Test Report: PMP22125

Battery Back-up Switch, Charger and Monitor Reference Design

Description

A complete battery back-up, charger and monitoring are implemented with this reference design. It includes switching between a 12/24-VDC source and 12/24-V lead acid battery, constant current battery charging at 1-A typical, battery maintenance float charge and monitoring circuits for the input source and battery.

Test Prerequisites

1.1 Voltage and Current Requirements

Table 1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
12 Vdc input voltage	8.5-17.5 Vdc
12 Vdc input current	16 A continuous
24 Vdc input voltage	18.5-36.5 Vdc
24 Vdc input current	16 A continuous
12 V battery input voltage	10.5-15.0 Vdc
12 V battery input current	16 A continuous
12 V battery float charge voltage	14 Vdc typical
24 V battery input voltage	21.0-30.0 Vdc
24 V battery input current	16 A continuous
24 V battery float charge voltage	28 Vdc tpical
12/24 V battery charging current	1A typical

1.2 Required Equipment

- Isolated DC power source, 0-40 V, 20 A minimum
- Lead acid battery, 12 Vdc, 7 Ahr (2 required for 24 V operation)
- 40 V/30 A electronic load

1.3 Circuit Descriptions

All descriptions referenced to PMP22125 Rev C schematic.

1.3.1 Page 1: Input Line Monitoring

U10 is a window comparator that monitors Vin with a 12 Vdc input. If Vin is between 8.5-17.5 Vdc, 9_18V_OUTA and OUTB are high (5 V). If Vin is less than 8.5 V, OUTA is low; if greater than 17.5 V, OUTB is low.

U12 is a window comparator that monitors Vin with a 24 Vdc input. If Vin is between 18.5-36.5 Vdc, 18_36V_OUTA and OUTB are high. If Vin is less than 18.5 V, OUTA is low; if greater than 36.5 V, OUTB is low.

U8A/B and U13A provide a high signal at VIN_EN when either input is within its specified acceptable range.

U6 monitors the input voltage. When the input is above 18V, 24V_VIN_DIS pulls low, indicating a 24 Vdc input is connected. Load switch U17 is then used to disable the 12 V monitoring circuit.

U9 is an LDO used to power the monitoring circuits and LEDs. Diodes D7 an D12 allow it to be powered from either Vin or Vbat.

D10 is the input status LED. A single multi-color LED for green/within range and red/outside of range is used for both the 12 Vdc and 24 Vdc input.

K1 and K2 are solid state relays that provide an isolated status of the dc input and battery. The VIN_EN and BAT_EN signals are both high when within range. A low resistance (xx ohms typical) between the NO and C terminals indicate the input or battery are within acceptable range. A low resistance between NC and C indicates that the input or battery is out of range.

1.3.2 Page 2: Battery Monitoring

U1 is a window comparator that monitors Vbat with a 12 V battery connected. If Vbat is between 10.5-15.0 Vdc, 12V_OUTA and OUTB are high (5 V). If Vbat is less than 10.5 V, OUTA is low; if greater than 15.0 V, OUTB is low.

U1 is a window comparator that monitors Vbat with a 24 V battery connected. If Vbat is between 21.0-30.0 Vdc, 24V_OUTA and OUTB are high. If Vbat is less than 21.0 V, OUTA is low; if greater than 30.0 V, OUTB is low.

U3A/B and U15A provide a high signal at BAT_EN when either input is within its specified acceptable range.

U14 monitors the battery voltage. When the battery is above 18V, 24V_BAT_DIS pulls low, indicating a 24 V battery is connected. Load switch U18 is then used to disable the 12 V battery monitoring circuit.

D1 is the battery status LED. A single multi-color LED for green/within range, red/outside of range and yellow/charging greater than 150mA is used for both the 12 V and 24 V batteries. BAT_CHRG pulls low when the battery charging current is greater than 150mA.

1.3.3 Page 3: Input to Battery Hot Swap Controllers

The U4 and U5 hot swap circuits are used to switch power output between the dc input and battery back-up. Back to back switches are used to prevent current flow in either direction when the FETs are off. When a dc input is present, VIN_EN is high, turning on U4 and turning off U5. The various protection circuits are explained in the LM5060 datasheet. Note the connection of R30 and R40 to the center tap of the switch FETs. The datasheet shows this connection to Vbat. There is a leakage path through OUT to GATE on the LM5060 that allows the FETs to turn on when they are supposed to be off. An E2E post suggested this fix to avoid unwanted turn on of the FETs. The body diode of Q16/Q18 or Q25/Q29 blocks the voltage that was creating the leakage current. Link to E2E post on back feed issue: https://e2e.ti.com/support/power-management/f/196/t/813947?tisearch=e2e-sitesearch&keymatch=lm5060%2525252520gate

1.3.4 Page 4: Four Switch Buck-Boost Battery Charger

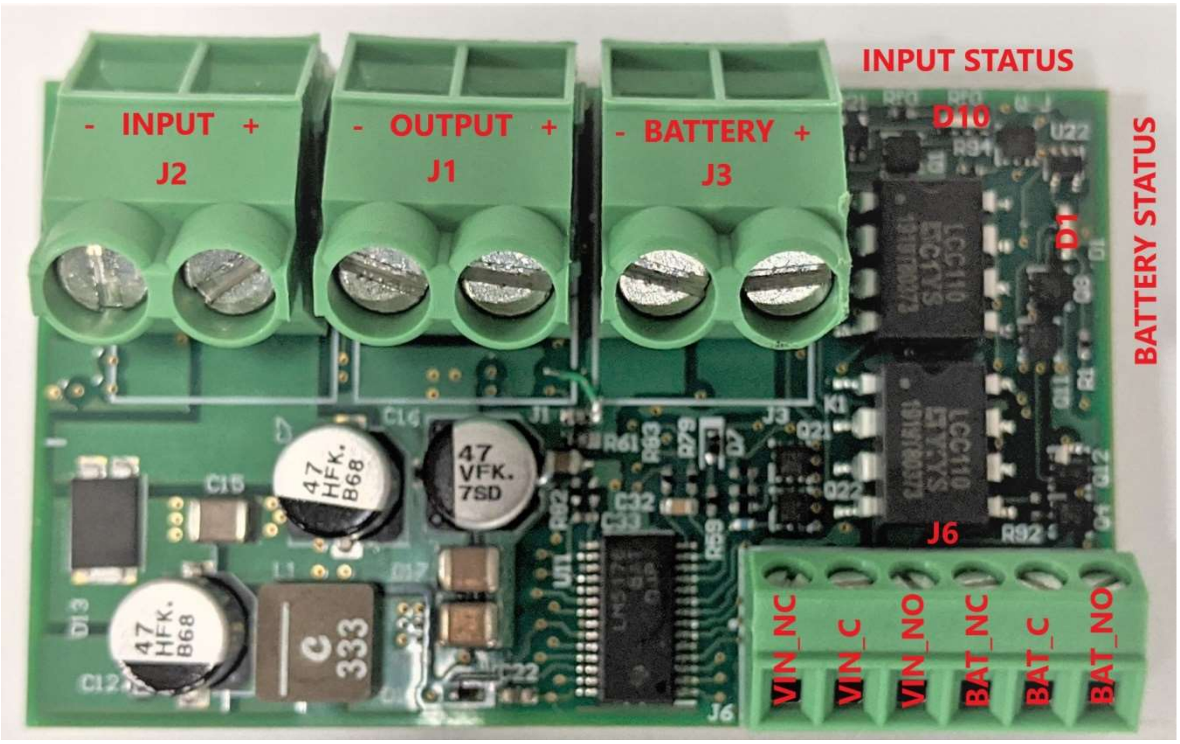
The LM5176 (U11) is a four-switch buck-boost controller. It provides a regulated output voltage from an input voltage that can be higher or lower than the output voltage. For a 12 Vdc input (8.5-17.5 Vdc) the output voltage is set to 14.0 V to provide a maintenance charge to the battery. With a 24 Vdc input (18.5-36.5 Vdc) the voltage is set to 28.0 V. The output is regulated to these voltages for load currents up to 1 A. A current of 1 A through R60/R61 generates 50mV across ISNS+/ISNS-. The LM5176 contains a second current error amplifier across these pins. At load current above 1 A, the voltage loop is disabled and the current is regulated to 1 A. The voltage (Vbat) tracks the battery voltage until the current drops below 1 A (the battery is charged).

U16 is a current amplifier used to monitor the Vbat load current. It contains a comparator that is used to set a trip level for the ALERT signal. The trip level is adjusted with R90. When the load current is less than 150mA, BAT_CHRG goes high (5 V), indicating the battery is fully charged. This signal is used to turn the battery status LED from yellow to green when fully charged.

D16 is a transient voltage suppressor (TVS) used to clamp voltage spikes. C7 also helps stabilize the input voltage. D13 is reverse polarity protection.

2 Connections and Operation

2.1 Photo



2.2 INPUT Testing – 12 Vdc

a. Connect the isolated DC power source to J2 with the indicated polarity.
b. Connect the electronic load to J1 with the indicated polarity. Set load for 0 A.
c. Connect DVMs to J1 and J2.
d. Turn on the DC power and slowly increase the voltage. The D10 INPUT STATUS LED should be red when the input reaches approximately 5 Vdc. At approximately 8.5 Vdc the D10 LED should change from red to green.
e. The D1 BATTERY STATUS LED should change from red to green at approximately 8 Vdc. Although a battery is not connected, the LM5176 battery charger will start to operate at the float voltage of 14 Vdc.
f. Below approximately 8.5 V, VIN_C to VIN_NO should measure open and VIN_C to VIN_NC should measure less than 35 ohms. Above 8.5 V, VIN_C to VIN_NO should measure less than 35 ohms and VIN_C to VIN_NC should measure open.
g. Below approximately 8.5 V, VBAT_C to VBAT_NO should measure open and VBAT_C to VBAT_NC should measure less than 35 ohms. Above 8.5 V, VBAT_C to VBAT_NO should measure less than 35 ohms and VBAT_C to VBAT_NC should measure open.
h. With the input above 8 Vdc, confirm the voltage across J1 is the same as J2, within 50 mV.
i. NOTE: The input voltage may be raised and lowered above 8.0-8.5 V as needed to check each of these functions.
j. When the above functions are verified, increase the power source to 12 Vdc.
k. Verify that the voltage across J3 is the float voltage of 14 Vdc +/-0.4 V.
l. Increase the electronic load to 5 Adc.
m. Verify the voltage across J1 is the same as J2, within 100 mV. This confirms the INPUT hot swap has turned on.
n. Increase the electronic load to 20 Adc.
o. Verify the voltage across J1 is within 400 mV of the voltage across J2.

2.3 INPUT Testing – 24 Vdc

a. Starting with the DC power source at 12 Vdc and 0 Adc load, slowly increase the voltage. The D10 INPUT STATUS LED should change from green to red when the input reaches approximately 17.5 Vdc. At approximately 18.5 Vdc the D10 LED should change from red to green.
b. The D1 BATTERY STATUS LED should also change from green to red at approximately 17.5 Vdc and back to green at 18.5 Vdc. Although a battery is not connected, the LM5176 battery charger will start to operate again at the float voltage of 28 Vdc.
c. Between 17.5-18.5 Vdc, VIN_C to VIN_NO should measure open and VIN_C to VIN_NC should measure less tha 35 ohms. Above 18.5 Vdc, VIN_C to VIN_NO should measure less than 35 ohms and VIN_C to VIN_NC should measure open.
d. Between 17.5-18.5 Vdc, VBAT_C to VBAT_NO should measure open and VBAT_C to VBAT_NC should measure less than 35. Above 18.5 V, VBAT_C to VBAT_NO should measure less than 35 ohms and VBAT_C to VBAT_NC should measure open.
e. With the input above 18.5 Vdc, confirm the voltage across J1 is the same as J2, within 50 mV.
f. NOTE: The input voltage may be raised and lowered above 17.5-18.5 V as needed to check each of these functions.
g. When the above functions are verified, increase the power source to 24 Vdc.
h. Verify that the voltage across J3 is the float voltage of 28 Vdc +/-0.8 V.
i. Increase the electronic load to 5 Adc.
j. Verify the voltage across J1 is the same a J2, within 100 mV. This confirms the INPUT hot swap has turned on.
k. Increase the electronic load to 20 Adc.
l. Verify the voltage across J1 is still within 400 mV of the voltage across J2.
m. Reduce the load back to 0 Adc. Slowly increase the input source to 36.5 Vdc. The D10 INPUT STATUS LED and the D1 BATTERY STATUS LED should change from green to red. VIN_C to VIN_NO and VBAT_C to VBAT_NO should measure open.

2.4 BATTERY Testing – 12 V

a. Reduce the input source to 12 Vdc and turn off.
b. (NOTE: It is easier to test the battery functions with an electronic load set in constant voltage (CV) mode. A super capacitor can also be substituted for the battery. Final testing should be done with a battery.)
c. Connect an electronic load to J3 with the indicated polarity. Set the load to CV mode and adjust the voltage higher than 15 Vdc. Use a DVM or the electronic load meters to monitor the current.
d. Turn on the input source. The BATTERY voltage on J3 should be the float voltage of 14 Vdc +/-0.4 V. There should be no battery current. The D1 BATTERY STATUS LED should be green.
e. Slowly decrease the voltage on the electronic load. As the voltage goes below 14 Vdc the load should begin to draw current. At 150 mAdc load the D1 BATTERY STATUS LED should change from green to yellow. This indicates the battery is charging, but the voltage is still within normal range.
f. Continue to decrease the load voltage until the current begins to regulate at 1 Adc. Further reduction of the load voltage should not increase the current.
g. Continue to decrease the load voltage. Below 10.5 Vdc the D1 BATTERY STATUS LED should change from yellow to red.
h. Slowly increase the load voltage back to 15 Vdc. At 150 mAdc the D1 BATTERY STATUS LED should change from yellow to green, indicating a fully charged battery. (NOTE: When a lead acid battery is connected there will be some trickle charging current. The 150 mAdc trip level will have to be adjusted for the battery being used.).

2.5 BATTERY Testing – 24 V

a. Increase the load voltage to 29 Vdc.
b. Increase the input source to 24 Vdc.
c. The BATTERY voltage on J3 should be the float voltage of 28 Vdc +/-0.8 V. There should be no battery current. The D1 BATTERY STATUS LED should be green.
d. Slowly decrease the voltage on the electronic load. As the voltage goes below 28 Vdc the load should begin to draw current. At 150 mAdc load the D1 BATTERY STATUS LED should change from green to yellow. This indicates the battery is charging, but the voltage is still within normal range.
e. Continue to decrease the load voltage until the current begins to regulate at 1 Adc. Further reduction of the load voltage should not increase the current.
f. Continue to decrease the load voltage. Below 21.0 Vdc the D1 BATTERY STATUS LED should change from yellow to red.
g. Slowly increase the load voltage back to 29 Vdc. At 150 mAdc the D1 BATTERY STATUS LED should change from yellow to green, indicating a fully charged battery. (NOTE: When a lead acid battery is connected there will be some trickle charging current. The 150 mAdc trip level will have to be adjusted for the battery being used.).

2.6 Battery Hot Swap Testing – 12 V

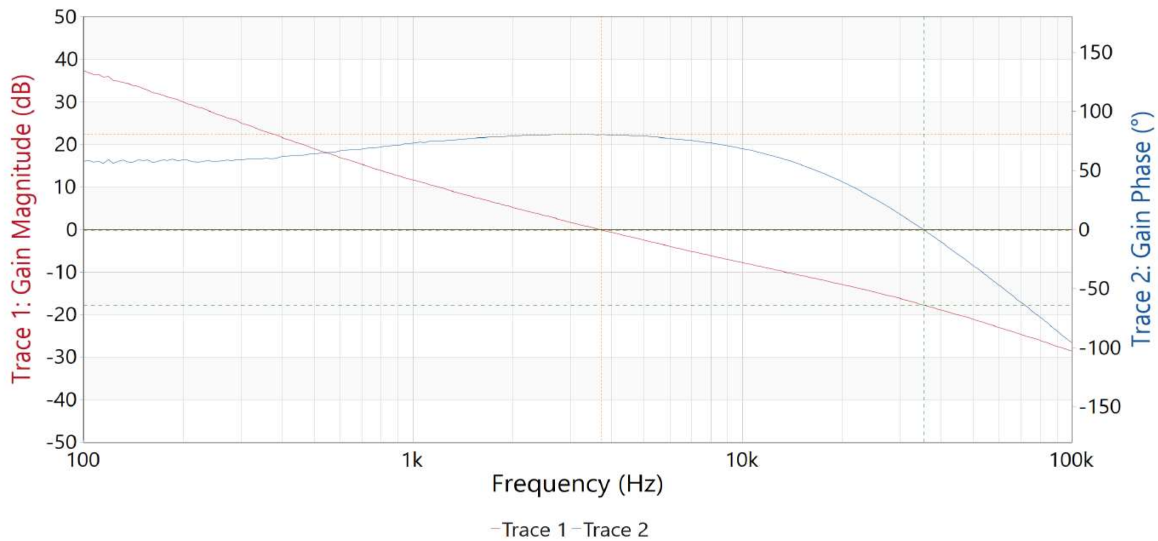
a. Disconnect the input source from J2. Connect the electronic load to J1 and set to constant current mode (CC). Set the load for 0 Adc.
b. Connect the input source to J3 with the indicated polarity.
c. Turn on the input source and slowly increase the input voltage. At 8 Vdc the battery hot swap should turn on. The voltage at J1 should be within 50 mVdc of the voltage at J3. The voltage on J2 should be less than 50 mVdc, indicating the input hot swap is off. The D10 INPUT STATUS LED should be red.
d. Increase the voltage on J3 to 12 Vdc.
e. Increase the load current on J1 to 5 Adc. Verify the voltage across J1 is still within 100 mVdc of the voltage across J3.
f. Increase the load current on J1 to 20 Adc. Verify the voltage across J1 is still within 400 mVdc of the voltage across J3.
g. Decrease the load current to 0 Adc.

2.7 Battery Hot Swap Testing – 24 V

a. Slowly increase the voltage on J3 to 24 Vdc. The D1 BATTERY STATUS LED will change to red at 15.0 Vdc and back to green at 21.0 Vdc. The voltage across J1 will be 0 Vdc between 18.0-18.5 Vdc.
b. With the voltage on J3 at 24 Vdc, verify the voltage across J1 is within 50 mVdc of the voltage on J3. The voltage on J2 should be less than 50 mVdc, indicating the input hot swap is off. The D10 INPUT STATUS LED should be red.
c. Increase the load current on J1 to 5 Adc. Verify the voltage across J1 is still within 100 mVdc of the voltage across J3.
d. Increase the load current on J1 to 20 Adc. Verify the voltage across J1 is still within 400 mVdc of the voltage across J3.
e. Decrease the load current to 0 Adc.
f. Increase the voltage on J3 to 30.0 Vdc. Verify the voltage across J1 is 0 Vdc, indicating the battery hot swap has turned off.
g. Decrease the voltage on J3 to 0 Vdc and turn off the source.

3 Test Results/Waveforms

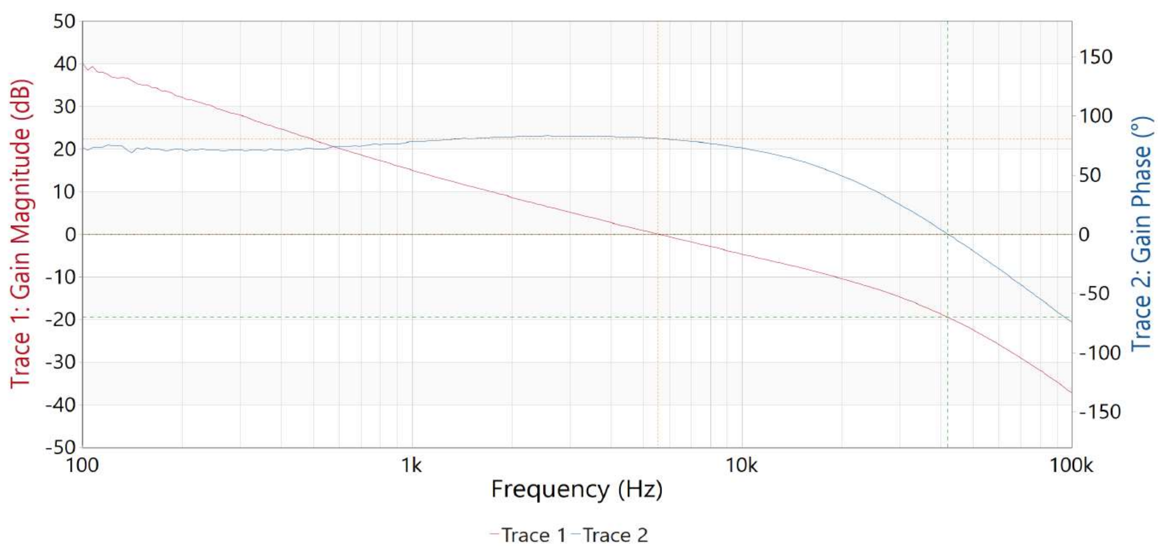
3.1 Bode Plot – LM5176 – 10 V Input, 14 V Output/0.5 A



Bandwidth = 3.7 kHz Phase Margin = 80.2 degrees Gain Margin = 17.7 dB

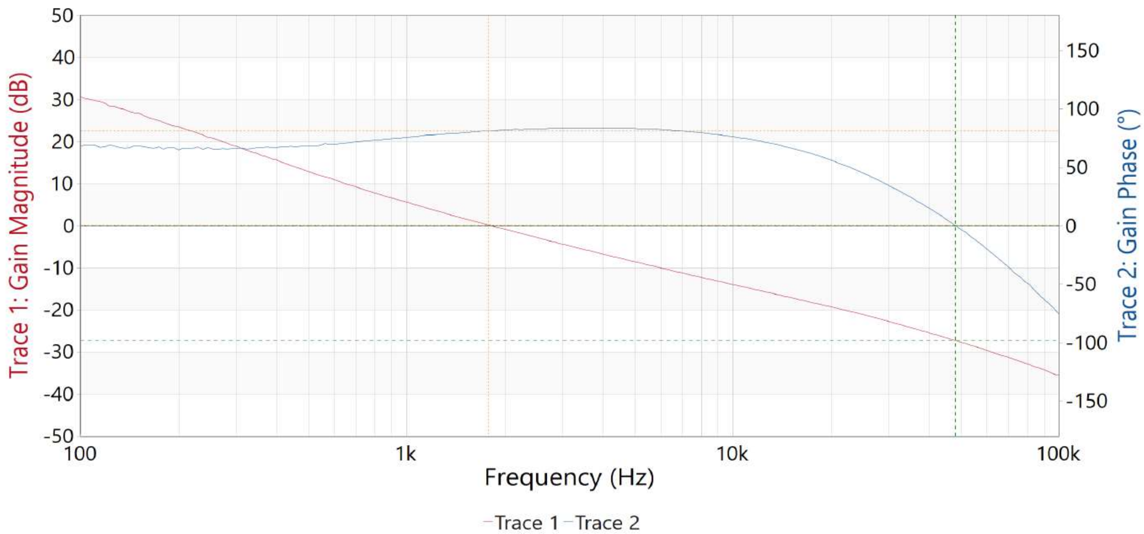
Note: Bode plots were taken in voltage regulation with a constant current load of 0.5A. This ensures the current regulation loop is not active.

3.2 Bode Plot – LM5176 – 16 V Input, 14 V Output/0.5 A



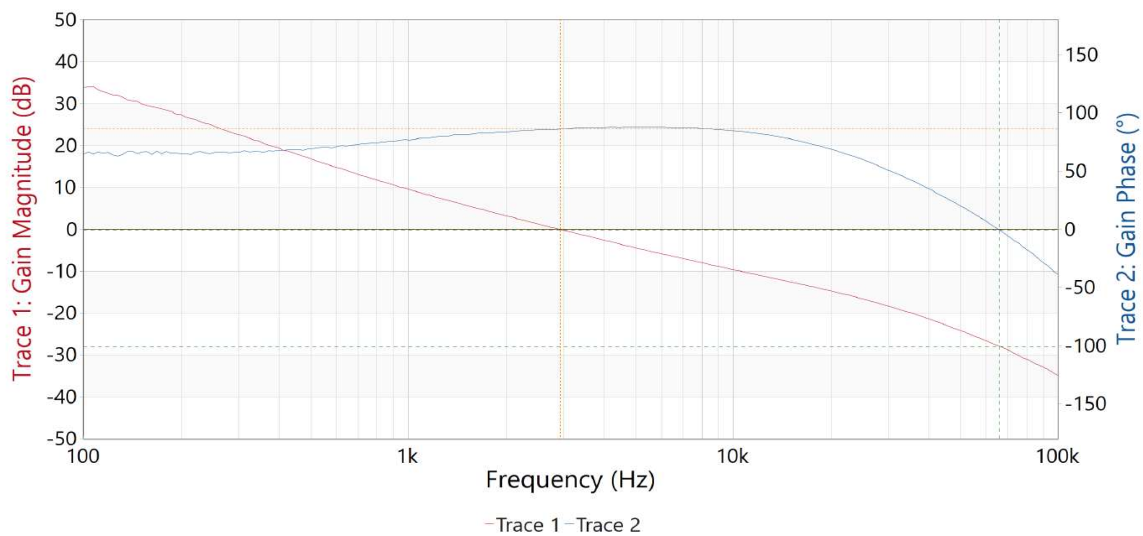
Bandwidth = 5.5 kHz Phase Margin = 80.8 degrees Gain Margin = 19.4 dB

3.3 Bode Plot – LM5176 – 22 V Input, 28 V Output/0.5 A



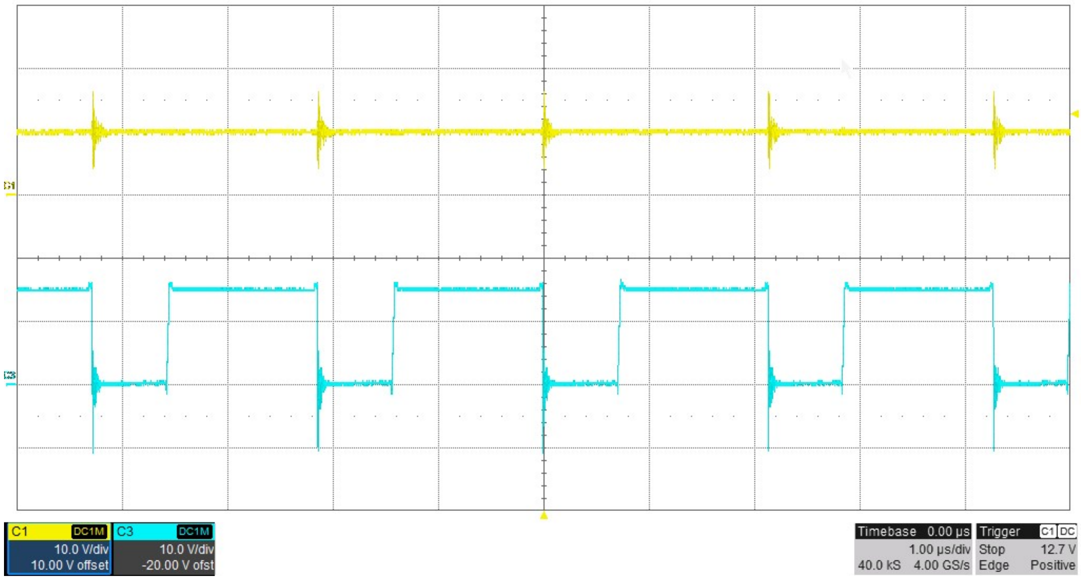
Bandwidth = 1.7 kHz Phase Margin = 81.0 degrees Gain Margin = 27.2 dB

3.4 Bode Plot – LM5176 – 32 V Input, 28 V Output/0.5 A



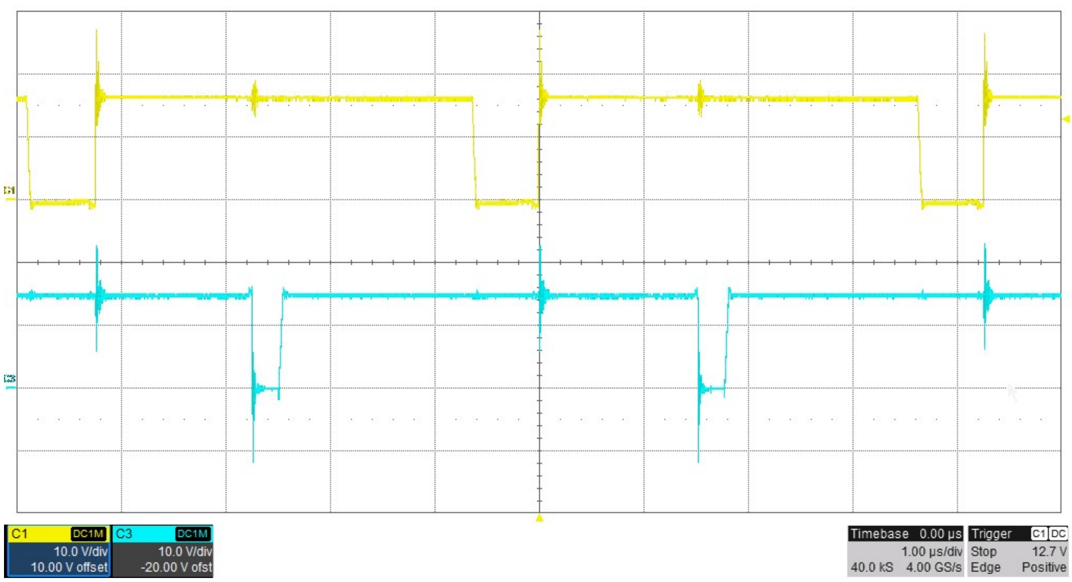
Bandwidth = 2.9 kHz Phase Margin = 86.1 degrees Gain Margin = 27.9 dB

3.5 LM5176 SW1 and SW2 Waveforms, 10 V Input, 14 V Output/0.5A



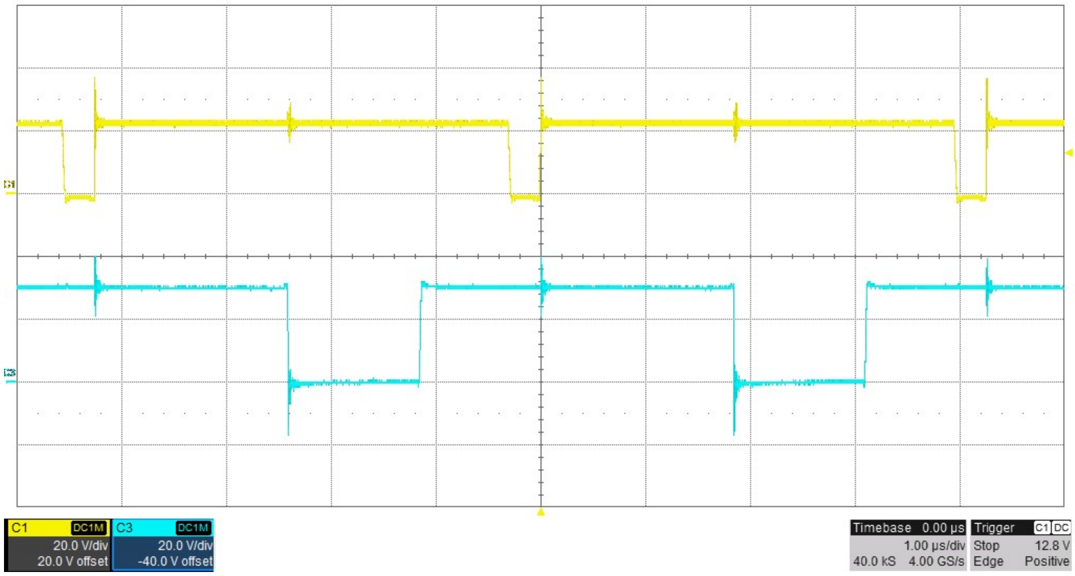
The converter is in fixed boost mode operation.

3.6 LM5176 SW1 and SW2 Waveforms, 16 V Input, 14 V Output/0.5A



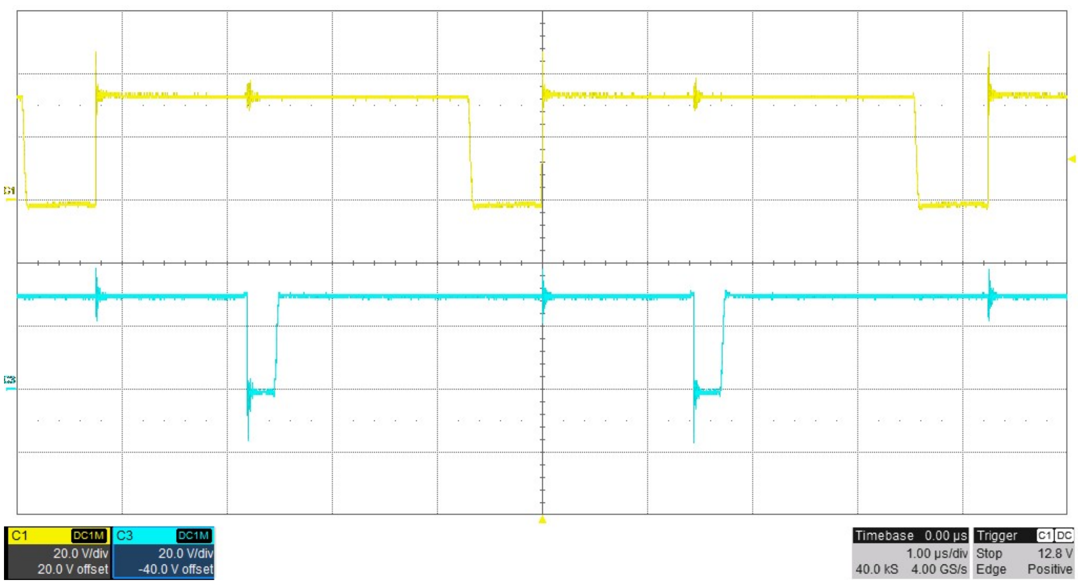
The converter is in buck-boost mode of operation.

3.7 LM5176 SW1 and SW2 Waveforms, 22 V Input, 28 V Output/0.5A



The converter is in buck-boost mode of operation.

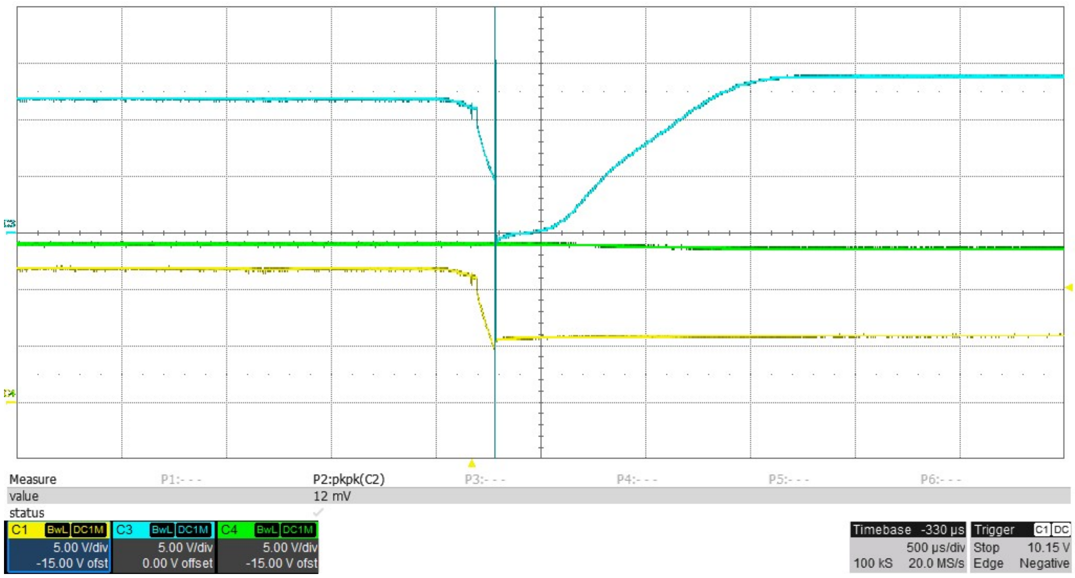
3.8 LM5176 SW1 and SW2 Waveforms, 32 V Input, 28 V Output/0.5A



The converter is in buck-boost mode of operation.

3.9 Hot Swap Switching, 12 V Input, 5.0 A Load

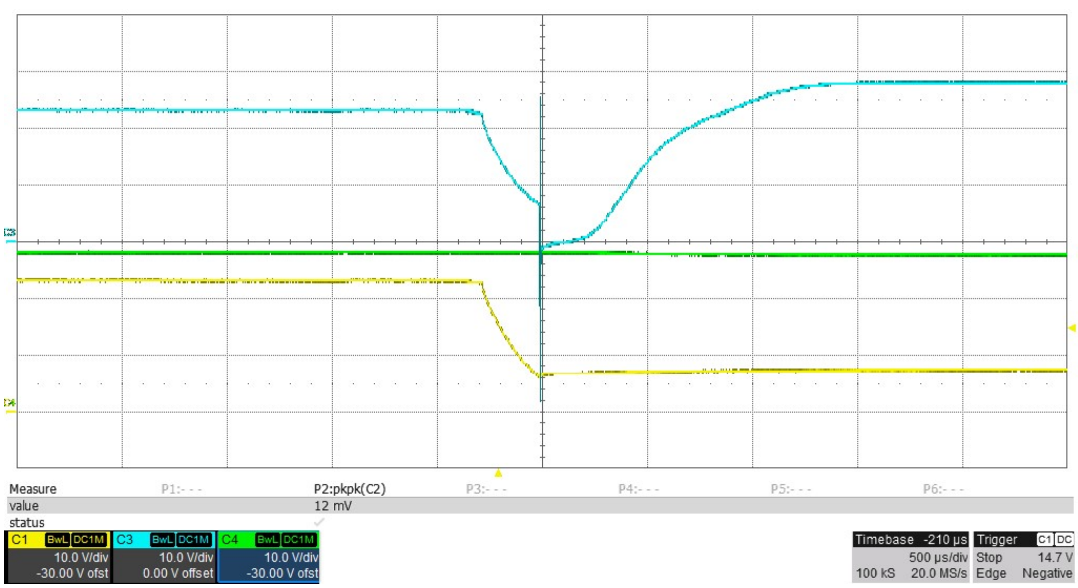
Resistive load. Battery substitute is Maxwell Technologies BOOSTCAP D cells, 12 in series, 28.2F, 29.8V maximum.



CH1 (YEL): INPUT (J2), 5 V/div
CH4 (GRN): BATTERY (J3), 5 V/div
CH3 (BLU): OUTPUT (J1), 5 V/div
500 usec/div

3.10 Hot Swap Switching, 24 V Input, 5.0 A Load

Resistive load. Battery substitute is Maxwell Technologies BOOSTCAP D cells, 12 in series, 28.2F, 29.8V maximum.



CH1 (YEL): INPUT (J2), 10 V/div
CH4 (GRN): BATTERY (J3), 10 V/div
CH3 (BLU): OUTPUT (J1), 10 V/div
500 usec/div

3.11 LM5176 Efficiency, 12 V Input

Ibat	Vbat	Iin	Vin	Eff		
0.000	14.14	0.056	12.015	0.0%		Load constant current; LM5176 in voltage regulation
0.100	14.14	0.179	12.005	65.8%		Load constant current; LM5176 in voltage regulation
0.200	14.14	0.302	12.013	78.0%		Load constant current; LM5176 in voltage regulation
0.300	14.14	0.427	12.007	82.7%		Load constant current; LM5176 in voltage regulation
0.400	14.14	0.552	12.013	85.3%		Load constant current; LM5176 in voltage regulation
0.500	14.14	0.678	12.016	86.8%		Load constant current; LM5176 in voltage regulation
0.600	14.14	0.806	12.007	87.7%		Load constant current; LM5176 in voltage regulation
0.700	14.15	0.934	12.007	88.3%		Load constant current; LM5176 in voltage regulation
0.800	14.15	1.062	12.012	88.7%		Load constant current; LM5176 in voltage regulation
0.900	14.15	1.191	12.018	89.0%		Load constant current; LM5176 in voltage regulation
0.963	13.89	1.249	12.007	89.2%		Load constant voltage; LM5176 in current regulation

3.12 LM5176 Efficiency, 24 V Input

Ibat	Vbat	Iin	Vin	Eff		
0.000	28.32	0.069	24.020	0.0%		Load constant current; LM5176 in voltage regulation
0.100	28.35	0.188	24.015	62.8%		Load constant current; LM5176 in voltage regulation
0.200	28.36	0.309	25.010	73.4%		Load constant current; LM5176 in voltage regulation
0.300	28.36	0.430	24.015	82.4%		Load constant current; LM5176 in voltage regulation
0.400	28.37	0.551	24.019	85.7%		Load constant current; LM5176 in voltage regulation
0.500	28.37	0.674	24.008	87.7%		Load constant current; LM5176 in voltage regulation
0.600	28.37	0.795	24.009	89.2%		Load constant current; LM5176 in voltage regulation
0.700	28.38	0.920	24.003	90.0%		Load constant current; LM5176 in voltage regulation
0.800	28.39	1.043	24.013	90.7%		Load constant current; LM5176 in voltage regulation
0.900	28.37	1.166	24.017	91.2%		Load constant current; LM5176 in voltage regulation
0.943	27.83	1.201	24.003	91.0%		Load constant voltage; LM5176 in current regulation