Preliminary

AN-1025
Application Note

Using the EnerChip™ in Pulse Current Applications

Introduction
EnerChips are solid state, reflow solder tolerant batteries packaged in standard surface mount, low profile packages. They can be placed onto printed circuit boards (PCBs) using high speed pick-and-place equipment on PCB assembly lines. They are ideal as rechargeable backup power sources for clocks, memories, micro-controllers and other low power circuits where data or timing information must be retained in the absence of main system power. EnerChips are also used in wireless sensor and transmitter systems, often operating over extreme temperature ranges. This Application Note describes methods of improving system performance when using the EnerChip in applications that require pulse currents greater than the EnerChip's capability, as when driving a radio transmitter or receiver in wireless sensor networks. Designing these types of battery powered systems begins with a characterization of battery performance specifications followed by determining whether an external boost capacitor might be required.

Background
All batteries have an internal impedance that ultimately limits the peak current that can be drawn from the cell. Each battery chemistry, design, and manufacturing process has inherent mechanisms and dependencies at work, resulting in peak currents that vary over temperature, state-of-charge, age of the cell, and other factors.

When the load placed on the battery exceeds the peak current delivery capability of the battery, the power to the load can be supplemented through the use of an external capacitor as shown in Figure 1. The capacitor holds very little charge relative to the EnerChip but the low internal resistance allows the reservoir of energy stored in the EnerChip to be delivered efficiently to the load when brief pulses of current are needed - for example to power a wireless transmitter. Between transmissions, the EnerChip recharges the capacitor and delivers steady state power to the load.

This Application Note provides detailed information on:
- Understanding the capacity and charge/discharge profile of the EnerChip thin film battery
- Determining the load pulse current requirements
- Calculating the optimal value for the external boost capacitor

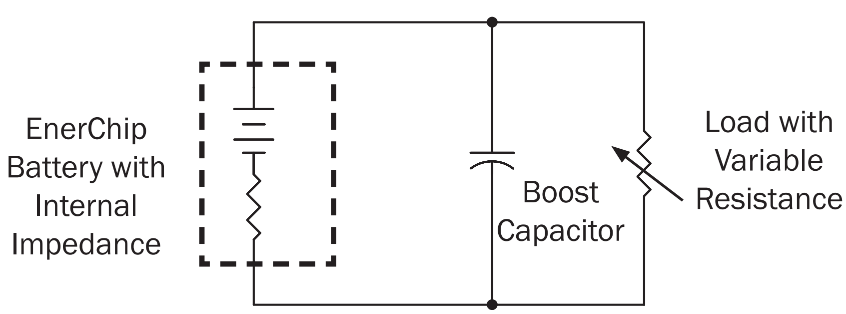

Figure 1. EnerChip with External Capacitor to Supplement Power to the Load.

Battery Capacity Ratings

The rated discharge capacity of a battery is specified at a particular discharge rate. As the discharge rate increases, there is a reduction in the available discharge capacity. The term known as the C-rate, specifies the current that a battery will deliver when discharged to 100% depth-of-discharge in a period of one hour. Conversely, battery capacity can be specified at a particular C-rate. For example, a cell's capacity might be rated at a discharge rate of C/4, or 0.25C, which means that it will deliver its rated capacity when completely discharged over a 4-hour period. A cell with a rating of 1 Ampere-hour at a C/4 rate would be completely discharged in 4 hours at a constant current of 250mA. At a higher discharge current, the discharge capacity would be less than that available at the lower rate. Some cells are rated at low discharge rates of C/100 or less. C-rate terminology is also applied to the charging rate of a cell.

The rated capacity of an EnerChip solid state battery is largely retained over a range of C-rates, as shown in Figure 2. This allows the cell to be used in a variety of applications without sacrificing much discharge capacity as the load currents vary across applications or from one operating condition to another within an application.

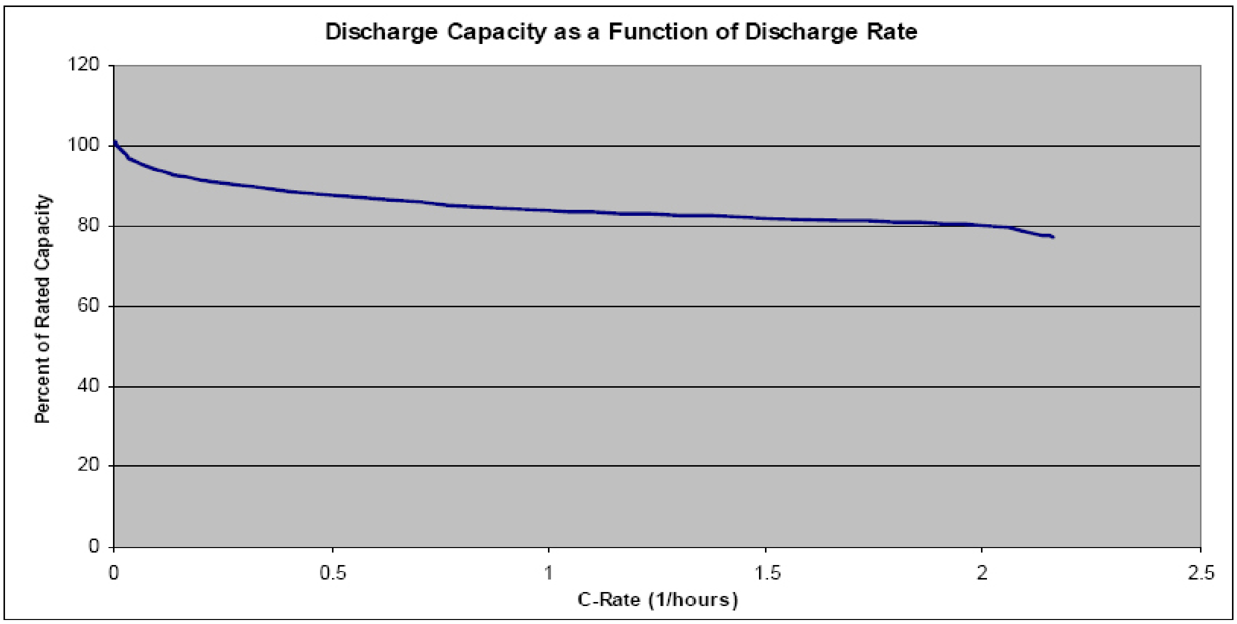

Figure 2. EnerChip Discharge Capacity at Various Discharge Rates.

Maintaining performance over a broad range of C-rates makes a cell well suited for pulse current applications. The EnerChip also has a favorable charge rate, with 30 minutes being a typical time for the EnerChip to reach 80% of its rated capacity.

Cell Impedance

Another factor to consider when specifying a battery for a particular application is its internal impedance. As with other battery chemistries, the electrical impedance of the EnerChip increases as the ambient temperature decreases. A rule of thumb is that the cell impedance increases (decreases) by a factor of two for every 10°C decrease (increase) in temperature. This translates to a reduction in the maximum discharge current that a cell will be capable of delivering as the ambient temperature decreases. A commensurate increase in the charging rate occurs at reduced temperatures.

In addition to the influence operating temperature has on a cell's impedance, the impedance is also a function of a cell's state-of-charge. As the cell becomes discharged, its impedance generally increases, most dramatically as the charge becomes nearly fully depleted. Figure 3 illustrates the dependence of EnerChip cell impedance at various states of charge, both at room temperature and 0°C.

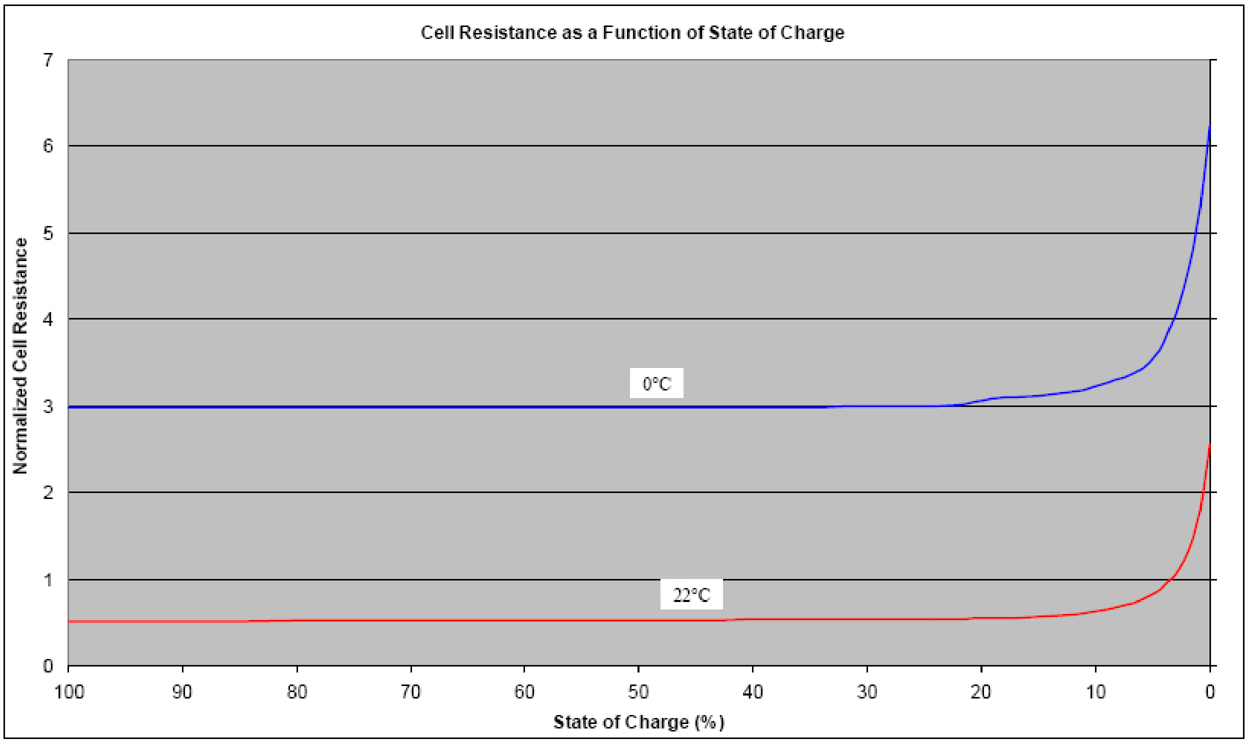

Figure 3. Dependence of Cell Resistance on State-of-Charge.

Discharge Profile

The discharge profile is an important consideration when specifying a cell for a particular application. Under a constant load, capacitors exhibit an output profile whereby the capacitor voltage decreases linearly over time. Depending on the external circuit being powered, the charge on the capacitor can not be fully utilized because at some point, the capacitor voltage is insufficient to operate the external circuit. In contrast, the EnerChip has a relatively flat discharge profile over its normal operating range. Consequently, nearly all of the discharge capacity is available to power the load. Figure 4 illustrates the typical discharge profile over a 50-hour discharge. The average output voltage is about 3.8V. In systems operating with components that have a maximum rating of 3.6V, the simplest remedy is to place a diode between the EnerChip and the external circuit in order to drop the output level by a few tenths of a Volt without sacrificing battery discharge capacity. If this is done, note that the diode characteristics will affect the series impedance between the EnerChip and the load and must be accounted for when calculating holding capacitor values and time constants. Capacitor charging time and pulse current delivery will be affected to a different degree depending on the placement of the diode - whether between the EnerChip and the capacitor, or between the capacitor and the load.

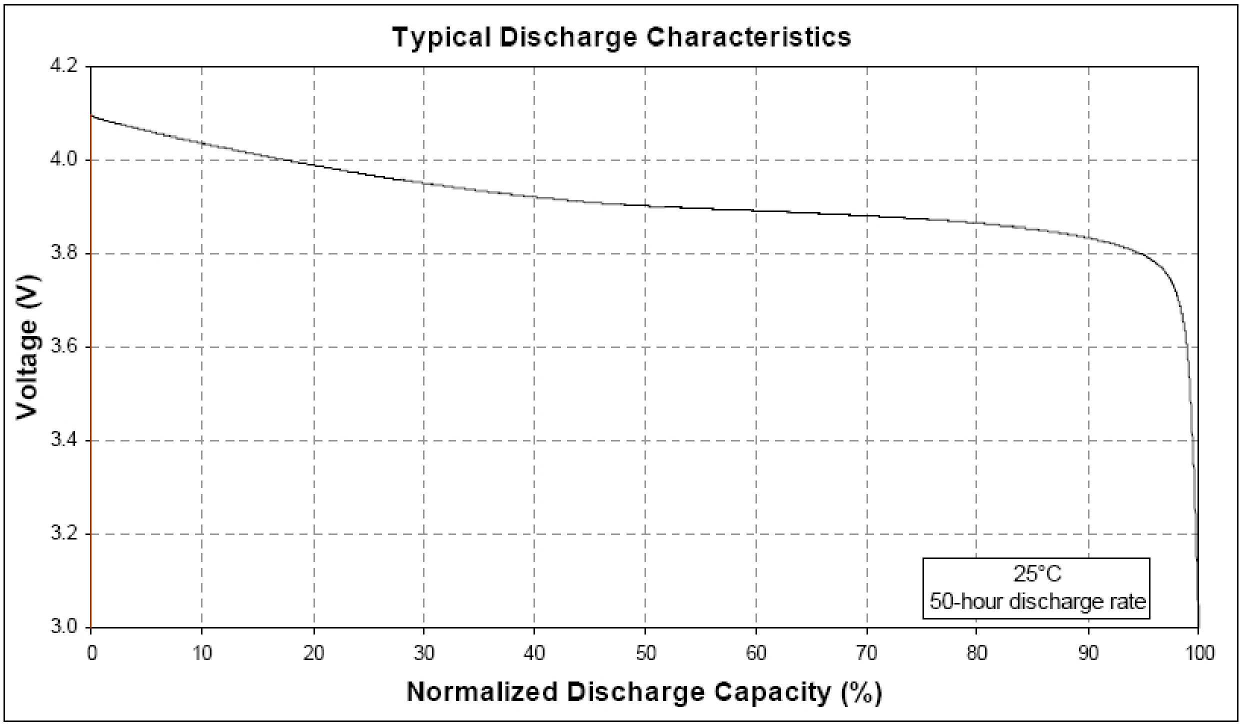

Figure 4. Typical EnerChip Discharge Profile.

Pulse Discharge Current

Pulse discharge currents place special demands on batteries. Repeated delivery of pulse currents exceeding the recommended load current of a given chemistry will diminish the useful life of the cell. The effects can be severe, depending on the amplitude of the current and the particular cell chemistry and construction. Pulse currents of tens of milliAmperes are common in wireless sensor systems during transmit and receive modes. Moreover, the internal impedance of the cell often results in an internal voltage drop that precludes the cell from delivering the pulse current at the voltage necessary to operate the external circuit. One method of mitigating such effects is to place a low Equivalent Series Resistance (ESR) capacitor across the battery. The battery charges the capacitor between discharge pulses and the capacitor delivers the pulse current to the load. Specifying the capacitance for a given battery in an application is a straightforward procedure, once a few key parameters are known. The key parameters are:

- Battery impedance (at temperature and state-of-charge)
- Battery voltage (as a function of state-of-charge)
- Operating temperature
- Pulse current amplitude
- Pulse current duration
- Allowable voltage droop during pulse discharge

Two equations will be used to calculate two unknown parameters:

1) the output capacitance needed to deliver the specified pulse current of a known duration;
2) the latency time that must be imposed between pulses to allow the capacitor to be recharged by the battery.

Both formulae will assume that the capacitor ESR is sufficiently low to result in negligible internal voltage drop while delivering the specified pulse current; consequently, only the battery resistance will be considered in the formula used to compute capacitor charging time and only the load resistance will be considered when computing the capacitance needed to deliver the discharge current.

The first step in creating a battery-capacitor couple for pulse current applications is to size the capacitance using the following formula:

Discharge formula: $C = t / [R * \ln (V_{max} / V_{min})]$

where:
C = output capacitance, in parallel with battery;
t = pulse duration;
R = load resistance = Vout(average) / Ipulse

Vmin and Vmax are determined by the combination of the battery voltage at a given state-of-charge and the operating voltage requirement of the external circuit.

Once the capacitance has been determined, the capacitor charging time can be calculated using the following formula:

Charge formula: $t = - R * C * \ln [(V_{max} - V_{chg}) / (V_{min} - V_{chg})]$

where:
t = capacitor charging time, from Vmin to Vmax
R = battery resistance
C = output capacitance, in parallel with battery
Vmax = final voltage to which the capacitor must be charged prior to delivering the next current pulse
Vmin = initial voltage on the capacitor when charging begins
Vchg = applied charging voltage on the capacitor

Battery resistance varies according to temperature and state-of-charge as described above. Worst-case conditions are often applied to the calculations to ensure proper system operation over temperature extremes, battery condition, capacitance tolerance, etc.

Application Example

A typical wireless sensor node requires pulse currents on the order of 10-30mA, with pulse widths in the 5-50ms range. Using an EnerChip rechargeable battery, coupled with an output capacitor, these typical pulse currents are readily attained with a relatively brief latency time needed between pulses to recharge the output capacitor, thus ensuring that the output voltage does not drop below the minimum circuit operating voltage at any time. Between pulses, the EnerChip would typically be delivering a low operating current to other circuit elements – perhaps a sensor and/or microcontroller. Figure 5 shows a string of 20mA pulses, each 20ms in duration, with a one minute recovery time between pulses, delivered from a circuit consisting of a CBC050 EnerChip with a 50µAh capacity rating, paired with a 1000µF tantalum capacitor. Note that the nominal EnerChip charging voltage of 4.1V is attained between successive pulses and the output voltage never drops below 3.0V.

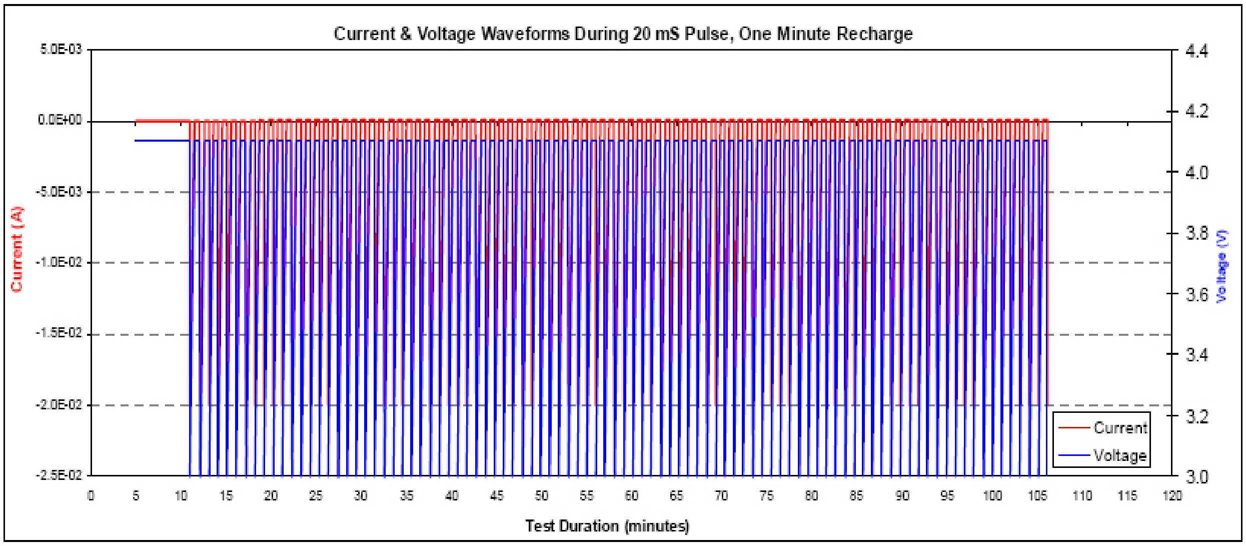

Figure 5. Pulse Discharge Current and Voltage Waveforms. EnerChip CBC050 with 1000µF Capacitor in Parallel.

Figure 6 illustrates the output capacitance required to deliver the typical transmit pulses in a wireless sensor node. The data are derived from the discharge formula given above. Similarly, Figure 7 depicts the required latency time between pulses for a given output capacitance and battery resistance, to allow the capacitor to fully charge before the next pulse is delivered. The line in the figure is generated from the charge formula given above.

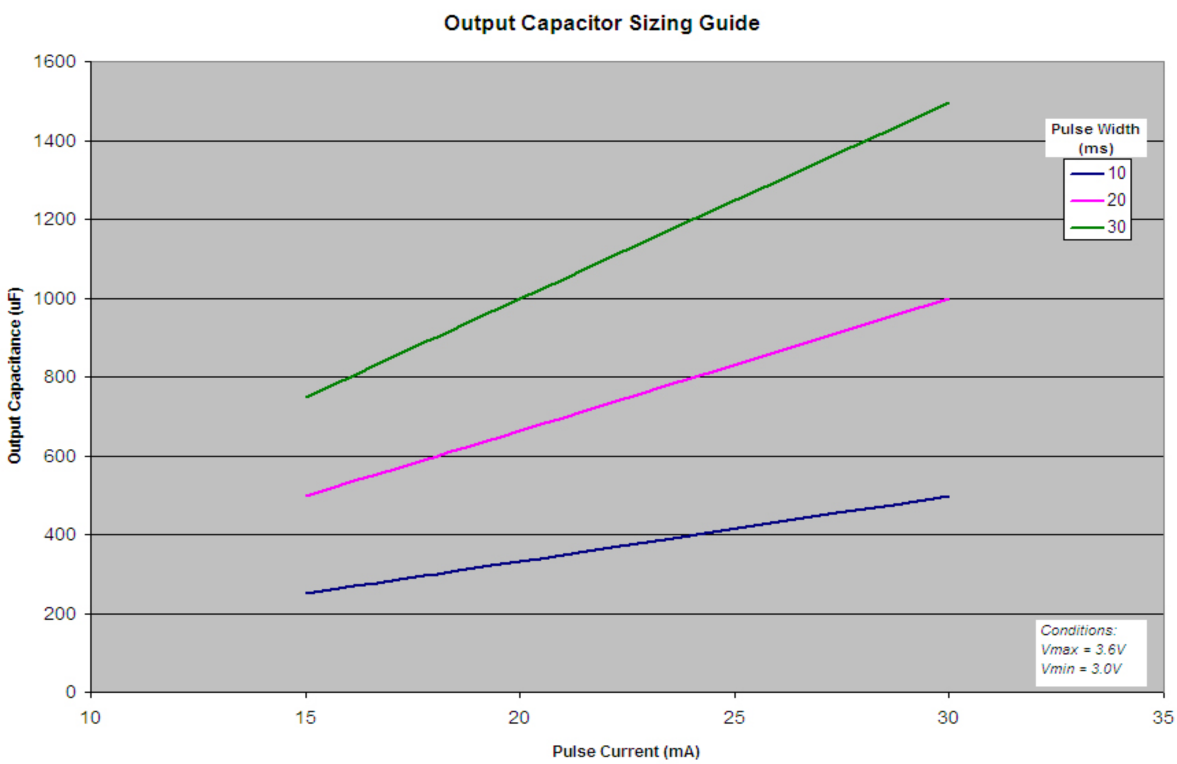

Figure 6. Output Capacitance Required for Typical Transmitter Pulse Currents.

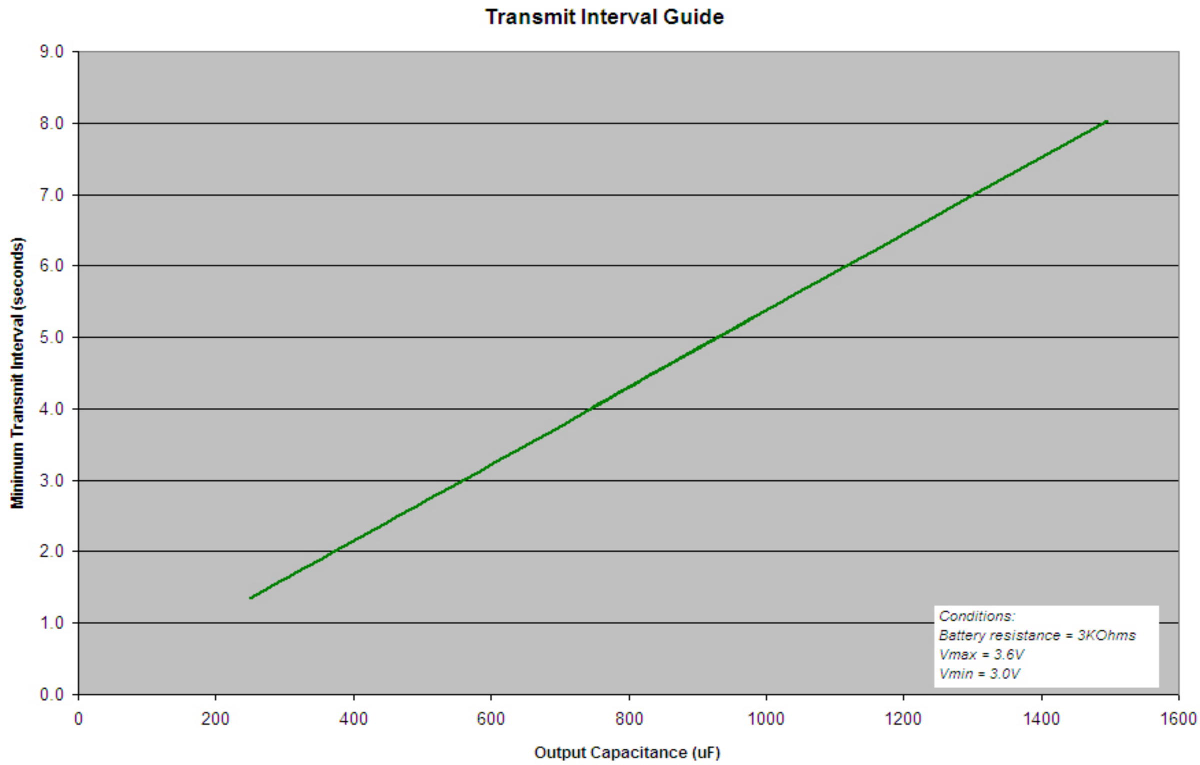

Figure 7. Transmitter Intervals Required for a Given Output Capacitance.

Let's use an application example with the following system considerations:

- Minimum voltage necessary to operate the external circuit is 3.0V.
- Radio pulse current is 20mA for a duration of 20ms, worst case.
- Output capacitor must reach 3.8V before delivering the next current pulse.
- Battery charging voltage is 4.1V.
- Operating temperature is 0°C.
- Battery must operate down to 10% state-of-charge.

Applying the discharge formula to determine the output capacitance: C = t / [R * ln (Vmax / Vmin)], we first find it necessary to know the cell resistance at the stated operating temperature. From the manufacturer's data sheet for the EnerChip, we learn that the room temperature cell resistance in a fully charged state is 1KΩ. From Figure 3, we know that the cell resistance will increase by ~ 7x from a 100% state-of-charge at room temperature, to a 10% state-of-charge at 0°C. Therefore we will use 7KΩ as the cell impedance when calculating the minimum charge time between pulses.

Since Vmin is given as 3.0V, we study the discharge profile in Figure 4 and see that at 10% state-of-charge, the cell voltage is about 3.8V under a nominal load (i.e., a much lower current than the pulse current required here - hence the need for the output capacitor). At 3.8V, we have 0.8V of margin to the 3.0V required by the external circuit. The load resistance is simply the average output voltage divided by the load current, equal to [(3.8V + 3.0V) / 2] / 20 mA = 170Ω. We already know the pulse current is 20ms - hence the equation can be solved:

C = t / [R * ln (Vmax / Vmin)] = 20ms / [170Ω * ln (3.8V / 3.0V)] = 498μF. To be conservative in our design, we will use the next largest standard capacitor size, which is 680μF.

Had the Vmin and Vmax values been the same as that in Figure 6, the same answer would have resulted by simply selecting a point on the 20ms line where it aligns with the 20mA pulse current on the x-axis, rather than applying the discharge formula directly.

Now that the capacitance is known, it is straightforward to calculate the time needed between pulses to ensure the output capacitor is fully charged before the next successive transmit pulse occurs:

$$t = - R * C * \ln [(V_{max} - V_{chg}) / (V_{min} - V_{chg})] = 7K\Omega * 680\mu F * \ln [(V_{max} - V_{chg}) / (V_{min} - V_{chg})]$$
$$= 6.2 \text{ seconds.}$$

A 10 second transmit interval ensures a robust design.

Conclusion

Careful selection of energy storage devices is essential for the delivery of stable and dependable power to electronic components for the service life of the system. System operating conditions demand that the designer consider worst-case operating temperature; battery state-of-charge and discharge profile; variations in component tolerances; and steady state and pulse operating modes when specifying the power source and auxiliary components. By following the guidelines herein, the designer can ensure a robust implementation of a long-life power source.