

ON Semiconductor

Is Now

onsemi™

To learn more about onsemi™, please visit our website at
www.onsemi.com

onsemi and **onsemi** and other names, marks, and brands are registered and/or common law trademarks of Semiconductor Components Industries, LLC dba "**onsemi**" or its affiliates and/or subsidiaries in the United States and/or other countries. **onsemi** owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of **onsemi** product/patent coverage may be accessed at www.onsemi.com/site/pdf/Patent-Marking.pdf. **onsemi** reserves the right to make changes at any time to any products or information herein, without notice. The information herein is provided "as-is" and **onsemi** makes no warranty, representation or guarantee regarding the accuracy of the information, product features, availability, functionality, or suitability of its products for any particular purpose, nor does **onsemi** assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using **onsemi** products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by **onsemi**. "Typical" parameters which may be provided in **onsemi** data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. **onsemi** does not convey any license under any of its intellectual property rights nor the rights of others. **onsemi** products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use **onsemi** products for any such unintended or unauthorized application, Buyer shall indemnify and hold **onsemi** and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that **onsemi** was negligent regarding the design or manufacture of the part. **onsemi** is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner. Other names and brands may be claimed as the property of others.

Evaluating the Power Capability of NCP101X Members

Prepared by: Christophe Basso
ON Semiconductor



ON Semiconductor®

<http://onsemi.com>

APPLICATION NOTE

The NCP101X series is available in various combinations of peak current and switching frequencies. To help the designer quickly picking up the right part, it is important to present guidelines aimed to simplify the selection process. This application note details how to evaluate the power handled by each device and offers an overview of each part capability.

Each reference is affected by a key parameter that needs to be accounted for at the very beginning like the switching frequency, the maximum peak current and the $R_{ds}(ON)$. Among these parameters, we also find another set of constraints but linked to the adopted topology, i.e. current mode in our case:

- **DCM Operation:** As the device operates in current-mode, it is mandatory to keep operating in discontinuous mode with a duty-cycle bounded below 50% to avoid sub-harmonic oscillations when accidentally entering Continuous Conduction Mode (CCM). We will use 0.45 as the maximum value in our examples.
- **Nonnegative Reflection:** The built-in lateral MOSFET does not accept to see its body diode forward biased by an excessive Flyback voltage greater than the bulk voltage during the OFF time. Hence, for universal mains operation, the turn ratio $N_s:N_p$ will be selected to keep $V_{reflect} = (N_s/N_p) \times (V_{out} + V_f)$ below the very minimum operating DC input voltage of your converter (including the input 120/100 Hz ripple in offline applications). For instance, if we have a 100 VAC input, it becomes 141 V once rectified minus the selected ripple. If choose a $\pm 20\%$ ripple, then the very minimum DC voltage is $141 - 20\% = 112$ V. We can select a 100 V maximum reflection voltage (noted V_r) for a safe operation on wide mains, whereas this number will grow-up above 200 V for European mains operation (230 VAC $\pm 15\%$).

- **Maximum Peak Current:** In the NCP101X series, the peak current is internally fixed. This parameter plays an obvious role in the maximum transmitted power since it obeys the DCM Flyback formula, $P_{out} = 0.5 \times \eta \times L_p \times I_p^2 \times F_{sw}$. One input of our process selection will thus be the reference peak current, 100 mA, 250 mA, 350 mA or 450 mA.

Once the theoretical power capability has been evaluated, it will finally be necessary to check the power dissipation of the switcher itself (given conduction losses, switching losses, etc.) and see what remains available for a reliable operation.

Operating in DCM

When the switch closes, V_{in} is applied across the primary inductance L_p until the current reaches the level imposed by the feedback loop. The duration of this event is called the ON time and can be defined by:

$$T_{on} = \frac{L_p \cdot I_p}{V_{in}} \quad (\text{eq. 1})$$

L_p , primary inductance, V_{in} the input voltage, I_p the operating peak current.

At the switch opening, the primary energy is transferred to the secondary and the flyback voltage appears across L_p , resetting the transformer core with a slope of $\frac{N \cdot (V_{out} + V_f)}{L_p}$. T_{off} , the OFF time is thus:

$$T_{off} = \frac{L_p \cdot I_p}{N \cdot (V_{out} + V_f)} \quad (\text{eq. 2})$$

L_p , primary inductance, V_{out} the output voltage, I_p the operating peak current, V_f the secondary rectifier voltage drop, N the transformer turn ratio, $N_s:N_p$.

If one wants to keep DCM only, but still need to pass the maximum power, we will not allow a dead-time after the core is reset, but rather immediately restart (fixed frequency boundary mode operation). The switching period can be expressed by:

$$T_{sw} = T_{off} + T_{on} = L_p \cdot I_p \cdot \left(\frac{1}{V_{in}} + \frac{1}{N \cdot (V_{out} + V_f)} \right) \quad (\text{eq. 3})$$

with V_{in} the input voltage

The Flyback transfer formula dictates that:

$$\frac{P_{out}}{\eta} = \frac{1}{2} \cdot L_p \cdot I_p^2 \cdot F_{sw} \quad (\text{eq. 4})$$

(with η the converter efficiency)

and plugging into equation 3, leads to:

$$T_{sw} = L_p \sqrt{\frac{2 \cdot P_{out}}{\eta \cdot F_{sw} \cdot L_p}} \cdot \left(\frac{1}{V_{in}} + \frac{1}{N \cdot (V_{out} + V_f)} \right) \quad (\text{eq. 5})$$

Maximum Peak Current

The maximum peak current is given by the particular part reference. If we follow the data sheet, these values are:

	NCP1010			NCP1011			NCP1012			NCP1013			NCP1014	
Rdson (Ω)	23						11							
Ipeak (mA)	100			250			250			350			450	
Freq (kHz)	65	100	130	65	100	130	65	100	130	65	100	130	65	100

Combining all these parameters together, we can finally calculate what theoretical maximum power we can pass satisfying the three bullets expressed at the beginning of this document.

From the maximum peak current, duty-cycle constraint and minimum input voltage (universal or narrow mains), we deduce the maximum inductor L_{pmax} we can use:

If we now equate equation 9 with equation 6, we can obtain the maximum power constrained by a 45% duty-cycle, a maximum peak current and a given minimum input voltage:

$$P_{max} := T_{sw}^2 \cdot V_{inmin}^2 \cdot V_r^2 \cdot \eta \cdot \frac{F_{sw}}{(2 \cdot L_{pmax} \cdot V_r^2 + 4 \cdot L_{pmax} \cdot V_r \cdot V_{inmin} + 2 \cdot L_{pmax} \cdot V_{inmin}^2)} \quad (\text{eq. 10})$$

Keep the same parameters as above, we obtain, $P_{max} = 2.2$ W. Please note that increasing the switching frequency will not expand the power capability of the given converter but will reduce the inductance and allow a smaller magnetic element (the $L \times I^2$ goes down). Running the same chart with all the listed references, gives the first following correspondence between a given peak current and a *theoretical* maximum power obtained from a *converter* operated at high line and low line:

Extracting L_p from equation 5 gives:

$$L_{pcritical} = \frac{(V_{in} \cdot V_r)^2 \cdot \eta}{2 \cdot F_{sw} \cdot [P_{out} \cdot (V_r^2 + 2 \cdot V_r \cdot V_{in} + V_{in}^2)]}$$

(eq. 6) , with $V_r = N \cdot (V_{out} + V_f)$ our reflected voltage...

Selecting a primary inductance value lower than the one given by equation 6 ensures discontinuous operation at the lowest line for a given reflected voltage.

Nonnegative Reflection

If we operate on universal mains from 100 VAC to 250 VAC, then the maximum reflected voltage is:

$V_{inAC} \times 1.414 - \text{ripple} = 112$ V with a selected $\pm 20\%$ ripple (eq. 7) . We can take 100 V to include a safety margin.

Running the part from a single Europeans mains offers greater flexibility. The voltage is 230 VAC $\pm 15\%$, which leads to a minimum AC operating voltage of: $230 - 15\% = 195$ VAC. The maximum reflected voltage is thus:

$V_{inAC} \times 1.414 - \text{ripple} = 220$ V with a selected $\pm 10\%$ ripple (eq. 8) . We can take 210 V to include a safety margin.

$$L_{pmax} = \frac{DC_{max} \cdot V_{input\ min} \cdot T_{sw}}{I_p\ max} \quad (\text{eq. 9})$$

If we apply the following parameters (45% max DC, 120 VDC minimum voltage, 65 kHz switching frequency and 100 mA peak current), it gives an upper inductance boundary of: $0.45 \times 120 \times 15.4 \mu / 0.1 = 8.3$ mH.

Table 1. Theoretical Transmitted Power Depending on Peak Current Only

Peak Current	Wide Mains Operation	230 ± 15% Operation
450 mA	8.9 W	18.6 W
350 mA	6.9 W	14.5 W
250 mA	5.0 W	10.3 W
100 mA	2.0 W	4.1 W

Accounting for the Part Parameters

We now need to refine these calculations knowing our thermal constraints and internal power dissipation (conduction and switching losses, Dynamic Self-Supply, etc.) in order to offer a final selection table. The following chart will be used to assess all possible power combinations given the NCP101X family:

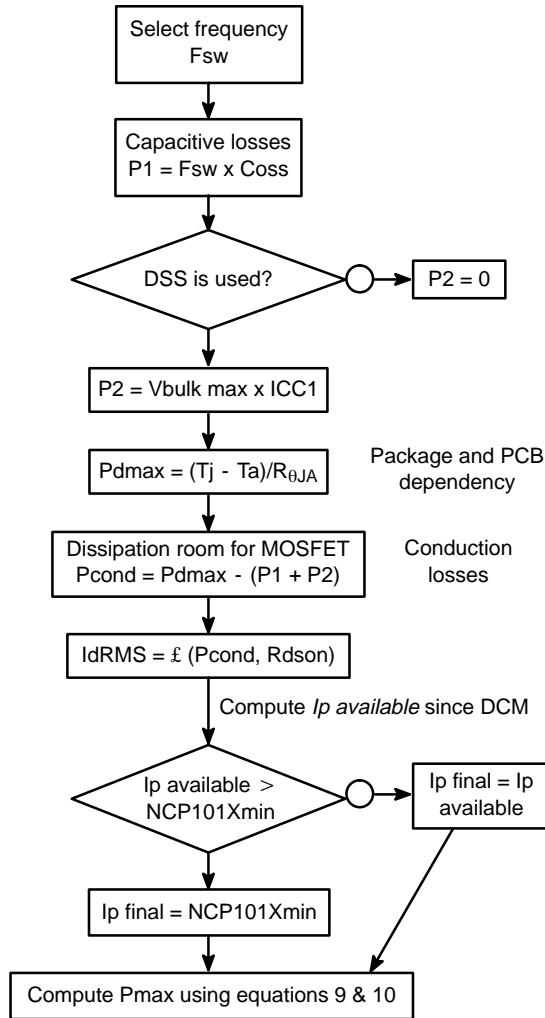


Figure 1. Power Flowchart - Used methodology for assessing the maximum power capability from a particular part number.

Power Dissipation of the PDIP7 Package

The power dissipated by the PDIP7 package is dependent upon its internal consumption and the total thermal resistance junction-to-ambient $R_{\theta JA}$. If we start from a 70°C ambient temperature and a $R_{\theta JA}$ of 75°C/W (which was measured on the demoboard with 35 μ added copper – please see data sheet for suggested layout), then the maximum dissipation from the PDIP7 is: $(Max T_j - Ta) / R_{\theta JA} = (125 - 70) / 75 = 730 \text{ mW}$ which grows up to 1.0 W for a lower maximum ambient temperature of $T_a = 50^\circ\text{C}$.

Calculating the total power consumption of a monolithic circuit implies splitting the budget with the various contributors:

1. **Dynamic Self Supply (DSS):** The average current flowing through the DSS is directly the current needed by the chip to operate (neglecting the switching losses on the DSS itself. Therefore, $P_{DSS} = ICC1 \times V_{HV}$. Therefore, if we in average, the parts exhibit an average ICC1 consumption of 1.0 mA, then the maximum DSS dissipated power is: $1.0 \text{ m} \times 370 \text{ V} = 0.37 \text{ W}$. (This number drops to 0 W with an auxiliary winding and thus offers better margin for the MOSFET.)
2. **Switching Losses:** Theoretically, the turn-on losses are null since we turn on the MOSFET at zero current (DCM). However, there still is a parasitic capacitance on the MOSFET (C_{oss} and C_{rss}) which play a role in the power dissipation budget. To assess the value of this capacitor, we can measure the time taken by the current to come back to zero:

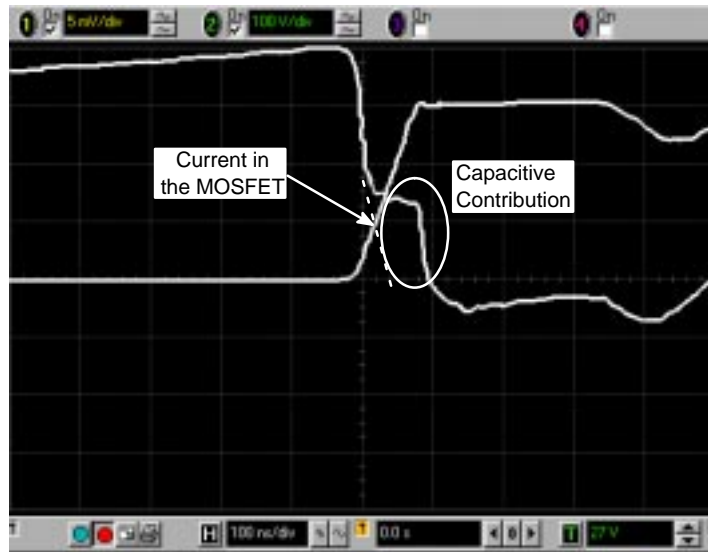


Figure 2. Typical Turn-Off Behavior of an NCP101X Series Member

The presence of the “square” corresponds to a capacitive current flowing inside the MOSFET...but also through the 10 pF scope probe. This current does not create turn-off losses (except losses due to ohmic paths) but it reveals the existence of a capacitor that will create additional losses during turn-on. Based on Figure 2, this capacitor roughly equals: $70 \text{ mA} \times 100 \text{ ns} / 300 \text{ V} = 25 \text{ pF} - 10 \text{ pF} = 15 \text{ pF}$. This is pretty low and is typical of lateral MOSFETs. In DCM, this capacitor can be charged to V_{in} in the worse case. Therefore, the energy stored in the capacitor is: $0.5 \times 15 \text{ p} \times 370^2 = 1.03 \text{ }\mu\text{J}$. Depending on the switching frequency, we will have the following average losses:

- $1.03 \text{ }\mu \times 65000 = 67 \text{ mW}$
- $1.03 \text{ }\mu \times 100000 = 103 \text{ mW}$
- $1.03 \text{ }\mu \times 130000 = 134 \text{ mW}$

3. **Conduction Losses:** These losses are dependent on the device $R_{ds(ON)}$ and the RMS current flowing into it. In lack of internal ramp compensation, the converter has to operate in Discontinuous Conduction Mode (DCM) to avoid sub-harmonic oscillations. If we add powers described at bullets 1 and 2, we have the remaining power for the MOSFET alone at different ambient temperatures (P_{loss} in the previous chart):

Table 2. Available Losses Budget in Function of the Switching Frequency Selection

Fswitching	DSS 50°C	DSS 70°C	A.W. 50°C	A.W. 70°C
65 kHz	490 mW	220 mW	930 mW	670 mW
100 kHz	450 mW	190 mW	900 mW	630 mW
130 kHz	420 mW	150 mW	860 mW	600 mW

As we can see from Table 2, applications needing the maximum power at high ambient temperature will require the use of an auxiliary to improve the room for MOSFET power dissipation. By definition, we know that $P_{cond} = I_{drms}^2 \times R_{ds(ON)}$, hence the maximum allowable **RMS** current can be deducted from the previous table. For instance, $490 \text{ mW} = I_{drms}^2 \times R_{ds(ON)} \rightarrow I_{drms} < \sqrt{\frac{P_{cond}}{R_{ds(ON)}}} = \sqrt{\frac{0.49}{25}} = 140 \text{ mA RMS}$ (eq. 11) .

By definition, the RMS value of a triangular current waveform (SMPS operated in DCM) is: $I_{rms} = I_{peak} \times \text{sqrt}(d/3)$. Since $d = 45\%$ maximum, then $I_{peak} = I_{rms} / 387 \text{ m}$. By computing all RMS and peak values for the different versions, we obtain the following arrays (RMS current/ Peak current):

AND8125/D

Rdson of 25 Ω @ Tj = 125°C (NCP1012/13/14)

Table 3. Available RMS/Peak Current for the 11 Ω Version, Respecting Table 2 Figures

Fswitching	DSS 50°C	DSS 70°C	A.W. 50°C	A.W. 70°C
65 kHz	140 mA/361 mA	94 mA/242 mA	193 mA/498 mA	163 mA/423 mA
100 kHz	134 mA/346 mA	87 mA/225 mA	190 mA/490 mA	158 mA/410 mA
130 kHz	129 mA/335 mA	77 mA/200 mA	185 mA/479 mA	155 mA/400 mA

Rdson of 52 Ω @ Tj = 125°C (NCP1010/11)

Table 4. Available RMS/Peak Current for the 23 Ω Version, Respecting Table 2 Figures

Fswitching	DSS 50°C	DSS 70°C	A.W. 50°C	A.W. 70°C
65 kHz	97 mA/250 mA	65 mA/168 mA	130 mA/345 mA	113 mA/293 mA
100 kHz	93 mA/240 mA	60 mA/156 mA	131 mA/340 mA	110 mA/284 mA
130 kHz	90 mA/232 mA	54 mA/139 mA	129 mA/332 mA	107 mA/277 mA

Final Selection Table

From the two above tables 3 and 4, we can now compute the maximum power handled by the component applying equations 9 and 10, where the duty-cycle is constrained to 45%, $V_{reflec} = 100$ V for universal mains but rises up to 210 V in single mains, offering more flexibility. If the device offers a peak current capability greater than the value recommended by table 3 or 4, then unfortunately table 3 and 4 set the priority as the flow chart indicated. To the opposite, if the available peak current room exceeds the maximum part peak setpoint, then the part peak current takes the lead. Two short examples can detail this methodology with a 100 kHz, 350 mA device featuring a 12 Ω $R_{ds(ON)}$:

Table 3 states that the maximum peak current at $T_a = 70^\circ\text{C}$ equals 225 mA when the DSS is used. The peak current

value entered in equation 9 is thus 225 mA which gives a maximum power of 3.41 W (eq. 10). Here, we cannot use the full dynamic of the 350 mA because of the dissipation constraint imposed by table 3.

If we now wire an auxiliary winding, the peak current room given by table 3 rises up to 410 mA. But this time, the peak limit is bounded by the part setpoint of 350 mA – 10% = 315 mA min (350 m < 465 m). This value will therefore be entered into equation 9 and gives a maximum power of 6.8 W.

These calculations were performed for a universal mains application ($V_{reflect} = 100$ V) and can also for a narrow mains input with a $V_{reflect}$ of 210 V. All results are gathered in table 5 and 6, offering a power handling capability device by device.

Universal Mains Applications (100-260 VAC)

Table 5. Power Capability Per Selected Device in Universal Mains Applications

Part Reference	Key Parameters	DSS 50°C	DSS 70°C	A.W. 50°C	A.W. 70°C
NCP1012P06	65 kHz – 23 Ω – 250 mA	4.9	4.9	4.9	4.9
NCP1013P06	65 kHz – 23 Ω – 350 mA	6.8	5.3	6.8	6.8
NCP1014P06	65 kHz – 23 Ω – 450 mA	7.8	5.3	8.8	8.8
NCP1012P10	100 kHz – 23 Ω – 250 mA	4.9	4.8	4.9	4.9
NCP1013P10	100 kHz – 23 Ω – 350 mA	6.8	4.8	6.8	6.8
NCP1014P10	100 kHz – 23 Ω – 450 mA	7.6	4.8	8.8	8.8
NCP1012P13	130 kHz – 23 Ω – 250 mA	4.9	4.4	4.9	4.9
NCP1013P13	130 kHz – 23 Ω – 350 mA	6.8	4.4	6.8	6.8
NCP1010P06	65 kHz – 52 Ω – 100 mA	2.0	2.0	2.0	2.0
NCP1011P06	65 kHz – 52 Ω – 250 mA	4.9	3.7	4.9	4.9
NCP1010P10	100 kHz – 52 Ω – 100 mA	2.0	2.0	2.0	2.0
NCP1011P10	100 kHz – 52 Ω – 250 mA	4.9	3.3	4.9	4.9
NCP1010P13	130 kHz – 52 Ω – 100 mA	1.9	1.9	1.9	1.9
NCP1011P13	130 kHz – 52 Ω – 250 mA	4.9	3.0	4.9	4.9

Narrow Mains Applications (230 VAC ± 15%)

Table 6. Power Capability Per Selected Device in Narrow Mains Applications

Part Reference	Key Parameters	DSS 50°C	DSS 70°C	A.W. 50°C	A.W. 70°C
NCP1012P06	65 kHz – 23 Ω – 250 mA	10.6	10.6	10.6	10.6
NCP1013P06	65 kHz – 23 Ω – 350 mA	14.8	11.7	14.8	14.8
NCP1014P06	65 kHz – 23 Ω – 450 mA	17.3	11.7	19	19
NCP1012P10	100 kHz – 23 Ω – 250 mA	10.6	10.6	10.6	10.6
NCP1013P10	100 kHz – 23 Ω – 350 mA	14.8	10.6	14.8	14.8
NCP1014P10	100 kHz – 23 Ω – 450 mA	16.6	10.7	19	19
NCP1012P13	130 kHz – 23 Ω – 250 mA	10.6	9.6	10.6	10.6
NCP1013P13	130 kHz – 23 Ω – 350 mA	14.8	9.6	14.8	14.8
NCP1010P06	65 kHz – 52 Ω – 100 mA	4.2	4.2	4.2	4.2
NCP1011P06	65 kHz – 52 Ω – 250 mA	10.6	8	10.6	10.6
NCP1010P10	100 kHz – 52 Ω – 100 mA	4.2	4.2	4.2	4.2
NCP1011P10	100 kHz – 52 Ω – 250 mA	10.6	7.4	10.6	10.6
NCP1010P13	130 kHz – 52 Ω – 100 mA	4.2	4.2	4.2	4.2
NCP1011P13	130 kHz – 52 Ω – 250 mA	10.6	6.7	10.6	10.6


Taking the Right Part

As one can see, there is a lot of overlap between the part themselves. We can use this characteristic to fine tune the final design and reach the optimal price/performance ratio. For instance, there are a few questions which, once answered, will naturally push toward the exact reference.

1. “Do I need an accurate Over Current Protection point?”: If the answer is yes, then go to the DSS option only. If the answer is no, an auxiliary winding will help you passing more power with a cooler part.
2. “Is the EMI filtering a big constraint on my design?”: A yes means you need the DSS to provide the frequency jittering. If not, auxiliary winding is an option as in point 1. Also, filtering a 65 kHz pattern is easier than a 100 kHz or 130 kHz.

3. “I need to operate my converter at the highest ambient temp!”: In that case, go for the auxiliary winding.
4. “My application requires a protection against optocoupler failures...”: By sensing the auxiliary current flowing into the Vcc pin, the part self-protects against open-loop runaways. Go for the auxiliary winding option.
5. “I have a converter that already runs at 130 kHz with an auxiliary winding!”: In that case, no option, provided that power budget is compatible...
6. “I need the smallest possible size...”: If the frequency increase does not help to pass more power, it certainly provides a size reduction in the magnetic element. Go for a 130 kHz version.

Notes

ON Semiconductor and  are registered trademarks of Semiconductor Components Industries, LLC (SCILLC). SCILLC reserves the right to make changes without further notice to any products herein. SCILLC makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does SCILLC assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. "Typical" parameters which may be provided in SCILLC data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. SCILLC does not convey any license under its patent rights nor the rights of others. SCILLC products are not designed, intended, or authorized for use as components in systems intended for surgical implant into the body, or other applications intended to support or sustain life, or for any other application in which the failure of the SCILLC product could create a situation where personal injury or death may occur. Should Buyer purchase or use SCILLC products for any such unintended or unauthorized application, Buyer shall indemnify and hold SCILLC and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that SCILLC was negligent regarding the design or manufacture of the part. SCILLC is an Equal Opportunity/Affirmative Action Employer.

PUBLICATION ORDERING INFORMATION

Literature Fulfillment:

Literature Distribution Center for ON Semiconductor
P.O. Box 5163, Denver, Colorado 80217 USA
Phone: 303-675-2175 or 800-344-3860 Toll Free USA/Canada
Fax: 303-675-2176 or 800-344-3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800-282-9855 Toll Free USA/Canada

JAPAN: ON Semiconductor, Japan Customer Focus Center
2-9-1 Kamimeguro, Meguro-ku, Tokyo, Japan 153-0051
Phone: 81-3-5773-3850

ON Semiconductor Website: <http://onsemi.com>

For additional information, please contact your local Sales Representative.