Analog circuit is accurate battery fuel gauge

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There are many new devices and algorithms available today which can predict the remaining capacity of a battery. Good examples are found in laptop computers and cell phones. However, these often rely on software and ADCs or specialized integrated circuits. What about very low cost applications such as battery powered toys? Figure 1 shows a schematic of such a low cost circuit which linearizes the cell discharge voltage curve to create an estimate of remaining capacity.

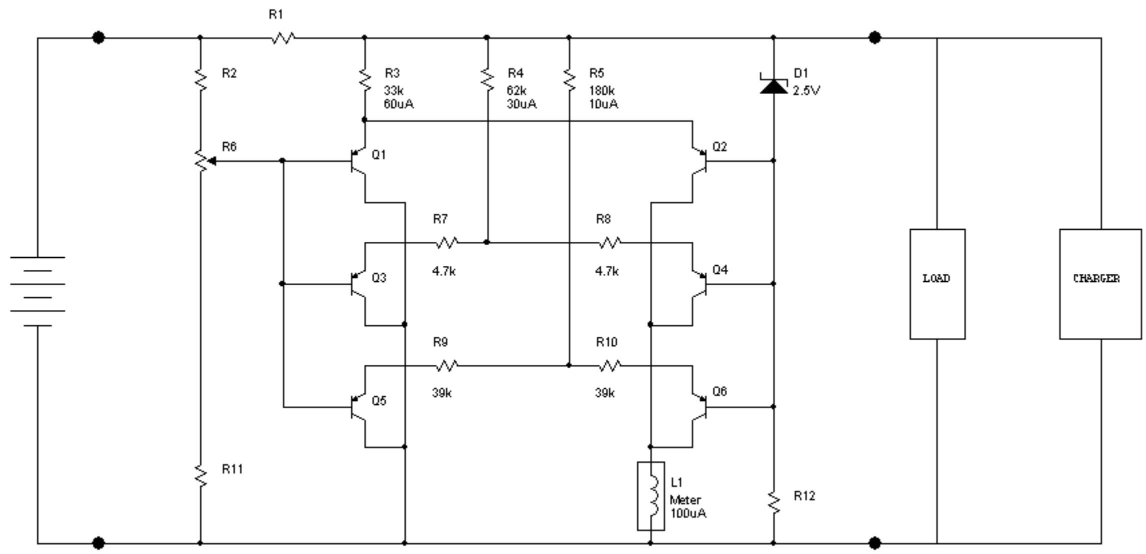

Figure 1. Schematic of analog circuit which acts as accurate battery monitor.
L1 is an analog current meter for a true “fuel gauge” appearance.

A 500 mAh NiMH battery was measured at different discharge rates, normalized, and plotted in Figure 2. The shapes of the curves are very non-linear but consistent over varying loads. The offset between them is due to the internal equivalent series resistance (ESR) of the battery. Knowing these characteristics, the circuit of Figure 1 was designed with an inverse non-linearity and offset, thereby creating an output current that is proportional to remaining capacity.

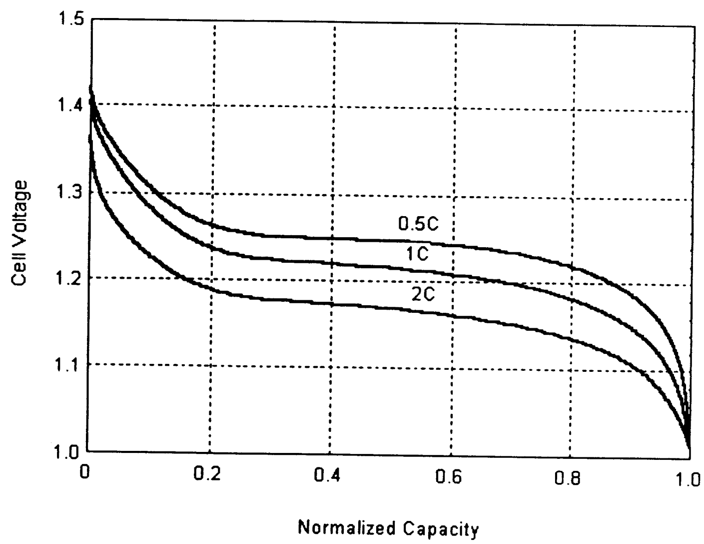

Figure 2. Normalized discharge voltage curves of NiMH cell.

The key to this circuit is the non-linear transfer function of an emitter coupled pair amplifier. By combining output currents of several amplifiers, a new transfer function is created. Each pair operates at a different gain and current thereby covering different portions of the desired response. Greater accuracy can be obtained by adding more amplifiers and introducing voltage offsets.

Compensation for load offset is accomplished by R1. As the load current increases so does the voltage drop across R1 which shifts the reference voltage D1 lower relative to the R2/R11 voltage divider. Compensation for thermal drift in cell voltage is possible by adding a positive tempco to D1. Interestingly, because of R1, this circuit also works in reverse while the battery is being charged. The meter still reads correctly empty-to-full even though load current is negative. R1 is a function of battery ESR and is calculated by

$$R1 = \left(\frac{2.5}{Vbat} \right) \cdot ESR$$

where Vbat is the mid-capacity voltage at no load.

Resistor values shown are for a 100uA meter. Any number of cells (NiCd or NiMH) greater than or equal to three is accommodated by the input divider network. R6 is only a tolerance trim. R12 is symbolic of a current source and is often included in the voltage reference.

Circuit simulation using SPICE shows a very good match to actual battery performance (for SPICE the Y axis is the input). Figure 4 shows the resulting error – almost the equivalent of a ten segment display.

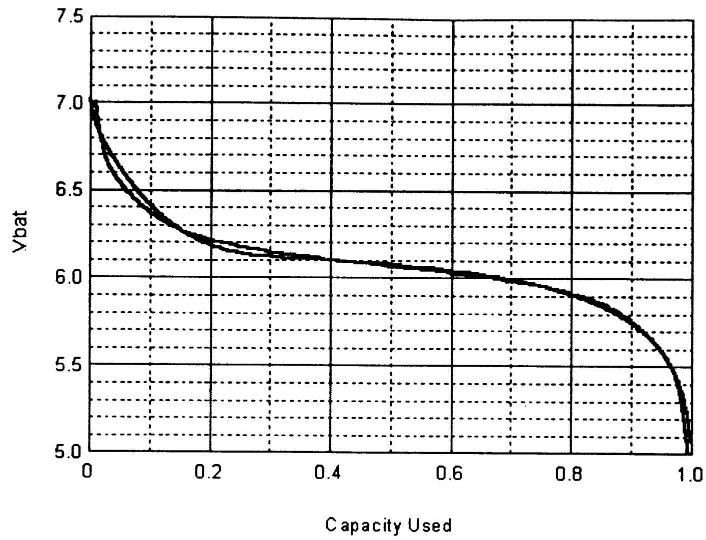

Figure 3. SPICE versus actual.

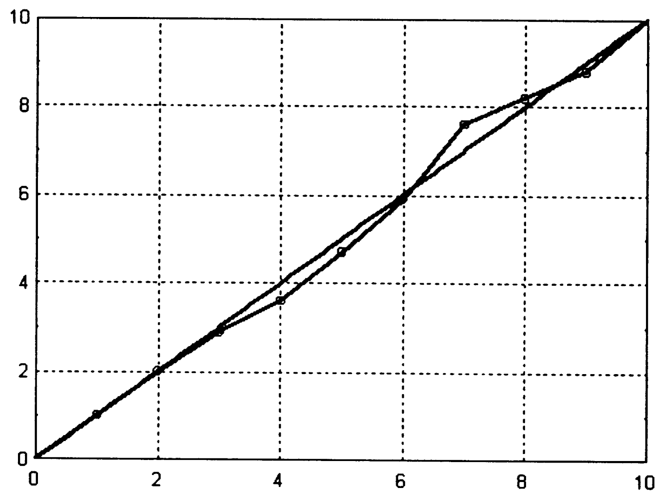

Figure 4. Accuracy between SPICE output and actual battery.

Reference:

[1] Hagerman, James; U.S. Patent 5,461,430 “Dynamic Gamma Correction Circuit For Use In Image Projectors”, 10/24/95.