AND9134/D

Boost Optimized Schottky Diodes for High Frequency Switching Power Supplies

ON Semiconductor®

http://onsemi.com

APPLICATION NOTE

Introduction

As wireless devices become smaller and thinner more compact, energy efficient, solutions are necessary. To reduce the solution size many people will integrate various discrete devices into the IC. While this may reduce the physical size and part count this has some adverse side effects, such as performance degradation. The best way to avoid this is to use discrete devices that have been electrically optimized with very small footprints such as the NSR05F40NXT5G. In this paper we will discuss the intricacies of choosing an optimized schottky diode for wireless devices.

We will start with a discussion of high frequency boost converters. Then various trends in space saving and energy saving design will be discussed. Finally stress and bench tests will be reviewed.

Background – Application

Most mobile phones use white LEDs to backlight the LCD display. These white LEDs typically have a forward voltage near 3.6 V. The typical power source in a mobile phone is a single-cell Li-Ion battery with an operating voltage range of 2.7 V to 4.2 V. When the voltage reduces to 2.7 V there is not enough voltage to run even a single LED. To solve this issue, an inductive boost converter is commonly used. Since more than one LED is required to backlight a LCD panel either a single string (~up to 10 LEDs in series) or multiple strings of LEDs (~ up to 10 LEDs in series) in parallel are used.

As a side note; LED brightness is nearly linear with the current flowing through the LED. When using multiple strings of LEDs a higher precision linear regulator is needed to match the current on all of the LED strings to make sure that a uniform backlight is achieved.

During steady state operation of an inductive boost circuit the input inductor is shorted to ground, placing the input voltage across it's terminals. This voltage across the inductor ramps up the current (inversely proportional to the inductor size) and the magnetic field in the inductor. Next the transistor turns off and the energy stored in the magnetic field "flips" the voltage over the inductor creating a voltage higher than the input voltage at the drain of the transistor. At this point the inductor discharges its magnetic field by flowing charge through the diode and into the output capacitor and through the LED load. The output capacitor gets enough current from the inductor, in steady state, to discharge a constant current to the LED load when the transistor turns back on again to charge up the inductor for the next cycle. An example of a single string inductive boost circuit is shown in Figure 1. Typically, a very small voltage is measured over a precision resistor in series with the LEDs to feedback the output operation condition to the controller. Many of today's controllers integrate the transistors and the diode to save space.

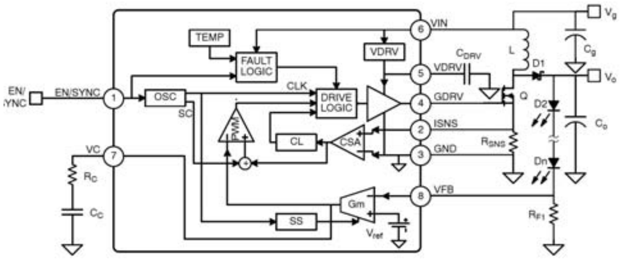


Figure 1. Simplified Typical Single Channel Converter

Space Saving Ideas

The real issue with integrating all of the devices into the controller is that these power devices have an increased junction temperature compared to the controller. This increased junction temperature can lead to reliability issues due to the limited thermal conductivity of I.C. packages.

Another method for shrinking the size of an inductive boost application is to increase the switching frequency. When the switching frequency is increased lower value inductors can be used to keep a constant inductor current ripple. Lower value capacitors can also then be used because they become re-charged more frequently.

Unfortunately the transistor and the diode still need to carry the same average and peak currents. The LEDs for a backlight are generally set between 20 – 150 mA. This means that the transistor and diode need to conduct up to and above 1 A of current. If every element shrinks with exception to the diode and FET then all of this effort is for nothing. ON Semiconductor's High Frequency optimized schottky diodes solve this problem.

May, 2013 – Rev. 0

Using ON’s Optimized Schottky Diodes

To continue to reduce space requirements for a non-integrated, inductive boost circuit, two aspects need to be adressed. The diode and transistor need to become smaller while reducing power dissipation during operation. In addition the package has to have high thermal conductivity to allow smaller heat sink. With the compact nature of wireless applications the space is very constrained and there is no place for a large heat sink (so a thermally efficient package is required).

Typically for a 1 A diode with a $R_{\theta JA}$ = 86 C/W a SMA package is used. The SMA package is 5.21 mm x 2.60 mm x 2.10 mm (L x W x H). ON Semiconductor’s new optimized Schottky diodes come in DSN2 form factors. These parts have a $R_{\theta JA}$ = 85 C/W and are only 1.4 mm x 0.6 mm x 0.27 mm (L x W x H). This means that the same power can be dissipated in only 8% of the total space. Not only is there a thermal conductivity density advantage but there is also a performance improvement with these new optimized Schottky diodes.

The improved lower forward voltage (up to 20%) of the optimized Schottky diodes effects not only the power consumption of the diode directly but now the converter does not to build up as large of a magnetic field in the inductor. This smaller magnetic field directly affects the duty ratio of the converter and causes the transistor to conduct for a shorter time, creating even less inefficiencies caused by the $R_{DS(on)}$ in the FET. $R_{DS(on)}$ is directly related to the power dissipation of the FET when the FET is conducting. Reducing the time the FET is conducting reduces the power dissipation of the FET making the converter more efficient.

Operation – Parasitic Contribution

Due to the high frequency operation, the inductance and capacitance in the critical path, as seen in Figure 2 become more important. Figure 2 shows a simplified circuit with parasitic elements included. Lpara1, Lpara2, and Lpara3 come from long lead lines and 90 degree angles on the printed circuit board layout. Cpara1 and Cpara2 come from the transistor and Schottky diode capacitance respectively. The main contributor to noise in the system comes from Lpara1, Lpara2, Lpara3, Cpara2 and the reverse recovery time of the Schottky diode.

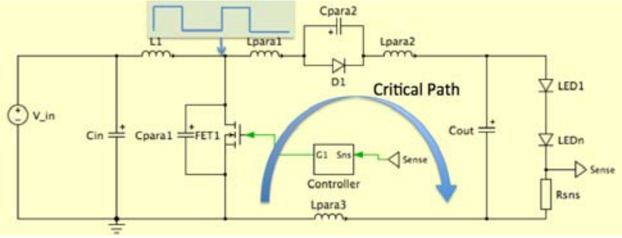


Figure 2. Boost Converter with parasitic passive components

A large issue that mainly concerns high frequency boost converters is the reverse recovery time. Due to the majority carrier nature of ON Semiconductor’s new Boost Optimized Schottky diodes, the lifetime carrier recombination effect that causes slow reverse recovery is negated, thus placing the Cpara2 as a negligible device consideration.

Thermal Stress Testing Bench Results

Before being tested a set of Boost Optimized Schottky diodes were characterized for forward voltage and reverse current over temperature. Next these diodes were placed in a “1 MHz” Boost converter, operating at near 750 kHz.

To augment the electrical stress seen on the ON Semiconductor Schottky Diodes an inductive boost regulator was set up with the following criteria: Input Voltage = 2.3 V, Output Voltage = 32 V, Output Load Current = 150 mA, L1 = 10 μH. This will cause higher than normal currents to conduct through the diode.

To further augment the stress seen by the Schottky diode a thermal component to the test was added when the Schottky diodes were mounted to external PCBs with only a minimum footprint pad size. Twisted, shielded pair cables with an inductance of less then 0.125 μH attached the diode PCBs to the “1MHz” Boost board. This additional inductance is modeled in Figure 2 as Lpara1 and Lpara2 and seen as ringing. These cables allowed for the diode to run inside of an oven set to 85°C for 48 Hours.

After the 48-hour test was completed the diodes were taken back to the characterization lab for a post condition analysis. This analysis showed that there was no shift in any of the parameters (forward voltage, reverse leakage current, and capacitance).

The reverse leakage and forward voltage graphs below show the Pre-Stress and Post-Stress characterization. There is only one curve per temperature due to the 0% shift from Pre-Stress and Post-Stress characterization.

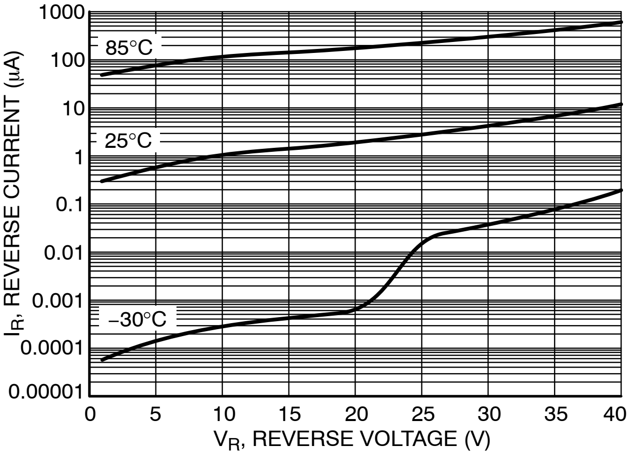


Figure 3. Reverse Leakage Characteristics

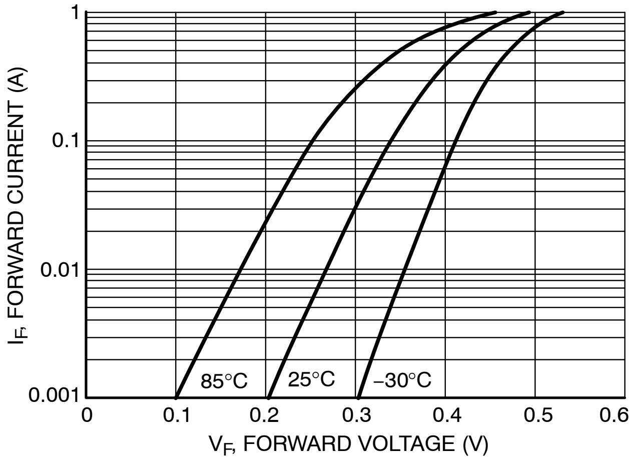
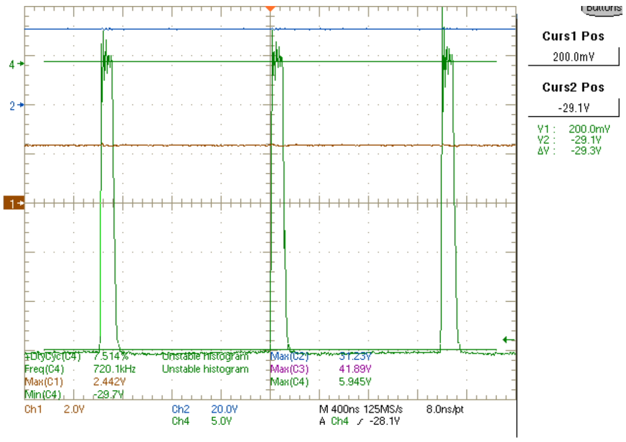


Figure 4. Forward Voltage Characterization

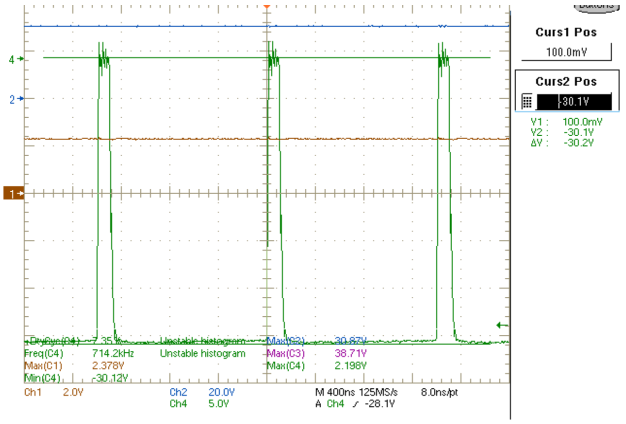
Finally these diodes were placed in the same circuit at 25°C for 1 week of continuous operation. The screen shots below in Figure 5 and Figure 6 show the operation on the first day of continuous operation and on day 5 respectively.



```
Curs1 Pos
200.0mV
Curs2 Pos
-29.1V
V1 :   200.0mV
V2 :   -29.1V
ΔV :   -29.3V

+DtyCyc(C4)   7.514%     Unstable histogram   Max(C2)   31.23V
Freq(C4)      720.1kHz   Unstable histogram   Max(C3)   41.89V
Max(C1)       2.442V                          Max(C4)   5.945V
Min(C4)       -29.7V
Ch1    2.0V          Ch2   20.0V              M 400ns 125MS/s    8.0ns/pt
                     Ch4   5.0V               A  Ch4  ⁄  -28.1V
```

Figure 5. NSR05F40QNXT5G on Day 1 at 25°C



```
Curs1 Pos
100.0mV
Curs2 Pos
-30.1V
V1 :   100.0mV
V2 :   -30.1V
ΔV :   -30.2V

+DtyCyc(C4)   7.35 %     Unstable histogram   Max(C2)   30.87V
Freq(C4)      714.2kHz   Unstable histogram   Max(C3)   38.71V
Max(C1)       2.378V                          Max(C4)   2.198V
Min(C4)       -30.12V
Ch1    2.0V          Ch2   20.0V              M 400ns 125MS/s    8.0ns/pt
                     Ch4   5.0V               A  Ch4  ⁄  -28.1V
```

Figure 6. NSR05F40QNXT5G on Day 5 at 25°C

To further evaluate the performance, a thermal camera was used to take pictures of the NSR05F40QNXT5G during heavy load operation and 25°C. As seen in Figure 7 the case only got to 29.2 C. This translates to less than 20 mW of total power dissipation.

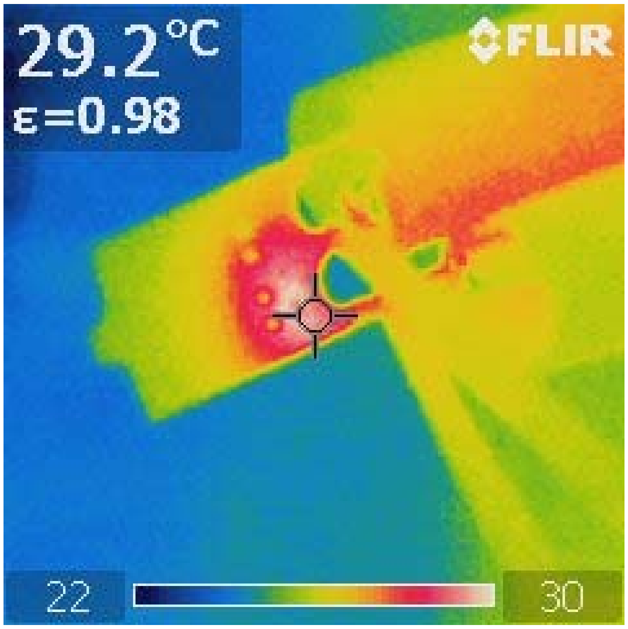


Figure 7. Case Temperature of NSR05F40NXT5G in operation at 25°C, 150 mA 34 V output

With a heavy load condition (up to 1.2 A) through the NSR05F40QNXT5G on a minimum pad size the ambient temperature can rise up to 145°C and not degrade the performance.

After conducting stress and bench tests using ON Semiconductor’s new ultra low profile Wireless Boost Application Optimized Schottky diodes it was proven that the overall efficiency and battery life will increase while reducing board size and cost associated with thermal pads.

ON Semiconductor and ON are registered trademarks of Semiconductor Components Industries, LLC (SCILLC). SCILLC owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of SCILLC's product/patent coverage may be accessed at www.onsemi.com/site/pdf/Patent−Marking.pdf. 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. This literature is subject to all applicable copyright laws and is not for resale in any manner.

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
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5817−1050

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative