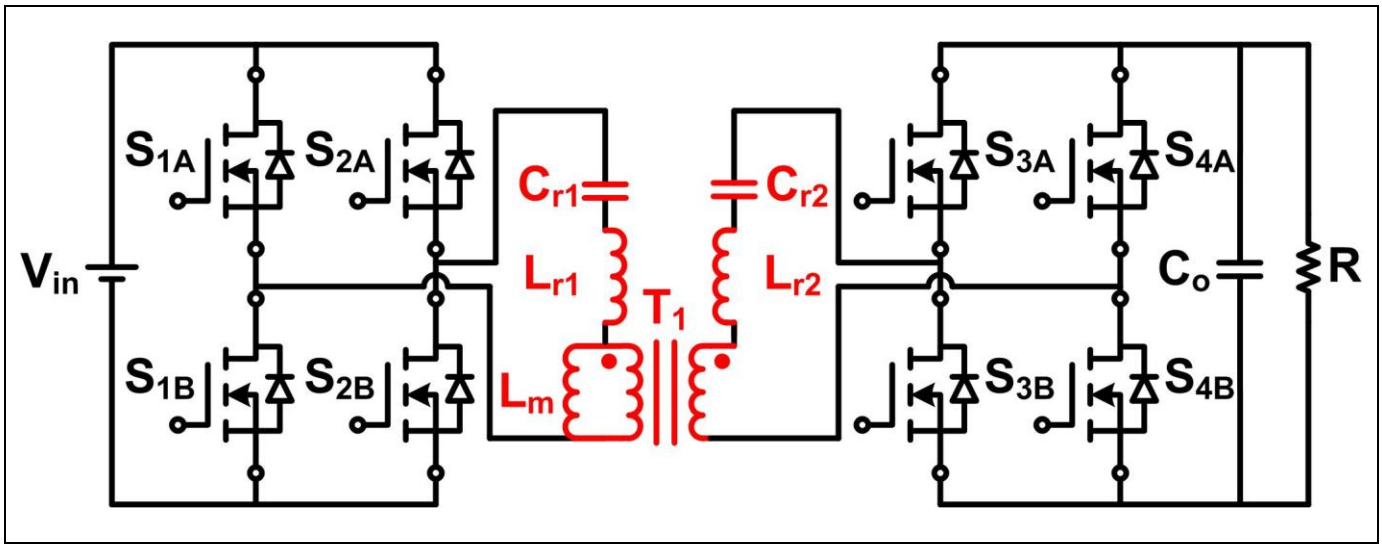
Test Report: PMP21999

6.6-kW, Bi-Directional CLLLC Resonant Converter Reference Design Using PCB Winding Transformer

TEXAS INSTRUMENTS

Description

The PMP21999 reference design is a 6.6 kW bi-directional dual-active-bridge resonant converter reference design that allows 380 V_{DC} to 600 V_{DC} input and 280 V_{DC} to 450 V_{DC} output. This design uses C2000 Micro-controller TMS320F280049 along with silicon-carbide (SiC) driver UCC21530-Q1 to drive bridges both on primary and secondary sides. Daughter card approach has been implemented to C2000 controller (TMDSCNCD280049C) and SiC drivers (PMP21553 and PMP21561). Rogowski coil is applied for synchronous rectifier (SR) optimization along with high bandwidth OpAmp LMV116MF. With 500 kHz resonant frequency and 300 kHz~700 kHz operational frequencies, this design is able to reach peak 98% efficiency.



1 System Specification

1.1 Board Dimension:

Board dimension should be within 5.8” x 7.5” x 3”.

1.2 Input/output Characteristics

- $380V_{DC}$ to $600V_{DC}$ input.
- $280V_{DC}$ to $450V_{DC}$ output.
- Maximum 6.6kW output power.
- >98% peak efficiency.

1.3 Protections

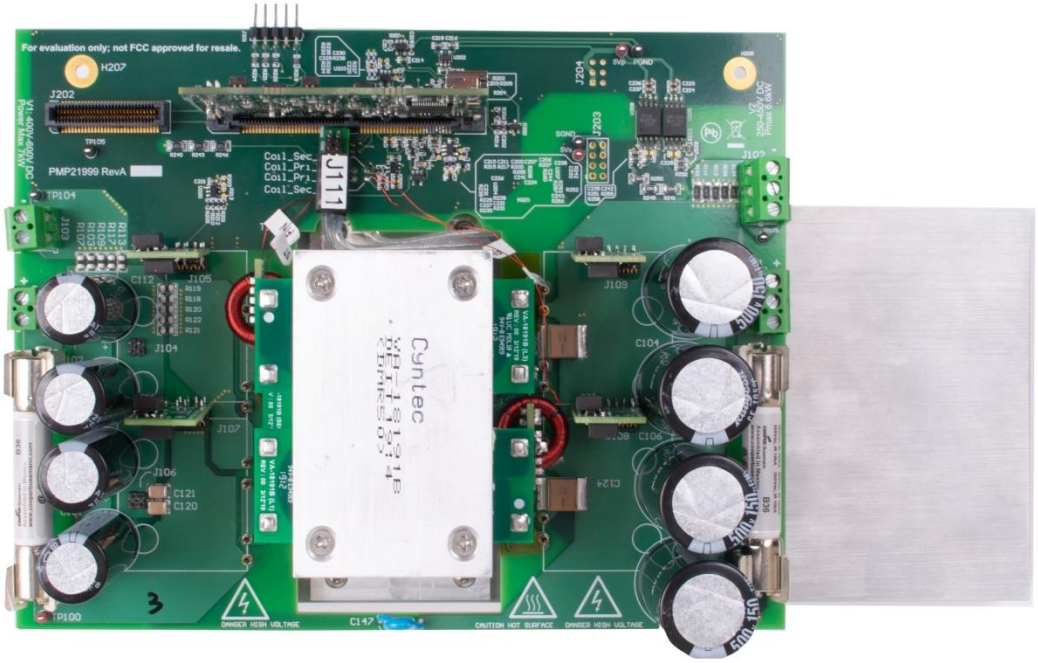
Provide over-current-protection (OCP) and over-voltage-protection (OVP) functions both at primary and secondary sides.

2 Testing and Results

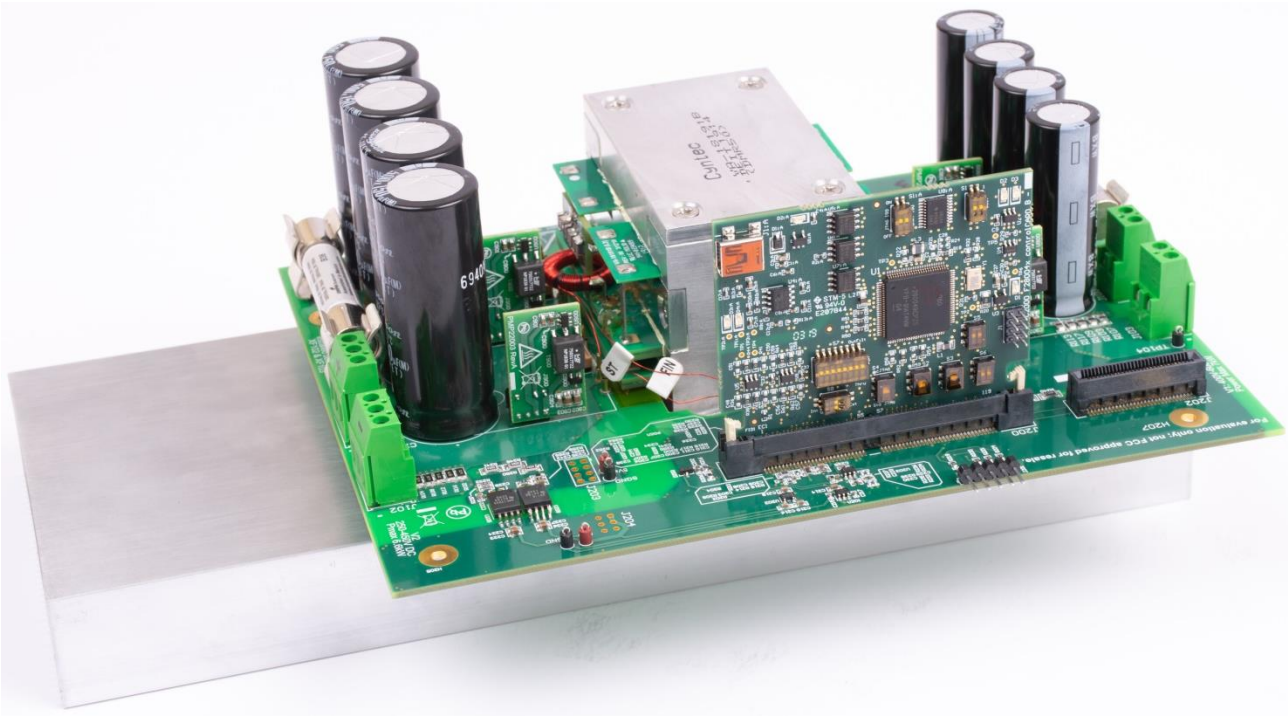
2.1 Board Photos

The photographs below show the top and side view of the PMP21999Rev A board.

2.1.1 Top View



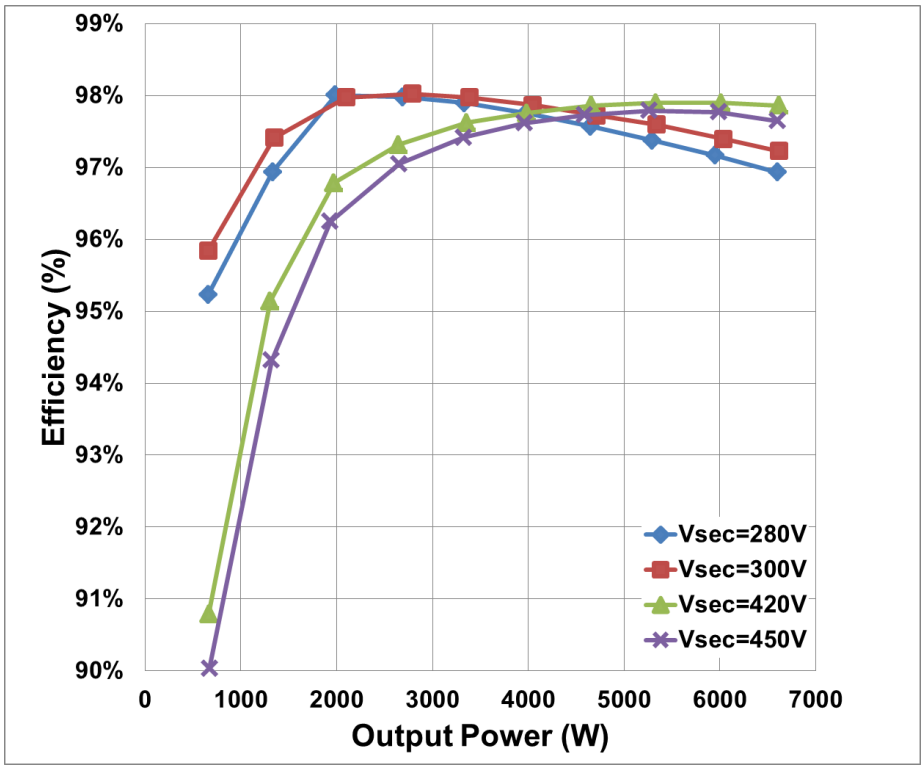
2.1.2 Side View



2.2 Efficiency Data

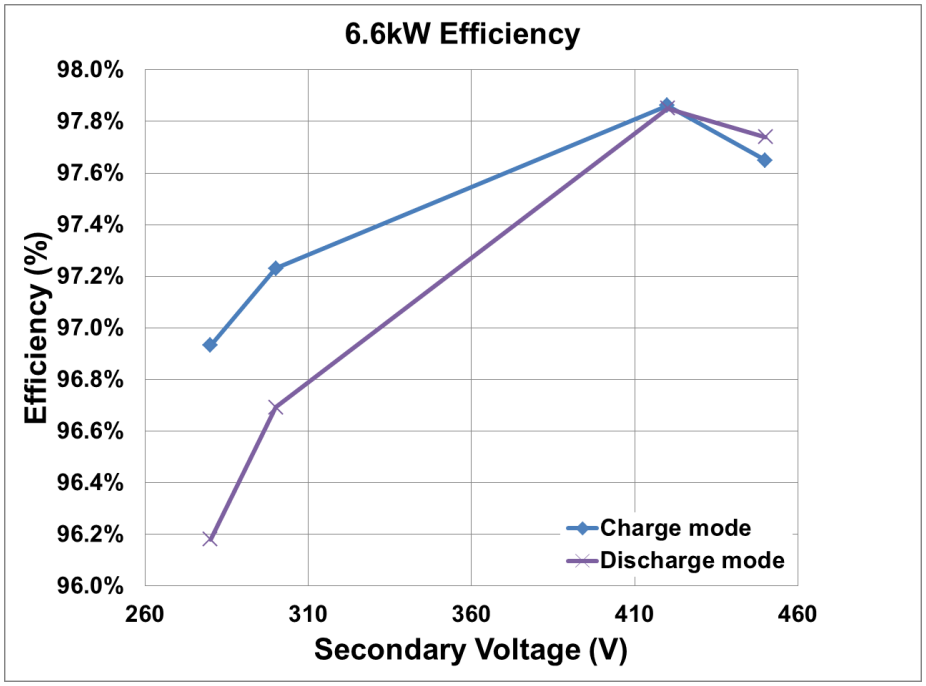
During efficiency test, 2 x 12V fans (Delta FFB0412EN-00Y2E, operate at 12V) were apply to bottom heatsink and blow from the primary side. A DC power supply is applied on the primary side and a DC load is applied on the secondary side.

2.2.1 Open Loop Efficiency Measurement – Energy Flows From HV to LV

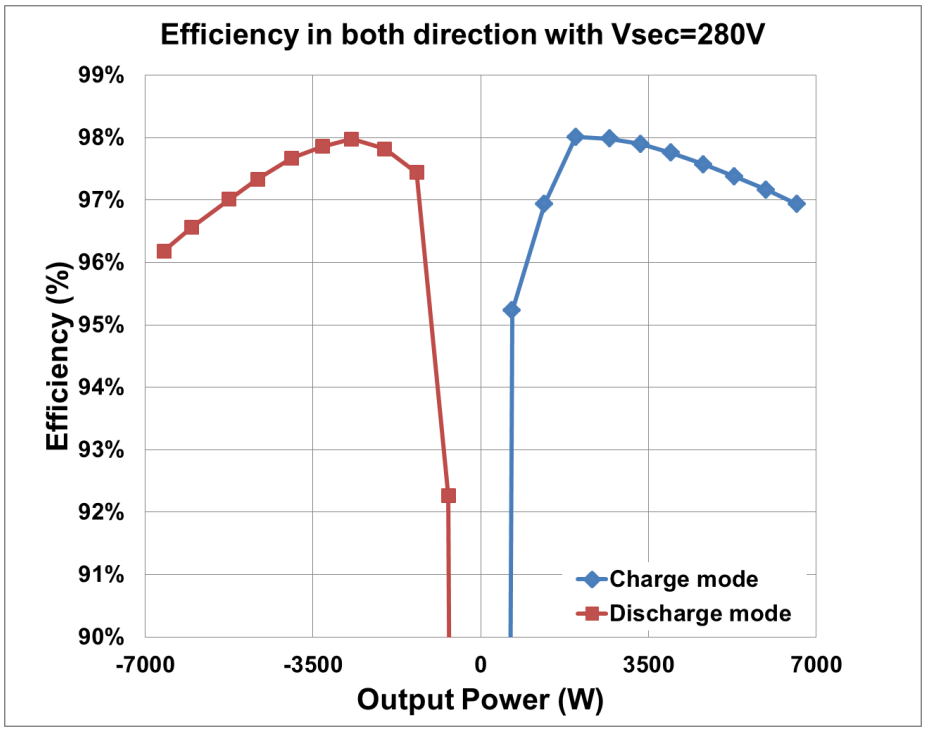


Vpri(V)	Vsec(V)	Pout(W)	Efficiency (%)	Frequency(kHz)
374.57	280.01	657.90	95.23%	600
375.68	280.01	1332.90	96.94%	566
374.97	280.03	1987.20	98.01%	517
376.28	280.02	2686.90	97.98%	517
377.46	280.03	3331.00	97.90%	517
378.46	280.07	3975.20	97.76%	508
379.54	280.02	4646.20	97.57%	508
380.63	280.05	5290.50	97.38%	508
381.69	280.06	5954.70	97.17%	508
382.78	280.05	6604.70	96.93%	508
399.36	300.05	658.70	95.84%	625
401.45	300.06	1349.20	97.41%	566
401.63	300.08	2099.60	97.97%	526
402.53	300.03	2789.10	98.03%	517
403.55	300.02	3388.70	97.98%	517
404.68	300.02	4048.50	97.87%	517
405.76	300.05	4708.00	97.73%	517
406.66	300.10	5339.50	97.60%	508
407.67	300.00	6033.80	97.40%	508
408.68	300.06	6615.80	97.23%	508
535.70	420.07	667.40	90.79%	566
561.82	420.05	1304.90	95.14%	638
560.96	420.06	1972.20	96.79%	566
561.87	420.06	2643.80	97.32%	566
561.91	420.06	3358.10	97.63%	536
562.55	419.99	3987.00	97.75%	536
562.78	420.00	4659.70	97.86%	526
563.71	420.03	5331.30	97.90%	526
564.13	420.01	6011.00	97.90%	517
564.99	420.04	6615.80	97.86%	517
573.01	450.08	672.90	90.03%	577
601.76	450.05	1321.40	94.32%	638
600.40	450.08	1932.60	96.25%	566
600.83	450.02	2652.70	97.05%	546
600.76	450.08	3327.70	97.42%	526
601.52	450.00	3957.10	97.62%	526
602.33	450.02	4587.50	97.73%	526
603.06	450.04	5262.30	97.79%	526
603.71	450.05	5988.10	97.77%	517
604.46	449.98	6601.10	97.65%	517

2.2.2 6.6kW Efficiency in Two Energy Flow Directions (Charge Mode: From HV to LV; Discharge Mode: From LV to HV)



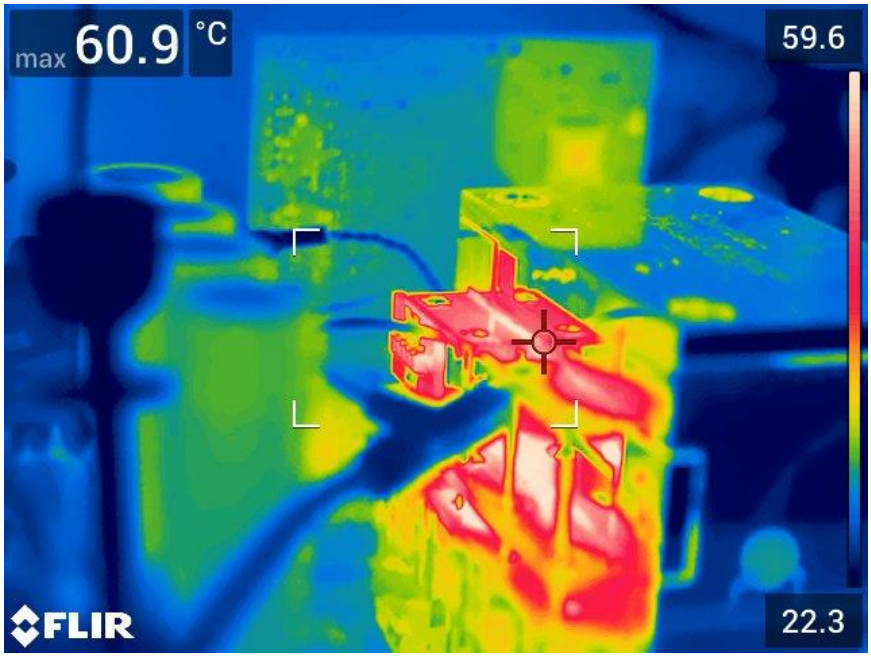
2.2.3 Efficiency in Two Energy Flow Directions (Charge Mode: From HV to LV; Discharge Mode: From LV to HV)

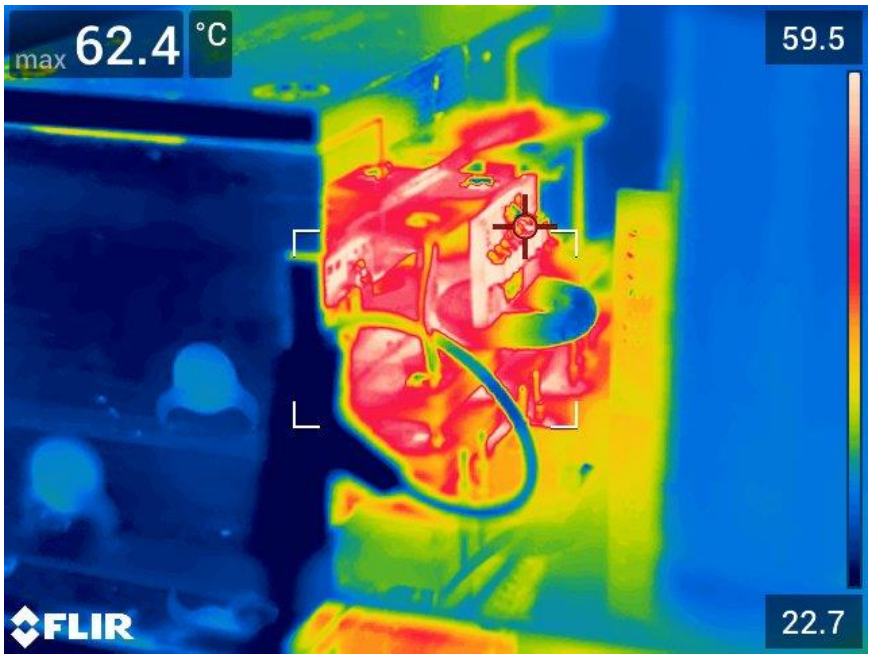


2.3 Thermal Images

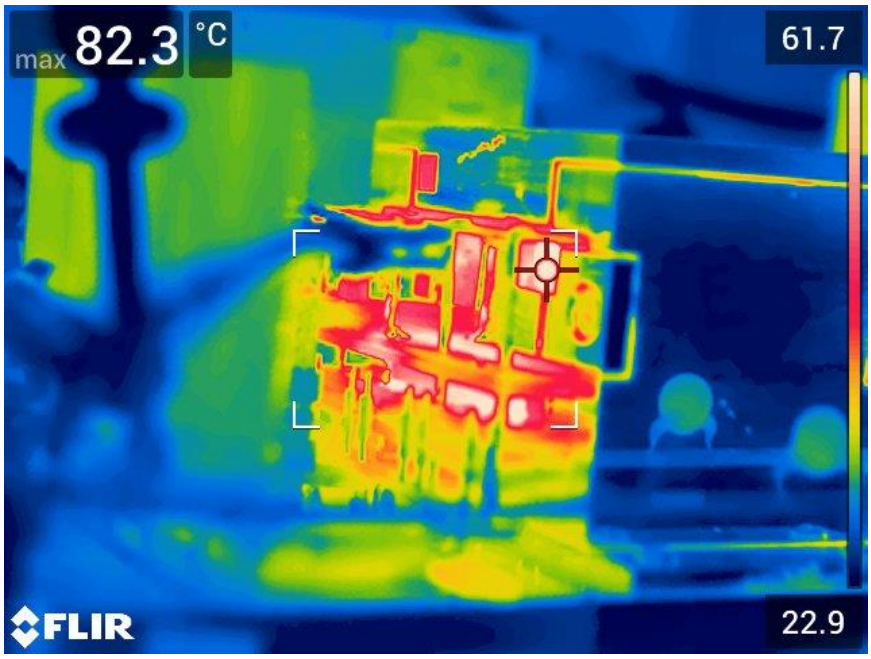
The thermal images below were taken with 6.6kW output power. During the test, 2 x 12V fans (Delta FFB0412EN-00Y2E, operate at 12V) were apply to bottom heatsink and blow from the primary side. The ambient temperature was 25ºC

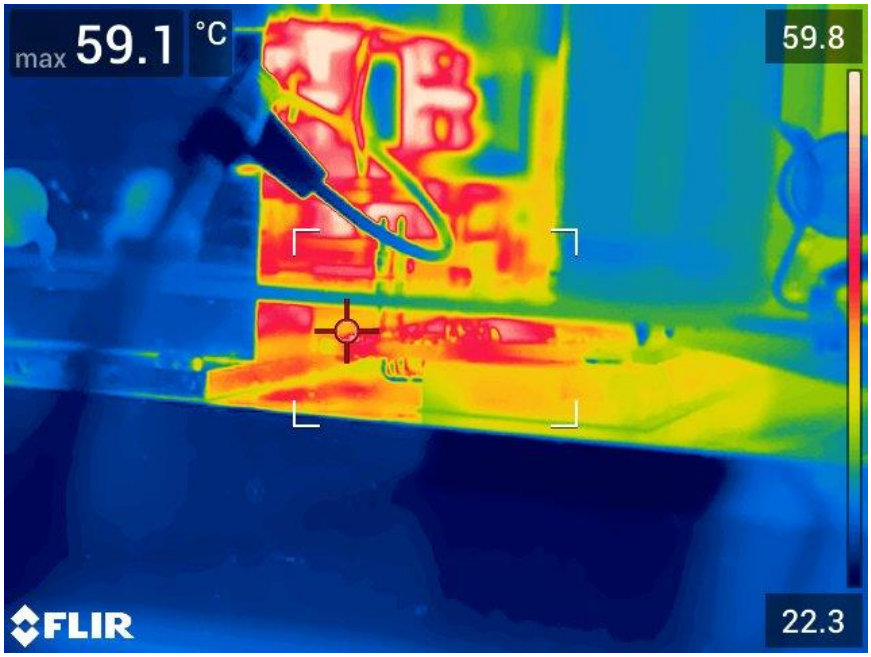
2.3.1 Charge mode: 383Vprim, 280Vsec/6.6kW, Fsw=508kHz, η=96.93%





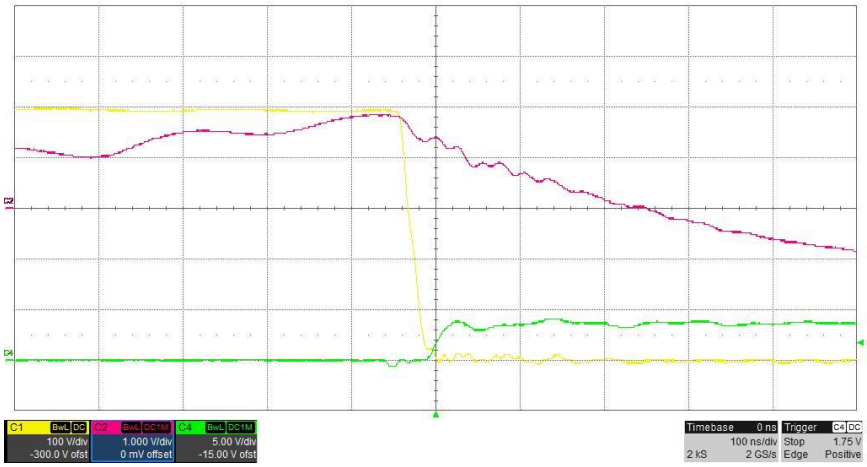
2.3.2 Charge mode: 565Vprim, 420Vsec/6.6kW, Fsw=517kHz, η=97.9%



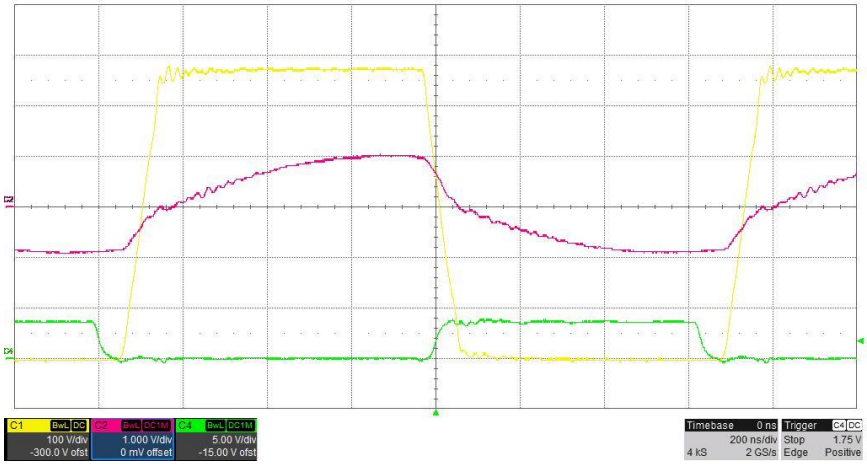


2.4 Key Waveforms

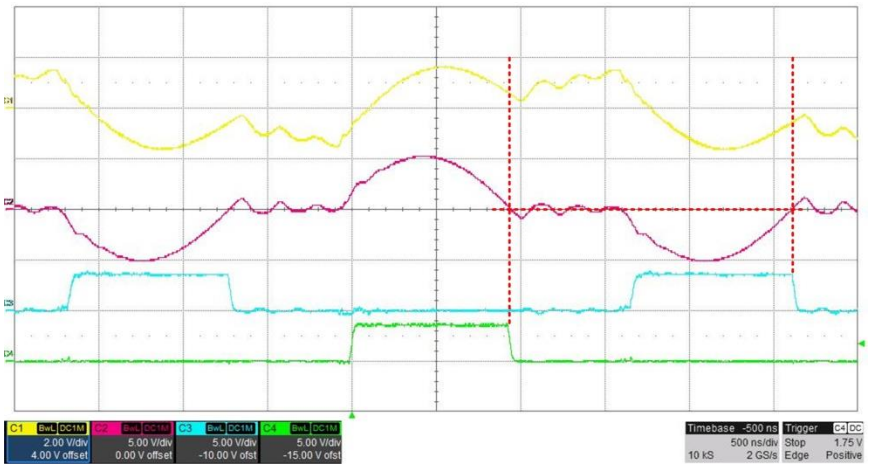
2.4.1 Soft-switching waveforms at 493Vprim, 420Vsec/3.3kW – Fsw=300kHz: C1: Primary LS FET VDS, C2: XFMR Primary Winding Current (100mV/A), C4: PWM2B – Primary LS FET Driving Signal.



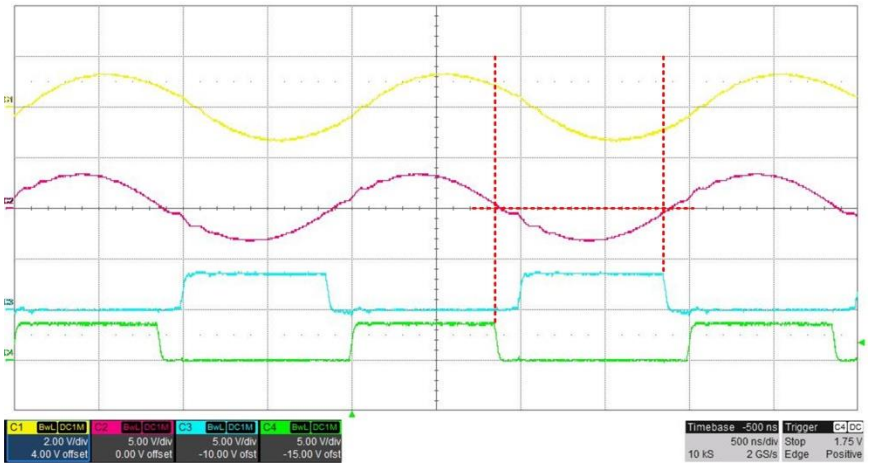
2.4.2 Soft-switching waveforms at 566Vprim, 420Vsec/3.3kW – 700kHz: C1: Primary LS FET VDS, C2: XFMR Primary Winding Current (100mV/A), C4: PWM2B – Primary LS FET Driving Signal.



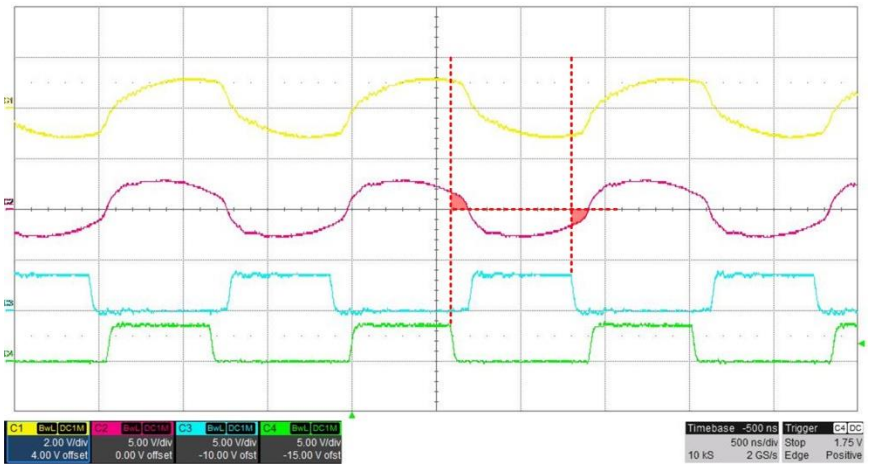
2.4.3 F_{sw}=300kHz, 3.3kW: C1: XFMR Primary Winding Current (100mV/A), CH2: XFMR Secondary Winding Current (200mV/A), CH3: SR Driving Signal (PWM3A), CH4: SR Driving Signal (PWM3B)



2.4.4 F_{sw}=500kHz, 3kW: C1: XFMR Primary Winding Current (100mV/A), CH2: XFMR Secondary Winding Current (200mV/A), CH3: SR Driving Signal (PWM3A), CH4: SR Driving Signal (PWM3B)



2.4.5 F_{sw}=700kHz, 2.9kW: C1: XFMR Primary Winding Current (100mV/A), CH2: XFMR Secondary Winding Current (200mV/A), CH3: SR Driving Signal (PWM3A), CH4: SR Driving Signal (PWM3B)



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