Tired of Low Battery Voltage?
Build a Step-Up DC-DC Converter!

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Have you ever been annoyed by output power drop-off when operating your portable station due to sagging battery voltage? Have you ever wished that you could power your QRP rig from that spare 7.2V camcorder battery? Or maybe you have a neat piece of surplus equipment that requires 24V and you only have 12V power supplies. If any of these situations apply to you—or you just like to build useful little gadgets—then read on!

The basic idea of a switching DC to DC "step-up converter" is shown in Figure 1. When the switching transistor turns ON, it grounds the "bottom end" of the inductor, L, resulting in current being stored in the inductor. When the switch turns OFF, the voltage at the bottom end of the inductor momentarily increases above V_{IN} and discharges its current through the diode into the output capacitor, C_{OUT}. In other words, energy stored in the inductor while the switch is ON is transferred to the output during the switch OFF time. The output voltage is determined by the amount of energy transferred. That is determined by the duty cycle of the switch, which is controlled by a
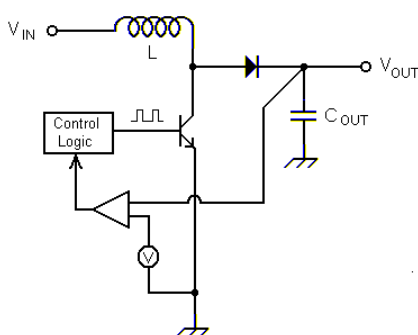

Figure 1. Conceptual diagram of a step-up DC-DC switching converter.

voltage comparator monitoring the output and controlling the logic that drives the switch. Note that output voltage regulation is only possible if V_{IN} is less than V_{OUT} (minus the drop across the diode). More complex circuits that operate when V_{IN} is above *or* below V_{OUT} are described in the manufacturer's application notes for the devices listed below.

A switching step-up DC-DC converter with regulated output can be easily—and relatively inexpensively—built using any one of several ICs designed just for that application. Some switching regulator ICs that are suitable for QRP applications are as follows:

LM2577 (National Semiconductor). This device is available in several package styles in fixed voltage (12V or 15V) or adjustable output versions. It can supply up to about 2A and operate from supply voltages from 3.5V to 40V. Conversion efficiency is typically 80% or better. Available from *Digi-Key* and *Allied Electronics*.

LM2587 (National Semiconductor). This device operates at a higher switching frequency (~100kHz) than the LM2577 allowing smaller storage inductors and capacitors and is capable of supplying more output current. It is available in three fixed voltage (3.3V, 5V and 12V) and one adjustable voltage versions. Minimum input voltage is 4V. Conversion efficiency is typically 90%. Possibly available from *Allied Electronics* or *Digi-Key*.

LM2588 (National Semiconductor). This is essentially a fancier (and more expensive) version of the LM2587 that has adjustable switching frequency (100kHz to 200kHz) and external shutdown capability. Available from *Digi-Key*.

MAX773 (Maxim Integrated Products). Step-up switching controller that provides 90% efficiency for loads ranging from 10mA to 1A. Available in a 14-pin DIP package. Input voltage range is 3V to 16.5V. Output voltage can be fixed at 5V, 12V, 15V or can be set using external resistors. High switching frequency (~300kHz) allows use of small

storage inductor and capacitor. Very low quiescent current (110μA). Includes input voltage monitoring circuit that can be used to drive a low battery indicator (LED, for example). An external power MOSFET switch (such as an MTP3055EL) is required.

MAX1771 (Maxim Integrated Products). Similar to the MAX773; can supply output currents of 2A or more with high conversion efficiency but does not have voltage-monitoring capability. Available in an 8-pin DIP package. Input voltage from 2V to 16.5V. Output voltage 12V or adjustable. 110μA quiescent current. Requires external MOSFET switch (MTP3055EL or similar). Available from *Digi-Key*.

Data sheets for these (and other) devices that also contain extensive design information are available from their manufacturers and can be downloaded from the WEB: *www.national.com* for National Semiconductor devices and *www.maxim-ic.com* for Maxim devices. Free software for designing switching regulators using National Semiconductor "Simple Switcher" ICs can be downloaded from *www.national.com/sw/SimpleSwitcher/*. Using this software greatly simplifies the task of designing DC-DC converters.

Although the Maxim ICs require more supporting parts than the National devices, their high efficiency and low "idle current" makes them attractive for use in battery powered applications. They are also less expensive than the National devices.[1]

A kit containing a small PC board and all parts necessary to make a DC-DC up-converter is available from *Embedded Research* (see their WEB site at *www.frontiernet.net/~embres* for complete details, or send email to *embres@frontiernet.net*). This device will supply a fixed 12V output at up to 0.5A from an input of 4-12V.

Figure 2 is the schematic diagram of a DC-DC up-converter that I built recently using an LM2577T-ADJ (adjustable output version in a 5-pin TO220 package). A similar circuit using an LM2587 was described in *QST* a while back.[2] I used an LM2577 rather than an LM2587 (or '88) because I happened to have an "Engineering Sample". I built my up-converter on a piece of "perf-board" and mounted it in a small metal box (obtained from Radio Shack). Input and output connections are via "five-way terminals" mounted on top of the box. The perf-board is attached to the terminals, and one end of the box is used as a heat sink for the LM2577 (see Figure 3).

The output voltage of my circuit is adjustable from about 10V to 15V and will operate from input voltages as low as 4V. When the input voltage exceeds the preset output voltage by about 0.5V, the input is simply passed directly to the output through D_1 and no output voltage regulation occurs. In this case, the output current is limited by the 3A fuse (chosen to protect D_1). When operating in the "up-converter" domain, the maximum current that can be drawn form the output, I_{MAX}, and still maintain output voltage regulation is a function of the ratio of the input and output voltages:

$$I_{MAX} \leq \frac{2.1 \times V_{IN}}{V_{OUT}} \text{ Amp.}$$

The high-speed transistor switch that is a basic part of the DC-DC step-up converter can generate a significant amount of high frequency noise. The following guidelines should be followed to keep the output as "clean" as possible:

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[1] You might even be able to obtain free samples of the Maxim devices! See their WEB site or one of their data books for details.

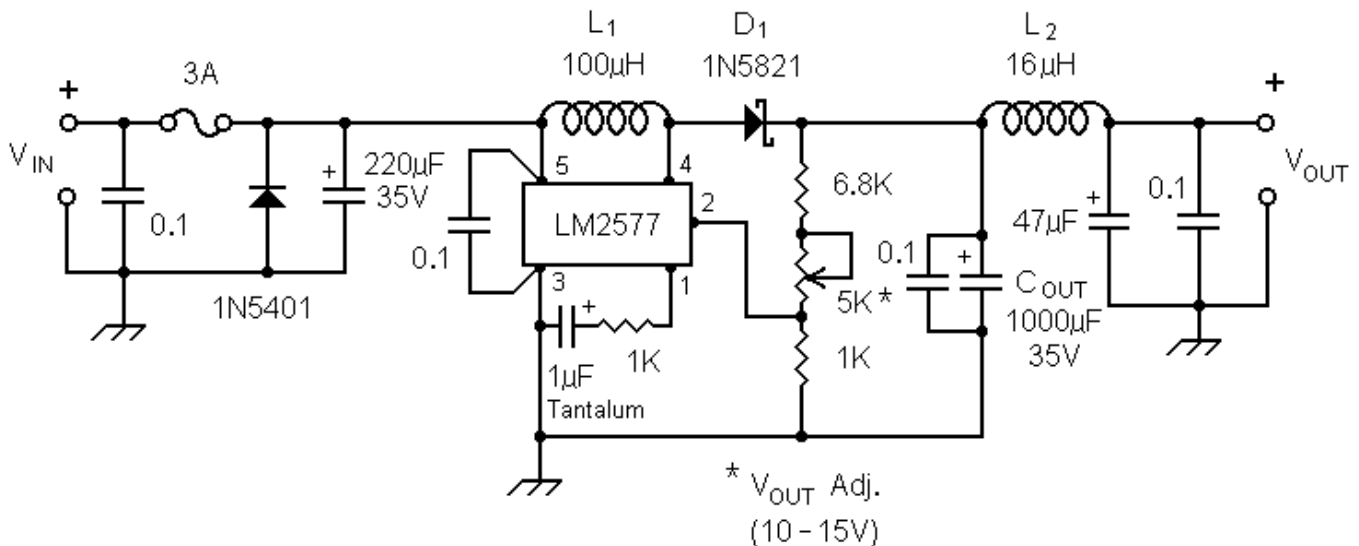[2] Sam Ulbing, N4UAU, "My All-Purpose Voltage Booster," *QST* July 1997, page 40.

Figure 2. Practical DC-DC up-converter using an LM2577. The diode from the fuse to ground is for reverse polarity protection and must be able to safely pass a current greater than that required to open the fuse. Note the 0.1µF bypass capacitor connected directly between pins 3 and 5 of the LM2577. C_{OUT} should be a low ESR electrolytic (see text). The inductors are as follows:

*L_1 – MagneTec FIT80-1 (**Digi-Key** part number 10577-ND) or 38T #24 wire on an FT82-61 toroid core.*

*L_2 – MagneTec FIT50-4 (**Digi-Key** part number 10567-ND) or 15T #20 wire on an FT82-61 toroid core.*

1. All bypass and filtering capacitors, especially C_{OUT}, should be low "effective series resistance" (ESR) types designed for use in switching power supplies. Low ESR electrolytic capacitors are available from most of the larger mail-order parts suppliers (several types are listed in the **Digi-Key** catalog). Physically large capacitors will generally have a lower ESR than a smaller unit with the same capacitance. Capacitors with higher than required voltage ratings (hence the use of 35V rather than 16V electrolytics in the circuit shown in Figure 2) and multiple capacitors in parallel can be used to achieve a low ESR.

2. Wind the storage inductor on a ferrite torid or pot-core. A powered iron core should *not* be used in this application.

3. Use short ground connections; if a printed circuit board is used, use wide ground traces and/or a ground plane. Pay particular attention to the grounding of C_{OUT}. Very important: *Avoid ground loops between the input and output!*

4. Build the DC-DC converter in a metal rather than plastic enclosure. If you simply *must* put one within the cabinet of a QRP rig, shield it completely and use a large amount of filtering on the power output *and* input connections.

The 16µH inductor (L_2) and 47µF capacitor in the output of the DC-DC converter shown in Figure 2 filter the switching frequency (the LM2577 runs at about 52 kHz) and its harmonics from the output. Nevertheless, when I first tested my DC-DC converter, switching spikes (in the form of high frequency "ringing about 200mV in magnitude appeared at the output and input power connectors. No amount of extra bypassing seemed to have much effect. Finally, I cut a ground wire that I had run along the edge of the perf-board between the input and output ground connectors (which were also grounded to the metal case) and the ringing disappeared completely! A prime example of a "ground loop" in action! After eliminating the ground loop, the output appeared quite clean on a 'scope. With an input voltage of 10V and the output set to 13.6V, the 52 kHz ripple as seen on the 'scope was about 5mV peak-to-peak (PP) with a 150mA load and about 40mV PP with a 1.5A load. Connecting the converter output to an HP 403B AC Voltmeter produced readings of about 1mV RMS at 150mA and 10mV RMS at 1.5A load.

I could not detect any noise generated in a NorCal 40A receiver powered from the DC-DC converter when using an outside antenna.
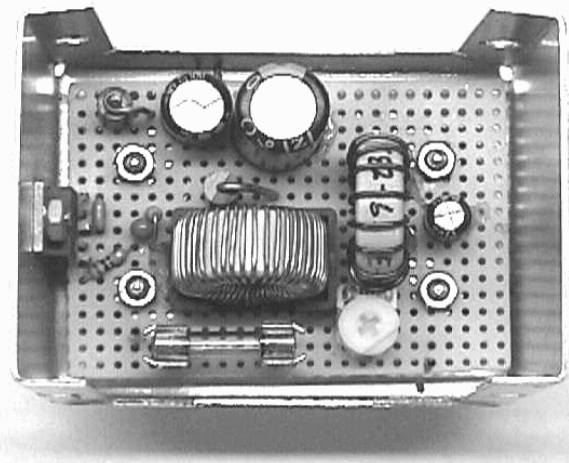

Figure 3. View of the DC-DC converter mounted in its case. The 0.1µF bypass capacitors across the input/output terminals and C_{OUT} (see Figure 2 above) are mounted under the perf-board.

However, when I used a short piece of wire lying on the workbench as an antenna, there was a noticeable band of "hash" around 7.015 MHz. I added a 0.1µF bypass cap directly across the *input* terminals (as shown in Figure 2) and that reduced the noise to a barely perceptible level. Scanning the bands on my QRP+ using an indoor antenna, I could hear weak "birdies" from the converter about every 52 kHz below 15 meters. However, none could be heard when using an outside antenna— something to keep in mind when operating in the field.

The converter that I built can easily supply a small QRP transceiver with well-regulated 13.6VDC from a 6-12VDC power source. It has good (80-85%) conversion efficiency and generates very little RFI. However, if I ever build another one, I will probably design it around a Maxim 1771 to take advantage of its higher switching frequency, greater conversion efficiency and lower idling current. (Maybe an even better choice will come along by then.) A higher switching frequency means smaller inductors and capacitors can be used allowing more compact construction.