LINEAR TECHNOLOGY

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Power Management IC Digitally Monitors and Controls Eight Supplies

by Andrew Gardner

Introduction

Today's high reliability systems require complex digital power management solutions to sequence, supervise, monitor and margin a large number of voltage rails. Indeed, it is not unusual for a single application board to have dozens of rails, each with its own unique requirements. Typically the power management solutions for these systems require that several discrete devices controlled by an FPGA or a microcontroller are sprinkled around the board in order to sequence, supervise, monitor and margin the power supply array. In this scheme, significant time is required to develop the necessary firmware, and the tendency to underestimate the complexity and duration of that task is well known.

The LTC®2978 octal PMBus power supply monitor and controller with EEPROM offers power supply system designers an integrated, modular solution that reduces debugging time and effort over microcontroller solutions. The LTC2978 can sequence on, sequence off, monitor, supervise, margin and trim up to eight power supplies. Multiple LTC2978s can be

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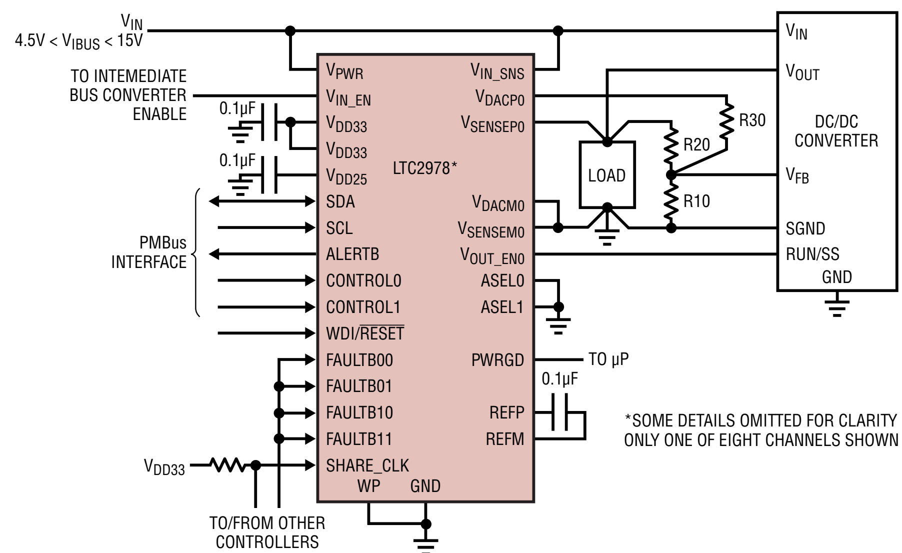


Figure 1. Octal power supply controller with PMBus communication. One channel is shown.

Linear in the News…

On the Road in China

For the past several years, Linear has participated in the IIC China Conference. Traditionally, this has been an opportunity for major electronics companies to showcase their product capabilities in the major Chinese centers in Beijing, Shenzhen and Shanghai. This year, for the first time, the IIC is also holding a trade show in the remote area of Wuhan, since this area is a growing technology center, and Linear will participate. This follows Linear's participation at the IIC Conference in February/March in Shenzhen, Beijing and Xian.

At the IIC in Wuhan on September 14–15, Linear will focus on products for the automotive, industrial and telecom markets. Some of the product highlights include:

- ❑ LED drivers for a range of applications
- ❑ µModule® receiver products for cellular basestations
- ❑ DC/DC µModule regulators, providing easy-to-implement power solutions
- ❑ Battery stack monitors for hybrid and electric vehicles

At its booth, Linear will run a demo of the LTC6802 Battery Stack Monitor, showing automotive electronics designers how to use the device to precisely monitor every cell in long strings of series-connected lithium-ion batteries.

Linear Debuts Isolated µModule Transceiver with Power

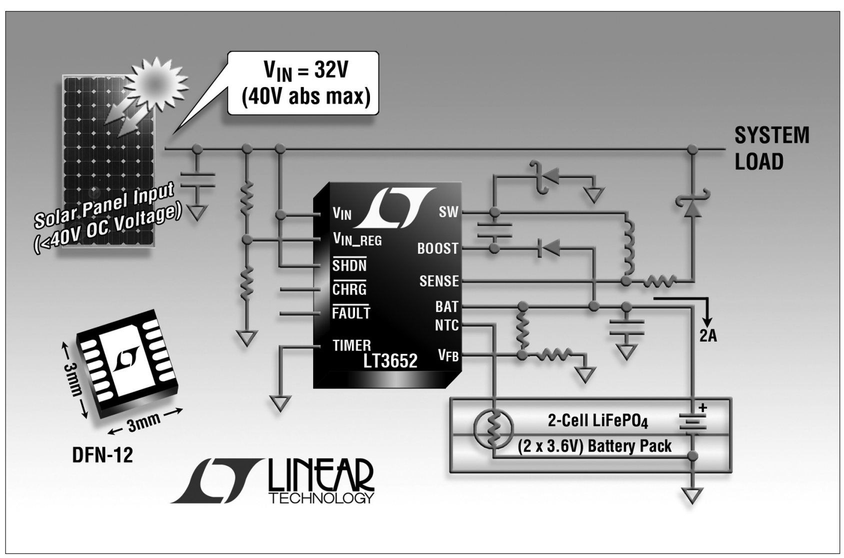
Leveraging its experience in µModule technology, Linear has just announced the first product in a new family of galvanically isolated µModule products aimed for use in industrial networks. The LTM®2881 is a complete isolated RS485/RS422 solution and the first transceiver product to utilize Linear's isolator µModule technology, integrating a 2500V_{RMS} galvanic isolation barrier, a high performance transceiver and all necessary power components into low profile LGA and BGA packages. No external components are required, eliminating issues with sourcing transformers. In addition, the LTM2881's 1W DC/DC converter provides surplus current for powering external ICs and LEDs via a 5V regulated output. The LTM2881 exhibits high common mode transient immunity, >30kV/µs, allowing the LTM2881 to continue communicating, rather than merely holding a data state, through severe transient events.

The features of the LTM2881 make it suitable for a wide range of applications, including breaking ground loops, working with large common mode voltages and when using multiple unterminated line taps. Integrated selectable termination allows cables to be properly terminated to avoid signal reflections and distorted waveforms, with the flexibility to add or remove termination anywhere onto the bus via a software switch. Users will appreciate how the self-powered LTM2881 takes many precautions to guarantee safe and reliable communications in RS485 or RS422 systems.

Solar Power Battery Charger Improves Panel Efficiency

For a given amount of light energy, a solar panel has a certain output voltage for peak output power production. Bypass diodes inside a panel can create complex power versus current characteristics that are not easily optimized when partial shading exists on the panel. However, virtually all of the 12V system solar panels currently on the market that are specified with maximum output power less than 25W are constructed from a simple series cell arrangement with no bypass diodes. This type of arrangement yields peak output power within a narrow band of panel output voltages, regardless of lighting conditions. Peak power in excess of 95% may be produced from panel voltages of 12.5V–18.5V, depending on the characteristics of the panel.

Linear has just announced a solar power battery charger, the LT®3652, designed to provide an elegant electrical operating characteristic while extracting the maximum available power from the solar panel. The LT3652 employs a simple but innovative input voltage regulation loop, which controls charge current to hold the input voltage at a programmed level. This input regulation loop maintains the panel at the output voltage corresponding to the peak output power point for the particular solar panel used. The specific desired peak-power voltage is programmed via a resistor divider. This method yields charging efficiencies virtually the same as more costly maximum peak power tracking (MPPT) solar charging techniques.



LTC2978, continued from page 1

easily cascaded using the 1-wire share-clock bus and one or more bidirectional fault pins (Figure 1 shows a typical application).

In addition, the LTC2978 uses a protected block of nonvolatile memory to record system voltage and fault information in the event of a critical system failure. Preserving critical system data in nonvolatile memory allows users to identify a failing voltage rail and isolate the cause of board failures during system development, test debug or failure analysis.

A free, downloadable graphical PC interface is available to facilitate interaction with the part in design and testing. The LTC2978 utilizes the industry standard PMBus command protocol in order to simplify firmware development. The LTC2978's most important feature, though, is that its precision integrated reference and 15-bit ΔΣ ADC delivers ±0.25% absolute accuracy when measuring or adjusting power supply voltages.

Improve Manufacturing Yields with Precision Margin Testing

Margin testing of system voltages is an effective means of weeding out premature failures in high reliability systems. Typically, voltages are margined at least ±5% in order to guarantee that the system under test is robust enough to operate reliably in the field. Depending on system tolerances, however, this approach can lead to excessive test fallout. Many of these test rejects might have been avoided if the tolerances of the supply voltages in question were tighter.

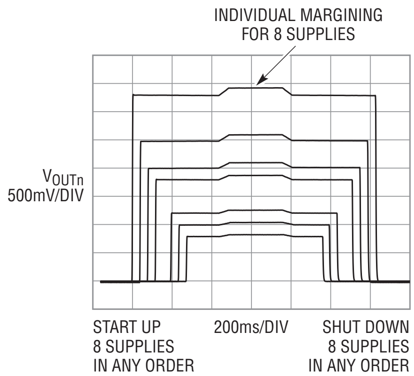


Figure 2. The LTC2978 offers flexible sequencing and precision margining.

With its precision reference, multiplexed 15-bit ΔΣ ADC, eight margin DACs and integrated servo algorithm, the LTC2978 offers a relatively easy-to-use, yet powerful, solution to this problem (see Figure 4 for the LTC2978 bock diagram). By simply writing an I^2C command to either trim or margin to a specific voltage, the LTC2978 adjusts the DC/DC point-of-load converter within the prescribed software and hardware limits to *deliver the commanded output voltage to ±0.25% absolute accuracy*.

The margin DAC outputs are connected to the feedback nodes or trim inputs of the DC/DC POL converters via a resistor. The value of this resistor sets a limit on the range over which the output voltage can be margined, an important limitation for power supplies under software control. Another significant benefit of the 10-bit margin DACs is that they enable very fine resolution when margining voltages. This makes it possible to extract useful data from failure testing, as opposed to a trashcan full of failed, but not well understood, boards.

Flexible Power Sequencing and Fault Management

Many traditional power sequencing solutions rely on comparators and daisy-chained PCB connections. While relatively easy to implement for a handful of supplies, this approach quickly becomes complicated as the number of voltage rails grows, and is relatively inflexible in the face of specification changes. It's also extremely difficult to implement turn-off sequencing with this type of approach.

The LTC2978 makes sequencing easy for any number of supplies. By using a time-based algorithm, users can dynamically sequence on and sequence off in any order (see Figure 2). Sequencing across multiple LTC2978s is also possible using the 1-wire share-clock bus and one or more of the bidirectional fault pins (see Figure 3). This approach greatly simplifies system design because channels can be sequenced in any order, regardless of which LTC2978 provides control. Additional LTC2978s can also be added later without having to worry about system constraints such as a limited supply of daughter card connector pins.

On sequencing can be triggered in response to a variety of conditions. For example, the LTC2978s can auto-sequence when the downstream DC/DC POL converters' intermediate bus voltage exceeds a particular turn-on voltage. Alternatively, on sequencing

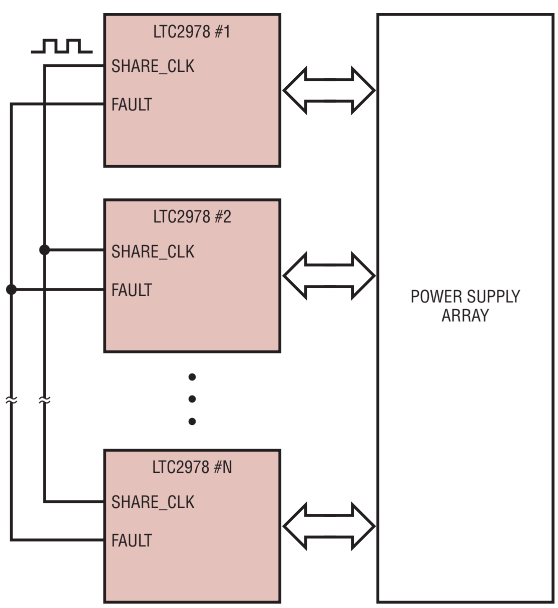


Figure 3. Multiple LTC2978s can be cascaded using only two connections.

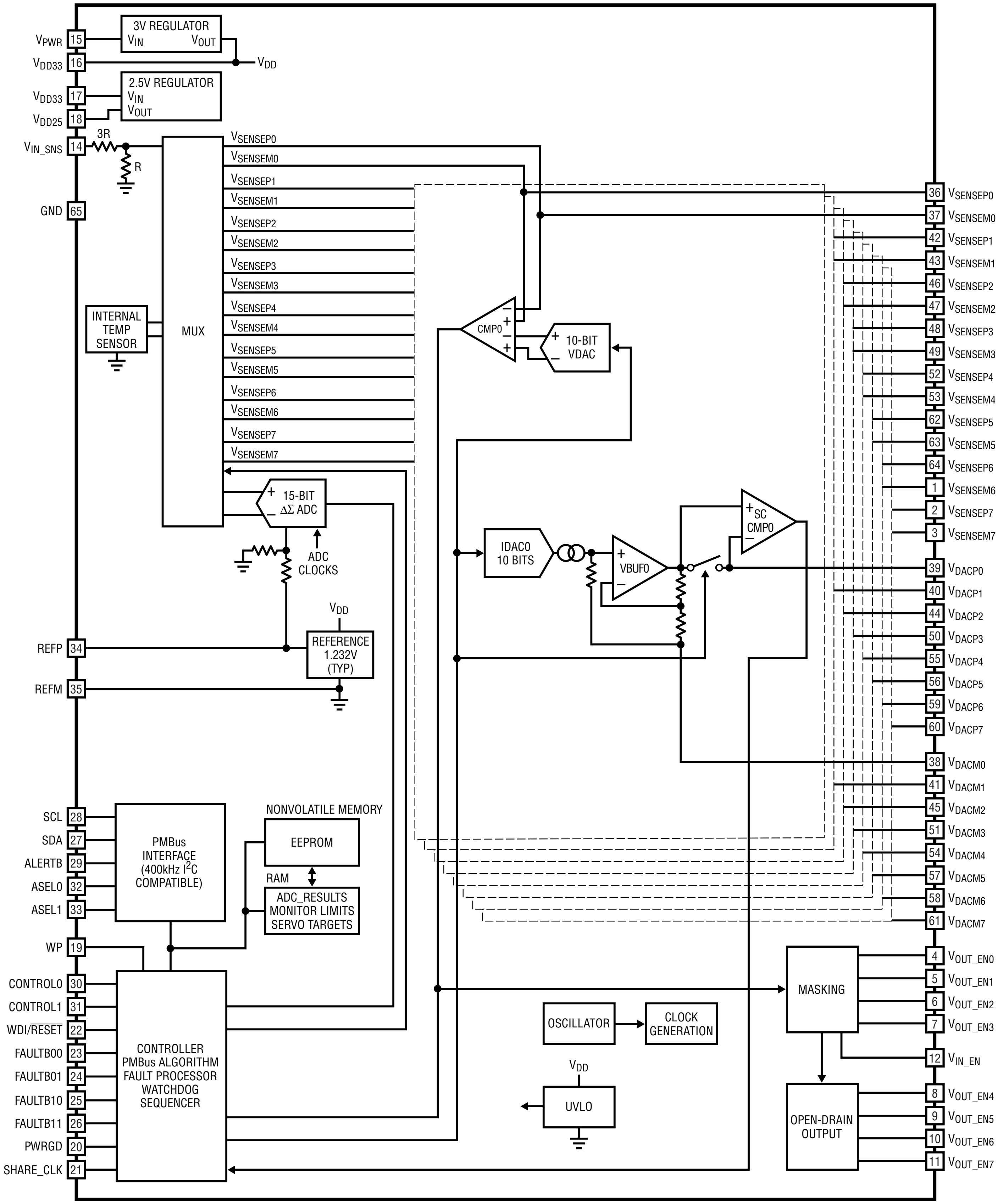


Figure 4. Block diagram of the LTC2978

can initiate in response to the rising- or falling-edge of the control pin input. Sequencing can also be initiated by a simple I^2C command. The LTC2978 supports any combination of these conditions.

The bidirectional fault pins can be used for various fault response dependencies between channels. For instance, on sequencing can be aborted for one or more channels in the event of short-circuit. Once a rail has powered-up, the undervoltage supervisor function is enabled (the overvoltage function is always enabled). The overvoltage and undervoltage thresholds and response times of the voltage supervisors are all programmable. In addition, input voltage and temperature are also monitored. If any of these quantities exceed their over- or under-value limits, the customer can select from a rich variety of fault responses. Examples include immediate latchoff, deglitched latchoff, and latchoff with retry.

An integrated watchdog timer is available for supervising external microcontrollers. Two timeout intervals are available: the first watchdog interval and subsequent intervals. This makes it possible to specify a longer timeout interval for the micro just after the assertion of the power good signal. In the event of a watchdog fault, the LTC2978 can be configured to reset the micro for a predetermined amount of time before reasserting the power good output.

Multifaceted Telemetry

The LTC2978 serves up a variety of telemetry data in its registers. The multiplexed, 15-bit ΔΣ ADC monitors input and output voltages and on-chip temperature, storing minimum and maximum values for all voltages and temperature readings. In addition, the ADC inputs for odd-numbered output channels can be reconfigured to measure sense resistor voltages. In this mode, the ΔΣ ADC can resolve voltages down to 15.3μV, which is invaluable when attempting to measure current with inductor DCR circuits.

Although the LTC2978 can be directly powered from a 3.0V to 3.6V supply, the ADC is capable of accepting input voltages of up to 6V—no need to worry about body diodes or exotic standby supply voltages. The LTC2978 can also run off of a 4.5V to 15V input supply using its internal regulator. A separate high voltage (15V max) sense input is provided for measuring the input supply voltage for the DC/DC POL converters controlled by the LTC2978.

Black Box Data Recorder

In the event a channel is disabled in response to a fault, the LTC2978's data log can be dumped into protected EEPROM. This 255-byte block of data is held in NVM until it is cleared with an I^2C command. The data block contains output and input voltages and temperature data for the 500ms preceding the fault as well as the corresponding minimum and maximum values. Status register values and total up time since the last system reset are also stored in the log.

Figure 5 shows the data log contents viewed in the PC-based LTC2978 interface. In this way, the LTC2978 provides a complete snapshot of the state of the power system immediately preceding the critical fault, thus making it possible to isolate the source of the fault well after the fact. This is an invaluable feature for debugging both prerelease characterization or in-field failures in high reliability systems.

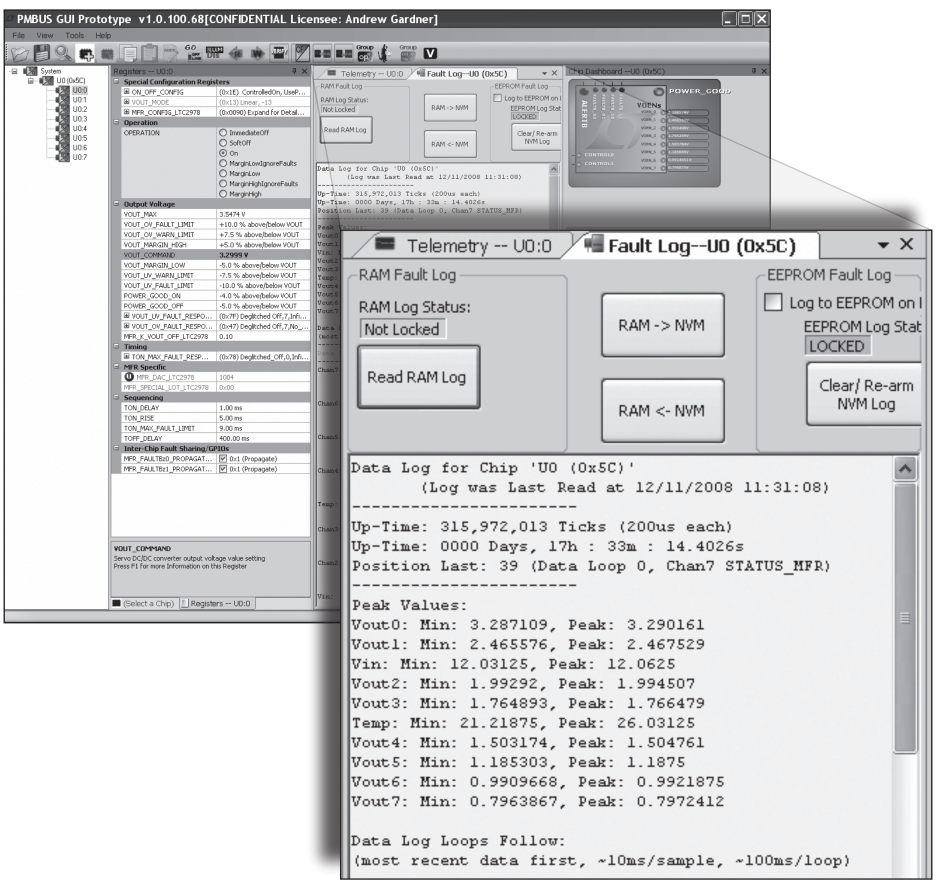


Figure 5. The LTC2978 comes with free software that allows easy data monitoring and cofiguration. The data log shows monitor readings just before a failure for debugging analysis.

Graphical User Interface and PMBus

Linear Technology's easy-to-use PC-based graphical user interface (GUI) allows users to configure the LTC2978 via a USB interface and a dongle card. The GUI, which is free and downloadable, takes much of the coding out of the development process and improves time-to-market by allowing the designer to configure all device parameters within an intuitive framework. Once the device configura-

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PD Controller ICs with Integrated Flyback or Forward Controllers Meet Demands of 25.5W PoE+

by Ryan Huff

Introduction

The IEEE 802.3af Power over Ethernet (PoE) standard allows a powered device (PD), such as an internet protocol (IP) telephone, to draw up to 12.95W from an Ethernet cable. When the 802.3af standard was drafted, 12.95W appeared sufficient to cover the immediately imaginable range of PD products (primarily IP phones). Of course, application developers are always far more innovative than standards committees anticipate, so new power-hungry applications for PoE immediately started to appear, such as dual-radio IEEE 802.11a/g and 802.11n wireless access points, security cameras with pan/tilt/zoom motors, and color LCD IP video phones. 12.95W was suddenly not enough. The IEEE committee responded with the 802.3at standard, which raises the available PD power to 25.5W. The new "at" standard, commonly referred to as PoE+, also adds a "handshaking" communications requirement between PDs and power sourcing equipment (PSEs), while allowing backward compatibility with the legacy "af" standard.

New power control ICs are required to take advantage of these expanded requirements. The DC/DC conversion and control schemes used for legacy "af" PDs are not optimized for the increased power capability and feature requirements of PoE+. For instance, in both standards the 37V to 57V PoE voltage is converted to lower voltages that digital circuitry can tolerate. This DC/DC conversion is handled in the lower power 12.95W standard with a conventionally rectified (i.e., diode rectified) flyback converter. The higher power 25.5W standard is better served by a synchronously rectified (i.e. MOSFET rectified) flyback or a forward power supply topology.

To meet the new performance requirements of PoE+, including handshaking, Linear Technology offers a new family of PD controller ICs that integrate a front-end PD controller with a high performance synchronously rectified flyback (LTC4269-1) or a forward (LTC4269-2) power supply controller.

Features

Both parts combine a PD controller—which includes the handshaking circuitry, Hot Swap™ FET, and input protection—with a DC/DC power supply controller. While the power supply sections of the two parts are very different, the PD controller in both is identical.

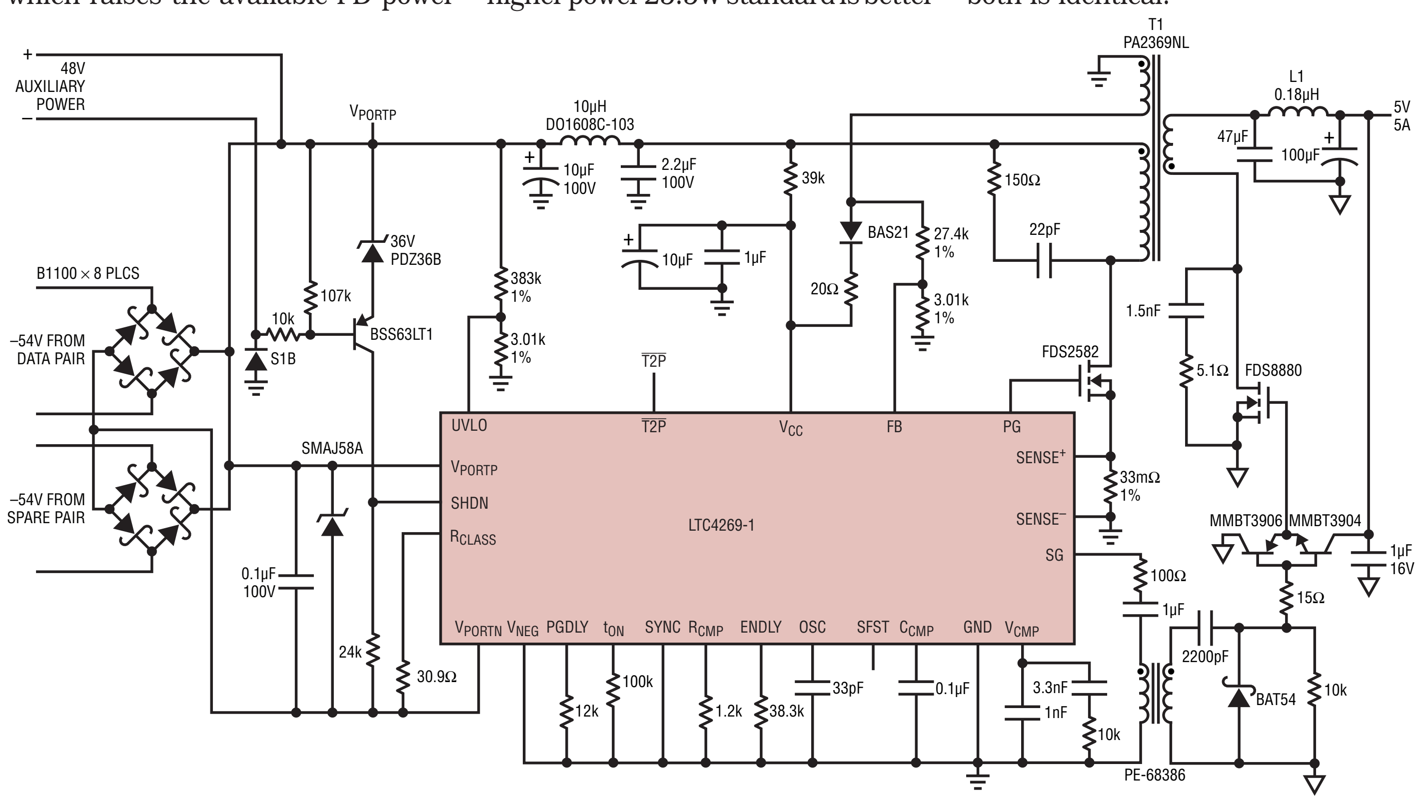

Figure 1. LTC4269-1-based synchronous flyback converter

In the LTC4269, handshaking circuitry, also known as the "High Power Available," "Two Finger Detect," or "Ping Pong" indicator, allows the PD to take full advantage of a new PSE's full 25.5W of available power. Both parts include an integrated Hot Swap MOSFET for a controlled power up of the PD. The switch has a low 700mΩ (typical) resistance and a robust 100V max rating, thus meeting the needs of a wide range of applications. Auxiliary power supplies ("wall warts") can be accommodated by interfacing to the SHDN pin to disable the PoE power path. Setting a programmable classification current allows different power leveled PDs to be recognized by the PSE. Achieving this is as easy as choosing the proper resistor and placing it from the R_{CLASS} pin to V_{PORTN} pin. The ICs are chock-full of protection features, including overvoltage, undervoltage, and overtemperature to name a few. Finally, complementary power good indicators signal that the PD Hot Swap MOSFET is out of the inrush limit and ready to draw full power.

The power supply controllers of the LTC4269s also share some features. Both offer programmable switching frequency, which allows the designer to optimize the trade-off between efficiency and size, or the designer can choose a specific frequency to meet application specific EMI requirements. The power supply soft-start time is also adjustable to prevent the PSE from dropping out its power due to excessive inrush current and virtually eliminate any power supply

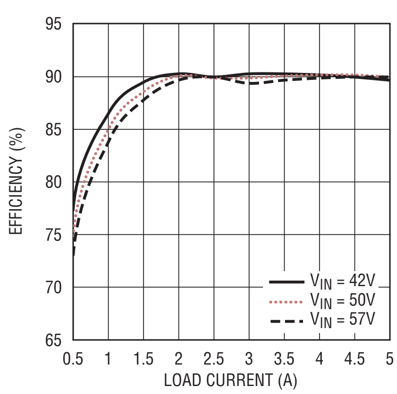

Figure 2. Efficiency of the circuit in Figure 1

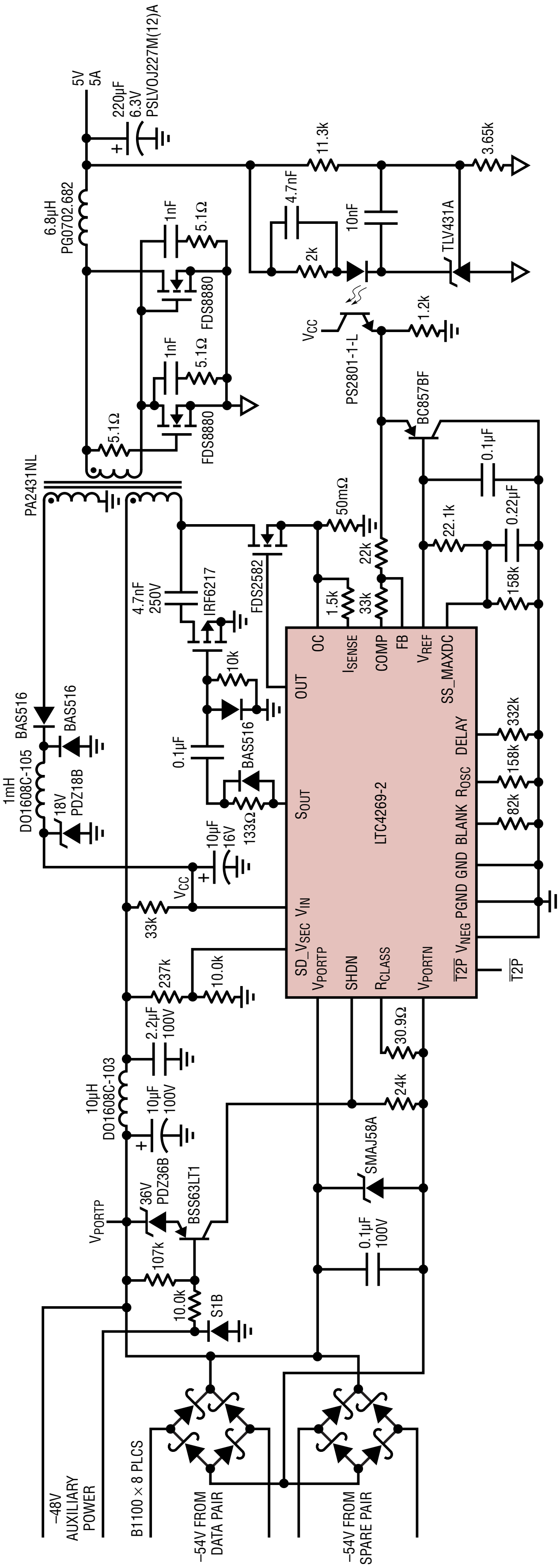

Figure 3. LTC4269-2-based self-driven synchronous forward converter

output voltage overshoot. Both parts include short circuit protection with automatic restart.

LTC4269-1 Synchronous Flyback for Optimized Combination of Efficiency, Simplicity, Size and Cost

A synchronous flyback supply utilizing the LTC4269-1 offers the best combination of efficiency, simplicity, size and cost. See Figures 1 and 2 for the schematic and efficiency curves, respectively, for an LTC4269-1-based PD power supply capable of a 5V output voltage at 5A.

The flyback parts count is low for a few reasons. There is no need for the large output inductor that a forward converter (see Figure 3) needs, for this function is rolled into the isolation transformer (T1). A small, inexpensive second-stage filter inductor (L1) is used in the flyback in order to reduce output voltage ripple, but it should not be confused with a traditional output inductor.

In the case of the LTC4269-1, neither a secondary side reference nor an optocoupler are needed to transmit the output voltage regulation information across the isolation boundary. This is because the IC uses the third (bias) winding on the transformer, T1, to get the output voltage information across the boundary. Finally, the synchronous flyback topology requires half of the switching MOSFETs (only two) needed by the forward converter.

Performance, in terms of efficiency, tops out at above 90% for the LTC4269-1 synchronous flyback. As a contrast, typical PoE efficiencies at the “af” power level for a conventionally rectified flyback were in the lower half of the 80%’s. This higher efficiency is due to the IC’s well-controlled implementation of the synchronous rectifier’s gate drive. This efficiency is not attainable with an uncontrolled self-driven synchronous rectification scheme that is sometimes used.

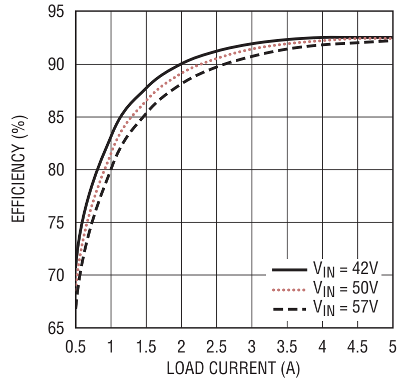

Figure 4. Efficiency of the circuit in Figure 3

Regulation over the full PoE+ input voltage range and 0A to 5A output current range for the LTC4269-1 is better than ±1%. Output voltage ripple for the fundamental switching frequency is less than 30mV peak-to-peak.

LTC4269-2 Synchronous Forward to Maximize Efficiency

If the efficiency of a PoE+ power supply is paramount, an LTC4269-2-based synchronous forward supply is the answer at 92.5% efficiency. The increased efficiency comes with the trade-off of increased circuit size and complexity.

Figure 3 shows a complete PD power supply. Figure 4 shows efficiency, and Figure 5 compares the physical size of the flyback (LTC4269-1) versus the forward (LTC4269-2). The forward supplies 5V at 5A.

The increase in the forward’s efficiency comes about in part from decreased RMS currents in the secondary side MOSFETs and in part from separating the transformer and output inductor. Both of these changes from the flyback reduce resistive losses. The forward supply uses twice the number of MOSFETs as a flyback so each switch handles just a portion of the current that the switches in the flyback do, thus reducing the I^2R power losses. By separating the isolation transformer and output inductor, instead of using the transformer for both as in the flyback, the same power is processed through two components instead of one. The net effect is more copper, thus less resistance and lower resistive losses.

The cost of the circuit obviously increases with the addition of larger and more expensive power path components. Complexity also goes up with the need to control twice as many MOSFETs. Also, the forward topology does not lend itself to the third winding feedback method. This means extra complexity in the design and compensation of a secondary side reference and opto-coupler circuitry.

Other than the ultra high efficiency of the LTC4269-2’s synchronous forward, the solution has similar performance to the flyback. The output ripple of the fundamental switching frequency is about 40mV peak-to-peak. The regulation over the entire input voltage and load current range is well under ±1%.

Conclusion

Two new highly integrated PD controller ICs are fully compliant with, and take full advantage of, the upcoming IEEE 802.3at PoE+ standard. The LTC4269 family of parts support the preferred high performance power supply topologies for use in the new standard.

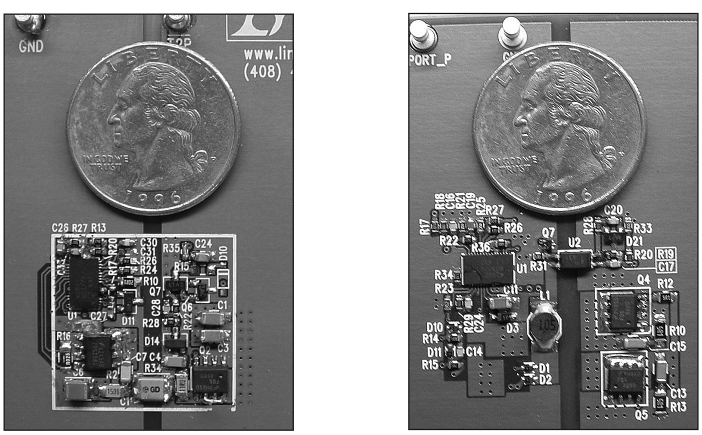

Figure 5. LTC4269-1 and -2 solutions

Surge Stopper IC Simplifies Design of Intrinsic Safety Barrier for Electronics Destined for Hazardous Environments

by Murphy Pickard, Hach Co.

Introduction

As applications for electronic instrumentation proliferate, an increasing number of applications require equipment safe enough to operate in hazardous environments. Chemical plants, refineries, oil/gas wells, coal, and textile operations are all examples of potentially explosive environments that use electronic instrumentation. In order to operate safely in such environments, instrumentation must be made explosion proof.

Companies that supply apparatus to these markets must integrate protection into the design. It falls to the electronic designer to consider available safety measures and implement them with minimum cost and impact on proper circuit operation. This is a daunting task from a design standpoint, made even more difficult by the number of hazardous environment standards that must be met to satisfy global or domestic markets. Although the various standards are moving slowly to harmonization, in some cases they still contradict themselves and each other.

This article discusses the essential requirements of safety standards, and methodologies for meeting these requirements. In particular, the LT4356 series of overvoltage/overcurrent protection devices offers an efficient and elegant means of creating protection barriers in electronic apparatus. To fully understand the requirements and solutions, one must become moderately acquainted with the standards themselves, and the agencies that enforce them.

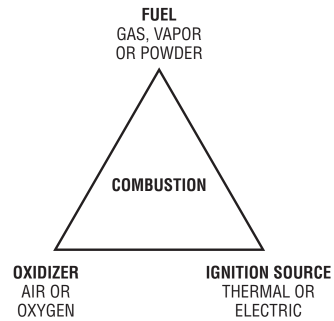

Figure 1. The ignition triangle

About the Author

Murphy Pickard is an Electronic Engineer in the Flow & Sampling Business Unit of Hach Company (www.hach.com) of Loveland, CO. If you have questions about this article or intrinsic safety barrier design, feel free to contact the author at 800-227-4224 or mpickard@hach.com.

LT4356 series surge stopper IC can be used to design an active barrier with parameters that can be easily altered to quickly produce custom barriers.

Since the fundamental circuit topology won't be changing much, once such an active design is approved, it will be more readily approved when only component value changes are made.

Table 1. Established protection techniques

'Ex' Designation	Technique	Description	Application
'p'	Separation: Gas	Pressurization	Equipment Rooms
'o'	Separation: Liquid	Oil Fill	Transformers
'q'	Separation: Semi-Solid	Sand Fill	Instrumentation
'm'	Separation: Solid	Encapsulation	Instrumentation
'n'	Construction	Nonincendive	Switchgear
'e'	Construction	Increased Safety	Lighting, Motors
'd'	Containment	Flameproof	Pumps
'i'	Electrical Design	Intrinsic Safety	Instrumentation

Intrinsic Safety and the Classification of Hazardous Environments

Simply put, in a hazardous environment, the designer's task is to prevent an ignition source from meeting an explosive atmosphere. There are several techniques for achieving this end, and this article focuses on a design discipline referred to as intrinsically safe (IS) design. Figure 1 depicts the ignition triangle, illustrating that a fuel, an oxidizer and an ignition source must all be present for an explosion to occur. Several techniques simply prevent an existing ignition source from contacting an explosive atmosphere, while Intrinsically Safe design actually eliminates the ignition source. The principal protection techniques are listed in Table 1.

Separation techniques are well suited for many applications but require special sealing methods and substances, often creating a permanent barrier, making repair or service impossible. Construction techniques are mechanical approaches, and again require special materials.

Only the Intrinsic Safety technique allows normal instrument fabrication methods and materials and requires no exotic construction or packaging. Additionally, IS circuits may be serviced with power present, and are generally the lowest cost approach to gaining certification. Further, only IS certified equipment is allowed in ATEX Zone 0 areas (Directive 94/9/EC ATEX "Atmosphères Explosibles"). This is true because the instrument design ensures that there is not enough electrical (spark) or thermal energy present to serve as an ignition source. Specifically, an Intrinsically Safe circuit is one in which any spark or any thermal effect produced in the conditions specified in the principal Standard (IEC 60079-2006), which includes normal operation and specified fault conditions, is not capable of causing ignition of a given explosive gas atmosphere.

Several bodies oversee compliance to standards and issue certifications to manufacturers. In North America FM, UL and CSA govern IEC-79 series standard certification, while ATEX standard compliance in the European Union is certified principally by DEMKO. The level of protection required depends on the environment in which the instrument will operate. International Standards and Codes of Practice classify environments according to the risk of explosion. The type and the volatility of the gas/vapor/dust present and the likelihood of its presence determine such risk. Depending on the jurisdiction, the classification system is by Class/Division (North America) or Zone (EU). These systems are generally compatible, and for the purposes of this article, we concentrate on the Class/Division system as many countries have adopted IEC79 series Standards, the most fully utilized and harmonized of all standards extant.

When electrical equipment and flammable materials are present simultaneously, both the equipment and explosive atmospheres must be classified. The level of protection provided must be the same or better than that required by the standards for use in such environment. The environment, or "plant," is classified according to the type (Class and Group) and probability of presence (Division) of the explosive atmosphere. The equipment is classified according to the maximum surface temperature (Temperature Code) of any component of the equipment exposed to the hazardous atmosphere, and by the maximum amount of energy (Apparatus Group) it can produce or release in a spark event. It is important to understand that there is no relationship between the surface temperature and the spark ignition energy necessary to ignite a given gas. These limits are summarized in Table 2.

Table 2. Hazardous environment classification systems

<table>
<tr><th>Class</th><th colspan="3">Hazard</th></tr>
<tr><td>I</td><td colspan="3">Gas/Vapor</td></tr>
<tr><td>II</td><td colspan="3">Dust</td></tr>
<tr><td>III</td><td colspan="3">Particles/Fibers/Filings</td></tr>
<tr><th>Division (North America)</th><th>Presence</th><th>Zone (Europe)</th><th>Presence</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Likely</td><td>0</td><td>Continually</td></tr>
<tr><td>1</td><td>Likely</td></tr>
<tr><td>2</td><td>Unlikely</td><td>2</td><td>Unlikely</td></tr>
<tr><th>Gas Group</th><th colspan="3">Industry</th></tr>
<tr><td>I</td><td colspan="3">Underground</td></tr>
<tr><td>II</td><td colspan="3">Surface</td></tr>
<tr><th>Apparatus Group</th><th colspan="3">Representative Gas</th></tr>
<tr><td>IIA</td><td colspan="3">Propane</td></tr>
<tr><td>IIB</td><td colspan="3">Ethylene</td></tr>
<tr><td>IIC</td><td colspan="3">Hydrogen</td></tr>
<tr><th>Temperature Code</th><th colspan="3">Maximum Surface Temperature °C (40°C Ambient)</th></tr>
<tr><td>T1</td><td colspan="3">450</td></tr>
<tr><td>T2</td><td colspan="3">300</td></tr>
<tr><td>T3</td><td colspan="3">200</td></tr>
<tr><td>T4</td><td colspan="3">135</td></tr>
<tr><td>T5</td><td colspan="3">100</td></tr>
<tr><td>T6</td><td colspan="3">85</td></tr>
</table>

The Role of Electronic Design in Intrinsic Safety

An IS circuit is defined in Standard IEC79-11 as:

"A circuit in which any spark or thermal effect produced in the condition specified in this International Standard, which include normal operation and specified fault conditions, is not capable of causing ignition in a given explosive gas atmosphere."

Thus, a circuit must contain safety components that prevent spark or heat energy of a sufficient level to cause an explosion under fault conditions. It is the responsibility of the circuit designer to incorporate these protective components into the design while still maintaining proper circuit operation. This is seldom an easy task.

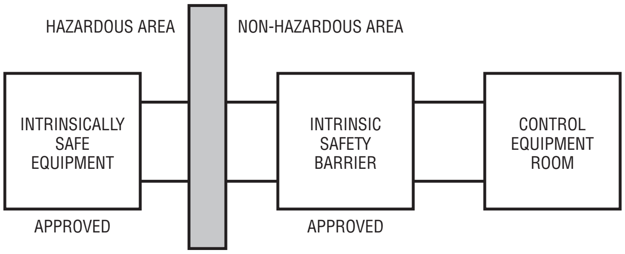

Figure 2. Isolation/protective barrier location

Any device designed for use in hazardous environments may be categorized as either a simple or non-simple apparatus. Without going into detail, a simple apparatus requires no agency certification if it contains passive components, does not generate or store significant energy greater than 1.5V, 100mA, and 25mW. Examples of simple apparatus are resistors, diodes, LEDs, photocells, thermocouples, switches, terminal blocks and the like. For obvious reasons we will not dwell on this class of equipment.

A non-simple IS apparatus, with which electronic instrument designers are concerned, are categorized as either "Ex ib," which may have one countable fault, and "Ex ia," which may have two countable faults. Countable faults refer to arbitrary faults imposed by the examiner to analyze efficacy of protection against thermal and spark ignition faults. A non-countable fault occurs not from component failures, but from circuit spacing issues such as creepage/clearance, improper component voltage/current/power rating or component construction. It is the designer's job to ensure that his component selection and circuit layout do not contain any non-countable faults or he may fail certification from these alone.

During the compliance examination the assessor is allowed to fail one (Ex ib) or two (Ex ia) protective components and explore the implications for safety of these failures. If these failures do not degrade the circuit's safety features, the apparatus is awarded a hazardous location certification. Referring to Table 2, a certification to Class I, Division 1, Group IIC, T6 allows operation in any hazardous environment, including ATEX Zone 0 areas. Clearly, Ex ia is the most difficult certification to obtain, and the manufacturer should determine that he must have this level of protection before incurring the cost of doing so. Most applications require only Class I/Div 1 or 2 (Zone 1) certification.

The Barrier Concept

A barrier that limits power/voltage/current to safe levels for the particular environment must moderate any power or signaling flow between a hazardous location and a non-hazardous location. Such a barrier is termed an Associated Apparatus in the Standards. It is important to realize that an IS barrier, containing protective components, resides in the non-hazardous area and supplies power to the IS certified apparatus in the hazardous area, including Simple Apparatus. Both pieces of equipment must comply with IS rules. That is to say that for an Ex ia certification, both units must be approved to suffer double faults while maintaining safety from ignition as Figure 2 illustrates. Proper or merchantable operation of the apparatus is irrelevant to the examiner, as long as it is safe.

The concept of a barrier is a powerful tool in gaining compliance. It is clear that the non-hazardous area barrier in Figure 2 must limit the total power available to the IS apparatus in the hazardous area. However, multiple barriers may also exist within the hazardous area apparatus. Internal barriers may be used to further limit power to sub-circuits within the equipment to prevent application of multiple countable faults.

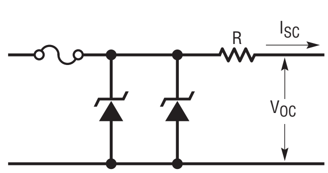

Figure 3. Simple passive component barrier

In the broadest terms, protective components are either series type or shunt type. A current-limiting resistor is the most common series protective device, while a voltage-limiting Zener diode is the most common shunt protective device. When used in combinations to limit power, protective devices are referred to as barriers. Barriers in which true galvanic isolation is maintained are referred to as "isolators." Examples of isolators are transformers, capacitive couplers and optical couplers. Isolators however will not provide DC power or transfer DC signals and are not germane to this discussion. We will not delve into the use of resistors or diodes to isolate energy-storing components to provide spark ignition protection, but this is provided for in the Standards and is a different concept from galvanic isolators.

Safety Components and Barrier Design

Barriers can be categorized as either passive or active according to the components used to design them. Passive barriers have the advantage of conceptual simplicity, ease of design and ready availability in the market. However, the protected field apparatus must suffer the voltage burden imposed by the barrier and still function properly. Passive barriers are energy inefficient and bulky. If any significant power must be transferred to the field device beyond a few milliwatts, the safety components become very large.

Active barriers have a tremendous advantage in efficiency and component size, but are generally more difficult to design and may be more expensive to produce. Additionally, these are typically custom designs that are not easily reused. The most serious disadvantage of active barriers is not conceptual, but bureaucratic. The examiners who analyze the barrier design are completely familiar with common passive designs, and may require actual spark testing (at your expense) before approving active designs. However, as we will see, the LT4356 series surge stopper IC can be used to design an active barrier whose parameters can be easily altered to quickly provide custom barriers. Since the fundamental circuit topology won't be changing much, once such an active design is approved, it will be more readily approved when only component value changes are made. If the IS instrument supplier is performing even a few IS barrier designs, significant savings are realized in energy efficiency, barrier size and cost.

A passive design for associated apparatus, the barrier, that supplies DC power to the field apparatus utilizes three venerable passive devices to implement protection: fuses, resistors and Zener diodes. Safety factors of 1.5 or 1.7 are applied to these device parameters. Furthermore, for double-fault protection at 'ia' protection level, multiply redundant components are necessary. Figure 3 shows the most common type of passive barrier design as an example.

Only the Zener diodes can limit open circuit voltage and only the resistor and fuse can limit current. Fuses are not considered as a spark-ignition energy limit device because of its slow reaction time. In each case, the devices dissipate power and must be properly rated. The Zeners actually do sink some reverse leakage current even though they are not fully on.

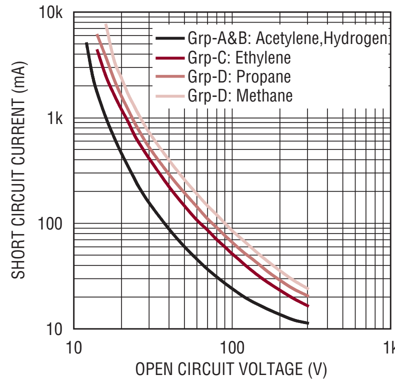

Figure 4. Resistive circuit spark ignition curves

The examiner assumes the Zener voltage knee to occur at the high end of its tolerance, usually 5%. The Zener must be rated at 1.5 times the maximum power of the barrier, the resistors must be rated at 1.5 times the maximum power and the fuse is presumed to pass 1.7 times its rated current. The resistor is presumed to be at the low end of its tolerance range. All active and passive devices must also have an absolute maximum breakdown voltage specification that is 1.5 times the maximum operating voltage they will encounter in normal or fault conditions. These presumptions are imposed not to frustrate the electronic designer, but to arrive at a worst-case barrier performance, always erring on the side of safety.

The barrier is assumed to pass a maximum power of $V_{OC} \bullet I_{SC} = P_{MAX}/2$ when the field apparatus impedance is equal to the barrier source impedance, the point of maximum power transfer. For this analysis the resistor value is assumed to be (R – %tolerance) and V_{OC} at (Vz + %tolerance). Any component in the field apparatus must be able to tolerate $P_{MAX}/2$ unless protected at lower values by secondary means. If we assume that the field apparatus is nothing more than an LED, the LED must be able to dissipate $P_{MAX}/2$ without exceeding the apparatus Surface Temperature code, such as 85°C for a T6 rated product.

In practical barrier designs, protective component redundancy is necessary for compliance, especially for Zener diodes. Two Zeners in parallel are required for Ex ib rated equipment, and three parallel Zeners for Ex ia protection level. Note that the Zener power dissipation rating depends on the fuse clearing. If the fuse were not present, proof must be supplied that the Zener can dissipate the full barrier power indefinitely without failing or exceeding the temperature rating of the apparatus. In addition, the IEC79 Standard requires that all fuses not contained in approved holders must be encapsulated. Further requirements exist for the protective resistor: it must be "infallible." If two resistors are used in series, each resistor must be of a high enough value as to limit current if one of them fails short. If two resistors are used in parallel, each must be specified to dissipate the maximum fault power if one resistor fails open. An infallible resistor is one of metal film, ceramic glazed wirewound, or thick film SMD type with a conformal coating, all with suitable creepage/clearance spacing to avoid a non-countable fault. The infallible resistor is considered to fail only to an open circuit. The examiner may take this as one countable fault, but unless it reveals failures downstream of the resistor, it does not inform the analysis.

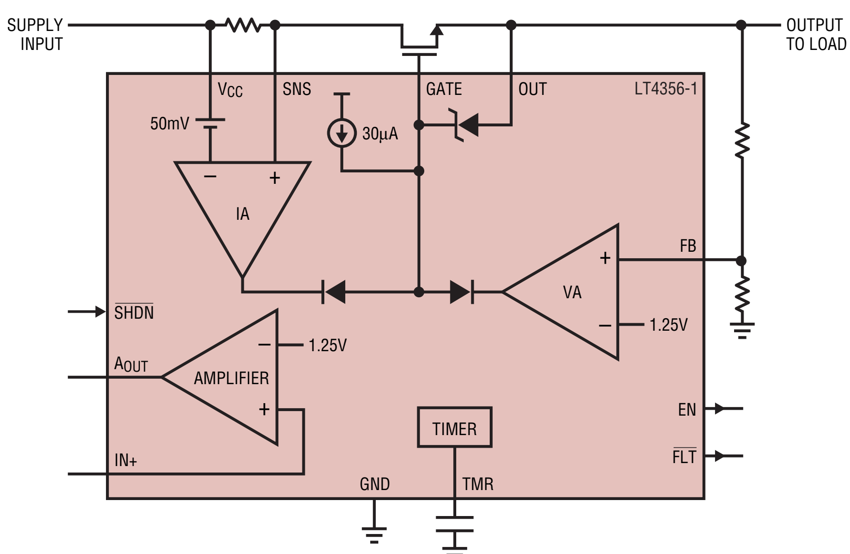

Figure 5. Simplified block diagram of the LT4356

Despite their simplicity, passive barriers exact a high price in power loss and size. Maximum power is transferred to field apparatus only when its input impedance is equal to the resistance of the current limiting resistor in the barrier, and this is only half of the power supplied to the barrier. If more than a few milliwatts are required in the field apparatus, the barrier resistor may become physically large. Such resistors are understandably expensive, have a limited value range and are difficult to source and mount. If a fuse is not included in the design, the Zener diodes likewise become bulky and expensive. The fact that the fuse must be encapsulated (Paragraph 7.3) usually dictates that the entire barrier is encapsulated, making it impossible to service as well as messy and more expensive to manufacture.

Determining Maximum Safe Field Apparatus Power Limits

The actual power that may be transferred to a field apparatus through the associated apparatus barrier is determined entirely by the level of certification the instrument supplier is seeking. This in turn is determined entirely by the environment it will encounter.

The Class and Division rating desired is easily determined. However, the flammable gas/dust type is what determines the Apparatus Group and T code. The fact that hydrogen has a relatively high ignition temperature (560°C) and very low spark ignition energy (20µJ) demonstrates that careful thought must given to these parameters before seeking certification testing. Here we confine our discussions to Class I locations, gasses and vapors in surface operations, Group II. To determine how much power can be available at the output of a barrier, and still be safely faulted open or shorted, we utilize the empirically determined gas ignition curves published in the standards. These curves indicate the maximum voltage and current allowable for a given gas group.

There are three charts published in the standards, one for resistive, inductive and capacitive circuits. Figure 4 shows the curve for a simple resistive circuit. For sake of discussion, we assume that we are dealing with the worst environment for spark ignition, acetylene, Group IIA. Referring to Figure 4, at $20V_{OC}$ it appears that up to 400mA I_{SC} is allowed without danger of ignition. Additionally, this power must not permit a corresponding surface temperature rise high enough to thermally ignite the gas in normal or fault conditions.

Some authorities recommend derating the voltage V_{OC} by 10% and the current I_{SC} by 33%. This is stated in the standards (IEC 60079-11, 10.1.4.2) under safety factors. The calculated value of the current limiting series resistor is simply V_{OC}/I_{SC} = 20/0.4 = 5Ω. The power the resistor must dissipate is $V_{OC} \bullet I_{SC}$ or $(I_{SC})2/R$ or $(V_{OC})2/R$, whichever is highest during circuit operation or fault. Simple calculations show that even small amounts of power may require rather physically large current-limiting resistors. A final note: the Standards state that from empirical and analytical data, a T4 (135°C) temperature code is automatically awarded to any circuit using 1.3 watts or less.

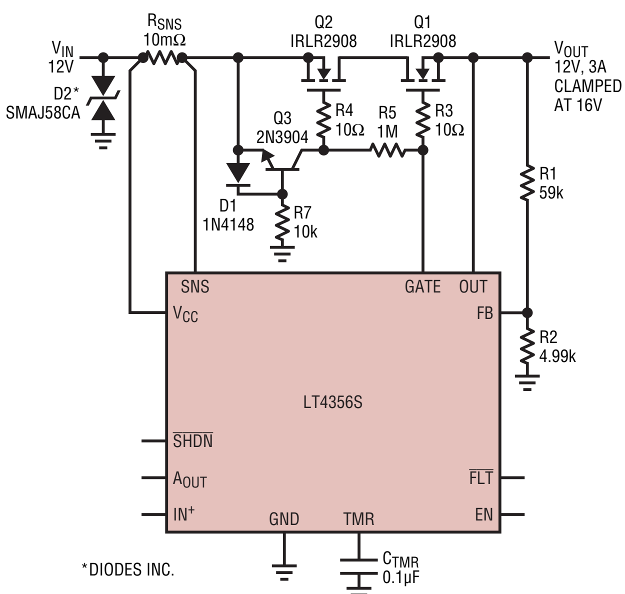

Figure 6. Redundant pass transistors

Using the LT4356 Surge Stopper as an Intrinsic Safety Barrier

The LT4356 series of overvoltage/overcurrent limiters are excellent choices for designing active protective barriers with minimum parts count and wasted power. Recognizing this fact, Linear Technology offers the IC in a 16-lead SO package with pin spacing sufficient to avoid penalizing the design with a non-countable fault when encapsulated. For voltages up to 10V, some Standards require a 1.5mm (59.1mil) creepage spacing, and 2.0mm (78.7 mil) for up to 30V. Before the 2006 79 series Standard, the IC must be encapsulated to meet these requirements because of the 50 mil (1.2mm) lead spacing of the 16-lead SO package, but encapsulation has the added advantage of raising the thermal limits on any associated components in the circuit.

However, the latest version of the harmonized Standard, IEC60079-11 (5th edition 2006-07) dramatically reduces these creepage requirements on printed circuit boards when the apparatus is enclosed in such a way as to meet ingress protection standards. These standards, known as IP levels, prevent ingress of dust or moisture, thereby guaranteeing a pollution degree of 2 or less. The idea is that the cleaner and drier the circuit board stays, the lower the board's CTI (Comparative Tracking Index) and the less likely leakage current will occur.

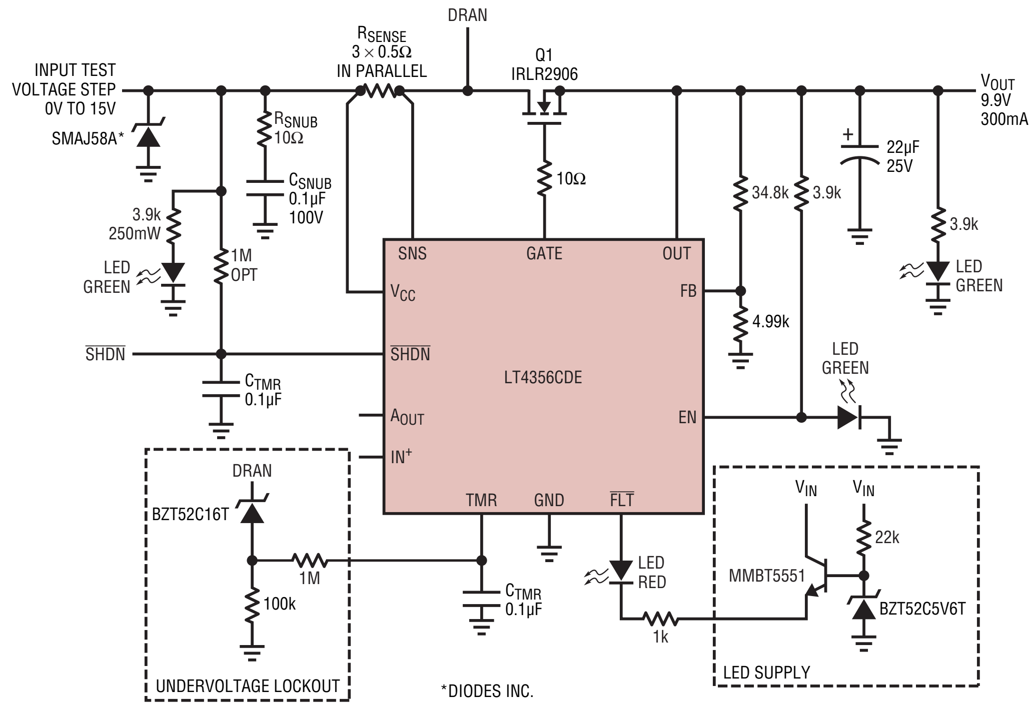

Figure 7. Schematic of a modified DC1018A evaluation board

Annex F of 79-11 therefore allows only 0.2mm creepage all the way up to 50V for Class I environments. Since most instrumentation is enclosed anyway, it behooves the designer to use an enclosure with a high IP rating, such as IP67 or IP68 to avoid encapsulation requirements. Unless encapsulation is necessary to meet thermal limits, its cost and associated problems are best avoided.

Figure 5 is a simplified block diagram of the LT4356 IC. The LT4356 monitors both current and voltage continually and turns off the series pass MOSFET quickly if a fault occurs. Both current and voltage limits are set by external components, so limits may be changed easily. The current shunt resistor and the voltage feedback resistors should be made infallible to achieve certification. Usually the feedback resistors can be made arbitrarily large so that a MOSFET fault that shorts input power directly to the feedback resistors cannot cause significant power dissipation.

Nevertheless, two cautionary notes are in order. The first is that active devices (controllable semiconductors) can be used in Ex ib situations for power limitation (thermal ignition) but not for spark ignition protection. See paragraphs 7.5.2 and 7.5.3 in the Standards. Some interpretations may allow active barrier use in Zone 0, but only in triplicate form. The second caution is that, as with any IS barrier, even for Ex ib (single fault) applications, barrier failure usually results in non-countable thermal fault failure downstream of the barrier. Therefore, redundancy is required in case one of the barriers fails.

The LT4356 provides for two series pass transistors, typically for reverse polarity protection. Protection against polarity reversal is required "where this could occur." A single diode is deemed acceptable to satisfy this requirement, but two pass transistors offer better protection from countable faults without a significant voltage drop.

For Ex ib environments, the examiner can use his single countable fault to internally short all the pins on the IC to analyze resultant failures. While properly rated redundant Zeners could be positioned at the output of the LT4356 to provide a voltage limit, at any appreciable power level the cost and difficulty of specifying these Zeners makes it more cost effective to simply duplicate the entire barrier. Note that for Ex ia applications, either triplicate barriers, or two barriers with a series infallible resistor are required to meet the double-fault analysis rule.

From here on, we assume that spacing and thermal rise, component ratings, PCB tack width and redundancy rules are followed and the circuit cannot be failed with either countable or non-countable faults. The remaining question is that of spark ignition energy. For this purpose, the LT4356 may not prove useful, depending on the application.

The LT4356 reacts to both current and voltage faults by turning off the pass transistor(s). However, since it does not shut down instantaneously, some amount of energy squirts through the barrier. In the standards this is termed the let-through energy, and is usually assessed using oscilloscope measurements and/or an actual spark ignition test in a chamber. If this energy is enough to ignite the subject gas, the barrier has failed certification. Acceptable let-through energy is summarized in Table 3.

Bench tests reveal that the LT4356 is much more than adequate for even Ex ia thermal ignition applications. Bench testing was done using a modified

LT4356 evaluation board DC1018A. The schematic for the setup appears in Figure 7. The feedback resistors were selected for an IS-specific 9.9V voltage limit and the current sense resistor value was changed to allow a 300mA current limit. Both overvoltage and overcurrent limit performance were tested. The voltage limit was evaluated by a step change in input from zero to 15V. The current limit was evaluated by applying a direct short to the output ground through a low $R_{DS(ON)}$ MOSFET driven by a 5V square wave.

The IC series offers a number of fault recovery options using fault timers that may be exploited by the designer of IS apparatus, depending on the application, but these are not discussed here. The automatic fault reset enabled on the evaluation board is left enabled for testing.

Figure 8 shows a scope trace of the voltage clamping action when the evaluation board is powered up with a 15V supply and a 9.9V clamp limit. The action of the fault reset timer is obvious.

More importantly, Figure 9 shows the current fault action. It shows that when the short circuit is applied, by turning on the load MOSFET, voltage is clamped to ground in less than 6μs. Channel 1 is the trigger pulse and Channel 2 is the barrier output voltage. Although not shown, the current is also declining , though not as rapidly as voltage. The slew rate of the current is dependent on the power supply source impedance, the circuit inductance and the MOSFET gate capacitance, among other variables. In general, as small a MOSFET die size as possible should be used, and it may be necessary to use a low value resistor in series with the barrier output to stay below the spark ignition thresholds.

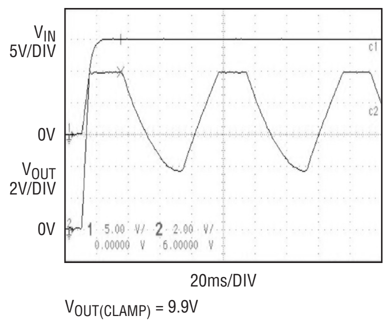

Figure 8. Overvoltage fault operation

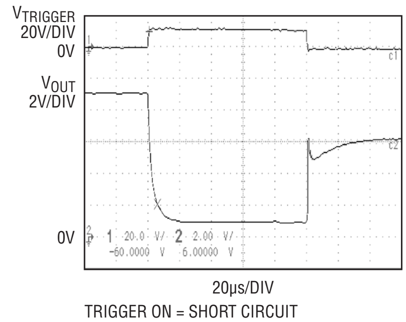

Figure 9. Overcurrent fault operation

To properly calculate the let-through energy, the power profile must be derived from both current and voltage curves and then integrated over time. Spark ignition testing is only done on connections that may be broken without opening the instrument enclosure. That is, cables or connectors to devices outside and beyond the barrier itself. The examiner may cut the cable or disconnect connectors to measure spark ignition potential. Within the enclosure, only thermal ignition potential must be assessed.

Conclusion

Any supplier wishing to sell equipment into markets and environments that may be explosive must follow design rules that make their operation in such environments nonincendive. That is, they must not be capable of providing either thermal or spark ignition sources. Several standard methods exist for providing such protection, but for electronic instrumentation, the preferred and least costly approach is usually Intrinsic Safety. The International Standards that govern electrical devices in explosive atmospheres are convoluted and in many cases vague as to the design methods necessary to achieve compliance. In today's safety conscious world, both governments and markets demand that the apparatus be certified to compliance with the standards. Certification is done by a number of regulatory bodies known as Nationally Recognized Test Laboratories, and a thorough and detailed analysis process is performed before certification is awarded.

Obtaining certification of instrumentation for IS environments is greatly eased by proper protective barrier design. While passive barriers are simple to design, they exact heavy penalties in size and cost when more than a few milliwatts are needed for proper operation. Active barriers can achieve safe operation while delivering several watts of energy, but the design rules are more complex.

Integrated circuits such as the LT4356 make active barrier designs considerably easier to certify if basic rules are followed. The superb response times of the LT4356 series voltage/current clamps are key to meeting regulatory requirements for limiting power that could cause thermal ignition. Careful design, and possibly additional fast clamps may be needed if the LT4356 is to be used to limit spark ignition also.

This article does not cover all of the details necessary for a compliant barrier design and thorough study of the applicable standards is still required of an IS designer. Nevertheless, certification-ready active barriers are now very accessible, giving designers and their companies an unprecedented opportunity to expand into heretofore, relatively closed markets.

Table 3. Permissible let-through energy by IEC/NEC gas group

Apparatus Group Classification	Let-Through Energy
Class I Group IIC = Ethylene	20μJ
Class I Group IIB = Hydrogen	80μJ
Class I Group IIA = Acetylene	160μJ
Class I Group I = Methane	226μJ

Consider New Precision Amplifiers for Updated Industrial Equipment Designs

by Brian Black

Introduction

Industrial equipment is designed for long life cycles, so the electronic components used in industrial applications are often chosen with significant emphasis on proven performance, quality and reliability. Precision amplifiers are no exception. Even if new and innovative amplifiers become available over a product's lifetime, a redesigned board is often built using the same proven op amps in the old board. Even for entirely new applications, designers will choose amplifiers that have proven their mettle in other circuits, making a choice based more on familiarity than performance.

Although an amplifier may have been tried and proven in a design, it is not necessarily the best solution for every new design. Many can benefit from using more recently released amplifiers, which can improve overall system performance, reduce power consumption, shrink the board real estate and expand the capability of the system while reducing component count.

Table 1 shows is a list of high performance amplifiers and their features. Many are pin compatible with older amplifiers, making it easy to swap them into existing designs to update industrial applications.

Table 1. Comparison of old and new high performance industrial amplifiers

Industry Standard Amplifiers	Features	Alternative Amplifiers	Feature Improvements
LT1078 LT2078	❏ Precision ❏ Micropower ❏ Single Supply	LTC6078*	❏ Higher Precision ❏ Lower Noise ❏ Faster
LT1012 LT1097	❏ Precision ❏ Low Noise ❏ Stable with any C-Load	LT1880	❏ Rail-to-Rail Out
LT1112 LT1114	❏ Low Power ❏ Matching Specs ❏ C-Load Stable	LT1881 Family LT6010 Family	❏ Higher Precision ❏ Rail-to-Rail Out
LT1494	❏ Ultralow Power ❏ Rail-to-Rail ❏ Precision	LT6003*	❏ Lower Power ❏ Lower Supply Range ❏ Smaller Package
LT1008 LT1055 Family LT1169	❏ Picoamp Input Bias Current	LTC6240 Family* LTC6084 Family* LTC6088 Family*	❏ Lower Power ❏ Lower Noise ❏ Higher Precision ❏ Faster ❏ Rail-to-Rail Out
LT1013 LT1014	❏ Low Offset	LT1490A LT1491A	❏ Rail-to-Rail In/Out ❏ Over-The-Top ❏ Lower Noise
LT1028	❏ Low Noise ❏ Low Drift ❏ Unity Gain Stable	LT6200 Family* LT6230 Family*	❏ Lower Power ❏ Faster ❏ Rail-to-Rail In/Out
LT1007 LT1037	❏ Low Noise	LT1677 Family	❏ Rail-to-Rail In/Out
LT1124 Family	❏ Low Noise ❏ Low 1/f Corner ❏ Precision	LT6202 Family* LT6233 Family*	❏ Lower Power ❏ Lower Noise ❏ Faster ❏ Rail-to-Rail In/Out
LTC1050 Family	❏ Zero Drift ❏ No External Capacitors	LTC2050 Family*	❏ Shutdown ❏ Lower Offset/Drift

* Maximum supply voltage is lower than predecessor

Old and New Amplifiers Go Head-to-Head

What follows is a comparison of some old and new amplifiers, where the new can easily be swapped in for the old. Figures 1 and 2 show two applications that can benefit from the updated features offered in recently released amps.

Rugged LT1494 vs Miniscule LT6003

The LT1494 (introduced in 1997) is a precision micropower (375µV offset voltage at 1.5µA supply current) rail-to-rail input and output amplifier ideal

Table 2. LT1056 vs LTC6240HV

Feature:	LTC1056	LTC6240HV
Rail-to-Rail Outputs	NO	YES
Minimum Supply Voltage	10V	2.8V
Maximum Supply Voltage	40V	12V
Single Supply	NO	YES
Supply Current	7mA	3.3mA
V_{OS}	800µV	250µV
I_B	150pA	1pA
Noise Voltage Density	22nV/√Hz	10nV/√Hz
GBW	5.5MHz	18mHz
Slew Rate	14V/µs	10V/µs
Settling Time	600ns	900ns

for low power battery operated applications. Its rugged design includes reverse battery protection along with Linear Technology's Over-The-Top® feature, which allows inputs to operate above the voltage rails without affecting the amplifier.

For handheld systems where reducing space and extending battery life are top design priorities, the LT6003 can be swapped for the LT1494. The LT6003 is designed specifically with handheld devices in mind with higher integration, a smaller package, and a lower supply voltage than the LT1494.

The LT6003 also has a lower minimum supply voltage, 1.6V vs 2.2V for the LT1494. This feature allows the LT6003 to operate on a wider range of supplies and allows for a deeper discharge of alkaline batteries (known for the steep dropoff in battery voltage when depleted). The LT6003 further extends battery life with a lower supply current of 1µA vs 1.5µA for the LT1494. Consistent rail-to-rail inputs and outputs preserve dynamic range even at low supply voltages.

Furthermore, the LT6003 is offered in a tiny 2mm × 2mm DFN package, which is three times smaller than the LT1494's MSOP package. The LT1494 still has the advantage of higher maximum supply voltage of up to 36V vs the 18V of the LT6003. Also, the Over-The-Top inputs of the LT1494 make it a great choice for applications in which the inputs may go above the positive supply.

The LT1677 Updates the LT1007 with Rail-to-Rail Inputs and Outputs

The LT1007, introduced in 1985 as one of Linear Technology's first product releases, is a precision low noise 40V amplifier with a great combination of DC performance, high gain, and low noise performance, making it ideal for small signal applications. However, since neither the inputs nor the outputs are rail-to-rail, the designer must take care to consider the headroom required for the part to function properly. Systems that can benefit from rail-to-rail inputs and outputs as a way to increase dynamic range, to reduce the supply voltage, or to eliminate the negative supply rail altogether, should consider using the LT1677.

The LT1677 is a single supply drop-in update to the LT1007 with the added benefits of rail-to-rail inputs and outputs. An important feature in low voltage (as low as 3V), single-supply applications is the ability to maximize the dynamic range. The LT1677's input common mode range can swing 100mV beyond either rail and the output is guaranteed to swing to within 170mV of either rail. This rail-to-rail benefit comes with minimal impact on noise and DC precision.

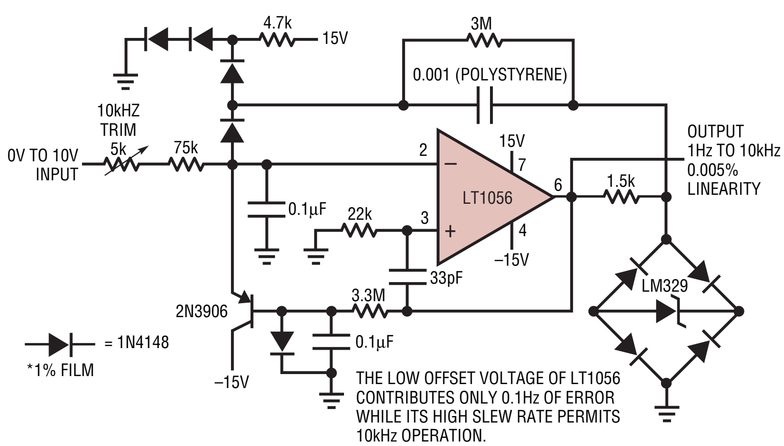

Figure 1. Precision: 1Hz to 10kHz voltage-to-frequency converter

The LT1112 and LT1114 vs LT1881 Family and LT6010 Family

The LT1112 and LT1114 have a wide supply range of 2V to 40V, high precision and very low noise; there is not much missing from these older standards. An alternative to these parts is the LT1881 family, which adds rail-to-rail outputs. The LT1881 family brings the performance of the LT1112 to applications that need the wide dynamic range. Another option is the LT6010 family, which achieves higher precision than the LT1112/LT1114 and includes rail-to-rail outputs. It is especially attractive for low power applications due to its lower supply current and shutdown capability.

Conclusion

Amplifiers are highly versatile building blocks that can often be reused from one system design to the next, which can simplify redesign. The pitfall of reuse is that designers can miss out on the benefits offered by newer amplifiers, sometimes settling for sub-optimal performance, higher costs and larger system size, when a better solution is just as easy to use. Not only are most of the newer devices pin-to-pin functional equivalents, they offer additional benefits such as lower power, smaller size, or rail-to-rail outputs which can help next generation designs achieve longer battery life, better precision and smaller form factors.

Table 3. LT1078 vs LTC6078

Feature:	LT1078	LTC6078
Rail-to-Rail Outputs	NO	YES
Minimum Supply Voltage	2.3V	2.7V
Maximum Supply Voltage	44V	6V
Shutdown Mode	NO	YES
Supply Current	50µA	72µA
V_{OS}	120µV	25µV
I_B	10nA	1pA
Noise Voltage Density	$28nV/\sqrt{Hz}$	$16\ nV/\sqrt{Hz}$
GBW	200kHz	750kHz

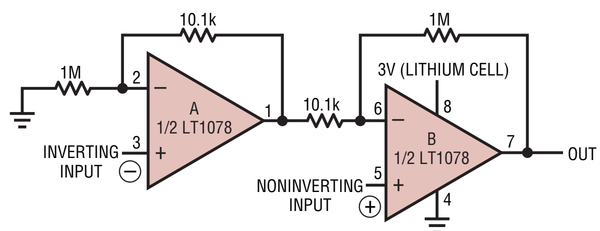

Figure 2. AC speed: single battery, micropower, gain = 100 instrumentation amplifier

LTC2978, continued from page 5

tion has been selected, the designer can save the parameters to a file and upload it to the LTC factory. LTC can use the file to pre-program parts, thus allowing the customer to bring up their boards with minimum hassle.

The LTC2978 utilizes the industry standard PMBus interface protocol which is a superset of the I^2C compatible SMBus standard. PMBus is an open and widely adopted standard that clearly defines the protocols for digital power management of individual DC/DC POL converters. The LTC2978 supports a large number of the PMBus commands. It also features a number of DC/DC converter manufacturer-specific commands to keep complexity low and versatility high.

Conclusion

With its unprecedented parametric accuracy, rich feature set, and modular architecture, the LTC2978 is an ideal solution for managing large arrays of DC/DC POL converters.

The industry standard PMBus interface, free PC-based graphical setup software, and integrated EEPROM make it easy to customize the LTC2978 for any application. Designers can use the PC-based graphical interface to configure a device and upload the configuration to the LTC factory. From this, Linear Technology can provide ready-to-use, pre-programmed devices, customized for the particular application.

Other features include an integrated precision reference, a multiplexed 15-bit ΔΣ ADC, eight 10-bit voltage-buffered IDACs, eight overvoltage and undervoltage 10-bit voltage supervisors with programmable thresholds and response times, and an integrated EEPROM for storing configuration parameters and fault-log information. The LTC2978 is offered in a 64-lead 9mm × 9mm QFN package.

Analog VGA Simplifies Design and Outperforms Competing Gain Control Methods

by Walter Strifler

Introduction

Variable gain amplifiers (VGAs) are widely used in communications and imaging applications such as cellular radio, satellite receivers, global positioning, radar, and ultrasound applications. Most of these applications involve transmit and receive signals of varying amplitude that need to be managed within the constraints of the overall system design. On the transmit side, the signal amplitude is usually adjusted near a maximum limit imposed by the transmit power amplifier or below a power limit imposed by the receivers or reflectors of the signal. On the receive side, the signal amplitude is usually amplified and tailored to take optimum advantage of the demodulator or ADC that decodes the signal. In both the transmit and receive case, the optimum signal gain targets change over time and temperature, so most systems share a common requirement of controlling signal amplitude through the use of adjustable gain stages commonly known as variable gain amplifiers.

This article introduces the LTC6412, Linear Technology's first high frequency, analog-controlled VGA—now added to Linear Technology's existing portfolio of digitally controlled VGAs. The design considerations for analog vs digital control are also discussed. This is followed by a brief introduction to the important design and performance features of the LTC6412 along with a discussion of a few application examples.

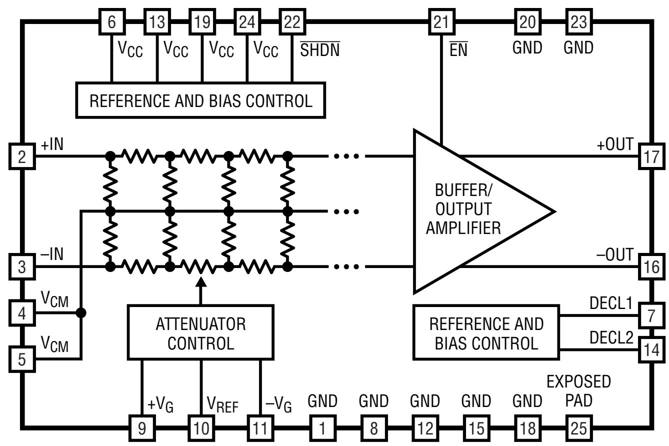

Figure 1. Block diagram of the LTC6412

Analog vs Digital Control of VGAs

The vast majority of modern communication and imaging equipment contains significant digital hardware in the form of microprocessors, controllers, memory, data busses and the like, so the choice of analog vs digital system control would seem to be a forgone conclusion in favor of the digitally controlled VGA. While this trend statement is largely true, it overlooks important distinctions between the two types of VGA control.

The digitally controlled VGA is a natural choice when the system parameters that determine optimum gain are known to the digital control system and are readily available across a data bus. This information is piped to the data inputs of the VGA, and the desired gain is step-adjusted during noncritical periods in the time-slotted signal.

The digital control scenario is the goal of most system designs, but it leaves many application gaps for

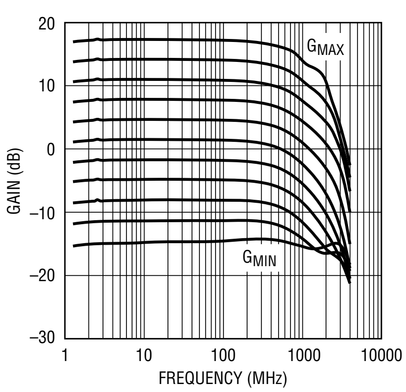

Figure 2. LTC6412 gain vs frequency over gain control range

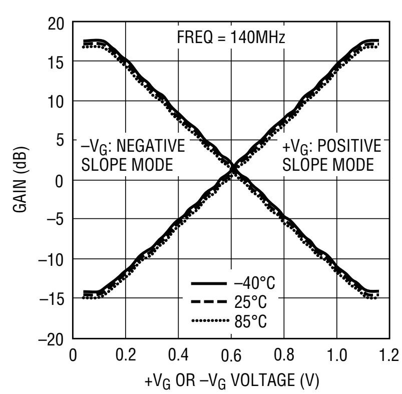

Figure 3. Differential gain vs control voltage over temperature for the LTC6412

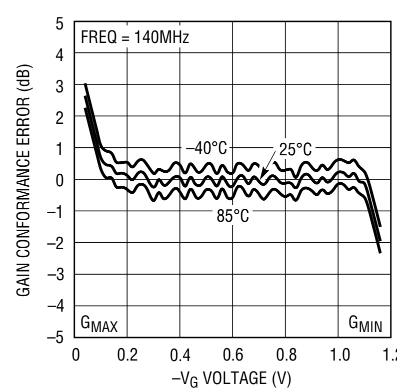

Figure 4. LTC6412 gain conformance error vs control voltage over temperature

clever analog solutions. For example, what if the information needed to control the amplifier gain is not known to the digital control system or no practical data bus is available? What if the RF signal through the amplifier chain cannot tolerate any step disturbance in amplitude or phase? These kinds of situations arise often enough to sustain a healthy market for analog-controlled VGAs. A few such applications are discussed later in this article.

Design Features

The LTC6412 is an 800MHz analog-controlled VGA manufactured on an advanced silicon-germanium (SiGe) BiCMOS process that offers the speed and performance of a complementary SiGe bipolar process along with the flexibility and compactness of a CMOS process. The term SiGe refers to the material composition of the bipolar base layers whereby a SiGe semiconductor alloy is used to create critical bandgap discontinuities and drift fields within the bipolar devices to improve high speed performance.

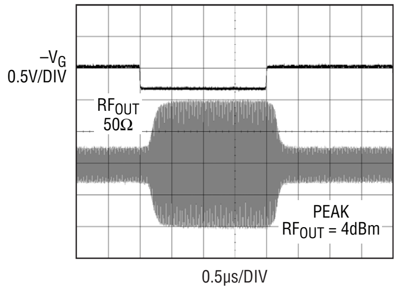

Figure 5. LTC6412 gain control 10dB step response at IF = 70MHz

Figure 1 shows a block diagram of the LTC6412. The design employs an interpolated, tapped attenuator circuit architecture to generate the variable gain characteristic of the amplifier. The tapped attenuator is fed to a buffer and output amplifier to complete the differential signal path. The circuit architecture provides good RF input handling capability along with a constant output noise and output IP3 characteristic that are desirable for most IF signal chain applications.

The internal circuitry takes the gain control signal from the $\pm V_G$ terminals and converts this to an appropriate set of control signals to the attenuator ladder. The attenuator control preserves OIP3 through the interpolated transitions and ensures that the linear-in-dB gain response is continuous and monotonic over the 31dB gain range for both slow and fast moving input control signals, all while maintaining a fixed input and output terminal impedance. The control terminal inputs can be configured for positive or negative gain slope mode by connecting the unused control terminal to the V_{REF} pin provided.

The output amplifier employs an open-collector topology and linearizing techniques similar to the LT5554. Enhanced clamping circuits provide fast overdrive recovery up to 15dB signal compression. The entire circuit runs off a 3.3V supply at a nominal total supply current of 110mA.

Electrical Performance

The LTC6412 is a fully differential VGA designed for AC-coupled operation in signal chains from 1MHz–500MHz and provides a typical maximum gain of 17dB and minimum noise figure (NF) of 10dB over this frequency range.

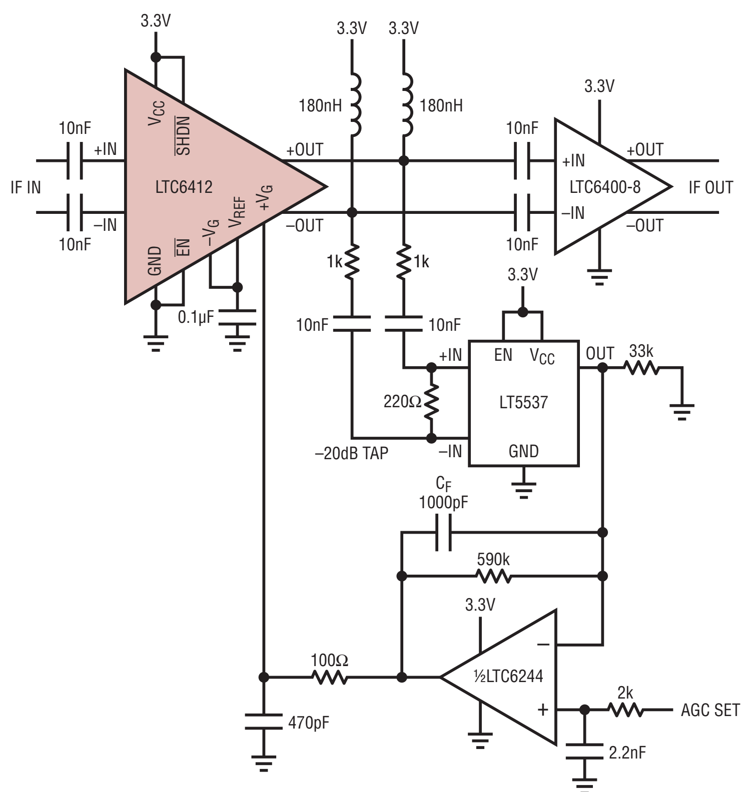

Figure 6. Analog control loop application circuit at IF = 240MHz. LTC6412 bypass capacitors to ground omitted for clarity.

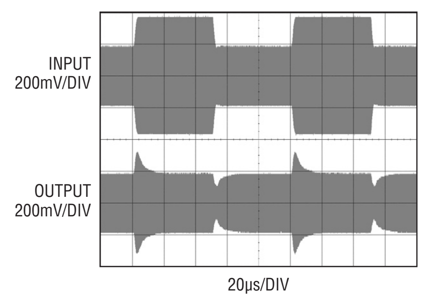

Figure 7. Measured analog control loop circuit response to 6dB step changes in input signal amplitude for C_F = 1000pF

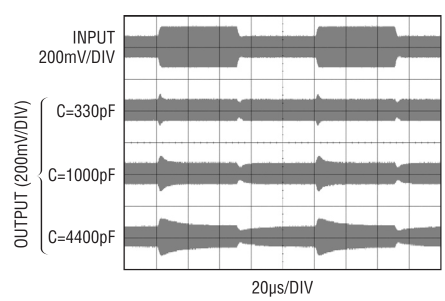

Figure 8. Measured analog control loop response to 6dB step changes in input signal amplitude over a range of C_F values

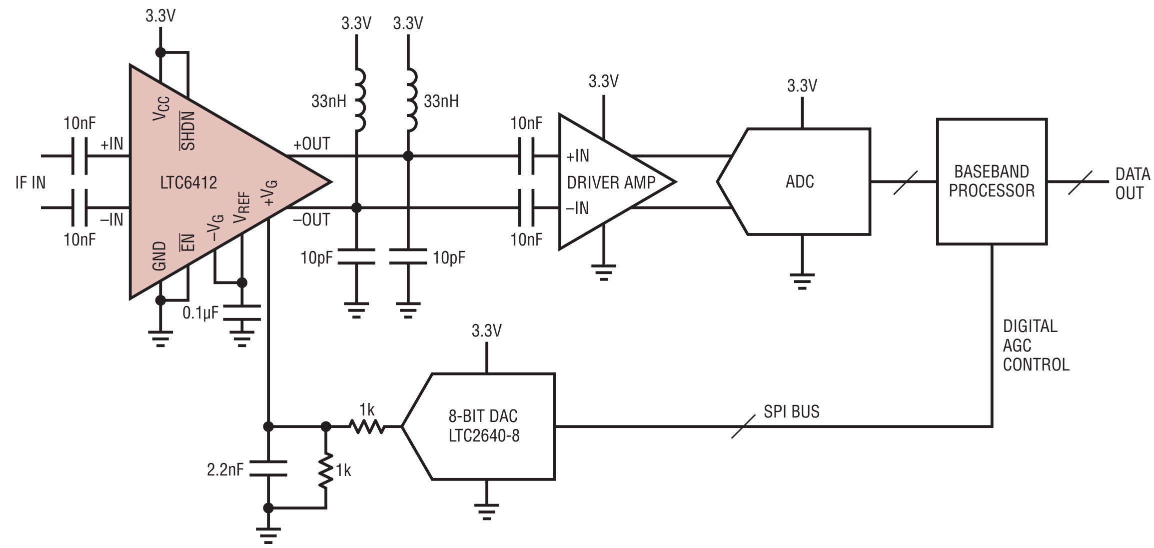

Figure 9. Digital control loop application circuit at IF = 240MHz. LTC6412 bypass capacitors to ground omitted for clarity.

At a typical operating intermediate frequency (IF) of 240MHz, the part delivers a constant OIP3 = 35dBm and constant (IIP-NF) = 8dBm over the –14dB to +17dB gain range. The flat output noise (NF + Gain) and flat OIP3 combination produces a uniform spurious-free dynamic range (SRDR) > 120dB over the full gain control range at 240MHz. The data sheet describes the operating performance in more detail, but a few excerpts are worth noting here.

Figure 2 illustrates the gain vs frequency performance of the LTC6412. Uniform gain slope and spacing are maintained throughout the gain control range and across the recommended operating frequency range.

Figure 3 illustrates the gain control response to the ±V_G inputs. The linear-in-dB response is accurately maintained throughout the gain control range with an RMS error ripple of approximately 0.1dB as depicted in Figure 4.

Figure 5 illustrates a typical gain step response. The settling time of 400ns is smooth and roughly independent of the step size. The phase change is also continuous through any step and typically less than 5° for signals of 240MHz or lower.

Typical Applications

Analog AGC

Automatic gain control (AGC) is usually the first application that comes to mind for an analog-controlled VGA. The idea is to use the linear-in-dB VGA together with a linear-in-dB detector to form a servo control loop that automatically adjusts the signal amplitude to a set level. An example of such a control loop is shown in Figure 6. The loop gain of 100 provides an AGC accuracy of a few tenths of a dB, and the dominant pole compensation from C_F = 1000pF provides a well-damped response time of 15µs shown in Figure 7. Adjusting C_F over a 13:1 range produces a similar proportional range in settling time (see Figure 8).

The analog gain control loop is an attractive solution for simple signals. The linear-in-dB nature of both the VGA and detector produces control dynamics that are constant and linear throughout the control range. The detector shown in the example is a peak detector, but an RMS detector can also be used.

Digital AGC

The analog gain control loop is less attractive for 3G and 4G communication signals with a high crest factor

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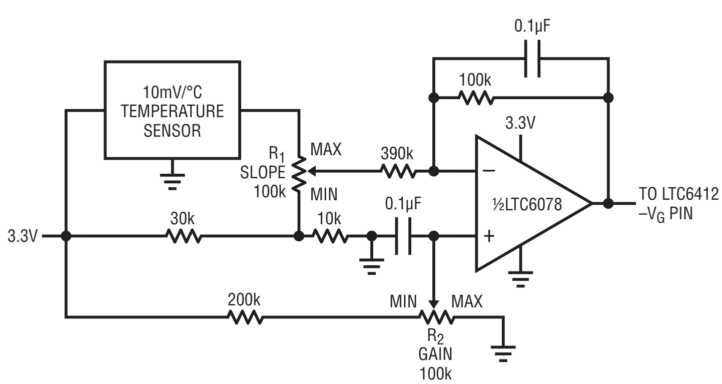

Figure 10. Application circuit for static gain adjust and temperature gain slope compensation using a PTAT temperature sensing IC. Adjust R1 and R2 as needed and route output to –V_G control terminal of the LTC6412.

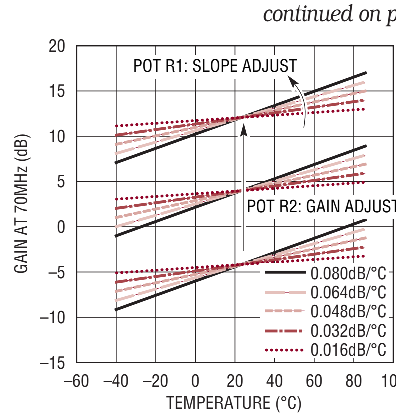

Figure 11. Gain vs temperature performance characteristics of the PTAT sensor based circuit shown in Figure 10

Accurate Silicon Oscillator Reduces Overall System Power Consumption

by Albert Huntington

Introduction

Choosing a clock used to be simple: grab an off-the-shelf fixed-frequency super-accurate, low jitter quartz crystal, or cobble together a rather noisy, inaccurate RC oscillator using discrete components. Recently, though, the number of clock choices has expanded, making the decision tougher, giving rise to a number of important questions. Is crystal accuracy absolutely necessary? Are low power consumption and reliability important, suggesting an all silicon solution? What about cheap ceramic resonators—are they up to the task?

Each of these solutions has strengths and weaknesses. Power consumption, accuracy, noise and durability must all come into consideration when choosing a clock. The LTC6930 is a self-contained, fully integrated all silicon oscillator that occupies a unique space within the world of clock solutions, providing a combination of accuracy and low power features that is hard to beat.

The LTC6930, which requires no additional external components, can accurately provide fixed frequencies between 32.768kHz and 8.192MHz over a wide supply range of 1.7V–5.5V (Table 1). It typically dissipates between 100µA and 500µA depending on frequency and load, and is available in both 8-lead 2mm × 3mm DFN and standard MS8 packages.

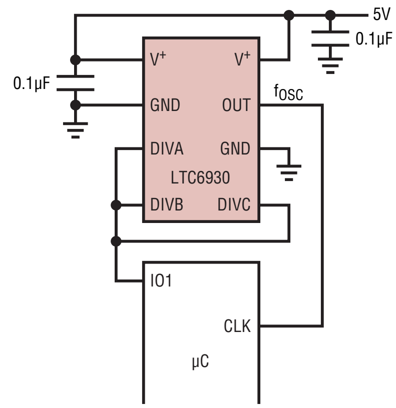

Figure 1. The LTC6930 clock configured as a 2-speed clock, slow and fast clock speeds are set via one I/O pin on a microprocessor

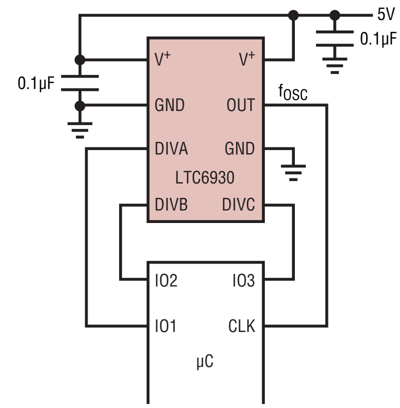

Figure 2. Fine control of the the LTC6930's frequency via three microprocessor I/O pins

What is not immediately obvious about the LTC6930 is that its low power dissipation represents only a small part of its power-saving abilities. Its accurate and fast start-up and switching times save substantially more system power than the device consumes by itself.

What is not immediately obvious about the LTC6930 is that its low power dissipation represents only a small part of its power-saving abilities. Its accurate and fast start-up and switching times save substantially more *system power* than the device consumes by itself.

Smart Power Savings

Many electronic devices, especially battery powered portable applications, use low power sleep mode to conserve power during times of low activity. The depth and effectiveness of sleep modes is limited by recovery requirements—namely, how fast must the system come back up to full power. A standard crystal oscillator can be a major contributor to recovery delays.

Crystal oscillators can take tens of milliseconds to produce an accurate output when recovering from

Table 1. LTC6930 available frequencies and settings

	÷1	÷2	÷4	÷8	÷16	÷32	÷64	÷128
DIV Pin Settings [DIVC][DIVB][DIVA]	000	001	010	011	100	101	110	111
LTC6930-4.19	4.194304MHz	2.097152MHz	1.048576MHz	524.288kHz	262.144kHz	131.072kHz	65.536kHz	32.768kHz
LTC6930-5.00	5.000MHz	2.500MHz	1.250MHz	625.0kHz	312.5kHz	156.25kHz	78.125kHz	39.0625kHz
LTC6930-7.37	7.3728MHz	3.6864MHz	1.8432MHz	921.6kHz	460.8kHz	230.4kHz	115.2kHz	57.6kHZ
LTC6930-8.00	8.000MHz	4.000MHz	2.000MHz	1000kHz	500.0kHz	250.0kHz	125.0kHz	62.5kHz
LTC6930-8.19	8.192MHz	4.096MHZ	2.048MHz	1024kHz	512.0kHz	256.0kHz	128.0kHz	64.0kHz

a shutdown. The technique of using two clocks, a fast clock for full power operation and a slower sleep mode clock, can degrade the accuracy and recovery performance of the system—where clock switching generates runt pulses and slivers that can sabotage sleep recovery times.

In contrast, the LTC6930 easily and accurately transitions between fast clock mode and a slower sleep mode. The transition from one clock frequency to another takes less than a single clock cycle, and no runt pulses or slivers are generated. The LTC6930 also features a fast 100µs start-up time and the first clock-out is guaranteed to be clean. This makes it possible for the designer to apply sleep mode liberally, without worrying about clock recovery, thus saving significant overall system power.

Shifting the Clock Frequency

The output frequency of the LTC6930 is set by three DIV pins, which control an internal clock divider. The factory set master oscillator frequency may be divided by a factor of up to 128, and switching between these division modes is accomplished within a single clock period and without slivers or runt pulses. All three pins may be tied together to enable a simple digital signal from a microcontroller to shift the clock down by a factor of 128 as shown in Figure 1. This is enough to bring an 8MHz clock down to 64kHz.

The DIV pins can be addressed in various combinations for smaller frequency shifts or independently for complex power modulating systems where a microcontroller has fine control over its own clock speed, as shown in Figure 2.

Although there are some power savings within the LTC6930 when the output frequency is lowered (Figure 3), far greater savings are realized in the overall system. Power consumption in CMOS devices such as microcontrollers is roughly proportional to their operating clock speed. Slowing down the clock by a factor of 128 during a sleep condition can reduce the system power by a factor of 100—very important in a system that spends significant time in sleep mode.

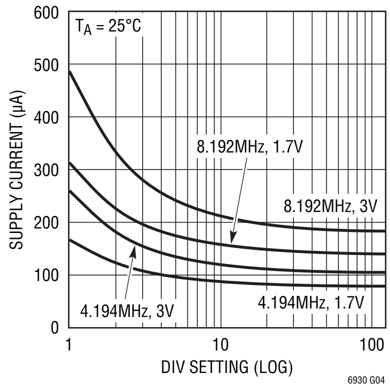

Figure 3. The LTC6930 supply current at different divide ratios

Power Savings from Fast Start-Up

Many systems are designed to sleep most of the time and wake up briefly on occasion to perform some task. If a task requires particularly little time, the total power dissipated for the task may be dominated not by the awake time, but by the time it takes for the oscillator and associated sensory electronics to power up. The guaranteed fast start-up time of the LTC6930 allows system designers to budget minimal recovery time and thus save power in start-up settling time.

Crystal oscillators often specify start-up times of up to 20ms, if they specify them at all, and the first clocks out may be of low amplitude and otherwise out of spec. The designers task is further complicated by the fact that start-up time may vary randomly. See Figures 4 and 5 to see how a crystal oscillator start-up time compares quite unfavorably to the LTC6930 start-up. A system that needs to wake up occasionally for a millisecond to take a single measurement may end up spending 100ms waiting for its clock to come up without a clean signal and then settle in order to take that single measurement. The fast and clean 100µs start-up of the LTC6930 allows the designer of such a system to reduce wake time, and therefore power dissipation, again by a factor of around 100.

A Word on Accuracy

The big question when moving from a quartz crystal to a silicon oscillator will always be one of accuracy. If crystal oscillators do anything well, it is provide a stable and accurate frequency source, but accuracy is just one concern out of many.

While each individual application is different, Linear's years of experience with silicon oscillators allows us to make some general recommendations based on actual customer applications. With an initial accuracy of better than 0.09% and a commercial grade accuracy over temperature of better than 0.45%, the LTC6930 does not compete with crystal oscillators in all areas, but does provide a clock accurate enough for the most applications.

Of course, there are applications that require either accuracy or jitter characteristics out of the reach of the LTC6930, such as clocking high speed analog-to-digital converters such as the LTC2242 series, clocking jitter sensitive high speed serial communications systems such as Ethernet, and long term timekeeping functions such as a digital alarm clocks. Nevertheless, silicon oscillators like the LTC6930 perform far better than crystal oscillators when power consumption is a

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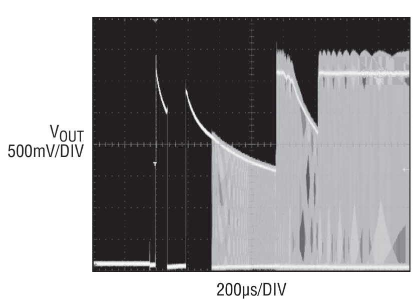

Figure 4. Typical crystal oscillator start-up transients

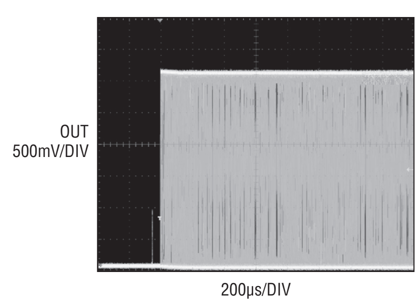

Figure 5. Typical LTC6930 start-up

Easy Multivoltage Layout with Complete Dual and Triple Output Point-of-Load µModule Regulators in 15mm × 15mm Packages

by Eddie Beville and Alan Chern

Introduction

Imagine a multivoltage printed circuit board so space-constrained that even the most experienced layout engineer would shiver at the thought of putting together the puzzle of components for DC/DC conversion. A typical multivoltage solution either incorporates a single multioutput DC/DC regulator IC or several independent regulators. Either solution requires a number of discrete support components, such as inductors, capacitors and resistors. Since there is a wide range of available small, high performance ICs, this type of system design is typical. Unfortunately, even the best of these regulators require careful placement of support components to take into account both electrical effects and heat dissipation concerns.

Board-mounted point-of-load (POL) DC/DC power supplies are becoming increasingly popular as they simplify board assembly and reduce external components. The ideal setup would have nearly everything packaged into a single chip, with the following features in a board-mounted POL power supply.

- ❑ Minimal components—far fewer than a discrete solution
- ❑ Multiple voltage input and output rails with available current sharing
- ❑ Independent input and output regulation for application flexibility
- ❑ Worry-free thermal dissipation
- ❑ Low noise output
- ❑ High efficiency

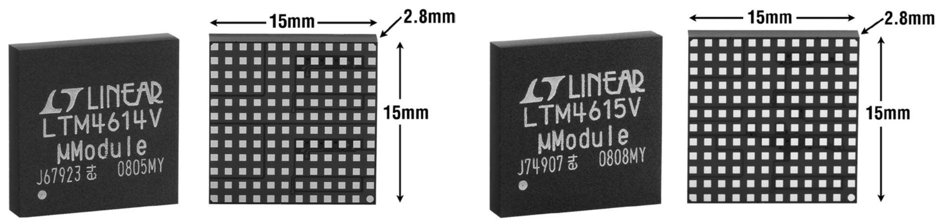

Figure 1. The LTM4614 dual output and LTM4615 triple output µModule regulators

The LTM4614 (dual output) and LTM4615 (triple) cure the headaches inherent in laying out multivoltage systems for space-constrained applications. The MOSFETs, inductor and other support components are all built into the package, so layout involves little more than finding a 15mm × 15mm space on the board.

Complete Dual and Triple DC/DC Regulators in IC Form Factors

The LTM4614 and LTM4615 cure the headaches inherent in laying out multivoltage systems for space-constrained applications. Both devices are point-of-load power supplies in a 15mm × 15mm × 2.8mm LGA surface mount packages, each with two switching 4A DC/DC regulators (see Figure 1). The LTM4615 adds a VLDO™ (very low dropout) linear regulator, making it a triple output voltage regulator. The MOSFETs, inductor and other support components are all built into the package, so layout involves little

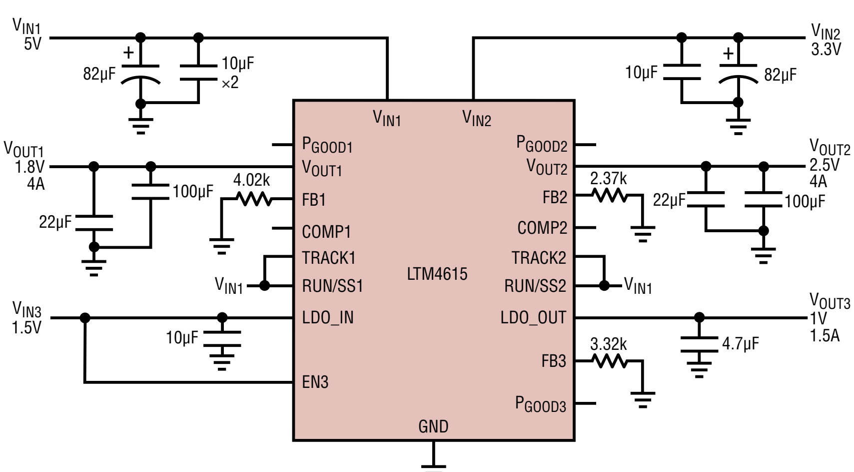

Figure 2. Very few components are required for a triple independent input (5V, 3.3V, 1.5V) to triple output (1.8V, 2.5V, 1V) µModule regulator design.

more than finding a 15mm × 15mm space on the board.

The two switching regulators operate from input voltages between 2.375V to 5.5V (6V peak) and each delivers a resistor-set output voltage of 0.8V to 5V at 4A of continuous current (5A peak). They operate at a 1.25MHz switching frequency using current mode architecture to enable fast transient response to line and load changes with no sacrifice in stability. The output voltages can track each other or another voltage. Other features include low output voltage ripple and excellent thermal dissipation.

The LTM4615's VLDO regulator accepts input voltages from 1.14V to 3.5V and is capable of up to 1.5A of output current with an adjustable output range of 0.4V to 2.6V, also via a resistor. The VLDO regulator has a low voltage dropout of 200mV at maximum load. The regulator can be used independently or used in conjunction with either of the two switching regulators to create a high efficiency, low noise, large ratio step down supply—simply tie one of the switching regulator's outputs to the input of the VLDO regulator.

Flexible Input and Output Combinations

The LTM4614 and LTM4615 power supplies can be used in a wide range of input and output combinations; from entirely independent inputs and outputs to single input, single output designs where a parallel, current sharing design enables high current applications.

Independent Inputs and Outputs

The LTM4614's and LTM4615's separate inputs and outputs make it possible to run each internal regulator from a different input. Figure 2 shows an application converting 5V, 3.3V, and 1.5V inputs to 1.8V, 2.5V, and 1V output voltage rails, respectively.

Single Input, Independent Outputs

For designs that only have a single source input voltage, tie the input voltage rails together as in Figure 3, where both inputs run off the 5V source input voltage, for example. If the input source voltage is too high for the VLDO regulator and a separate source is not available, the VLDO input of the LTM4615 can be tied to one of the outputs as in Figure 4.

Single Input, Current-Shared Outputs

For designs that require more than the 4A-per-regulator maximum output current, the two switching regulators can be tied together to form a paralleled, single-output 8A design (see Figure 5). This design also has efficiency advantages over a higher-current rated, single switching regulator design. In the case of the LTM4615, the VLDO linear regulator can still be used as an independent supply.

Power Sharing Multiple Inputs, Current-Shared Outputs

When a single input source cannot provide enough current to support a high power, single current-shared output, another input, even at a different voltage, can be used to provide the additional current. Figure 6 shows two different input voltages to power a single voltage current sharing output.

High Efficiency and Low Noise Output Voltage Ripple

The LTM4615 is capable of operating with all three regulators at full load while maintaining optimum efficiency. Figure 7 shows a typical LTM4615 design for a 3.3V input to three outputs. In Figure 7, the VLDO input is driven by V_{OUT2}. The expected efficiency

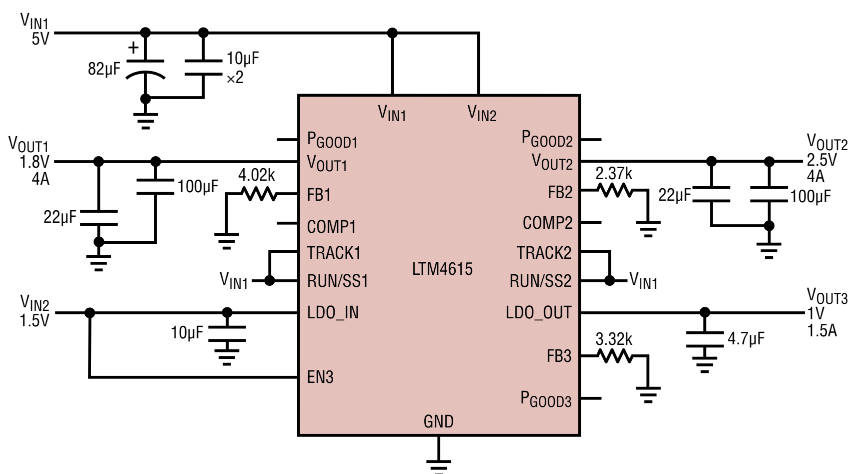

Figure 3. Single switching regulator input (5V) and single linear regulator input (1.5V) to triple output (1.8V, 2.5V, 1V) µModule regulator design

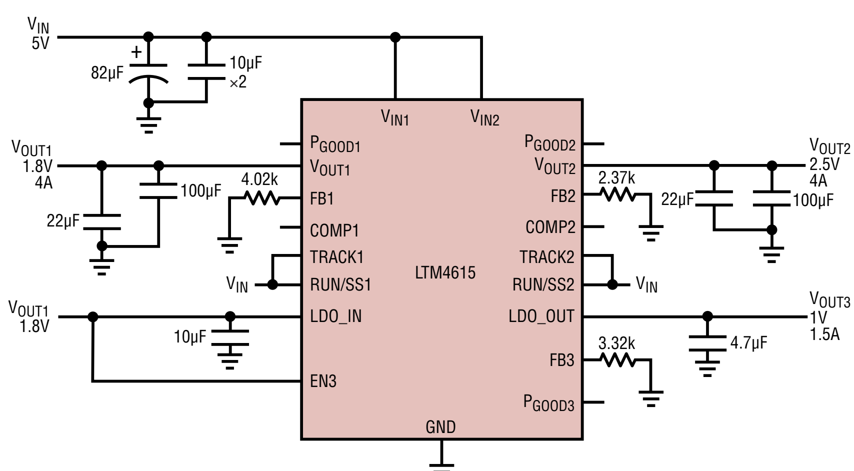

Figure 4. Single input (5V) to dual output (1.8V, 2.5V), with the linear regulator serving up a third output (1V) from an input tied to V_{OUT1} (1.8V)

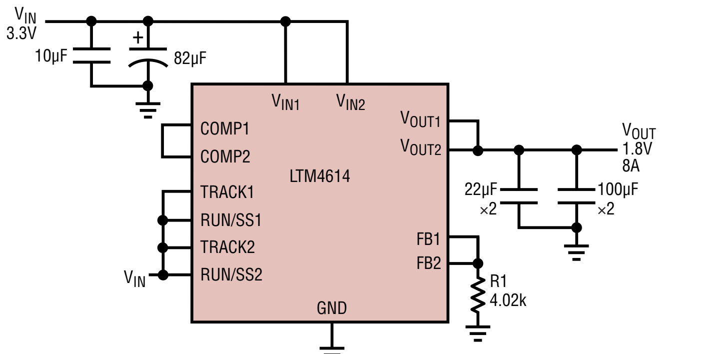

Figure 5. The two switching regulators share the load in a 1.8V/8A output system. (For an alternative 8A µModule regulator, see the LTM4608A data sheet.)

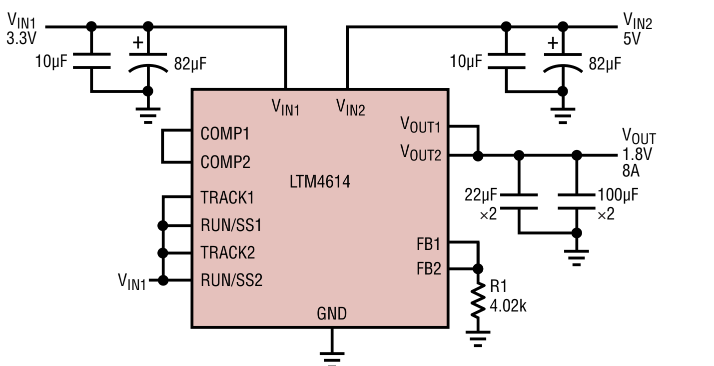

Figure 6. The two switching regulators combine available power from two independent input voltage rails (3.3V and 5V) and produce a single current-shared 1.8V/8A output.

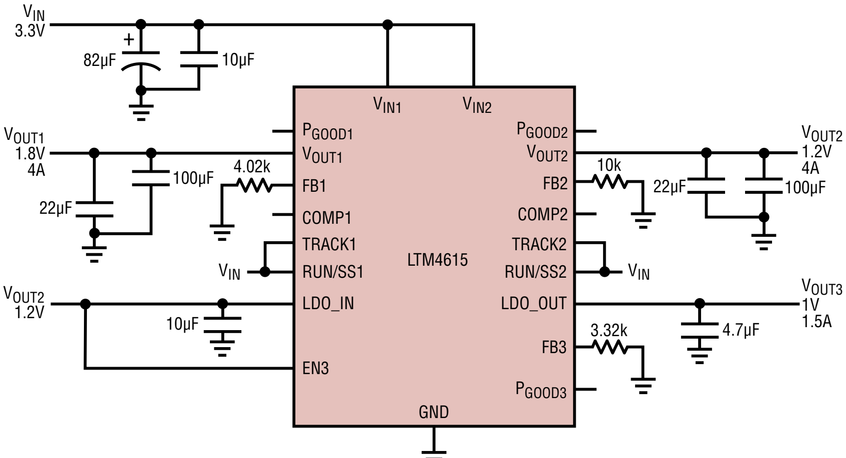

Figure 7. A single input, 3-output design using the LTM4615's VLDO regulator

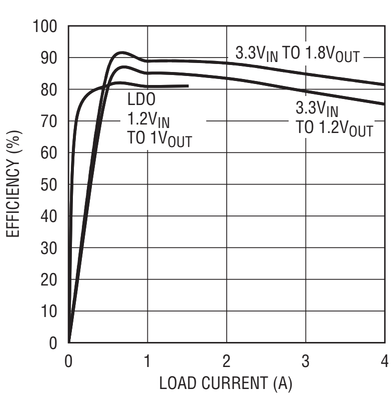

Figure 8. Efficiency of the circuit in Figure 7

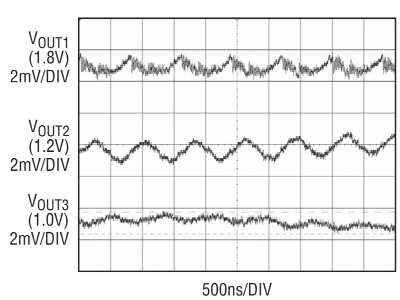

Figure 9. Low voltage ripple on all three outputs of Figure 7

of this design is shown in Figure 8. Expect similar efficiency results with the LTM4614 minus the additional VLDO output.

To minimize the number of support discrete components, both LTM4614 and LTM4615 include internal ceramic capacitors. Layout problems associated with placing external support components are eliminated. Additional output capacitors are needed if load steps from 0A to the full 4A are expected and if the input source impedance is compromised by long inductive leads or traces.

The benefit of combining a switching regulator with a linear regulator is the noise reduction benefits that can be gained. By utilizing the switching regulator's high efficiency step-down function and feeding its output to the input of the VLDO regulator, an exceptionally low ripple output is produced—ideal for systems that require a particularly clean signal. Figure 9 shows the low output voltage ripple for all three outputs. The VLDO regulator provides a very low noise 1V supply as it is driven by the output of the 1.2V switching regulator.

Thermally Enhanced Packaging

The LGA packaging allows heat sinking from both the top and bottom. From the bottom, the PCB copper layout draws heat away from the part and into the board. A heat sink can be placed on top of the device, such as a metal chassis,

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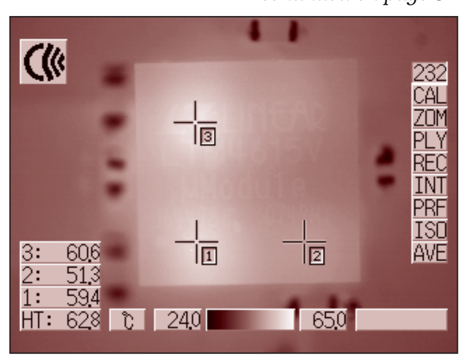

Figure 10. Top view thermal imaging of the unit at full load in an ambient temperature environment with no airflow. Cursors 1 and 3 mark the temperature hot spots on the unit for each of the two switching regulators. Both temperatures are fairly similar indicating balanced thermal conductivity.

Programmable Baseband Filter for Software-Defined UHF RFID Readers

by Philip Karantzalis

Introduction

Radio frequency identification (RFID) is an auto-ID technology that identifies any object that contains a coded tag. A UHF RFID system consists of a reader (or interrogator) that transmits information to a tag by modulating an RF signal in the 860MHz–960MHz frequency range. Typically, the tag is passive—it receives all of its operating energy from a reader that transmits a continuous-wave (CW) RF signal. A tag responds by modulating the reflection coefficient of its antenna, thereby backscattering an information signal to the reader.

Tag signal detection requires measuring the time interval between signal transitions (a data "1" symbol has a longer interval than a data "0" symbol). The reader initiates a tag inventory by sending a signal that instructs a tag to set its backscatter data rate and encoding. RFID readers can operate in a noisy RF environment where many readers are in close proximity. The three operating modes, single-interrogator, multiple interrogator and dense-interrogator, define the spectral limits of reader and tag signals. Software programmability of the receiver provides an optimum balance of reliable multitag detection and high data throughput. The programmable reader contains a high linearity direct conversion I and Q demodulator, low noise amplifiers, a dual baseband filter with variable gain and bandwidth and a dual analog-to-digital converter (ADC). The LTC6602 dual, matched, programmable bandpass filter can optimize high performance RFID readers.

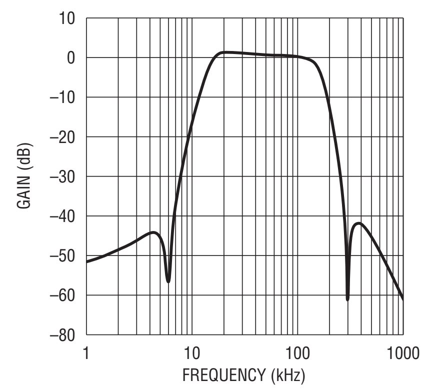

Figure 1. Filter response for a 15kHz–150kHz passband

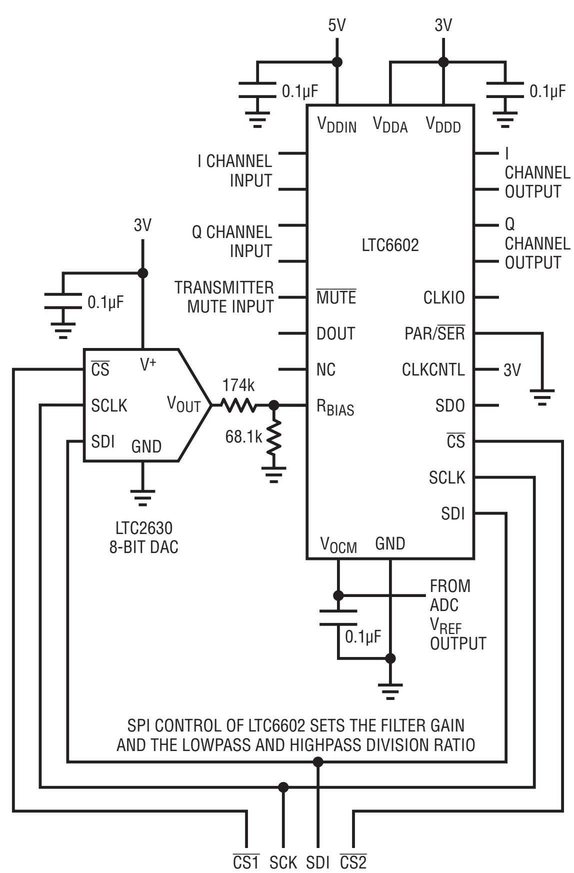

Figure 2. An Adaptable RFID baseband filter with SPI control

The LTC6602 Dual Bandpass Filter

The LTC6602 features two identical filter channels with matched gain control and frequency-controlled lowpass and highpass networks. The phase shift through each channel is matched to ±1 degree. A clock frequency, either internal or external, positions the passband of the filter at the required frequency spectrum.

The lowpass and highpass corner frequencies, as well as, the filter bandwidth are set by division ratios of the clock frequency. The lowpass division ratio options are 100, 300, 600 and the highpass division ratios are 1000, 2000, 6000. Figure 1 shows a typical filter response with a 90MHz internal clock and the division ratios set to 6000 and 600 for the highpass and lowpass, respectively. A sharp 4th order elliptical stopband response helps eliminate out-of-band noise. Controlling the baseband bandwidth permits software definition of the operating mode of the RFID receiver as it adapts to the operating environment.

An Adaptable Baseband Filter for an RFID Reader

Figure 2 shows a simple LTC6602-based filter circuit that uses SPI serial control to vary the filter's gain and bandwidth to adapt to a complex set of data rates and encoding. (The backscatter link frequency range is 40kHz to 640kHz and the data rate range is 5kbps to 640kbps.)

For fine resolution positioning of the filter, the internal clock frequency is set by an 8-bit LTC2630 DAC. A 0V to 3V DAC output range positions the clock frequency between 40MHz and 100MHz (234.4kHz per bit). The lowpass and highpass division ratios are set by serial SPI control of the LTC6602. The cutoff range for the highpass filter is 6.7kHz to 100kHz and 66.7kHz to 1MHz for the lowpass filter. The optimum filter bandwidth setting can be adjusted by a software algorithm and is a function of the data clock, data rate and encoding. The filter bandwidth must be sufficiently narrow to maximize the dynamic range of the ADC input and wide enough to preserve signal transitions and pulse widths (the proper filter setting ensures reliable DSP tag signal detection).

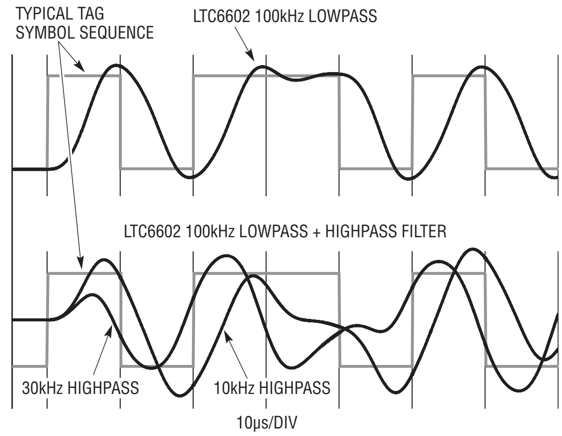

Figure 3. Filter transient response to a tag symbol sequence

Figure 3 shows an example of the filter's time domain response to a typical tag symbol sequence (a "short" pulse interval followed by a "long" pulse interval). The lowpass cutoff frequency is set equal to the reciprocal of the shortest interval (f_{CUTOFF} = 1/10µs = 100kHz). If the lowpass cutoff frequency is lower, the signal transition and time interval will be distorted beyond recognition. The setting of the highpass cutoff frequency is more qualitative than specific. The highpass cutoff frequency must be lower than the reciprocal of the longest interval (for the example shown, highpass f_{CUTOFF} < 1/20µs) and as high as possible to decrease the receiver's low frequency noise (of the baseband amplifier and the down-converted phase and amplitude noise). The lower half of Figure 3 shows the filter's overall response (lowpass plus highpass filter). Comparing the filter outputs with a 10kHz and a 30kHz highpass setting, the signal transitions and time intervals of the 10kHz output are adequate for detecting the symbol sequence (in an RFID environment, noise will be superimposed on the output signal). In general, increasing the lowpass f_{CUTOFF} and/or decreasing the highpass f_{CUTOFF} "enhances" signal transitions and intervals at the expense of increased filter output noise.

The LTC6602 dual bandpass filter is a programmable baseband filter for high performance UHF RFID readers. Using the LTC6602 under software control provides the ability to operate at high data rates with a single interrogator or with optimum tag signal detection in a multiple or dense interrogator physical setting. The LTC6602 is a very compact IC in a 4mm × 4mm QFN package and is programmable with parallel or serial control.

Conclusion

The LTC6602 dual bandpass filter is a programmable baseband filter for high performance UHF RFID readers. Using the LTC6602 under software control provides the ability to operate at high data rates with a single interrogator or with optimum tag signal detection in a multiple or dense interrogator physical setting. The LTC6602 is a very compact IC in a 4mm × 4mm QFN package and is programmable with parallel or serial control.

References:

1 The RF in RFID, Daniel M. Dobkin, 9/07, Elsevier Inc.

2 Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz to 960 MHz, Version 1.1.0, www.epcglobalinc.org/standards/specs/

µModule LED Driver Integrates All Circuitry, Including the Inductor, in a Surface Mount Package

by David Ng

Introduction

Once relegated to the hinterlands of low cost indicator lights, the LED is again in the spotlight of the lighting world. LED lighting is now ubiquitous, from car headlights to USB-powered lava lamps. Car headlights exemplify applications that capitalize on the LED's clear advantages—unwavering high quality light output, tough-as-steel robustness, inherent high efficiency—while a USB lava lamp exemplifies applications where *only* LEDs work. Despite these clear advantages, their requirement for regulated voltage *and* current make LED driver circuits more complex than the venerable light bulb, but some new devices are closing the gap. For instance, the LTM®8040 µModule LED driver integrates all the driver circuitry into a single package, allowing designers to refocus their time and effort on the details of lighting design critical to a product's success.

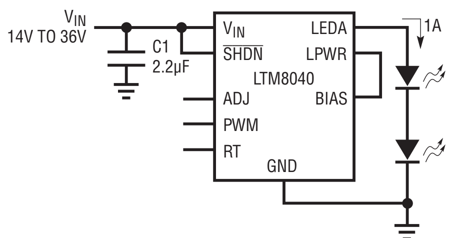

Figure 1. Driving an LED string with the LTM8040 is simple—just add the input capacitor and connect the LED string

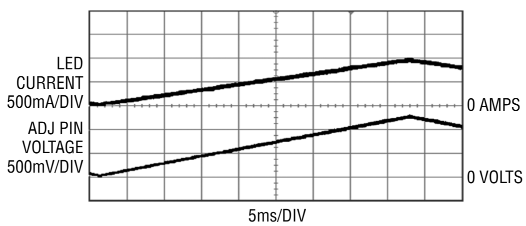

Figure 2. Drive a 0V to 1.25V voltage into the ADJ pin to control the LED current amplitude

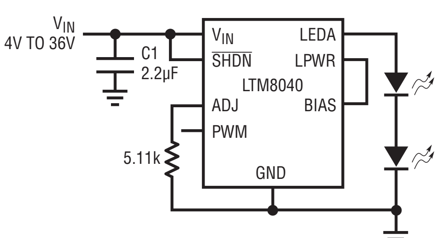

Figure 3. Control the LED current with a single resistor from ADJ to ground

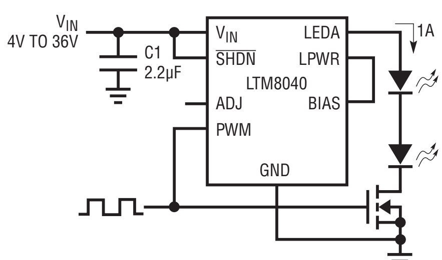

Figure 4. The LTM8040 can PWM its LED string with an external MOSFET.

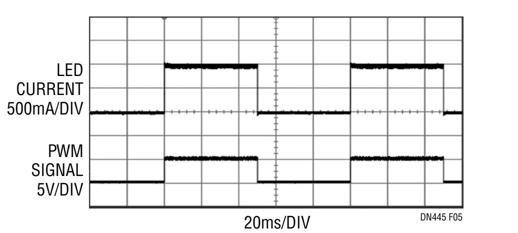

Figure 5. The LTM8040 can PWM LED current with minimal distortion, even at frequencies as low as 10Hz.

A Superior LED Driver

The LTM8040 is a complete step-down DC/DC switching converter system that can drive up to 1A through a string of LEDs. Its 4V to 36V input voltage range makes it suitable for a wide range of power sources, including 2-cell lithium-ion battery packs, rectified 12VAC and industrial 24V. The LTM8040 features both analog and PWM dimming, allowing a 250:1 dimming range. The built-in 14V output voltage clamp prevents damage in the case of an accidental open LED string. The default switching frequency of the LTM8040 is 500kHz, but switching frequencies to 2MHz can be set with a resistor from the RT pin to GND.

Easy to Use

The high level of integration in the LTM8040 minimizes external components and simplifies board layout. As shown in Figure 1, all that is necessary to drive an LED string up to 1A is the LTM8040 and an input decoupling capacitor. Even with all this built-in functionality, the LTM8040 itself is small, measuring only 15mm × 9mm × 4.32mm.

Rich Feature Set

The LTM8040 features an ADJ pin for precise LED current amplitude control. The ADJ pin accepts a full-scale input voltage range of 0V to 1.25V, linearly adjusting the output LED current from 0A to 1A. Figure 2 shows the ratiometric response of the output LED current versus the ADJ voltage. The ADJ pin is internally pulled up through a 5.11k precision resistor to an internal 1.25V reference, so the output LED current can also be adjusted by applying a single resistor from ADJ to ground, as shown in Figure 3.

The PWM control pin allows high dimming ratios. With an external MOSFET in series with the LED string as shown in Figure 4, the LTM8040 can achieve dimming ratios in excess of 250:1. As seen in Figure 5, there is little distortion of the PWM LED current, even at frequencies as low as 10Hz. The 10Hz performance is shown to illustrate the capabilities of the LTM8040—this frequency is too low for practical pulse width modulation, being well within the discrimination range of the human eye.

The LTM8040 also features a low power shutdown state. When the $\overline{\text{SHDN}}$ pin is active low, the input quiescent current is less than 1µA.

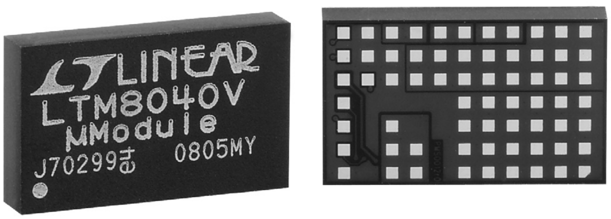

Figure 6. Only 9mm × 15mm × 4.32mm, the LTM8040 LED Driver is a complete system in an LGA package

Conclusion

The LTM8040 µModule LED driver makes it easy to drive LEDs. Its high level of integration and rich feature set, including open LED protection, analog and PWM dimming, save significant design time and board space.

LTC6412, continued from page 21

because the control target is often more complicated than a simple peak or RMS amplitude, and the amplitude noise introduced by the analog control loop may be unacceptable. A common solution for these systems is an analog VGA driven by a DAC as depicted in Figure 9.

The contradiction of a DAC controlling an analog-controlled VGA may appear at first as unusual and unecessary, but the arrangement provides key benefits. The gain step resolution is not determined by the VGA, and 8–12 bit DAC's are relatively inexpensive. More importantly, the signal gain can be adjusted with arbitrary smoothness, so the baseband processor can continue its demodulation/decoding operation without interruption. Most digital VGAs produce unacceptable signal discontinuities. The DAC does have a glitch of its own, but it is a baseband glitch that can be smoothed with filters. The glitch in many digital VGAs has no such remedy.

Gain and Temperature Compensation

Many communication receivers require frequent gain optimization, but others are designed with over-performing ADCs that can tolerate moderate signal amplitude variation and avoid much of the AGC hardware problem. However, even these "fixed gain" system blocks often require a gain

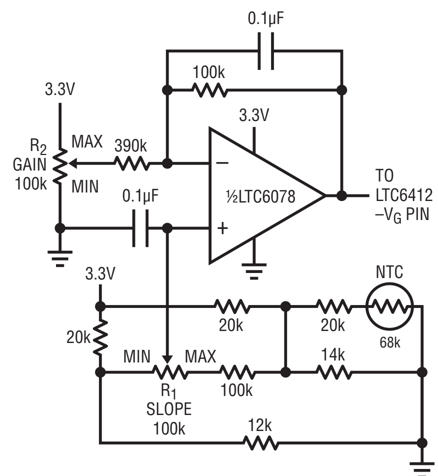

Figure 12. Thermistor-based application circuit for static gain adjust and temperature gain slope compensation. Adjust R1 and R2 as needed and route output to $-V_G$ control terminal of the LTC6412.

adjustment to compensate gain drift overtemperature and any cumulative gain tolerance of the other components. Several system components are cascaded to form a chain that usually includes a VGA to perform a one-time adjustment of gain and temperature slope to compensate the tolerances and slopes of the other components. In this scenario, the required temperature and compensation information is not known to the baseband processor or it is impractical to send this data to a suitably located VGA.

An analog-controlled VGA is a natural solution for this application because it can easily interpret the output of most temperature transducers without digitization. Figure 10 shows

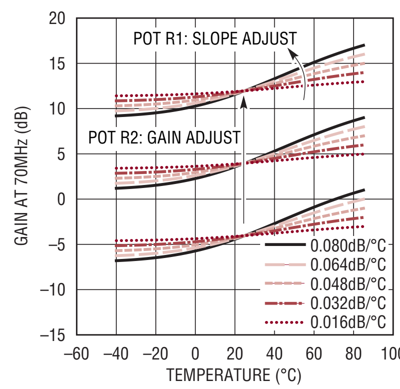

Figure 13. Gain vs temperature performance characteristics of the thermistor-based circuit shown in Figure 12

a simple application circuit using a common PTAT temperature sensor and an op amp to create the required $-V_G$ signal to adjust room temperature gain and temperature slope as shown in Figure 11. If temperature slope accuracy is only important for T > 0°C, then the same function can be performed with an inexpensive NTC thermistor as shown in Figures 12 and 13. Trying doing that with a digitally controlled VGA!

Conclusion

By combining the advanced SiGe process with an innovative design, the LTC6412 offers unparalleled analog VGA performance at 3.3V. The tiny 16mm² leadless package and minimal external components produce a cost effective, fully differential VGA solution in less than 1cm² of PCB area.

Low Power Boost Regulator with Dual Half-Bridge in 3mm × 2mm DFN Drives MEMS and Piezo Actuators

by Jesus Rosales

Introduction

Advances in manufacturing technology have made it possible for actuators, sensors, RF relays, and other moveable parts to be manufactured at a very small scale. These devices, referred to as MEMS (micro-electro-mechanical systems) or micro-machines, are finding their way into daily life in applications unheard of just a few years ago. MEMS are used in automotive, military, medical and consumer product applications.

Many types of MEMS devices consume very little power to operate and generally require the use of two support circuits, a step-up converter and a dual half-bridge driver. These support circuits must be very small and highly efficient to keep pace with ever-shrinking MEMS applications. To this end, the LT8415 integrates the step-up converter power switch and diode and the dual half-bridge driver in a 12-pin, 3mm × 2mm DFN package. Its novel switching architecture consumes very little power throughout the load range, making it an ideal match for driving low current MEMS.

The LT8415 generates output voltages up to 40V from sources ranging from 2.5V to 16V. The output is then available for the integrated complementary half-bridge drivers and is available via OUT1 and OUT2 (see Figure 1). Each half-bridge is made up of an N-channel MOSFET and a P-channel MOSFET, which are synchronously controlled by a single pin and never turn on at the same time. OUT1 and OUT2 are of the same polarity as IN1 and IN2, respectively. When the part is turned off, all MOSFETs are turned off, and the OUT1 and OUT2 nodes revert to a high impedance state with 20MΩ pull-down resistors to ground.

2.6V–5V Input to 34V Output MEMS Driver

Figure 2 shows a MEMS driver that takes a 2.6V–5V input and produces a 34V output. This circuit draws very little source current when the dual half-bridge is disabled. The input current is only 320µA at $2.6V_{IN}$ and 128µA at $5V_{IN}$. A logic level signal at IN1 and IN2 activates the dual half-bridge switches. Figure 3 shows the turn-on delay and rise time for OUT1 and OUT2 with both half-bridges activated. Figure 4 shows the turn-off delay and fall time with the 200pF and 1nF capacitive loads shown in Figure 2. See the data sheet details for measuring delay time.

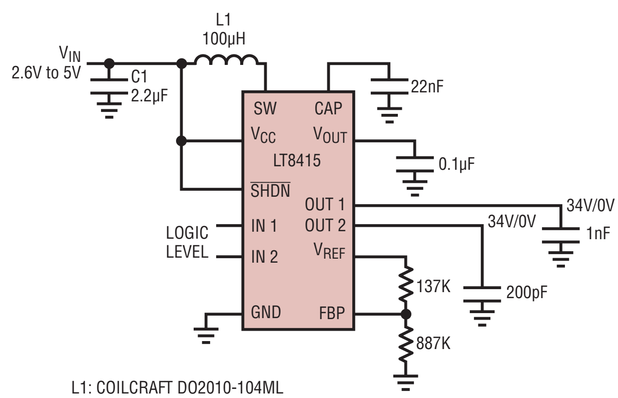

Figure 2. 2.6V–5V input to 34V dual half-bridge boost converter

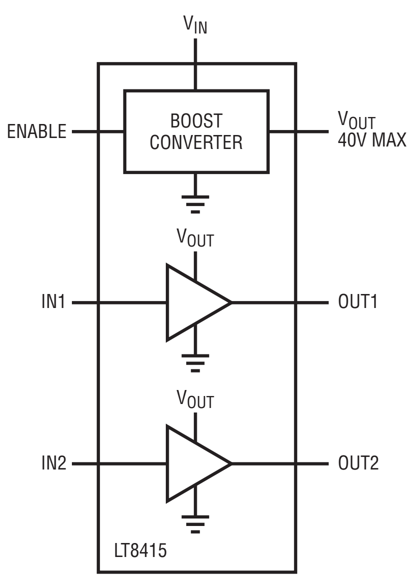

Figure 1. Simplified block diagram of the LT8415

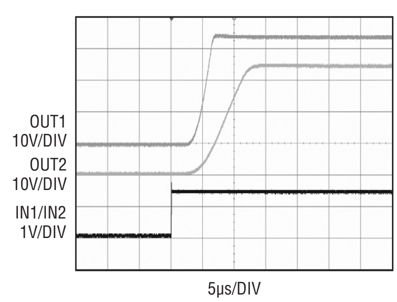

Figure 3. Turn-on delay and rise time for OUT1 and OUT2

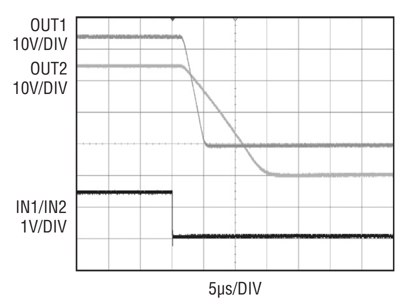

Figure 4. Turn-off delay and fall time for OUT1 and OUT2

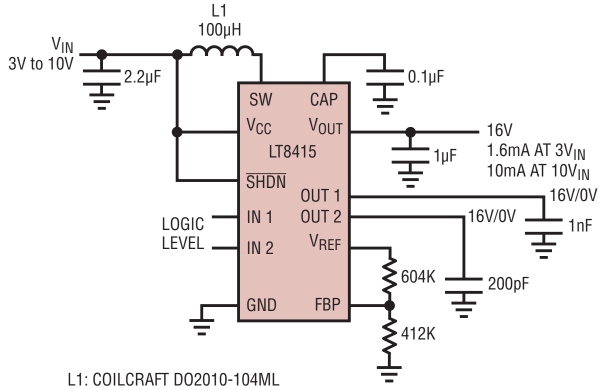

Figure 5. 3V–10V input to 16V dual half-bridge plus 16V output boost converter

3V–10V Input to 16V Output MEMS Driver and Bias Supply

Figure 5 shows a 3V–10V input to 16V output converter, where the output drives the dual half-bridge and also provides bias current for other circuitry. The converter in Figure 2 can be used in a similar fashion, but the current available at the output is reduced as the output voltage is increased. See the data sheet for details about maximum output current.

Integrated Resistor Divider

The LT8415 contains an integrated resistor divider such that if the FBP pin is at 1.235V or higher, the output is clamped at 40V. For lower output voltage levels use R1 and R2, calculating their values as instructed by the data sheet. This method of setting the output voltage ensures the voltage divider draws minimal current from the input when the part is turned off.

Conclusion

The LT8415 is an ideal match for driving low power MEMS. It integrates a step-up converter power switch and diode, a complementary dual half-bridge, and a novel switching architecture that minimizes power dissipation.

LTM4614/15, continued from page 26

to promote good thermal conductivity. Figure 10 shows that thermal dissipation is well-balanced between the two switching regulators.

Output Voltage Tracking

Tracking can be programmed using the TRACK1 and TRACK2 pins. To implement coincident tracking, at the slave's TRACK pin, divide the master regulator's output with a resistor divider that is the same as the slave regulator's feedback divider. Figure 11 shows a tracking design and Figure 12 shows the output. V_{OUT2} tracks V_{OUT1} in master-slave design with both outputs ramping up coincidently. The smooth start-up time is attributed to the soft-start capacitor.

Conclusion

The cumbersome designs typical of multivoltage regulation are a thing of the past. The LTM4614 and LTM4615 µModule multiple-output regulators can be easily fit into space-constrained system boards with far fewer components than discrete solutions. The dual-output LTM4614 µModule regulator and triple-output LTM4615 are small in size, have excellent thermal dissipation and have high efficiency. Independent input and output voltage rails give these µModule regulators unmatched flexibility. They can be used in a variety of input-output combinations, including input and output current sharing, output voltage tracking, and low noise output.

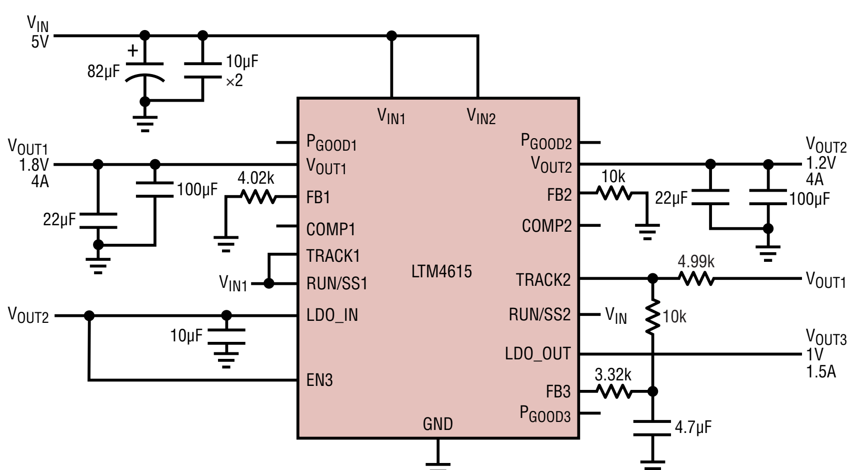

Figure 11. Output voltage tracking design example

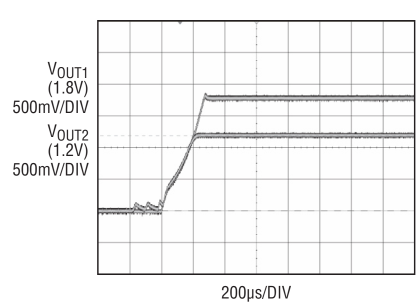

Figure 12. Start-up waveforms for the circuit in Figure 11

Synchronous Boost Converter with Fault Handling Generates 5V at 500mA in 1cm² of Board Space

by Eddy Wells

Introduction

Today's power supply designs must meet a number of stringent and sometimes competing requirements. In many cases the requirement for a small solution is at odds with the need for high conversion efficiency and the need to safely deal with fault conditions. The LTC3529 step-up DC/DC converter is designed to provide a "no compromises" design, offering high efficiency to minimize dissipated heat and maximize battery life while still maintaining a small footprint for size-constrained power applications requiring a 5V supply.

The LTC3529 can detect a shorted output condition, disable the IC, and report the event to a host microprocessor. This feature is important for portable applications where devices communicate with each other directly, or system power applications where voltages on multiple boards must be monitored and maintained. As shown in Figure 1, the LTC3529 offers a compact and efficient solution consisting of only three tiny external components.

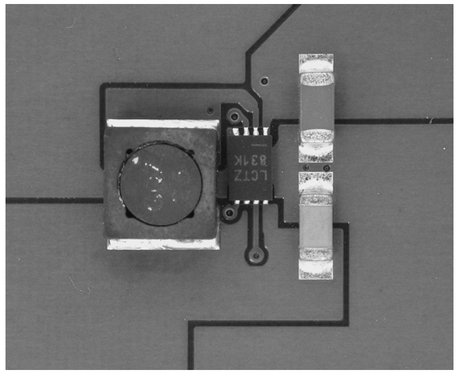

Figure 1. A tiny (1cm²) yet complete solution drives USB On-The-Go bus power.

Lithium-Ion to 5V, 2.5W Converter

Figure 2 shows an LTC3529-based solution for converting from a single lithium-ion battery or 3.3V board supply to 5V with up to 500mA of load current. Requiring only an inductor and input/output filter capacitors, the entire converter occupies only about 1cm² of board space. The IC includes internal compensation, the output divider, and soft-start circuitry to minimize external components. In shutdown, the LTC3529 disconnects the output from the input and draws less than 1µA from the source.

In fixed frequency PWM mode, the efficiency for a typical Li-Ion source to 5V peaks at 92%, as shown in Figure 4, and remains above 80% for load currents greater than 30mA. The LTC3529 delivers up to 500mA of current at a 5V output and is therefore suitable for both low and high power USB applications. As with any DC/DC converter, a tradeoff exists between switching frequency, inductor value, output capacitance and output ripple.

To allow the use of tiny external components, the LTC3529 operates at 1.5MHz and is stable with a 4.7µH inductor and output capacitances of 4.7µF (compatible with USB On-The-Go specifications) or greater. The Li-Ion-to-5V converter in Figure 3 utilizes a 10µF output capacitor, and exhibits a peak-to-peak output ripple of only 10mV. Low ESR and ESL ceramic capacitors (such as X5R) are recommended for both V_{IN} and V_{OUT} bypassing.

Fault Detection

The LTC3529 is robust to output short circuits, a problem that arises as the terminals of the IC are exposed to the outside world to facilitate connection between portable devices or system board edge connectors. To defend against output shorts, the LTC3529 shuts down when an excessive current draw is detected through the internal MOSFET switches continuously for 15ms.

Figure 4 illustrates the fault handling protocol of the LTC3529. Based

continued on page 35

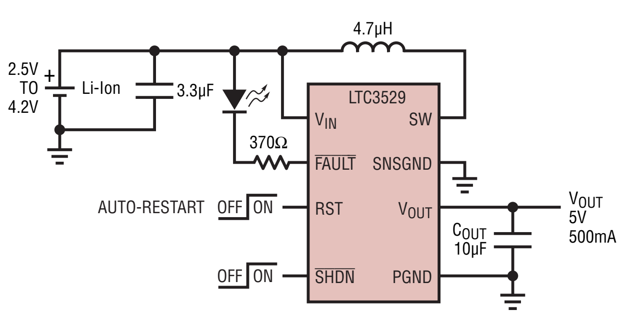

Figure 2. Li-Ion to 5V synchronous boost converter

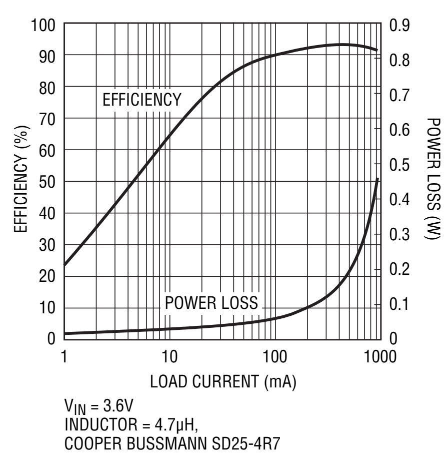

Figure 3. Efficiency for the circuit in Figure 2

Robust DC/DC Step-Down Converter in 3mm × 3mm DFN Resists 60V Input Surges

by Chuen Ming Tan

Introduction

Industrial and test equipment must often run on relatively unregulated 9V-to-24V rails that also support high current and inductive load switching of electromechanical devices. When such devices switch on and off, momentary power surges disrupt power flow, causing voltage fluctuations and large overvoltage spikes on the rail.

The LTC3631, LTC3632 and LTC3642 are robust, monolithic DC/DC step-down solutions that produce a well-regulated supply even in volatile voltage environments. All can operate from a wide input voltage ranges and sustain repetitive 60V surges (see Table 1). The output voltage is immune to large voltage swings in the input (see Figure 1).

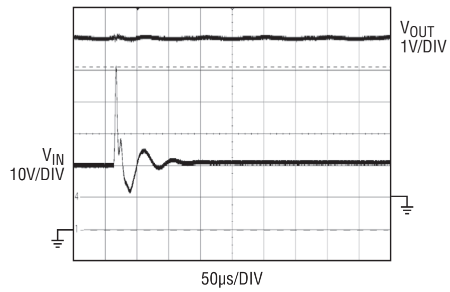

Figure 1. The LTC3642 continues to regulate the output despite a >45V spike on the input.

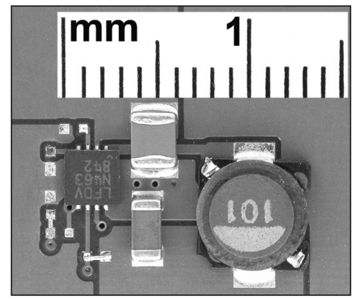

Figure 2. The solution size of LTC3642-3.3/5 in a 3mm × 3mm DFN package

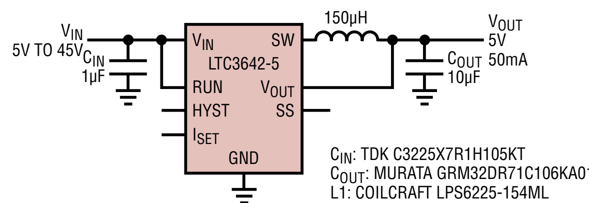

Figure 3. With the LTC3642EDD-3.3/5 only two capacitors and an inductor are required for operation

Compact and Easy to Use

The LTC3642 comes in compact 3mm × 3mm DFN and MS8E packages with integrated MOSFETs, as shown in Figure 2. It is extremely easy to use, requiring no loop compensation. The 3.3V and 5V fixed output versions only need two capacitors and an inductor for operation (see Figure 3).

The constant peak switch current thresholds of these devices inherently protect them from output short circuits. Moreover, each of these devices can reduce its peak switch current threshold such that smaller input and output capacitors can be used.

When operating with a high input voltage source, the LTC3642's RUN pin can be optionally configured to increase its undervoltage lockout (UVLO). Until the input voltage exceeds the UVLO, the input remains disconnected from the load. The RUN pin can be tied directly to the input voltage and can be used together with the hysteresis pin to prevent unwanted UVLO triggering due to noisy input supplies and high voltage coupling in harsh environments. When above the UVLO, the LTC3642 soft starts its output with an internal 0.75ms timer. The duration of the soft-start timer can be increased by adding an external capacitor in the SS pin.

High Efficiency

Unlike a linear regulator, the LTC3642 is a monolithic synchronous buck regulator which does not suffer significant power loss as a result of IR drop between the input and output. High efficiency is also achieved with Burst Mode® operation, which reduces switching activity at light loads to minimize switching losses. Figure 4 shows a fairly constant efficiency curve from light load all the way to full load. During shutdown, this device only draws 3μA even at a maximum input voltage of 45V. With such high efficiency, the LTC3642 is a good fit in battery-operated motorized vehicles,

Table 1. Comparison of monolithic wide input range buck regulators

	LTC3631	LTC3632	LTC3642
Maximum Output Current	100mA	20mA	50mA
Input Voltage Operating Range	4.5V–45V	4.5V–50V	4.5V–45V
Input Voltage Abs Max	60V	60V	60V

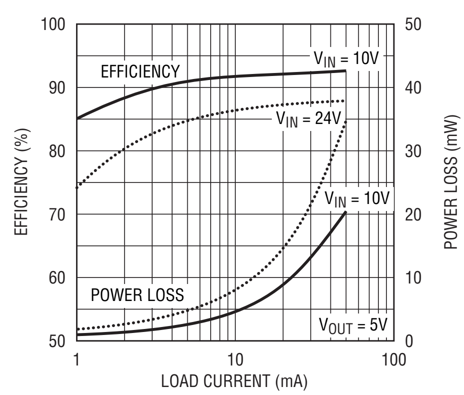

Figure 4. Efficiency for circuit in Figure 3

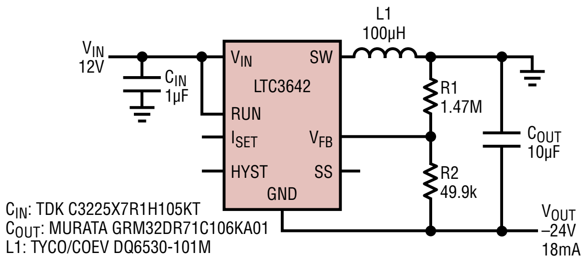

Figure 5. Generating a negative 24V output voltage from a positive 12V input voltage

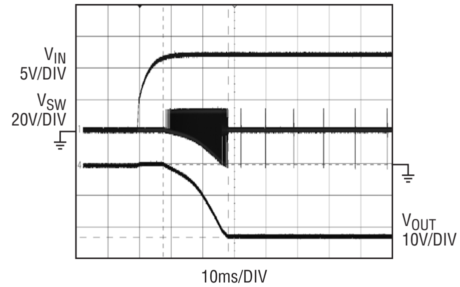

Figure 6. The LTC3642's wide input voltage swing makes it suitable for generating a negative output from positive input voltage.

portable medical instruments and certain automotive applications.

Positive-to-Negative Converter

The LTC3642 can produce a negative output voltage from a positive input voltage without the use of transformers (see Figure 5). In this configuration, the LTC3642 actually operates in an inverting buck-boost mode. Its wide input voltage range, up to 45V, provides sufficient headroom to generate any negative voltage between –0.8V and –40.5V. Figure 6 shows LTC3642 producing a –24V output from a 12V input supply from start-up. The LTC3642 is inherently stable in this configuration with no external compensation components required.

Conclusion

The LTC3642, LTC3631 and LTC3632 are a rugged DC/DC converters for use in applications where a stable voltage output must be produced from poorly regulated high voltage rails. Their compact size and high efficiency make them easy to use in a wide variety of low power applications, including mobile and battery powered devices.

LTC6930, continued from page 23

concern, and extreme accuracy is not paramount. Such applications include clocking microprocessors and microcontrollers, acting as a time base for low speed serial communication protocols such as USB and RS232, digital audio applications, clocking switching power supplies and anywhere a general purpose clock is needed.

Conclusion

When comparing clock power dissipation it is important to consider not just the dissipation of the oscillator itself, but also how the oscillator's features and start-up times effect the dissipation of the entire system. Crystal oscillators not only dissipate more current than other solutions, but can have other start-up and control characteristics that lead to power waste. When the LTC6930's on-the-fly frequency programmability and one-clock-cycle settling time are considered, it is clear that it conserves much more system power than its dissipation specification would indicate

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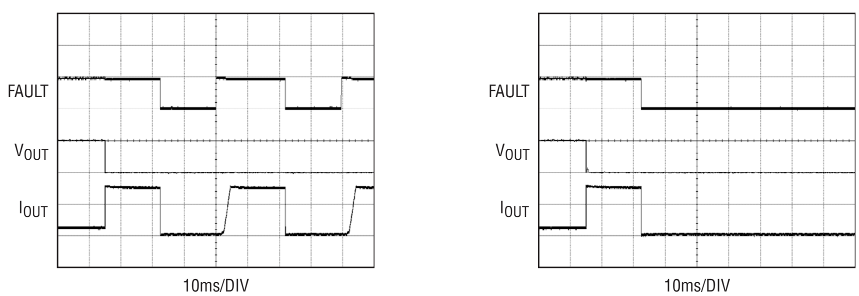
LTC3529, continued from page 33

on a pin-selectable setting, the IC can be configured to either periodically attempt to power up (RST pin high, Figure 4a), or remain shut down until power is cycled to the device (RST pin low, Figure 4b). The waveform indicating the fault condition is seen at the Fault pin and is produced by an internal open-drain device whose input is pulled high in the event of a fault. The Fault pin can either be connected to a microprocessor or drive an LED.



4a. RST high: converter attempts power-up every 15ms.

4b. RST low: converter remains shut down until power is cycled.

Figure 4. A fault detection mechanism powers down the converter, providing robustness to output shorts

Conclusion

High conversion efficiency and the ability to detect and handle output shorts make the LTC3529 an ideal solution for either peer-to-peer portable applications or point-of-load board power with robust fault handling. The 1.5MHz switching frequency and highly integrated design of the LTC3529 yield compact solutions with minimal design effort.

4W LED Driver Includes Power Switch, Compensation Components and Schottky in 16-Pin MSOP

by Keith Szolusha

Introduction

As the number of applications for medium power (1W–4W) LED strings grows, so does the need for compact, efficient, high performance LED drivers. The LT3519 LED driver satisfies the needs of a wide variety of applications, including LCD displays, automotive and avionic applications, architectural and industrial lighting, portable projection and scanners. It's 16-pin MSOP package includes accurate LED current regulation, small size, high efficiency, PWM and analog dimming for brightness control and open circuit protection with fault detect.

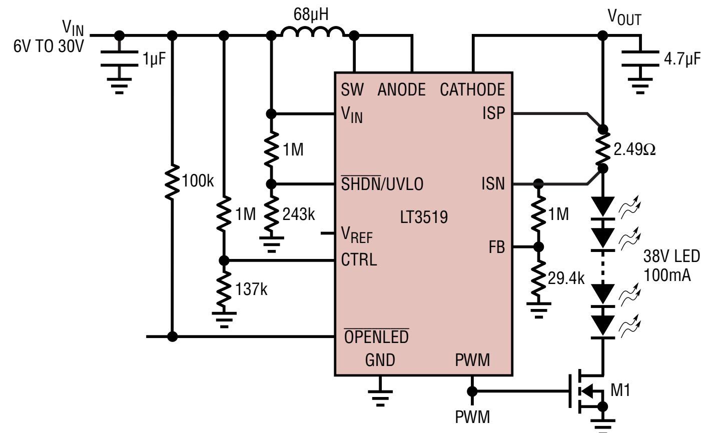


Figure 1. A 4W boost LED driver with 89% efficiency at $12V_{IN}$

Easy Layout: Integrated Power Switch, Compensation Components and Schottky

The 400kHz LT3519 LED driver features an integrated 750mA 45V peak power switch, integrated compensation components and an integrated low leakage Schottky diode, making designs simple and small. Despite this high level of integration, it can be used in a wide variety of topologies, including boost, SEPIC, buck mode or buck-boost mode. For maximum versatility, the Schottky diode anode (ANODE) and internal power switch emitter (SW) pins are separately pinned out, so a SEPIC coupling capacitor can be inserted between these two.

The internal compensation components are chosen to match the 2.2µF to 4.7µF output capacitors in all of the topologies mentioned above. The integrated compensation network combined with current mode control yields fast and stable transient response.

$\overline{\text{OPENLED}}$ detection and fault reporting are included. A simple resistor divider sets the overvoltage protection output voltage in case of an open LED string and a small pull-up resistor is all that is needed to assert the open collector $\overline{\text{OPENLED}}$ output pin during a fault.

4W Boost LED Driver

The simple boost LED driver in Figure 1 drives up to 38V of LEDs at 100mA from an automotive input voltage range. The 400kHz switching frequency is common for automotive, avionic and industrial solutions; it combines

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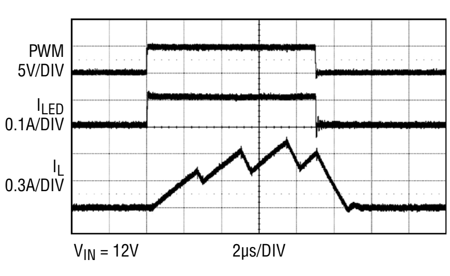

Figure 2. Integrated PWM dimming yields 1000:1 dimming at 120Hz

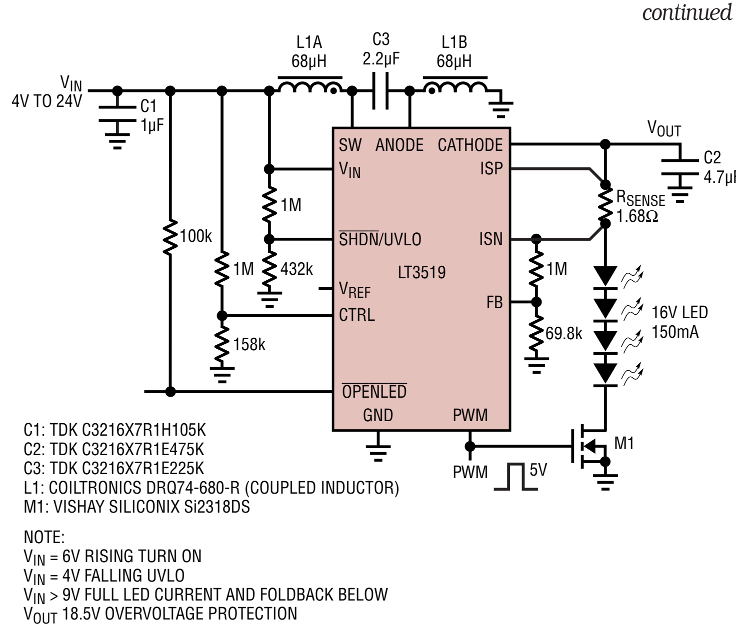

Figure 3. A SEPIC LED driver with short-circuit protection

3mm × 3mm, 16-Bit ADC Brings Accurate, Precise High Side Current Sensing to Tight Spaces

by Leo Chen

Introduction

Power monitoring circuits are increasingly used throughout automotive, industrial, communications and computing applications as electronics designers strive to continually improve thermal performance, increase efficiency and generally make their products more "green."

The problem is that power monitoring always looks like the perfect feature until space and cost constraints come into play. Power monitoring is usually considered an ancillary function, so its footprint should be as small as possible to maximize space available to the main application. The LTC2460 16-bit Delta-Sigma ADC solves the space and design cost problem when paired with one of Linear Technology's current sense amplifiers, such as the LTC6102.

The LTC2460 proves that big-feature ADCs can come in tiny packages. It is available in a 3mm × 3mm DFN (or a 12-pin MSOP), and integrates a 10ppm/°C precision reference. The integrated reference paired together with an extremely easy to drive input stage (50nA average input current) makes it possible to use the LTC2460 with little to no support circuitry.

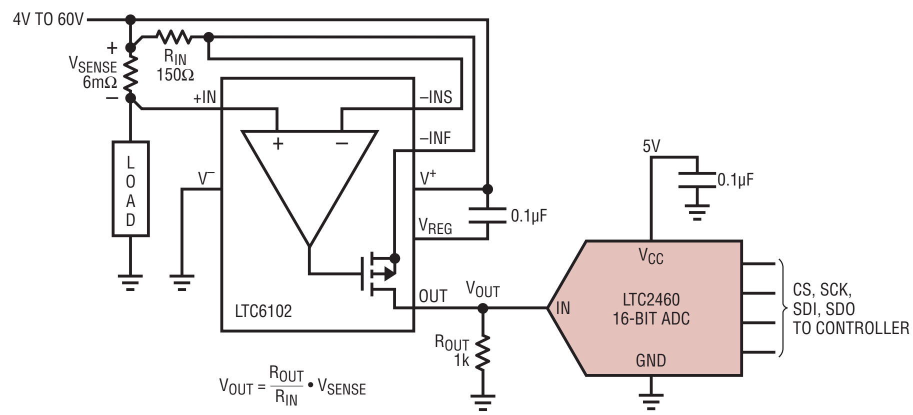

Figure 1. A simple and compact high side current sensing solution that combines a high resolution ΔΣ ADC (LTC2460) with a high precision current sensing amplifier (LTC6102).

Measuring Power Means Measuring Current

Measuring power supply input and output voltages is fairly straightforward, as any voltage can be scaled with a simple divider or amplifier and compared to a voltage reference. Current measurement is generally more complicated, especially at commonly used high voltages such as –12V, 24V and 48V.

To measure current, a small sense resistor is placed directly in series with the supply. A current sense amplifier takes the small voltage drop across this sense resistor and sources a proportional signal current. If the current is monitored on a high voltage power supply, an accurate and precise current sense amplifier, such as the LTC6102, is required to accurately resolve the small voltage drop riding on the high common mode voltage.

Typically the signal current produced by the current sense amp is converted via a grounded resistor to a properly scaled voltage, which, in this case, can be measured directly using the LTC2460's easy to drive input. The 16-bit output data can then be used to compute power consumption and efficiency.

Accurate, Precise and Very Compact High Side Current Sense Design

Figure 1 shows a 48V, 8A current measurement application. The LTC6102 is a precision current sense amplifier that offers 10µV maximum input offset voltage, 50nV/°C input offset drift (maximum), and low 3nA (maximum) input bias current.

This current sense amplifier has zero-drift and sources a 1mA maximum current out of its OUT pin. This current is converted into a voltage across the 1kΩ resistor to ground, which allows the connected LTC2460 to measure a 0V to 1V input. This input range spans 80% of the ADC's input resolution. Of course, the output of the current sense amplifier can be scaled to use as much of the LTC2460's input range as needed, while providing for overrange conditions.

Another advantage to the LTC2460 is the narrow input bandwidth of approximately 30Hz. This provides excellent rejection of power supply ripple noise, and allows accurate measurement of the DC component of the current.

Conclusion

The LTC2460 and the LTC6102 facilitate a compact, high resolution, high accuracy current sense solution. The LTC2460 is a 16-bit ADC in a tiny package that includes an integrated precision reference, while the LTC6102 provides high precision, current measurements that in turn can be easily digitized by the ADC.

Dual 8A DC/DC µModule Regulator Is Easily Paralleled for 16A

by Eddie Beville and Alan Chern

Two Independent 8A Regulator Systems in a Single Package

The LTM4616 is a dual input, dual output DC/DC µModule regulator in a 15mm × 15mm × 2.8mm LGA surface mount package. Only a few external components are needed since the switching controller, MOSFETs, inductor and other support components are integrated within the tiny package.

Both regulators feature an input supply voltage range of 2.375V to 5.5V and an adjustable output voltage range of 0.6V to 5V with up to 8A of continuous output current (10A peak). For higher output current designs, the LTM4616 can operate in a 2-phase parallel mode allowing the part to deliver a total output current of 16A. The default switching frequency is set to 1.5MHz, but can be adjusted to either 1MHz or 2MHz via the PLLLPF pins. Moreover, CLKIN can be externally synchronized from 750kHz to 2.25MHz. The device supports output voltage tracking for supply rail sequencing. Safety features include protection against short circuit, overvoltage and thermal shutdown conditions.

Simple and Efficient

The LTM4616 can be used as completely independent dual switching regulators with different inputs and outputs or paralleled to provide a single output. Figure 1 shows a typical design for a 5V common input and two independent outputs, 1.8V and 1.2V. Figure 2 shows the efficiency of the circuit at both 5V and 3.3V inputs.

Few external components are needed since the integrated output capacitors can accommodate load steps to the full 8A. Each output voltage is set by a single set resistor from FB1 (or FB2) to GND. In parallel operation, the FB pins can be tied together with a single resistor for adjustable output voltage.

Parallel Operation for Increased Output Current

You can double the maximum output current to 16A by running the two outputs in parallel as shown in Figure 3. Note that the FB pins share a single voltage-set feedback resistor that is half the value of the feedback resistor in the usual two output configuration. This is because the internal 10k top feedback resistors are in parallel with one another, making the top value 5k.

It is preferred to connect CLKOUT1 to CLKIN2 when operating from a single input voltage. This minimizes the input voltage ripple by running the two regulators out of phase with each other. If more than 16A output current is required, then multiple LTM4616 regulators can be configured for multiphase operation with up to 12 phases via the PHMODE pin. Figure 4 shows the expected efficiency of the parallel system at 5V and 3.3V inputs to 1.8V output. Note that the

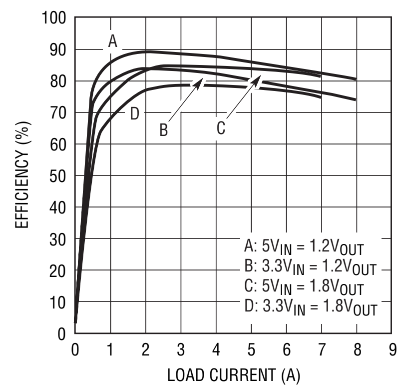

Figure 2. LTM4616 efficiency: dual output

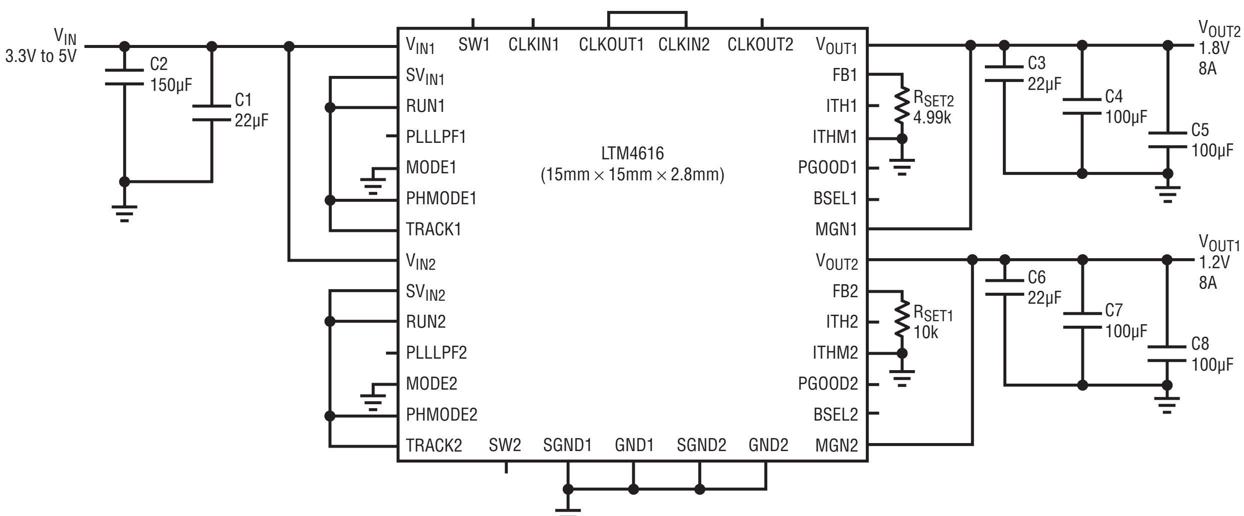

Figure 1. Dual output LTM4616 for a single 3.3V to 5V input, independent 1.8V and 1.2V outputs at 8A each

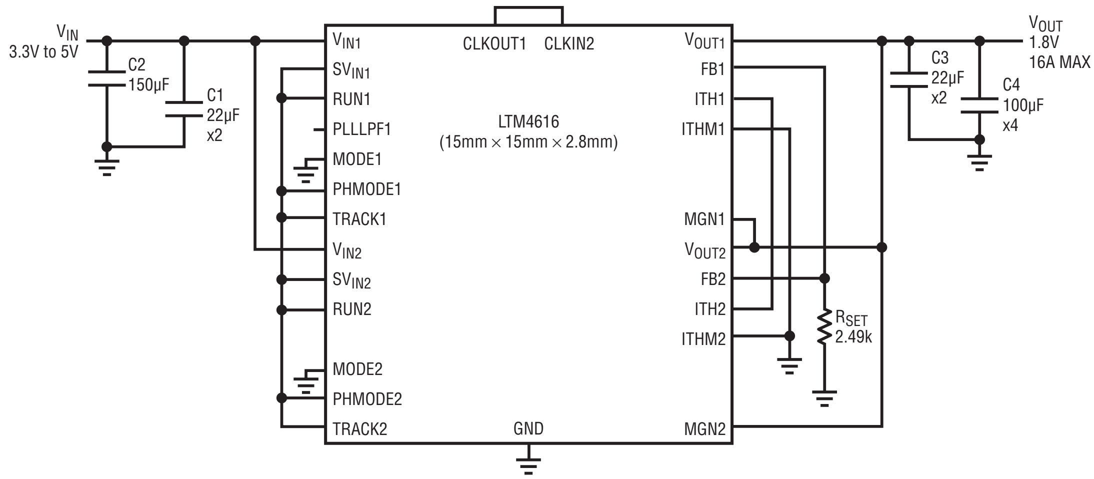

Figure 3. LTM4616 with 16A parallel operation

two regulators drive equal output current even during soft-start, as shown in Figure 5.

Conclusion

Whether you require a single 16A high current output or dual 8A outputs with sequencing, the LTM4616 provides a simple and efficient solution.

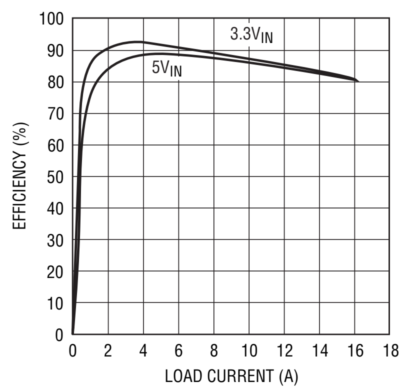

Figure 4. Efficiency: single 1.8V output

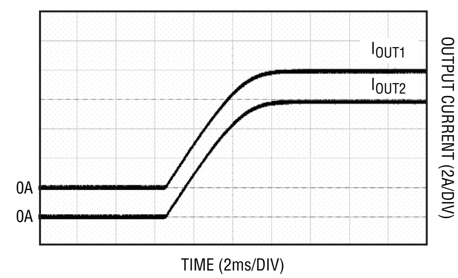

Figure 5. Balanced current sharing for even heat dissipation [$5V_{IN}$ to $1.8V_{OUT}$ at 16A]

LT3519, continued from page 36

high efficiency, small inductor and capacitor size, and high PWM dimming capability while avoiding frequencies in the AM broadcast band. A small inductor with about 750mA saturation current rating, a few ceramic capacitors and several tiny resistors are all that are needed to complete the design. As shown in Figure 2, the tiny PWM dimming MOSFET can be used to provide over 1000:1 pwm dimming at 120Hz using the integrated LT3519 PWM dimming architecture and an extremely low leakage integrated Schottky diode.

A 1000:1 dimming ratio at 120Hz is exceptionally high for a 400kHz switching regulator. It can be tempting to bump up the dimming ratio by choosing a higher frequency driver, since in general, higher switching frequency corresponds to higher PWM dimming ratios. In this case, avoiding the AM band means jumping to 2MHz, which in the end reduces the maximum duty cycle and the efficiency. The 400kHz switching frequency of the LT3519 does what 2MHz converters cannot do: it provides high duty cycle for operation down to $6V_{IN}$ with $38V_{LED}$ and as high as 89% efficiency at $12V_{IN}$. If PWM dimming is not needed, the MOSFET M1 can be removed and the analog dimming (CTRL) pin can be used to adjust the regulated LED current below 100mA for simple brightness control.

2.4W SEPIC LED Driver

When the LED string voltage is within the input rail voltage range, a SEPIC topology is called for. The SEPIC produces a high PWM dimming ratio and also gives short-circuit protection. The SEPIC in Figure 3 drives 16V LEDs at 150mA from a 4V to 24V input range. Since the anode of the integrated catch diode (ANODE) is made available at a pin independent of the npn power switch emitter (SW), the coupling capacitor is easily inserted between the two. The maximum voltage that the SW pin sees is a little above the input voltage plus the output voltage, so the 45V 750mA integrated power switch is a perfect match for these specifications.

Conclusion

The 400kHz LT3519 is a 4W LED driver that integrates a number of required components, including a 45V, 750mA power switch, a low leakage Schottky diode and compensation components. It also features PWM dimming, overvoltage protection and $\overline{\text{OPENLED}}$ fault detection, making it a small, simple, and efficient choice for automotive, avionic, industrial and other LED driver applications.

Self-Contained 3A µModule Buck Regulator Produces 0.8V–24V Output from 3.6V–36V Input

by David Ng

Introduction

Ask any group of engineers, "What would you do with a 3A DC/DC converter?" and you will probably get a wide range of answers—from powering a DSP rail at 1.8V to running a bank of 24V switching I/O. Typically, these two particular applications would require completely different DC/DC controller ICs and topologies. However, the LTM8025 µModule DC/DC converter can satisfy the requirements of these and just about any other 3A applications.

The LTM8025 3A µModule DC/DC buck converter operates from 3.6V to 36V inputs to produce output voltages as low as 0.8V and as high as 24V. Furthermore, the LTM8025 features single cycle Burst Mode® operation, so it is able to handle a wide range of load currents, from no load to 3A, with minimum ripple.

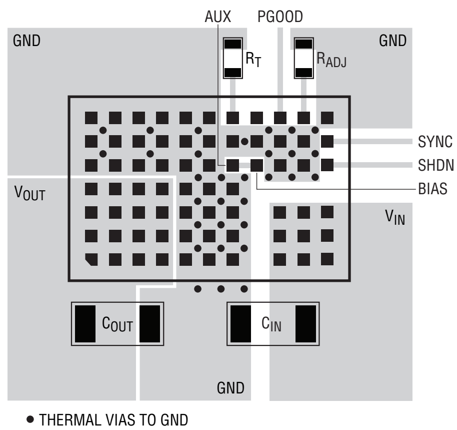

Figure 1. Layout is easy with the LTM8025.

The LTM8025 integrates the controller, control circuitry, inductor, power switch and rectifier all into a single IC form factor 15mm × 9mm × 4.32mm package. This LGA package is RoHS (e3) compliant, and features gold pads for easy assembly in both leaded and unleaded solder processes.

Easy Layout

The LTM8025's high level of integration simplifies the design of just about any 3A power supply. Just add two resistors, input and output capacitance to make a complete power supply. Layout is easy, as shown in Figure 1. Figures 2 and 3 show the schematic and efficiency of the LTM8025 producing 12V bus power from a 24V source, while Figure 4 shows the LTM8025 producing 1.8V from an input range of 3.6V to 36V.

Versatile Feature Set

The LTM8025 may be operated over a wide frequency, from 200kHz to 2.4MHz, and may be synchronized to an external clock source through the SYNC pin. The LTM8025 start-up is controlled through its RUN/SS pin, which also serves to put the part into

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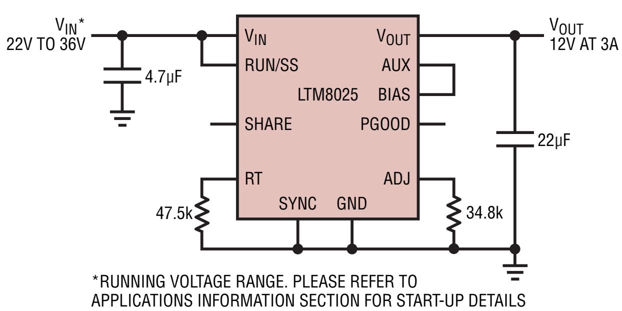


Figure 2. A complete 12V at 3A power supply requires only the LTM8025, two capacitors and two resistors.

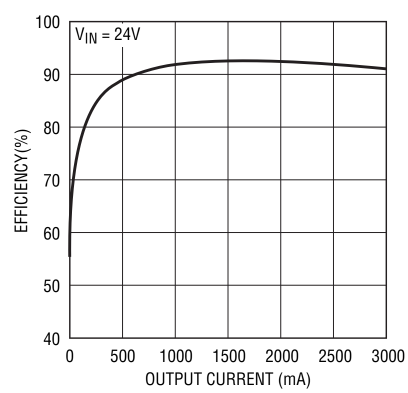


Figure 3. The LTM8025 boasts high efficiency.

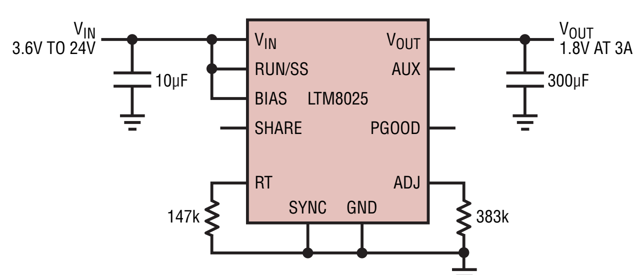


Figure 4. The LTM8025 can produce low voltages from a wide input range.

New Device Cameos

16-Bit Quad SPI DAC Achieves ±1LSB INL & DNL with Software-Programmable Unipolar & Bipolar Outputs

The LTC2754-16 is a quad 16-bit current output digital-to-analog converter (DAC) that achieves ±1LSB integral nonlinearity (INL) and differential nonlinearity (DNL). All four DACs can be software programmed or pin-strapped for one of six unipolar or bipolar output ranges via a simple 4-wire serial interface. Software programmability eliminates the need for expensive precision resistors, gain stages and manual jumpers. The LTC2754-16's precision DC specifications and flexible SoftSpan™ output configurability make it ideal for multichannel data acquisition modules and automated test equipment. A pin- and software-compatible 12-bit option is also available, making it easy to transition between different resolutions in the end-product.

The LTC2754-16 is capable of producing six unique software-programmable unipolar and bipolar output ranges up to ±10V. The six SoftSpan output voltage ranges include two unipolar ranges (0V to 5V, 0V to 10V) and four bipolar ranges (±10V, ±5V, ±2.5V, –2.5V to +7.5V). Voltage controlled offset and gain adjustment pins are also included for each DAC, making it possible to fine-tune each DAC output. The LTC2754-16 outputs any of the six SoftSpan ranges while operating from a single 2.7V to 5.5V supply and drawing only 1µA maximum supply current.

The LTC2754-16 also offers very good AC specifications, including full-scale settling time of only 2µs and low glitch impulse of 0.26nV•s with a 3V supply or 1.25nV•s with a 5V supply .

The LTC2754-16's 2MHz multiplying bandwidth and good AC specifications are key for applications such as waveform generation. Fast settling and low glitch reduce the harmonic distortion, making it possible to produce higher frequency, lower noise output waveforms. The LTC2754-16's serial interface operates at clock rates up to 40MHz and allows readback of any internal register, as well as the DAC output span setting.

The LTC2754-12 is a pin-compatible 12-bit device, with both 16-bit and 12-bit versions available in 7mm × 8mm QFN-52 packages. The serial LTC2754 joins a family of quad, dual and single DACs (LTC2755/LTC2753/LTC2751) that communicate via parallel I/O. The entire family is available in commercial and industrial temperature ranges.

Ultralow Power Supervisor

The LTC2935 is an ultralow power voltage supervisor that features system initialization, power-fail warning and reset generation functions. Low quiescent current (500nA) makes the LTC2935 an ideal choice for battery operated applications.

The reset output ($\overline{\text{RST}}$) holds a system in reset during low battery conditions. The reset output pulls high once the supervised voltage has been in compliance for 200ms. The power fail output ($\overline{\text{PFO}}$) provides an early warning of impending battery failure. Supervisor accuracy is ±1.5% over the full temperature range (–40°C to 85°C).

Three binary threshold-select inputs configure one of eight integrated reset thresholds ranging from 1.6V to 3.45V in fixed increments. The LTC2935-1 and LTC2935-2 incorporate thresholds tailored for lithium-ion battery applications while the LTC2935-3 and LTC2935-4 incorporate lower voltage thresholds tailored for alkaline battery applications.

The LTC2935 voltage comparators apply hysteresis during power-up to prevent load step oscillations. Load steps can cause battery voltage to drop due to internal battery resistance. The LTC2935 requires the input voltage to exceed the configured reset threshold by 5% and the power-fail threshold by 2.5% during power-up. The voltage comparators reduce the monitor thresholds back to the configured settings after passing the turn-on thresholds.

A manual reset can be invoked at any time through a pushbutton switch connected to the manual reset input ($\overline{\text{MR}}$). Outputs $\overline{\text{RST}}$ and $\overline{\text{PFO}}$ are available with open-drain (LTC2935-1, LTC2935-3) or active pull-up (LTC2935-2, LTC2935-4) circuits. The supervisor is available in a compact 8-lead 2mm × 2mm DFN and TSOT-23.

Surge Stopper with Fault Latchoff

The LT4356-2 and LT4356-3 are surge stoppers that protect loads from high voltage transients. They regulate the output during an over voltage event by controlling the gate of an external N-channel MOSFET. The output is limited to a safe value, thereby allowing the loads to continue functioning. The current is also monitored through a sense resistor and limited to 50mV.

A fault timer is started in the event of either type of fault, voltage or current, and the pass transistor is turned off if the condition persists. After a cool down period set by the timer capacitor, the MOSFET turns back on for LT4356-2. For the LT4356-3, the pass transistor is latched off after the fault timer has expired. Toggling the $\overline{\text{SHDN}}$ pin resets the part and allows the MOSFET to turn back on.

The LT4356 operates over a wide supply range of 4V to 80V and wide temperature range of –45°C to 125°C, making it suitable for automotive applications. In a reverse battery condition, the V_{CC}, SNS, and $\overline{\text{SHDN}}$ pins can be pulled to 60V below the GND potential without damage. The LT4356-2 also has an auxiliary amplifier that is active during shutdown, allowing it to continue monitoring the input supply or keep the output alive to the load. On the other hand, the LT4356-3 shuts down to a low current mode, 7µA, with all the functional circuitry turned off.

The LT4356-2 is offered in 12-pin DFN and 16-pin SO packages, while the LT4356-3 is available in 12-pin DFN, 16-pin SO, and 10-pin MSOP packages.

Dual Output Synchronous DC/DC Controller Draws Only 170µA in Battery-Powered Systems

The LTC3868/-1 is a low quiescent current, 2-phase dual output synchronous step-down DC/DC controller. The LTC3868/-1 draws only 170µA with one output active and only 300µA when both outputs are active, making it ideal for battery-powered applications. With both outputs shut down, the LTC3868/-1 draws only 8µA. The LTC3868/-1 has an input supply range of 4V to 24V and each output can be set from 0.8V to 14V at output currents up to 20A. With efficiency as high as 95%, a LTC3868/-1 based DC/DC converter is well suited for powering industrial and medical devices, along with portable instruments, notebook and netbook computers.

The LTC3868/-1 operates with a user-adjustable, fixed frequency between 50kHz and 900kHz, and can be synchronized to an external clock from 75kHz to 850kHz using its phase-locked-loop (PLL). The user can select from continuous operation, pulse-skipping and low ripple Burst Mode operation during light loads. These parts also safely start up with a prebiased load by powering up and down in pulse-skipping mode.

The LTC3868/-1's 2-phase operation reduces input capacitance requirements and its current mode architecture provides easy loop compensation and fast transient response. Both outputs have adjustable soft-start to control the turn-on time, and the output overload protection feature latches off the converter until the input voltage is recycled. The LTC3868/LTC3868-1 also features a tight ±1.5% reference voltage accuracy over a –40°C to 85°C operating temperature range. The LTC3868 is the fully featured part with additional functions beyond the LTC3868-1 including a clock out, phase modulation, two power good outputs and adjustable current limit.

The LTC3868 is offered in a 32-lead 5mm × 5mm QFN package and the LTC3868-1 in a 28-pin SSOP or 4mm × 5mm QFN-28 packages.

Boost & Inverting DC/DC Converter for Active Matrix OLED & CCD Bias

The LT3582, LT3582-5 and LT3582-12 dual channel DC/DC converters that deliver both positive and negative outputs required in many biasing applications such as active matrix OLED (organic light-emitting diode) displays as well as CCD (charge coupled device) applications. The LT3582/-5/-12 offer an I^2C interface that can dynamically program output voltages, power sequencing and output voltage ramps as the application requires. Alternatively, these parameters can be set in manufacturing and made permanent via the built in nonvolatile OTP (one time programmable) memory. The LT3582's positive output voltage can be set between 3.2V and 12.775 in 25mV steps, whereas the negative output can be set between –1.2V and –13.95V in 50mV steps. The LT3582-5 and LT3582-12 are pre-configured with ±5V and ±12V outputs respectively, useful in many signal conditioning applications.

LTM8025, continued from page 40

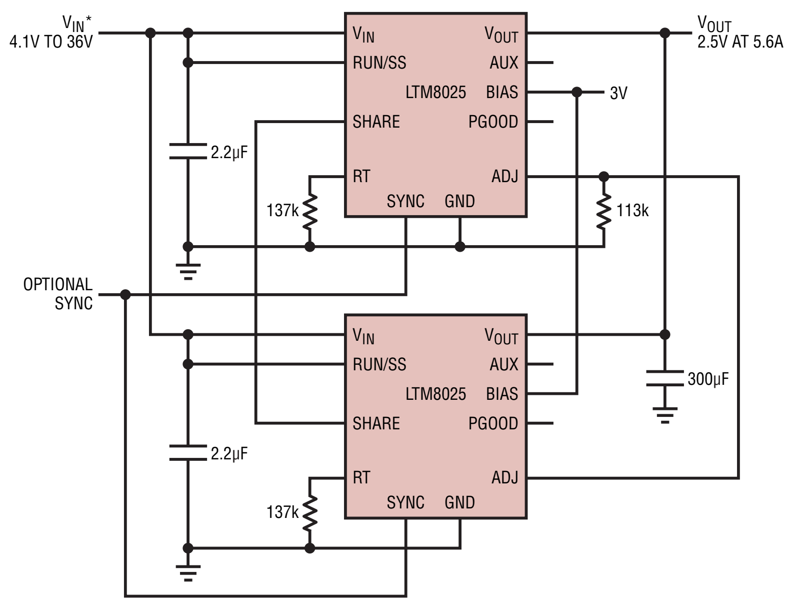
a low power off state in which the part draws less than 1µA. Furthermore, the part comes with a PGOOD pin to indicate that the output is within 90% of its target voltage.

Parallel Multiple LTM8025s for High Current Capability

The LTM8025 is equipped with a SHARE pin to allow parallel operation for applications requiring more than 3A load current. Figure 5 shows two synchronized LTM8025's providing $2.5V_{OUT}$ at 5.6A.

Conclusion

The highly versatile LTM8025 3A µModule DC/DC buck converter is easy to use and fits just about any step-down regulator need. Its wide input and output ranges and high level of integration reduce design effort and associated costs.



*RUNNING VOLTAGE RANGE. PLEASE REFER TO APPLICATIONS INFORMATION SECTION FOR START-UP DETAILS
NOTE: SYNCHRONIZE THE TWO MODULES TO AVOID BEAT FREQUENCIES, IF NECESSARY. OTHERWISE, TIE EACH SYNC TO GND

Figure 5. Two LTM8025s can be operated in parallel for more than 3A load current.

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