Application Report
SLVAEQ2–April 2020

How to Pass MFi Overcurrent Protection Test With USB Charger and Switch Device

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ABSTRACT

Apple™ has defined new overcurrent protection (OCP) requirements in its recent Accessory Design Guidelines for Apple Device spec, so the USB power providing accessories need to meet the new overcurrent protection requirements. Many RTMed USB chargers and USB controller devices cannot pass this test without making design adjustments. This application report introduces solutions to pass the MFi OCP test based on TPS2583x/4x-Q1. These methods can be used as reference for other USB controllers and USB switches.

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1 The Instruction of MFi OCP Requirement

The section discusses the overcurrent and short circuit protection requirements. More information regarding Figure 1 and Table 1 through Table 3 can be found in the *Overcurrent and Short Circuit Protection* chapter of the Accessory Design Guidelines for Apple Device Specification.

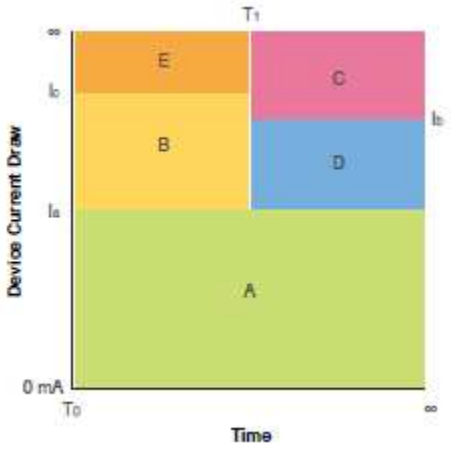

Figure 1. Overcurrent and Short Circuit Protection

Power-providing accessories must implement overcurrent and short circuit protection for each region as listed in Table 1 through Table 3.

Table 1. Overcurrent/Short Circuit Protection Current Thresholds

Threshold	Definition
I_a	Nominal accessory output current (1000 mA, 2100 mA, 2400 mA, 3000 mA)
I_b	I_a + 60%
I_c	Lowest device current draw that causes accessory output voltage (measured at Lightning Device Power) to drop below 2 V.

Table 2. Overcurrent/Short Circuit Protection Time Thresholds

Threshold	Definition
T_0	Start of any device current draw transient.
T_1	Accessory overcurrent/short circuit deglitch/debounce time, must ≥ T_0 + 1 ms.

Table 3. Overcurrent/Short Circuit Protection Time Thresholds

Threshold	Name	Definition
A	Normal Operation	Accessory must not limit or shutdown output current.
B	Overcurrent Transient	Accessory must not shutdown output current. Accessory may limit output current to I_a or higher.
C	Overcurrent	Accessory must shut down output current.
D	Potential Overcurrent	Accessory must shut down output current.

Table 3. Overcurrent/Short Circuit Protection Time Thresholds (continued)

Threshold	Name	Definition
E	Portential Short Circuit	If Lightning Device Power voltage drops below 2 V, the accessory may trigger short circuit protection. Accessories must not trigger short circuit protection on device current draw.

The above descriptions divide different load conditions into several regions and indicate the accessory behavior of different regions. The problems faced by customers in the certification process are mainly related to region B. Region B is an overcurrent transient region that needs the accessory to not shut down the output current during .1 ms overcurrent load.

2 Test Standard and Requirements

The following test setup and requirements are based on the TPS2583X/4X-Q1 EVM to pass MFi OCP test:

1. The test load waveform is shown in Figure 2.
2. The test setup between the TPS2583x/4x-Q1 EVM and E-load includes lightning cable, test connection board. The setup as Figure 3.
3. In practice, whether the test is passed is determined by whether the voltage at the E-load drops to 0 V.
4. Due to the voltage drop on the cable and some characteristic of the connection board, the output voltage of TPS2583x/4x-Q1 should be higher to pass the test.

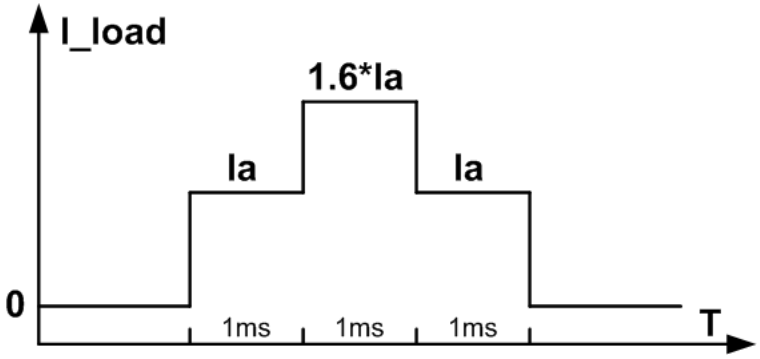

Figure 2. Load Waveform of MFi OCP Test

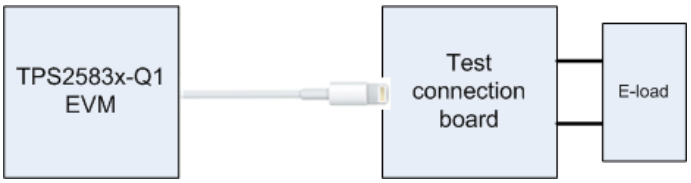

Figure 3. TPS2583x/4x-Q1 EVM MFi OCP Test Setup

3 The Solution to Pass MFi OCP Test

Due to the load waveform of the OCP test related to I_a, the different applications need to be sorted by current. For standard USB type-A and type-C applications, the typical current type is 1.5A, 2.1A, 2.4A and 3A. Previously, you needed to respond quickly to overcurrent by either turning off the output voltage or limiting the current. Now, to pass the MFi OCP test, the device should not shutdown the current and the voltage cannot have a big drop. In view of this situation, here are two solutions:

- Increase the current limit point higher than 1.6*Ia, when the IC support 1.6*Ia continues current.
- Set the normal current limit, such as 1.2*Ia, paralleling RC with Rlimit to delay the current limit response. This solution can apply to just TPS2583x/4x-Q1.

These two solutions are the main ideas. Sometimes, capacitors need to be added to make up the IC limitations. I will use TPS25830-Q1 EVM board to do experiments to verify the above two methods, we have set the cable compensation on the EVM board, so you can see that the output voltage has a little changes with load current in the later test result. For more information on this board, see the *TPS25830-Q1 Evaluation Module User's Guide.* The main points to be mentioned in this application report are shown in Figure 4.

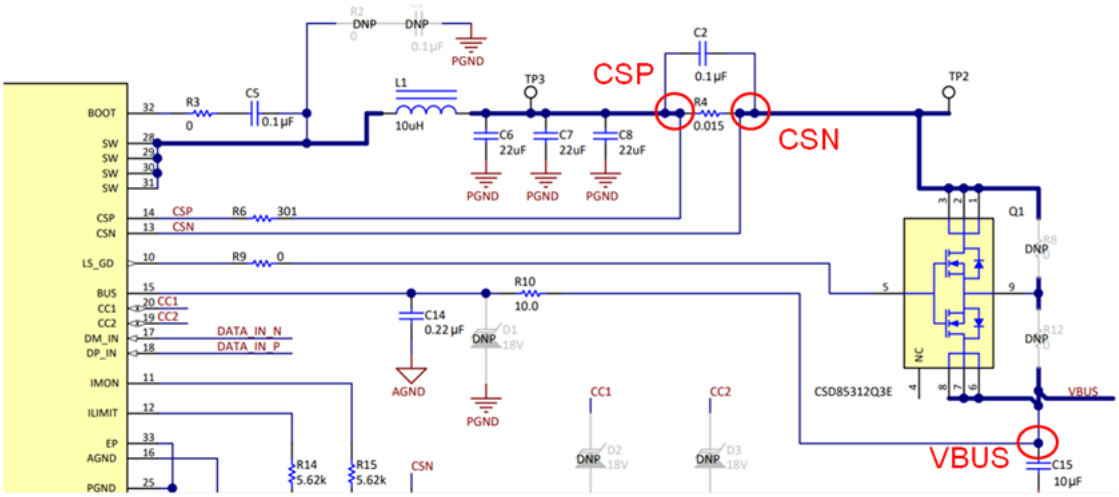

Figure 4. Key Test Points

3.1 Solution 1: Increasing Current Limit Point Higher Than 1.6*Ia

This solution is easy to understand. When the current limit point is higher than 1.6*Ia, the IC will not do any response to the OCP test. What you need to consider is whether or not the IC can support 1.6*Ia at a continuous current. TPS2583x/4x-Q1 internal FET has a peak current limit. If 10 µH inductors are used as EVM, it can support 4.5A maximum continuous output current. So, the solution can be summarized as shown in Table 4.

Table 4. Set Higher Current Limit

I_a of USB Port	Methods (set current limit .1.6*Ia)
1.5A	Set current limit > 2.4A
2.1A	Set current limit >3.36A
2.4A	Set current limit > 3.84A
3A	Set current limit > 4.8A and add 330 µF cap on CSP

Below are the test results of the four cases listed in Table 4.

- For the 1.5A USB port, set the current limit to 2.45A with external FET, the Vbus does not have any drop under the certification load.

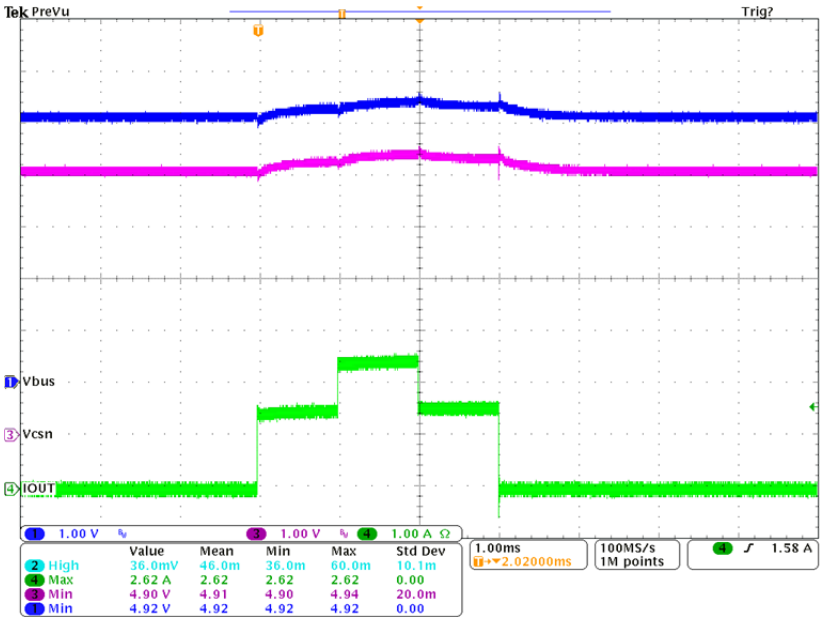

Figure 5. Set 2.45A Current Limit for 1.5A Port

- For the 2.1A USB port, set the current limit to 3.45A with external FET. The Vbus does not have any drop under the certification load.

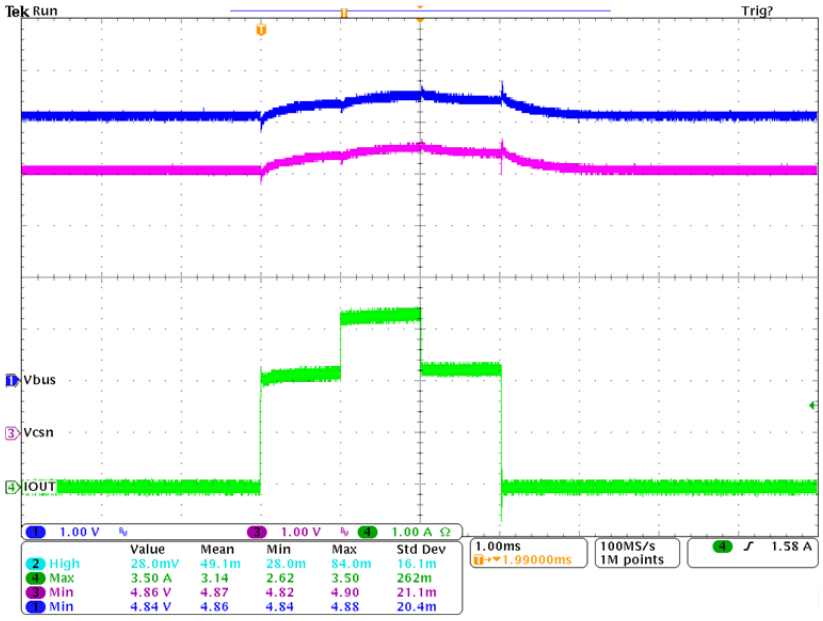

Figure 6. Set 3.45A Current Limit for 2.1A Port

- For the 2.4A USB port, set the current limit to 3.96A with external FET. The Vbus does not have any drop under the certification load.

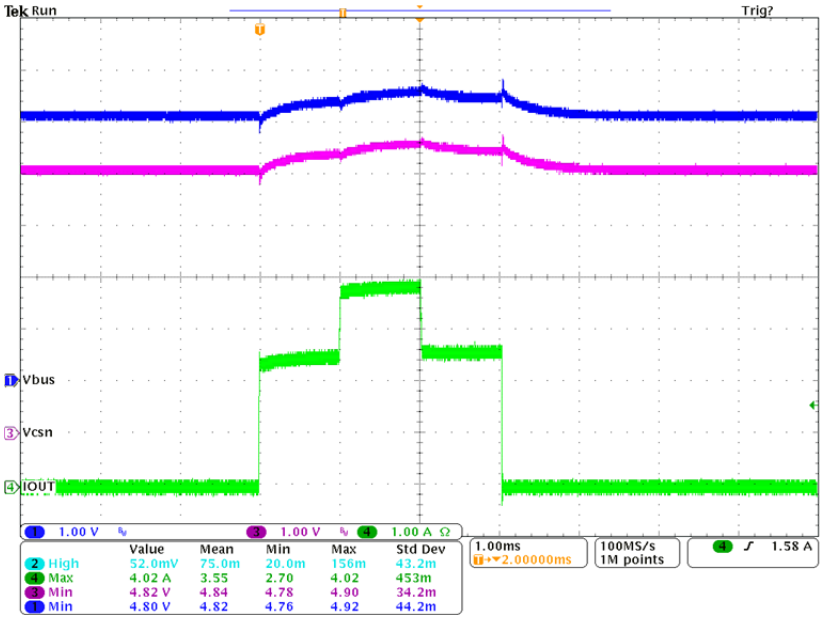

Figure 7. Set 3.96A Current Limit for 2.4A Port

- For the 3A USB port, set the current limit to 5A with external FET, and add 330 µF cap on CSP. The Vbus drops to 4.18 V under the certification load. For the 3A port, 1.6*Ia is 4.8A. It is higher than 4.5A (the maximum continuous output current of TPS2583x/4x-Q1). Cap needs to be added to make sure the voltage drop is within the acceptable range during the 1 ms overcurrent.

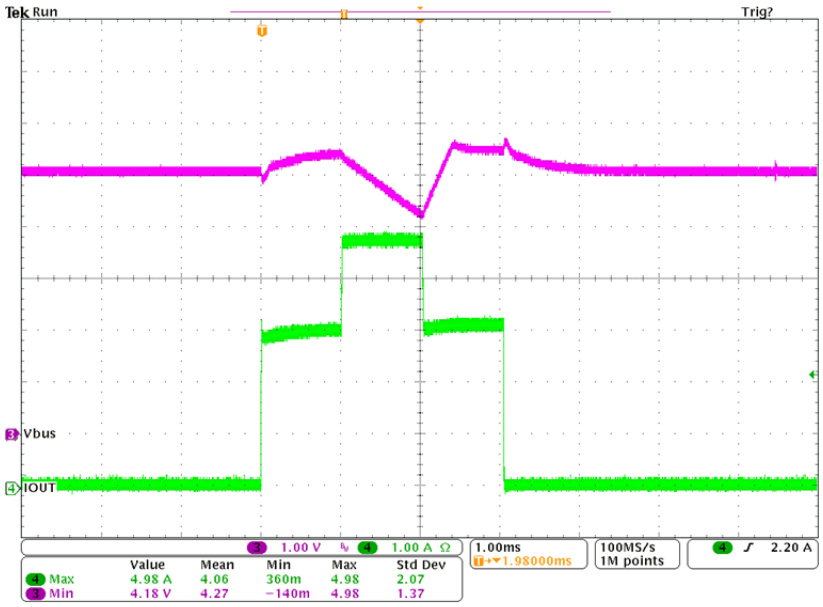

Figure 8. Set 5A Current Limit, and Add 330 µf Cap on CSP for 3A Port

Overall, increasing the current limit higher than 1.6*Ia is a solution with the least change to the schematic to pass the MFi OCP test. However, it has an obvious limitation that some devices cannot support 1.6*Ia continuous output current. Extra capacitance needs to be added to make up for this limitation. At the same time, some customers do not want to set the current limit so high, even if it does not affect the IC function. They prefer to set a current limiting value similar to Ia, such as 1.2*Ia. Solution 2 is for the application of setting small current limit point.

3.2 Solution 2: Paralleling RC With Rlimit to Delay the Current Limit Response

This solution just can apply to TPS2583x/4x-Q1. TPS2583x/4x-Q1 is based on the voltage of Rlimit to determine whether or not it is overcurrent, as shown in Figure 8. So if you can delay the voltage rise, you can delay the current limit response. Think of parallel capacitors with Rlimit to achieve the delay. However, the internal circuit of the ILIMIT pin is a current source circuit. If you just parallel a capacitor with Rlimit as shown in Figure 9, it will introduce a pole into the current limit circuit as shown in Equation 1. The attenuation of gain and phase by pole will affect the loop stability. In order to eliminate the effect of the pole, you can add a resistor in the series with the capacitor to add a zero, as shown in Figure 10. This resistor introduces an additional zero point to reduce the influence of the pole, as shown in Equation 2. In order to ensure that the positions of zero and pole are close, setting Rpara = Rlimit is recommended. From the test result to ensure delay 1 ms, 82 nF is a suitable value for Cpara. In this section, the response under certification load is tested when using external FET or no external FET.

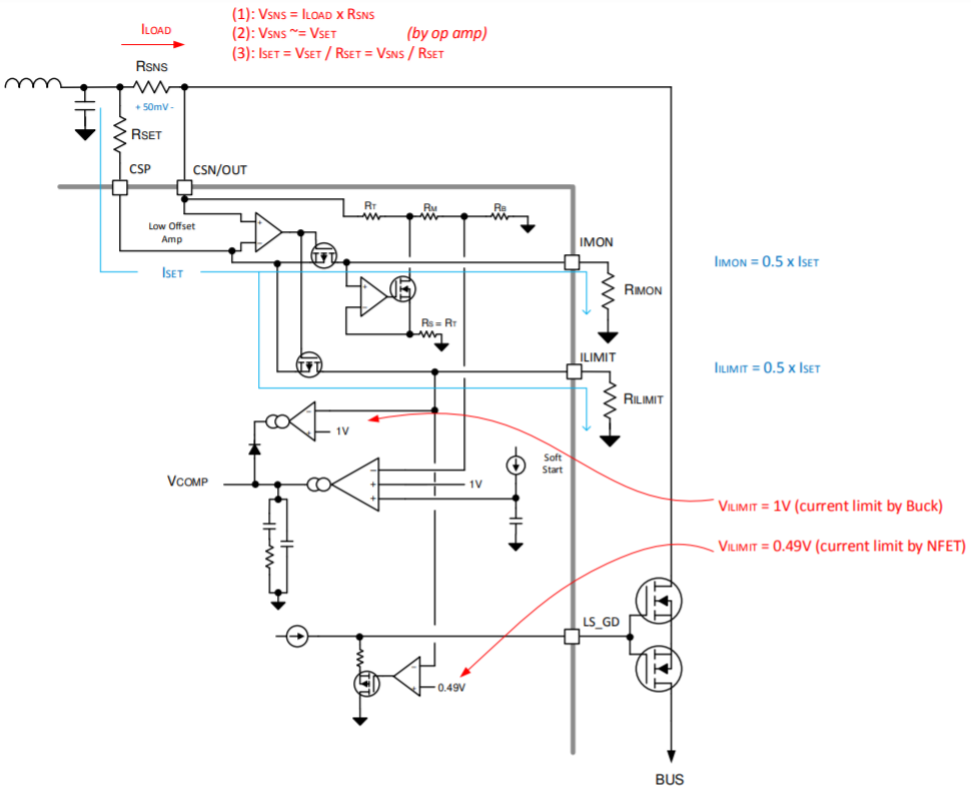

Figure 9. Current Limit Function Diagrams

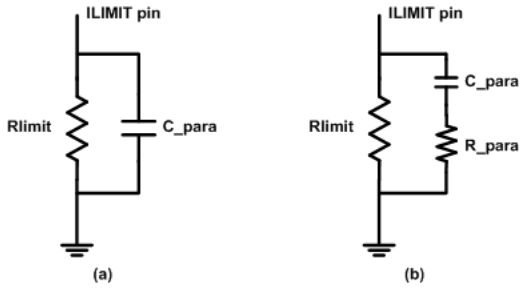

Figure 10. Parallel RC Circuit

$$\frac{V(s)}{I(s)} = \frac{R_{limit}}{1+sC_{para}R_{limit}} \quad \text{Formula 1} \quad (1)$$

$$\frac{V(s)}{I(s)} = \frac{R_{limit}\times(1+sC_{para}R_{para})}{1+sC_{para}(R_{limit}+R_{para})} \quad \text{Formula 2} \quad (2)$$

3.2.1 For the 1.5A USB Port With External FET

For the 1.5A USB port, set current limit to 1.8A with external FET, parallel 10.7 kΩ + 82 nF RC with 10.7kΩ Rlimit. The Vbus does not have any drop under the certification load.

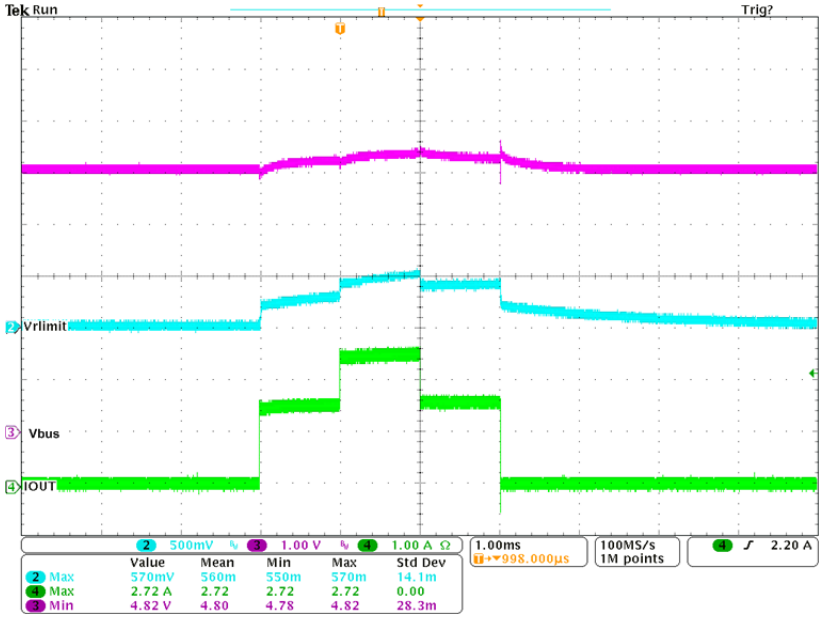

Figure 11. Set 1.8A Current Limit for 1.5A Port With External

3.2.2 For the 1.5A Port Without External FET

For 1.5A USB port, set the current limit to 1.8A without external FET, parallel 21.5kΩ + 82 nF RC with 21.5kΩ Rlimit. The Vcsn does not have any drop under the certification load.

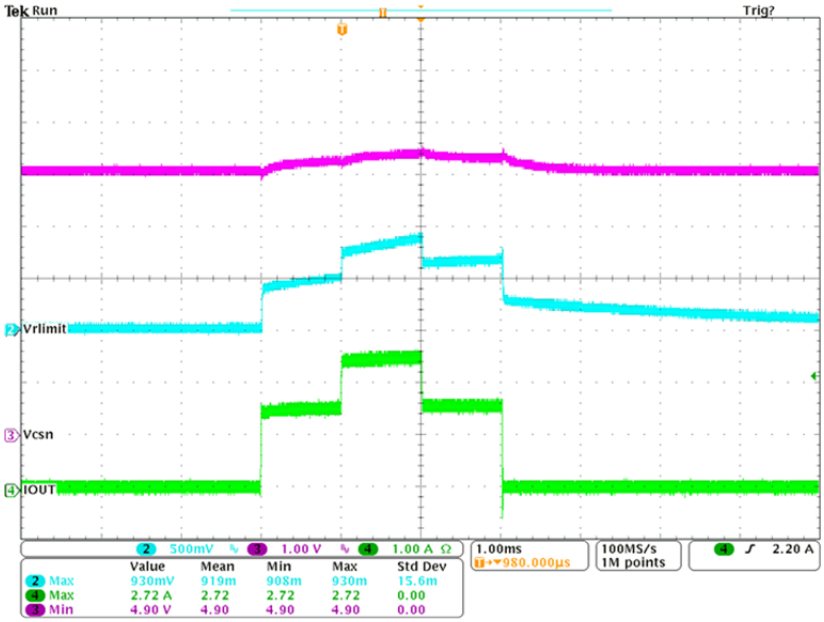

Figure 12. Set 1.8A Current Limit for 1.5A Port Without External FET

3.2.3 For 2.1A USB Port With External FET

For 2.1A USB port, set the current limit to 2.52A with external FET, parallel 7.68kΩ + 82 nF RC with a 7.68kΩ Rlimit. The Vbus does not have any drop under the certification load.

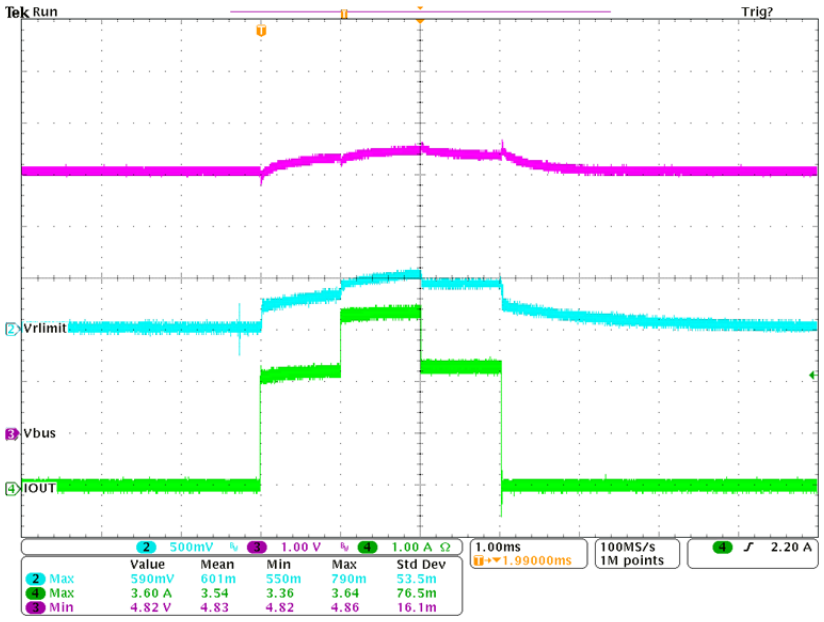

Figure 13. Set 2.52A Current Limit for 2.1A Port With External

3.2.4 For 2.1A USB Port Without External FET

For 2.1A USB port, set the current limit to 2.52A without external FET, parallel 15.8kΩ + 82 nF RC with a 15.8kΩ Rlimit. The Vcsn does not have any drop under the certification load.

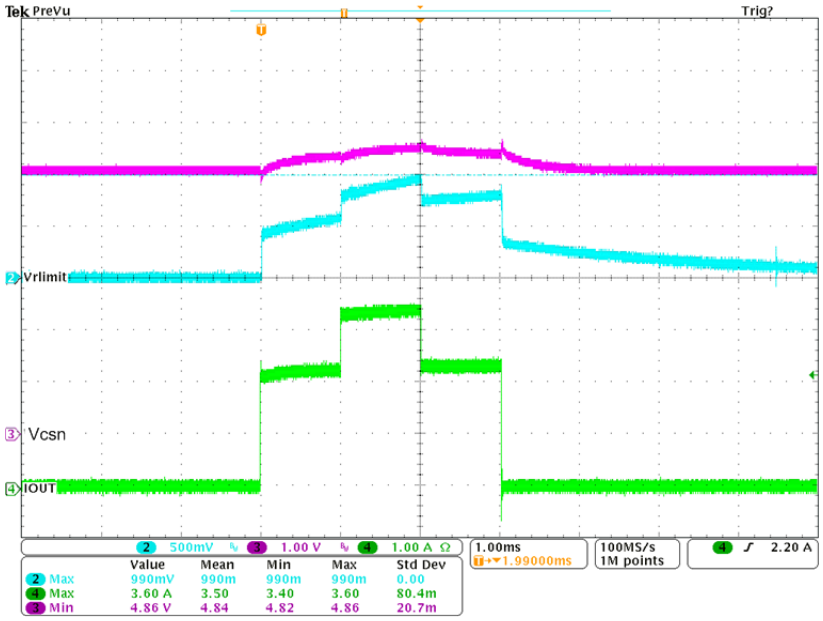

Figure 14. Set 2.52A Current Limit for 2.1A Port Without External FET

3.2.5 For 2.4A USB Port With External FET

For 2.4A USB port with external FET, set current limit to 2.88A with external FET, parallel 6.65kΩ+82nF RC with 6.65kΩ, the Vbus doesn't have obvious drop under the certification load.

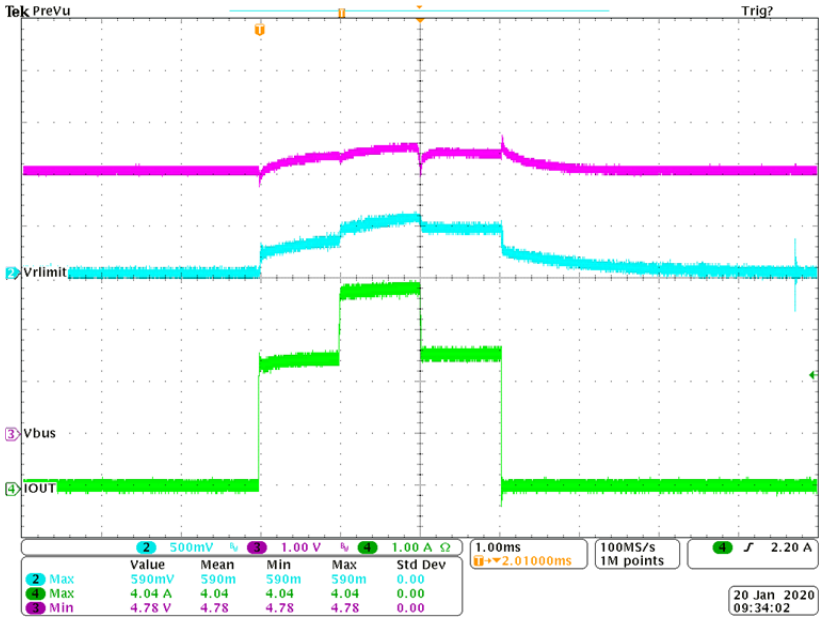

Figure 15. Set 2.88A Current Limit for 2.4A Port With External FET

3.2.6 For 2.4A USB Port Without External FET

For 2.4A USB port, set the current limit to 2.88A without external FET, parallel 13.7kΩ + 82 nF RC with 13.7kΩ Rlimit. The Vcsn does not have any drop under the certification load.

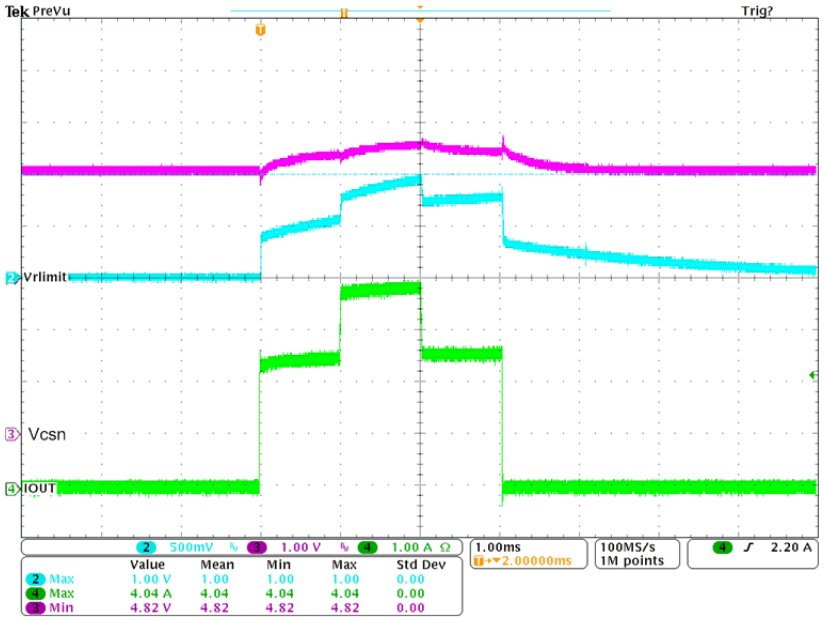

Figure 16. Set 2.88A Current Limit for 2.4A Port Without External FET

3.2.7 For 3A USB Port With External FET

For 3A USB port with external FET, set current limit to 3.5A with external FET, parallel 3.5kΩ+220nF RC with 5.49kΩ Rlimit, the Vbus drop to 3.96V under the certification load.

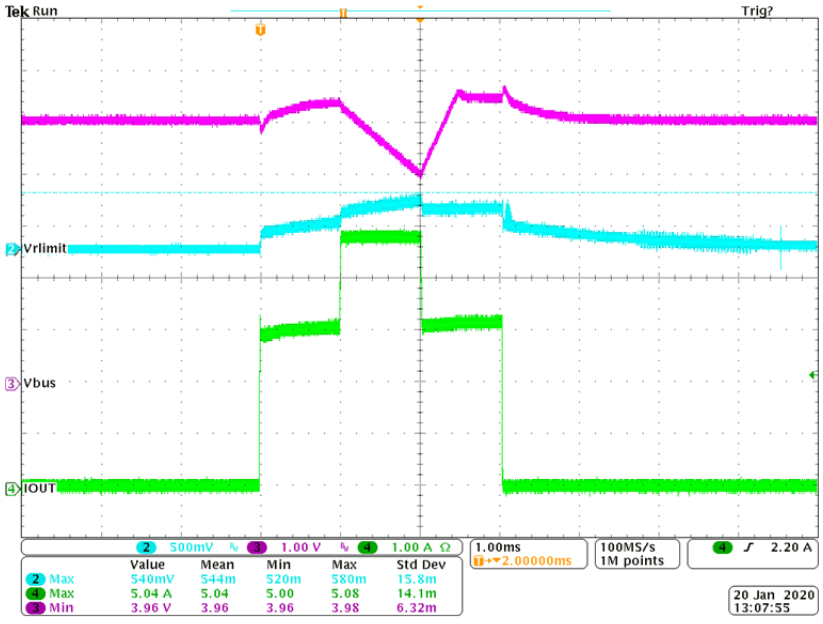

Figure 17. Set 3.5A Current Limit for 3A Port With External FET

3.2.8 For 3A USB Port Without FET

For 3A USB port, set the current limit to 3.5A without external FET, parallel 11.3kΩ + 82 nF RC with 11.3kΩ Rlimit. The Vcsn drop is 4.02 V under the certification load.

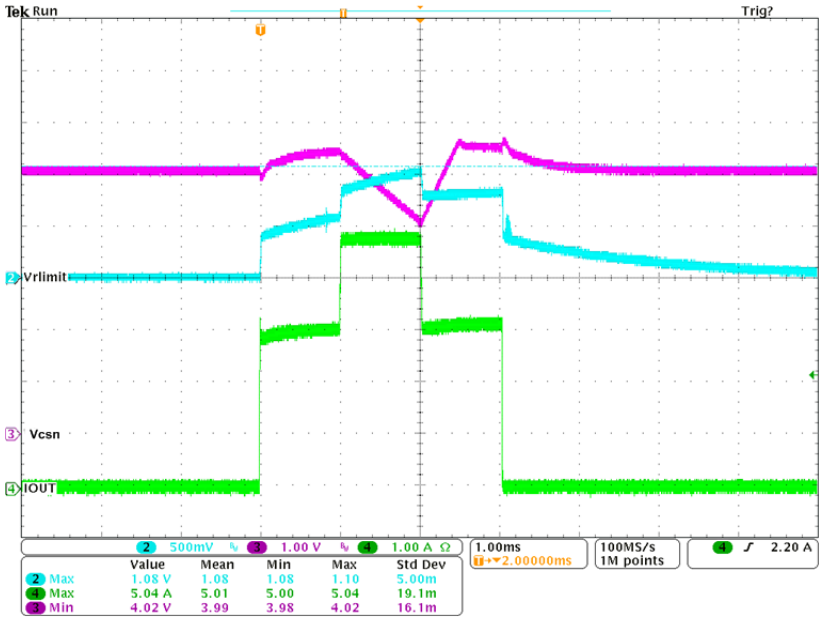

Figure 18. Set 3.5A Current Limit for 3A Port Without External FET

According to above test results, solution 2 can be summarized as shown in Table 5.

Table 5. Summary of Solution 2

Solution and Result	With External FET-- Rlimit//(Rpara+Cpara)	Without External FET--Rlimit//(Rpara+Cpara)
1.5A port (1.8A current limit)	10.7kΩ//(10.7kΩ + 82nF) Result: Vbus no drop	21.5kΩ//(21.5KΩ + 82nF) Result : Vcsn no drop
2.1A port (2.52A current limit)	7.68kΩ//(7.68kΩ + 82nF) Result: Vbus no drop	15.8kΩ//(15.8kΩ + 82nF) Result: Vcsn no drop
2.4A port (2.88A current limit)	6.65kΩ//(6.65kΩ + 82nF) Result: Vbus no drop	13.7kΩ//(13.7kΩ + 82nF) Result: Vcsn no drop
3A port (3.5A current limit)	5.45kΩ//(3.5kΩ + 220nF) add 330 µf on CSP Result: Vbus drop to 3.96V	11.3kΩ//(11.3kΩ + 82nF) add 330 µf on CSP Result: Vcsn drop to 4.02 V

4 Summary

This application report summarizes two solutions to pass the MFi OCP test based on TPS2583x/4x-Q1. Solution 1 can also apply to other USB power switches and USB controllers, such as TPS2556-Q1, TPS2549- Q1 and TPS254900-Q1, and so forth. Solution 2 just applies to TPS2583x/4x-Q1. At the same time, new devices are being developed for the latest MFi OCP requirements. You can get the latest USB IC from TI usbpower- switches-charging-port-controllers.

5 References

- *TPS25830-Q1 Evaluation Module User's Guide.*
- Accessory Design Guidelines for Apple Device Specification

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