LT

LINEAR TECHNOLOGY

Journal of Analog Innovation

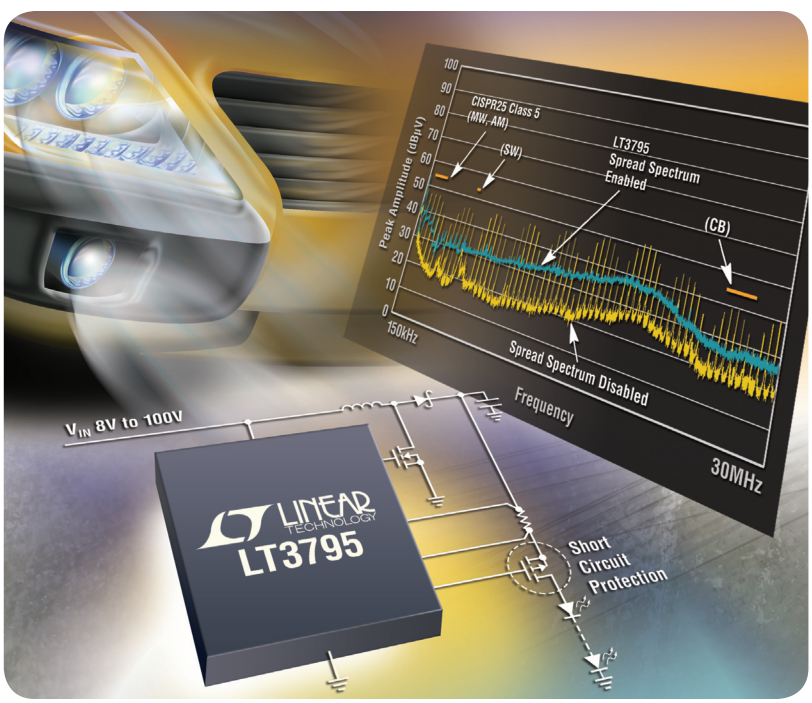
October 2013 Volume 23 Number 3

IN THIS ISSUE

RF/IF Amplifiers with OIP3 of 47dBm/50dBm at 240MHz Ease Implementation, Guarantee Performance

Greg Fung

Our communication infrastructure's limited bandwidth is nearly filled to capacity by our increasing thirst for data transmitted via smartphone, TV, GPS and Wi-Fi. To quench this thirst, communications architects define systems that pack increasingly more data into limited bandwidth, but data rate improvements come at a price: the need for increasingly higher fidelity transmit and receive signal chains.



The LT®3795 LED driver reduces peak EMI without incurring LED flicker. See page 12.

When it comes to amplifiers, low noise and high linearity are required to faithfully reproduce a signal without degrading the original signal. At low signal powers, undesired noise must be low enough to allow the intended signal to rise above the noise floor. At high signal levels, a linear amplifier must prevent unwanted harmonics and intermodulation products from masking the intended signal. The LTC®6431-15 and LTC6430-15 achieve both of these goals.

The LTC6431-15 and LTC6430-15 are two fixed gain amplifiers that feature very high OIP3 (linearity) with very low associated noise. The LTC6431-15 is a single-ended radio frequency (RF)/intermediate frequency

(continued on page 4)

LINEAR TECHNOLOGY

Linear in the News

In this issue...

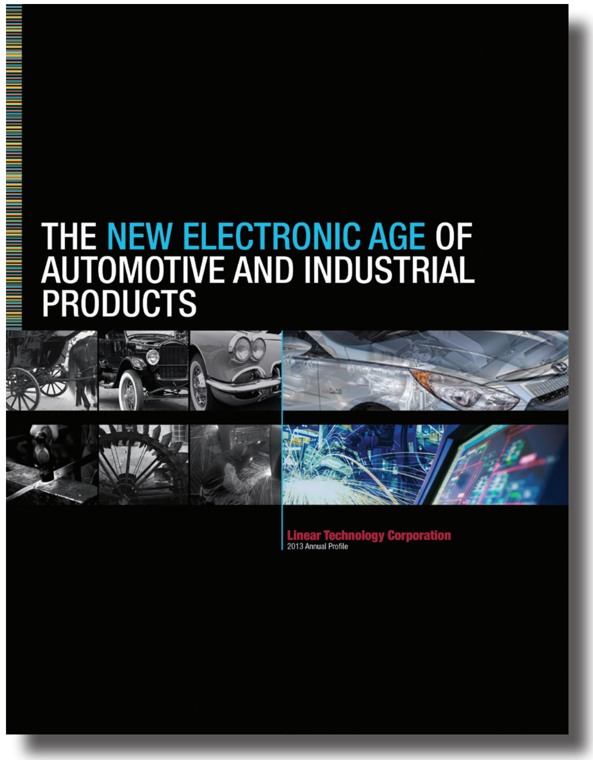
NEW ELECTRONIC AGE OF AUTOMOTIVE AND INDUSTRIAL PRODUCTS

We are now in the midst of a new electronic age in automotive and industrial products. This is the theme of the just-released Linear Technology 2013 Annual Profile. If you examine the history of industrial output, you can see various trends—from an industrial cottage industry in the early 1800s, to the industrial revolution in which mechanization overtook many tasks previously performed by workers, to the current electronics revolution. The latter includes implementation of such systems as wireless transmission of sensor measurements, electronically activated valves, digital x-ray machines and proliferation of industrial robotics. To this, you can add smart manufacturing systems and a new level of focus on energy efficient systems. Linear's electronics are being widely deployed across a range of industrial systems, including medical equipment, factory automation, industrial process control, manufacturing equipment, inventory control systems, industrial wireless sensor networks, security, instrumentation, test and measurement, and renewable energy generation.

This new age is even more evident in automotive systems. Operations that were previously purely mechanical, such as braking and steering, can now be performed electronically. Valuable safety features, such as collision avoidance, lane departure and parking assistance are now a reality in many vehicles. Stored, alternatively sourced energy now assists automotive acceleration.

These new electronic automotive and industrial systems demand exceptional performance, quality, reliability and repeatability. And a large portion of the electronic content is analog, given that signal clarity and power efficiency are significant design considerations. We see these new electronics in a range of automotive systems, including body electronics, exhaust systems, navigation and entertainment, battery management systems, LED lighting, electronic braking, electronic steering and engine management. The electronic content is especially significant in the growing market for hybrid and all-electric vehicles.

Over the past several years, Linear Technology has introduced an array of high performance analog products to meet the growing demands in automotive and industrial electronics. Linear's products have been designed to operate at lower power and high voltages, and to perform flawlessly in harsh environmental conditions.



The Linear Technology 2013 Annual Profile focuses on the increasingly important role that electronics play in automotive and industrial systems.

A few of Linear's innovations that have impacted the growing industrial and automotive markets include:

- Battery management systems for hybrid/electric vehicles
- Power systems management solutions that provide control and monitoring of power usage, voltages, sequencing, margining and fault logging
- Low power ultra-precise SAR (successive approximation register) analog-to-digital converters (ADCs) that enable more accurate product testing
- Enhanced Power over Ethernet (LTPoE++™) solutions that enable delivery of up to 90W of power over traditional Ethernet cables
- µModule® power devices that combine several functions into one integrated solution
- Wireless sensor network solutions that transmit sensor output from low power sources and operate in harsh environments

All told, Linear is providing designers with a broad range of products that enable solutions for expanding applications in automotive and industrial systems. To download Linear Technology's 2013 Annual Profile, visit www.linear.com/docs/43732.

LINEAR PRODUCTS AWARDED

ElectroniqueS Electron d'Or Award for best power and energy conversion product, LTC3300-1 multicell active battery balancer—With the LTC3300-1, applications such as electric vehicles (EVs), plug-in hybrid EVs and large energy storage systems using cells with mismatched capacities are no longer limited by the lowest capacity cell in the stack.

Electronic Products China Top 10 Power Award, LTC3300-1 multicell active battery balancer—The LTC3300-1 goes beyond purely dissipative passive balancing solutions, enhancing battery performance by efficiently transferring charge to or from adjacent cells in order to bring mismatched cells into state-of-charge (SoC) balance within the stack. By redistributing charge throughout the stack, the LTC3300-1 compensates for lost capacity due to the weakest cells, enabling faster charging and extending the run time and usable lifetime of the battery stack.

CONFERENCES & EVENTS

Home of the Analog Gurus Seminar, Tokyo Conference Center Shinagawa, Tokyo, Japan, October 30—Linear Technology and co-sponsor Nikkei Electronics will provide an overview of today's analog design challenges. Speakers include Linear CTO and co-founder Bob Dobkin, Steve Pietkiewicz, Vice President, Power Management Products for Linear, and Prof. A. Matsuzawa of Tokyo Institute of Technology. More at ac.nikkeibp.co.jp/ne/ag1030/

Measurement and Control Show, Tokyo Bigsight, Tokyo, Japan, November 6-8—Presenting Linear's high speed ADCs, power management and wireless sensor network products. More at www.jemima.or.jp/event/keisoku2013/en/index.html

Energy Harvesting & Storage Conference, Santa Clara Convention Center, Santa Clara, California, November 20-21, Booths S7-S8—Linear will showcase its energy harvesting and wireless sensor network products. Speakers include Dave Loconto on energy harvesting battery charging and Ross Yu on wireless sensor networks. More at www.idtechex.com/energy-harvesting-usa/eh.asp. ■

The LTC6431-15 boasts a typical OIP3 of 47dBm at 240MHz—essentially hammering the intermodulation products (IM3) into the noise floor so they don't interfere with the intended signals.

(LTC6430/1-15 continued from page 1)

(IF) gain block that can directly drive a 50Ω load, whereas the LTC6430-15 is a differential RF/IF gain block with higher power and an even wider linear bandwidth. These gain blocks combine state-of-the-art performance with ease of use—eliminating implementation difficulties by internally handling of biasing, impedance matching, temperature compensation and stability.

LOW NF FOR LOW INPUT SIGNALS

Noise limits communication system sensitivity at low input signal levels. Noise in a communication system is characterized by the noise figure (NF), which is the signal-to-noise power ratio at the output divided by the signal-to-noise power ratio at the input expressed in decibels. There is always noise at the input of an amplifier and it is gained up along with desired signal. The NF is an indicator of how much unwanted noise the amplifier itself adds to the signal. Ideally, the amplifier would have a NF of 0dB, but any real amplifier adds noise, so the goal is to minimize noise impairment. Typical IF amplifiers have noise figures of 3dB to 12dB. The LTC6431-15 and LTC6430-15 both exhibit a 3.3dB NF at 240MHz.

Figure 1. A single tone at the input of a nonlinear device creates harmonics at the output.

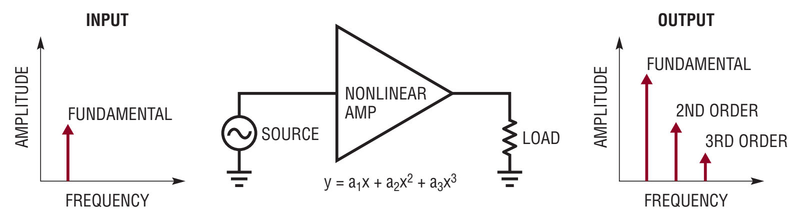
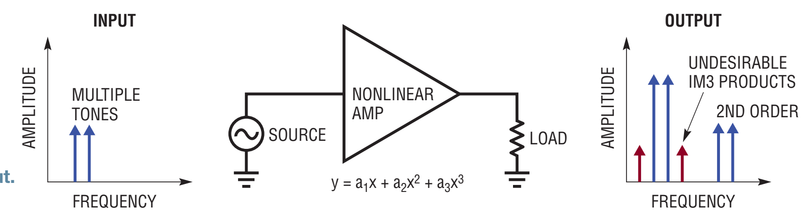


Figure 2. Two tones at the input of a nonlinear device create intermodulation product at the output.



IMPRESSIVE OIP3 HAMMERS DOWN IM PRODUCTS

Linearity limits the ability to isolate the desired signal from unwanted signals in the frequency domain. At high input signal levels, the desired signal rises far above the noise floor, so noise is less of an issue, but an amplifier's linearity becomes increasingly important.

For instance, if a single tone is injected into a nonlinear amplifier, the result is the desired tone plus its harmonics. Normally, these harmonics can be filtered out, as they are far enough in frequency from the desired tone. If two tones are injected into

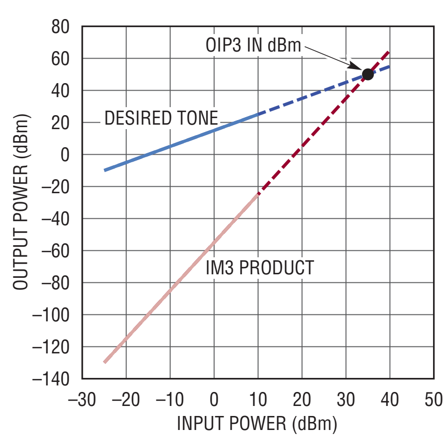


Figure 3. Output 3rd order intercept point (OIP3)

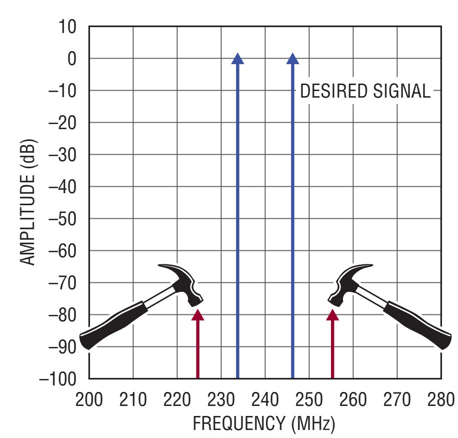


Figure 4. The LTC6431-15 boasts an OIP3 of 47dBm at 240MHz—essentially hammering the IM3 products of a 2-tone signal into the noise floor so that they don't interfere with the intended signals.

The single-ended LTC6431-15 excels as an IF amplifier to overcome filter losses, or as an ADC driver when used with a balun transformer. With its wide bandwidth, the LTC6431-15 can cover the entire CATV band.

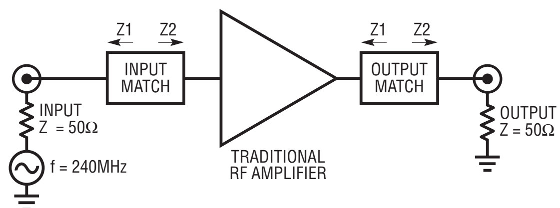


Figure 5. Adding matching networks to the input and output

a nonlinear amplifier, the result is a far more complicated mix of the two desired tones and a multitude of unwanted tones, including harmonics of the two tones, the sum and difference of the two input tones, and other intermodulation products.

Intermodulation (IM3) products ($2f_1 - f_2$ and $2f_2 - f_1$) are a subset of these unwanted tones and they are particularly onerous. IM3 products can fall very close to the intended signal's frequency, making them nearly impossible to filter out.

Amplifier linearity is most often characterized by the 3rd order output intercept point (OIP3)—the hypothetical point where the power of the IM3 products intersects the fundamental power (Figure 3). The LTC6431-15 exhibits very small IM3 products and thus its OIP3 is very good. Minimizing the IM3 product is especially important when a blocker (interferer) or an adjacent channel is nearby. Figure 3 shows that IM3 products grow three times faster than the desired tones. This limits the acceptable output power, and therefore the input power, that the amplifier can handle without distorting the desired signal.

Noise (characterized by NF) limits an amplifier's sensitivity at low input signal amplitudes, while linearity (characterized by OIP3) limits sensitivity at high input amplitudes. Taken together, these two metrics, NF and OIP3, define the amplifier's useful dynamic range for a signal.

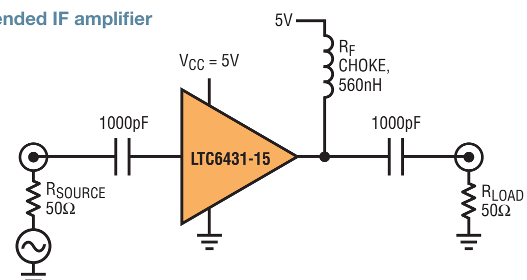
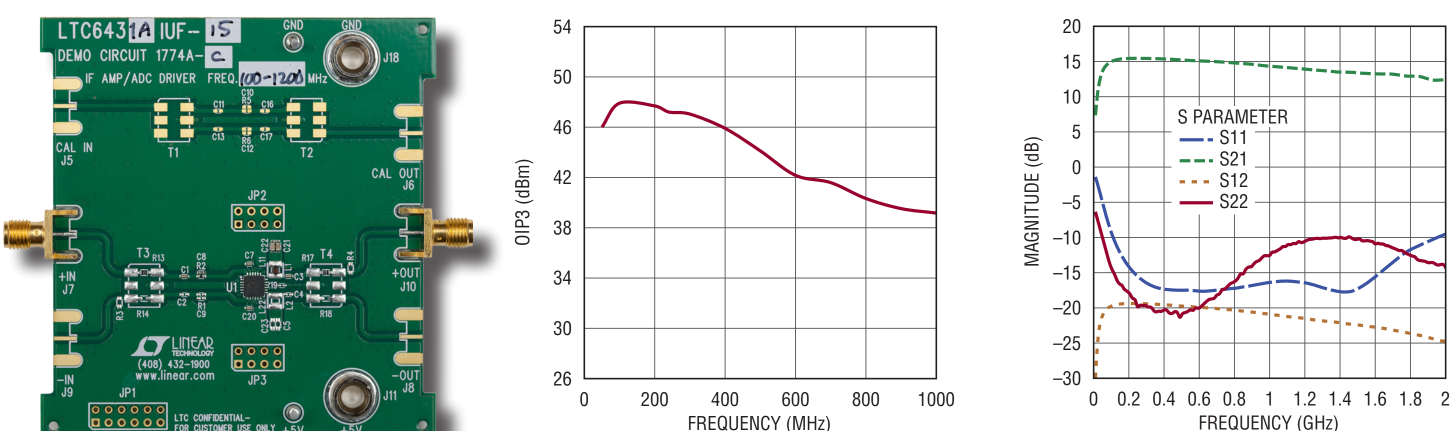


Figure 6. Single-ended IF amplifier



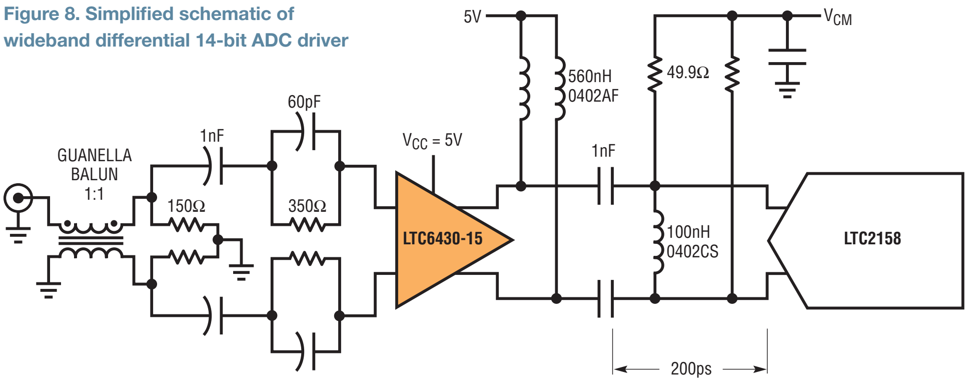
LTC6431-15 OIP3 vs frequency

LTC6431-15 S parameter vs frequency

Figure 7. LTC6431-15 100MHz–1700MHz single-ended evaluation circuit and performance

The LTC6430-15 excels as an ADC driver for high speed, high resolution ADCs. The challenge in these applications is to drive the unbuffered ADC inputs to their required input voltage levels while preserving the signal-to-noise ratio (SNR) and spurious free dynamic range (SFDR) of the ADC.

Figure 8. Simplified schematic of wideband differential 14-bit ADC driver



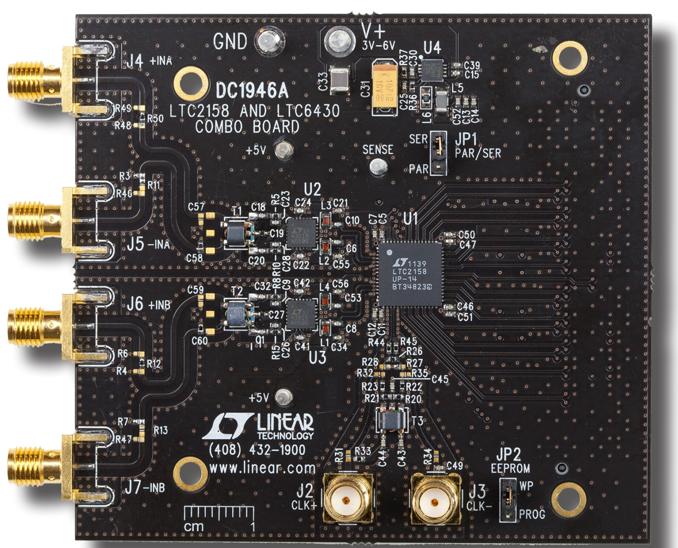
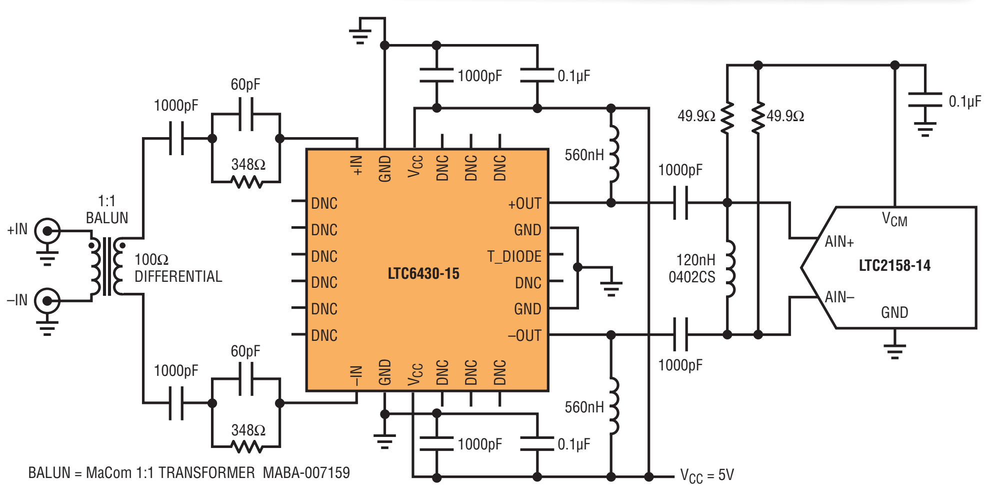


Figure 9. LTC6430-15 driver and LTC2158-14, dual 14-bit ADC combination evaluation circuit



HIGH LINEARITY SOLVES THE TOUGHEST COMMUNICATION PROBLEMS

The LTC6431-15 boasts a typical OIP3 of 47dBm at 240MHz—essentially hammering the IM3 products into the noise floor so that they don't interfere with the intended signals (Figure 4). Not to be outdone, the LTC6430-15 features an OIP3 of 50dBm at 240MHz. Both amplifiers offer a very wide dynamic range when combined with their 3.3dB NFs—addressing the high data rate challenge by maintaining high fidelity at both high and low signal levels.

EASY TO INSERT

Implementing an RF/IF gain stage has not always been easy. Traditionally, the designer must first consider circuit biasing. The LTC6431-15 has an internal bias circuit that requires only 90mA from a single 5V supply, while the LTC6430-15 draws 160mA from a single 5V supply.

The internal bias circuit optimizes the device operating point for maximum linearity. A temperature compensation circuit maintains performance over environmental changes and prevents current run-away at high temperature. These devices also include an internal voltage regulator to minimize performance changes due to imperfections in the power supply.

An RF/IF amplifier must also be impedance matched at the input and the output to maximize power transfer and minimize reflections. This is traditionally a time-consuming iterative task. Typically the designer must add input and output networks to match the amplifier impedance to the system impedance, normally 50Ω (Figure 5). These matching networks in turn alter the amplifier's NF and OIP3—often compromising the NF and OIP3 to achieve a reasonable impedance match.

The LTC6431-15 and LTC6430-15 amplifiers internally match their input and output impedance over the 20MHz–1700MHz band, simplifying design while preserving their NF and OIP3. The single ended LTC6431-15 is internally input and output matched to 50Ω, whereas the LTC6430-15 is internally matched to 100Ω differential impedance at the input and the output. This is allows the devices to be easily inserted into various applications without additional matching elements.

GUARANTEED STABILITY AND PERFORMANCE

The LTC6431-15 and LTC6430-15 are unconditionally stable when implemented with our applications circuits. A-grade versions of the LTC6431-15 are individually characterized for OIP3 at 240MHz, guaranteeing a minimum OIP3 of 44dBm. Similarly, A-grade versions of the LTC6430-15 are individually characterized for OIP3 at 240MHz, guaranteeing a minimum OIP3 of 47dBm.

A NEW BREED OF RF AMPLIFIER

Linear Technology has a long history of producing superior op amp style amplifiers that handle low frequency signals with minimal noise and distortion. While the LTC6431-15 and LTC6430-15 are not capable of amplifying DC signals like an op amp, they are capable of amplifying

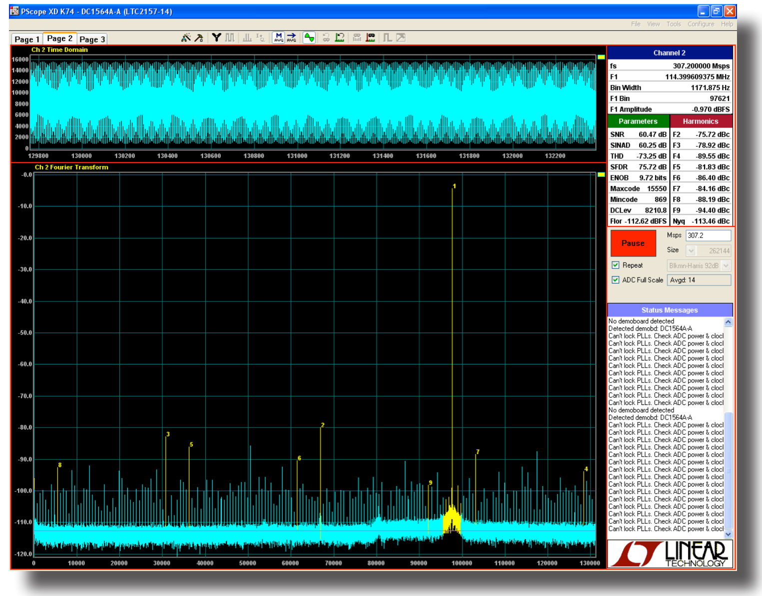


Figure 10. 500MHz single tone SFDR and SNR of LTC6430-15 and LTC2158 driver/ADC combo board (SNR = 61.5dB, SFDR = 75.7dB)

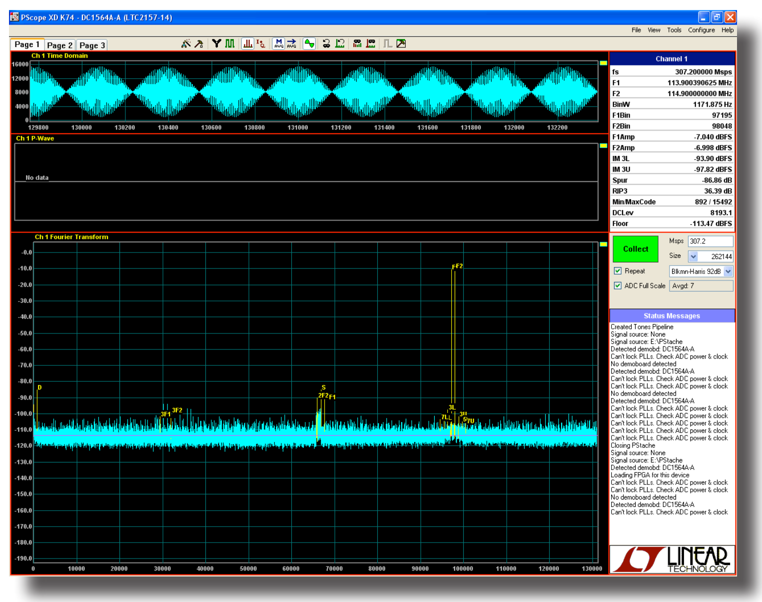


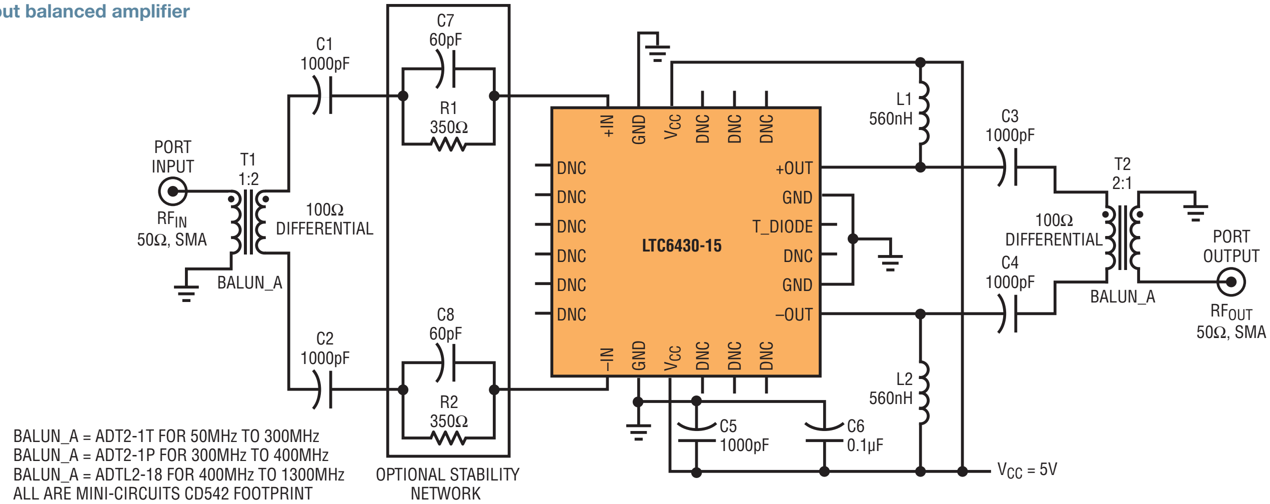
Figure 11. 500MHz 2-tone measurement of IM3 products of LTC6430-15 and LTC2158 driver/ADC combo board (IM3 low = –101dBfs, IM3 high = –102dBfs)

Table 1. Summary of results over frequency for ADC driver evaluation circuit

	LTC6430/LT2158 COMBO CIRCUIT			LT2158 ADC ALONE		
FREQ.(MHz)	1M	SFDR	SNR	1M	SFDR	SNR
250	–87	73.8	63.1	–95	78	66.5
300	–86	77.5	62.8	–94	78	65.5
400	–87	75.0	62.3	–92	78	64.5
500	–101	75.7	61.5	–84	70	63.0
600	–88	72.0	60.7	–88	62.5	62.5
700	–92	67.5	60.0	–86	62.0	61.0
800	–94	84.0	59.5	–85	61.5	60.0
900	–82	73.0	58.6	–80	61.0	59.0
1000	–85	61.4	58.1	–83	60.5	58.0

Using an appropriate pair of 2:1 balun transformers, the LTC6430-15 provides wideband amplification with low noise and low distortion. In this balanced configuration, the amplifier is matched to 50Ω at the input and output. The balanced configuration also has the advantage of suppressing 2nd order distortion which is critical in multi-octave wideband applications.

Figure 12. 50Ω input/output balanced amplifier



signals up to 2GHz. Op amps typically struggle to operate above 200MHz.

With an op amp, feedback typically needs to be added to set the gain. Increasing the gain of a voltage feedback op amp further decreases its operational bandwidth. On the other hand, our RF style amplifiers offer a fixed power gain of 15dB. The RF solution lacks the versatility of gain adjustment, but the usable bandwidth far exceeds that attainable from an op amp.

Op amps are designed to drive high impedance loads, while the LTC6430/31 amplifiers can drive a 50Ω load and deliver real power over a wide frequency range (20MHz–1700MHz). Unlike an op amp, this RF-focused design does not require termination resistors at the input nor at the output, as impedance matching is done internally. Termination resistors at the input add noise and termination resistors at the output attenuate the power delivered to the load. Therefore, the RF amplifier solution results in better overall noise and linearity. The LTC6430-15 and LTC6431-15 amplifiers offer a superior solution for AC signal applications that do not require DC-coupled performance.

LTC6431-15 SINGLE-ENDED 50Ω AMPLIFIER

The single-ended LTC6431-15 is an ideal solution for a number of applications. It excels as an IF amplifier to overcome filter losses, or as an ADC driver when used with a balun transformer. With its wide bandwidth, the LTC6431-15 can cover the entire CATV band.

Figure 6 shows a single-ended IF amplifier, while Figure 7 shows an LTC6431-15 100MHz–1700MHz evaluation board and performance.

LTC6430-15 DIFFERENTIAL APPLICATIONS

The differentially configured inputs and outputs of the LTC6430-15 lend themselves to a variety of system applications. In the following examples, the LTC6430-15 linearity, low noise and wideband performance are put to the test.

In the first example, its differential outputs mate well to the differential inputs of an ADC. The LTC6430-15 is internally input/output matched to 100Ω differential impedance. 100Ω is a convenient impedance for driving high speed ADCs. Next, using 2:1 balun transformers in a balanced configuration, the LTC6430-15 delivers wideband amplification with low distortion into 50Ω. Finally, using 1.33:1 balun transformers, the LTC6430-15 can be matched to a 75Ω system to deliver wideband amplification across the entire CATV band.

A single balun cannot cover the entire LTC6430-15 band of operation. Linear offers several evaluation circuits that cover the amplifier's intended bandwidth. Conveniently transformed to 50Ω at the input and output(s) for ease of bench characterization, these evaluation circuits also demonstrate the performance of the LTC6430-15 when used in a purely differential application without the baluns.

Figure 13. Evaluation circuit of balanced amplifier shown in Figure 12: 50MHz–300MHz (ADT2-1T baluns)

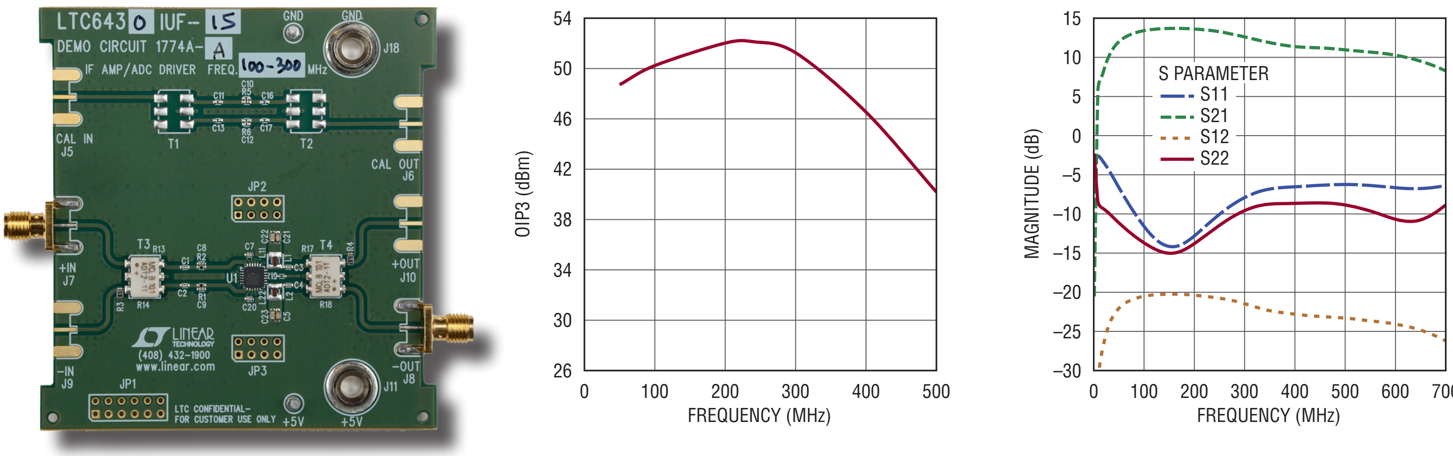


Figure 14. Evaluation circuit of balanced amplifier shown in Figure 12: 300MHz–1100MHz (ADTL2 baluns)

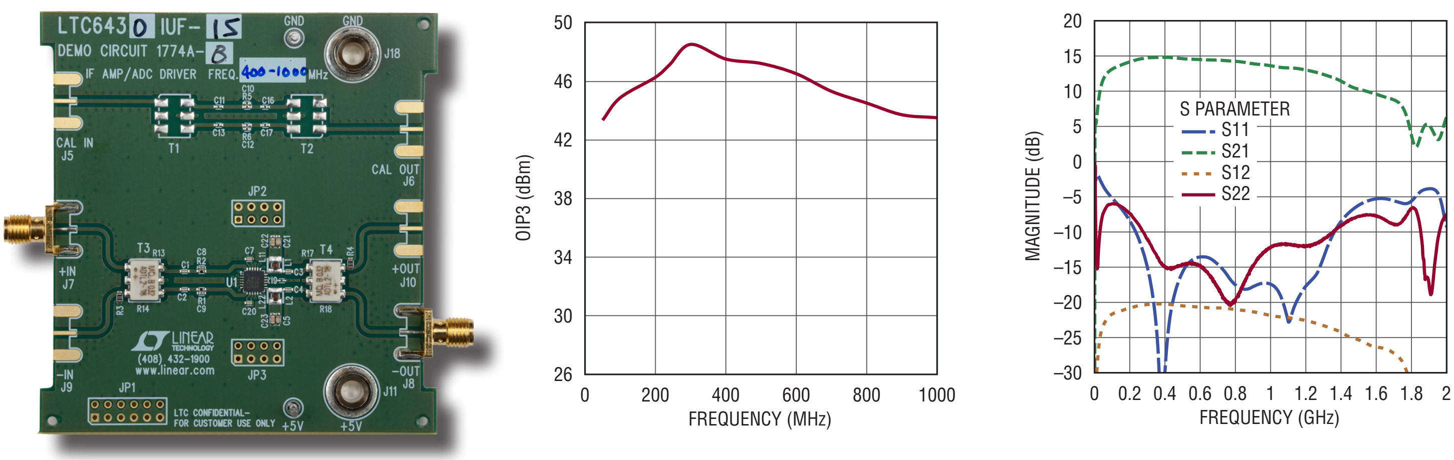
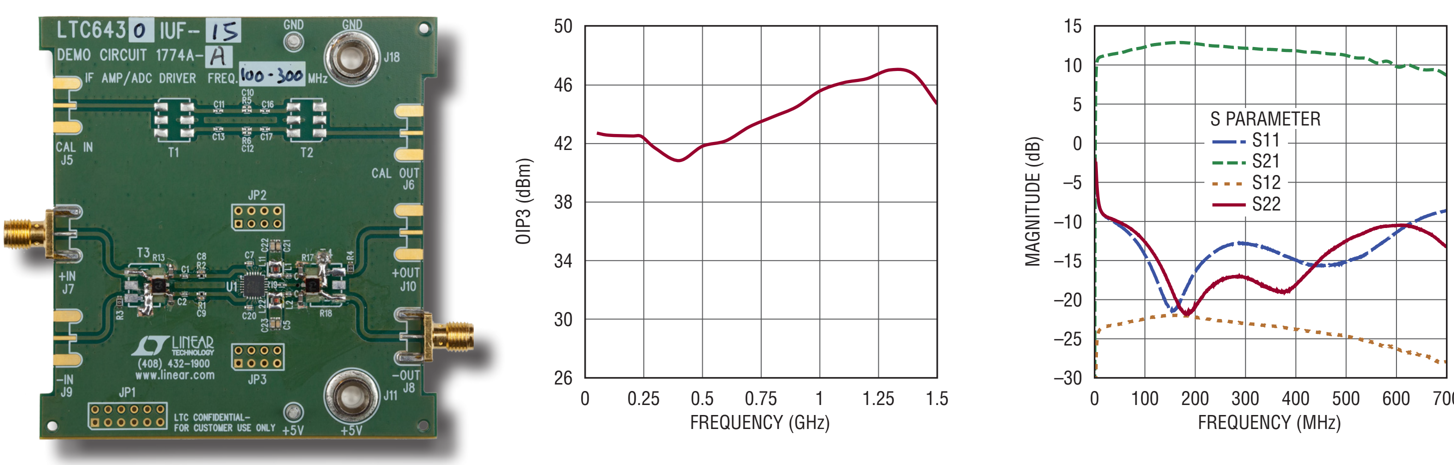


Figure 15. Evaluation circuit of balanced amplifier shown in Figure 12: 200MHz–1500MHz (TCM2-43X baluns)



Cable TV offers unique challenges for an amplifier. A high channel count requires excellent 3rd order linearity and due to the multiple octave environment, 2nd order products must be suppressed as well. The LTC6430-15 meets these challenges using a pair of 1.33:1 baluns to transform its inherent 100Ω differential impedance to 75Ω.

ADC Driver

The LTC6430-15 excels as an ADC driver for high speed, high resolution ADCs (Figure 8). The challenge in these applications is to drive the unbuffered ADC inputs to their required input voltage levels while preserving the signal-to-noise ratio (SNR) and spurious free dynamic range (SFDR) of the ADC. As shown by the performance results for the evaluation circuit in Figure 9, the LTC6430-15 is able to drive the LTC2158 (dual 14-bit, 310Msps ADC) over its full input bandwidth with very little degradation in SFDR and SNR (Figure 10).

Table 1 displays minimal degradation of SNR and SFDR for this high speed, high resolution ADC. The LTC6430-15's high linearity (Figures 10 and 11) and low noise allow the designer to drive the ADC with minimal filtering at the ADC input. All measurements are taken from a single application circuit without adjusting the matching networks. This highlights the LTC6430-15 wide bandwidth and linearity performance.

Balanced Amplifier Drives 50Ω Loads

Using an appropriate pair of 2:1 balun transformers, the LTC6430-15 provides wideband amplification with low noise and low distortion (Figure 12). In this balanced configuration, the amplifier is matched to 50Ω at the input and output. The balanced configuration also has the advantage of suppressing 2nd order distortion which is critical in multi-octave wideband applications.

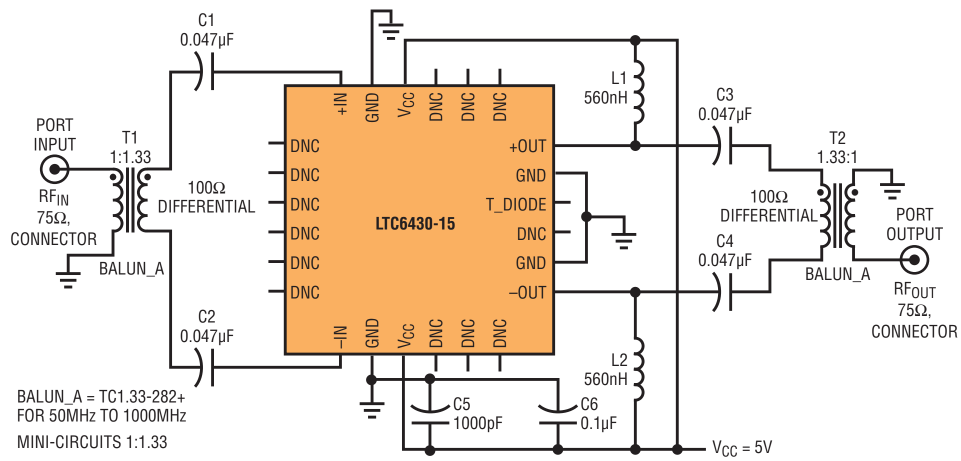


Figure 16. 50MHz to 1000MHz CATV push-pull amplifier with 75Ω input and 75Ω output

Unfortunately, a single balun cannot cover the entire LTC6430-15 band of operation. Linear Technology offers a number of evaluation circuits that cover the amplifier's intended bandwidth (Figures 13–15). Conveniently transformed to 50Ω at the input and output(s) for ease of bench characterization, these evaluation circuits also demonstrate the performance of the LTC6430-15 when used in a purely differential application without the baluns.

The results reveal the importance of selecting the correct balun transformer for the frequency of interest. Due to their limited bandwidth, the balun transformers limit the LTC6430-15 performance. Together, these three balanced circuits demonstrate the linearity and wide bandwidth attainable with the LTC6430-15.

CATV Application

A CATV application circuit is the final example of the LTC6430-15's versatility (Figure 16). Cable TV offers unique challenges for an amplifier. Often the required frequency band covers more than four octaves and the amplifier must have flat gain and impedance matching to a 75Ω environment. A high channel count requires excellent 3rd order linearity and due to the multiple octave environment, 2nd order products must be suppressed as well. The LTC6430-15 meets these challenges using a pair of 1.33:1 baluns to transform its inherent 100Ω differential impedance to 75Ω (Figure 17).

Given its low noise, low 2nd and 3rd order distortion, and flat gain, this circuit can handle CATV demands while consuming only 800mW from a 5V supply.

The LTC6431-15 and LTC6430-15 are manufactured using a high performance SiGe BiCMOS process, compared to other RF gain blocks manufactured using GaAs transistors. Using a silicon-based process yields better reproducibility over comparable GaAs processes. A BiCMOS process also allows Linear to integrate distortion cancellation, bias control and voltage regulator functions into the devices.

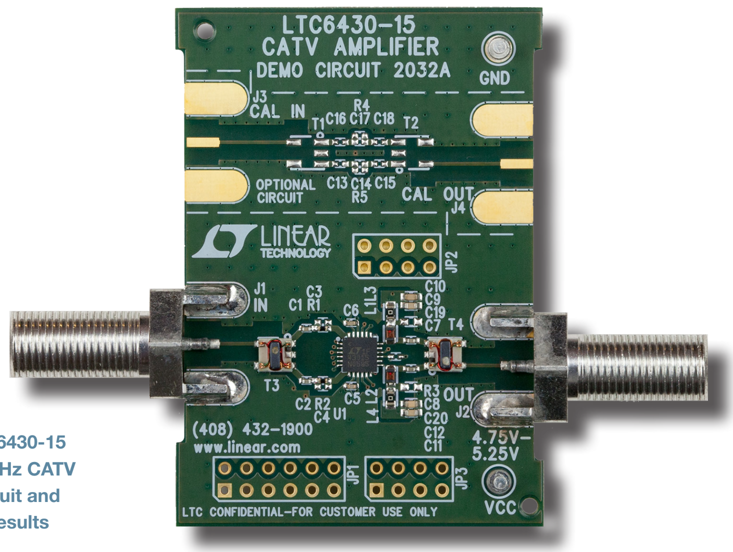
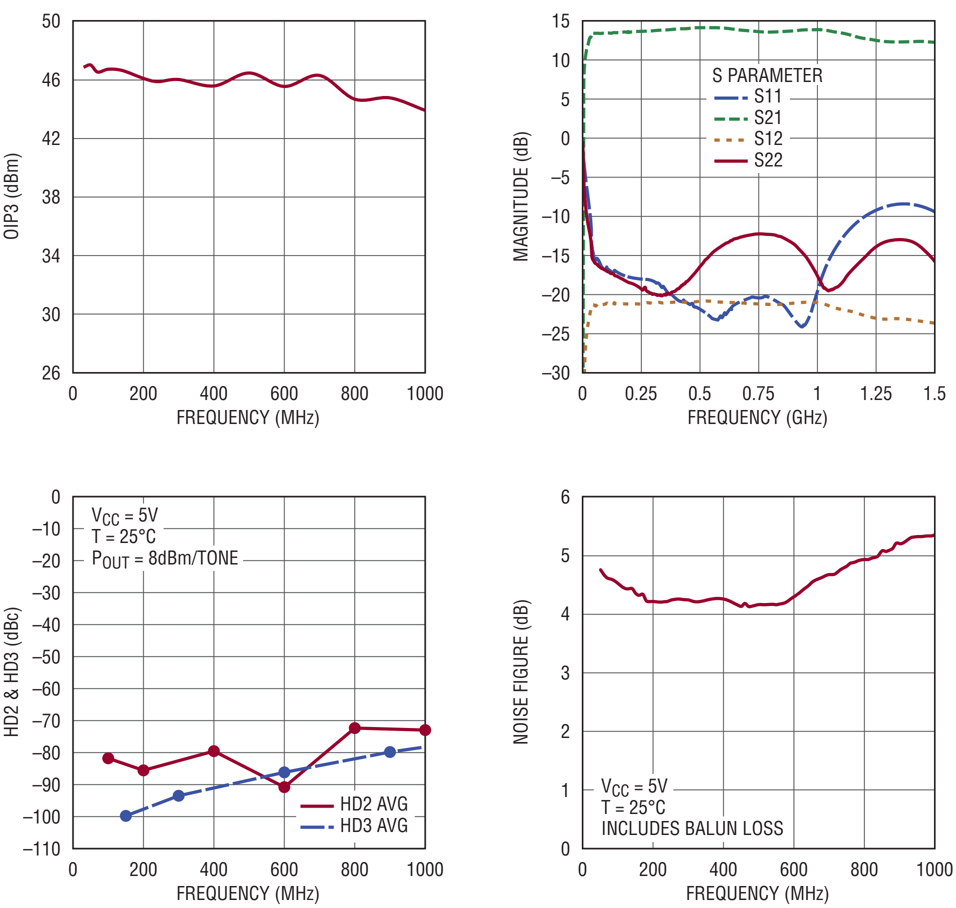


Figure 17. LTC6430-15 50MHz–1000MHz CATV evaluation circuit and performance results



SILICON-BASED PROCESS FOR BETTER REPRODUCIBILITY

The LTC6431-15 and LTC6430-15 are manufactured using a high performance SiGe BiCMOS process, compared to other RF gain blocks manufactured using GaAs transistors. Using a silicon-based process yields better reproducibility over comparable GaAs processes. A BiCMOS process also allows Linear to integrate distortion cancellation, bias control and voltage regulator functions into the devices.

CONCLUSION

To meet the demands of modern communications standards, and simplify RF/IF designs, the LTC6431-15 and the LTC6430-15 achieve best-in-class noise and linearity at the lowest DC power dissipation. They are easy to use, versatile, and guarantee performance over a wide range of conditions. ■

LED Driver with Integrated Spread Spectrum Reduces EMI without Adding Flicker

Keith Szolusha

Automotive LED drivers should be compact, efficient and support flicker-free PWM dimming. They should *not* produce significant conducted EMI at and around the AM radio band. Unfortunately, low EMI is not in the nature of high power switch mode power supplies—the constant switching frequency produces a significant EMI signature at a number of frequencies, including the power supply's fundamental operating frequency and its harmonics. Odds are good that something will fall into the AM band.

One way to minimize EMI peaks is to allow the switch mode power supply (SMPS) operating frequency to cover a range of values, namely spread spectrum switching. The desired effect of spread spectrum switching is to push down the EMI peaks that would occur at the SMPS fundamental operating frequency and harmonics, spreading the EMI energy over a range of frequencies instead.

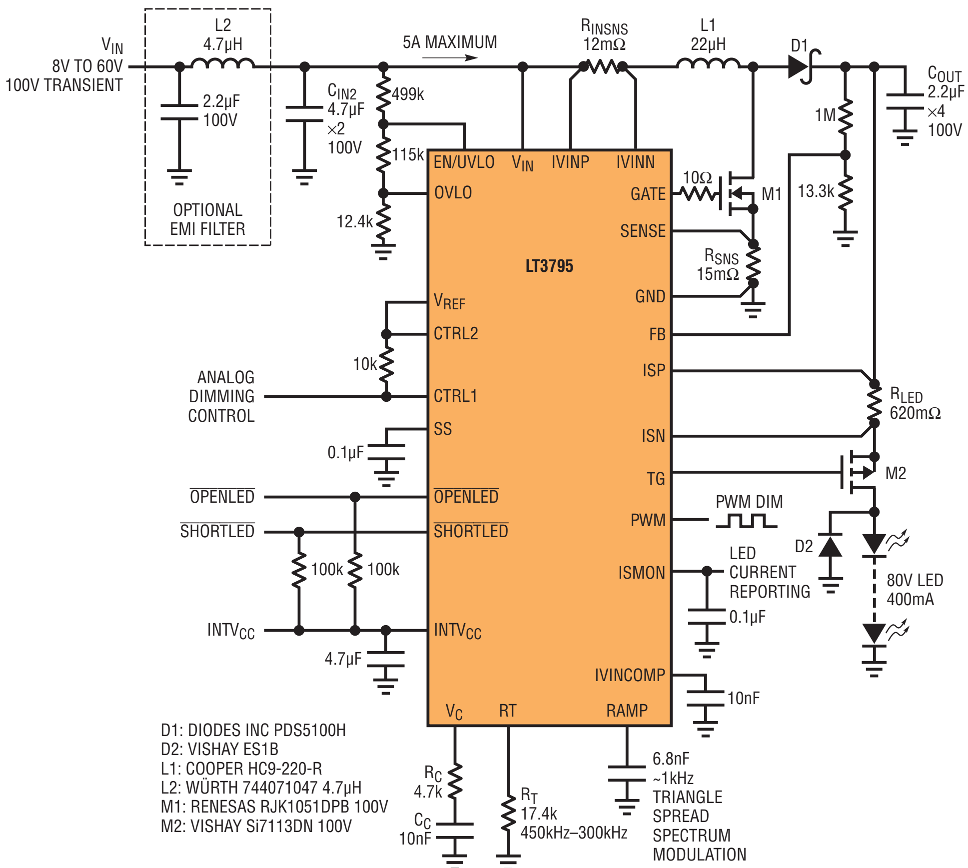


Figure 1. 80V, 400mA automotive LED driver with internal spread spectrum for low EMI

LED driver SPMSs have an additional requirement: the frequency spreading should also be synchronized with the PWM dimming (brightness control) frequency to ensure that there is no resulting LED flicker.

To this end, the LT3795 generates its own spread spectrum ramp signal and aligns it with the lower frequency PWM dimming input with a patent pending technique. This eliminates the chance that the spread spectrum frequency could combine with the PWM signal to produce visible flicker in the LEDs—even at the highest PWM dimming ratio.

HIGH POWER LED DRIVER

The LT3795 is a high power LED driver that uses the same high performance PWM dimming scheme as the LT3756/LT3796 family, but with the additional feature of the internal spread spectrum ramp for reduced EMI. It is a 4.5V-to-110V input to 0V-to-110V output single-switch controller IC that can be configured as a boost, SEPIC, buck-boost mode or buck mode LED driver. It features a 100kHz to 1MHz switching frequency range, open LED protection, short-circuit protection, and can also be operated as a constant voltage regulator with current limit or as a constant current SLA battery or supercapacitor charger.

The LT3795 generates its own spread spectrum ramp signal and aligns it with the lower frequency PWM dimming input with a patent pending technique. This eliminates the chance that the spread spectrum frequency could combine with the PWM signal to produce visible flicker in the LEDs—even at the highest PWM dimming ratio.

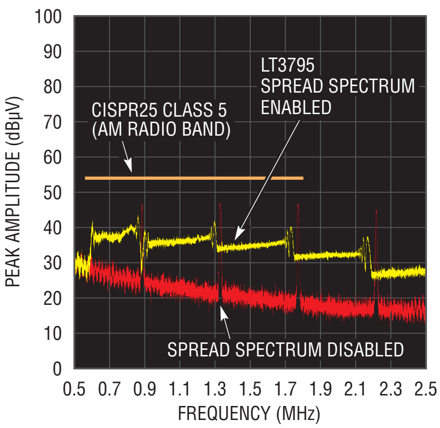


Figure 2. Conducted peak EMI around the AM band is reduced by 3dBμV–6dBμV when the LT3795's spread spectrum frequency modulation is used. The CISPR25 Class 5 AM-band limit is provided for reference.

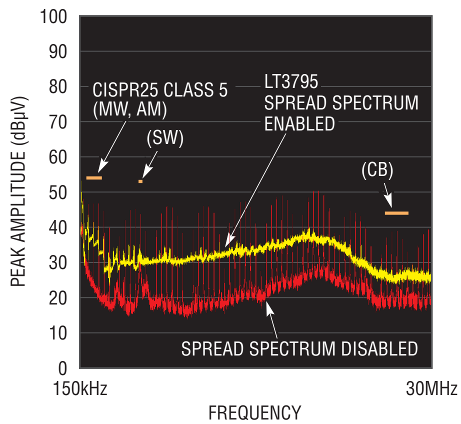


Figure 3. Spectrum analyzer scan of the LT3795 150kHz–30MHz peak conducted EMI shows the reduction in peak EMI over a broad frequency range.

Figure 1 shows a 92% high efficiency 80V, 400mA, 300kHz-450kHz automotive LED headlamp driver with spread spectrum frequency modulation and short-circuit protection.

INTERNAL SPREAD SPECTRUM SIMPLIFIES DESIGN

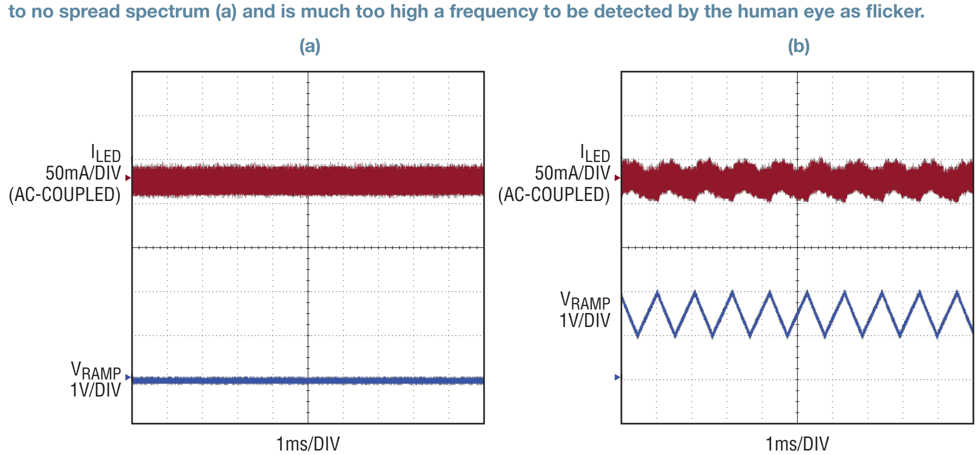
Unlike other high power LED drivers, the LT3795 generates its own spread spectrum ramp to produce 30% switching frequency modulation below the programmed switching frequency. This lowers its conducted EMI peaks, reducing the need for costly and bulky EMI input filter capacitors and inductors.

Using an external, or separate, spread spectrum clock to produce the switching frequency in an LED driver can produce visible flicker during PWM dimming since the spread spectrum frequency pattern is not synchronized with the PWM period. For this reason, in many high end LED driver applications, implementing spread spectrum is not trivial. Without spread spectrum, designers must rely upon bulky EMI filters, gate resistors that slow down switching edges (but reduce efficiency) and snubbers on the switch and catch diode.

Figure 2 shows a comparison of the conducted EMI measurements of the LT3795 LED driver around the AM band when spread spectrum is enabled and disabled. Normal (non-spread spectrum) operation yields high energy peaks at the switching frequency and its harmonics. These peaks can prevent the design from passing stringent EMI requirements in EMI sensitive applications such as automobiles. For reference, the CISPR 25 class 5 automotive conducted EMI limits are shown in Figure 2. Figure 3 shows the effect of spread spectrum over a wider frequency band.

Since there is no limit between 300kHz and 580kHz, that is an excellent place for the fundamental frequency to be placed. In this application it is placed at 450kHz and spread down to 300kHz. Spread spectrum can be disabled by simply grounding the RAMP pin.

Figure 4. Spread spectrum as implemented in the LT3795 has no discernable effect on LED brightness. The 1kHz spread spectrum sweep set in Figure 1 has a negligible effect on LED ripple current (b) when compared to no spread spectrum (a) and is much too high a frequency to be detected by the human eye as flicker.



The 6.8nF capacitor at the RAMP pin sets the spread spectrum frequency modulation rate to a 1kHz triangle—that is, the LT3795's operating frequeny sweeps from 300kHz to 450kHz and back every millisecond. The addition of the triangular 1kHz spread spectrum signal has a negligible effect on LED ripple current, as shown in Figure 4.

The modulation frequency of 1kHz is chosen because it is low enough to be within the LT3795's bandwidth, yet high enough to signicantly attenuate AM-band conducted EMI peaks. Further reducing the modulation frequency degrades peak attenuation in the AM band, where it may be most important for classification. The choice of spread spectrum modulation frequency does not appear to affect EMI peak attenuation at higher frequencies. Nothing above 100Hz is perceived by the human eye.

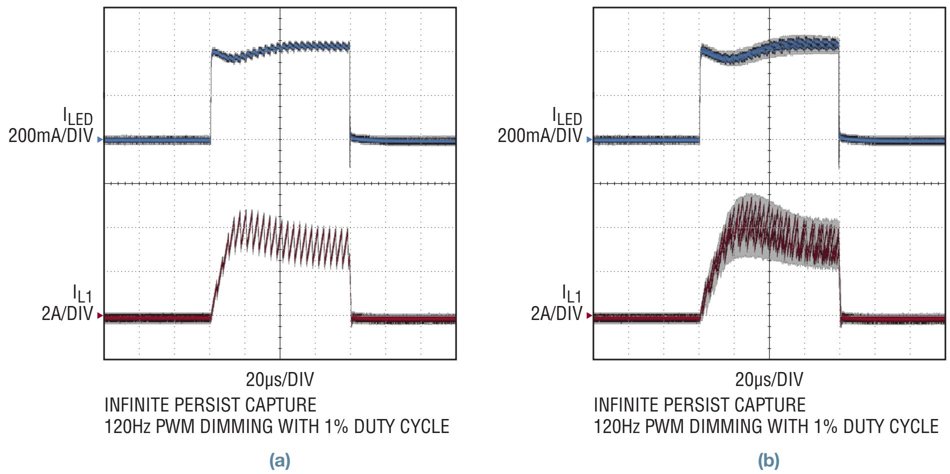


Figure 5. Comparison of two spread spectrum LED driver solutions and the effect on PWM dimming. The infinite persist scope captures show repeated and overlaid PWM LED current waveforms. In (a), the patent-pending spread spectrum technique of the LT3795 produces consistent cycle-to-cycle LED PWM on-time shape. The result is flicker-free operation at high dimming ratios. The waveforms in (b) show a comparable, non-LT3795, spread spectrum LED driver result. In this case, without the spread-spectrum-to-PWM synchronization of the LT3795, the LED current waveform is inconsistent cycle-to-cycle, producing perceivable flicker at high PWM dimming ratios.

FLICKER-FREE PWM DIMMING

It is possible to reduce EMI with a spread spectrum source that is not synchronized with the PWM signal, but the beat of the switching frequency and PWM signal can produce visible flicker in the LED. The spread spectrum ramp generated inside the LT3795 synchronizes itself with the PWM period when PWM dimming is used. This provides repeatable, flicker-free PWM dimming, even at high dimming ratios of 1000:1.

Figure 5 compares the PWM dimming current waveforms of two spread spectrum solutions: one with the LT3795's patent-pending spread-spectrum-to-PWM synchronization technique, and one without. Both captures are produced with infinite persist, showing an overlay of a number of cycles of a 1% PWM dimming waveform. Figure 5(a) shows the result of LT3795's spread spectrum operation on the PWM LED current. The waveform is consistent cycle-to-cycle, which results in flicker-free operation. Figure 5(b) shows the results of a comparable, non-LT3795, spread spectrum solution. The cycle-to-cycle variation in on-time shape produces variation in average LED current, which can be seen as LED flicker at high dimming ratios.

Note that spread spectrum driver ICs without the LT3795's patented technique might produce a clean spread spectrum EMI reduction result, the flicker may still be present. One has to observe the LEDs or the LED current waveform to understand if flicker is present. In the case of the LT3795, both the conducted EMI scan and the scope shot of LED current are good.

SHORT-CIRCUIT PROOF BOOST

The LT3795 boost LED driver shown in Figure 1 is short-circuit proof. The high side PMOS disconnect is not only used for PWM dimming, but also for short-circuit protection when the LED+ terminal is shorted to ground. Unique internal circuitry monitors when the output current is too high and the LED+ voltage is too low, turns off the disconnect PMOS and reports a short LED fault. Similarly, if the LED string is removed or opened, the IC limits its maximum output voltage and reports an open LED fault.

MULTITOPOLOGY SOLUTION

The LT3795 can be used to drive LEDs in a boost setup as shown here, or it can be used in buck mode, buck-boost mode, SEPIC and flyback topologies when the relationship of the LED string voltage and input voltage ranges requires it. All topologies feature the same spread spectrum and short-circuit protection. The LT3795 can even be configured as a constant boost or SEPIC voltage regulator with spread spectrum frequency modulation.

CONCLUSION

The LT3795 is a 110V, versatile LED driver IC with built-in spread spectrum frequency modulation to reduce EMI. This simplifies the design of LED applications that must pass stringent EMI testing. Spread spectrum requires only a single capacitor, and unlike external-clock-based spread spectrum solutions, produces flicker-free LED operation during PWM dimming. Short-circuit protection is available in all topologies, making this IC a robust and powerful solution for driving automotive LEDs. ■

15V Buck-Boost Converters with Ultralow 1.3μA Quiescent Current are Tailored to Micropower Applications and the Internet of Things

Dave Salerno

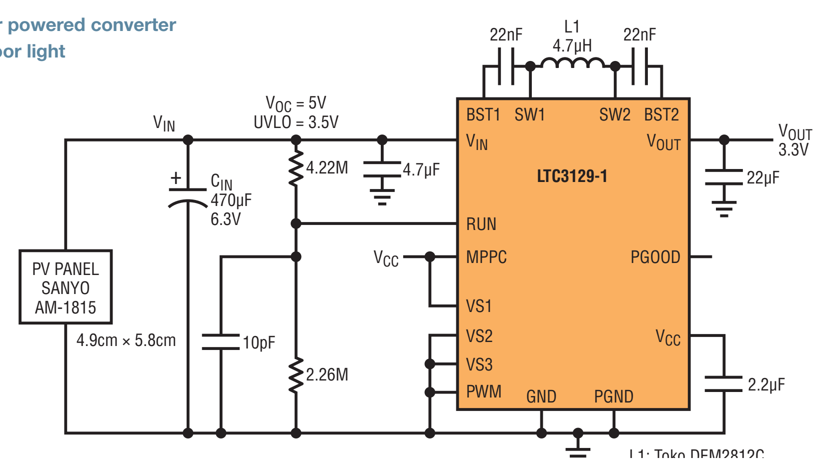
The proliferation of wireless sensors supporting the "Internet of Things" has increased the need for small, efficient power converters tailored to untethered low power devices. The new LTC3129 and LTC3129-1 are designed to satisfy this need. The LTC3129 and LTC3129-1 are monolithic buck-boost DC/DC converters with an input voltage range of 2.42V to 15V. The LTC3129 has an output voltage range of 1.4V to 15.75V, while the LTC3129-1 offers eight pin-selectable fixed output voltages between 1.8V and 15V. Both parts can supply a minimum output current of 200mA in buck mode.

Low power sensors can take advantage the LTC3129's and LTC3129-1's zero current when disabled (on both V_{IN} and V_{OUT}), and a quiescent current on V_{IN} of just 1.3μA when power saving Burst Mode® operation is selected, making them ideal for μPower and energy harvesting applications, where high efficiency at extremely light loads is crucial. Their buck-boost architecture makes them well suited to a wide variety of power sources.

Other key features of the LTC3129 and LTC3129-1 include a fixed 1.2MHz operating frequency, current mode control, internal loop compensation, automatic Burst Mode operation or low noise PWM mode, an accurate RUN pin threshold to allow the UVLO threshold to be programmed, a power good output and an MPPC (maximum power point control) function for optimizing power transfer when operating from photovoltaic cells.

The compact 3mm × 3mm QFN package and the high level of integration ease the LTC3129/LTC3129-1's placement into space-constrained applications. Only a few external components and an inductor, which can be as small as 2mm × 3mm, are required to complete the power supply design. Internal loop compensation further simplifies the design process.

Figure 1. 3.3V solar powered converter operates from indoor light



3.3V CONVERTER OPERATES FROM INDOOR LIGHT USING A SMALL SOLAR CELL

The circuit in Figure 1 exploits the unique ability of the LTC3129 and LTC3129-1 to start up and operate from an input power source *as weak as 7.5 microwatts*—making them capable of operating from small (less than 1in²), low cost solar cells with indoor light levels less than 200-lux. This enables such applications as indoor light powered wireless sensors, where the DC/DC converter must support an extremely low average power requirement, due to a low duty cycle of operation, from very low available power, while consuming as little power as possible.

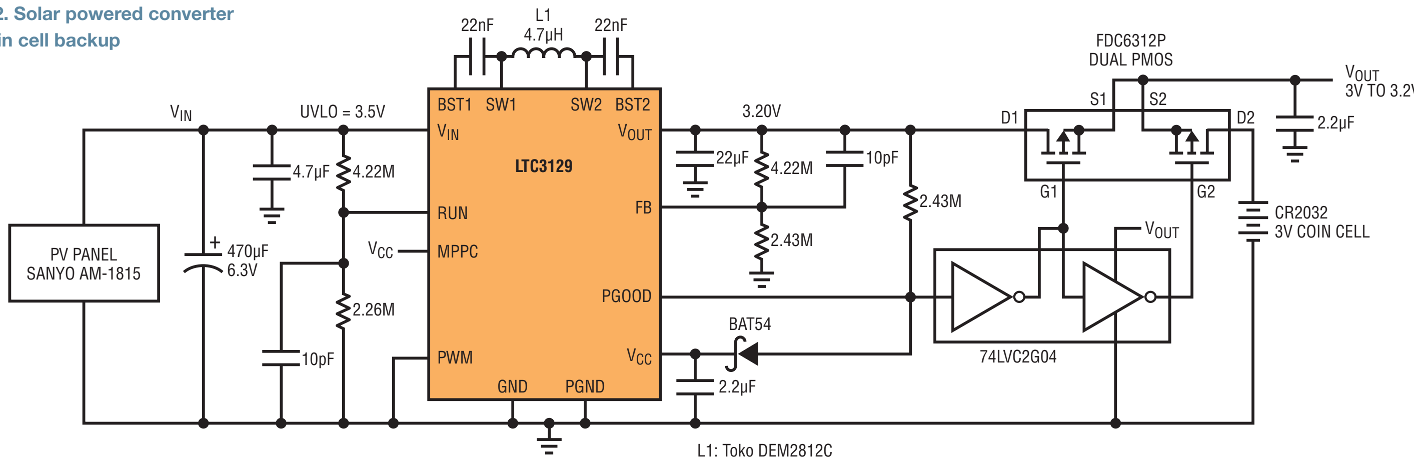
To make this low current start-up possible, the LTC3129 and LTC3129-1 draw a meager two microamps of current (less in shutdown) until three conditions are satisfied:

- The RUN pin must exceed 1.22V (typical).
- The V_{IN} pin must exceed 1.9V (typical).
- V_{CC} (which is internally generated from V_{IN} but can also be supplied externally) must exceed 2.25V (typical).

Until all three of these conditions are satisfied, the part remains in a "soft-shutdown" or standby state, drawing just 2μA.

The LTC3129 and LTC3129-1 can start up and operate from an input power source *as weak as 7.5 microwatts*—making them capable of operating from small (less than 1in^2), low cost solar cells with indoor light levels less than 200-lux. This enables such applications as indoor light powered wireless sensors.

Figure 2. Solar powered converter with coin cell backup



This allows a weak input source to charge the input storage capacitor until the voltage is high enough to satisfy all three previously mentioned conditions, at which point the LTC3129/LTC3129-1 begins switching, and V_{OUT} rises to regulation, provided the input capacitor has sufficient stored energy. The input voltage at which the part exits UVLO can be set anywhere from 2.4V to 15V using the external resistive divider on the RUN pin. With a RUN pin current of less than 1nA typical, high value resistors may be used to minimize current draw on V_{IN}.

In the application example shown in Figure 1, the energy stored on C_{IN} is used to bring V_{OUT} into regulation once the converter starts. If the average power demand on V_{OUT} is less than the power delivered by the solar cell, the LTC3129/LTC3129-1 remains in Burst Mode operation, and V_{OUT} remains in regulation.

If the average output power demand exceeds the input power available, then V_{IN} drops until UVLO is reached, at which point the converter reenters soft-shutdown. At this point, V_{IN} begins recharging, allowing the cycle to repeat. In this hiccup mode of operation, V_{IN} is positioned hysteretically about the UVLO point, with a V_{IN} ripple of approximately 290mV in this example. This ripple is set by the 100mV hysteresis at the RUN pin, gained up by the UVLO divider ratio.

Note that by setting the converter's UVLO voltage to the MPP (maximum power point) voltage for the chosen solar cell (typically between 70% to 80% of the open-circuit voltage), the cell always operates near its maximum power transfer voltage (unless the average load requirement is less than the power output of the solar cell, in which case V_{IN} climbs and remains above the UVLO voltage).

To further optimize efficiency and eliminate unnecessary loading of V_{OUT}, the LTC3129/LTC3129-1 does not draw any current from V_{OUT} during soft-start or at any time if Burst Mode operation is selected. This prevents the converter from discharging V_{OUT} during soft-start, thereby preserving charge on the output capacitor. In fact, when the LTC3129 is sleeping, there is no current draw at all on V_{OUT}. In the case of the LTC3129-1, the V_{OUT} current draw is sub-microamp, due to the high resistance internal feedback divider.

ADDING A BATTERY BACKUP

In many solar powered applications, a backup battery provides power when solar power is insufficient. Figure 2 shows an application where a primary lithium coin cell and a few external components have been added to the converter from the previous example to provide backup power to the output in the event that the light source is unable to provide the necessary power to maintain V_{OUT}. The LTC3129 is used in this case, allowing V_{OUT} to be programmed for 3.2V to better match the voltage of the coin cell.

In this example, the battery is used on the output side of the converter, and the LTC3129 is set to regulate V_{OUT} slightly

The LTC3129-1 can operate at high efficiency over a wide range of loads and input voltages, with a minimal number of external components. The flexibility of running seamlessly from a wide variety of power sources is an asset in critical field applications, such as military radios.

above the battery voltage. This assures that there is no load on the battery whenever V_{OUT} can be powered by the solar input. In the event that V_{OUT} droops due to insufficient light to power the load, the PGOOD output from the LTC3129 goes low, switching the load from the converter output to the battery, thus holding V_{OUT} at the battery voltage. During this time, the converter's input and output capacitors are able to recharge (if some light is available), enabling the load to be periodically switched from the battery back to the converter by the PGOOD signal. In this manner the load is powered by the solar input as much as possible, and the battery is only used in a time-shared manner, extending its life.

The diode connected from PGOOD to V_{CC} is used to hold PGOOD low during start-up, before V_{CC} (and therefore PGOOD) is valid.

CHOOSING WHERE TO PUT THE BACKUP BATTERY

In the previous example, the backup battery was placed on the output. For light load applications, this has the advantage of not exposing the battery—which may be a low capacity battery with high internal resistance—to relatively high converter start-up input current bursts, causing significant battery droop and lossy internal power dissipation, in turn reducing battery life.

The disadvantages of putting the backup battery on the output of the converter are that the battery voltage must be well matched to the desired output voltage, and it must have a relatively flat discharge curve so as to maintain reasonable regulation of V_{OUT}. The 3V lithium cell satisfies both of these requirements.

Putting the backup battery on the input side of the converter allows its voltage to be different from the desired output voltage, but it must be able to withstand the higher currents that the converter draws during start-up or load transients. If used on the input side, a lithium-thionyl chloride battery is generally a better choice for long life applications. It can be diode-OR'd with the solar cell or switched in and out with MOSFET switches, in a similar manner to Figure 2.

5V CONVERTER OPERATES SEAMLESSLY FROM A VARIETY OF INPUT SOURCES

The ability of the LTC3129-1 to operate at high efficiency over a wide range of loads and input voltages with a minimal number of external components is illustrated in Figure 3. In this example, the output, which has been programmed for 5V using the VS1–VS3 pins, can be powered from a 5V USB input, a variety of battery options or a 3V to 15V wall adapter. The flexibility of running seamlessly from a wide variety of power sources is an asset in critical field applications, such as military radios.

The LTC3129-1's low I_Q of just 1.3µA in sleep mode, combined with a high resistance internal feedback divider, enables it to maintain high efficiency over a wide range of loads, as shown in Figure 4. At a load current of just 100µA, the efficiency is ~80% over nearly the entire V_{IN} range. This is an important feature for extending battery life in applications that spend a large percentage of the time in a low power state.

The line step response (V_{IN} is stepped from 5V to 12V) is shown in Figure 5, with V_{OUT} measured under both heavy and light load conditions. At a load of 200mA, the part is operating in PWM mode, and V_{OUT} overshoot is only 150mV (3%). At a load of 10mA, the part is in Burst Mode operation, with a burst ripple of

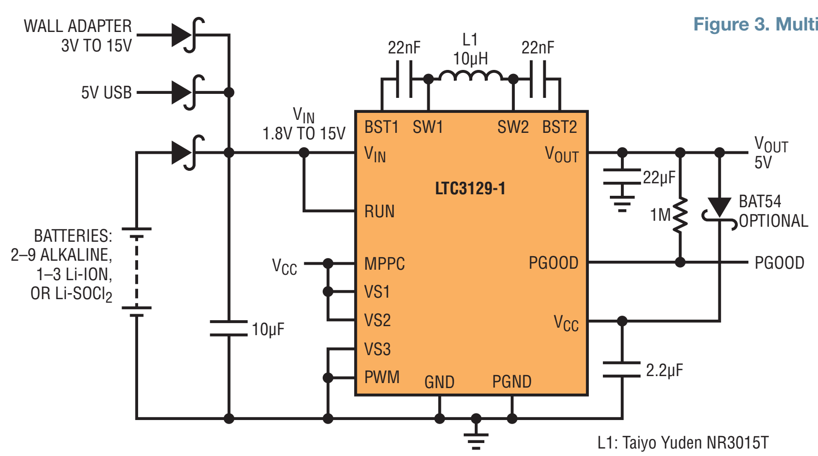


Figure 3. Multi-input 5V converter

The LTC3129 and LTC3129-1 include a maximum power point control (MPPC) feature that allows the converter to servo V_{IN} to a minimum voltage under load, as set by the user. Regulating V_{IN} maintains optimal power transfer in applications using higher current solar cells or other sources with high internal resistance. This feature prevents the converter from crashing the input voltage when operating from a current-limited source.

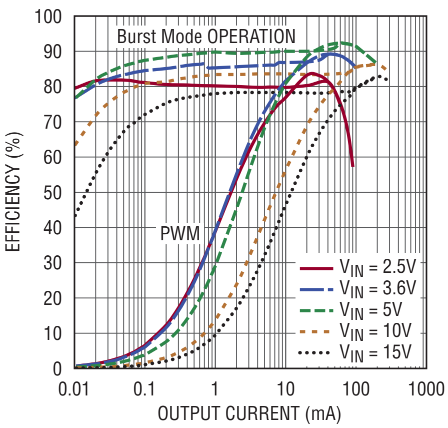


Figure 4. Efficiency vs V_{IN} and load of the 5V converter in Figure 3

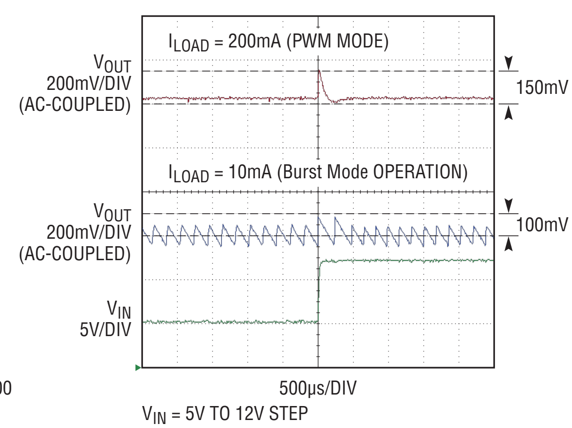


Figure 5. Line transient response of the 5V converter in Figure 3

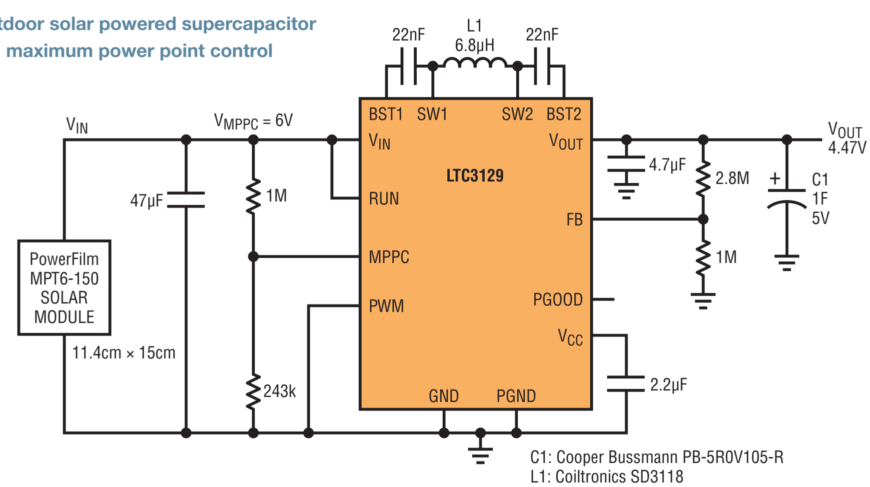
$100mV_{PK-PK}$ (2%), and less than 100mV of V_{OUT} overshoot due to the line step.

The V_{CC} pin is the output of an internal LDO that generates a nominal 3.9V from V_{IN} to power the IC. The LDO is designed so that it can be externally back-driven up to 5V. In this example, an optional bootstrap diode is shown from V_{OUT} to V_{CC}.

The addition of this external bootstrap diode has two advantages. First, it improves efficiency at low V_{IN} and high load current by providing a higher gate drive voltage to the internal switches, lowering their $R_{DS(ON)}$. Also, at high V_{IN} and light load, it improves efficiency by reducing the power lost in the internal LDO used to generate V_{CC}. (Note that the V_{CC} pin must not be raised above 6V, so it cannot be diode-connected to higher output voltages.)

The second advantage of adding a bootstrap diode is that it allows operation from a lower V_{IN}. After start-up, if V_{CC} is held above its minimum value of 2.2V (by the output voltage in this case), then the converter can operate at a lower input voltage, down to 1.75V, where the fixed internal V_{IN} UVLO threshold is reached. This capability extends the usable voltage range enough to make it possible to run from two depleted alkaline batteries. Note that if the battery voltage is below 2.4V and the converter is shut down (or V_{OUT} is shorted), the IC is not be able to restart.

Figure 6. Outdoor solar powered supercapacitor charger with maximum power point control



OUTDOOR SOLAR CONVERTER/ CHARGER WITH MPPC

The LTC3129 and LTC3129-1 include a maximum power point control (MPPC) feature that allows the converter to servo V_{IN} to a minimum voltage under load, as set by the user. Regulating V_{IN} maintains optimal power transfer in applications using higher current solar cells or other sources with high internal resistance. This feature prevents the converter from crashing the input voltage when operating from a current-limited source.

The MPPC control loop operates by reducing the average inductor current commanded by the converter, thus maintaining the minimum programmed V_{IN} voltage under load. This voltage is set using an external resistor divider connected to V_{IN} and the MPPC pin, as shown in the supercapacitor charging example of Figure 6. The MPPC control loop is designed to be stable with a minimum input capacitance of 22μF.

The LTC3129 and LTC3129-1 monolithic buck-boost DC/DC converters offer exceptional low power performance and power source flexibility demanded by real-world wireless sensor and portable electronic instruments. The ultralow 1.3μA quiescent current and high conversion efficiency can extend battery lifetime indefinitely if used in concert with energy harvesting.

Note that reducing the inductor current under MPPC would cause the output voltage to droop if it were driving a conventional load. Therefore, most applications employing MPPC involve charging a large storage capacitor (or trickle charging a battery) from a solar cell. The MPPC feature assures that the capacitor or battery is charged at the highest current possible, while operating the solar cell at its maximum power point voltage.

It is important to note that when the LTC3129/LTC3129-1 is in MPPC control, Burst Mode operation is inhibited, and the V_{IN} quiescent current is several milliamps, since the IC is switching continuously at 1.2MHz. Therefore, MPPC is not appropriate for use with sources that cannot supply a minimum of about 10mA. For applications requiring an MPPC-like function with very weak input sources, the accurate RUN pin should be used to program a UVLO threshold, as described in the example of Figure 1.

INTRINSIC SAFETY USING MPPC

The MPPC feature can be used in other applications, including those designed for intrinsic safety, where the input source has a series current limiting resistor between it and the DC/DC converter. In this case, the MPPC loop prevents the LTC3129/LTC3129-1 from drawing too much current, especially during start-up when the output capacitor is being charged, and crashing the input voltage. An example of this is shown in Figure 7, where the input voltage is maintained at a minimum of 3V, as set by the MPPC divider.

In this case, because the input capacitor value is limited to just 10μF for safety (less than the recommended minimum value of 22μF when using MPPC), an additional RC compensation network is added to the MPPC pin for improved phase margin of the MPPC loop.

INPUT CURRENT LIMIT USING MPPC

Note that the MPPC feature can be used to set the maximum input current to a given value. By choosing a series input resistor value and setting the MPPC voltage to a value below a fixed input source voltage, the maximum input current is limited to:

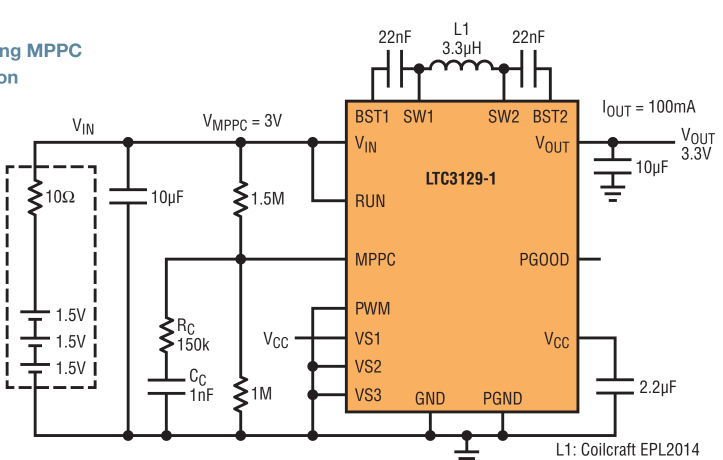
$$I_{IN} = \frac{V_{SOURCE} - V_{MPPC}}{R_{SERIES}}$$

CONCLUSION

The LTC3129 and LTC3129-1 monolithic buck-boost DC/DC converters offer exceptional low power performance and power source flexibility demanded by real-world wireless sensor and portable electronic instruments. The ultralow 1.3μA quiescent current and high conversion efficiency can extend battery lifetime indefinitely if used in concert with energy harvesting.

A choice of maximum power point control schemes allows optimization of power performance over a wide range of power sources. The expanding reach of wireless monitoring applications demands easy to use, efficient and flexible DC/DC power converter solutions. The LTC3129 and LTC3129-1 are ready to meet this challenge. ■

Figure 7. 3.3V Converter using MPPC for intrinsic safety application



NOTE: R_C AND C_C HAVE BEEN ADDED FOR IMPROVED MPPC LOOP STABILITY WHEN USING AN INPUT CAPACITOR VALUE LESS THAN THE RECOMMENDED MINIMUM OF 22μF

Inverting DC/DC Controller Converts a Positive Input to a Negative Output with a Single Inductor

David Burgoon

There are a number of ways to produce a negative voltage from a positive voltage source, including using a transformer or two inductors and/or multiple switches, but none are as easy as using the LTC3863, which is elegant in its simplicity, has superior efficiency at light loads and reduces parts count when compared to these solutions.

ADVANCED CONTROLLER CAPABILITIES

The LTC3863 can produce a −0.4V to −150V negative output voltage from a positive input range of 3.5V to 60V. It uses a single-inductor topology with one active P-channel MOSFET switch and one diode. The high level of integration yields a simple, low parts count solution.

The LTC3863 offers excellent light load efficiency, drawing only 70μA quiescent current in user programmable Burst Mode® operation. Its peak current mode, constant frequency PWM architecture provides positive control of inductor current, easy loop compensation and top-notch loop dynamics. The switching frequency can be programmed from 50kHz to 850kHz with an external resistor and can be synchronized to an external clock from 75kHz to 750kHz. The LTC3863 offers programmable soft-start or output tracking. Safety features include overvoltage, overcurrent, and short-circuit protection including frequency foldback.

−12V, 1A CONVERTER OPERATES FROM 4.5V–16V SOURCE

The circuit shown in Figure 1 produces a −12V, 1A output from a 4.5V–16V input. Operation is similar to a flyback converter, storing energy in the inductor when the switch is on and releasing it through the diode to the output when the switch is off, except that with the LTC3863, no transformer is required. To prevent excessive current that can result from minimum on-time when the output is short-circuited, the controller folds back the switching frequency when the output is below half of nominal.

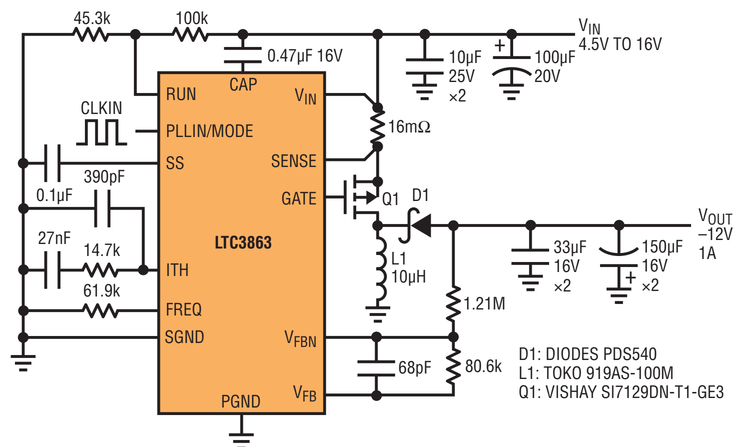


Figure 1. Inverting converter produces −12V at 1A from a 4.5V–16V source

Figure 2. Switch node voltage, inductor current and ripple waveforms at 5V input and −12V output at 1A

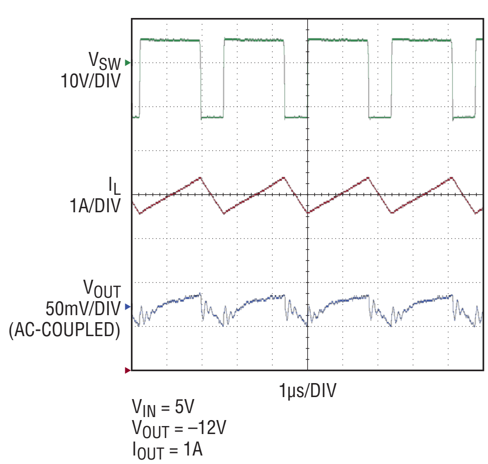
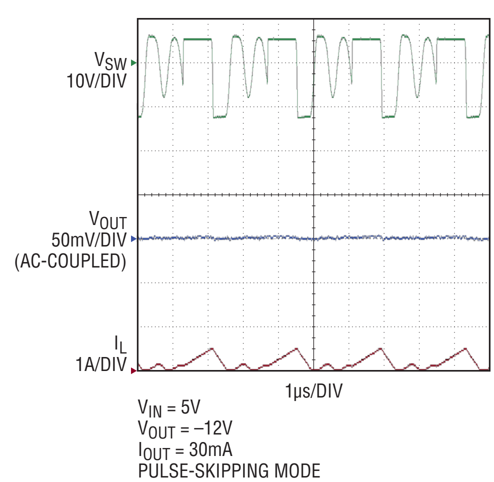


Figure 3. Switch node voltage, inductor current and ripple waveforms at 5V input and −12V output at 30mA in pulse-skipping mode



The LTC3863 can produce a –0.4V to –150V negative output voltage from a positive input range of 3.5V to 60V. It uses a single-inductor topology with one active P-channel MOSFET switch and one diode. The high level of integration yields a simple, low parts count solution.

The LTC3863 can be programmed to enter either high efficiency Burst Mode operation or pulse-skipping mode at light loads. In Burst Mode operation, the controller directs fewer, higher current pulses and then enters a low current quiescent state for a period of time depending on load. In pulse-skipping mode, the LTC3863 skips pulses at light loads. In this mode, the modulation comparator may remain tripped for several cycles and force the external MOSFET to remain off, thereby skipping pulses. This mode offers the benefits of smaller output ripple, lower audible noise, and reduced RF interference, at the expense of lower efficiency when compared to Burst Mode operation. This circuit fits in about 0.5in² (3.2cm²) with components on both sides of the board.

Figure 2 shows switch node voltage, inductor current, and ripple waveforms at 5V input and –12V output at 1A. The inductor is charged (current rises) when the PMOSFET is on, and discharges through the diode to the output when the PMOS turns off. Figure 3 shows the same waveforms at 30mA out in pulse-skipping mode. Notice how the switch node rings out around 0V when the inductor current reaches zero. The effective period stops when the current reaches zero. Figure 4 shows the same load condition with Burst Mode operation enabled. Power dissipation drops by 36% at this operating point, and efficiency increases from 72% to 80%. Figure 5 shows waveforms with the output shorted. The switching frequency is reduced to about 80kHz in this condition to prevent excessive current that could otherwise result.

HIGH EFFICIENCY

Figure 6 shows efficiency curves for both pulse-skipping and Burst Mode operation. Exceptional efficiency of 89.3% is achieved at 1A load and 12V input. Notice how Burst Mode operation dramatically improves efficiency at loads less than 0.1A. Pulse-skipping efficiency at light loads is still much higher than that obtained from synchronous operation.

CONCLUSION

The LTC3863 simplifies the design of converters producing a negative output from a positive source. It is elegant in its simplicity, high in efficiency, and requires only a small number of inexpensive external components to form a complete converter. ■

Figure 4. Switch node voltage, inductor current and ripple waveforms at 5V input and –12V output at 30mA in Burst Mode operation

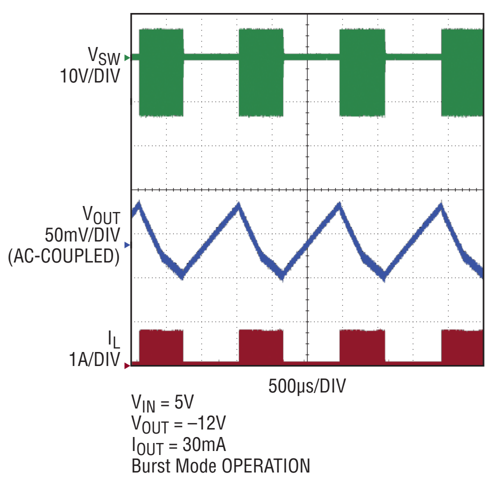


Figure 5. Switch node voltage, inductor current and ripple waveforms at 5V input with the output shorted

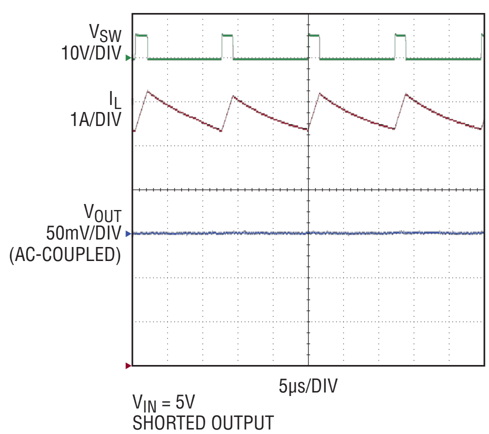
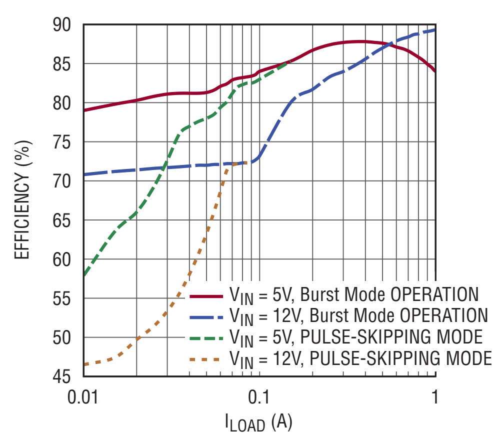


Figure 6. Efficiency in normal and Burst Mode operation



What's New with LTspice IV?

Gabino Alonso

www.linear.com/blog/LTspice

Follow @LTspice on Twitter for up-to-date information on models, demo circuits, events and user tips: *www.twitter.com/LTspice*

LTspice BLOG

Check out the new LTspice blog (www.linear.com/blog/LTspice) for tech news, insider tips and interesting points of view regarding LTspice. Here are just a few of the topics:

- Simulating Power Planes
- Parametric Plots
- Importing & Exporting Data
- Noise Simulations
- Adding Third-Party Models

SELECTED DEMO CIRCUITS

Linear Regulators

- **LT3055:** 5V supply with 497mA precision current limit, 10mA I_{MIN} (5.4V–45V to 5V at 497mA) www.linear.com/LT3055
- **LT3081:** Extended safe operating area supply (2.7V–40V to 1.5V at 1.5A) www.linear.com/LT3081

Buck Regulators

- **LT3514:** 36V triple buck regulator (5.4V–36V to 5V at 1A, 3.3V at 2A and 1.8V at 1A) www.linear.com/LT3514
- **LT3995:** 3.3V step-down converter (4.3V–60V to 3.3V at 3A) www.linear.com/LT3995
- **LT8697:** 2MHz 5V step-down converter with cable drop compensation (6V–42V to 5V at 2.1A) www.linear.com/LT8697

LED Driver

- **LT3761:** 94% efficient boost LED driver for automotive headlamp with 25:1 PWM dimming (8V–60V to 60V LED string at 1A) www.linear.com/LT3761

Supercapcitor Charger

- **LTC3122:** Dual supercapacitor backup power supply (0.5V–5V to 5V at 50mA) www.linear.com/LTC3122

µModule Regulators

- **LTM®4637:** High efficiency 20A µModule buck regulator (4.5V–20V to 1.2V at 20A) www.linear.com/LTM4637
- **LTM8028:** Low output noise, 1.8V, 5A regulator (6V–36V to 1.8V at 5A) www.linear.com/LTM8028
- **LTM8045:** –5V inverting converter (2.8V–18V to –5V at 430mA) www.linear.com/LTM8045
- **LTM8050:** 5V step-down converter (7.5V–58V to 5V at 2A) www.linear.com/LTM8050

Linear Regulator

- **LT3030:** Dual, µPower, low noise linear regulator (2.2V–20V to 1.8V at 750mA and 1.5V at 250mA) www.linear.com/LT3030

TimerBlox® Silicon Timing Devices

- **LTC6995-1:** Active low power-on reset timer (1s POR) www.linear.com/LTC6995–1

Precision Amplifiers

- **LTC6090 and LT5400:** Wide common mode range 10× gain instrumentation amplifier www.linear.com/LTC6090

SELECTED MODELS

Buck Regulators

- **LT3514:** Triple step-down switching regulator with 100% duty cycle operation www.linear.com/LT3514
- **LT3995:** 60V, 3A, 2MHz step-down switching regulator with 2.7µA quiescent current www.linear.com/LT3995
- **LT8697:** USB 5V 2.5A output, 42V input synchronous buck with cable drop compensation www.linear.com/LT8697
- **LTC3374:** 8-channel parallelable 1A buck DC/DCs www.linear.com/LTC3374

LED Driver

- **LT3954:** 40V input LED converter with internal PWM generator www.linear.com/LT3954

Inverting Regulators

- **LTC3863:** 60V low IQ inverting DC/DC controller www.linear.com/LTC3863

What is LTspice IV?

LTspice® IV is a high performance SPICE simulator, schematic capture and waveform viewer designed to speed the process of power supply design. LTspice IV adds enhancements and models to SPICE, significantly reducing simulation time compared to typical SPICE simulators, allowing one to view waveforms for most switching regulators in minutes compared to hours for other SPICE simulators.

LTspice IV is available free from Linear Technology at www.linear.com/LTspice. Included in the download is a complete working version of LTspice IV, macro models for Linear Technology's power products, over 200 op amp models, as well as models for resistors, transistors and MOSFETs.

Like us on Facebook at *facebook.com/LTspice*

μModule Regulators

- **LTM4624:** 14V input, 4A step-down DC/DC μModule regulator www.linear.com/LTM4624
- **LTM4630:** Dual 18A or single 36A DC/DC μModule regulator www.linear.com/product/LTM4630
- **LTM4649:** 10A step-down DC/DC μModule regulator www.linear.com/LTM4649
- **LTM4676:** Dual 13A or single 26A μModule regulator with digital power system management www.linear.com/LTM4676
- **LTM8050:** 58V, 2A step-down μModule regulator www.linear.com/product/LTM8050

Linear Regulator

- **LT3007 Series:** 3μA I_Q, 20mA, 45V low dropout fault tolerant linear regulators www.linear.com/LT3007
- **LT3030 :** Dual 750mA/250mA low dropout, low noise, micropower linear regulator www.linear.com/LT3030
- **LT3081:** 1.5A single resistor rugged linear regulator with monitors www.linear.com/LT3081
- **LT3055:** 500mA, linear regulator with precision current limit and diagnostics www.linear.com/LT3055

Precision Amplifiers

- **LTC2057:** High voltage, low noise zero-drift operational amplifier www.linear.com/LTC2057

Ideal Diode

- **LT4320/-1:** Ideal diode bridge controller www.linear.com/LT4320

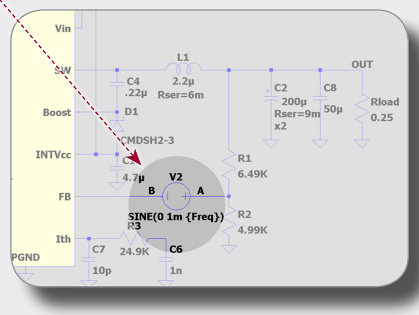
Power User Tip

GENERATING A BODE PLOT OF A SWITCH MODE POWER SUPPLY IN LTspice IV

Determining the open loop gain from a closed loop switch mode power supply (SMPS) is best solved using Middlebrook's method, which appears in the *International Journal of Electronics*, Volume 38, Number 4, 1975. This method injects test signals into the closed loop system to independently solve for the voltage and current gains so that the loop remains closed and operating points undisturbed. Using the voltage gain portion of the Middlebrook method is particularly useful in performing a frequency response analysis (FRA) of an SMPS in LTspice.

To perform a FRA of a switch mode power supply in LTspice:

- Insert a voltage source with a value of "SINE(0 1m {Freq})" in the SMPS feedback loop in series with the feedback pin and label the nodes of this voltage source "A" and "B" as shown. The choice of amplitude (1mV) impacts accuracy and the signal to noise ratio. Lower amplitudes lower the signal to noise and the larger the amplitude the less relevant the frequency response will be. A good starting point is 1mV to 20mV.



- Paste the following .measure statements on the schematic as a SPICE directive. These statements perform the Fourier transform of nodes A and B, compute the complex open loop gain of the SMPS, resulting magnitude in dB and phase in degrees.

```
.measure Aavg avg V(a)
.measure Bavg avg V(b)
.measure Are avg (V(a)-Aavg)*cos(360*time*Freq)
.measure Aim avg -(V(a)-Aavg)*sin(360*time*Freq)
.measure Bre avg (V(b)-Bavg)*cos(360*time*Freq)
.measure Bim avg -(V(b)-Bavg)*sin(360*time*Freq)
.measure GainMag param 20*log10(hypot(Are,Aim) / hypot(Bre,Bim))
.measure GainPhi param mod(atan2(Aim, Are) - atan2(Bim, Bre)+180,360)-180
```

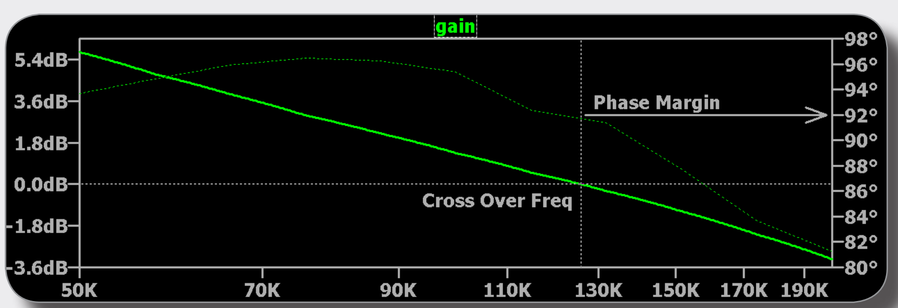
- Paste the following SPICE directive on the schematic. Parameter t0 is the length of time required for the system to settle to steady state and also sets when the simulator starts saving data. The difference between start and stop times in this case has been chosen as 25/freq so that the error from a non-integral number of switching cycles is small, since many cycles are included.

```
.param t0=.2m
.tran 0 {t0+25/freq} {t0}
```

- Insert a .step command to set the frequency range over which you want to perform the analysis. In this example, the simulation runs from 50kHz to 200kHz using five points per octave. Hint: Before stepping through the entire frequency range, test at a couple of frequencies (e.g., insert ".param Freq = 125K") and look at V(A) and V(B) to ensure you have sufficient amplitude in your voltage source, and if possible, tighten up the frequency range to minimize simulation time.

```
.step oct param freq 5K 500K 5
.save V(a) V(b)
.option plotwinsize=0 numdgt=15
```

- Run your simulation (see bottom left corner for status update).
- To view the Bode plot, open the SPICE Error Log (choose SPICE Error Log from the View menu) and right-click on the log to select "Plot .step'ed .meas data". Choose Visible Traces from the Plot Settings Menu. Select gain. From this plot you can then determine the crossover frequency and phase margin of your SMPS design.



Further examples and documentation can be found in the educational examples (..\LTspiceIV\examples\Educational\FRA\) and under the FAQ section of the Help Topics (press F1).

Happy simulations!

Solar Battery Charger Maintains High Efficiency in Low Light

J. Celani

An important characteristic of any solar panel is that it achieves peak power output at a relatively constant operating voltage (V_{MP}) regardless of illumination level (see Figure 1). The LT3652 2A battery charger exploits this characteristic to maintain a solar panel at peak operating efficiency by implementing input voltage regulation (patent pending). When available solar power is inadequate to meet the power requirements of an LT3652 battery charger, input voltage regulation reduces the battery charge current. This reduces the load on the solar panel to maintain the panel voltage at V_{MP}, maximizing the panel output power. This method of achieving peak panel efficiency is called maximum power point control (MPPC).

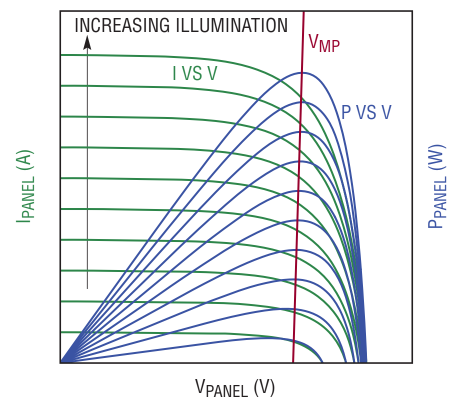


Figure 1. A solar panel produces maximum power at a particular output voltage, V_{MP}, which is relatively independent of illumination level. The LT3652 2A battery charger maximizes the output power of a solar panel by regulating the input panel voltage at V_{MP}.

While MPPC optimizes *solar panel efficiency* during periods of low illumination, the power conversion *efficiency of the battery charger* suffers when power levels are low, degrading the overall power transfer efficiency from the panel to the battery. This article shows how to improve battery charger efficiency by applying a simple PWM charging technique that forces the battery charger to release energy in bursts when power levels are low.

USING THE CURRENT MONITOR STATUS PIN TO INDICATE LOW POWER CONDITIONS

The $\overline{\text{CHRG}}$ current monitor status pin on the LT3652 indicates the state of battery charge current, and is used here to control the PWM function. The pin is pulled low when the charger output current is greater than C/10, or 1/10 of the programmed maximum current, and high impedance when the output current is below C/10.

During periods of low illumination, the input regulation loop can reduce the output current of the charger to below C/10, causing the $\overline{\text{CHRG}}$ pin to become high impedance. This status pin change-of-state is used to disable the IC by triggering an input undervoltage lockout (UVLO) with the falling threshold at a solar panel voltage that is higher than the input regulation voltage ($V_{IN(REG)}$). The solar panel voltage climbs through the UVLO hysteresis range in response to the charger being disabled until the UVLO rising threshold is achieved, when the charger is re-enabled at full power. The charger then provides charge current until

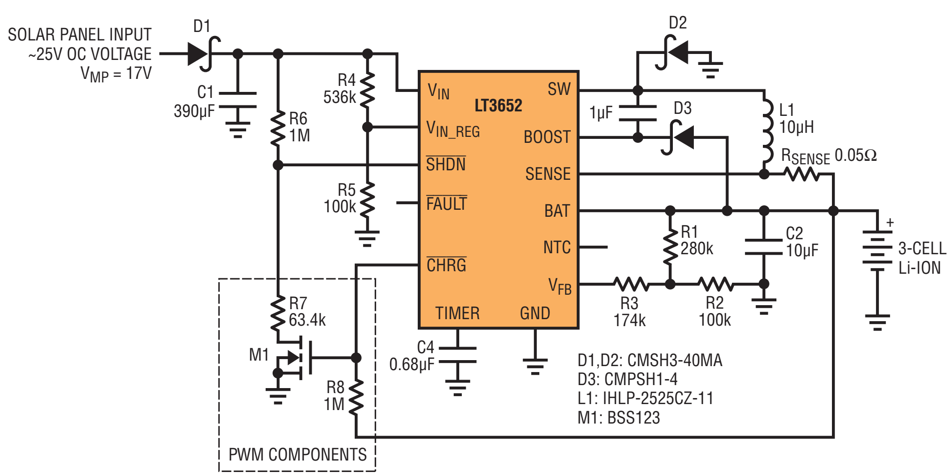


Figure 2. 17V V_{MP} solar panel to 3-cell Li-ion (12.6V) 2A charger

While MPPC optimizes *solar panel efficiency* during periods of low illumination, the power conversion *efficiency of the battery charger* suffers when power levels are low. This article shows how to improve battery charger efficiency by applying a simple PWM charging technique that forces the battery charger to release energy in bursts at low power levels.

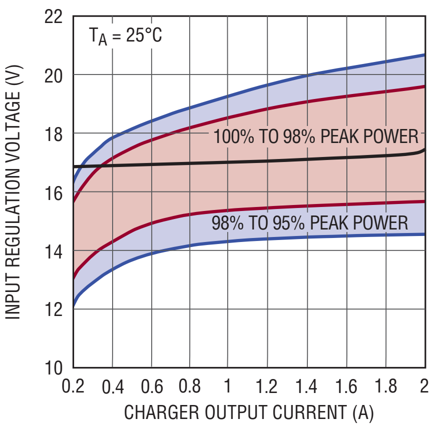


Figure 3. Typical "12V system" (V_{MP} = 17V) solar panel efficiency

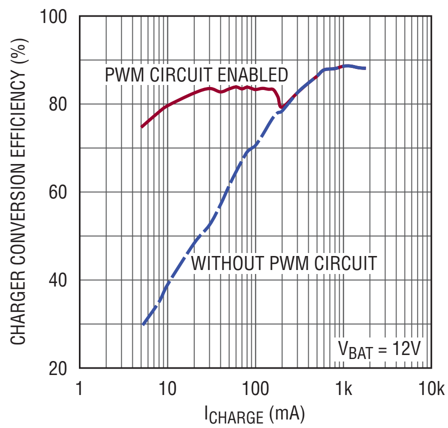


Figure 4. Efficiency for the circuit in Figure 2

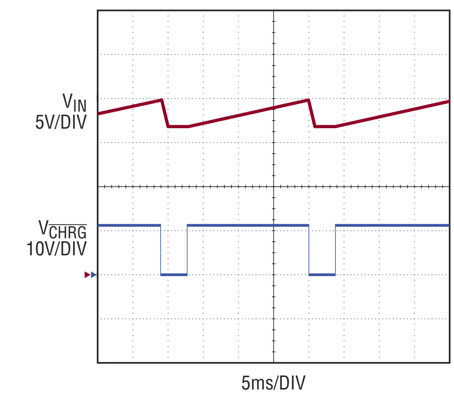


Figure 5. Waveform of V_{IN} during PWM for the circuit in Figure 2

input voltage regulation again disables the charger. This cycle repeats, generating a charger output that is a series of high current bursts, which maximizes the efficiency of the charger as well as the efficiency of the entire solar charger system at any illumination level.

HIGH EFFICIENCY LI-ION CHARGER

Figure 2 shows a solar panel to 3-cell Li-Ion charger with low power PWM functionality. This charger employs a 17V input regulation voltage (a common V_{MP} for "12V system" panels), programmed using the resistor divider R4 and R5 at the V_{IN_REG} pin. Keeping the operating voltage of a typical 12V system solar panel near its 17V rated V_{MP} voltage yields panel efficiencies close to 100%, as shown in Figure 3. The low power PWM function is implemented using M1, R6, R7 and R8. Figure 4 shows that the addition of the PWM circuitry significantly increases efficiency at battery charge currents below 200mA.

The LT3652's $\overline{\text{CHRG}}$ pin is pulled low while required charge current exceeds 1/10 of the 2A programmed maximum charge current, or 200mA. When charge current is reduced by the input regulation loop below the 200mA level, the $\overline{\text{CHRG}}$ pin becomes high impedance, which allows the gate of M1 to be pulled up to V_{BAT}, enabling the FET, M1. This FET pulls R7 to ground, engaging an input voltage UVLO function using the SHDN pin and the resistor divider made from R6 and R7. The UVLO function is programmed with that divider to have a falling threshold of 18V and a rising threshold of 20V. The falling threshold is the critical design value, and must be programmed to a voltage that is higher than the input regulation voltage, and is 10% lower than the rising threshold, as is dictated by the LT3652 shutdown threshold hysteresis.

During low illumination conditions, when available panel power is insufficient for the LT3652 to provide required charge current, the LT3652's input voltage regulation reduces the output charge current until the charger input power is equivalent to the available power provided by the panel. With input regulation active, the panel voltage at V_{IN} is held at the programmed 17V peak power voltage, maximizing the power produced from the panel. If the panel illumination becomes low enough that the available panel power corresponds to charge current less than 200mA, the $\overline{\text{CHRG}}$ pin becomes high impedance and the UVLO function is enabled via M1, R6 and R7.

Since V_{IN} is at 17V, which is lower than the UVLO falling threshold, the LT3652 shuts down, disabling all of the battery charging functions. With the battery charger disabled, virtually all of the panel output current charges the input capacitor (C1), increasing the voltage at V_{IN} until the 20V UVLO rising threshold is achieved, re-enabling the LT3652. The battery charger is re-enabled with V_{IN} well above the

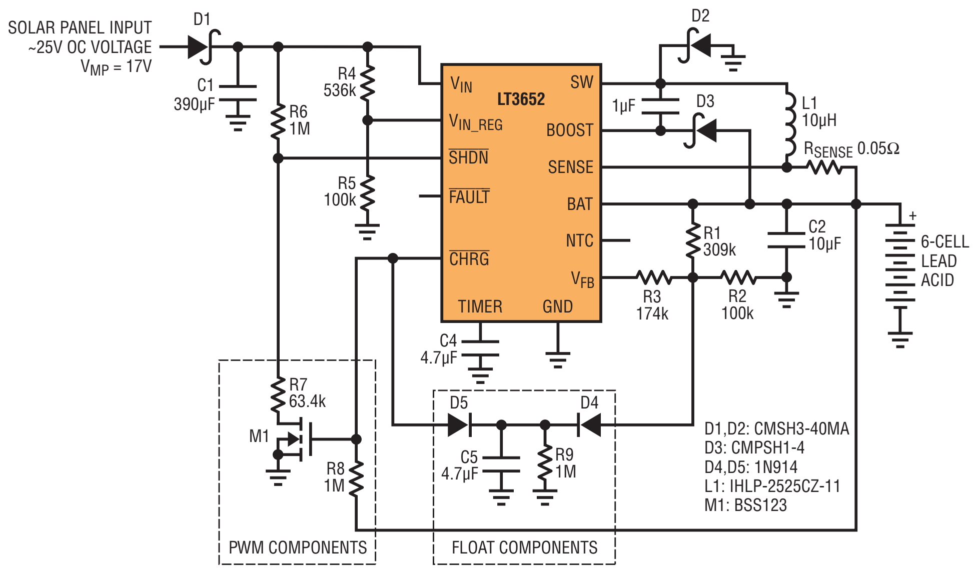


Figure 6. 17V V_{MP} panel to 6-cell 2A lead-acid charger

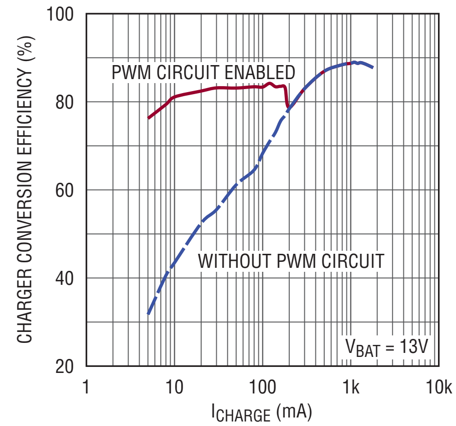


Figure 7. Efficiency curve for circuit in Figure 6

17V input regulation threshold, so full charge current flows into the battery. The $\overline{CHRG}$ status pin is pulled low in response to the high battery charge current level, which disables the UVLO function. As long as the power required by the battery charger remains less than that available from the solar panel, the panel voltage will collapse until V_{IN} is reduced to 17V, when the battery charge current is reduced by input regulation to maintain that voltage. When the charge current is again reduced to 200mA, the $\overline{CHRG}$ pin becomes high impedance, the UVLO circuit is reengaged, and the disable/enable cycle repeats, resulting in a string of charge current 'bursts' that average to the battery charge current corresponding to the available power from the solar panel.

Figure 5 shows the PWM operation of the circuit in Figure 2. While the LT3652 is disabled, the voltage on V_{IN} ramps from the input regulation threshold of 17V to the shutdown threshold of 20V. The voltage on the LT3652 $\overline{CHRG}$ pin is low while the charger is enabled and high while the charger is disabled. While the charger is disabled, the panel energy is stored in the input capacitor, so the output power from the panel remains continuous. The efficiency of the solar panel corresponds to the average voltage on the panel during PWM operation, which is about 18.5V.

HIGH EFFICIENCY LEAD-ACID CHARGER

Figure 6 shows a 6-cell lead-acid battery charger with low current PWM functionality. The battery charger is designed for a solar panel that has similar characteristics to that used for the charger in Figure 2.

This lead-acid charger performs a 3-stage lead-acid charging profile, employing 2A bulk mode charging, absorption mode charging to 14.4V, and float charge maintenance at 13.5V. The battery charger provides up to 2A while charging with CC/CV characteristics up to the absorption mode regulation voltage of 14.4V, provided there is ample input power available from the solar panel. As the battery nears the 14.4V regulation voltage, charge current is reduced, completing absorption mode charging when the charge current falls to 200mA, or 1/10 the maximum charge current (C/10).

When absorption mode charging is completed, the $\overline{CHRG}$ pin becomes high impedance in response to achieving the C/10 charge current threshold, and float mode maintenance charging begins. The regulation voltage is reduced from 14.4V to 13.5V in float mode, achieved by effectively removing R9 from the V_{FB} summing node—accomplished by a diode-OR circuit (D4 and D5) when $\overline{CHRG}$ is pulled high by R8, via the reverse-biased D4.

Float mode charging regulation is also implemented if the LT3652 charger experiences inadequate input power due to low solar panel illumination levels. If charge current is reduced to less than 200mA via input regulation and PWM operation begins, the $\overline{CHRG}$ pin voltage becomes a pulsed waveform. D5 and C5 implement a peak-detect filter that maintains a continuous reverse-bias on D4, keeping the charger in float mode (V_{CHARGE} = 13.5V) during PWM operation. Figure 7 shows that the addition of the PWM circuitry significantly increases efficiency at battery charge currents below 200mA.

During PWM operation, the input voltage ramps from the input regulation threshold of 17V to the shutdown threshold of 20V during the period the IC is disabled, as previously described for the battery charger in Figure 2. The output power from the solar panel corresponds to the

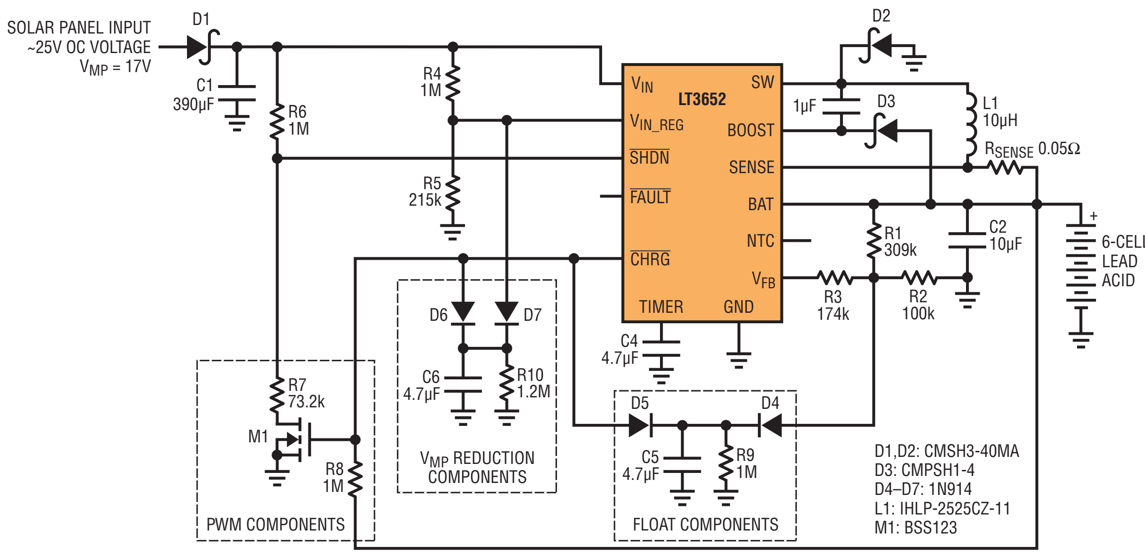


Figure 8. 17V V_{MP} panel to 6-cell 2A lead-acid charger with low current V_{MP} tracking

average voltage of the panel, or about 18.5V. Figure 3 shows that this voltage is within the optimum operational range for higher output currents, but is above that range at currents less than 200mA. To maximize both solar panel output efficiency and battery charger efficiency in applications with extended low light operation, the $V_{IN(REG)}$ and UVLO voltages should be reduced during the burst period. A method to do so is described below.

HIGH EFFICIENCY LEAD-ACID CHARGER WITH LOW CURRENT V_{MP} TRACKING

The LT3652 lead-acid battery charger in Figure 8 is similar to the battery charger in Figure 6, but also lowers the input regulation voltage ($V_{IN(REG)}$) while the charge current is below 200mA. This improves panel efficiency by tracking the panel's characteristic reduction in V_{MP} at low currents.

Low current V_{MP} tracking is implemented by adding R10 to the input regulation divider of R4 and R5. R10 is connected to the input regulation summing node through a diode-OR circuit (D6 and D7). When the $\overline{\text{CHRG}}$ pin voltage is high, R10 is effectively removed from the summing node via the reverse-biased D7, lowering $V_{IN(REG)}$ from 17V to 15V.

If the charger experiences inadequate input power due to low illumination levels, charge current is reduced via the input regulation loop to maintain the V_{MP} solar panel voltage of 17V. If charge current is reduced to less than 200mA, the charger begins PWM operation and the regulation threshold is reduced for float charging, as in the previous lead-acid battery charger circuit. Additionally, this charger reduces $V_{IN(REG)}$ to 15V, tracking the reduction of the solar panel V_{MP} at low currents.

D6 and C6 implement a peak-detect filter, similar to the previously described D5 and C5. This filter maintains a continuous reverse-bias on D7, keeping the charger input regulation voltage at the 15V low illumination level during PWM operation. The PWM control components (M1 and R6-R8) implement UVLO thresholds of 16V (falling) and 17.5V (rising). During PWM operation, the panel voltage at V_{IN} ramps from the 15V input regulation voltage to the 17.5V UVLO rising threshold, yielding an average panel voltage of about 16.25V. This charger maximizes both charger conversion efficiency and solar panel output power efficiency by reducing the operational panel voltage while implementing PWM operation during periods of low illumination.

CONCLUSION

The LT3652 battery charger IC features a patent pending input voltage regulation circuit that is used to maintain a solar panel at its maximum power voltage, V_{MP}. While the power output efficiency of a solar panel is optimized using this technique, the efficiency of the battery charger drops at low output currents. The efficiency of a LT3652 solar-powered battery charger can be greatly improved during low illumination conditions with a simple PWM technique, implemented using only a few external components, maximizing the operational efficiency of both the charger and the solar panel. ■

Meet Green Standards in 24VAC and 12VAC Lighting Systems: Replace Halogen Bulbs with LEDs Driven by High Power Factor, High Efficiency Converter

Keith Szolusha

LEDs are increasingly used in 24VAC and 12VAC lighting systems as a robust, energy efficient and high performance alternative to halogen lamps. Power converters that drive the LEDs should have a high power factor (above 90% in order to meet generally accepted green standards), should be efficient, use a minimal number of components and should run cool. They do not need isolation.

One solution that meets these requirements combines a rectifier bridge and a current-controlled synchronous step-up/step-down converter. Specifically, a synchronous 4-switch buck-boost converter can be paired with a 4-switch ideal diode rectifier bridge for high power LEDs; lower power solutions can use a standard diode bridge. Both solutions are shown here.

The LT3791 60V 4-switch synchronous buck-boost controller IC can drive constant current (either DC or pulsating) into a string of high power LEDs. It features an output current feedback loop used to drive constant current through a string of LEDs, and a CTRL dimming input pin that can be tied to the 120Hz half-sine wave

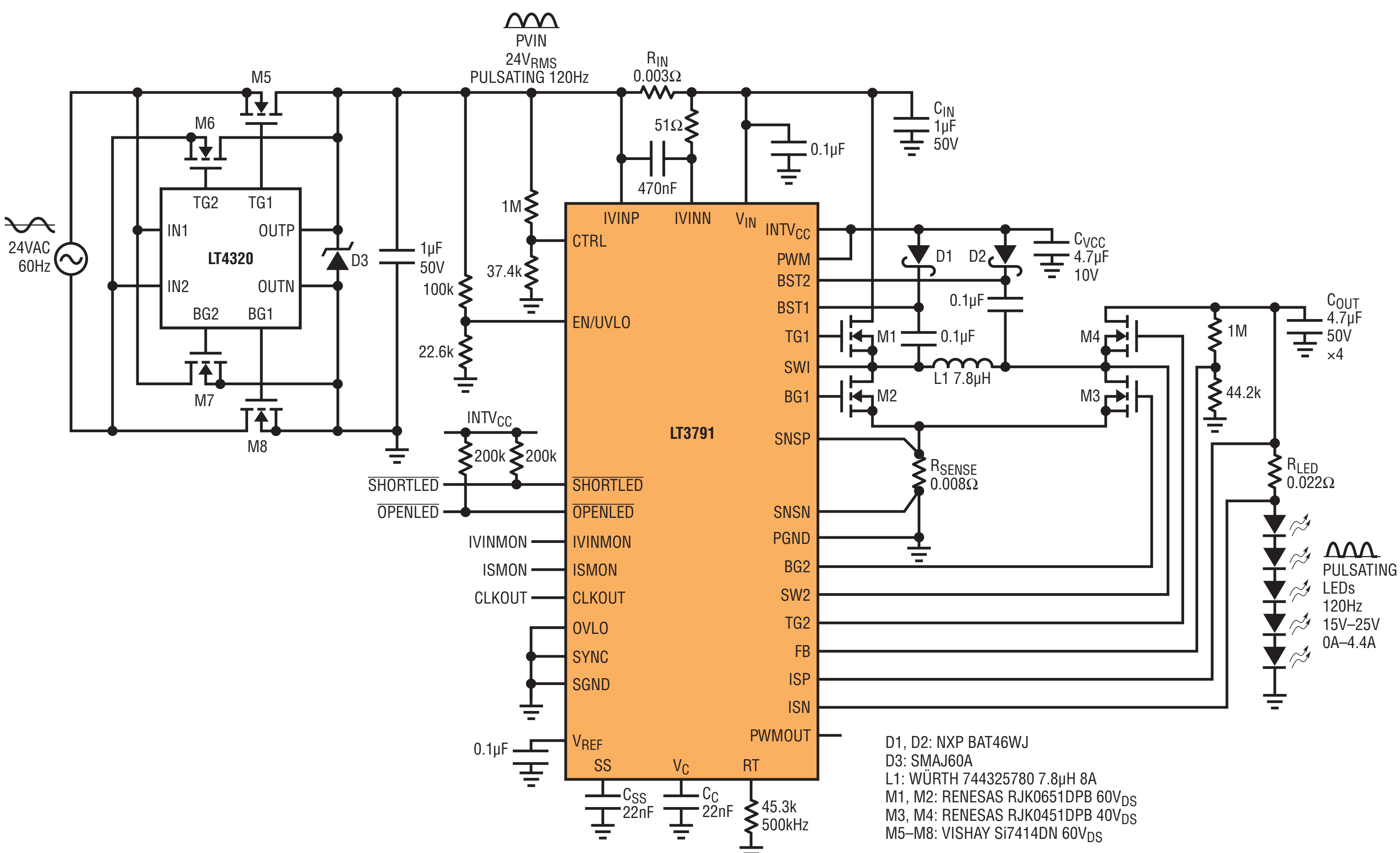


Figure 1. 24V AC to 60W LED driver (600W halogen equivalent) features high power factor and high efficiency

This eco-friendly 60W LED lighting solution is roughly equivalent to 600W of halogen lighting without using lead, mercury, argon, xenon or krypton gases.

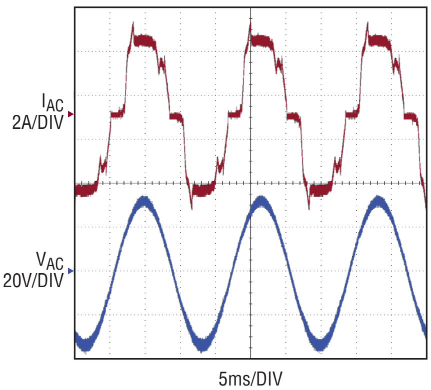


Figure 2. 60Hz 24VAC input waveforms

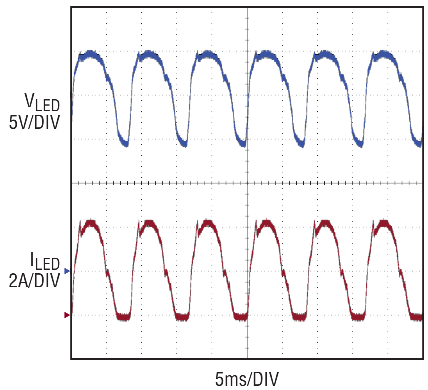


Figure 3. 120Hz pulsating LED driver waveforms

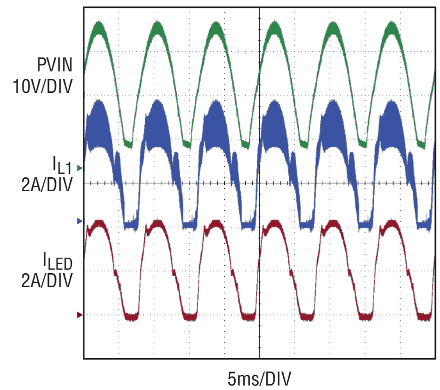


Figure 4. 120Hz pulsating PVIN

output of a rectifier bridge to create a high power factor pulsating LED current output.

The LT4320 is an ideal diode rectifier bridge that drives four MOSFETs in place of four typical rectifier diodes for highest efficiency conversion of the 60Hz 24VAC input to $24V_{RMS}$ 120Hz pulsating output. When currents reach 5A and higher, the diodes in a standard rectifier bridge dissipate significant power and heat up. The LT4320 helps high power AC applications run efficient and cool by driving low resistance external N-channel FETs.

98.1% POWER FACTOR

Figure 1 shows an LED driver that operates with 98.1% power factor directly from 24VAC. It can drive up to 25V of LEDs with 120Hz pulsating power with LED current peaking at 4.4A. At 120Hz, the pulsing of the light is not detectable by the human

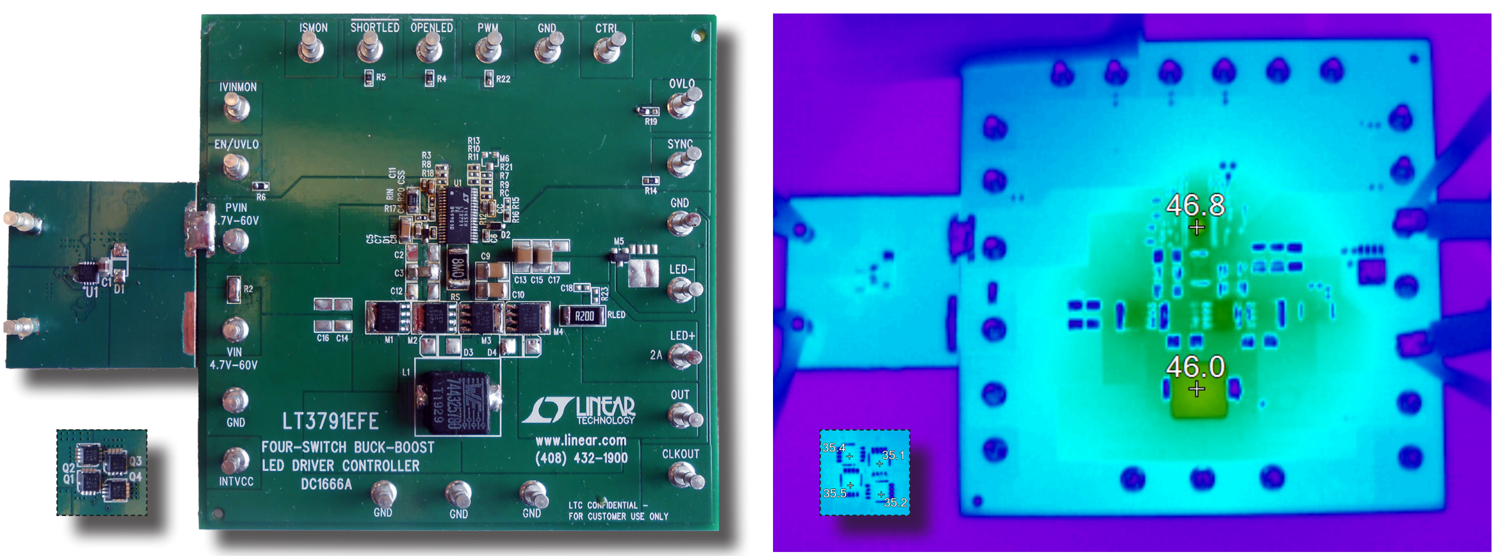


Figure 5. Components remain cool in the high efficiency LED driver shown in Figure 1. Note that the The LT4320 ideal driver remains cool at full LED current. The LT3791 high power buck-boost converter and supporting components rise less than 24°C while delivering 60W of LED power. The four ideal diode bridge MOSFETs on the back of the board (inset) temperature rise less than 13°C (23°C ambient).

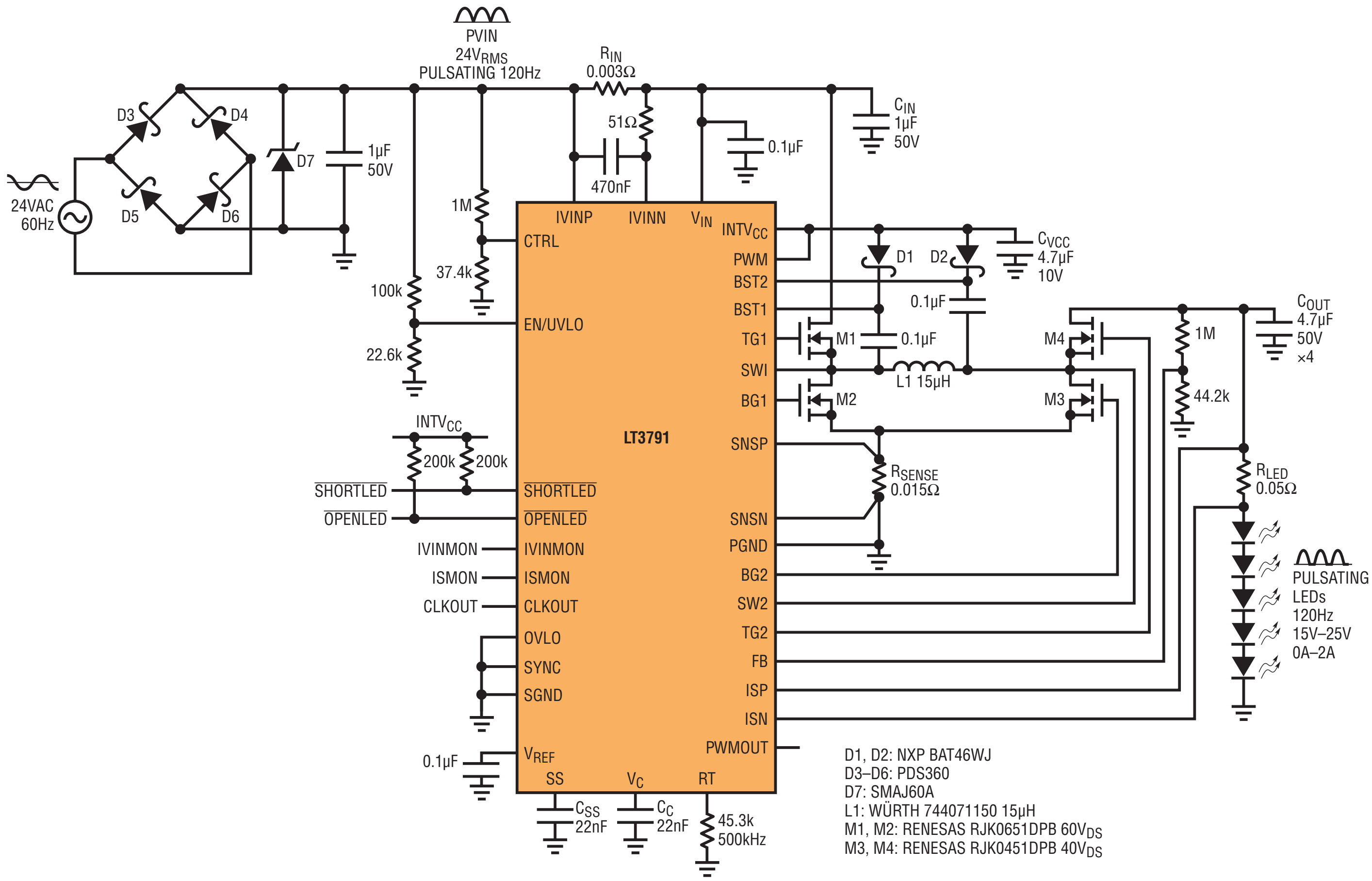


Figure 6. Alternate, 24W solution uses a standard diode rectifier for simplicity

eye and is seen as constant brightness. The high power factor 24VAC input voltage and current waveforms are shown in Figure 2. The 120Hz pulsating LED current waveforms are shown in Figure 3.

LED current foldback with the CTRL pin voltage is used to achieve the high power factor. The maximum LED current is set by R_{LED} at 4.5A, but the CTRL pin monitors the post-rectifier 120Hz PVIN input voltage (see Figure 4) and shapes the LED current waveform to match the input. When the input drops below the shutdown pin threshold, the IC goes into shutdown and switching stops. The LED current trails off as the output capacitors are discharged and soon enough, the input rises above the shutdown pin threshold and the LT3791 starts back up. With the CTRL pin folding back the LED current at low input, start-up is not harsh and inrush currents do not affect the high power factor.

HIGH EFFICIENCY & HIGH POWER FACTOR 60W PULSATING LED DRIVER

The 24VAC pulsating LED driver converter in Figure 1 delivers approximately 60W of LED lighting at 94% efficiency. This eco-friendly solution is roughly equivalent to 600W of halogen lighting replacement without using lead, mercury, argon, xenon or krypton gases. The four synchronous switches of the LT3791 buck-boost converter and those of the LT4320 ideal diode bridge are responsible for the high efficiency. Figure 5 shows the circuit components remaining cool despite the 60W conversion. The components have less than 24°C temperature rise, showing that there is plenty of room to spare for even higher power applications.

A standard rectifier bridge would produce about a 50°C temperature rise and run several efficiency points lower.

Total efficiency is calculated by measuring the input power, the power factor, and the delivered output power separately. The values of 63.0W real input power, 64.4W apparent input power and 98.1% power factor are measured with an HP 6812A AC power source.

Measurement of the output power is a bit more complex. A current probe and oscilloscope are used to capture the pulsing current and voltage waveforms at the output of the converter. From these waveforms, the converter output RMS current and voltage is calculated for the on-time (t_{ON}) of the LED. The on-time output power is $P_{OUT(ON)} = V_{RMS(ON)} \bullet I_{RMS(ON)}$. Output power is zero during LED off-time, where

The principals of the 24W circuit are the same as the 60W circuit and the two operate in the same manner. Efficiency of the 24W circuit is 90%, lower than the 94% achieved by the 60W circuit. Nevertheless, this loss is acceptable due to the overall lower power.

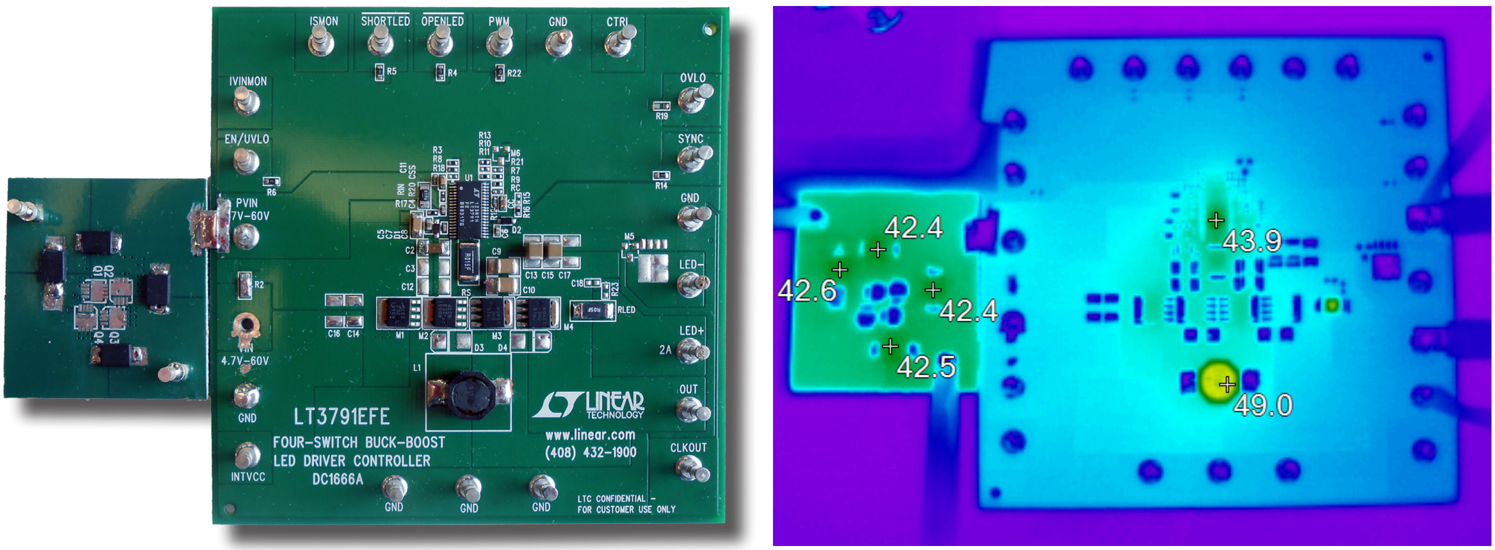


Figure 7. Thermal performance of 24W solution

the current is zero. The output power of 60W is calculated via a simple duty cycle equation: $P_{OUT} = P_{OUT(ON)} \bullet t_{ON} \bullet 120Hz$. Overall efficiency = output power divided by real input power.

HIGH EFFICIENCY & HIGH POWER FACTOR 24W PULSATING LED DRIVER

The circuit in Figure 6 is a high efficiency and high power factor 24W pulsating LED driver that operates from 24VAC input. Because the power level here is less than half of the 60W LED driver in Figure 1, the rectifier bridge shown in Figure 8 is made from four discrete Schottky diodes, instead of ideal diodes. The trade-offs for simplicity are slightly lower efficiency and additional heat dissipation.

The principals of the 24W circuit are the same as the 60W circuit and the two operate in the same manner. Efficiency of the 24W circuit is 90%, lower than the 94% achieved by the 60W circuit. Nevertheless, this loss is acceptable due to the overall lower power, making the temperature rise in the discrete rectifier bridge components comparable between the two. With the discrete diode rectifier bridge, the components only heat up to 49°C as shown in Figure 7, well within the requirements of most high power LED drivers.

For higher efficiency, simply replace the discrete rectifier with a LT4320-based rectifier. In general, as power levels and temperatures rise, the need for synchronous rectification in both the converter and rectifier goes up.

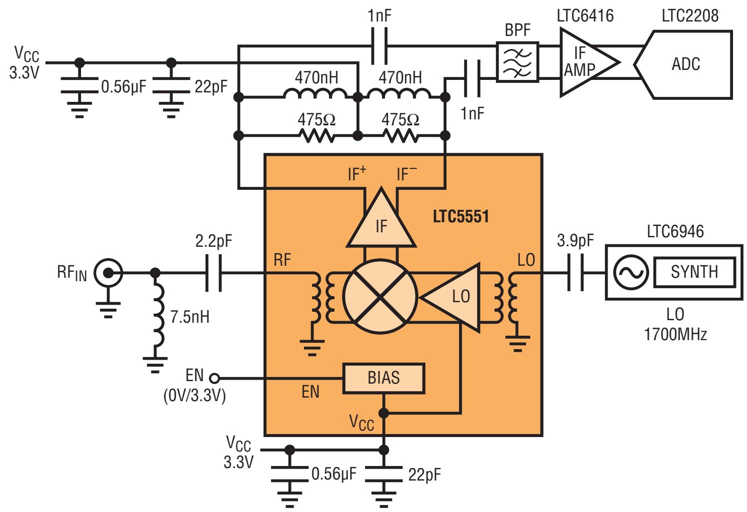
CONCLUSION

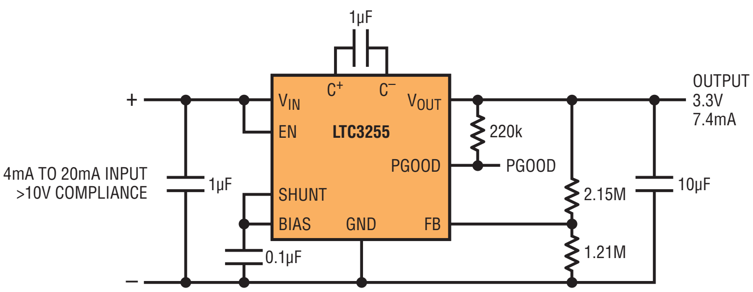
The LT4320 and LT3791 synchronous buck-boost pulsating LED driver combine to deliver 60W of LED power at 120Hz with 98.1% power factor and 94% efficiency. This circuit can be used to easily replace high power 24VAC halogen lighting with more robust and eco-friendly LEDs. At lower power levels, the LT3791 can be used with a simple discrete diode rectifier bridge—such as in a 24W LED driver with 90% efficiency and similarly high power factor. ■

WIDEBAND RECEIVER

The LTC5551 is a 2.5V to 3.6V mixer optimized for RF downconverting mixer applications that require very high dynamic range. The LTC5551 covers the 300MHz to 3.5GHz RF frequency range with LO frequency range of 200MHz to 3.5GHz. The LTC5551 provides very high IIP3 and P1dB with low power consumption. A typical application is a base station receiver covering 700MHz to 2.7GHz frequency range. The RF input can be matched for a wide range of frequencies and the IF is usable up to 1GHz.

circuits.linear.com/644

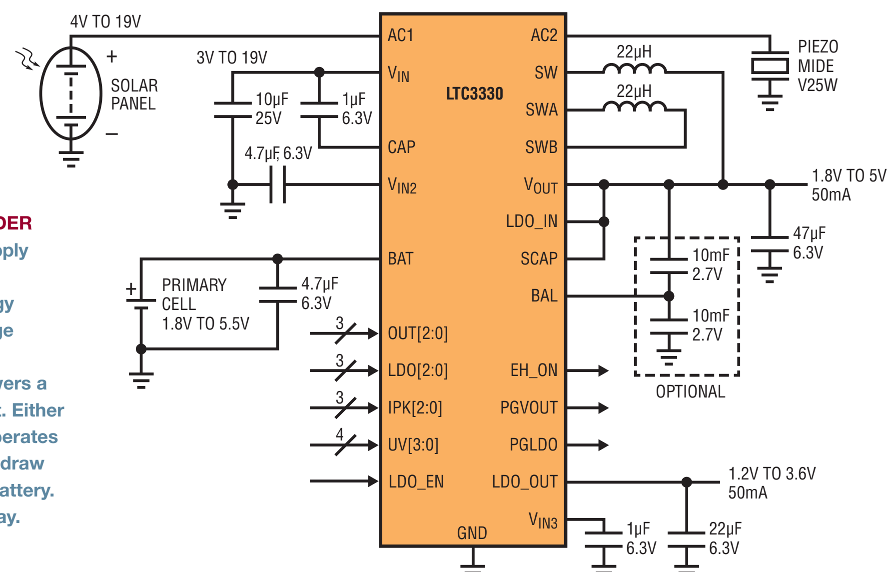




7.4mA DC SUPPLY FROM 4mA TO 20mA CURRENT LOOP

The LTC3255 is a switched-capacitor step-down DC/DC converter that produces a regulated output (2.4V to 12.5V adjustable) from a 4V to 48V input. In applications where the input voltage exceeds twice the output voltage, 2:1 capacitive charge pumping extends output current capability beyond input supply current limits. At no load, Burst Mode® operation cuts V_{IN} quiescent current to 16µA. With its integrated V_{IN} shunt regulator, the LTC3255 excels in 4mA to 20mA current loop applications. The device enables current multiplication; a 4mA input current can power a 7.4mA load continuously. Alternatively, the LTC3255 serves as a higher efficiency replacement for linear regulators and saves space.

circuits.linear.com/643



SOLAR & PIEZO ENERGY HARVESTER AND BATTERY LIFE EXTENDER

The LTC3330 integrates a high voltage energy harvesting power supply plus a DC/DC converter powered by a primary cell battery to create a single output supply for alternative energy applications. The energy harvesting power supply, consisting of an integrated full-wave bridge rectifier and a high voltage buck converter, harvests energy from piezoelectric, solar or magnetic sources. The primary cell input powers a buck-boost converter capable of operation down to 1.8V at its input. Either DC/DC converter can deliver energy to a single output. The buck operates when harvested energy is available, reducing the quiescent current draw on the battery to essentially zero, thereby extending the life of the battery. The buck-boost powers V_{OUT} only when harvested energy goes away.

circuits.linear.com/642

LINEAR TECHNOLOGY

Linear Technology Corporation
1630 McCarthy Boulevard, Milpitas, CA 95035
(408) 432-1900

www.linear.com