

# LM27952,LM27965

*Optimizing Efficiency in White LED Backlight Applications*



Literature Number: SNVA596

# POWER | *designer*

Expert tips, tricks, and techniques for powerful designs

No. 113

Feature Article.....1-7

White-LED Drivers with  
PC Compatible  
Brightness Control.....2

White-LED Switched  
Capacitor Current  
Driver .....4

Dual Display  
White-LED Driver .....6

Power Design Tools.....8



## Optimizing Efficiency in White LED Backlight Applications

— By Dario Nurzad, Applications Engineer

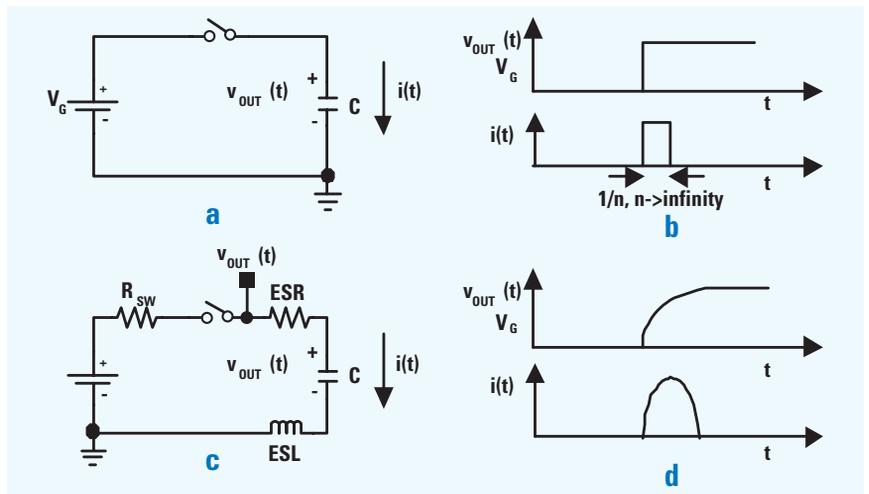


Figure 1. Charging a Capacitor From a Voltage Source (Both the ideal [a, b] and real [c, d] cases are shown)

White LEDs are typically driven with a constant DC current source to maintain constant luminosity. In portable applications with a single-cell Li-Ion source, the sum of the voltage drop across the white LED and the current source can be lower or higher than the battery voltage. This means that a white LED requires the battery voltage to be occasionally boosted. The best way to accomplish this is to use a step-up DC-DC converter. This method significantly optimizes efficiency at the expense of cost and PCB area. An alternative method of boosting the battery voltage is to use a charge pump, also called a switched capacitor converter. Here we will analyze in more detail the principle of operation of such a device.

### Basic Principles of Charge Pumps

A capacitor is a component that stores electrical charge or energy for release at some predetermined rate and time. If an ideal capacitor is charged with an ideal voltage source  $V_G$  (Figure 1a) the charge storage occurs instantly

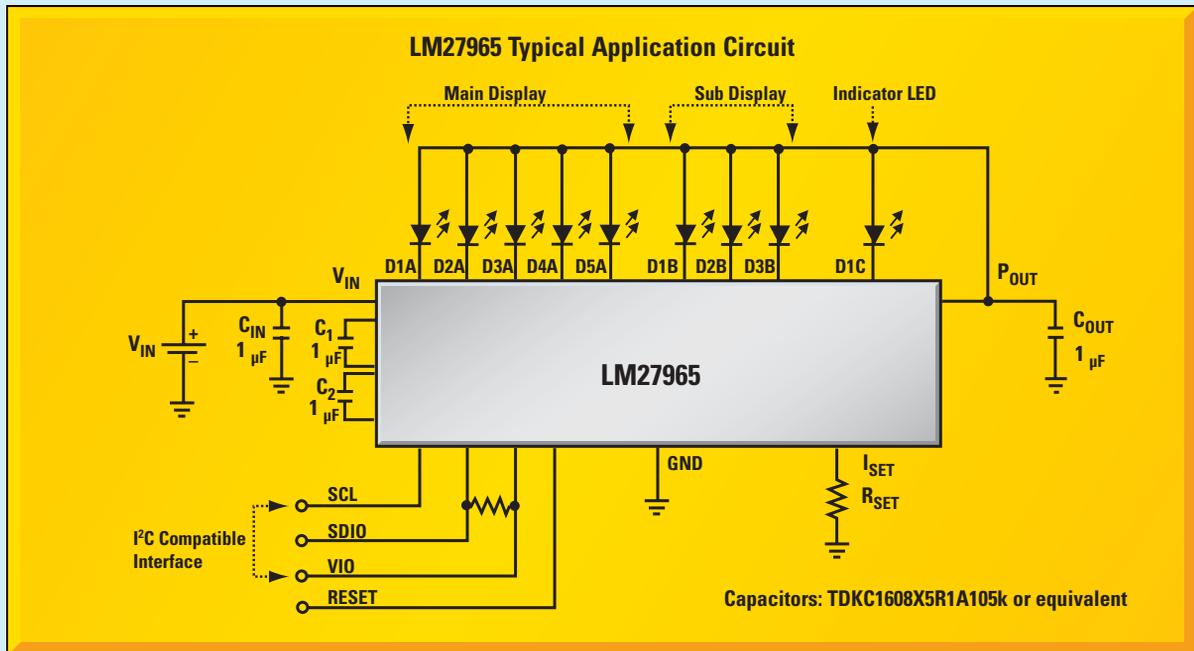
**NEXT ISSUE:**

**Switching Controller Layouts**

 **National  
Semiconductor**  
The Sight & Sound of Information

# White LED Driver System with I<sup>2</sup>C Compatible Brightness Control

## Inductorless LM27965 Drives Up to 9 LEDs at 91% Efficiency



### Features

- 91% peak LED drive efficiency
- No inductor required: 25 mm<sup>2</sup> total solution size
- 0.3% typ. current matching
- Drives LEDs with up to 30 mA per LED
- Adaptive 1x to 3/2x charge pump
- I<sup>2</sup>C compatible brightness control interface
- Extended Li-Ion input: 2.7V to 5.5V
- Available in LLP-24 packaging

**AVAILABLE  
LEAD-FREE**

Ideal for use in mobile phone display and keypad lighting, PDA backlighting, and general LED lighting

For **FREE** samples, datasheets, and more information, visit

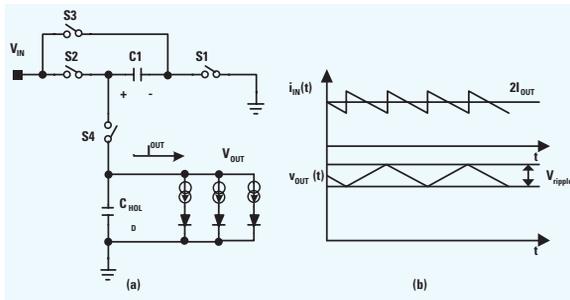
[www.national.com/pf/LM/LM27965.html](http://www.national.com/pf/LM/LM27965.html)

## Optimizing Efficiency in White LED Backlight Applications

corresponding to a Dirac impulse function for the current (*Figure 1b*). The total stored charge is given by:  $Q = CV_G$ .

Real capacitors have Equivalent Series Resistance (ESR) and Equivalent Series Inductance (ESL). Neither affects the ability of the capacitor to store energy; however, they have a large effect on the overall efficiency of the switched capacitor voltage converter. An equivalent circuit for the charge of an actual capacitor is shown in *Figure 1c*, where  $R_{SW}$  is the resistance of the switch. The charging current path will have a series inductance, which can be reduced with proper component layout.

As soon as the circuit is energized, transient conditions of an exponential nature occur until a steady-state condition is reached. The capacitor parasitics limit the peak charge current and increase the charge transfer time (*Figure 1d*). Therefore, the capacitor charge build-up cannot occur instantly, meaning that the initial voltage variation across the capacitor is equal to zero. Charge pumps use this property of capacitors as shown in *Figure 2a*.



**Figure 2. Charge Pump Circuit (a) with Relevant Waveforms (b)**

The voltage conversion is achieved in two phases. During the first phase, switches  $S_1$  and  $S_2$  are closed, whereas switches  $S_3$  and  $S_4$  are open and are charged to the input voltage:

$$V_{C1+} - V_{C1-} = V_{C1+} = V_{IN}$$

During the second phase, switches  $S_3$  and  $S_4$  are closed, whereas switches  $S_1$  and  $S_2$  are open. Because the voltage drop across the capacitor cannot change instantly, the output voltage jumps to twice the value of the input voltage:

$$V_{C1+} - V_{C1-} = V_{OUT} - V_{IN} = V_{IN} \rightarrow V_{OUT} = 2V_{IN}$$

Voltage doubling can be accomplished using this technique. The duty cycle of the switching signal is usually 50%; which generally yields the optimal charge transfer efficiency. Let us examine in more detail the charge transfer procedure and how the switched capacitor converter parasitics influence its operation.

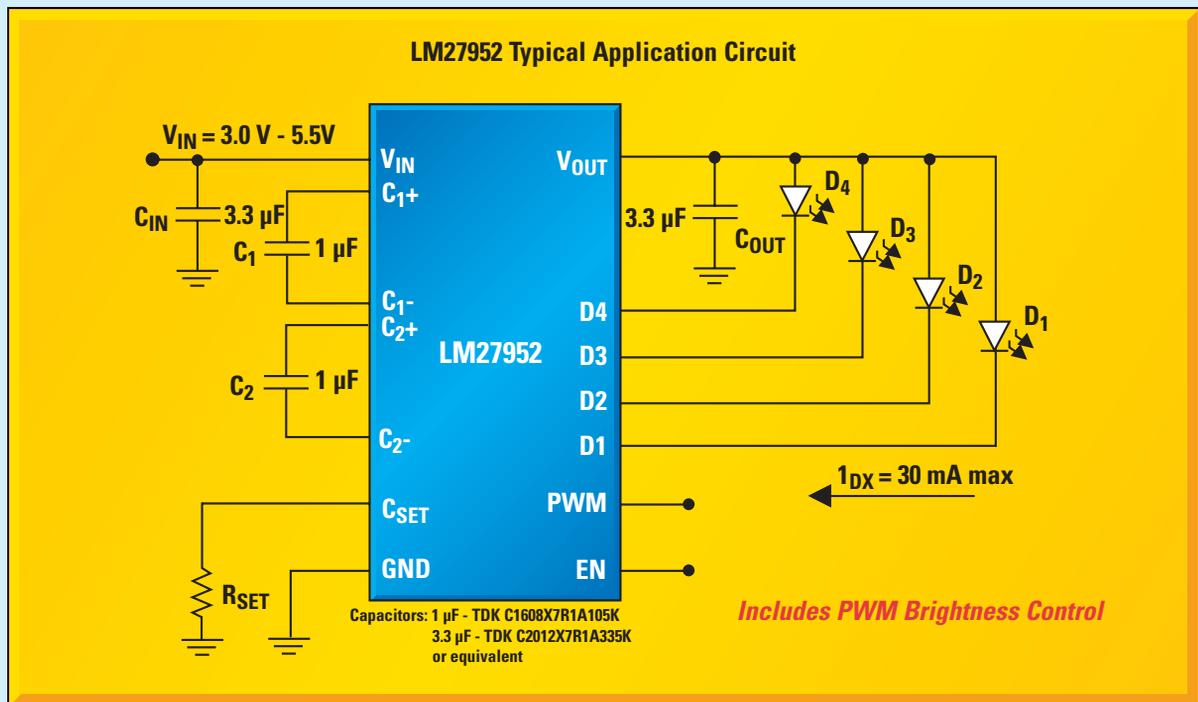
The steady-state current and voltage waveforms for a switched capacitor voltage doubler are shown in *Figure 2b*. Due to power conservation, the average input current is twice the output current. During the first phase, a charging current flows into  $C_1$ . The initial value of this charging current depends upon the initial voltage across  $C_1$ , the ESR of  $C_1$ , and the resistance of the switches. The charging current then decays exponentially as  $C_1$  is charged. The charging time constant is several times greater than the switching period. Smaller time constants will cause the peak currents to increase. During this time the output capacitor  $C_{HOLD}$  supplies the load current discharging linearly by an amount equal to:

$$\Delta V_{OUT} = \frac{I_{OUT}}{2fC_{HOLD}}$$

During the second phase when  $C_{1+}$  is connected to the output, a discharge current (whose magnitude is the same as the previous charging current,) flows through  $C_1$  to the load. In this phase, the step change in the output capacitor current is approximately  $2I_{OUT}$ . Although this current step should create an output voltage step equal to  $2I_{OUT}ESR_{C_{HOLD}}$ , the use of low-ESR ceramic capacitors renders this step change negligible. At this point,  $C_{HOLD}$  charges

# White LED Adaptive 1.5X/1X Switched Capacitor Current Driver

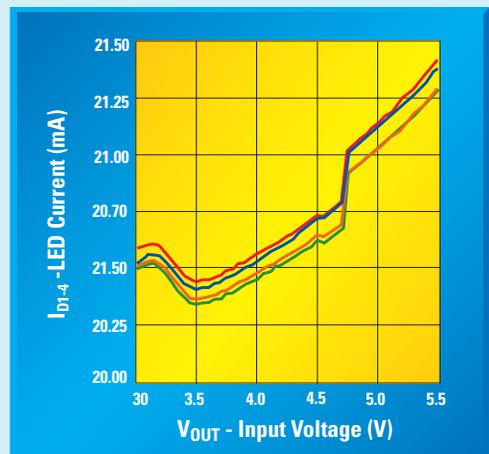
## LM27952 Drives Up to 4 LEDs with Up to 30 mA Each



### LM27952 Features

- Regulated current sources with 0.2% (typ.) matching
- 3/2x, 1x gain transition based on LED  $V_F$
- Peak efficiency over 85%
- Input voltage range: 3.0V to 5.5V
- Fixed 750 kHz switching frequency
- $<1 \mu\text{A}$  shutdown current
- Available in LLP-14 packaging

AVAILABLE  
LEAD-FREE



Ideal for use in white LED display and keypad backlights, and general purpose LED lighting

For **FREE** samples, datasheets, and more information, visit

[www.national.com/pf/LM/LM27952.html](http://www.national.com/pf/LM/LM27952.html)

## Optimizing Efficiency in White LED Backlight Applications

linearly by an amount equal to:  $\Delta V_{OUT} = \frac{I_{OUT}}{2fC_{HOLD}}$

When  $C_1$  is connected back between the input and ground,  $C_{HOLD}$  discharges linearly by an amount equal to:

$$\Delta V_{OUT} = \frac{I_{OUT}}{2fC_{HOLD}}$$

The total peak-to-peak output ripple voltage is given by:

$$V_{RIPPLE} \cong \frac{I_{OUT}}{2fC_{HOLD}}$$

Higher switching frequencies allow smaller output capacitors for the same amount of ripple.

Parasitics of the charge pump cause the output voltage to fall as the load current increases. As a matter of fact, there is always an RMS current of  $2I_{OUT}$  flowing through  $C_1$  and two switches ( $2R_{SW}$ ) resulting in a power dissipation of:

$$P_{SW} = (2I_{OUT})^2 (2R_{SW} + ESR_{C1}) = I_{OUT}^2 (8R_{SW} + 4ESR_{C1})$$

In addition to these purely resistive losses, an RMS current of  $I_{OUT}$  flows through the equivalent resistance of the switching capacitor  $C_1$ :

$$P_{C1} = I_{OUT}^2 R_{C1} = I_{OUT}^2 \frac{1}{fC_1}$$

The RMS current flowing through  $C_{HOLD}$  is equal to  $I_{OUT}$ , resulting in a power dissipation of:

$$P_{ESR-HOLD} = I_{OUT}^2 ESR_{C-HOLD}$$

All of the losses can be grouped in an equivalent output resistance:

$$R_{OUT} = 8R_{SW} + 4ESR_{C1} + \frac{1}{fC_1} + ESR_{C-HOLD}$$

Thus the output voltage of the charge pump can be modeled as follows:  $V_{OUT} = 2V_{IN} - I_{OUT}R_{OUT}$

In general, because of the low ESR of ceramic capacitors and the high switching frequency, the output ripple and output voltage drop depends on the switch resistances. Utilizing more switches and capacitors enables additional voltage conversions.

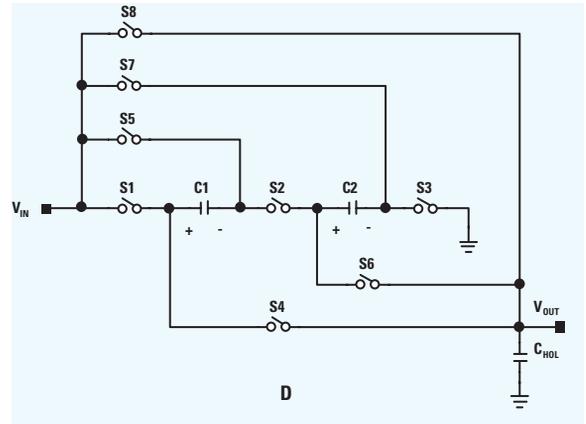


Figure 3. Switched Capacitor Circuit with 1x and 1.5x Gains

Figure 3 demonstrates this property using capacitors.

Once more, the voltage conversion is achieved in two phases. During the first phase switches S1 to S3 are closed, whereas switches S4 to S8 are open. Therefore  $C_1$  and  $C_2$  are stacked and—assuming  $C_1$  equal to  $C_2$ —charged to half the input voltage:

$$V_{C1+} - V_{C1-} = V_{C2+} - V_{C2-} = \frac{V_{IN}}{2}$$

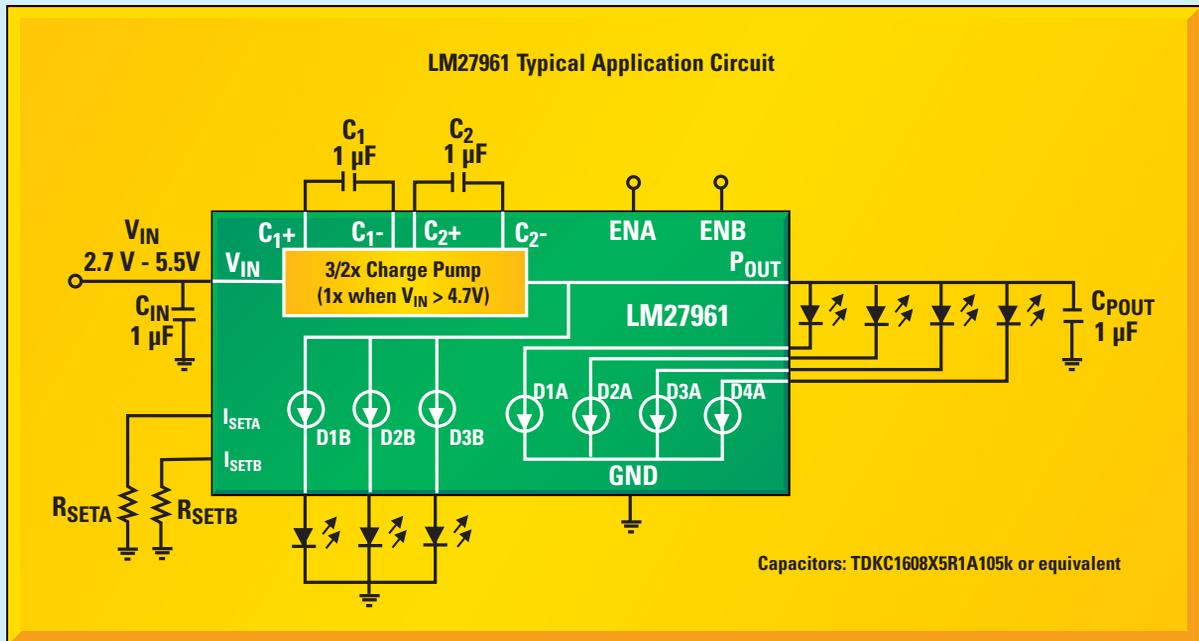
The output load current is provided by the output capacitor  $C_{HOLD}$ . As this capacitor discharges and the output voltage falls below the desired output voltage, the second phase is activated to boost the output voltage above this value. During the second phase,  $C_1$  and  $C_2$  are in parallel, tied between  $V_{IN}$  and  $V_{OUT}$ . Switches S4 to S7 are closed, whereas switches S1 to S3 and S8 are open. Because the voltage drop across the capacitor can not change instantly, the output voltage jumps to 1.5X the value of the input voltage:

$$V_{C1+} - V_{C1-} = V_{C2+} - V_{C2-} = V_{OUT} - V_{IN} = \frac{V_{IN}}{2} \Rightarrow V_{OUT} = \frac{3}{2}V_{IN}$$

The voltage boost operation is accomplished this way: A voltage conversion with a gain of 1x is achieved by closing switch S8 and leaving switches S1 to S7 open.

# Dual-Display White LED Driver with 3/2x Switched Capacitor Boost

Inductorless LM27961 Only Uses Tiny Ceramic Capacitors to Provide Superior Performance



## LM27961 Features

- Drives 4 individual common-anode LEDs with up to 20 mA each for a main display backlight
- Drives 3 individual common-cathode LEDs with up to 20 mA each for a sub-display backlight
- Independent resistor-programmable current setting
- Excellent current and brightness matching
- Extended Li-Ion input: 2.7V to 5.5V
- PWM brightness control: 100 Hz to 1 kHz
- Available in micro SMD packaging

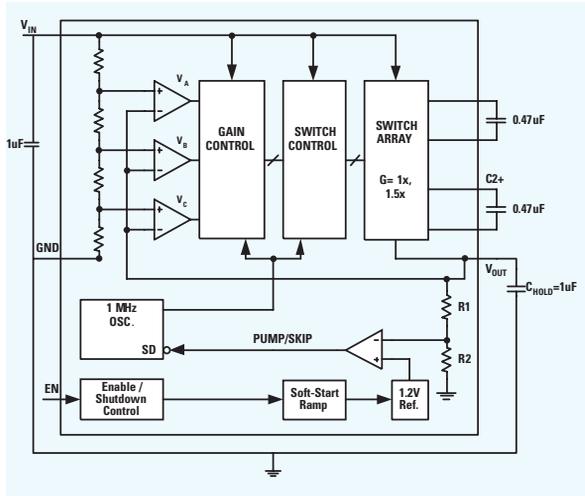
Ideal for use in mobile phone display and keypad lighting, PDAs, and general LED lighting

AVAILABLE  
LEAD-FREE

For FREE samples, datasheets, and more information, visit

[www.national.com/pf/LM/LM27961.html](http://www.national.com/pf/LM/LM27961.html)

## Optimizing Efficiency in White LED Backlight Applications



**Figure 4. Switched Capacitor Regulator Block Diagram**

### Pulse Frequency Modulation (PFM) Scheme

A simplified Pulse Frequency Modulated (PFM) regulation scheme, which utilizes multiple gains, is depicted in *Figure 4*. The down-scaled output voltage is compared by the PUMP/SKIP comparator to a 1.2V voltage reference. The PUMP/SKIP comparator is ramped up linearly on start up to provide the soft-start function. When the output voltage is above the desired limit the device does not switch, consuming minimal supply current. During this idle state the output load current is provided by the output capacitor. As this capacitor discharges and the output voltage falls below the desired output voltage, the charge pump is activated until the output voltage is above this value again.

The primary advantage of the PFM regulation architecture is evident at light loads. Typically the load is provided with energy by the output capacitor. The supply current is very low, as the output capacitor only needs to be re-charged occasionally by enabling the charge pump.

In general, regulated charge pumps do not maintain a high efficiency over a wide input range. Because the input-to-output current ratio is scaled

according to the basic voltage conversion, any output voltage magnitude less than the input-voltage-times-the-charge-pump-gain will result in additional power dissipation within the converter and efficiency will be degraded proportionally:

$$\eta_{IDEAL} = \frac{V_{OUT} I_{OUT}}{V_{IN} I_{IN}} = \frac{V_{OUT} I_{OUT}}{V_{IN} G I_{OUT}} = \frac{V_{OUT}}{V_{IN} G}$$

$$\eta_{IDEAL} \rightarrow 1 \Leftrightarrow V_{OUT} = G V_{IN}$$

The ability of the converter to change gains according to the input/output ratio allows for optimal efficiency over the entire input voltage range. Ideally, the gain should vary linearly. In reality, given a certain number of capacitors and switches, only a finite number of gain configurations are possible.

Referring to *Figure 4* the input voltage is scaled and fed into the non-inverting nodes of three comparators. All inverting nodes of the comparators are connected to the output voltage. Based on the input-to-output voltage ratio the outputs of the comparators provide the gain control circuitry with a three-bit word, which is used to select the minimum gain  $G$ , able to achieve the desired voltage conversion. In white LED applications, however, the selection of the proper gain  $G$  is not only based on the input and output voltages.

### Conclusion

There are certain advantages in using switched capacitor rather than inductor-based switching techniques. An obvious advantage of switched capacitor converters is the elimination of the inductor and the related magnetic design issues. They usually have relatively low noise and minimal radiated EMI. Additionally, the applications circuits are simple and only a few small capacitors are needed.

Because there is no inductor, the final PCB component height is generally smaller than a comparable switching converter. ■

# Power Design Tools

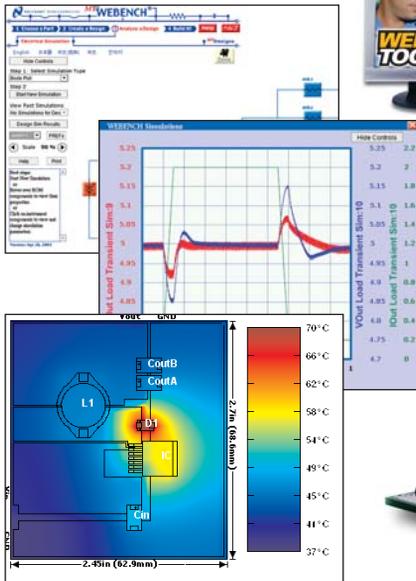


## WEBENCH® Online Design Environment

Our design and prototyping environment simplifies and expedites the entire design process.

1. Choose a part
2. Create a design
3. Analyze a power supply design
  - Perform electrical simulation
  - Simulate thermal behavior
4. Build it
  - Receive your custom prototype kit 24 hours later

[webench.national.com](http://webench.national.com)



## Reference Designs

National's power reference design library provides a comprehensive library of practical reference designs to speed system design and time-to-market.

[www.national.com/refdesigns](http://www.national.com/refdesigns)

### National Semiconductor

2900 Semiconductor Drive  
PO Box 58090  
Santa Clara, CA 95052  
1 800 272 9959

Visit our website at:  
[power.national.com](http://power.national.com)

For more information,  
send email to:  
[new.feedback@nsc.com](mailto:new.feedback@nsc.com)

*Don't miss a single issue!*



Subscribe now to receive email alerts when new issues of Power Designer are available:

[power.national.com/designer](http://power.national.com/designer)

Read our Signal Path Designer<sup>SM</sup> online today at:

[signalpath.national.com/designer](http://signalpath.national.com/designer)



## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

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

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI 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 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. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

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

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Mobile Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Transportation and Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

TI E2E Community Home Page

[e2e.ti.com](http://e2e.ti.com)

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2011, Texas Instruments Incorporated