NCP1406

25 V/25 mA PFM Step-Up DC-DC Converter

The NCP1406 is a monolithic PFM step−up DC−DC converter. This device is designed to boost single Lithium or two cells AA/AAA battery voltage up to 25 V (with internal MOSFET) output for handheld applications. A pullup Chip Enable feature is built−in with this device to extend battery−operating life. In addition to standard boost converter topologies, this device can be configured for voltage−inverting and step−down applications. This device is available in space−saving TSOP−5 package. With its small footprint, the device is also ideal for generating a boosted voltage from a 3.3 V or 5.0 V power rail.

Features

- 85% Efficiency at V_{OUT} = 25 V, I_{OUT} = 25 mA, V_{IN} = 5.0 V
- Low Operating Current of 15 μA (Not Switching)
- Low Shutdown Current of 0.3 μA
- Low Startup Voltage of 1.8 V Typical at 0 mA
- Output Voltage up to 25 V with Built−in 26 V MOSFET Switch
- PFM Switching Frequency up to 1.0 MHz
- Chip Enable
- Output Voltage Soft−Start
- Feedback Pin Open/Short Circuit Protection
- Input Undervoltage Lockout
- Thermal Shutdown
- Low Profile and Minimum External Parts
- Micro Miniature TSOP−5 Package
- Pb−Free Package is Available

Typical Applications

- LCD Bias
- White LED Driver
- OLED Driver
- Personal Digital Assistants (PDA)
- Digital Still Camera
- Cellular Telephone
- Hand−Held Games
- Hand−Held Instrument

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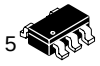
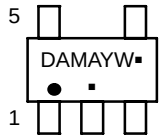
MARKING DIAGRAM

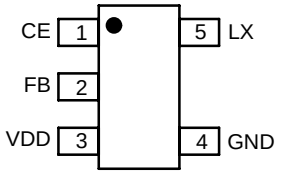




TSOP−5/SOT23−5/SC59−5
SN SUFFIX
CASE 483

DAM = Device Marking
A = Assembly Location
Y = Year
W = Work Week
▪ = Pb−Free Package
(Note: Microdot may be in either location)

PIN CONNECTIONS



(Top View)

ORDERING INFORMATION

Device	Package	Shipping†
NCP1406SNT1	TSOP−5	3000 Tape & Reel
NCP1406SNT1G	TSOP−5 (Pb−Free)	3000 Tape & Reel

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

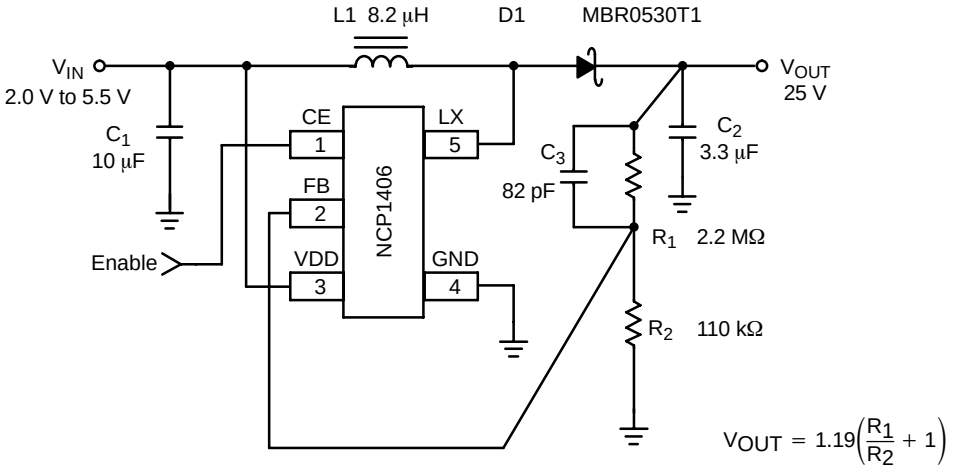


Figure 1. Typical 25 V Step−Up Application Circuit

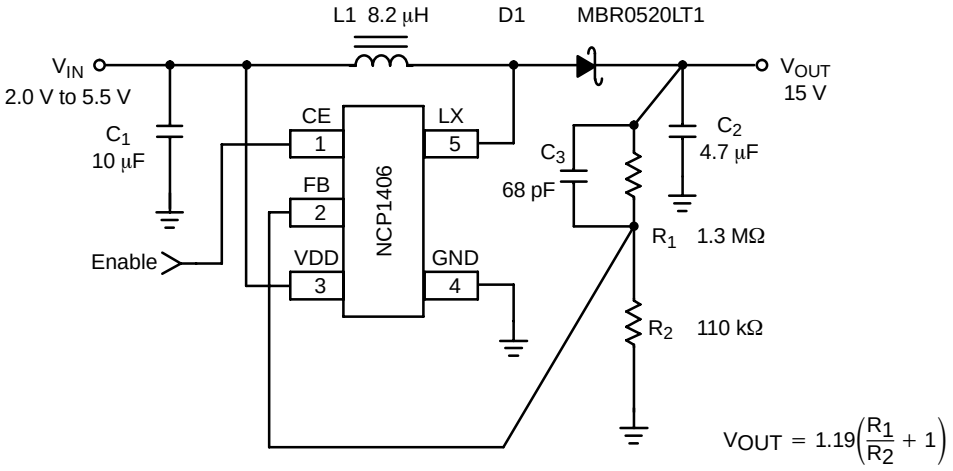


Figure 2. Typical 15 V Step−Up Application Circuit

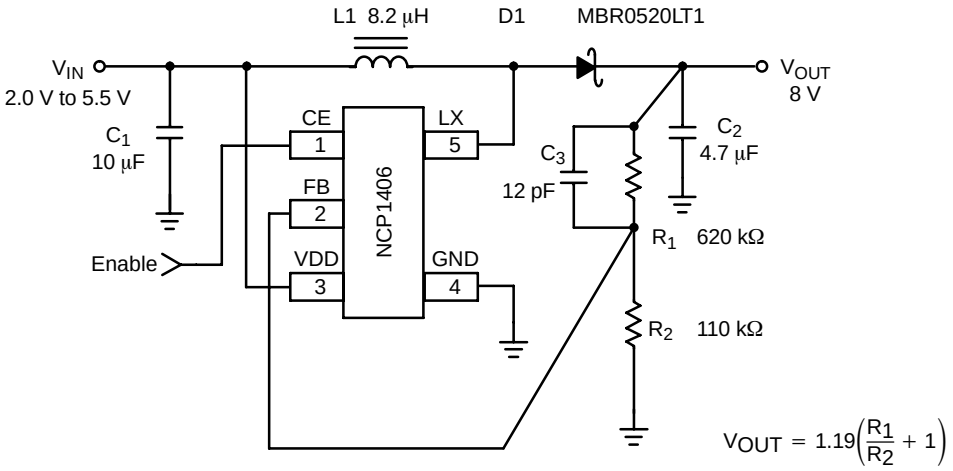


Figure 3. Typical 8.0 V Step−Up Application Circuit

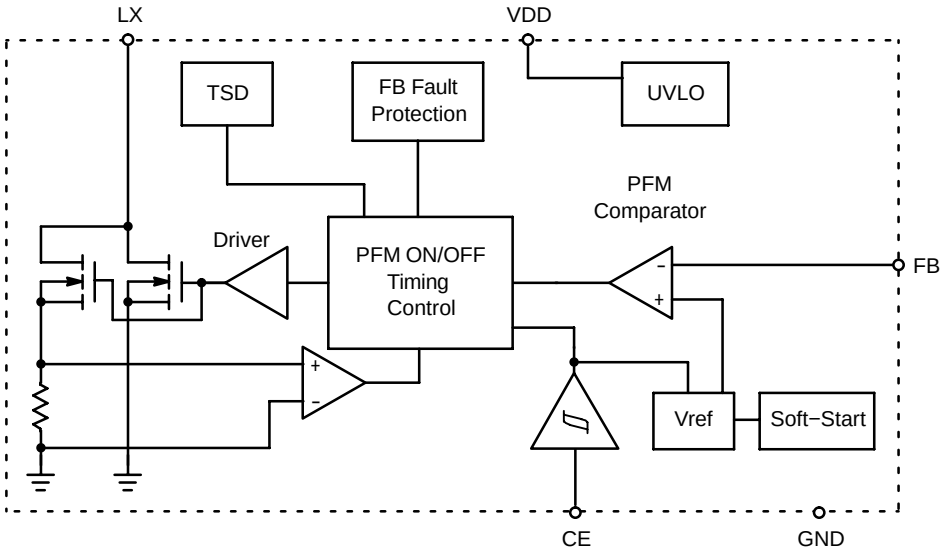


Figure 4. Representative Block Diagram

PIN FUNCTION DESCRIPTION

Pin	Symbol	Description
1	CE	Chip Enable Pin (1) The chip is enabled if a voltage which is equal to or greater than 0.9 V is applied. (2) The chip is disabled if a voltage which is less than 0.3 V is applied. (3) The chip will be enabled if it is left floating.
2	FB	PFM comparator inverting input, and is connected to off−chip resistor divider which sets output voltage.
3	VDD	Power supply pin for internal circuit.
4	GND	Ground pin.
5	LX	External inductor connection pin.

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Power Supply Voltage (Pin 3)	VDD	−0.3 to 6.0	V
Input/Output Pin LX (Pin 5) LX Peak Sink Current FB (Pin 2)	 V_{LX} I_{LX} V_{FB}	 −0.3 to 27 1.5 −0.3 to 6.0	 V A V
CE (Pin 1) Input Voltage Range	 V_{CE}	 −0.3 to 6.0	 V
Power Dissipation and Thermal Characteristics Maximum Power Dissipation @ T_A = 25°C Thermal Resistance, Junction−to−Air	 P_D $R_{\theta JA}$	 500 250	 mW °C/W
Operating Ambient Temperature Range	T_A	−40 to +85	°C
Operating Junction Temperature Range	T_J	−40 to +150	°C
Storage Temperature Range	T_{stg}	−55 to +150	°C

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

1. This device series contains ESD protection and exceeds the following tests:
   Human Body Model (HBM) ±2.0 kV per JEDEC standard: JESD22−A114 for all pins.
   Machine Model (MM) ±200 V per JEDEC standard: JESD22−A115 for all pins.
2. Latchup Current Maximum Rating: ±150 mA per JEDEC standard: JESD78.
3. Moisture Sensitivity Level (MSL): 1 per IPC/JEDEC standard: J−STD−020A.

DISSIPATION RATINGS

Package	Power Rating @$T_A \leq$ 25°C	Derating Factor @$T_A >$ 25°C	Power Rating @T_A = 70°C	Power Rating @T_A = 85°C
TSOP−5	500 mW	4.0 mW/°C	320 mW	260 mW

ELECTRICAL CHARACTERISTICS (V_{OUT} = 25 V, T_A = −40°C to +85°C for min/max values, typical values are at T_A = 25°C, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
ON/OFF TIMING CONTROL					
Minimum Off Time (V_{DD} = 3.0 V, V_{FB} = 0 V)	t_{off}	0.08	0.13	0.20	μs
Maximum On Time (Current Not Asserted)	t_{on}	0.58	0.90	1.40	μs
Maximum Duty Cycle	D_{MAX}	84	90	96	%
Minimum Startup Voltage (I_{OUT} = 0 mA)	V_{start}	−	1.8	2.0	V
Minimum Startup Voltage Temperature Coefficient (T_A = −40 to +85°C)	ΔV_{start}	−	1.6	−	mV/°C
Minimum Hold Voltage (I_{OUT} = 0 mA)	V_{hold}	−	1.7	1.9	V
Soft−Start Time	t_{SS}	−	3.0	8.0	ms
LX (PIN 5)					
Internal Switch Voltage (Note 4) (Note 5)	V_{LX}	−	−	26	V
LX Pin On−State Resistance (V_{LX} = 0.4 V, V_{DD} = 5.0 V)	$R_{sw(on)}$	−	0.7	−	Ω
Current Limit (When I_{LX} reaches I_{LIM}, the LX switch is turned off by the LX switch protection circuit) (Note 5)	I_{LIM}	−	0.80	−	A
Off−State Leakage Current (V_{LX} = 26 V)	I_{LKG}	−	0.1	1.0	μA
CE (PIN 1)					
CE Input Voltage (V_{DD} = 3.0 V, V_{FB} = 0 V) High State, Device Enabled Low State, Device Disabled	 $V_{CE(high)}$ $V_{CE(low)}$	 0.9 −	 − −	 − 0.3	 V V
CE Input Current High State, Device Enabled (V_{DD} = V_{CE} = 5.5 V) Low State, Device Disabled (V_{DD} = 5.5 V, V_{CE} = V_{FB} = 0 V)	 $I_{CE(high)}$ $I_{CE(low)}$	 − −500	 10 −150	 500 −	 nA nA
TOTAL DEVICE					
Supply Voltage	V_{DD}	1.4	−	5.5	V
Undervoltage Lockout (V_{DD} Falling)	V_{UVLO}	−	1.0	1.3	V
Feedback Voltage T_A = 25°C T_A = −40 to +85°C	V_{FB}	1.178 1.170	1.190 1.190	1.202 1.210	V
Feedback Pin Bias Current (V_{FB} = 1.19 V)	I_{FB}	−	15	45	nA
Operating Current 1 (V_{FB} = 0 V, V_{DD} = V_{CE} = 3.0 V, Maximum Duty Cycle)	I_{DD1}	−	0.7	1.5	mA
Operating Current 2 (V_{DD} = V_{CE} = V_{FB} = 3.0 V, Not Switching)	I_{DD2}	−	15	25	μA
Off−State Current (V_{DD} = 5.0 V, V_{CE} = 0 V)	I_{OFF}	−	0.3	1.3	μA
Thermal Shutdown (Note 5)	T_{SD}	−	140	−	°C
Thermal Shutdown Hysteresis (Note 5)	T_{SDHYS}	−	10	−	°C

4. Recommended maximum V_{OUT} up to 25 V.
5. Guaranteed by design, not tested.

TYPICAL CHARACTERISTICS

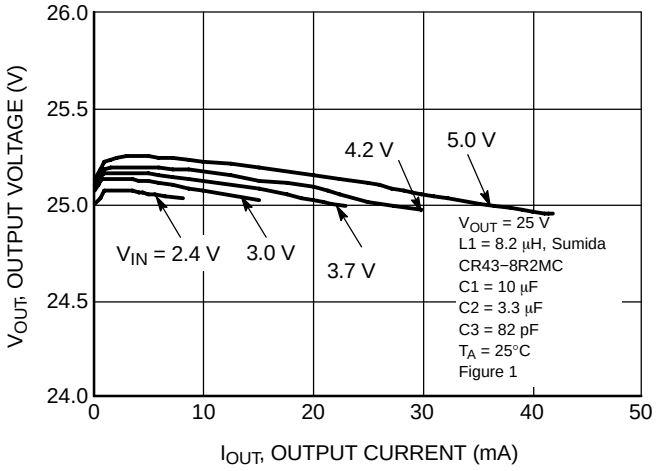


Figure 5. Output Voltage versus Output Current (V_{OUT} = 25 V, L = 8.2 μH)

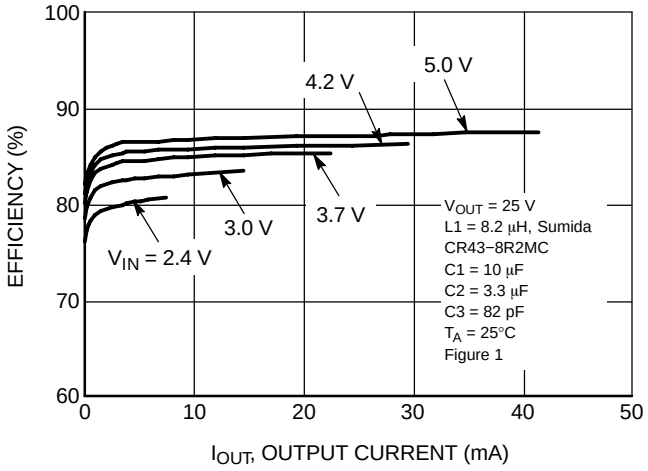


Figure 6. Efficiency versus Output Current (V_{OUT} = 25 V, L = 8.2 μH)

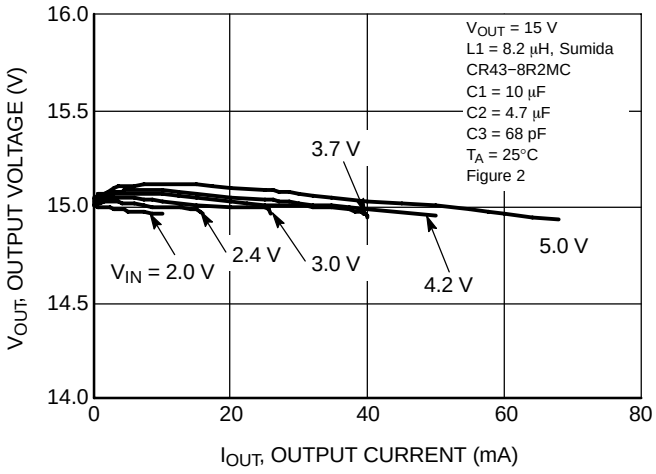


Figure 7. Output Voltage versus Output Current (V_{OUT} = 15 V, L = 8.2 μH)

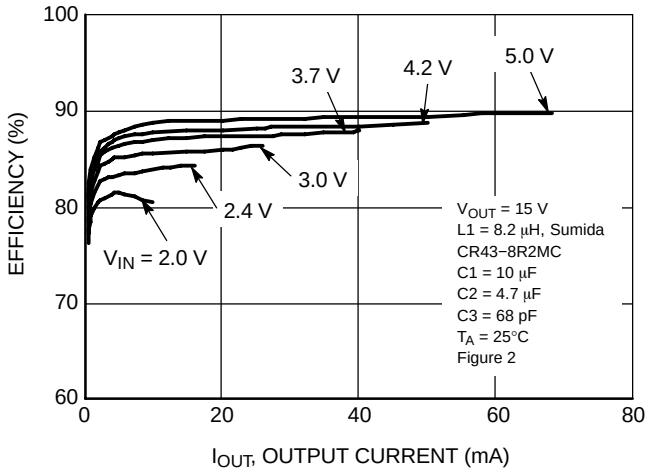


Figure 8. Efficiency versus Output Current (V_{OUT} = 15 V, L = 8.2 μH)

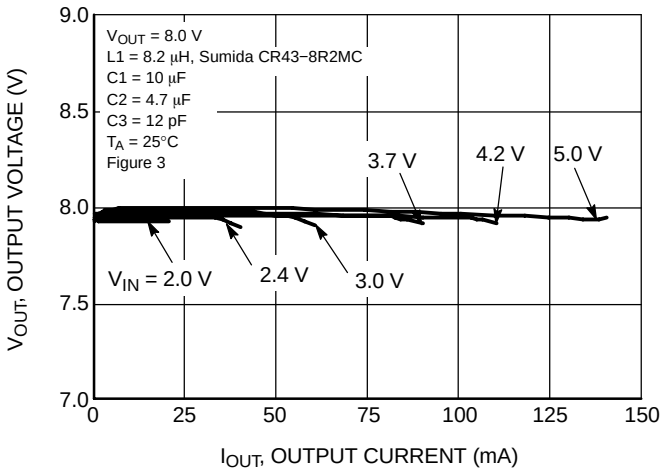


Figure 9. Output Voltage versus Output Current (V_{OUT} = 8.0 V, L = 8.2 μH)

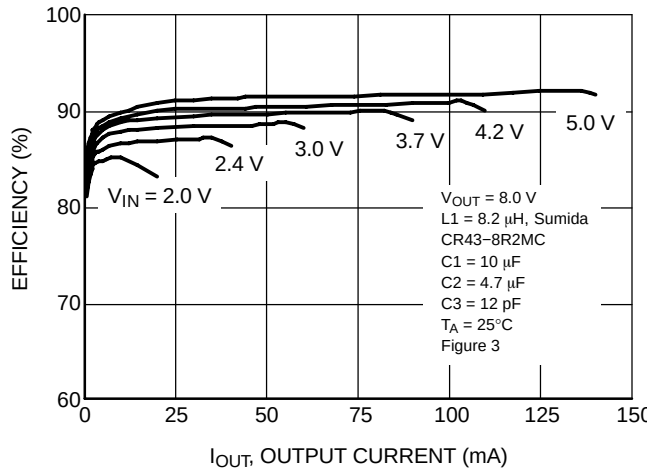


Figure 10. Efficiency versus Output Current (V_{OUT} = 8.0 V, L = 8.2 μH)

TYPICAL CHARACTERISTICS

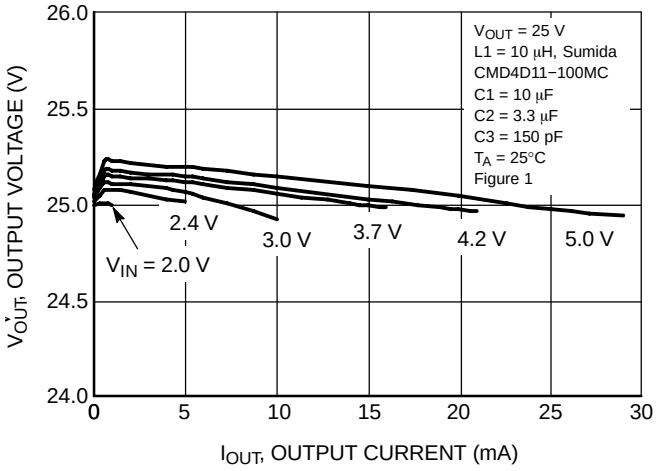


Figure 11. Output Voltage versus Output Current (V_{OUT} = 25 V, L = 10 μH)

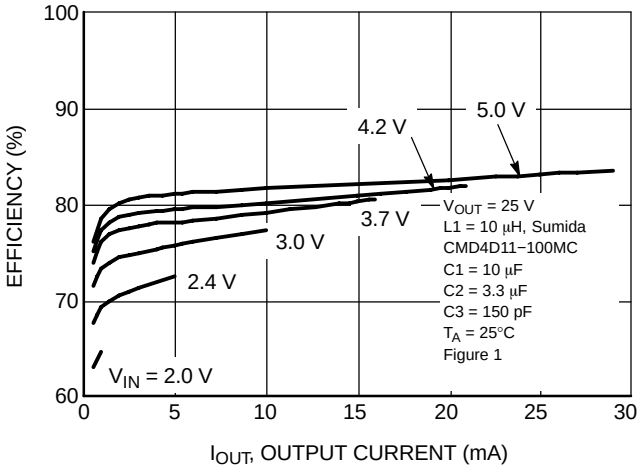


Figure 12. Efficiency versus Output Current (V_{OUT} = 25 V, L = 10 μH)

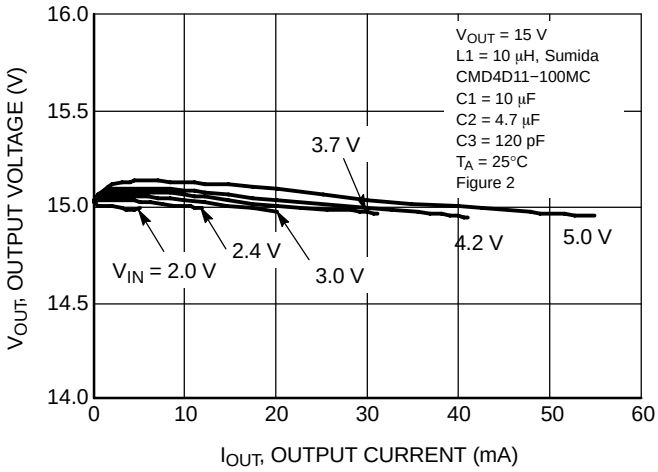


Figure 13. Output Voltage versus Output Current (V_{OUT} = 15 V, L = 10 μH)

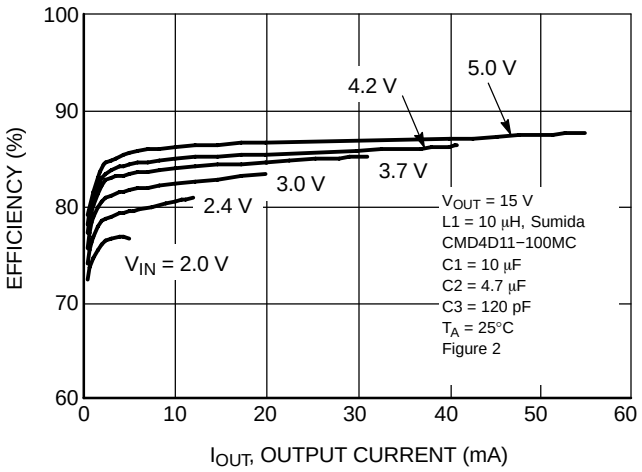


Figure 14. Efficiency versus Output Current (V_{OUT} = 15 V, L = 10 μH)

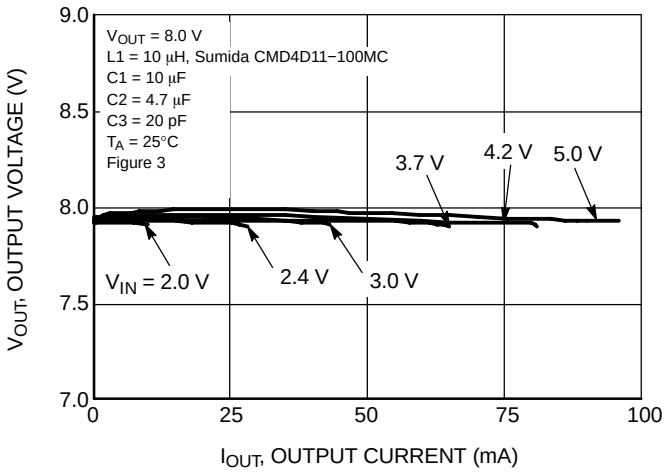


Figure 15. Output Voltage versus Output Current (V_{OUT} = 8.0 V, L = 10 μH)

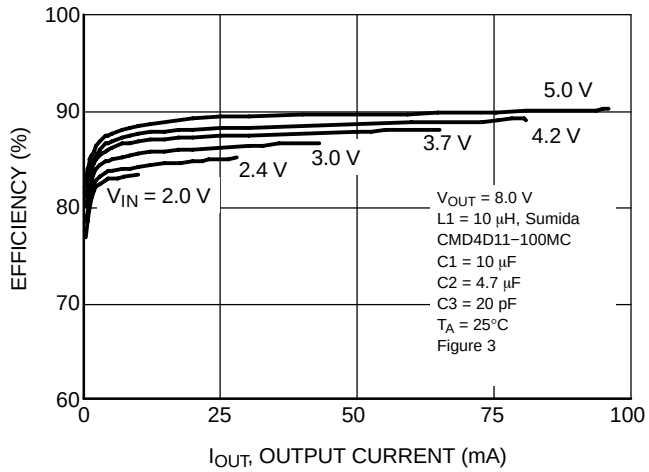


Figure 16. Efficiency versus Output Current (V_{OUT} = 8.0 V, L = 10 μH)

TYPICAL CHARACTERISTICS

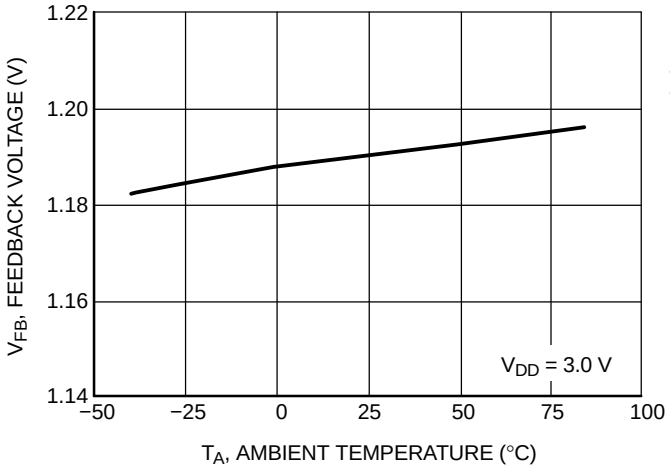


Figure 17. Feedback Voltage versus Ambient Temperature

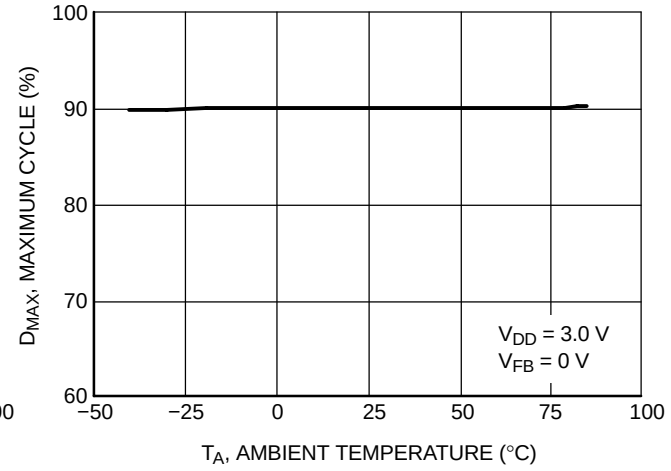


Figure 18. Maximum Duty Cycle versus Ambient Temperature

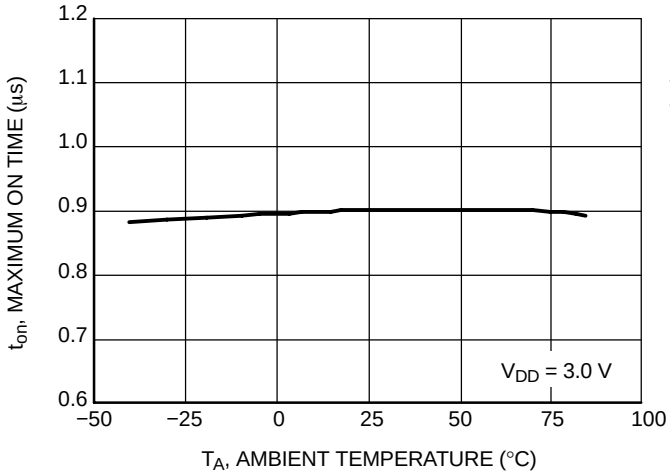


Figure 19. Maximum On Time versus Ambient Temperature

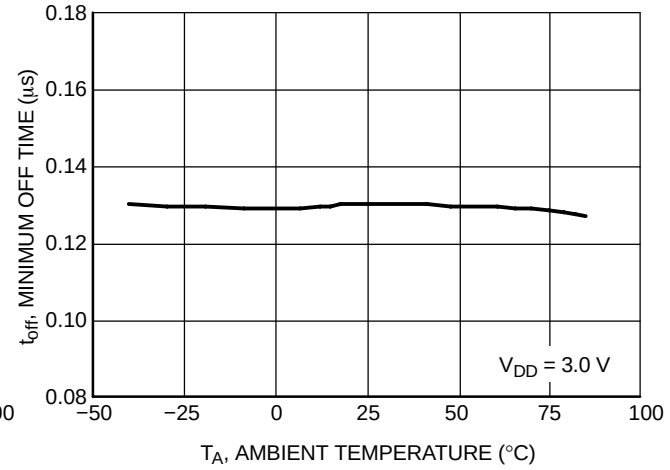


Figure 20. Minimum Off Time versus Ambient Temperature

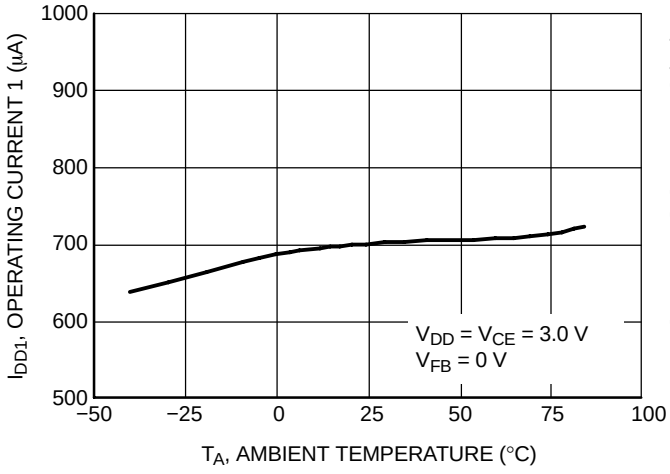


Figure 21. Operating Current 1 versus Ambient Temperature

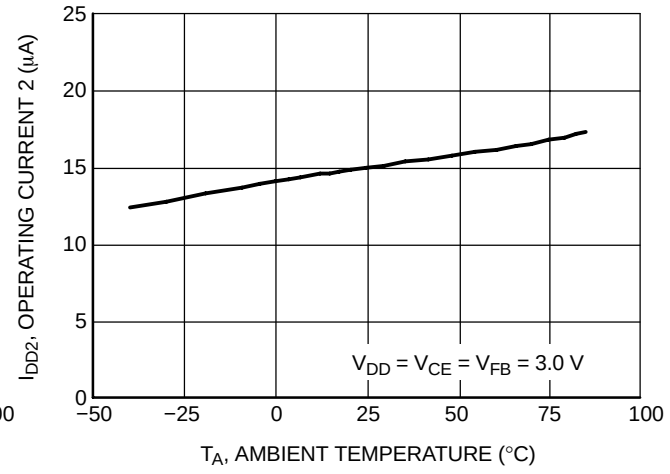


Figure 22. Operating Current 2 versus Ambient Temperature

TYPICAL CHARACTERISTICS

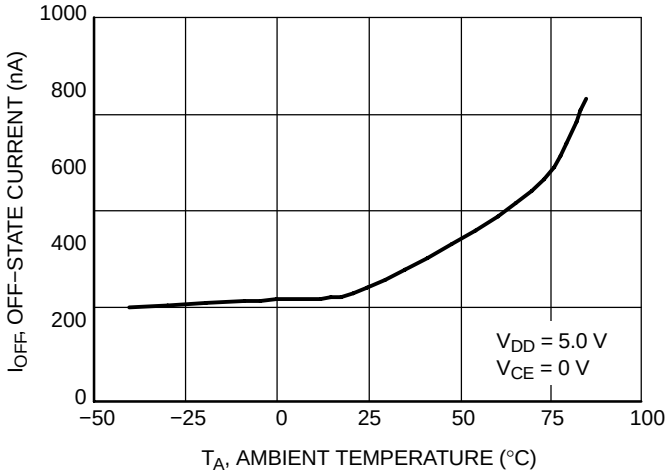


Figure 23. Off−State Current versus Ambient Temperature

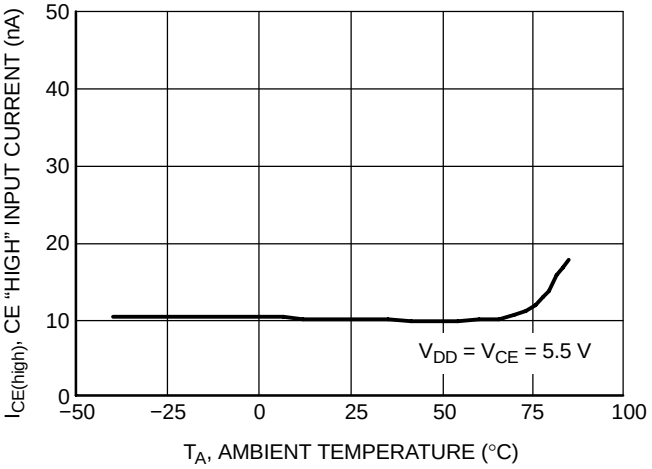


Figure 24. CE "High" Input Current versus Ambient Temperature

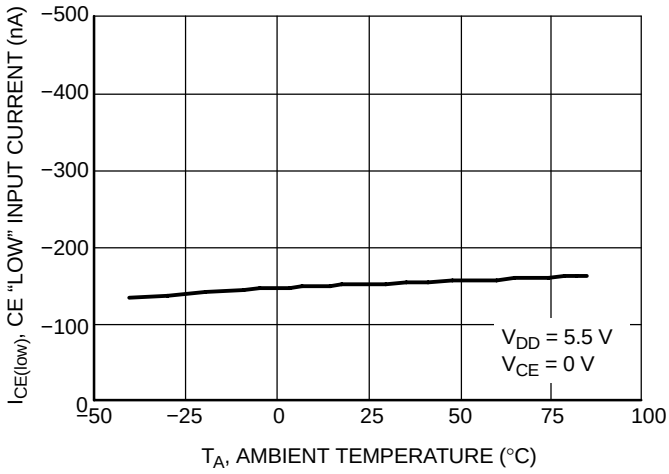


Figure 25. CE "Low" Input Current versus Ambient Temperature

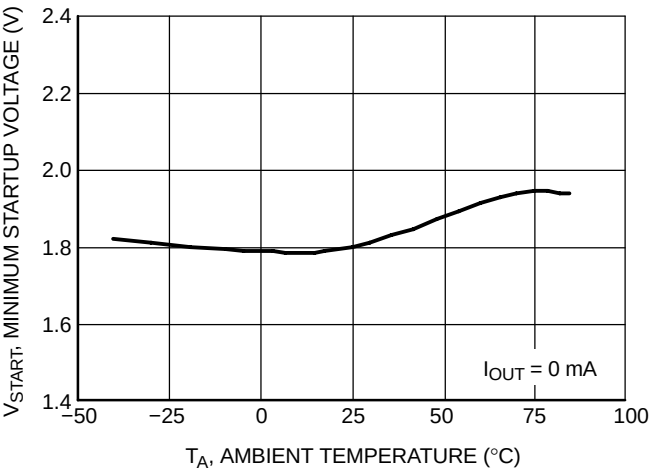


Figure 26. Minimum Startup Voltage versus Ambient Temperature

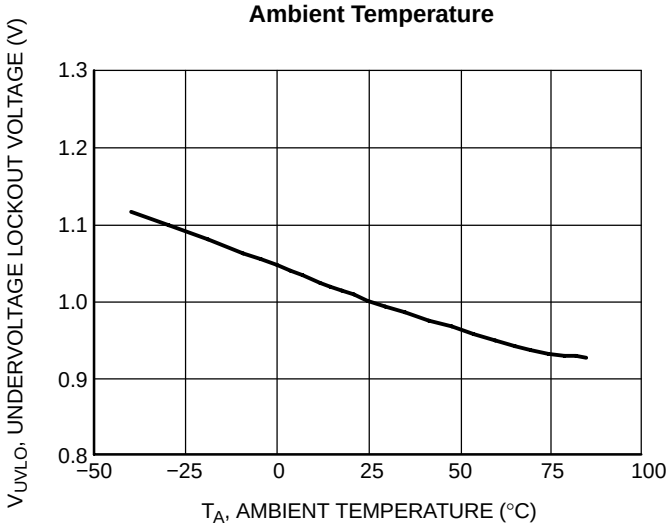


Figure 27. Undervoltage Lockout Voltage versus Ambient Temperature

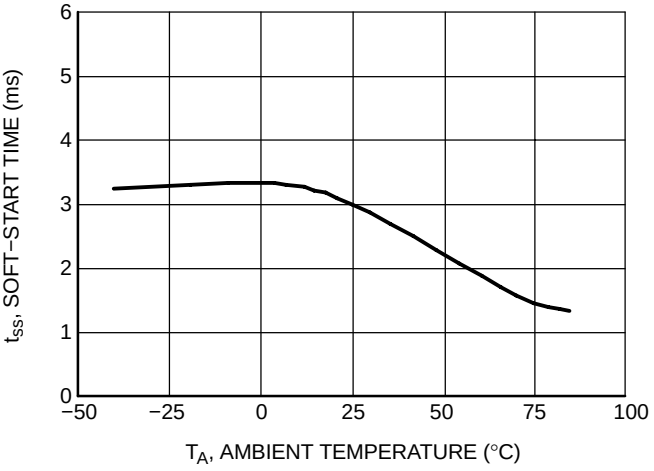


Figure 28. Soft−start Time versus Ambient Temperature

TYPICAL CHARACTERISTICS

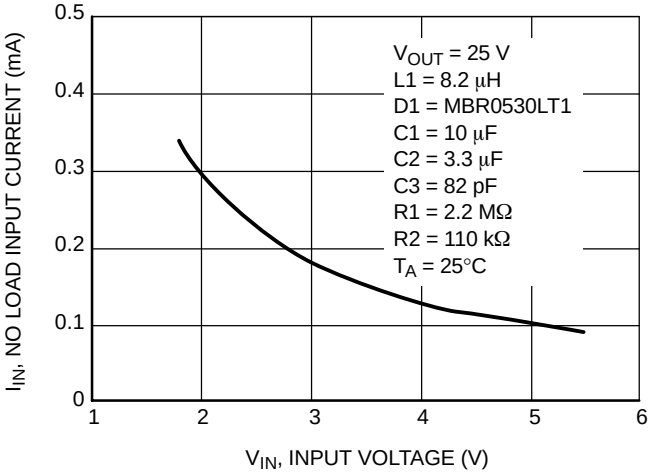


Figure 29. No Load Input Current versus Input Voltage

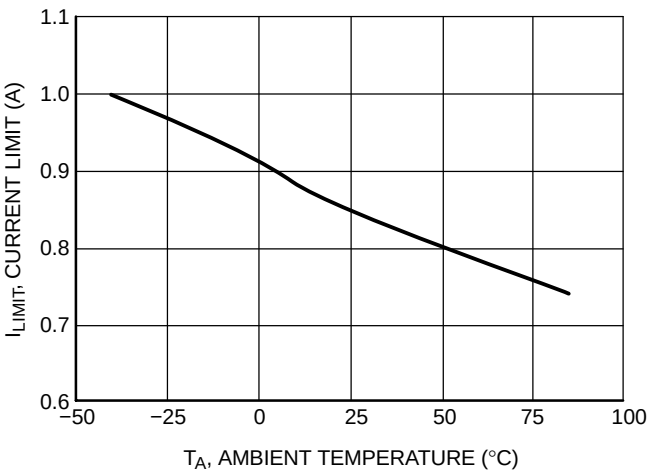


Figure 30. Current Limit versus Ambient Temperature

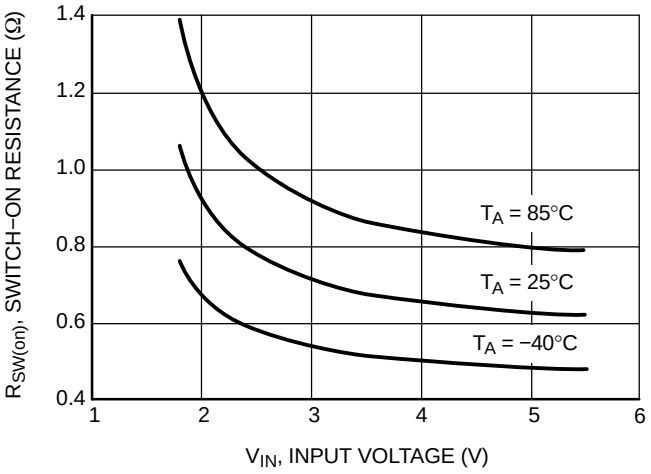


Figure 31. Switch−ON Resistance versus Input Voltage

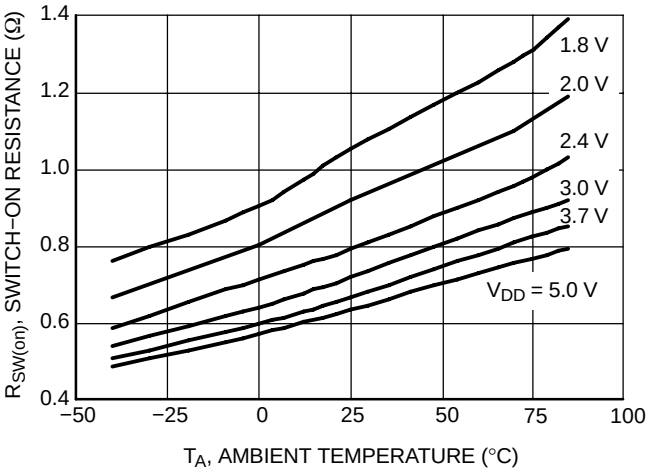


Figure 32. Switch−ON Resistance versus Ambient Temperature

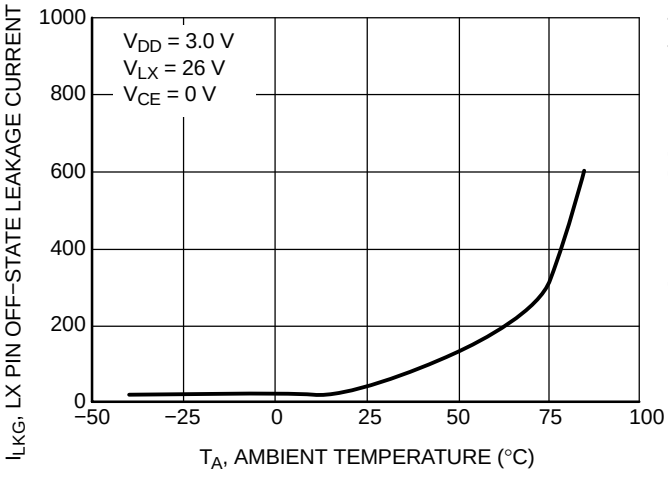


Figure 33. LX Pin OFF−State Leakage Current versus Ambient Temperature

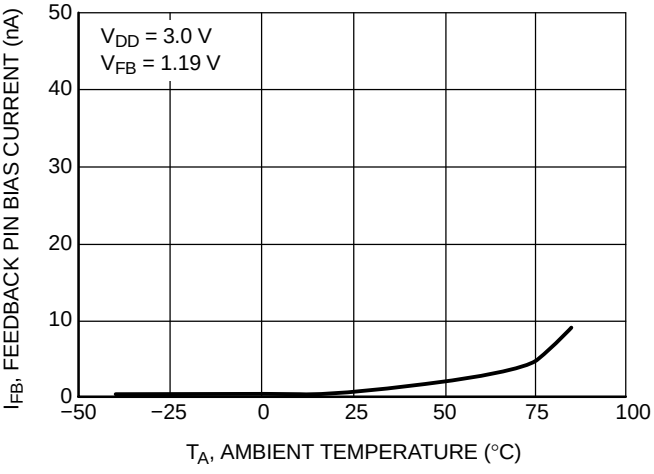
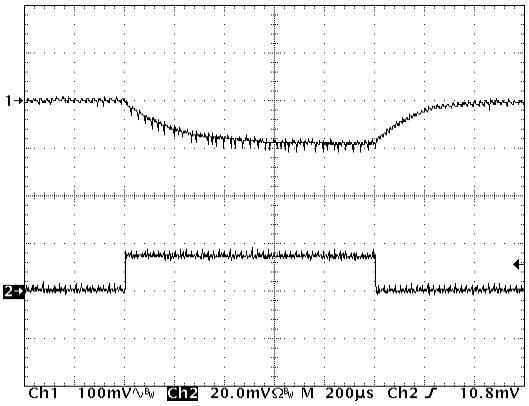


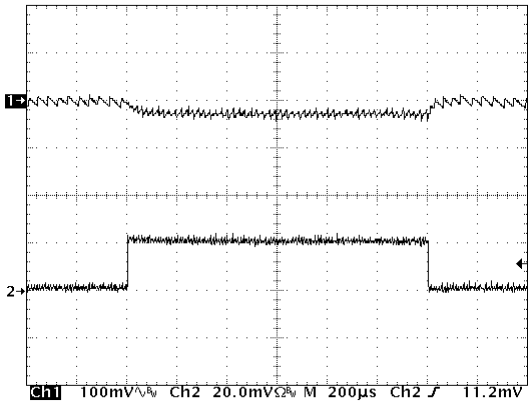
Figure 34. Feedback Pin Bias Current versus Ambient Temperature

TYPICAL CHARACTERISTICS



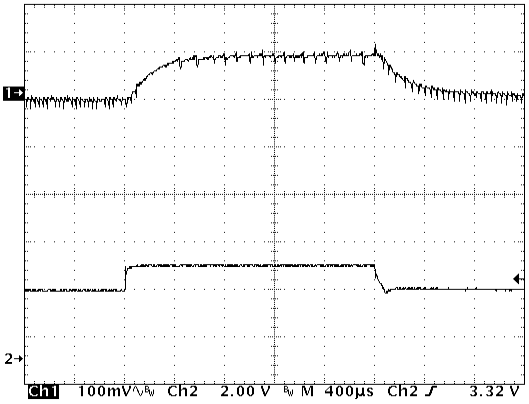
L1 = 8.2 µH, C1 = 10 µF, C2 = 3.3 µF, V_{IN} = 3.7 V
1. V_{OUT} = 25 V (AC Coupled), 100 mV/div
2. I_{OUT} = 1.0 mA to 15 mA, 20 mA/div

Figure 35. Load Transient Response (V_{OUT} = 25 V)



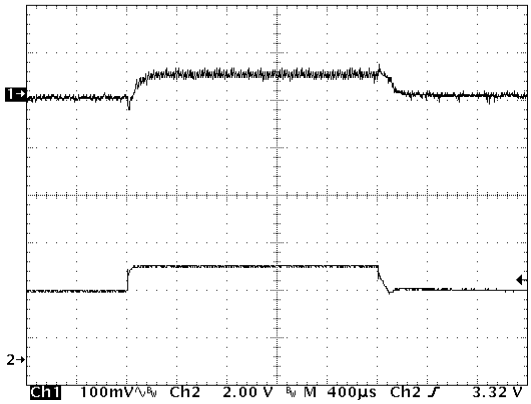
L1 = 8.2 µH, C1 = 10 µF, C2 = 4.7 µF, V_{IN} = 3.7 V
1. V_{OUT} = 15 V (AC Coupled), 100 mV/div
2. I_{OUT} = 1.0 mA to 20 mA, 20 mA/div

Figure 36. Load Transient Response (V_{OUT} = 15 V)



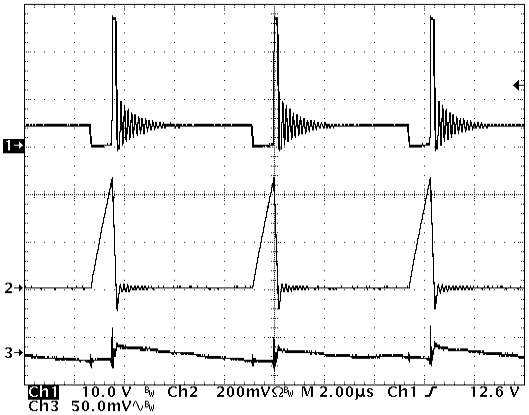
L1 = 8.2 µH, C1 = 10 µF, C2 = 3.3 µF, I_{OUT} = 15 mA
1. V_{OUT} = 25 V (AC Coupled), 100 mV/div
2. V_{IN} = 3.0 V to 4.0 V, 2.0 V/div

Figure 37. Line Transient Response (V_{OUT} = 25 V)



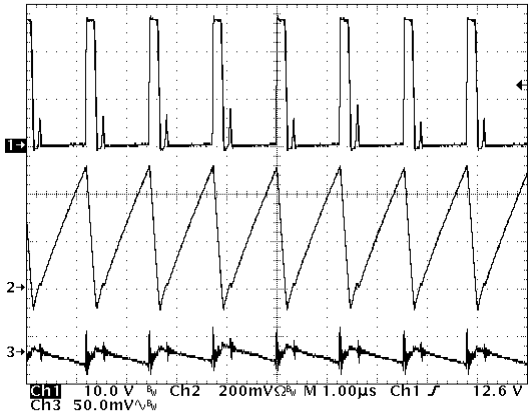
L1 = 8.2 µH, C1 = 10 µF, C2 = 4.7 µF, I_{OUT} = 15 mA
1. V_{OUT} = 15 V (AC Coupled), 100 mV/div
2. V_{IN} = 3.0 V to 4.0 V, 2.0 V/div

Figure 38. Line Transient Response (V_{OUT} = 15 V)



L1 = 8.2 µH, C1 = 10 µF, C2 = 3.3 µF, V_{IN} = 4.2 V,
V_{OUT} = 25 V, I_{OUT} = 5.0 mA
1. V_{LX}, 10 V/div
2. I_L, 200 mA/div
3. V_{ripple}, 50 mV/div

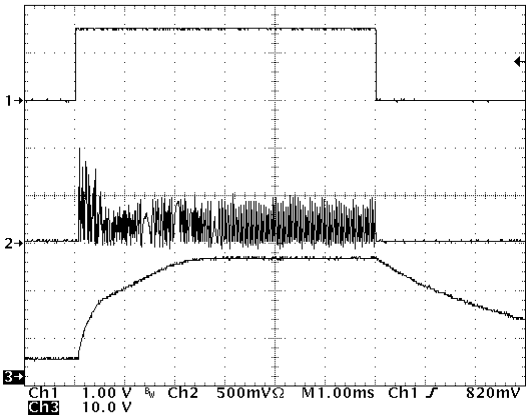
Figure 39. Operating Waveforms (Light Load)



L1 = 8.2 µH, C1 = 10 µF, C2 = 3.3 µF, V_{IN} = 4.2 V,
V_{OUT} = 25 V, I_{OUT} = 30 mA
1. V_{LX}, 10 V/div
2. I_L, 200 mA/div
3. V_{ripple}, 50 mV/div

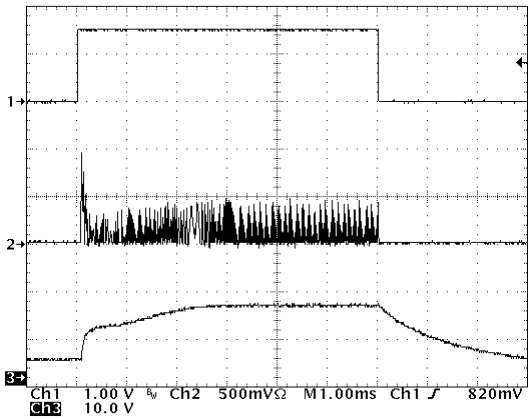
Figure 40. Operating Waveforms (Heavy Load)

TYPICAL CHARACTERISTICS



L1 = 8.2 μH, C1 = 10 μF, C2 = 3.3 μF, V_{IN} = 4.2 V,
I_{OUT} = 20 mA
1. V_{CE}, 0 V to 1.0 V to 0 V, 1.0 V/div
2. I_L, 500 mA/div
3. V_{OUT}, 10 mV/div

Figure 41. Startup/Shutdown Waveforms (V_{OUT} = 25 V)



L1 = 8.2 μH, C1 = 10 μF, C2 = 4.7 μF, V_{IN} = 4.2 V,
I_{OUT} = 25 mA
1. V_{CE}, 0 V to 1.0 V to 0 V, 1.0 V/div
2. I_L, 500 mA/div
3. V_{OUT}, 10 mV/div

Figure 42. Startup/Shutdown Waveforms (V_{OUT} = 15 V)

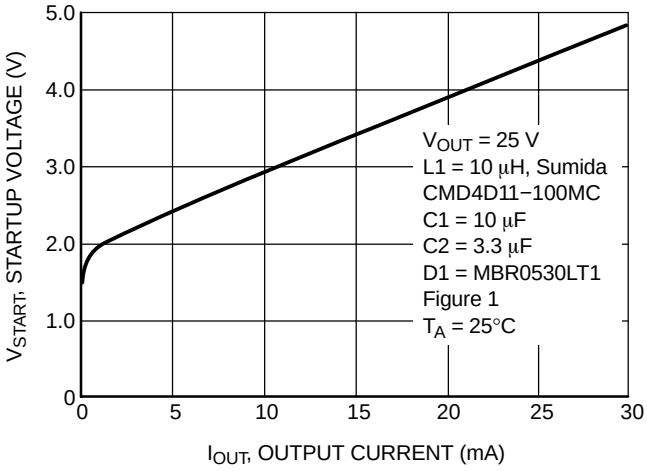


Figure 43. Startup Voltage versus Output Current (V_{OUT} = 25 V)

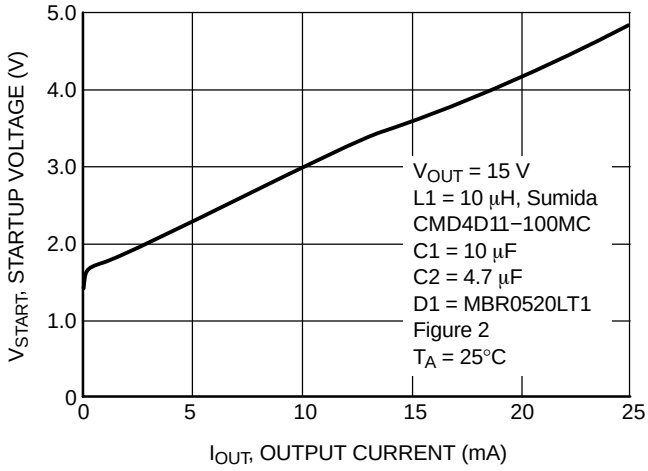


Figure 44. Startup Voltage versus Output Current (V_{OUT} = 15 V)

DETAILED OPERATING DESCRIPTION

Operation

The NCP1406 is a monolithic DC−DC switching converter optimized for single Lithium or two cells AA/AAA size batteries powered portable products.

The NCP1406 device consists of soft−start circuit, chip enable circuit, PFM comparator, voltage reference, PFM on/off timing control circuit, driver, current limit circuit, open−drain MOSFET switch, input voltage UVLO, thermal shutdown, and feedback pin short−circuit/ open−circuit protection. The device operating current is typically 15 μA, and can be further reduced to about 0.3 μA when the chip is disabled (V_{CE} < 0.3 V).

The operation of NCP1406 can be best understood by referring to the block diagram and typical application circuit in Figures 1 and 4. The PFM comparator monitors the output voltage via the external feedback resistor divider by comparing the feedback voltage with the reference voltage. When the feedback voltage is lower than the reference voltage, the PFM control and driver circuit turns on the N−Channel MOSFET switch and the current ramps up in the inductor. The switch will remain on for the maximum on−time, 0.90 μs, or until the current limit is reached, whichever occurs first. The MOSFET switch is then turned off and energy stored in the inductor will be discharged to the output capacitor and load through the Schottky diode. The MOSFET switch will be turned off for at least the minimum off−time, 0.13 μs, and will remain off if the feedback voltage is higher than the reference voltage and output capacitor will be discharged to sustain the output current, until the feedback voltage is again lower than reference voltage. This switching cycle is then repeated to attain voltage regulation.

Soft−Start

There is a soft−start circuit in NCP1406. When power is applied to the device, the soft−start circuit limits the device to switch at a small duty cycle initially, the duty cycle is then increased gradually until the output voltage is in regulation. With the soft−start circuit, the output voltage over−shoot is minimized and the startup capability with heavy loads is also improved.

ON/OFF Timing Control

The maximum on−time is typically 0.90 μs, whereas, the minimum off−time is typically 0.13 μs. The switching frequency can be up to 1.0 MHz.

Voltage Reference and Output Voltage

The internal bandgap voltage reference is trimmed to 1.19 V at an accuracy of ±1.0% at 25°C. The voltage reference is connected to the non−inverting input of the PFM comparator and the inverting input of the PFM comparator is connected to the FB pin. The output voltage can be set by connected an external resistor voltage divider from the V_{OUT} to the FB pin. With the internal 26 V MOSFET switch, the output voltage can be set between V_{IN} to 25 V.

Current Limit

The current limit circuit limits the maximum current flowing through the LX pin to typical 0.80 A during the MOSFET switch turn−on period. When the current limit is exceeded, the switch will be turned off. With the current limit circuit, the peak inductor current is limited to the current limit, saturation of inductor is prevented and output voltage over−shoot during startup can also be minimized.

N−Channel MOSFET Switch

The NCP1406 is built−in with a 26 V open drain N−Channel MOSFET switch which allows high output voltage up to 25 V to be generated from simple step−up topology.

Input Voltage Undervoltage Lockout

There is an undervoltage lockout circuit continuously monitoring the voltage at the VDD pin. The device will be disabled if the VDD pin voltage drops below the UVLO threshold voltage.

FB Pin Short−Circuit/Open−Circuit Protection

With the FB protection circuit, the drain−to−source leakage current of the N−Ch MOSFET is sensed. When the FB pin connection is shorted or opened, the converter switches at maximum duty cycle, the peak of V_{LX} and the V_{OUT} will build up, and the leakage current will increase. When the leakage current increases to a certain level, the converter will stop switching with the protection circuit. Therefore, the peak of V_{LX} will stop increasing at a certain level before the N−Ch MOSFET is damaged immediately. However, the sensing of the leakage current is not very accurate and cannot be too close to the normal 26 V maximum operating condition. Therefore, the V_{LX} is around 30 V to 40 V during a FB pin protection fault.

Thermal Shutdown

When the chip junction temperature exceeds 140°C, the entire IC is shutdown. The IC will resume operation when the junction temperature drops below 130°C.

Enable/Disable Operation

The NCP1406 offers IC shutdown mode by the chip enable pin (CE pin) to reduce current consumption. An internal 150 nA pullup current source ties the CE pin to the VDD pin by default. Therefore, the user can float the CE pin for permanent “ON”. When the voltage at the CE pin is equal to or greater than 0.9 V, the chip will be enabled, which means the device is in normal operation. When the voltage at the CE pin is less than 0.3 V, the chip is disabled, which means IC is shutdown. During shutdown, the IC supply current reduces to 0.3 μA and the LX pin enters high impedance state. However, the input remains connected to the output through the inductor and the Schottky diode, keeping the output voltage one diode forward voltage drop below the input voltage.

APPLICATIONS CIRCUIT INFORMATION

External Component Selection

Inductor

The NCP1406 is designed to work well with a range of inductance values; the actual inductance value depends on the specific application, output current, efficiency, and output ripple voltage. For step−up conversion, the device works well with inductance ranging from 1.0 μH to 47 μH. In general, an inductor with small DCR, usually less than 1.0 Ω, should be used to minimize loss. It is necessary to choose an inductor with saturation current greater than the peak switching current in the application.

NCP1406 is designed to operate in discontinuous conduction mode (DCM). Stable operation in continuous conduction mode is not guaranteed. For each switching cycle, if the internal MOSFET is switched on, it will be switched off only when either the maximum on−time, t_{on}, of typical 0.9 μs is reached or the inductor current limit of 0.8 A is met, whichever is earlier. Therefore, the designer can choose to use either the maximum on−time or the current limit to turn off the MOSFET switch. If the goal is targeted to minimize output ripple voltage, the maximum on−time of 0.9 μs should be used to turn off the MOSFET; however, the maximum output current will be reduced. If we target to maximize the output current, the current limit should be chosen to turn off the MOSFET, but this method will result in a larger output ripple voltage.

If the maximum on−time is used to turn off the MOSFET in order to achieve a smaller output ripple voltage, it is critical to ensure that the maximum on−time has been reached before the current limit is met. To ensure this condition is met, the inductance L should be selected according to the following inequality:

$$L > \frac{V_{IN}}{I_{LIM}} \times t_{on(max)}$$

Where V_{IN} is the input voltage, I_{LIM} is the current limit which is typically 0.8 A, and $t_{on(max)}$ is the maximum on−time which is typically 0.9 μs.

The maximum output current under this maximum on−time control can be calculated from the equation below:

$$I_{OUT(max)} = \frac{V_{IN}^2 \times t_{on(max)}}{2L(V_{OUT} + V_D)} \times \eta$$

Where V_{IN} is the input voltage, $t_{on(max)}$ is the maximum on−time which is typically 0.9 μs, L is the selected inductance, V_{OUT} is the desired output voltage, V_D is the Schottky diode forward voltage, and η is the conversion efficiency which can be assumed typically 80% for better margin for estimation.

The above equation for calculating $I_{OUT(max)}$ is for DCM mode operation only. In fact, the operation can go beyond the critical conduction mode if the current loading further increases above the maximum output current in DCM mode. However, stable operation in continuous conduction mode is hard to achieve, and double pulsing or group pulsing will occur which will lead to much larger inductor current ripple and result in larger output ripple voltage.

If the current limit is used to turn off the MOSFET in order to maximize the output current, it is critical to make sure that the current limit has been reached before the maximum on−time is met. To ensure this condition is met, the inductance L should be selected according the following inequality:

$$L < \frac{V_{IN}}{I_{LIM}} \times t_{on(max)}$$

Since there is 100 ns internal propagation delay between the time the current limit is reached and the time the MOSFET is switched off, the actual peak inductor current can be obtained from the equation below:

$$I_{PK} = I_{LIM} + \frac{V_{IN}}{L} \times 100\ ns$$

Where I_{LIM} is the current limit which is typically 0.8 A, V_{IN} is the input voltage, L is the selected inductance.

Then the maximum output current under the current limit control can be calculated by the equation below:

$$I_{OUT(max)} = \frac{V_{IN} \times I_{PK}}{2(V_{OUT} + V_D)} \times \eta$$

This method can achieve larger maximum output current in DCM mode. Since the current limit is reached in each switching cycle, the inductor current ripple is larger resulting in larger output voltage ripple. Two ceramic capacitors in parallel can be used at the output to keep the output ripple small.

Diode

The diode is the main source of loss in DC–DC converters. The key parameters which affect their efficiency are the forward voltage drop, V_D, and the reverse recovery time, trr. The forward voltage drop creates a loss just by having a voltage across the device while a current flowing through it. The reverse recovery time generates a loss when the diode is reverse biased, and the current appears to actually flow backwards through the diode due to the minority carriers being swept from the P–N junction. A Schottky diode with the following characteristics is recommended:

1. Small forward voltage, $V_D < 0.3$ V.
2. Small reverse leakage current.
3. Fast reverse recovery time/switching speed.
4. Rated current larger than peak inductor current, $I_{rated} > I_{PK}$.
5. Reverse voltage larger than output voltage, $V_{reverse} > V_{OUT}$.

Input Capacitor

The input capacitor stabilizes the input voltage and minimizes peak current ripple from the power source. The capacitor should be connected directly to the inductor pin where the input voltage is applied in order to effectively smooth the input current ripple and voltage due to the inductor current ripple. The input capacitor is also used to decouple the high frequency noise from the VDD supply to the internal control circuit; therefore, the capacitor should be placed close to the VDD pin. For some particular applications, separate decoupling capacitors should be provided and connected directly to the VDD pin for better decoupling effect. A larger input capacitor can better reduce ripple current at the input. By reducing the ripple current at the input, the converter efficiency can be improved. In general, a 4.7 μF to 22 μF ceramic input capacitor is sufficient for most applications. X5R and X7R type ceramic capacitors are recommended due to their good capacitance tolerance and stable temperature behavior.

Output Capacitor

The output capacitor is used for sustaining the output voltage when no current is delivering from the input, and smoothing the ripple voltage. Ceramic capacitors should be used for the output capacitor due to their low ESR at high switching frequency and low profile in physical size. In general, a 3.3 μF to 22 μF ceramic capacitor should be appropriate for most applications. X5R and X7R type ceramic capacitors are recommended due to their good capacitance tolerance and temperature coefficient, while Y5V type ceramic capacitors are not recommended since both their capacitance tolerance and temperature coefficient are too large. The output voltage ripple and switching frequency at nominal load current can be calculated by the following equations:

$$V_{ripple} = \frac{I_{OUT}}{C_{OUT}}\left(\frac{1}{f_{SW(Load)}} - \frac{I_{PK} \times L}{V_{OUT} + V_D - V_{IN}}\right) - (I_{PK} - I_{OUT}) \times ESR$$

$$f_{SW(Load)} = \frac{2I_{OUT}(V_{OUT} + V_D - V_{IN})}{I_{PK}^2 \times L}$$

Where I_{OUT} is the nominal load current, C_{OUT} is the selected output capacitance, I_{PK} is the peak inductor current, L is the selected inductance, V_{OUT} is the output voltage, V_D is the Schottky diode forward voltage, V_{IN} is the input voltage, ESR is the ESR of the output capacitor.

Feedback Resistors

To achieve better efficiency at light load, a high impedance feedback resistor divider should be used. Choose the lower resistor R2 value from the range of 10 kΩ to 200 kΩ. The value of the upper resistor R1 can then be calculated from the equation below:

$$R_1 = R_2\left(\frac{V_{OUT}}{1.19} - 1\right)$$

1% tolerance resistors should be used for both R_1 and R_2 for better V_{OUT} accuracy.

Feedforward Capacitor

A feedforward capacitor is required to add across the upper feedback resistor to avoid double pulsing or group pulsing at the switching node which will cause larger inductor ripple current and higher output voltage ripple. With adequate feedforward capacitance, evenly distributed single pulses at the switching node can be achieved. The range of the capacitor value is from 5.0 pF to 200 pF for most applications. For NCP1406, the lower the switching frequency, the larger the feedforward capacitance is needed; besides, the higher the output voltage, the larger the feedforward capacitance is required. For the initial trial value of the feedforward capacitor, the following equation can be used; however, the actual value needs fine tuning:

$$C_{FF} \approx \frac{1}{2 \times \pi \times \frac{f_{SW(Load)}}{20} \times R1}$$

Output Voltage Higher than 25 V

The NCP1406 can be used to generate output voltage higher than 25 V by adding an external high voltage N−Ch MOSFET in series with the internal MOSFET switch as shown in Figure 51. The drain−to−source breakdown voltage of the external MOSFET must be at least 1.0 V higher than the output voltage. The diode D2 connected across the gate and the source of the external MOSFET helps the external MOSFET to turn off and ensures that most of the voltage drops across the external MOSFET during the switch−off period. Since the high voltage external MOSFET is in series with the internal MOSFET, higher break down voltage is achieved but the current capability is not increased.

There is an alternative application circuit shown in Figure 53 which can output voltage up to 30 V. For this circuit, a diode−capacitor charge−pump voltage doubler constructed by D2, D3 and C1 is added. During the internal MOSFET switch−on time, the LX pin is shorted to ground and D2 will charge up C1 to the stepped up voltage at the cathode of D1. During the MOSFET switch−off time, the voltage at V_{OUT} will be almost equal to the double of the voltage at the cathode of D1. The V_{OUT} is monitored by the FB pin via the resistor divider and can be set by the resistor values. Since the maximum voltage at the cathode of D1 is 15 V, the maximum V_{OUT} is 30 V. The value of C1 can be in the range of 0.47 μF to 2.2 μF.

Negative Voltage Generation

The NCP1406 can be used to produce a negative voltage output by adding a diode−capacitor charge−pump circuit (D2, D3, and C1) to the LX pin as shown in Figure 50. The feedback voltage resistor divider is still connected to the positive output to monitor the positive output voltage and a small value capacitor is used at C2. When the internal MOSFET switches off, the voltage at the LX pin charges up the capacitor through diode D2. When the MOSFET

switches on, the capacitor C1 is effectively connected like a reversed battery and C1 discharges the stored charge through the $R_{DS(on)}$ of the internal MOSFET and D3 to charge up C_{OUT} and builds up a negative voltage at V_{OUT}. Since the negative voltage output is not directly monitored by the NCP1406, the output load regulation of the negative output is not as good as the standard positive output circuit. The resistance values of the resistors of the voltage divider can be one−tenth of those used in the positive output circuit in order to improve the regulation at light load.

The application circuit in Figure 54, is actually the combination of the application circuits in Figures 50 and 51.

Step−Down Converter

NCP1406 can be configured as a simple step−down converter by using the open−drain LX pin to drive an external P−Ch MOSFET as shown in Figure 52. The resistor R_{GS} is used to switch off the P−Ch MOSFET during the switch−off period. Too small a resistance value should not be used for R_{GS}, otherwise, the efficiency will be reduced. R_{GS} should be in the range of 510 Ω to 5.1 kΩ.

White LED Driver

The NCP1406 can be used as a constant current LED driver which can drive up to 6 white LEDs in series as shown in Figure 57. The LED current can be set by the resistance value of R_S. The desired LED current can be calculated by the equation below:

$$I_{LED} = \frac{1.19}{R_S}$$

Moreover, the brightness of the LEDs can be adjusted by a DC voltage or a PWM signal with an additional circuit illustrated below:

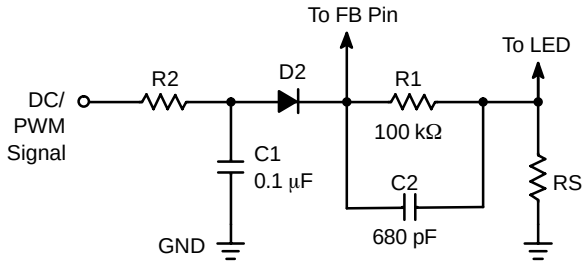


Figure 45.

With this additional circuit, the maximum LED current is set by the above equation. The value of R2 can be obtained by the following equation:

$$R2 = \frac{V_{MAX} \times D_{CTL(MAX)} - V_D - 1.19}{\left(\frac{(I_{LED(MAX)} - I_{LED(MIN)}) \times R_S}{R1}\right)}$$

V_{MAX} is the maximum voltage of the control signal, $D_{CTL(MAX)}$ is the maximum duty cycle of the control signal, V_D is the diode forward voltage, $I_{LED(MAX)}$ is the maximum LED current and $I_{LED(MIN)}$ is the minimum LED current. If a PWM control signal is used, the signal frequency can be in the range of 5.0 kHz to 30 kHz. It is recommended to keep the input PWM frequency about 15 kHz to avoid generating audio noise.

PCB Layout Guidelines

PCB layout is very important for switching converter performance. All the converter's external components should be placed closed to the IC. The schematic, PCB trace layout, and component placement of the step−up DC−DC converter demonstration board are shown in Figure 46 to Figure 49 for PCB layout design reference. The following guidelines should be observed:

1. Grounding

Single−point grounding should be used for the output power return ground, the input power return ground, and the device switch ground to reduce noise. The input ground and output ground traces must be thick and short enough for current to flow through. A ground plane should be used to reduce ground bounce.

2. Power Traces

Low resistance conducting paths (short and thick traces) should be used for the power carrying traces to reduce power loss so as to improve efficiency (short and thick traces for connecting the inductor L can also reduce stray inductance). The path between C1, L1, D1, and C2 should be kept short. The trace from L to LX pin of the IC should also be kept short.

3. External Feedback Components

Feedback resistors R1 and R2, and feedforward capacitor C3 should be located as close to the FB pin as possible to minimize noise picked up by the FB pin. The ground connection of the feedback resistor divider should be connected directly to the GND pin.

4. Input Capacitor

The input capacitor should be located close to both the input to the inductor and the VDD pin of the IC.

5. Output Capacitor

The output capacitor should be placed close to the output terminals to obtain better smoothing effect on output ripple voltage.

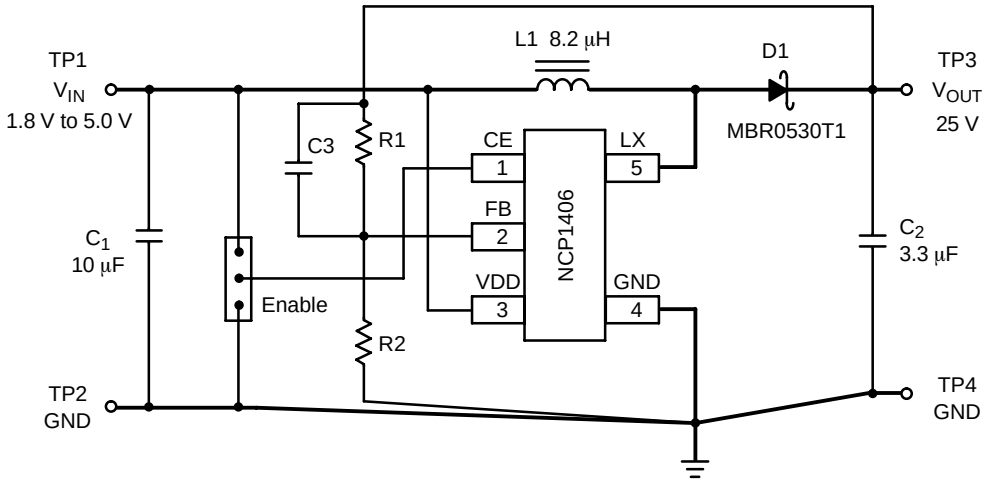


Figure 46. Step−Up Converter Demonstration Board Schematic

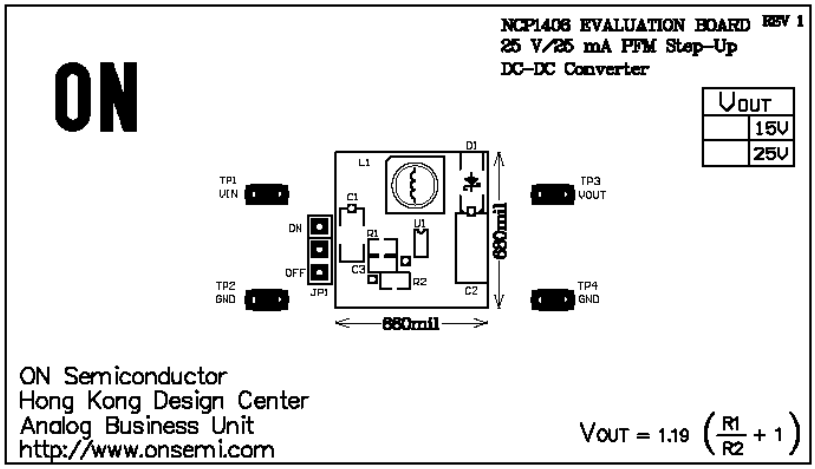


Figure 47. Step−Up Converter Demonstration Board Top Layer Component Silkscreen

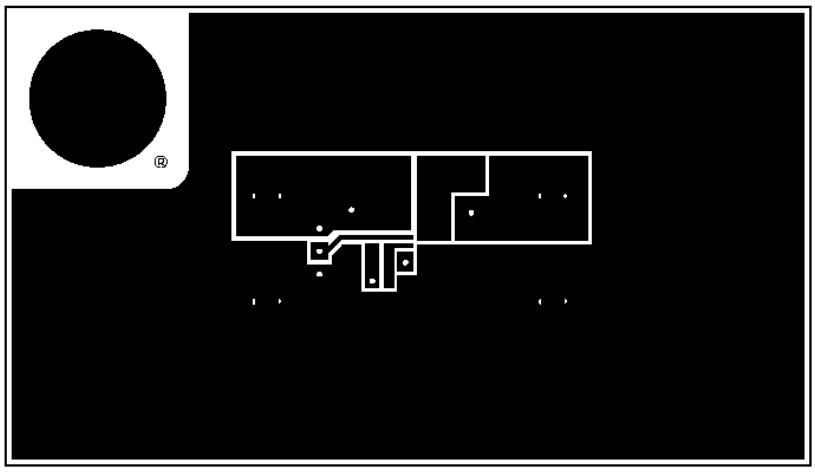


Figure 48. Step−Up Converter Demonstration Board Top Layer Copper

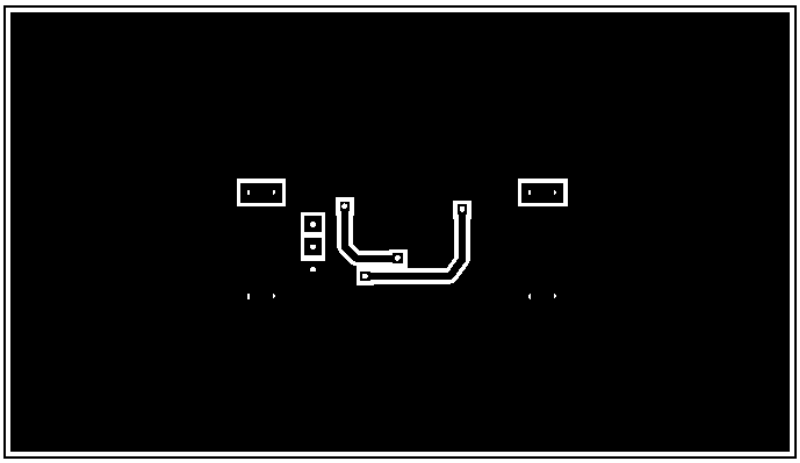
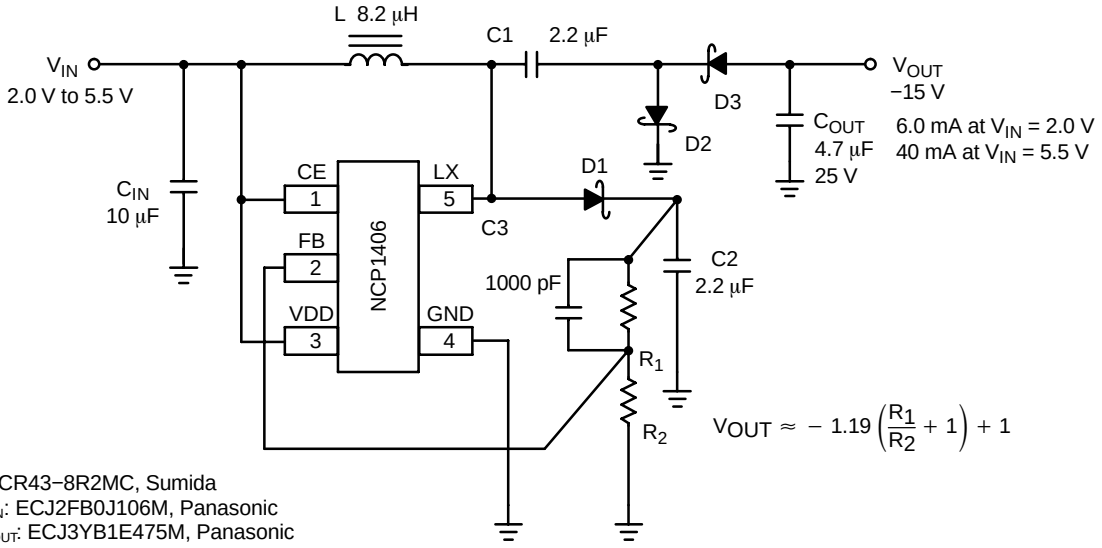


Figure 49. Step−Up Converter Demonstration Board Bottom Layer Copper

Components Supplier

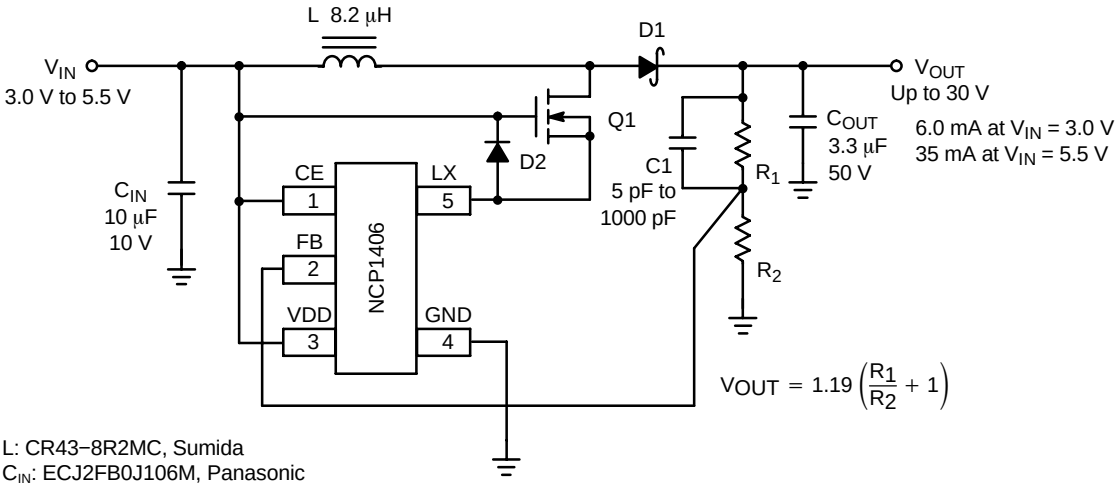
Output Voltage	Parts	Supplier	Part Number	Description	Website
15 V	C1	Panasonic	ECJ2FB0J106M	Ceramic Capacitor 0805 10 μF/6.3 V	www.panasonic.com
	C2	Panasonic	ECJ3YB1E475M	Ceramic Capacitor 1206 4.7 μF/25 V	www.panasonic.com
	C3	Panasonic	ECJ1VC1H560K	Ceramic Capacitor 0603 56 pF/50 V	www.panasonic.com
	D1	ON Semiconductor	MBR0520LT1	Schottky Power Rectifier 20 V/500 mA	www.onsemi.com
	L1	Sumida Electric Co. Ltd	CMD4D11−100MC	Inductor 10 μH 1.2 mm Low Profile	www.sumida.com
	R1	Panasonic	ERJ3GEYJ135V	Resistor 0603 1.3 MΩ	www.panasonic.com
	R2	Panasonic	ERJ3GEYJ114V	Resistor 0603 110 kΩ	www.panasonic.com
	U1	ON Semiconductor	NCP1406SNT1	25 V Step−up DC−DC Converter	www.onsemi.com
25 V	C1	Panasonic	ECJ2FB0J106M	Ceramic Capacitor 0805 10 μF/6.3 V	www.panasonic.com
	C2	Panasonic	ECJ5YB1H335M	Ceramic Capacitor 1812 3.3 μF/50 V	www.panasonic.com
	C3	Panasonic	ECJ1VC1H151K	Ceramic Capacitor 0603 150 pF/50 V	www.panasonic.com
	D1	ON Semiconductor	MBR0530LT1	Schottky Power Rectifier 30 V/500 mA	www.onsemi.com
	L1	Sumida Electric Co. Ltd	CMD4D11−100MC	Inductor 10 μH 1.2 mm Low Profile	www.sumida.com
	R1	Panasonic	ERJ3GEYJ225V	Resistor 0603 2.2 MΩ	www.panasonic.com
	R2	Panasonic	ERJ3GEYJ114V	Resistor 0603 110 kΩ	www.panasonic.com
	U1	ON Semiconductor	NCP1406SNT1	25 V Step−up DC−DC Converter	www.onsemi.com

OTHER APPLICATION CIRCUITS



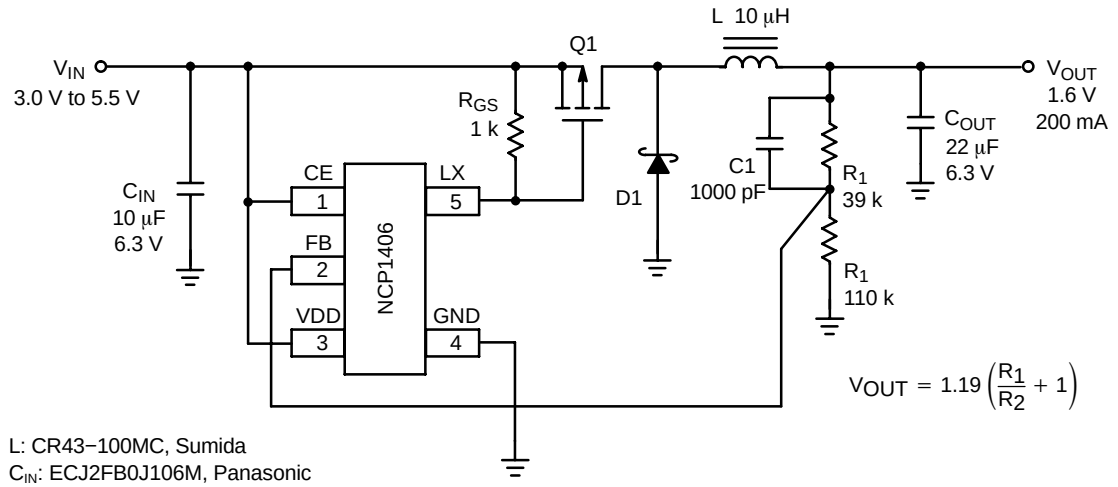
L: CR43−8R2MC, Sumida
C_{IN}: ECJ2FB0J106M, Panasonic
C_{OUT}: ECJ3YB1E475M, Panasonic
C1: ECJ2FB1C225K, Panasonic
C2: ECJ2FB1C225K, Panasonic
C3: ECJ1VC1H102J, Panasonic
D1, D2: MBR0520LT1, ON Semiconductor
D3: MBR0520LT1 x 2, ON Semiconductor

Figure 50. Positive−to−Negative Output Converter for Negative LCD Bias



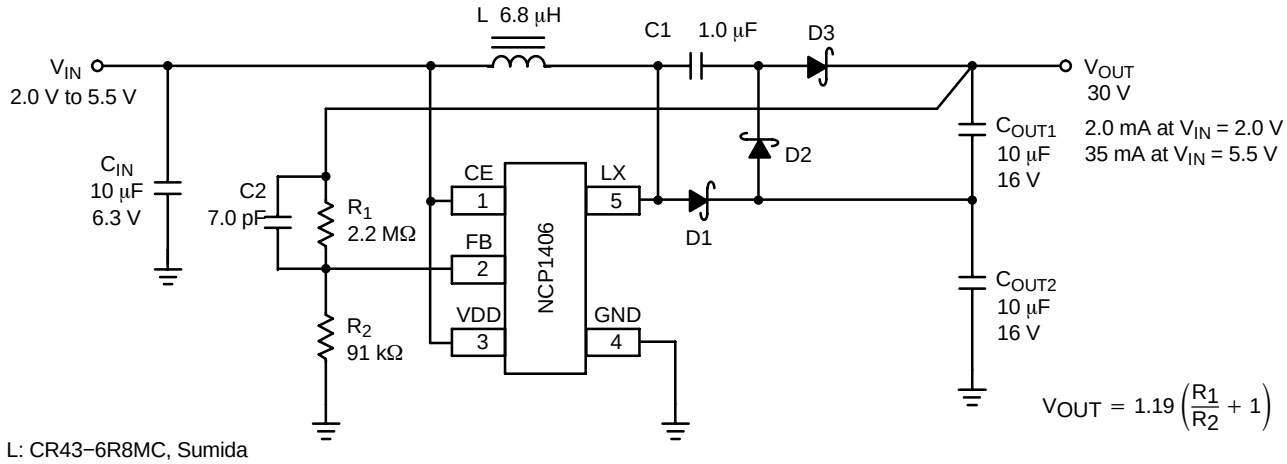
L: CR43−8R2MC, Sumida
C_{IN}: ECJ2FB0J106M, Panasonic
C_{OUT}: ECJ5YB1H335M, Panasonic
Q1: MGSF1N03T1, ON Semiconductor / NTHS5402T1, ON Semiconductor
D1: MBR0530T1, ON Semiconductor
D2: MMSD914T1, ON Semiconductor

Figure 51. Step−Up DC−DC Converter with 30 V Output Voltage



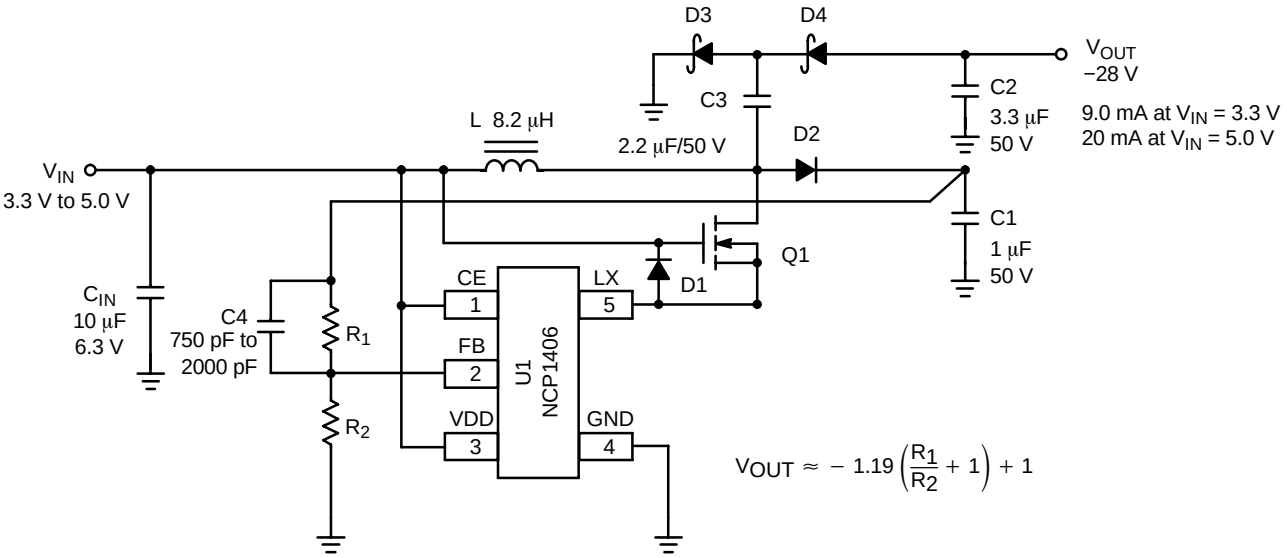
L: CR43−100MC, Sumida
C_{IN}: ECJ2FB0J106M, Panasonic
C_{OUT}: ECJHVB0J226M, Panasonic
Q1: MGSF1P02LT1, ON Semiconductor
D1: MBR0530T1, ON Semiconductor

Figure 52. Step−Down DC−DC Converter with 1.6 V Output Voltage for DSP Circuit



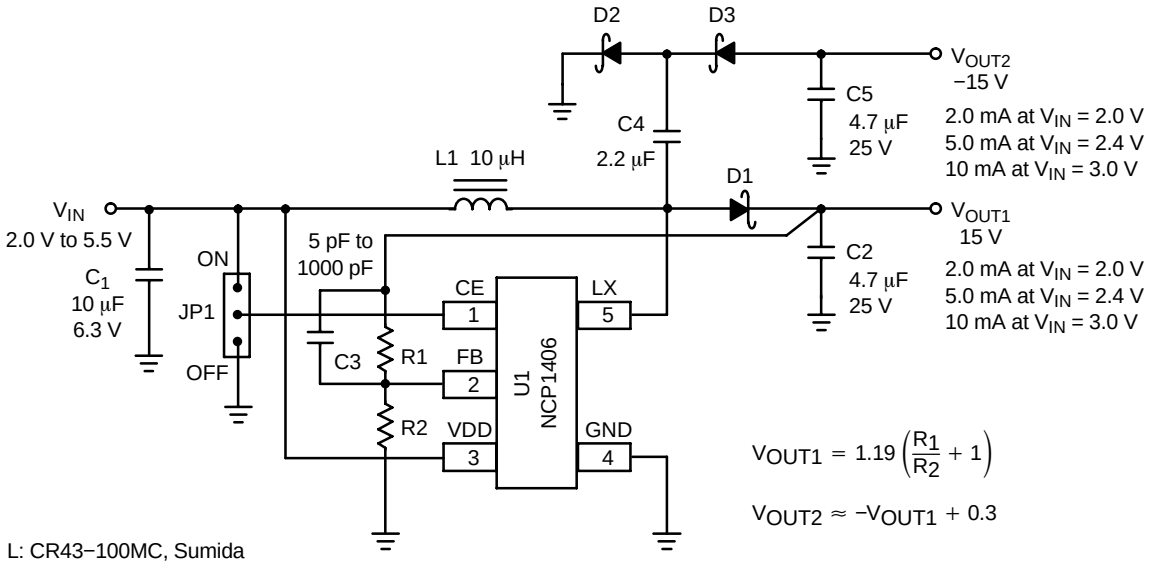
L: CR43−6R8MC, Sumida
C_{IN}: ECJ2FB0J106M, Panasonic
C_{OUT1}, C_{OUT2}: ECJ3YB1C106M, Panasonic
C1: ECJ2FB1C225K, Panasonic
D1, D2, D3: MBR0540T1, ON Semiconductor

Figure 53. Step−Up DC−DC Converter with 30 V Output Voltage



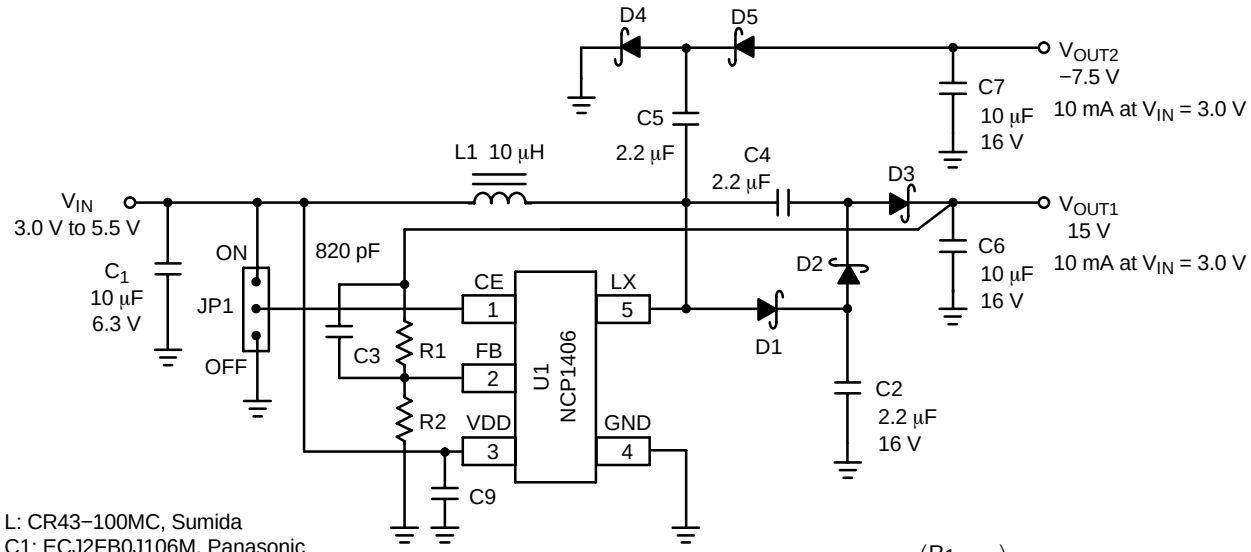
L: CR43−8R2MC, Sumida
C_{IN}: ECJ2FB0J106M, Panasonic
C1: ECJGVB1C105M, Panasonic
C2: ECJ5YB1H335M, Panasonic
C3: ECJ4YB1H105M, Panasonic
Q1: MGSF1N03T1, ON Semiconductor /
NTHS5402T1, ON Semiconductor
D1, D2: MMSD914T1, ON Semiconductor
D3: MBR0530T1, ON Semiconductor
D4: MBR0530T1 x 2, ON Semiconductor

Figure 54. Voltage Inverting DC−DC Converter with −28 V Output Voltage



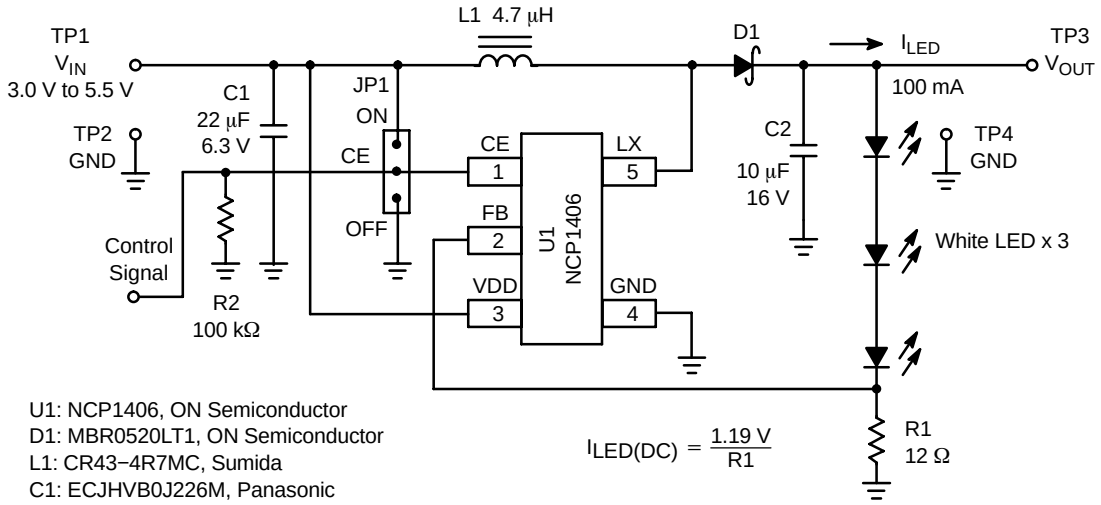
L: CR43−100MC, Sumida
C1: ECJ2FB0J106M, Panasonic
C2, C5: ECJ3YB1E475M, Panasonic
C3: ECJ1VC1H102J, Panasonic
C4: ECJ2FB1C225K, Panasonic
D1: MBR0520LT1, ON Semiconductor
D2, D3: MBR0520LT1 x 2, ON Semiconductor
R1: 1.3 MΩ
R2: 110 kΩ

Figure 55. +15 V, −15 V Outputs Converter for LCD Bias Supply



L: CR43−100MC, Sumida
C1: ECJ2FB0J106M, Panasonic
C6, C7: ECJ3YB1C106M, Panasonic
C3: ECJ1VC1H821J, Panasonic
C2, C4, C5: ECJ2FB1C225K, Panasonic
D1, D2, D3, D4, D5: MBR0520LT1, ON Semiconductor
R1: 1.3 MΩ
R2: 110 kΩ

Figure 56. +15 V, −7.5 V Outputs Converter for CCD Supply Circuit

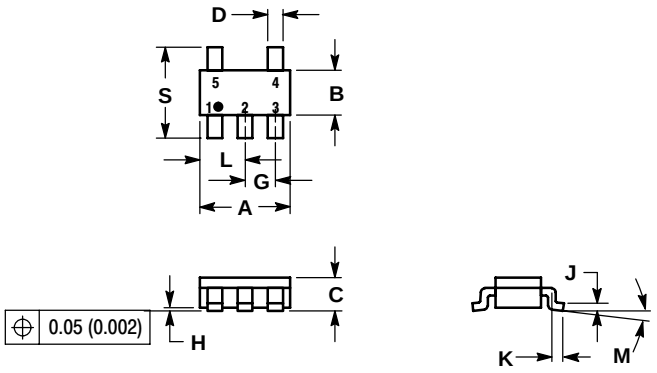


U1: NCP1406, ON Semiconductor
D1: MBR0520LT1, ON Semiconductor
L1: CR43−4R7MC, Sumida
C1: ECJHVB0J226M, Panasonic
C2: ECJ3YB1C106M, Panasonic
LED1, LED2, LED3: LWH1033 (Luxpia)
R1: 12 Ω
R2: 100 kΩ

Figure 57. White LEDs Driver Circuit

PACKAGE DIMENSIONS

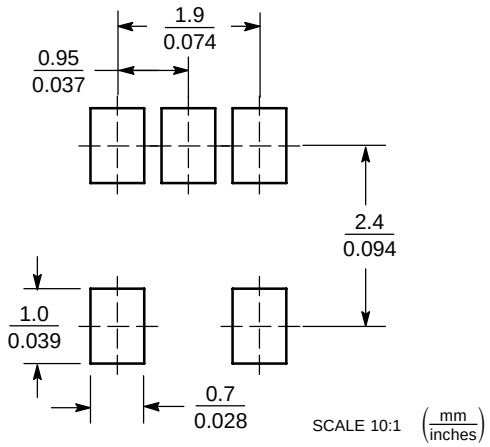
TSOP−5
SN SUFFIX
CASE 483−02
ISSUE E



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. MAXIMUM LEAD THICKNESS INCLUDES LEAD FINISH THICKNESS. MINIMUM LEAD THICKNESS IS THE MINIMUM THICKNESS OF BASE MATERIAL.
4. A AND B DIMENSIONS DO NOT INCLUDE MOLD FLASH, PROTRUSIONS, OR GATE BURRS.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	2.90	3.10	0.1142	0.1220
B	1.30	1.70	0.0512	0.0669
C	0.90	1.10	0.0354	0.0433
D	0.25	0.50	0.0098	0.0197
G	0.85	1.05	0.0335	0.0413
H	0.013	0.100	0.0005	0.0040
J	0.10	0.26	0.0040	0.0102
K	0.20	0.60	0.0079	0.0236
L	1.25	1.55	0.0493	0.0610
M	0 °	10 °	0 °	10 °
S	2.50	3.00	0.0985	0.1181

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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