



APPLICATION NOTE 658

Ultra-Thin DC-DC Converters Suit Compact PCMCIA Cards

Shrinking electronic circuits place demands on power supplies to keep pace. The latest PCMCIA-card formats force designers to consider converter topologies and keep a watchful eye for components that meet ultrathin-design requirements.

Besides having to minimize noise, achieve high efficiency, and avoid surge currents during power-up, power-supply designers must adhere to strict height limitations for components on PCMCIA cards. DC/DC converters for PCMCIA cards have a range of applications that generate an array of conversion requirements. Applications include 12V generation for flash-memory devices, -5V generation for analog circuits, and 3.3V-to-5V and 5V-to-3.3V conversions. Some of these applications arose because of 5V-intolerant DRAM chips and the emergence of the 3.3V PC-card standard.

Potential power-supply circuits for these applications include linear regulators; charge pumps; and buck, boost, flyback, and inverting switch-mode regulators. Regulator control schemes include linear, free-running, pulse-width modulation (PWM), and pulse-frequency modulation (PFM). Conflicting design requirements encompass low height, small area, low cost, high efficiency, low inrush current, and, in some cases, low EMI emissions.

The conversion of 3.3V to 5V is a key DC/DC converter application, as the PCMCIA 3V/5V Working Group prepares to release the 3.3V PC-card standard, which is scheduled for release in September. The standard supercedes version 2.1 and allows hosts systems that operate on 3.3V only. It specifies hardware keys that prevent insertion of 5V-only cards in 3.3V-only host sockets, and vice versa. For compatibility with a wide range of host systems, a PC card's Vline should accept 3.3V or 5V from the host. However, many cards don't accept 3.3V and require step-up DC/DC converters to achieve higher voltages.

Among the circuits that step up 3.3V to 5V are PWM boost regulators, PFM boost regulators, and charge pumps. Charge pumps (**Figure 1a**) are the smallest and lowest-cost option. You can fabricate charge pumps having low profiles, because the pumps lack an inductor or a transformer. However, a charge pump's half-load efficiency at 3.3V is only 75%, which is 10% to 12% lower than the efficiencies that inductor-based switching regulators produce.

In operation, a charge pump charges external capacitors to different voltages and then connects them in parallel. The resulting losses cause the charge-pump efficiency to depend strongly on the ratio of input-to-output voltages. The plot of efficiency-versus-input voltage exhibits peaks when V_{out} is an even multiple of V_{in} (**Figure 1b**). In any case, 75% efficiency is comparable to the efficiency that inductor-switched regulators on Type-1 PCMCIA cards achieve because of the high DC resistance inherent in low-profile inductors. Unlike inductor-based circuits, the efficiency of a charge pump is constant with load current as small as 1mA.

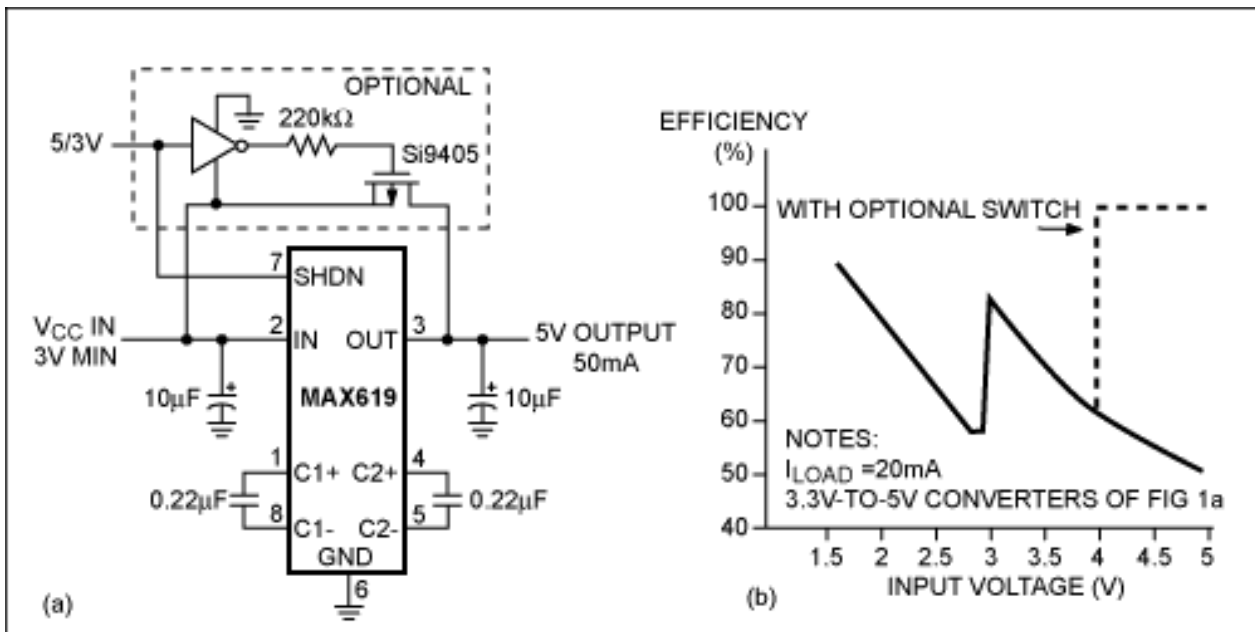


Figure 1. Because they offer low cost and small size, charge pumps (a) may be a good choice for 3.3V-to-5V converters. A charge pump's efficiency versus input voltage (b) displays a curve that peaks at even multiples of the input voltage.

The numerous high-current switches in a charge pump limit its output-current capability relative to inductive-based circuits. However, the switches let you obtain higher current by connecting charge pumps in parallel. In addition, charge pumps draw smaller surge current at startup than most inductor circuits, and the output voltage drops to zero in shutdown mode, unlike inductor boost circuits. Charge pumps also offer fast startup, which helps the system achieve fast memory access following a sleep mode.

A high switching frequency allows you to use small capacitors in the charge-pump circuit. The circuit includes an optional V_{CC} -bypass MOSFET that improves efficiency for 3V/5V systems when V_{CC} is 5V. Startup time for worst-case load conditions is 500µsec, and the corresponding peak surge current is 600mA. You can improve the startup conditions even further by using a PWM or another gated-clock signal to drive the chip's shutdown pin for a millisecond or two during startup.

Inductor-Based Regulators Are Efficient

Inductor-based boost regulators provide several key advantages over other regulator topologies. First, boost regulators are simple and efficient. Their series-aiding connection of the inductor and input source provides lower peak inductor current than that of other options, such as flyback and forward converters. Low peak currents allow small capacitors and inductors, which have low I^2 losses and provide high efficiency. Low resistance provides better efficiency but usually requires larger and more expensive components.

High inrush current and the inability to shut down the circuit offset the inductor-based boost regulator's advantages. You can add an optional high-side switch with slow turn-on characteristics to accommodate these shortcomings. Boost regulators (**Figure 2**) employ a PFM control loop that provides excellent light-load efficiency using small external components. Noise and EMI emissions are higher than those of traditional PWM regulators. The quiescent supply current averages only 50µA at $V_{in} = 3.3V$, and the relatively high switching frequency of 300kHz permits the use of low-valued inductors of 5µH or less.

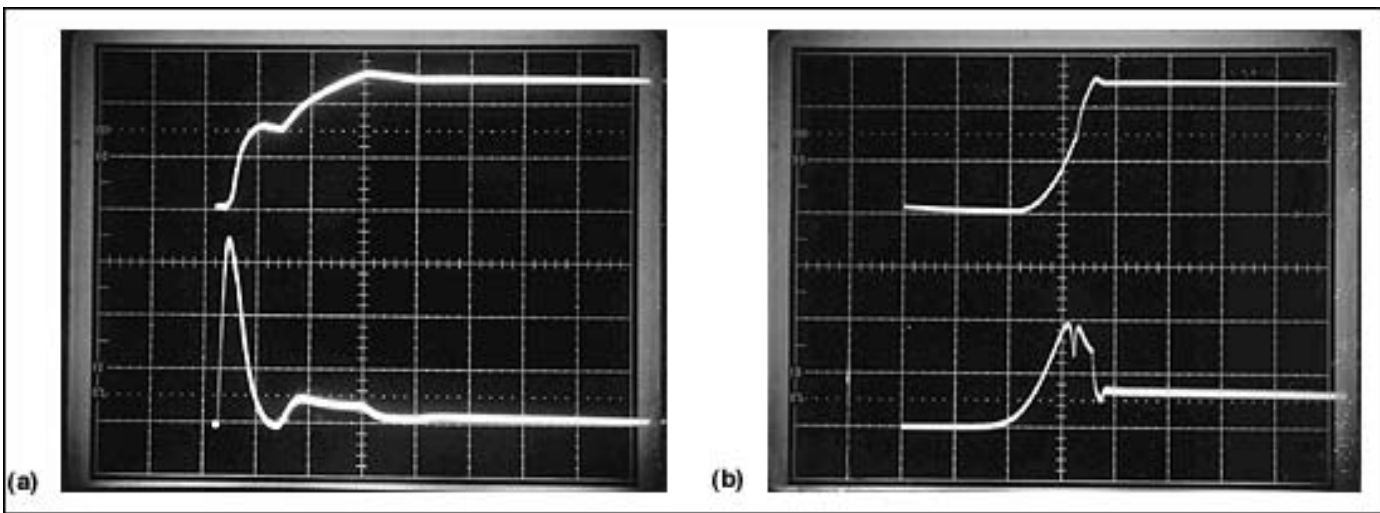


Figure 3. Output voltage (upper waveform at 2V/div) (a) and input current (lower waveform at 2A/div) of a boost regulator without a high-side switch. Circuit response with $V_{in} = 3.3V$ and $R_{load} = 25$ microhms. Horizontal scale is 100 μ sec/div. Output voltage (upper waveform at 2V/div) (b) and input current (lower waveform at 500mA/div) of a boost regulator with a slow high-side switch. Horizontal scale is 500 μ sec/div.

The best way to suppress an inrush-current spike is to add a high-side switch (**Figure 4**). The switch is a logic-level p-channel MOSFET, plus an RC network in the gate circuit to delay turn-on. Adding Miller capacitance across the gate-drain junction further lowers the PFET's switching speed. To delay startup for 200 μ sec, control the IC's shutdown pin. The shutdown pin allows the bypass capacitor's input surge current to settle before enabling the switching regulator.

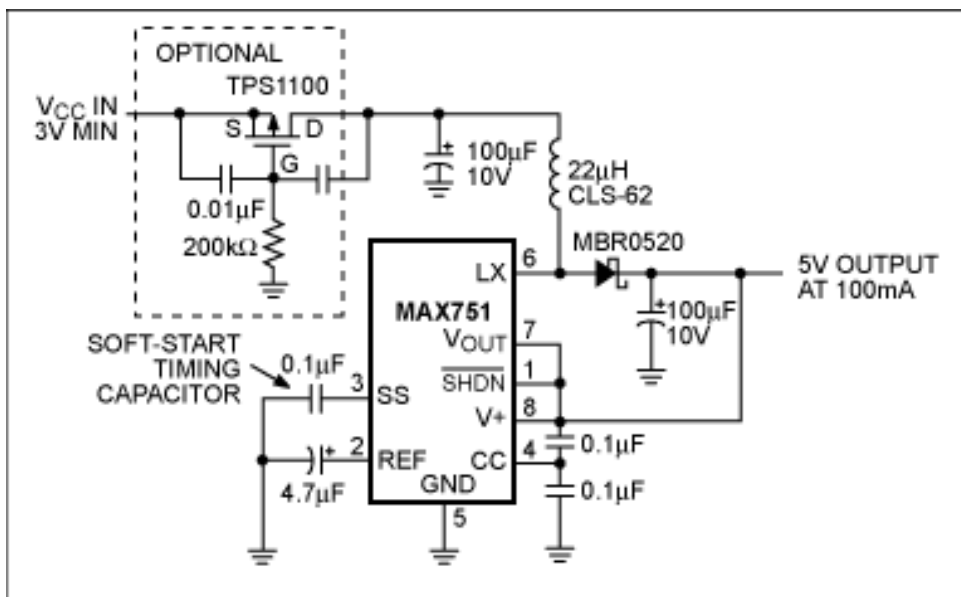


Figure 4. You can suppress the inrush current spike by using an FET switch whose turn-on characteristics are delayed by an RC time constant.

The high-side switch also solves the problem in boost converters of the output voltage's not turning off completely when the switching regulator is turned off. Instead, V_{out} sags to a voltage equal to V_{in} minus a diode drop. This voltage level can inadvertently power the PCMCIA card during suspend and standby modes. The high-side switch blocks the unwanted power source by disconnecting the source from the circuit.

Soft-start is another timing method for reducing surge currents at startup. Soft-start circuitry usually includes an external timing capacitor that allows the regulator's peak current limit to ramp up gradually. When combined with the slow-response input switch, soft-start capability provides a solution to the trade-off in output rise time versus input surge current.

Step-Down Regulators to Tolerate 5V

Step-down regulators are important when a card full of low-voltage ICs must tolerate 5V inputs to be compatible with

5V-only host machines. The trade-off in step-down design is the choice of using a linear regulator or a switching regulator. Linear regulators are small and cheap, and the low value for the required filter capacitor reduces the inrush current. Their drawback is low efficiency. If you ignore base and quiescent current, the efficiency of a linear regulator is theoretically equal to V_{out}/V_{in} , or 66% for a 5V-to-3.3V converter. The PFET-based circuit (**Figure 5a**) approaches the theoretical efficiency, because it has no pnp base current and its quiescent current is a low 7 μ A.

Among the switching regulators, the buck topology is a clear winner over the flyback and single-ended primary inductance converters (SEPIC) in step-down applications. Similar to their boost-regulator counterparts, buck regulators have relatively low levels of peak inductor current, which results in high efficiency and small switching components.

No discussion of memory-card power supplies is complete without a mention of on-card V_{pp} generation for flash-memory cards and solid-state disk drives. Though most portable host systems can supply adequate V_{pp} power to the 12V pin at the card connector, 12V is an optional level in the PCMCIA specifications. For compatibility with a range of host systems, you may want to add on-card conversion from V_{cc} to 12V.

The design goals for a 12V converter are similar to those for the 3.3V-to-5V case: low costs, small components, and low inrush current. Efficiency is less important, because V_{pp} programmers operate on a low duty cycle where the V_{pp} current experiences an intermittent load that occurs only during program and erase operations. You can use charge pumps for low-current applications and boost-topology switchers for high power levels.

Figure 5b shows a 12V boost regulator that employs a pulse-skipping PFM control scheme for high levels of load current. The circuit is bootstrapped, which means that the IC's output voltage provides the supply voltage. The result is a high level of gate-drive voltage for the internal n-channel power MOSFET, which, in turn, provides low on-resistance and high efficiency.

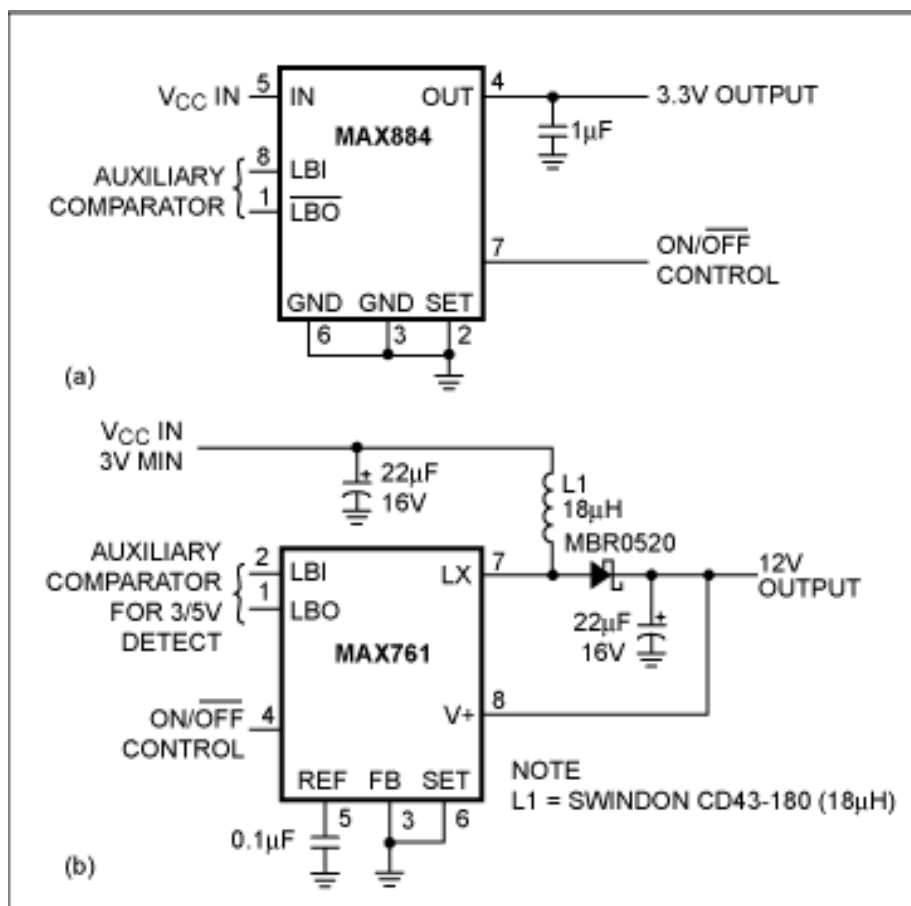


Figure 5. This PFET-based linear regulator (a) approaches its theoretical efficiency, because it has low quiescent current and no base current. The 12V boost regulator (b) for flash memories employs a pulse-skipping PFM control scheme.

PCMCIA-Card Voltages Span Wide Range

Although a PCMCIA card usually requires two power supplies, the diversity of applications for the PCMCIA format opens the range of potential voltage conversions on a card. For example, a wireless PCMCIA card that employs GaAs FETs in

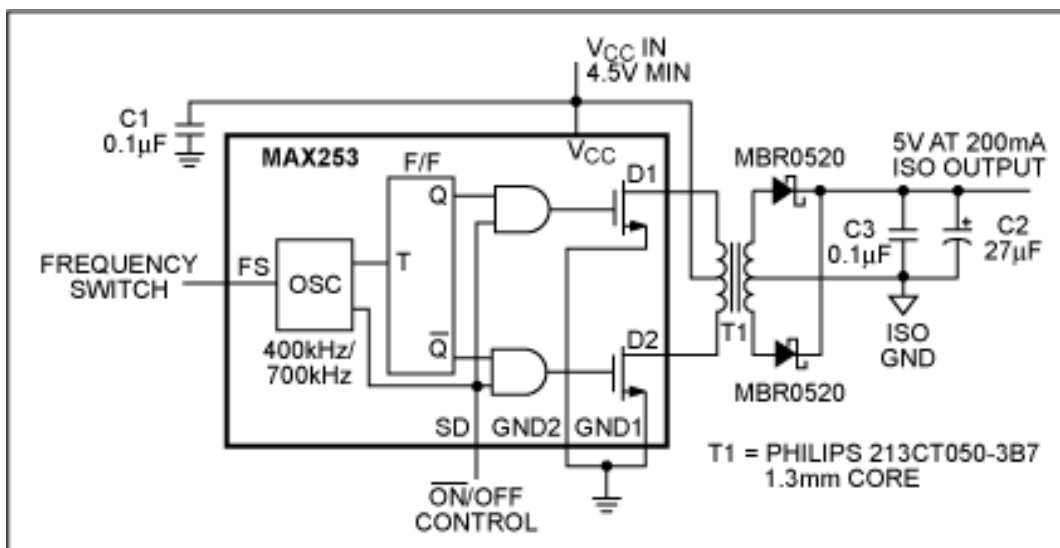


Figure 7. An isolated power supply requires a transformer to isolate the output voltage from the input voltage. This regulator converts DC to AC voltage to forward-drive the DC transformer.

After examining various power-supply designs, your first choice for these small on-card supplies should be linear regulators followed by charge pumps and then inductor-based switching regulators. Boost and buck topologies are the best of the inductor-based circuits. Avoid flyback regulators if possible, because their transformers store energy and consequently have large cores. If isolation is a must, use DC transformers.

For best light-load efficiency, choose a pulse-skipping PFM control architecture over the PWM type. An exception would be a design for a low-noise analog circuit that requires you to avoid spectral contamination of sensitive frequency bands. Don't underestimate the importance of reducing surge currents. This problem plagues designers continually.

Finally, keep your eyes open for new components and technologies for thin power supplies. Few of the components and ICs discussed in this article existed a year ago. Market pressures should ensure that IC and component manufacturers continue to develop products for PCMCIA applications.

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