ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

Understanding Silent Switcher Technology: High Efficiency, Low EMI

VISIT ANALOG.COM/POWER

Table of Contents

How the Smart Hardware Engineer Can Easily Design Power Supplies: Mini Tutorial

Frederik Dostal

Abstract

This mini tutorial gives an overview of the possibilities for power supply design. It will address the basic and commonly used isolated and nonisolated power supply topologies along with their advantages and disadvantages. We will also cover electromagnetic interference (EMI) and filtering considerations. This mini tutorial aims to provide a simplified understanding and renewed appreciation for the art of power supply design.

Introduction

Most electronic systems require some sort of voltage conversion between the voltage of the energy supply and the voltage of the circuitry that needs to be powered. As batteries lose charge, the voltage will drop. Some DC-to-DC conversion can ensure that much more of the stored energy in the battery is used to power the circuitry. Also, for example, with a 110 V AC line, we cannot power a semiconductor such as a microcontroller directly. Since voltage converters, also named power supplies, are used in almost every electronic system, they have been optimized for different purposes over the years. Certainly, some of the usual targets for optimization are solution size, conversion efficiency, EMI, and cost.

The Simplest Power Supply: The LDO

One of the simplest forms of a power supply is the low dropout (LDO) regulator. LDOs are linear regulators as opposed to switching regulators. Linear regulators put a tunable resistor between the input voltage and the output voltage, which means the output voltage is fixed independent of how the input voltage changes and which load current is running through the device. Figure 1 shows the basic principle of this simple voltage converter.

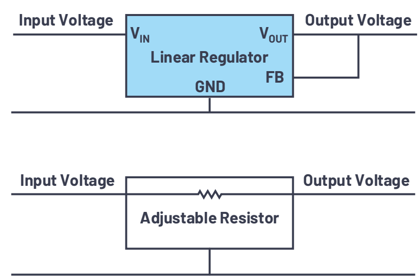


Figure 1. A linear regulator converts one voltage into another.

For many years, a typical power converter consisted of a 50 Hz or 60 Hz transformer, connected to the power grid, with a certain windings ratio to generate a nonregulated output voltage, a few volts higher than the needed supply voltage in a system. Then, a linear regulator was used to convert this voltage to a well-regulated one as needed by the electronics. Figure 2 shows the block diagram of this concept.

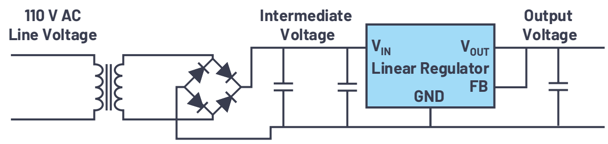


Figure 2. A line transformer followed by a linear regulator.

The problem with the basic setup in Figure 2 is that the 50 Hz/60 Hz transformer is relatively bulky and expensive. Also, the linear regulator dissipates quite a lot of heat, so the total system efficiency is low and getting rid of the generated heat is difficult with high system power.

Switch-Mode Power Supplies to the Rescue

To avoid the disadvantages of a power supply as shown in Figure 2, switch-mode power supplies were invented. They do not rely on 50 Hz or 60 Hz AC voltage. They take a DC voltage, sometimes rectified AC voltage, and generate a much higher frequency AC voltage to use a much smaller transformer or, in nonisolated systems, to rectify the voltage with an LC filter to generate a DC output voltage. The advantages are small solution size and relatively low cost. The AC voltage being generated does not need to be a sine voltage waveform. A simple PWM signal shape will work just fine and is easy to generate with a PWM generator and a switch.

Up until the year 2000, bipolar transistors were the most commonly used switches. They would work well but had relatively slow switching transition speed. They were not very power efficient, limiting the switching frequency to 50 kHz or maybe 100 kHz. Today we use switching MOSFETs instead of bipolar transistors, allowing for much faster switching transitions. This in turn gives us lower switching losses, allowing for switching frequencies of up to 5 MHz. Such high switching frequencies enable the use of very small inductors and capacitors in the power stage.

Switching regulators bring a lot of benefits. They generally offer a power efficient voltage conversion, allow voltage step-up and step-down, and offer relatively compact and low cost designs. The disadvantages are that they are not so simple to design and optimize, and they generate EMI from the switching transitions and the switching frequency. The availability of switch-mode power supply regulators, along with power supply design tools such as LTpowerCAD® and LTspice®, has greatly simplified this difficult design process. With such tools, the circuit design process of a switch-mode power supply can be semi-automated.

Isolation in Power Supplies

When designing a power supply, the first question to answer is whether or not galvanic isolation is required. Galvanic isolation is used for multiple reasons. It can make circuits safer, it allows for floating system operation, and it prevents noisy ground currents from spreading through different electronic devices in one circuitry. The two most common isolated topologies are the flyback and forward converters. However, for higher power, other isolated topologies such as push-pull, half-bridge, and full-bridge are used.

If galvanic isolation is not required, in most cases a nonisolated topology is used. Isolated topologies always require a transformer and such a device tends to be expensive, bulky, and often difficult to get off-the-shelf with the exact requirements that a custom power supply requires.

Most Common Topologies When Isolation Is Not Required

The most common nonisolated switch-mode power supply topology is the buck converter. It is also known as the step-down converter. It accepts a positive input voltage and generates an output voltage lower than the input voltage. It is one of the three most basic switch-mode power supply topologies that only require two switches, an inductor, and two capacitors. Figure 3 shows the basic principle of this topology. The high-side switch pulses a current from the input and generates a switch node voltage alternating between the input voltage and ground voltage. The LC filter takes that pulsed voltage on the switch node and generates a DC output voltage. Depending on the duty cycle of the PWM signal controlling the high-side switch, a different level of DC output voltage is generated. This DC-to-DC buck converter is very power efficient, is relatively easy to build, and requires few components.

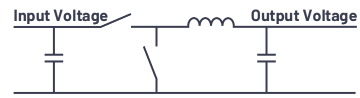


Figure 3. Concept of a simple buck step-down converter.

The buck converter pulses current on the input side, while the output side has continuous current coming from the inductor. This is the reason why a buck regulator is very noisy on the input side and not so noisy on the output side. Understanding this is important when low noise systems need to be designed.

Besides the buck topology, the second basic topology is the boost, or step-up, topology. It uses the same five basic power components as the buck converter, but rearranged, so that the inductor is placed on the input side and the high-side switch is placed on the output side. The boost topology is used to step up a certain input voltage to an output voltage that is higher than the input voltage.

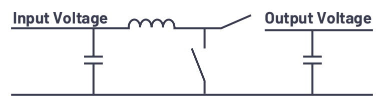


Figure 4. Concept of a simple boost step-up converter.

When selecting a boost converter, it is important to note that boost converters always specify the maximum rated switch current and not the maximum output current in their data sheets. In a buck converter, the maximum switch current is directly related to the maximum achievable output current, independent of voltage ratio between the input voltage and the output voltage. In a boost regulator, the voltage ratio directly affects the possible maximum output current based on a fixed maximum switch current. When selecting a suitable boost regulator IC, you need to not only know the desired output current, but also the input and output voltage of the design in development.

A boost converter is very low noise on the input side, since the inductor in line with the input connection prevents rapid changes in current flow. However, on the output side this topology is quite noisy. We only see pulsed current flow through the outside switch, and thus output ripple is more of a concern compared to the buck topology.

The third basic topology, only consisting of the five basic components, is the inverting buck-boost converter. The name is derived from the fact that this converter takes a positive input voltage and converts it into a negative output voltage. Besides this, the input voltage may be higher or lower than the absolute of the inverted output voltage. For example, –12 V output voltage may be generated out of 5 V or 24 V on the input. This is possible without making any special circuit modifications. Figure 5 shows the circuit concept of the inverting buck-boost converter.

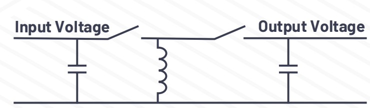


Figure 5. Concept of a simple inverting buck-boost converter.

In the inverting buck-boost topology, the inductor is connected from the switch node to ground. Both the input side as well as the output side of the converter see pulsed current flow, making this topology relatively noisy on both the input side as well as the output side. In low noise applications, this nature is compensated by adding additional input and output filtering.

One quite positive aspect of the inverting buck-boost topology is the fact that any buck switching regulator IC may be used for such a converter. It is as simple as attaching the output voltage of the buck circuit to system ground. The buck IC circuit ground will become the adjusted negative voltage. This trait yields a very large selection in switching regulator ICs on the market.

Specialized Topologies

Besides the three basic nonisolated switch-mode power supply topologies previously discussed, there are many more topologies available. However, they all require additional power components. This typically makes them higher cost with lower power conversion efficiency. While there are certain exceptions, generally, adding additional components in the power path will add losses. Some of the most popular topologies are SEPIC, Zeta, Ćuk, and the 4-switch buck-boost. They each offer features that the three basic topologies do not offer. The following is a list of the most important features of each topology:

- SEPIC
  The SEPIC can generate a positive output voltage out of a positive input voltage that may be higher or lower than the output voltage. Boost regulator ICs may be used to design a SEPIC power supply. The drawback of this topology is the need for a second inductor or one coupled inductor and also a SEPIC capacitor.

- Zeta
  The Zeta converter is similar to the SEPIC, but it is capable of generating a positive or negative output voltage. Also, it does not have a right-half-plane zero (RHPZ), thereby simplifying the regulation loop. A buck converter IC can be used for such a topology.

- Ćuk
  The Ćuk converter offers an inversion of a positive input voltage into a negative output voltage. It uses two inductors, one on the input side and one on the output side, making it quite low noise on the input and output sides. The drawback is that there are not very many switch-mode power conversion ICs supporting this topology, since a negative voltage feedback pin is required for the regulation loop.

- 4-Switch Buck-Boost
  This converter type became quite popular in recent years. It offers a positive output voltage from a positive input voltage. The input voltage may be higher or lower than the adjusted output voltage. This converter replaces a lot of SEPIC designs, as it offers higher power conversion efficiency and only requires one inductor.

Most Common Isolated Topologies

Besides nonisolated topologies, some applications require galvanically isolated power converters. The reasons may be safety concerns, the need to have floating grounds in larger systems where different circuits are interconnected, or the prevention of ground current loops in noise sensitive applications. The most common isolated converter topologies are the flyback and forward converters.

The flyback converter is typically used for power levels up to 60 W. The circuit operates in a way that during the on-time, energy is stored in a transformer. During the off-time, this energy is released to the secondary side of the converter, powering the output. This converter is simple to build, but it requires relatively large transformers to store all the energy necessary for proper operation. This aspect limits the topology to lower power levels. Figure 6 shows a flyback converter on the top and a forward converter on the bottom.

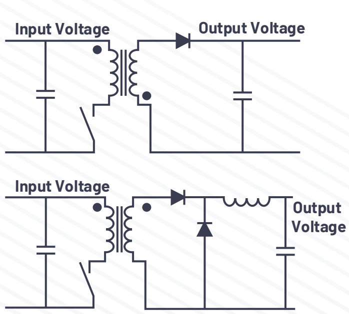


Figure 6. A flyback converter (top) and a forward converter (bottom).

Besides the flyback converter, the forward converter is also very popular. It uses a transformer in a different way than the flyback. During the on-time, while there is current flow through the primary side winding, there is also current flow through the secondary winding. Energy should not be stored in the core of the transformer. After each switching cycle, we have to make sure that all the magnetization of the core is released to zero, so that the transformer will not saturate after a number of switching cycles. This energy release out of the core can be achieved with a few different technologies. One popular way is to use an active clamp with a small additional switch and capacitor.

Figure 7 shows the LTspice simulation environment schematic of a forward active clamp design using the ADP1074. In the forward converter, there is an additional inductor in the output path compared to the flyback, as shown in Figure 6. While this is one additional component with associated space and cost implications, it helps to generate a lower noise output voltage compared to a flyback converter. Also, the transformer size needed for a forward converter at the same power level as a flyback may be much smaller.

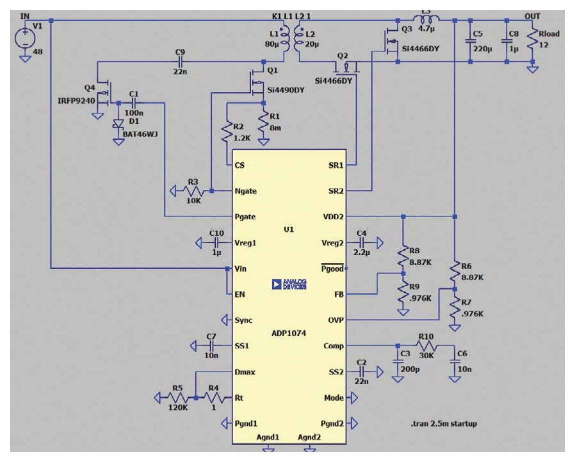


Figure 7. A forward active clamp circuit using the ADP1074 for generating an isolated output voltage, as simulated in LTspice.

Advanced Isolated Topologies

Besides the flyback and the forward topologies, there are very many different transformer-based galvanically isolated converter concepts. The following list gives some very basic explanations about the most common converters:

- Push-Pull
  The push-pull topology is similar to that of the forward converter. However, instead of one low-side switch, this topology requires two active low-side switches. Also, it requires a primary transformer winding with a center tap. The advantage of the push-pull is an operation with generally lower noise compared to a forward converter, and also a smaller transformer is needed. The hysteresis of the BH curve of a transformer is utilized in two quadrants rather than just one.

- Half-Bridge/Full-Bridge
  These two topologies are typically used for higher power designs starting at a few hundred watts all the way to a few kilowatts. They require high-side switches besides low-side switches but enable very high power transfer with relatively small transformers.

- ZVS
  This term comes up often when discussing high power isolated converters. It stands for zero voltage switching. Another term for such converters is LLC (inductor-inductor-capacitor) converters. These architectures aim for very high efficiency conversion. They generate a resonance circuit and switch the power switches while the voltage or current across the switches is close to zero. Thus, the switching losses are minimized. However, such designs may be difficult to design and the switching frequency is not fixed, sometimes yielding EMI problems.

Switched Capacitor Converters

Besides linear regulators and switch-mode power supplies, there is also a third group of power converters: the switched capacitor converters. They are also referred to as charge pumps. They use switches and capacitors to multiply or invert voltages. They offer the big advantage of not needing any inductor. Typically, such converters are used for low power levels of below 5 W. However, recently major advancements have been made to allow for much higher power switched capacitor converters. Figure 8 shows the LTC7820 in a 120 W design at 98.5% efficiency, converting 48 V to 24 V.

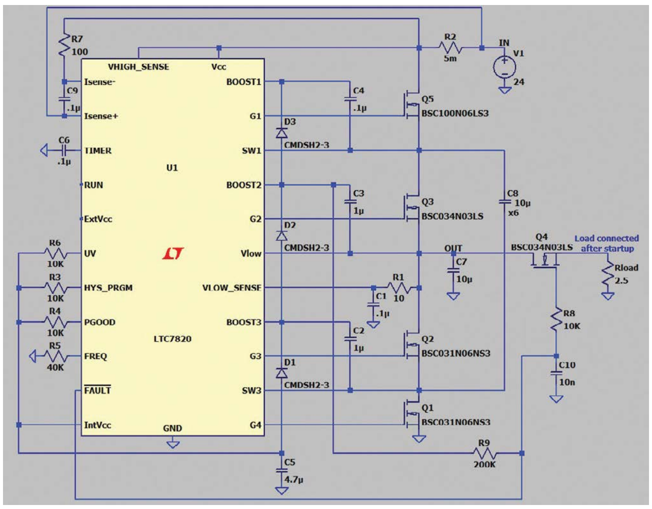


Figure 8. An LTC7820 fixed ratio high power charge pump DC-to-DC controller.

Digital Power Supplies

All the power supplies discussed in this article can be implemented as analog or digital power supplies. What are digital power supplies, really? Power must always run through an analog power stage with switches, inductors, transformers, and capacitors. The digital aspect is introduced by two digital building blocks. The first one is digital interfacing, which allows an electronic system to "talk" and "listen" to a power supply. Different parameters may be set on-the-fly to optimize the power supply for different operating conditions. Also, the power supply can communicate with a main processor and raise warning or fault flags. For example, load current, crossing a preset threshold, or excessive temperature of a power supply may easily be monitored by a system.

The second digital building block replaces an analog regulation loop with a digital loop. This can work successfully, but for most applications, the optimum is a standard analog feedback loop with some digital influence on some parameters, such as adjusting the gain of the error amplifier on-the-fly or dynamically setting the loop compensation parameters to enable a stable but fast feedback loop. An example of a device with a purely digital control loop is the ADP1046A from Analog Devices. One example of a digitally interfaced buck regulator with an analog control loop, optimized by digital influences, is the LTC3883.

EMI Considerations

Electromagnetic interference (EMI) is always a topic to pay attention to when designing switch-mode power supplies. The reason is that switch-mode power supplies switch high current flow on and off within very short periods of time. The faster the switching, the better for total system efficiency. Faster switcting transitions reduce the time during which the switch is partially turned on. During this partial turn-on time, most switching losses are generated. Figure 9 shows the waveform of the switch node of a switch-mode power supply. Let's imagine a buck regulator. High voltage is defined by current flow through the high-side switch, and low voltage is defined by lack of current flow through the high-side switch.

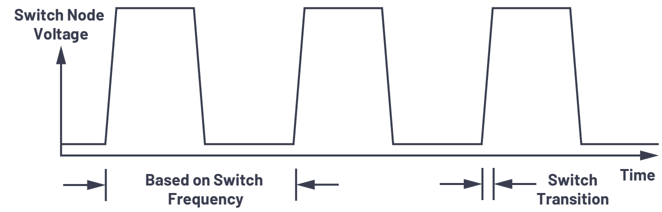


Figure 9. Switching transition speed as well as switching frequency of a switch-mode power supply.

In Figure 9 we can see that a switch-mode power supply does not only generate noise coming from the adjusted switching frequency, but also from the switching transition speed, which is much higher in frequency. While the switching frequency usually runs between 500 kHz and 3 MHz, the switching transition time may be a few nanoseconds long. At 1 ns switching transition time, we will see 1 GHz corresponding frequency in the spectrum. At least both of those frequencies will be seen as radiated and conducted emissions. Other frequencies may also show up coming from oscillations of the regulation loop or interactions between the power supply and filters.

There are two reasons why EMI should be reduced. The first reason is to protect the functionality of the electronic system that a specific power supply is powering. For example, a 16-bit ADC that is used in the signal path of the system should not pick up switching noise coming from the power supply. The second reason is to fulfill certain EMI regulations that are put in place by governments all over the world to protect reliable functionality of different electronic systems simultaneously.

EMI comes in two forms, radiated EMI and conducted EMI. The most effective ways of reducing radiated EMI is to optimize the PCB layout and to use technologies such as the Silent Switcher® technology from Analog Devices. Certainly, it is also effective to put the circuit into a shielded metal box. However, this may not be practical and in most cases is very costly.

Conducted EMI is typically attenuated by additional filtering. The next section will discuss additional filtering to reduce conducted emissions.

Filtering

RC filters are basic low-pass filters. However, in power supply design, every filter is nothing but an LC filter. Often, just adding some inductance in series is enough, since it will form an LC or CLC filter together with the input or output capacitors of a switch-mode power supply. Sometimes only capacitors are used as filters, but, considering the parasitic inductance on power cables or traces, together with a capacitor we form an LC filter as well. The inductor L may be an inductor with a core, or it may be a ferrite bead. The purpose of the LC filter really is a low-pass effect, so that DC power can run through and higher frequency disturbances are attenuated to a large degree. An LC filter has a double pole, so we get a high frequency attenuation of 40 dB per decade. This filter has a relatively sharp drop-off. Designing a filter is not rocket science; however, since parasitic components of the circuit, such as trace inductance, have an effect, modeling a filter also requires modeling the major parasitic effects. This can make simulating a filter quite time consuming. Many designers with filter design experience know which filters have worked before, and they may iteratively optimize a certain filter for a new design.

In all filter design, one needs to not only consider the small signal behavior, such as a transfer function of a filter in a Bode plot, but one also needs to be aware of the large signal effect. In any LC filter, power runs through the inductor. If that power is not needed at the output anymore, due to a sudden load transient, the energy stored in the inductor needs to go somewhere. It charges up the capacitance of the filter. If the filter is not designed for such worst-case conditions, that stored power may cause voltage overshoots that can possibly harm circuitry.

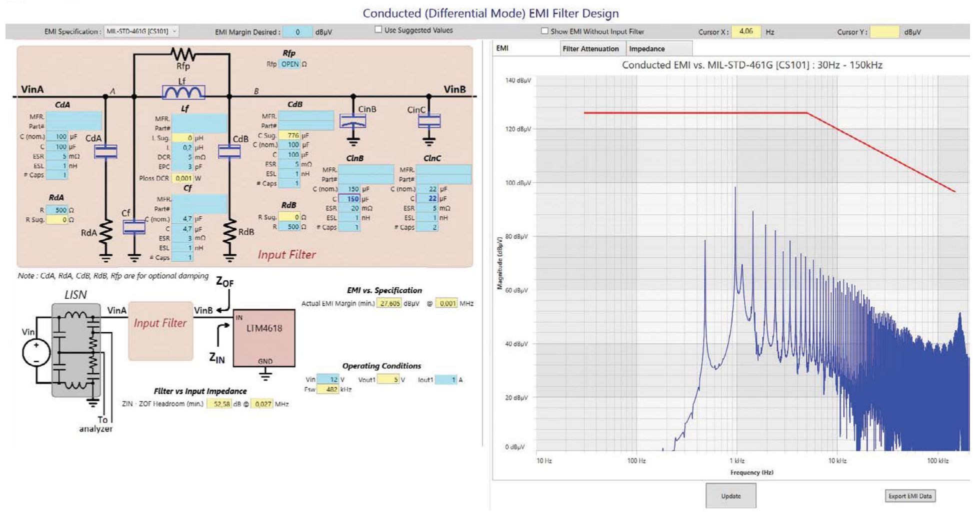


Figure 10. Designing an input filter for a buck regulator with LTpowerCAD.

Finally, filters have a certain impedance. That impedance interacts with the impedances of the power converters that are attached to the filter. This interaction may lead to instabilities and oscillations. Simulation tools such as LTspice and LTpowerCAD from Analog Devices can be a big help in answering all these questions and designing a perfect filter. Figure 10 shows the graphical user interface of the filter designer within the LTpowerCAD design environment. With this tool, filter design is very simple.

Silent Switchers

Radiated emissions are difficult to block. A special shielding with some metal material is needed. This can be very costly. For a long time, engineers were looking for ways to reduce the radiated emissions that switch-mode power supplies generated. A few years ago, a great breakthrough was made with Silent Switcher technology. By reducing the parasitic inductances in the hot loops of a switch-mode power supply, and by splitting the hot loops into two and setting them up in a very symmetrical way, radiated emissions mostly cancel each other out. Today, many Silent Switcher devices are available offering much lower radiated emissions than heritage products. Reducing the radiated emissions allows for switching transition speeds to increase without a serious EMI penalty. Making the switching transitions faster reduces switching losses and thus allows for much higher switching frequencies. One example of this innovation is the LTC3310S, which can operate at 5 MHz switching frequency, enabling extremely compact designs with very low cost external components.

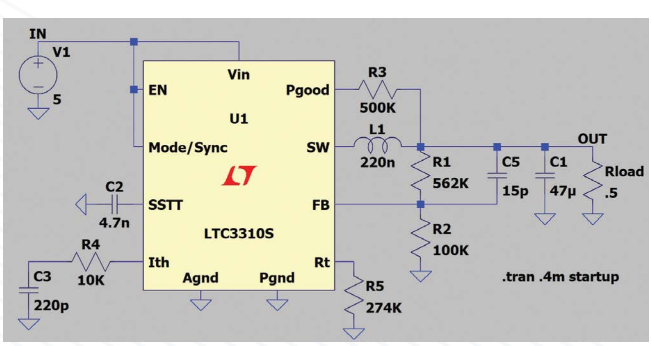


Figure 11. LTC3310S Silent Switcher design for the lowest radiated emissions.

Power Management Is a Necessity but Can Be Enjoyable Too

In this tutorial we looked at many aspects of power supply design, including the different power supply topologies and their advantages and disadvantages. For power supply engineers, this information can be very basic, but for experts and non-experts alike, it is helpful to have software tools such as LTpowerCAD and LTspice to aid in the design process. With these tools, power converters can be designed and optimized in very little time. Hopefully this tutorial inspired you to look forward to your next power supply design challenge.

About the Author

Frederik Dostal studied microelectronics at the University of Erlangen in Germany. Starting work in the power management business in 2001, he has been active in various applications positions including four years in Phoenix, Arizona, where he worked on switch-mode power supplies. He joined Analog Devices in 2009 and works as a field applications engineer for power management at Analog Devices in München.

Improving Power Supply Design Using Semi-Automation—Five Steps to Quick and Efficient Design

Designing the correct power source is essential and complex, since there is no one typical application. While total automation of power supply design is yet to be achieved, a comprehensive range of semi-automated tools are available today. This article details the use of semi-automated design tools through five critical steps of the power supply design process. These tools can be valuable to both the novice and expert power supply design engineer.

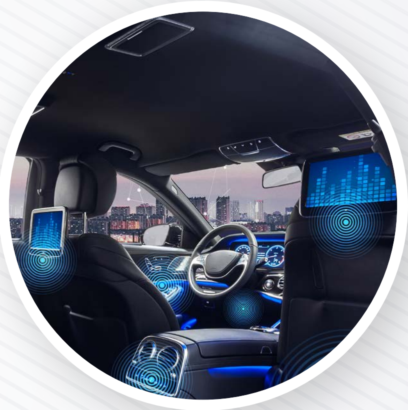
Download Now

Ultralow Noise, High Current, Compact DC-to-DC Converter Solution for Signal and Data Processing Circuits

Data processing ICs—such as field programmable gate arrays (FPGAs), systems on a chip (SoCs), and microprocessors—continually increase their reach into telecommunications, networking, industrial, automotive, avionics, and defense systems. One common thread throughout these systems is ever increasing processing power, resulting in corresponding increases in raw power requirements. Designers are well aware of the thermal management problems of high power processors but may not consider the thermal management issues of power supplies. Not unlike the transistor-packed processors themselves, worst-case thermal problems are inevitable when low core voltages require high current—the overall trend for the power supplies for all data processing systems.

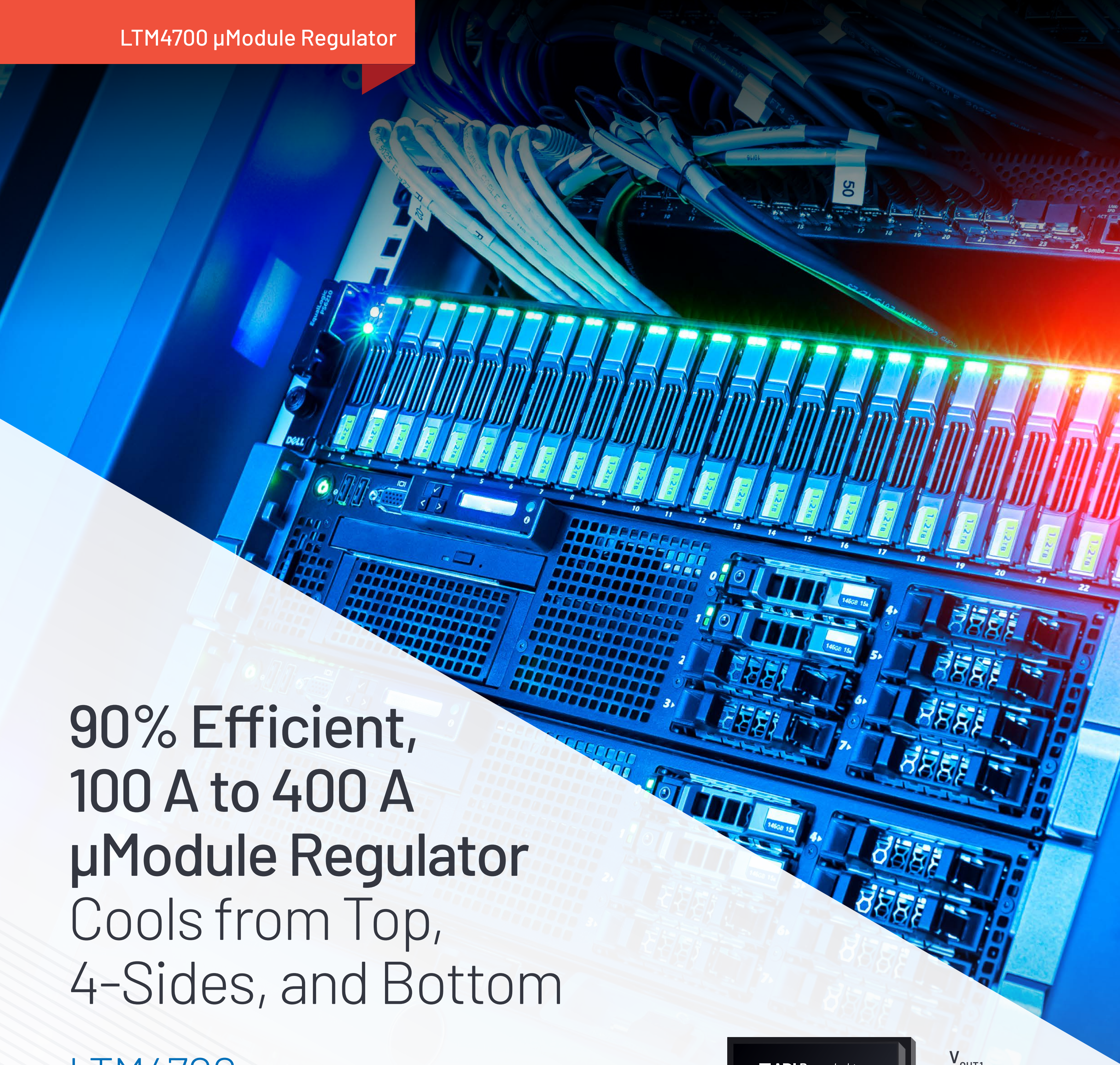
Download Now

Increasing the Common-Mode Rejection Ratio of Differential Amplifiers Through Precisely Matched Resistor Networks



The increasing volume of data collected, communicated, and stored in everything from 5G to industrial applications has expanded the performance limits of analog signal processing devices, some into the gigasamples per second. As the pace of innovation never slows, the next generation of electronics solutions will lead to further shrinking in solution volumes, increasing power efficiency, and greater demand for better noise performance.

Download Now

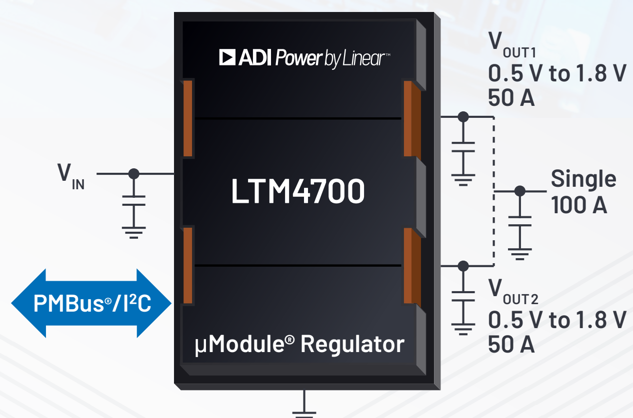


90% Efficient, 100 A to 400 A µModule Regulator

Cools from Top, 4-Sides, and Bottom

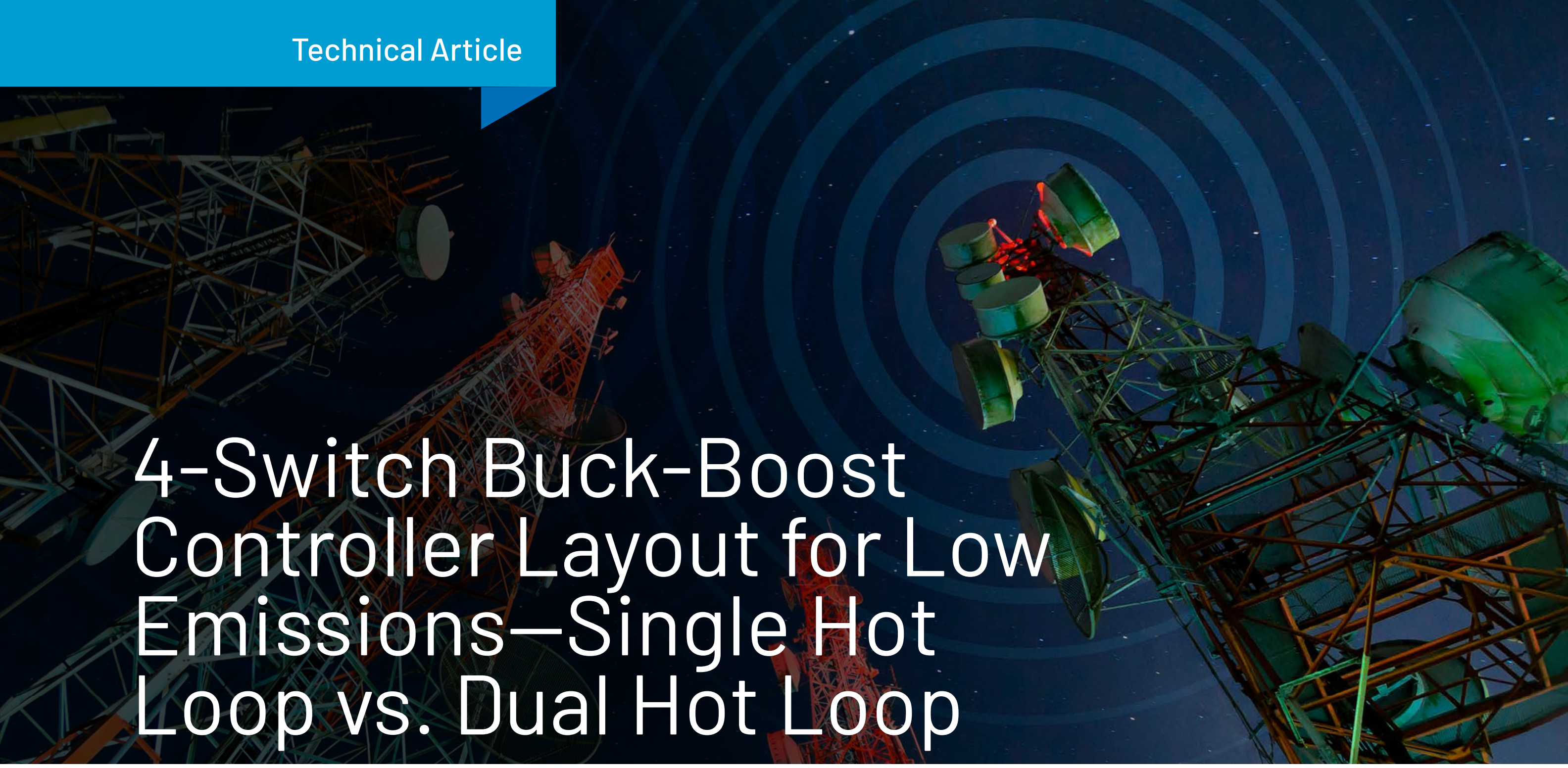
LTM4700

- Single 100 A or dual 50 A µModule® regulator
- Scalable up to 400 A (eval board DC2784A-C)
- 12 V_{IN} to 1 V_{OUT}
  - 90% efficiency at 100 A
  - 47°C temperature rise with 200 LFM airflow, TA: 25°C



15 mm × 22 mm × 7.87 mm BGA

Buy Now at analog.com/LTM4700



Technical Article

4-Switch Buck-Boost Controller Layout for Low Emissions—Single Hot Loop vs. Dual Hot Loop

Yonghwan Cho and Keith Szolusha

Automotive application circuits must meet strict EMI standards to avoid interfering with broadcast and mobile service frequency bands. In many cases, Silent Switcher® and Silent Switcher 2 solutions can make a significant difference in the ability to meet these standards. Nevertheless, in all cases, careful layout is imperative. In this article we look specifically at two possible solutions for a 4-switch buck-boost controller and compare EMI chamber results.

A 4-switch buck-boost combines a buck and boost controller into a single IC, where the converter operates as a buck when the output is lower than the input, and as a boost when the output is higher than the input. In the region where the output and input are similar, all four switches may operate.

Using ADI's in-house EMI chamber at Santa Clara, CA, the Power Products research team launched an investigation into the effectiveness of the original dual hot loop synchronous layout and if an alternative layout could be used for lower EMI noise to pass the EMI standard.

The dual hot loop layout involves the symmetrical placement of hot loop ceramic capacitors around power MOSFETs to contain EMI noise. ADI's unique sense resistor location—alongside the inductor and outside of the hot loops—allows these loops to be very small, and thus minimize the antenna effect of the hot loops. To achieve this symmetry and enable the switch node(s) to reach the nearby inductor, switching node vias are required, which may compromise the hot loop area. Using the CISPR 25 compliant EMI chamber, the research team found that exposure of the switching node and large hot loop area results in unwanted conducted EMI especially at >30 MHz (the FM radio band), which is the most challenging frequency range to attenuate.

The original buck-boost layout, which has a single hot loop, can improve its smallest hot loop by rearranging the power MOSFETs and hot loop capacitors. This layout is known as a single hot loop as a counterpart of the dual hot loop. The benefit of using a single hot loop is not only smaller switching loss but also that >30 MHz conducted emissions (CE) are attenuated due to the minimized hot loop area and the exposure of the switching node. Its effectiveness is verified by comparing the EMI noise of the new layout to a dual hot loop using the same controller IC and same power components. A 4-switch buck-boost controller, LT8392, and its two versions of demo circuit (DC2626A rev.2 and rev.3) were used for the experiment.

Layout Comparison

Figure 1 shows the layout and assembled board pictures of a dual hot loop and single hot loop. Each board has four layers: a top layer (Layer 1), Layer 2, Layer 3, and a bottom layer (Layer 4). However, only the top and bottom layers are shown. As shown in Figure 1(a), hot loop capacitors are placed at the left and right side of the center MOSFETs and form identical hot loops. Switching node vias are used to connect the switching nodes, SW1 and SW2, to the main power inductor through the bottom layer (shown in Figure 1(c)) and Layer 3. The SW1 and SW2 top layer copper nodes are laid out with large area to dissipate the heat of the inductor and MOSFETs. But at the same time, the largely exposed SW1 and SW2 copper nodes are a source of EMI emission. If the board is mounted near chassis ground, parasitic capacitance is formed between the chassis and the switching node copper. It makes high frequency noise flow from the switching node to chassis ground and affects other circuits in the system. In the CISPR 25 compliant EMI chamber, the high frequency noise flows through the ground table of the EMI setup and LISN. The exposed switching node also acts as an antenna and, thus, causes radiated EMI noise.

However, a single hot loop does not have the exposed switching node copper at the bottom layer, as shown in Figure 1(d). At the top layer, shown in Figure 1(b), the hot loop capacitors are placed at only one side of the MOSFETs, which makes it possible for the switching node to be connected to the inductor without using switching node vias.

In the single hot loop layout, the top and bottom MOSFETs are not aligned, but one of them is 90° rotated to make the hot loop as small as possible. The size of the hot loop of the dual hot loop and the single hot loop are compared in Figure 1(e) and Figure 1(f) with the yellow highlighted box. These boxes show that the hot loop of a single hot loop is half the size of the dual hot loop.

It should be noted that the two 0402 hot loop capacitors of the dual hot loop shown in Figure 1(a) are not used and the 1210 hot loop capacitors are squeezed to the MOSFETs to make the smallest hot loop.

A solder mask near the 0402 capacitor pads is peeled off for good connectivity of 1210 capacitors. Also, the solder mask near the inductor pad is removed to use the same inductor in the single hot loop circuit. A smaller hot loop means that the total

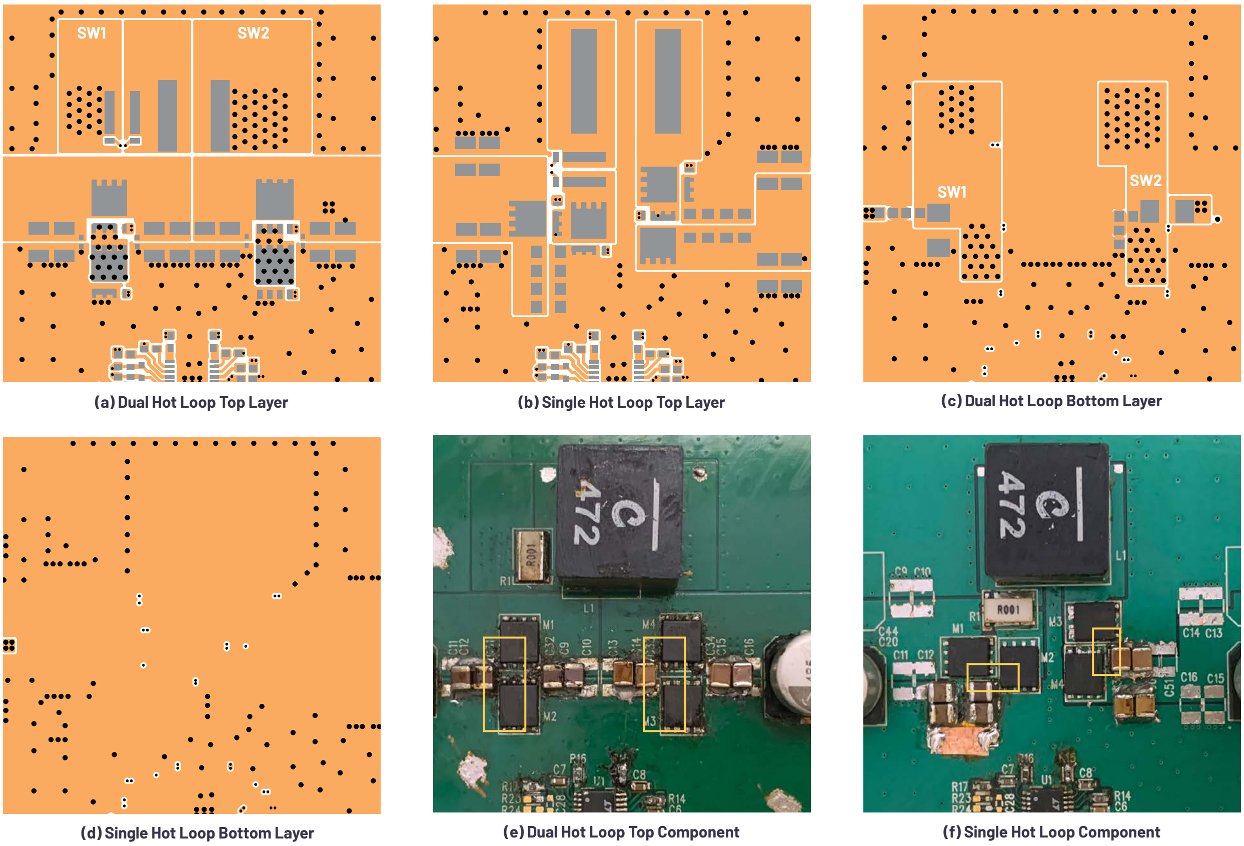


Figure 1. Layout and photograph of a dual hot loop and single hot loop.

inductance of the loop is smaller. Thus, switching loss is reduced and LC ringing of the switching node and switching current is attenuated. Also, the smaller loop contributes to lower conducted EMI above 30 MHz as radiated emissions affect conducted EMI in that range.

ADI's 4-switch buck-boost controller can form the smallest hot loop due to the proprietary peak buck/peak boost current-mode control scheme. The current sense resistor is connected in series with the main inductor. In contrast, competitors' controller parts use a valley buck/peak boost current-mode control scheme where the current sense resistor should be put between the source of the bottom MOSFETs and ground. Figure 2 shows the recommended buck-boost layout of one of these parts. As shown with the yellow box, the hot loop is larger than the dual hot loop or single hot loop. Moreover, the parasitic inductance of the sense resistor increases the total inductance of the hot loop.

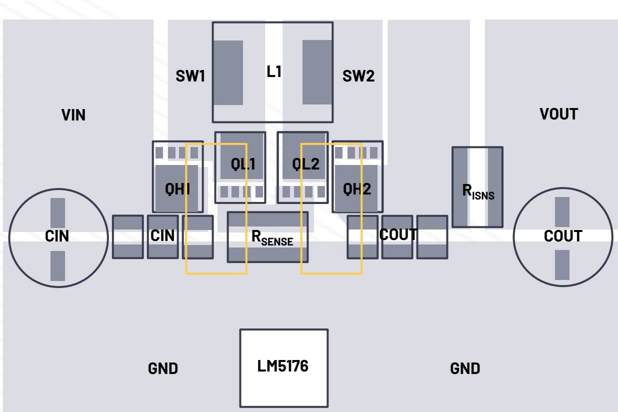


Figure 2. The recommended buck-boost layout of competitor part LM5176.

EMI Comparison

The EMI of the dual hot loop and single hot loop is measured in the CISPR 25 compliant EMI chamber and shown in Figure 3 with a CISPR 25 Class 5 standards limit. The EMI results are plotted in the same graph to compare the difference, with a dual hot loop marked with a yellow line and a single hot loop marked with a red line. The gray line is the noise floor that is measured at ambient condition. As shown in Figure 4, the exposed switching nodes of the bottom layers of a dual hot loop were ground shielded with copper tape to show how effective the smaller hot loop is. The emission of a dual hot loop without the copper shield is much higher than the result in Figure 3. The output is 12 V, 8 A and the input voltage was set to 13 V to make the circuit operate in 4-switch switching mode.

Figure 3(a) shows the peak and average of voltage method conducted emissions, respectively. A single hot loop has 5 dBμV lower CE above 30 MHz and it satisfies the CISPR 25 Class 5 standard for both peak and average CE while dual hot loops have overshoot in average at FM and VHF band (68 MHz to ~108 MHz), as shown in the yellow highlighted box.

Note that reducing 5 dBμV in that frequency range is really challenging. A single hot loop is effective not only at the high frequency range of 30 MHz, which is the most challenging region to attenuate, but also at low frequency (<2 MHz) that includes AM band (0.53 MHz to ~1.8 MHz). It is always better to have lower emissions, especially if they are CE, since they affect all of an electrically connected system.

The current probe method is another measurement method that CISPR 25 Class 5 specifies. It measures common-mode conducted emissions at two different positions, 50 mm and 750 mm from DUT, while the voltage method measures mixed conducted emissions of both common mode and differential mode. Figure 3(b) and 3(c) compare the current probe method conducted emissions of the dual hot loop and single hot loop. They show that the single hot loop has lower

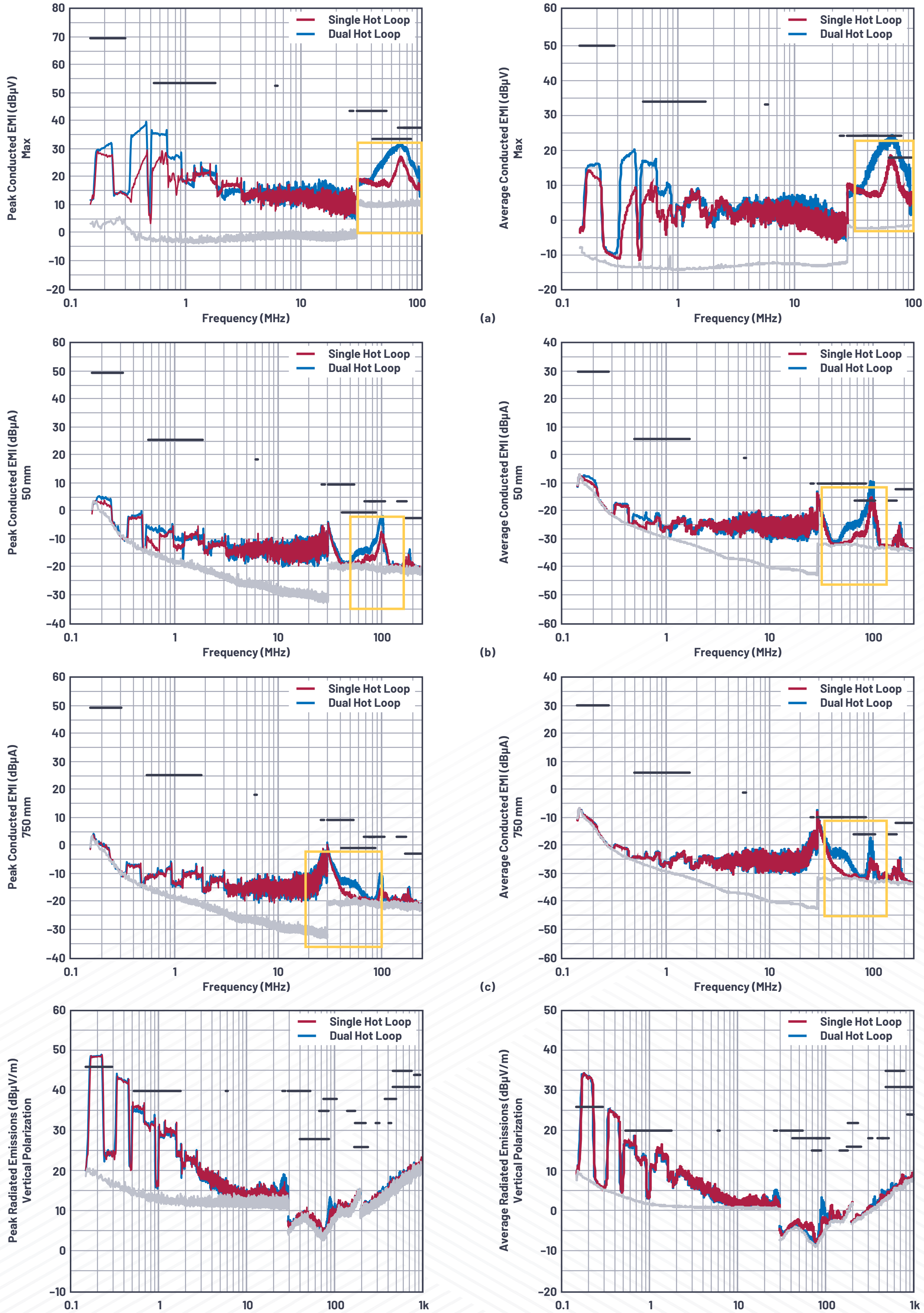


Figure 3. EMI comparison graph of a dual hot loop and single hot loop: (a) voltage method conducted emissions peak and average, (b) current probe method conducted emissions 50 mm peak and average, (c) current probe method conducted emissions 750 mm peak and average, and (d) radiated emissions vertical peak and average.

conducted emissions above 30 MHz, and especially at FM band, as shown in the yellow highlighted boxes. Unlike the voltage method conducted emissions, there is no significant benefit of a single hot loop over dual hot loop at the low frequency around the AM band.

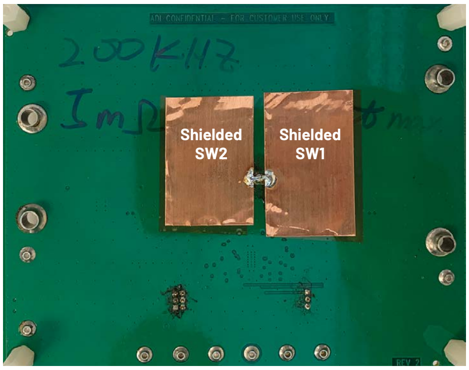
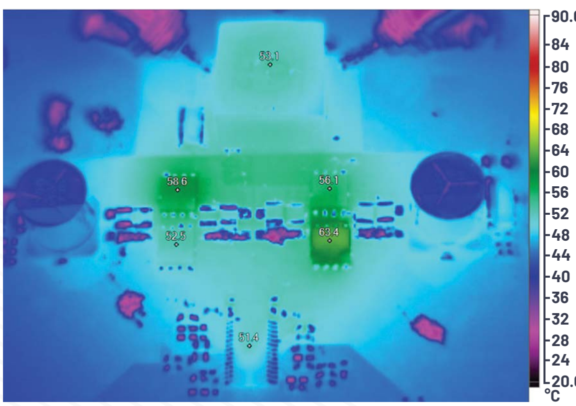


Figure 4. Shielded switching nodes of bottom layer of a dual hot loop.

Lastly, Figure 3(d) shows the radiated emissions (RE) of the two different buck-boost layouts. The results are almost identical except that the dual hot loop has a spike around 90 MHz, which is 5 dBµV/m higher than the single hot loop.

Thermal Comparison

A thermal comparison between the dual hot loop and the single hot loop is made in Figure 5. The thermal images are taken at 9.4 V input voltage with SSFM on. 9.4 V is the lowest point of the 4-switch operation region before the operating mode is changed to 2-switch pure boost when the output voltage is 12 V. Thus, the test condition is the harshest. The hottest component of the dual hot loop, the boost-side bottom MOSFET, and the single hot loop have almost the same temperature. Although the single hot loop does not have the switching node vias and copper at the bottom layer that can dissipate heat, its switching loss is lower than the dual hot loop due to the smaller hot loop. Also, by not using the switching node vias, the single hot loop has better heat dissipation at the top layer because the contact area of the MOSFET drain pad and the switching node copper is larger than that of the dual hot loop.



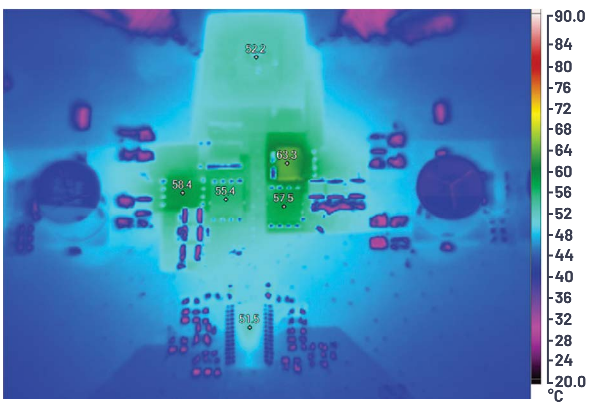


Figure 5. (a) Thermal image of a dual hot loop, and (b) thermal image of a single hot loop.

Conclusion

The suggested new buck-boost layout, single hot loop, is recommended for new, high power designs. Due to the minimized exposure of the switching node and the hot loop area, the single hot loop has significant benefit to reduce both conducted and radiated emissions without any thermal disadvantages. Notably, it reduces conducted emissions above 30 MHz, which is the most challenging frequency region to attenuate. Thanks to the proprietary peak buck/peak boost current-mode control feature of ADI's 4-switch buck-boost controllers (LT8390/LT8390A, LT8391/LT8391A, LT8392, LT8393, LT8253, etc.), the hot loop can be made much smaller than those with competitors' parts. The control feature results in higher efficiency and lower EMI, making ADI's 4-switch buck-boost controllers the best choice for automotive applications or any EMI sensitive applications.

About the Authors

Yonghwan Cho is a senior applications engineer with Analog Devices in Santa Clara, California. He works on DC-to-DC switching regulators, including 4-switch buck-boost voltage regulators and LED drivers for automotive applications. Yonghwan received his Ph.D. degree in electrical engineering in 2017 from North Carolina State University in Raleigh, North Carolina.

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.

Technical Article

High Power Density in a Small Form Factor

Steve Knoth

Background

Sophisticated high power density digital integrated circuits (ICs), such as graphics processor units (GPUs) and field programmable gate arrays (FPGAs), can be found in a broad range of feature-rich electronic environments, including:

- Automotive
- Medical
- Telecom
- Datacom
- Industrial
- Communications
- Gaming
- Consumer audio/video

With this level of market penetration, it is no surprise that the global demand for high current, low voltage digital ICs is exploding. The current global market is assessed at more than US $1.8B, and this is expected to rise annually by 10.87% to reach US $3.7B over the 2018 to 2025 period. As one of the biggest slices of this market, FPGAs account for a projected US $1.53B by the end of 2025. The rest of the digital IC market is represented by GPUs, microcontrollers and microprocessors, programmable logic devices (PLDs), digital signal processors (DSPs), and application-specific integrated circuits (ASICs).

High power density digital ICs have penetrated virtually every embedded system. FPGAs enable cutting-edge applications in the market segments listed above. For example, in automotive applications, advanced driver assistance systems (ADASs) and collision avoidance systems prevent catastrophe due to human error. Likewise, government-mandated safety features such as antilock brake systems, stability control, and electronically controlled independent suspension systems require FPGAs to function.

In consumer electronics, the demand for Internet of Things (IoT) functionality, sophisticated graphic engine functionality, and machine-to-machine (M2M) functionality call for advanced digital ICs. Massive data storage and cloud computing centers and expansive networks of optical networking modules drive the need for FPGAs and digital ICs.

These digital ICs are powerful, yet temperamental, especially regarding power requirements. Traditionally, efficient switching regulator controllers that drive high power MOSFETs have been used to power FPGAs and ASICs, but these controller-based power schemes have potential noise interference issues, relatively slow transient response, and layout limitations. In recent years, small and quiet low dropout (LDO) regulators that minimize heat have been used as an alternative, but not without their own set of limitations. Recent power conversion innovations have introduced high power monolithic switching regulators that are able to efficiently power digital ICs with low noise and high efficiency while minimizing space requirements.

Switching Regulators vs. Charge Pumps vs. LDO Regulators

Low voltage, high current step-down conversion and regulation can be achieved via a variety of methods, each with its own performance and design trade-offs. Switching regulator controllers feature high efficiency at high load currents over a wide range of voltages, but they require several external components such as inductors, capacitors, and FETs to operate; and they can be a source of high and low frequency noise. Inductorless charge pumps (or switched capacitor voltage converters) can also be used to produce low voltages, but are limited in output current capability, suffer from poor transient performance, and require several external components. For these reasons, charge pumps are not commonly found in digital IC power applications. Linear regulators—especially LDO regulators—are simple in that they only require two external capacitors to operate. However, they may be power limited depending on the size of the input-to-output voltage differential across the IC and how much current is demanded by the load, plus the thermal resistance characteristics of the package. This certainly limits their ability to power digital ICs.

Monolithic Buck Converter Design Challenges

Moore's Law has proven to be visionary and valid since its debut in 1965. Wafer fabrication technology line widths are continually being reduced, pushing digital IC voltages lower. Smaller geometry processes allow higher integration of more power-hungry features in the end product. For example, modern computer servers and optical communication routing systems demand higher bandwidth to process more computing data and internet traffic; these systems also generate a lot of heat, and therefore highly efficient ICs are required. Cars have more on-board electronics for entertainment, navigation, self-driving features, and even engine control. As a result, there is an increase in both the system's current consumption and the associated total power required. Therefore, state-of-the-art packaging and innovative, internal power-stage design are required to drive the heat out of the power IC while delivering unprecedented power.

High power supply rejection ratio (PSRR) and low output voltage noise, or ripple, are important considerations. A device with high supply rejection can filter and reject noise at the input, resulting in a clean and stable output. Furthermore, power solutions with low output voltage noise across a wide bandwidth or low output ripple are desirable—modern digital systems have several rails where noise sensitivity is a major design consideration. As speed requirements for high end FPGAs increase, supply noise tolerance decreases in order to minimize bit errors. Noise-induced digital faults drastically reduce the effective data throughput speeds for these high speed PLDs. Input supply noise at high current is one of the more demanding specifications placed on power supplies.

Higher transceiver speeds—in FPGAs, for example—dictate high current levels due to high power consumption from fine geometry circuit switching. These ICs are fast. They may cycle load current from near-zero to several amps within tens to hundreds of nanoseconds, requiring a regulator with ultrafast transient response.

With board area reserved for the power regulators ever-decreasing, many system designers turn to monolithic switching regulators operating at fast switching frequencies to reduce the size of external components and total solution size—accepting the trade-off of some efficiency loss due to switching losses at higher frequencies. This trade-off is eliminated by a new generation of monolithic switching regulators. These new regulators feature synchronous operation with integrated high-side and low-side switches, allowing for tight control of switch gate voltages, greatly reducing dead time, and resulting in higher efficiencies even at high frequencies.

One of the biggest challenges with high current monolithic switchers is their ability to dissipate heat that results from power loss in the IC. This challenge can be met by using multiple power and ground pins, plus thermally enhanced laminate-based packages with copper (Cu) pillars where the heat can be easily transferred from the IC into the board. The large copper planes on the board connected to these power pins allow for the heat to spread more evenly.

New Family of Silent Switcher Buck Converters

It's clear that buck converter solutions for high performance digital ICs must have the following attributes:

- Fast switching frequency to minimize the size of external components
- Zero dead-time design to maximize efficiency at high frequency
- Monolithic chip on-board power device for smaller solution size
- Multiphase operation enables parallel operation for high output currents and reduced ripple
- Low EMI to meet low system noise requirements
- Synchronous operation for high efficiency and minimal power loss
- Easy design simplifies design cycle, qualification, and testing
- Very low output ripple
- Fast transient response time
- Operation over a wide input/output voltage range
- High output current capability
- Excellent thermal performance
- Compact footprint

These features can be found in Analog Devices' Power by Linear™ LTC33xx family of monolithic high, medium, and low current buck regulators. The highest current member is the LTC3310S, a 5 V, 10 A, high power density, low EMI, Silent Switcher® 2, monolithic, synchronous buck converter in a 9 mm^2 package (power density = 1.11 A/mm^2). The device's fixed frequency peak current-mode architecture is ideal for applications that demand fast transient response. The LTC3310S uses the Silent Switcher 2 architecture with integrated hot loop bypass capacitors to deliver a highly efficient, small footprint solution at frequencies up to 5 MHz with excellent EMI performance. Multiphase operation enables direct paralleling of up to four devices for higher current up to 40 A.

The LTC3310S' 2.25 V to 5.5 V input range supports a wide variety of applications, including most intermediate bus voltages. Integrated low on-resistance MOSFETs deliver continuous load currents as high as 10 A with minimal thermal derating. Output voltages ranging from 0.5 V to V_{IN} are ideal for point-of-load applications such as high current, low voltage DSP/FPGA/GPU/ASIC designs. Other key applications include optical networking, telecom/datacom, automotive systems, distributed power architectures, or any medium-to-high power density systems. Figure 1 shows the simplicity of a typical design, while Figure 2 shows how easy it is to produce a 4-phase, 40 A configuration.

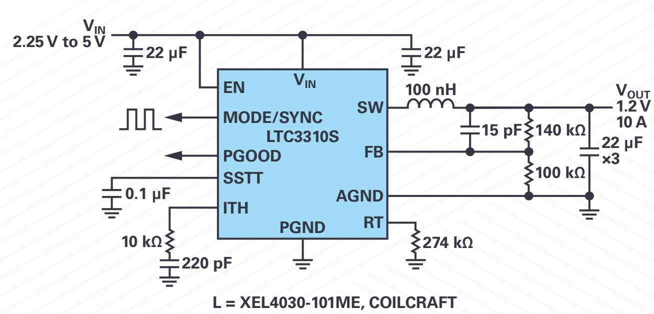


Figure 1. LTC3310S typical application.

The LTC3310S' low 35 ns minimum on-time enables a large step-down ratio at high frequency, and 100% duty-cycle operation delivers low dropout performance when the input and output voltages are close in value. The operating frequency can be synchronized to an external clock. The LTC3310S total reference voltage accuracy is better than ±1% over the –40°C to +125°C operating junction temperature range. Additional features include a power good signal when the output is in regulation, precision enable threshold, output overvoltage protection, thermal shutdown, die temperature monitor, programmable soft start, tracking, clock synchronization, mode selection, and output short-circuit protection.

The LTC3310S is available in a thermally enhanced 18-lead, 3 mm × 3 mm × 0.94 mm LQFN package. The E- and I-grades are specified from the –40°C to +125°C operating junction temperature range, while the J- and H-grades are specified from the –40°C to +150°C operating junction temperature range.

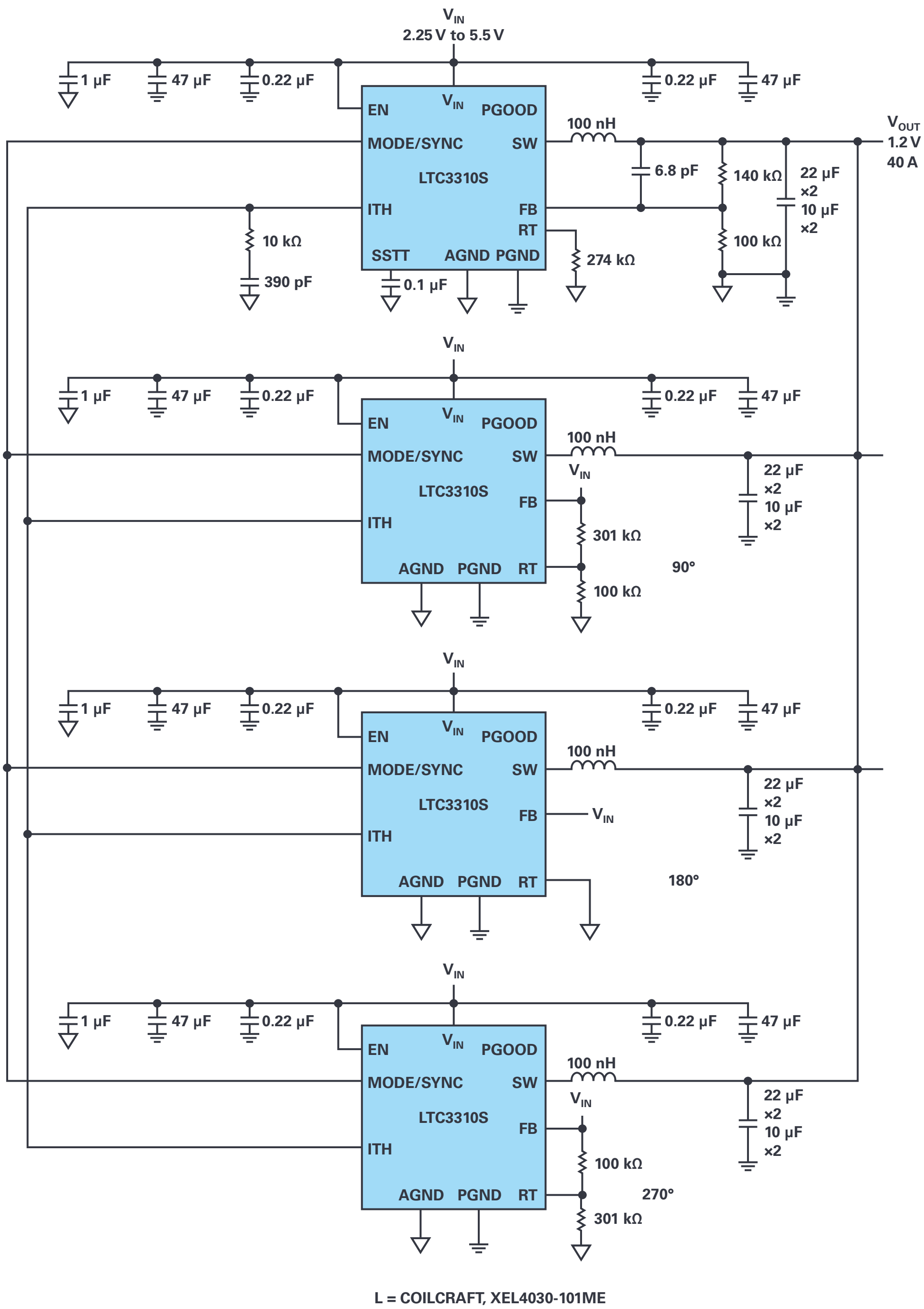


Figure 2. Four LTC3310S monolithic regulators in parallel, forming a 4-phase, 40 A step-down regulator.

High Efficiency, Low EMI, and Fast Transient Response

Silent Switcher buck regulator designs offer high efficiency at high switching frequencies (>2 MHz) with ultralow electromagnetic interference (EMI) emissions, offering very compact and quiet step-down solutions. The Silent Switcher family uses special design and packaging techniques to enable >92% efficiency at 2 MHz while easily passing the CISPR 25 Class 5 peak EMI limits. The next-generation Silent Switcher 2 technology internal construction uses copper pillars in lieu of bond wires, adds internal bypass capacitors, and an integrated substrate ground plane to further improve EMI, which is not sensitive to PCB layout, simplifying designs and reducing performance risks.

The "S" in the LTC3310S part number indicates its second-generation Silent Switcher technology. The IC has integrated V_{IN} ceramic capacitors to keep all fast ac current loops small, improving the EMI performance. This technology allows fast switching edges for high efficiency at high switching frequencies, while simultaneously achieving good EMI performance (see Figure 3, Figure 4, and Figure 5). Furthermore, it allows for faster, cleaner, low overshoot switching edges, greatly improving efficiency at high switching frequencies. The graph in Figure 6 shows the LTC3310S's high efficiency performance.

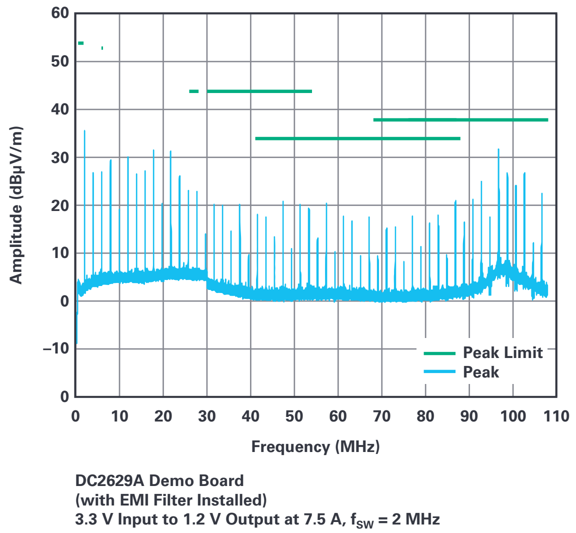


Figure 3. CISPR 25 conducted EMI emissions with Class 5 peak limits (voltage method).

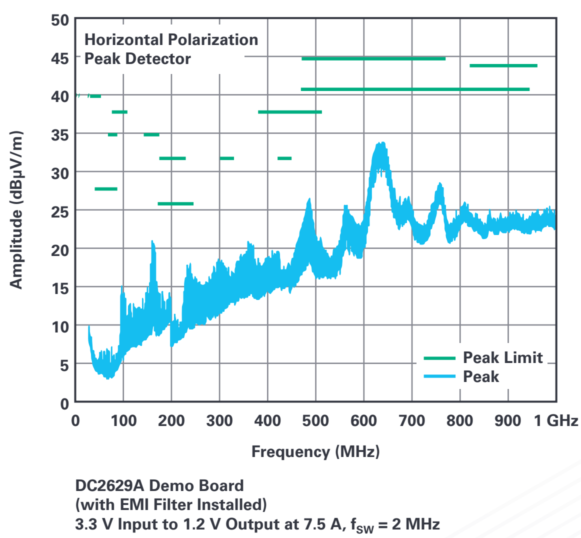


Figure 4. Radiated emissions for horizontal polarization.

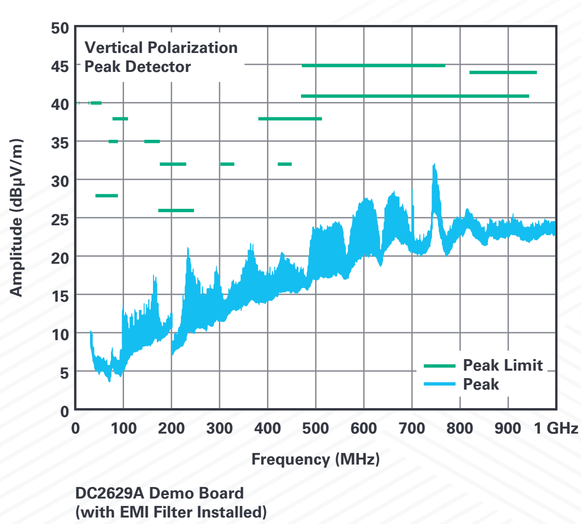


Figure 5. Radiated emissions for vertical polarization.

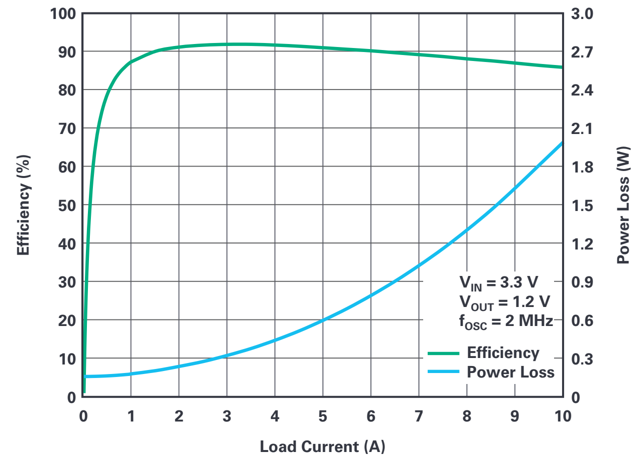


Figure 6. LTC3310S efficiency performance.

The LTC3310S's fixed frequency peak-current mode architecture eases compensation and allows the IC to rapidly respond to transient steps. External compensation components allow the control loop to be optimized for the highest bandwidth and fastest transient response.

6 A, 4 A, and 3 A Silent Switcher Bucks in a 2 mm × 2 mm Package

For increased power density, first-generation Silent Switcher architecture is a good solution. Silent Switcher topology is like Silent Switcher 2 topology except the V_{IN} bypass capacitors are external instead of within the plastic encapsulation flip-chip laminate style package. For full Silent Switcher, low EMI performance, external V_{IN} bypass capacitors are placed symmetrically, external to the package. This split cap, symmetrical arrangement minimizes the effective hot loop area, thereby reducing EMI and allowing for a smaller package footprint size.

LTC3309A, LTC3308A, and LTC3307A are 5 V input regulators that can support 6 A, 4 A, and 3 A (respectively), for high power density, low EMI monolithic synchronous buck conversion. They all operate at up to 3 MHz in a 4 mm^2 footprint package (LTC3309A power density = 1.5 A/mm^2).

Figure 7 shows a typical LTC3309A application. The fixed frequency peak current-mode architecture is ideal for fast transient response, including fast transient response during Burst Mode® operation (see Figure 8). The LTC3309A features Silent Switcher architecture, utilizing external hot loop bypass capacitors. This design enables highly efficient, small footprint solutions at high operating frequencies with excellent EMI performance.

The family's 2.25 V to 5.5 V input voltage range supports a wide variety of applications, including most intermediate bus voltages, and is compatible with lithium and nickel-based battery types. Integrated low on-resistance MOSFETs deliver continuous load currents as high as 6 A. Output voltages, ranging from 0.5 V to V_{IN}, are ideal for point-of-load applications such as high current/low voltage DSP/FPGA/GPU/ASIC reference designs. Other key applications include telecom/datacom and automotive systems, distributed power architectures, and general-purpose power systems.

The LTC3309A, LTC3308A, and LTC3307A operate in forced continuous or pulse skip modes for low noise, or low ripple, low I_Q Burst Mode operation for high efficiency at light loads, ideal for battery-powered systems. Low 22 ns minimum on-time enables high step-down ratios even as the power supply operates at high frequency, and 100% duty cycle operation delivers low dropout performance when input and output voltages are the same. The operating frequency can be synchronized to an external clock. The total reference voltage accuracy is better than ±1% over the –55°C to +150°C operating junction temperature range. The device safely tolerates inductor saturation in overload. Additional features include a power good signal when the output is in regulation, internal soft start, precision enable threshold, output overvoltage and short-circuit protection, thermal shutdown, and clock synchronization.

The LTC3309A, LTC3308A, and LTC3307A are all pin-compatible devices available in a thermally enhanced, compact, and low profile 12-lead, 2 mm × 2 mm × 0.74 mm LQFN package. The E- and I-grades are specified from a –40°C to +125°C operating junction temperature range. The J- and H-grades are specified from a –40°C to +150°C operating junction temperature range, and the MP-grade is specified from a –55°C to +150°C operating junction temperature range.

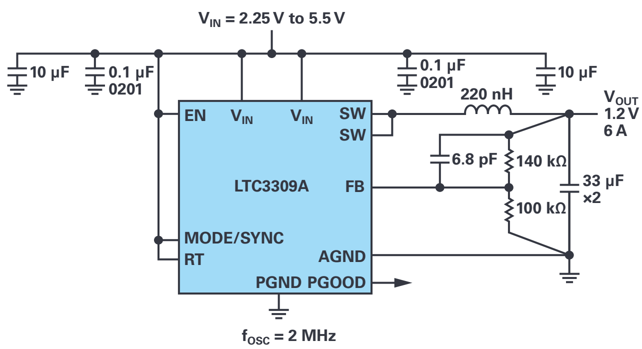


Figure 7. LTC3309A typical application circuit.

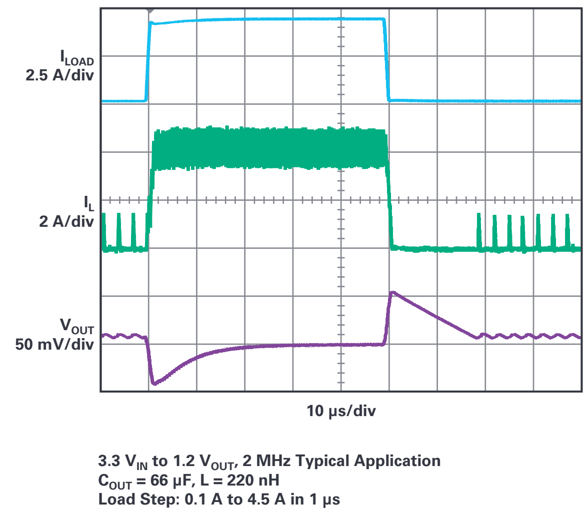


Figure 8. LTC3309A transient response in Burst Mode operation.

Table 1 compares the features of the members of the LTC33xx Silent Switcher and Silent Switcher 2 family.

Table 1. Fault Mode and Supported Range

Vendor	ADI	ADI	ADI	ADI
Part #	LTC3307A	LTC3308A	LTC3309A	LTC3310S
Topology	Single synchronous monolithic, Silent Switcher	Single synchronous monolithic, Silent Switcher	Single synchronous monolithic, Silent Switcher	Single synchronous monolithic, Silent Switcher 2
V_{IN} Range	2.25 V to 5.5 V	2.25 V to 5.5 V	2.25 V to 5.5 V	2.25 V to 5.5 V
V_{OUT} Range	0.5 V to V_{IN}	0.5 V to V_{IN}	0.5 V to V_{IN}	0.5 V to V_{IN}
Output Current	3 A	4 A	6 A	10 A
Efficiency	92% (3.3 V_{IN}/1.2 V_{OUT}/2 A)	92% (3.3 V_{IN}/1.2 V_{OUT}/2 A)	92% (3.3 V_{IN}/1.2 V_{OUT}/2 A)	92% (3.3 V_{IN}/1.2 V_{OUT}/3 A)
Switching Frequency	1 MHz to 3 MHz	1 MHz to 3 MHz	1 MHz to 3 MHz	500 kHz to 5 MHz
Control Mode	Constant-frequency, peak current mode	Constant-frequency, peak current mode	Constant-frequency, peak current mode	Constant-frequency, peak current mode
V_{REF} Accuracy Room/Temp	±0.2%/±1%	±0.2%/±1%	±0.2%/±1%	±1%
Current Limit Accuracy	±15%	±15%	±15%	±9%
Minimum On-Time	22 ns	22 ns	22 ns	35 ns
Directly Parallelable x Phase?	No	No	No	Yes, 4 phase
I_Q Supply Burst Mode/Non-Burst	40 µA BM/1.3 mA	40 µA BM/1.3 mA	40 µA BM/1.3 mA	1.3 mA
Package Theta JA	51°C/W	51°C/W	51°C/W	40°C/W
Solution Size	~20 mm²	~20 mm²	~20 mm²	47 mm²
Package	2 mm × 2 mm × 0.74 mm, 12-lead LQFN	2 mm × 2 mm × 0.74 mm, 12-lead LQFN	2 mm × 2 mm × 0.74 mm, 12-lead LQFN	3 mm × 3 mm × 0.94 mm, 18-lead LQFN

Conclusion

The trend in high performance digital ICs—such as GPUs, FPGAs, and microprocessors—is rapidly raising current demands coupled with dropping operating voltages, a result of shrinking line width wafer fabrication technologies. Current and voltage demands are only part of the power supply picture. Digital IC advancements come with a host of other requirements, including fast transient response, low EMI, low noise/ripple, and efficient operation to minimize heat.

Traditionally, digital ICs has been powered by LDO regulators or inductor-based switching regulator controllers with off-board power devices. With increased power supply performance and space requirements, in many cases these traditional approaches are not up to the task. ADI's new generation of monolithic power supplies are up to the task, including the LTC3310S, LTC3309A, LTC3308A, and LTC3307A, which support 10 A, 6 A, 4 A, and 3 A, respectively. These high power density Silent Switcher and Silent Switcher 2 buck regulators are housed in thermally efficient, compact flip-chip laminate packages, and have a variety of feature sets to satisfy the requirements of a wide range of digital IC power problems.

About the Author

Steve Knoth is a senior product marketing manager in Analog Devices' Power Group. He is responsible for all power management integrated circuit (PMIC) products, low dropout (LDO) regulators, battery chargers, charge pumps, charge pump-based LED drivers, supercapacitor chargers, and low voltage monolithic switching regulators. Prior to rejoining Analog Devices in 2004, Steve held various marketing and product engineering positions since 1990 at Micro Power Systems, Analog Devices, and Micrel Semiconductor. He earned his bachelor's degree in electrical engineering in 1988 and a master's degree in physics in 1995, both from San Jose State University. Steve also received an M.B.A. in technology management from the University of Phoenix in 2000. In addition to enjoying time with his kids, Steve is an avid music lover and can be found tinkering with pinball and arcade games or muscle cars, and buying, selling, and collecting vintage toys, movie, sports, and automotive memorabilia.

Analog Devices is committed to delivering the most innovative products that sense, measure, connect, interpret, power, and secure to help you solve your toughest design problems and create solutions that are Ahead of What's Possible.™ The latest Silent Switcher and power management products and solutions from some of the best designers in the world are listed below.

LTC3310S

5 V, 10 A Synchronous Step-Down Silent Switcher 2 Device in 3 mm × 3 mm LQFN

The LTC3310S is a very small, low noise, monolithic step-down DC-to-DC converter capable of providing up to 10 A of output current from a 2.25 V to 5.5 V input supply. The device employs Silent Switcher 2 architecture with internal hot loop bypass capacitors to achieve both low EMI and high efficiency at switching frequencies as high as 5 MHz. For systems with higher power requirements, multiphasing parallel converters are readily implemented.

Visit the Product Page

Download the Data Sheet

Buy the Eval Board

Sample and Buy

LT8652S

Dual-Channel 8.5 A, 18 V Synchronous Step-Down Silent Switcher Device with 16 μA Quiescent Current

The LT8652S is a dual step-down regulator that delivers up to 8.5 A of continuous current from both channels and supports loads up to 12 A from each channel. The LT8652S uses second generation Silent Switcher technology including integrated bypass capacitors to deliver a high frequency, high efficiency, small solution with excellent EMI performance.

Visit the Product Page

Download the Data Sheet

Buy the Eval Board

Sample and Buy

LTM8060

Quad 40 V_{IN}, Silent Switcher µModule Regulator with Configurable 3 A Output Array

The LTM8060 is a quad 40 V_{IN}, 3A step-down Silent Switcher µModule regulator. The Silent Switcher architecture minimizes EMI while delivering high efficiency at frequencies up to 3 MHz. Included in the package are the controllers, power switches, inductors, and support components. Operating over a wide input voltage range, the LTM8060 supports output voltages from 0.8 V to 8 V, and a switching frequency range of 200 kHz to 3 MHz, each set by a single resistor.

Visit the Product Page

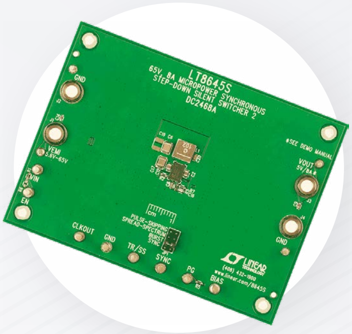
Buy the Eval Board

Download the Data Sheet

Sample and Buy

LT8645S

65 V, 8 A Synchronous Step-Down Silent Switcher 2 Device with 2.5 µA Quiescent Current



The LT8645S/LT8646S synchronous step-down regulators feature second generation Silent Switcher architecture designed to minimize EMI emissions while delivering high efficiency at high switching frequencies. This includes the integration of bypass capacitors to optimize all the fast current loops inside and make it easy to achieve advertised EMI performance by eliminating layout sensitivity.

Visit the Product Page

Buy the Eval Board

Download the Data Sheet

Sample and Buy

LT8609

42 V, 3 A Synchronous Step-Down Regulator with 2.5 µA Quiescent Current

The LT8609/LT8609A/LT8609B are compact, high efficiency, high speed synchronous monolithic step-down switching regulators that consume only 1.7 µA of nonswitching quiescent current. The LT8609/LT8609A/LT8609B can deliver 3 A of continuous current. Burst Mode® operation enables high efficiency down to very low output currents while keeping the output ripple below 10 mV p-p.

Visit the Product Page

Buy the Eval Board

Download the Data Sheet

Sample and Buy

42 V, 2 A/3 A Peak Synchronous Step-Down Regulators with 2.5 µA Quiescent Current and Ultralow EMI Emission

Dong Wang

Introduction

The LT8609, LT8609A, LT8609B, and LT8609S are synchronous monolithic step-down regulators that feature a wide 3 V to 42 V input range. This device family is optimized for applications requiring low EMI, high efficiency, and a small solution size—suitable for demanding automotive, industrial, computing, and communications applications. All regulators in this series have the same 2 A continuous, 3 A transient (<1 second) load current capability. Their features are summarized in Table 1.

The LT8609, LT8609A, and LT8609S feature 2.5 µA ultralow quiescent current, which is important for battery-powered systems. With integrated top and bottom N-channel MOSFETs, the regulators exhibit impressive light load efficiency. The LT8609B operates in pulse-skipping mode only, with higher quiescent current than the other devices, and it offers lower ripple during light load operation.

All of these devices can pass CISPR 25 Class 5 radiated EMI regulation, the most rigorous EMI standard for automotive equipment. Furthermore, the LT8609, LT8609A, and LT8609S feature spread spectrum frequency operation to reduce EMI peaks. The LT8609S displays the most impressive EMI performance in this family, based on its proprietary Silent Switcher® 2 technology, described below.

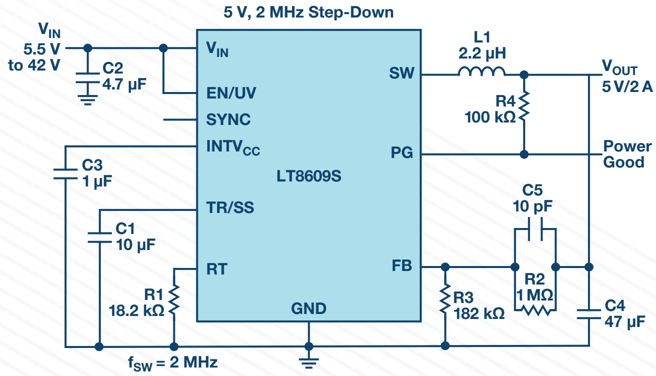


Figure 1. Ultralow EMI emission LT8609S 12 V to 5 V synchronous step-down converter.

5.5 V to 42 V Input, Low EMI, High Efficiency 5 V, 2 A Supply

A 5.5 V to 42 V input to 5 V/2 A output power supply is shown in Figure 1. This solution features a 16-lead LT8609S regulator with a 2 MHz switching frequency. Only a few components are required for the complete solution, including inductor L1 and a few passive components. Figure 2 shows that this solution can achieve 92.9% peak efficiency.

Burst Mode Operation to Improve Light Load Efficiency

During light load operation and no-load standby mode, high efficiency and low idle current are important for battery-powered applications. The LT8609, LT8609A, and LT8609S feature a low 2.5 µA quiescent current in Burst Mode® operation. During light load and no-load conditions, the switching frequency is gradually reduced, greatly reducing power loss while keeping the output voltage ripple relatively low. Figure 2 shows that light load efficiency remains above 85% while the power loss approaches zero at minimal loads.

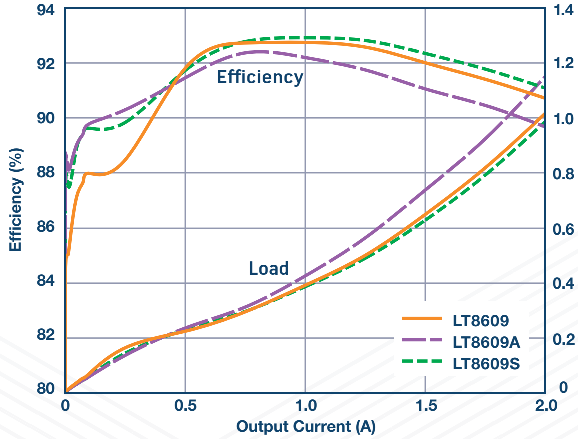


Figure 2. Efficiency vs. load current for LT8609/LT8609A/LT8609S-based 12 V_{IN} to 5 V_{OUT} step-down converter.

High Switching Frequency with Ultralow EMI Emission and Improved Thermal Performance

EMI compliance is a concern in a number of environments, including automotive systems. With integrated MOSFETs, advanced process technology, and up to 2.2 MHz operation, all of the devices in this family can achieve a small solution size while satisfying the most stringent EMI standards. Spread spectrum frequency operation, which reduces EMI peaks, is available in all but the LT8609B. Furthermore, the LT8609S incorporates Silent Switcher 2 technology. Silent Switcher 2 devices feature integrated hot loop and warm loop caps to make EMI performance insensitive to board layout and the number of board layers. A board with fewer layers can be used to reduce manufacturing costs without sacrificing EMI and thermal performance.

Figure 2 shows that the LT8609S features the best peak and full load efficiency of the device family. Figure 3 and Figure 4 show a CISPR 25 EMI and thermal performance comparison of the Figure 1 solution on 2- and 4-layer boards.

Conclusion

The devices in the LT8609 family are easy to use monolithic step-down regulators with integrated power MOSFETs and built-in compensation circuits. They are optimized for applications with wide input voltage range and low EMI noise requirements. Low, 2.5 μA quiescent current and Burst Mode operation make them excellent battery-powered step-down converter solutions. A 200 kHz to 2.2 MHz switching frequency range make them suitable for most low power to micropower applications. Integrated MOSFETs and up to 2.2 MHz switching frequency capability minimize solution size. CISPR 25 scanning results show excellent radiated EMI performance, compliant with the most stringent EMI standards. Silent Switcher 2 technology in the LT8609S makes its performance immune to layout and layer changes, which greatly reduces development and manufacturing costs.

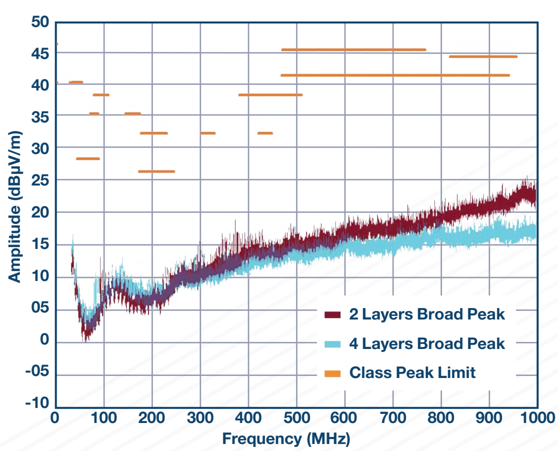


Figure 3. CISPR 25 radiated EMI performance comparison between 2- and 4-layer boards for the circuit in Figure 1.

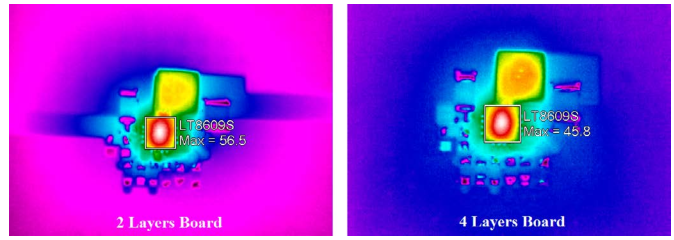


Figure 4. Thermal performance comparison between 2- and 4-layer boards for the circuit in Figure 1.

Part	Package	Performance	Operation Mode
LT8609	10-lead MSE	High efficiency	Burst Mode operation, pulse-skipping mode, spread spectrum mode, sync mode
LT8609A	10-lead MSE	Optimized for both efficiency and EMI performance	Burst Mode operation, pulse-skipping mode, spread spectrum mode, sync mode
LT8609B	10-lead MSE	High efficiency	Pulse-skipping mode
LT8609S	16-lead LQFN	Silent Switcher 2 technology incorporated with best efficiency and EMI performance	Burst Mode operation, pulse-skipping mode, spread spectrum mode, sync mode

About the Author

Dong Wang is a senior applications engineer for power products at Analog Devices who began his career at Linear Technology (now part of ADI) in 2013. He currently provides applications support for nonisolated monolithic step-down converters. Dong Wang has broad interests in power management solutions and analog circuits, including high frequency power conversion, distributed power systems, power factor correction techniques, low voltage, high current conversion techniques, high frequency magnetic integration, and modeling and control of converters. Dong Wang graduated from Zhejiang University in Hangzhou, China with a Ph.D. in electrical engineering.

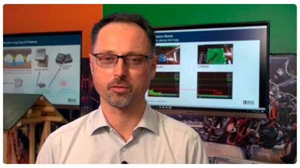

ANALOG
DEVICES
LTC3310S

Design Note: Monolithic 65 V, 8 A Step-Down Regulators with Fast Transient Response and Ultralow EMI Emissions

The LT8645S and LT8646S are 65 V synchronous step-down monolithic regulators capable of supporting 8 A outputs. Their Silent Switcher 2 architecture enables exceptional EMI performance regardless of layout. The LT8646S features RC external compensation to optimize transient response.

Read More

Video: Silent Switcher 2 Monolithic Buck Regulator



See the EMC capability of our Silent Switcher 2 monolithic buck regulators. Discover how they can reduce the risk of EMC-related redesigns due to power, and how you can eliminate the need for additional EMI shielding and simplify layouts.

Watch Now

LT8336 Video: 4 V, 2.5 A, Low I_Q Synchronous Step-Up Silent Switcher Device

LT8336 is a low I_Q, synchronous step-up DC-to-DC converter. It features Silent Switcher architecture and optional spread spectrum frequency modulation to minimize EMI emissions while delivering high efficiencies at high switching frequencies.

Watch Now

LTM8060 Video: 40 V_{IN}, Quad 3 A Silent Switcher μModule Regulator

Analog Devices' LTM8060's Silent Switcher architecture minimizes EMI emissions, enabling it to pass the CISPR 22 Class B and CISPR 25 Class 5 standards with no input filter. This is critical for noise-sensitive applications such as signal processing in medical imaging and RF. Furthermore, multi-output capability allows customers to use the LTM8060 as quad 3 A, dual 6 A, or single 6 A for a variety of voltage and load current requirements.

Watch Now

LTM8051 Video: Silent Switcher μModule Regulator

The LTM8051 is a quad 40 V_{IN}, 1.2 A step-down Silent Switcher μModule regulator. Silent Switcher technology minimizes EMI while delivering high efficiency at frequencies up to 3 MHz. Included: controllers, power switches, inductors, and support components.

Watch Now

BR23545-11/23(A)