NCP1536

3.0 A, Step-Down Switching Regulator

The NCP1536 series of regulators are monolithic integrated circuits ideally suited for easy and convenient design of a step−down switching regulator (buck converter). This circuit is capable of driving a 3.0 A load with excellent line and load regulation. It has an adjustable output voltage and is internally compensated to minimize the number of external components which simplifies the power supply design.

Since the NCP1536 converter is a switch−mode power supply, its efficiency is significantly higher in comparison with popular three−terminal linear regulators, especially with higher input voltages. In many cases, the power dissipated is so low that no heatsink is required or its size could be reduced dramatically.

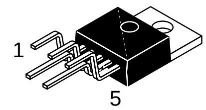
The NCP1536 features include a guaranteed ±4% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency (±2% over 0°C to 125°C). External shutdown is included, featuring 80 mA (typical) standby current. The output switch includes cycle−by−cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

Features

- Adjustable Output Voltage
- Adjustable Version Output Voltage Range, 1.23 to 40 V ±4% Maximum Over Line and Load Conditions
- Guaranteed 3.0 A Output Current
- Wide Input Voltage Range
- Requires Only 4 External Components
- 52 kHz Fixed Frequency Internal Oscillator
- TTL Shutdown Capability, Low Power Standby Mode
- High Efficiency
- Uses Readily Available Standard Inductors
- Thermal Shutdown and Current Limit Protection
- Moisture Sensitivity Level (MSL) Equals 1
- Pb−Free Packages are Available

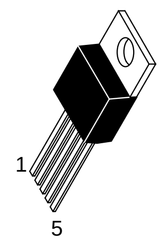
ON Semiconductor®

http://onsemi.com



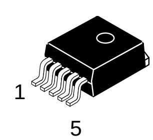
TO−220
TV SUFFIX
CASE 314B

Heatsink surface connected to Pin 3



TO−220
T SUFFIX
CASE 314D

Pin 1. V_{in}
2. Output
3. Ground
4. Feedback
5. $\overline{ON}$/OFF



D²PAK
D2T SUFFIX
CASE 936A

Heatsink surface (shown as terminal 6 in case outline drawing) is connected to Pin 3

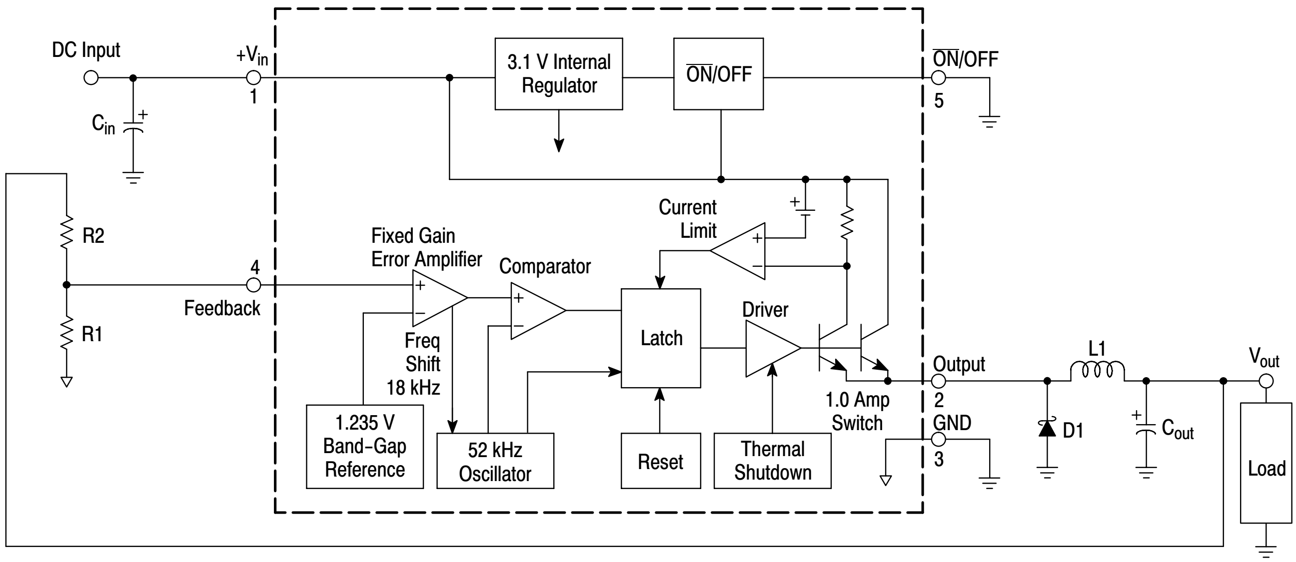
ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 15 of this data sheet.

DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 15 of this data sheet.

Representative Block Diagram and Typical Application



This device contains 162 active transistors.

Figure 1. Block Diagram

PIN FUNCTION DESCRIPTION

Pin	Symbol	Description (Refer to Figure 1)
1	V_{in}	This pin is the positive input supply for the NCP1536 step−down switching regulator. In order to minimize voltage transients and to supply the switching currents needed by the regulator, a suitable input bypass capacitor must be present (C_{in} in Figure 1).
2	Output	This is the emitter of the internal switch. The saturation voltage V_{sat} of this output switch is typically 1.5 V. It should be kept in mind that the PCB area connected to this pin should be kept to a minimum in order to minimize coupling to sensitive circuitry.
3	GND	Circuit ground pin. See the information about the printed circuit board layout.
4	Feedback	This pin is the direct input of the error amplifier and the resistor network R2, R1 is connected externally to allow programming of the output voltage.
5	ON/OFF	It allows the switching regulator circuit to be shut down using logic level signals, thus dropping the total input supply current to approximately 80 mA. The threshold voltage is typically 1.4 V. Applying a voltage above this value (up to $+V_{in}$) shuts the regulator off. If the voltage applied to this pin is lower than 1.4 V or if this pin is left open, the regulator will be in the “on” condition.

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Maximum Supply Voltage	V_{in}	45	V
ON/OFF Pin Input Voltage	−	$-0.3\ V \le V \le +V_{in}$	V
Output Voltage to Ground (Steady−State)	−	−1.0	V
Power Dissipation Case 314B and 314D (TO−220, 5−Lead) Thermal Resistance, Junction−to−Ambient Thermal Resistance, Junction−to−Case Case 936A (D^2PAK) Thermal Resistance, Junction−to−Ambient Thermal Resistance, Junction−to−Case	 P_D $R_{\theta JA}$ $R_{\theta JC}$ P_D $R_{\theta JA}$ $R_{\theta JC}$	 Internally Limited 65 5.0 Internally Limited 70 5.0	 W °C/W °C/W W °C/W °C/W
Storage Temperature Range	T_{stg}	−65 to +150	°C
Minimum ESD Rating (Human Body Model: C = 100 pF, R = 1.5 kΩ)	−	2.0	kV
Lead Temperature (Soldering, 10 seconds)	−	260	°C
Maximum Junction Temperature	T_J	150	°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.

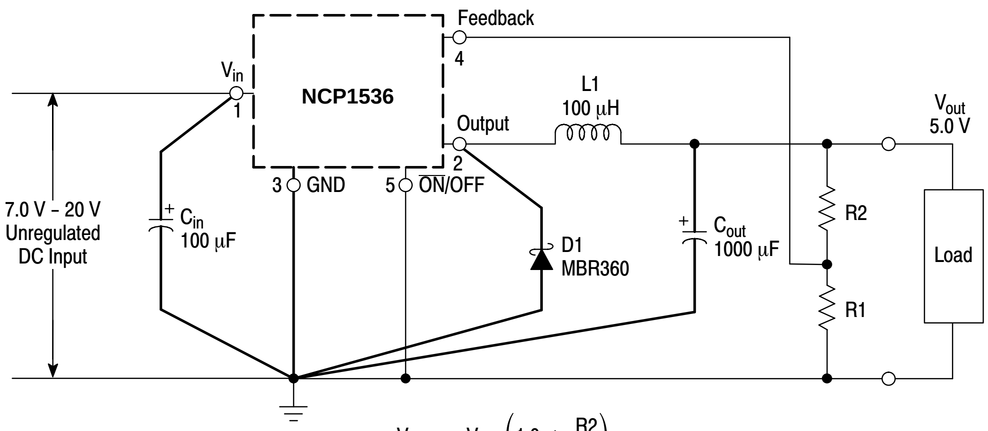
OPERATING RATINGS (Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.)

Rating	Symbol	Value	Unit
Operating Junction Temperature Range	T_J	−40 to +125	°C
Supply Voltage	V_{in}	40	V

ELECTRICAL CHARACTERISTICS (Unless otherwise specified, V_{in} = 12 V, I_{Load} = 500 mA. For typical values T_J = 25°C, for min/max values T_J is the operating junction temperature range that applies, unless otherwise noted.) (Note 1)

Characteristics	Symbol	Min	Typ	Max	Unit
SYSTEM PARAMETERS (Note 2, Typical Test Circuit)					
Feedback Voltage (V_{in} = 12 V, I_{Load} = 0.5 A, V_{out} = 5.0 V, T_J = 25°C)	V_{out}	1.217	1.23	1.243	V
Feedback Voltage (8.0 V ≤ V_{in} ≤ 40 V, 0.5 A ≤ I_{Load} ≤ 3.0 A, V_{out} = 5.0 V)	V_{out}				V
T_J = 25°C		1.193	1.23	1.267	
T_J = −40 to +125°C		1.18	−	1.28	
Efficiency (V_{in} = 12 V, I_{Load} = 3.0 A, V_{out} = 5.0 V)	η	−	77	−	%
DEVICE PARAMETERS					
Feedback Bias Current (V_{out} = 5.0 V)	I_b				nA
T_J = 25°C		−	25	100	
T_J = −40 to +125°C		−	−	200	
Oscillator Frequency (Note 3)	f_{osc}				kHz
T_J = 25°C		−	52	−	
T_J = 0 to +125°C		47	−	58	
T_J = −40 to +125°C		42	−	63	
Saturation Voltage (I_{out} = 3.0 A, Note 4)	V_{sat}				V
T_J = 25°C		−	1.5	1.8	
T_J = −40 to +125°C		−	−	2.0	
Max Duty Cycle (“on”) (Note 5)	DC	94	98	−	%
Current Limit (Peak Current, Notes 3 and 4)	I_{CL}				A
T_J = 25°C		4.2	5.8	6.9	
T_J = −40 to +125°C		3.5	−	7.5	
Output Leakage Current, T_J = 25°C (Notes 6 and 7)	I_L				mA
Output = 0 V		−	0.8	2.0	
Output = −1.0 V		−	6.0	20	
Quiescent Current (Note 6)	I_Q				mA
T_J = 25°C		−	5.0	9.0	
T_J = −40 to +125°C		−	−	11	
Standby Quiescent Current (ON/OFF Pin = 5.0 V (“off”))	I_{stby}				mA
T_J = 25°C		−	80	200	
T_J = −40 to +125°C		−	−	400	
ON/OFF Pin Logic Input Level (Test Circuit Figure 2)					V
V_{out} = 0 V	V_{IH}				
T_J = 25°C		2.2	1.4	−	
T_J = −40 to +125°C		2.4	−	−	
V_{out} = Nominal Output Voltage	V_{IL}				
T_J = 25°C		−	1.2	1.0	
T_J = −40 to +125°C		−	−	0.8	
ON/OFF Pin Input Current (Test Circuit Figure 2)					mA
ON/OFF Pin = 5.0 V (“off”), T_J = 25°C	I_{IH}	−	15	30	
ON/OFF Pin = 0 V (“on”), T_J = 25°C	I_{IL}	−	0	5.0	

1. Tested junction temperature range for the NCP1536: T_{low} = −40°C T_{high} = +125°C
2. External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the NCP1536 is used as shown in the Figure 2 test circuit, system performance will be as shown in system parameters section.
3. The oscillator frequency reduces to approximately 18 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.
4. Output (Pin 2) sourcing current. No diode, inductor or capacitor connected to output pin.
5. Feedback (Pin 4) removed from output and connected to 0 V.
6. Feedback (Pin 4) removed from output and connected to +12 V to force the output transistor “off”.
7. V_{in} = 20 V.



$$V_{out} = V_{ref}\left(1.0 + \frac{R2}{R1}\right)$$

$$R2 = R1\left(\frac{V_{out}}{V_{ref}} - 1.0\right)$$

Where V_{ref} = 1.23 V, R1 between 1.0 k and 5.0 k

Figure 2. Typical Test Circuit

PCB LAYOUT GUIDELINES

As in any switching regulator, the layout of the printed circuit board is very important. Rapidly switching currents associated with wiring inductance, stray capacitance and parasitic inductance of the printed circuit board traces can generate voltage transients which can generate electromagnetic interferences (EMI) and affect the desired operation. As indicated in the Figure 2, to minimize inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible.

For best results, single−point grounding (as indicated) or ground plane construction should be used.

On the other hand, the PCB area connected to the Pin 2 (emitter of the internal switch) of the NCP1536 should be kept to a minimum in order to minimize coupling to sensitive circuitry.

Another sensitive part of the circuit is the feedback. It is important to keep the sensitive feedback wiring short. To assure this, physically locate the programming resistors near to the regulator.

DESIGN PROCEDURE

Buck Converter Basics

The NCP1536 is a “Buck” or Step−Down Converter which is the most elementary forward−mode converter. Its basic schematic can be seen in Figure 3.

The operation of this regulator topology has two distinct time periods. The first one occurs when the series switch is on, the input voltage is connected to the input of the inductor.

The output of the inductor is the output voltage, and the rectifier (or catch diode) is reverse biased. During this period, since there is a constant voltage source connected across the inductor, the inductor current begins to linearly ramp upwards, as described by the following equation:

$$I_{L(on)} = \frac{(V_{in} - V_{out})\, t_{on}}{L}$$

During this “on” period, energy is stored within the core material in the form of magnetic flux. If the inductor is properly designed, there is sufficient energy stored to carry the requirements of the load during the “off” period.

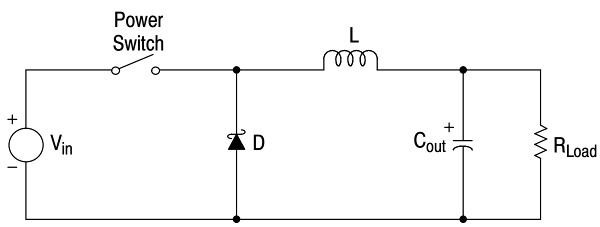


Figure 3. Basic Buck Converter

The next period is the “off” period of the power switch. When the power switch turns off, the voltage across the inductor reverses its polarity and is clamped at one diode voltage drop below ground by the catch diode. The current now flows through the catch diode thus maintaining the load current loop. This removes the stored energy from the inductor. The inductor current during this time is:

$$I_{L(off)} = \frac{(V_{out} - V_D)\, t_{off}}{L}$$

This period ends when the power switch is once again turned on. Regulation of the converter is accomplished by varying the duty cycle of the power switch. It is possible to describe the duty cycle as follows:

$$d = \frac{t_{on}}{T}, \text{ where T is the period of switching.}$$

For the buck converter with ideal components, the duty cycle can also be described as:

$$d = \frac{V_{out}}{V_{in}}$$

Figure 4 shows the buck converter, idealized waveforms of the catch diode voltage and the inductor current.

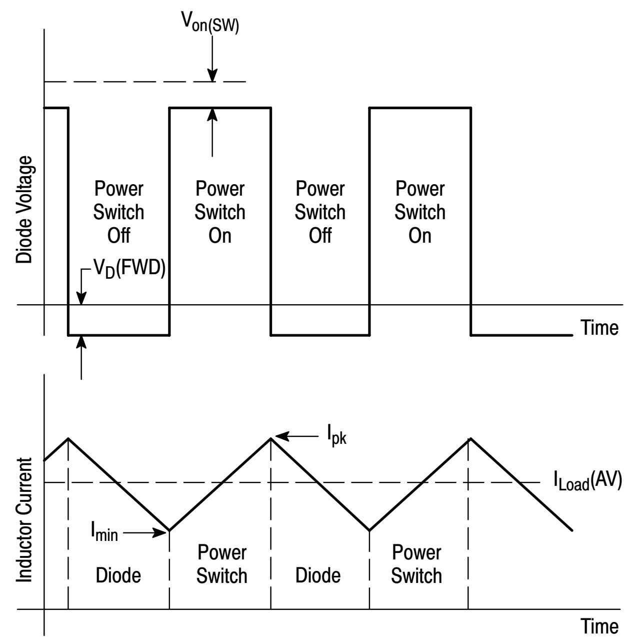


Figure 4. Buck Converter Idealized Waveforms

Procedure In order to simplify the switching regulator design, a step−by−step design procedure and some examples are provided.

<table>
<tr><th>Procedure</th><th>Example</th></tr>
<tr><td>Given Parameters:
V_{out} = Regulated Output Voltage
$V_{in(max)}$ = Maximum DC Input Voltage
$I_{Load(max)}$ = Maximum Load Current</td><td>Given Parameters:
V_{out} = 8.0 V
$V_{in(max)}$ = 25 V
$I_{Load(max)}$ = 2.5 A</td></tr>
<tr><td>1. Programming Output Voltage
To select the right programming resistor R1 and R2 value use the following formula:
$$V_{out} = V_{ref}\left(1.0 + \frac{R2}{R1}\right) \quad \text{where } V_{ref} = 1.23\ V$$
Resistor R1 can be between 1.0 k and 5.0 kΩ. (For best temperature coefficient and stability with time, use 1% metal film resistors).
$$R2 = R1\left(\frac{V_{out}}{V_{ref}} - 1.0\right)$$</td><td>1. Programming Output Voltage (selecting R1 and R2)
Select R1 and R2:
$$V_{out} = 1.23\left(1.0 + \frac{R2}{R1}\right) \quad \text{Select R1} = 1.8\ k\Omega$$
$$R2 = R1\left(\frac{V_{out}}{V_{ref}} - 1.0\right) = 1.8\ k\left(\frac{8.0\ V}{1.23\ V} - 1.0\right)$$
R2 = 9.91 kΩ, choose a 9.88 k metal film resistor.</td></tr>
<tr><td>2. Input Capacitor Selection (C_{in})
To prevent large voltage transients from appearing at the input and for stable operation of the converter, an aluminium or tantalum electrolytic bypass capacitor is needed between the input pin $+V_{in}$ and ground pin GND This capacitor should be located close to the IC using short leads. This capacitor should have a low ESR (Equivalent Series Resistance) value.

For additional information see input capacitor section in the “Application Hints” section of this data sheet.</td><td>2. Input Capacitor Selection (C_{in})
A 100 μF, 150 V aluminium electrolytic capacitor located near the input and ground pin provides sufficient bypassing.</td></tr>
<tr><td>3. Catch Diode Selection (D1)
A. Since the diode maximum peak current exceeds the regulator maximum load current the catch diode current rating must be at least 1.2 times greater than the maximum load current. For a robust design, the diode should have a current rating equal to the maximum current limit of the NCP1536 to be able to withstand a continuous output short.
B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.</td><td>3. Catch Diode Selection (D1)
A. For this example, a 3.0 A current rating is adequate.

B. Use a 30 V 1N5821 Schottky diode or any suggested fast recovery diode in the Table 1.</td></tr>
</table>

Procedure (continued) In order to simplify the switching regulator design, a step−by−step design procedure and some examples are provided.

Procedure	Example
4. Inductor Selection (L1) **A.** Use the following formula to calculate the inductor Volt x microsecond [V x µs] constant: $E \times T = \left(V_{in} - V_{out}\right) \frac{V_{out}}{V_{in}} \times \frac{10^6}{F[Hz]}$ [V x µs] **B.** Match the calculated E x T value with the corresponding number on the vertical axis of the Inductor Value Selection Guide shown in Figure 9. This E x T constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle. **C.** Next step is to identify the inductance region intersected by the E x T value and the maximum load current value on the horizontal axis shown in Figure 12. **D.** From the inductor code, identify the inductor value. Then select an appropriate inductor from Table 2. The inductor chosen must be rated for a switching frequency of 52 kHz and for a current rating of 1.15 x I_{Load}. The inductor current rating can also be determined by calculating the inductor peak current: $I_{p(max)} = I_{Load(max)} + \frac{\left(V_{in} - V_{out}\right) t_{on}}{2L}$ where t_{on} is the “on” time of the power switch and $t_{on} = \frac{V_{out}}{V_{in}} \times \frac{1.0}{f_{osc}}$ For additional information about the inductor, see the inductor section in the “External Components” section of this data sheet.	**4. Inductor Selection (L1)** **A.** Calculate E x T [V x µs] constant: $E \times T = (25 - 8.0) \times \frac{8.0}{25} \times \frac{1000}{52} = 80$ [V x µs] **B.** E x T = 80 [V x µs] **C.** $I_{Load(max)}$ = 2.5 A Inductance Region = H150 **D.** Proper inductor value = 150 µH Choose the inductor from Table 2.
5. Output Capacitor Selection (C_{out}) **A.** Since the NCP1536 is a forward−mode switching regulator with voltage mode control, its open loop 2−pole−1−zero frequency characteristic has the dominant pole−pair determined by the output capacitor and inductor values. For stable operation, the capacitor must satisfy the following requirement: $C_{out} \geq 13,300 \frac{V_{in(max)}}{V_{out} \times L\ [\mu H]}$ [µF] **B.** Capacitor values between 10 µF and 2000 µF will satisfy the loop requirements for stable operation. To achieve an acceptable output ripple voltage and transient response, the output capacitor may need to be several times larger than the above formula yields. **C.** Due to the fact that the higher voltage electrolytic capacitors generally have lower ESR (Equivalent Series Resistance) numbers, the output capacitor’s voltage rating should be at least 1.5 times greater than the output voltage. For a 5.0 V regulator, a rating of at least 8.0 V is appropriate, and a 10 V or 16 V rating is recommended.	**5. Output Capacitor Selection (C_{out})** **A.** $C_{out} \geq 13,300 \times \frac{25}{8 \times 150} = 332.5$ µF To achieve an acceptable ripple voltage, select C_{out} = 680 µF electrolytic capacitor.

NCP1536 Series Buck Regulator Design Procedures (continued)

Indicator Value Selection Guide (For Continuous Mode Operation)

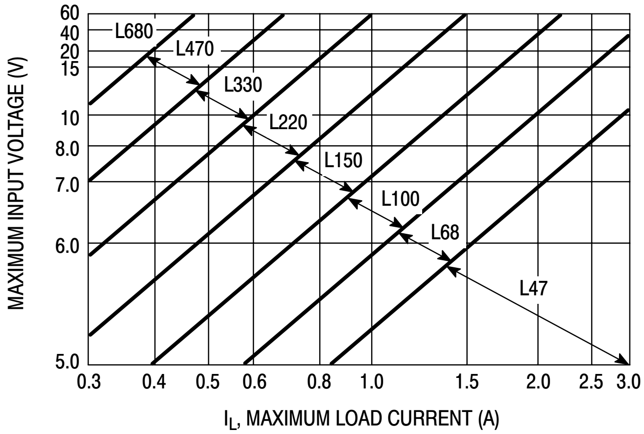


Figure 5. NCP1536−3.3

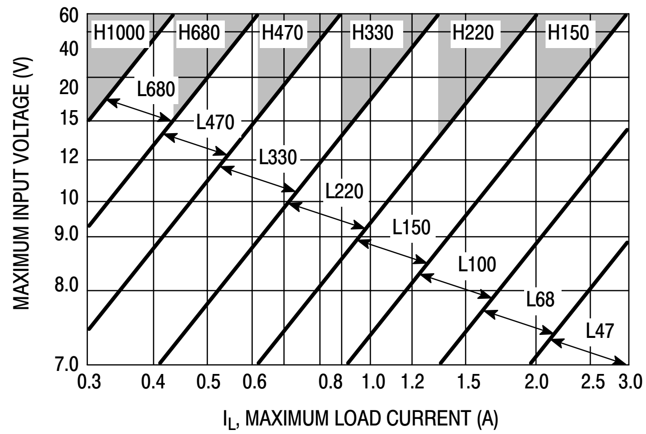


Figure 6. NCP1536−5

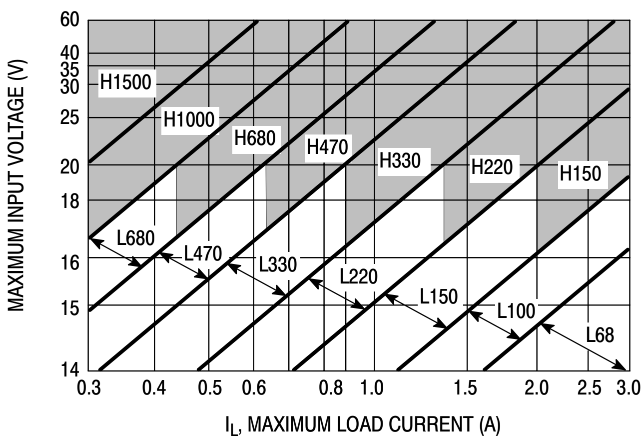


Figure 7. NCP1536−12

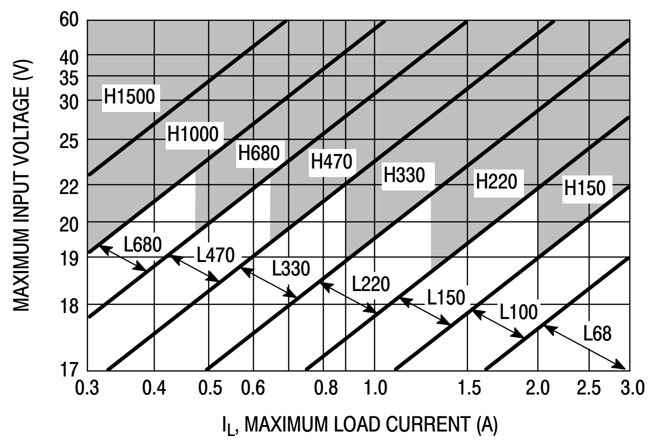


Figure 8. NCP1536−15

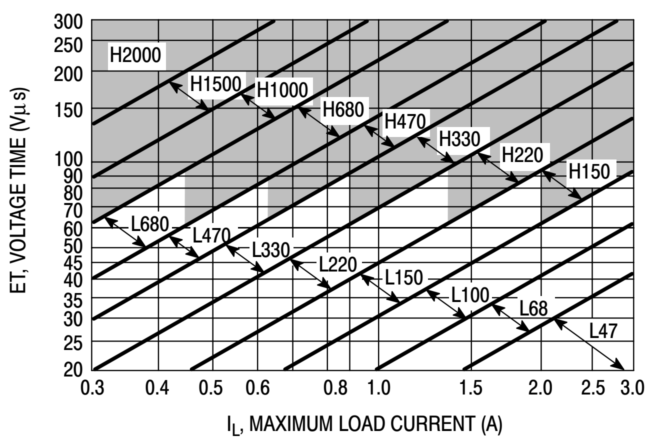


Figure 9. NCP1536−ADJ

Table 1. Diode Selection Guide

<table>
<tr><th rowspan="3">V_R</th><th colspan="4">Schottky</th><th colspan="4">Fast Recovery</th></tr>
<tr><th colspan="2">3.0 A</th><th colspan="2">4.0 − 6.0 A</th><th colspan="2">3.0 A</th><th colspan="2">4.0 − 6.0 A</th></tr>
<tr><th>Through Hole</th><th>Surface Mount</th><th>Through Hole</th><th>Surface Mount</th><th>Through Hole</th><th>Surface Mount</th><th>Through Hole</th><th>Surface Mount</th></tr>
<tr><td>20 V</td><td>1N5820
MBR320P
SR302</td><td>SK32</td><td>1N5823
SR502
SB520</td><td></td><td rowspan="5">MUR320
31DF1
HER302

(all diodes rated to at least 100 V)</td><td rowspan="5">MURS320T3
MURD320
30WF10

(all diodes rated to at least 100 V)</td><td rowspan="5">MUR420
HER602

(all diodes rated to at least 100 V)</td><td rowspan="5">MURD620CT
50WF10

(all diodes rated to at least 100 V)</td></tr>
<tr><td>30 V</td><td>1N5821
MBR330
SR303
31DQ03</td><td>SK33
30WQ03</td><td>1N5824
SR503
SB530</td><td>50WQ03</td></tr>
<tr><td>40 V</td><td>1N5822
MBR340
SR304
31DQ04</td><td>SK34
30WQ04
MBRS340T3
MBRD340</td><td>1N5825
SR504
SB540</td><td>MBRD640CT
50WQ04</td></tr>
<tr><td>50 V</td><td>MBR350
31DQ05
SR305</td><td>SK35
30WQ05</td><td>SB550</td><td>50WQ05</td></tr>
<tr><td>60 V</td><td>MBR360
DQ06
SR306</td><td>MBRS360T3
MBRD360</td><td>50SQ080</td><td>MBRD660CT</td></tr>
</table>

NOTE: Diodes listed in bold are available from ON Semiconductor.

Table 2. Inductor Selection by Manufacturer's Part Number

Inductor Code	Inductor Value	Tech 39	Schott Corp.	Pulse Eng.	Renco
L47	47 μH	77 212	671 26980	PE−53112	RL2442
L68	68 μH	77 262	671 26990	PE−92114	RL2443
L100	100 μH	77 312	671 27000	PE−92108	RL2444
L150	150 μH	77 360	671 27010	PE−53113	RL1954
L220	220 μH	77 408	671 27020	PE−52626	RL1953
L330	330 μH	77 456	671 27030	PE−52627	RL1952
L470	470 μH	*	671 27040	PE−53114	RL1951
L680	680 μH	77 506	671 27050	PE−52629	RL1950
H150	150 μH	77 362	671 27060	PE−53115	RL2445
H220	220 μH	77 412	671 27070	PE−53116	RL2446
H330	330 μH	77 462	671 27080	PE−53117	RL2447
H470	470 μH	*	671 27090	PE−53118	RL1961
H680	680 μH	77 508	671 27100	PE−53119	RL1960
H1000	1000 μH	77 556	671 27110	PE−53120	RL1959
H1500	1500 μH	*	671 27120	PE−53121	RL1958
H2200	2200 μH	*	671 27130	PE−53122	RL2448

NOTE: *Contact Manufacturer

Table 3. Example of Several Inductor Manufacturers Phone/Fax Numbers

Pulse Engineering, Inc.	Phone Fax	+ 1−619−674−8100 + 1−619−674−8262
Pulse Engineering, Inc. Europe	Phone Fax	+ 353−9324−107 + 353−9324−459
Renco Electronics, Inc.	Phone Fax	+ 1−516−645−5828 + 1−516−586−5562
Tech 39	Phone Fax	+ 33−1−4115−1681 + 33−1−4709−5051
Schott Corporation	Phone Fax	+ 1−612−475−1173 + 1−612−475−1786

EXTERNAL COMPONENTS

Input Capacitor (C_{in})

The Input Capacitor Should Have a Low ESR

For stable operation of the switch mode converter a low ESR (Equivalent Series Resistance) aluminium or solid tantalum bypass capacitor is needed between the input pin and the ground pin, to prevent large voltage transients from appearing at the input. It must be located near the regulator and use short leads. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures. For reliable operation in temperatures below −25°C larger values of the input capacitor may be needed. Also paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures.

RMS Current Rating of C_{in}

The important parameter of the input capacitor is the RMS current rating. Capacitors that are physically large and have large surface area will typically have higher RMS current ratings. For a given capacitor value, a higher voltage electrolytic capacitor will be physically larger than a lower voltage capacitor, and thus be able to dissipate more heat to the surrounding air, and therefore will have a higher RMS current rating. The consequence of operating an electrolytic capacitor beyond the RMS current rating is a shortened operating life. In order to assure maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be:

$$I_{rms} > 1.2 \times d \times I_{Load}$$

where d is the duty cycle, for a buck regulator

$$d = \frac{t_{on}}{T} = \frac{V_{out}}{V_{in}}$$

$$\text{and } d = \frac{t_{on}}{T} = \frac{|V_{out}|}{|V_{out}| + V_{in}} \text{ for a buck−boost regulator.}$$

Output Capacitor (C_{out})

For low output ripple voltage and good stability, low ESR output capacitors are recommended. An output capacitor has two main functions: it filters the output and provides regulator loop stability. The ESR of the output capacitor and the peak−to−peak value of the inductor ripple current are the main factors contributing to the output ripple voltage value. Standard aluminium electrolytics could be adequate for some applications but for quality design, low ESR types are recommended.

An aluminium electrolytic capacitor's ESR value is related to many factors such as the capacitance value, the voltage rating, the physical size and the type of construction. In most cases, the higher voltage electrolytic capacitors have lower ESR value. Often capacitors with much higher voltage ratings may be needed to provide low ESR values that, are required for low output ripple voltage.

The Output Capacitor Requires an ESR Value That Has an Upper and Lower Limit

As mentioned above, a low ESR value is needed for low output ripple voltage, typically 1% to 2% of the output voltage. But if the selected capacitor's ESR is extremely low (below 0.05 Ω), there is a possibility of an unstable feedback loop, resulting in oscillation at the output. This situation can occur when a tantalum capacitor, that can have a very low ESR, is used as the only output capacitor.

At Low Temperatures, Put in Parallel Aluminium Electrolytic Capacitors with Tantalum Capacitors

Electrolytic capacitors are not recommended for temperatures below −25°C. The ESR rises dramatically at cold temperatures and typically rises 3 times at −25°C and as much as 10 times at −40°C. Solid tantalum capacitors have much better ESR spec at cold temperatures and are recommended for temperatures below −25°C. They can be also used in parallel with aluminium electrolytics. The value of the tantalum capacitor should be about 10% or 20% of the total capacitance. The output capacitor should have at least 50% higher RMS ripple current rating at 52 kHz than the peak−to−peak inductor ripple current.

Catch Diode

Locate the Catch Diode Close to the NCP1536

The NCP1536 is a step−down buck converter; it requires a fast diode to provide a return path for the inductor current when the switch turns off. This diode must be located close to the NCP1536 using short leads and short printed circuit traces to avoid EMI problems.

Use a Schottky or a Soft Switching Ultra−Fast Recovery Diode

Since the rectifier diodes are very significant sources of losses within switching power supplies, choosing the rectifier that best fits into the converter design is an important process. Schottky diodes provide the best performance because of their fast switching speed and low forward voltage drop.

They provide the best efficiency especially in low output voltage applications (5.0 V and lower). Another choice could be Fast−Recovery, or Ultra−Fast Recovery diodes. It has to be noted, that some types of these diodes with an abrupt turnoff characteristic may cause instability or EMI troubles.

A fast−recovery diode with soft recovery characteristics can better fulfill some quality, low noise design requirements. Table 1 provides a list of suitable diodes for the NCP1536 regulator. Standard 50/60 Hz rectifier diodes, such as the 1N4001 series or 1N5400 series are **NOT** suitable.

Inductor

The magnetic components are the cornerstone of all switching power supply designs. The style of the core and the winding technique used in the magnetic component's design has a great influence on the reliability of the overall power supply.

Using an improper or poorly designed inductor can cause high voltage spikes generated by the rate of transitions in current within the switching power supply, and the possibility of core saturation can arise during an abnormal operational mode. Voltage spikes can cause the semiconductors to enter avalanche breakdown and the part can instantly fail if enough energy is applied. It can also cause significant RFI (Radio Frequency Interference) and EMI (Electro−Magnetic Interference) problems.

Continuous and Discontinuous Mode of Operation

The NCP1536 step−down converter can operate in both the continuous and the discontinuous modes of operation. The regulator works in the continuous mode when loads are relatively heavy, the current flows through the inductor continuously and never falls to zero. Under light load conditions, the circuit will be forced to the discontinuous mode when inductor current falls to zero for certain period of time (see Figure 10 and Figure 11). Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements. In many cases the preferred mode of operation is the continuous mode. It offers greater output power, lower peak currents in the switch, inductor and diode, and can have a lower output ripple voltage. On the other hand it does require larger inductor values to keep the inductor current flowing continuously, especially at low output load currents and/or high input voltages.

To simplify the inductor selection process, an inductor selection guide for the NCP1536 regulator was added to this data sheet (Figures 5 through 9). This guide assumes that the regulator is operating in the continuous mode, and selects an inductor that will allow a peak−to−peak inductor ripple current to be a certain percentage of the maximum design load current. This percentage is allowed to change as different design load currents are selected. For light loads (less than approximately 300 mA) it may be desirable to operate the regulator in the discontinuous mode, because the inductor value and size can be kept relatively low. Consequently, the percentage of inductor peak−to−peak current increases. This discontinuous mode of operation is perfectly acceptable for this type of switching converter. Any buck regulator will be forced to enter discontinuous mode if the load current is light enough.

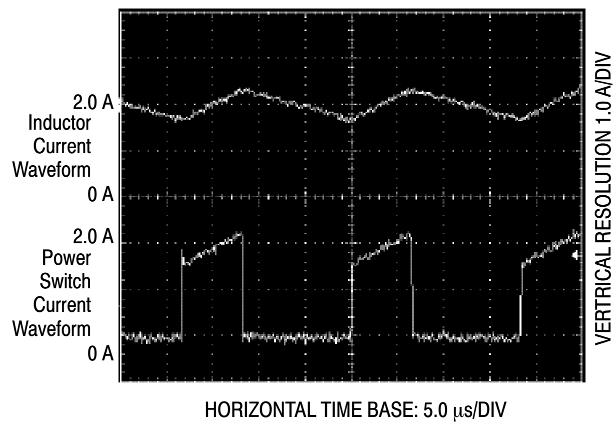


Figure 10. Continuous Mode Switching Current Waveforms

Selecting the Right Inductor Style

Some important considerations when selecting a core type are core material, cost, the output power of the power supply, the physical volume the inductor must fit within, and the amount of EMI (Electro−Magnetic Interference) shielding that the core must provide. The inductor selection guide covers different styles of inductors, such as pot core, E−core, toroid and bobbin core, as well as different core materials such as ferrites and powdered iron from different manufacturers.

For high quality design regulators the toroid core seems to be the best choice. Since the magnetic flux is contained within the core, it generates less EMI, reducing noise problems in sensitive circuits. The least expensive is the bobbin core type, which consists of wire wound on a ferrite rod core. This type of inductor generates more EMI due to the fact that its core is open, and the magnetic flux is not contained within the core.

When multiple switching regulators are located on the same printed circuit board, open core magnetics can cause interference between two or more of the regulator circuits, especially at high currents due to mutual coupling. A toroid, pot core or E−core (closed magnetic structure) should be used in such applications.

Do Not Operate an Inductor Beyond its Maximum Rated Current

Exceeding an inductor's maximum current rating may cause the inductor to overheat because of the copper wire losses, or the core may saturate. Core saturation occurs when the flux density is too high and consequently the cross sectional area of the core can no longer support additional lines of magnetic flux.

This causes the permeability of the core to drop, the inductance value decreases rapidly and the inductor begins to look mainly resistive. It has only the DC resistance of the winding. This can cause the switch current to rise very rapidly and force the NCP1536 internal switch into cycle−by−cycle current limit, thus reducing the DC output load current. This can also result in overheating of the inductor and/or the NCP1536. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

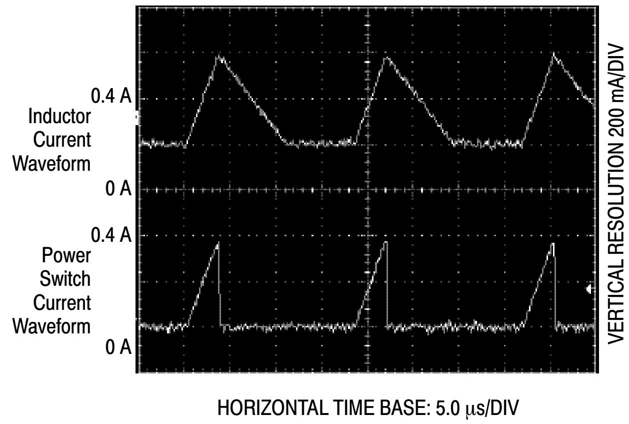


Figure 11. Discontinuous Mode Switching Current Waveforms

GENERAL RECOMMENDATIONS

Output Voltage Ripple and Transients

Source of the Output Ripple

Since the NCP1536 is a switch mode power supply regulator, its output voltage, if left unfiltered, will contain a sawtooth ripple voltage at the switching frequency. The output ripple voltage value ranges from 0.5% to 3% of the output voltage. It is caused mainly by the inductor sawtooth ripple current multiplied by the ESR of the output capacitor.

Short Voltage Spikes and How to Reduce Them

The regulator output voltage may also contain short voltage spikes at the peaks of the sawtooth waveform (see Figure 12). These voltage spikes are present because of the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. There are some other important factors such as wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all these contribute to the amplitude of these spikes. To minimize these voltage spikes, low inductance capacitors should be used, and their lead lengths must be kept short. The importance of quality printed circuit board layout design should also be highlighted.

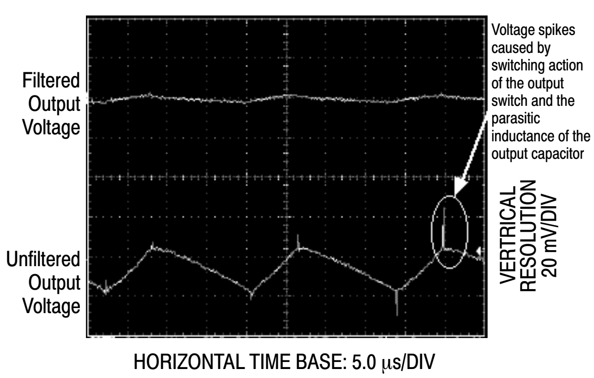


Figure 12. Output Ripple Voltage Waveforms

Minimizing the Output Ripple

In order to minimize the output ripple voltage it is possible to enlarge the inductance value of the inductor L1 and/or to use a larger value output capacitor. There is also another way to smooth the output by means of an additional LC filter (20 μH, 100 μF), that can be added to the output to further reduce the amount of output ripple and transients. With such a filter it is possible to reduce the output ripple voltage transients 10 times or more. Figure 12 shows the difference between filtered and unfiltered output waveforms of the regulator.

The lower waveform is from the normal unfiltered output of the converter, while the upper waveform shows the output ripple voltage filtered by an additional LC filter.

Heatsinking and Thermal Considerations

The Through−Hole Package TO−220

The NCP1536 is available in two packages, a 5−pin TO−220(T, TV) and a 5−pin surface mount D^2PAK(D2T). Although the TO−220(T) package needs a heatsink under most conditions, there are some applications that require no heatsink to keep the NCP1536 junction temperature within the allowed operating range. Higher ambient temperatures require some heat sinking, either to the printed circuit (PC) board or an external heatsink.

The Surface Mount Package D^2PAK and its Heatsinking

The other type of package, the surface mount D^2PAK, is designed to be soldered to the copper on the PC board. The copper and the board are the heatsink for this package and the other heat producing components, such as the catch diode and inductor. The PC board copper area that the package is soldered to should be at least 0.4 in^2 (or 260 mm^2) and ideally should have 2 or more square inches (1300 mm^2) of 0.0028 inch copper. Additional increases of copper area beyond approximately 6.0 in^2 (4000 mm^2) will not improve heat dissipation significantly. If further thermal improvements are needed, double sided or multilayer PC boards with large copper areas should be considered. In order to achieve the best thermal performance, it is highly recommended to use wide copper traces as well as large areas of copper in the printed circuit board layout. The only exception to this is the OUTPUT (switch) pin, which should not have large areas of copper (see page 5 'PCB Layout Guideline').

Thermal Analysis and Design

The following procedure must be performed to determine whether or not a heatsink will be required. First determine:

1. $P_{D(max)}$ maximum regulator power dissipation in the application.
2. $T_{A(max)}$ maximum ambient temperature in the application.
3. $T_{J(max)}$ maximum allowed junction temperature (125°C for the NCP1536). For a conservative design, the maximum junction temperature should not exceed 110°C to assure safe operation. For every additional +10°C temperature rise that the junction must withstand, the estimated operating lifetime of the component is halved.
4. $R_{\theta JC}$ package thermal resistance junction−case.
5. $R_{\theta JA}$ package thermal resistance junction−ambient.

(Refer to Maximum Ratings on page 3 of this data sheet or $R_{\theta JC}$ and $R_{\theta JA}$ values).

The following formula is to calculate the approximate total power dissipated by the NCP1536:

$$P_D = (V_{in} \times I_Q) + d \times I_{Load} \times V_{sat}$$

where d is the duty cycle and for buck converter

$$d = \frac{t_{on}}{T} = \frac{V_O}{V_{in}},$$

I_Q (quiescent current) and V_{sat} can be found in the NCP1536 data sheet,

V_{in} is minimum input voltage applied,

V_O is the regulator output voltage,

I_{Load} is the load current.

The dynamic switching losses during turn−on and turn−off can be neglected if proper type catch diode is used.

Packages Not on a Heatsink (Free−Standing)

For a free−standing application when no heatsink is used, the junction temperature can be determined by the following expression:

$$T_J = (R_{\theta JA})(P_D) + T_A$$

where $(R_{\theta JA})(P_D)$ represents the junction temperature rise caused by the dissipated power and T_A is the maximum ambient temperature.

Packages on a Heatsink

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined in step 3, than a heatsink is required. The junction temperature will be calculated as follows:

$$T_J = P_D (R_{\theta JA} + R_{\theta CS} + R_{\theta SA}) + T_A$$

where $R_{\theta JC}$ is the thermal resistance junction−case,
$R_{\theta CS}$ is the thermal resistance case−heatsink,
$R_{\theta SA}$ is the thermal resistance heatsink−ambient.

If the actual operating temperature is greater than the selected safe operating junction temperature, then a larger heatsink is required.

Some Aspects That can Influence Thermal Design

It should be noted that the package thermal resistance and the junction temperature rise numbers are all approximate, and there are many factors that will affect these numbers, such as PC board size, shape, thickness, physical position, location, board temperature, as well as whether the surrounding air is moving or still.

Other factors are trace width, total printed circuit copper area, copper thickness, single− or double−sided, multilayer board, the amount of solder on the board or even color of the traces.

The size, quantity and spacing of other components on the board can also influence its effectiveness to dissipate the heat.

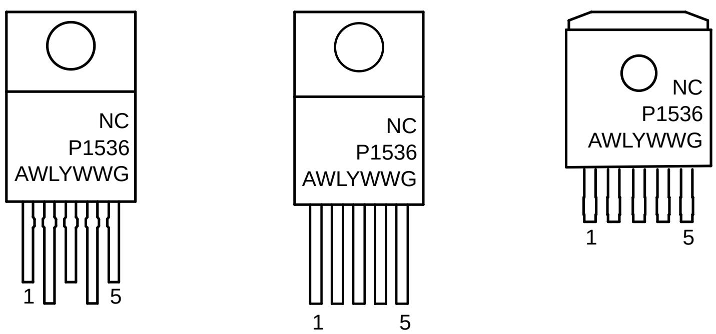
ORDERING INFORMATION

Device	Package	Shipping†
NCP1536TVG	TO−220 (Vertical Mount) (Pb−Free)	50 Units/Rail
NCP1536TG	TO−220 (Straight Lead) (Pb−Free)	
NCP1536DSR4G	D^2PAK (Surface Mount) (Pb−Free)	2500 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.

MARKING DIAGRAMS

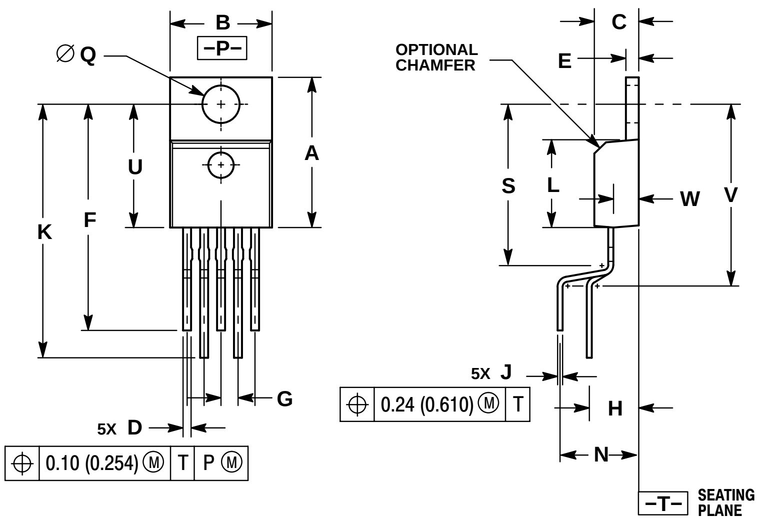
TO−220 TV SUFFIX CASE 314B | **TO−220 T SUFFIX CASE 314D** | **D^2PAK D2T SUFFIX CASE 936A**



A = Assembly Location
WL = Wafer Lot
Y = Year
WW = Work Week
G = Pb−Free Package

PACKAGE DIMENSIONS

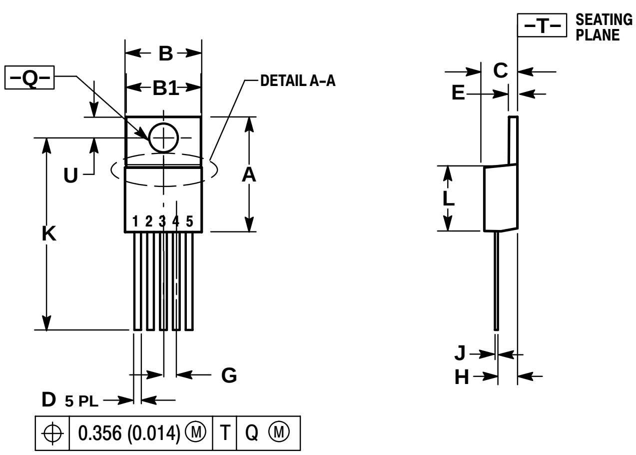
TO−220
TV SUFFIX
CASE 314B−05
ISSUE L



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION D DOES NOT INCLUDE INTERCONNECT BAR (DAMBAR) PROTRUSION. DIMENSION D INCLUDING PROTRUSION SHALL NOT EXCEED 0.043 (1.092) MAXIMUM.

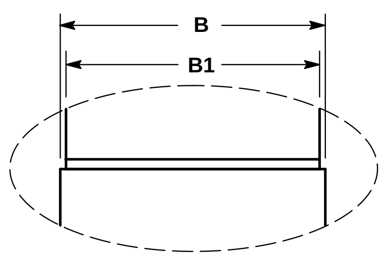
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.572	0.613	14.529	15.570
B	0.390	0.415	9.906	10.541
C	0.170	0.180	4.318	4.572
D	0.025	0.038	0.635	0.965
E	0.048	0.055	1.219	1.397
F	0.850	0.935	21.590	23.749
G	0.067 BSC		1.702 BSC	
H	0.166 BSC		4.216 BSC	
J	0.015	0.025	0.381	0.635
K	0.900	1.100	22.860	27.940
L	0.320	0.365	8.128	9.271
N	0.320 BSC		8.128 BSC	
Q	0.140	0.153	3.556	3.886
S	---	0.620	---	15.748
U	0.468	0.505	11.888	12.827
V	---	0.735	---	18.669
W	0.090	0.110	2.286	2.794

TO−220
T SUFFIX
CASE 314D−04
ISSUE F



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION D DOES NOT INCLUDE INTERCONNECT BAR (DAMBAR) PROTRUSION. DIMENSION D INCLUDING PROTRUSION SHALL NOT EXCEED 10.92 (0.043) MAXIMUM.

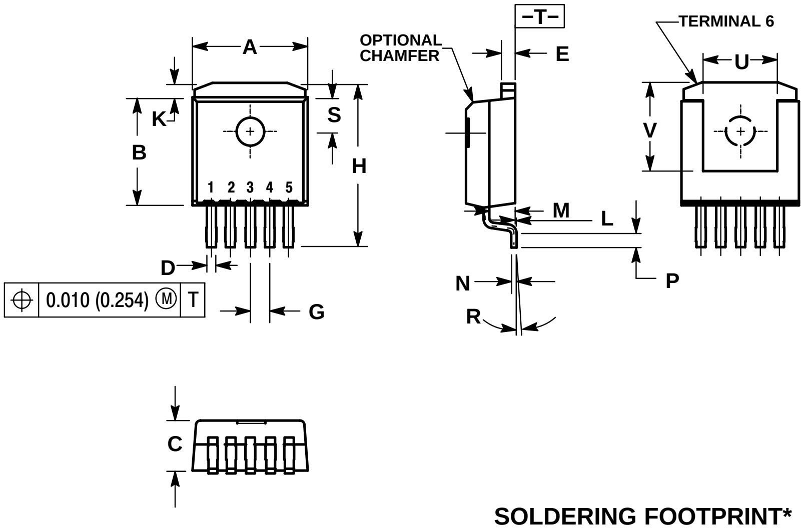
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.572	0.613	14.529	15.570
B	0.390	0.415	9.906	10.541
B1	0.375	0.415	9.525	10.541
C	0.170	0.180	4.318	4.572
D	0.025	0.038	0.635	0.965
E	0.048	0.055	1.219	1.397
G	0.067 BSC		1.702 BSC	
H	0.087	0.112	2.210	2.845
J	0.015	0.025	0.381	0.635
K	0.977	1.045	24.810	26.543
L	0.320	0.365	8.128	9.271
Q	0.140	0.153	3.556	3.886
U	0.105	0.117	2.667	2.972



DETAIL A−A

PACKAGE DIMENSIONS

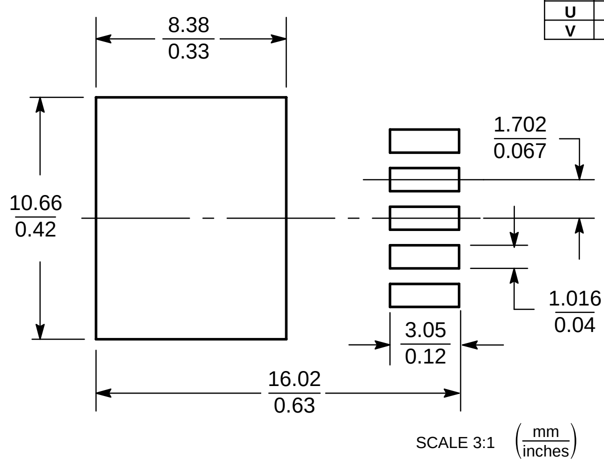
D2PAK
D2T SUFFIX
CASE 936A−02
ISSUE C



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. TAB CONTOUR OPTIONAL WITHIN DIMENSIONS A AND K.
4. DIMENSIONS U AND V ESTABLISH A MINIMUM MOUNTING SURFACE FOR TERMINAL 6.
5. DIMENSIONS A AND B DO NOT INCLUDE MOLD FLASH OR GATE PROTRUSIONS. MOLD FLASH AND GATE PROTRUSIONS NOT TO EXCEED 0.025 (0.635) MAXIMUM.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.386	0.403	9.804	10.236
B	0.356	0.368	9.042	9.347
C	0.170	0.180	4.318	4.572
D	0.026	0.036	0.660	0.914
E	0.045	0.055	1.143	1.397
G	0.067 BSC		1.702 BSC	
H	0.539	0.579	13.691	14.707
K	0.050 REF		1.270 REF	
L	0.000	0.010	0.000	0.254
M	0.088	0.102	2.235	2.591
N	0.018	0.026	0.457	0.660
P	0.058	0.078	1.473	1.981
R	5° REF		5° REF	
S	0.116 REF		2.946 REF	
U	0.200 MIN		5.080 MIN	
V	0.250 MIN		6.350 MIN	

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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