

Achieving CISPR-22 EMI Standards With HotRod™ Buck Designs

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ABSTRACT

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1 Overview

Achieving a low-noise power supply design is often a primary objective for electronic systems. How “low-noise” a power supply must be is governed by system constraints or specific emissions standards. Passing CISPR-conducted and radiated standards is most often the noise metric power supply designs must achieve. To better understand CISPR and other emission standards, refer to the [An Overview of Conducted EMI Specifications for Power Supplies White Paper](#).

HVAC products like thermostats, electronic expansion valves, and damper controllers are typically powered from 24-V AC supply, which can vary by $\pm 10\%$ to $\pm 20\%$. The power requirements may vary from 5 W to 20 W, with typical supply voltages of 12 V, 5 V, and 3.3 V derived using buck converters. These products need to comply with various EMC immunity and emission norms listed under IEC 60730, IEC 61000-6-3, and IEC 61000-6-2. Meeting CISPR 22 Class B requires careful product design, more specifically power supply design, to avoid any unintended radiated emissions. This application note shows a strategy for achieving CISPR EMI standards.

2 EMI Optimized Buck Converter Solutions

Achieving good EMI performance in buck converter designs can be both challenging and expensive. This is partly due to the combination of higher frequency buck converters gaining popularity and more stringent EMI standards. Many power designers are opting to use high-speed converter designs due to the ability to reduce the component values (and sizes) contained in the output power stage. While this allows for a smaller implementation size for the power supply design, this poses a problem for passing EMI. Often, for the majority of EMI standards, the emissions standards for higher frequencies are more stringent. For example, CISPR-22 has a more stringent standard at higher frequencies (for conducted emissions, then lower frequencies (Figure 1)). This can be an issue as the switching frequency and the lower-order harmonics of the switching frequency are high in energy. These frequencies fall in the more stringent frequency band for the EMI standard of interest in contrast to a slower speed buck converter (for example, CISPR-22). Fortunately, new technologies are constantly being implemented into regulators to reduce noise.

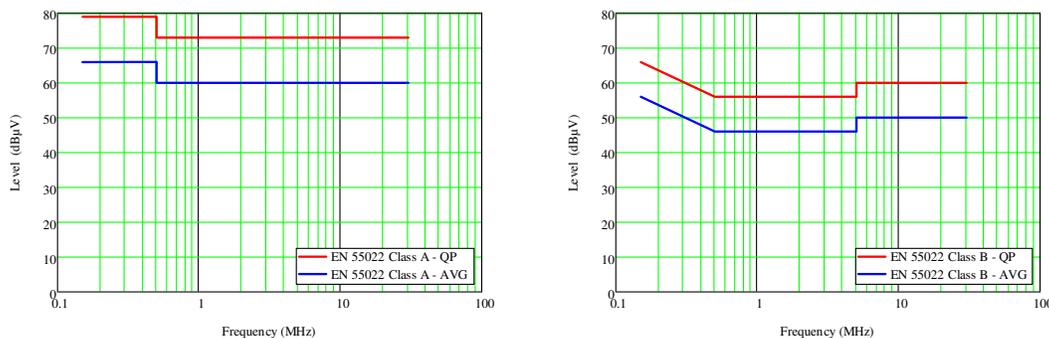


Figure 1. CISPR-22 Conducted EMI standards

The LMR33630 is a wide- V_{IN} buck converter design with proven low EMI performance. The LMR33630 has a 3 V to 36 V V_{IN} range and is capable of delivering up to 3 A of load current. A wide- V_{IN} buck converter allows for a well-regulated output over all harsh system conditions where the input voltage fluctuates. Furthermore, a wide V_{IN} approach allows for the system design to relax the requirements of input protection, input filtering, and eliminate a pre-boost stage.

The LMR33630 comes in two different packages: a leaded and unlead package. The unlead package is Texas Instruments' HotRod package design.

2.1 HotRod Package Design

TI's current and next-generation solution offers an innovative package design to make life easier when designing an EMI-optimized board. The new HotRod package has several key features that help improve EMI performance, the first being the pinout configuration.

It can be seen that the HotRod package (Figure 2) has two power (V_{IN}) and two ground (GND) pins on opposite sides of the package. This configuration allows for the reduction in the parasitic loop inductance formed by V_{IN} and GND nets. Assuming there is a symmetric layout of the input capacitors on each side of the device, the equivalent parasitic loop inductance of the two equal, parallel inductances, is halved. This allows for reduction in the noise generated by high di/dt waveforms, as better high-frequency filtering occurs. Additionally, this package allows for two high-frequency capacitors to be used to supply the high di/dt waveforms while keeping the relative current loop area small. This allows for the magnetic field magnitude being generated by this loop to be reduced, as loop area is directly proportionate to the magnetic field magnitude. Furthermore, by performing the symmetric layout of the high di/dt input loops, the magnetic fields generated (of opposing directions) can cancel each other out (Figure 2).

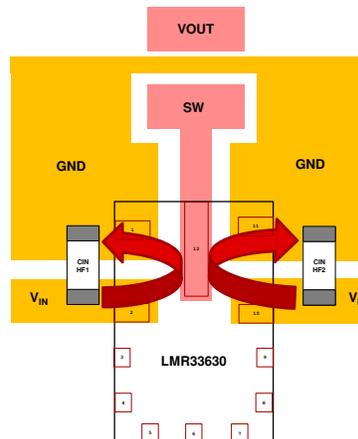


Figure 2. Demonstrating the HotRod Package Design of the LMR33630

Additionally, the HotRod package has conveniently routed the switch node pin (pin 12, [Figure 2](#)) directly below the IC. This allows for reduced routing to the boot capacitor which, in turn, reduces the switch node area. This results in reducing the likelihood of the switch node AC waveform, which is abundant in harmonics, to capacitively couple to nearby traces. All of these aspects contribute to a very dense layout ([Figure 3](#)).

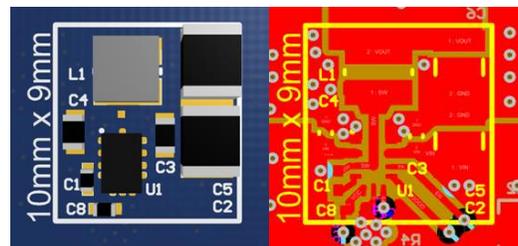


Figure 3. Illustrating Example Hotrod Layout

The second feature that the HotRod package offers for improved EMI performance is that it is a flipped chip design, meaning that there is no bond wire connection (see [Figure 4](#)) from the die to lead frame.

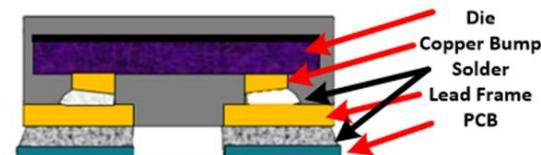


Figure 4. HotRod Mechanical Diagram

What this ultimately allows is a reduction in switch node ringing ([Figure 5](#)) that occurs as a result of the series resonance circuit formed internal to the converter. This is achieved by the reducing the parasitic inductance contained in that loop by eliminating the bond wire. This results in increasing the frequency of oscillation for the ringing on the rising and falling edges of the switch node waveform, in turn reducing energy stored in the network.

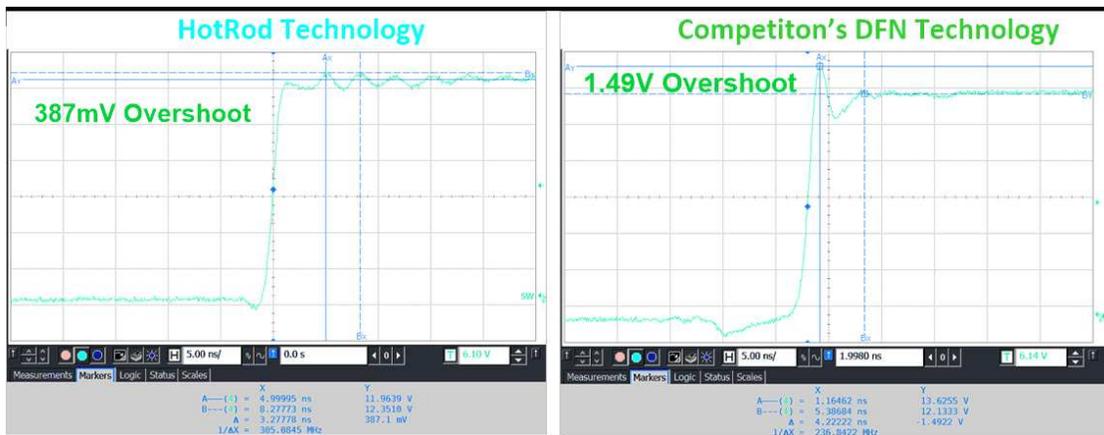


Figure 5. Illustrating Benefit of HotRod Technology for Switch Node Performance (Less Ringing)

3 Design Example: LMR36015B

The following is a design using the LMR36015B, a 4.2 V to 60 V, 1.5 A DC/DC step-down converter. The focus is on optimizing the design for CISPR-22 EMI standards.

3.1 EMI Filter Optimization

Figure 6 shows an EMI sweep on the device without an EMI filter installed. The sweep demonstrates the device failing to meet CISPR-22 emission limit standards by greater than 20 dB at the switching frequency (1 MHz) of the device. Additionally, as the pulsed current delivered by V_{IN} to the high side FET is not done at a 50% duty cycle, both the even and odd harmonics of the switching frequency are shown in the EMI sweep and exceed the set limits.

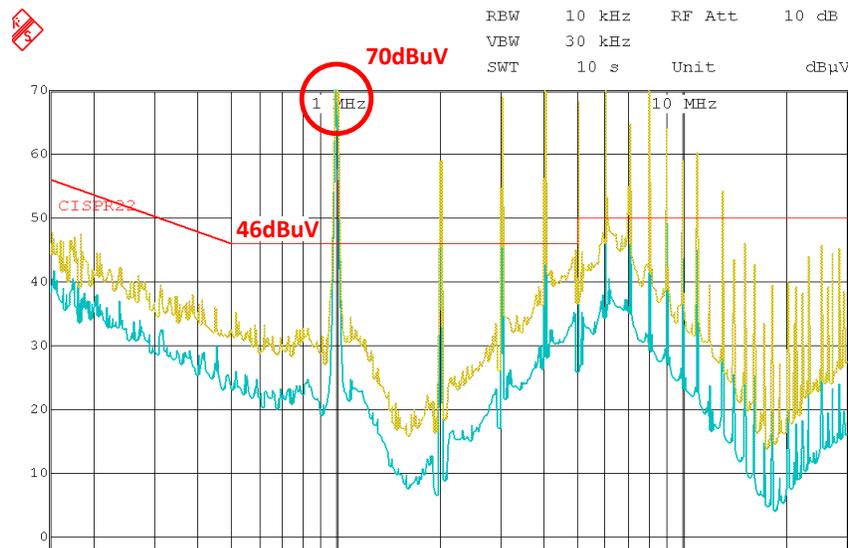


Figure 6. Initial EMI Sweep With CISPR-22 Average Limit Lines

To have a CISPR-22-compliant design, an EMI filter must be designed and installed in front of the DC/DC converter.

3.1.1 LC Filter Design

An inductor-capacitor (LC) filter is designed to attenuate the switching frequency and harmonics that cause the EMI limits to be exceeded. The respective values of these components are selected in ensuring that the fundamental frequency is attenuated enough by setting up the corner frequency appropriately. A second-order (LC) filter has a -40 dB/decade rolloff. This information allows a designer to determine the required corner frequency (f_c) based on the required attenuation (A) in decibel microvolts of the noise at a particular frequency (f).

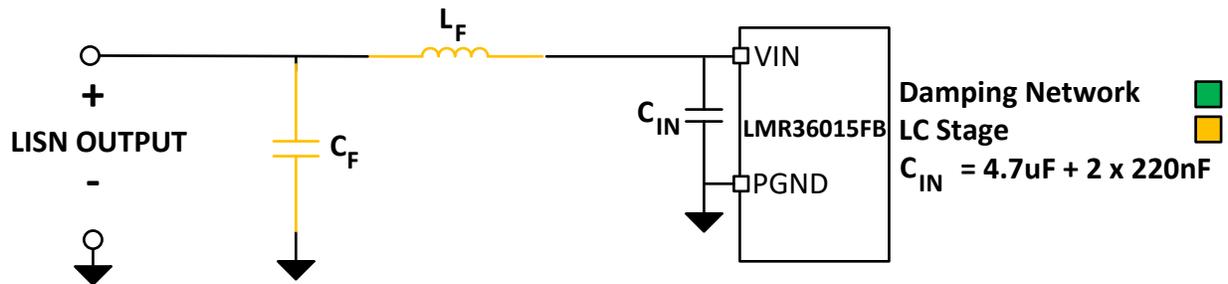


Figure 7. LC Filter Implementation

Equation 1 solves for the required corner frequency (f_c) to achieve the required attenuation (A) based on the specific EMI standard emission limits and noise level of the initial sweep data (Figure 6). The fundamental frequency is measured at 70 dB μ V. The average emission limit set by CISPR-22 is 46 dB μ V. To achieve a compliant design and have sufficient headroom, the required attenuation at the switching frequency (1 MHz) is set to 35 dB and the corner frequency is solved for (Equation 1 and Equation 2).

$$f_c = f \times 10^{\frac{-A}{40}} \tag{1}$$

$$f_c = 1 \times 10^6 \times 10^{\frac{-35}{40}} = 133 \text{ kHz} \tag{2}$$

Equation 3 allows for the required component values to be determined based on the attenuation needed. It selects the inductor value (L_F) for the LC filter. It also solves for the required capacitance value and selects the next closest standard value (Equation 4). The inductor value was selected to be 2.2 μ H, as the value of inductance for most converters can be easy to procure in a small package size with sufficient DC current rating. For higher valued inductance, the reduction in high-frequency performance due to larger geometries is often found, and in turn, parasitics contained in the inductor. This results in a lower self-resonance frequency, which causes the inductor to become capacitive at lower frequencies. This can cause problems for the attenuation for the higher-order harmonics that fall in the emissions limit range.

$$f_c = \frac{1}{2\pi\sqrt{L_F C_F}} \tag{3}$$

$$f_c = \frac{1}{2\pi\sqrt{L_F C_F}} = 133 \text{ kHz} = \frac{1}{2\pi\sqrt{2.2\mu\text{H} \times C_F}}; C_F = 0.65\mu\text{F} \approx 1\mu\text{F} \tag{4}$$

Figure 8 reflects the EMI performance of the LMR36015B with the implementation of an LC filter with component values being $L_F = 2.2 \mu\text{H}$ and $C_F = 1 \mu\text{F}$.

NOTE: The competitively priced inductor selected was part number NRS5014T2R2NMGGV. The selected part number allows for the required attenuation and has a sufficient DC current rating of 2 A.

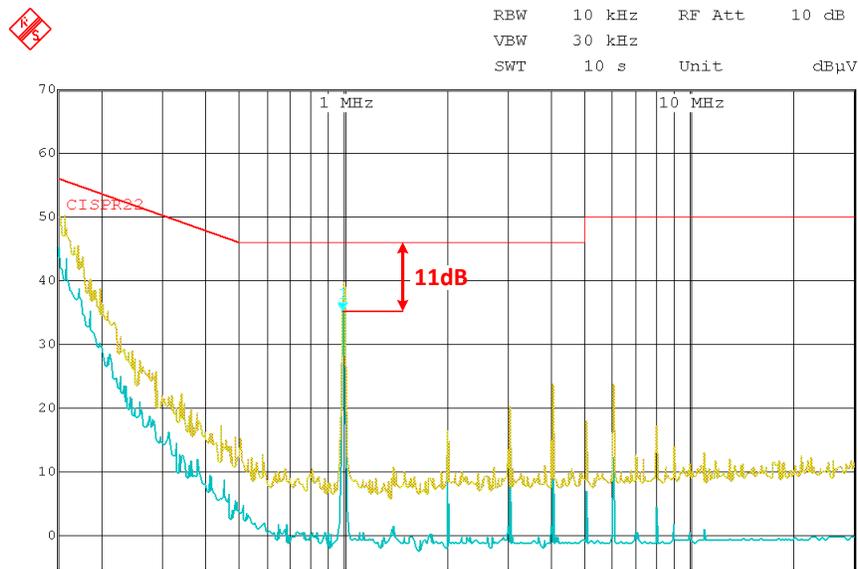


Figure 8. Passing CISPR-22 EMI Limits With a Simple LC Filter

3.1.2 Damping Network Design

The design is now compliant with the addition of the LC filter. Achieving additional headroom might be required for the design, especially at lower frequencies where the design is only passing by approximately 6 dB (Figure 8). Notice the noise in this area is at 150 kHz. Recall that the corner frequency of the filter was designed to be about 110 kHz. This leads into one non-ideality of a filter, that is, resonance at the corner frequency.

A filter requires damping, so resonance at the corner frequency of the filter can be reduced. This is illustrated in Figure 9. This figure also shows the bode plot of an LC filter with non-ideal circuit components. This resonance can result in significant amplification of noise at low frequency, resulting in a non-compliant design.

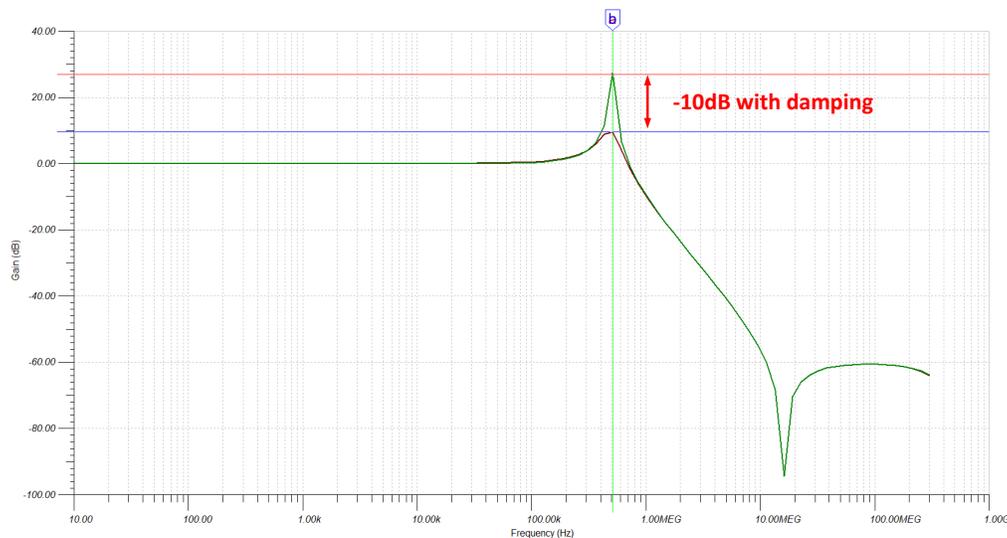


Figure 9. Bode Plot Comparison Between Parallel Damped (Red) and Undamped (Green) Filter

A typical approach for damping the filter is to use a parallel resistor-capacitor (RC) circuit (Figure 10). This replicates the electrical characteristics of an electrolytic capacitor, providing similar rejection at low frequencies without taking up a significant portion of the available board space.

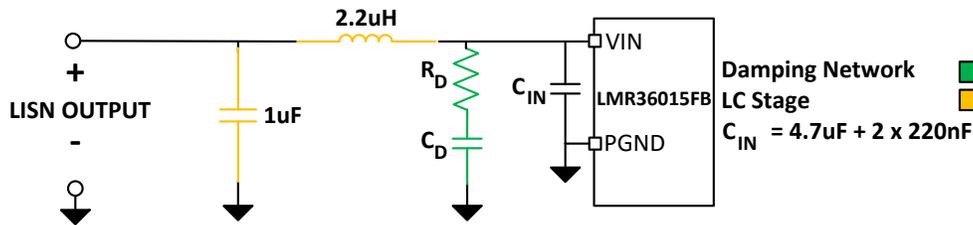


Figure 10. Parallel RC Damping Network Filter Implementation

Equation 5 and Equation 6 determine the optimal damping resistor, R_D :

$$R_D = \sqrt{\frac{L_F}{C_{IN}}} \tag{5}$$

$$R_D = \sqrt{\frac{2.2\mu H}{4.7\mu F}} = 0.68\Omega \approx 0.5\Omega \tag{6}$$

Equation 7 and Equation 8 determine the optimal damping capacitance, C_D . These equations are formed for optimal impedance of the capacitor C_D at the resonant frequency of the filter and the R_D used to reduce the output impedance of the filter at resonance. Parallel damping ensures that designers can achieve sufficient damping without creating excessive power loss, in contrast to placing a series resistance in the power path.

$$C_D \geq 4 \times C_{IN} \tag{7}$$

$$C_D \geq 4 \times 4.7\mu F = 18.8\mu F \approx 22\mu F \tag{8}$$

Figure 11 shows the improvement in EMI sweep by comparing the sweep results before and after the damping network is added.

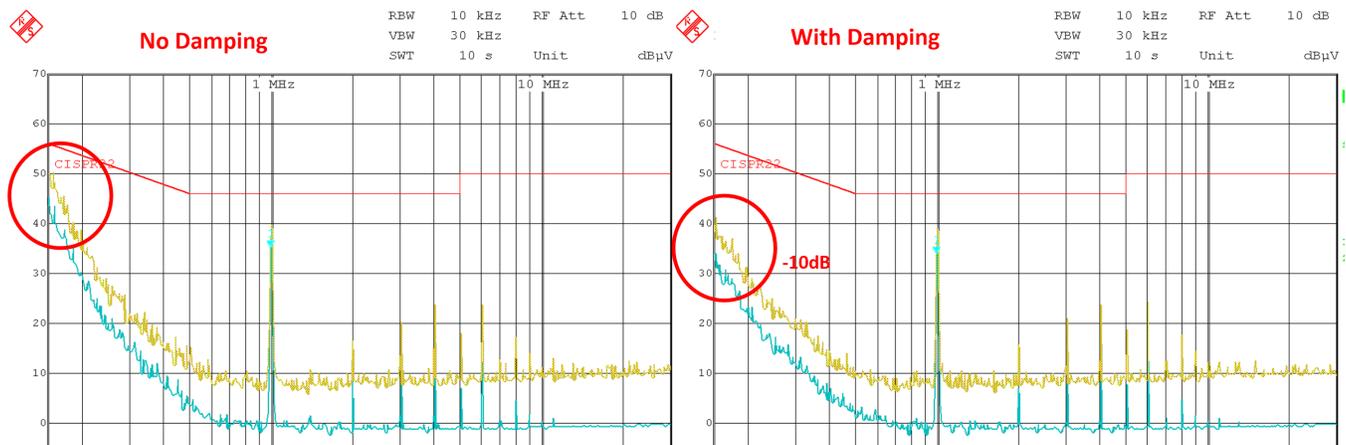


Figure 11. Comparing EMI Sweep Results With and Without a Damping Filter

Additionally, an EMI sweep data was conducted with a smaller, not optimal, damping capacitance. The results (Figure 13) of the final filter show a compliant design across the whole frequency range with a small BOM (Figure 12) for the filter design.

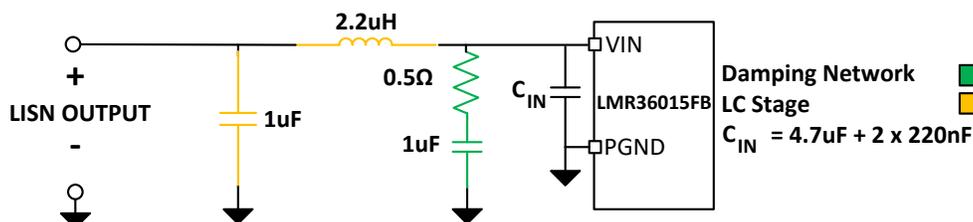


Figure 12. Final Optimized EMI Filter

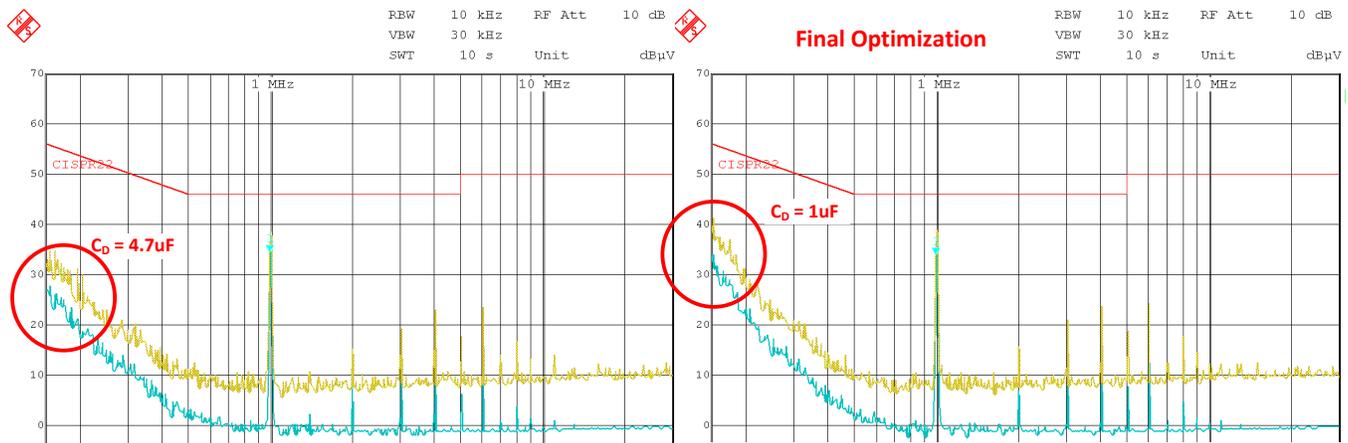


Figure 13. Damping Capacitor Filtering Comparison and Final Optimization

4 Summary

This application report illustrated an example buck converter design with LMR36015B that passed CISPR-22 with good margin without needing a complex EMI filter. Ultimately, this demonstrates the simplicity in passing CISPR-22 and other emission standards with the LMR36015B and in doing so, reducing the time-to-market for new product designs.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (August 2019) to A Revision**Page**

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