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TI Designs: PMP9755 Reference Guide
Backup Power Solution Using Supercap with TPS61030 for Data Concentrator Circuit

TI Designs

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Design Resources

Design Page	All Design files
TPS61030	Product Folder
TL321A	Product Folder

Circuit Description

This reference design delivers a backup power circuits using a supercap with the boost converter TPS61030. In the low-power system that requires a backup switchover circuit at system's failure, a supercap together with TPS61030 could provide sufficient power to maintain data communication prior to the whole system's complete shutdown.

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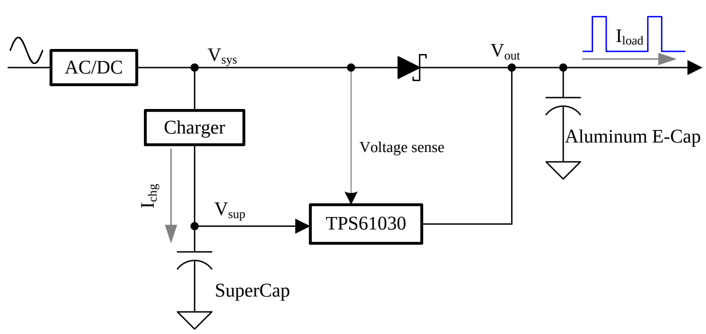

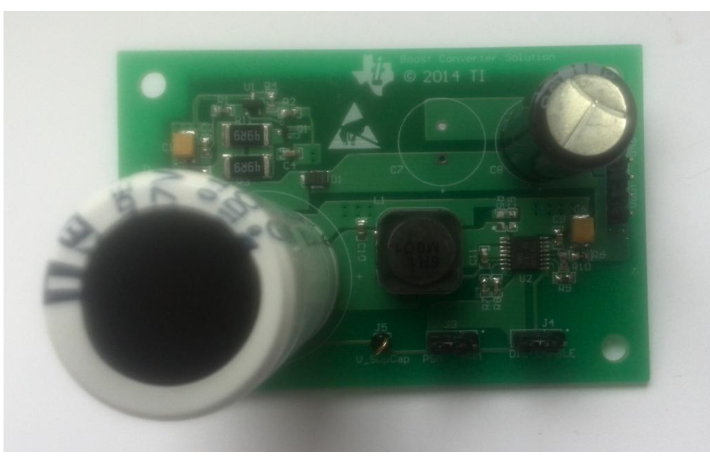

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1 Introduction

Data concentrator is a critical device in automated metering infrastructure of smart grid. It securely aggregates the data from a number of meters and sends the data to the centralized utility servers via GPRS, GSM or other telecom networks. The data concentrator must operate for a period of time in case of the power supply failure or system brownout, which requires sufficient backup power for the equipment to the data storage or communication. So an additional energy storage device is applied in the data concentrator, either the battery or supercap. Battery has higher energy density while the supercap has better performance at output inrush current capability and lifetime which makes the supercap more competitive for the application in the data concentrator.

As the output voltage of one cell supercap is not higher than 2.7V, a boost converter is needed to raise the output voltage to power the GSM/GPRS module, the voltage of which is higher than 3.6V normally. Furthermore, the low input voltage boost converter can fully utilize the supercap's energy.

This reference design illustrates a backup power solution for the data concentrator using the boost converter TPS61030 and a supercap. The design includes the schematic and layout design, components selection and performance waveforms.

2 Design Process

2.1 Block Diagram and Operating Principle

Figure 1 shows the block diagram of the reference design. It mainly consists of a supercap, a charger circuit for supercap, and a boost converter.

Normally, the V_{sys} is powered by the grid and the voltage can be set to 5.3V, using device such as an adaptor. The output voltage V_{out} is around 5V considering 0.3V forward voltage of the schottky diode. At the meantime, the boost converter TPS61030 stops switching and the V_{sys} charges the supercap if its voltage V_{sup} is lower than 2.65V

If the grid browns out and V_{sys} drops down to lower than 5V, TPS61030 starts switching and maintains V_{out} at 5V utilizing the energy of supercap. The schottky diode prevents the current flow from V_{out} to V_{sys}.

Figure 2 shows the theoretical operating waveforms of this reference design. The main load I_{load} is a GPRS class 10 module, of which the average current is about 500mA. But the pulse current of I_{load} reaches 2A and lasts 1.154ms. In order to deal with the pulse current, aluminum electrolytic capacitors are applied at output to support V_{out} during 1.154ms period. Using this aluminum E-capacitor, the output current requirement for the adapter and boost converter is reduced to 500mA, which will also reduce the cost of the system.

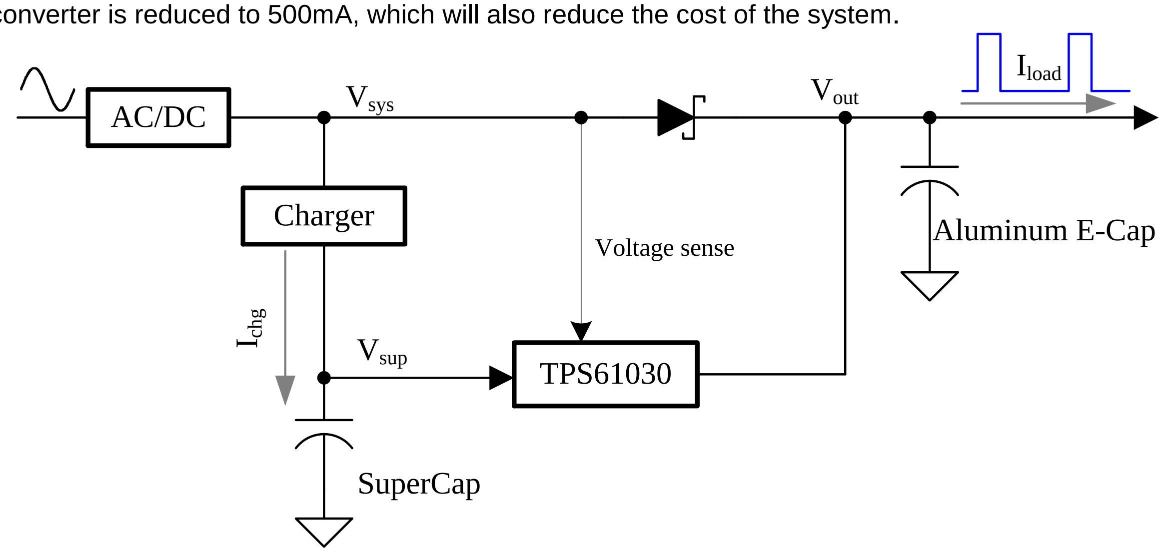

Figure 1: Reference Design Block Diagram

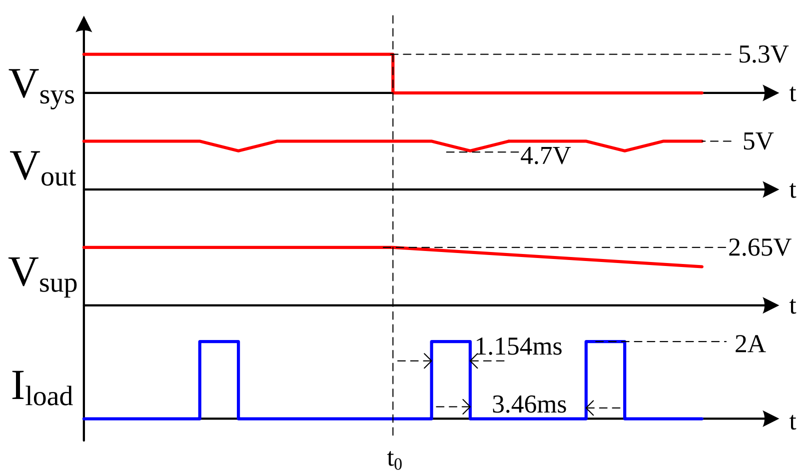

Figure 2: Reference Design Operating Waveform

2.2 Schematic and Component Design

Figure 3 illustrates the charging circuit for the supercap. The two 49.9ohm resistors control the charging current. The N-MOSFET and the TL431A limit the supercap voltage to 2.65V when the supercap is fully charged. The Schottky diode D2 prevents reverse current when Vsys is at low voltage.

When the voltage of supercap is lower than 2.65V, the voltage at TL431A PIN 2 is lower than 2.5V, so its PIN 1 voltage is almost equal to V_{SYS}, and the SI1012 turns on. The charging current is defined by equation (1).

$$I_{chg} = \frac{V_{SYS} - V_{D2} - V_{\sup}}{R_{ch}} \tag{1}$$

Where
V_{sys}: input voltage of charger; V_{D2}: Forward voltage of Schottky diode D2
R_{ch}: resistor to set the charging current

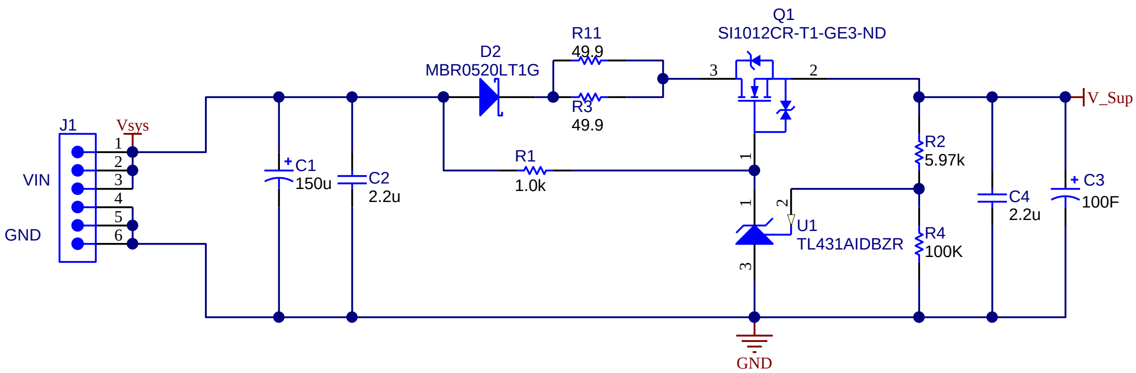

Figure 3: Supercap Charger Circuit

As V_{sys} = 5.3V, V_{D2} = 0.3V, R_{ch} = 49.9/2, the charging current linearly decreases with the increase of V_{sup}. When V_{sup}=0V, the charging current will be

$$I_{chg\_\max} = \frac{5.3 - 0.3}{49.9/2} \approx 200mA$$

When V_{sup}=2.6V, the charging current is

$$I_{chg\_\max} = \frac{5.3 - 0.3 - 2.6}{49.9/2} \approx 96mA$$

The maximum power dissipation on the charge current setting resistors happens at V_{sup}=0V, as shown in following equation (2), around 1W. Considering 50% power margin, two 2512 package resistors in parallel are used. Each of them can supports maximum 1W at 70^{o}C ambient temperature from datasheet.

$$P_{chg\_\max} = (V_{SYS} - V_{D2}) \cdot I_{chg\_\max} \approx 1W \tag{2}$$

When the supercap voltage reaches the setting point 2.65V, the N-MOSFET SI1012 is turned off, the supercap stop charging.

This kind of charging circuit benefits the cost-effective, but results in low efficiency and long charging time. One of the other solutions is a buck converter like TPS62750, which has a current setting pin to configure the charging current and its efficiency is around 90% at the output current ranging from 100mA to 600mA .

The boost converter circuit is shown at Figure 4. When the V_{sys} powers on, the schottky diode D1 conducts. The output voltage V_{out} will be the V_{sys} minus the D1 forward voltage, which is about 0.3V when I_{load} = 500mA. The V_{sys} can be set to 5.3V to make sure that the V_{out} keeps at 5V in high load.

In order to stop the TPS61030 from switching at the V_{sys} power on condition, the boost converter TPS61030 must adjust its regulation voltage to a point lower than the V_{out}. This function is implemented by TPS61030 LBI pin and LBO pin (pin 6 and pin 7). When V_{sys} =5.3V, the voltage of LBI is defined by the divider resistors in Figure 4.

$$V_{LBI} = \frac{R_7}{R_7 + R_8} \cdot V_{SYS} = \frac{100}{100+909} \times 5.3 \approx 525mV$$

As the V_{LBI} is higher than 510mV, the LBO pin will be high impedance, and the TPS61030 regulation voltage V_{out_re} is defined by equation (3), where R_6 and R_{10} are the feedback divide resistors, and the V_{ref} is the reference voltage for FB pin.

$$V_{out\_re} = \frac{R_6 + R_{10}}{R_{10}} \cdot V_{ref} = \frac{1000+124}{124} \times 0.5 \approx 4.5V \tag{3}$$

As the real V_{out} =5V, V_{out_re} can be set to 4.5V, which is lower than real V_{out} even considering the voltage drop caused by load transient. The V_{out_re} at this condition should be not too low; otherwise the high power dissipation may occur at the feedback resistor. At the same time, the power save mode of TPS61030 must be enable (SYNC PIN connect to GND) to stop the TPS61030 from switching. The boost converter only consumes quiescent current, 20µA typically.

When the V_{sys} powers off, and becomes lower than 5V, the V_{LBI} will be lower than 510mV. An internal MOSFET shorts the LBO pin to GND, thus V_{out_re} will be

$$V_{out\_re} = \frac{R_6 + R_{10} // R_9}{R_{10} // R_9} \cdot V_{ref} = \frac{1000+124//1000}{124//1000} \times 0.5 \approx 5.0V$$

The TPS61030 starts operating and maintains the V_{out} = V_{out_re} = 5V. As V_{out} > V_{sys}, the Schottky diode D1 prevents reverse current flowing from V_{out} to V_{sys}.

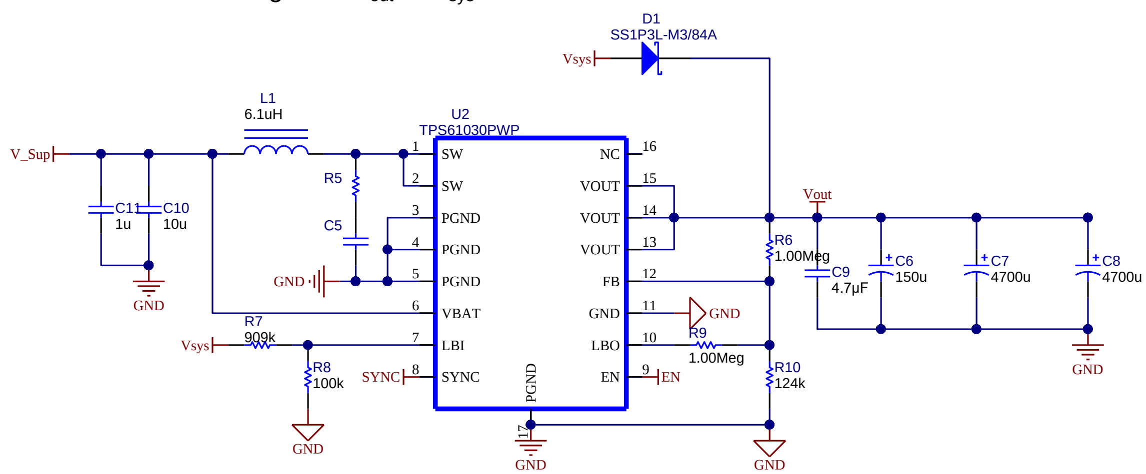

Figure 4: Boost Converter Circuit

As in Figure 2, the main load is the GPRS class 10 module with an average output current around 500mA. The capacity of the supercap is defined by equation (4), obtained from energy conversation principle.

$$\frac{C_{\sup}}{2}\left(V_{\sup\_max}^2 - V_{\sup\_min}^2\right) = \frac{V_{out} \cdot Iout}{\eta} \cdot T \tag{4}$$

Where
V_{sup_max}: maximum voltage of the supercap;
V_{sup_min}: minimum voltage of the supercap, defined by the UVLO of the TPS61030;
η: efficiency of the TPS61030; T: operating period after V_{sys} power off;

Giving V_{sup_max} = 2.65V, V_{sup_min} = 1.7V, η = 75%, T = 60s, the C_{sup} is

$$C_{\sup} = \frac{2\times5\times0.5}{0.75\times\left(2.65\times2.65-1.75\times1.75\right)} \cdot 60 = 97 Farad$$

A 100Farad/2.7V supercap is selected in the reference design.

The inductor peak current of TPS61030 is defined by the equation (5) from its datasheet, where L is the input inductor, and f_s is the switching frequency. The TPS61030 limits its inductor peak current at typical 4A, so the maximum output current is defined by equation (6).

$$I_{L\_peak} = \frac{V_{out} \cdot I_{out}}{V_{in} \cdot \eta} + \frac{1}{2} \frac{(V_{out} - V_{in}) \cdot V_{in}}{L \cdot V_{out} \cdot f_s} \tag{5}$$

$$I_{out} = \frac{V_{in} \cdot \eta}{V_{out}} \left[I_{L\_peak} - \frac{1}{2} \frac{(V_{out} - V_{in}) \cdot V_{in}}{L \cdot V_{out} \cdot f_s} \right] \tag{6}$$

In the reference design, L = 6.1µH, and f_s = 600kHz according to the TPS61030 datasheet. The maximum output current at V_{in}=1.7V is the smallest, which is

$$I_{\max\_1.7} = \frac{1.7 \times 0.75}{5} \times \left[4 - \frac{1}{2} \frac{(5 - 1.7) \times 1.7}{6.1\mu \times 5 \times 600k} \right] \approx 0.98A$$

This maximum output current at V_{in} = 1.7V is higher than the average load current 500mA, but smaller than the peak current 2A. So an aluminum electrolytic capacitor is added at the output to support current gap during this 1.154mS period. The V_{out} drop can be calculated by equation (7), where C_{alu} and ESR_{alu} are the capacitance and effect series resistor of the aluminum electrolytic capacitor respectively.

$$\Delta V_{alu} = \frac{I_{load\_peak} - I_{\max\_1.7}}{C_{alu}} \cdot 1.154ms + (I_{Load\_peak} - I_{\max\_1.7}) \cdot ESR_{alu} \tag{7}$$

A 4700µF capacitor EEUFR0J472 is adopted in the reference design. Its ESR is 15mΩ at 20^{o}C. According to the equation (7), the voltage drop of the V_{out} is

$$\Delta V_{alu} = \frac{2A - 0.98A}{4700\mu F} \times 1.154ms + (2A - 0.98A) \times 15m\Omega \approx 265mV$$

So the minimum output voltage of V_{out} is about 4.74V, which is high enough to support the GPRS module.

Although a large aluminum electrolytic capacitor is used, A small ceramic capacitor combined with a tantalum capacitor or a ceramic capacitor larger than 47µF is still needed to absorb the switching current of the inductor, because ESL (Effective Series Inductor) of an aluminum capacitor make it not suitable to smooth high frequency voltage ripple. The small ceramic capacitor combined with a tantalum capacitor is adopted at this reference design.

2.3 PCB Layout

The reference design is implemented using 7.8cm by 5cm and 2 layers PCB. Figure 5 shows the top layer and top silk screen. All the components are placed in top layer. The C3 is the 100F/2.7V supercap. The C7 and C8 are the output aluminum capacitors. The charger circuit is placed in upper left corner of the PCB, while boost converter with its external component is placed at the bottom right. Make sure the output ceramic capacitor is as close as possible to the TPS61030.

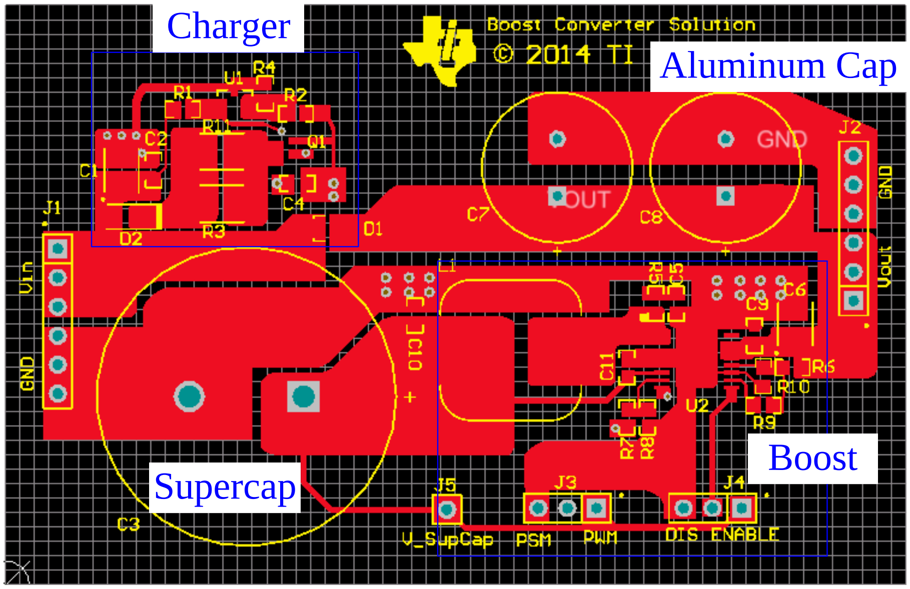

Figure 5: Top Layer and Top Silkscreen

The Figure 6 shows the layout of bottom layer.

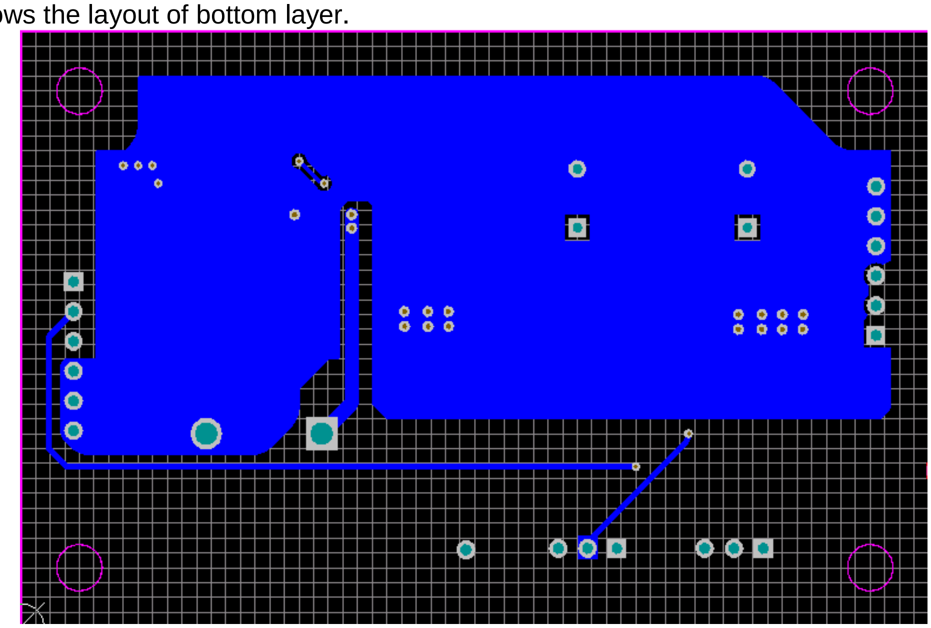

Figure 6: Bottom Layer

The final reference design board is shown in Figure 7

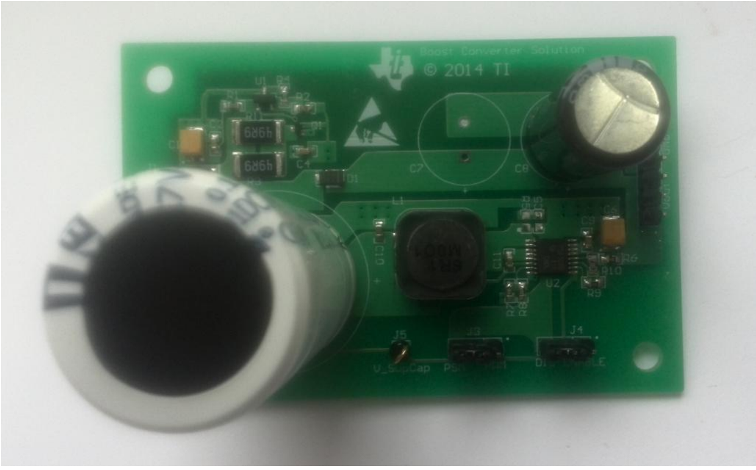

Figure 7: Reference Design Board

3 Bench Test Result

3.1 The Output Voltage after V_{SYS} Failure

A power supply Agilent E3634A is used to power the V_{sys}. The power supply is turned on and off to simulate the blackout and recovery of the grid.

The output voltage V_{out} before and after the grid failure at I_{out}=100mA condition is showed in Figure 8, where CH1 is the supercap voltage V_{sup}; CH2 is the boost converter output voltage V_{out}; CH3 is the V_{sys}; and CH4 is the SW pin voltage of TPS61030 V_{sw}.

When the V_{sys} voltage is at 5.3V, it supports the V_{out} through a Schottky diode and also charges the supercap, so the TPS61030 doesn't switch; when grid fails, the V_{sys} drops down. The boost converter starts switching to support V_{out} using energy in the supercap. It is observed from the waveform that the V_{out} keeps stable all the time.

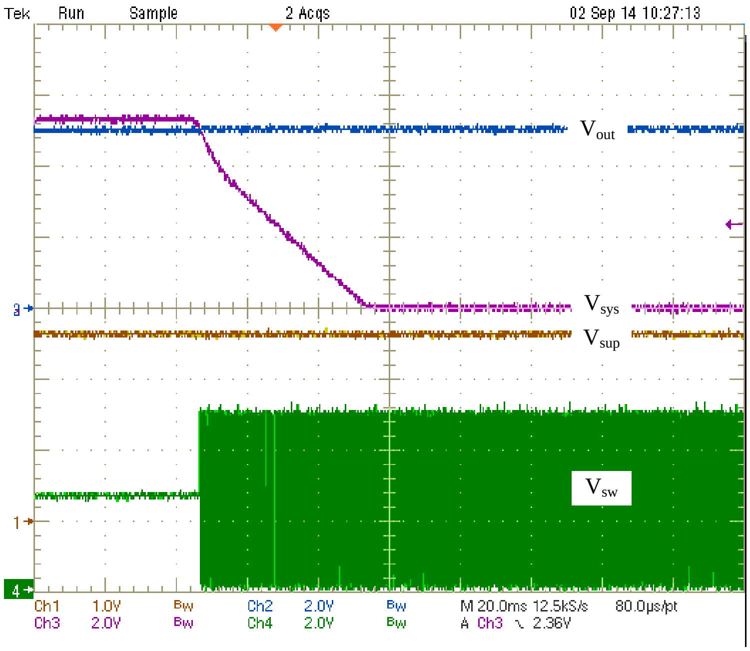

Figure 8: V_{out} at Grid Blackout

In Figure 9, the V_{sys} voltage returns to 5.3V to power the V_{out}, and the TPS61030 stop switching again. The V_{out} keeps stable in the transient period.

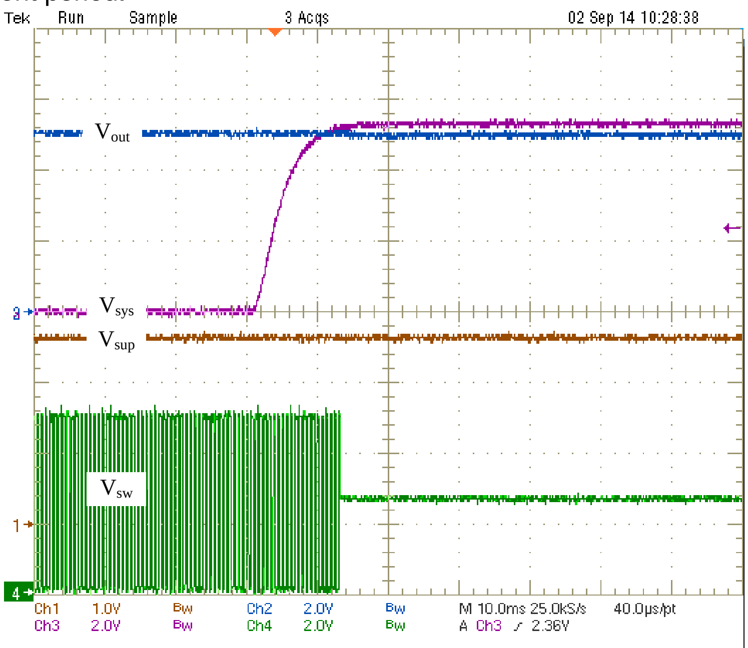

Figure 9: V_{out} at Grid Recovery

3.2 Output Voltage at GPRS Module Operating

Figure 10 shows the output voltage waveform at GPRS module operation when The V_{sys} voltage is normal. In the figure, I_{load} is the GPRS module current simulated by the resistor load. The V_{out} drops to 4.76V from 4.98V when I_{load} =2A, and returns back to 4.98V if I_{load} comes to zero. The voltage under-shoot is mainly caused by the Schottky diode forward voltage at different current.

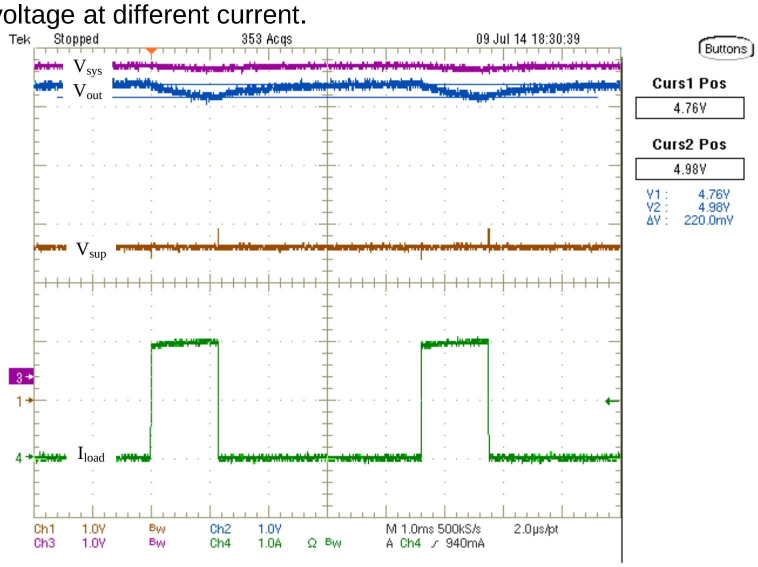

Figure 10: V_{out} at V_{sys} Voltage Normal

Figure 11 shows the V_{out} waveform when the V_{sys} fails and the GPRS module is still operating. The V_{out} is powered by the supercap, which is 2.6V at this condition. The under-shoot is only about 180mV, and the V_{out} keeps above 4.8V.

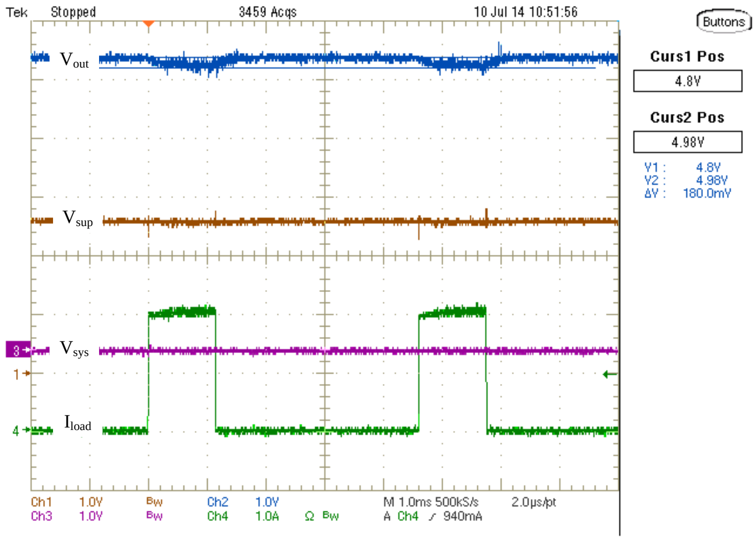

Figure 11: V_{out} Load Transient at V_{sup}=2.6V

The V_{out} switching frequency ripple at I_{out}=2A, V_{sup}=2.6V condition is showed as Figure 12, where the V_{out}(AC) is the output switching ripple. The peak-peak voltage ripple is about 136mV, which mainly be caused by the ESR of the tantalum capacitor and the aluminum capacitor.

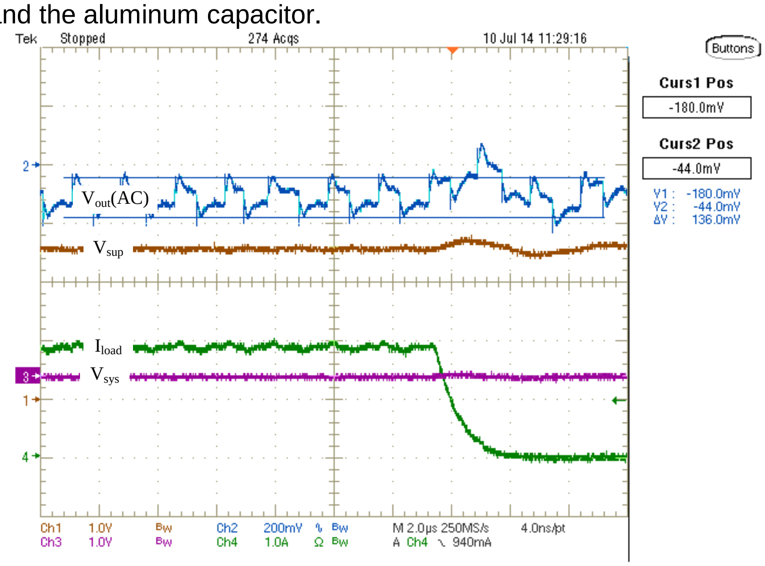

Figure 12: V_{out} Switching Ripple at V_{sup}=2.6V

Figure 13 and Figure 14 show the V_{out} load transient performance and output switching ripple at V_{sup}=1.7V condition respectively. The V_{out} keeps between 4.98V and 4.72V and switching frequency ripple is about 140mV peak to peak.

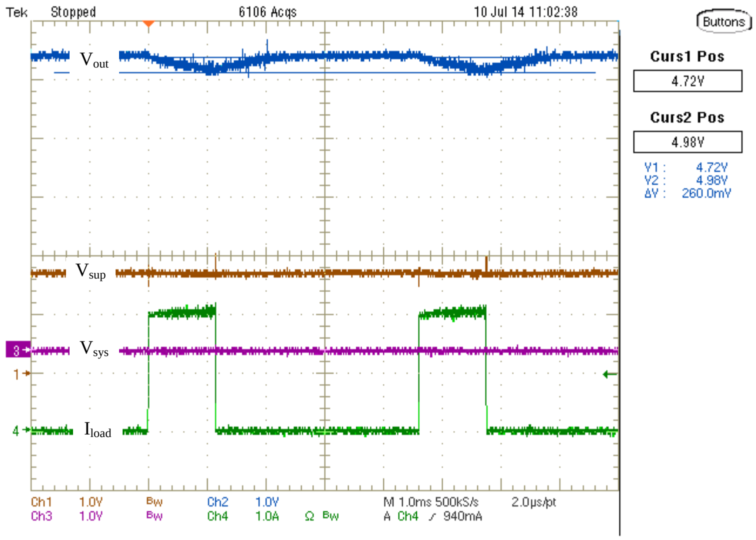

Figure 13: V_{out} Load Transient when V_{sup} =1.7V

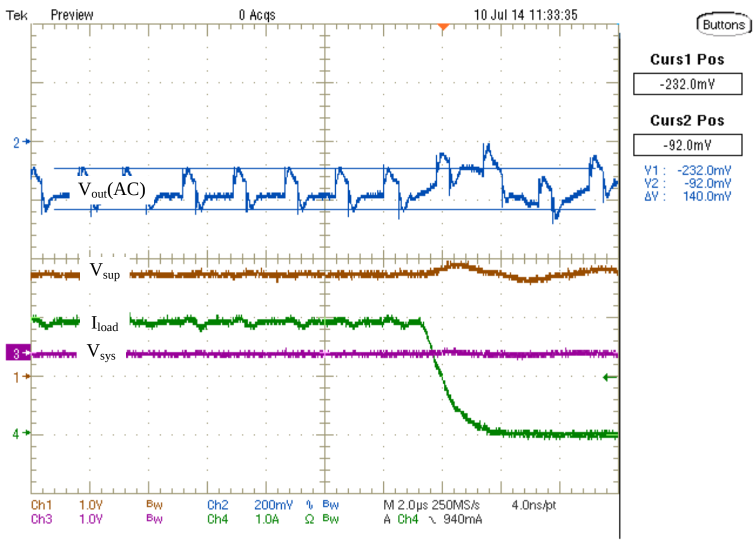

Figure 14: V_{out} Switching Ripple at V_{sup} =1.7V

3.3 Charging and Discharging the Supercap

The supercap charging curve from 0V to the targeted 2.65V is shown in Figure 15. It takes around 50 minutes to fully charge the supercap.

The supercap discharge curve when GPRS module operates is showing at Figure 16. The boost converter starts to power the load at V_{sup}=2.64V and stop at V_{sup}=1.65V, which is the UVLO point of the TPS61030. The lasting time is 63s, which meets the design requirement but a little smaller than the expectation. One main reason is that some energy in the supercap can't be utilized when discharged fast.

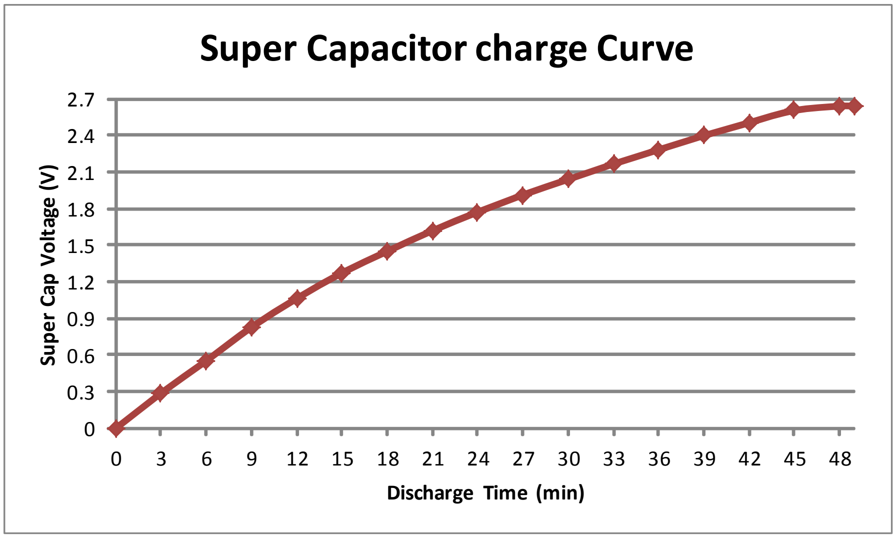

Figure 15: Supercap Charging Curve

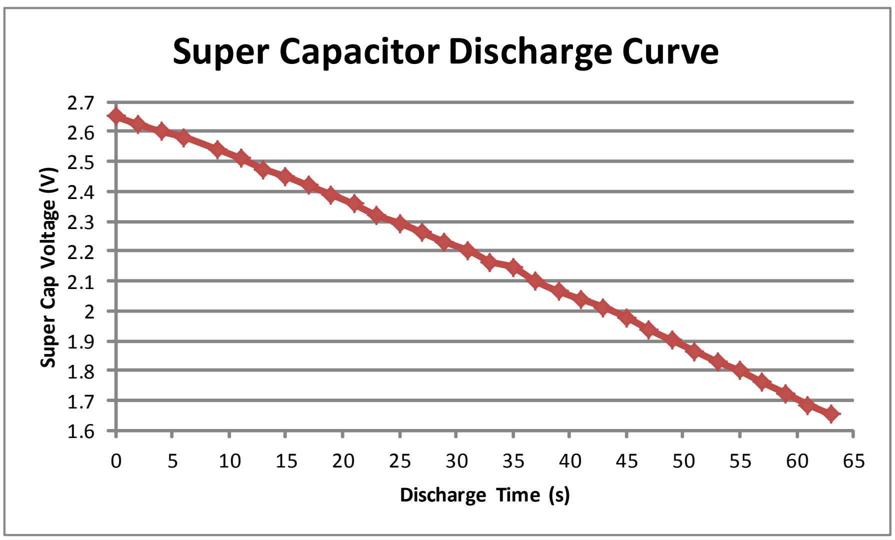

Figure 16: Supercap Discharge Curve