Automatic Voltage Reducer for LiPo 4S Batteries
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Introduction

Lithium batteries are great for portable QRP ham operations as they provide excellent capacity for their size and weight. For example, I can run my Elecraft KX3 pretty much all weekend with a 5200mah LiPo battery that is about the size of my fist! But there is a problem. A LiPo 3-cell battery (3S) has a nominal voltage of 10.8VDC, and a fully charged voltage of 12.6V. A LiPo 4-cell battery (4S) has a nominal voltage of 14.4VDC, and a fully charged voltage of 16.8VDC. So a 3-cell battery is nominally under-voltage for many 12VDC QRP transceivers operating at full power (like my KX3 at 10 watts). The 4-cell battery is much more suitable for 12V transceivers. But the fully charged 4S LiPo voltage of 16.8VDC exceeds the maximum input permitted by many transceivers, such as the +15VDC maximum input specification of my KX3.

A simple way to drop the voltage is to put power diodes in series with the battery. A 1N5401 3-amp diode has a 1V (typical) drop, so two diodes have about a 2VDC drop (the voltage drop is current dependant, but reasonably constant over fairly wide current variations). However, you should remove or short the diodes when battery voltage drops below 15V or you'll continue to dissipate power in the diodes. This wastes battery capacity and drops voltage which further reduces full-power operation time. I decided that an automatic voltage reducer would be a better solution as it would permit me to focus on operating!

The Solution

The automatic battery voltage reducer schematic is shown in Figure 1, and the Parts List is given in Table 1. The circuit works as follows: When the battery voltage is below 15VDC the diodes are shorted by the DPDT relay's normally closed contacts. The relay contacts are rated at 3-amps, and both sets of contacts are wired in parallel for plenty of margin. When voltage exceeds 15VDC (14.3V zener plus the 2N3904 0.7V B-E junction voltage), 2N3904 base current is drawn and the relay is enabled which opens the contacts across the two 1N5401 3-amp diodes. The 3900uf electrolytic capacitor provides noise and ripple immunity, and the LED indicates when the relay is actuated.

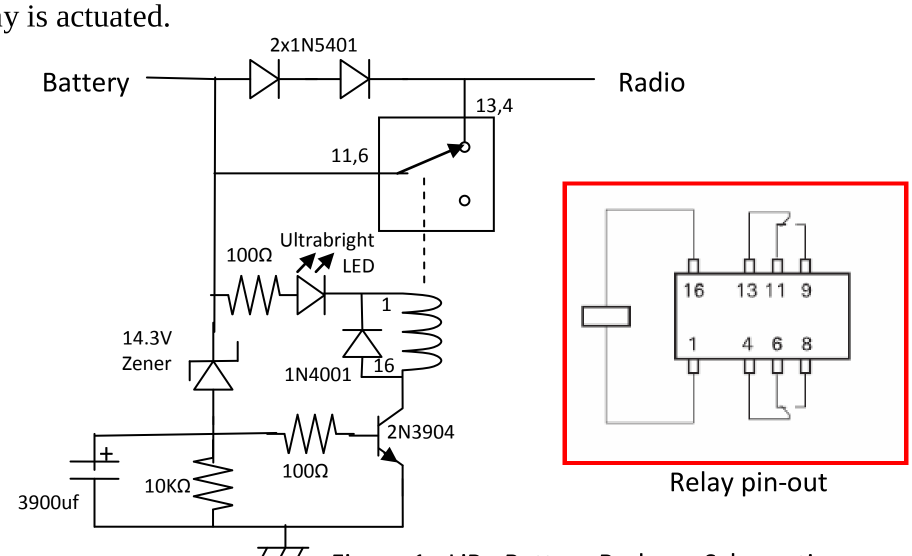


Figure 1: LiPo Battery Reducer Schematic

The circuit draws 26ma at 16.8VDC. This falls to 19ma at 16VDC and 10ma at 15VDC just before the relay drops out. No current is drawn by the circuit once the relay drops out. Operation is completely automatic, and voltage to your radio is not interrupted during the relay switching action.

This design has several advantages over any solid-state solution. It is simple, inexpensive and easy to build. The relay provides hysteresis as it requires more current to enable it than to keep it enabled (typically 10ma to enable, 0.6ma to stay enabled). There is essentially no voltage drop across the relay contacts, and no current is drawn when the relay drops out. Finally this sealed relay is very reliable (lifetime is spec'd at 500,000 operations typical in this application), but it is easily replaced should it ever fail.

Table 1: Parts List for the LiPo Battery Voltage Reducer

QTY	Description	Mouser Part Number
2	100Ω 1/4W	660-MF1/4DCT52R1000F
1	Ultrabright LED	941-C503BRCNCW0Z0AA1
1	10KΩ 1/4W	660-MF1/4DCT52R1002F
2	1N5401	821-1N5401
*1	14.3V zener diode (14V zener diode)	771-NZX14C,133 (78-TZX14C)
1	DPDT Relay	655-V23105A5003A201
1	Machined-pin IC socket, 16 pin	575-199316
1	2N3904	610-2N3904
1	3900uF 2.5V electrolytic capacitor	647-PLG0E392MDO1
1	3.3x2.2x1.4" plastic box	546-1591LS-BK
2 sets	PowerPole™ mounting bracket (see text)	879-1462G1
2	Black PowerPole™ connector & contact	879-1330G4
2	Red PowerPole™ connector & contact	879-1330
2	4-40 x ¼" threaded standoff	636-160-000-006R032
2	9/16" 4-40 screws, nuts and lockwashers	

*The 14.3V zener diode provides a drop-out voltage right at the KX3 15VDC maximum voltage spec. This minimizes power lost in the circuit, thereby maximizing battery life. The KX3 tolerates 15VDC very well, and doesn't actually self-protect until the input voltage reaches 16VDC. Should you wish a little more margin, a 14V zener is called out in parenthesis. This results in a drop-out voltage of about 14.7V.

While everything can be built on a perf-board, I decided to lay out a printed circuit board. The component locator for my layout is shown in Figure 2. The important thing to note is that the LED is mounted such that the anode (long lead) is positioned closest to the 2N3904 transistor. Contact me for printed circuit board availability.

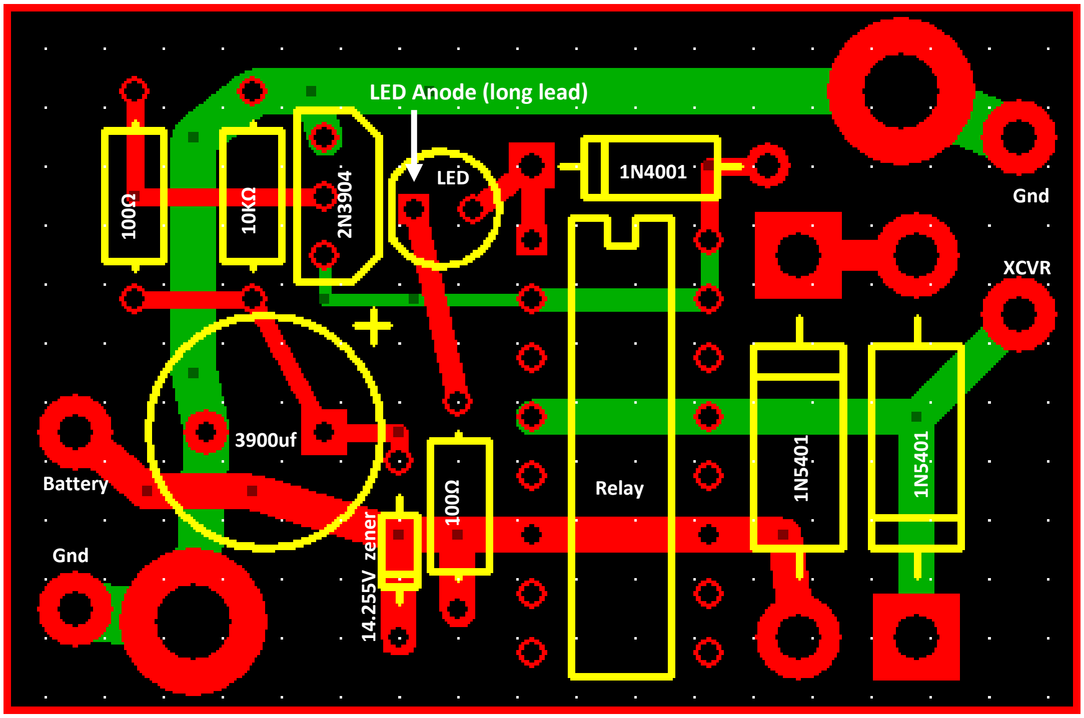


Figure 2: Printed circuit board component locator. The LED anode (longest lead) is closest to the 2N3904.

A small plastic box houses the voltage reducer. Prepare the PowerPole™ connectors by attaching 1.5" long 16 gauge stranded wires to the connector pairs. The PowerPole™ connectors slide into 0.6"-wide-by-0.4"-deep slots cut on either side of the box (an inexpensive nibbling tool makes this easy), and are held firmly in place by the slot and cover – or you can use the PowerPole™ mounting brackets called out in the parts list. Solder the LED to the pc board so the LED base is 0.9" above the printed circuit board. The LED will now just poke through a hole in the top cover. Figure 3 shows the assembly ready for mounting in the box. Figure 4 is an internal view of the completed voltage reducer. Figure 5 is an external view of the voltage reducer next to the 4S2P 5200mah LiPo battery I use. Labeling was done with Casio white-on-clear labeling tape. Or you can mark the box with a Sharpie™ silver permanent marker pen.

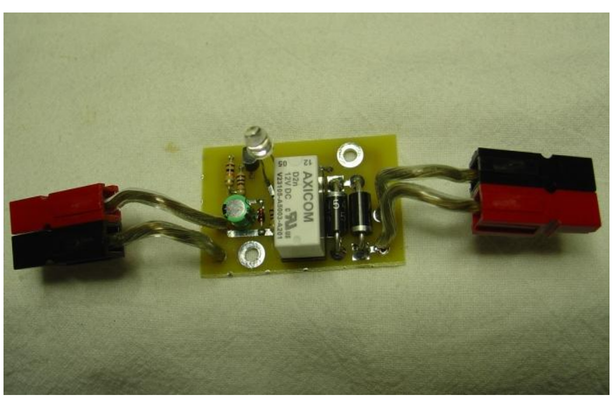


Figure 3: Reducer ready for mounting

Figure 4: Mounted assembly internal view

Figure 5: Assembled voltage reducer & Sanyo 5200mah LiPo battery

Finally, as you can see in Figure 5 the LiPo battery pack leads have "standard" Anderson PowerPole™ connectors. These battery packs normally come with R/C (radio control) connectors. Replacing R/C connectors with PowerPole™ connectors can be dangerous due to the very high current output capability of these batteries. Unless you really know what you are doing, build or buy an adapter cable.

Operation

There is really nothing to think about when using the unit. Connect the battery to the input PowerPole™, and your transceiver to the output PowerPole™. With the 14.3V zener diode, the relay activates at exactly 15V as indicated by the LED. For voltages below 15V, the relay opens and full battery voltage is applied to the transceiver. And again, when the relay opens no current is drawn by the circuit.

I made some voltage measurements with my KX3 connected to a fully charged 4S2P LiPo battery with the automatic voltage reducer in-line. KX3 output power was set to 10-watts, and DC current was nominally 2-amps. The KX3 voltage was monitored by the KX3 internal voltmeter. The results were as follows:

LiPo Battery Voltage	Reducer/Rcv	Reducer/TX key-up	Reducer/TX key-down (10W)
16.8VDC	14.9VDC	14.6VDC	14.1VDC

I continued to monitor the battery voltage over time. When the battery voltage dropped below 15VDC, the reducer automatically shorted the diodes. Key down voltage was 13VDC just before this occurred. Finally, even though LiPo batteries have a low-impedance high-current output there is some battery voltage variation under keying conditions. However, the hysteresis of the relay coupled with the filtering provided by the 3900uF capacitor results in no relay chatter during keying even as the battery voltage passes the voltage reducer trip point. Figure 6 shows the battery voltage (top trace), and the filtered base control voltage (bottom trace) under 2-amp keying. While there is a 400mv p-p ripple on the battery output voltage under the 2-amp keying load, there is almost no ripple on the 2N3904 base control voltage.

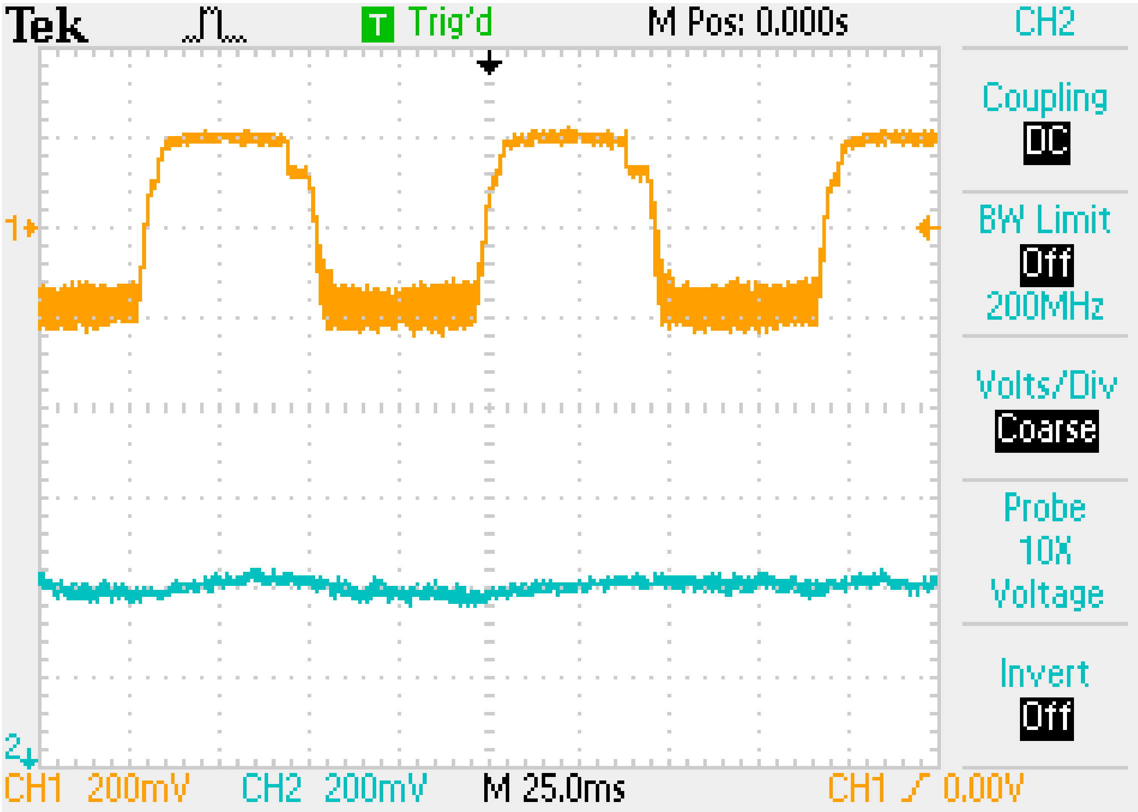


Figure 6: Battery output voltage (top) & transistor control voltage (bottom), 2-amp keying

Circuit modifications for other transceivers

While optimized for the KX3 15VDC max voltage, this circuit is easily changed for other max voltage requirements. For transceivers with a 14VDC maximum input voltage, change the 14.3V zener to a 13V zener and use three 1N5401 diodes to drop the LiPo fully charged 16.8V to less than 14V. Use the same printed circuit board but replace one horizontal 1N5401 diode with two vertically-mounted 1N5401 diodes with their open leads (anode to cathode) soldered together.

Single Pack Design

The plastic-box design is easilt built and not battery specific. However, as my Sanyo 5200mah LiPo battery is just 1.5" x 2.9" x 2.8" I packaged the battery and reducer into a 4.7x3.7x2.1" cast aluminum box (Mouser 563-CU-234). This is more convenient for portable operation, and also protects against battery fire which some have attributed to LiPo batteries. A lot of drill and file work was required, but the results were worth it. The DPDT slide switch, a Mouser 629-GF11261110, bypasses the voltage reducer so the battery can be charged through the PowerPole™ connector. The wiring diagram is shown in Figure 7.

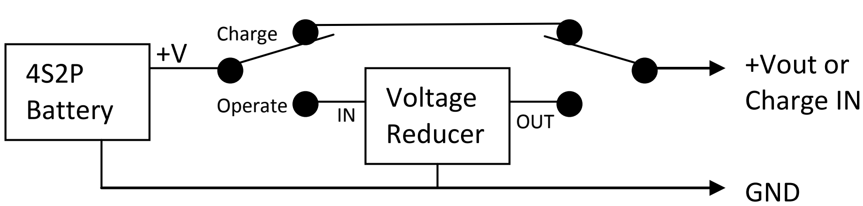


Figure 7: Common Box Wiring

Figures 8 and 9 show the inside wiring and the outside of the finished unit, respectively. I used the PowerPole mounting brackets that were called out as optional in Table 1. I also mounted the LED on the back of the pc board so it would be convenient to view because of the way I mounted the pc board assembly in the aluminum box. The wooden block keeps the battery from moving around in the box. Casio "Black on Clear" labeling tape completed the product.

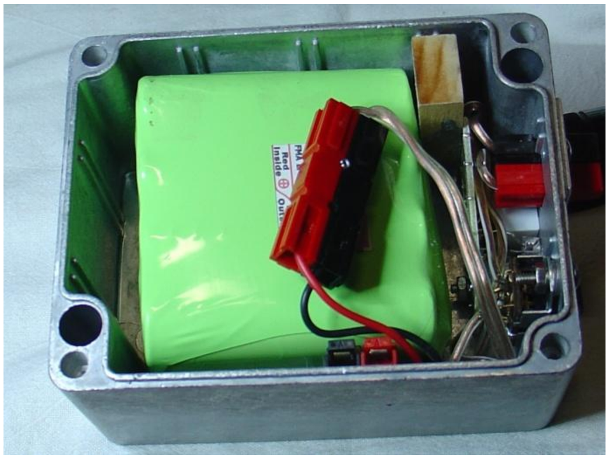


Figure 8: Internal wiring

Figure 9: External view of final package

Conclusion

New battery technologies continue to improve the ease and convenience of portable operation, especially for the QRP operator. Of course, there are usually trade-offs when any new technology is implemented. The circuit described here automatically overcomes the potential over-voltage problem when using some lithium-ion battery packs with existing 12V QRP transceivers.

Addendum – Battery Type and Test

My main interest is portable battery operation of my Elecraft KX3 transceiver. So I made some KX3 current measurements at 5- and 10-watts transmit power. Typical measured currents were:

Receive (backlight on):	210ma
Receive (backlight off):	170ma
Transmit, key-up (5W/10W semi break-in):	540ma
Transmit, key-up (5W/10W full break-in):	Same as receive current
Transmit, key-down @10W:	2200ma
Transmit, key-down @ 5W:	1230ma

When operating portable, my specific purpose is to make QSOs, so I operate approximately 50% listening and 50% QSOs - a much higher duty cycle than a typical non-contest home operation. During a QSO I assume 50% receiving and 50% transmitting. And the CW duty cycle using the standard PARIS format is 44% (key-down 44% of the time, key-up 66% during transmission.

For 50% listening, backlight on, and 50% QSOs at 5- and 10-watts transmit power:

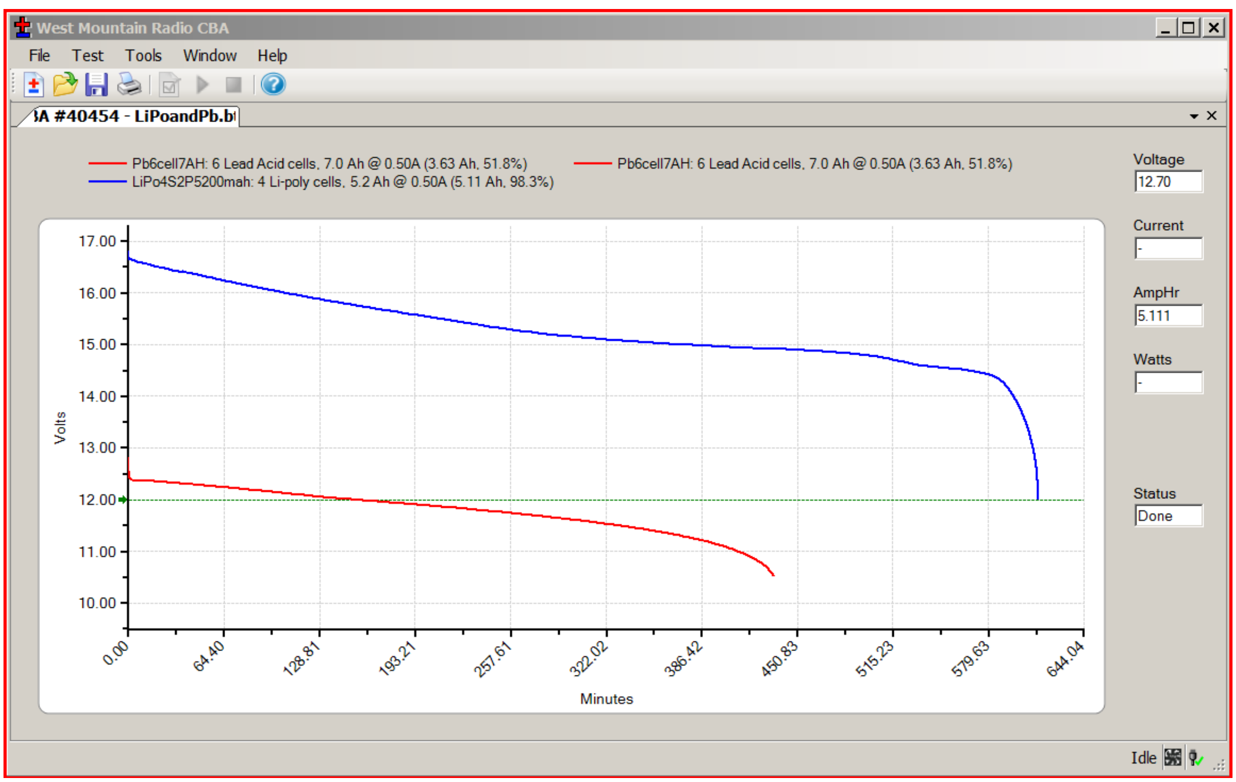
Listening: 0.50(0.21) = 0.105A
QSO: Receive: 0.25(0.21) = 0.053A
Transmit 5W semi break-in: 0.25(0.44x1.23 + 0.66x0.54) = 0.224A
Transmit 5W full break-in: 0.25(0.44x1.23 + 0.66x0.21) = 0.170A
Transmit 10W semi break-in: 0.25(0.44x2.2 + 0.66x0.54) = 0.331A
Transmit 10W full break-in: 0.25(0.44x2.2 + 0.66x0.21) = 0.277A

So with back-light on and semi break-in operation, the average current is 382ma at 5-watts and 489ma at 10-watts. I rounded these to 400ma and 500ma, respectively to provide some operating margin. You can save another 80ma if you keep the backlight off and operate full break-in.

The Sanyo battery pack was purchased on eBay for $70 (search “Sanyo 18650 4S2P 5200mah”). A smart charger (search “Battery Charger 16.8V LiPo”) was purchased for about $15. The battery specifications are as follows:

Chemistry/Make	#cells/Amp-Hr	Nominal V	Discharged V	Charged V
LiPo/Sanyo 18650	4S2P/5.2AH	14.8V	12V	16.8V

I tested this battery at the 500ma average determined for 10-watts transmit power as this battery easily sources the required 2.2-amp peak current required. The figure below shows the results plotted versus minutes at the 500ma average current (the lower curve is an old sealed lead-acid battery I had for comparison). The LiPo battery and delivers 5.11 amp-hours of capacity – nearly identical to its 5.2 amp-hour specification – or about 10 hours of expected KX3 operation.



LiPo 4S2P Battery Test (blue curve) showing minutes of use at 500ma average current