

# NCP1654

## Product Preview

# Power Factor Controller for Compact and Robust, Continuous Conduction Mode Pre-Converters

The NCP1654 is a controller for Continuous Conduction Mode (CCM) Power Factor Correction step-up pre-converters. It controls the power switch conduction time (PWM) in a fixed frequency mode and in dependence on the instantaneous coil current.

Housed in a DIP8 or SO8 package, the circuit minimizes the number of external components and drastically simplifies the PFC implementation. It also integrates high safety protection features that make the NCP1654 a driver for robust and compact PFC stages like an effective input power runaway clamping circuitry.

### Features

- IEC1000-3-2 Compliant
- Average Current Continuous Conduction Mode
- Fast Transient Response
- Very Few External Components
- Very Low Startup Currents (<75  $\mu$ A)
- Very Low Shutdown Currents (< 400  $\mu$ A)
- Low Operating Consumption
- $\pm 1.5$  A Totem Pole Gate Drive
- Accurate Fully Integrated 65 kHz Oscillator
- Latching PWM for cycle-by-cycle Duty-Cycle Control
- Internally Trimmed Internal Reference
- 2 versions of Undervoltage Lockout with Hysteresis
- Soft-Start for Smoothly Startup Operation (B version only)
- Shutdown Function

### Safety Features

- Inrush Currents Detection
- Overvoltage Protection
- Undervoltage Detection for Open Loop Detection (shutdown)
- Brown-Out Detection
- Soft-Start
- Accurate Overcurrent Limitation
- True Overpower Limitation

### Typical Applications

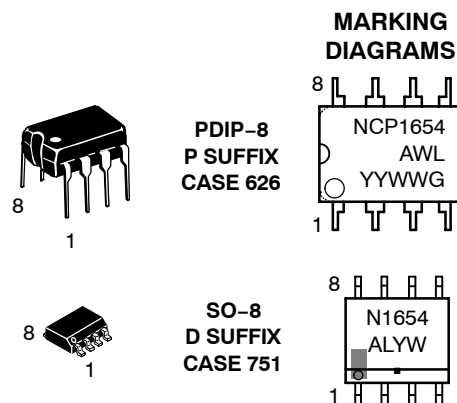
- TV, Monitors, PC Desktop SMPS
- AC Adapters SMPS
- White Goods, other Off-line SMPS

This document contains information on a product under development. ON Semiconductor reserves the right to change or discontinue this product without notice.



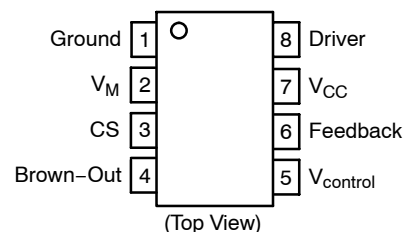
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<http://onsemi.com>



NCP1654,  
N1654 = Device Code  
A = Assembly Location  
WL, L = Wafer Lot  
YY, Y = Year  
WW, W = Work Week  
▪ or G = Pb-Free Package

### PIN CONNECTIONS



### ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 8 of this data sheet.

# NCP1654

**Maximum Ratings Table**

Symbol	Pin	Rating	Value	Unit
DRV	8	Output Drive Capability – Source Output Drive Capability – Sink	-1.5 +1.5	A
V <sub>CC</sub>	7	Power Supply voltage, V <sub>CC</sub> pin, continuous voltage	-0.3, +20	V
	7	Transient Power Supply voltage, duration < 10 ms, I <sub>VCC</sub> < 10 mA	+25	V
V <sub>in</sub>	2, 3, 4, 5, 6	Input Voltage	-0.3, +10	V
P <sub>D</sub> (DIP) R <sub>θJA</sub> (DIP)		Power Dissipation and Thermal Characteristics P suffix, Plastic Package, Case 626 Maximum Power Dissipation @ T <sub>A</sub> = 70°C Thermal Resistance Junction-to-Air	800 100	mW °C/W
P <sub>D</sub> (SO) R <sub>θJA</sub> (SO)		D suffix, Plastic Package, Case 751 Maximum Power Dissipation @ T <sub>A</sub> = -70°C Thermal Resistance Junction to Air	450 178	mW °C/W
T <sub>J</sub>		Operating Junction Temperature Range	-40 to +125	°C
T <sub>Jmax</sub>		Maximum Junction Temperature	150	°C
T <sub>Smax</sub>		Storage Temperature Range	-65 to +150	°C
T <sub>Lmax</sub>		Lead Temperature (Soldering, 10 s)	300	°C

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.

- This device series contains ESD protection and exceeds the following tests:  
Pins 1 – 8: Human Body Model 2000 V per MIL-STD-883, Method 3015.  
Machine Model Method 200 V (except pin#7 which complies 150 V)
- This device contains Latch-up Protection and exceeds ±100 mA per JEDEC Standard JESD78.

# NCP1654

**Typical Electrical Characteristics Table** ( $V_{CC} = 15\text{ V}$ ,  $T_J$  from  $-40^\circ\text{C}$  to  $+125^\circ\text{C}$ , unless otherwise specified) (Note 3)

Symbol	Rating	Min	Typ	Max	Unit
<b>GATE DRIVE SECTION</b>					
R <sub>source</sub>	Source Resistance @ I <sub>pin8</sub> = 100 mA	–	9	20	Ω
R <sub>sink</sub>	Sink Resistance @ I <sub>pin8</sub> = –100 mA	–	6.6	18	Ω
T <sub>rise</sub>	Gate Drive Voltage Rise Time from 1.5 V to 13.5 V (C <sub>L</sub> = 2.2 nF)	–	60	–	ns
T <sub>fall</sub>	Gate Drive Voltage Fall Time from 13.5 V to 1.5 V (C <sub>L</sub> = 2.2 nF)	–	40	–	ns
<b>REGULATION BLOCK</b>					
V <sub>ref</sub>	Voltage Reference	2.425	2.5	2.575	V
I <sub>EA</sub>	Error Amplifier Current Capability	–	±20	–	μA
G <sub>EA</sub>	Error Amplifier Gain	100	200	300	μS
I <sub>Bpin6</sub>	Pin 6 Bias Current @ V <sub>FB</sub> = V <sub>ref</sub>	–500	–	500	nA
V <sub>control</sub>	Pin5 Voltage	–	3.7	–	V
V <sub>control(max)</sub>	Maximum Control Voltage @ V <sub>FB</sub> = 2 V	–	0.7	–	
V <sub>control(min)</sub>	Minimum Control Voltage @ V <sub>FB</sub> = 3 V	2.7	3	3.3	
ΔV <sub>control</sub>					
V <sub>outL</sub> / V <sub>ref</sub>	Ratio (V <sub>out</sub> Low Detect Threshold / V <sub>ref</sub> )	94	95	96	%
H <sub>outL</sub> / V <sub>ref</sub>	Ratio (V <sub>out</sub> Low Detect Hysteresis / V <sub>ref</sub> )	–	0.5	–	%
I <sub>BOOST</sub>	Pin 5 Source Current when (V <sub>out</sub> Low Detect) is activated	180	220	250	μA
<b>CURRENT SENSE BLOCK</b>					
V <sub>S</sub>	Current Sense Pin Offset Voltage, (I <sub>CS</sub> = 100 μA)	–	10	–	mV
I <sub>S(OCP)</sub>	Over-Current Protection Threshold	185	200	215	μA
<b>POWER LIMITATION BLOCK</b>					
I <sub>CS</sub> × I <sub>lin</sub>	Over Power Limitation Threshold $\left( = I_{CS} \times \frac{V_{BO}}{2 \times R} \right)$	–	4	–	nA <sup>2</sup>
I <sub>CS(OPL1)</sub>	Over-Power Current Threshold (V <sub>BO</sub> = 0.9 V, V <sub>M</sub> = 3 V)	174	222	308	μA
I <sub>CS(OPL2)</sub>	Over-Power Current Threshold (V <sub>BO</sub> = 2.67 V, V <sub>M</sub> = 3 V)	56	75	110	μA
<b>PWM BLOCK</b>					
D <sub>cycle</sub>	Duty Cycle Range		0–97		%
<b>OSCILLATOR / RAMP GENERATOR BLOCK</b>					
F <sub>sw</sub>	Switching Frequency	58	65	72	kHz
<b>BROWN-OUT DETECTION BLOCK</b>					
V <sub>BOH</sub>	Brown-Out Voltage Threshold (rising)	TBD	1.3	TBD	V
V <sub>BO-L</sub>	Brown-Out Voltage Threshold (falling)	0.65	0.7	0.75	V
I <sub>IB</sub>	Pin 4 Input Bias Current @ V <sub>BO</sub> = 1 V	–500	–	500	nA
<b>CURRENT MODULATION BLOCK</b>					
I <sub>M1</sub>	Multiplier Output Current (V <sub>control</sub> = V <sub>control(max)</sub> , V <sub>BO</sub> = 0.9 V, I <sub>CS</sub> = 25 μA)	0.7	1.9	3.8	μA
I <sub>M2</sub>	Multiplier Output Current (V <sub>control</sub> = V <sub>control(max)</sub> , V <sub>BO</sub> = 0.9 V, I <sub>CS</sub> = 75 μA)	2.1	5.6	10.3	
I <sub>M3</sub>	Multiplier Output Current (V <sub>control</sub> = V <sub>control(min)</sub> + 0.2 V, V <sub>BO</sub> = 0.9 V, I <sub>CS</sub> = 25 μA)	8.3	28.1	46.4	
I <sub>M4</sub>	Multiplier Output Current (V <sub>control</sub> = V <sub>control(min)</sub> + 0.2 V, V <sub>BO</sub> = 0.9 V, I <sub>CS</sub> = 75 μA)	24.2	84.4	146	
<b>OVER-VOLTAGE PROTECTION</b>					
V <sub>OVP</sub> / V <sub>ref</sub>	Ratio (Over Voltage Threshold / V <sub>ref</sub> )	103	105	107	%
T <sub>OVP</sub>	Propagation Delay (V <sub>FB</sub> – 107% V <sub>ref</sub> ) to Drive Low	–	500	–	ns

3. The above specification gives the targeted values of the parameters. The final specification will be available once the complete circuit characterization has been performed.

# NCP1654

**Typical Electrical Characteristics Table** ( $V_{CC} = 15\text{ V}$ ,  $T_J$  from  $-40^\circ\text{C}$  to  $+125^\circ\text{C}$ , unless otherwise specified) (Note 3)

Symbol	Rating	Min	Typ	Max	Unit
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## UNDER-VOLTAGE PROTECTION / SHUTDOWN

$V_{UVP(on)}/V_{ref}$	UVP Activate Threshold Ratio ( $T_J = 0^\circ\text{C}$ to $+105^\circ\text{C}$ )	4	8	12	%
$V_{UVP(off)}/V_{ref}$	UVP Deactivate Threshold Ratio ( $T_J = 0^\circ\text{C}$ to $+105^\circ\text{C}$ )	6	12	18	%
$V_{UVP(H)}$	UVP Lockout Hysteresis	–	4	–	%
$T_{UVP}$	Propagation Delay ( $V_{FB} < 8\% V_{ref}$ ) to Drive Low	–	500	–	ns

## THERMAL SHUTDOWN

$T_{limit}$	Thermal Shutdown Threshold	150	–	–	$^\circ\text{C}$
$H_{temp}$	Thermal Shutdown Hysteresis	–	30	–	$^\circ\text{C}$

## $V_{CC}$ UNDER-VOLTAGE LOCKOUT SECTION

$V_{stup}$	Start-Up Threshold (Under-Voltage Lockout Threshold, $V_{CC}$ rising) – Version A – Version B	12.5 9.6	13.75 10.5	15 11.4	V
$V_{disable}$	Disable Voltage after Turn-On (Under-Voltage Lockout Threshold, $V_{CC}$ falling) Version A & B	8.25	9	9.75	V
$H_{UVLO}$	Under-Voltage Lockout Hysteresis – Version A – Version B	4 1	4.75 1.5	– –	V

## DEVICE CONSUMPTION

	Power Supply Current:				
$I_{cc\_stup}$	Start-Up (@ $V_{CC} = 12.4\text{ V}$ , version A and $V_{CC} = 9.4\text{ V}$ , version B)	–	–	75	$\mu\text{A}$
$I_{cc\_op1}$	Operating (@ $V_{CC} = 15\text{ V}$ , no load, no switching)	–	3.7	5	mA
$I_{cc\_op2}$	Operating (@ $V_{CC} = 15\text{ V}$ , no load, switching)	–	4.7	6	mA
$I_{cc\_stdwn}$	Shutdown Mode (@ $V_{CC} = 15\text{ V}$ and $V_{FB} = 0\text{ V}$ )	–	300	400	$\mu\text{A}$

3. The above specification gives the targeted values of the parameters. The final specification will be available once the complete circuit characterization has been performed.

NOTE:  $I_M = \frac{I_{cs} \times I_{in}}{2 \times I_{control}}$ ,  $I_{in} = \frac{V_{BO}}{2 \times R}$ ,  $I_{control} = \frac{V_{control} - V_f}{R}$

# NCP1654

## Detailed Pin Description(s)

Pin Number	Name	Function
6	Feed-Back / Shutdown	<p>This pin receives a feedback signal <math>V_{FB}</math> that is proportional to the PFC circuits output voltage. This information is used for both the output regulation, the over-voltage protection (OVP), and output undervoltage protection (UVP).</p> <p>When <math>V_{FB}</math> goes above 105% <math>V_{ref}</math>, OVP is activated and the Drive Output is disabled.</p> <p>When <math>V_{FB}</math> goes below 8% <math>V_{ref}</math>, the device enters a low-consumption shutdown mode.</p>
5	Vcontrol / Soft-Start	<p>The voltage of this pin <math>V_{control}</math> directly controls the input impedance and hence the power factor of the circuit. This pin is connected to an external capacitor <math>C_{control}</math> to limit the <math>V_{control}</math> bandwidth typically below 20 Hz to achieve near unity power factor.</p> <p>The device provides no output when <math>V_{control} &lt; 0.7</math> V.</p> <p><math>V_{control}</math> is grounded when the circuits is off.</p> <p>In B version, when it starts to operate, <math>V_{control}</math> raises slowly by inside 20 <math>\mu</math>A current source after <math>V_{FB}</math> is higher than 95% of <math>V_{ref}</math>, which obtains a linear control of the increasing duty cycle as a function of time. Hence reduce the voltage and current stress on the MOSFET. Soft Start function is achieved.</p> <p>In A version, when it starts to operate, <math>V_{control}</math> raises rapidly by inside 200 <math>\mu</math>A current source. It is to boost the PFC output in a short time before the operation of the converter behind the PFC stage.</p>
4	Brown-Out / In	<p>Connect a resistor network among the rectified input voltage, pin4, and ground. And connect a capacitor between pin4 and ground. Pin4 detects a voltage signal proportional to the average input voltage.</p> <p>When <math>V_{BO}</math> goes below 0.7 V, the circuit that detects too low input voltage conditions (brown-out), turns off the output driver and keeps it in low state till <math>V_{BO}</math> exceeds 1.3 V (0.6 V hysteresis).</p> <p>This signal which is proportional to the RMS input voltage <math>V_{ac}</math> is also for over-power limitation (OPL) and PFC duty cycle modulation. When the product</p> $I_{CS} \times \frac{V_{BO}}{2 \times R} > 4nA^2,$ <p>OPL is activated and the Drive Output duty ratio is reduced by pulling down <math>V_{control}</math> indirectly to reduce the input power.</p>
3	Current Sense Input	<p>This pin sources a current <math>I_{CS}</math> which is proportional to the inductor current <math>I_L</math>. The sense current <math>I_{CS}</math> is for over-current protection (OCP), over-power limitation (OPL) and PFC duty cycle modulation. When <math>I_{CS}</math> goes above 200 <math>\mu</math>A, OCP is activated and the Drive Output is disabled.</p>
2	Multiplier Voltage	<p>This pin provides a voltage <math>V_M</math> for the PFC duty cycle modulation. The input impedance of the PFC circuits is proportional to the resistor <math>R_M</math> externally connected to this pin. The device operates in average current mode if an external capacitor <math>C_M</math> is connected to the pin. Otherwise, it operates in peak current mode.</p>
1	Ground	-
8	Drive	<p>The high current capability of the totem pole gate drive (<math>\pm 1.5</math> A) makes it suitable to effectively drive high gate charge power MOSFET.</p>
7	$V_{CC}$	<p>This pin is the positive supply of the IC. The circuit typically starts to operate when <math>V_{CC}</math> exceeds 13.75 V (version A), 10.5 V (version B) and turns off when <math>V_{CC}</math> goes below 9 V. After start-up, the operating range is 9 V up to 20 V.</p>

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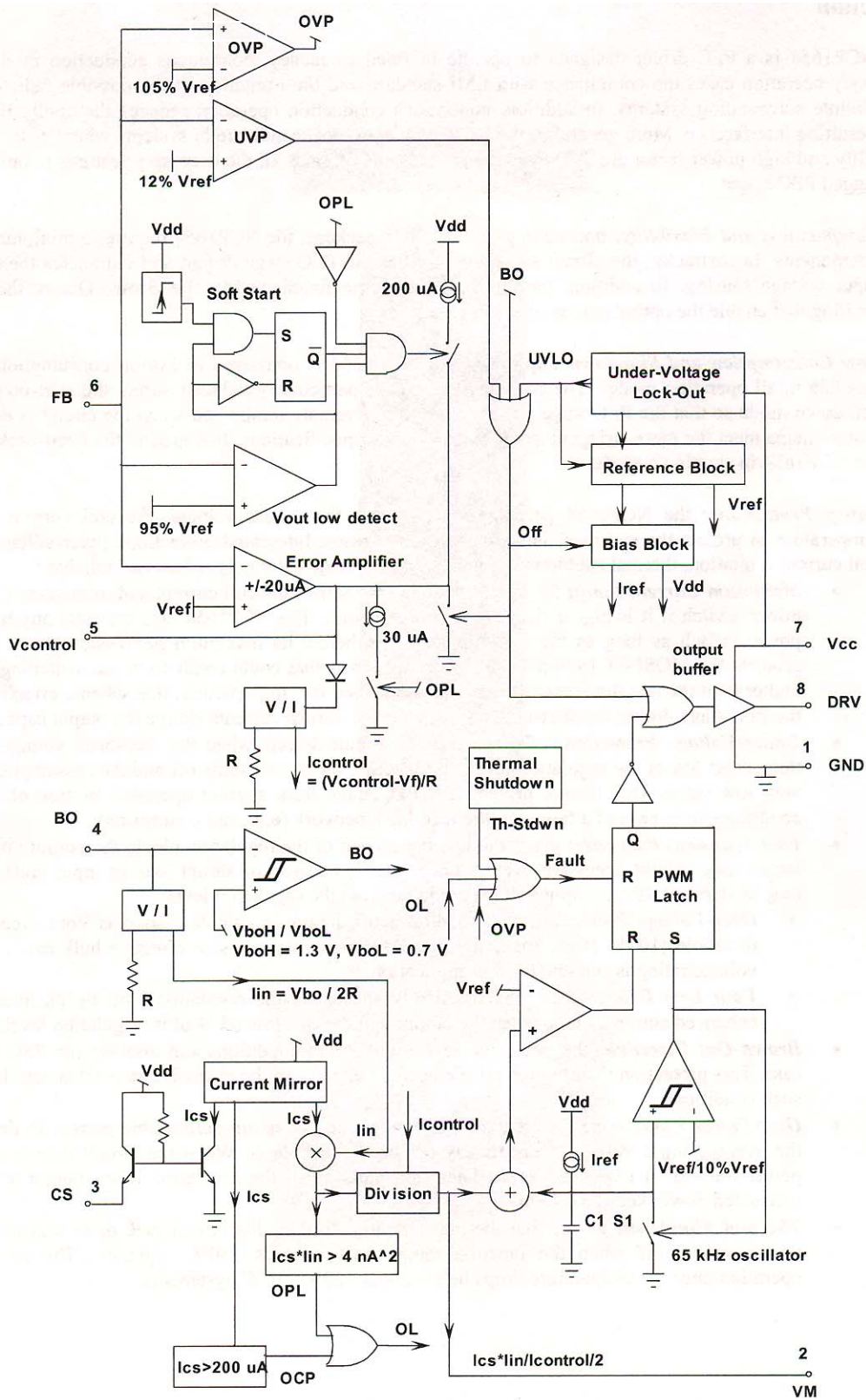


Figure 1. Block Diagram



## DETAILED OPERATING DESCRIPTION

### Introduction

The NCP1654 is a PFC driver designed to operate in fixed frequency, continuous conduction mode. The fixed frequency operation eases the compliance with EMI standard and the limitation of the possible radiated noise that may pollute surrounding systems. In addition, continuous conduction operation reduces the application  $di/dt$  and their resulting interference. More generally, the NCP1654 is an ideal candidate in systems where cost-effectiveness, reliability and high power factor are the key parameters. It incorporates all the necessary features to build a compact and rugged PFC stage:

- **Compactness and Flexibility:** housed in a DIP8 or SO8 package, the NCP1654 requires a minimum of external components. In particular, the circuit scheme simplifies the PFC stage design and eliminates the need for any input voltage sensing. In addition, the circuit offers some functions like the Brown-Out or the true power limiting that enable the optimizations of the PFC design,
- **Low Consumption and Shutdown Capability:** the NCP1654 is optimized to exhibit consumption as small as possible in all operation modes. The consumed current is particularly reduced during the start-up phase and in shutdown mode so that the PFC stage power losses are extremely minimized when the circuit is disabled. This feature helps meet the more stringent stand-by low power specifications. Just ground the Feed-back pin to force the NCP1654 in shutdown mode,
- **Safety Protections:** the NCP1654 permanently monitors the output voltage, the coil current and the die temperature to protect the system from possible over-stresses. Integrated protections (over-voltage protection, coil current limitation, thermal shutdown...) make the PFC stage extremely robust and reliable:
  - **Maximum Current Limit:** the circuit permanently senses the coil current and immediately turns off the power switch if it is higher than the set current limit. The NCP1654 also prevents any turn on of the power switch as long as the coil current is not below its maximum permissible level. This feature protects the MOSFET from possible excessive stress that could result from the switching of a current higher than the one the power switch is dimensioned for. In particular, this scheme effectively protects the PFC stage during the start-up phase when large in-rush currents charge the output capacitor,
  - **Under-Voltage Protection / Shut-down:** the circuit detects when the feed-back voltage goes below than about 8% of the regulation level. In this case, the circuit turns off and its consumption drops to a very low value. This feature protects the PFC stage from starting operation in case of low AC line conditions

or in case of a failure in the feed-back network (e.g., bad connection),

- **Fast Transient Response:** given the low bandwidth of the regulation block, the output voltage of PFC stages may exhibit excessive over or under-shoots because of abrupt load or input voltage variations (e.g. at start up). If the output voltage is too far from the regulation level:
  - Over-Voltage Protection:* NCP1654 turns off the power switch as soon as  $V_{out}$  exceeds the OVP threshold (105% of the regulation level). Hence a cost & size effective bulk capacitor of lower voltage rating is suitable for this application,
  - Vout Low Detect:* NCP1654 drastically speeds up the regulation loop by its internal 200  $\mu A$  enhanced current source when the output voltage is below 95% of its regulation level.
- **Brown-Out Detection:** the circuit detects low AC line conditions and disables the PFC stage in this case. This protection mainly protects the power switch from the excessive stress that could damage it in such conditions,
- **Over-Power Limitation:** the NCP1654 computes the maximum permissible current in dependence of the average input voltage measured by the brown-out block. When the circuit detects an excessive power transfer, it resets the PWM latch and pulls down the regulation block output as long as the calculated power keeps too high,
- **Thermal Shutdown:** an internal thermal circuitry disables the circuit gate drive and then keeps the power switch off when the junction temperature exceeds 150°C typically. The circuit resumes operation once the temperature drops below about 120°C (30°C hysteresis),
- **Soft Start:**  $V_{control}$  is pulled low as the IC is off, which  $V_{CC}$  is lower than UVLO off, brown-out detection activates, or under-voltage protection activates, and no drive is provided. The soft-start function is done by disable the “200  $\mu A$  enhanced current source” at start up. So there is only 20  $\mu A$  to charge the  $C_{control}$ , and makes  $V_{control}$  increase slowly. This is to obtain a slow increasing duty cycle and hence reduce the voltage and current stress on the MOSFET. This soft-start function is designed in **B version only**. **A version** doesn't have this soft-start function, because  $V_{CC}$  of A version is supposed to start up by the resistors connected to input voltage and should be able to boost the PFC output as soon as possible before the 2<sup>nd</sup> stage converter operates. So at start up period,  $C_{control}$  will be charged by 220  $\mu A$  current source and the PFC output will rise rapidly.
- **Output Stage Totem Pole:** the NCP1654 incorporates a  $\pm 1.5A$  gate driver to efficiently drive TO220 or TO247 power MOSFETs.

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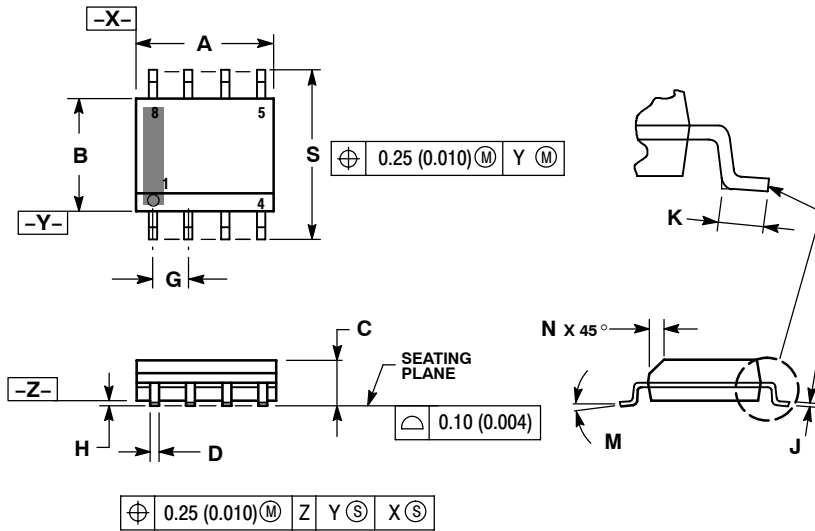
## ORDERING INFORMATION

Device	Package	Shipping†
NCP1654P	PDIP-8	50 Units / Rail
NCP1654PG	PDIP-8 (Pb-Free)	50 Units / Rail
NCP1654DR2	SO-8	2500 Units / Tape & Reel
NCP1654DR2G	SO-8 (Pb-Free)	2500 Units / 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.

## PACKAGE DIMENSIONS

### SO-8 D SUFFIX CASE 751-07 ISSUE AG

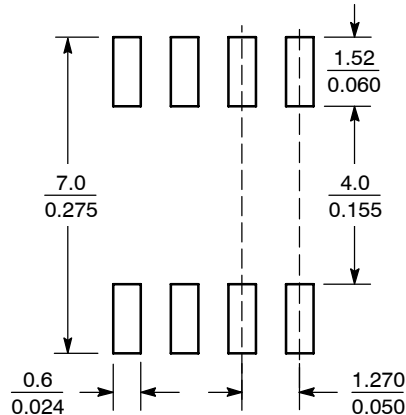


#### NOTES:

- DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
- CONTROLLING DIMENSION: MILLIMETER.
- DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
- MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
- DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.
- 751-01 THRU 751-06 ARE OBSOLETE. NEW STANDARD IS 751-07.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	4.80	5.00	0.189	0.197
B	3.80	4.00	0.150	0.157
C	1.35	1.75	0.053	0.069
D	0.33	0.51	0.013	0.020
G	1.27 BSC		0.050 BSC	
H	0.10	0.25	0.004	0.010
J	0.19	0.25	0.007	0.010
K	0.40	1.27	0.016	0.050
M	0°	8°	0°	8°
N	0.25	0.50	0.010	0.020
S	5.80	6.20	0.228	0.244

### SOLDERING FOOTPRINT\*



SCALE 6:1  $\left(\frac{\text{mm}}{\text{inches}}\right)$

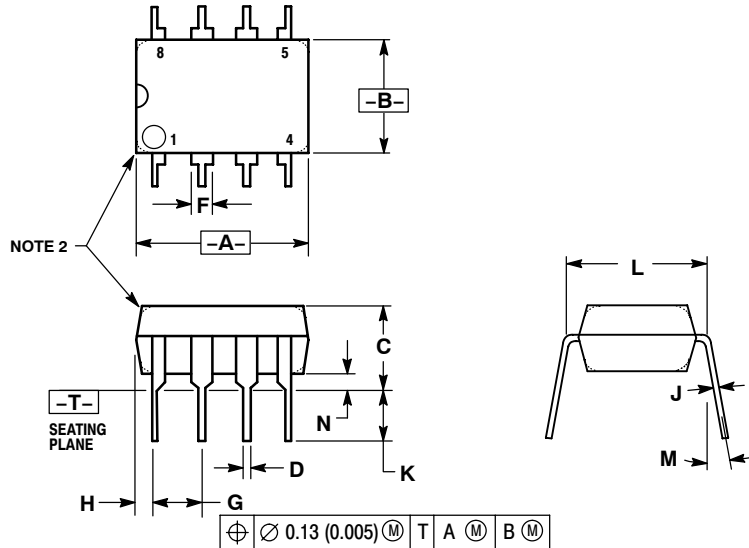
\*For additional information on our Pb-Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.



# NCP1654

## PACKAGE DIMENSIONS

PDIP-8  
P SUFFIX  
CASE 626-05  
ISSUE L



### NOTES:

1. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
2. PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	9.40	10.16	0.370	0.400
B	6.10	6.60	0.240	0.260
C	3.94	4.45	0.155	0.175
D	0.38	0.51	0.015	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
H	0.76	1.27	0.030	0.050
J	0.20	0.30	0.008	0.012
K	2.92	3.43	0.115	0.135
L	7.62 BSC		0.300 BSC	
M	---	10°	---	10°
N	0.76	1.01	0.030	0.040

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