1 GENERAL

1.1 PURPOSE

The purpose of this reference design test report is to provide detailed data for evaluating and verifying the TI Designs number 00160. This reference design uses the Texas Instruments buck controller LM25117 and the TPS2546 to compensate for cable resistive losses to provide a stable 5V supply to USB devices. Compared to some other solutions, this design has the advantage that the cable compensation is linear with load current, which will stabilize the voltage delivered to the USB load better than step-wise methods of cable compensation.

1.2 REFERENCE DOCUMENTATION

Schematic PMP4399_SCH.PDF
Assembly PMP4399_PCB.PDF

1.3 TEST EQUIPMENT

Multi-meter(current): Fluke 287C*2
Multi-meter(voltage): Agilent 34401A
DC Source: GPS 3303C
E-Load: Chroma 63101 module
USB device as load
USB charging port cable – 2 meters in length

2 Performance data and waveform

2.1 EFFICIENCY

The efficiency is tested with 19V input voltage. For light loads, the efficiency is less critical, as there is little power dissipation. As the load current increases, the efficiency increases to 90% or better.

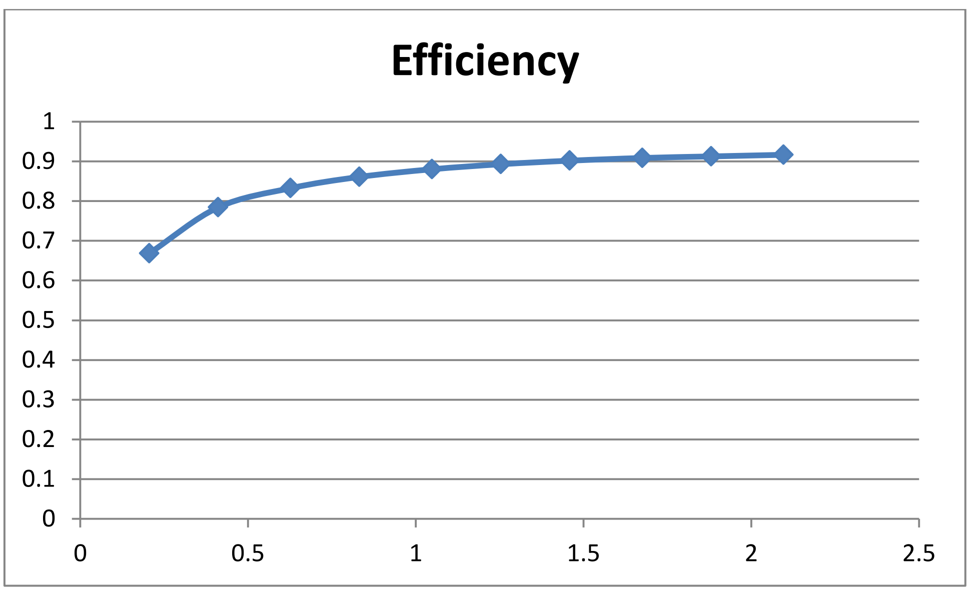

Figure 1 Efficiency versus load current (in Amps)

2.2 Cable compensation with different output currents

Figure 2 shows the effect of the output voltage compensation feature. Ideally, the Vcc supplied to the load end of the USB cable will not vary with the load current. The figure shows that without compensation, the Ohmic losses in the cable cause the delivered voltage to “droop” below 5V when the load current increases.

The top blue line shows that the DC-to-DC output voltage compensates for cable losses, increasing as the current increases. The middle lines show that the overall voltage at the load, including the compensation and cable loss, gives a very stable Vcc voltage at the USB port, almost independent of the load current.

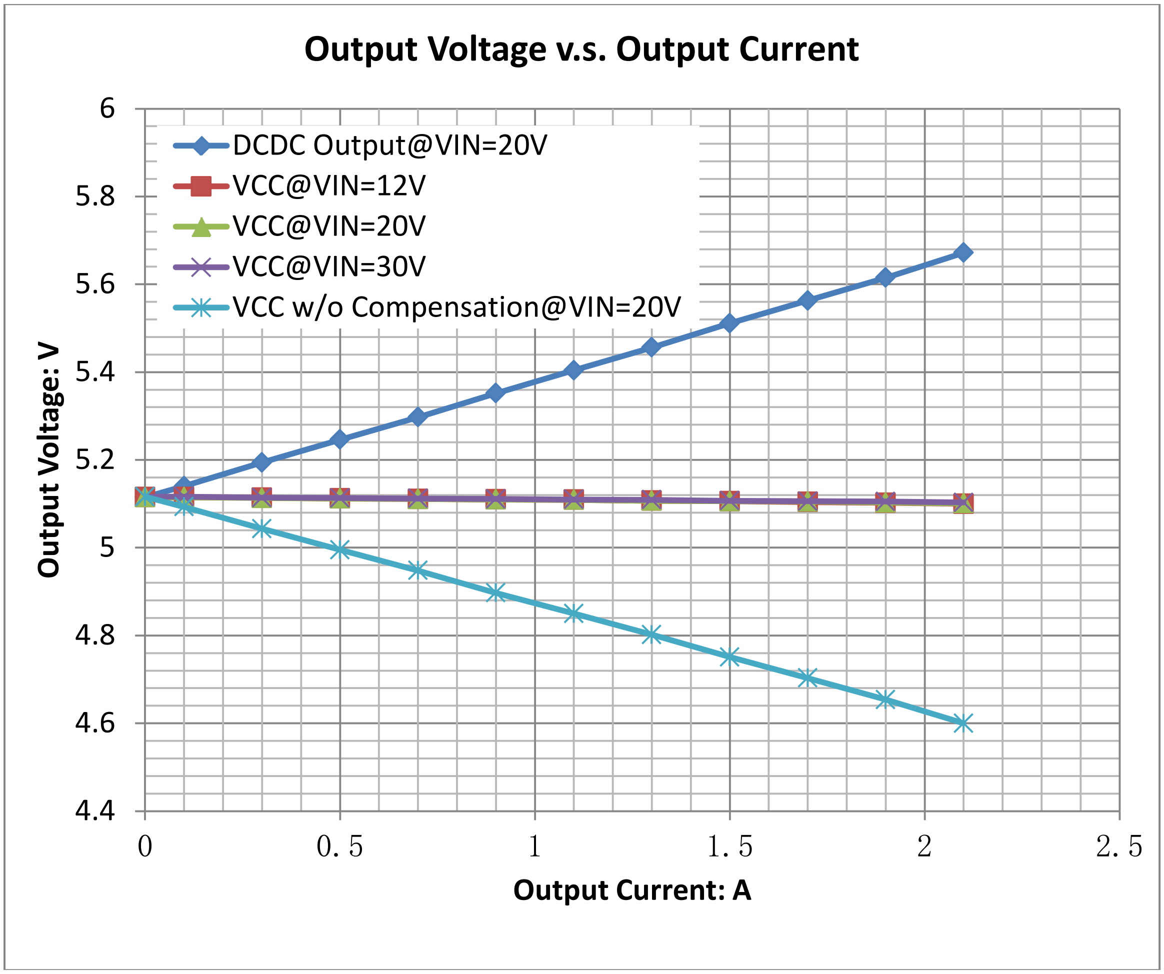

Figure 2 Output compensation versus load current

2.3 Start Up

During start up, the external supply is applied, and the 5V (nominal) output voltage should increase to a final value monotonically, and settle to the desired voltage without significant overshoot. Figure 3 and Figure 4 show the output 5V after a 19V supply is applied to the input. Figure 3 shows the start-up transition with no USB power load. Figure 4 shows the start-up transition after a 19V supply is applied to the input with a full USB load on the output.

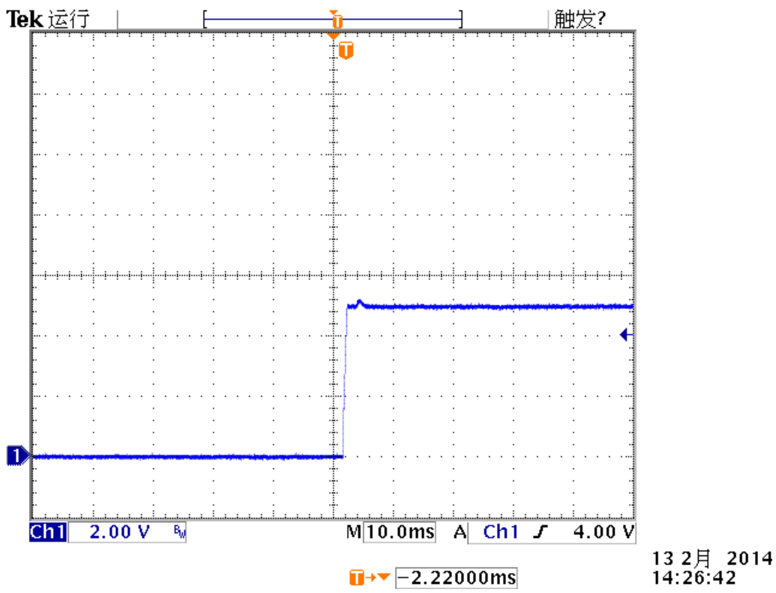

Figure 3 Start-up transition with 19V input and zero load

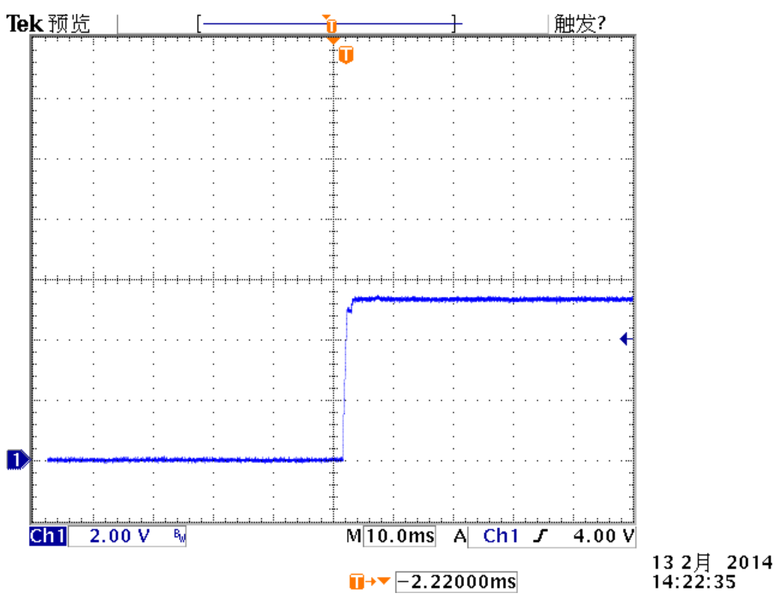

Figure 4 Start-up transition with 19V input and full load (2.1 Amps)

2.4 Shut down

During shut down, the external supply voltage is removed, and the 5V (nominal) output voltage should decrease to a final zero value monotonically, and settle without significant overshoot. Figure 5 and Figure 6 show the output 5V after a 19V supply is removed from the input.

Figure 5 shows the shut-down transition with no USB power load. Note that with no load applied, the charging voltage takes about a second to discharge. The voltage discharges monotonically, with no observable overshoot or oscillation.

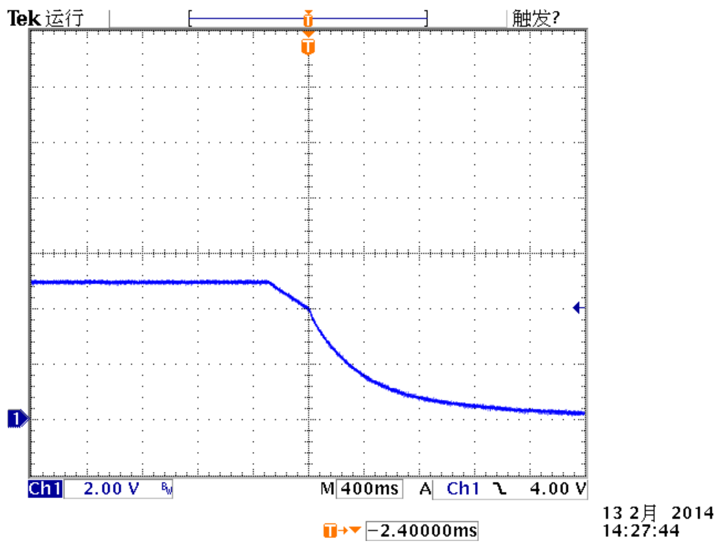

Figure 5 Shut-down transition with 19V input and zero load

Figure 6 shows the shut-down transition after a 19V supply is removed from the input with a full USB load on the output. Note that the supply quickly transitions from a stable charging output to zero, with no appreciable overshoot.

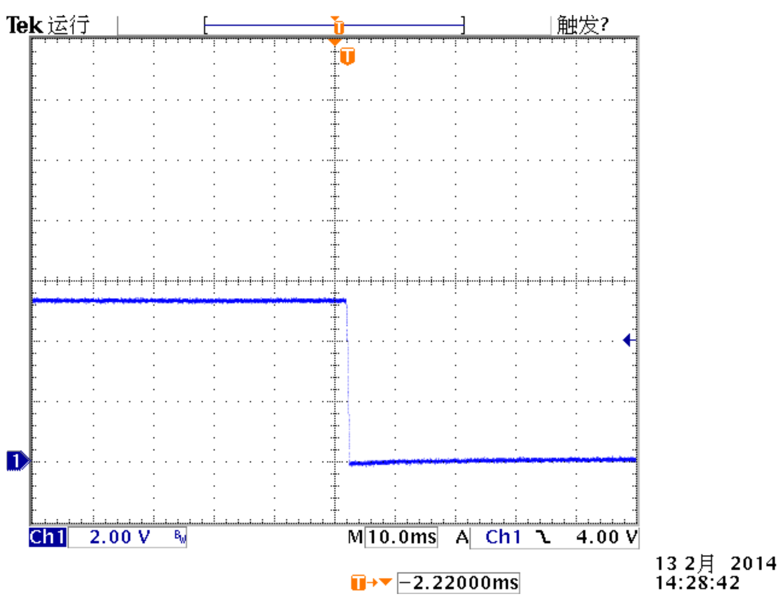

Figure 6 Shut-down transition with 19V input and full load (2.1 Amps)

2.5 Dynamic Performance

The dynamic performance of the USB charging circuit is especially important in situations where more than device is being charged from the same USB charging port. If one device is already being charged, it is desired that the charging voltage does not change significantly if a second load is applied or removed.

Figure 7 shows the response of the output charging voltage as the load is changed rapidly between 10% of full load and 90% of full load. (Changed between load current of 210 mA and load current of 1.9 Amps) Note that in this plot the trace is ac-coupled, so that only the change in the charging voltage is observed.

The plot shows that the total variation in the charging voltage is on the order of 500 mV, or ±5% of the 5V nominal USB charging voltage. The overshoot and ringing during each transition is less than 250 mV on each transition.

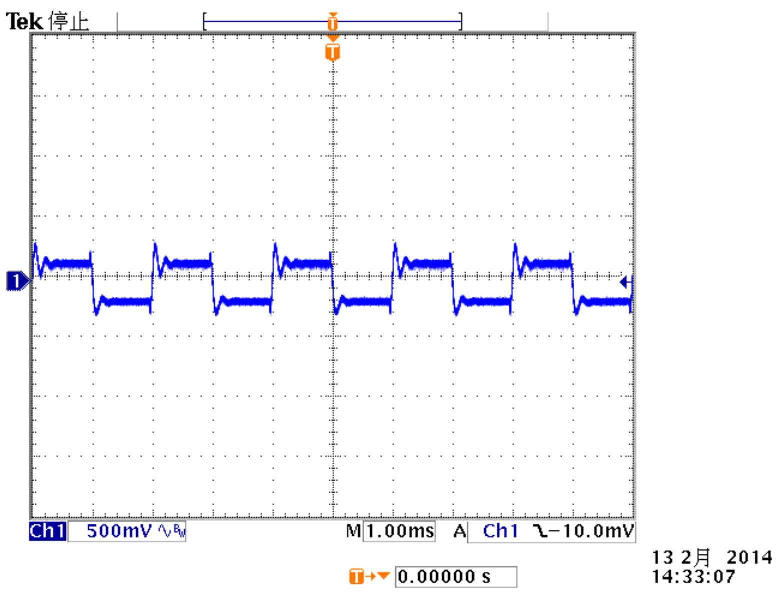

Figure 7 19Vin 10%~90% dynamic load response

In addition to resistive voltage loss on the high-side of the circuit, there is resistance on the return (or ground) side of the cable, so the GND of the board and GND at the USB port's voltage is different. In the following series of figures, measurements of the voltage are recorded at different points along the circuit. These are best referred to in Figure 8, which shows the charging output including a simple model of the 2 meter USB charging cable.

The purpose of the following figures is to measure the differential voltage at the TPS2564 output and at the DC to DC output is to check whether there is any "glitch" which would disrupt charging during the circuit transient.

The measurements in these figures are noted with the following for the different oscilloscope channels:

- POUT_GND is measured at the board output, while reference GND of the probe is at USB port.
- POUT_OUT: probe at TPS2546 output pin
- PIN_OUT: DC to DC output
- PIN: differential voltage at DC t DC output pin
- POUT: differential voltage at TPS2546 output pin;

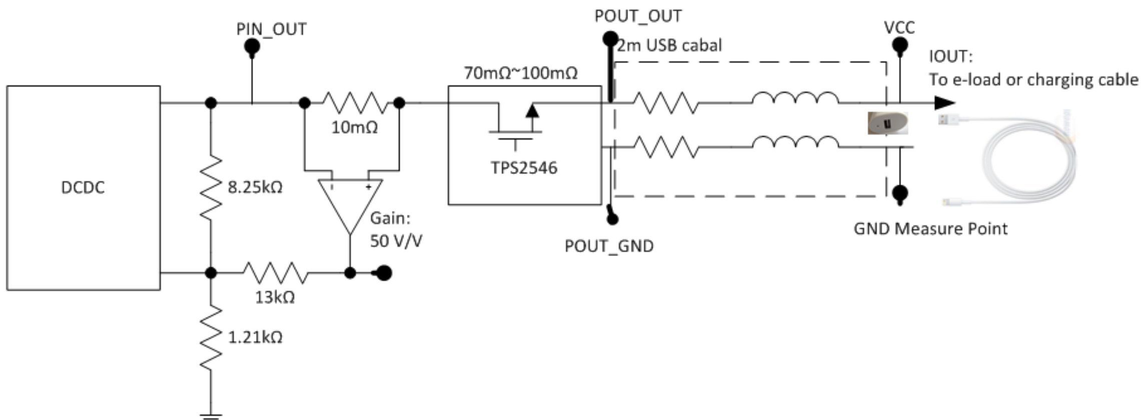

Figure 8 Dynamic load transient measurement scheme

Figure 9 shows the circuit response when the load transitions from no load (0 Amps) to a 2 Amp load. Note that Vcc initially drops due to the increased load, but then recovers to near zero-load conditions within less than 5 ms.

Note that in this case, the “M” trace is the POUT signal, which is a calculated voltage based on the difference between the “POUT_OUT” and “POUT_GND” points. This is of interest for the voltage at the supply side of the 2 meter cable.

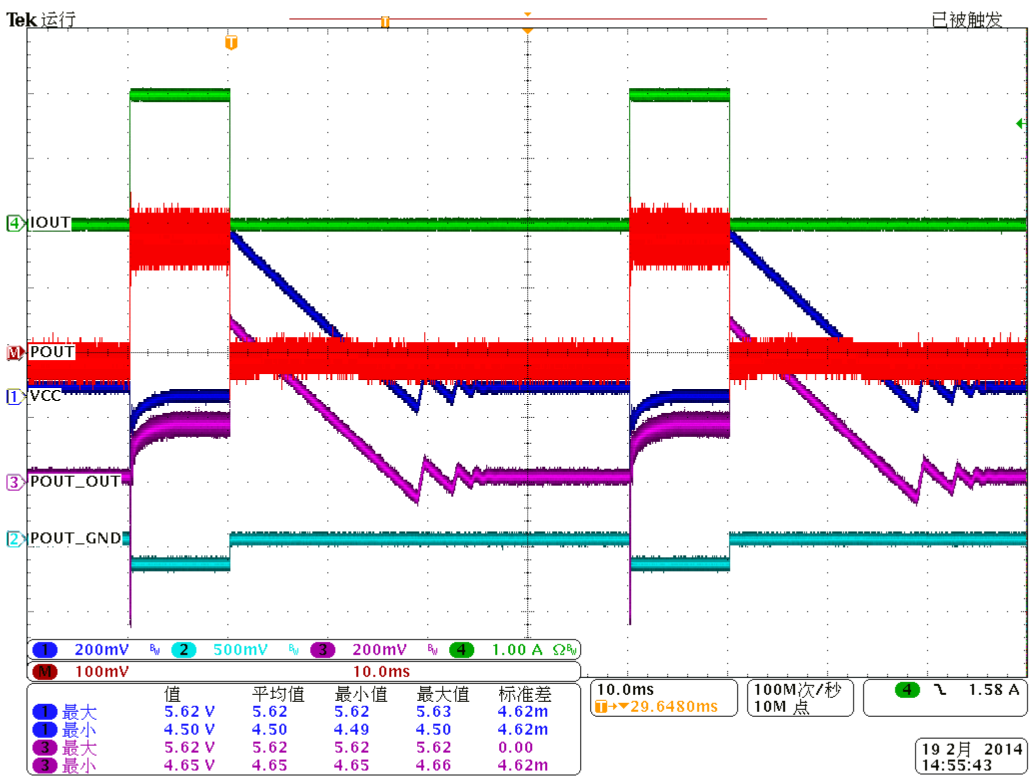

Figure 9 Circuit response with load current transients, 0 Amp to 2 Amp levels

When the load is removed, Vcc initially responds by jumping to a higher level, and then recovers to original level within 15 to 20 ms of the 2A-to-0A load transition.

In Figure 10, the same conditions as above apply, with the difference that the calculated "M" trace is measured at the PIN ("power in" to the TPS2546, power out of the DC/DC) rather than the output of the TPS2546.

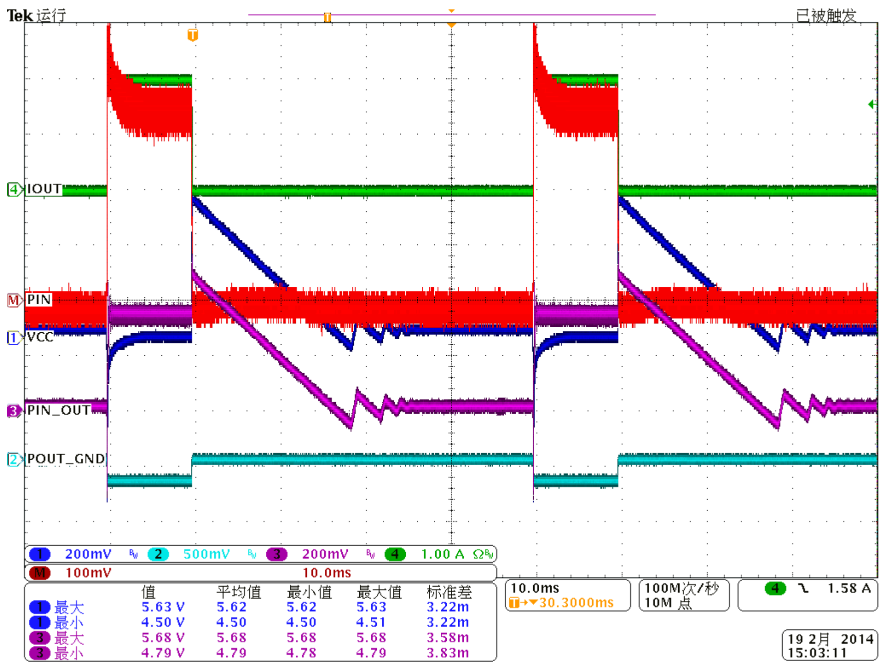

Figure 10 Circuit response with 0 Amp to 2 Amp load transients

The details of the transient of increasing load (0 Amp to 2 Amp) are shown in Figure 11. Note that there is some "ringing" due to small amounts of inductance in the circuit.

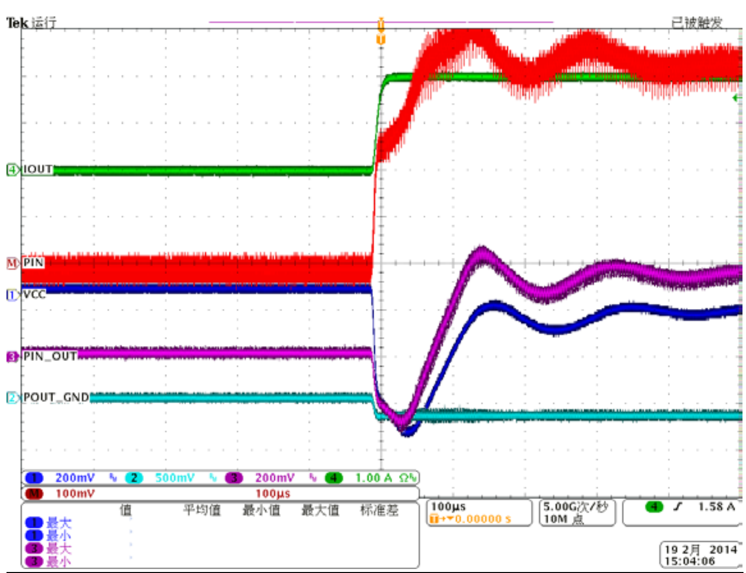

Figure 11 Detail of 0 Amp to 2 Amp load transient

The details of the transient of decreasing load (2 Amp to 0 Amp) are shown in Figure 12Figure 11. Note that there is again a small amount of "ringing" due to stray inductance in the circuit, and that the final voltages take a finite time to decay to zero due to stray capacitance of the circuit and cable.

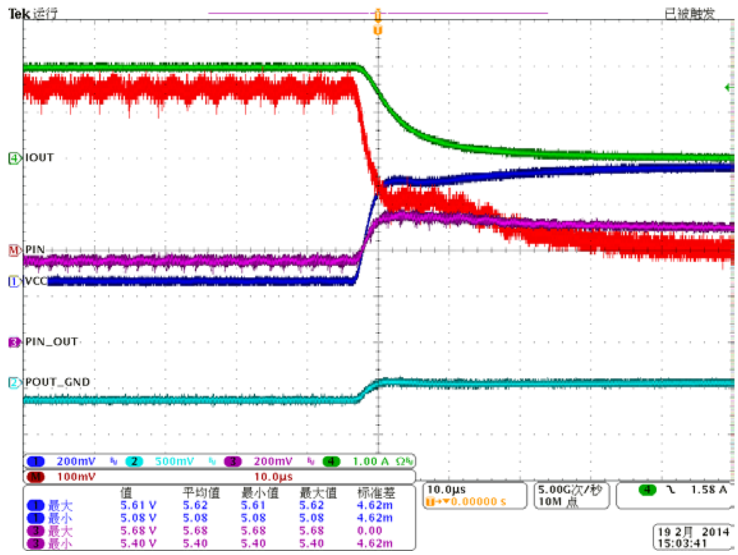

Figure 12 Detail of 2 Amp to 0 Amp load transient

2.6 OUTPUT Voltage Ripple

The output ripple during operation should be minimized; the oscilloscope plots in Figure 13 and Figure 14 show the output ripple under two conditions; in the first case the charging output is unloaded, and in the second case the charging voltage is fully loaded.

Note that for the unloaded case, the total peak-to-peak ripple is less than 30 mV.

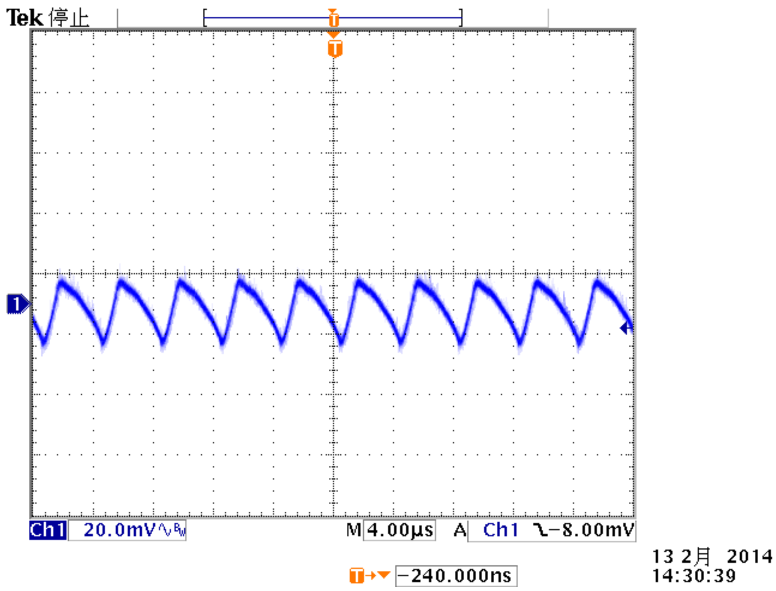

Figure 13 19V in zero load ripple

Note that for the fully loaded case, the total peak-to-peak ripple is less than 50 mV. This is illustrated in Figure 14.

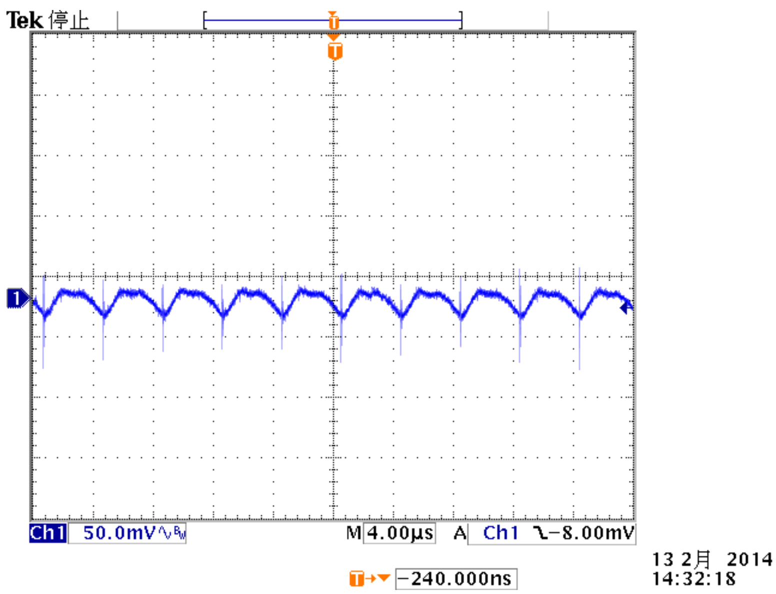

Figure 14 19V in full load (2.1 A load current) ripple

2.7 Charging Current

To validate the system performance with an actual USB device as a load, the test set-up of Figure 15 was used. The ultimate load is a tablet device. The connection of interest is the cable between the charging circuit and the USB charging port, which is through a typical 2 meter USB cable.

Figure 15 USB device charging test set-up

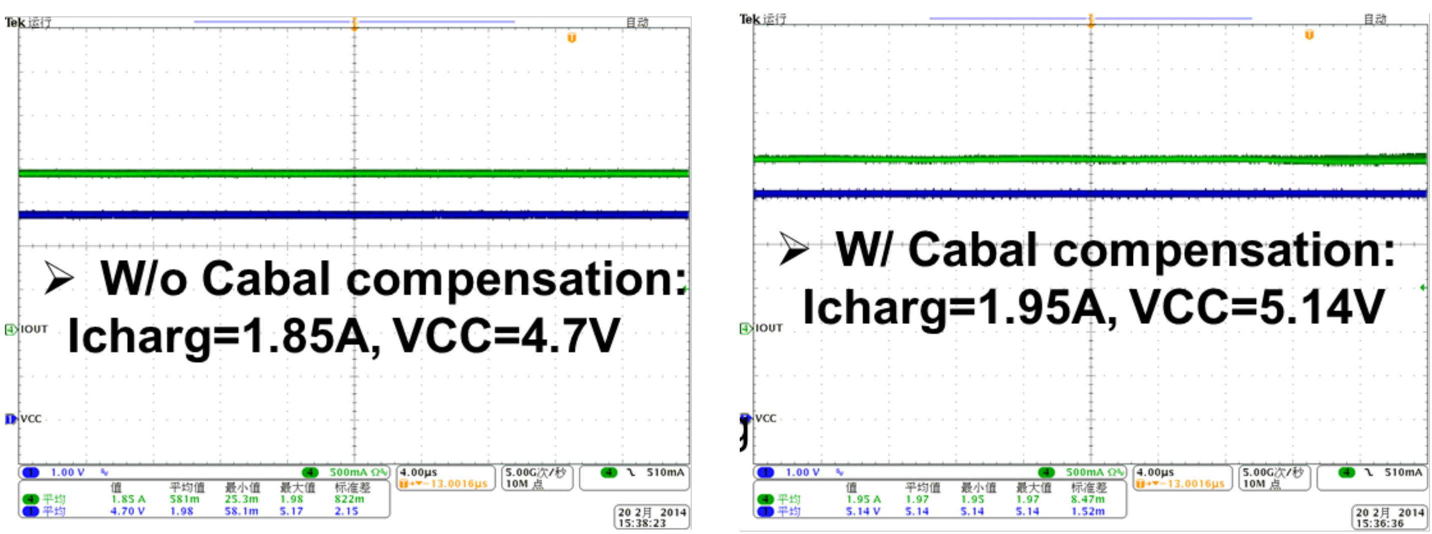

Figure 16 USB charging tests –
(left) without cable compensation (right) with cable compensation

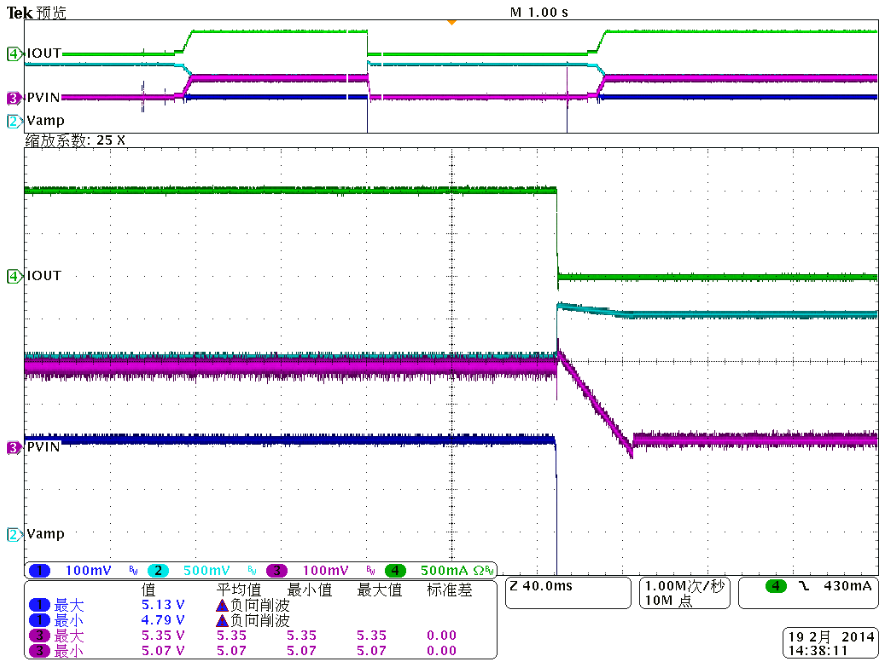

Figure 17 Circuit response with tablet attach (plug-in) event (DCP_Auto Mode change)

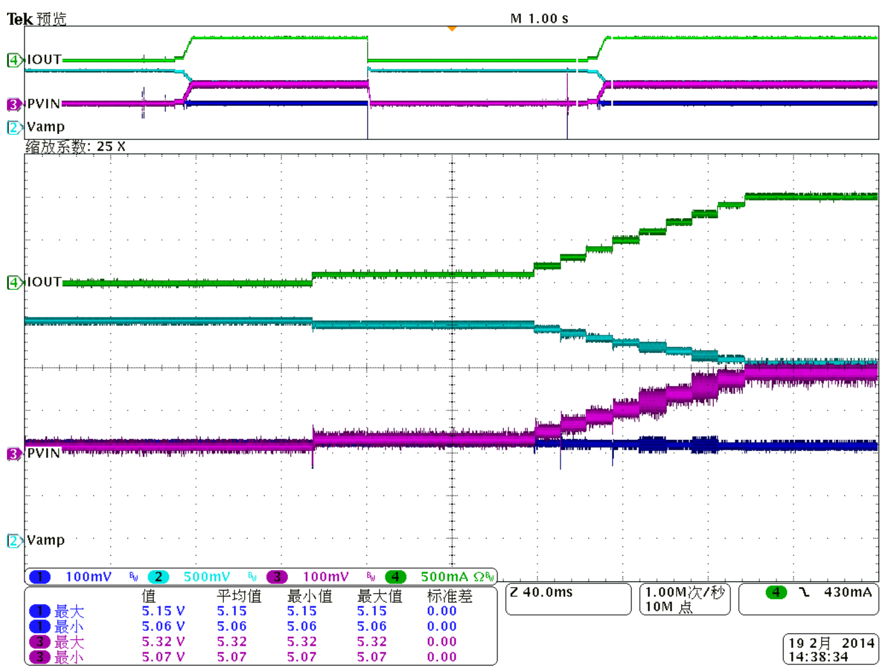

Figure 18 Circuit response during tablet attach (plug-in) event
- Vcc compensated during plug-in step increase loading current

The oscilloscope plots in Figure 19 and Figure 20 show the response when the load is removed. In Figure 19, the USB load (tablet) is unplugged from the tablet cable (the white cable in Figure 15), which remains plugged into the USB charger cable (the black cable in Figure 15).

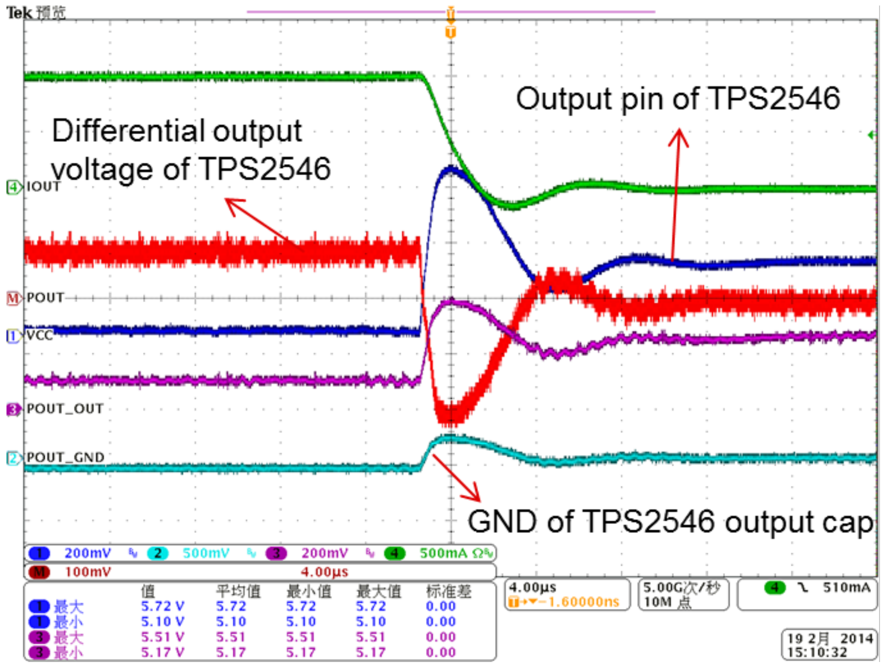

Figure 19 Circuit response during tablet un-attach (plug-out) event - tablet unplugs from device cable

In Figure 19, the oscilloscope traces show the circuit response when the USB load (tablet) and tablet cable (the white cable in Figure 15), are un-plugged from the USB charger port cable (the black cable in Figure 15).

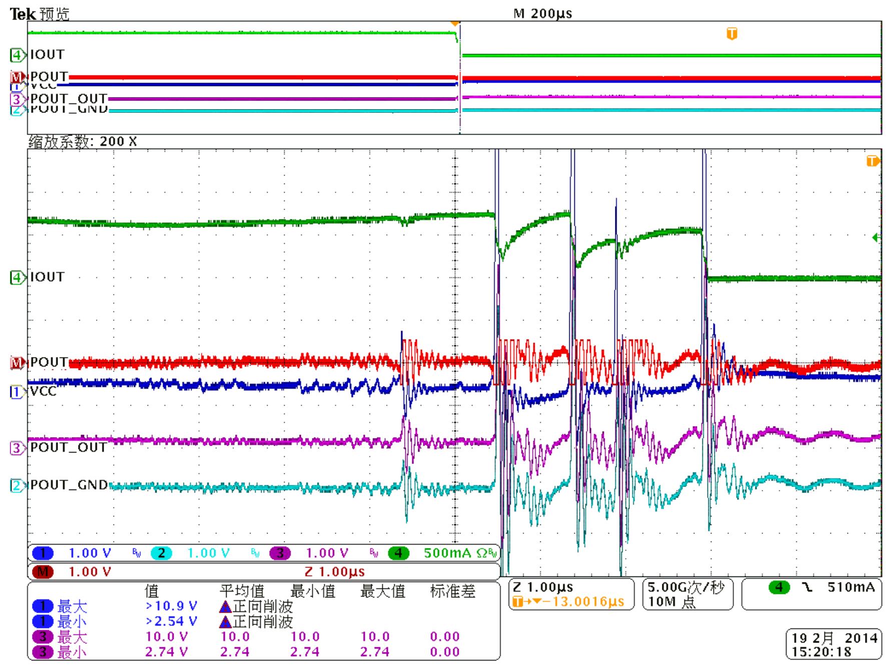

Figure 20 Circuit response during tablet un-attach - device cable unplugs from USB charging port

3 Conclusions:

1. After optimizing the circuit, the voltage compensation ranges to about 500mV at a maximum of 2.1 Amp loading condition.
2. With cable compensation, the charging current will be larger than un-compensated tablet charger.
3. When the USB load (smart-phone or tablet) plug is removed from the charging cable, the overshoot caused by parasitic inductance and resistance is about 600mV. This voltage is NOT canceled by DC/DC loop or current sense loop.