Can Nonsynchronous DC-to-DC Boost Converters (with a Catch Diode) Still Have Low Emissions?

Does a DC-to-DC Converter Have to Be Synchronous for Low Emissions?

Keith Szolusha, Applications Director
Kevin Thai, Applications Engineer

Abstract

This article seeks to show how nonsynchronous converters with discrete catch diodes can still achieve low emissions. It will provide an introduction to the different types of converters, layouts, and packages, and why controlled switching is effective. It will also detail passing test results for low EMI evaluation circuits for the CISPR 25 Class 5 emissions test.

Introduction

Synchronous Silent Switcher® converters have set the gold standard for powerful, compact, and quiet DC-to-DC conversion. We have been introduced to a plethora of these low EMI synchronous buck and boost converters in the past 5+ years. These DC-to-DC converters have simplified the system-level EMC design in high power, noise-sensitive environments such as cold-crank preboosts, driving high current LED strings, and high voltage power amplifier sound systems. Monolithic (integrated power switch) boost regulators provide an efficient and more compact solution compared to a controller-based design and are commonly used from source voltages of 5 V, 12 V, and 24 V.

Integrated synchronous switches and their unique layout within the silicon[1] are part of the secret sauce of Silent Switcher converters. On-board (integrated) switches create super-tiny hot loops, which help keep emissions at a bare minimum. However, this can come with a cost, and synchronous switches may not be necessary in all applications. Switching converters can have lower cost if only a single power switch is integrated into the silicon and we can rely upon an external, low cost, discrete catch diode to act as the second switch. This is common practice for lower cost converters, but is this okay to do when low emissions are important?

Nonsynchronous converters with discrete catch diodes can still achieve low emissions. It is possible to design low EMI switching applications with nonsynchronous converters by paying special attention to both the hot loop layout and the dV/dt switching edge rate. Incorporating additional emission reduction with spread spectrum frequency modulation (SSFM) is a must. Monolithic switching regulators such as the LT3950 60 V, 1.5 A nonsynchronous LED driver and the LT8334 40 V, 5 A nonsynchronous boost converter each have a single, low-side power switch integrated into their devices, but they rely upon external catch diodes while still achieving low emissions! How does this work?

Catch Diodes vs. Dead Time

Integrating a single power switch vs. two in a monolithic converter can reduce die size by 30% to 40%. Die size reduction has direct silicon cost savings and an additional, secondary cost savings when the silicon can fit into a smaller package. Although some PCB space still needs to be dedicated to an external, discrete catch diode, these diodes are plentiful, robust, and cheap. In a boost converter, the Schottky diodes with low V_F perform with high efficiency at high output voltage and low duty cycle—arguably outperforming expensive high voltage power FETs.

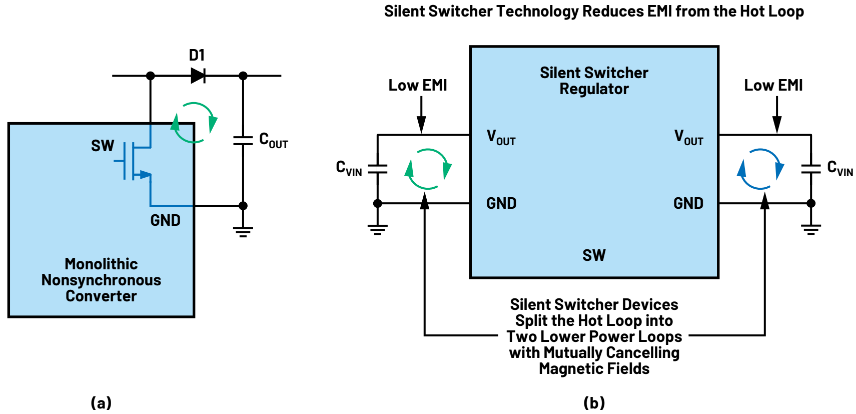


Figure 1. (a) Nonsynchronous monolithic boost converters have a single hot loop, which includes an external catch diode. (b) Silent Switcher converters have two (opposing) hot loops and fully integrated switches.

One reason might be due to dead time. In typical synchronous converters, power switch body diode conduction occurs during a preset dead time to prevent potential shoot-through disasters. Shoot-through occurs when the synchronous switch turns on before the main switch is able to completely turn off—creating a direct short to GND from the input or output (buck or boost). Dead time control can be a limiting aspect of switcher design at high switching frequency and minimum and maximum duty cycle limits. Low cost catch diodes with low forward voltage eliminate the need for dead time logic in a switcher—simple. In most cases, they also outperform the forward voltage drop of the inherent body diodes inside the power switches (which do conduct during dead time).

Simple Layouts and Packages

First, we can start with a simple monolithic boost converter to demonstrate a basic layout. The LT3950 60 V, 1.5 A LED driver in Figure 2 has a simple PCB hot loop. This hot loop, highlighted in Figure 3, only includes the small, ceramic output capacitor and the discrete catch diode of similar size, PMEG6010CEH. These components fit snuggly with the LT3950 16-lead MSE package and the switching pins and GND plane of the thermal pad. Is this enough for low emissions? It sure is part of the equation. The wire-bonded 16-lead MSE package and tight hot loop can achieve low emissions when combined with SSFM and well-controlled switching behavior (switching edge transitions that do not ring due to very high speed and parasitic trace inductance).

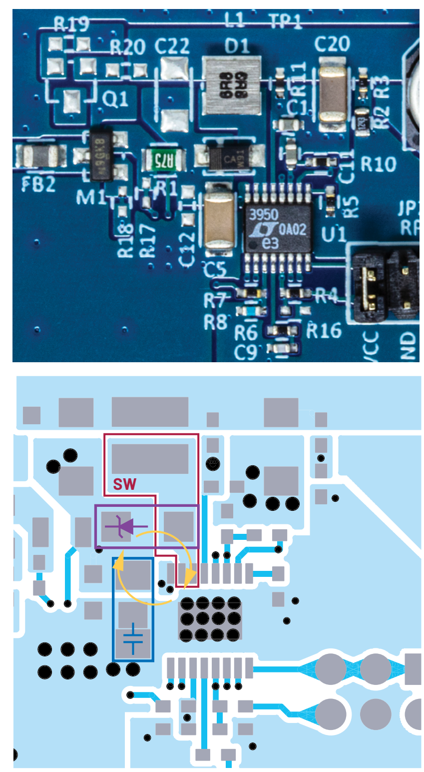


Figure 2. LT3950 (DC2788A) nonsynchronous hot loop includes the D1 catch diode. Nonetheless, the catch diode and output capacitor are fit tightly with the LT3950 16-lead MSE package. The highlighted nonsynchronous switching node is small and compact, but not impossibly so. The layout of the switching node can be critical to low emission results.

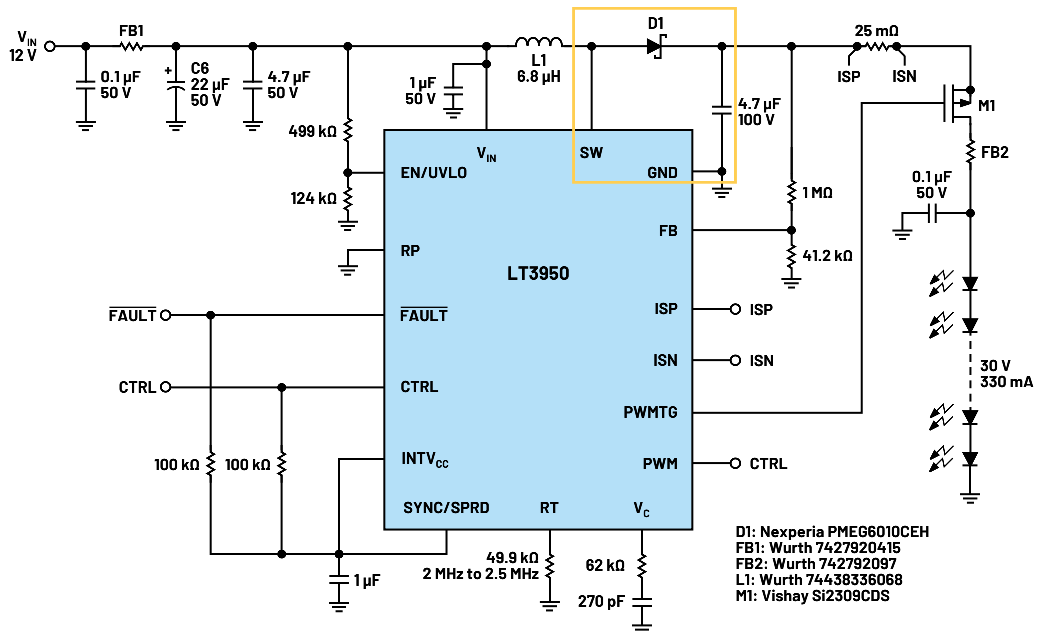


Figure 3. The LT3950 LED driver is a nonsynchronous monolithic 1.5 A, 60 V boost converter. The boost converter hot loop, highlighted in yellow, includes a discrete catch diode without compromising high frequency emissions.

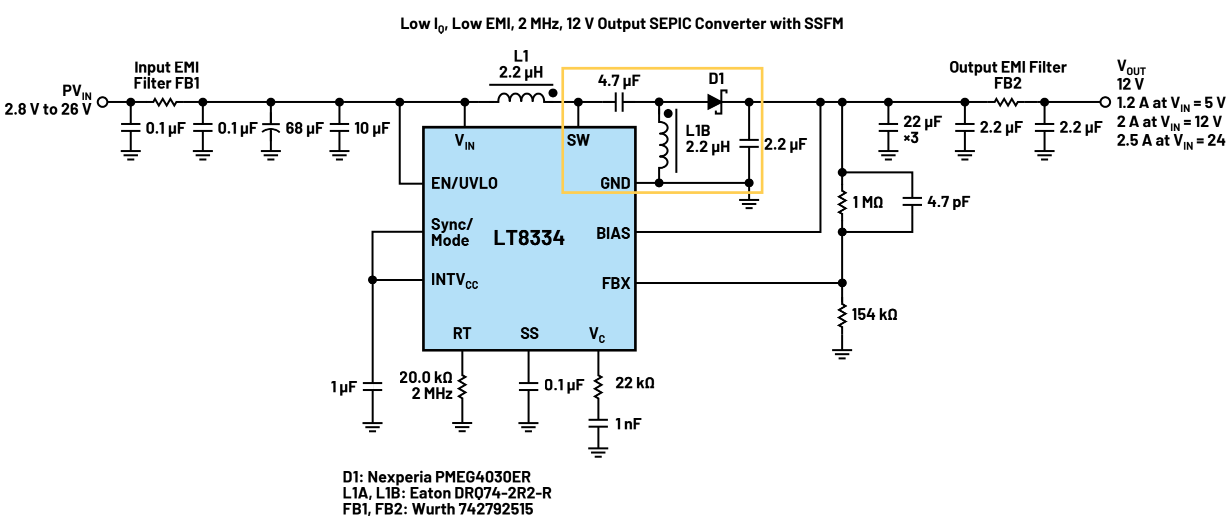


Figure 4. LT8334 40 V, 5 A nonsynchronous monolithic boost IC is used in a SEPIC application. The SEPIC converter hot loop, highlighted in yellow, includes both a discrete catch diode and a coupling capacitor without compromising emissions.

Next, the single switch of a nonsynchronous converter can be used to create a SEPIC topology (step-up and step-down), extending the usefulness beyond just the intended boost designation. The single switch makes it easy to break the hot loop of the boost and add the SEPIC coupling capacitor shown in Figure 4 and Figure 5. Most synchronous boost converters whose top and bottom switches are connected permanently at a single switch node cannot be converted into a SEPIC. The SEPIC hot loop can remain small if attention is paid to the loop formed by the coupling capacitor, the catch diode, and the output capacitor.

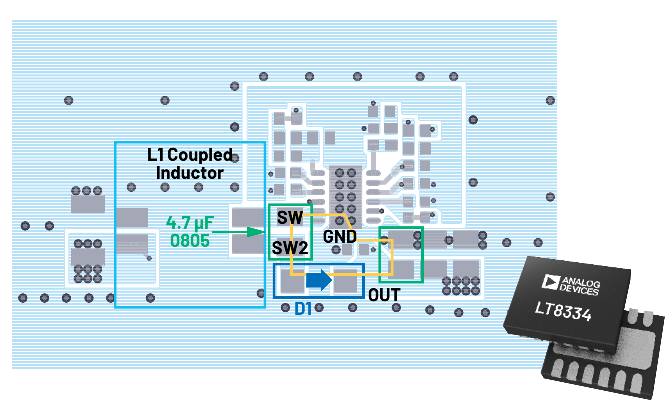
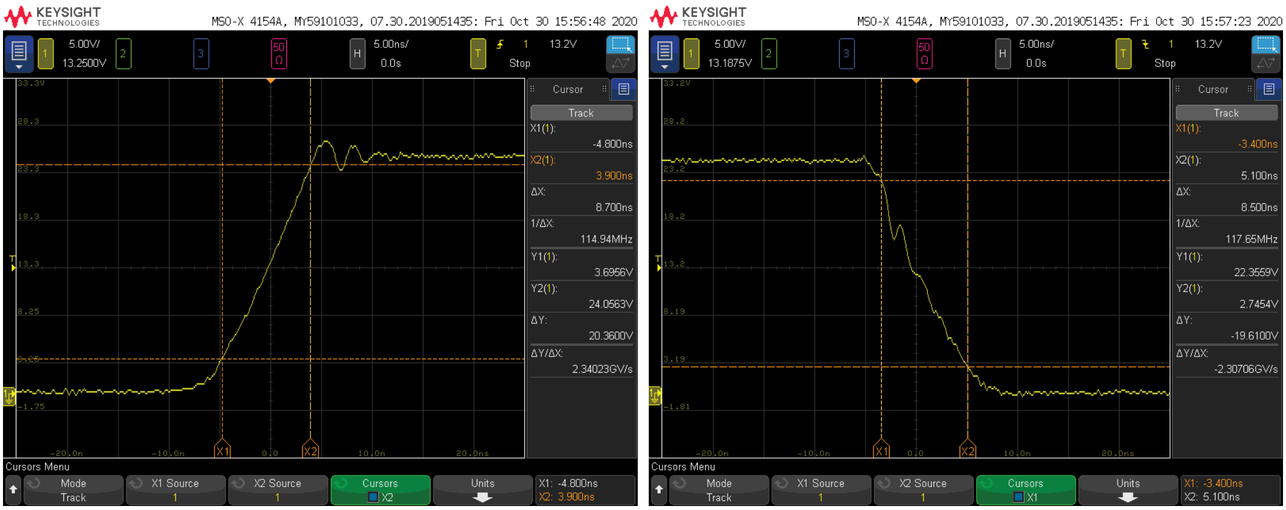


Figure 5. LT8334 single 40 V, 5 A nonsynchronous switch fits into a tiny 4 mm × 3 mm 12-lead thermally enhanced DFN package. The hot-loop layout of an LT8334 SEPIC (EVAL-LT8334-AZ) includes this tiny DFN, a ceramic coupling capacitor, a ceramic output capacitor, and a small catch diode.



(a) **(b)**

Figure 6. LT3950 controlled switching slew rate of 2 V/ns rise and 2 V/ns fall is effective in maintaining high efficiency and low EMI in LED driver applications with little switching node ring.

The LT8334 nonsynchronous boost converter has an integrated 5 A, 40 V switch. This monolithic step-up converter IC is useful for making 12 V output SEPIC converters. Figure 4 shows a standard 12 V, 2 A+ SEPIC converter with coupling capacitor C1 and two inductive windings of a coupled inductor. Since the tiny PMEG4030ER catch diode, D1, is not affixed directly to the switching node, the 4.7 µF 0805 ceramic, DC-blocking, coupling capacitor can be placed between the diode and the switching node with ease. The hot-loop layout remains small on the EVAL-LT8334-AZ SEPIC evaluation board. Keeping the switching node copper as small as possible and as close to the switching pin as possible helps minimize radiated emissions. Please note that the entire hot loop is placed on Layer 1 and there are no vias on either the switching node or the coupled switching node on the other side of the coupling capacitor. Both of these switching nodes should be kept to minimum size and as close as possible for the best results. The 12-lead DFN package of the LT8334 helps to keep the hot loop and emissions as small as possible.

Controlled Switching Is Effective

Monolithic (switch-included) switching converters are quite effective at emission reduction when combined with SSFM, 2 MHz fundamental switching frequency, excellent PCB layout, and well-controlled switching. If they are effective enough, they may not need the extreme benefits of Silent Switcher architecture for low emissions (The Silent Switcher architecture is the gold standard for ultralow emissions, but not necessary in all circumstances just to pass emission standards). In LT3950 and LT8334, SSFM spreads from the fundamental frequency to about 20% higher and back in a triangle pattern. SSFM is a common feature among low EMI switching regulators. There are a variety of types of SSFM, but the overall goal of each type is to spread out the emission energy and to reduce the highest points of peak and average emissions below the required limits. One goal of 2 MHz switching frequency is to set the fundamental switching frequency above the AM radio band (530 kHz to 1.8 MHz) limit so that the fundamental itself and all of its harmonics create emissions without disturbing the radio. When there is no concern for the AM band, a lower switching frequency can be used without concern.

Independent of switching frequency, the internal switch and driver should be designed carefully to avoid certain unwanted behaviors, which result in deteriorated EMI performance in switching converters. Ultrafast, ringing switch waveforms can cause unwanted emissions in the 100 MHz to 400 MHz range, which can be most noticeable on radiated emission measurements. A well-controlled switch inside the IC should act less like an emission hammer and more like an effective rubber mallet with its switching edges dampened. A controlled power switch moves high voltage and current up and down at a slightly reduced rate below what is possible. The 2 V/ns switch rate and lack of ringing in Figure 6b is a great example of this controlled switching in a monolithic converter. You can see how soft this internal switching turns on and lands gently at 0 V, without a harsh ring beyond. This is a major contribution to the emission results of the LT3950 (see figures 9 to 11 below). Normally, in a monolithic switching regulator, the speed of switch drives up the maximum power and reduces the thermal dissipation. However, when carefully designed, less can be more.

Nonsynchronous Boost Controller with Gate Rate Control

At some point, high power DC-to-DC conversion requires a controller and high voltage, high current switches external to the IC. In this case, the gate driver for an external switch remains inside the IC, but the entire switching hot loop moves outside of the IC. Some creative hot loops and layout are possible, but the hot loop itself typically grows due to the size of the discrete MOSFET(s) alone.

The LT8357 high power (nonsynchronous) boost controller provides 24 V, 2 A (48 W) with very low emissions. It powers a 3.5 mm × 3.5 mm MOSFET at a low switching frequency for efficient conversion. In addition to the tight hot loop (Figure 7), it also has rising and falling gate control pins for edge-rate control and emission reduction. A simple 5.1 Ω resistor RP (on GATEP) is enough to reduce the turn-on edge rate of the M1 power MOSFET and keep radiated emissions at a minimum. Of course, some emission filters and SSFM help with emission reduction. An additional place for an emission shield is provided for the

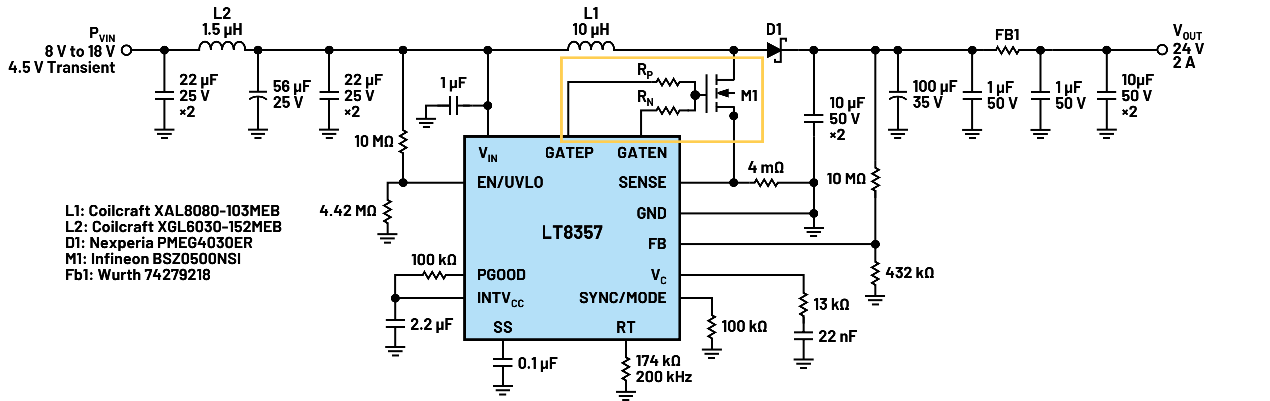


Figure 7. LT8357 high voltage boost controller has split gate pins for separate control of rising and falling edge of the high power discrete MOSFET switching edge. The yellow outline focuses on the split gate pins.

EVAL-LT8357-AZ evaluation board, but it might not be necessary for most applications. This nonsynchronous boost controller, much like its monolithic counterparts, has all of the features necessary for high power, low EMI boost, and SEPIC applications.

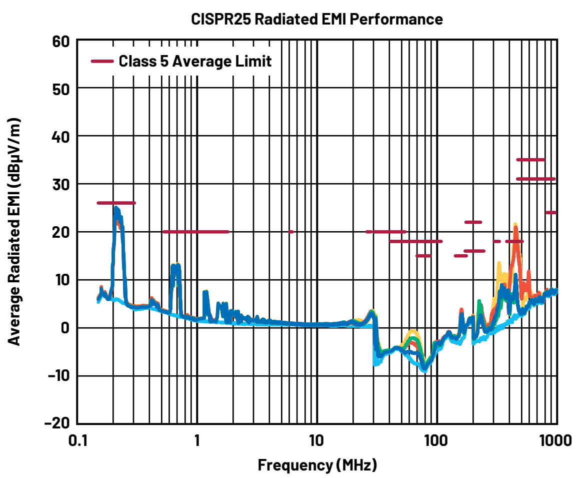


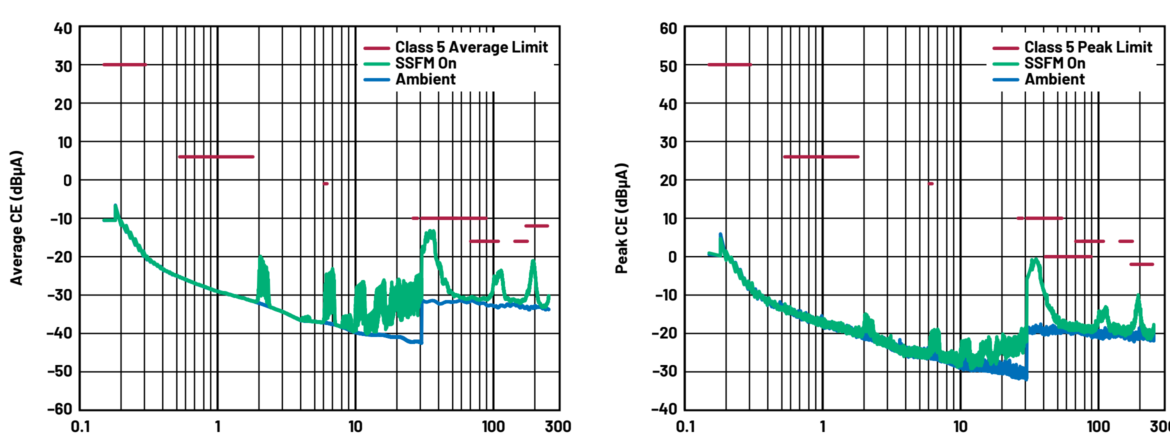
Figure 8. The LT8357 Figure 7 boost has the best emission and efficiency performance with R_P = 5.1 Ω and R_N = 0 Ω. A separate gate drive pins allow a controlled switching turn-on while providing a fast turn-off. In the diagram, the colors represent: red R_P = 0, R_N = 5.1; yellow R_P = 0, R_N = 0; green R_P = 5.1, R_N = 0; and blue R_P = 5.1, R_N = 5.1.

Passes CISPR 25 Class 5 Emissions

Low EMI evaluation circuits like the LT3950 DC2788A have been tested extensively for radiated and conducted emissions. The successful emission test results in figures 9 to 11 were captured with SSFM turned on, 12 V input, and 330 mA current through a 25 V LED string. Both current probe and voltage method CE results pass the most stringent limits. It is common to have FM band CE challenges in switchers, but LT3950 coasts by the FM band.

Setting the switching frequency to 2 MHz (300 kHz to 2 MHz adjustable range) allows the fundamental switching emissions to remain above the AM radio band (530 kHz to 1.8 MHz) and out of trouble while eliminating the need for a bulky LC AM band filter on the front end. Instead, the EMI filters used by the LT3950 can be small, high frequency ferrite beads.

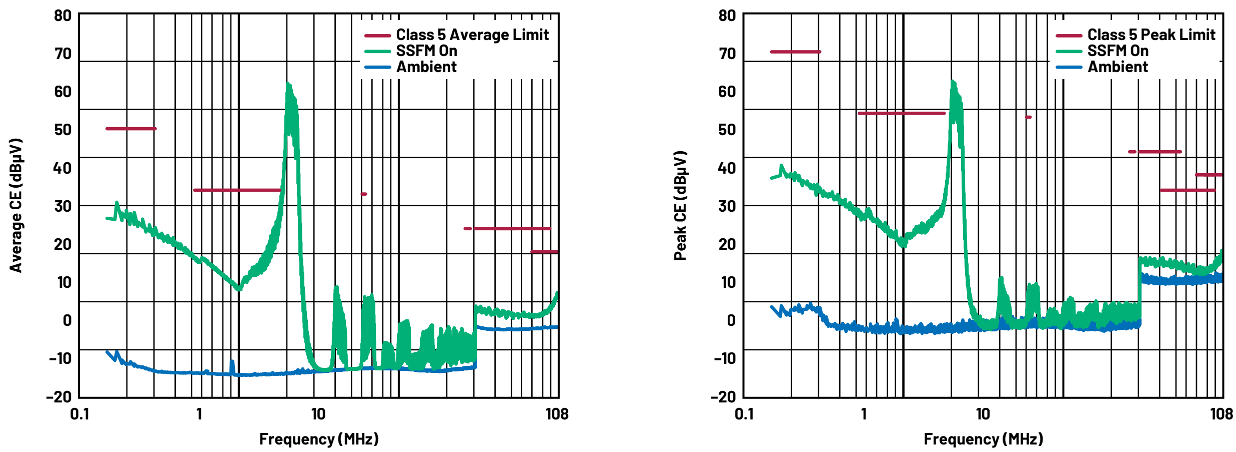
The LT8334 SEPIC also has low emissions despite the additional coupling capacitor in the hot loop and the extra terminals of the coupled inductor (which doubles the number of switching nodes). Also using 2 MHz and SSFM, the EVAL-LT8334-AZ SEPIC 12 VOUT evaluation kit has low emissions. EVAL-LT8357-AZ boost controller can achieve similar performance. Full emission results, schematics, and testing options can be found on the product landing pages for these devices on analog.com. A new family of low EMI nonsynchronous boost and SEPIC converters is listed in Table 1. Monolithic and controller ICs are useful for their simple construction, low cost, multiple topologies, high power capability, and low emissions. High current Silent Switcher boost converters are also available when the ultralow emissions are needed above all else.



(a) CISPR25 Conducted EMI Performance Current Method

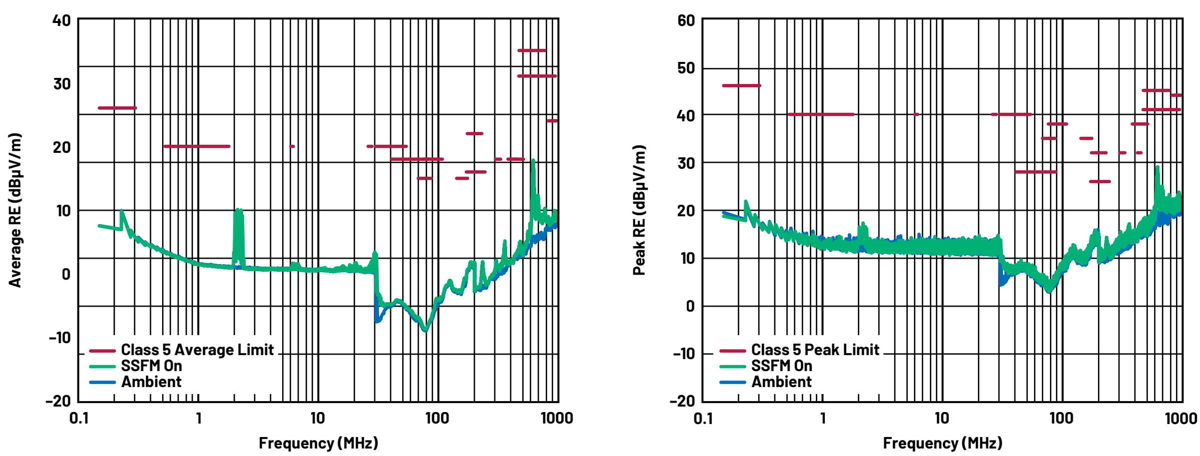
(b) CISPR25 Conducted EMI Performance Current Method

Figure 9. DC2788A LT3950 passes both (a) average (b) and peak CISPR 25 Class 5 conducted emissions (current probe method).



(a) CISPR25 Conducted EMI Performance Voltage Method (b) CISPR25 Conducted EMI Performance Voltage Method

Figure 10. DC2788A LT3950 passes both (a) average and (b) peak CISPR 25 Class 5 conducted emissions (voltage method).



(a) CISPR25 Radiated EMI Performance (b) CISPR25 Radiated EMI Performance

Figure 11. DC2788A LT3950 passes both (a) average and (b) peak CISPR 25 Class 5 radiated emissions.

Table 1. New Low EMI Monolithic Boost Converters with Switching Edge Rate Control

	V_{IN} Range	Integrated SW1	Integrated SW2	f_{SW}	Boost	Buck-Boost	IC Package	AEC-Q100	Special
LT8336	2.7 V to 40 V	2.5 A, 40 V	2.5 A, 40 V	300 k to 3 MHz + SSFM	✓	X	LQFN(16) 3 × 3 mm^2	✓	4 µA Low Iq Burst Mode PassThru™
LT8337	2.7 V to 28 V	5 A, 28 V	5 A, 28 V	300 k to 3 MHz + SSFM	✓	X	LQFN(16) 3 × 3 mm^2		4 µA Low Iq Burst Mode PassThru
LT3922-1	2.8 V to 36 V	2.3 A to 40 V	2.3 A to 40 V	200 k to 2 MHz + SSFM	✓	Buck-Boost Mode LED	QFN(28) 4 × 5 mm^2	✓	LED Driver HUD
LT8386	4 V to 56 V	3.3 A, 60 V	3.3 A, 60 V	200 k to 2 MHz + SSFM	✓	Buck-Boost Mode LED	LQFN(28) 4 × 5 mm^2	✓	LED Driver HUD
LT8362	2.8 V to 60 V	2 A, 60 V	X	300 k to 2 MHz + SSFM	✓	SEPIC	DFN(10) 3 × 3 mm^2 MSOP16(12)	✓	9 µA Low Iq Burst Mode
LT8333	2.8 V to 40 V	3 A, 60 V	X	300 k to 2 MHz + SSFM	✓	SEPIC	DFN(10) 3 × 3 mm^2		9 µA Low Iq Burst Mode
LT8364	2.8 V to 60 V	4 A, 60 V	X	300 k to 2 MHz + SSFM	✓	SEPIC	DFN(12) 4 × 3 mm^2 MSOP16(12)	✓	9 µA Low Iq Burst Mode
LT8334	2.8 V to 40 V	5 A, 60 V	X	300 k to 2 MHz + SSFM	✓	SEPIC	DFN(12) 4 × 3 mm^2		9 µA Low Iq Burst Mode
LT3950	3 V to 60 V	1.5 A, 60 V	X	300 k to 2 MHz + SSFM	✓	Buck-Boost Mode LED	MSOP(16)		LED Driver
LT8357	3 V to 60 V	X Controller	X	100 k to 2 MHz + SSFM	✓	SEPIC	MSOP(12)		8 µA Low Iq Burst Mode Split Gate
LT8356-1	5 V to 100 V	X Controller	X	100 k to 2 MHz + SSFM	✓	Buck-Boost Mode LED	SS.QFN(20) 3 × 4 mm^2	✓	LED Driver

Conclusion

Both synchronous Silent Switcher and nonsynchronous monolithic switching regulators can be used in low emission applications. Nonsynchronous boost converters have a lower cost when compared to the ultrahigh performing Silent Switcher converters. The second switch is replaced by low cost catch diode, which has some advantages at high voltage and for flexibility to be reconfigured as a SEPIC. Small plastic packages and well-designed, small hot switching loop areas of the PCB have low emissions when the power switch edge rate is well controlled with limited ringing. These features should be combined with other low EMI features such as SSFM and EMI filters. Even in high power boost controllers, gate drive control is useful to slow down and smooth out the switching edges for low emissions. Pay special attention to the best possible top-layer layout of the hot loop and choose your DC-to-DC converters wisely for low emission designs. The family of low EMI boost converters from Analog Devices might be just what you need.

References

[1] Steve Knoth. "High Power Density in a Small Form Factor." *Analog Dialogue*, Vo. 53, No. 4, October 2019.

About the Authors

Keith Szolusha is an applications director with Analog Devices in Santa Clara, California. Keith has worked in the BBI Power Products Group since 2000, focusing on boost, buck-boost, and LED driver products, while also managing the power products EMI chamber. He received his B.S.E.E. in 1997 and M.S.E.E. in 1998 from MIT in Cambridge, Massachusetts, with a concentration in technical writing. He can be reached at keith.szolusha@analog.com.

Kevin Thai is an applications engineer with Analog Devices in Santa Clara, California. He works in the CTL Power Products Group and oversees the monolithic boost product line along with other boost, buck-boost, and LED driver products. He received his B.S. degree in electrical engineering from Cal Poly, San Luis Obispo, in 2017, and M.S. degree in electrical engineering from University of California, Los Angeles, in 2018. He can be reached at kevin.thai@analog.com.

TA23609-3/22