Application Report

Designing Boost Converter TPS61022 for Supercap Backup Power Applications

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ABSTRACT

TPS61022 is a synchronous boost converter with a wide input voltage range of 0.5 V to 5.5 V, which supports supercapacitor backup power applications as it is able to deeply discharge the supercapacitor. This application report introduces how to select and design TPS61022 external components. The stable and transient performances are measured to show the behavior of the converter.

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1 Introduction

Smart meters must continue to operate during brief power outages and send notification messages through a wireless radio, which consumes significant amount energy. As the output voltage of one cell supercap is not higher than 2.7 V, a boost converter is needed to step up the output voltage to power the GSM/GPRS module or MCU. The GSM/GPRS module voltage is normally higher than 3.6 V. The low input voltage boost converter can fully utilize the energy of the supercap and extend the backup power time.

The TPS61022 provides a power-supply solution for portable equipment and IoT devices powered by various batteries and super capacitors. The TPS61022 has minimum 6.5-A valley switch current limit over the full temperature range. With a wide input voltage range of 0.5 V to 5.5 V, the TPS61022 supports supercapacitor backup power applications, which may deeply discharge the supercapacitor.

Figure 1-1 is the schematic in the TPS61022EVM user's guide designed for a 3.0 V to 4.2 V lithium-ion battery input, 5-V output power supply application. However, for low V_{IN} of 0.5 V to 2.7 V supercap backup power application, an extra feedforward capacitor and big output capacitance is needed to increase the phase margin to make the loop stable.

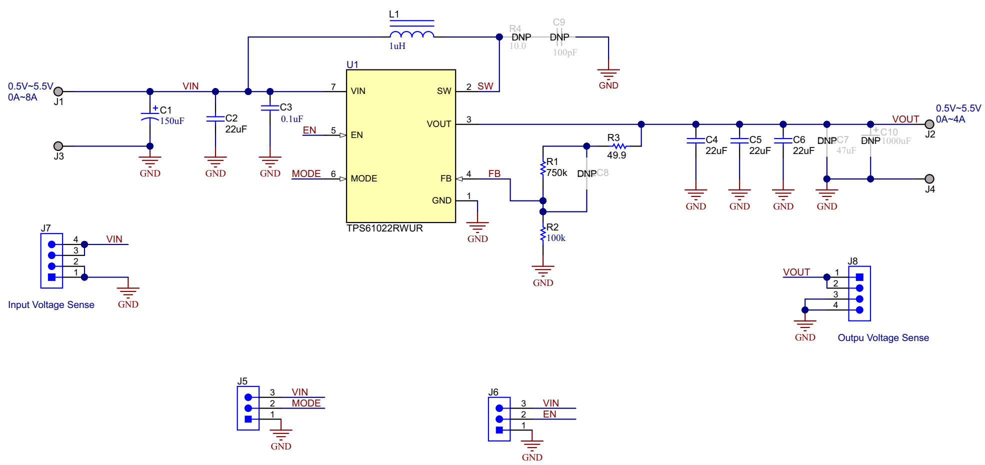

Figure 1-1. TPS61022 EVM Schematic

This application report introduces how to select the TPS61022 external components for supercap backup power applications. Detailed calculation methods and bench test results are presented to verify the proposed circuit.

2 Proposed Circuit Principle

Figure 2-1 shows the theoretical circuit of the TPS61022 boost converter circuit in a supercap backup power system. The V_{sys} is the brief power, coming from other DC/DC converter or the grid. The TPS61022 has a MODE pin to set the operation mode. When the mode is logic high, the device operates at forced pulse width modulation (PWM) mode. At forced PWM mode, the device keeps switching with 1 MHz (V_{IN} > 1.5 V) and 600 kHz (V_{IN} < 1.0 V) disregarding the loading. This results in very low efficiency at light load conditions. There may be a reverse current from V_{OUT} to charge the supercap by setting the MODE pin to logic high if the voltage of V_{sys} is higher than the TPS61022 setting output voltage. When the MODE is connected to a logic low voltage, the device works in auto PFM mode and there is no reverse current from V_{OUT} to V_{IN} by using the following configurations:

- It is recommended to connect the MODE pin to GND to set the device working at auto PFM mode. Efficiency at light load is increased and total supercap discharging time is extended.
- Set the TPS61022 V_{OUT} 3 to 5% less than V_{sys}. The device does not switch when V_{sys} exists.
- The EN pin is connected to V_{IN} to make the device stay in theenable state. The TPS61022 device consumes very little quiescent current (3.0 μA into V_{IN} pin and 32 μA into the V_{OUT} pin).

When the brief power V_{sys} browns out and drops less than the TPS61022 programmed output voltage V_{OUT}, the TPS61022 starts switching and maintains V_{OUT} at the programmed output voltage level.

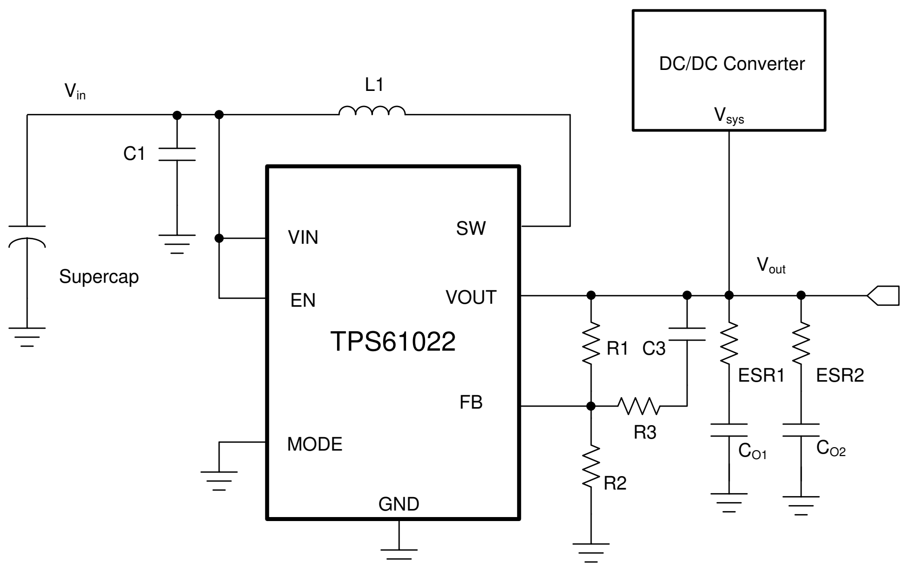

Figure 2-1. TPS61022 Boost Converter in Supercap Backup Power Applications

3 Loop Stability, Feedforward Capacitor Selection

To fully utilize the supercap energy and extend the backup power time, the TPS61022 device is used to regulate until the supercap voltage discharges to as low as 0.5 V. For low V_{IN} < 1.5 V condition, TI recommends using a large output capacitance at TPS61022 output to lower the crossover frequency because the right half plane zero (RHPZ) frequency reduces with decreasing V_{IN}.

$$f_{RHPZ} = \frac{Rout \times (1-D)^2}{2\pi \times L} \quad (1)$$

where

- R_{out} = output load resistor
- D = duty cycle
- L = inductance

For instance, when V_{IN} = 0.7 V, V_{OUT} = 3.3 V, I_{OUT} = 0.8 A, L = 1 µH, f_{RHPZ} = 29.5 kHz. It is generally accepted that the loop gain crossover no higher than the lower of either 1/10 of the switching frequency, f_{SW}, or 1/5 of the RHPZ frequency, f_{RHPZ}.

The TPS61022 Calculation Tool helps calculate the loop bode plot with 30-µF effective output capacitance by inputting the previously listed parameters. Figure 3-1 shows the crossover frequency is 6.2 kHz and phase margin is only 34.5°, which causes an unstable loop issue.

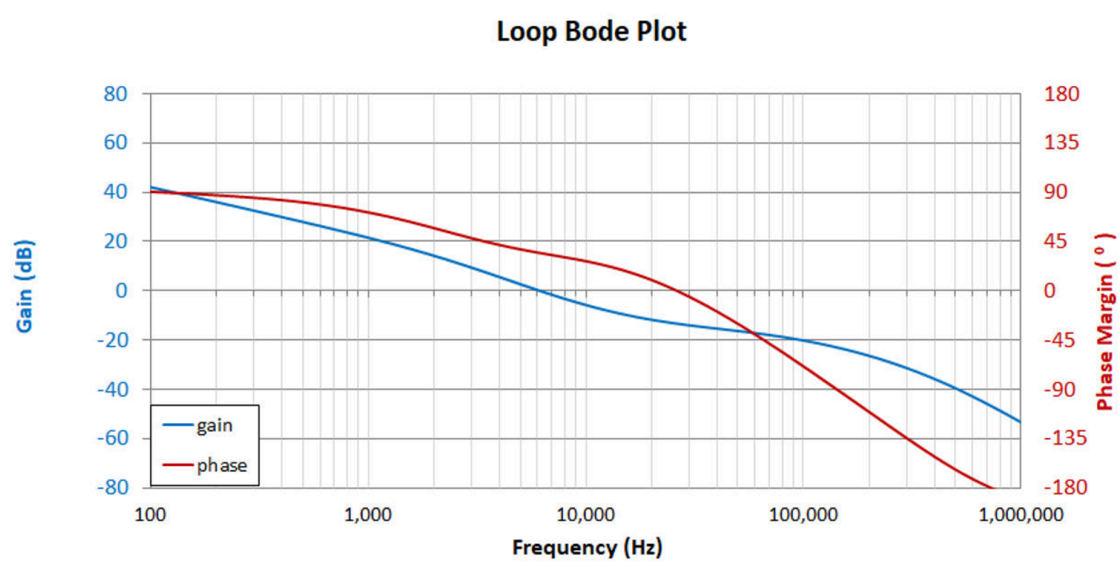

Figure 3-1. Bode Plot in V_{IN} = 0.7 V, V_{OUT} = 3.3 V, I_{OUT} = 0.8 A, C_{OUT}= 30 µF Condition

Therefore, to set the loop crossover frequency f_c lower than 1/5 of the RHPZ frequency, a large output capacitance can decrease the crossover frequency. In the meantime, a feedforward capacitor (C3 in Figure 2-1) and resistor R3 in parallel with upper feedback resistor R1 introduces a pair of zero f_{FFZ} and pole f_{ZZP} in the loop transfer function. By setting the proper zero frequency f_{FFZ}, the feedforward capacitor can increase the phase margin to improve the loop stability. The pole f_{ZZP} can increase the phase margin by adjusting R3 resistance by Equation 2 and Equation 3.

$$f_{FFZ} = \frac{1}{2\pi(R_1+R_3)C2} \quad (2)$$

$$f_{FFP} = \frac{1}{2\pi(R_1//R_2 + R_3)C_2} \tag{3}$$

Therefore, the ESR of the output capacitor creates a zero frequency:

$$f_{ESR} = \frac{1}{2\pi \times R_{ESR} \times C_{out}} \tag{4}$$

Big ESR leads to a small zero f_{ESR} into the loop. Combining with the feedforward capacitor zero f_{FFZ}, the crossover frequency fc will be increased to very high and phase margin is not big enough. Therefore, it is recommended to put a low ESR (< 50 mΩ) 100-µF aluminum electrolytic capacitor or aluminum polymer capacitor at the TPS61022 output. TI recommends setting the zero frequency f_{FFZ} to 2 kHz. R3 is set to 2 kΩ in default, which helps eliminate the output AC noise coupled to the FB pin.

4 Schematic and Bench Test Results

4.1 Schematic

Figure 4-1 shows the schematic for a typical supercap backup power application.

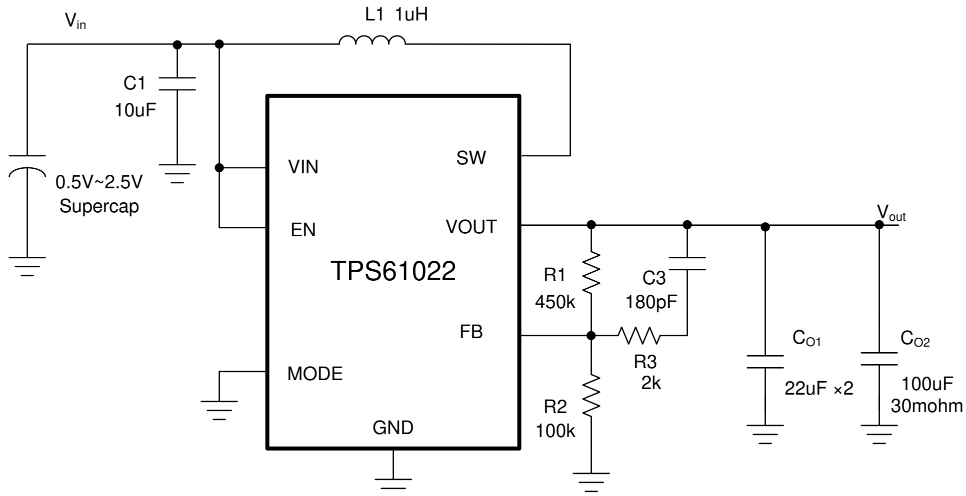

Figure 4-1. TPS61022 Circuit With Feedfoward Capacitor

Although a large aluminum polymer capacitor C_{O2} is used, 1 to 2 multilayer X5R or X7R low ESR, 22-µF ceramic capacitors are also necessary and must be placed close to the VOUT pin and GND pin.

By inputting the parameter shown in Figure 4-1, TPS61022 calculation tool generate the loop bode plot shown in Figure 4-2 for V_{IN} = 0.7 V. The crossover frequency is 5.6 kHz with 67.8° phase margin and 9.5-dB gain margin.

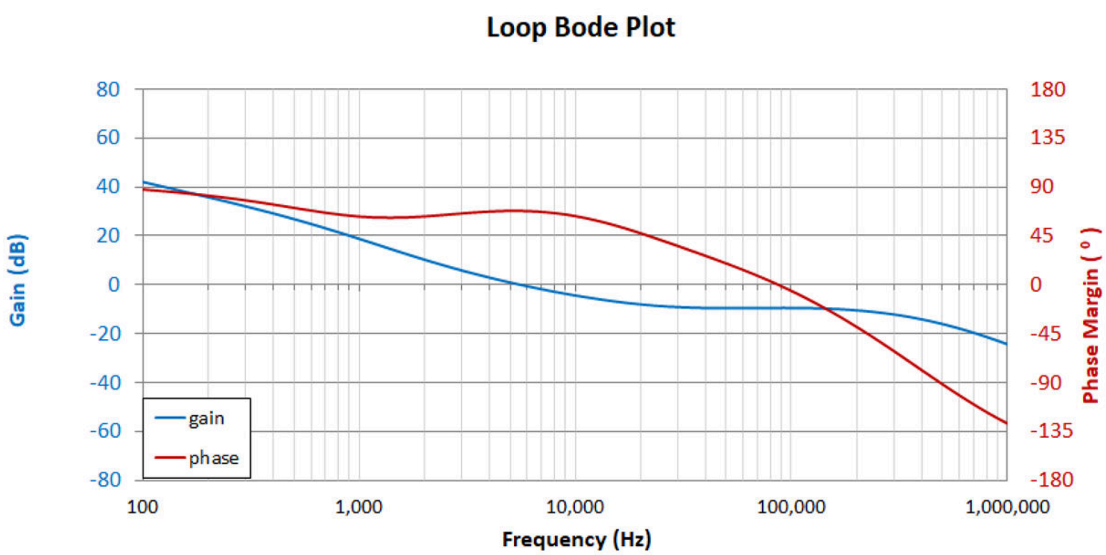

Figure 4-2. Bode Plot With Recommended External Components

4.2 Bench Test Results

Figure 4-3 shows the load transient waveform from 0.3 A to 0.6 A when V_{IN} = 0.7 V. Figure 4-4 shows the load transient waveform from 0.3 A to 0.6 A when V_{IN} = 1.5 V.

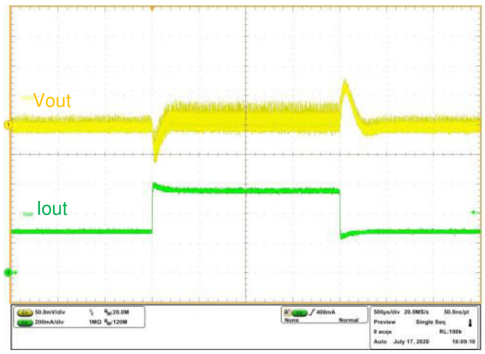

Figure 4-3. Load Transient - V_{IN} = 0.7 V, V_{OUT} = 3.3 V, I_{OUT} = 0.3 A to 0.6 A

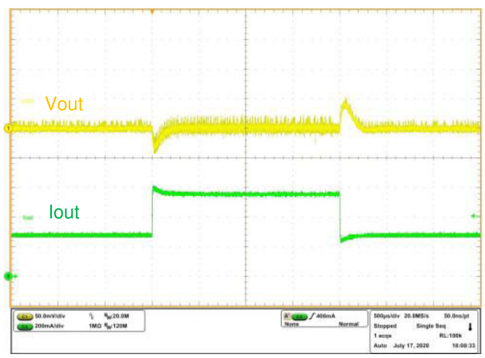

Figure 4-4. Load Transient - V_{IN} = 1.5 V, V_{OUT} = 3.3 V, I_{OUT} = 0.3 A to 0.6 A

Figure 4-5 shows the bode plot when V_{IN} = 0.7 V, I_{OUT} = 0.6 A. Figure 4-6 shows the bode plot when V_{IN} = 0.7 V, I_{OUT} = 0.6 A.

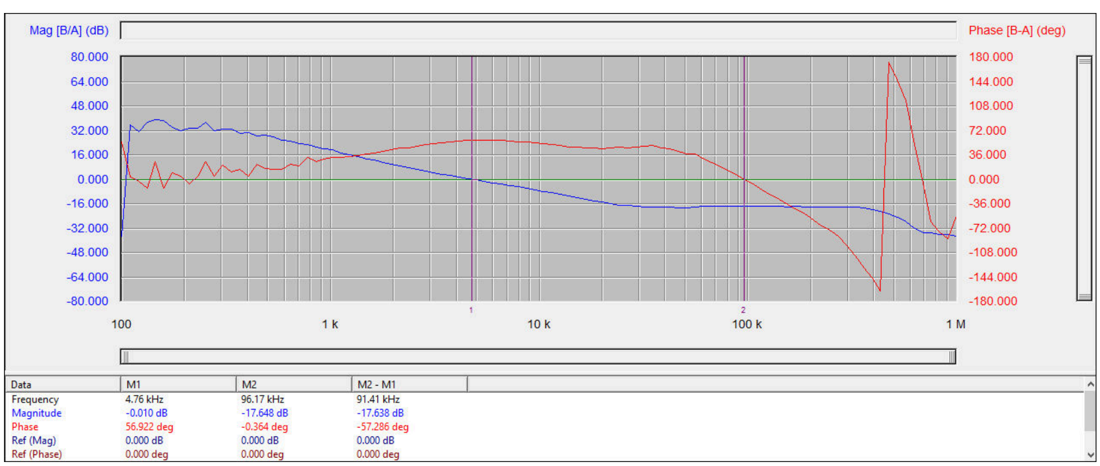

Figure 4-5. Bode Plot - V_{IN} = 0.7 V, V_{OUT} = 3.3V, I_{OUT} = 0.6 A

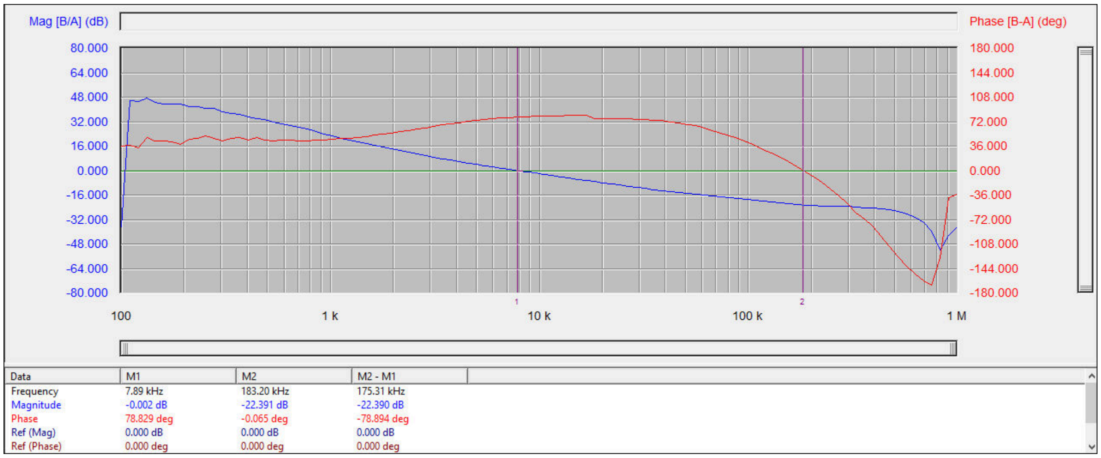

Figure 4-6. Bode Plot - V_{IN} = 1.5 V, V_{OUT} = 3.3 V, I_{OUT} = 0.6 A

Figure 4-7 shows the efficiency curve with different input voltage in auto PFM mode when V_{OUT} = 3.3 V.

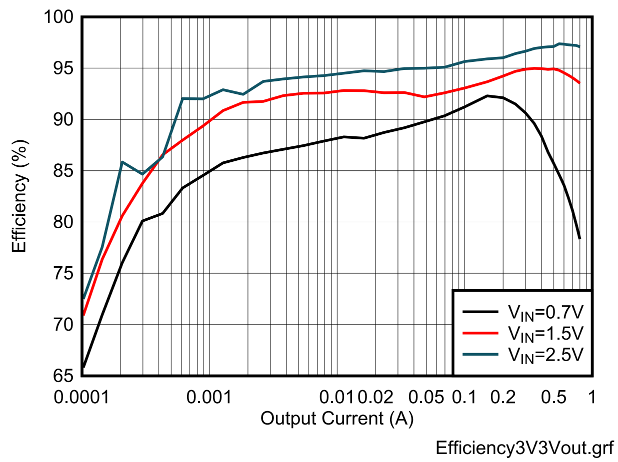

Figure 4-7. Load Efficiency With Different Input in Auto PFM

5 Summary

This application note instruct how to design external components for supercap backup power applications. With detailed design guideline, stability performance and efficiency are tested to verify the solution.

6 References

1. Texas Instruments, *TPS61022 8-A Boost converter with 0.5-V ultra-low input voltage Data Sheet*
2. Texas Instruments, *TPS61022EVM-034 Evaluation module User's Guide*
3. Texas Instruments, TPS61022 and TPS61023 Boost Converters Layout Guidelines