BATTERTY LIFE EXTENDING

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Abstract

Batteries powering RF transmitters have a generally short life span. Extending this life span, to and beyond 10 years while using a lightweight lithium coin cell, will result in an easy to use semi permanent installation. Through the use of a supercapacitor and intelligent boost regulator, current will be drained from the battery without reducing the total battery capacity.

1. INTRODUCTION

Small and efficient battery powered RF transmitters is in great demand for a very wide range of applications, for example, gauges on any moving devices, like measuring air pressure in a moving tire, and any area were no wires can be used, like censoring temperature on remote locations. The size and weight of these devices are usually determent by the battery size. In most of these applications a smaller device is preferred. Lithium coin cell batteries are the best choice for a battery because of its small size, and relatively high capacity and high voltage compared to other batteries on the market [1]. RF transmitters use a relatively large amount of current to transmit. This is a problem, for lightweight batteries can supply only a small amount of current and have a limited capacity. Drawing too much current at a time from a lithium battery will reduce the total capacity of the battery as shown in Figure 1 [5, p.1]. In most cases continues transmission is not necessary. 10-minute intervals are usually more than enough. Having a supercap charged for ten minutes and then discharged for one transmission seems like an easy way out, but while a cap discharges its voltage drops in a quadratic curve. This means most of the energy stored in the cap will be unusable.

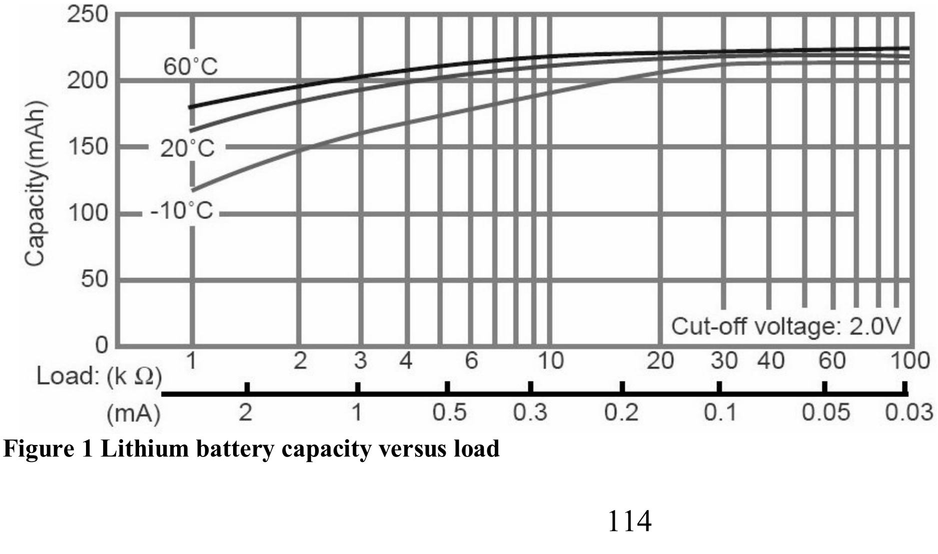

Figure 1 Lithium battery capacity versus load

2. BATTERY LIFETIME

The most obvious limitation of the lifetime will be an electrical load placed on the battery [3, p.1]. The lifetime based on electrical load is easy to calculate. Simply divide the available battery capacity in milliamp hours by the current demand in milliamps to get the lifetime in hours.

Because these batteries are used in very low to zero-current applications, other possible mechanisms that will deplete any of the reactive components should be looked at. One such mechanism is electrolyte loss through the crimp seal. This mechanism has been shown to be temperature-accelerated with activation energy of approximately 1.0eV. At room temperature the batteries will exhibit an electrical loss of less than 0.5% per year, and this mechanism can safely be ignored as can be seen in Figure 2 [3, p.1]. However at elevated temperatures the loss rate of electrolyte can become significant and must be considered.

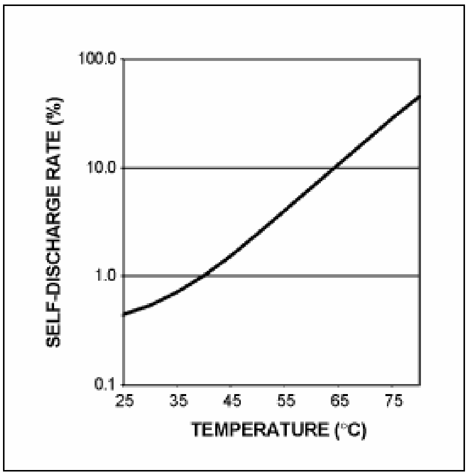

Figure 2 The self-discharge rate increases as temperature increases.

Because of the reactive component's balanced nature, it does not matter whether the electrical reaction consumes the electrolyte or it is expelled through the seal because of elevated temperatures. When the battery does not have enough electrolyte to continue the reaction, the battery will no longer provide current [3, p.1]. Therefore, a parallel model for lifetime predictions that considers the electrical demand and temperature when predicting the system lifetime is recommended. There are models that treat the electrical and temperature depletion legs as independent and predict a lifetime as if there were no interaction between the two components of electrolyte loss [3, p.1]. Using such a model will overstate the true lifetime if the system is exposed to temperatures much higher than room temperature.

Calculating the lifetime of the battery is similar in concept to calculating the effective resistance of two parallel resistors. Both of the legs can be controlled, the electrical load leg is controlled by the current drain, and the system ambient temperature controls the temperature-accelerated leg. Providing adequate cooling and proper component placement can help reduce the temperature exposure of the battery and, thereby, extend the system's lifetime.

2.1. Lifetime calculation

Assume the system is at room temperature. The electrolyte evaporation at room temperature is very low and can be virtually ignored. The lifetime is limited by the system's current drain.

Electrical Consumption Leg:

Battery capacity (CR2032) = 220mAh
IC current drain = 2.5μA

$$\text{Battery lifetime} = \frac{0{,}22\text{mAh}}{2.5\text{x}10\text{-}6\text{A}}$$

$$= 88{,}000 \text{ hours}$$

$$= 10.3 \text{ years}$$

Electrolyte Evaporation leg:

Self discharge of 0.4% at +25°C

Battery lifetime = 250 years

Combining the two consumption legs:

$$\frac{\text{Electrolyte Evaporation leg x Electrical Consumption Leg}}{\text{Electrolyte Evaporation leg} + \text{Electrical Consumption Leg}}$$

$$\frac{250\text{x}10.3}{(250 + 10.3} = 10.7 \text{ years}$$

[3]

3. VOLTAGE CONVERTER

The voltage supplied by the supercap must be regulated and has to be boosted to the required voltage level as soon as the voltage from the cap drops below this value. Based on an astable multivibrator configuration (Figure 3.1), this voltage converter uses the back e.m.f. of a coil to boost the voltage to a higher level. This higher voltage will also start to fall as soon as its input voltage starts to fall [4, p.14]. By using a microprocessor the on and off time of a transistor can be regulated according to the input and output voltages measured by the onboard analogue to digital converter.

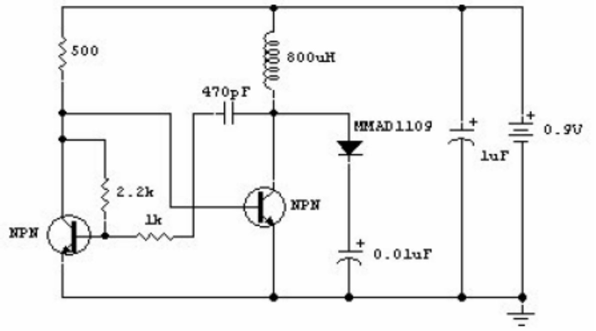

Figure 3.1 Boost regulator circuit

The step-up voltage regulator in Figure 3.2 is formed by L1, MOSFET T1, diode D1 and smoothing capacitor C1 to supply the transmitter with a controlled power source. Analogue input VDD measures the input voltage from a supercap, which is a falling voltage curve. The voltage reference is measured at the AN0 pin, which is connected directly via a resistor to the lithium battery.
The microcontroller adjusts the mark-space ratio of the output on pin RB0 [2, p.59].

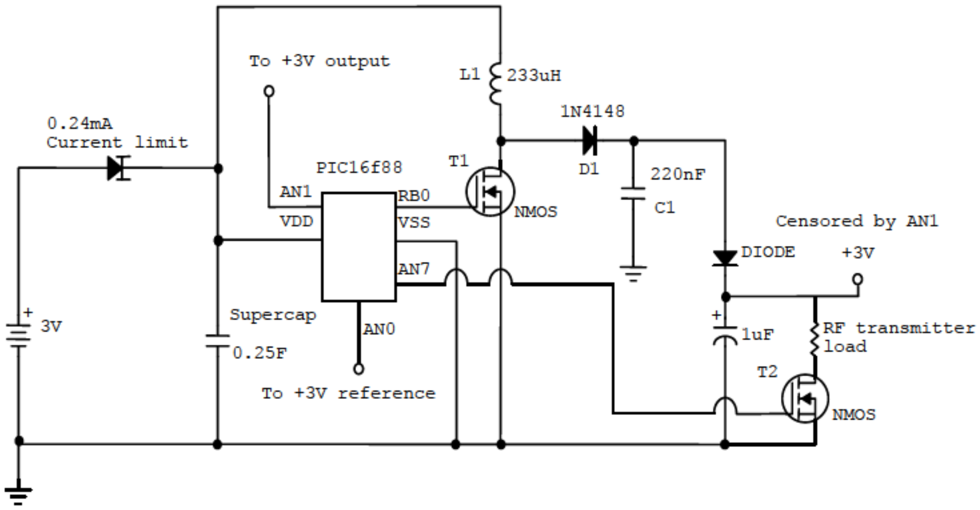

Figure 3.2 Boost regulator circuit diagram

4. POWER CONTROL

The function of the step-up regulator is to provide a regulated supply voltage despite the falling input voltage [2, p.50].

$$P = \frac{1}{2} \cdot \frac{(V_{IN}{}^{2} \cdot T_{ON}{}^{2})}{L \cdot (T_{ON} + T_{OFF})} \qquad (1)$$

The power to the transmitter is a factor of the battery voltage so that if no regulation were used the power would vary by a factor of 2 as the input voltage drops from 3 V to 0.8 V. The average current is P/V_{IN}. The on and off ratio of the transistor (T_{ON} and T_{OFF}) is altered by the microcontroller to keep P constant. The microcontroller must know the input or output voltage in order to regulate the power. The input voltage where monitored and found to be unstable because of the high current-drain pulses as shown in Figure 4.1. For the 8-bit ADC the measurement result stored in the internal register
A_D_{res} is given by:

$$A\_D_{RES} = \frac{V_{REF} - V_{IN}}{V_{IN}} \cdot 255 \qquad (2)$$

Or

$$V_{IN} = \frac{V_{REF}}{1 + AD_{RES}/255} \qquad (3)$$

The T_{ON} and T_{OFF} of RB0 must be altered in order to keep the output at a desired level. Output levels will be dependent on the power consumption of the transmitter. As soon as the output drops below the desired level the duty cycle must be increased and then decreased when exceeding.

The value or the back e.m.f. generated across inductor L1 is approximately 6 times V_{IN} when the transistor T1 is switched off (T_{OFF}). The transistor off time will be T_{OFF} greater than 1/6 T_{ON} this ensures that the current (I) has time to fall to zero [2 p.50]. With the T_{ON} and T_{OFF} times and a smoothing capacitor the correct voltage can be maintained. This is the same as regulating a voltage with PWM.

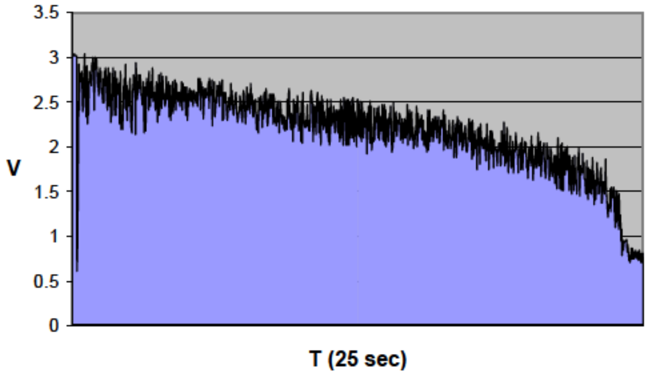

Figure 4.1 Input voltage from 3V charged cap

5. MEASUREMENTS ON A SINGLE DISCHARGE EVENT

Test1: 10mA at 5V for 9dBm Transmission

In Figure 5.1 a stable 5V can be noticed for 0.35 sec. The input voltage in Figure 5.2 is very unstable with large voltage drops that will result in a low efficiency of 16.7 % [6, pp. 86-95]. If the transmitter transmits for 200µ seconds every 2 seconds, while using an 1000mAh lithium battery is will last for an estimated 9.57 years.

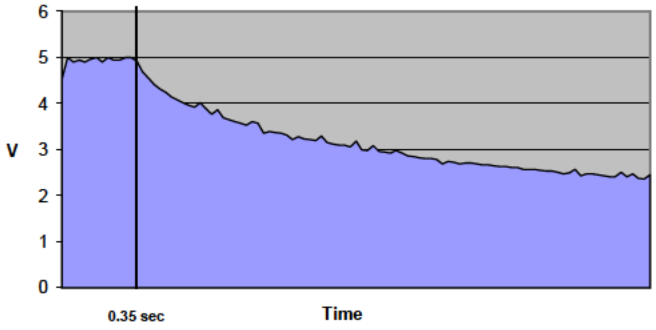

Figure 5.1 5V is maintained for 0.35 sec

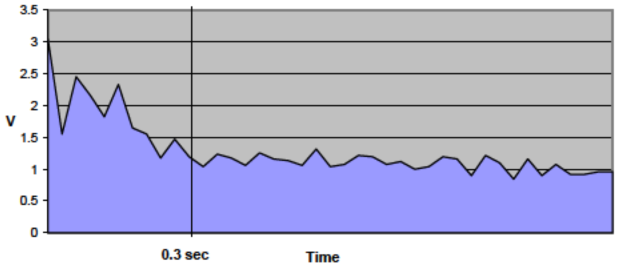

Figure 5.2 Input voltage applied with high current pulses regulating 10mA at 5V for 0.3 sec

Test2: 5mA at 3V for -4db transmission:

In Figure 5.3 a stable 3V can be noticed for 1.55 sec. The input voltage in Figure 5.4 is much more stable with a much higher overall input voltage. This is why a high efficiency of 70% is accomplished [4, p.14]. If the transmitter transmits for 200µ seconds every 2 seconds, while using a 220mAh lithium battery is will last for an estimated 12.47 years.

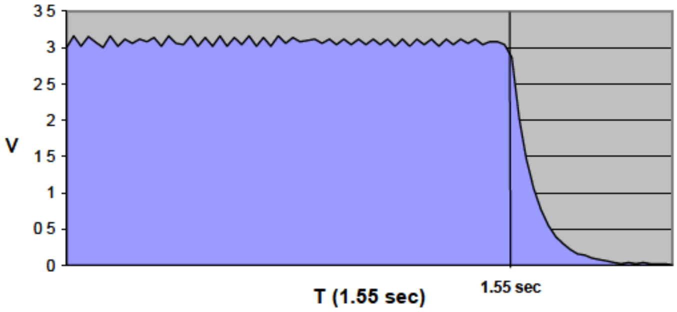

Figure 5.3 Regulated 5mA at 3V for 1.55s

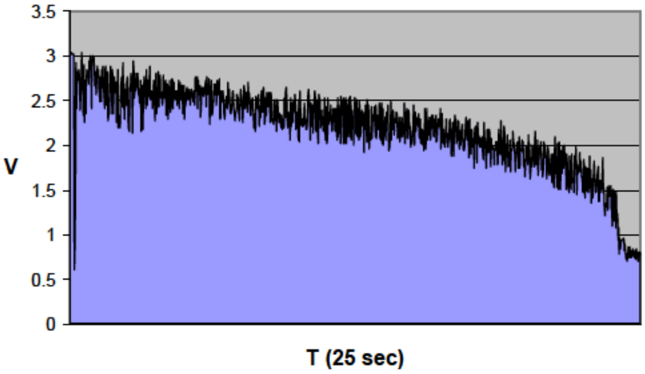

Figure 5.4 Input voltage from 3V charged cap

6. MEASUREMENTS ON CONTINUES OPERATION

The current out of the Lithium battery is very important to never exceed the amount that will reduce the total rated capacity. Figure 6.1 shows the battery current supply monitored for 8 seconds (which will continue for +/- 10 years) with 1 millisecond transmission and 2 seconds charge time at 10mA, 3.5 volts. Transmission power is set to its max (7dB), the Equivalent Series Resistance (ESR) of the supercapacitor prevents it form any higher current drainage. Even with this high transmission power and relatively long transmission time plus only two second charge time, the current drainage never went over 0.2mA.

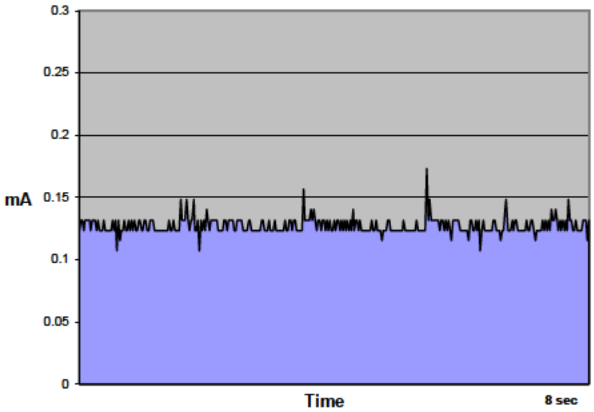

Figure 6.1 Current drainage from Lithium battery

The transmitter needed a stable power supply at 2V up till 5V with a current the lithium battery cannot supply.

The supercapacitor stores enough energy for the needed supply. The relatively high ESR of the supercapacitor presented a problem. The energy stored in the supercapacitor could not be utilized as fast as desired to regulate an efficient high current supply. When drawing high current pulses from the supercapacitor the voltage over its terminals, drop and take to much time to stabilize. The microcontroller cannot regulate the output according to the input, because of this unstable input. With each current pulse the input will drop and with such a low input voltage reading the duty cycle will skyrocket and regulation will not be possible. Using the output for a reference to regulate it self is the only way. The low voltage pulses result in a much lower average input voltage. The efficiency drops when the input voltage drops. This is why only 16.7% efficiency was obtained with a 10mA, 5V regulated supply. A definite rise of efficiency was seen when the current pulses where reduced. When the boost regulator must regulate a higher voltage, it rises the duty cycle. The high current pulses are in fact just longer ones. This reduces the input voltage even more. The efficiency improved to 70% with the lower current and voltage regulated supply. With these low power settings a very small battery with only 220mAh can be used.

All the initial problems are solved with the inductor boost regulator. The boost regulator never draws too much current that will reduce the lithium batteries total capacity and regulate a stable output from an unusable lower input.

New supercapacitors with much lower ESR are already on the market, this will dramatically improve the results.

7. REFERENCES

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