Output Voltage Ripple Measurement and Reduction for DC/DC Voltage Regulators

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Introduction

Many modern servers, as well as telecom and networking equipment, have multiple voltage regulators on the system board to provide power to ICs or sub-circuits. These power rails often have very tight voltage tolerances (<1%). Power integrity measurement, such as measuring ripple voltage in full bandwidth, becomes crucial to meet the system design requirement.

This article provides measurement guidelines and ripple reduction methodology based on implementation of constant-on-time (COT) regulators, with specific results given using the MPQ8633B from Monolithic Power Systems (MPS).

Ripple and Noise Origin

Full-bandwidth output ripple typically includes LF ripple and HF noise. Figure 1 shows that the LF ripple in buck converters is an AC component of the output voltage.

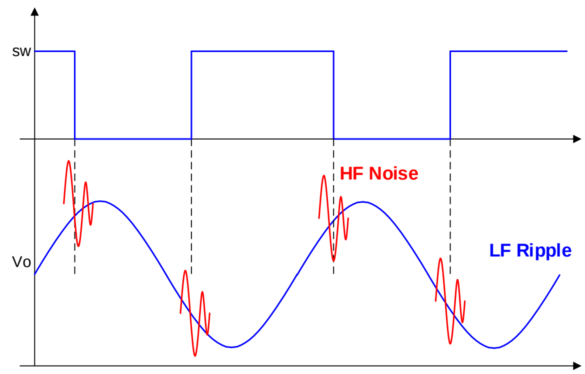


Figure 1: Output Voltage Ripple and Noise

However, there is another AC component in practical circuits, which is referred to as high-frequency (HF) noise. This noise always occurs when the switch turns on and off. Figure 2 shows the practical circuit for the buck converter output stage. Considering the HF operating condition, a real inductor performs like the capacitive impedance, and a real capacitor performs like the inductive impedance. Therefore, the output-stage circuit can be simplified (see Figure 3). HF noise is induced mainly by the high dV/dt of the switch coupling through inductor parasitic capacitance (C_L) and equivalent series inductance (ESL).

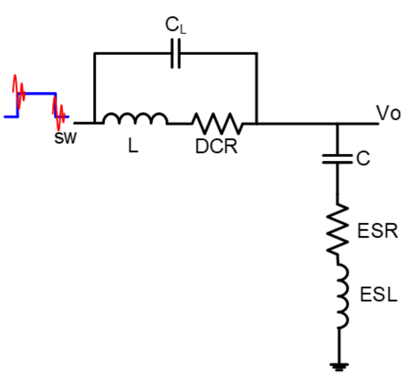


Figure 2: Practical Output-Stage Circuit of Buck Converter

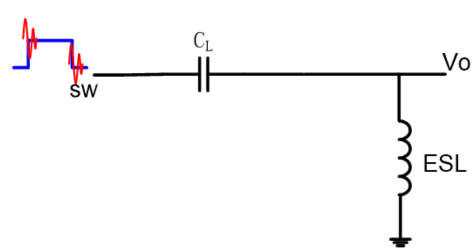


Figure 3: Simplified Output-Stage Circuit of Buck Converter in HF Domain

Output Measurement Set-Up

To obtain an accurate experimental result, it is very important to have a proper measurement set-up. The conventional method is to use 1MΩ passive probes (see Figure 4). This set-up cannot achieve true voltage ripple and noise because the large loop picks up much of the surrounding noise and introduces parasitic inductance. Figure 5 shows a much smaller loop area than the passive probe, based on 50Ω coaxial cable. Coaxial cables have several advantages, including a well-shielded feature, small loop area, and no signal attenuation.

Figure 4: Ripple Measurement with Passive Probe

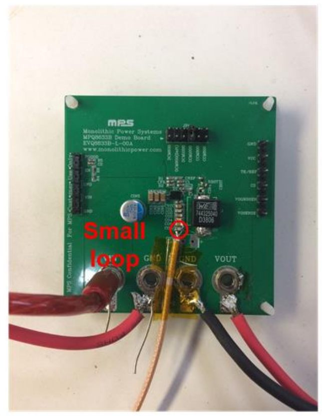
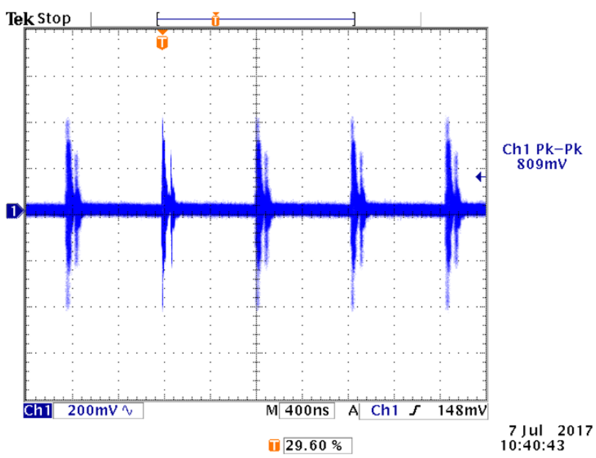
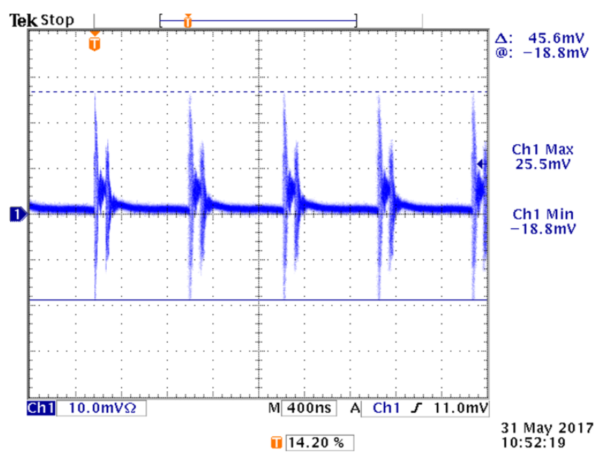


Figure 5: Ripple Measurement with 50Ω Coaxial Cable

Figure 6 shows the output ripple comparison at the same operating condition. The HF noise is effectively reduced by the coaxial cable. In the following section, all experimental results are based on the 50Ω coaxial cable.



a) Output Ripple Based on Ten 1MΩ Passive Probes



b) Output Ripple Based on One 50Ω Coaxial Cable

Figure 6: Output Ripple Comparison in Full Bandwidth

Output Ripple Reduction

As discussed earlier, HF noise is related to the inductor, output capacitor, and switching node voltage. Three methods can be used to reduce HF noise:

1. Reduce the switching node voltage spike.
2. Reduce the inductor impedance in high-frequency operation.
3. Reduce the output capacitor impedance in high-frequency operation.

For Item 1, the most effective strategy is to reduce the switch's turn-on and turn-off slew rate. This can be implemented by adding a bootstrap resistor in series or an RC snubber circuit.

Once the switching node spikes are reduced as low as possible, the noise coupling loop can be optimized. First, choose an inductor with a low parasitic capacitance according to the vendor datasheet. Second, minimize the output capacitor impedance around the noise ringing frequency. Normally, the noise ringing frequency in a buck converter is around several hundred MHz.

X5R/X7R ceramic capacitors are popular for reducing full bandwidth ripple due to their lower ESR and ESL compared to electrolytic capacitors and tantalum capacitors. Generally, a smaller ceramic capacitor results in lower impedance at high frequencies. However, the small ceramic capacitor also has a limited capacitance value. Therefore, the conventional X5R/X7R ceramic capacitor is not the best way to reduce the impedance to about several hundred MHz.

Figure 7 shows an NP0 ceramic capacitor selected for HF noise reduction due to its low-impedance characteristic. Moreover, the impedance characteristic is also related to the capacitance value (see Figure 8). According to the HF noise ringing frequency, an NP0 capacitor of several hundred pF is appropriate for this case.

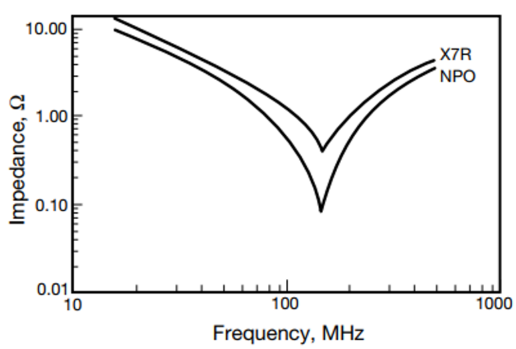


Figure 7: Impedance Comparison between 1000pF X7R Cap and NP0 Capacitor (0603 Size)

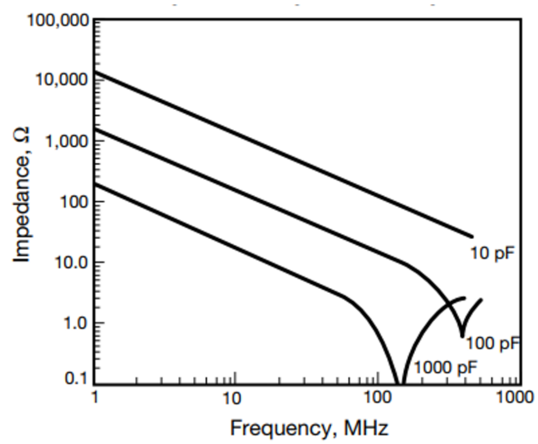


Figure 8: Impedance Variation with Different Value NP0 Capacitor (0603 Size)

In the application schematic below, an NP0 capacitor is placed close to the IC, and the ripple test point is placed at the end of the output capacitor (see Figure 9). In this way, most of the HF noise is filtered by the NP0 capacitor, and most of the LF ripple is filtered by a large-value X5R/X7R capacitor.

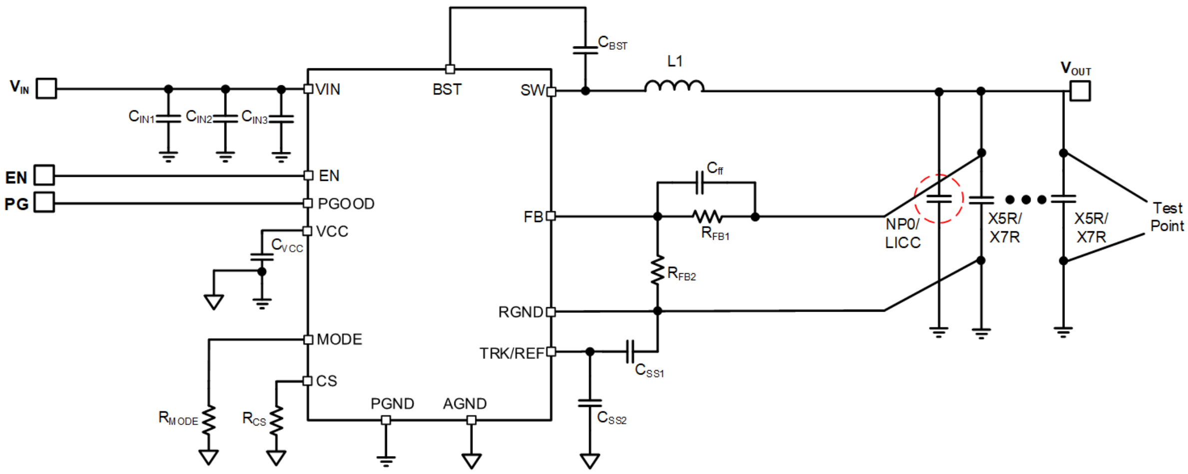
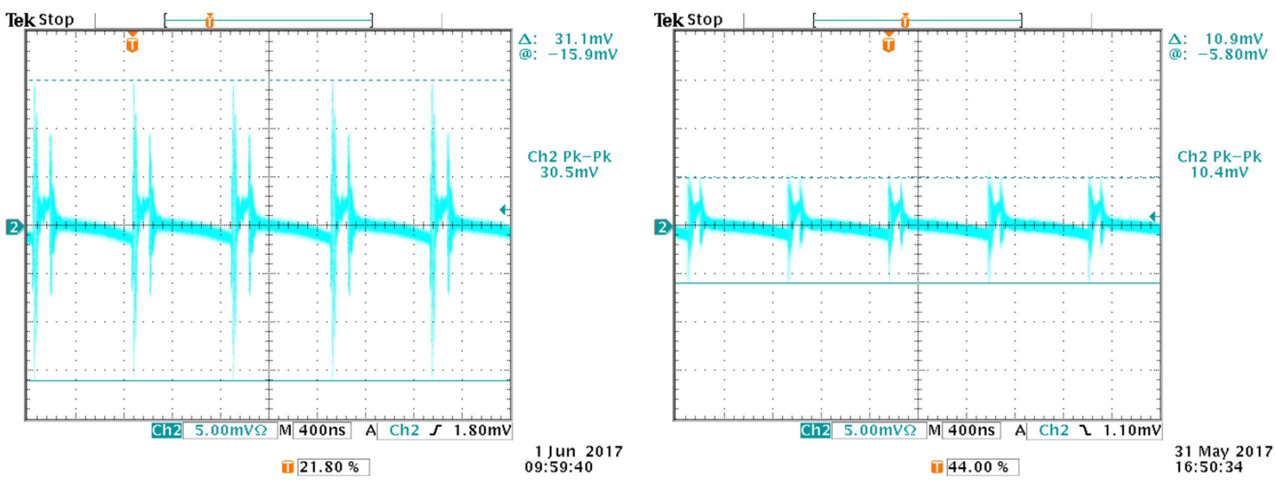


Figure 9: COT Regulator Application Schematic with NP0 Capacitor or LICC

Figure 10 shows a comparison of the output ripple voltage with a general ceramic capacitor and NP0 capacitor, which proves the validity of the NP0 capacitor. HF noise is reduced significantly by using NP0.



a) Output Ripple with 1x180pF 0603 X7R Capacitor and 3x100µF 1206 X7R Capacitor

b) Output Ripple with 1x180pF 0603 NP0 Capacitor and 3x100µF 1206 X7R Capacitor

Figure 10: Full-Bandwidth Output Ripple Voltage Comparison with Different Output Capacitor Types

Conclusion

This article analyzed the source of output ripple in a DC/DC voltage regulator, compared the different measurement set-ups, and discussed how to reduce the output ripple. COT regulators optimize the SW voltage spike, inductor impedance, and output capacitor impedance in the high-frequency range, therefore reducing the output ripple and high-frequency noise. A 50Ω coaxial cable is the ideal test tool for output ripple voltage measurement. The MPQ8633B from MPS is a COT regulator ideally suited for addressing these issues.