Application Note
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Simple CC/CV Charger using TPS54331

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Abstract

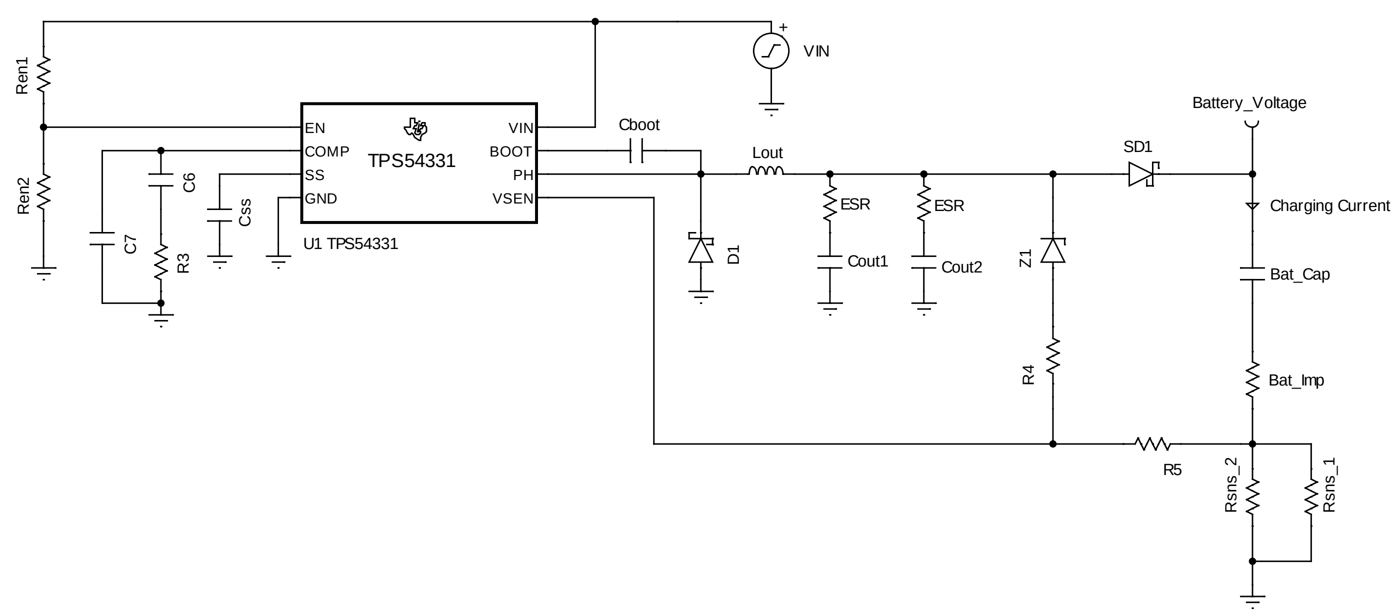
The TPS54331 is a non-synchronous buck converter that integrates a low $R_{DS(on)}$ high side MOSFET and is designed to provide up to a 3A output from an input voltage source of 3.5 V to 28 V. This application note explains the procedure of converting a simple buck converter into a CC/CV charger with low component count for charging a SMF Lead Acid Battery. This concept can be extended to multiple parts in the same family.

Specifications

Vin	Input Voltage Range	16.5V to 21V
Battery Specifications	Capacity	12V, 7.2Ah
Output Specifications	Charging Current	0.3C
	Voltage during CV Mode Charging	14.2V
Fsw	Switch Frequency	570KHz

Design Notes

Shown below is the generic schematic of the implementation.



Circuit Explanation

Assuming that we connect an uncharged battery to the output terminals, when the circuit is enabled, the Zener diode Z1 is reverse biased and will not conduct. Since the battery can consume all the current given to it, limiting the current is mandatory. During this stage, the current sensing resistor will provide the necessary closed loop feedback to the chip to maintain a constant current (CC) based charging. As the battery starts charging the voltage starts building on the battery and reaches the value of the zener voltage breakdown limit. Once it exceeds this value, the zener will now maintain a constant voltage (CV) of Vz + Vref on the battery. The resistors R4 and R5 are added to have better control of voltage during the CV mode of charging rather than depending only the breakdown tolerance between different zener diodes. The constant voltage output with these resistors is governed by the equation:

$$Vout = Vz + (Vref\ x \frac{R4 + R5}{R5})$$

Effect of different values of the R4 and R5 in CV Mode

1. If R4 is 0, then Vout = Vz + Vref
2. If R4 >> R5, then Vout will rise abnormally resulting in damage to the life of the battery and the device.
3. If R5 is 0, then Vout will rise abnormally resulting in damage to the life of the battery and the device.
4. If R5 >> R4, then will be Vout ~ Vz + Vref.

All these effects can be visualized in the simulation. The results are shown in the last section.

Selection of Power Stage Components (Inductor, Capacitors, Freewheeling Diode and Protection Diode)

The power stage components are designed using the standard equations given the datasheet of this device (http://www.ti.com/lit/ds/symlink/tps54331.pdf). Based on the above specifications

- Lout (min) = 13.55µH, Selected **Lout – 15µH**
- Diode D1 needs to carry a maximum current of Iout x (1-D) and must have a voltage rating of > Vinmax + 0.7, Selected **D1 - MBR340**
- Selected **Cout1 and 2 – 47µF, 5m ESR**
- Since the battery can discharge into the resistors R4 and R5 if the power supply is turned off, a battery current leakage prevention diode is added at the output. **SD1 – MBRS340**

Connecting the battery

Connect the battery positive to the Output terminal and the battery negative to the Current Sense Resistor. In the schematic above the battery is modeled as a large capacitor (battery capacitance) with a series resistor (battery impedance) to produce the required charging characteristics.

Selection of Sense Resistor (RSNS)

The sense resistors are chosen according to the required charging current and buck converter feedback sense voltage available on the VSEN pin. For TPS54331 it is 0.8V. For a charging current of 2A, the sense resistor value will be:

$$Rsns = \frac{Vsns}{Iout} = 0.4\ \Omega$$

The power rating of the resistor needs to be

$$P_{rsns} = Iout^2 x\ Rsns = 1.6\ W$$

To thermally size the resistor correctly we chose two resistors in parallel. **Rsns_1 = 800mΩ and Rsns_2 = 800mΩ**

Selection of Z1

Depending the desired battery voltage required, select either a 13V or **12V Zener**.

Selection of R4 and R5

For producing a 14.2V Output, using a 12V Zener and a diode drop of 0.3V on SD1, we can make **R4 = 85Ω and R5 = 40Ω**.

Selection of Compensation Components (R3, C6 and C7)

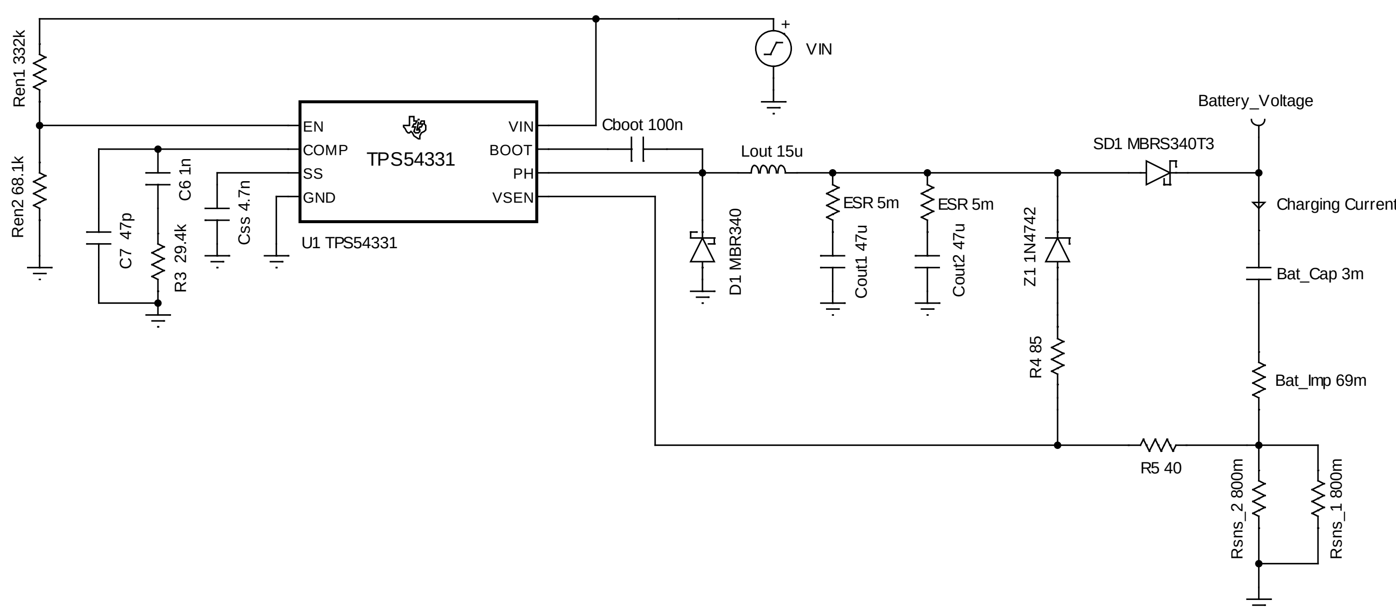
The TPS54331 follows current mode compensation and has a transconductance amplifier for the error amplifier. The error amplifier compares the VSENSE voltage to the internal effective voltage reference presented at the input of the error amplifier. Since the reference feedback is coming from the voltage developed across the sense resistor, the compensation will be similar to that of a normal voltage feedback based output and can be calculated as per the standard equations in the datasheet and the components R3, C6 and C7 can be connected as shown in the schematic on the first page. So we can use **R3 = 29.4KΩ, C6 = 1nF, C7 = 47pF.**

Enable Circuit

Enable can be adjusted to either work from a external controller or in a self enabled mode. Care should be taken to ensure that the enable signal should not exceed 6V. By using **Ren1 = 332kΩ and Ren2 = 68.1kΩ**, the enable is between 2.7V to 3.5V.

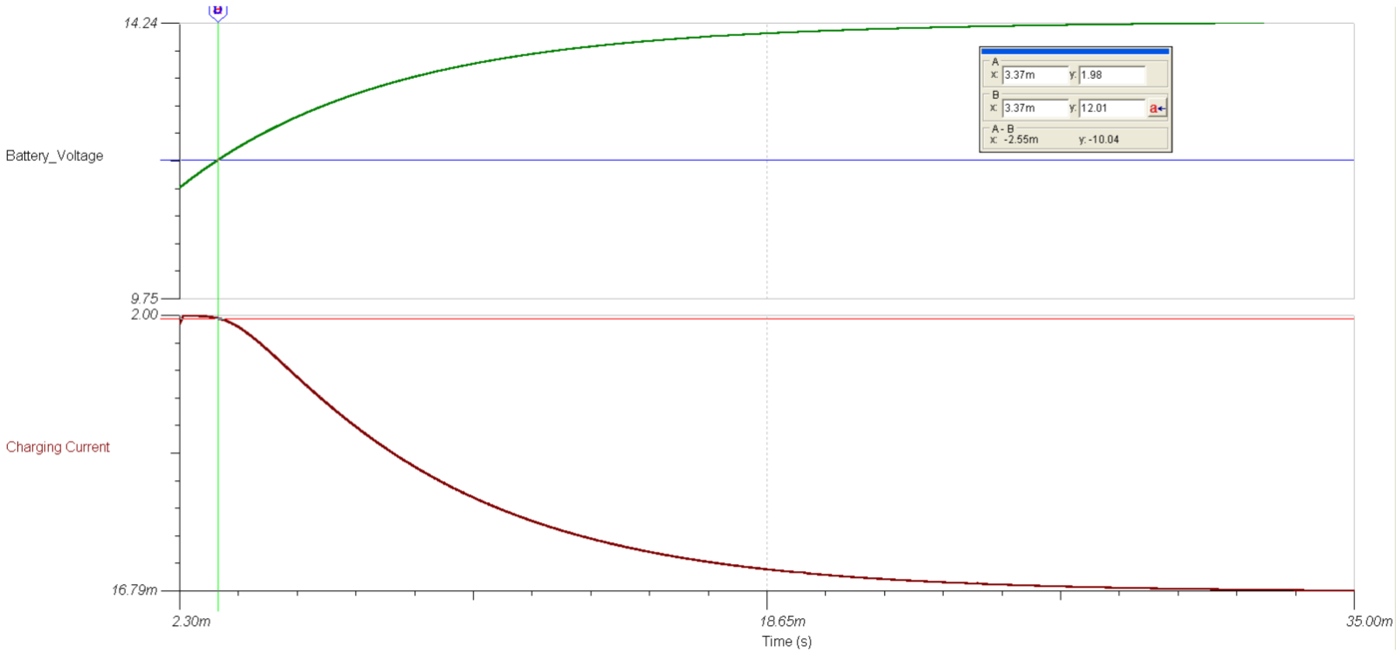
Final Circuit

The final circuit after the adding the designed values are:



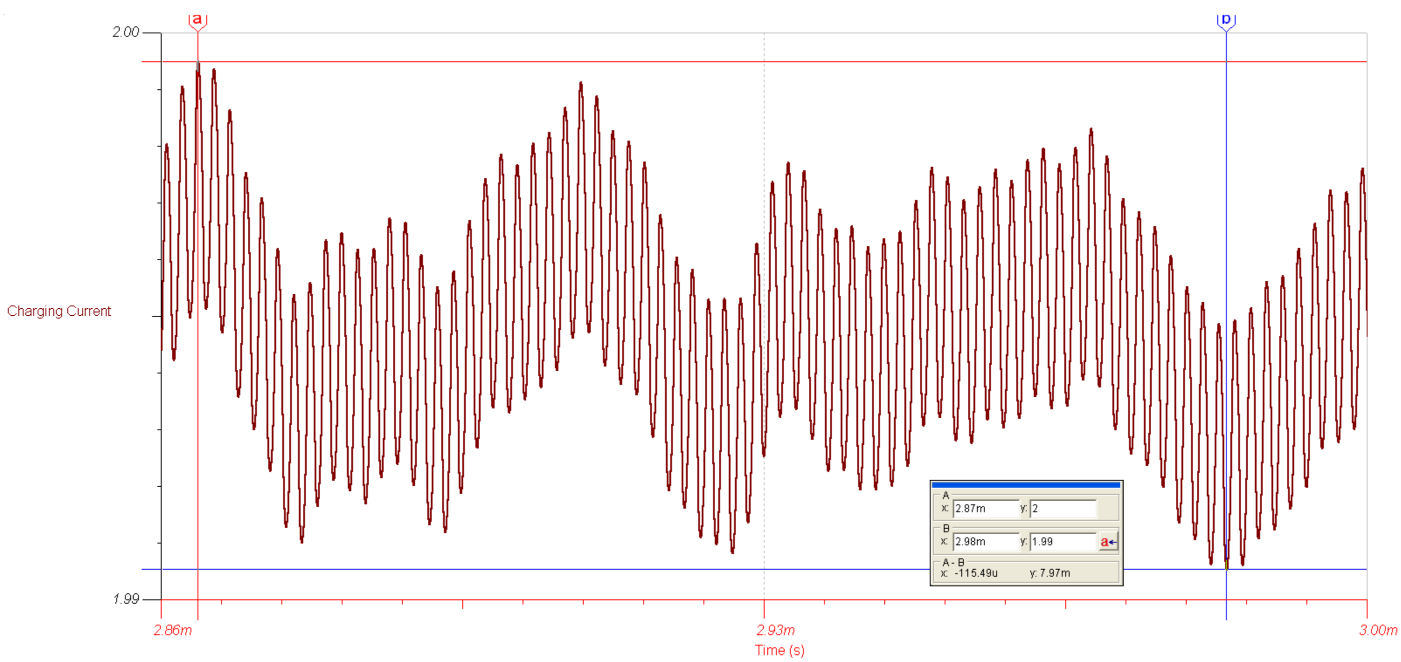
Simulation Results

Complete CC/CV Charging Profile Waveform



The initial condition assumed it that the battery is in a discharged mode. As observed, the CC Mode lasts till the 12V zener breaks down. At 12V, the CV Mode beings and the current begins to reduce. The voltage builds to Vz = 12V + 2.5V due to the resistor network of R4 and R5.

CC Mode Current Waveform



The current ripple during the CC Mode is found to be around 8mA. The ripple frequency noticed is that of the switching frequency.

Conclusion

Although it may not be the most accurate way to do a CC/CV charger due to the regulation of the zener, a simple low cost solution can still be realized. Depending on charging current requirements we can have discrete implementation of the converter.

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