AN1466

Reduction of the High-Frequency Switching Noise in the MCP16301 High-Voltage Buck Converter

Author: Valentin Constantin
Microchip Technology Inc.

INTRODUCTION

When developing high-input voltage DC-DC buck converters, there is a trade-off that has to be made between efficiency and size. For devices with an integrated switch, driver and control system, there are still some design changes that can be used to optimize the design for specific applications. The MCP16301 integrated MOSFET was developed to maximize efficiency resulting in high, very fast turn on and off of the integrated N-Channel MOSFET. Depending on the number of layers of the printed circuit board and external components chosen, some high-frequency noise will be present in the output voltage and input voltage and can have a negative impact for some designs.

This application note will discuss circuit design and layout techniques used to significantly reduce this noise to an acceptable level, using the MCP16301 as an example. MCP16301 is a highly-integrated, high-efficiency, fixed-frequency step-down DC-DC converter in a popular 6-pin SOT-23 package, that operates from input voltage sources up to 30V.

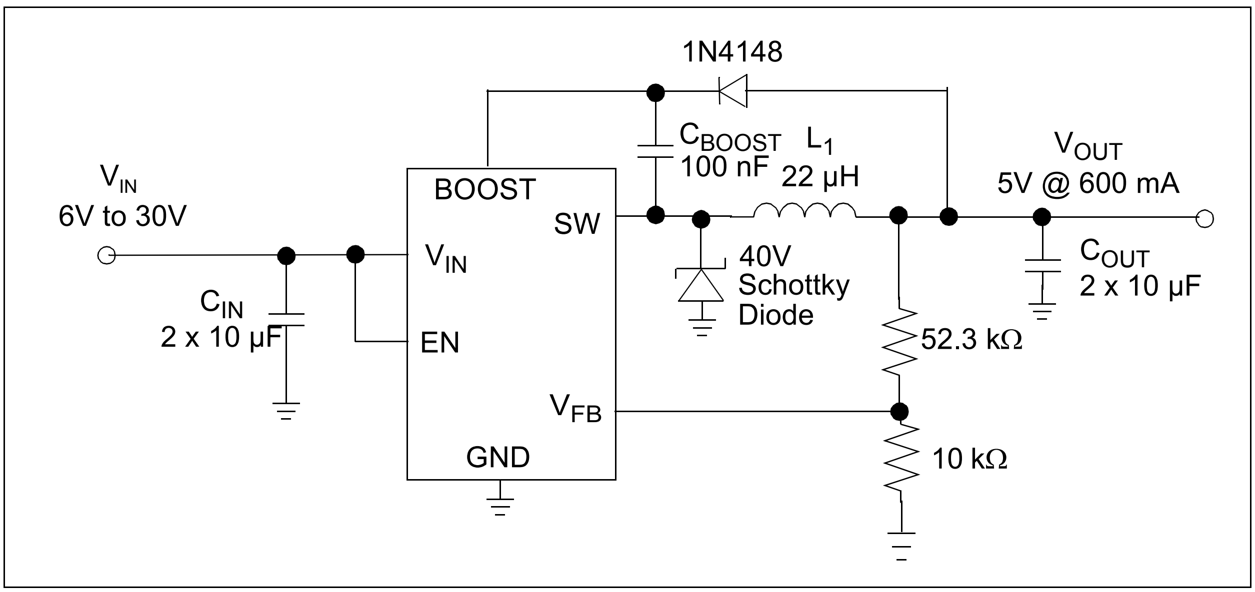

FIGURE 1: *Typical 5.0V MCP16301 Buck Converter Application.*

MCP16301 DEVICE SHORT OVERVIEW

The MCP16301 is a high input voltage step-down regulator, capable of supplying a maximum of 600 mA to a regulated output voltage from 2.0V to 15V. An integrated, precise 0.8V reference, combined with an external resistor divider sets the desired converter output voltage. The internal reference voltage rate of rise is controlled during start-up, minimizing the output voltage overshoot and the inrush current while soft starting the output voltage.

Internally, the trimmed 500 kHz oscillator provides a fixed frequency, while the Peak Current Mode Control architecture varies the duty cycle for output voltage regulation. An internal floating driver is used to turn the high-side integrated N-Channel MOSFET on and off. The power for this driver is derived from an external boost capacitor, whose energy is supplied from a fixed voltage (between 3.0V and 5.5V), typically the output voltage of the converter. For applications with 5.5V < V_{OUT} < 15.0V, boost supply can derive from the input, output or an auxiliary system voltage (more information and examples can be found in the MCP16301 data sheet (DS25004), [1]).

The enable input (EN) is used to enable and disable the device. If disabled, the MCP16301 device consumes a minimal current from the input (quiescent current in shutdown is typically 7 µA). A logic high (> 1.4V) will enable the regulator output. A logic low (< 0.4V) will ensure that the regulator is disabled.

An integrated Under Voltage Lockout (UVLO) prevents the converter from starting until the input voltage is high enough for normal operation. The converter will typically start at 3.5V and operate down to 3.0V.

When the device is switching at no load, the current drained from the power supply is approximately 2 mA.

Overtemperature protection limits the silicon die temperature to +150°C by turning the converter off. The normal switching resumes at +120°C.

A typical 5V buck converter from 6 to 30V input, using the MCP16301 device, is shown in Figure 1. It uses a ceramic capacitor for input and output, a small 22 µH inductor, sense resistors for feedback and a rectifying Schottky diode. The diode should be connected close to the SW node and GND. The 1N4148 boost diode and boost capacitor are used to bias the internal driver for the main switch, as described above.

The input source should be decoupled to GND with a 4.7 µF-20 µF capacitor, depending on the impedance of the source and the output current. The input capacitor provides current for the switch node and a stable voltage source for the internal device power. This capacitor should be connected as close as possible to the V_{IN} and GND pins. For light-load applications, a 1 µF X7R or X5R ceramic capacitor can be used.

Detailed information is available in the MCP16301 data sheet (DS25004), [1].

RIPPLE AND NOISE IN BUCK CONVERTERS

Step-down converters use higher switching frequency to take advantage of smaller inductor and input and output ceramic capacitors. But switching at high frequency generates another problem for an entire power system: switching noise. This switching noise is a result of the fast switching edges of the integrated N-Channel MOSFET and is typically in the hundreds of MHz.

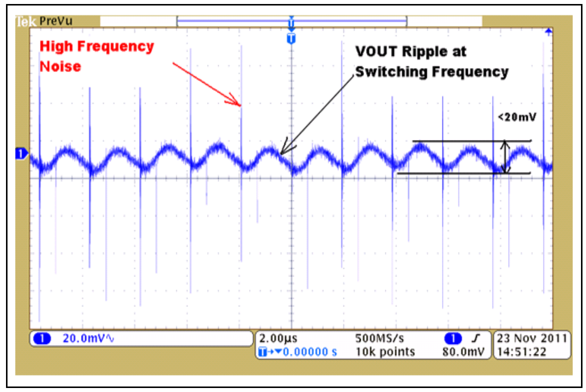

FIGURE 2: The Two Noise Components for a Buck Converter. Example for 12V Input, 5V Output and 100 mA Load Using MCP16301 Without Any Noise Removing Components.

Switching converters' input/output ripple and noise can reach levels high enough to interfere with other devices powered from the same source.

There are two noise sources:

- Output Ripple – occurs at the fundamental switching frequency
- Switching Noise – is associated with high frequency ringing that occurs during on-off transition of semiconductor switches. This type of noise has hundreds of MHz and up to hundreds of mV peak value (Figure 2).

Noisy components require separate filtering. The low-frequency output ripple of the MCP16301 is generally 20 mV peak-to-peak, and it depends on the output capacitor value and capacitor dielectric type. Low ESR and ESL ceramic capacitors significantly decrease the output-voltage, low-frequency ripple. The output ripple is easy to reduce, using a low ESR and ESL ceramic capacitor (X7R or X5R-type). Switching noise requires more attention. Overall, there are a couple of simple methods to reduce the noise. This document focuses on how the switching noise can be reduced for a MCP16301 buck converter.

REDUCTION OF THE HIGH FREQUENCY SWITCHING NOISE

The MCP16301 operates at a high-switching frequency (500 kHz, typical). If the target application using MCP16301 requires high efficiency and a low-switching noise, additional components and a good PCB design practice will sufficiently reduce that noise to a safe level.

Measuring Output Ripple and Noise Correctly

The output ripple is millivolts peak-to-peak (mV_{p-p}) and requires special attention when measuring. Accurate results are obtained when the measurement is taken as closely as possible to the output capacitor. The total loop area in the signal and ground connections has to be small. To minimize the area, remove the ground lead of the scope probe and measure the output capacitor voltage differentially, using a short wire wrapped on the ground body's scope probe (barrel), close to the tip's probe.

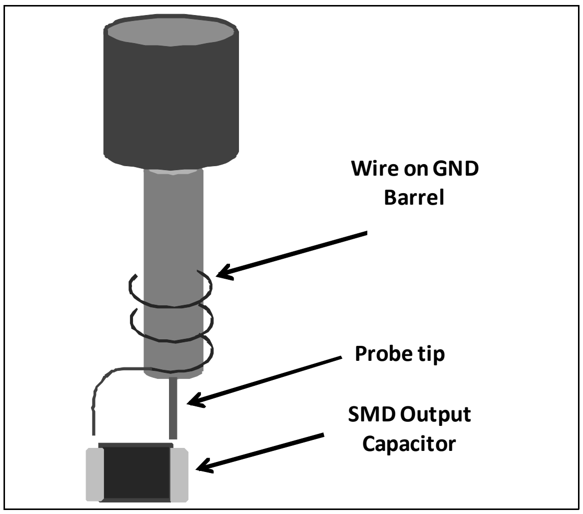

FIGURE 3: Correct Measurement of the Output Ripple/Noise Using an Oscilloscope Probe.

The test is done with an oscilloscope, properly calibrated to avoid errors. To measure only the output ripple, limit the bandwidth of the test channel to 20 MHz. To measure the output ripple plus high-frequency noise, do not limit the band of the oscilloscope!

Why Additional Output Capacitance Does Not Help?

Generally, ceramic capacitors significantly decrease the output voltage low-frequency ripple. But additional output capacitance does not remove the high-frequency noise. Ceramic capacitors have high-impedance in the frequency band in which this noise occurs. The ringing frequency is very high (see Figure 5), and the output capacitor alone or an extra low-value capacitor in parallel with it are ineffective in attenuating this noise. Figure 4 shows exactly why a small capacitor is ineffective in attenuating noise on today's converters. Even if the impedance is lower at high frequency, the value is not sufficient to reduce the ringing.

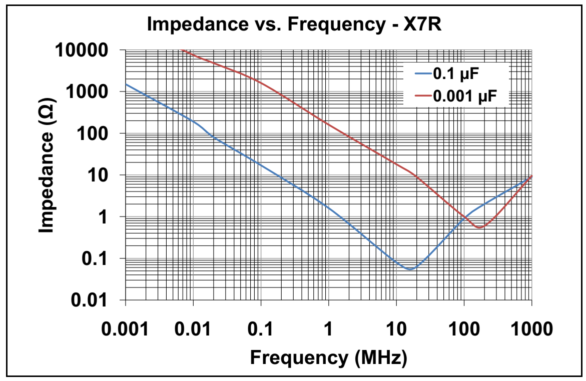

FIGURE 4: Variation of Impedance with Capacitor Value in the Frequency Band for an X7R Capacitor.

Using an RC Snubber

Using an RC Snubber to remove the high-frequency noise is a well-known method. It requires a minimum of mathematics to get a good estimation of the snubber's resistor and capacitor values, and some knowledge on the parasitic values of the switching elements. High-frequency ringing is generated by the parasitic elements of the converter's power stage. Typically, this ringing runs above hundreds of MHz and it repeats itself at each switching cycle (Figure 2).

To determine the values of the Snubber circuit, follow the steps:

1. The ringing frequency must be measured with a high-band oscilloscope (see Figure 5) by zooming the spike area.

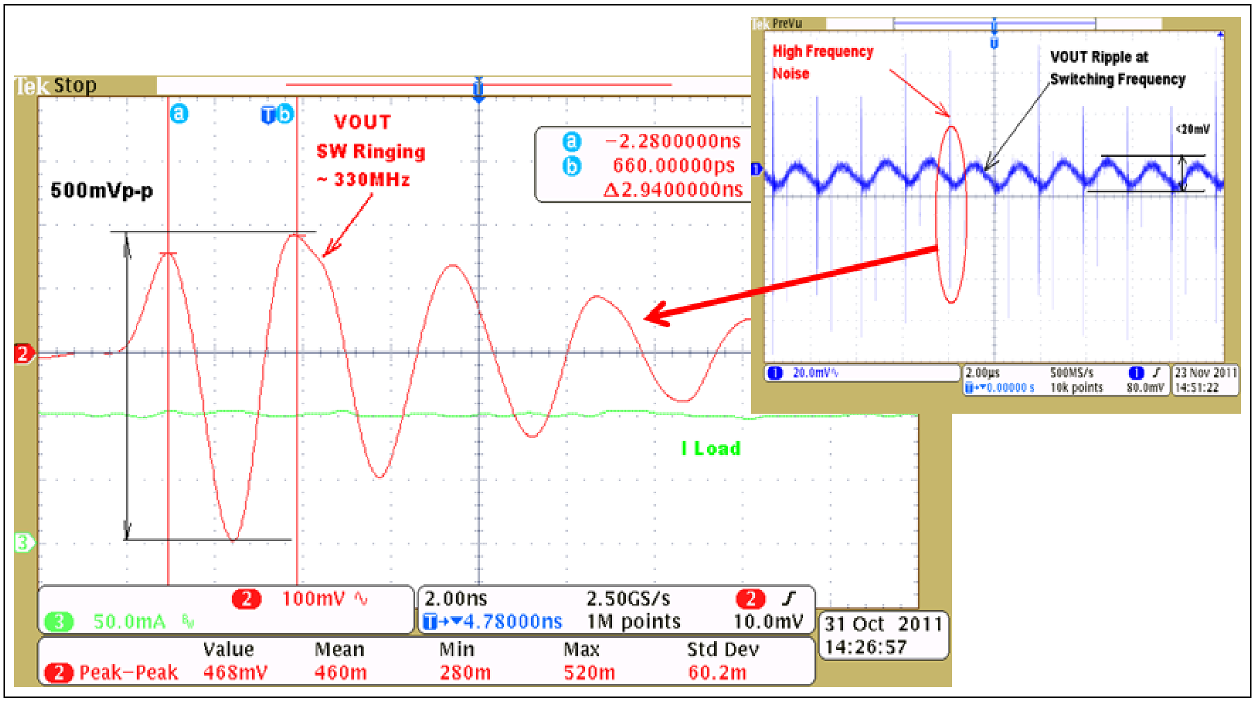

FIGURE 5: Buck Converter's AC Output. Measurement of the Ringing Frequency on a Two Layers 12V/5V MCP16301 Buck Converter.

2. The parasitic value of the power components must be identified in the data sheet, measured or estimated. The easy way for MCP16301 is to take into account the parasitic inductance of the rectifier Schottky diode (L_p). With this value known, calculate the impedance of the equivalent parasitic circuit at resonant frequency as:

EQUATION 1:

$$Z_p = 2 \times \pi \times f_{ring} \times L_p$$

The Snubber resistors should be greater than Z_p to attenuate the noise.

EQUATION 2:

$$Z_p \leq R_{Snubber}$$

With the $R_{Snubber}$ established, the value of the Snubber's capacitor results from Equation 3:

EQUATION 3:

$$C_{Snubber} = \frac{1}{2 \times \pi \times f_{ring} \times R_{Snubber}}$$

When choosing the $R_{Snubber}$, keep the value as close to Z_p as possible to damp the high-frequency oscillation. For example, the MBRA140T, which is a 1A and 40V Schottky diode, has a parasitic inductance of 2 nH (data extracted from the device data sheet). Measuring the ringing frequency as in Figure 4, the f_{ring} = 250 MHz. The calculated Z_p is approximately 3 Ohms. If the 4.7 Ohms value of the $R_{Snubber}$ is selected (which is greater than Z_p value), the $C_{snubber}$ is 120 pF. The power dissipation in the snubber resistor is equal to $C_{snubber} \cdot V^2 \cdot f_{switching}$.

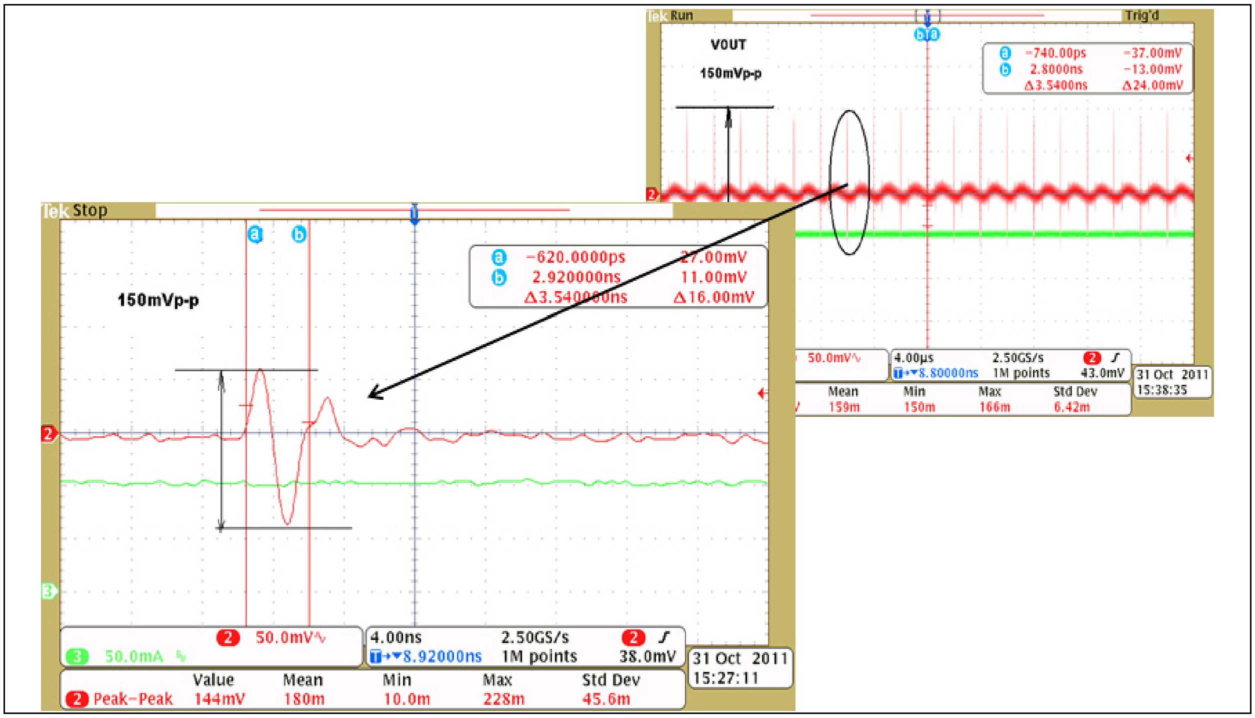

FIGURE 6: Using an RC Snubber, the Ringing is Attenuated Significantly, comparing to Figure 5 (Two Layers Board, Bottom Layer is GND Plane).

Results are analyzed in Figures 5 and 6. It is important to mention that the Snubber is effective for the measured ringing frequency, which can vary with the input and output parameters. If the input voltage or load current changes, higher noise is observed. So, it is recommended to know where the maximum attenuation should be.

RC Snubber circuits also reduce the efficiency of the converter with a small amount as shown in Figure 8.

Using an R_{BOOST} Resistor

As mentioned before, bias for the N-MOS driver is derived from an external boost capacitor (C_{BOOST}, see Figure 1) whose energy is supplied from the output voltage of the converter. An effective method to reduce the high-frequency noise is to add a resistor (R_{BOOST}) in series with the boost capacitor. This method lowers the efficiency of the converter by approximately 1% (see Figure 8), but the noise in the entire system will be significantly reduced, which can be a good trade-off. R_{BOOST} reduces the slew rate of the switching signal (SW pin, see Figure 1) by slowing down the turn on of the integrated MOSFET.

A value between 47 and 100 Ohms can be used. A complete schematic modified to minimize noise (RC Snubber and R_{BOOST}) is shown in Figure 7.

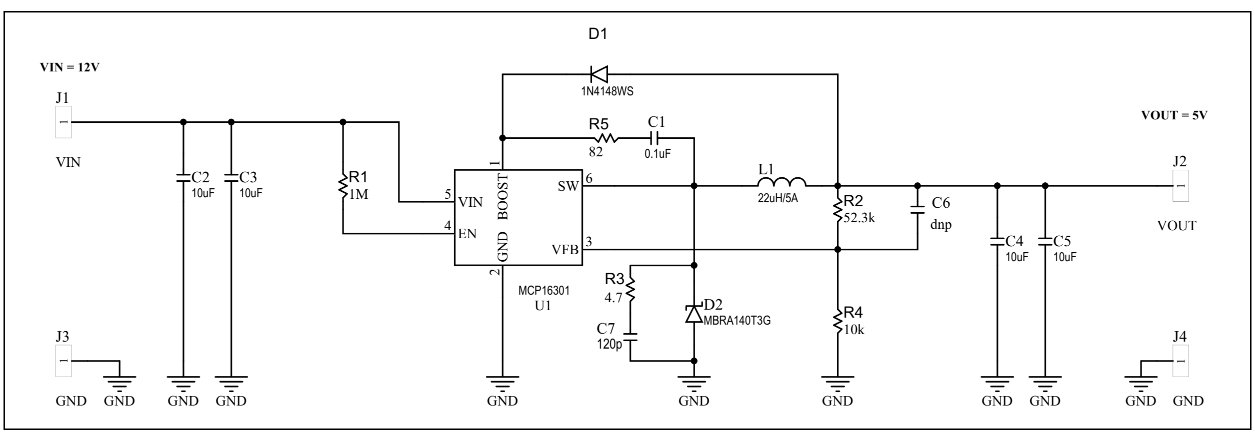

FIGURE 7: 12V/5V Low-Noise Buck Converter with RC Snubber (R3-C7) and R_{BOOST} (R5).

HOW EFFICIENCY IS AFFECTED BY THE RC SNUBBER AND R_{BOOST}

All high-frequency noise removing components decrease the converter efficiency. Sometimes a trade-off between a low-noise and efficiency is necessary.

Figure 8 depicts the effect of these components. Data is collected using a MCP16301 High-Performance Low-Noise 5V Output Buck Converter Evaluation Board, equipped with a low-ESR inductor.

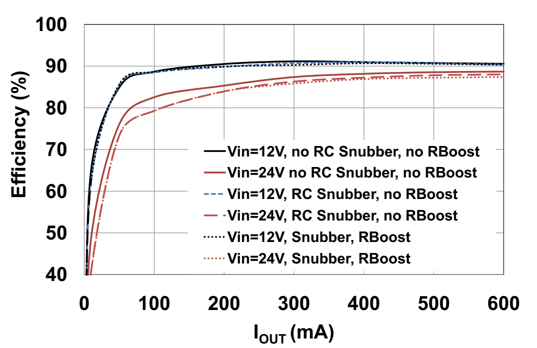

FIGURE 8: *MCP16301 – Efficiency Comparison with RC Snubber and R_{BOOST}.*

Using an Inductor that Spreads Low-Electromagnetic Field

Another way to reduce the noise, especially radiated noise, is to use shielded inductors, which avoids spreading the electromagnetic field.

Inductors have different electromagnetic pattern fields based on their type. Before choosing the inductor and its parameters, look at its magnetic drum core. Choose an inductor that has rugged-magnetic shielding body construction.

Inductor manufacturers have a large inductor portfolio. Small, low-ESR shielded inductors typically cost more.

For example, an XLP series inductor from Coilcraft has a larger electromagnetic field then an XFL or an XAL inductor. A good XAL series inductor to use with the MCP16301 to minimize radiated noise at maximum power is an XAL6060.

Practicing Good PCB Design

Designing a good PCB is an important step in high-switching power converter applications. Microchip's documentation regarding MCP16301 provide good references when designing a high-performance custom board. Low-noise level is a result of a good placement of the components and wire routing strategies.

For a lower-cost two-layer board, noise is minimized by the following actions:

- keep the input capacitors, output capacitors and rectifier Schottky diode GND pads close to one another
- use short tracks and small cooper area for SW node
- keep the feedback sense resistors away from the noisy areas and close to the FB pin. Connect the feedback bottom resistor to the bottom GND plane using a via close to its pad
- wire the output voltage sense close to the V_{OUT} terminal using a track routed away from the noisy area

Notice that in two-layer boards, noise can be minimized by using an RC snubber and an R_{Boost} resistor.

Note:	An example of a two-layers board is available in the MCP16301 High-Voltage Buck Converter 600 mA Demo Board User's Guide (DS51978).

Using a Four-Layer Board

A moderate cost solution to attenuate high-frequency noise in power-switching supply is to use a four-layer board.

A good layout contains two ground planes: GND mid-inner layer 1, which is under the top layer, and GND bottom plane. The trick is to route the SW node plane into a separate mid layer 2, between the two GND planes. A big part of the switching noise will be attenuated using this strategy. The input/output voltage signals and the bias for the boost pin (from output) are routed on the top layers. Feedback-sense track has to be routed on the bottom plane, using the output connector as a starting point.

Figure 9 shows the top layer of the 12V/5V Low-Noise Buck Converter (Figure 7). Figure 10 shows the mid-inner layer 2, where the SW node is routed as a small copper area.

Detailed information can be found in the MCP16301 High-Performance Low-Noise 5V Output Buck Converter Evaluation Board User's Guide [2].

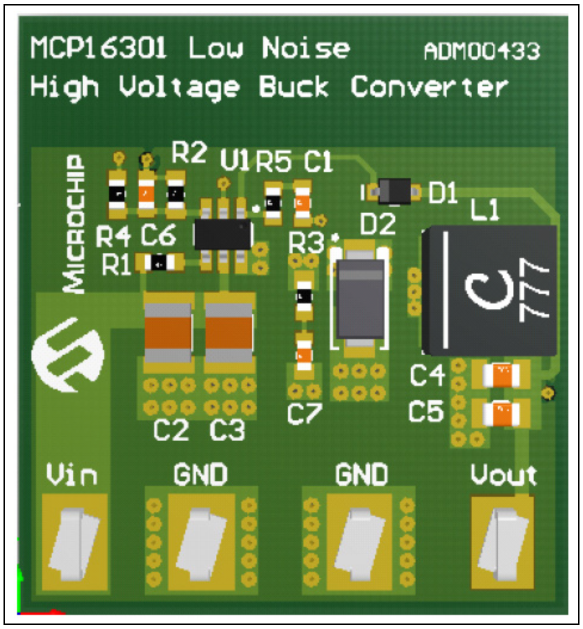

FIGURE 9: *Top Layer of the MCP16301 High-Performance Low-Noise 5V Output Buck Converter Evaluation Board (ADM00433).*

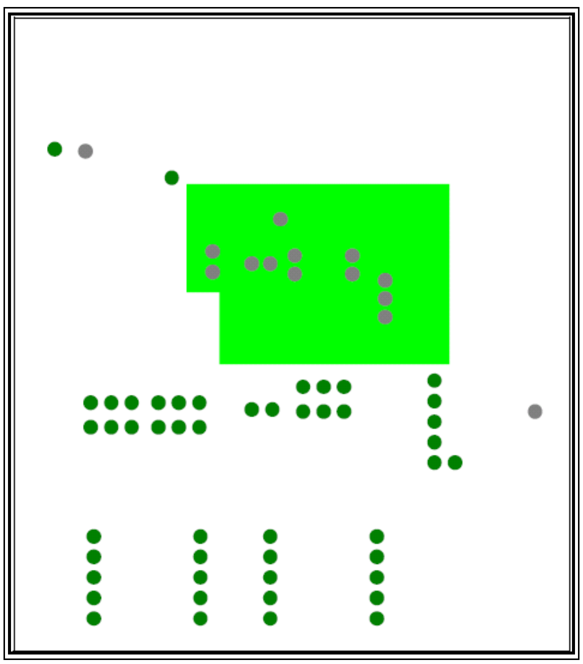

FIGURE 10: *Mid-Inner Layer 2 of the Evaluation Board. SW node is routed as a small copper area between GND plane on Mid-Layer 1 and GND plane on the Bottom Layer.*

The test done on the MCP16301 High-Performance Low-Noise 5V Output Buck Converter Evaluation Board demonstrates that high-frequency noise has significantly lower levels. With 100 mA load and 12V input, the output ripple plus noise is less than 30 mV using a high-bandwidth scope (Figure 11).

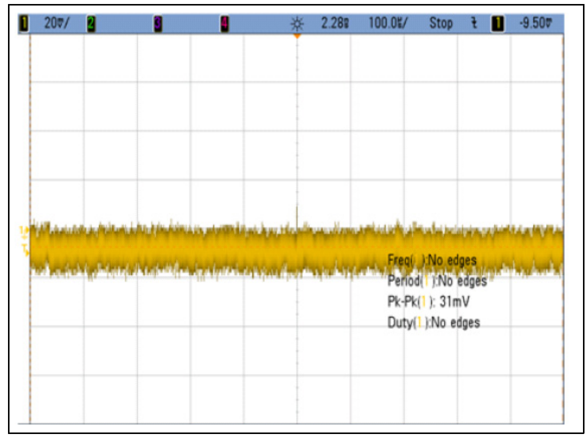

FIGURE 11: *MCP16301 Evaluation Board output ripple plus noise at 12V input, 5V/100 mA output.*

CONCLUSION

The output ripple of the MCP16301 is low and is not an issue for the majority of powered loads. Because MCP16301 is switching fast to achieve high efficiency, the output may have high-frequency noise components in the hundreds of MHz range, typical to all buck converters. If this noise causes issues for the system, it can be reduced using one of the following:

- using a simple RC Snubber and/or a R_{BOOST} resistor
- using a high-performance shielded inductor (consult the manufactures data sheet)
- using small SMD (0805/0603 type) output ceramic capacitors
- using good PCB design (two or four layers).

REFERENCES

[1] MCP16301 Data Sheet, “High-Voltage Input Integrated Switch Step-Down Regulator”, Microchip Technology Inc., DS22234, ©2011.

[2] MCP16301 High-Performance Low-Noise 5V Output Buck Converter Evaluation Board User’s Guide, Microchip Technology Inc., DS52063, ©2012.

[3] MCP16301 High-Voltage Buck Converter 600 mA Demo Board User’s Guide, Microchip Technology Inc., DS51978, ©2011.

[4] MCP16301 300 mA D^2PAK Demo Board User’s Guide, Microchip Technology Inc., DS51983, ©2011.

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Trademarks

Printed on recycled paper.

ISBN: 9781620769881

QUALITY MANAGEMENT SYSTEM CERTIFIED BY DNV

ISO/TS 16949

Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

Worldwide Sales and Service

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
http://www.microchip.com/support
Web Address:
www.microchip.com

Atlanta
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Cleveland
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Farmington Hills, MI
Tel: 248-538-2250
Fax: 248-538-2260

Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

Santa Clara
Santa Clara, CA
Tel: 408-961-6444
Fax: 408-961-6445

Toronto
Mississauga, Ontario, Canada
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

Australia - Sydney
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing
Tel: 86-10-8569-7000
Fax: 86-10-8528-2104

China - Chengdu
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

China - Chongqing
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

China - Hangzhou
Tel: 86-571-2819-3187
Fax: 86-571-2819-3189

China - Hong Kong SAR
Tel: 852-2943-5100
Fax: 852-2401-3431

China - Nanjing
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

China - Qingdao
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

China - Shenyang
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

China - Shenzhen
Tel: 86-755-8864-2200
Fax: 86-755-8203-1760

China - Wuhan
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

China - Xian
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

China - Xiamen
Tel: 86-592-2388138
Fax: 86-592-2388130

China - Zhuhai
Tel: 86-756-3210040
Fax: 86-756-3210049

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

India - New Delhi
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

India - Pune
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

Japan - Osaka
Tel: 81-6-6152-7160
Fax: 81-6-6152-9310

Japan - Tokyo
Tel: 81-3-6880- 3770
Fax: 81-3-6880-3771

Korea - Daegu
Tel: 82-53-744-4301
Fax: 82-53-744-4302

Korea - Seoul
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

Malaysia - Kuala Lumpur
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

Malaysia - Penang
Tel: 60-4-227-8870
Fax: 60-4-227-4068

Philippines - Manila
Tel: 63-2-634-9065
Fax: 63-2-634-9069

Singapore
Tel: 65-6334-8870
Fax: 65-6334-8850

Taiwan - Hsin Chu
Tel: 886-3-5778-366
Fax: 886-3-5770-955

Taiwan - Kaohsiung
Tel: 886-7-213-7828
Fax: 886-7-330-9305

Taiwan - Taipei
Tel: 886-2-2508-8600
Fax: 886-2-2508-0102

Thailand - Bangkok
Tel: 66-2-694-1351
Fax: 66-2-694-1350

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4450-2828
Fax: 45-4485-2829

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

UK - Wokingham
Tel: 44-118-921-5869
Fax: 44-118-921-5820

11/29/12