Application Report
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TPS25830, TPS25831-Q1, and TPS25840-Q1 Short-to-Battery Application

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ABSTRACT

In the automotive USB application system, USB port short to battery is a common issue, which can damage the equipment. This application report focuses on how to solve the problem of USB port short to battery through circuit design with TPS25830/31/40.

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1 Introduction

TPS2583x-Q1 is a highly-integrated USB Type-C and BC1.2 charging port controller that includes a synchronous DC/DC converter. It also supports DP_IN/DM_IN/CC1/CC2 short-to-battery protect. During the assembly, manufacturing, and maintenance of a car, there is a common problem where the USB port randomly shorts to the car battery, causing chip damage, or the USB lightning port accidentally hits the cigarette lighter during the daily application, which also causes chip damage. The TPS25830, TPS25831-Q1, and TPS25840-Q1 provide DP_IN/DM_IN/CC1/ CC2 short-to-battery protection, and supports 18-V maximum protection voltage, thus avoiding chip damage. All the following tests are based on the TPS25830Q1EVM-040. A power supply plus an external 30-mF electrolytic capacitor was used to simulate the car battery. The test input voltage was 14.5 V, R3 external. The recommended value for External FET is 10R/0603. The recommended value for External FET without External R3 is 100R/0805.

2 Short-to-Battery Conventional Application

After the car is started, the exposed USB lightning cable usually accidentally touches the positive pole of the cigarette lighter (see Figure 1). The equivalent test condition is VIN = 14.5 V, VOUT = 5.1 V, and IOUT = 0 A. Turn on the power supply, then test VBUS/Vout/DP_IN/DM_IN/CC1/CC2 short to battery, respectively (battery VBAT) (see Figure 2).

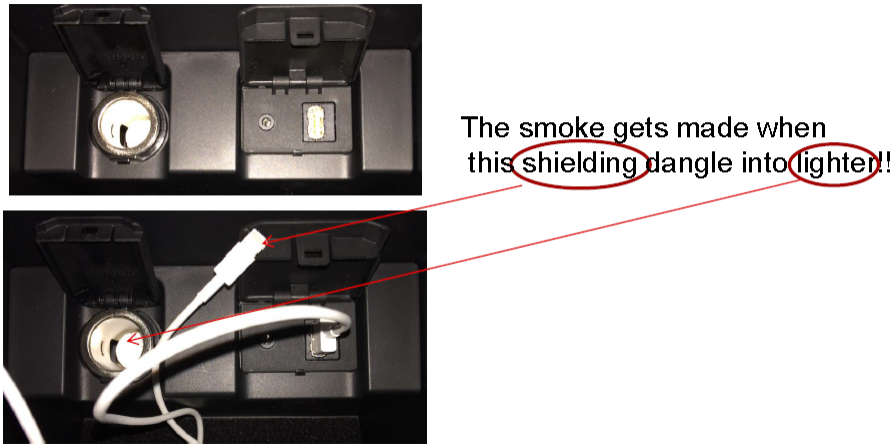


Figure 1. Cigarette Lighter Application

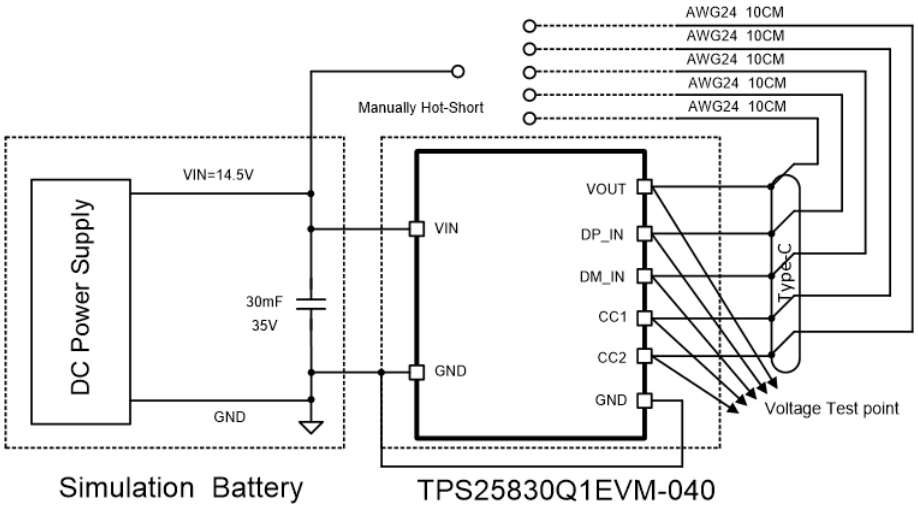


Figure 2. Short-to-Battery System Test Setup

2.1 External FET VBUS/DP_IN/DM-IN Short-to-VBAT Application

For short-to-battery protection, TI recommends connecting an N-channel back-to-back MOS FET between the CSN PIN and VBUS as seen in Figure 3.

2.1.1 VBUS Short-to-VBAT Application

When the output VBUS is short circuited to VBAT, the VBAT voltage charges the output capacitor C4, and at the same time charges C3 through R3. When the voltage of BUS pin exceeds 7 V, the external FET is closed, and the LS_GD is set from high to low. Figure 4 shows the test results.

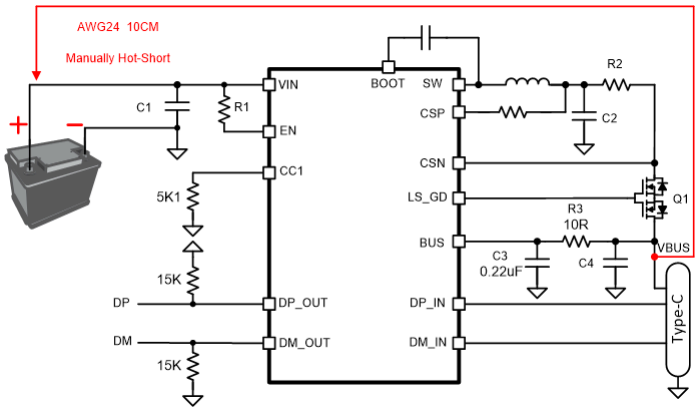
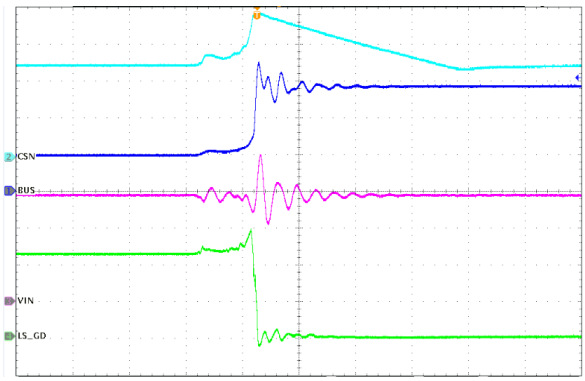


Figure 3. Power On VBUS Short-to-VBAT Test Setup



CH1 = 5 V/div, CH2 = 2 V/div, CH3 = 5 V/div, CH4 = 5 V/div, 20 µS/div

Figure 4. Power on VBUS Short-to-VBAT Test

2.1.2 DP_IN/DM_IN Short-to-VBAT Application

DP_IN/DM_IN shorts to the VBAT protection function, which is realized by the internal protection circuit and external capacitance, C3 (see Figure 5). When DP_IN/DM_IN shorts to VBAT, some voltage spikes are clamped by an internal protection circuit, and the other part is absorbed by the external C3 through the internal diode Z1 or Z2. At the same time, output capacitance C4 and C2 are also charged to effectively absorb voltage spikes. Figure 6 shows the test results.

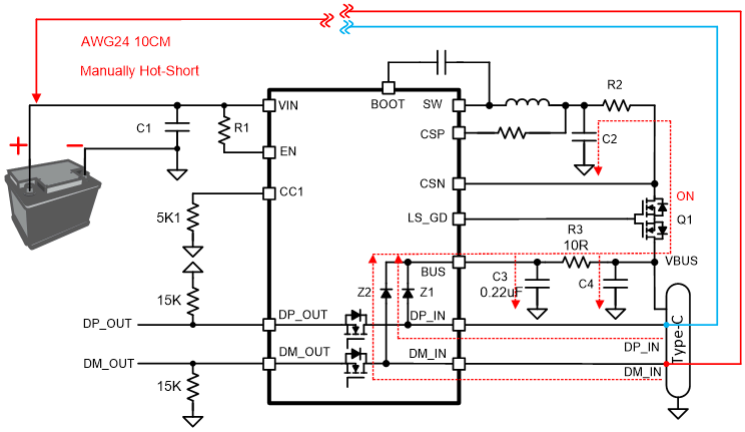
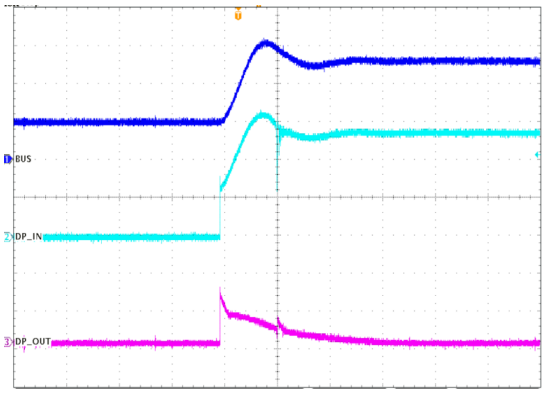


Figure 5. Power On DP_IN/DM_IN Short-to-VBAT Test Setup



CH1 = 5 V/div, CH2 = 5 V/div, CH3 = 5 V/div, 1 µS/div

Figure 6. Power On DP_IN Short-to-VBAT Test

2.1.3 VBUS /DP_IN/DP_IN Short-to-VBAT Application Summary

Table 1. VBUS /DP_IN/DP_IN Short-to-VBAT Application Summary

TEST ITEM	DP_IN SHORT-TO-VBAT	DM_IN SHORT-TO-VBAT	VBUS SHORT-TO-VBAT
Fist the power on ,then VBUS/DP_IN/DM_IN short to VBAT	PASS	PASS	PASS

2.2 Without External FET VOUT/DP_IN/DM-IN Short-to-VBAT Application

Sometimes, to save costs, customers omit external FET (see Figure 7). For special applications without external FET, refer to *Section 3*.

2.2.1 VOUT/CSN Short-to-VBAT Application

When there is no back-to-back MOSFET, VOUT and CSN are directly connected. At this time, short VOUT to VBAT and VBAT charges the output capacitors C4 and C2. When the voltage of BUS pin exceeds 7 V, the fault is set from high to low. When the Vout/CSN pin voltage exceeds 7.5 V, the converter stops switching. Figure 8 shows the test results.

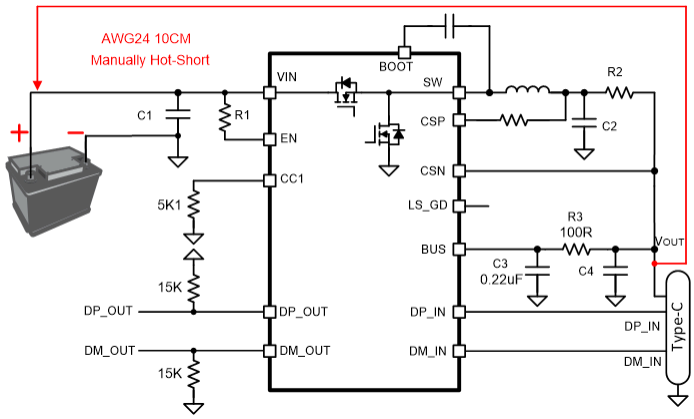
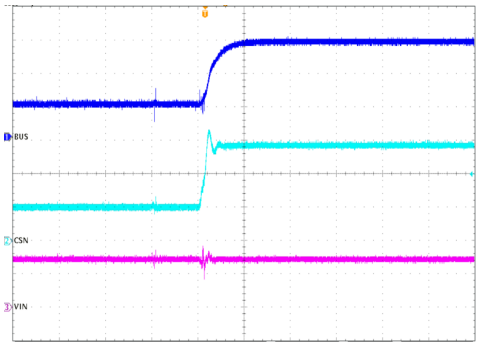


Figure 7. Power On VOUT Short-to-VBAT Test Setup



CH1 = 5 V/div, CH2 = 5 V/div, CH3 = 10 V/div, 100 µS/div

Figure 8. Power On VOUT Short-to-VBAT Test

2.2.2 DP_IN/DM_IN Short-to-VBAT Application

DP_IN/DM_IN shorts to VBAT without an external MOSFET (see Figure 9). Its working principle is described in *Section 2.1.2*. Figure 10 shows the results.

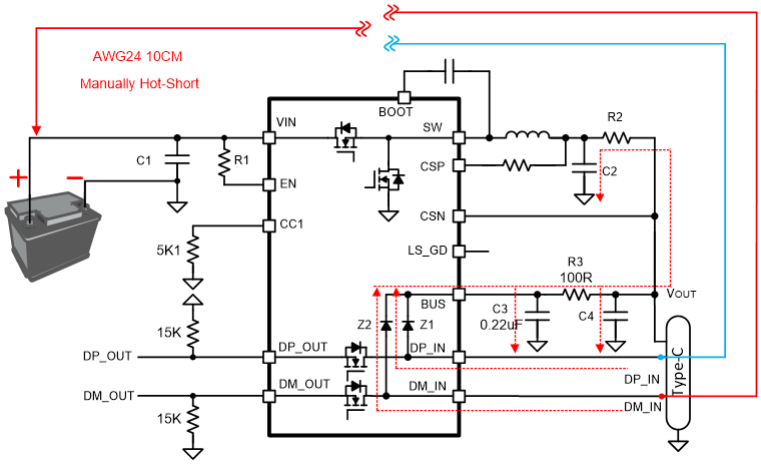
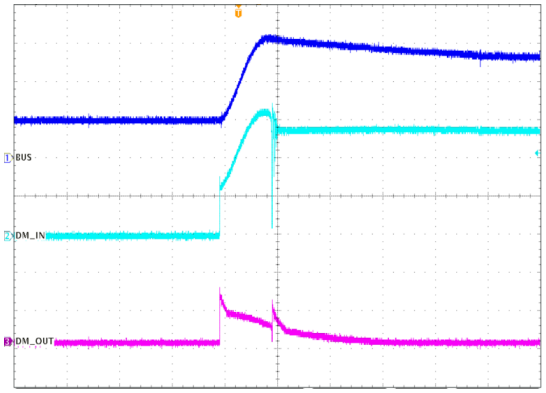


Figure 9. Power On DP_IN/DM_IN Short-to-VBAT Test Setup



CH1 = 5 V/div, CH2 = 5 V/div, CH3 = 5 V/div, 1 µS/div

Figure 10. Power On DM_IN Short-to-VBAT Test

2.2.3 VOUT/DP_IN/DP_IN Short-to-VBAT Application Summary

Table 2. VOUT/DP_IN/DP_IN Short-to-VBAT Application Summary

ITEM	DP_IN SHORT-TO-VBAT	DM_IN SHORT-TO-VBAT	VOUT (CSN) SHORT-TO-VBAT
Fist the power on, then VOUT/DP_IN/DM_IN short to VBAT	PASS	PASS	PASS

2.3 CC1/CC2 Short-to-VBAT Application

The result of CC1/CC2 shorting to VBAT has nothing to do with the external MOSFET Q1. Figure 11 shows the test setup. Figure 12 and Figure 13 show the test results.

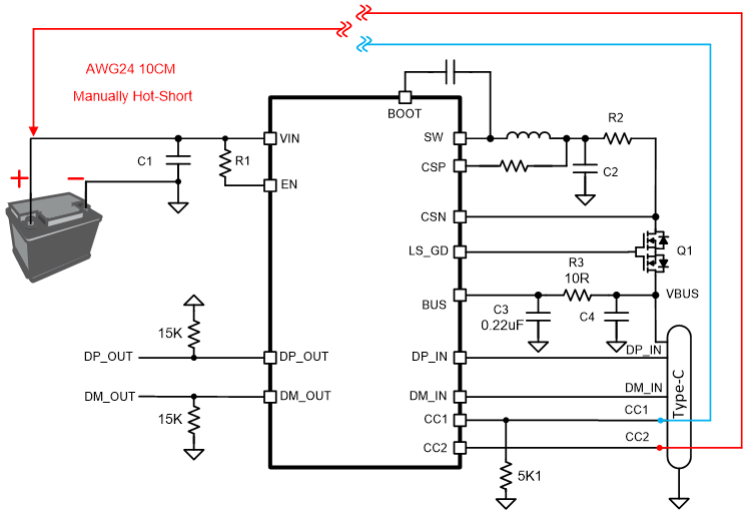
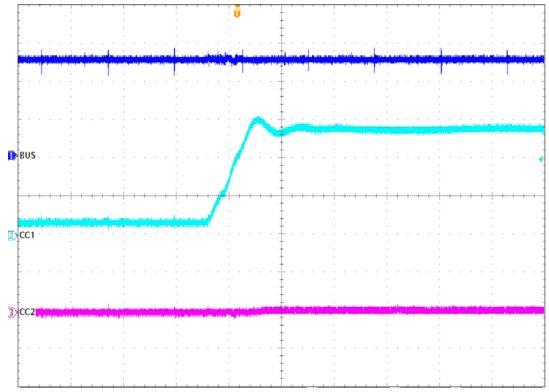
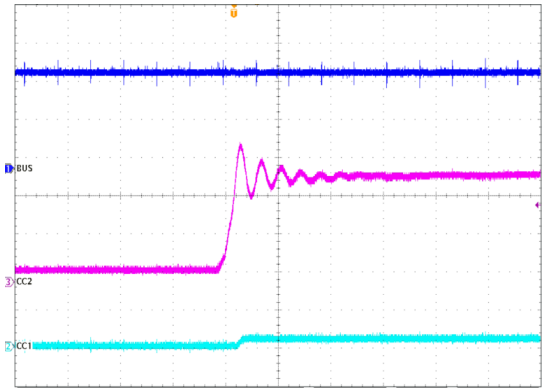


Figure 11. Power On CC1/CC2 Short-to-VBAT Test Setup



CH1 = 2 V/div, CH2 = 5 V/div, CH3 = 5 V/div, 4 µS/div, CC1 = Rd

Figure 12. Power On CC1 Short-to-VBAT Test



CH1 = 2 V/div, CH2 = 5 V/div, CH3 = 5 V/div, 4 µS/div, CC2 = Rd

Figure 13. Power On CC2 Short-to-VBAT Test

3 Short-to-Battery Special Application

In the customer applications, there are usually some special applications, which can be summarized as the following:

Application 1: Customers usually add a MOSFET Q2 protection circuit before the TPS25830, TPS25831-Q1, or TPS25840-Q1 system to realize overvoltage, undervoltage, and anti-reverse connection functions. When input voltage is overvoltage or undervoltage, Q2 is closed. When Q2 is closed, the USB lighting output port can accidentally touch the positive pole of the cigarette lighter. This is a possible situation that needs to be tested. Equivalent test conditions are power off, then VBUS/DP_IN/DM_IN short-to-battery VBAT (see Figure 14):

- VBAT = 14.5 V
- VIN = 0 V
- EN = VIN
- Vout = 0 V
- IOUT = 0 A

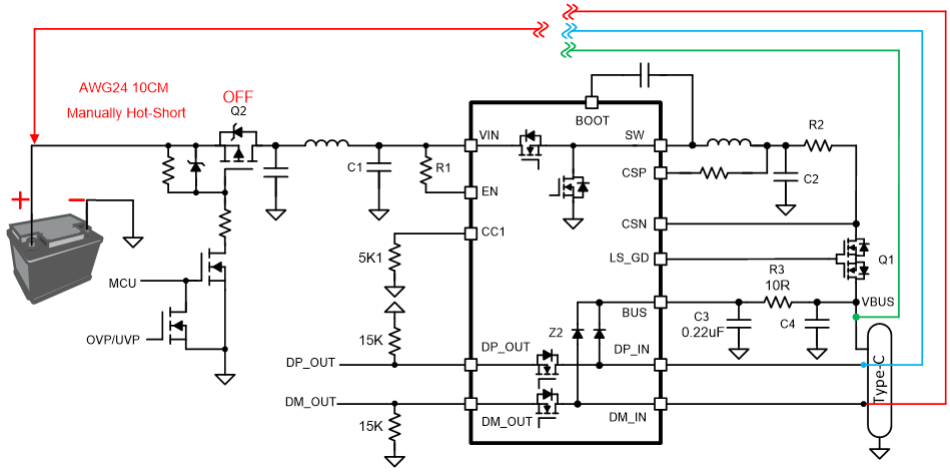


Figure 14. VBUS/DP_IN/DM_IN Short-to-VBAT Test Setup

Application 2: After the end user drives to the destination, they shut down the car engine and pull out the USB lightning port from their device. If the USB lightning port accidentally touches the positive pole of the cigarette lighter at this time, the next time the car starts, it has a short circuit between VBUS and VBAT. Equivalent test conditions are: VBUS/DP_IN/DM_IN shorts to the VBAT, then the power on TPS25830, TPS25831-Q1, or TPS25840-Q1 (Figure 15).

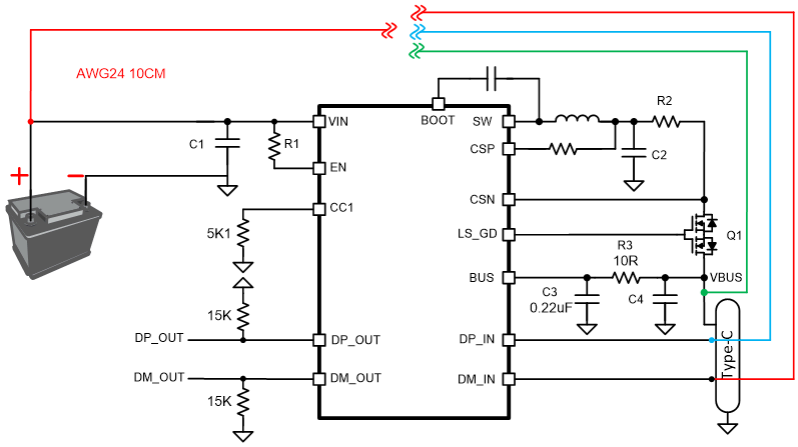


Figure 15. VBUS/DP_IN/DM_IN Short-to-VBAT Test Setup

Application 3 is similar to application 2. The only difference is that EN is controlled by an external MCU or other control signals due to customer timing requirements. Equivalent test conditions are to first, VBUS/DP_IN/DM_IN short to VBAT and power on, then EN enable. Figure 16 shows the test setup.

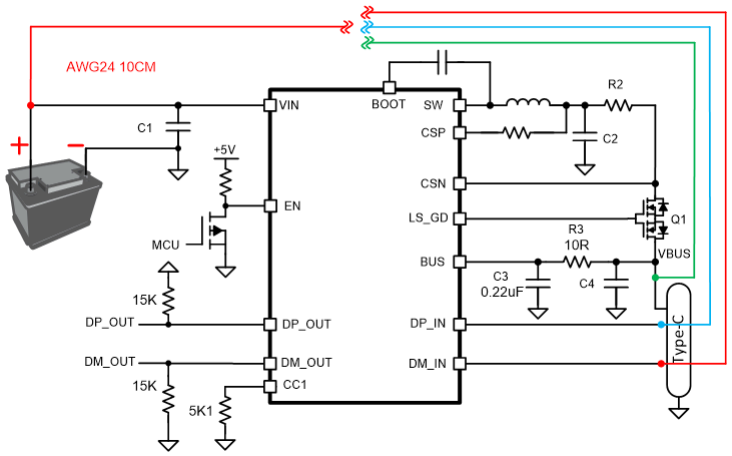


Figure 16. VBUS/DP_IN/DM_IN Short-to-VBAT Test Setup

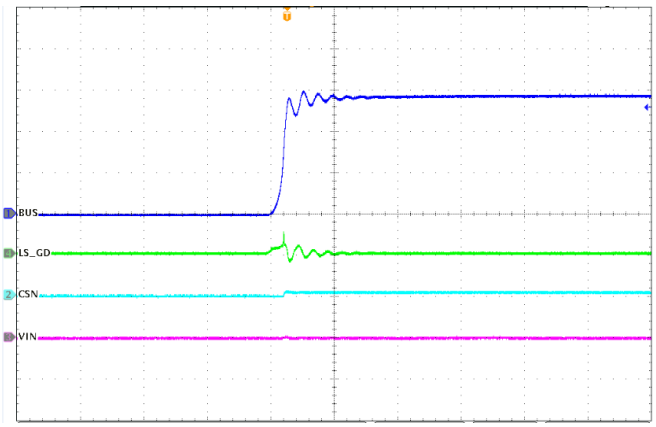
3.1 External FET VBUS/DP_IN/DM-IN Short-to-VBAT Application

3.1.1 VBUS Short-to-VBAT Application

Application 1: Figure 14 shows the test setup. The state at each point is power supply off (VBUS = 0 V, LS_GD is low, and Q1 is off). Short VBUS to VBAT. The voltage of VBUS rushes to the same height as VBAT. Figure 17 shows the test results.

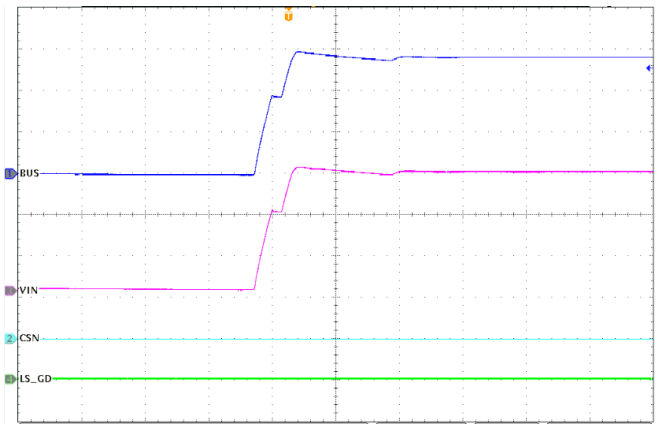
Application 2: Figure 15 shows the test setup. VBUS shorts to VBAT. The input voltage and VBUS are rushed to the same height as VBAT together. Figure 18 shows the test results.

Application 3: Figure 16 shows the test setup. First, short VBUS to VBAT and power on the power supply, then enable EN. Figure 19 shows the test results.



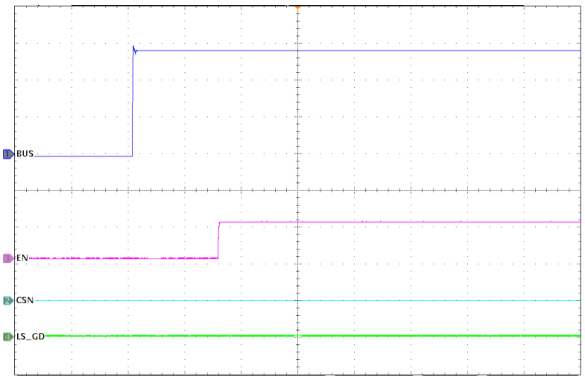
CH1 = 5 V/div, CH2 = 2 V/div, CH3 = 5 V/div, CH4 = 5 V/div, 20 µS/div

Figure 17. Power Off VBUS Short-to-VBAT Test



CH1 = 5 V/div, CH2= 2 V/div, CH3 = 5 V/div, CH4 = 5 V/div, 10 mS/div

Figure 18. VBUS Short to VBAT, then Power On Test



CH1 = 5 V/div, CH2 = 2 V/div, CH3 = 5 V/div, CH4 = 2 V/div, 400 mS/div

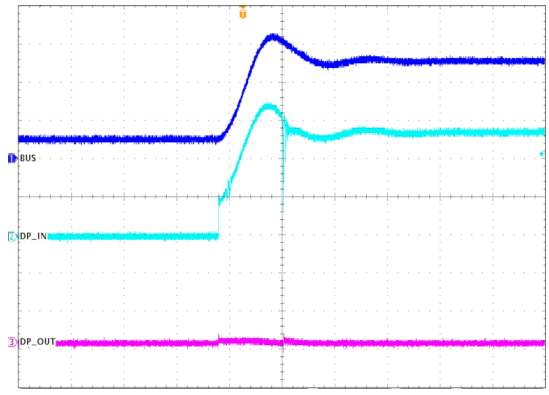
Figure 19. VBUS Short to VBAT and Power On, then Enable On Test

3.1.2 DP_IN/DM_IN Short-to-VBAT Application

Application 1: Figure 14 shows the test setup. The state at each point is power supply off (Vout = 0 V, LS_GD is low, and Q1 is off). Short DP_IN/DM_IN to VBAT. The voltage of DP_IN/DM_IN rushes to the same height as VBAT. Figure 20 and Figure 21 show the test results.

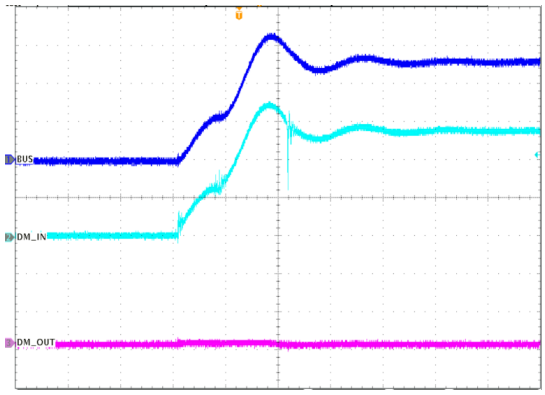
Application 2: Figure 15 shows the test setup. DP_IN/DM_IN shorts to VBAT. The input voltage and DP_IN/DM_IN voltage are rushed to the same height as VBAT together. Figure 22 and Figure 23 show the test results.

Application 3: Figure 16 shows the test setup. First, short DP_IN/DM_IN to VBAT and power on the power supply, then enable EN. Figure 24 and Figure 25 show the test results.



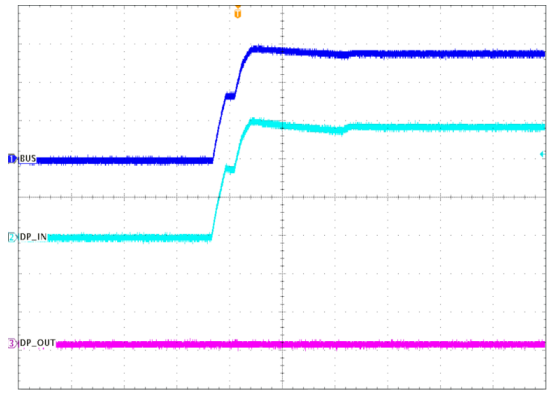
CH1 = 5 V/div, CH2 = 5 V/div, CH3 = 5 V/div, 2 µS/div

Figure 20. Power Off, DP_IN Short-to-VBAT Test



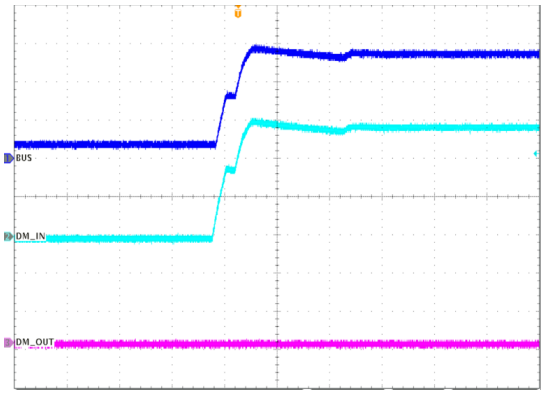
CH1 = 5 V/div, CH2 = 5 V/div, CH3 = 5 V/div, 2 µS/div

Figure 21. Power Off, DM_IN Short-VBAT Test



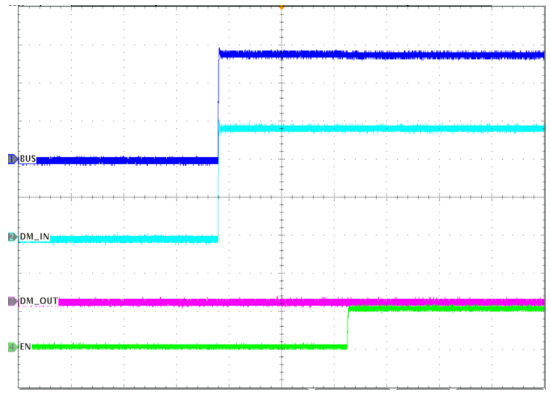
CH1 = 5 V/div, CH2 = 5 V/div, CH3 = 5 V/div, 10 mS/div

Figure 22. DP_IN Short to VBAT, then Power On Test



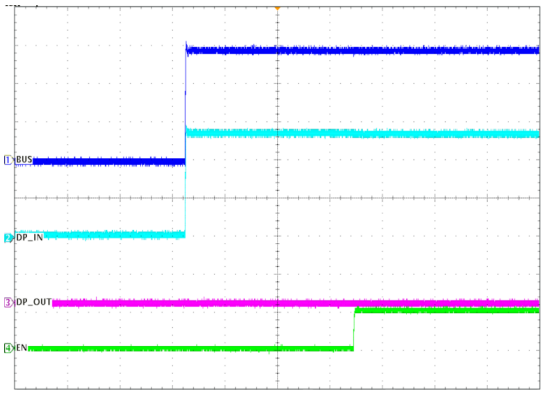
CH1 = 5 V/div, CH2 = 5 V/div, CH3 = 5 V/div, 10 mS/div

Figure 23. DM_IN Short to VBAT, then Power On Test



CH1 = 5 V/div, CH2 = 5 V/div, CH3 = 5 V/div, CH3 = 5 V/div, 400 mS/div

Figure 24. DM_IN Short to VBAT and Power On, then Enable On Test



CH1 = 5 V/div, CH2 = 5 V/div, CH3 = 5 V/div, CH3 = 5 V/div, 400 mS/div

Figure 25. DP_IN Short to VBAT and Power On, then Enable On Test

3.1.3 VBUS/DP_IN/DM-IN Short-toVBAT Application Summary

Table 3. VBUS/DP_IN/DM-IN Short-to-VBAT Application Summary

ITEM	DP_IN SHORT-TO-VBAT	DM_IN SHORT-TO-VBAT	VBUS SHORT-TO-VBAT
Fist the power off, then VBUS/DP_IN/DM_IN Short to VBAT	PASS	PASS	PASS
Fist the VBUS/DP_IN/DM_IN Short to VBAT, then Power on	PASS	PASS	PASS
Fist the VBUS/DP_IN/DM_IN Short to VBAT and Power on, then EN on	PASS	PASS	PASS

3.2 Without External FET VOUT/DP_IN/DM-IN Short-to-VBAT Application

This application is the same as the application in *Section 3.1*, this case also can be summarized as the following:

Application 1: Figure 26 shows the test setup. First, power off the power supply, then short VOUT/DP_IN/DM_IN to VBAT. The state at each point is the following:

- VBAT = 14.5 V
- VIN = 0 V
- EN = VIN

- VOUT = 0 V
- IOUT = 0 A

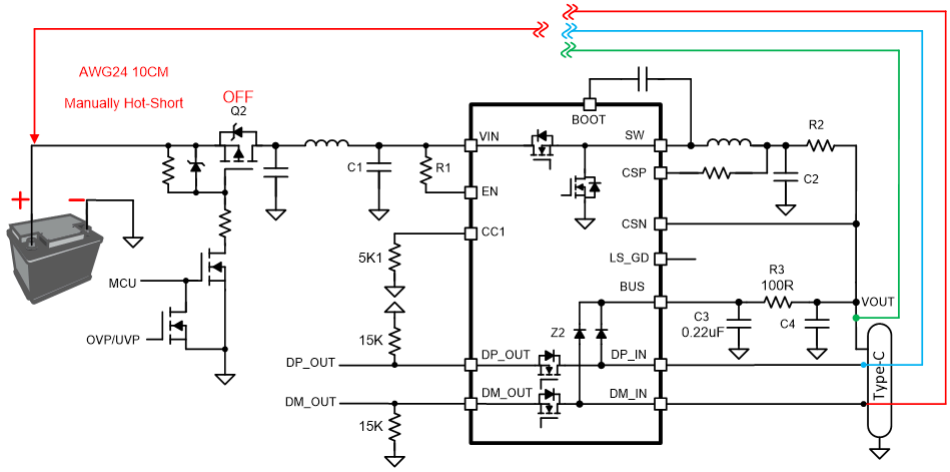


Figure 26. VOUT/DP_IN/DM_IN Short-to-VBAT Test Setup

Application 2: Figure 27 shows the test setup. First, short VOUT/DP_IN/DM_IN to VBAT, then power on the power supply.

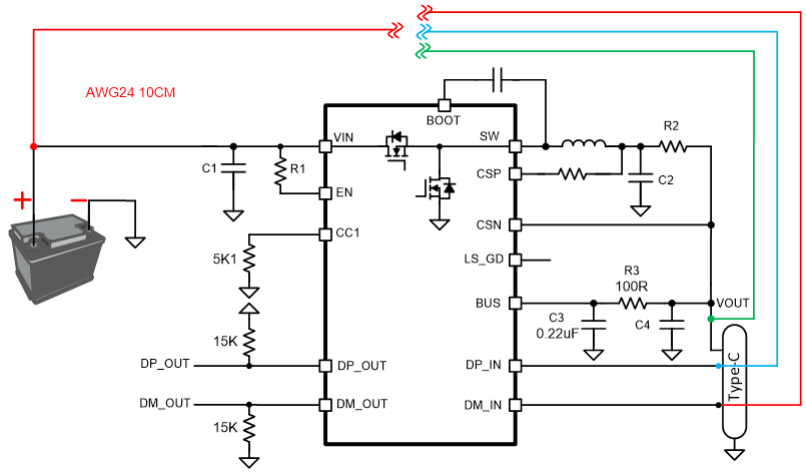


Figure 27. VOUT/DP_IN/DM_IN Short-to-VBAT Test Setup

Application 3: Figure 28 shows the test setup. Short VOUT/DP_IN/DM_IN to VBAT and power on the power supply, then enable EN.

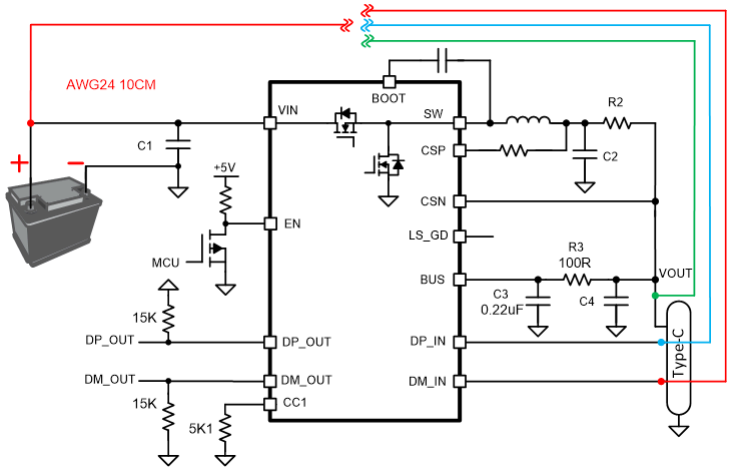


Figure 28. VOUT/DP_IN/DM_IN Short-to-VBAT Test Setup

3.2.1 VOUT Short-to-VBAT Application

- Application 1: Power off the power supply, then short CSN to VBAT. TPS25830, TPS25831-Q1, and TPS25840-Q1 do not support short-to-battery protection in this case.
- Application 2: Short CSN to VBAT, then power on the power supply. TPS25830, TPS25831-Q1, and TPS25840-Q1 do not support short-to-battery protection in this case.
- Application 3: Short CSN to VBAT and power on the power supply, then enable EN. TPS25830, TPS25831-Q1, and TPS25840-Q1 do not support short-to-battery protection in this case.

3.2.2 DP_IN/DM_IN Short-to-VBAT Application

- Application 1: Power off the power supply, then short DP_IN/DM_IN to VBAT. Figure 29 and Figure 30 show the test results.
- Application 2: Short DP_IN/DM_IN to VBAT, then power on the power supply. Figure 31 and Figure 32 show the test results.
- Application 3: Short DP_IN/DM_IN to VBAT, power on the power supply, then enable EN. Figure 33 and Figure 34 show the test results.

3.2.3 VOUT /DP_IN/DM-IN Short-to-VBAT Application Summary

Table 4. VOUT/DP_IN/DM-IN Short to VBAT Application Summary

ITEM	DP_IN SHORT-TO-VBAT	DM_IN SHORT-TO-VBAT	VOUT SHORT-TO-VBAT
Fist the power off, then VOUT/DP_IN/DM_IN Short to VBAT	PASS	PASS	Does not support
Fist the VOUT /DP_IN/DM_IN Short to VBAT, then Power on	PASS	PASS	Does not support
Fist the VOUT/DP_IN/DM_IN Short to VBAT and Power on, then EN on	PASS	PASS	Does not support

4 Short-to-Battery Connect to TVS Application

During the actual process of shorting to VBAT, the parasitic inductance and capacitance of PCB generate resonance. The resonance voltage usually exceeds 18 V. The maximum voltage of the following on the TPS25830-Q1, TPS25831-Q1, and TPS25840-Q1 is 18 V:

- VBUS

- Vout
- DP_IN
- DM_IN
- CC1 and CC2 pins

If the voltage of those pins exceeds 18 V, you need to add a TVS diode. The TVS diode TI used in the demo is SMAJ18A with the TVS PCB Layout as close as possible to the IC PIN.

4.1 VBUS Short-to-VBAT Connect to TVS Application

If the voltage exceeds 18 V when VBUS shorts to VBAT, TI recommends connecting a 18-V TVS diode between VBUS and GND, as shown with Z3 in Figure 35.

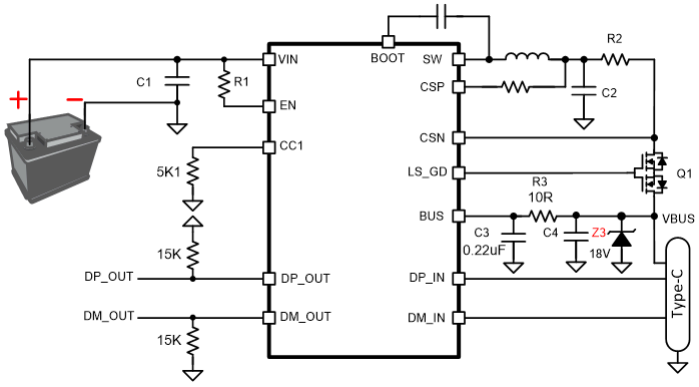


Figure 35. VBUS Short-to-VBAT Connect to TVS Setup

4.2 VOUT Short-to-VBAT Connect to TVS Application

If the voltage exceeds 18 V when Vout shorts to VBAT, TI recommends connecting a 18-V TVS diode between VBUS and GND, as shown with Z3 in Figure 36.

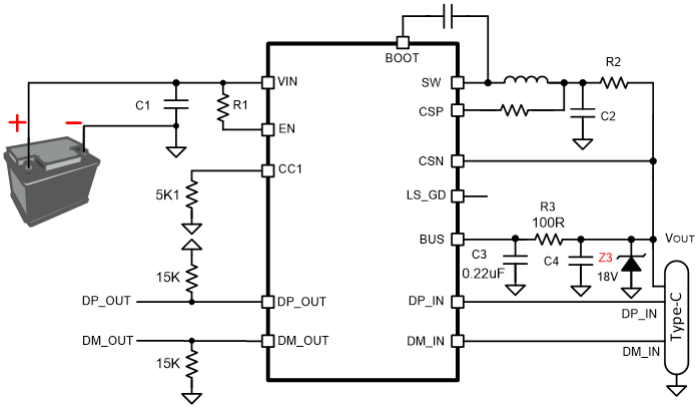


Figure 36. VOUT Short-to-VBAT Connect to TVS Setup

4.3 DP/DM Short-to-VBAT Connect to TVS Application

If the voltage exceeds 18 V when DP_IN/DM_IN shorts to VBAT, TI recommends connecting a 18-V TVS diode between VBUS and GND, as shown with Z3 in Figure 37.

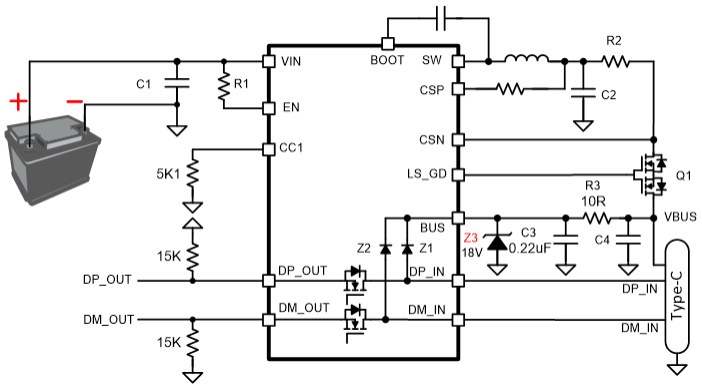


Figure 37. DP_IN/DM_IN Short-to-VBAT Connect to TVS Setup

4.4 CC1/CC2 Short-to-VBAT Connect to TVS Application

If the voltage exceeds 18 V when CC1/CC2 shorts to VBAT, TI recommends connecting a 18-V TVS diode between VBUS and GND, as shown with Z3 in Figure 38.

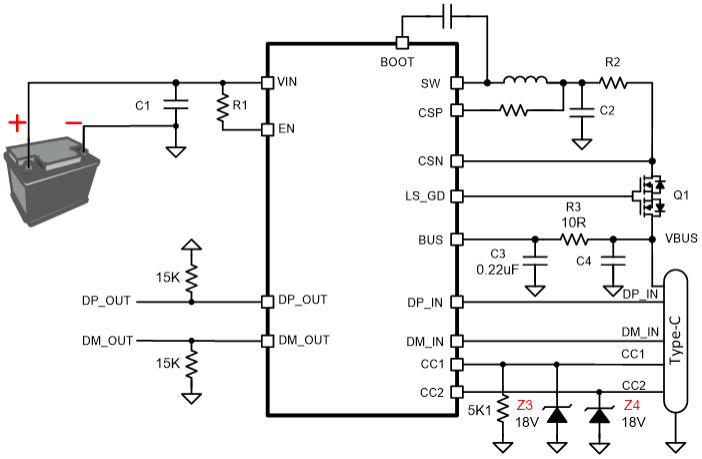


Figure 38. CC1/CC2 Short-to-VBAT Connect to TVS Setup

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