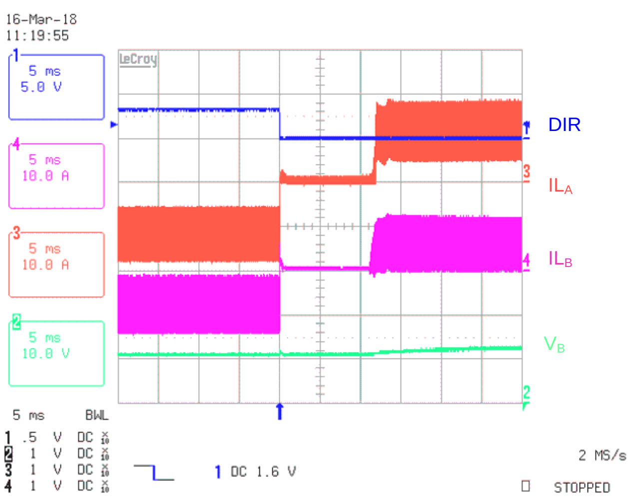
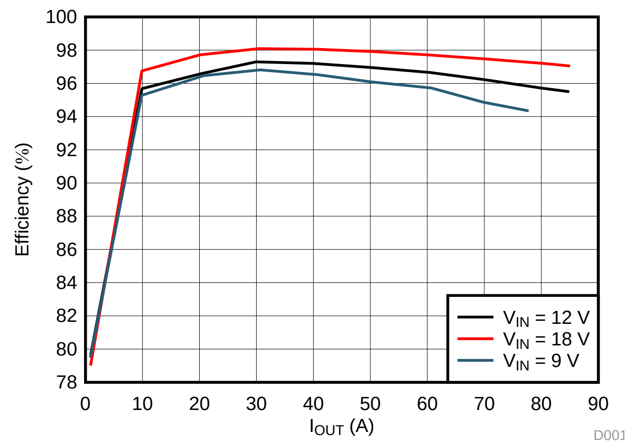
PMP15035

1000-W, Bidirectional, 12-V to 12-V Converter Reference Design

Description

Many automotive companies consider setting a 12-V, dual-battery system in automotive applications. One battery is the cranking battery, and the other one is the auxiliary battery. The advantage of using a 12-V, dual-battery system is that it is better than the original technique in regards to the management of state of charge (SOC) and state of health (SOH). This reference design helps users create a high-performance, 1-kW, bidirectional, 12-V to 12-V converter for 12-V, dual-battery system automotive applications, using two LM5170-Q1 controllers. This test report discusses various design considerations and presents the test results and waveforms, from a demonstration board to specific design requirements.





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1 System Parameters

1.1 System Description

This reference design is a dual-channel, bidirectional converter suitable for 12-V to 12-V, dual-battery system, automotive applications (see Figure 1). Automotive 12-V batteries typically operate in the range of 9 V to 18 V and has large input voltage transients because of cold cranking. This reference design has a wide input range (3 V to 40 V) and could give full load (1kW) in the input voltage from 9V to 18V. The first LM5170-Q1 operates as a boost controller, to regulate the middle-rail voltage (V_{mid}) to 18 V. The second LM5170-Q1 operates as a buck controller, to regulate the 18-V output. The LM5170-Q1 uses an outer-voltage control loop to regulate the output voltage. Either an external command signal or the onboard jumper can control the direction of the power flow. The board is operated and shut down through the onboard interface headers.

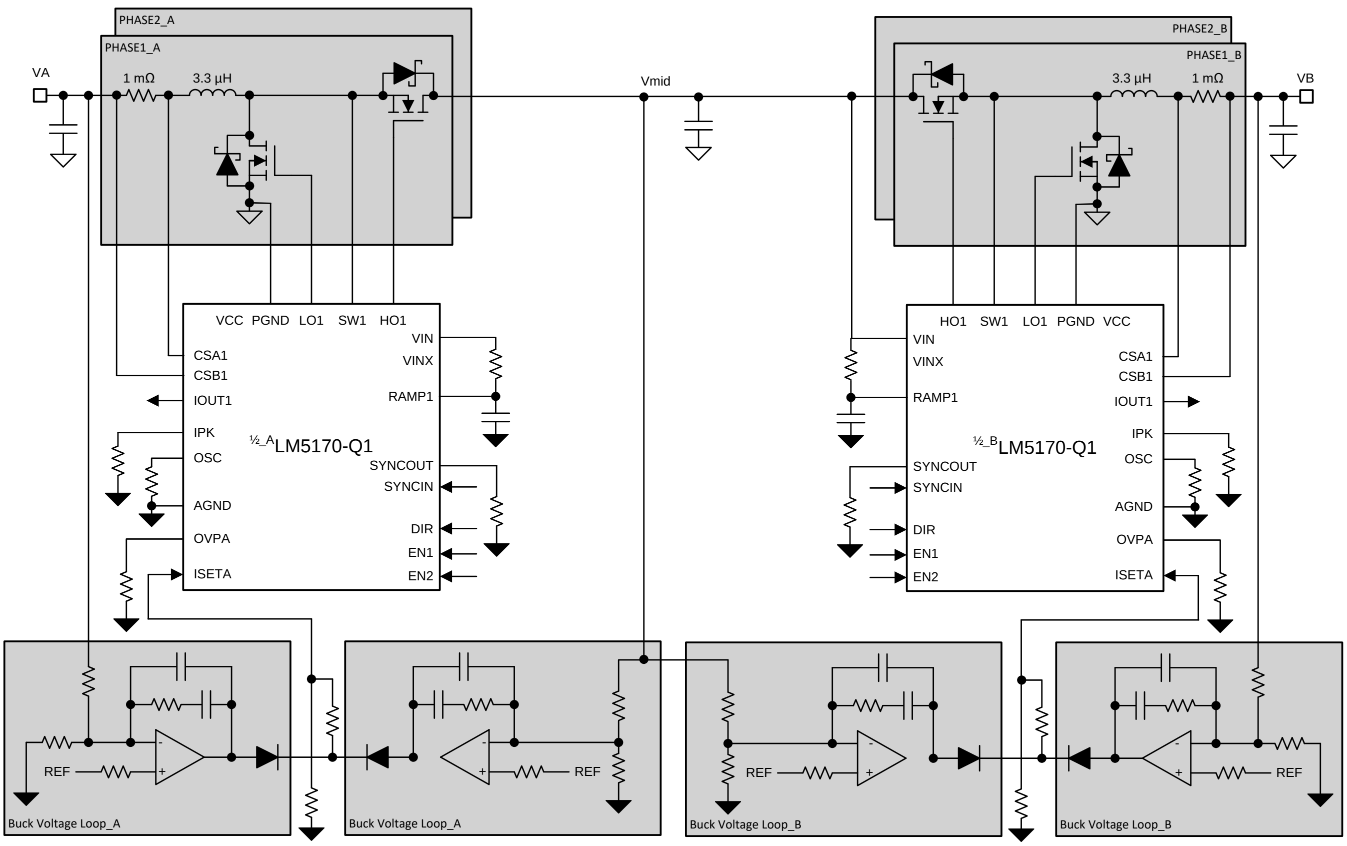


Figure 1. System Block Diagram

1.2 Voltage and Current Requirements

Table 1. Voltage and Current Requirements

PARAMETER	SPECIFICATION
V_A (DC range)	9 V to 18 V
V_A (transient range)	3 V to 40 V
V_B (DC range)	9 V to 18 V
V_B (transient range)	3 V to 40 V
V_{out}	12 V
P_{power}	1 kW
Nominal switching frequency	100 kHz

This reference design has two ports, A port and B port. When the direction is from A port to B port, B port is output port, which could regulate to 12V and vice versa.

1.3 Required Equipment

- Power supply
- Electronic load
- Oscilloscope

2 Testing and Results

2.1 Performance Graphs

Figure 2 and Figure 3 show the efficiency and load regulation performance graphs.

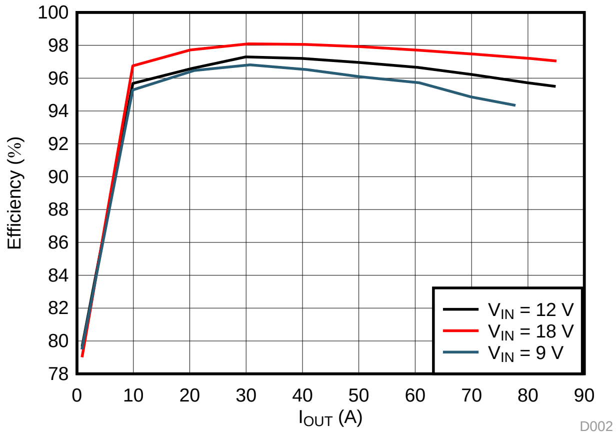


Figure 2. Efficiency Versus Output Current

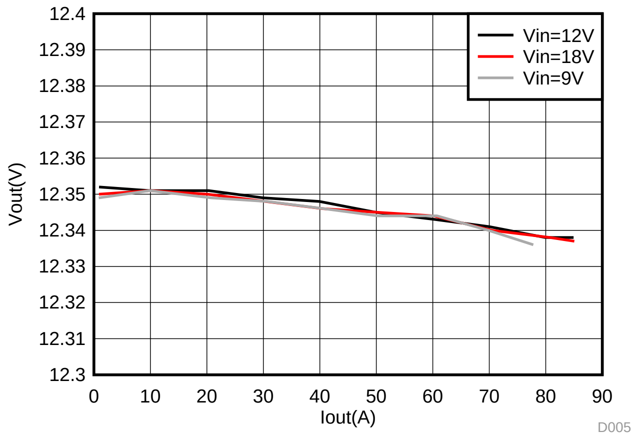


Figure 3. Load Regulation

2.2 Efficiency Data

Table 2 through Table 4 list the efficiency data of the test report.

Table 2. Efficiency Data (V_{IN}= 9 V)

V_{IN} (V)	I_{IN} (A)	V_{OUT}(V)	I_{OUT} (A)	Efficiency (%)
9.006	1.510	12.349	0.876	79.48
9.009	14.217	12.351	9.881	95.28
9.004	29.560	12.349	20.792	96.46
9.020	43.408	12.348	30.696	96.81
9.030	57.653	12.346	40.699	96.52
9.009	71.717	12.344	50.293	96.08
9.022	86.796	12.344	60.723	95.72
9.023	100.731	12.340	69.868	94.86
9.074	112.096	12.336	77.792	94.34

Table 3. Efficiency Data (V_{IN}= 12 V)

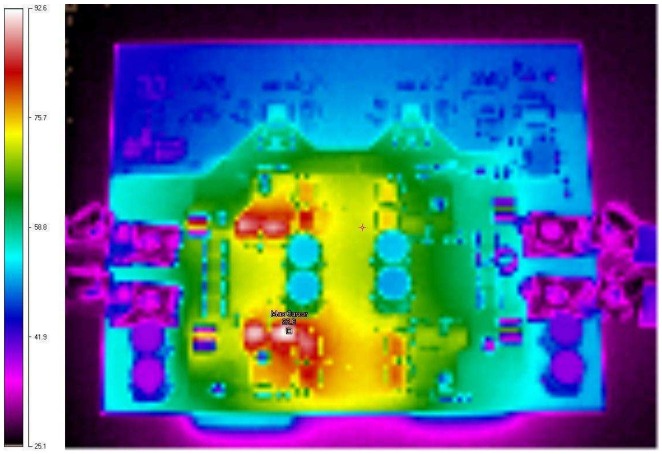
V_{IN} (V)	I_{IN} (A)	V_{OUT}(V)	I_{OUT} (A)	Efficiency (%)
12.013	1.171	12.352	0.907	79.66
12 .000	10.662	12.351	9.911	95.68
12.028	21.614	12.351	20.331	96.59
12.006	31.646	12.349	29.934	97.29
12.028	42.183	12.348	39.939	97.20
12.026	52.872	12.345	49.938	96.96
12.016	64.219	12.343	60.427	96.65
12.022	74.700	12.341	70.020	96.22
12.022	85.683	12.338	79.914	95.72
12.014	91.315	12.338	84.915	95.50

Table 4. Efficiency Data (V_{IN}= 18 V)

V_{IN} (V)	I_{IN} (A)	V_{OUT}(V)	I_{OUT} (A)	Efficiency (%)
18.016	0.772	12.350	0.890	79.01
18.019	7.011	12.351	9.895	96.75
18.030	14.095	12.350	20.108	97.72
18.020	21.246	12.348	30.411	98.09
18.031	28.292	12.346	40.514	98.05
18.024	35.190	12.345	50.308	97.92
18.017	42.137	12.344	60.097	97.71
18.012	49.542	12.340	70.477	97.46
18.009	56.931	12.338	80.760	97.19
18.025	59.991	12.337	85.058	97.04

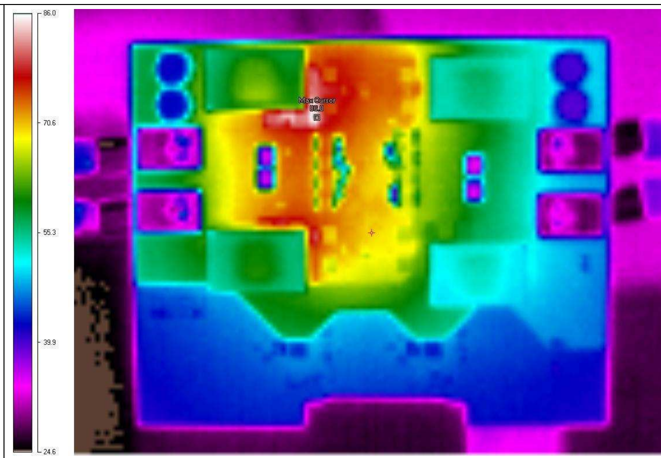
2.3 Thermal Images

Figure 4 through Figure 9 show the temperature of the board with different input voltages and a continuous load of 84A.



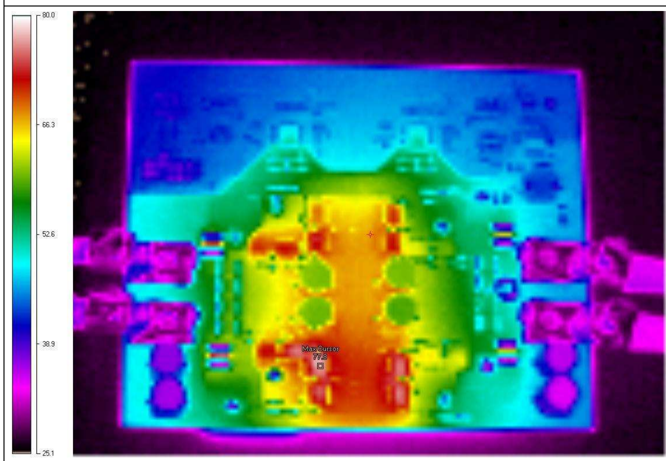
Maximum temperature = 92.6℃

Figure 4. Front Side: V_{IN} = 9 V, I_{OUT} = 84 A



Maximum temperature = 86℃

Figure 5. Rear Side: V_{IN} = 9 V, I_{OUT} = 84 A

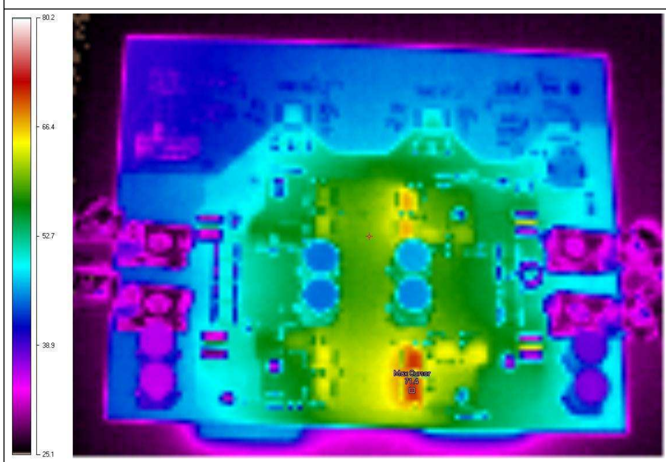


Maximum temperature = 77.8℃

Figure 6. Front Side: V_{IN} = 12 V, I_{OUT} = 84 A

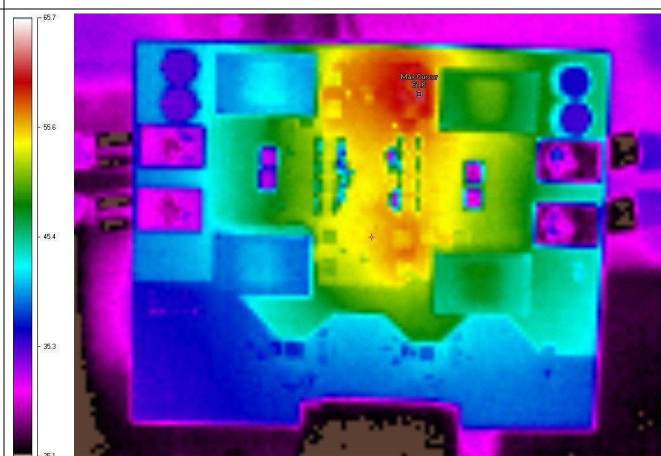
Maximum temperature = 73.2℃

Figure 7. Rear Side: V_{IN} = 12 V, I_{OUT} = 84 A



Maximum temperature = 71.4℃

Figure 8. Front Side: V_{IN} = 18 V, I_{OUT} = 84 A



Maximum temperature = 61.6℃

Figure 9. Rear Side: V_{IN} = 18 V, I_{OUT} = 84 A

2.4 Dimensions

The board dimensions are 4.6 inches × 5.6 inches (see Figure 10 and Figure 11).

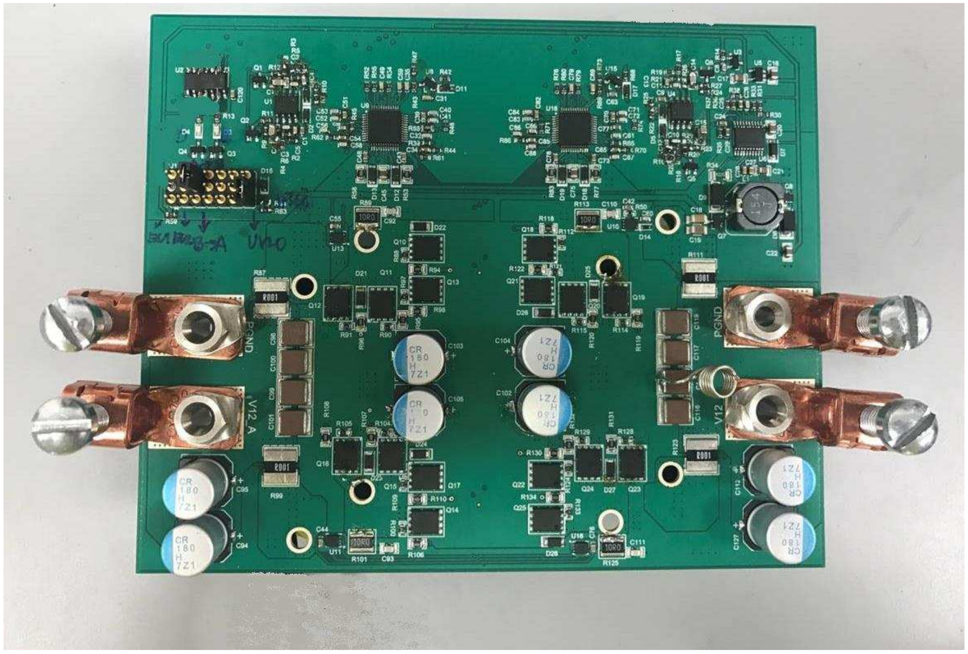


Figure 10. Front of Evaluation Board

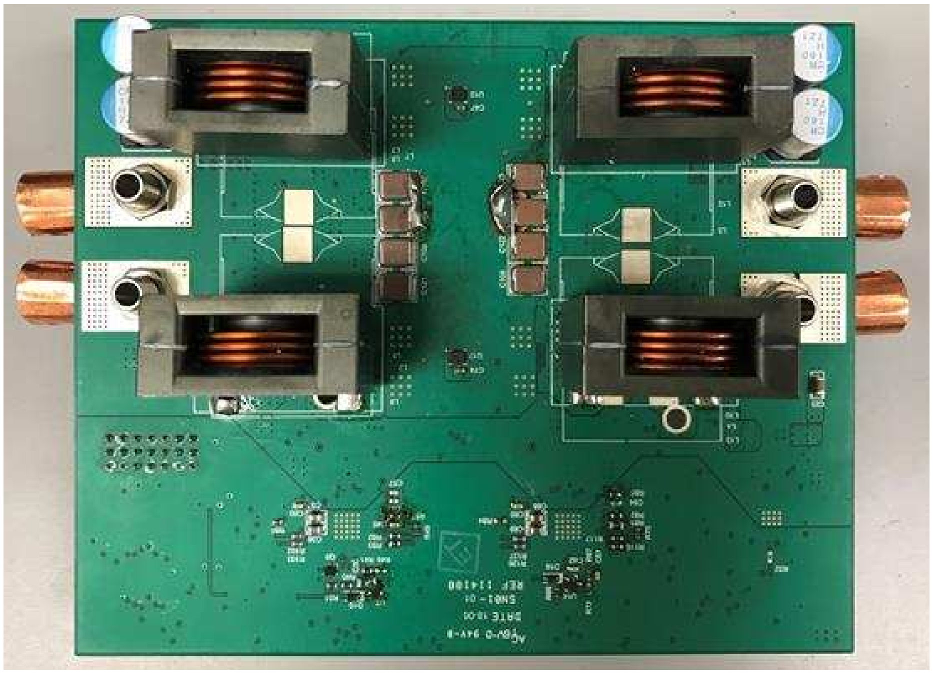


Figure 11. Rear of Evaluation Board

3 Waveforms

3.1 Output Voltage Ripple

The direction is from A port to B port.Figure 12 shows the output voltage ripple waveform.

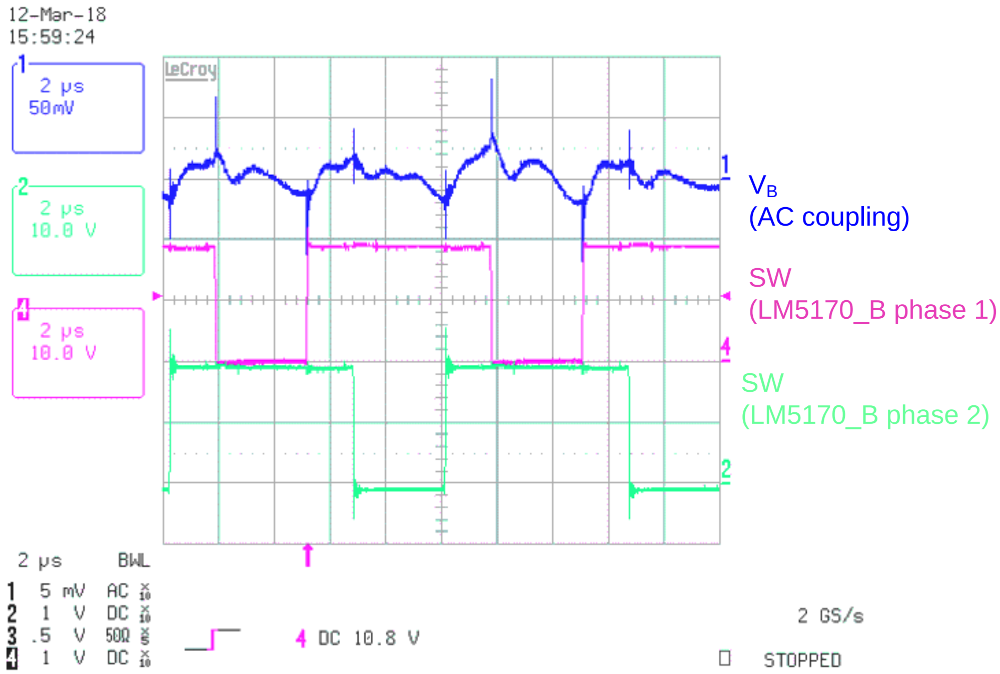


Figure 12. V_{IN} = 12 V, I_{OUT} = 84 A

3.2 Start Up and Shutdown by EN

The direction is from A port to B port.Figure 13 through Figure 16 show the start up and shut down waveforms.

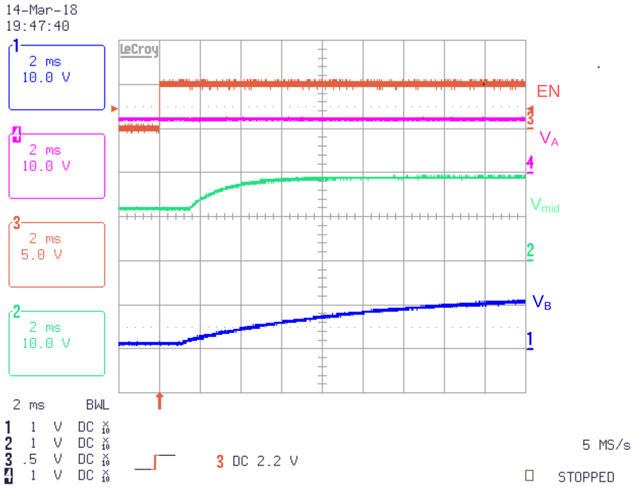


Figure 13. Start Up: V_{IN} = 12 V Open Load

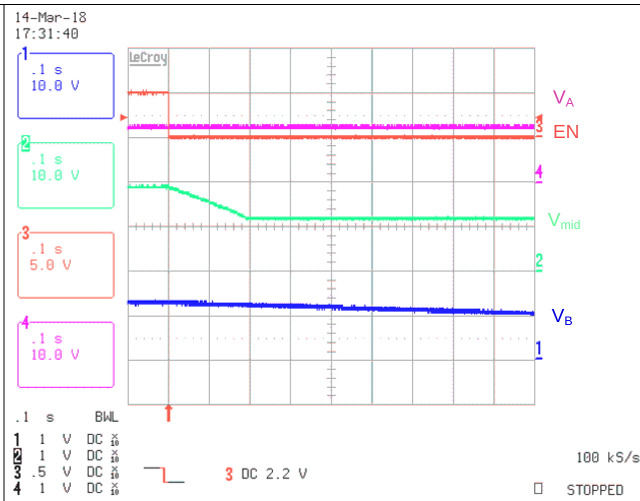


Figure 14. Shutdown: V_{IN} = 12 V Open Load

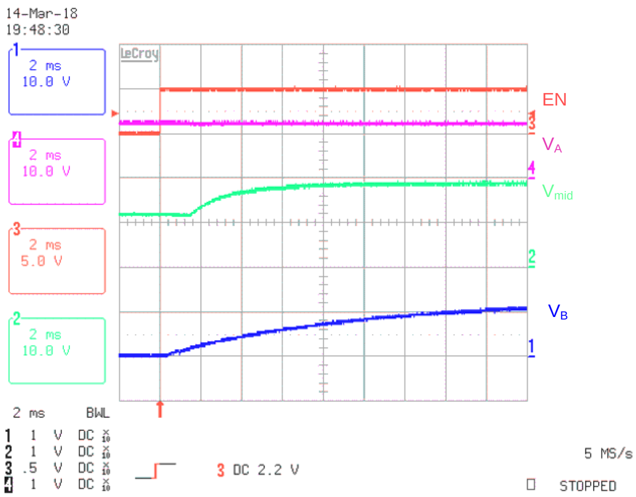


Figure 15. Start Up: V_{IN} = 12 V, I_{OUT} = 84 A

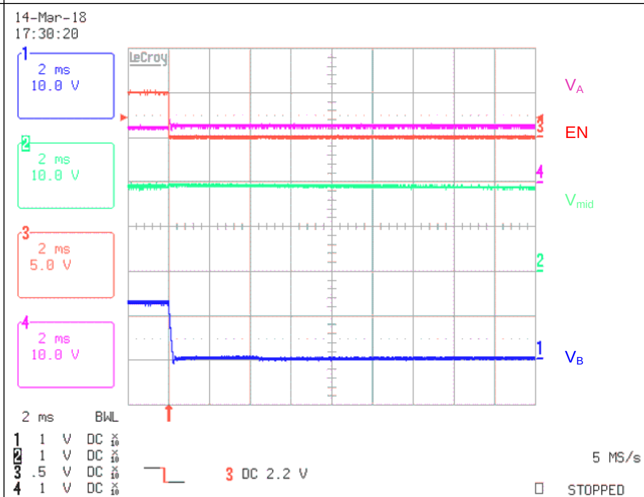


Figure 16. Shutdown: V_{IN} = 12 V, I_{OUT} = 84 A

3.3 Load Transient

The direction is from A port to B port. Figure 17 shows the load transient waveform.

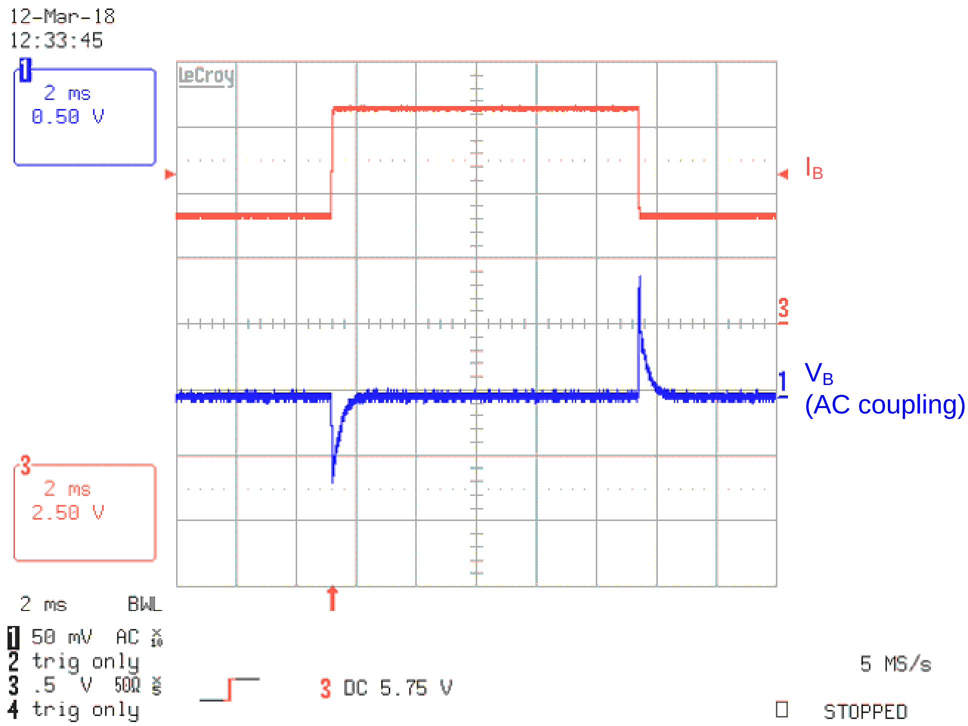


Figure 17. Load Transient: V_{IN} = 12 V, I_{OUT} = 42 A to 84 A

3.4 Line Transient and Cold Cranking

The direction is from A port to B port. Figure 18 and Figure 19 show the line transient and cold cranking waveforms.

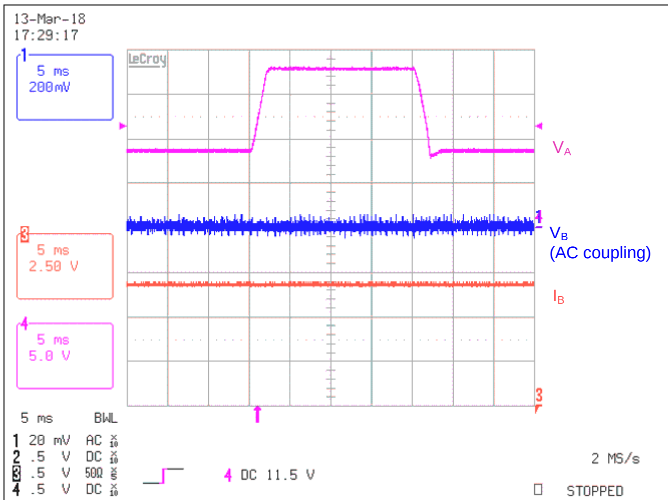


Figure 18. Line Transient: V_{IN} = 12 V, I_{OUT} = 42 A to 84 A

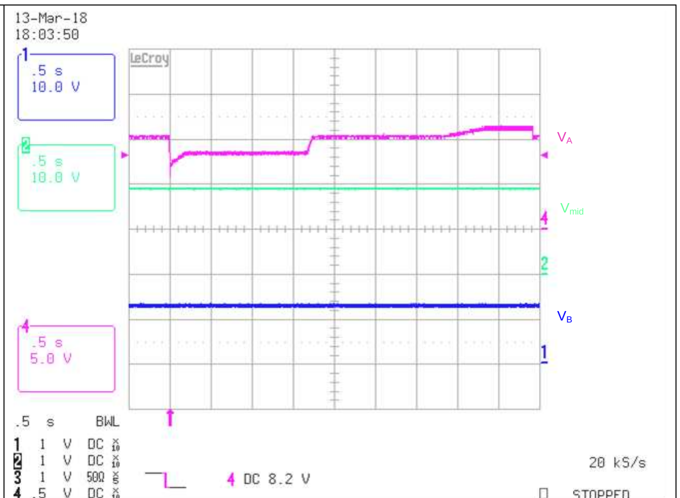


Figure 19. Cold Cranking Open Load

3.5 Dynamic DIR Change

This reference design could change the direction by DIR signal. Pulling DIR above 2 V sets the board's direction from B port to A port. Pulling DIR below 1 V sets the board's direction from A port to B port.Figure 20 and Figure 21 show the dynamic DIR change waveforms.

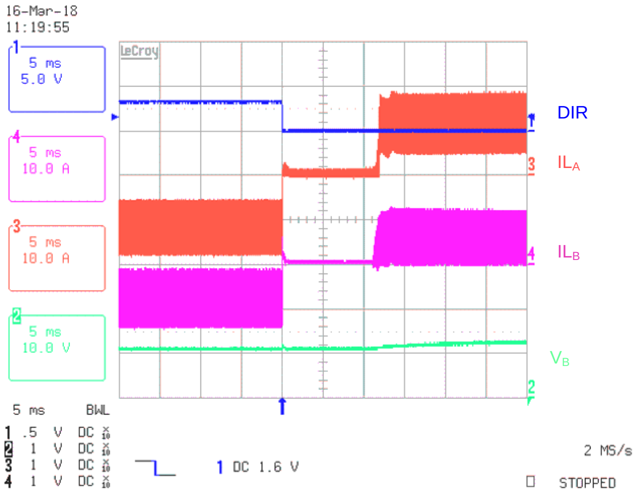


Figure 20. Response to Dynamic DIR Change (1/2)

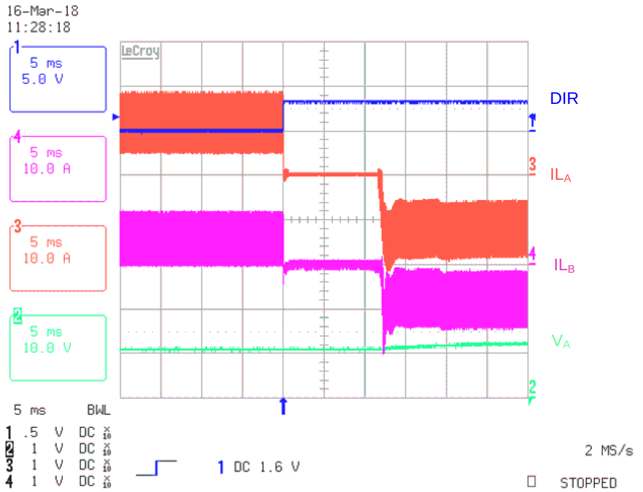


Figure 21. Response to Dynamic DIR Change (2/2)

3.6 Short Protection

The direction is from A port to B port.Figure 22 and Figure 23 show the short-protection waveforms.

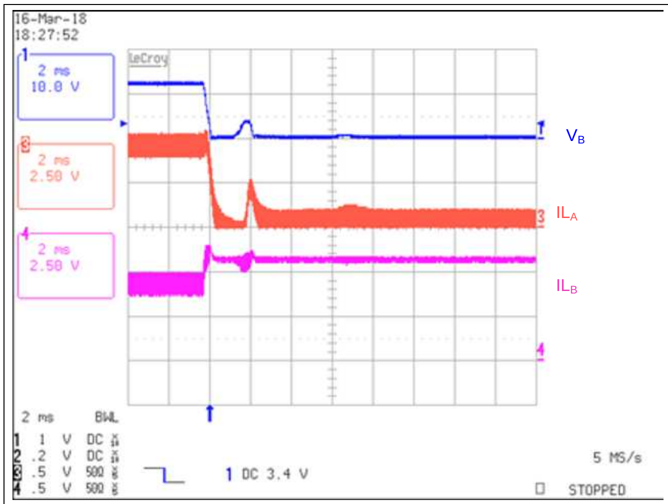


Figure 22. Short Protection (1/2)

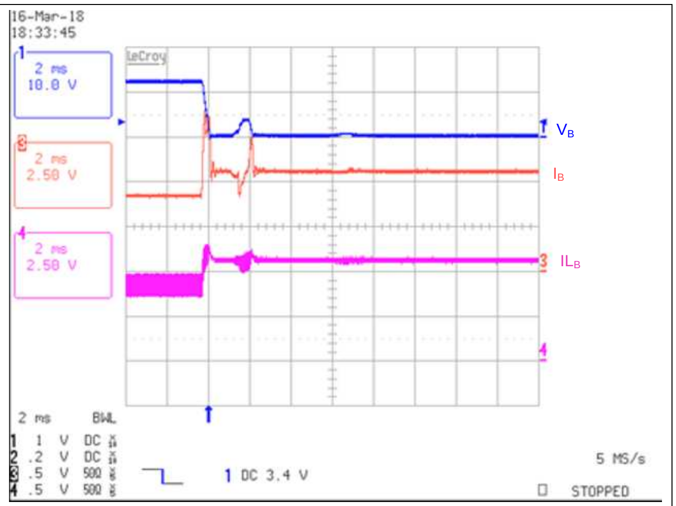
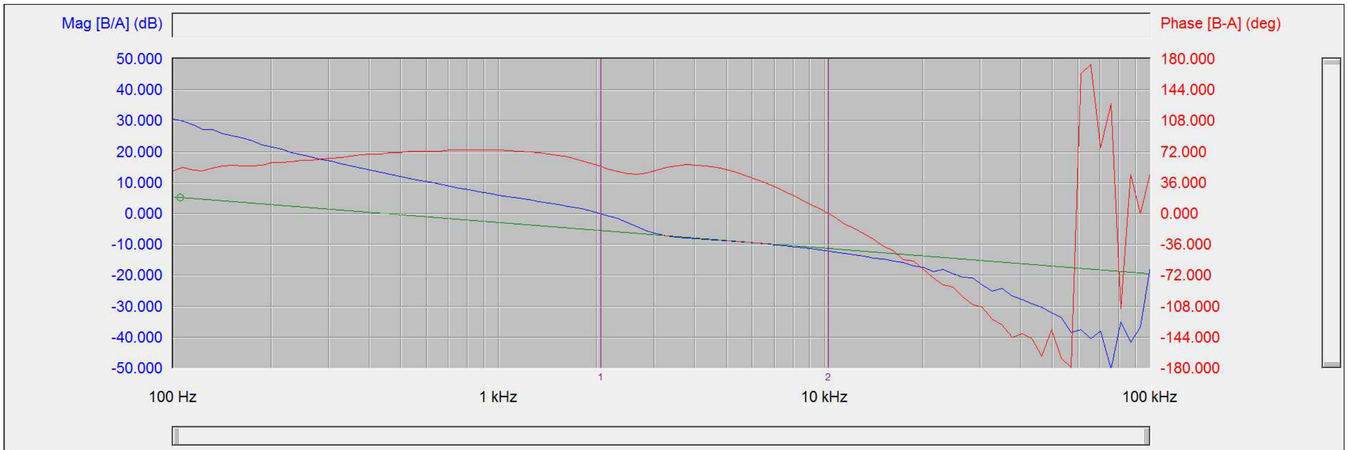


Figure 23. Short Protection (2/2)

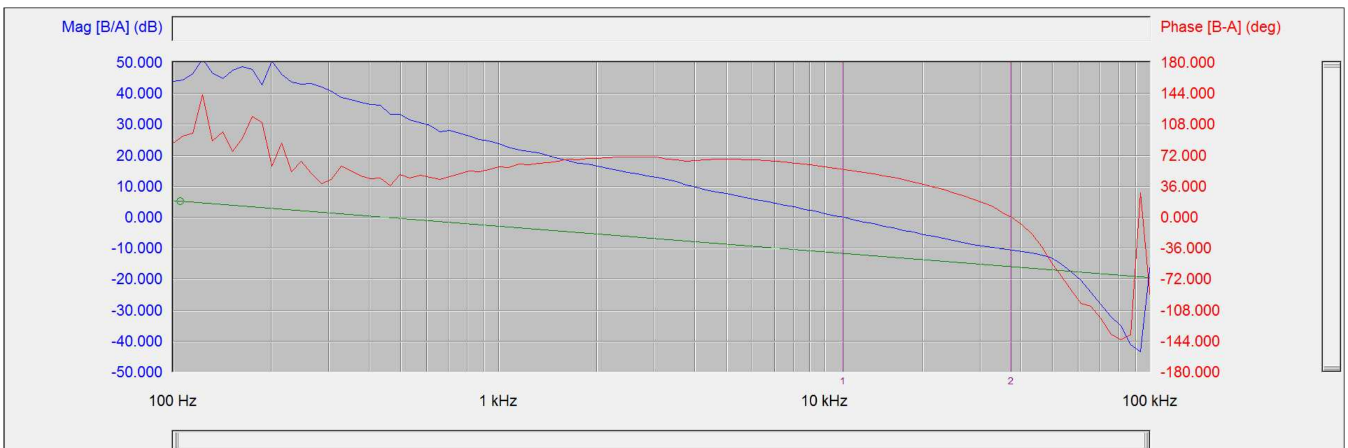
3.7 Bode Plot

Figure 24 and Figure 25 show the boost and buck bode plot waveforms.



Data	M1	M2	M2 - M1
Frequency	2.06 kHz	10.27 kHz	8.21 kHz
Magnitude	-0.007 dB	-12.163 dB	-12.156 dB
Phase	54.917 deg	-0.050 deg	-54.967 deg
Var. Source	28.61 mV	16.93 mV	-11.68 mV

Figure 24. Boost Stage Bode Plot, V_{IN} = 12 V I_{OUT} = 84 A



Data	M1	M2	M2 - M1
Frequency	11.40 kHz	37.33 kHz	25.93 kHz
Magnitude	-0.003 dB	-10.641 dB	-10.638 dB
Phase	55.836 deg	-0.027 deg	-55.863 deg
Var. Source	16.36 mV	11.11 mV	-5.25 mV

Figure 25. Buck Stage Bode Plot, V_{IN} = 12 V I_{OUT} = 84 A