Power Gadgets from USB Sources with this Simple Switching Boost Supply

Replace your 9 V battery tray with a rechargeable 5 V USB power block and this versatile voltage booster.

Tom Wheeler, NØGSG

I have bad luck with batteries; they're always dead or weak when I need them the most — and a lot of my ham gadgets rely on them. For example, my trusty MFJ antenna analyzer requires periodic feeding with six AA cells adding up to 9 V, and my JYE Tech oscilloscope also requires 9 V.

Batteries just don't last very long at moderate current drains, and end up in a landfill rather quickly. With a linear regulator, 12 V batteries can be conditioned down to 9 V, but that's bulky and not very efficient. However, hams likely have several very handy, rechargeable power sources hanging around the house in the form of USB 5 V power sticks or power blocks, as shown in Figure 1 and the lead photo.

Advantages and Disadvantages

There are several advantages of using USB power sources. They can be readily charged with standard ac adapters, and often from 12 V supplies in automobiles. They are energy-dense power sources, as they're usually equipped with lithium-ion cells, and tend to have a low self-discharge rate — typically less than 10% over a year. As a bonus, they also contain the circuitry to provide for safe charge and discharge, proving to be a relatively inexpensive, widely available, and pretty universal "plug-and-play" power source.

Figure 1 — A USB 5 V power stick.

The devices have few disadvantages. They produce only 5 V, so the output must be conditioned to get lower or higher output voltages. The current they can provide is limited, often to less than an ampere. In order to get higher output voltages, some sort of switching power supply is needed.

Most hams cringe at the thought of the "black art" inside of switchers, but they're pretty straightforward to design and build, especially given today's dedicated integrated circuits (ICs).

Switching Supply Modes

Switching power supplies can be made to operate in several modes, but the two primary modes are boost and buck. A *boost-type* supply adds a series-aiding voltage to the provided dc input — think of putting flashlight batteries together in series, one after another with the batteries facing the same direction, thus increasing the output voltage. A *buck-type* supply adds a series-opposing voltage — think of adding one or more extra flashlight batteries in series, but backwards, reducing the overall output voltage.

These boost and buck voltages can be obtained by using either capacitors or inductors as energy storage tanks. The circuit demonstrated here operates in a boost mode using an inductor to store the boost energy, which is the most common method because it can be very efficient. Figure 2 shows the basic operation of a boost-type supply.

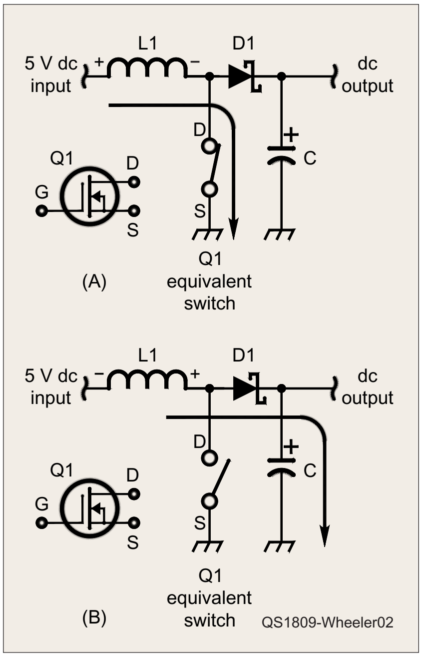

Figure 2 — Operation of a boost-mode switching supply. The switch cycles between “closed” in (A), to charge the inductor L1, and “open” in (B) when the inductor current rushes into the filter capacitor C.

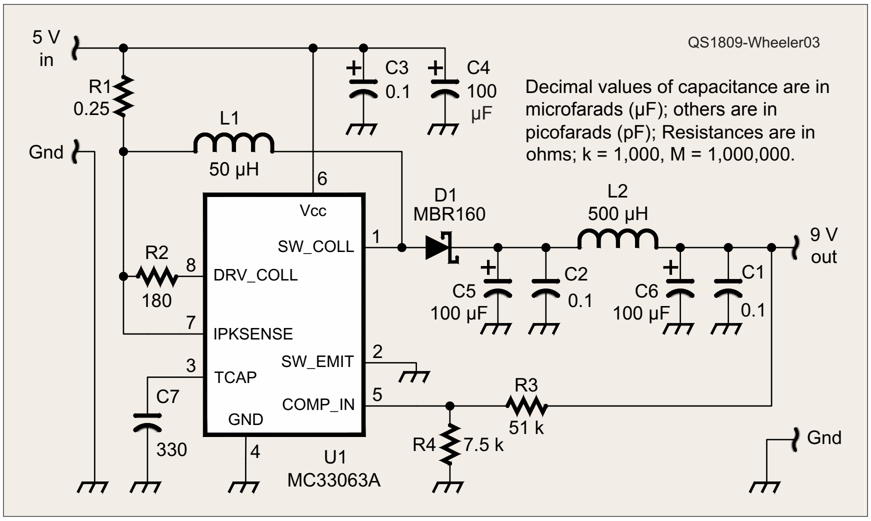

Figure 3 — This boost-mode supply uses just a handful of components.

C1 – C3 — 0.1 µF, 50 V polyester or ceramic capacitors
C4 – C6 — 100 µF, 16 V electrolytic capacitors
C7 — 330 pF, 50 V polyester capacitor
D1 — MBR-160 Schottky diode
L1 — 50 µH inductor, 40 turns AWG #24 on a FT50-26 toroidal core
L2 — 500 µH inductor, Mouser P/N 815-AIAP02471K
R1 — ¼ Ω, ¼ W resistor (or four 1 Ω resistors in parallel)
R2 — 180 Ω, ¼ W resistor
R3 — 51 kΩ, ¼ W resistor (adjust this resistor to alter the dc output voltage)
R4 — 7.5 kΩ, ¼ W resistor
U1 — Texas Instruments MC33063A SMPS controller
USB A-B cable vector breadboard

The Boost Supply

In Figure 2, a transistor Q1 is made to act as a rapidly alternating on/off switch. When Q1 is **ON**, it’s a closed switch (see Figure 2A) and the inductor L1 charges up from the power supply, storing energy in a magnetic field. The more energy stored by the inductor, the stronger its magnetic field becomes.

Note that there’s a limit to how long the inductor can charge, so we can’t leave the switch on for too long. The inductor will draw more and more current the longer it’s connected to the input voltage. Eventually, it will draw a very large current that’s limited only by the resistance of the wiring in the circuit and the current capabilities of the power source. If not interrupted, that large current will soon be followed by a cloud of smoke!

Before that maximum current is reached, the switch is opened — Q1 is turned **OFF**. Inductors cannot change their current instantaneously, so the current now flows in the same direction through L1, through the diode D1, and into capacitor C. The inductor voltage flips polarity in Figure 2B, causing it to add to the battery voltage, thus boosting the output voltage above the original input value.

Because of the rapid on/off switching, D1 *must* be a fast diode. Schottky rectifiers are typically used in switching power supplies for this very reason. Note the unusual symbol for the Schottky rectifier; the cathode is a bar with two hooks.

You might guess that this switching must be precisely controlled, and you’re right. Typically we use an oscillator circuit with a variable **ON** percentage time — or duty cycle — to control how hard L1 is charged, and thus regulate the output voltage. Figure 3 shows such a circuit crafted around a switch-mode power supply (SMPS) controller IC.

The Universal Switch-Mode Power Supply

The MC33063A (**www.ti.com/lit/ds/symlink/mc33063a.pdf**) is a universal SMPS controller IC containing a built-in switch rated at 1.5 A, voltage regulation, and soft-start control circuitry, as well as overload protection. The circuit is simplicity itself. On the input side of U1, C7 sets the switching frequency to about 80 kHz, R1 sets the current limit at 800 mA to protect U1 in case of a short circuit, and R2 limits the drive current to the internal switching transistor of U1.

Inductor L1 stores the energy during each switching cycle, and diode D1 provides a path for current to flow to the load, switching off when the inductor is being charged. C2, C5, C6, C1, and L2 filter the output voltage, which is dc with 80 kHz pulses, to provide smooth dc for the load and minimize RF interference.

For applications requiring very low RF emissions, such as for powering receivers, the circuit should be

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shielded within a metal box to discourage unwanted signal radiation.

Resistors R4 and R3 set the output voltage according to the following relationship:

$$V_{OUT} = 1.25\left(1+\frac{R_3}{R_4}\right) \qquad \text{[Eq. 1]}$$

With the values of R3 and R4 shown in Figure 3, the output voltage will be close to 9.75 V. The circuit of Figure 3 can easily supply 200 mA to a load, which is more than twice the amount needed to run my oscilloscope, and is also quite adequate for loads such as my antenna analyzer.

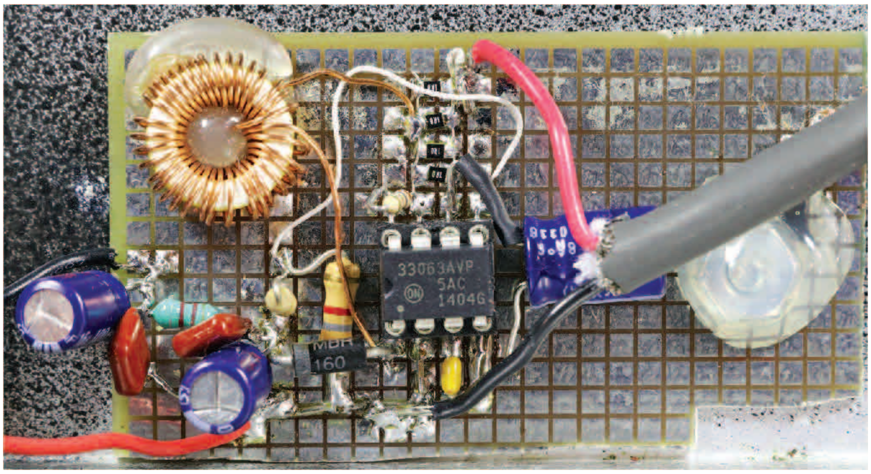

Figure 4 — Prototype circuit constructed on vector board.

Construction

Figure 4 shows the unit constructed on a small piece of vector board. Because high frequencies are used, leads should be kept as short as possible. R1 is a ¼ Ω, ¼ W resistor. I used four 1 Ω, ⅛ W surface-mount resistors in parallel to obtain the same resistance in the prototype. U1 should be in a socket, if possible.

Note that L2 is a small inductor that looks just like a resistor. The easiest way to get the USB interface is to simply sacrifice a regular USB A-B cable. There will be four conductors. The red and black are usually +5 V and ground, respectively.

L1 is simply hot-glued down to the board for mechanical stability, but you can fix it in place with a 1-inch 4-40 nylon screw and nut.

You will notice something very strange at the 9 V output terminals — the wire colors appear to be backwards, with black on the positive and red on the negative. This is necessary because these two wires connect to a 9 V battery snap connector, which has wire polarities arranged properly for something that connects to a standard battery. Male and female terminal polarities are interchanged for circuits that act as batteries.

Once you've wired this up, use a voltmeter to confirm that the output polarity is correct before connecting it to anything!

The Checkout

Before connecting the boost converter to your gadget, do a few simple checks. Start off with U1 removed and apply +5 V to the input of the circuit. You can plug in a USB power source if you wish. With a voltmeter, measure Pins 6, 7, and 8 of U1. Connect the voltmeter negative lead to circuit ground. Each pin should measure close to 5 V. Measure the voltage at the 9 V output terminal. It should be between 4½ and 5 V.

If all these check out okay, turn off the power and insert U1 into its socket. Connect a 50 Ω, 2 W resistor temporarily between the output terminal and ground. This resistor will act as a dummy load. Apply +5 V at the input again. You should now measure about 9.8 V dc at the output.

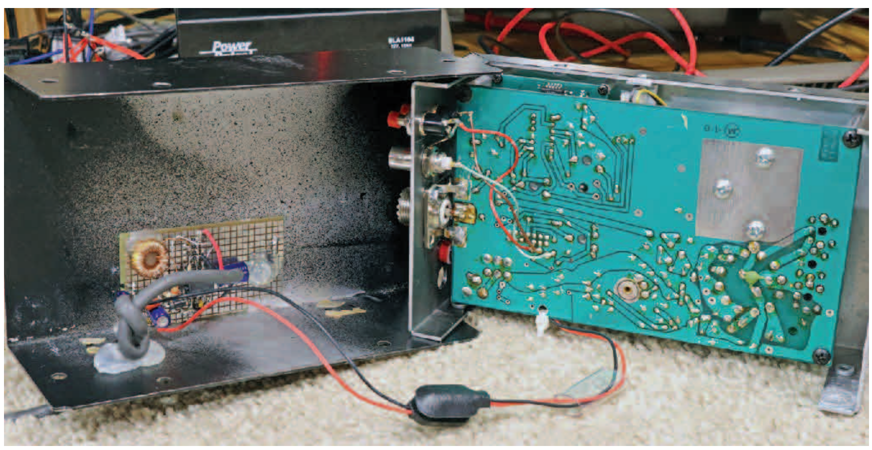

Figure 5 — Boost supply shown attached inside the case of an SWR analyzer.

> *"The circuit demonstrated here operates in a boost mode using an inductor to store the boost energy, which is the most common method."*

If everything agrees with the above, congratulations! You're ready to power your gadget from USB.

Figure 5 shows the boost converter installed within the case of my MFJ-249 SWR analyzer. The board is simply bolted to the back case of the SWR analyzer. The USB cable +5 and ground pins are connected to the input terminals of the board, and a 9 V battery connector is attached to the output. Watch the polarity as mentioned before, so that effectively the converter replaces the six-cell battery pack within the MFJ antenna analyzer.

Conclusion

The simple circuit described here lets me run my DSO-138 oscilloscope from a 5 V, 2,800 mAh USB power stick for more than 6 hours, and my MFJ-249 antenna analyzer for 5 hours. By changing a resistor, you can easily power devices requiring other output voltages. Also, you can operate these devices with confidence in the field. If the battery goes flat, you can swap in a new USB power stick.

Many hams fear switch-mode power supplies, and perhaps with good reason. There is a lot of mystery surrounding them, and extra care is needed to build them. However, modern ICs take away most of the drudgery of constructing these circuits, and the only really critical choice is the inductor, which will make or break the circuit's performance.

Don't fear switching supplies. They're easier than they look!

Dr. Tom Wheeler has been licensed as NØGSG since 1985, and is Director of Academic Systems for Metropolitan Community College in Kansas City, Missouri. Tom's technical interests include alternative energy, analog and digital signal processing, RF design, and computer languages. He holds Associate and Bachelor degrees in electronic engineering technology, a Master's degree in technology with emphasis in digital controls and signal processing, and a Doctorate in education.

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New Products

PreciseRF PreciseLoop Antenna

PreciseRF, maker of the popular PreciseLOOP antenna and ham radio test and measurement instruments, has introduced the HG-1 Remote Tuner. CEO of preciseRF Roger M. Stenbock, W1RMS, said, "This product was rumored to be in the works for quite a while and in high demand. We wanted to get it right and be especially useful for tuning the very narrow resonant magnetic loop antenna. It is, in fact, now a reality." Production started in early May.

The new HG-1 Remote Loop Tuner is a compact, easy-to-use remote tuner for a magnetic loop antenna (MLA). Now you can place your PreciseLOOP HG-1 MLA at a remote location (such as the top of your RV) away from obstructions, for better radiation efficiency and less interference. It is designed specifically as a retrofit for the popular preciseRF HG-1 MLA, but it may be possible to adapt it to other MLAs with similar drives (there is no standard). For more information or to order, visit **www.preciserf.com/shop/hg-1-portable-remote-loop-tuner**.