| Device        | Package            | Shipping†          |
|---------------|--------------------|--------------------|
| NCP81141MNTWG | QFN28<br>(Pb-Free) | 4000 / Tape & Reel |
| NCP81141MNTXG | QFN28<br>(Pb-Free) | 4000 / Tape & Reel |

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



(Not to scale)

**Figure 17. Alternative Extended Soldering Footprint**

ON Semiconductor claims no responsibility for damage or usage beyond that of specific recommended soldering footprint

# MECHANICAL CASE OUTLINE

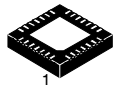
## PACKAGE DIMENSIONS

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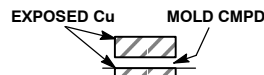
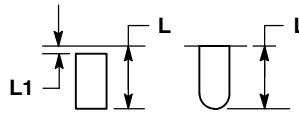
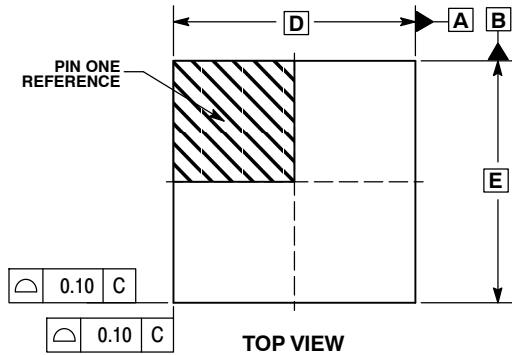


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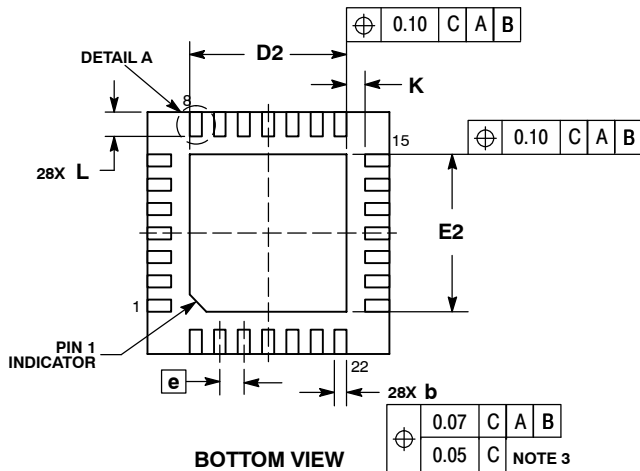
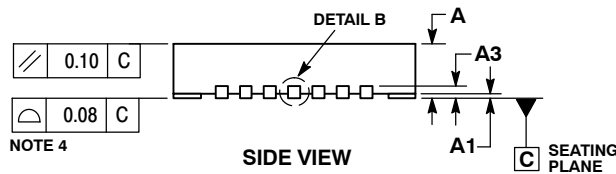
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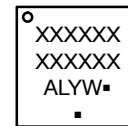
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1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
3. DIMENSION b APPLIES TO PLATED TERMINAL AND IS MEASURED BETWEEN 0.15 AND 0.30 MM FROM THE TERMINAL TIP.
4. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.

| MILLIMETERS |          |      |
|-------------|----------|------|
| DIM         | MIN      | MAX  |
| A           | 0.80     | 1.00 |
| A1          | 0.00     | 0.05 |
| A3          | 0.20 REF |      |
| b           | 0.15     | 0.25 |
| D           | 4.00 BSC |      |
| D2          | 2.50     | 2.70 |
| E           | 4.00 BSC |      |
| E2          | 2.50     | 2.70 |
| e           | 0.40 BSC |      |
| K           | 0.30 REF |      |
| L           | 0.30     | 0.50 |
| L1          | ---      | 0.15 |



**GENERIC MARKING DIAGRAM\***

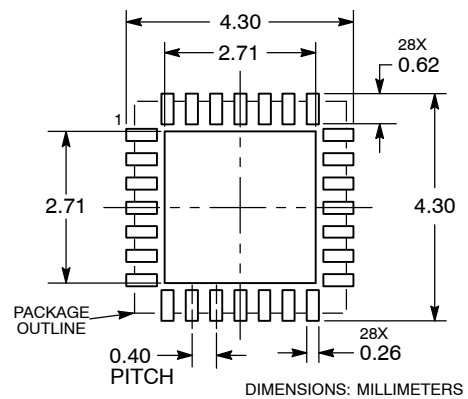


- XXXXX = Specific Device Code
- A = Assembly Location
- L = Wafer Lot
- Y = Year
- W = Work Week
- = Pb-Free Package

(Note: Microdot may be in either location)

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


**RECOMMENDED MOUNTING FOOTPRINT**



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| <b>DESCRIPTION:</b>     | QFN28 4X4, 0.4P           | <b>PAGE 1 OF 2</b>   |



| ISSUE | REVISION   | DATE        |
|-------|--|-------------|
| O     | RELEASED FOR PRODUCTION. REQ. BY M. LIN.   | 15 MAY 2008 |
| A     | CHANGED DIMENSIONS D2, E2, K, L, MOUNTING FOOTPRINT AND MARKING DIAGRAM INFORMATION. REQ. BY J. LIU. | 20 NOV 2009 |
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