High-Performance Analog Products

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Data Acquisition

Most touch-screen controllers (TSCs) have one or more auxiliary analog inputs that can be used to monitor battery voltage or other voltage signals in addition to the TSC signals. This article describes typical applications for these auxiliary inputs. Also discussed are design considerations for ESD protection, circuit isolation after power down, and input-voltage ranges accepted by several devices.

Power Management

This article investigates the myth that a boost converter is always required to drive white-light-emitting diodes (WLEDs). Several typical WLED datasheets are examined, revealing that many applications require far less than the maximum-rated LED voltage. This article also shows that many applications can be driven by an LDO-based LED driver, such as the Texas Instruments TPS75105, for an extremely small and efficient solution.

A host-side gas gauge offers economic advantages in systems with interchangeable battery packs since it eliminates most redundant pack components. This article covers the problems of existing gas gauges and the benefits of Impedance Track™ technology. Also included are design considerations for a host-side gas-gauge and battery-charging system.

The most common power-supply source for electronic devices has a positive output relative to ground. Some applications like audio amplifiers, line drivers/receivers, and instrumentation amplifiers may require a negative supply relative to ground. This article describes how to use a buck converter to obtain a negative supply output. Included are discussions of basic buck topology, inverting buck-boost topology, and design considerations required to obtain a stable negative power source.

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Introduction

Analog Applications Journal is a collection of analog application articles designed to give readers a basic understanding of TI products and to provide simple but practical examples for typical applications. Written not only for design engineers but also for engineering managers, technicians, system designers and marketing and sales personnel, the book emphasizes general application concepts over lengthy mathematical analyses.

These applications are not intended as "how-to" instructions for specific circuits but as examples of how devices could be used to solve specific design requirements. Readers will find tutorial information as well as practical engineering solutions on components from the following categories:

- Data Acquisition
- Power Management

Where applicable, readers will also find software routines and program structures. Finally, *Analog Applications Journal* includes helpful hints and rules of thumb to guide readers in preparing for their design.

Using a touch-screen controller's auxiliary inputs

By Wendy Fang, *Precision Analog Applications, High-Performance Analog,*
and Tony Chang, *Precision Analog Nyquist, High-Performance Analog*

Introduction

Texas Instruments (TI) touch-screen controllers (TSCs), including the ADS7843/45/46, TSC2046, and TSC2003/4/5/6/7, have touch-screen input pins and one or more non-touch-screen or auxiliary analog input pins, such as the battery-voltage-monitoring pin (V_{BAT}) of the TSC2046 or the AUX pin of the TSC2007. These auxiliary inputs make it possible to monitor the system's battery level or other voltage signals by sharing time with touch-screen inputs or using time periods when the touch screen is not touched.

The auxiliary analog inputs of different TI TSCs may have different input ranges and different levels of electrostatic-discharge (ESD) protection, so certain requirements or limitations should be considered when they are used. This article discusses the general and specific features and limitations of the TSC auxiliary (including battery-voltage) inputs.

Auxiliary analog inputs

Table 1 lists auxiliary analog input pins of TI's current TSCs. Inside a TSC, a MUX selects and connects one of the analog inputs to the ADC via commands sent through the SPI or I^2C ports. Figure 1 shows an example.

Auxiliary input mode

TI's TSCs can be operated in either differential or single-ended (SE) input mode, but auxiliary analog inputs can be measured and converted only in SE mode (see Figure 2).

Table 1. Auxiliary analog input(s) of TI TSC devices

TSC	AUXILIARY ANALOG INPUTS		V_{REF}	MAIN FEATURES[1]
	NUMBER OF INPUTS	PIN NAMES		
ADS7843	2	IN3, IN4	External	4-wire, SPI, command-based
ADS7845	1	AUXIN	External	5-wire, SPI, command-based
ADS7846	2	V_{BAT}, AUX	Internal	4-wire, SPI, command-based
TSC2046	2	V_{BAT}, AUX	Internal	4-wire, SPI, command-based
TSC2003	4	V_{BAT1}, IN1, V_{BAT2}, IN2	Internal	4-wire, I^2C, command-based
TSC2004	1	AUX	External	4-wire, I^2C, register-based
TSC2005	1	AUX	External	4-wire, SPI, register-based
TSC2006	1	AUX	External	4-wire, SPI, register-based
TSC2007	1	AUX	Shared with V_{DD}	4-wire, I^2C, command-based

Figure 1. Block diagram of TSC's internal input circuit

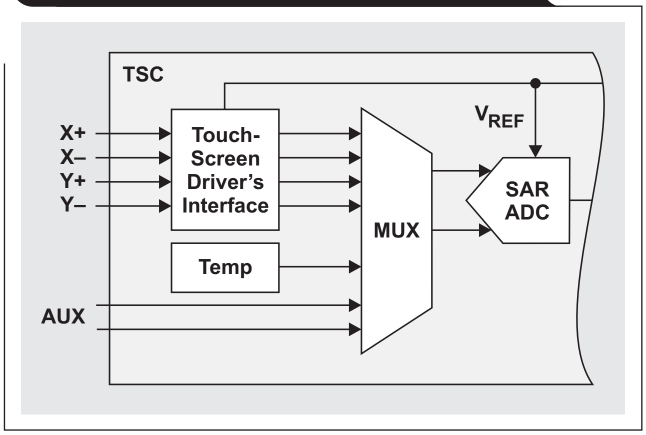
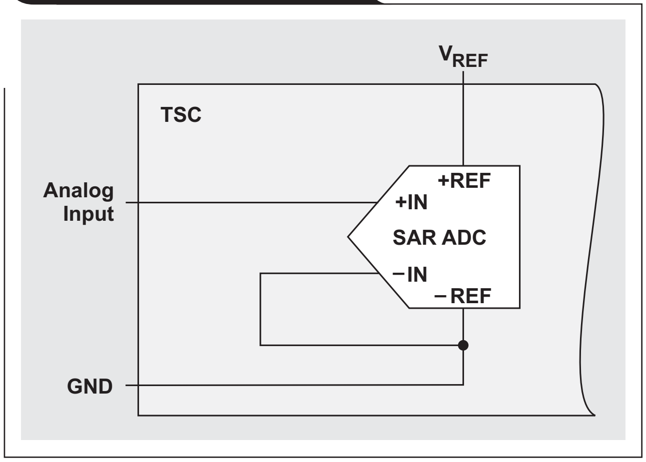


Figure 2. SE mode of a TSC



A TSC in differential mode does not need any reference, since the signal's driver is connected to +REF and –REF directly. However, the reference voltage, V_{REF}, is a must for SE operation and thus is always needed when an auxiliary input, such as the AUX or V_{BAT}, is measured.

The reference voltage can be provided to the TSC's ADC externally or internally for the ADS7846, TSC2046, and TSC2003. When an external reference is used, these devices can be powered up at the V_{CC} pin with a supply voltage between 2.2 and 5.25 V, and an external V_{REF} ranging from 1.0 V to V_{CC} can be provided. When the TSC's internal reference is used, the ADS7846, TSC2046, or TSC2003 should be powered up with a 2.7- to 5.25-V supply to guarantee that the internal V_{REF} will be around 2.5 V (2.45 V ~ 2.55 V). Other TI TSCs do not have the built-in voltage reference. In practical applications, one can simply route the same TSC power supply to the reference.

Auxiliary-input voltage range

The signal range for an auxiliary input should always be within 0 V to V_{REF}. Signals beyond this range will saturate the ADC and can even increase the temperature, damaging the input circuitry.

The signal range for a battery-monitor input, say V_{BAT}, can greatly exceed the V_{REF} level, since there is a voltage divider with each V_{BAT} pin (see Figure 3). The input divider circuit limits the range of the signal to the ADC to within 0 V to V_{REF}. Figure 3 shows that the signal to the ADC is only 25% of the signal at the V_{BAT} pin.

As shown in Table 1, the ADS7846, TSC2046, and TSC2003 have one or two battery-monitor input(s) designed to monitor/measure signals of up to 6.0 V while the device is powered with much lower voltage, down to 2.7 VDC.

TSC auxiliary-input features

The main features of TSC auxiliary (including battery) inputs can be summarized as follows:

- Auxiliary input signals can be measured only in SE mode.
- A reference voltage, V_{REF}, must be provided to the ADC when an auxiliary input is measured.
- The signal range of an auxiliary input must be within 0 V to V_{REF}.
- The battery input, V_{BAT}, can range from 0 V to as high as 4 × V_{REF}, up to 6.0 V.

Special applications

The following discussion focuses on the special applications of the auxiliary analog input pins of TSCs.

Unused input pins

If the TSC's analog input pins are not used, it is recommended that they be connected directly to an analog ground.

Using AUX input pin to monitor V_{BAT}

As Table 1 shows, several TI TSCs are not furnished with a battery-voltage-monitoring pin (V_{BAT}). A regular auxiliary input cannot be used directly for monitoring the battery, since the battery's voltage is normally higher than that of the TSC's power supply (and thus that of the V_{REF}).

Figure 3. Voltage divider reduces input to ADC

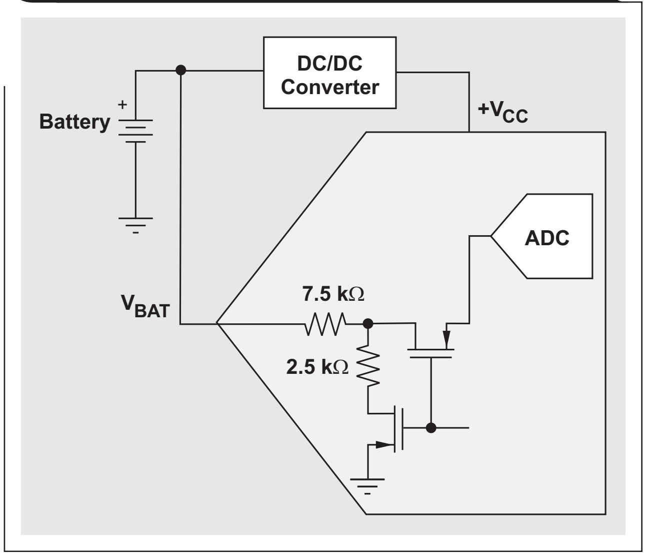
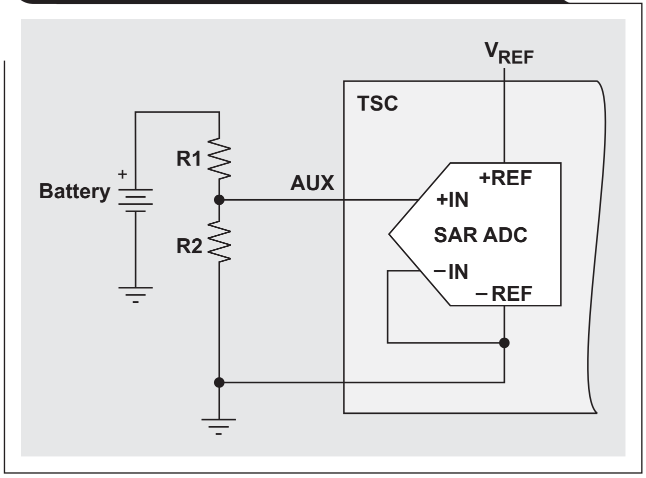


Figure 4. Using AUX with external voltage divider to monitor battery voltage



A TSC auxiliary pin such as AUX can still be used to measure/monitor the battery voltage if an external voltage divider is added between the battery and the AUX, as shown in Figure 4. R1 and R2 values should be selected with wide enough margins to ensure that the signal at the AUX pin is within 0 V to V_{REF}. Note that the voltage divider shown in Figure 4 consumes extra power since a current of $V_{CC}/(R1 + R2)$ continuously drains the battery. Larger resistance can reduce power consumption.

The V_{BAT} input circuit of TI TSCs does not consume extra power from the battery since there is a switcher between the divider and the power (ground) (see Figure 3), and the internal divider is powered up only during the short period of battery measurement.

Figure 5. Using TSC AUX pin to monitor battery with controllable switch

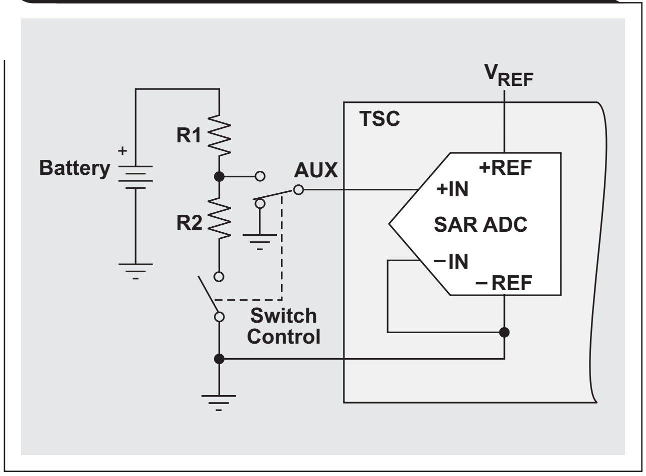
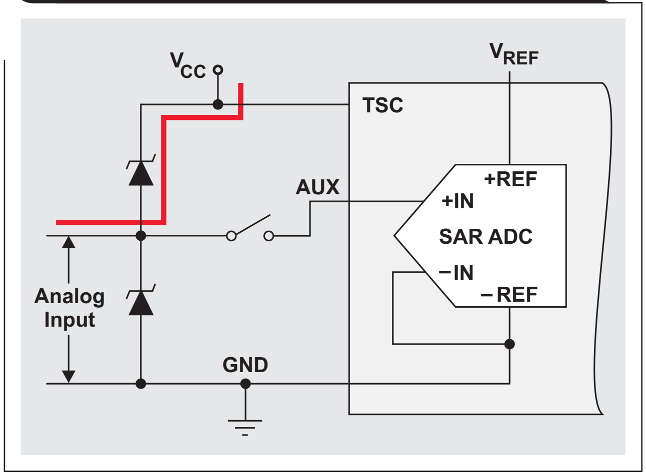


Figure 6. External ESD-protection circuit may supply pseudo power to TSC



Similarly, while a TSC's AUX pin is used to monitor battery voltage, adding a controllable switcher like that shown in Figure 5 can reduce power consumption and ensure disconnection of the signal from the AUX pin while the TSC is powered down.

ESD protection and auxiliary-input requirements during power down

It is very common in practical applications to power down a TSC when it is not in use to reduce system power consumption. A question then arises: Can the analog signal stay connected to the TSC when the TSC's power source is removed?

Figure 6 shows one case in which the analog input should be removed before the TSC is powered down. If the analog input signal is active (AUX is nonzero) when the TSC is powered down ($V_{CC} = 0$), the analog signal may be routed to the V_{CC} through the ESD-protection diode (see the red line in Figure 6). This may partially or fully power up the TSC, depending upon the amplitude of the input signal, consuming more power and possibly causing the TSC to malfunction. Thus the circuit configuration in Figure 6 should be avoided.

An alternative is to simply use ESD-protection circuitry as shown in Figure 7. Under extremely large electrostatic voltages, the circuit in Figure 7a may not be as efficient as that in Figure 7b due to the limited current flow through the ESD-protection diodes. On the other hand, the circuit in Figure 7b is not symmetric and therefore does not provide equal protection for positive and negative ESD bursts.

Figure 7. ESD-protection circuits for TSC analog input pin

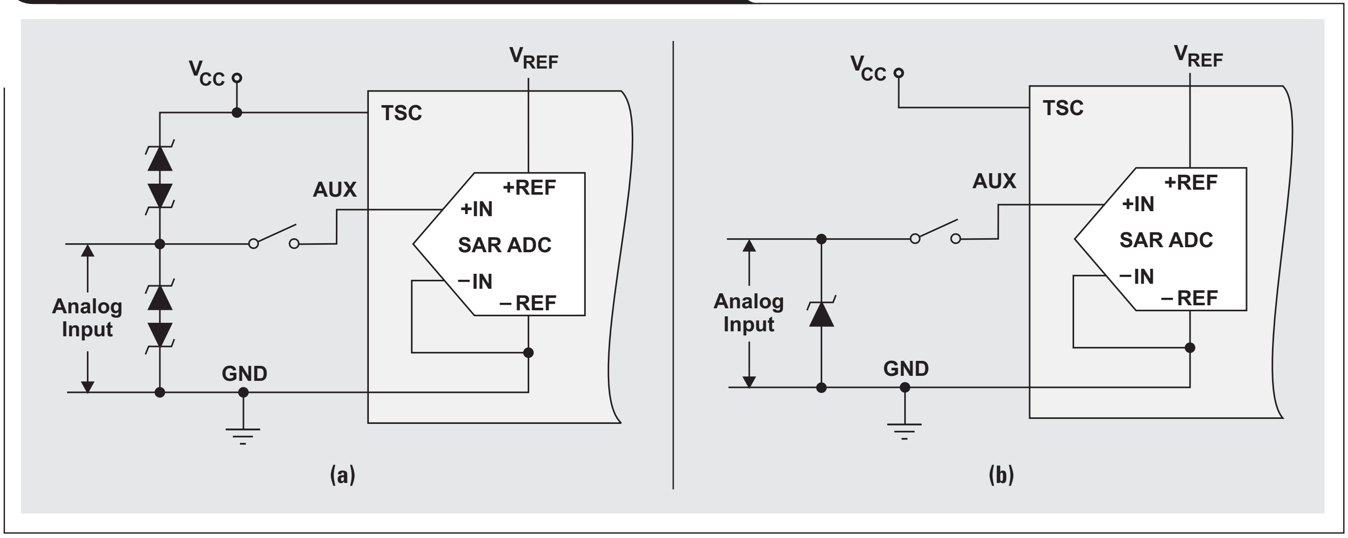


Figure 8. TSC2004/5/6/7 internal ESD protection for AUX input

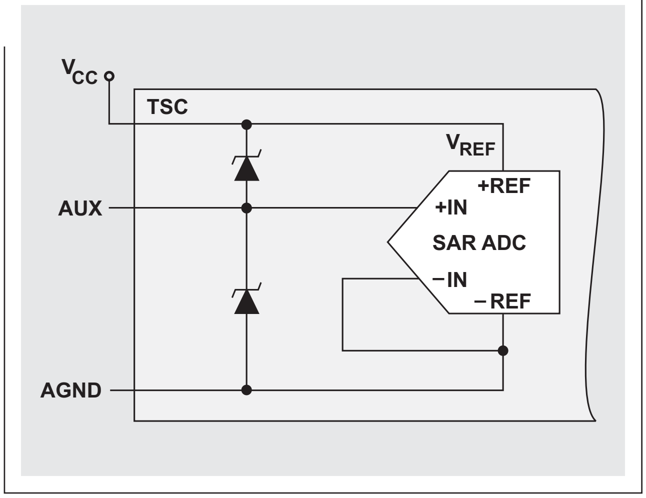
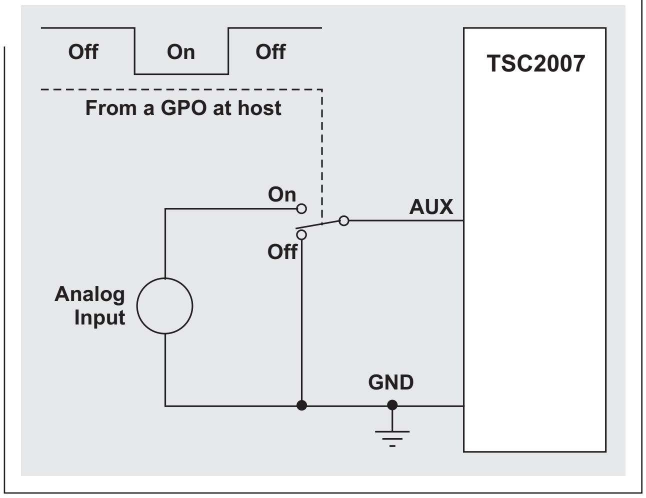


Figure 9. Switching off TSC2004/5/6/7 AUX before TSC is powered down



Some of TI's new TSCs, including the TSC2004/5/6/7, were designed with the enhanced, on-chip ESD protection shown by the simplified circuit in Figure 8. Obviously, for these devices, the input signal to the TSC's AUX should be removed before the TSC's V_{CC} power is shut down. An example of removing the AUX signal is shown in Figure 9.

Special applications summary

- An unused analog input pin should be connected directly to the analog ground.
- Pay attention to the divider's resistance values and power consumption when using an AUX to monitor the battery voltage.
- Before removing the TSC's power, always use software commands to disable the TSC's auxiliary functions.
- For the ADS7846, TSC2046, and TSC2003, the nonzero signal to the AUX or V_{BAT} pin can stay connected while the TSC's power source is removed.
- For the TSC2004/5/6/7, the nonzero signal to AUX should be removed from the analog input pin before the TSC power is removed.

Reference

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Driving a WLED does not always require 4 V

By Will Hadden

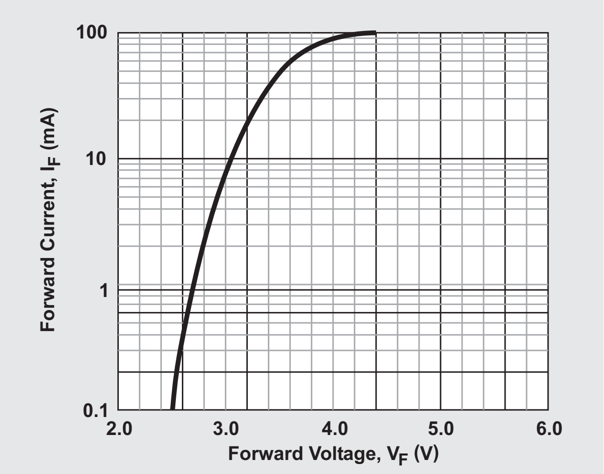
Power Management Products, Portable Power DC/DC Applications

The popularity of white-light-emitting diodes (WLEDs) has skyrocketed, primarily because they are used to provide backlight to portable electronics displays. The common belief is that a single WLED requires a 4-V drive voltage. Since a Li-ion battery provides an average voltage of 3.6 V, the general industry consensus is that a step-up converter is required to power WLEDs from a single-cell Li-ion battery. As a result, many ICs are available for driving WLEDs, most requiring an external inductor or flying capacitors to boost the cell voltage high enough. As WLED technology continues to mature, the forward-voltage requirements continue to drop. Currently, there are many LEDs available with typical forward voltages (V_F) in the 3.2- to 3.5-V range with maximum ratings at 3.7 to 4 V. The datasheets usually specify these voltages at LED currents of around 15 to 25 mA. This article discusses lower-current applications and how they affect the forward voltage of the WLED. It also introduces the Texas Instruments (TI) TPS75105, a new LED driver designed to efficiently drive these lower-voltage LEDs with a reduced solution size and cost.

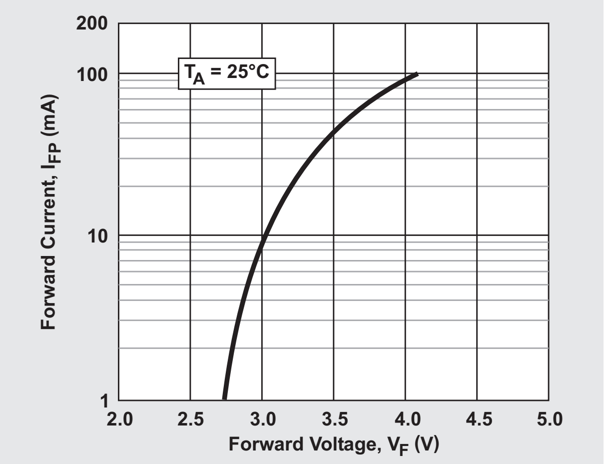
LED forward voltage

The WLED is similar to other standard p-n junction diodes. It does not conduct current until a sufficient forward voltage has been applied. After the threshold is exceeded, the forward current increases with the forward voltage of the WLED. Typical I-V curves for two WLEDs are shown in Figure 1.

Figure 1. Typical WLED I-V curves



(a) Kingbright AA3528RWC/A



(b) Nichia NSSW100CT

Utilizing these graphs is a simple task. As with typical diode I-V curves, the current rises sharply with the voltage after crossing the threshold. The typical forward voltage for the device in Figure 1a is specified to be 3.2 V at 20-mA forward current with a maximum of 3.7 V over process and temperature variations. This leads to the conclusion that the application requires a step-up DC/DC converter to properly drive the WLED from a single Li-ion cell with an output of 3 to 4.2 V. However, this is not necessarily the case. Take, for example, a 5-mA WLED-current application. The curve in Figure 1a shows that the forward voltage required to drive 5 mA is around 2.9 V, which is much less than the typical voltage required to drive 20 mA as specified in the datasheet. A boost converter is not required to drive a 2.9-V output voltage from a 3.6-V Li-ion cell.

WLEDs are specified with a typical value as well as a maximum value to cover lot-to-lot process and manufacturing variations. The I-V curves provided in the datasheet are usually specified with a part that falls at the typical specification. Although the curve shape is valid for every part that is manufactured, the curve shifts to the right or left depending on the forward voltage at the test conditions for that device. If we use another LED with the same part number as in the previous example, the forward voltage measures 3.7 V (the maximum rating) at the typical test conditions (20-mA forward current). This voltage, which is 0.5 V higher than a typical device, translates to a maximum forward voltage of 3.4 V (2.9 V + 0.5 V) required to drive this WLED at 5 mA. Depending on the cutoff voltage of the application, a boost converter is not needed to drive this particular WLED at 5 mA. This technique makes it easy to determine the maximum forward voltage for any application.

What about temperature variations?

Some applications require WLEDs to work in harsher conditions with extreme temperatures. Temperature variation affects LED characteristics, but the effect is not as drastic at low current levels as at higher ones. The graph in Figure 2 from a typical WLED datasheet shows forward voltage versus temperature.

This graph shows that the temperature dependence is much stronger with a higher current and forward voltage. Additionally, the forward voltage drops as the temperature increases. The 5-mA curve shows that the forward voltage drops approximately 0.1 V from room temperature (25°C) to the maximum-rated temperature (85°C). This should be taken into account when determining the required forward voltage, but the effect is negligible. If a particular application requires that the LED be driven in a very cold environment, the increased forward voltage may result in lower brightness at low input voltages.

An ultrasmall LED-driver solution

A typical solution for driving multiple WLEDs is to connect them in series and then drive the series string with either an inductive boost converter or a charge pump. This is an excellent method with higher WLED currents that require a higher forward voltage. However, as previously discussed, a boost converter is not required in every WLED driver application. A simpler and lower-cost driver for low-current WLED applications is the ultrasmall TPS75105 LED driver IC. The TPS75105, a linear current source with an ultralow 28-mV dropout voltage, is used for driving four parallel WLEDs in two separate banks. This device provides four 2%-matched current paths in two separately enabled banks. The device is available in the ultrasmall 9-ball, 1.5-mm^2 wafer-chip-scale package (WCSP), requires no external components when using the default current output, and therefore results in an incredibly small 1.5-mm^2 solution size. In addition, the TPS75105 is one of the most inexpensive WLED lighting solutions that TI offers. The application circuit for the TPS75105 is shown in Figure 3.

At first glance, using a low-dropout linear circuit to drive LEDs may seem impractical, given the linear regulator's reputation for low efficiency. However, the efficiency of LDOs is often misunderstood. LDO efficiency is entirely based on the input/output voltage ratio; therefore, the efficiency of driving WLEDs can be quite high. For example, driving a 3-V WLED from a 3.6-V Li-ion battery input

Figure 2. Forward voltage vs. temperature (Nichia NSSW100CT)

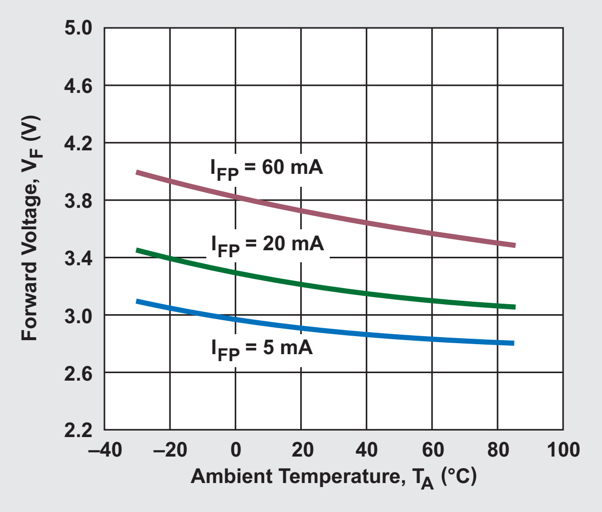


Figure 3. TPS75105 application circuit

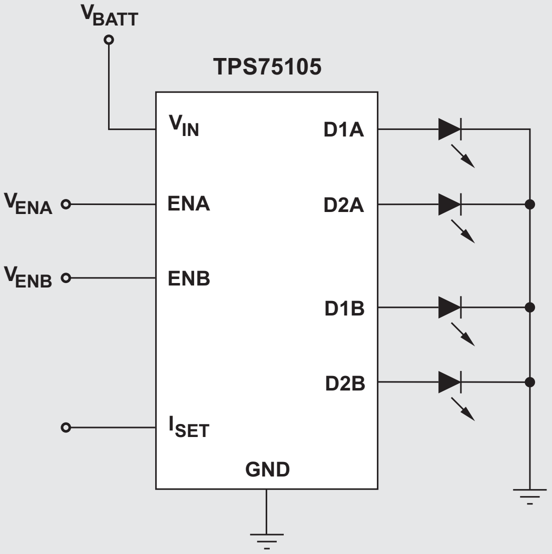
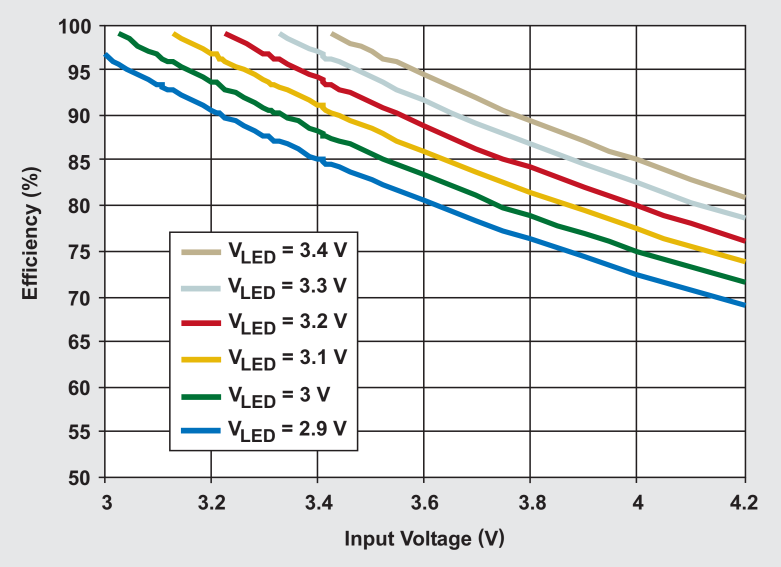


Figure 4. TPS75105 LED efficiency

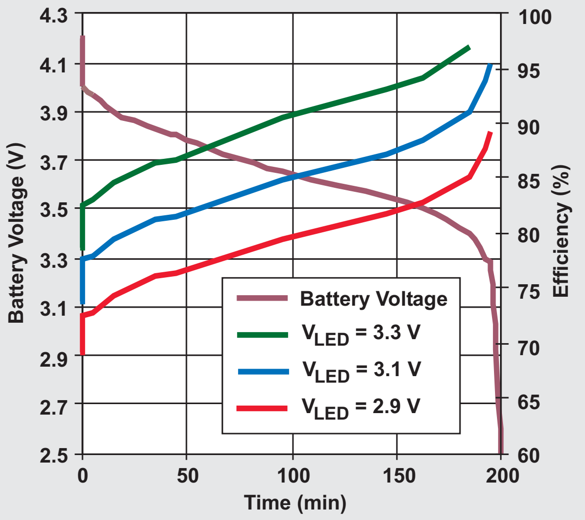


translates into an LED efficiency of 83%. Figure 4 shows the TPS75105 efficiency data for several different WLED forward voltages over the Li-ion battery range. The LED efficiency for the TPS75105 is comparable to or better than that of other WLED-driver solutions.

Figure 5 demonstrates the LED efficiency of the TPS7510x over the Li-ion discharge curve. The average efficiency for the entire discharge range is over 80% for all three curves, and up to 90% when V_{LED} = 3.3 V.

While this article concentrates on low-current applications, the TPS7510x can drive up to 25 mA per LED if the input voltage allows. These applications benefit from the very small size.

Figure 5. TPS7510x LED efficiency over the Li-ion discharge curve



Conclusion

When an LED-driver application is evaluated, special consideration should be given to how much current the application requires. If it is well below the current at which the application's WLED V_F is specified, the WLED datasheet I-V curves should be reviewed to determine the actual V_F in the application. The application may be able to use a low-dropout linear current source such as the TPS75105 to achieve an ultralow solution size and low cost without sacrificing the efficiency of a switching step-up converter.

References

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2. "Specifications for Nichia Chip Type White LED," Nichia Corporation, NSSW100CT Datasheet, No. STSE-CC6014B.	—
3. "Low Dropout, Two-Bank LED Driver with PWM Brightness Control," TPS7510x Datasheet	sbvs080
4. TPS75105EVM User's Guide	slvu182

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Host-side gas-gauge-system design considerations for single-cell handheld applications

(This article will be available December 2007)

Using a buck converter in an inverting buck-boost topology

By John Tucker
Applications Engineer

Introduction

Most practical electronic devices require an input voltage source. This may be a battery for handheld or portable devices, a 115-V AC line source or “wall wart” for home consumer electronics, or a regulated DC voltage bus for industrial or telecommunications applications. Typically, the input voltage source must be converted to one or more lower voltage sources to power individual circuits such as processors, memory, FPGAs, or other logic. Buck converters are commonly used to derive the required input voltage from a higher voltage source. In some cases, generating a negative voltage from a positive input voltage source may be required. These applications can include audio amplifiers, line drivers and receivers, or instrumentation amplifiers. In such instances it is possible to configure the buck converter into an inverting buck-boost topology, where the output voltage is negative with respect to ground.

Basic buck topology

To understand the inverting buck-boost circuit operation, first consider the basic topology of the buck converter as shown in Figure 1. The components inside the box with a blue dotted outline are typically integrated into the converter’s integrated circuit, while those outside are required external components.

When the FET switch is on, the voltage across the inductor is $V_{IN} - V_{OUT}$, and the current through the inductor increases at a rate of

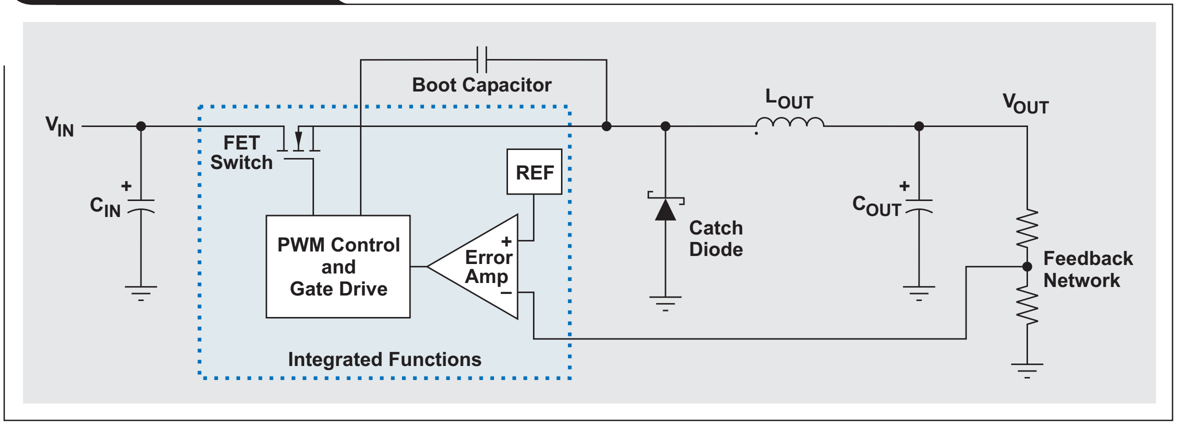
$$\frac{di}{dt} = \frac{V_{IN} - V_{OUT}}{L}.$$

When the switch is off, the inductor voltage reverses to keep the inductor current continuous. Assuming that the voltage drop across the diode is small, the inductor current ramps down at a rate of $di/dt = V_{OUT}/L$. The steady-state load current is always carried by the inductor during both the on and off times of the FET switch. The average inductor current is equal to the load current, and the peak-to-peak inductor ripple current is

$$I_{L(PP)} = \frac{(V_{IN} - V_{OUT})D}{f_{SW}L},$$

where V_{IN} is the input voltage, V_{OUT} is the output voltage, D is the duty cycle V_{OUT}/V_{IN}, f_{SW} is the switching frequency, and L is the output inductance.

Figure 1. Buck topology



Inverting buck-boost topology

Compare the preceding operation to that of the inverting buck-boost topology shown in Figure 2. The inductor and catch diode have switched places relative to the buck converter of Figure 1; and the output capacitor is reversed in polarity, as the output voltage is negative. During operation, when the FET switch is on, the voltage across the inductor is V_{IN} and the current ramps up at a rate of $di/dt = V_{IN}/L$. While the FET switch is on, the entire load current is supplied by energy stored in the output capacitor. When the FET switch turns off, the inductor reverses polarity to keep the inductor current continuous. The voltage across the inductor is approximately V_{OUT}, and the inductor current decreases at a rate of $di/dt = –V_{OUT}/L$. During the off time, the inductor supplies current both to the load and to replenish the energy lost by the capacitor during the on time. So for the buck-boost circuit, the average inductor current is

$$I_L = \frac{I_{OUT}}{1-D},$$

and the peak-to-peak inductor current is

$$I_{L(PP)} = \frac{V_{IN}D}{f_{SW}L}.$$

The duty cycle, D, is approximately

$$D = \frac{V_{OUT}}{V_{IN}+V_{OUT}}.$$

These basic differences in circuit operation are important when the buck converter is used as a buck-boost converter.

Design considerations

When a nonsynchronous buck converter is used in an inverting buck-boost configuration, certain considerations must be made. The design equations are presented in simplified form with the semiconductors idealized and other component losses neglected. To implement the buck-boost topology of Figure 2, the buck-converter ground pin is connected to V_{OUT}, and the positive lead of the output capacitor is connected to ground. The voltage across the device's V_{IN} pin to GND is then $V_{IN} – (–V_{OUT})$, rather than just V_{IN} as in the buck converter. This combined voltage must be less than the specified V_{IN} of the chosen device.

The operating duty cycle is

$$D = \frac{V_{OUT}}{V_{OUT}-V_{IN}},$$

and the average inductor current is

$$I_{L(avg)} = \frac{I_{OUT}}{1-D}.$$

These values also differ from those of the buck converter, whose duty cycle, $D = V_{OUT}/V_{IN}$, and average inductor current are equal to the output current.

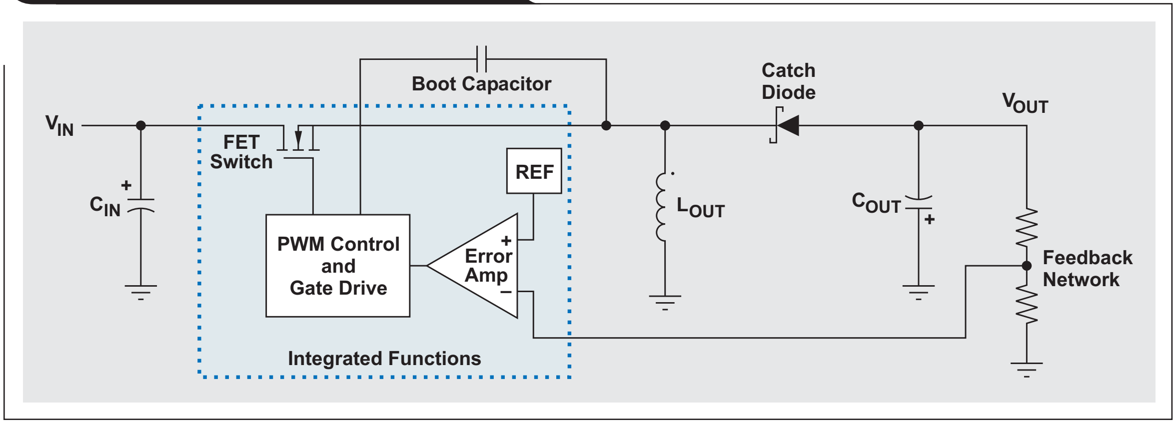
Since the average output current cannot exceed the device's rated output, the available load current is reduced by a factor of 1 – D. So for this design, the maximum available DC load current is $I_{SW} \times (1 – D) = I_{Load}$, where I_{SW} is the average rated current of the high-side switch FET.

In addition, the inductor AC ripple current should be kept small for several reasons. The peak inductor current, which is the average inductor current plus half the peak-to-peak AC current, must be below the internal circuit's current limit. The inductor AC ripple current also determines the DC output current below which the circuit begins to operate in the discontinuous conduction mode. This operation mode occurs when the DC output current is equal to half the peak-to-peak AC current. In general, this restriction will be more severe than the current limit. The ripple current also contributes significantly to the output-voltage ripple. Lower inductor ripple currents provide cleaner output voltages.

For the inverting buck-boost converter, there are significant differences between discontinuous- and continuous-mode operation. Designs that are stable in the discontinuous mode may become unstable when increased load current causes them to operate in the continuous mode, during which the feedback loop contains a right-half-plane zero.[1]

A bypass capacitor from V_{IN} to ground and from V_{IN} to V_{OUT} should be used on the input. The bypass from V_{IN} to V_{OUT} is across the device voltage input.

Figure 2. Inverting buck-boost topology



Typical waveforms

To demonstrate some of the performance differences between the two topologies, a test circuit was constructed for each type. Both circuits use a 24-V input. The buck converter has a 5-V output at 2 A, while the inverting buck-boost converter has a –5-V output, also at 2 A. Output voltage ripple and switching-node waveforms for the inverting buck-boost and buck converters are shown in Figures 3 and 4. Note that the switching-node voltage varies from V_{IN} to V_{OUT} for the inverting buck-boost converter, and from V_{IN} to ground for the buck converter. The ground reference line is indicated by the C2 marker at the left edge of each figure. Also observe that the output voltage ripple does not show the linear ramp characteristic typical of the buck converter. In the buck converter, the average inductor current is delivered to the load while the AC portion is shunted to ground through the output-filter capacitor. The primary component of the ripple voltage is the AC ripple current times the equivalent series resistance of the output cap, resulting in a waveform resembling a ramp that rises during the FET switch on time and falls during the switch off time. For the inverting buck-boost converter, the output capacitor supplies the load current during the switch on time and is recharged during the switch off time. This charge-and-discharge cycle is superimposed with the AC ripple current to create a more complex ripple current as shown in the figures. Remember that the output voltage is negative, so the positive portions of the waveform represent the output becoming less negative, or the discharge portion of the cycle.

Figures 5 and 6 show the current flowing in the high-side switch for the inverting buck-boost and buck converters, respectively, each with the same load current of 2 A. The positive pulse represents the current flowing through the switch into the inductor during the conduction time. When the switch is off, the inductor current for the inverting buck-boost converter in Figure 5 must remain continuous and flows through the catch diode rather than the high-side switching element. For the buck converter in Figure 6, the average current during conduction is equal to the output

Figure 3. Inverting buck-boost output voltage ripple and switching-node voltage

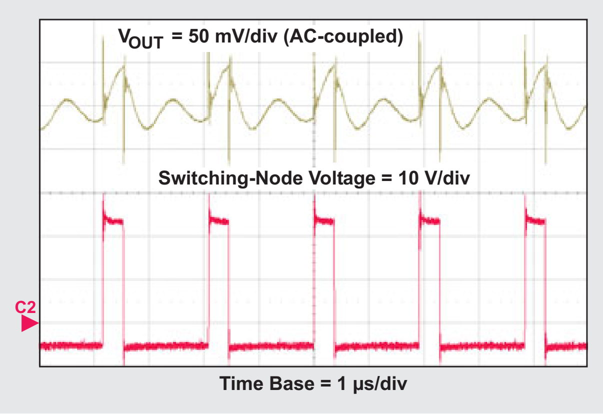


Figure 4. Buck output voltage ripple and switching-node voltage

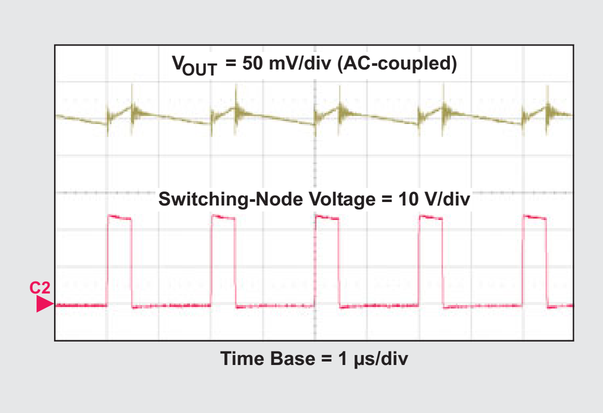


Figure 5. Inverting buck-boost switch current

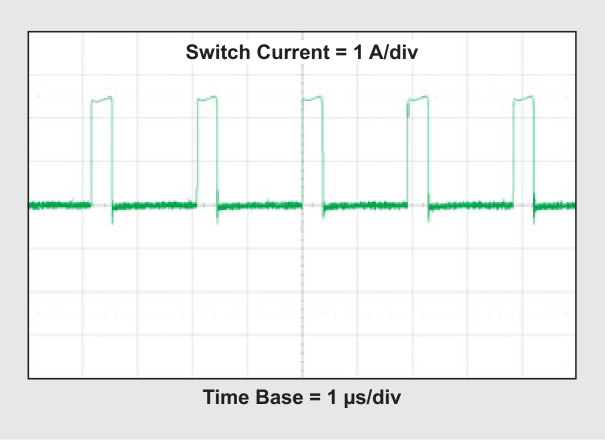
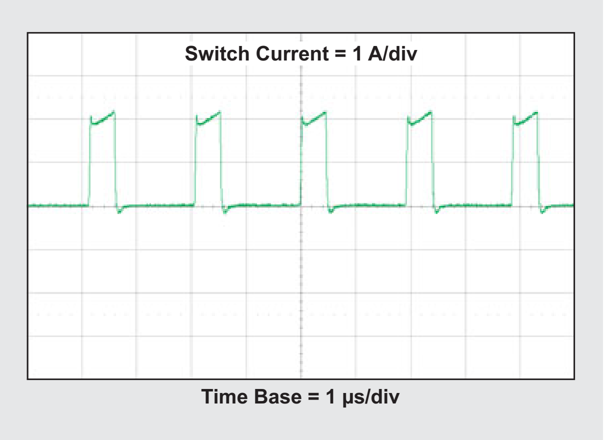


Figure 6. Buck switch current



current, as the inductor is connected directly to the output. In this topology the output current is supplied by the inductor during both the on and off times. For the inverting buck-boost converter, this is not the case; so the average switch current during the on time is $I_{OUT}/(1 – D)$.

Input-voltage limitations

In addition to the converter's input-voltage constraint of $V_{IN} – (–V_{OUT})$, there may also be a limit to the input voltage at the low end besides that required by any minimum duty cycle or on-time specifications. Many DC/DC converter circuits include an undervoltage lockout (UVLO) circuit. In the buck configuration, the minimum input voltage would be limited by the UVLO level. This limitation exists for the inverting buck-boost converter as well; however, the UVLO threshold is relative to the device ground, which is configured as V_{OUT}. At start-up, the output is 0 V; so the minimum input voltage to guarantee proper start-up is equal to the UVLO level, regardless of the difference between V_{IN} and V_{OUT}.

Conclusion

A buck converter can be used to generate a negative output voltage from a positive input voltage if the circuit is configured as an inverting buck-boost converter. The circuit design is straightforward, but these important points should be remembered. The output current is less than the average inductor current by a factor of 1 – D, so the available output current will be less than the device rating. The output voltage is negative and is available at the device ground pin, so the effective voltage across the input of the device is $V_{IN} – V_{OUT}$. This difference must not exceed the input-voltage rating of the device. Finally, the ground of the device should not be tied to the system ground.

For a detailed design example using this technique, see Reference 2.

References

For more information related to this article, you can download an Acrobat Reader file at www-s.ti.com/sc/techlit/*litnumber* and replace *"litnumber"* with the **TI Lit. #** for the materials listed below.

Document Title	**TI Lit. #**
1. "The Right-Half-Plane Zero—A Simplified Explanation"	slup084
2. John Tucker, "Using the TPS5430 as an Inverting Buck-Boost Converter," Application Report	slva257

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