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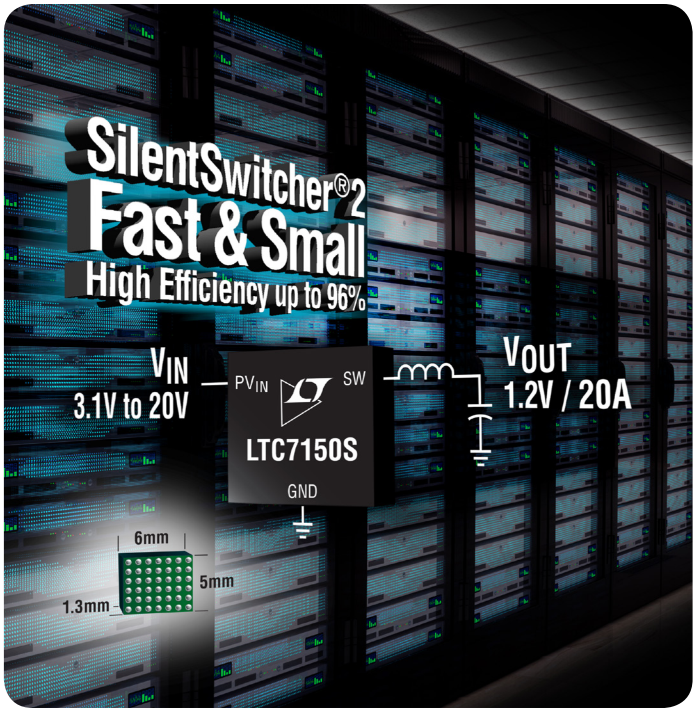
Tiny, High Efficiency Monolithic Regulators Power Advanced SoCs and µProcessors, Feature Silent Switcher 2 Technology for Low EMI

Ying Cheng and Zhongming Ye

Automotive, telecom, datacom and industrial systems continue to employ increasing numbers of advanced SoC (System on Chip), FPGA and µP solutions. Each successive SoC and FPGA generation expands in power budget as power-hungry components are added and data processing speeds rise to support live streams of telecom, audio or video data. These demands can only be met by robust, easy-to-use low voltage power supplies with high efficiency, high power density and low electromagnetic radiation.



Silent Switcher 2 regulators power SoCs, FPGAs and µProcessors in datacom and telecom systems

SoCs and FPGAs require a number of low voltage supplies, including 1.1V for DDR, 0.8V for core, and 3.3V/1.8V for I/O devices. Delivering sub-1V from a wide-ranging automotive battery or industrial bus voltage usually requires two stages: an intermediate regulation stage to 12V or 5V, and another to low voltage. Each DC/DC conversion must be efficient and pass EMI standards to enable the overall power system to perform to demanding automotive, telecom, datacom and industrial specifications.

(continued on page 4)

In this issue...

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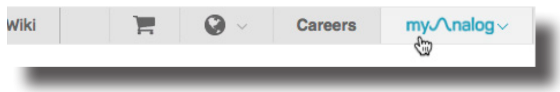

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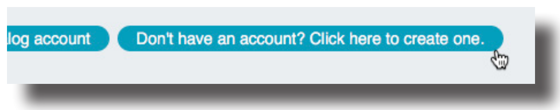

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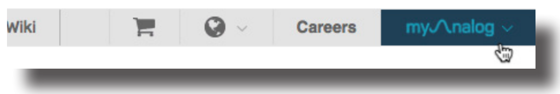

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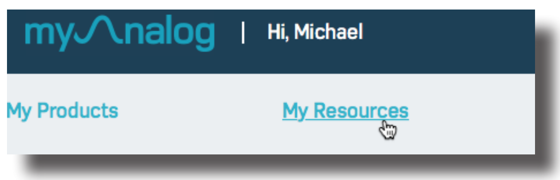

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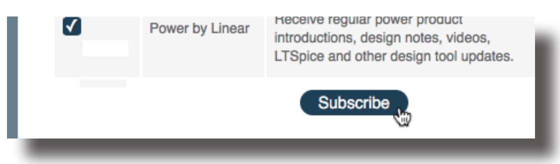


Open Circuit

LEARN THE INS AND OUTS OF LTspice® AS PRESENTED BY ITS CREATOR MIKE ENGELHARDT (WORLD TOUR)

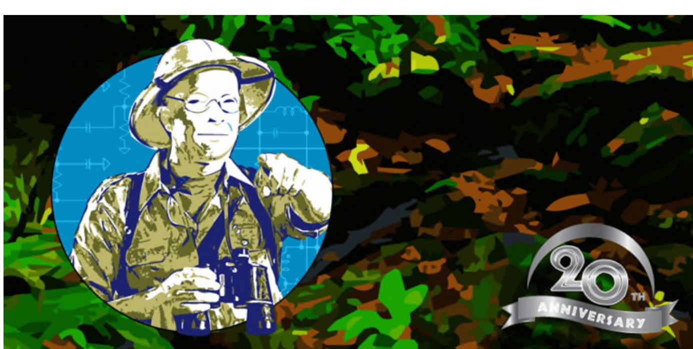
The workshop is designed to educate and inform both advanced and new users of LTspice. This is an excellent opportunity to gain the knowledge to successfully simulate circuit designs and predict circuit behavior for faster more efficient designs.

Attendees are encouraged to bring unique questions about LTspice, and get answers directly from the creator of the software, Mike Engelhardt.

There are still dates available in Europe and Asia. Register at https://www.arrow.com/en/research-and-events/events/free-ltspice-xvii-workshops.

About LTspice

Analog Devices' LTspice XVII is the number one high-performance SPICE simulator, schematic capture, and waveform viewer that has enhancements and models for easing the simulation of switching regulators. Analog Devices' enhancements to SPICE have made simulating switching regulators extremely fast compared to normal SPICE simulators, allowing the user to view waveforms for most switching regulators in just a few minutes. Included in the download are SPICE, Macro Models for most of the Power by Linear switching regulators, 500 opamp models, as well as resistors, transistors, and MOSFET models.



Mike Engelhardt takes LTspice workshop on world tour

ISOLATED 4-PORT POWER OVER ETHERNET PSE CONTROLLER PASSES IEEE 802.3bt CONFORMANCE TESTS

The LTC4291/92 isolated 4-port power source equipment (PSE) controller chipset, is the first of its kind to pass a series of IEEE 802.3bt (PoE++) Power over Ethernet (PoE) conformance tests administered by Sifos Technologies. PoE naturally presents system and network engineers with PSE evaluation challenges. PSEs are multichannel, intelligent DC power sources that are activated and deactivated through standardized processes without disrupting traditional Ethernet data transmission. At the same time, compliance testing is complicated by requirements to operate over several delivery and polarity configurations.

Rigorous compliance test suites augmented by specialized analysis features validated the LTC4291/92 to the IEEE 802.3at (PoE+) standard, the upcoming 802.3bt standard, and other proprietary specifications. These scalable design and test solutions build in extensive PoE knowledge and years of experience, reducing time-to-market and enabling deployment of IEEE 802.3bt PoE networks as the standard approaches ratification in 2018.

HIGHLY INTEGRATED 60V BUCK CONTROLLER PLUS CONFIGURABLE QUAD SYNC BUCKS OFFERS LOW IQ & POWER SYSTEM FLEXIBILITY

The Power by Linear™ LTC3372 is a highly integrated power management solution for systems that require multiple low voltage outputs generated from an input voltage as high as 60V. The LTC3372 features a 60V synchronous buck switching regulator controller followed by four configurable synchronous monolithic buck regulators. This combination provides up to five high efficiency low quiescent current outputs in a single IC, ideal for automotive, industrial and medical applications.

The LTC3372's buck controller operates over a 4.5V to 60V input voltage range and drives an all N-channel MOSFET power stage. Its output can be programmed to either 3.3V or 5V and can generate an output current up to 20A. The controller output is typically used to feed the four monolithic buck regulators. Each monolithic buck channel can be programmed to regulate an output voltage as low as 0.8V with a configurable output current up to 4A. ■

To assure EMI qualification throughout the power supply design process, EMI suppression is often prioritized, and sometimes over-engineered, at the expense of other desirable features, namely solution footprint, total efficiency, reliability and simplicity.

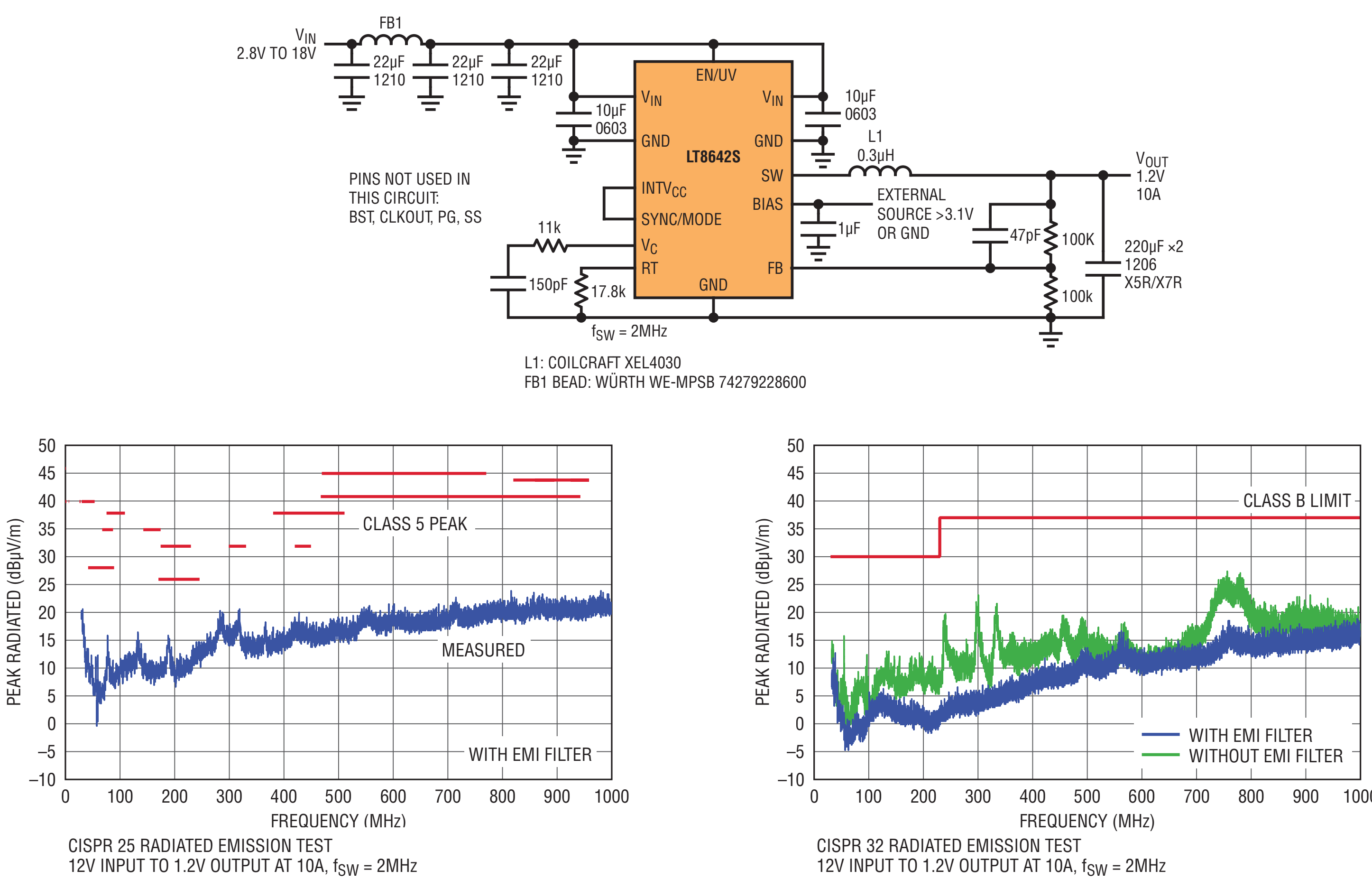
(LTC7150S/LT8642S, continued from page 1)

It can be difficult to meet size, efficiency and EMI design goals using conventional buck regulators. Sub-1V buck regulators traditionally rely on bulky and EMI-noisy PWM controllers and MOSFETs. The demands of automotive and industrial systems mean that devices must give way to something more compact, with higher current capability, higher efficiency, and more importantly, superior EMI performance. Power by Linear™ monolithic Silent Switcher® 2 buck regulators in the LTC7150S and LT8642S family are designed to fulfill advanced SoC power demands with high reliability and robustness, while meeting EMI, size and thermal constraints.

SILENT SWITCHER 2 ARCHITECTURE YIELDS EXCELLENT EMI PERFORMANCE

Published EMI standards can be difficult to meet using conventional DC/DC controllers, so EMI is typically addressed up front, if possible. EMI issues that crop up in the late phase of the design and development of a system can cost significant money and time in troubleshooting and redesign. The hazards of project delays, loss of market, and damage to business reputation are too risky to leave to chance. To assure EMI qualification throughout the power supply design process, EMI suppression is often prioritized, and sometimes over-engineered, at the expense of other desirable features, namely solution footprint, total efficiency, reliability and simplicity.

Figure 1. Ultralow EMI 1.2V/10A application using the LT8642S



Power by Linear monolithic Silent Switcher 2 buck regulators in the LTC7150S and LT8642S family are designed to meet the needs of advanced SoC power budgets and EMI specifications, while fitting SoC size and thermal constraints with high reliability and robustness.

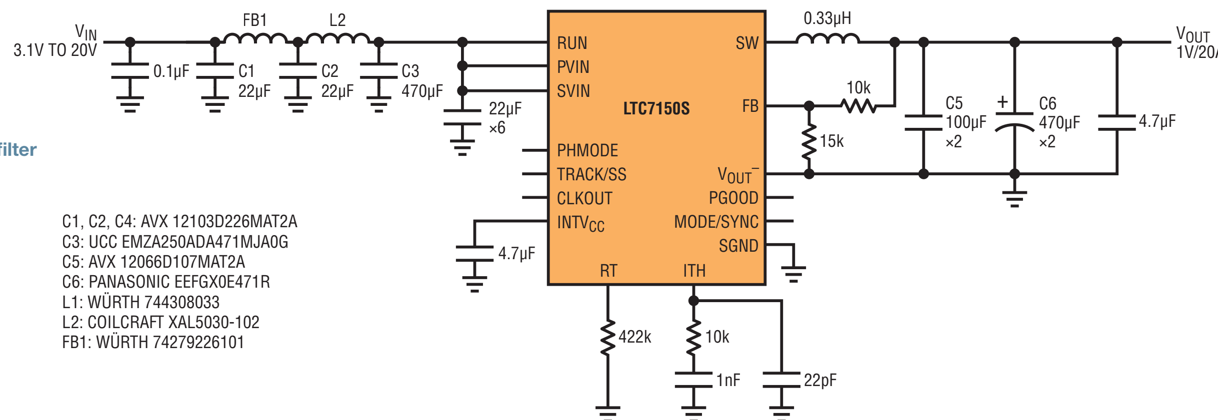


Figure 2. LTC7150S with EMI filter

Traditional approaches control EMI by slowing down switching edges and/or lowering switching frequency. For instance, a gate resistor or a snubber can be added to slow down the turn-on or turn-off of the switching edges, and the switching frequency reduced for lower EMI. However, these strategies come with significant tradeoffs, including increased minimum on times, limiting voltage conversion ratios, and larger solution size. Alternative mitigation techniques—such as bulky EMI filters or metal shielding—add significant costs in board space, component count and assembly complexity, while further complicating thermal management and testing. None of these strategies meet the requirements of the demanding SoC power budgets of compact size, high efficiency and low EMI.

LT8642S is an 18V/10A step-down monolithic Silent Switcher 2 in a 4mm × 4mm LQFN package. Figure 1 shows a 12V-to-1.2V/10A LT8642S solution and its ultralow EMI results. With only a ferrite bead and input capacitor as the input EMI filter, LT8642S is able to meet the stringent CISPR 25 Class 5 radiated EMI specification—widely adopted by the automotive industry—with abundant margin. Another popular EMI specification is CISPR 32, often cited by the consumer electronics manufacturers. LT8642S can easily meet CISPR 32 class B radiated EMI specification even without the input EMI filter.

LTC7150S is first-of-its-kind 20A high efficiency step-down regulator with Silent Switcher 2 technology incorporated to minimize the electrical-magnetic emission, greatly simplify the EMI filter design and layout, making it ideal for noise-sensitive environments. The Analog Devices' proprietary Silent Switcher 2 architecture brings in exceptional EMI performance while minimizing the AC switching losses in our monolithic regulators. Hot loop capacitors are included in the IC. This, combined with integrated MOSFETs, significantly reduces noisy antenna size; minimizing EMI.

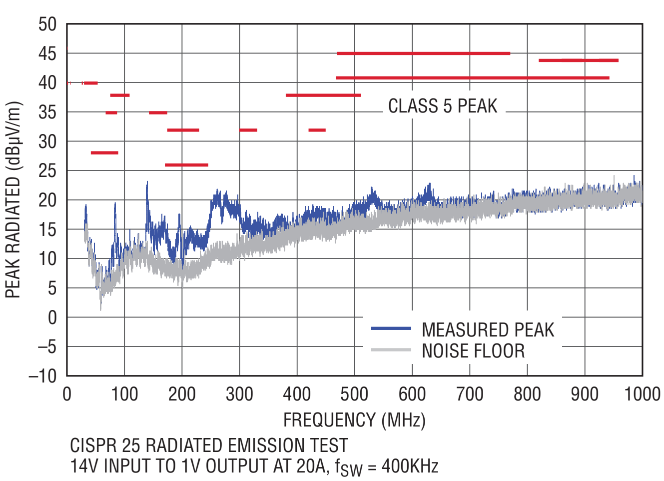


Figure 3. LTC7150S radiated EMI performance.

Multiphase operation is implemented by tying the PHMODE pin to $INTV_{CC}$, SGND or floating the pin to generate a phase difference corresponding to 2-phase, 3-phase, or 4-phase operation. A total of 12 channels can be run out-of-phase with respect to each other by programming the PHMODE pin of each LTC7150S to different voltage levels.

Switching node ringing is minimized on the very fast switch edges, reducing high frequency noise, and associated energy stored in the hot loop. Also, the hot loop is split in two, and symmetrically laid out for EMI self-cancellation. This yields quiet power for the noise-sensitive automotive environments, where powerful SoCs are employed for advanced drive assistance system (ADAS) or autonomous drive systems. This also satisfies the requirements of telecom, transportation and industrial systems, where high efficiency low noise power supplies are needed to power the next generation SoCs, CPUs and μPs.

LTC7150S passes the CISPR 25 radiated EMI peak limit with simple EMI filter installed in the front, as shown in the schematic in Figure 2, where a simple filter with a ferrite bead is installed. Figure 3 shows the radiated EMI CISPR 25 test result, and it passes the CISPR 25 Class 5 peak limit.

PARALLEL MULTIPLE CONVERTERS TO EXPAND OUTPUT CURRENT

Advanced functions such as autonomous drive, self-parking, etc. demand more powerful SoCs to implement live stream visuals, or artificial intelligence. Likewise, computing and server systems in telecom and big data installations include high performance SoC solutions, which demand more power than ever before. For processor systems that demand more than 20A current capability, multiple LTC7150Ss can be paralleled and run out-of-phase.

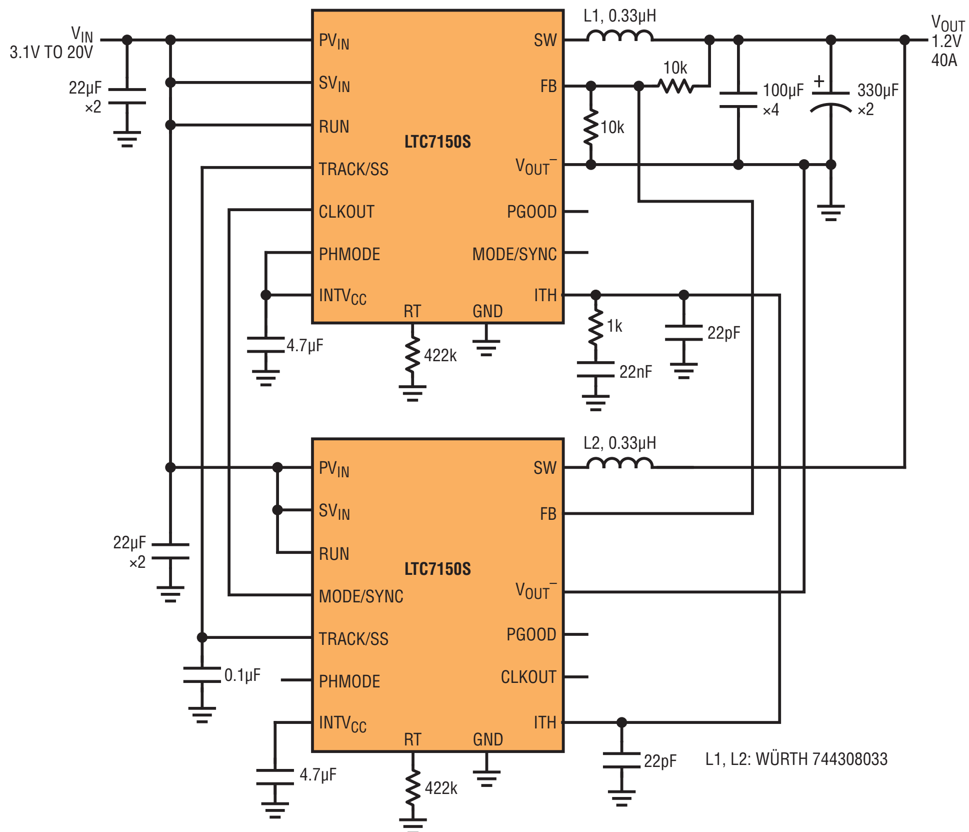


Figure 4. Parallel two LTC7150S regulators to extend output current capability to 40A.

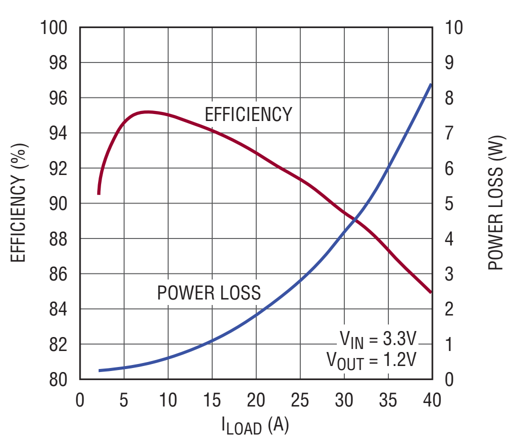


Figure 5. Efficiency of the 40A circuit in Figure 4.

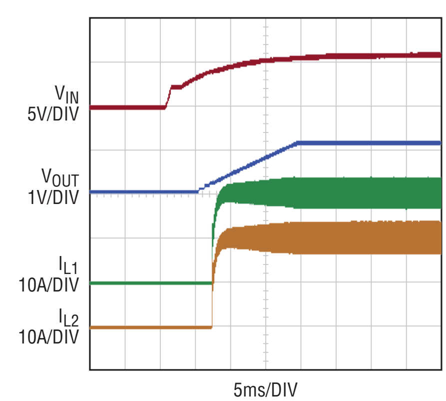
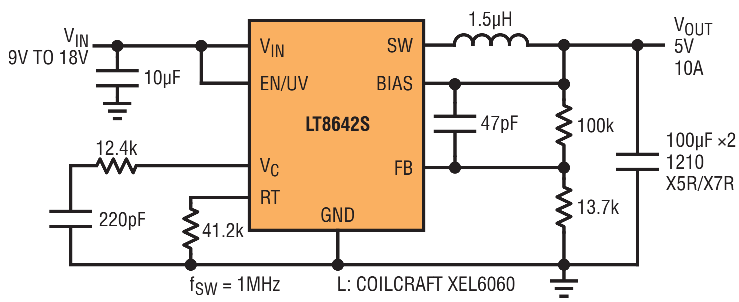


Figure 6. Inductor current waveforms for the parallel solution.

The Silent Switcher 2 architecture does more than just enable exceptional EMI performance in LT8642S applications, it also produces fast and clean switching edges, cutting down switching losses. Minimal switching losses, along with just 20ns of minimum on-time, enable high efficiency at high switching frequency and small solution size.



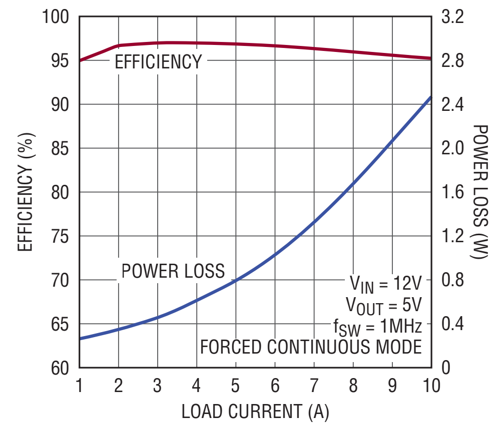


Figure 7. 50W (5V/10A) solution using the LT8642S

The LTC7150S features a SYNC function that allows it sync to an external clock, and the internal PLL (phase-locked loop) allows the LTC7150S to be operated out-of-phase for multichannel, multiphase operation to reduce ripple. The CLKOUT signal can be connected to the MODE/SYNC pin of a following LTC7150S to line up both the frequency and the phase of the entire system. Multiphase operation is implemented at the PHMODE pin. Tying the PHMODE pin to $INTV_{CC}$, SGND or floating the pin generates a phase difference between the clock applied on the MODE/SYNC pin and CLKOUT; differences of 180°, 120° or 90°, respectively, corresponding to 2-phase, 3-phase or 4-phase operation. A total of 12 channels can be run out-of-phase with respect to each other by programming the PHMODE pin of each LTC7150S to different voltage levels.

Figure 4 shows two converters connected in parallel to provide 40A output current at 1.2V. The clock from the master unit is synced to the slave unit by tying the CLKOUT of U1 to the MODE/SYNC of U2. The master PHMODE pin is tied to ground, and the slave PHMODE pin is left floating. This results in 180° phase difference between the two channels, reducing the input current ripple. To ensure better current sharing in steady state and during start-up, ITH, FB, and TRACK/SS are tied together. Local R_T resistors are needed, and should not be tied together. Kelvin connection is recommended for accurate feedback and noise immunity. Place as many power vias as possible in the vicinity of the ground pins to the bottom layer to improve the thermal performance. Ceramic caps of the input hot loops should be placed close to the V_{IN} pins.

The inductor current is balanced during startup and steady state as shown in Figure 6. Efficiency can be as high as 89% at 32A, when input is 3.3V.

Table 1. High current monolithic regulators

	INPUT VOLTAGE (V)	# OUTPUTS	CURRENT (A)	FREQUENCY (MHz)	MIN T_{ON} (ns) TYP.	PACKAGE
LT8642S	2.8–18	1	10	0.2–3	20	4mm × 4mm LQFN
LTC3636	3.1–20	2	6/6	0.5–4	30	4mm × 5mm QFN
LTC7124	3.1–17	2	3.5/3.5	0.5–4	50	3mm × 5mm QFN
LTC7150S	3.1–20	1	20	0.4–3	20	6mm × 5mm BGA
LTC7151S	3.1–20	1	15	0.4–3	20	4mm × 5mm LQFN

The demand for more intelligence, automation, and sensing in industry and automotive environments has resulted in a proliferation of electronic systems that require increasingly high performance power supplies. Low EMI has risen from afterthought to top priority, while solution size, high efficiency, thermal proficiency, robustness and ease-of-use remain important.

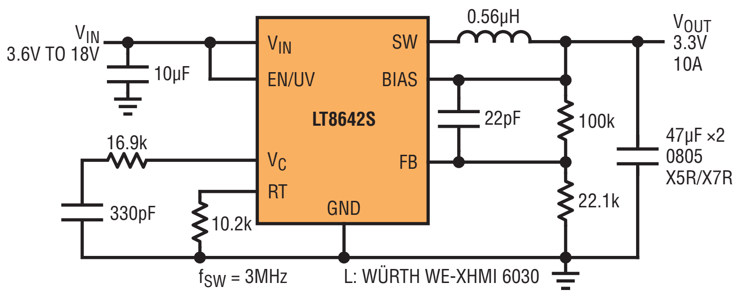


Figure 8. 3.3V, 3MHz application using LT8642S

HIGH SWITCHING FREQUENCY DELIVERS HIGH EFFICIENCY COMPACT SOLUTIONS

The Silent Switcher 2 architecture does more than just enable exceptional EMI performance in LT8642S applications, it also produces fast and clean switching edges, cutting down switching losses. Minimal switching losses, along with just 20ns of minimum on-time, enable high efficiency at high switching frequency and small solution size. For example, a 12V-to-1.2V LT8642S solution can achieve more than 88% efficiency at a 2MHz switching frequency. Furthermore, the LT8642S can be safely operated with a saturated inductor under the overload or short-circuit conditions, due to its high speed peak-current mode architecture. Therefore, the inductor can be chosen based on the output load requirement.

Compact power solutions usually in conflicts with thermal performance. The LT8642S is able to overcome this typical trade-off through high efficiency and enhanced thermal packaging. Figure 7 demonstrates a 5V/10A LT8642S solution switching at 1MHz. For a 12V input, the LT8642S operates with less than 47°C case temperature rise when delivering 50W power and peak efficiency reaches above 97%.

Figure 8 shows a 3MHz LT8642S solution. The high frequency operation minimizes the solution size by using a small inductor and a lower value output capacitor.

The LT8642S also features enable control, a power good indicator and soft-start. These functions are essential to the system power sequencing, required by SoC and FPGA power supplies.

Power by Linear offers a range of buck regulators to fulfill the wide-ranging power budgets of advanced SoCs, FPGAs and microprocessors. Table 1 lists some of the devices and their current capabilities.

CONCLUSION

The demand for more intelligence, automation, and sensing in industry and automotive environments has resulted in a proliferation of electronic systems that require increasingly high performance power supplies. Low EMI has risen from afterthought to top priority, while solution size, high efficiency, thermal proficiency, robustness and ease-of-use remain important.

Power by Linear monolithic regulators excel in these areas, satisfying the requirements of automotive, telecom, data center, and industry customers. In particular, the family of high performance monolithic regulators that include the LTC7150S and LT8642S meet stringent EMI standards in a compact size by incorporating proprietary Silent Switcher technology. Integrated MOSFETs and integrated thermal management features enable robust and reliable delivery of current from several amperes to beyond 20A from input ranges up to 20V. Enable control, power good indicator, and soft-start features are all included, so only a few components are needed to complete the power supply design. ■

One-Size-Fits-All Battery Charger

Zachary Pantely

The first step to designing a battery charger is choosing a battery charger IC from the vast field of available solutions. To make an informed decision, a design team must first clearly define the battery parameters (chemistry, cell count, etc.) and the input parameters (solar, USB, etc.). The team must then search for chargers that fit the input and output parameters, comparing numerous data sheets to settle on the best solution. The selection process should allow the team to pick the best solution for the application, until of course, the design parameters change, at which point: back to the data sheets.

What if this step could be skipped altogether? What if a designer could focus on an application solution, treating the battery charger IC as a black box, to be filled in with a real IC when the time comes to produce a working solution. At that time, the designer simply reaches to the shelf for a generic battery charger IC, regardless of the essential design parameters. Even if application parameters change (inputs switched out, battery type changed, etc.) the off-the-shelf battery charger IC still fits. No additional data sheet search required.

This problem can be illustrated by looking at two very different battery charger problems:

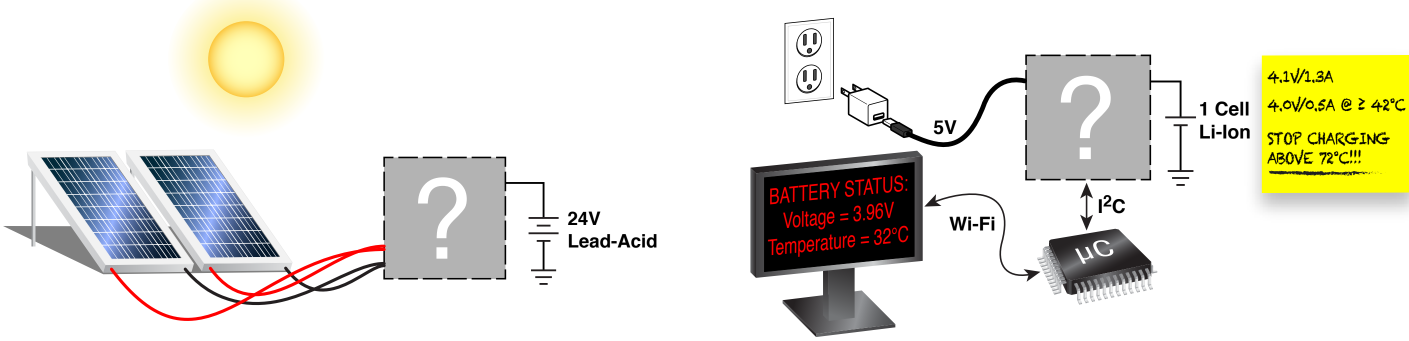
- Design team A is tasked with designing a battery charger that takes solar panel input and charges a lead-acid battery. The charger must stand alone—no microcontroller here—but should be versatile enough to support a few different solar panel models. They have one week to produce a schematic design.
- Design team B has a more involved charger problem. Their design takes a 5V USB supply and charges a 1-cell Li-ion battery with 1.3A to a termination voltage of 4.1V per cell. Above 47°C, they want to decrease their charge voltage to 4V per cell at 0.5A, and above 72°C, they want charging to stop. The microcontroller in their system needs to know the battery's voltage, current, temperature and health. They also have one week to produce a schematic design.

It turns out that both design teams can use the same battery charger IC, and that this device is arguably the best choice available for both applications.

Figure 1. What charger fits? Two very different battery charging systems; can they use the same charger IC?

(a) Standalone system with no host controller

(b) System with host control/monitoring and temperature-based charging algorithms



Although the LTC4162 can operate without a host controller, many aspects of charging can be monitored and controlled through the I^2C port. An on-chip telemetry system reads system and battery voltages and currents in real time.

GOOD THINGS AND SMALL PACKAGES

The LTC4162 35V, 3.2A monolithic buck charger boasts an elegant blend of simplicity and versatility. Capable of operating standalone or with a host controller, the LTC4162 enables solutions from basic to complex. A full-featured I^2C telemetry system allows a user to optionally monitor the battery and implement custom charging parameters specific to the battery model. A true maximum power point tracking (MPPT) algorithm allows the charger to operate optimally from any high impedance source, such as a solar panel. The charging algorithm is tailored to the chosen battery chemistry: Li-ion, $LiFePO_4$ or lead-acid.

These features are packed into a 4mm × 5mm QFN package with a typical solution size of about 1cm × 2cm.

FEEL THE POWER!

Don't let its small size fool you. Even with integrated switching FETs, the LTC4162 can support over 60W of charge power. Internal thermal self-monitoring of its die temperature enables the LTC4162 to regulate the charge current such that it never overheats, even in the hottest environments and tiniest enclosures.

The PowerPath™ FETs (INFET and BATFET) ensure that the system load (V_{OUT}) is always powered by the input voltage (V_{IN}) if it is present or by the battery if V_{IN} is absent. The use of external N-Channel FETs allows for low loss paths with no limit to the amount of current that can be passed to the load.

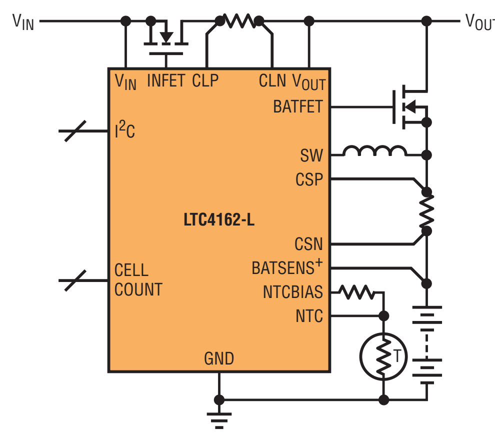


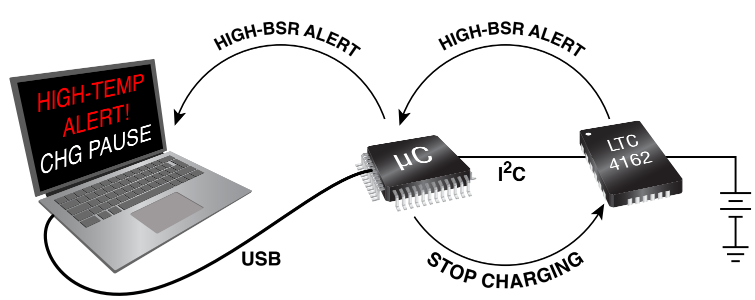
Figure 2. The application circuit for LTC4162 is as simple as it gets for a full-featured switching battery charger.

TELEMETRY AND CONTROL

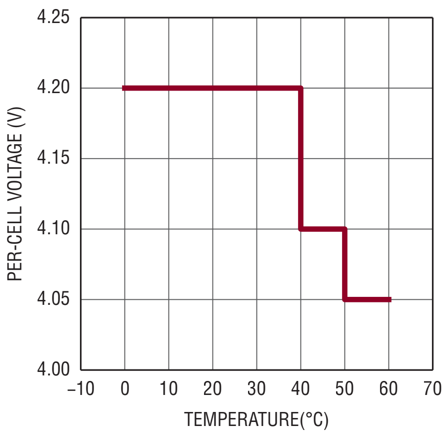
Although the LTC4162 can operate without a host controller, many aspects of charging can be monitored and controlled through the I^2C port. An on-chip telemetry system reads system and battery voltages and currents in real time. Various limits and alerts can be set to notify the host controller when a measured value meets a configurable threshold or when a particular charging state is entered. For example, a common design feature may be to enter a low power mode when the battery voltage drops to a certain lower limit. Rather than have a microcontroller continually poll the battery voltage, the LTC4162 can do the monitoring, and inform the host controller when this limit has been reached. At this point, the host can switch off the main load and enter a low power state.

The telemetry system is also capable of measuring the battery series resistance (BSR), which serves as an indication of battery health. The BSR measurement can be set to run automatically, and an alert can be configured to notify the host controller that a custom high BSR limit has been exceeded, at which

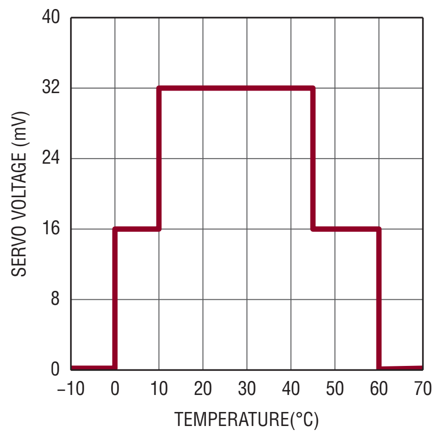
Figure 3. The LTC4162's integrated telemetry system will fulfill almost any monitoring and alert requirements.



The LTC4162 enables customizable temperature dependent charging. For lithium-based chemistries (Li-ion and $LiFePO_4$), the LTC4162 can employ JEITA temperature-controlled charging. Similarly, for lead-acid batteries, a temperature compensation algorithm linearly decreases the target voltage in each charging stage as temperature rises.



(a) Charge voltage profile



(b) Charge current profile servo voltage ($V_{CSP} - V_{CSN}$)

Figure 4. Default Li-ion JEITA Profile.

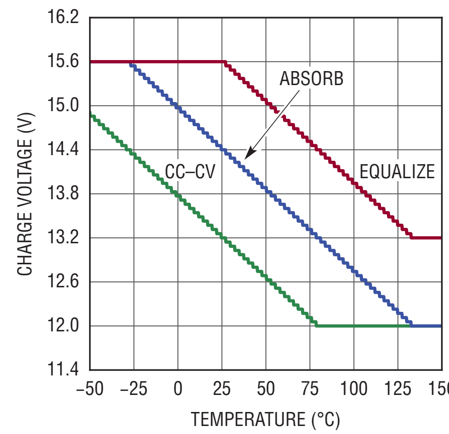


Figure 5. Default 12V lead-acid temperature profile.

point the host may signal to the user that the battery needs to be replaced.

When the input supply is removed and the system is powered by the battery, the LTC4162 automatically turns off the telemetry system to conserve battery life. If a measurement is needed, the telemetry system can be forced into action via an I^2C command, at which point it enters a slower, low power telemetry mode where measurements are taken every five seconds. If desired, the telemetry rate can be set to the high speed 11ms/read rate at any time.

IT'S GETTING HOT IN HERE

The LTC4162 enables customizable temperature-dependent charging. For lithium-based chemistries (Li-ion and $LiFePO_4$), the LTC4162 can employ JEITA temperature-controlled charging. JEITA allows the user to set custom temperature regions, wherein a custom battery charge voltage and current are used to charge the battery. This also allows the designer to decide the hot and cold temperatures at which the battery should stop charging. The default JEITA settings work for many batteries without the need for host processor intervention, but this capability enables the LTC4162 to work with any battery's temperature profile requirements.

Similarly, for lead-acid batteries, a temperature compensation algorithm linearly decreases the target voltage in each charging stage as temperature rises. These voltages can be offset with I^2C commands, and the compensation slope can be modified by simply changing the thermistor.

MPPT AND INPUT REGULATION

For the sake of simplicity, many solar panel regulation circuits set the maximum power point voltage as a constant value. In reality, V_{MPP} drifts with illumination, and a partially-obstructed solar panel can have multiple power peaks. By sweeping the entire voltage range of the panel connected to its input supply, the LTC4162's advanced maximum power point tracking (MPPT) algorithm accounts for all variables, always settling on the max power point. In addition to occasional sweeps of the solar panel range, the LTC4162 dithers the input regulation voltage, constantly seeking out minor changes in the V_{MPP}. These features require no custom programming, so panels can be switched out without charger modification.

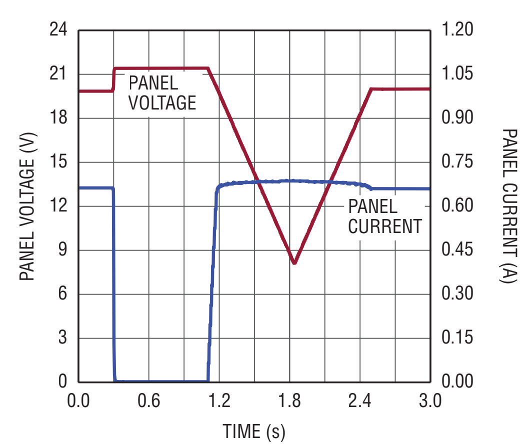


Figure 6. Solar panel global sweep.

Before members of a design team spend all day reading data sheets for various battery chargers, power monitors, and solar regulators—before spending hours writing code for a custom temperature-dependent charging algorithm and manually polling measurements to detect when limits are exceeded—they may want to consider reaching for a one-size-fits-all battery charger.

The benefits of input regulation extend beyond solar panel sources. Many USB cables, for example, have a significant amount of series impedance and this causes voltage droops at the charger input when current is drawn. The undervoltage current limit feature of the LTC4162 regulates this current such that a minimum voltage is maintained at the input.

USB POWER DELIVERY

LTC4162 is also compatible with the USB Power Delivery specification that allows up to 100W of power to be sourced through a USB Type C cable. The input current limit of the LTC4162 can be configured such that an input adapter is not overloaded. When the input current limit is reached, the system load can still pull as much power as it needs from the input, but the battery charge current is reduced such that the input current limit is not exceeded. For USB PD, this means that one LTC4162 circuit can be supplied by various power adapter profiles.

LOW POWER SHIP MODE

When a product needs to be shipped or stored for a long period of time, an I^2C command can place the LTC4162 into a low power state, reducing the current drain on the battery to about 3.5µA. Optionally, the circuit can be configured to cut power from the system load during this period.

IC VARIANTS

To simplify the design and documentation, the LTC4162 is broken into variants based on battery chemistry, charging parameters, and whether or not MPPT is enabled by default. Table 1 shows all of the available LTC4162 variants.

Each variant is pin-compatible and can be swapped out with another version during prototyping. LTC4162 variants are interchangeable, simplifying the creation of products that use the same circuit but use different battery chemistries, charging voltages or input sources.

To simplify the documentation, data sheets for the LTC4162 are broken into chemistry-based variants; there are separate data sheets for the Li-ion, $LiFePO_4$ and lead-acid versions.

CONCLUSION

Before members of a design team spend all day reading data sheets for various battery chargers, power monitors and solar regulators—before spending hours writing code for a custom temperature-dependent charging algorithm and manually polling measurements to detect when limits are exceeded—they may want to consider reaching for a one-size-fits-all battery charger. There is a good chance the LTC4162 is the best device for the job. ■

Table 1. 18 IC variants allow the user to choose the perfect part for any application.

IC PART NUMBER		BATTERY	
MPPT DISABLED BY DEFAULT	MPPT ENABLED BY DEFAULT	CHEMISTRY	CELL VOLTAGE
LTC4162EUFD-LAD	LTC4162EUFD-LADM	Li-ion	I^2C Adjustable
LTC4162EUFD-L40	LTC4162EUFD-L40M		4.0V Fixed
LTC4162EUFD-L41	LTC4162EUFD-L41M		4.1V Fixed
LTC4162EUFD-L42	LTC4162EUFD-L42M		4.2V Fixed
LTC4162EUFD-FAD	LTC4162EUFD-FADM	$LiFePO_4$	I^2C Adjustable
LTC4162EUFD-FST	LTC4162EUFD-FSTM		3.6V Fixed
LTC4162EUFD-FFS	LTC4162EUFD-FFSM		3.8V Rapid Charge
LTC4162EUFD-SAD	LTC4162EUFD-SADM	Lead-Acid	I^2C Adjustable
LTC4162EUFD-SST	LTC4162EUFD-SSTM		Fixed

Control Color of LED Stage and Architectural Lighting: Easy, Accurate 13-Bit Color using High Power 4×1A RGBW LEDs, I²C Control

Keith Szolusha

Red, green, and blue (RGB) LEDs can be used in architectural and stage lighting systems to create brightly projected colors—with a white LED sometimes added to the RGB mix to extend the color range in hue, saturation, and brightness (Figure 1). Regardless of the number of color components, the brightness of each component color must be accurately controlled to achieve predictable colors, or compensate for color discrepancies amongst LEDs. The number of available colors depends on the number of resolvable brightness levels of each component color. A few systems offer resolution down to 1/256 (8-bit) of full brightness. Higher resolution is possible and yields more colors (Figure 2) and control.

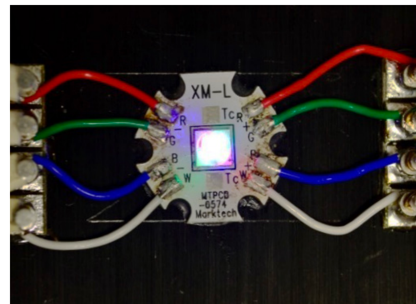


Figure 1. Cree XM-L RGBW high power LED can be driven by two LT3964 LED drivers for accurate 1:8192 per-channel dimming.

The most accurate way to control a wide LED brightness range is with PWM dimming control. LED drivers featuring internal PWM dimming clocks and digital registers (to set dimming ratios) are the best option for RGBW systems. For large and complicated systems—those with many different component RGBW LEDs—a serial communications bus enables on-the-fly setting of these registers in digitally-enhanced LED drivers.

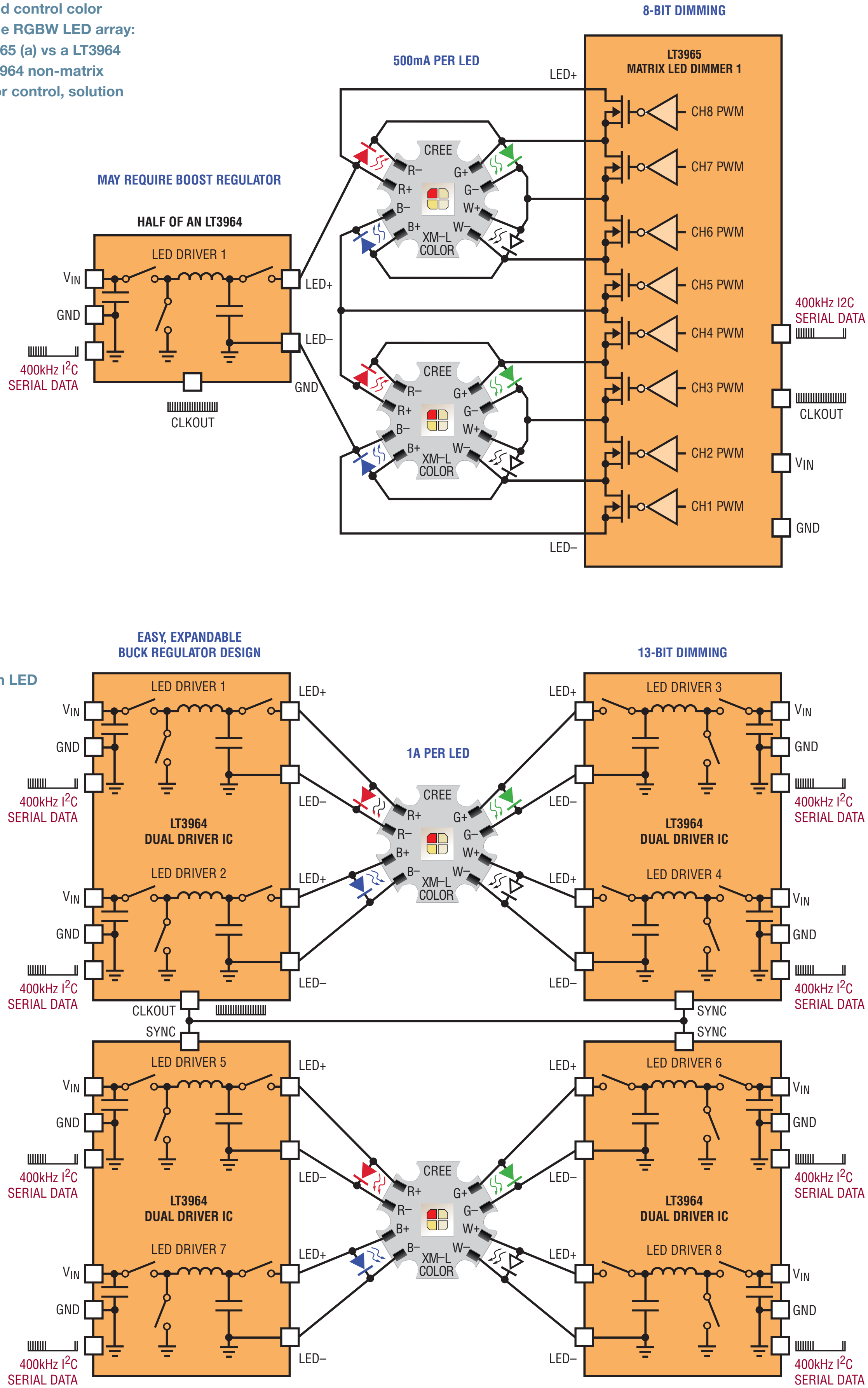
Figure 3 shows two ways to drive and dim RGBW LEDs. The first, a matrix LED dimmer solution, was until recently, the best way to digitally control a high power array of RGBW LEDs is with. The second, a "direct drive" solution, is a more accurate, efficient, and lower-ripple solution using four separate, digitally-enhanced LED drivers, one for each color (R, G, B and W). In such a system, the LED current, or PWM dimming, of each individual LED or string is driven by its own LED driver and control signals as shown in Figure 2. In the matrix dimmer solution, a single LED dimmer controls the PWM current for up to eight LEDs. The added requirements for this system are a high voltage line and a low output capacitor buck LED driver to drive the string of LEDs. The high voltage rail might require an additional boost regulator and the LED current (from the low output cap buck) can have high ripple.

Figure 2. The I²C-controlled LT3964 RGBW LED driver enables unprecedented color control of high power LEDs used in stage or architectural lighting installations. Driver solutions typically offer 8-bit color resolution. The solution based on the LT3964 enables 13-bit color resolution, easily achieved using the intuitive buck driver setup described in this article.

Figure 3. Two ways to power and control color (component dimming) for a large RGBW LED array: a matrix dimmer using the LT3965 (a) vs a LT3964 direct drive solution (b).The LT3964 non-matrix solution features improved color control, solution efficiency and lower ripple.

(a) matrix dimmer

(b) I2C controlled driver for each LED



Lighting systems with a large number of RGBW LEDs require a substantial number of drivers, and synchronization of the control signals to those drivers. The highest performance approach is to directly control each component LED with its own high performance LED driver.

Lighting systems with a large number of RGBW LEDs require a substantial number of drivers, and synchronization of the control signals to those drivers. The highest performance approach is to directly control each component LED with its own high performance LED driver. In this method, the PWM dimming and the DC current and voltage of each, and every, LED can be controlled with the least amount of ripple and greatest predictability. This type of system is easy to implement using LT3964 dual buck LED drivers controlled via serial bus.

DUAL BUCK LED DRIVER WITH I²C DIMMING CONTROL

The LT3964 dual buck LED driver with I²C control and reporting is an ideal solution for driving multiple LEDs or strings of LEDs with high current and high bandwidth—via serial communication. Buck regulators are inherently high bandwidth, and having two 36V, 2MHz, synchronous and high frequency buck LED drivers in a single package, with integrated 2A switches, makes driving multiple channels of high current LEDs relatively easy with the LT3964.

The I²C serial communications capability simplifies both analog and PWM dimming for two independent high current LED channels supported by each LT3964, with up to eight different LT3964 addresses on a single I²C bus. For instance, the 2MHz dual 1A buck LED driver example circuit in Figure 4 features high efficiency and very small size. It can be altered to power up to 30V of LEDs per channel from a 34–36V input—as shown in the data-sheet—with greater than 90% efficiency.

13-BIT RGBW COLOR CONTROL

Two LT3964 drivers are enough to drive a single, or a string of, RGBW LEDs at 1A (or higher,) as shown in Figure 5. Although RGBW color is commonly controlled with a 1:256, 8-bit resolution, the LT3964 can accomplish up to 1:8192, 13-bit, PWM dimming for each channel combined with 1:10 analog dimming—all controlled by I²C.

This direct drive approach allows for component RGBW LEDs to differ greatly in brightness and voltage—each channel is completely independent. In this example, a single Cree RGBW LED is driven by four LT3964 channels, each with 1A output. With a few digital register changes, the brightness and color control extends as far as 1:8192 PWM dimming and 1/10 analog dimming can provide for each

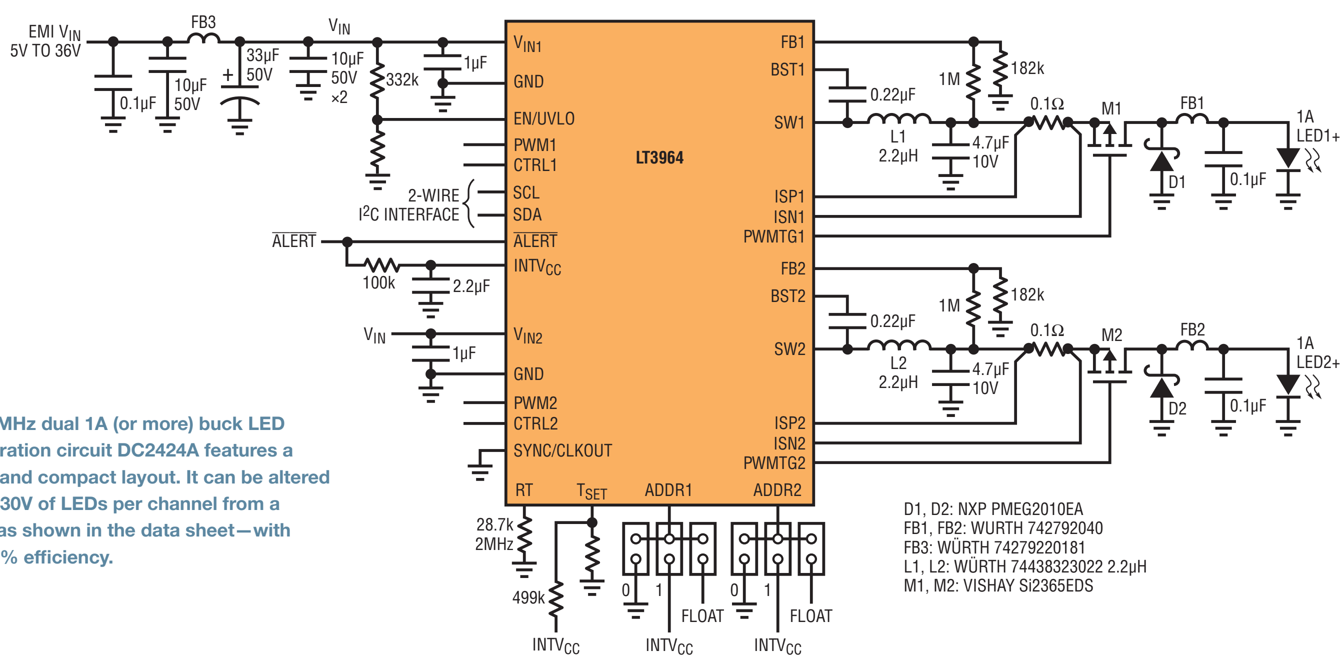
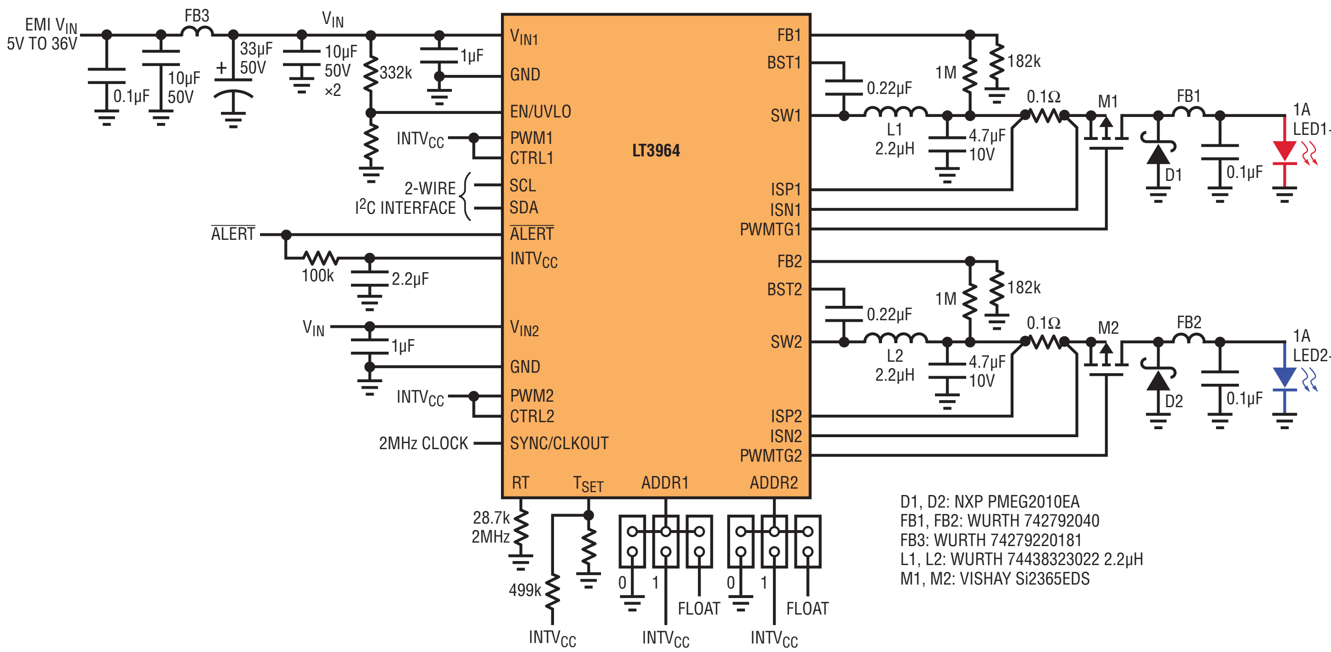


Figure 4. The 2MHz dual 1A (or more) buck LED driver demonstration circuit DC2424A features a high efficiency and compact layout. It can be altered to power up to 30V of LEDs per channel from a 34–36V input—as shown in the data sheet—with greater than 90% efficiency.

The integrated synchronous power switches and 2MHz switching frequency result in a very small solution size, with a small inductor and ceramic output capacitor for each LED channel.



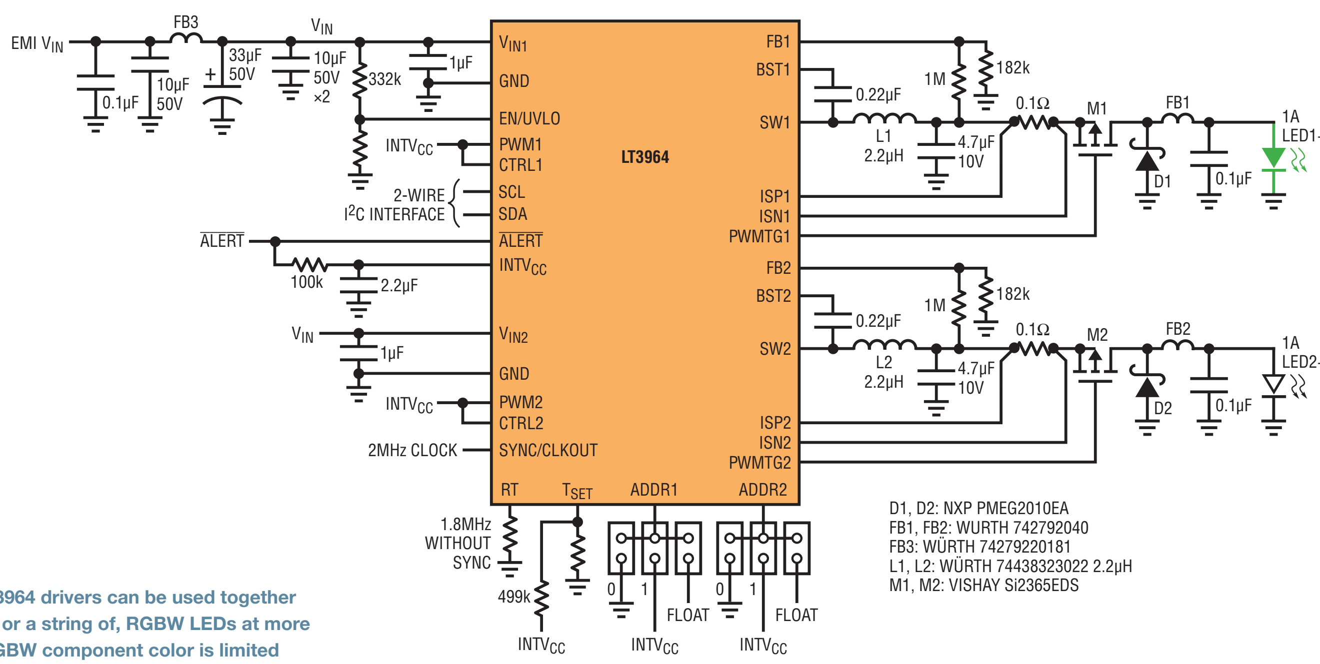


Figure 5. Two LT3964 drivers can be used together to drive a single, or a string of, RGBW LEDs at more than 1A. Each RGBW component color is limited by the dimming resolution, typically 1/256, or 8-bit resolution. Much higher resolution is available with a LT3964-based solution can accomplish up to 1/8192, or 13-bit PWM dimming for each channel combined with 1/10 analog dimming—all controlled by I^2C.

The LT3964 is flexible enough to support systems that require more than four color components. When a wider color range is needed, two additional LED elements such as amber, more green, or even cyan LEDs can be added. To drive the additional component colors, simply tie another LT3964 into the same I²C bus.

red, green, blue, and white LED. The only real color limitation is the LEDs themselves. In fact, having so much control over color mixing allows for color correction of LEDs if desired.

EASY SYNCING FOR LARGE ARRAYS AND LOW RIPPLE OPERATION

The integrated synchronous power switches and 2MHz switching frequency result in a very small solution size, with a small inductor and ceramic output capacitor for each LED channel. The CLKOUT and SYNC pins of the LT3964 allow two ICs to synchronize, preventing unwanted beat frequencies, and maintain uniform timing of PWM dimming through serial communications. This eliminates the need for both ICs to be clocked from an external clocking source, simplifying the solution.

Figure 6 illustrates the low ripple output current of this 4-channel, two IC solution in contrast to the higher ripple matrix LED dimmer solution referenced above. Clearly, the non-matrix, direct drive LT3964 solution presents a cleaner LED current waveform than the matrix dimmer solution, which has higher ripple content due to small output capacitor(s).

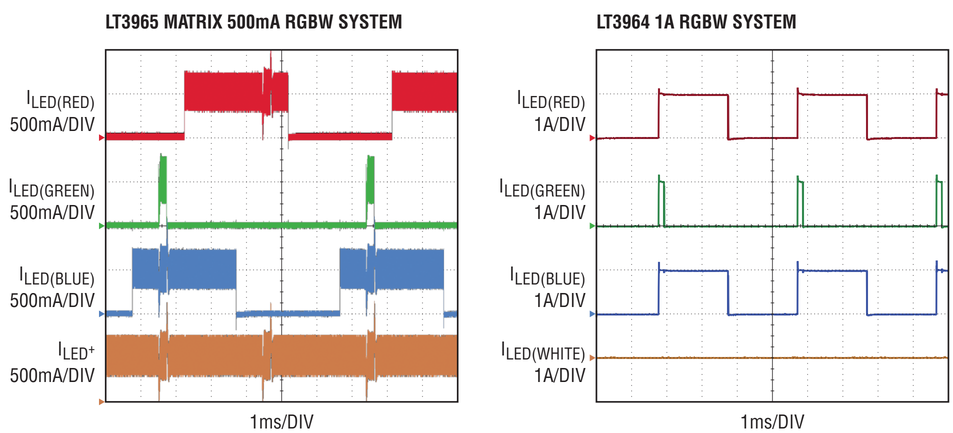


Figure 6. The 4-channel, two dual buck LED driver solution has low ripple current in contrast to the higher ripple matrix LED dimmer solution. The LT3964 presents a cleaner LED current waveform than the dimmer solution.

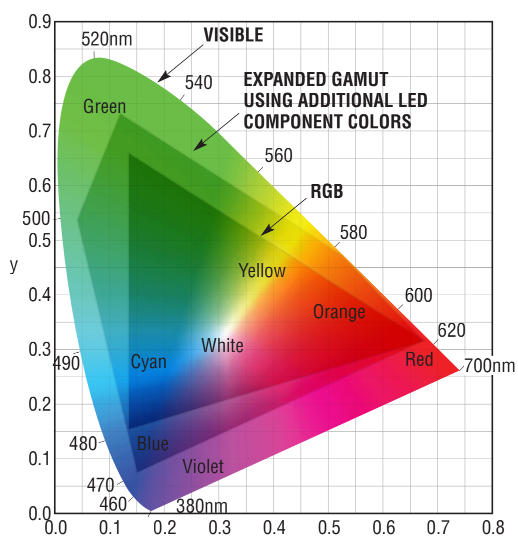


Figure 7. The visible color gamut includes colors not available in the RGB color gamut. When an expanded range is required, two additional LED elements, such as amber, additional green, or even cyan LEDs can be added by simply adding an LT3964 tied onto the same I²C bus.

FLEXIBLE, INTUITIVE BUCK SCHEME

The LT3964 is flexible enough to support systems that require more than four color components. The color gamut for RGB(W) LEDs is shown in Figure 7. When a wider color range is needed, two additional LED elements such as amber, more green, or even cyan LEDs can be added. To drive the additional component colors, simply tie another LT3964 into the same I²C bus.

Not all RGBW color-mixing LED systems use monolithic RGBW LED chips. In some systems, separate strings of red, green, and blue LEDs are built into larger, brighter fixtures. Strings of LEDs with different voltages can be driven by each LT3964 step-down channel, as long as the LED string voltages remain below the input voltage. Strings of up to 30V of LEDs at 1A and greater can be driven by a single LT3964 channel.

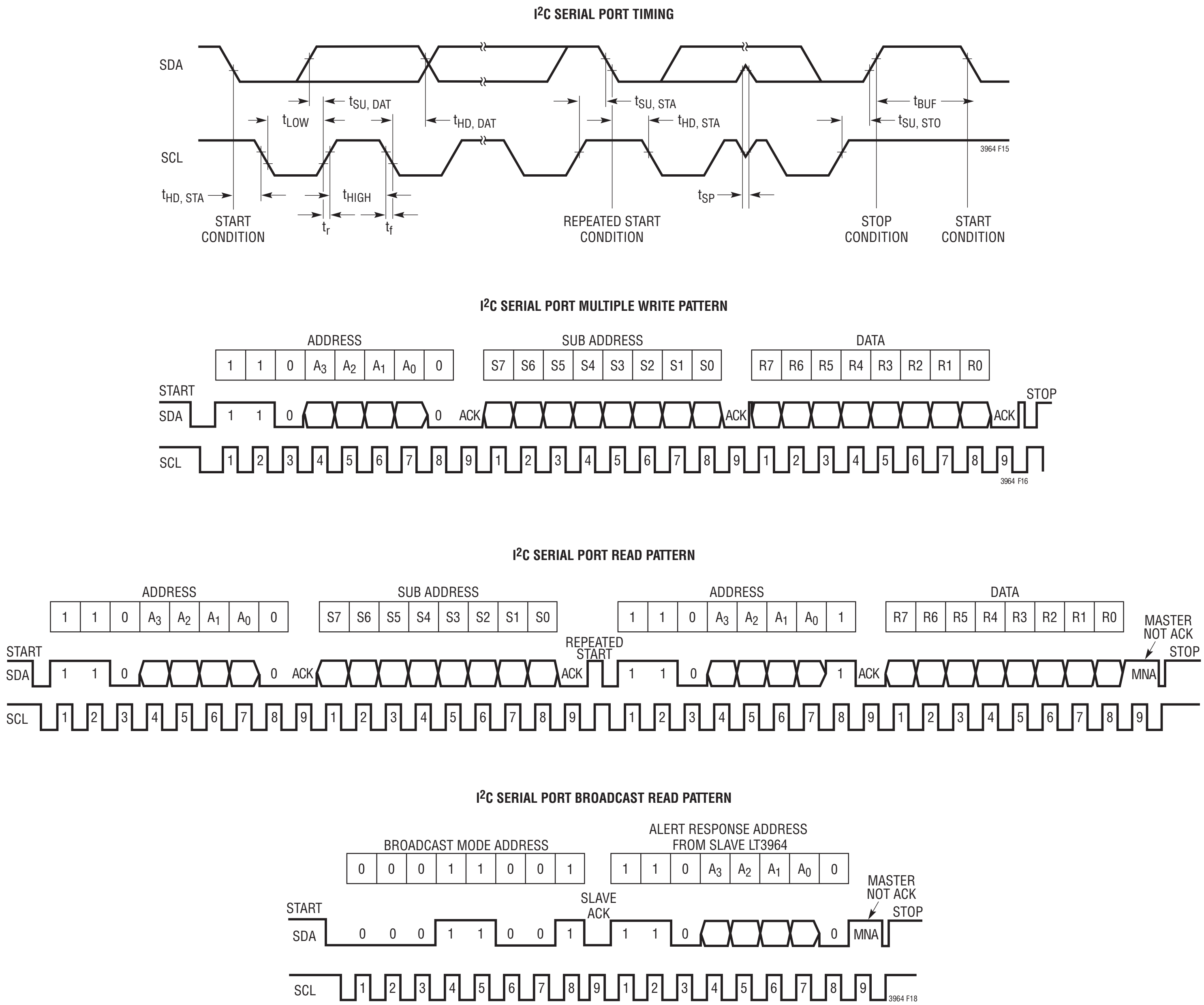


Figure 8. The LT3964 I²C serial communications use standard I²C WRITE and READ words.

I²C SERIAL COMMUNICATIONS

There are two options for controlling analog and PWM dimming with the LT3964 LED driver. One option is to directly drive the dimming pins with external voltages without using the serial bus. In non-I²C mode, the CTRL1 and CTRL2 pins are driven with adjustable DC voltages for analog dimming of the LEDs and the PWM1 and PWM2 pins are driven with pulsed signals with duty cycles that correspond to the PWM dimming brightness of the LEDs. In this method, the LED PWM frequency is synchronized to the PWM pin inputs and the LED brightness and LED current duty cycle matches the PWM pin input pulses. In larger systems, generating a combination of PWM and analog dimming input signals for a large number of channels can be complex.

The second and potentially more effective method is using a serial communications bus, such as I²C to control each LED channel or string. The simple 2-wire I²C bus is used to control the functions of eight different slave devices from a single master device such as a small microcontroller. Running at speeds of up to 400kHz, the I²C bus master only needs to generate three bytes to update each of the nine registers on the LT3964 slave devices. There are four PWM registers, two analog dimming registers, a Status Enable register for setting faults, a Status register for reading faults, and a Configuration register for a few global functions. The

LT3964 features 13-bit (1:8192) PWM dimming capability using I²C. The PWM dimming duty cycle and frequency are set by writing to the two PWM dimming registers for each channel.

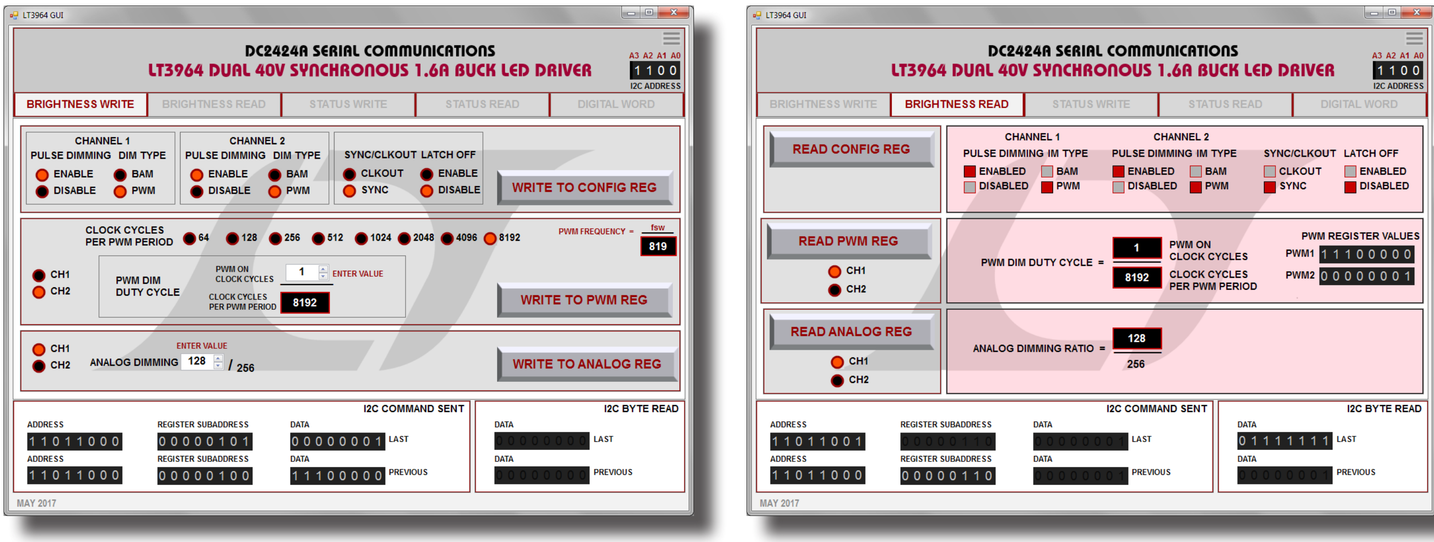


Figure 9. LT3964 features 13-bit (1:8192) PWM dimming capability with I²C. The PWM dimming duty cycle and frequency are set by writing to the two PWM dimming registers for each channel. Here, channel 2 is set to 1:8192 dimming while channel 1 is set to 128:256 analog dimming.

three bytes of I²C WRITE commands include the address, subaddress, and data words. Figure 8 demonstrates the different I²C WRITE and READ words used in the LT3964 serial communications.

LT3964 features 13-bit (1:8192) PWM dimming capability using I²C. The PWM dimming duty cycle and frequency are set by writing to the two PWM dimming registers for each channel as shown in Figure 9. Figure 10 shows the resulting I_{LED} waveform. It is easy to update up to 16 different channels (two channels each and eight addresses total) with a quick series of I²C writes.

In addition to PWM dimming control, each channel features an 8-bit analog dimming register, which can be updated with a single write command. Analog dimming, if invoked, is typically used only down to about 1/10 dimming. More often, PWM dimming is used exclusively for RGBW color mixing—it is sufficient for accurate and repeatable color creation without adding analog dimming. Nevertheless, in systems requiring expanded control, DC LED current adjustment is a useful tool to have in the box.

Other I²C registers include fault protection setting and reading. The LT3964 can report faults for each channel via its ALERT pin and I²C STATUS registers. The faults are only reported if the STATUS registers are individually enabled and a fault has occurred. Open LED, short LED, overcurrent, and overvoltage feedback faults for both channels can be enabled, reported, and read (Figure 9). They can also be disabled and ignored. Fault protection can be a critical part of any serial communications system.

2MHz DEMO CIRCUIT AND QUIKEVAL

It is easy to produce a prototype and evaluate an LT3964 LED system with I²C. Analog Devices has created a demonstration circuit, including a graphical user interface (GUI) for testing the serial communications. This system uses the QuikEval™ program when hooked up

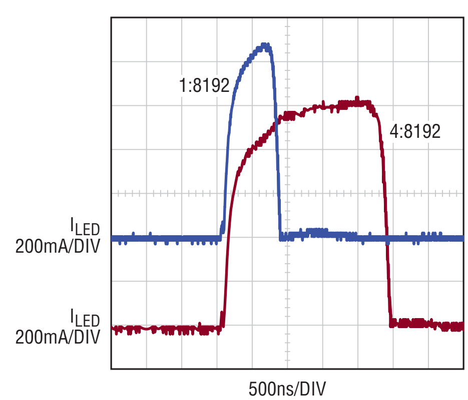


Figure 10. I_{LED} waveform showing 1:8192 dimming

It is easy to produce a prototype and evaluate an LT3964 LED system with I²C. The Analog Devices has created a complete demonstration circuit, including a graphical user interface (GUI) for testing the serial communications.

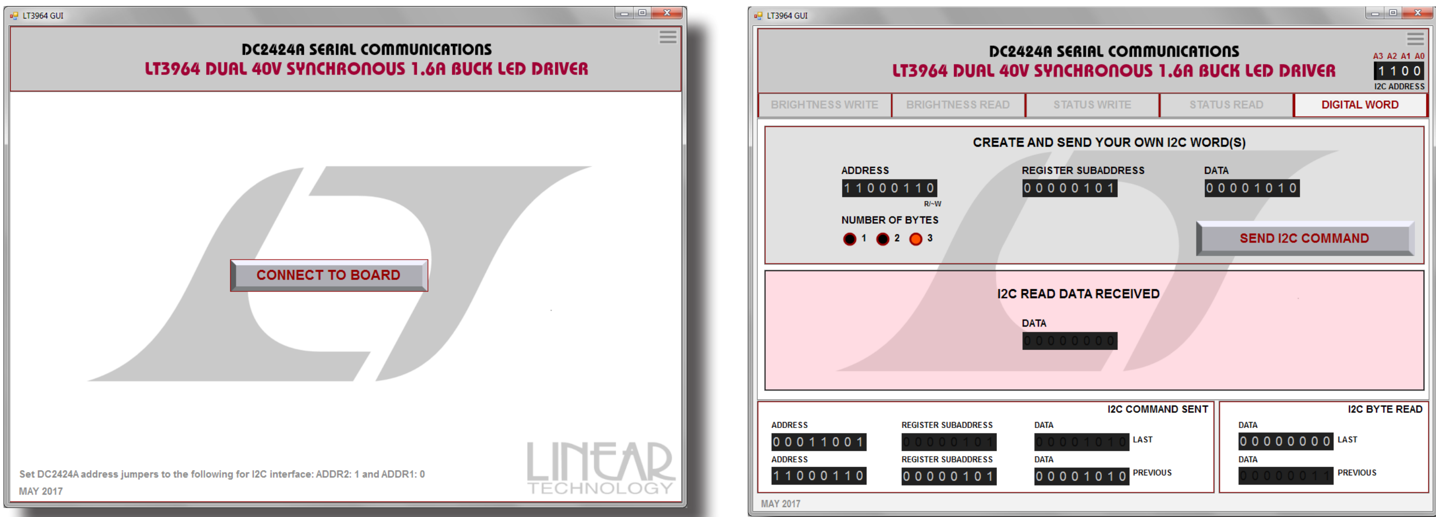


Figure 11. The LT3964 DC2424A demonstration circuit can be controlled with a free GUI through QuikEval. On each page, the register elements can be set and then I²C WRITE or READ commands can be sent with the press of a button through USB and a Linduino DC2026C demonstration circuit. The IC address bits can be set for any address and the GUI can communicate to many LT3964 ICs at once.

to a PC through a Linduino® One demo circuit (DC2026C) via USB. A quick start guide for connecting and evaluating the LT3964 demo circuit, DC2424A, is included in the manual for the demonstration circuit. In short, when connected to USB through a DC2026C (Linduino) the LT3964 demo circuit serial communications can be evaluated one command at a time.

Figures 9, 11 and 12 show the easy-to-use GUI pages of the LT3964 demo circuit. On each page, the register elements can be set, then updated over the I²C serial bus. The analog and PWM dimming registers can be updated for each channel as well as the status enable bits, the global configuration register, and the status enable bits. For each I²C command sent over the bus, the interface shows the address, subaddress, and data bits generated. The registers can also be read back through the GUI read commands. If a fault occurs during testing, the GUI displays an ALERT signal in the upper left (Figure 13) and steps can be taken to examine the nature of the fault and to clear the fault though the STATUS and STATUS ENABLE registers.

In a single RGBW system, there are two separate IC addresses needed (for four LED components) on the I²C bus. By default, the GUI sends all commands to a default address '1100', but this can be altered. The address is shown in the upper right of every page and can be changed by clicking on the digits. Thus the dimming and status registers of up to eight addresses can be controlled and read through the use of the GUI. Additionally, the Digital Word page of the GUI allows the user to enter any three address, subaddress and data words manually and send them as an I²C command. Users can consult the data sheet or the other pages of the GUI to generate READ and WRITE commands, which are shown in the serial data log at the bottom of the screen.

Figure 13 shows how easy it is to tie together two off-the-shelf DC2424A demo circuits with a ribbon cable for I²C control using the GUI and a Linduino. The SDA and SCL 2-wire I²C lines are shared on the bus and the ALERT signals are tied together with the Linduino ribbon cable. The ALERT pin of each LT3964 is an open collector pull-down, so the master can detect when there is a fault present on any IC. When this happens, the GUI displays a red ALERT flag circle in the upper left corner. Once a system fault is detected by the master microcontroller, an alert response protocol is followed to detect and/or clear the fault(s).

The LT3964 has extensive fault protection. It smoothly handles both open and short failures of the LED string. It can also handle overcurrent faults to the output, which are not necessarily short circuits.

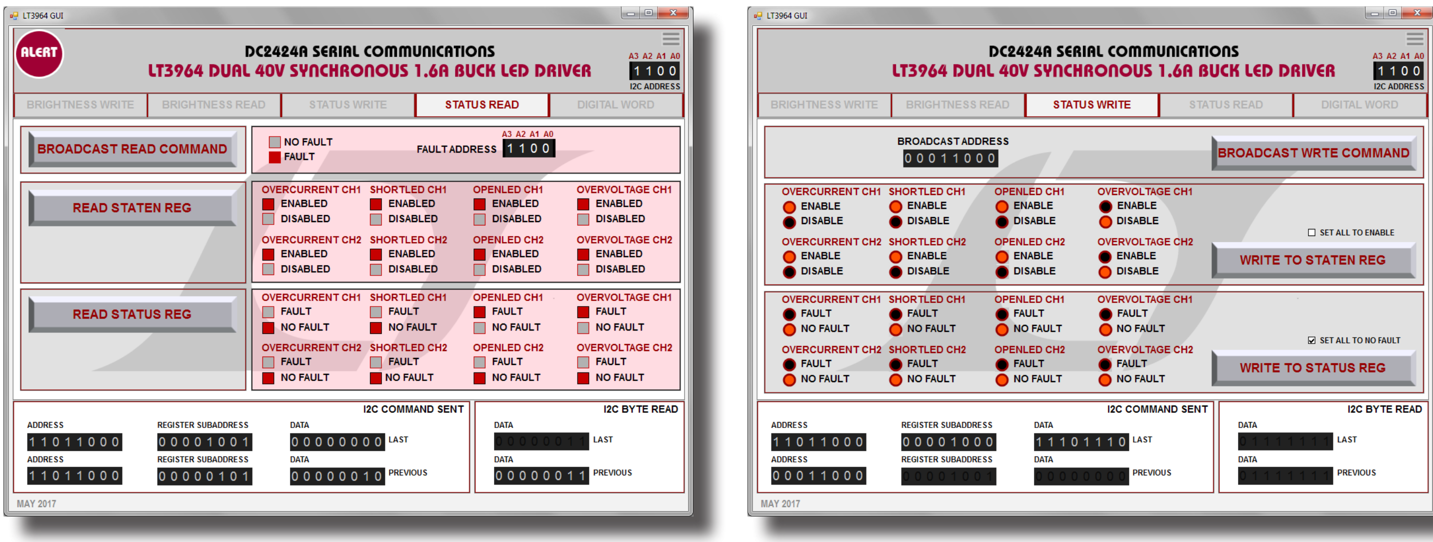


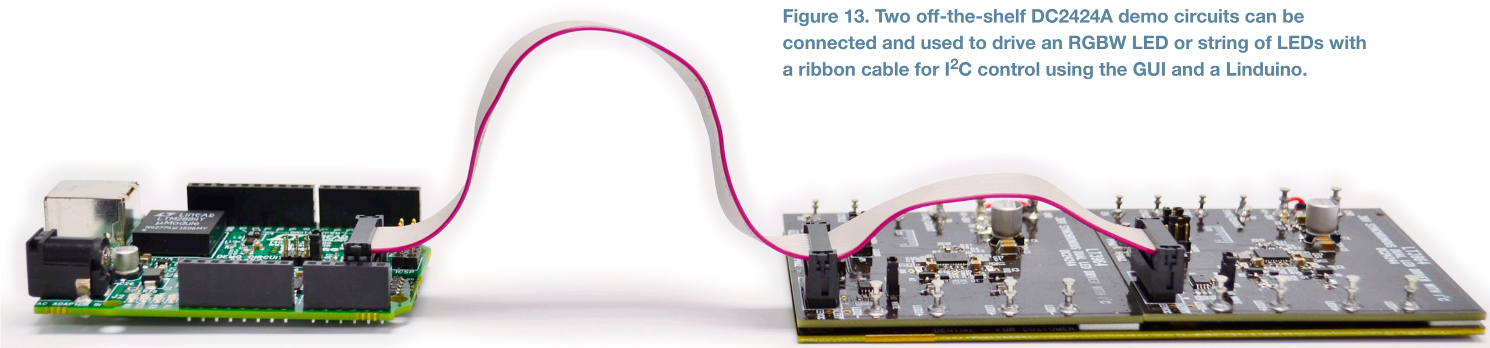
Figure 12. I²C registers include fault protection setting and reading. The LT3964 can report faults for each channel via its ALERT pin and I²C STATUS registers. The faults are only reported if the STATUS registers are individually enabled and a fault has occurred. Open LED, short LED, overcurrent, and overvoltage feedback faults for both channels can be enabled, reported, and read. They can also be disabled and ignored. .

FAULT DETECTION AND PROTOCOL

The LT3964 has extensive fault protection. It smoothly handles both open and short failures of the LED string. It can also handle overcurrent faults to the output, which are not necessarily short circuits. When these faults occur, the ALERT fault flag of the LT3964 asserts. When shared on the same bus, the ALERT bus line gets pulled low (asserted) when any of the LT3964s within a system experience a failure. The I²C communications can be used to locate the IC with the fault first, and then diagnose the fault itself. The types of faults that can assert the ALERT flag can be set within the Status Enable register. A fault such as short LED or LED overcurrent can be enabled or disabled here.

After an ALERT assertion, a BROADCAST READ command is used to poll the slave ICs to find out which IC is asserting ALERT. In the case of multiple alerts, the IC with the lower address sends its address first. The next step is to read the STATUS registers of the faulted address. This should give enough information to diagnose the fault and to clear the fault flag. If the fault flag remains asserted, another BROADCAST

Figure 13. Two off-the-shelf DC2424A demo circuits can be connected and used to drive an RGBW LED or string of LEDs with a ribbon cable for I²C control using the GUI and a Linduino.



READ command can check for subsequent faulted addresses. When the faulted addresses and the Status registers have been read, the faulted status bits can be cleared by sending a write command to the faulty address. If the fault does not clear, it can be reported that service is needed, or the fault can be ignored by turning off the status bit enabling the fault.

CONCLUSION

The LT3964 dual buck LED driver with I^2C serial communications can be used in computer-controlled lighting systems featuring a large number of high power LEDs and LED channels. Two LT3964s are enough to drive a single RGBW LED—or string of RGBW LEDs—at 1A with accurate and precise dimming to produce predictably repeatable color content.

Evaluation is easy using the off-the-shelf DC2424A demo circuit and free QuikEval PC-based software. The LT3964's shared I^2C 2-wire serial communications bus can be used to control up to eight addresses and 16 switching channels. Its wide input voltage range and compact, but powerful, integrated synchronous step-down switches can be used for up to 30V of LEDs on each channel. Switching frequency capability up to 2MHz enables compact designs and small inductors, important when the driver circuit is duplicated throughout large-scale systems that feature numerous LEDs and channels. ■

Complete digital control over high power RGBW LEDs using the LT3964 dual buck driver with I^2C serial communications. Two LT3964s are enough to drive a single RGBW LED—or string of RGBW LEDs—at 1A with accurate and precise dimming to produce predictably repeatable color content.

Silent Switcher µModule Regulators Quietly Power GSPS Sampling ADC in Half the Space

Aldrick Limjoco, Patrick Pasaquian and Jefferson Eco

High speed analog-to-digital converters (ADCs) have evolved into the giga samples per second (GSPS) realm, with a corresponding increase in serviceable bandwidth. These performance improvements come with a number of challenges, one of which is more complex power supply requirements. For example, the AD9625, a 2.6 giga samples per second (GSPS) ADC, requires seven independent power rails, divided into three voltage levels: 1.3V, 2.5V and 3.3V.

The complete ADC power system must be efficient, fit on an already crowded PCB, and produce output noise that matches the sensitivity of the load. Balancing these requirements, often at odds with each other, is an overriding parametric optimization problem for the system designer. Conventionally, the problem is solved by combining switching regulators—noisy, but efficient—with LDO post-regulators—relatively inefficient, but they reduce power supply noise. Figure 1 shows the block diagram for a typical system.

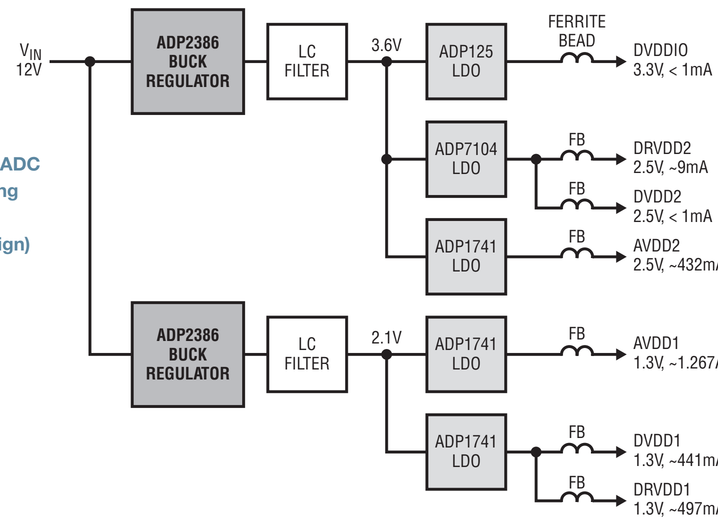


Figure 1. Baseline GSPS ADC power supply design using switching regulators and LDOs. (conventional design)

Unfortunately, efficiency and noise-performance optimization usually come at the expense of system complexity. Figure 2 shows an alternative power system using µModule® Silent Switcher regulators. This solution provides quiet power to the ADC in less space and is more efficient than the conventional solution.

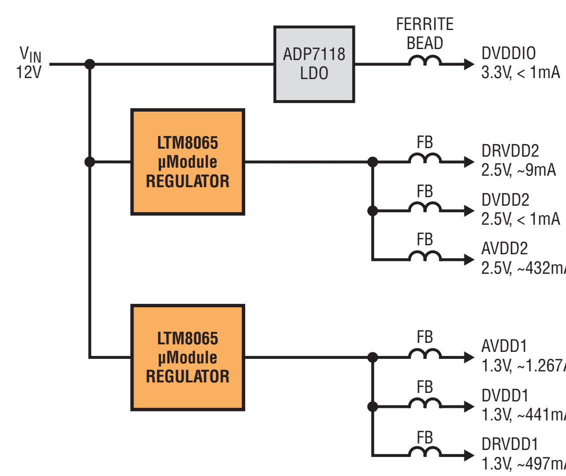


Figure 2. An alternative to the conventional switchers + LDOs power system shown in Figure 1. This design features two LTM8065 µModule Silent Switcher regulators directly powering an AD9625. This design is quiet, more compact and more efficient. (LTM8065 unfiltered design)

CONSIDER NOISE

A system designer must consider quantifying the sensitivity of the load and be able to match it to the power supply noise. Power supply noise can be minimized by using a low dropout (LDO) regulator in the power supply path, either as a standalone regulator (Figure 2), or as a post-regulator following a switching regulator as shown in Figure 1. An LDO has the ability to

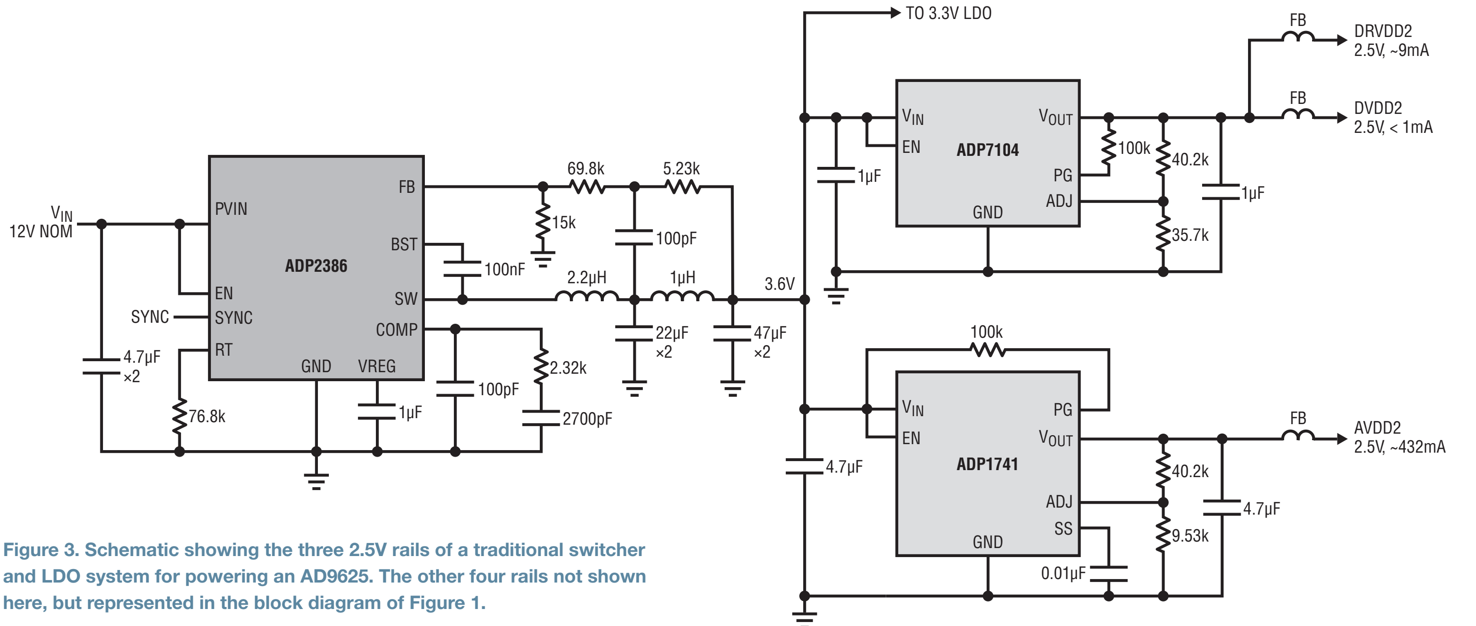


Figure 3. Schematic showing the three 2.5V rails of a traditional switcher and LDO system for powering an AD9625. The other four rails not shown here, but represented in the block diagram of Figure 1.

reject input supply noise—measured as its power supply rejection ratio (PSRR).

The trade-off to improved noise performance with LDOs is lower efficiency. LDOs are inefficient at high step-down ratios, as they must dissipate excess power across a pass element, so the goal when using LDOs is to minimize the step-down ratio to maximize efficiency. This is why they are often used as post regulators following inherently noisy, but efficient, switching regulators, which initially step-down a main rail before LDO inputs. Nevertheless, when used as a post regulator, maximizing the PSRR performance of the LDO requires extra headroom, further degrading overall power supply efficiency, especially at higher loads.

CONSIDER SIMPLICITY AND FOOTPRINT

Conventional switching-regulator-plus-LDO systems are often implemented using discrete components, resulting in a large, and complex PCB footprint, defeating the goal of economy in size and simplicity of design. In contrast, these goals can be achieved using μModule regulators, which enable a compact PCB solution because key regulator components are integrated in the package, especially the relatively large inductor.

Additionally, μModule regulators can typically handle enough load to allow designers to combine equivalent-voltage power rails on a single μModule output. High current capability also makes it possible to add rails to an existing μModule regulator based design, simplifying design modifications, and thus improving time to market.

The μModule regulator based solution shown here is highly efficient and compact, and well suited to the high performance AD9625 12-bit 2.6 GSPS ADC. Power is provided by the LTM8065, a Power by Linear™ Silent Switcher μModule regulator. Silent Switcher technology virtually eliminates unpredictable and difficult-to-filter high frequency noise, translating to a power source well matched to the sensitivity of the ADC.

To test a μModule regulator solution against a traditional power supply setup, the 1.3V and 2.5V rails of the AD9625 are powered by a LTM8065 2.5A step-down μModule regulator. The ADC power supply noise sensitivity on both rails and output spectrum of LTC power modules were inspected.

TRADITIONAL, BASELINE POWER SUPPLY SYSTEM DESIGN FOR THE AD9625 ADC

Figure 3 shows a partial schematic for the traditionally recommended power supply setup for an AD9625 2.6 GSPS ADC. Only the 2.5V rails are shown in Figure 3, which also shows the typical current requirements for each rail. In a complete power supply, seven different power domains are divided into three voltage levels: 1.3V, 2.5V and 3.3V. The block diagram in Figure 1 outlines the complete supply.

In this system, the switching regulators—two ADP2386, 20V 6A step-down converters with LC filters—act as a pre-regulator to 3.6V and 2.1V intermediate voltages. The 3.6V output regulator is shown in Figure 3. These intermediate voltages are further stepped down by LDOs on each regulated ADC input rail. The LDOs provide the regulated voltages to the ADC and are effective in diminishing the output ripple from the switching regulators.

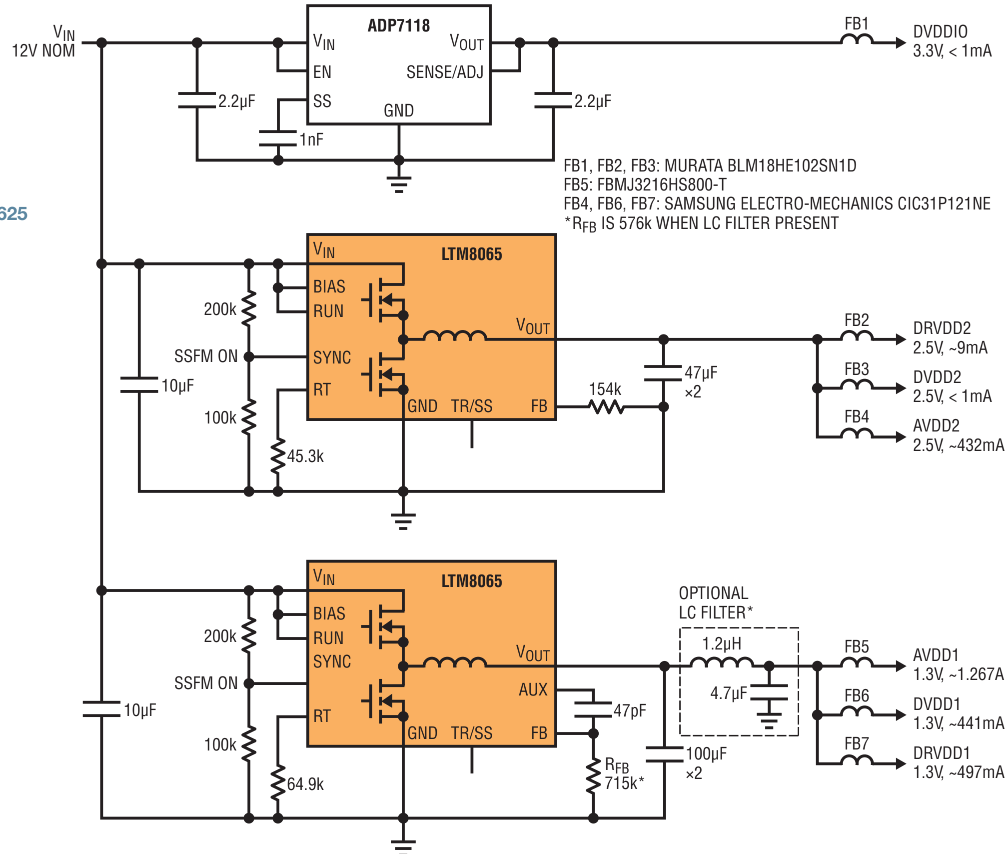


Figure 4. An alternative to the traditional ADC power system. This complete 7-rail solution powers an AD9625 GSPS ADC. Note that the complete schematic is not much different than the block diagram in Figure 2.

The traditional, baseline system successfully produces well-regulated, low noise outputs, but at the cost of complexity. It can be difficult to fit the numerous components on the board, and LDO efficiency can suffer at top loads, possibly creating thermal issues. Is there a better way? There is.

LTM8065 µMODULE REGULATOR DIRECTLY POWERING THE AD9625 ADC'S 1.3V AND 2.5V RAILS

Figure 4 shows the complete schematic for an alternative power solution outlined in the block diagram of Figure 2. This system consists of two LTM8065 µModule regulators and a single ADP7118 LDO. The LTM8065 is a 40V input, 2.5A Silent Switcher µModule regulator packaged in a thermally enhanced compact over-molded ball grid array (BGA). Included in this module are switching controller, inductor and other support components. The LTM8065 supports an output voltage range of 0.97V to 18V and a switching frequency range of 200kHz to 3MHz, with output voltage set by a single external resistor. The only other components required for a complete regulator are the input and output capacitors.

In this solution, the LTM8065s directly power the 1.3V rails and 2.5V rails. The 3.3V rail is powered directly by an ADP7118 low noise LDO coming from a 12V supply. The 3.3V rail current is less than 1mA, so power dissipation across the LDO is negligible.

ABOUT LOAD SENSITIVITY TO POWER SUPPLY NOISE

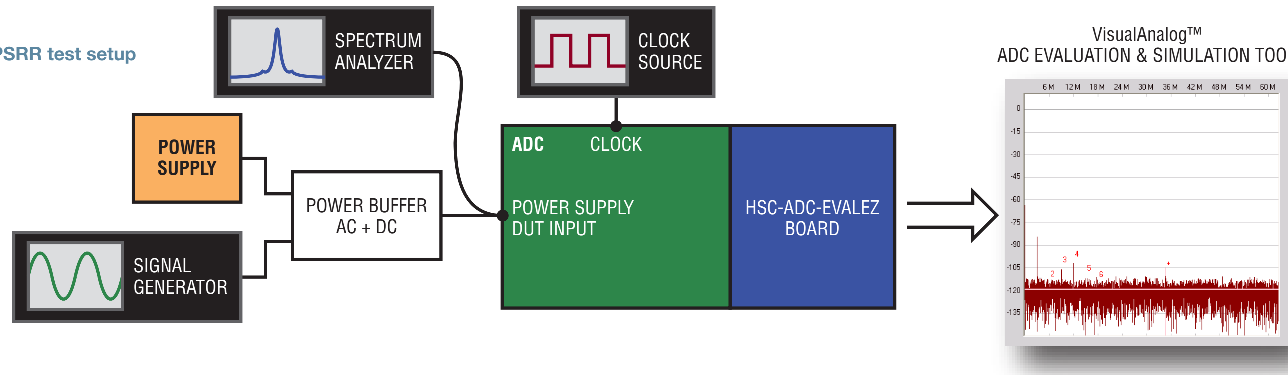
Power supply sensitivity of the ADC is a top consideration when designing the power supply system. Sensitivity to power supply noise can be determined by measuring the PSRR of the ADC itself, or by retrieving the PSRR from the data sheet. There are two types of PSRR: static PSRR and dynamic (AC) PSRR. Static PSRR is the ratio of the change in power supply voltage to the resulting change in the ADC offset error. This is not a major concern, as a DC/DC converter should provide a well-regulated voltage to the load. On the other hand, the dynamic (AC) PSRR is the measurement that concerns the power supply designer, as it represents the ability of the ADC to attenuate the noise on the power supply pin over a range of frequencies.

The ADC AC PSRR is acquired by injecting a sine wave signal on the power supply pin while measuring the injected sine wave signal amplitude directly at the power supply pin under test (probed at the decoupling cap close to the supply pin). A digitized spur appears on the noise floor of the ADC FFT at the corresponding frequency. The ratio of the measured amplitude of the injected signal and the corresponding amplitude of the digitized spur on the ADC FFT spectrum is the power supply rejection ratio (PSRR). Figure 5 shows a block diagram of a typical AC PSRR measurement setup.

Using an AD9625 2.6GSPS ADC, a 1MHz 100mV peak-to-peak sine wave is actively coupled at the 1.3V analog supply rail. A corresponding 1MHz digitized spur appears above the FFT noise floor of the ADC, where its amplitude depends on the PSRR at 1MHz. In this case, in the FFT, a 1MHz digitized spur appears above the converter noise floor at –61.8dBFS, corresponding to a peak-to-peak voltage of 892µ$V_{P–P}$ in reference with the analog input full-scale range of 1.1V.

Conventional switching-regulator-plus-LDO systems are often implemented using discrete components, resulting in a large, and complex PCB footprint, defeating the goal of economy in size and simplicity of design. In contrast, these goals can be achieved using μModule regulators, which enable a compact PCB solution because key regulator components are integrated in the package, especially the relatively large inductor.

Figure 5. ADC PSRR test setup



Calculating the AC PSRR at 1MHz using the equation 1 yields an AC PSRR of 41dB.

$$\text{AC PSRR(dB)} = 20\log\frac{\text{Injected Ripple}}{\text{Digitized Spur}} \quad (1)$$

Where:

- Digitized spur is the spur observed in the ADC FFT that corresponds to the injected ripple at the power supply pin. In this case, the spur is $892\mu V_{P-P}$.
- Injected ripple is the sinewave coupled and measured at the input supply pin. The ripple here has an amplitude of $100mV_{P-P}$.

LTM8065 μMODULE REGULATOR POWERING AD9625 ADC WITH ADDITIONAL LC FILTER ON THE 1.3V RAIL

Figure 6 shows that the 1.3V AVDD rail is more susceptible to power supply noise compared to the 2.5V AVDD rail—specifically over the switching frequency range of LTM8065 (200kHz – 3MHz). Figure 7 shows another LTM8065 solution, but with the addition of a low pass LC (inductor-capacitor) filter for the combined 1.3V rail.

The component recommendation for the low pass LC filter depends on how much filtering is required. For the 1.3V rail, a minimum of 20dB filtering is necessary to reduce the switching spur down to the noise floor of the data converter. A combination of 1.2μH and 4.7μF is used with the cut-off frequency of about 67kHz (~1 decade below the switching frequency of the LTM8065 1.3V rail). An inductor with small DCR (DC resistance) is recommended to prevent excessive voltage drop and power dissipation across the inductor.

As for the capacitor, a multilayer ceramic capacitor (MLCC) can be used. MLCCs have a low effective series resistance

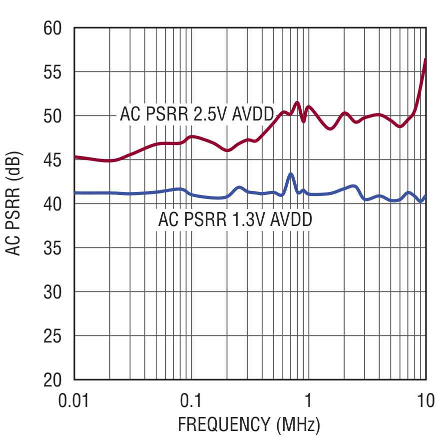


Figure 6. Power supply rejection ratio of the AD9625 analog power supply inputs

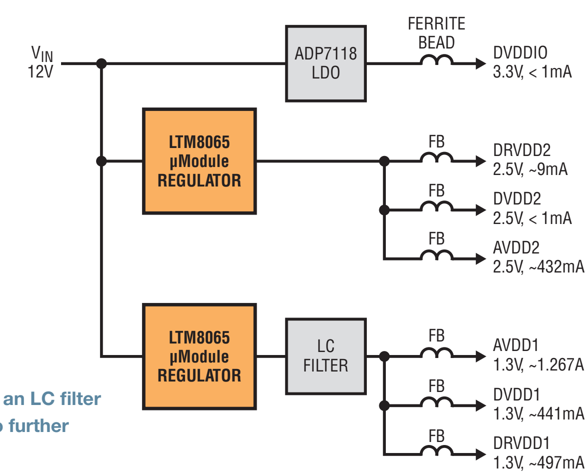


Figure 7. Adding an LC filter to the 1.3V rail to further reduce noise

When powered by the two LTM8065-based supplies, the SNR and SFDR results for the ADC are comparable to those of the baseline power supply. The data shows that LTM8065 can directly power the AD9625 without the use of additional LDOs, greatly simplifying the overall solution.

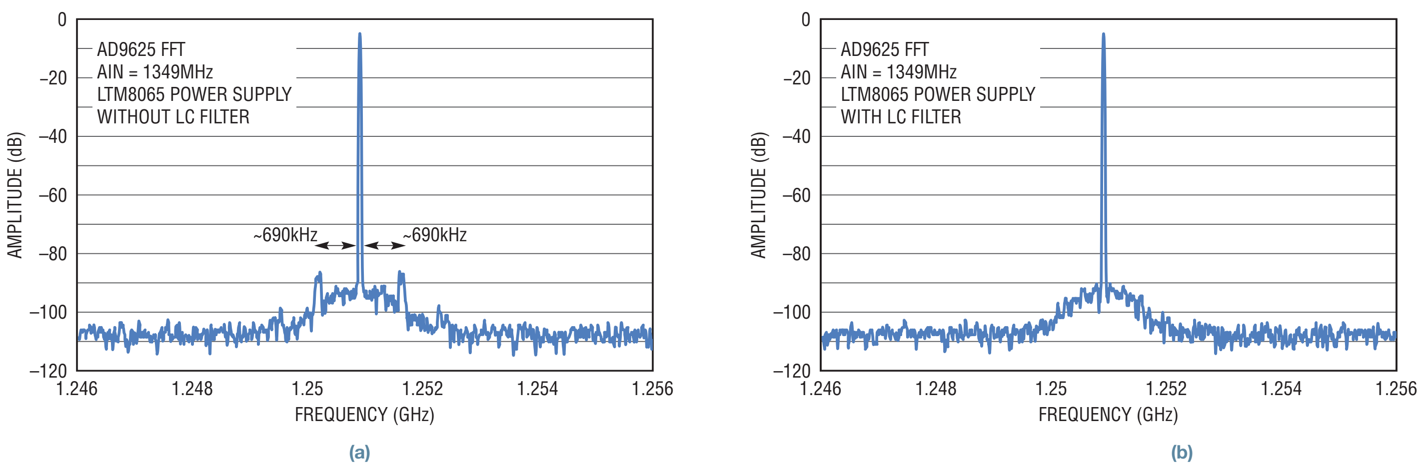


Figure 8. The effects of the LC filter on the modulation spurs around the 1349MHz carrier frequency can be seen by comparing AD9625 FFT results using two different power systems: a µModule regulator based power system without an LC filter (a) and one with the additional LC filter (b)

(ESR), which provides good attenuation at capacitor's self-resonance. The capacitor's minimum impedance is determined by its ESR. MLCCs also have a low effective series inductance (ESL), which offers excellent decoupling at high frequencies.

Ferrite beads are used to filter high frequency noise produced by the switching regulator at the ADC supply rail. These also provide high frequency noise isolation for each of the combined rails. The recommended current through the bead should be around 30% or less of the ferrite bead DC current rating to prevent the core from saturating, which can lower the bead's effective impedance and EMI filtering capability. A ferrite bead with low DC resistance minimizes the voltage drop and power dissipation across the beads, especially at high current rails, such as AVDD 1.3V.

EVALUATION RESULTS

The three power supply configurations shown here are compared through the acquisition of the signal-to-noise ratio (SNR) and spurious free dynamic range (SFDR) of the AD9625 from the fast Fourier transform (FFT) results having 262K data points. The first configuration is the traditional baseline power supply, as shown in Figure 1. The second configuration is the LTM8065 unfiltered, as shown in Figure 2. The third configuration is the LTM8065 with LC filter on the 1.3V rail, as shown in Figure 7. Both LTM8065-based solutions operate with spread spectrum modulation enabled.

Table 1 shows the dynamic performance of AD9625 while powered by each of the three supply configurations. Two different ADC analog input carrier frequencies were used (729MHz and 1349MHz). When powered by the two LTM8065-based supplies, the SNR and SFDR results for the ADC are comparable

Table 1. AD9625-2.6 GHz dynamic performance

	SNRFS (db)			SFDR (dbc)		
INPUT FREQUENCY (MHz)	BASELINE SUPPLY	LTM8065 UNFILTERED	LTM8065 WITH LC FILTER	BASELINE SUPPLY	LTM8065 UNFILTERED	LTM8065 WITH LC FILTER
729	57.01	57.03	57.01	79.87	79.72	80.11
1349	56.53	56.49	56.54	78.41	80.06	80.77

Spread spectrum frequency modulation (SSFM) lowers the peak amplitude of the ripple at the converter's fundamental operating frequency by continuously varying the switching frequency over a range covering the programmed value to about 20% higher than that value. SSFM is most useful in systems where lower *peak* EMI/ripple amplitude is required.

Figure 9. LTM8065 spectral content at the 1.3V rail (SSFM enabled)

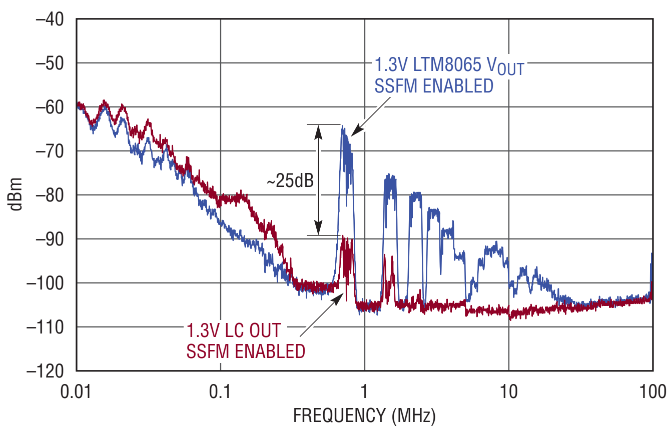
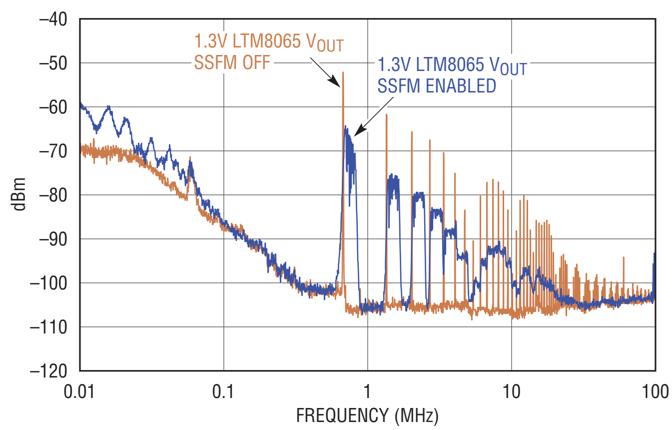


Figure 10. LTM8065 spectral content at the 1.3V rail with SSFM on and off



to those of the baseline power supply. The data shows that LTM8065 can directly power the AD9625 without the use of additional LDOs, greatly simplifying the overall solution.

A close examination of the band around 1349MHz reveals sideband spurs associated with the 690kHz switching frequency (spread spectrum enabled) of the LTM8065 (for the 1.3V rail), but the modulated amplitude is much less than the typical SFDR specification as seen in Figure 8a. Nevertheless, it is better if these sideband spurs are eliminated as shown in Figure 8b, so adding the LC filter to the LTM8065 solution is recommended.

The spectral output probed before and after the LC filter section is shown in Figure 9, illustrating an improvement of up to 25dB in terms of noise filtering.

Spread spectrum frequency modulation (SSFM) lowers the peak amplitude of the ripple at the converter's fundamental operating frequency by continuously varying the switching frequency over a range covering the programmed value to about 20% higher than that value. SSFM is most useful in systems where lower *peak* EMI/ripple amplitude is required. The benefits of SSFM are shown in Figure 10, which shows the spectral content of the LTM8065's 1.3V output with SSFM enabled and disabled. The reduction is about 10dB–12dB in terms of the ripple peak amplitude at the fundamental frequency, along with noticeable reduction in harmonic peaks.

Powering the 1.3V supply rail directly with LTM8065 (spread spectrum turned off) results in modulation peaks up to the second harmonic distortion as shown in Figure 11.

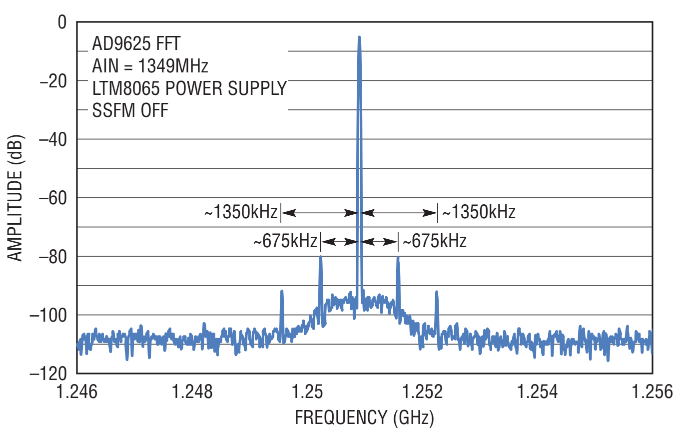
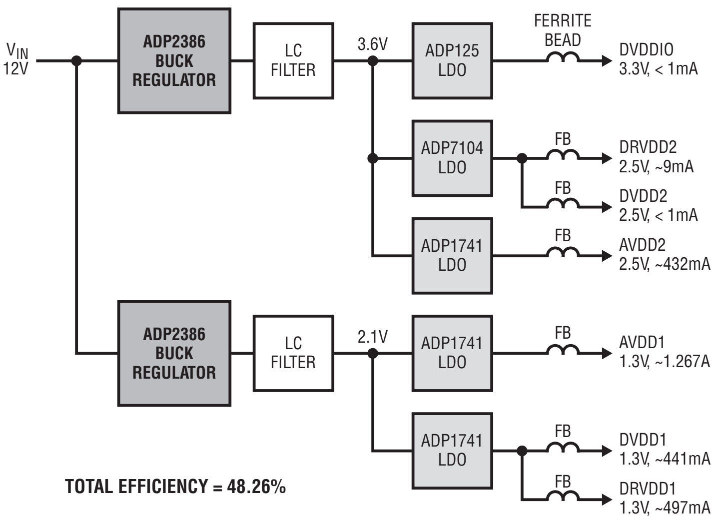


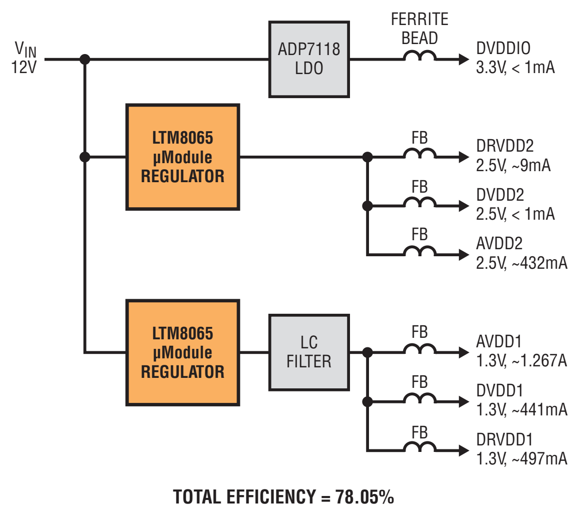
Figure 11. Detail of 1349MHz analog input carrier with SSFM disabled for the LTM8065 1.3V rail

Figure 12. Comparison of efficiencies for baseline (a) and µModule supply systems

(a) Baseline supply efficiency



(b) LTM8065 with LC filter efficiency



	RAIL	VOLTAGE (V)	CURRENT (A)	POWER (W)
P_{IN}	V_{IN}	11.729	0.676	7.929
P_{OUT}	AVDD_1.3V	1.268	1.222	1.549
	DRVDD_1.3V	1.301	0.521	0.678
	DVDD_1.3V	1.305	0.406	0.530
	AVDD_2.5V	2.589	0.408	1.056
	DRVDD_2.5V	2.590	0.0047	0.012
	DVDD_2.5V	2.590	0.0001	0.0003
	DVDDIO_3.3V	3.301	0.0004	0.0013
			P_{OUT} TOTAL	3.827
			EFFICIENCY	48.26%

	RAIL	VOLTAGE (V)	CURRENT (A)	POWER (W)
P_{IN}	V_{IN}	11.885	0.442	5.256
P_{OUT}	AVDD_1.3V	1.303	1.308	1.704324
	DRVDD_1.3V	1.302	0.531	0.691
	DVDD_1.3V	1.305	0.459	0.599
	AVDD_2.5V	2.486	0.440	1.094
	DRVDD_2.5V	2.494	0.005	0.012
	DVDD_2.5V	2.496	0.0001	0.0002
	DVDDIO_3.3V	3.301	0.0004	0.0013
			P_{OUT} TOTAL	4.102
			EFFICIENCY	78.05%

MEASURED SYSTEM EFFICIENCY

The efficiency comparison between the baseline power supply and LTM8065 system with LC filter is shown in Figure 12. The LTM8065 power solution improves efficiency by 30%.

PCB DIMENSION COMPARISON

To illustrate the size advantages of a µModule regulator solution, the LTM8065-based solution with LC filter was implemented on a PCB. The area of the resulting power section was then compared to the power section of an off-the-shelf EVAL-AD9625 evaluation board (using the baseline power supply design).

The standard EVAL-AD9625 evaluation board (baseline power supply) and the revised AD9625 evaluation board (LTM8065 µModule regulators with LC filter) are compared in Figure 13. The components of the power solution using the LTM8065 reside almost entirely on the topside of the PCB, while the discrete solution on the stock EVAL-AD9625 evaluation board requires power components on both the top (LDOs) and the bottom (switcher) sides. The LTM8065-based solution reduces the power supply footprint by over 70%.

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Table 2 compares of the LTM8065-based system and the baseline power supply system in terms of overall component count and component footprint. The LTM8065 solution uses less than half the components in about half the footprint.

CONCLUSION

The LTM8065 μModule Silent Switcher regulator can power the AD9625 GSPS ADC with significant improvements over traditional discrete solutions, without compromising the dynamic performance of the ADC. Significant reductions in component count and power supply board real estate are achieved by using the LTM8065 to directly power to the 1.3V and 2.5V power supply rails of AD9625.

A little filtering can help, though. At very high analog input frequencies, a modulation effect can be observed between the analog input carrier frequency and the regulator's output ripple frequency. The appearance of sideband spurs due to this modulation effect appear around the analog input carrier and are more pronounced at higher analog input frequencies.

Noise on the 1.3V rail is the main culprit in the modulation effect, due to its low power supply rejection around the switching frequency of the LTM8065 regulator. Although the amplitude of the modulation spurs does not exceed the spurious free dynamic range specification, it's a good idea to knock down the spurs with a simple LC low pass filter to attenuate the output ripple. Doing so produces a cleaner digitized analog input carrier with no modulation sidebands.

The μModule regulator power solution achieves a system efficiency of 78%, about a 30% improvement over the existing AD9625 demo board. In addition to higher efficiency (and resulting simplified thermal management), PCB board area and component count are significantly reduced due to the compact nature of the fully self-contained LTM8065 power supply. ■

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Acknowledgements

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Table 2. Overall component count and area for the power sections of the various supplies

	LTM8065 WITH LC FILTER		BASELINE POWER SUPPLY	
	COMPONENTS (pcs)	COMPONENT AREA (mm^2)	COMPONENTS (pcs)	COMPONENT AREA (mm^2)
Switching Regulator (IC/μModule)	2	78	2	32
LDO ICs	1	4	5	82
Passives	21	58	58	159
TOTALS	**24**	**140**	**65**	**273**

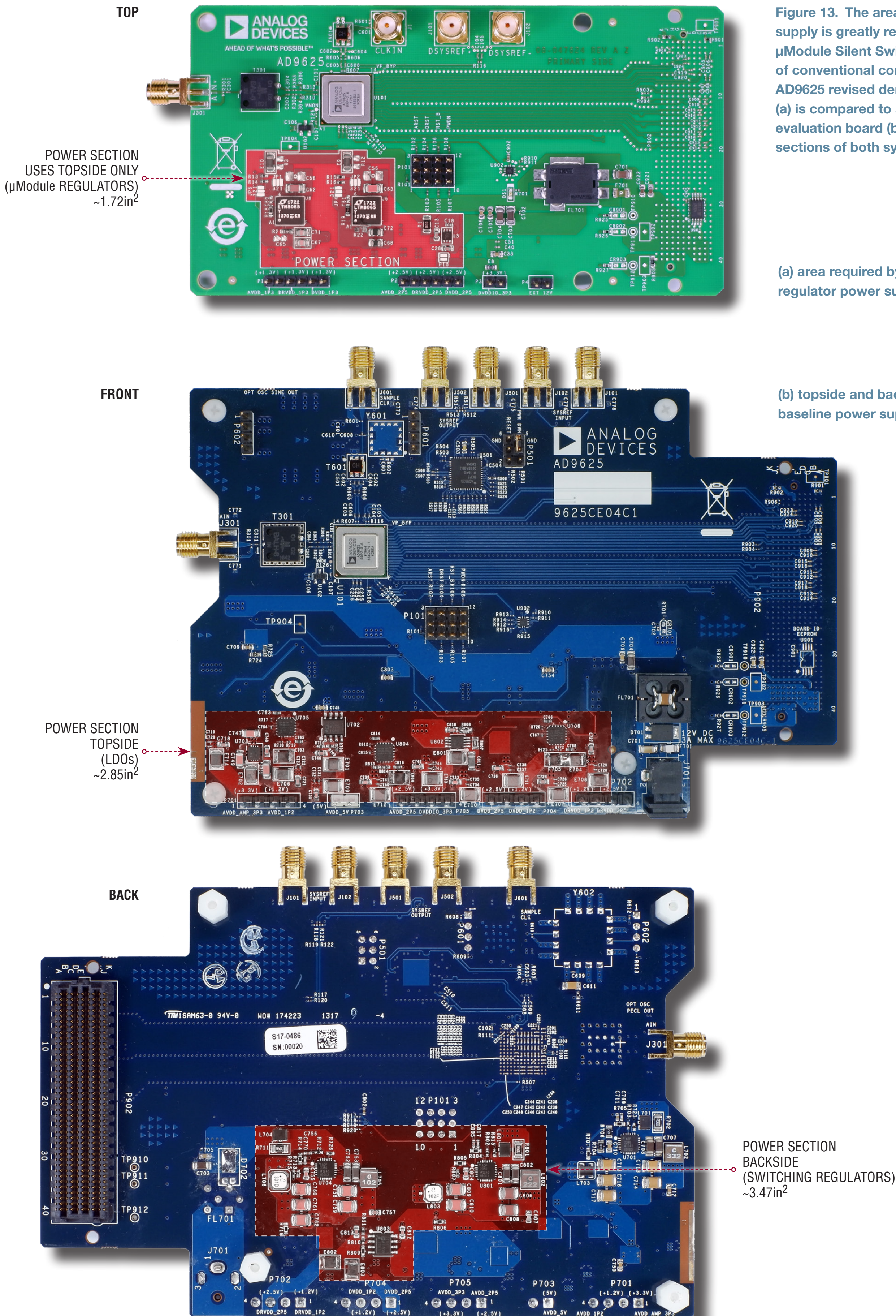


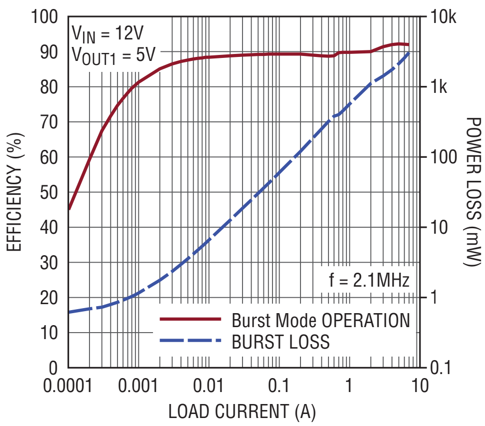
Figure 13. The area needed for a power supply is greatly reduced when using μModule Silent Switcher regulators in place of conventional controllers/regulators. The AD9625 revised demo board with LTM8065 (a) is compared to an off-the-shelf AD9625 evaluation board (b). The power supply sections of both systems are highlighted.

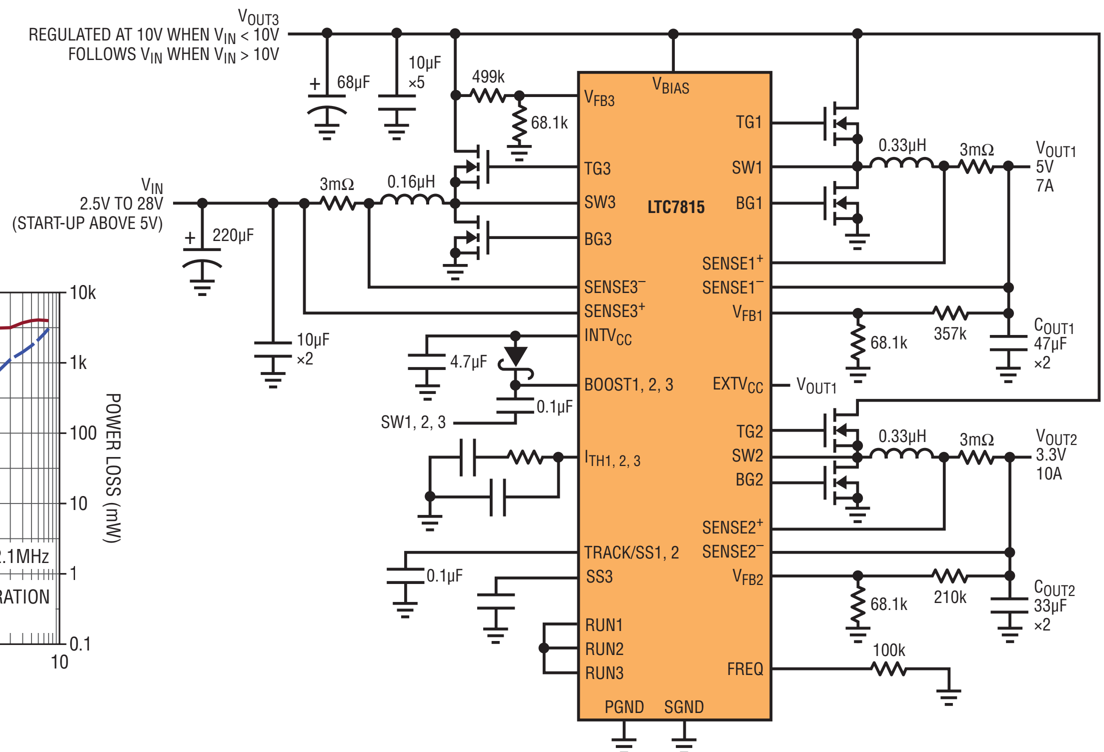
(a) area required by μModule regulator power supply design

(b) topside and backside area required by baseline power supply design

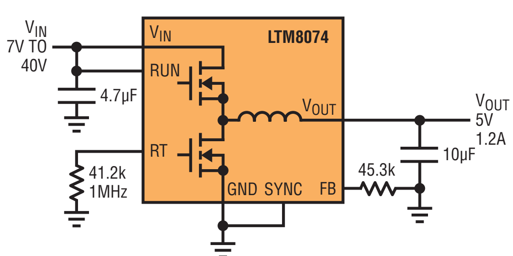
DEPENDABLE POWER FOR INFOTAINMENT DEVICES IN AUTOMOTIVE START/STOP SYSTEMS

Automotive Start/Stop systems require some care with regards to powering onboard infotainment and navigation systems that need up to, or can exceed 5 volts. These systems can reset when the car battery voltage droops to less than 5V at engine restart. The LTC7815 solves this problem by boosting the battery voltage to a safe operating level for onboard systems. In this solution, the LTC7815 boost converter supplies 10V to the step-down converters. In addition to powering the two step-down converters, which produce 5V/7A and 3.3V/10A, respectively, the boost converter can be used as a third output that can provide an additional 2A to loads. This circuit maintains 2.1MHz operation at up to 28V input and skips cycles above 28V. The LTC7815 operates from an input voltage of 4.5V to 38V during start-up and maintains operation down to 2.5V after start-up. The synchronous boost converter can produce output voltages up to 60V and can run with the synchronous switch fully on to pass through the input voltage when it is high enough to maximize efficiency. The two step-down converters can produce output voltages from 0.8V to 24V with the entire system achieving efficiency as high as 95%. The LTC7815 can be configured for Burst Mode® operation, reducing quiescent current to 28µA per channel (38µA for all three on) while regulating the output voltage at no load, a useful feature for preserving battery run times in always-on systems.





LOW EMI, SILENT SWITCHER, 1.2A µModule REGULATOR IN 4mm × 4mm × 1.92mm BGA PACKAGE EASILY FITS BACKSIDE OF PCB



The LTM8074 is a complete, ultralow EMI, high voltage input and output, DC/DC step-down switching power supply. The controller, power switches, inductor and all support components are included in a low profile 4mm × 4mm × 1.92mm surface mount RoHS compliant BGA package, enabling utilization of unused space on the bottom of PC boards for high power density point-of-load regulation. The LTM8074 operates over an input voltage range of 3.4V to 40V and output voltages from 0.78V to 15V. The output voltage is precisely regulated while delivering output current to 1.2A. High efficiency and a thermally enhanced packaging enable excellent thermal performance and high power density. The internal controller's peak current mode control architecture enables fast transient response and good loop stability. Design is simplified by optimized internal feedback loop compensation, which provides sufficient stability margins under a wide range of operating conditions with a broad range of output capacitors. The LTM8074 features Silent Switcher architecture, which minimizes radiated emissions, allowing it to easily meet stringent electromagnetic compatibility standards.

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