Yet Another Battery Replacement for Portable Tube Radios

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We all know that portable tube radios need a pair of awkwardly large and expensive batteries. Radios post 1945 designed for battery operation *only,* usually connect the tube filaments in parallel, and usually require a 1.5V “A” battery (often a “D” cell) for the filaments. (Radios designed for battery or line operation usually connect the tube filaments in series, so usually require an “A” battery of around 7.5V.) Clearly the “A” supply can be addressed with flashlight batteries. The high voltage “B” batteries are usually rated at 67.5 or 90V, and can be made awkwardly with 8-10 9-volt batteries in series. If you prefer practical batteries, converting “a few” volts up to 60-90V can be challenging. Gord Hamilton did an excellent article describing a design procedure for transformer-based high voltage supplies back in 2004 (ref. Summer 2001 and Fall 2004 OVRC newsletters).

Recently, portable rechargeable “cell phone chargers” have become available for as little as $6 (on sale at Canadian Tire). These devices generate a regulated voltage of 5V at 1A or 2A, accessible via USB jack. They are based on lithium-ion polymer battery technology that has high energy density, and are recharged thru another USB port or even directly from the wall. They all have built-in battery management circuits to generate the 5V and to control the charge and discharge cycles; lithium batteries are notoriously finicky about being fully depleted. They are available in many capacities from 2 to 10 Amp-Hour depending on the physical size. (Note that this Amp-Hour capacity is at the *internal* battery, which is generally 3.7V. The internal converter steps the 3.7V up to 5V, with an assumed 90% converter efficiency, which means that a charger sold as a 5.3Amp-Hour unit will actually deliver about 3.5 Amp-Hours at 5V.) The 5.3Amp-Hour version I have fits easily into the space formerly occupied by the B battery. My goal was to make a voltage converter that would fit into the remaining space, the form factor of the D-cell. Any transformer working at low frequencies (say, under 10kHz) would not fit into a D-cell form factor, so I focused on a high frequency supply, following Gordon Hamilton’s guidance.

My Approach

On the high-voltage side, I used push-pull MOSFETs to drive a small transformer (extracted from a 5V “wall wart” USB charger) at 100kHz. Normally, these transformers convert chopped high voltage down to 5V, but they will also work in reverse. For the filament voltage, I used a simple series resistor to supply the 1.5V. This is not efficient, as it results in only 30% efficiency; a switching “buck” regulator would have been at least twice as efficient but is more complicated and needs custom components. The high voltage power supply comes alive with the power switch on the radio; you can leave everything connected inside the radio all the time, just turn the radio on and off with its usual power switch, just as if the original batteries were present.

The schematic I used is shown below. The four MOS transistors Q1-Q4 form a bridge that drives the transformer T1 with a square wave of about 100kHz. The MOSFETS that I used were TSM680P06 and TSM900N06 from Digikey. I selected them because they are very small (TO-251 package, which is not much bigger than a small-signal transistor), have excellent on-resistance of about 0.1 ohm, and operate well with 5V switching the gate. None of the parts need heatsinks. The MOSFET gates are driven with CMOS Schmidt triggers U1A and U1B configured as an oscillator providing complimentary outputs. L1 was necessary because all 4 FETs are briefly “on” simultaneously (briefly shorting the supply) 100k times per second, causing a lot of wasted energy; L1 prevents this. I do not have a part number for the transformer. It was taken from a USB charger “wall wart”, this one in particular was a half-amp unit. Look for one for that is not potted. This transformer has a third winding that can be placed in series with the high voltage winding to increase or decrease output voltage.

The output side of the transformer drives a voltage doubler. A doubler might not be necessary with some transformers, and a tripler might be necessary if more voltage is needed. In fact, this circuit delivered 60V to the radio (at about 8.5mA) with a simple half-wave rectifier (that is, eliminating D1, D2, and shorting out C3), and the radio worked perfectly well, but I used the doubler anyway. I was surprised that “regular” rectifier diodes were very inefficient at this frequency and voltage (a 1N4148 got hot even without a load), so Schottky diodes are essential. The 1N5711 might seem an odd choice as they are considered small-signal diodes, but they have low capacitance and are very fast, and we only need 15mA average so they work very efficiently. With the transformer I used and a doubler, the output voltage is about 85V at 15mA current draw. Your results may vary depending on your transformer. C14 “tunes up” the transformer and increases efficiency a bit; it was determined experimentally.

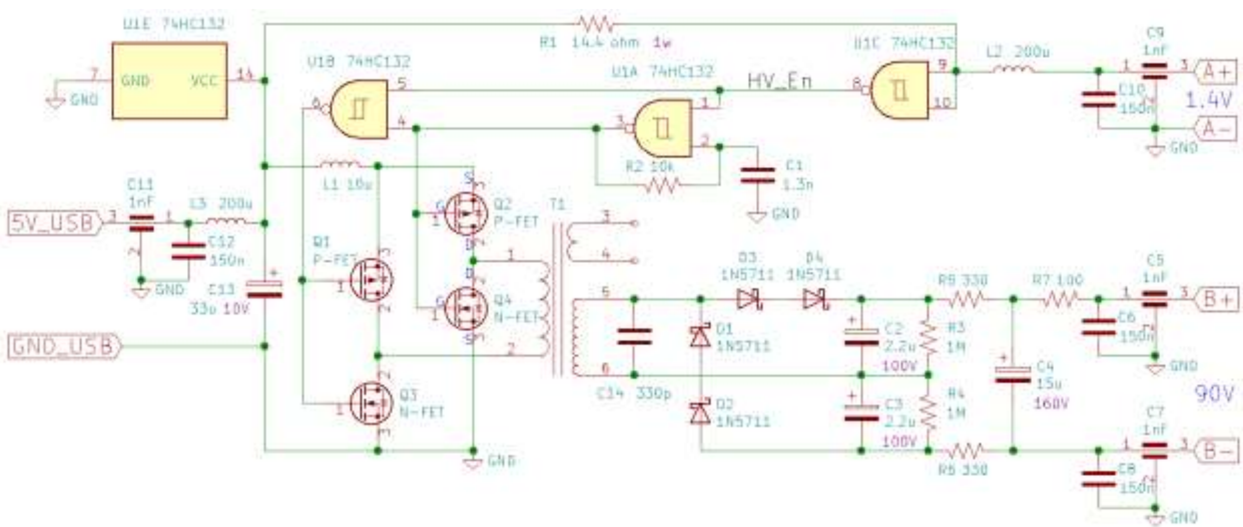

Figure 1 Schematic

The filament is supplied through a simple dropping resistor. R1 plus the resistance of L2 + L3 add up to drop the 5V down to 1.4V for the filaments. When the radio’s switch is open, the voltage at the A+ terminal is 5V, and, applied to U1C, keeps the oscillator off. When the radio is switched on, the A+ voltage drops to 1.4V, and this flips U1C such that the oscillator starts and the high voltage comes on. The value of R1 may need to change depending on the number of tubes in the radio. My radio has 4 tubes that draw a total of 250mA, so the total resistance needs to be (5V-1.4V)/0.25 = 14.4 ohms. This resistor needs to dissipate almost 1 watt, so I made it with 4 resistors: three 51 ohm plus one 100 ohm in parallel. They are the warmest parts on the board.

Figure 2 Assembly

The biggest challenge with this circuit was keeping the noise emissions from the switching supplies (EMI) from interfering with the radio. The cell phone charger uses a switching regulator and this put noise into the filament circuit, which was reduced with L2 and L3. These are not critical (but keep series resistance low) and were both taken from defective Compact Fluorescent Lamp power supplies. The high voltage converter also has a strong 100kHz square wave which can cause havoc on the AM band, and the capacitors at the perimeter (C5-12) tame that. All the circuitry fits on a 1" X 2" board that slides into a 1.25" brass pipe, the same length and diameter as a D-cell. A metal end-cap with edges bent over the side of the pipe support feed-through capacitors. Every line (5V in, A+, B- and B+) is filtered with feedthrough capacitors. It took some fiddling to tame the EMI, but it ended up quite quiet.

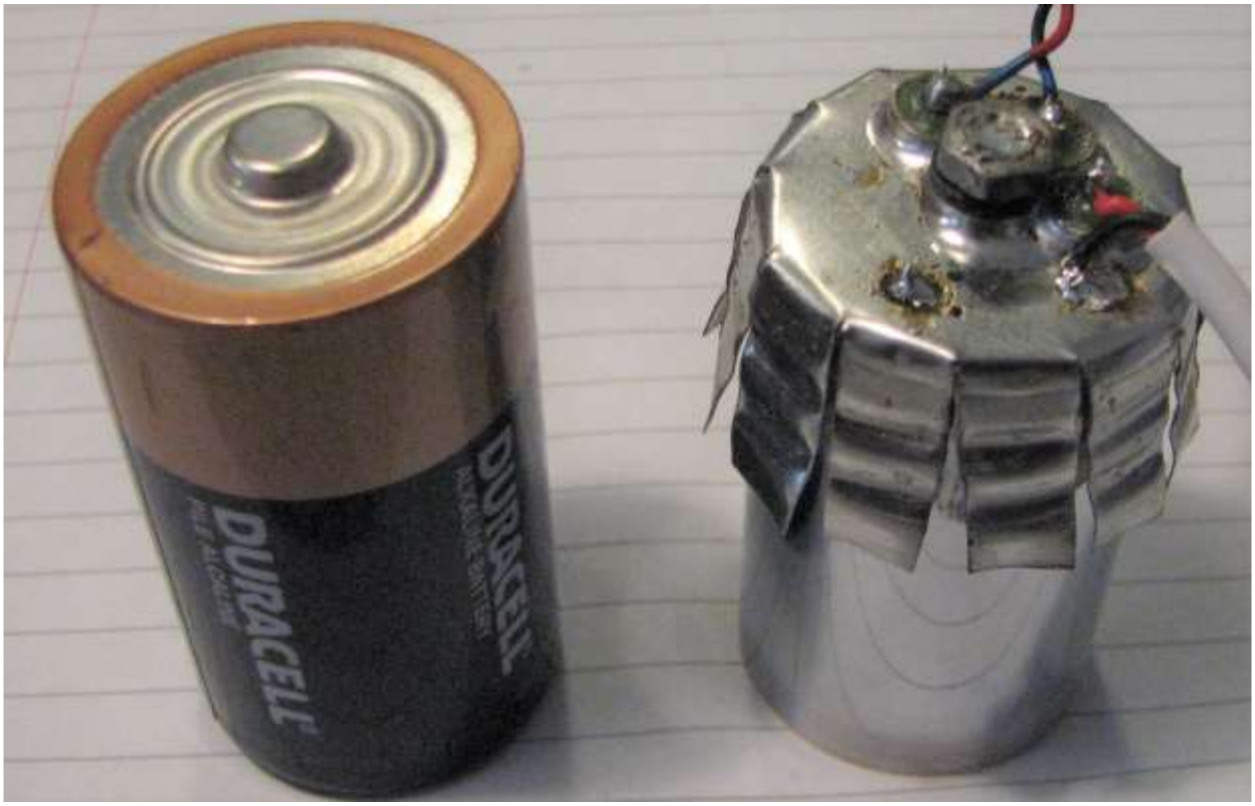

Figure 3 The voltage converter next to the "D" cell it will replace.

The efficiency of the high voltage converter is about 75% at 85V, 15mA (ignoring the effect of R5, R6, and R7) Overall, the circuit takes about 610mA; 230mA for the filaments and about 380mA for the plate (with an output of 15 mA at 85V) The battery I used has a capacity of 3.5A-H (calculation above) So, the battery should have a life of about 5.7 hours before needing recharging, and indeed that turns out to be accurate. Lifetime would be over 8 hours if the power supply was wired for 60V output (with a half-wave rectifier)

Note that the two output voltages are entirely isolated from each other, and this is a requirement of many battery radios that use, effectively, cathode bias on the output tube.

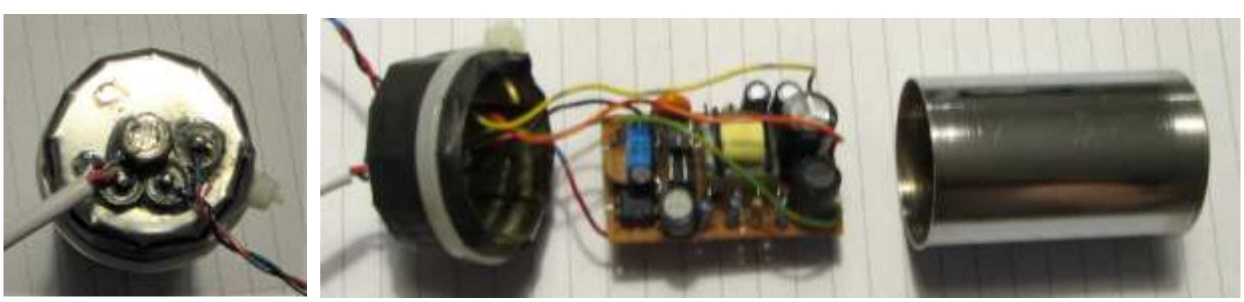

Figure 4 Exploded view of voltage converter.

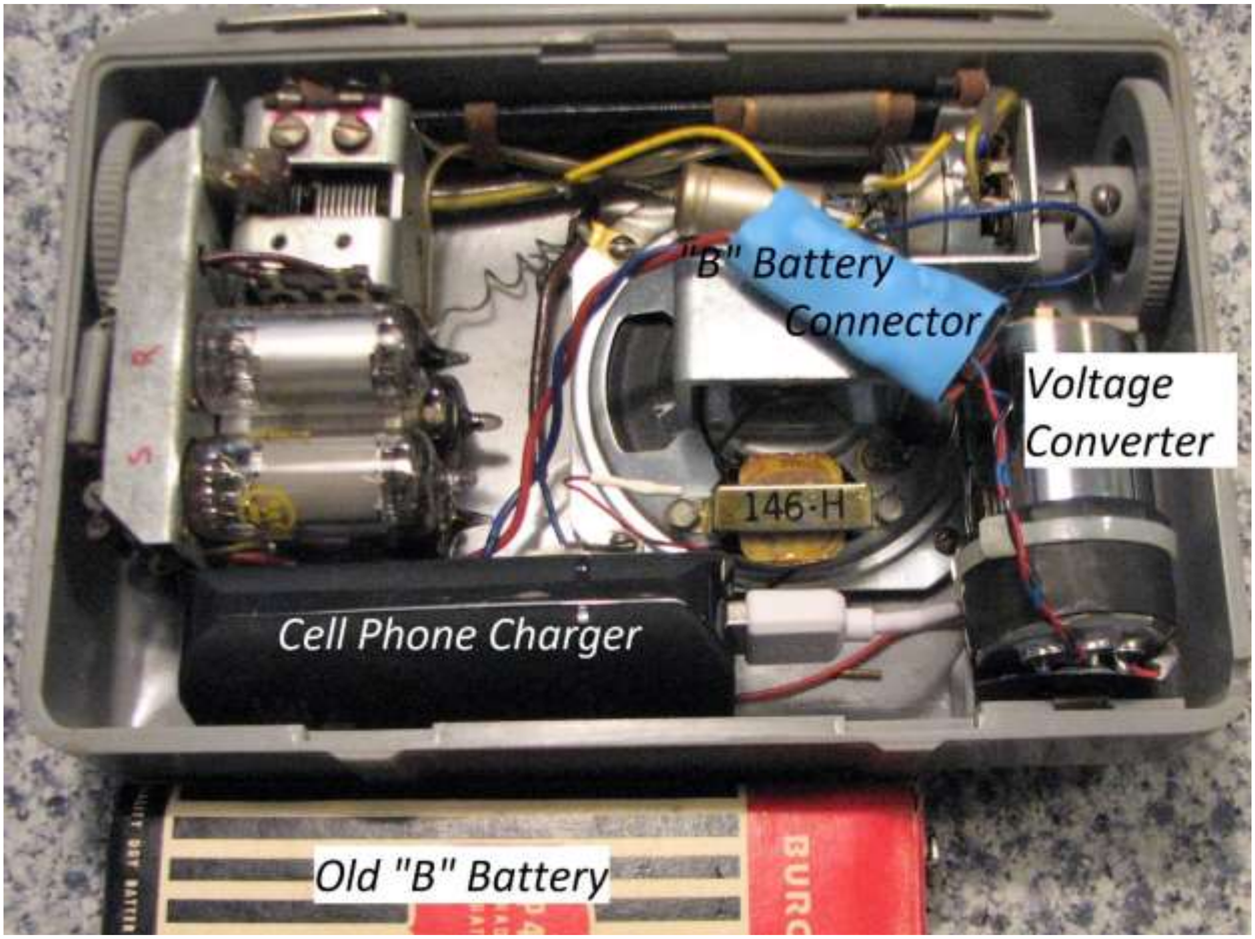

Figure 5 Inside a portable radio. The charger replaces the "B" battery, the voltage converter replaces the "A" battery (D cell)

Battery Lifetime

How long would this radio have played on a set of original batteries? I am too young to have owned a fresh 67.5V battery, so I do not have first-hand experience. The specifications of some of the carbon-zinc batteries (which would be the only economical battery available at that time) are available on the Energizer (Eveready) web site. https://data.energizer.com/ A fairly typical battery for a portable radio would be the Eveready 416 which is 67.5V. The 400 series of batteries are mainly based on stacks of "112" cells. Each cell measures about 3mm (terminal to terminal) X 25mm X 15mm. It has a rated capacity of about 140mA-hr to a voltage of 0.8V per cell with a 25mA constant current draw. I don't think the radio will function at a B voltage 36V, so that capacity is quite optimistic. If we allowed a drop to 48V, the capacity would be about 100mA-hr. A portable radio will generally take about 15mA of current, so one can expect about 7 hours of operation from this B battery. This radio used a 477 battery and I was unable to find any information about its capacity, however by looking at the battery volume, I estimate that it had about 300mA-hr capacity, for a life of about 15 hours.

Eveready	Burgess	NEDA	Voltage	# cells	Capacity
411	U10	208	15V	10 X #112	140mA-hr
412	U15	215	22.5V	15 X #112	“
413	U20	210	30V	20 X #112	“
415	U30	213	45V	30 X #112	“
416	UX45	217	67.5V	46 X #112	“
455	XX30	201	45V	30 X #130	550mA-hr
467	XX45	200	67.5V	45 X #130	“
457	K45	203	67.5V	88 X #112	280mA-hr
477	P45	211	67.5V	46 X ?	300mA-hr (est)

The capacity of the “D” cell typically used for a portable radio’s filament supply is actually more difficult to pin down, because there were several different cell chemistries available. Data on an Eveready 950 cell (the most basic D-size flashlight cell, at about $0.19 in 1954) shows a capacity of 4A-Hour at 25mA (0.8V end voltage) , but total capacity declines significantly at higher current, so at 250mA (1.1V end voltage) , it has about 1.5A-hr capacity, or about 6 hour of service . Note that alkaline D-cells were available at that time, but about 4X the price of the basic flashlight cells (ref. Electrosonic catalogue).

Transistor radios are far more practical than these tube radios, as they require a fraction of the power of even just the filaments of one of these tube radios. So, I’m guessing that you have more suitable radios for your next trip to the beach. However, the gizmo described here allows you to demonstrate and even use your “retro” tube portables without modification, and relive this era prior to the transistor radio.