Simple design of an ultra-low-ripple DC/DC boost converter with TPS60100 charge pump

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Introduction

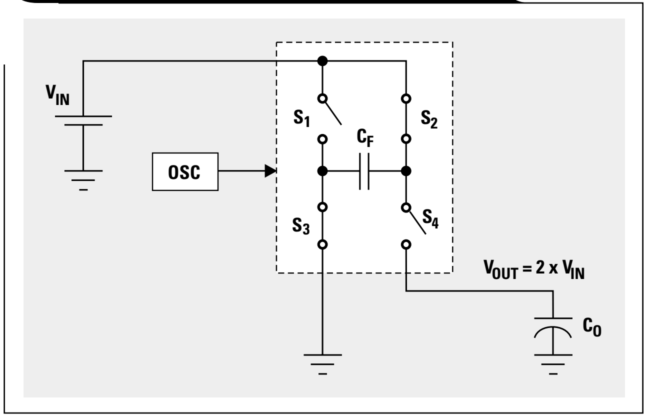
Battery-powered equipment uses DC/DC step-up converters to generate supply voltages for internal circuits that require higher voltages than the available battery voltage. These can be inductive or capacitive converters. Inductive step-up converters, also called boost converters, have a high efficiency over the entire input voltage range. Capacitive converters—i.e., charge pumps—provide a high efficiency over selected input voltage ranges. However, since their design doesn't require any knowledge of magnetics, charge pumps are easier to implement, reducing the design time to a minimum. Higher output currents can easily be attained by operating two charge pumps in parallel. Figure 1 shows the block diagram of a basic single-ended charge pump configured as a voltage doubler.

Charge pump operation in constant-frequency mode

The circuit operates in two phases, a charge phase and a transfer phase, which are controlled by an oscillator. During the charge phase the switches S_1 and S_4 are open, and switches S_2 and S_3 are closed. The battery charges the flying capacitor, C_F, to the input voltage level, V_{IN}. During the transfer phase, S_1 and S_4 are closed, and S_2 and S_3 are open. The voltage across C_F is in series with the input voltage. Both the battery and C_F are discharging into the output capacitor, C_O. The basic charge pump operates as a voltage doubler, generating an output voltage of

$$V_{OUT} = 2 \times V_{IN}$$

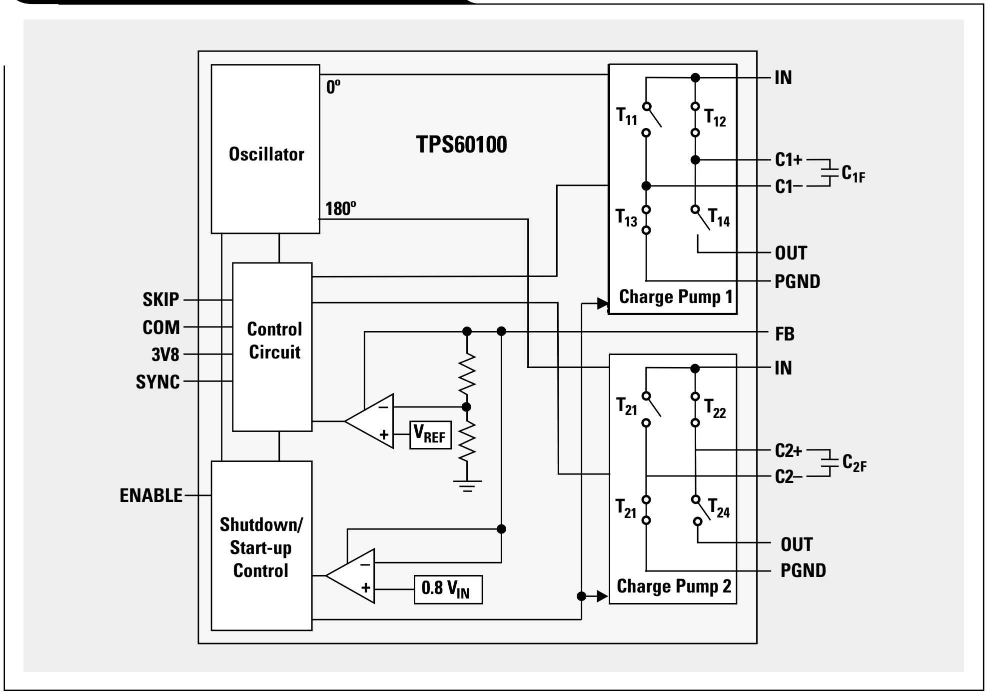
Figure 1. Basic charge pump (charge phase shown)



The new TPS60100 low-noise charge pump device from Texas Instruments contains two charge pumps that can operate in a complementary mode (push-pull mode) to minimize output ripple (Figure 2).

While one charge pump operates in the charge phase to charge its transfer capacitor, C_{1F}, the other charge pump is in the transfer phase discharging C_{2F} into the output capacitor, C_O. The TPS60100 also provides a regulated 3.3-V output over a 1.8-V to 3.6-V input voltage range. The on-chip error amplifier senses output voltage variations via the feedback input, FB. The control circuit fed from the error amplifier controls the charge transferred to the output by driving the gates of MOSFET switches T_{11} and T_{21}, respectively (see Figure 2). When the output voltage drops, the gate drive

Figure 2. TPS60100 block diagram



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increases, resulting in a larger charge being transferred to the output.

Although the TPS60100 provides a variety of programmable operating modes, the device needs to be set up for constant-frequency mode in push-pull operation to achieve the lowest output voltage ripple (see Figure 3).

Capacitor selection

For push-pull operation, a minimum of four capacitors is needed—one input capacitor (C_{IN}), two transfer capacitors (C_{1F}, C_{2F}), and one output capacitor (C_O). The following rules of thumb can be used to determine the values of the input and transfer capacitors with respect to the output capacitor:

$$C_O \geq 2 \times C_{IN} \quad \text{and} \quad C_O \geq 10 \times C_{xF}$$

In the constant-frequency mode, the value of C_O needs to be at least 22 µF or larger to ensure the stability of the regulation loop. With C_O = 22 µF, the recommended values for C_{IN} and C_{xF} are C_{IN} = 10 µF and C_{1F}, C_{2F} = 2.2 µF. To achieve a low output ripple, all capacitors should be ceramic capacitors because of their low equivalent series resistance (ESR). The low ESR of the transfer capacitors ensures minimum time constants when charging and discharging. The low ESR of C_{IN} and C_O is required to reduce the spikes that occur during the turnover from the transfer phase of one charge pump to that of the other. The lower the ESR of C_O, the lower is the output voltage ripple.

Figure 4 shows the AC output ripple of the circuit in Figure 3. The peak-to-peak ripple voltage is approximately 4 mV, while the spikes during the turnover of the transfer phases are reduced to 18 mV.

To further reduce the spikes, an L-C filter can be added to the output as shown in Figure 5. FB is connected to the filter output to avoid having the spikes enter the error amplifier. The series resistance of the inductor influences the regulation of the output voltage. A filter corner frequency of 2.3 MHz was chosen above the 300-kHz switching frequency to avoid loop stability issues.

Figure 3. Constant-frequency mode in push-pull operation for low output ripple

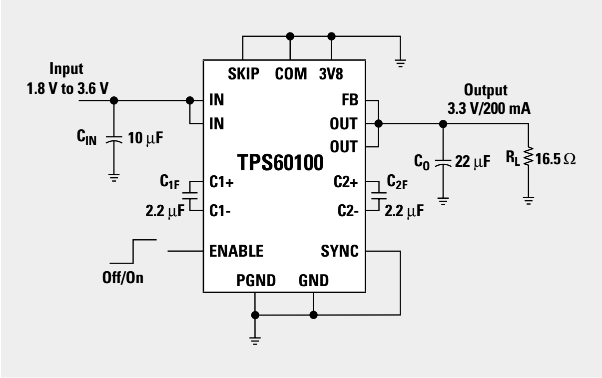

Figure 4. Output ripple without L-C filter

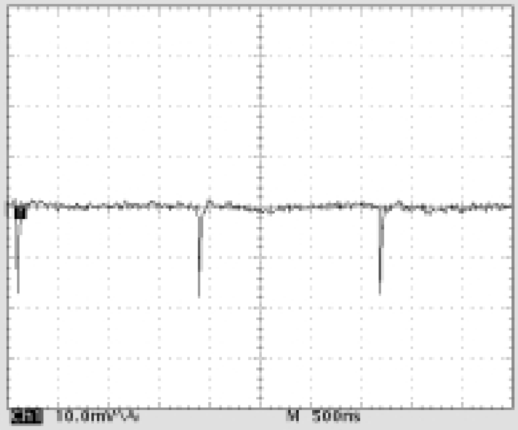

Figure 5. Output L-C filter reduces spikes and output ripples to an absolute minimum

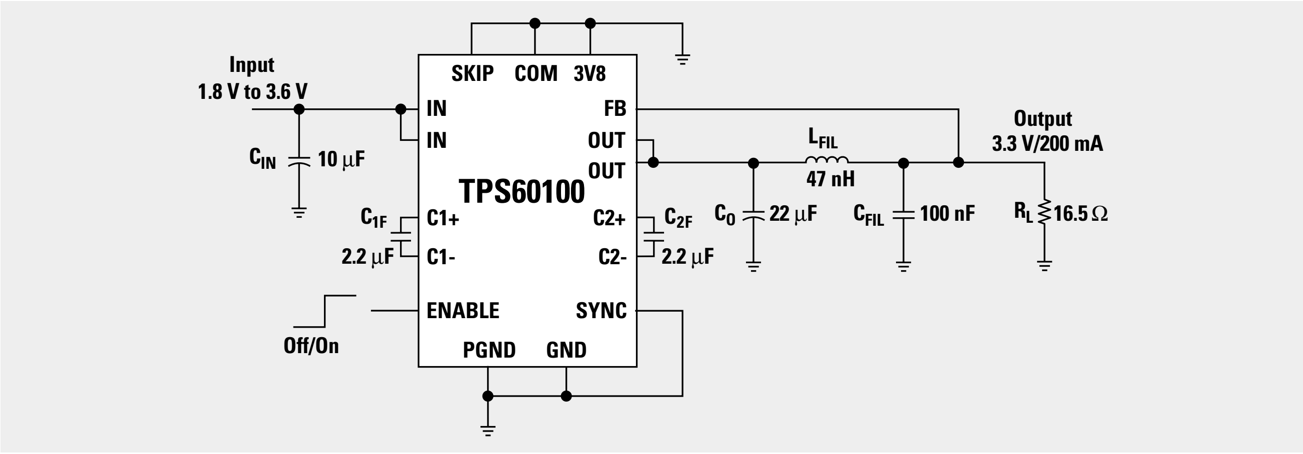

Figure 6 shows the same amount of AC output ripple; however, the spikes have been reduced to 6 mV by the L-C filter. All measurements were taken with a load resistance (R_L) of 16.5 Ω to draw the maximum output current of 200 mA.

The reader should be aware that the energy dissipated in the series resistance of the inductor has to be delivered by the charge pump; therefore, with low input voltages and high output currents, the output voltage may go out of the voltage or temperature limits given in the data sheet.

The part numbers for the capacitors and the inductor are given in Table 1.

Figure 6. Output ripple with L-C filter

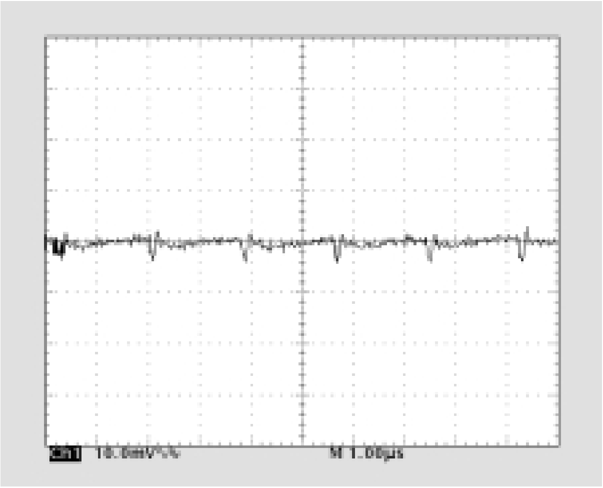

Table 1. Capacitor and inductor part numbers

PART	VALUE	PART NUMBER	MANUFACTURER
C_{IN}	10 µF/16 V	EMK325F106ZF (F/Y5V)	Taiyo Yuden
C_{1F}, C_{2F}	2.2 µF/16 V	LMK212BJ225MG-T	Taiyo Yuden
C_O	22 µF/10 V	LMK316F226ZL (F/Y5V)	Taiyo Yuden
L_{FIL}	47 nH/0.075 ΩΘ	1008G470GTE	Stetco
C_{FIL}	100 nF/16 V	EMK107BJ104AA (BJ/X7R)	Taiyo Yuden

For higher current requirements—i.e., 400 mA—two TPS60100s can operate in parallel as shown in Figure 7. Both devices, preferably operating in the same mode, share the output capacitor whose value doubles to 47 µF. Each device requires its own transfer capacitors and input capacitor.

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. TPS6010x/11x Application Report	slva070
2. TPS60100EVM-131 User's Guide	slvu016

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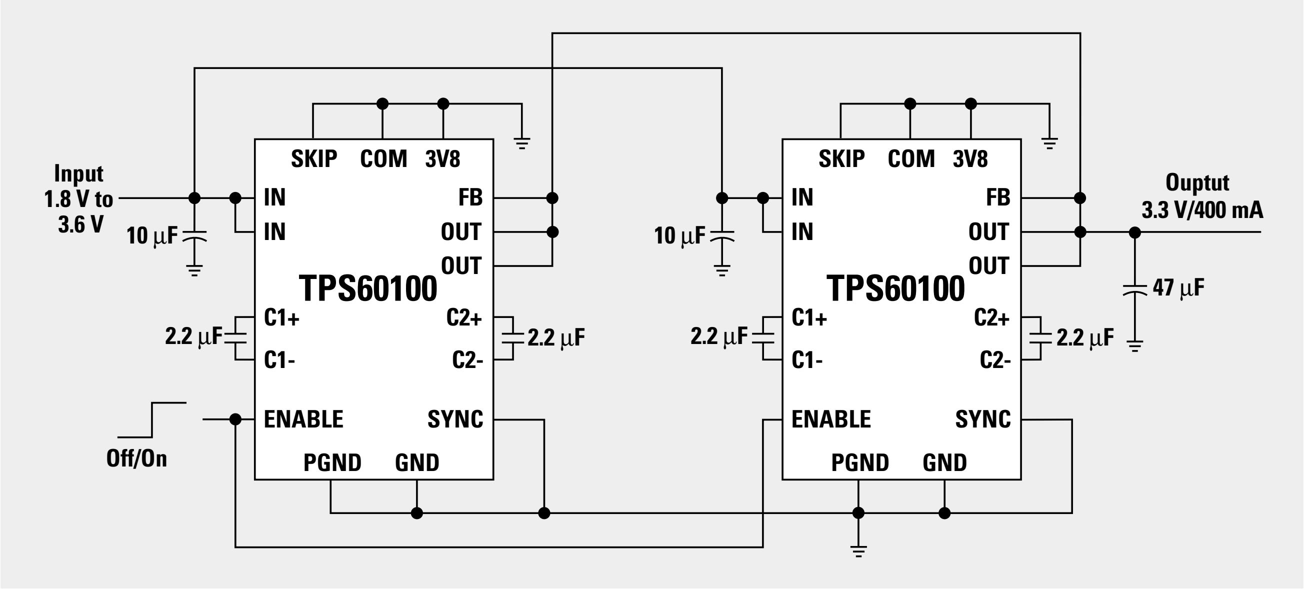
Replace *device* with tps60100, tps60101, tps60110, or tps60111

Figure 7. Two TPS60100 in parallel to provide 400-mA output current



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