Supercapacitor-Based Backup Solutions: A Design Toolkit

SLG46537

The application note gives step-by-step guidelines for creating a supercapacitor-Based Backup Solutions.

The application note comes complete with design files which can be found in the Reference section.

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1. Terms and Definitions

ACMP	Analog Comparator
DFF	D Flip-Flop
EDGE DET	Edge Detector
EN	Chip Enable
ESR	Equivalent Series Resistance
GND	Ground
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
Out	Output to Load
PG	Power Good Indicator
PWM	Pulse-Width Modulation
Vin	Input

2. References

For related documents and software, please visit:

GreenPAK Programmable Mixed-Signal Products | Renesas

Download our free GreenPAK Designer software [1] to open the .gp files [2] and view the proposed circuit design. Use the GreenPAK development tools [3] to freeze the design into your own customized IC in a matter of minutes. Renesas provides a complete library of application notes [4] featuring design examples as well as explanations of features and blocks within the Renesas IC.

[1] GreenPAK Designer Software, Software Download and User Guide, Renesas Electronics

[2] AN-1195 Supercapacitor-Based Backup Solutions.gp, GreenPAK Design File, Renesas Electronics

[3] GreenPAK Development Tools, GreenPAK Development Tools Webpage, Renesas Electronics

[4] Application Notes, GreenPAK Application Notes Webpage, Renesas Electronics

[5] SLG46537 Datasheet, Renesas Electronics

[6] “Murata Supercapacitor Technical Note,” Document No. C2M1CXS-053K, Murata Manufacturing Co. Ltd.

[7] Section 16, “Supercapacitor Charging” in Analog Circuit Design Volume Three: Design Note Collection, Ed. Bob Dobkin and John Hamburger, Newnes, 2015.

[8] “PowerStor Application Guidelines,” Cooper Bussmann Technical Note.

3. Introduction

Supercapacitors may be used in short-term backup solutions where they act as a source of alternate power, as well as long-term backup solutions where they act as a source of primary power. There are several unique challenges when we attempt to use supercapacitors in a backup solution. In this application note we present a collection of challenges and a set of corresponding design strategies that can be brought to bear to address these challenges.

It is important to bear in mind that supercaps come in various shapes, sizes and flavors, with vastly different specs. Some, for example have ESRs of the order of tens of Ω but are very compact and lowcost and are suitable for low-energy applications whereas others with ESRs of 50 mΩ are suitable for providing bursts of high power for short durations. To make a solution reliable it must explicitly consider these specs and the intended application so that maximum reliability and performance is obtained from a given product. Going a step further it is also important to be able to conceptualize a solution that can take advantage of ongoing rapid improvements in supercap technology. Therefore, it is important to have a flexible platform for building complete and tailorable solutions around them and this is a key value of GreenPAK™ ICs.

Keeping the above in mind, this Application Note is structured as a “toolkit” of design ideas. Each idea addresses a specific problem and suggests a solution – or the essence of it – in the form of a design “fragment”. This fragment in each case consists of a partial hardware schematic and a partial GreenPAK Designer diagram. A product designer can therefore pick the ones that are most relevant in each context and integrate them into a custom solution. The GreenPAK Designer diagrams presented here are shown using the SLG46537V Programmable Mixed-Signal ASIC but can be usually reconfigured to work on other GreenPAK products as well with only minor modifications, if at all.

Problem 1: Cell Mismatches Cause Cell Overvoltages

Supercapacitors rated for 5.5V are often available as a stack of two cells with a rated voltage of 2.7V each. Therefore, cell balancing is required to ensure each cell stays within its rated voltage, as supercaps are susceptible to damage from overvoltage faults.

Solution. The simplest form of cell balancing is passive: each cell has a resistor across it and all resistors have the same value. Some energy is therefore continuously lost in the resistors. In fact, the value of these resistors decreases quite dramatically for higher voltage applications. For example, with Murata’s 1F 5.5V DMF4B5R5G105M3DTA0 supercaps [1], if the maximum voltage applied is 4.5V, the balancing resistors are 47k, but if the maximum voltage is 5V, the resistors must be 4.7kΩ. A standard alternative usually proposed in the literature is active cell balancing. This, however, typically involves the use of an opamp and a couple of MOSFETs. In this Note we adopt a different strategy. This idea is shown in the following Figure 1 schematic and corresponding Figure 2 GreenPAK Designer diagram (see AN-1195 Supercapacitor-Based Backup Solutions.gp).

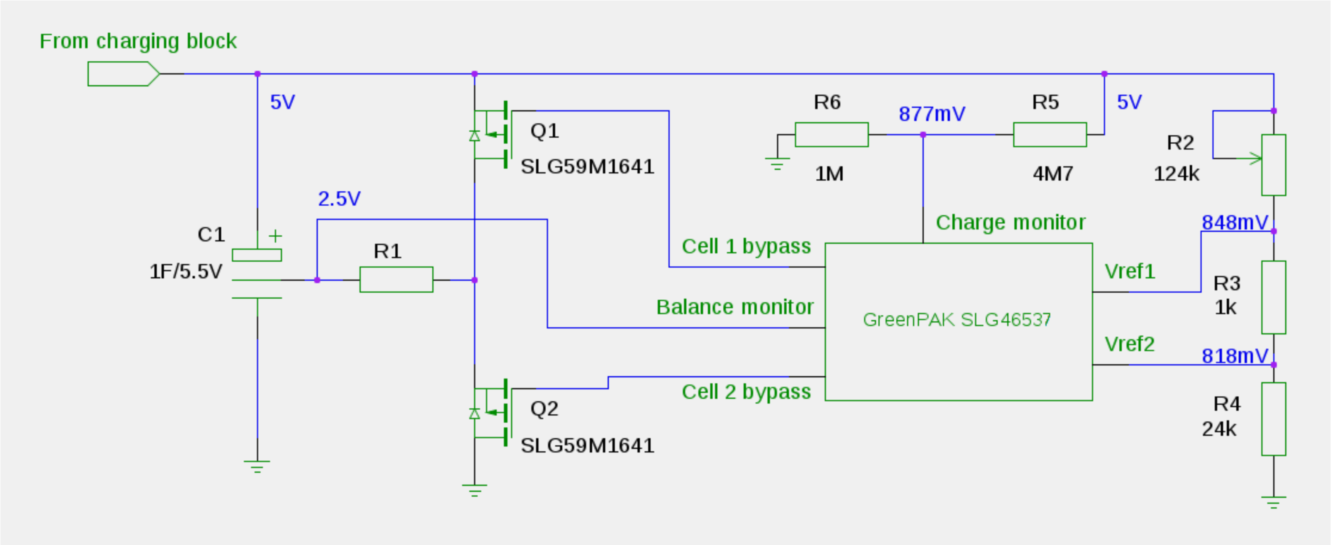

Figure 1. Cell Balancing – Schematic

Here SLG46537V monitors the overall charge state of the supercap. Note that we need to use a voltage divider to monitor the supercap voltage for two reasons: (1) the Vdd of the SLG46537V may be lower than the fully charged voltage of the supercap and (2) the ACMPs cannot take a reference voltage greater than 1.2V.

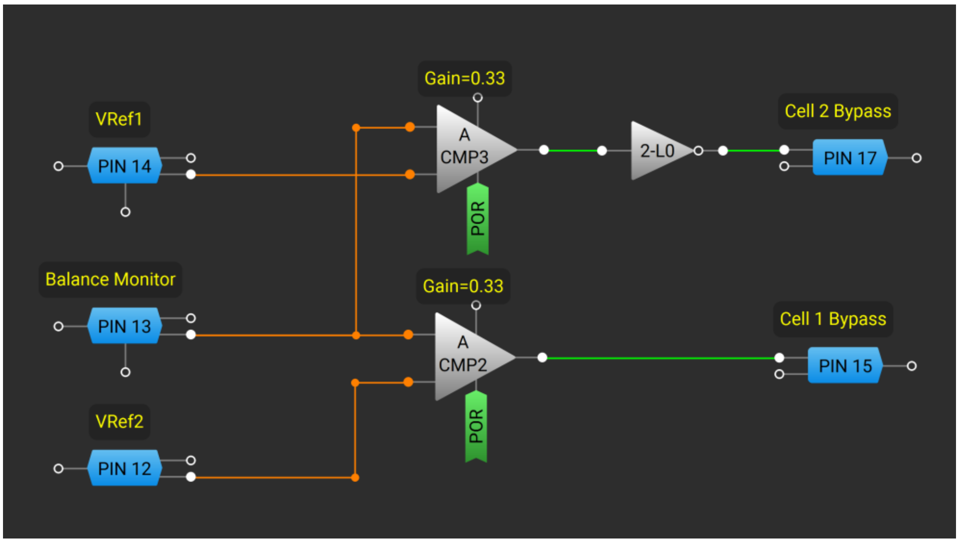

Figure 2. Cell Balancing – GreenPAK Designer Diagram

The schematic in Figure 1 shows the voltages present when the supercap is charged to 5V. The voltages at the ends of R4, VRef1 and VRef2, are taken as the bounds for the cell voltage difference. These voltages are taken as references for the two ACMPs depicted in the GreenPAK designer implementation (Figure 2) operated with a gain of 0.33 so that at a supercap voltage of 5V, the balance terminal reflects as a voltage of 833mV. If the balance terminal voltage is greater than VRef1, Q2 is turned on. When Q2 is turned on the midpoint voltage is dragged down, the upper cell's charge current increases, and the lower cell is slightly discharged. When the balance terminal voltage goes below VRef2, Q1 is turned on. The value of R1 is decided by the speed of rebalancing desired but we can usually choose it to match the lowest value prescribed by the manufacturer for passive balancing (e.g. 4.7k for the Murata). During the re-balancing act there is therefore some wasteful dissipation, but this dissipation takes place only when an imbalance occurs, unlike with pure passive balancing when wasteful dissipation occurs all the time. Once the supercap is fully charged and balanced, both Q1 and Q2 are off and no wasteful dissipation occurs. This allows retention of charge for a significantly longer time.

When using the GreenFET Load Switches instead of regular FETs, we must remember that the GreenFET Load Switches turn off when the input voltage is below 1.5V. What that means is that as long as one cell is less than 1.5V, it will not be bypassed even if the GreenFET Load Switch across it gets a bias signal. Once both cells cross

1.5V then the balancing is fully in effect. In practical terms what this means is that the cell voltages will not be equal at low voltages, which is usually not of any consequence.

Lab Test Notes. In the lab test of this design fragment, we used two different 1.5F supercaps of very different types instead of two cells of the same supercap. When charged without the balancing circuit the voltage difference between the two was about 1.5V when the stack was fully charged. When charged using the balancing circuit, the voltages advanced at different rates initially, till both reached 2.0V. Thereafter the voltages were matched to within 100mV till the stack was fully charged.

Problem 2: Maintaining a Fixed Output Voltage

A supercap's voltage, unlike that of a battery, decreases linearly as it is discharged. Therefore, we need a seamless transition from buck to boost conversion for a fixed output voltage to fully utilize the stored charge.

Solution. To hold the output voltage steady while the supercap voltage is either above or below the desired output voltage level, we need a buck/boost converter IC that handles the entire range of input voltage.

A simpler and lower-cost option is to have a GreenPAK handle the buck conversion via PWM but includes a provision to switch over to an external boost converter IC when the supercap voltage falls below a set threshold. There are many choices of boost converters. One example is PAM2401 from Diodes, Inc. which can provide an [adjustable] output of 3V3 from an input starting at 1V. Another candidate is Microchip’s MCP16251.

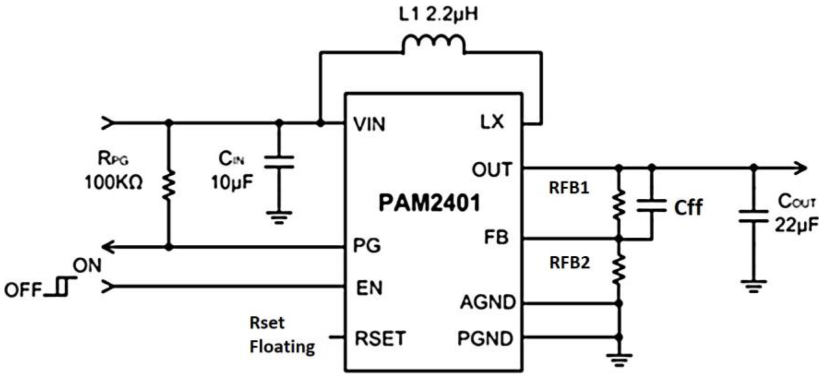

Figure 3. A Typical Boost Converter

The typical application schematic for PAM2401 is shown in Figure 3. There is very little that is specific to this particular IC; most boost converters have very similar input/output wiring relationships, so for our purposes we can depict it as a black box with 5 connections which may be added to a GreenPAK- based PWM control buck converter solution:

1. Vin – Input
2. PG – Power Good indicator (optional)
3. EN – Chip enable
4. Out – Output to load
5. GND – Ground

Problem 3: Monitoring Ambient Temperature and Supercap Ripple

The life of a supercap can be affected significantly if operated at even mildly elevated temperatures. Supercaps are also relatively more sensitive to ripple current, which is reflected in surface heating.

Solution. We are addressing two problems here. As described in [3], a 10 °C; increase in ambient temperature causes the life of the capacitor to halve. In general, it is good to operate the supercap at as low a temperature as practical. Further, supercaps are also sensitive to ripple current; there is an increase in surface temperature due to ripple current and we may measure this increase to determine if ripple is too high. The surface temperature rise in relation to ambient should not exceed 3 °C. To accomplish these objectives, we can have an analog temperature sensor physically attached to the supercap with another one mounted on the board to measure ambient temperature. Most low-cost analog temperature sensors have a sensitivity of 10 mV / °C – a good example is the MCP9700 from Microchip. The typical analog sensor consists of sup-ply terminals and an analog voltage output. For MCP9700 the output is specified at 500mV at 25 °C. Therefore, a surface temperature rise of 3 °C leads to a differential output of 30mV that needs to be detected.

In our scheme of things as illustrated in Figure 4, we have lifted the ground of the two sensors using two 1N914 diodes. The lift for the ambient temperature sensor is 530mV, and that for the surface temperature sensor is 500mV. We need diode D2 to be biased at about twice the current of D1 so that its drop is 30mV higher. We bias the diodes at a current of about 100/200uA respectively which is much higher than the supply current of the sensors themselves (6uA) so that temperature variations of the sensor draw do not materially affect the ratio of the diode currents. The potentiometer may be used to set the difference to exactly 30mV. Note that since it is the ratio of diode currents that sets the voltage drop difference, there is no effect of ambient temperature on this setting.

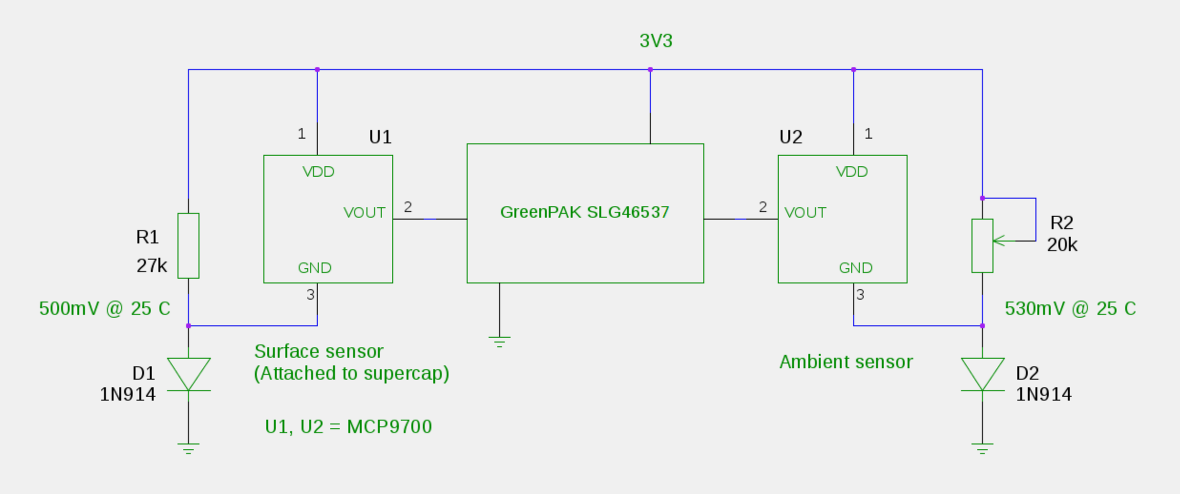

Figure 4: Temperature/Ripple Monitoring – Schematic

The part of the circuit that detects excessive ambient temperature is quite simple – the ambient sensor's output is fed to the ACMP whose reference may be set appropriately as show in Figure 5 (see AN-1195 Supercapacitor-Based Backup Solutions.gp). Since the sensor output is at 1V at 25 °C we set a gain of 0.5 to stay with allowable limits for the ACMP. With a reference voltage of 600mV, ACMP0 will trigger when the ambient temperature increases to 42 °C. ACMP1 on the other hand has as its reference half the voltage of the surface sensor which is compared with the voltage of the ambient sensor (with an IN+ gain of 0.5). Therefore, ACMP1 changes state when the surface sensor output matches the ambient sensor output, at which point we can deduce that the surface temperature has exceeded ambient by 3 °C and therefore that ripple current is too high.

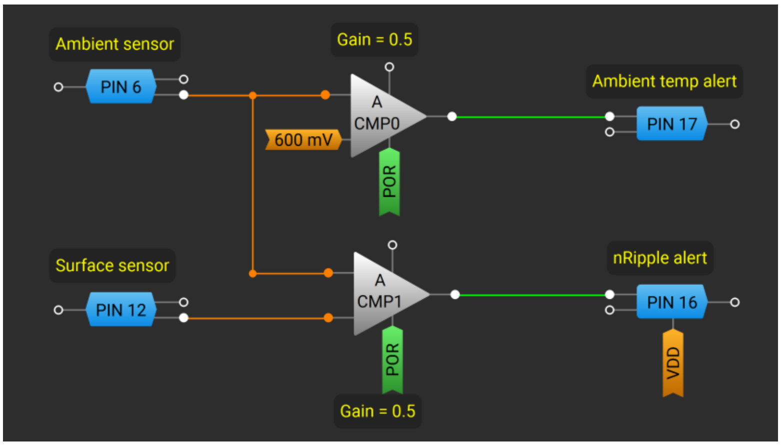

Figure 5: Temperature/Ripple Monitoring – GreenPAK Designer Diagram

In a given solution the outputs of the ACMP can be used to trigger an alert, stop charging and so on. A more interesting action (not described here) would be to actually reduce the voltage at which the supercap is charged to if the temperature is too high, since it is the combination of temperature and voltage that causes degradation of life.

Lab Test Notes. To test this design fragment a supercap is of course not necessary – what we are primarily interested in is to test that the circuit can reliably test a temperature rise of 3 °C or so. To do that the body of the surface sensor was touched with a finger while the ambient temperature was about 32 °C. In a matter of seconds, the nRippleAlert output started to flicker and then go low as the finger warmed up the sensor! Some initial calibration may be necessary due to the tolerances of the internal voltage dividers of the ACMP in 0.5x gain mode.

In addition to the problems discussed above, for completeness we include a few others that are relatively more straightforward to understand and address.

Problem 4: Preventing a Cell from Charging Backwards

When a stack of supercapacitors is discharged rapidly and deeply, some cells may be subjected to negative voltage. To prevent this, we may add diodes across each cell that are normally reverse-biased but become forward biased if the respective cell acquires a negative voltage.

Problem 5: Preventing Overcharging

Supercapacitors are sensitive to overvoltage. Overcharging can be addressed by using a GreenPAK, such as the SLG46537V, to actively monitor the supercap voltage during the charge cycle and halting charge current as soon as the desired voltage is reached.

Problem 6: Preventing Overcurrent and Short Circuiting

Supercaps hold a lot of energy and are capable of high current discharges when the ESR is as low as a few mΩ. It is important to have the usual methods for overcurrent protection which may be a fuse, circuit breaker or custom protection solution built around GreenPAK ICs.

4. Conclusion

In this application note we have outlined several interesting design problems and challenges that need to be addressed when crafting a supercap-based backup solution. Some of these are like challenges encountered with battery-based backup solutions, but some of them are unique to supercapacitors. It is hoped that the ideas and design fragments presented here can be adopted and adapted as necessary by product designers using the GreenPAK products to suit their specific context.

5. Revision History

Revision	Date	Description
1.00	Jul 10, 2017	Initial release.

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