**ALEXANDER BELL**
INFOSOFT INTERNATIONAL INC., REGO PARK, N.Y.
bell@alexanderbell.us

ED ONLINE 21005

# Capacitor-Powered Electronics Is At The Core Of Green Design

**The concept of using** supercapacitors (also known as ultracapacitors, supercaps, etc.), and replacing the batteries in portable micropower applications,[1] is gaining momentum. In fact, it has become one of the more noticeable technical trends of recent time.

Supercapacitors, such as the BOOSTCAP ultracapacitors from Maxwell Technologies *(www.maxwell.com)* or DYNACAP from Elna *(www.elna-america.com )*, when used as a power source, hold tremendous advantages over traditional rechargeable batteries. For instance, they feature high endurance to short circuits, very short charging cycle, and practically unlimited charge-discharge cyclomatic durability (up to 1 million cycles compared to 1000 for batteries), thus providing an environmentally clean, "no-disposable-part" solution. In addition, most supercaps comply with the European Union's Restrictions on Hazardous Substances (RoHS).

The fundamental difference between supercaps and batteries from a design prospective is the substantial voltage change during a capacitor's charge/discharge cycles, which goes theoretically from zero to the maximum rated voltage, while a battery's terminal voltage varies just a little during its operational cycle. Supercaps are the subset of electrical capacitors. Thus, the effective energy, $E_{EFF}$, that can be obtained from a supercap during its discharge cycle, when the terminal voltage changes from the maximum, $V_{MAX}$, to the minimal operating voltage, $V_{MIN}$, of the powered device could be calculated as:

$$E_{EFF} = 1/2 \times C \times (V^2_{MAX} - V^2_{MIN}) \quad (1)$$

Correspondingly, the effective energy ratio (EER) could be defined as:

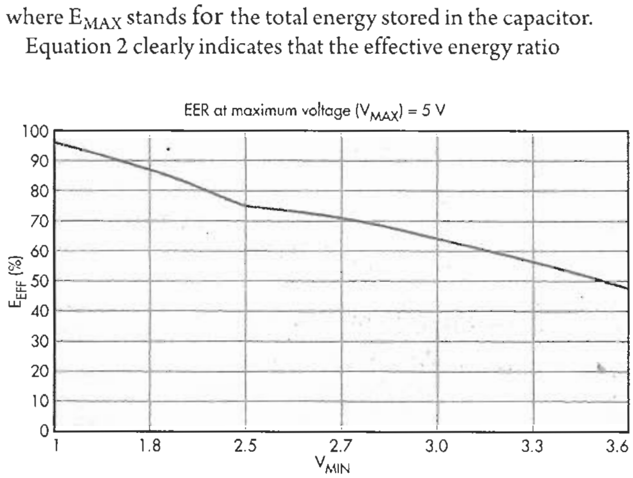
$$E_{EFF}/E_{MAX} = 1 - (V_{MIN}/V_{MAX})^2 \quad (2)$$

where $E_{MAX}$ stands for the total energy stored in the capacitor.

Equation 2 clearly indicates that the effective energy ratio increases dramatically as we lower the minimum operational voltage $V_{MIN}$ of the powered electronic circuit due to the lower amount of residual electrical energy left in the capacitor. EER is a very important design consideration to be applied to any capacitor-powered electronic circuit.

EER For $V_{MAX}$ = 5 V

| $V_{MIN}$ (V) | $E_{EFF}/E_{MAX}$ |
|---|---|
| 1.0 | 96% |
| 1.8 | 87% |
| 2.5 | 75% |
| 2.7 | 71% |
| 3.0 | 64% |
| 3.3 | 56% |
| 3.6 | 48% |




1. The graph of capacitor effective energy ratio (EER) for $V_{MAX}$ = 5 V shows a dramatic decrease as $V_{MIN}$ increases from 1.0 V to 3.6 V.

The table and the corresponding graph in Figure 1 show a sample EER calculated for a capacitor-powered circuit with maximum terminal voltage $V_{MAX}$ = 5 V. It's quite noticeable that EER increases from 48% to 96% when the minimal operational voltage, $V_{MIN}$, of the powered electronic device changes from 3.6 V to 1 V. Therefore, "squeezing the device operating voltage" is the primary design consideration of capacitor-powered electronics.

The goal could be achieved by using an ultra-low-power dc-dc boost converter (e.g., the inductor-less type described in Reference 2, operating from as low as 0.7 V), but it could add to the design cost and energy consumption. The second alternative is to use a special design technique targeted at providing ultra-low-voltage device operation.

A good example of such low-voltage circuit design is described in Reference 3. The suggested micropower, ultra-low-voltage, full-wave, diode-less rectifier is an excellent fit for the design paradigm of capacitor-powered electronics *(Fig. 2)*.

To understand the operational principle of the circuit, it's important to notice that the op amp works in a single-supply mode. If a positive signal is applied to the input ($V_{IN} > 0$), the op-amp output goes to zero and the whole circuit virtually transforms itself into a simple passive network of three resistors—R1, R2, and R3—connected in series. When the input signal goes negative, the op amp returns to "normal linear life" and performs like a regular inverting amplifier. To produce the symmetrical output for both negative and positive half-waves, R1, R2, and R3 must be selected to comply with the mathematical condition:

$$R1 \times R3 = R2 \times (R1 + R2 + R3) \quad (3)$$

As the condition of Equation 3 is fulfilled, the circuit has a gain of one-half at point 2 in the circuit. An optional non-inverting ampli-

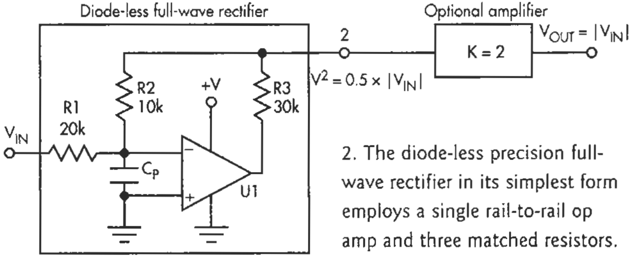
ALEXANDER BELL, CEO, holds a PhD in electrical engineering from the Moscow Power Engineering Institute (now Technical University), Russia.

fier with a gain of two could be added to produce the overall unity gain, providing the operational equation of $V_{OUT} = |V_{IN}|$.

The circuit has certain limitations: its input resistance is different for the positive and negative half-waves. Theoretically, resistance is R1 + R2 + R3 for the positive and just R1 for the negative signals. Also, the input parasitic capacitance, $C_P$, of the op amp affects the ac mode operation, especially in the high-frequency range. (Detailed analysis of ac performance goes far beyond the scope of this article. I would recommend using Spice simulation for the practical design).

The circuit could employ a variety of rail-to-rail micropower op amps—for example, the dual LM6442 from National Semiconductor ($V_{MIN}$ = 1.8 V), the dual MAX 4289 from Maxim Integrated Products ($V_{MIN}$ = 1.0 V), or a similar type.

Since a typical silicon diode has a forward-voltage drop of about 0.6 V, output dynamic range is reduced to "consuming" that very 0.6 V from the supply voltage. This consideration has become rather important in the case of building capacitor-powered electronics, where the circuit supply voltage should go as low as possible. For this reason, the suggested diode-less design is a better fit when running in capacitor-powered mode. It saves the valuable 0.6 V (which is a rather significant value considering the possibility of an op amp




2. The diode-less precision full-wave rectifier in its simplest form employs a single rail-to-rail op amp and three matched resistors.

running at 1 V), and thus squeezes the minimum operating voltage of the circuit and increases the overall EER of the solution.

References:


1. Bell, Alexander, "Single Capacitor Powers Audio Mixer," *EDN*, Mar. 14, 1997, *www.edn.com/archives/1997/031497/06DI_04.htm*.
2. Bell, Alexander, "Single NiCd Cells Drive Op Amp," *EDN*, Dec. 5, 1996; *www.edn.com/archives/1996/120596/25di_07.htm*.
3. Bell, Alexander, "Simple Full-Wave Rectifier," *Electronic Design*, Apr. 4, 1994, p. 78.