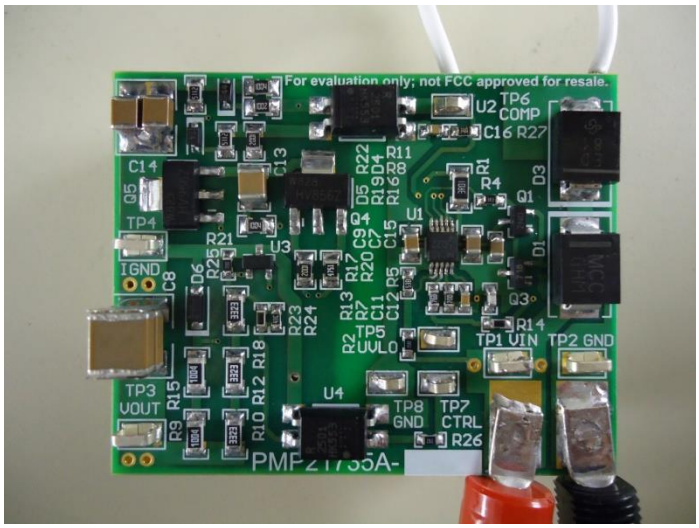
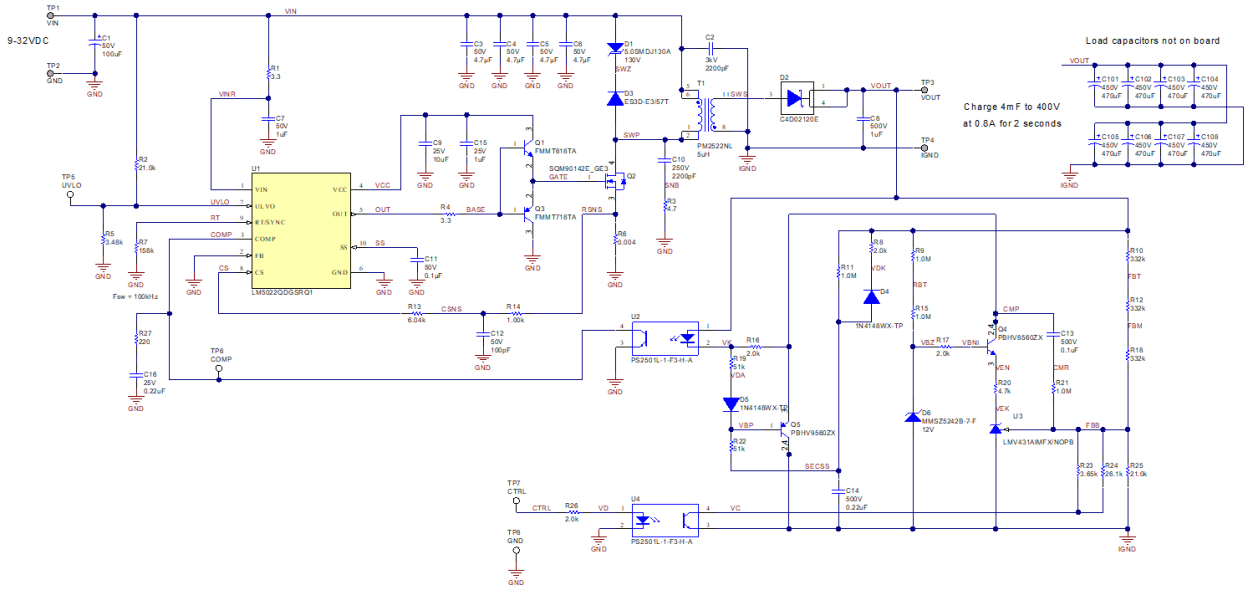
Test Report: PMP21735

400 V DC Link Capacitor Pre-Charger Reference Design for Automotive HEV/EV Applications

Description

This reference design is an automotive electric vehicle capacitor pre-charger power solution. The design is powered from the 12 V battery to charge a 4 mF capacitor bank to 400 V in 2 seconds. The design uses an isolated flyback controller operating at a switching frequency of 100 kHz. The initial output voltage is set for 60 V. A primary-side referenced control line is used to set the output to its final value of 400 V. Once the pre-charge sequence is complete, the UVLO function may be used to turn off the controller while the capacitor bank is connected to the rest of the system.





1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
Input Voltage	9-32 VDC
Initial Output Voltage Setting	60 V at 0.8 A
Final Output Voltage Setting	400 V at 0.8 A for 2 seconds (0.1 A sustained)

1.2 Required Equipment

- 9-32 V, 35 A power supply
- 500 V electronic load for transient testing
- Oscilloscope
- 8 x 470 µF, 450 V aluminum electrolytic capacitors
- Switched resistive load for capacitor discharging
- Safety enclosure

1.3 Considerations

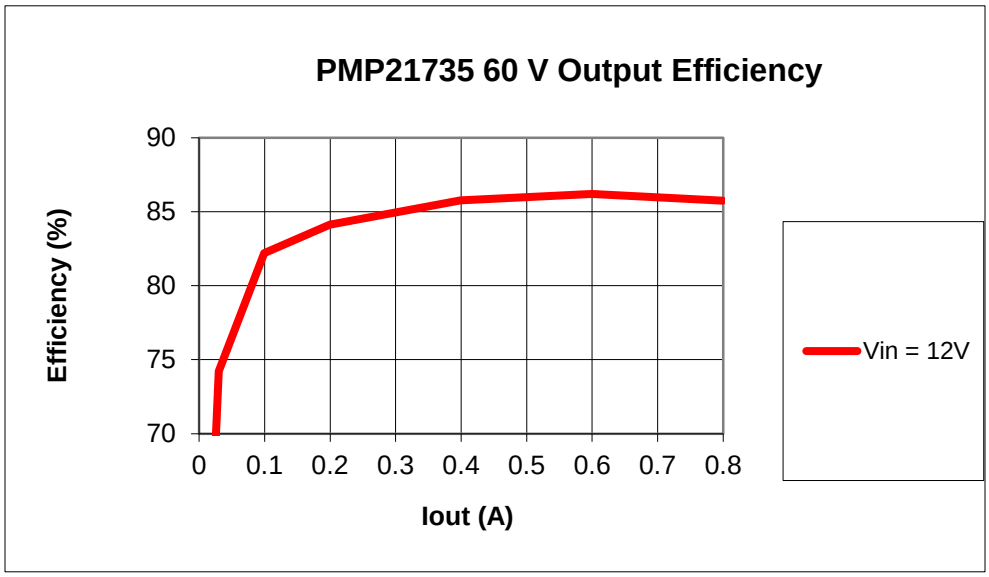
All tests were performed at room temperature on an open bench.

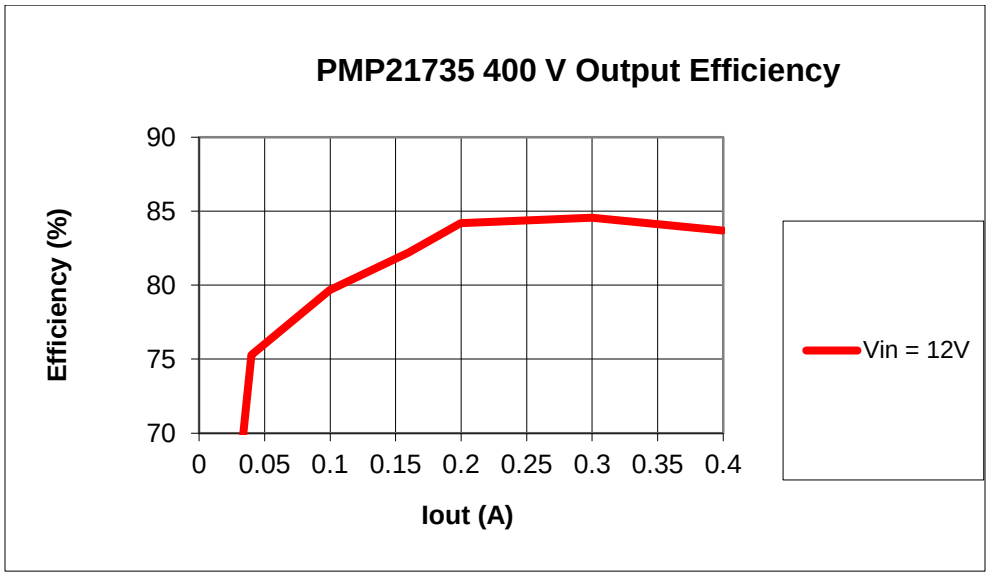
Danger: Lethal voltage potential is present on the output and must be discharged prior to handling.

2 Testing and Results

2.1 Efficiency Graphs

Figures show the converter efficiency with 60-V, and 400-V outputs.





2.2 Efficiency Data

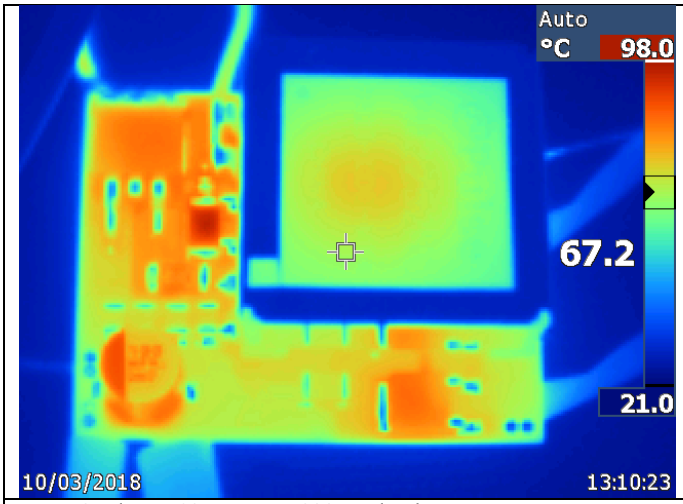
Tables show the efficiency data with 60-V, and 400-V outputs.

Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (W)	Pout (W)	Losses (W)	Efficiency (%)
12.019	0.0283	59.437	0.0000	0.340	0.000	0.340	0.00
12.051	0.0890	59.230	0.0098	1.073	0.580	0.492	54.12
12.051	0.1987	59.231	0.0300	2.395	1.777	0.618	74.21
12.007	0.5964	59.162	0.0995	7.161	5.887	1.274	82.20
11.994	1.1687	59.077	0.1996	14.017	11.792	2.226	84.12
11.996	2.3000	59.223	0.3995	27.591	23.660	3.931	85.75
11.939	3.4373	59.017	0.5994	41.038	35.375	5.663	86.20
11.910	4.6192	59.004	0.7994	55.015	47.168	7.847	85.74

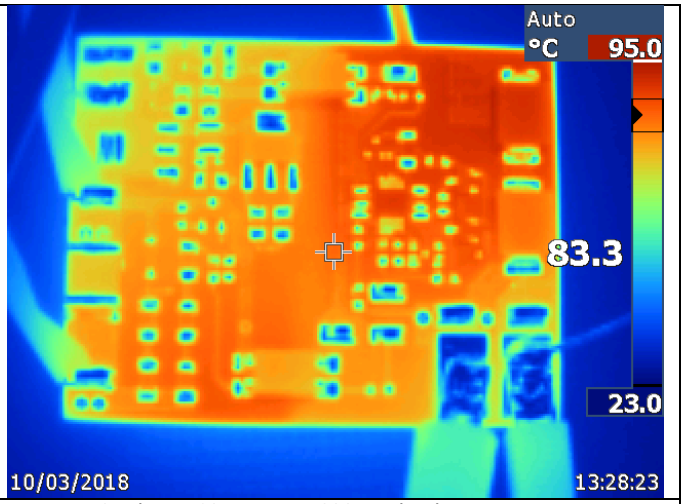
Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (W)	Pout (W)	Losses (W)	Efficiency (%)
12.051	0.359	393.83	0.0019	4.326	0.748	3.578	17.30
12.050	0.646	392.66	0.0098	7.784	3.848	3.936	49.43
12.050	1.715	389.90	0.0399	20.666	15.557	5.109	75.28
12.050	4.042	388.80	0.0998	48.706	38.802	9.904	79.67
12.052	6.267	388.70	0.1597	75.530	62.075	13.454	82.19
12.053	7.560	384.30	0.1996	91.121	76.706	14.414	84.18
12.055	11.210	381.20	0.2997	135.137	114.246	20.891	84.54
12.055	15.100	381.30	0.3995	182.031	152.329	29.701	83.68

2.3 Thermal Images

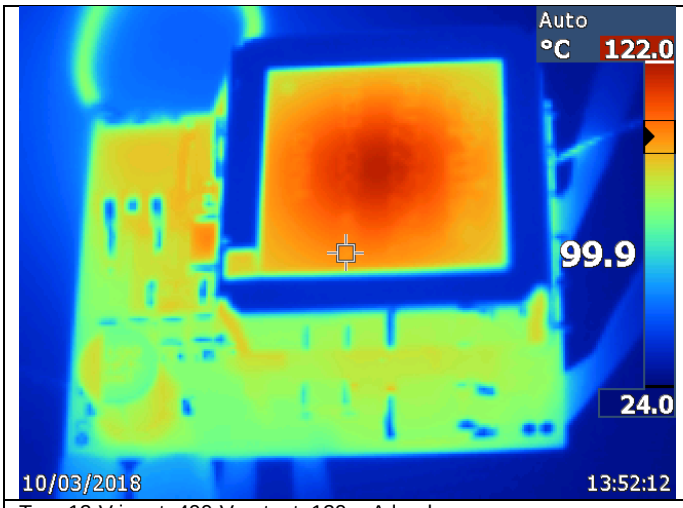
Figures show thermal performance at 12-V input with no airflow. The images were taken with the board at thermal equilibrium.



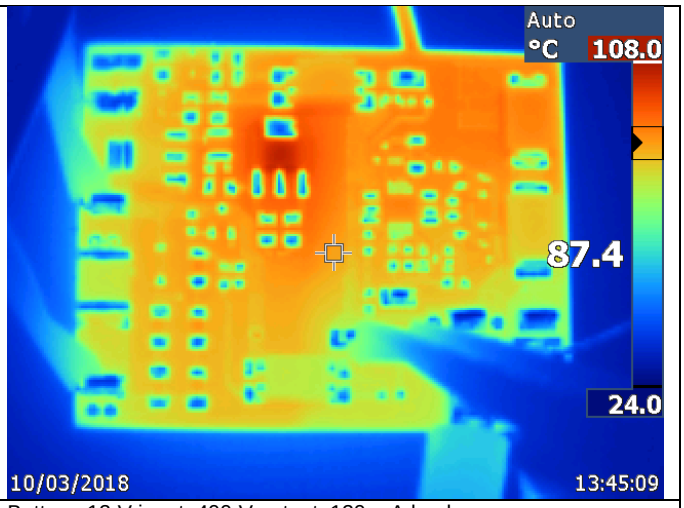
Top, 12-V input, 60-V output, 800-mA load



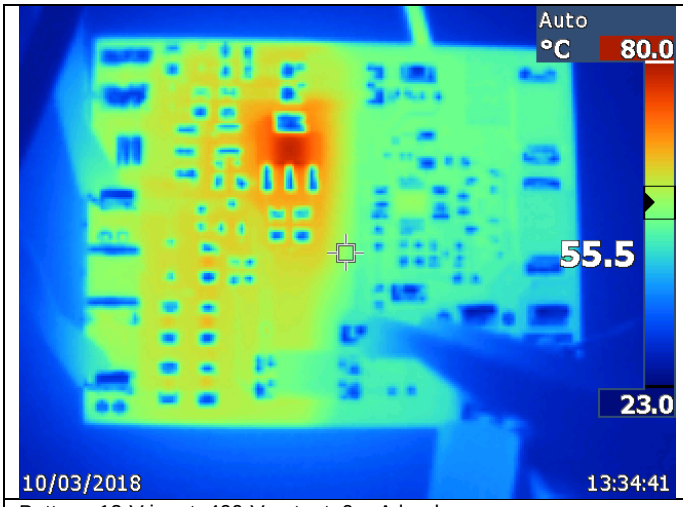
Bottom, 12-V input, 60-V output, 800-mA load



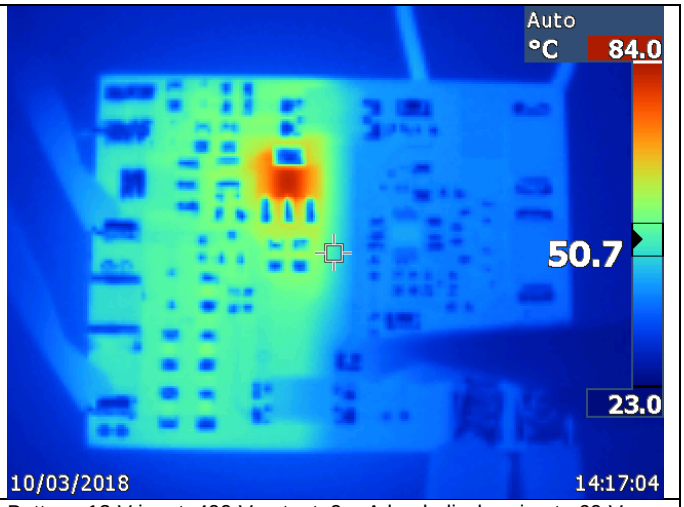
Top, 12-V input, 400-V output, 120-mA load



Bottom, 12-V input, 400-V output, 120-mA load



Bottom, 12-V input, 400-V output, 0-mA load

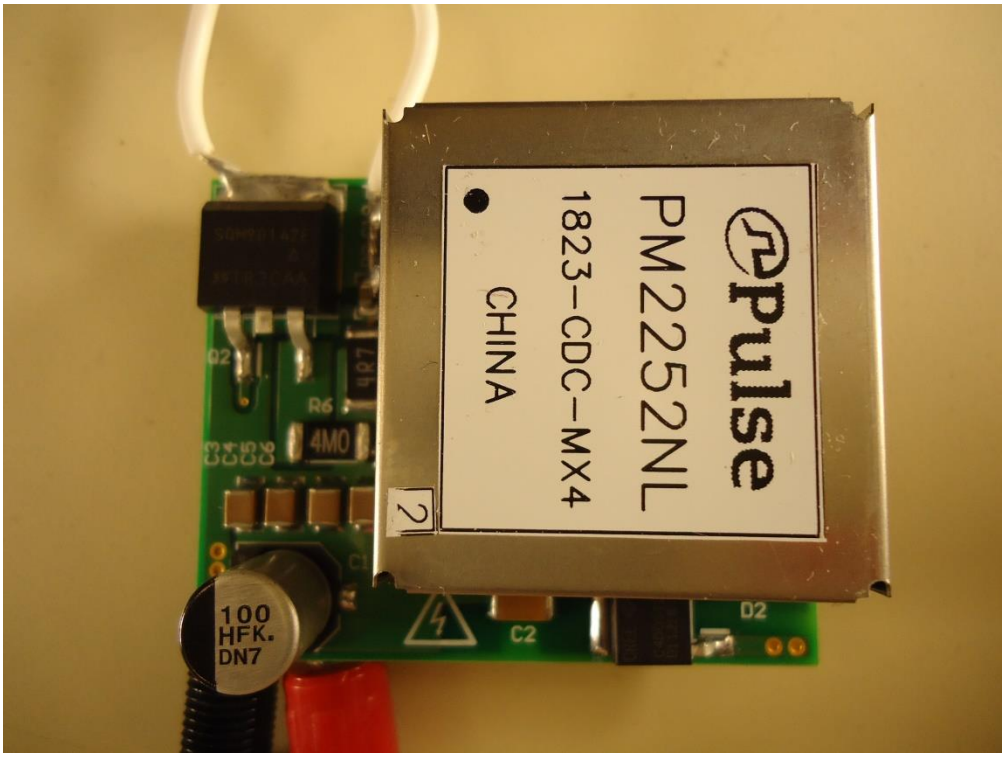


Bottom, 12-V input, 400-V output, 0-mA load, discharging to 60-V output

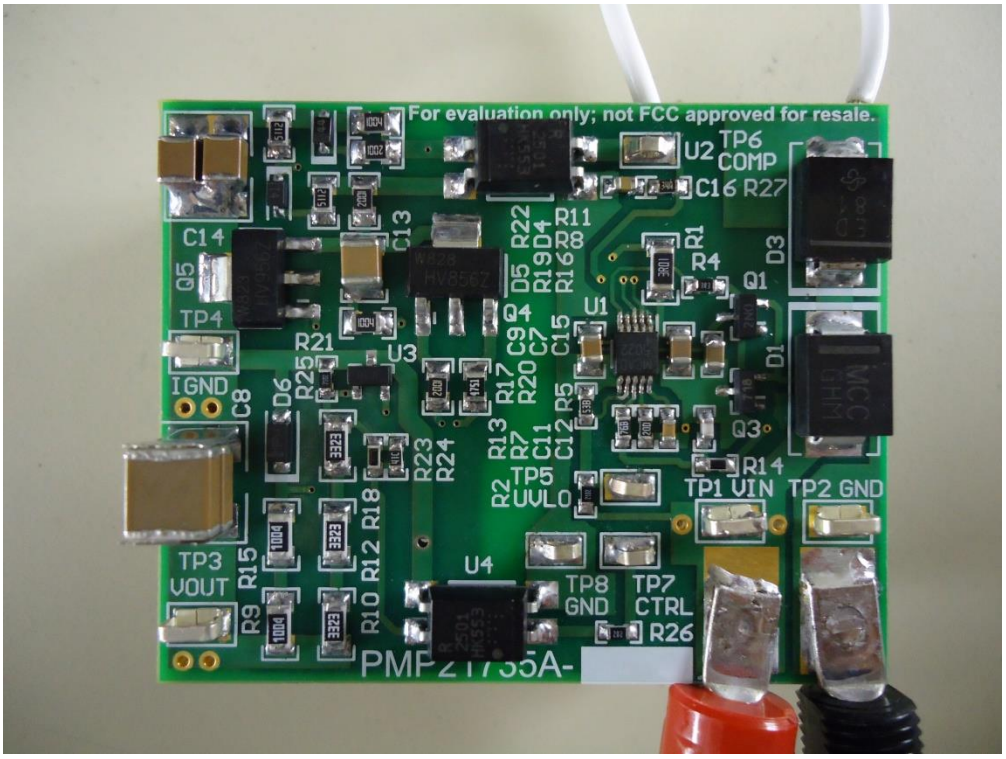
The hot spot at no load is the secondary-side high voltage standoff transistor. The maximum shunt regulator current is set for 2 mA, resulting in 0.8 W of power dissipation at 400 V out.

2.4 Dimensions

PMP21735 Rev A assembly was built on a 4-layer PCB with 1 oz. copper. Board dimensions are 1.570 in. x 1.970 in.



Top of PMP21735 Board

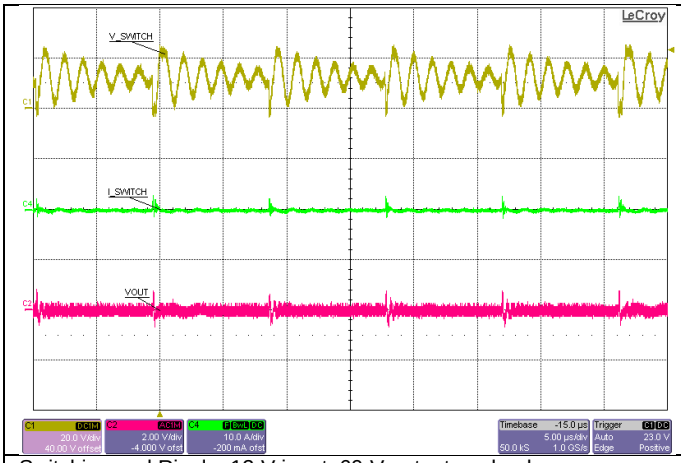


Bottom of PMP21735 Board

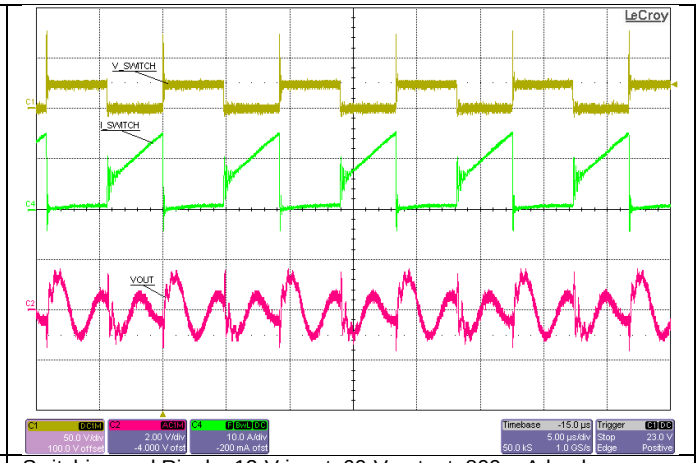
3 Waveforms

3.1 Switching and Output Voltage Ripple

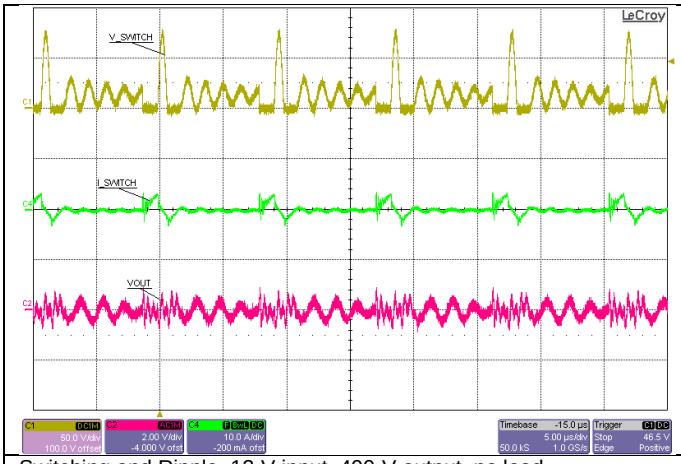
Figures show the switch node voltage, current and output voltage ripple of the converter. Operation was tested with up to 1-meter twisted pair wires to the load capacitors. Longer wires results in higher output voltage ripple at the converter. Discontinuous conduction mode ringing results in perturbation of the duty cycle at 400-V output with no load.



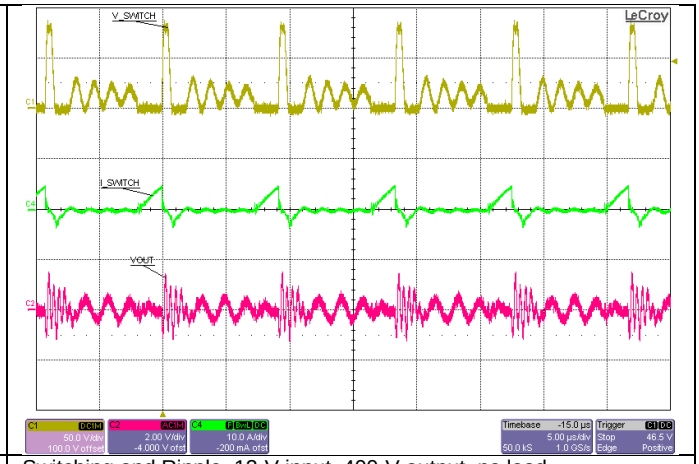
Switching and Ripple, 12-V input, 60-V output, no load



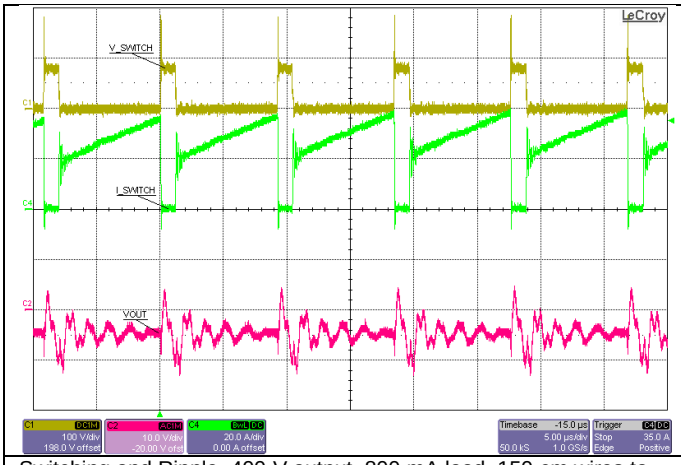
Switching and Ripple, 12-V input, 60-V output, 800-mA load



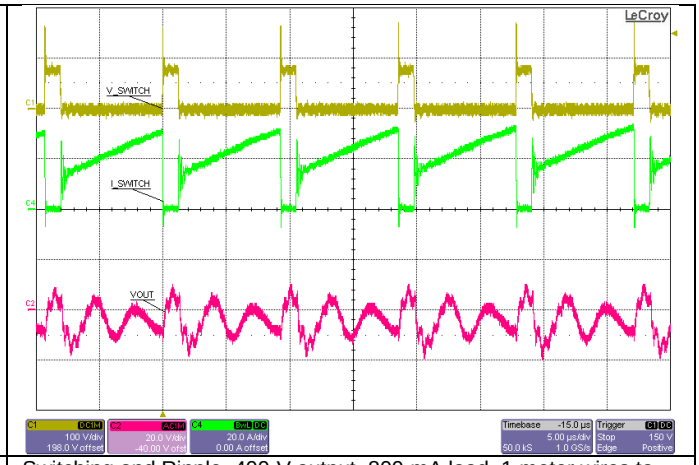
Switching and Ripple, 12-V input, 400-V output, no load



Switching and Ripple, 12-V input, 400-V output, no load



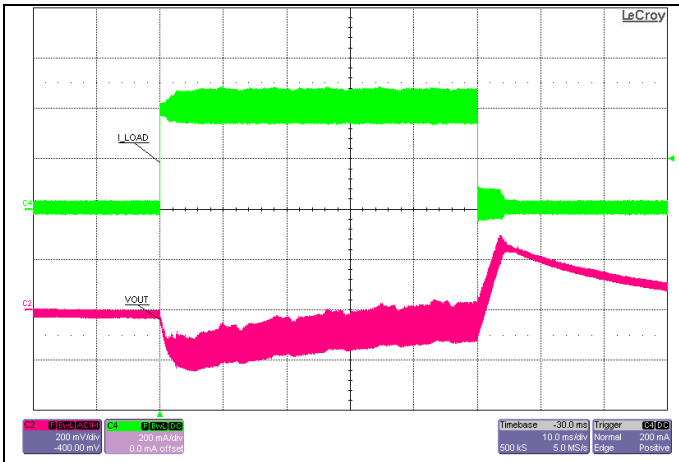
Switching and Ripple, 400-V output, 800-mA load, 150-cm wires to load capacitors



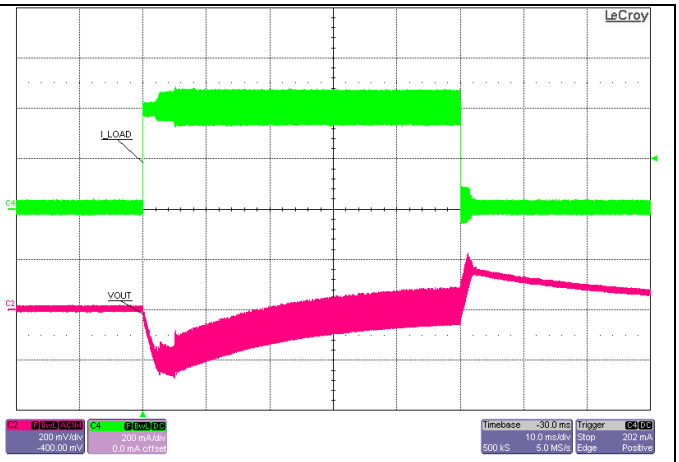
Switching and Ripple, 400-V output, 800-mA load, 1-meter wires to load capacitors

3.2 Load Transients

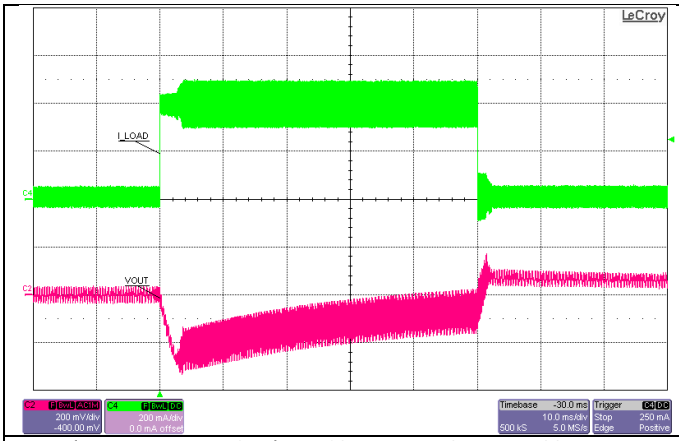
Figures show the load transient response of the converter. 60-V output transient shows perturbation due to discontinuous conduction mode ringing at 32-V input. At 400-V output, current limiting is evident with 400-mA load.



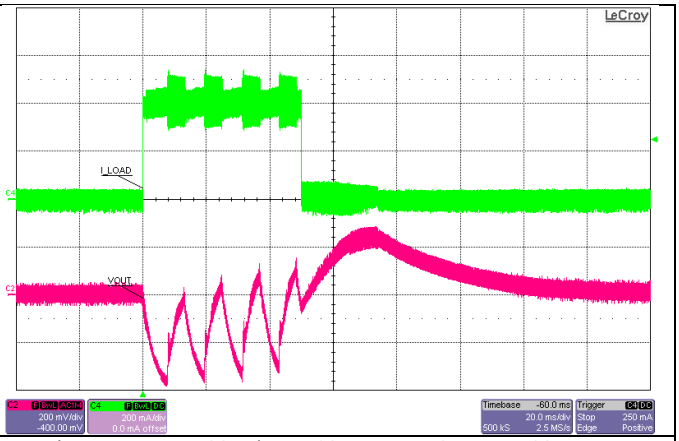
Transient Response, 9-V input, 60-V output, 0-mA to 400-mA



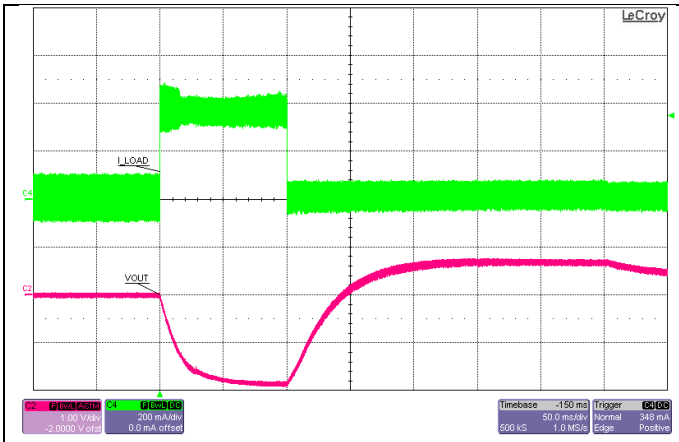
Transient Response, 12-V input, 60-V output, 0-mA to 400-mA



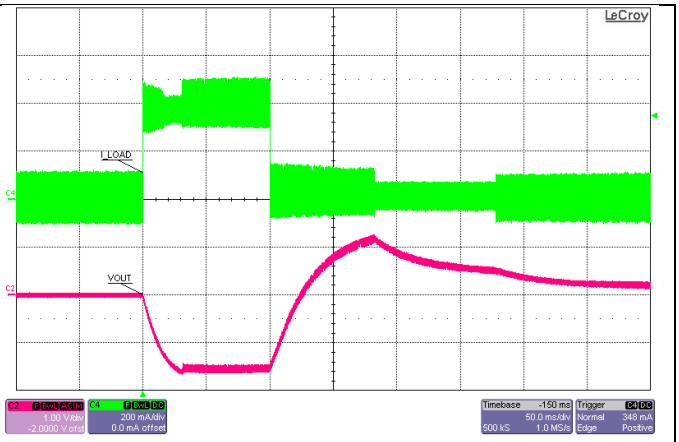
Transient Response, 18-V input 60-V output, 0-mA to 400-mA



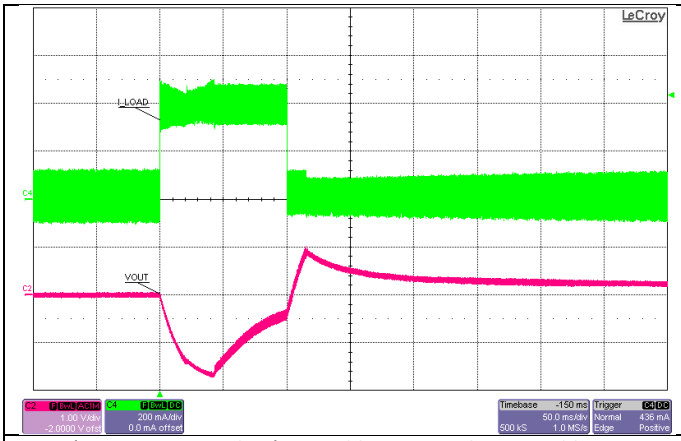
Transient Response, 32-V input, 60-V output, 0-mA to 400-mA



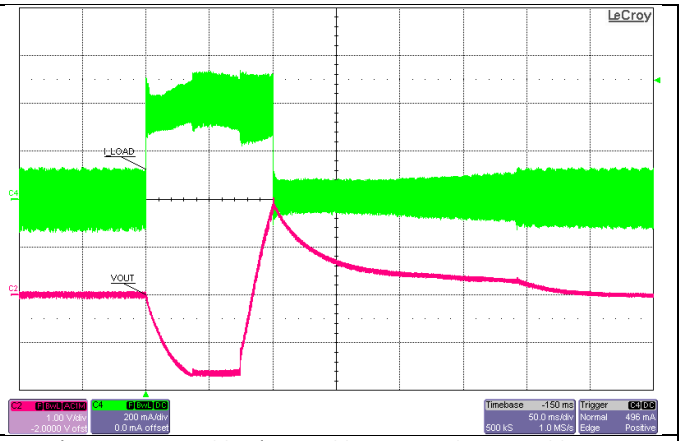
Transient Response, 9-V input, 400-V output, 0-mA to 400-mA



Transient Response, 12-V input, 400-V output, 0-mA to 400-mA



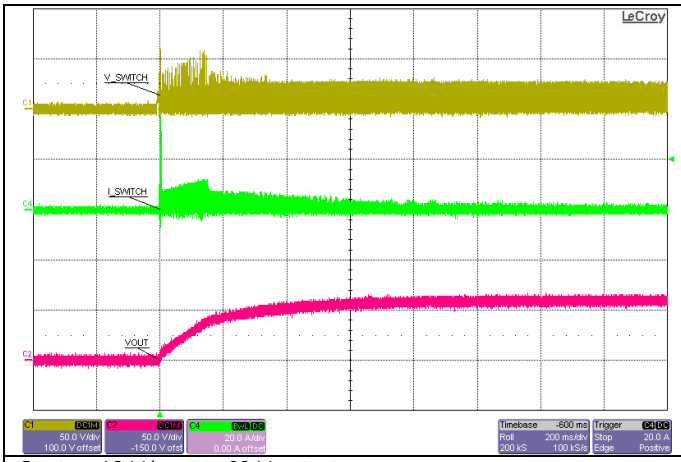
Transient Response, 18-V input, 400-V output, 0-mA to 400-mA



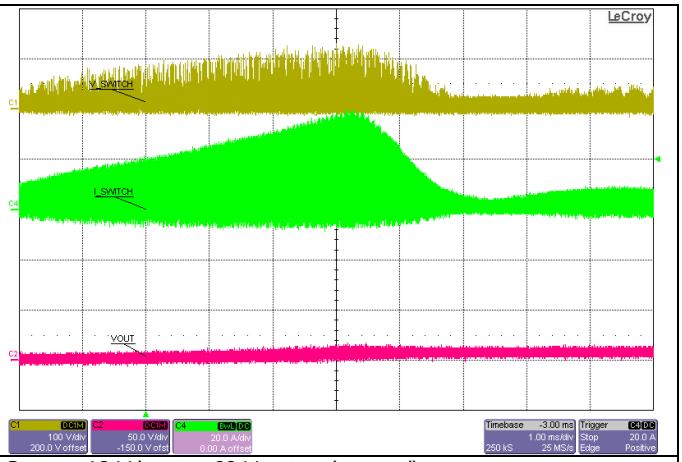
Transient Response, 32-V input, 400-V output, 0-mA to 400-mA

3.3 Start-up

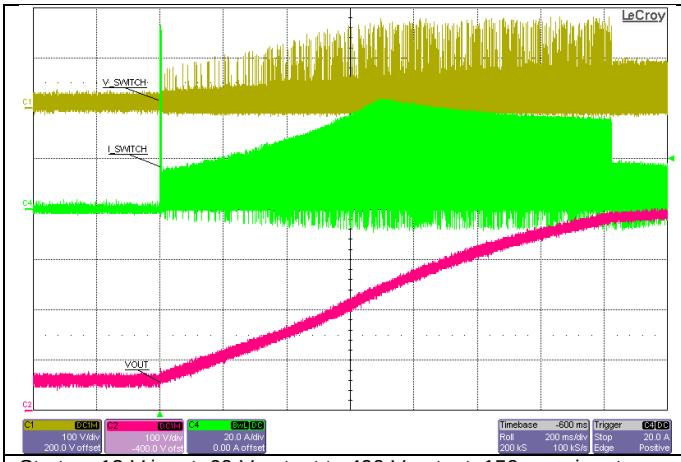
Figures show the startup performance into the capacitive load. Operation was tested with up to 1-meter twisted pair wires to the load capacitors. Longer wires results in a somewhat longer startup time.



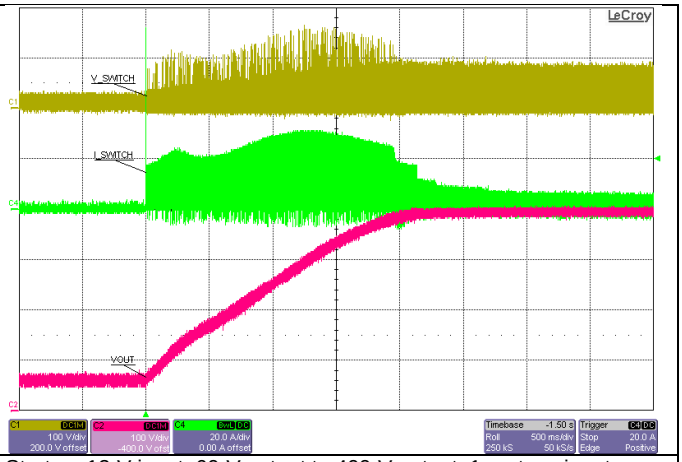
Startup, 12-V input to 60-V output



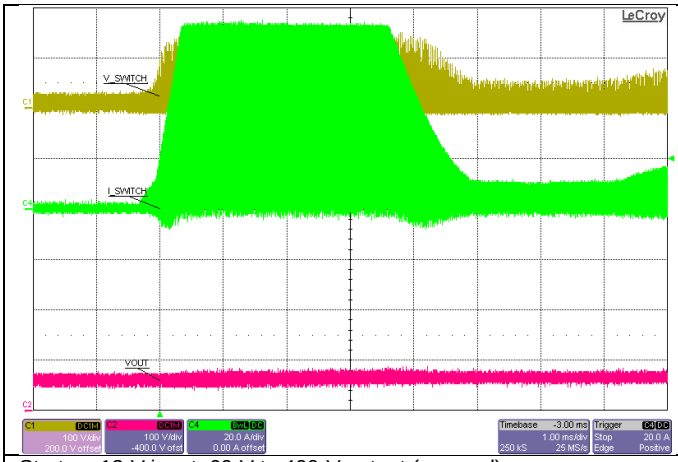
Startup, 12-V input to 60-V output (zoomed)



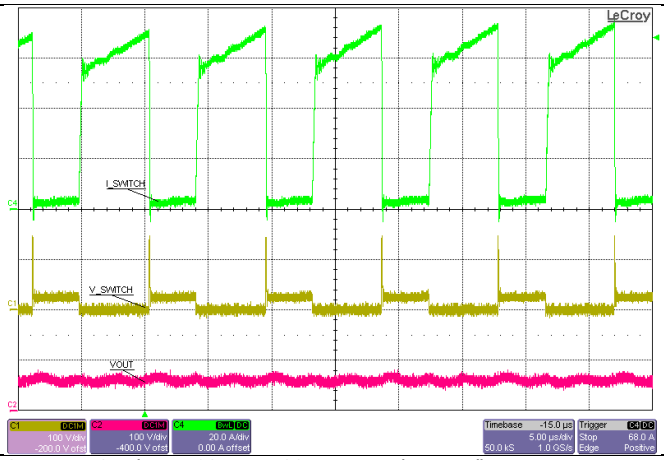
Startup, 12-V input, 60-V output to 400-V output, 150-cm wires to load capacitors



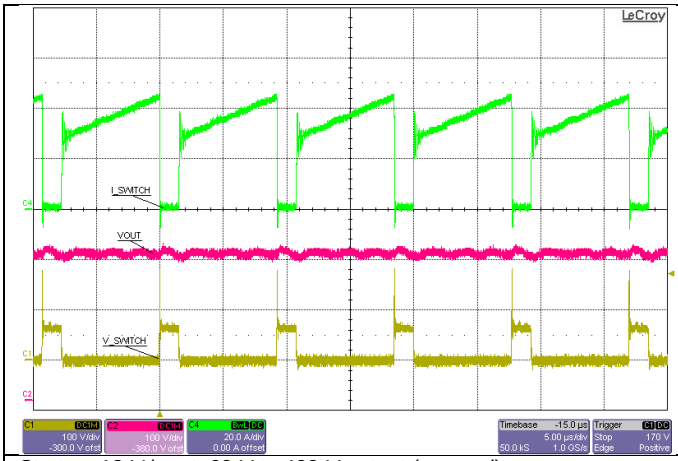
Startup, 12-V input, 60-V output to 400-V output, 1-meter wires to load capacitors



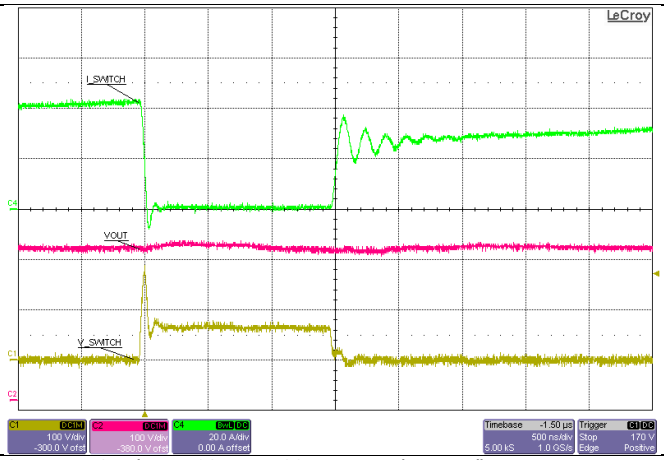
Startup, 12-V input, 60-V to 400-V output (zoomed)



Startup, 12-V input, 60-V to 400-V output (zoomed)



Startup, 12-V input, 60-V to 400-V output (zoomed)



Startup, 12-V input, 60-V to 400-V output (zoomed)

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