Breakthrough power delivery for space-constrained applications

Buck the trend in power conversion with a new topology

Texas Instruments

Pradeep Shenoy
Systems Engineer, DC Solutions
Texas Instruments

Rich Nowakowski
Marketing Manager, Power Management
Texas Instruments

Imagine if on-board electronic power supplies could suddenly shrink to 20 percent or less of their previous size.

For most end users, this doesn't mean much because they pay little attention to power supplies, even though power supplies typically consume up to half of the board space of an electronic system. Shrinking it to a fifth of its former size would mean that equipment could suddenly be much smaller and lighter-weight. Or the equipment could stay the same size and suddenly have much more space to include new high-performance functions. This is a game-changer for innovation in electronics.

To see how important this could be in the future, think about automobiles incorporating increasingly more image processing on the way to fully automated operation. Portable and wearable devices would become more mobile than ever. Large, rack-mounted equipment could pack more channels and features into less space without overheating. Aerial drones could use the weight reduction to stay aloft longer as they perform high-performance image processing.

In short, every area of electronics could benefit from such a radical rescaling of power supplies.

This level of system rescaling is now possible with a new capacitive conversion topology for on-board power supplies introduced by Texas Instruments (TI). The innovation is designed for step-down applications that convert power inputs from higher to lower voltages, and it enables much higher-frequency operation than was previously used in similar chips. TI's first integrated circuit (IC) product offerings employing the new topology – also the first of their kind in the industry – are targeted at communications infrastructure, mass storage and test and measurement applications. For such densely packed equipment, the new buck converters (or chips providing on-board functions to lower and regulate voltages), offer five to seven times the current density, allowing manufacturers to provide much more functionality without having to expand the system. Buck converters have not changed much in size for many years, and future products planned for other application areas may be able to push these advantages even further.

A sudden, significant resizing

Power rescaling has always been an incremental process, moving step-by-small-step up the long climb of miniaturization, rather than by great leaps. Think how the power supply on the cable (the "brick") has slowly diminished with each generation of laptop computers. The part of the power supply that resides on the system board has shrunk even more slowly within the same period.

With the new capacitive conversion topology, it is as if, all of a sudden, power supplies have ascended a whole flight of stairs on the way to product density and small scale, instead of climbing the steps one-by-one. This time, the change is due to innovative design rather than new materials or manufacturing advances, which are usually responsible for rescaling.

The new power supplies can be built with proven manufacturing processes, supporting high quality and a quick ramp to volume. Since buck converters made with the new series capacitor topology are potentially useful anywhere there is a steady, well-regulated voltage input, they will eventually have a tremendous impact throughout the electronics industry.

Space reduction challenges

Every electronic system operates on power supplied from a battery or line source. Eventually battery-operated systems will benefit from the new topology, but initial products are focused on line-powered systems, such as the one shown generically in *Figure 1*. As the drawing indicates, power conversion is often a multi-stage operation, especially when the initial input voltage is much greater than the voltages used by components in the equipment. The box in the dotted line on the left of the diagram is often found near the system, like the brick in the PC power cable, while the buck converters are found on the system board itself. Each converter takes an intermediate voltage (12 volts here) and steps it down to a lower voltage for the electronic components in the system. For some systems, the dotted box and the on-board converters might be broken down into more stages with additional intermediate voltages.

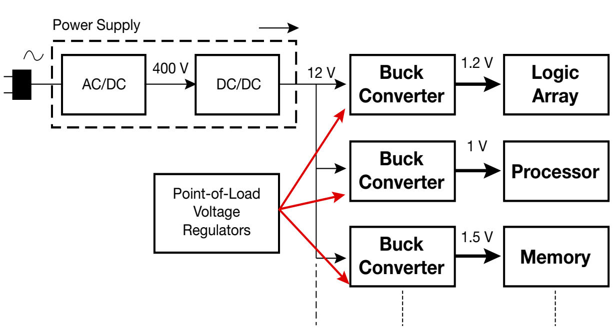

Figure 1. Power delivery system

One way to reduce the size of the overall power supply is to use fewer conversion stages, which is possible when the converters offer a large ratio of input voltage to output voltage (V_{IN}-to-V_{OUT}). That is, a 10-to-1 ratio permits stepping down a 12-V input to as low as a 1.2-V output, while a 5-to-1 ratio permits stepping the input down to no less than 2.4 V. If a device on the board requires power at 1.2 V, then a 10-to-1 converter saves space by supplying it in just one stage.

Another way to downsize the power supply is by rescaling the components within the converters. Given that power supplies account for about 30 to 50 percent of the space in many systems, the space savings can be significant. But slimming down buck converters has not been easy, as the following section explains. Finally, another important design challenge is that the power supply must provide a high output current, so that the converter can drive a high-current device such as a microcontroller, or several lower-current devices.

The innovative buck converter design meets these challenges by achieving high-frequency operation with a high voltage input-to-voltage output ratio and with a high output current. Without compromising operating efficiency, TI's capacitive conversion topology drastically reduces size, allowing innovators to design applications that are smaller and lighter-weight and pack more high-performance processing and features into the same space. The new converter also reduces the bill of materials, which could help reduce the overall system cost.

Achieving high-frequency operation

Buck converters are a type of switched-mode power supply, which get their name because of how they work. The input voltage (V_{IN}) is switched on and off very rapidly, then an inductor and other components smooth the pulses into a continuous output voltage (V_{OUT}) that is proportional to the time V_{IN} is switched on. For example, if V_{IN} is on 25 percent of the time, V_{OUT} should theoretically be 25 percent of the input voltage (a 4-to-1 voltage drop). However, the process is not fully efficient because the circuitry unavoidably wastes some power in switching.

The components of a basic buck converter are shown in *Figure 2*. The L is the inductor, the C is an output capacitor, and the Q_1 and Q_2 are field-effect transistors (FETs) that alternately turn on and off the voltage input, creating two phases of operation.

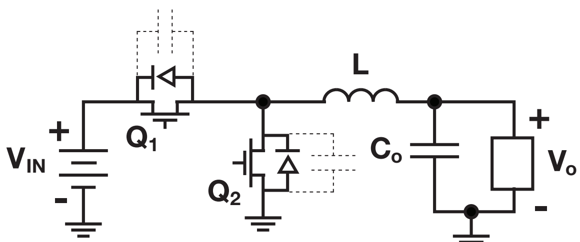

Figure 2. Basic buck converter

Besides contributing to power loss, inductors create another difficulty because they are large, heavy components that take up nearly as much space as the rest of the power supply put together. Inductors extend upward from the board, as well as across it, so that they require a lot of room in three dimensions. Inductor size is inversely proportional to the frequency at which the power supply is switching on and off, meaning that at higher frequencies, smaller inductors can be used. However, higher frequencies also create greater power loss in switching, so that high-frequency operation has been much less efficient.

Another factor that becomes difficult to handle at high frequencies is the signal on-time at the start of each pulse. The on-time can present problems when there is a high V_{IN}-to-V_{OUT} ratio, since the signal is in its on state during only a fraction of the pulse. For instance, for a 10-to-1 voltage drop with a 2-megahertz (MHz) signal, the voltage is on only 50 nanoseconds. For many converter designs, this isn't enough time to accurately control converter operation.

As a result, most buck converters have been constrained to operate at less than 1 MHz, with typical operation at much lower speeds. Those that do operate at higher frequencies have had low V_{IN}-to-V_{OUT} ratios, with longer pulses that give more on-time margin. Also, because of the power loss at high frequencies, these devices provide low output currents, limiting the type and number of components that they can power. Being limited in operating frequency, buck converters have not been able to rescale significantly, since they have been forced to use large inductors and other components.

Better by design

Introducing a capacitor in series, together with other circuit modifications that support the capacitive design, resolves these high-frequency issues. The following discussion provides a basic idea of how the converter design is different and why it achieves the design goals of limited space, high voltage output ratio and high current. Links to resources that provide a more in-depth technical explanation are listed at the end of the paper.

Figure 3 shows a two-phase series capacitor buck converter. One major difference between this design and that in *Figure 2* is that there are two parallel sections (or phases) of the converter, each of which has its own inductor (L_a and L_b). There are also additional switches that control the energy flow through the second phase.

As the capacitor alternately charges and discharges, and the FET power switches (Q_{2a} and Q_{2b}) are opened and closed, the current flows alternately through the two inductors in four-time intervals to establish a steady-state output at the appropriate stepped-down

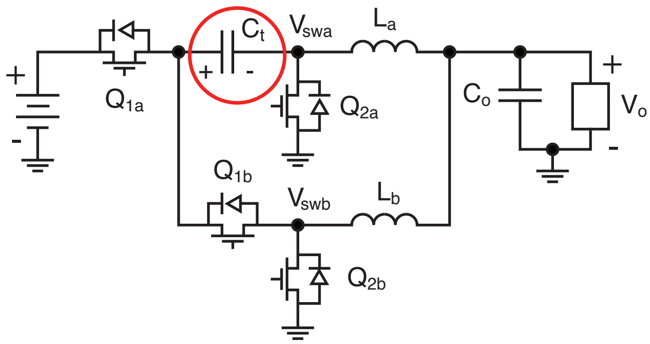

Figure 3. Series capacitor buck topology

level. The voltage across the capacitor is nominally 50 percent of V_{IN}, serving to minimize power losses during switching, since a lower voltage swing means less power loss on each cycle. This permits the use of higher-frequency switching, which in turn allows the inductors and capacitors to be scaled down, saving system space and weight. Other advantages that help improve the output quality and reduce design complexity include reduced inductor current ripple, automatic current balancing between inductors, a soft charge and discharge through the capacitor, a doubled on-time and excellent load transient response. All of these help in overcoming challenges to creating small-size, high-frequency voltage regulators.

Enabling space-constrained applications

TI's initial offering based on the capacitive conversion topology is the TPS54A20 SWIFT™ step-down buck converter, which provides point-of-load voltage regulation in high-density systems such as communications infrastructure and massive data storage, as well as compact systems with high-performance needs, such as test and measurement equipment. Since the devices deliver a full 10 amps of output current, manufacturers enjoy the benefit of plenty of drive for enabling system functions, as well as a high voltage conversion ratio to minimize the number of power stages used and improve overall system efficiency. The same high efficiency, over 90 percent, that is found in other buck converters is also present.

The TPS54A20 converter integrates the full design shown in *Figure 3*, other than passive devices. *Figure 4* compares the board space required by a conventional buck converter operating at 500 kHz, and one implemented using the new converter at 2 MHz. Notice that much of the difference in the converter's overall rescaling results from reduced inductor size. The inductors in the new design are 12 times smaller than in the conventional board design and potentially much lower in cost. Thermal studies show that heat is well dissipated in the smaller design, despite the higher-frequency operation.

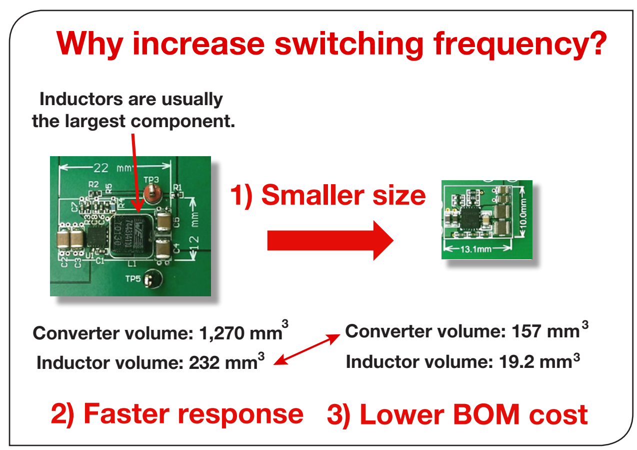

Figure 4. Rescaling buck converter designs

Wide-ranging application benefits

Systems realize three to seven times the current density with the new capacitive conversion topology, enabling manufacturers of rack-mounted cards with fixed dimensions to pack more functions into the same space. Inductors in the new converter designs are small enough that for the first time these power supplies can be placed on the backs of boards, where there is limited clearance, freeing up valuable space on the top of the board for other circuitry.

But the potential of capacitive conversion innovation is not limited to cards for rack-mounted equipment. As other buck converters are developed, applications will benefit at both extremes: higher voltage industrial and automotive equipment and low-voltage portable applications, even wearable electronics. The technology can even be reworked to create step-up or boost converters, which function to increase voltages, instead of reducing them as buck converters do. The series capacitor design is so significant, not only in its instantiation in specific early products but also in its wide-ranging potential over the long term, that it has been the source of a number of patent applications.

Powering the future

Implementing series capacitive buck conversion technology over a wide range of applications will take time, combined with careful IC product design and support for system designers and manufacturers. Fortunately, TI is well-positioned to lead the changeover. As the industry's leading supplier of power management ICs, the company has the design and manufacturing strength to implement a wide array of products based on its capacitive conversion topology. New power supply ICs based on it can be manufactured using proven processes, assuring quality and fast time to volume.

Power supply advances are essential to ongoing progress in electronics. By breaking through the size barrier that has existed for decades, TI demonstrates again its commitment to working hand-in-hand with its customers to enable smaller, more efficient electronics for a range of applications.

For more information:

- Visit the TPS54A20 product folder
- Check out our "Three Different Buck Converter Circuits to Convert 12 V to 1.2 V at >6 A Load Current Reference Design"
- Read the blog, "On the flip side: Power converters on the backs of circuit boards reimagine electronics"

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265