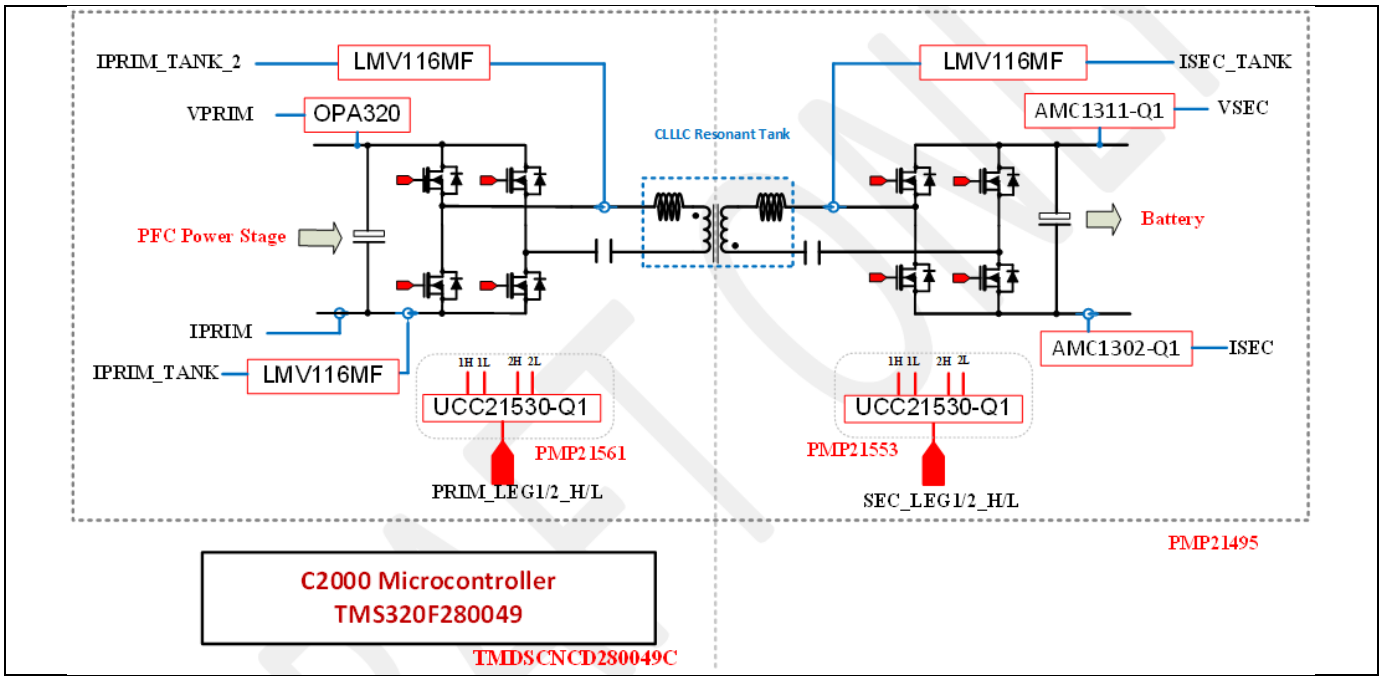
Test Report: PMP21495
6.6 kW bi-directional dual-active-bridge CLLLC resonant converter reference design

Description

The PMP21495 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 10.7” x 3”.

1.2 Input/output Characteristics

- $380V_{DC}$ to $600V_{DC}$ input.
- $280V_{DC}$ to $450V_{DC}$ output.
- Maximum 6.6kW output power.
- >97% peak efficiency.

1.3 Protections

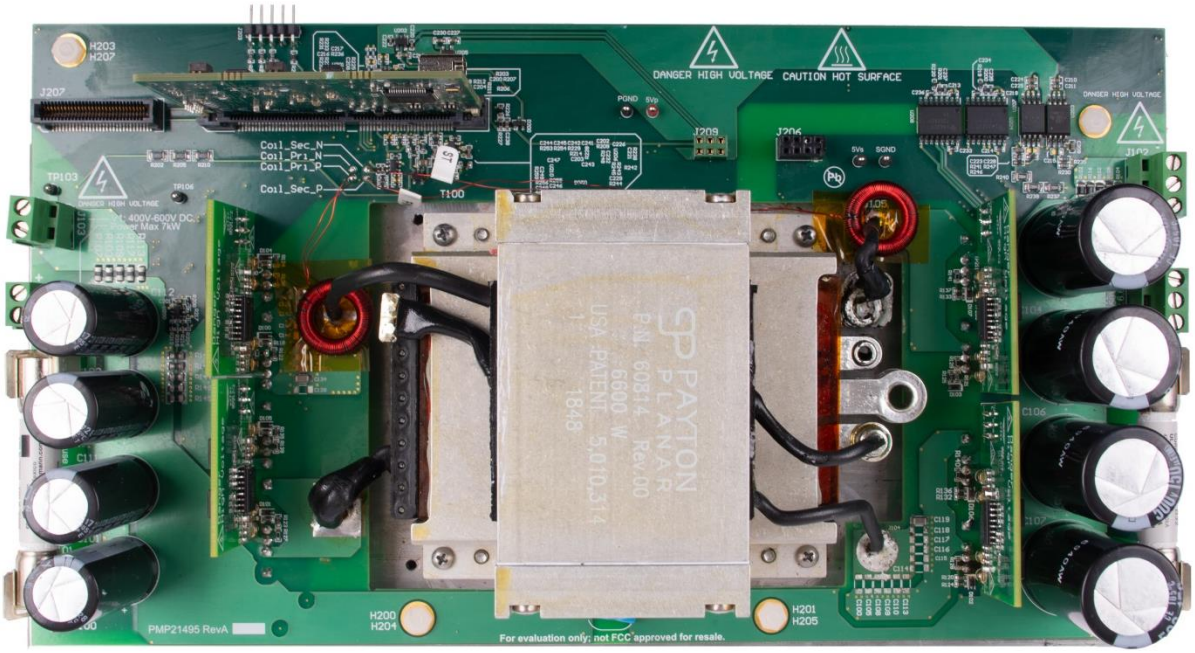
Provide over-current-protection (OCP) and over-voltage-protection (OVP) functions both at primary and secondary sides.

2 Testing and Results

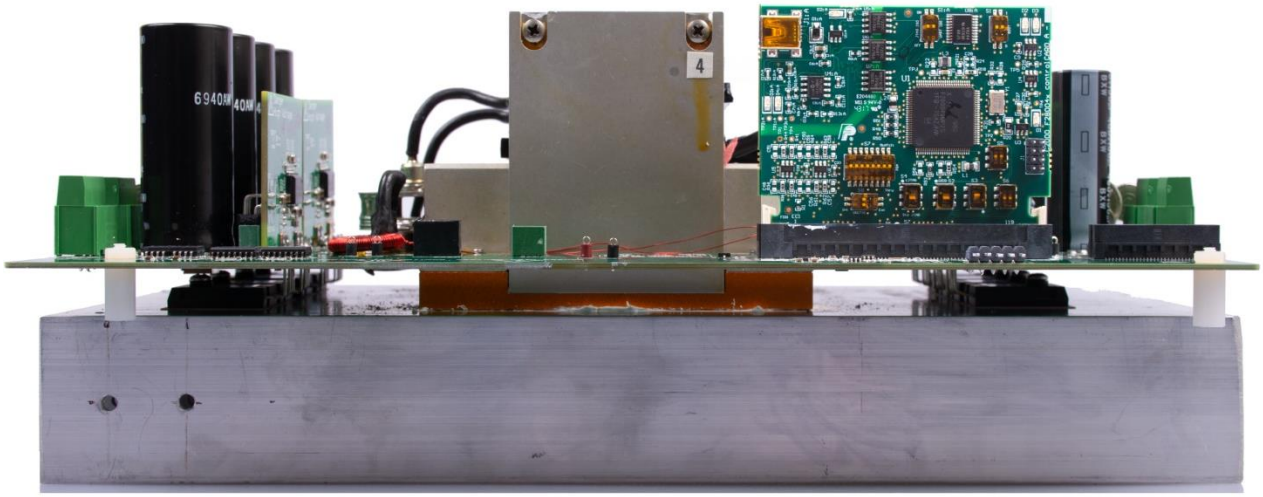
2.1 Board Photos

The photographs below show the top and side view of the PMP21495Rev B board.

2.1.1 Top View



2.1.2 Side View

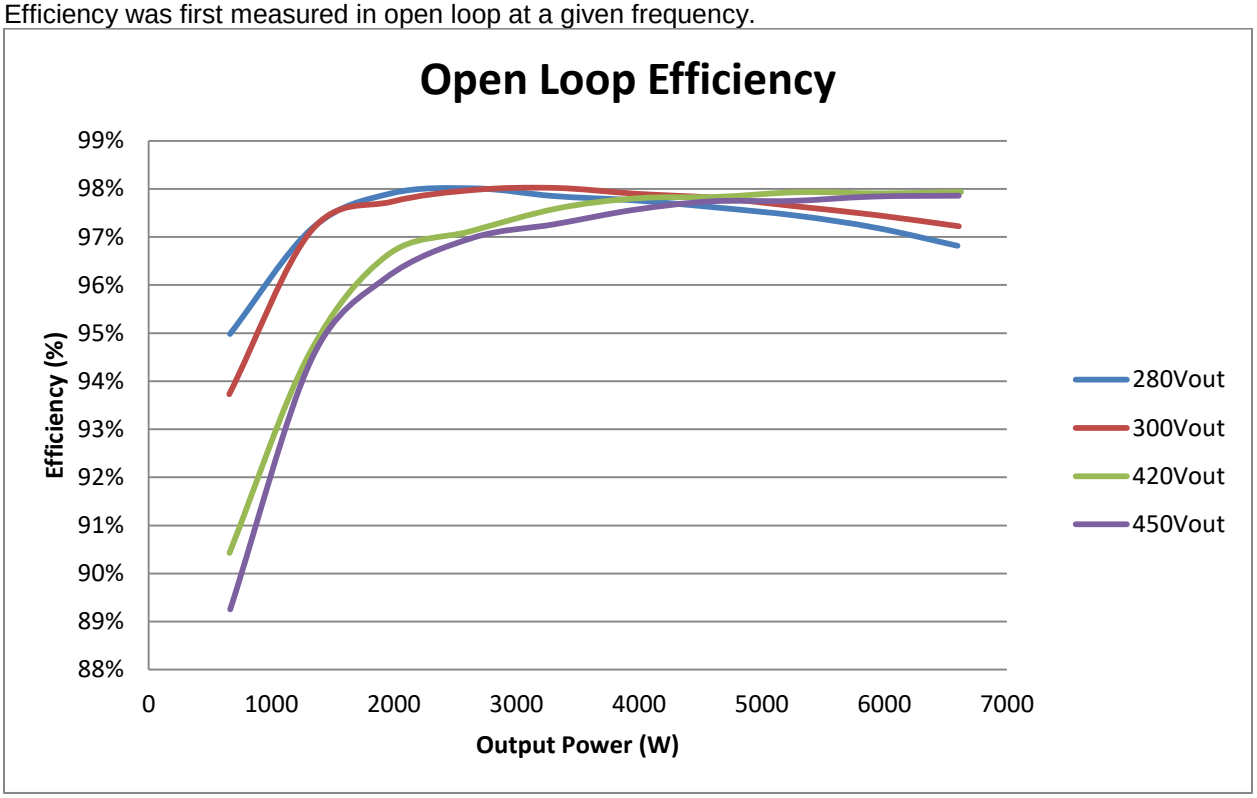


2.2 Efficiency Data

During efficiency test, 3 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

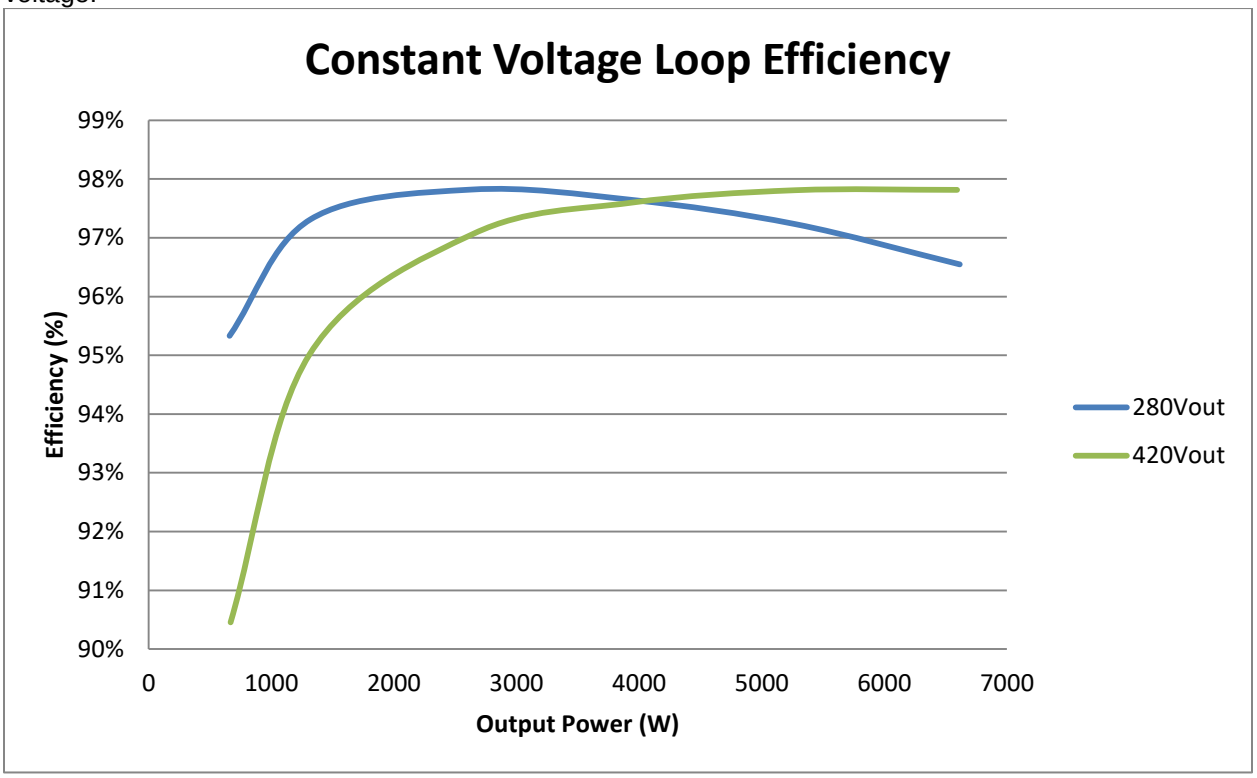
Efficiency was first measured in open loop at a given frequency.



Vpri(V)	Vsec(V)	Pout(W)	Efficiency (%)	Frequency(kHz)
376.66	280.09	662.60	94.98%	600
377.55	280.01	1337.10	97.19%	566
376.23	280.03	1978.90	97.91%	517
377.81	280.06	2660.90	98.01%	517
379.78	280.02	3301.10	97.85%	517
381.05	280.45	3967.00	97.76%	508
382.01	280.14	4620.50	97.62%	517
383.56	280.86	5296.70	97.44%	508
383.94	280.05	5937.90	97.19%	508
385.94	280.07	6597.30	96.82%	508
403.69	299.97	656.80	93.73%	625
404.21	300.50	1328.30	97.14%	566
404.11	300.17	1985.80	97.74%	526
404.01	300.14	2658.70	97.98%	517
405.07	300.30	3319.30	98.02%	517
406.78	300.03	3973.60	97.90%	517
408.02	300.29	4636.80	97.81%	517
408.96	300.38	5298.70	97.63%	508
409.65	300.05	5949.40	97.45%	508
411.13	300.05	6608.00	97.22%	508
544.35	420.03	658.80	90.43%	566
566.86	420.12	1302.60	94.53%	638
564.42	420.08	1944.20	96.62%	566
565.84	420.02	2624.40	97.12%	566
564.77	420.13	3329.90	97.59%	536
565.20	420.04	3986.20	97.81%	536
566.49	420.01	4643.80	97.83%	526
567.02	420.12	5306.80	97.93%	526
567.85	420.27	5971.30	97.91%	517
567.34	420.10	6626.10	97.94%	517
583.07	450.15	664.80	89.25%	577
605.77	450.00	1327.00	94.45%	638
604.40	450.02	1933.80	96.15%	566
603.53	450.08	2641.70	96.98%	546
604.77	450.03	3310.60	97.27%	526
605.00	450.04	3958.20	97.56%	526
605.55	450.05	4586.50	97.74%	526
607.38	450.08	5238.50	97.75%	526
607.29	450.04	5910.60	97.84%	517
608.08	450.06	6607.30	97.86%	517

2.2.2 Constant Voltage Loop Efficiency Measurement

The constant voltage loop efficiency measurement was taken with a closed voltage loop with a give target output voltage.

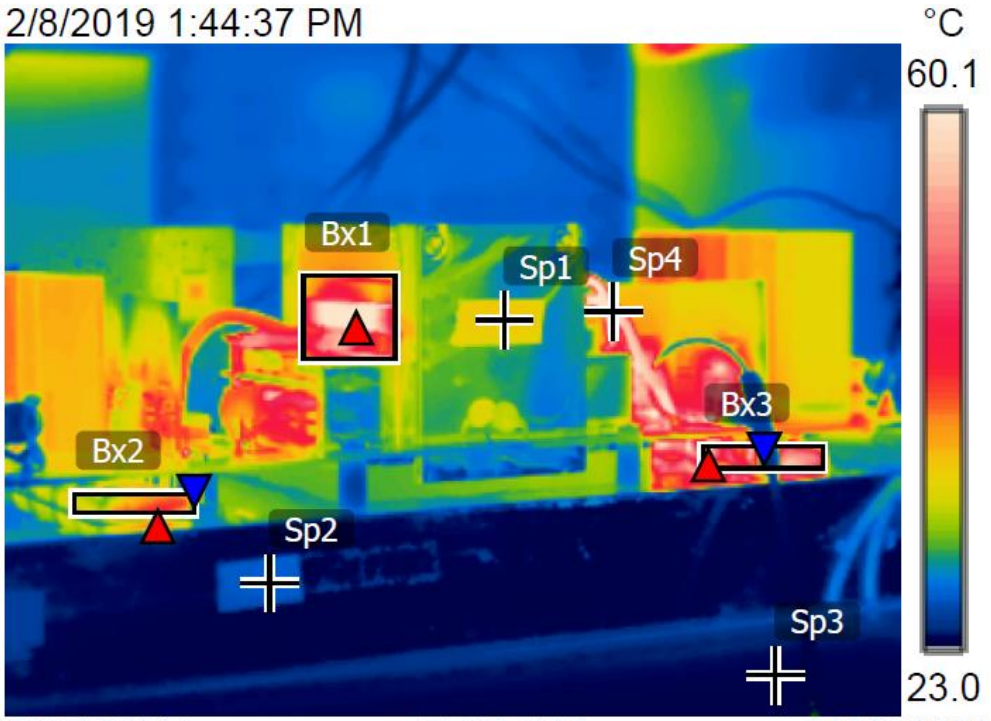


Vpri(V)	Vsec(V)	Pout(W)	Efficiency (%)
388.67	281.12	6615.30	96.55%
385.03	281.11	5271.20	97.23%
382.42	281.12	3950.50	97.64%
380.18	281.09	2630.40	97.82%
377.69	281.10	1320.30	97.31%
376.69	281.12	659.50	95.33%
569.90	420.88	6593.60	97.82%
568.83	420.89	5271.20	97.81%
566.75	420.88	3933.30	97.60%
565.41	420.87	2649.70	97.07%
565.67	420.89	1311.60	95.01%
544.52	420.87	667.80	90.46%

2.3 Thermal Images

The thermal images below were taken with 6.6kW output power. During the test, 3 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

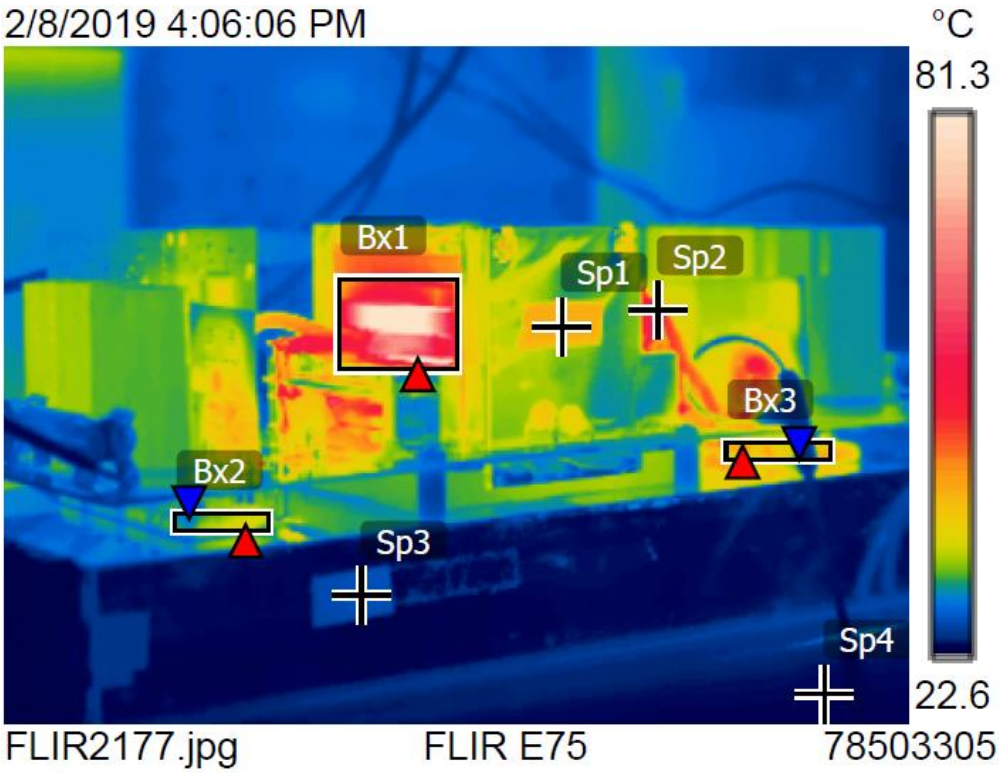
2.3.1 280Vout, 500kHz Operational Frequency, Efficiency = 96.8%



Measurements

Bx1	Max	65.1 °C
Bx2	Max	43.7 °C
	Min	28.7 °C
	Average	37.3 °C
Bx3	Max	59.9 °C
	Min	24.0 °C
	Average	43.7 °C
Sp1		36.4 °C
Sp2		26.7 °C
Sp3		23.4 °C
Sp4		59.3 °C

2.3.2 420Vout, 500kHz Operational Frequency, Efficiency = 97.6%

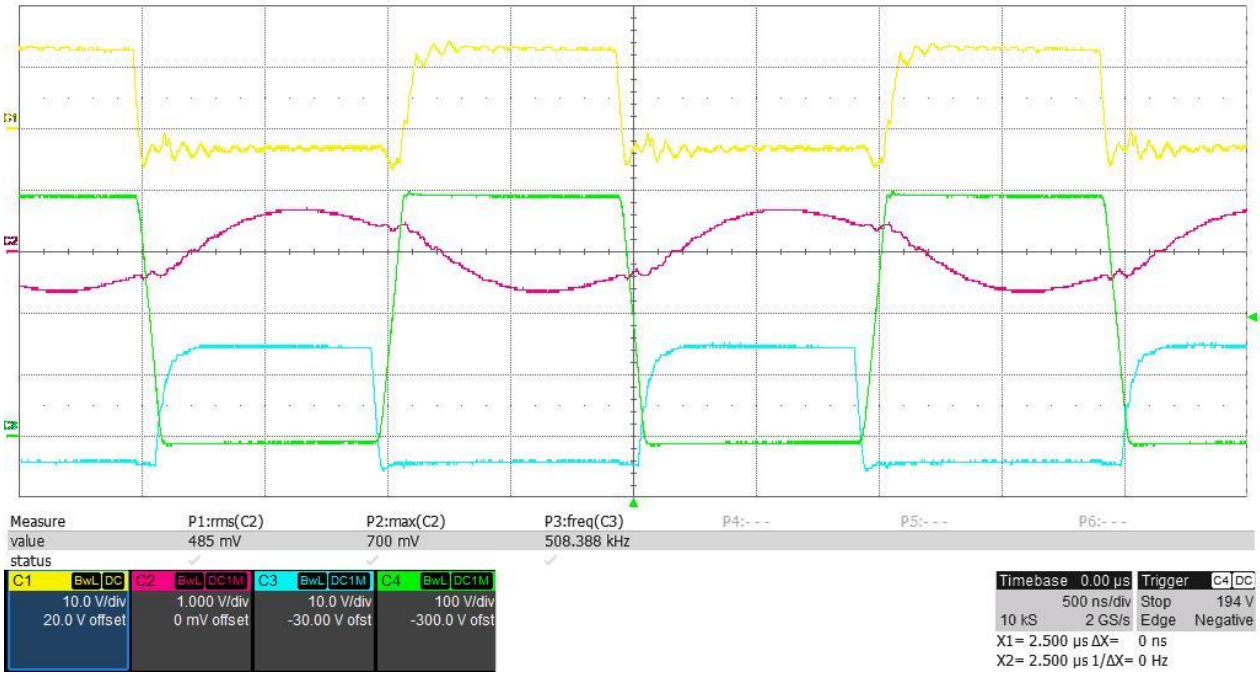


Measurements

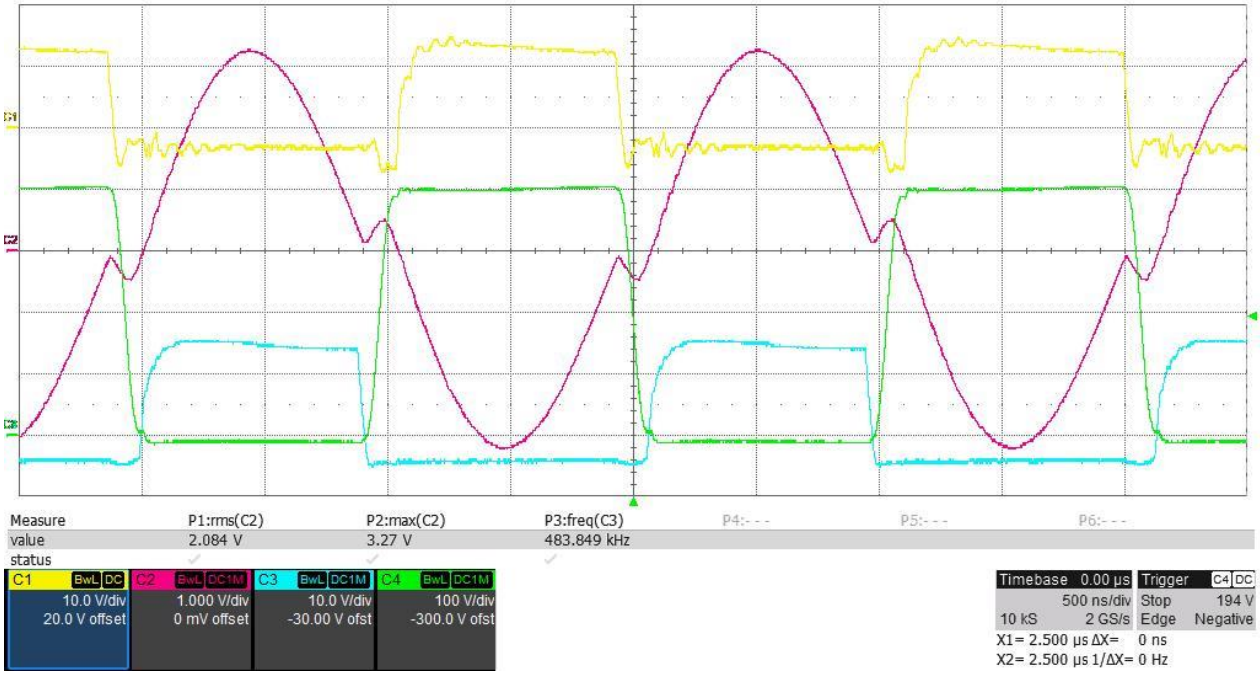
Bx1	Max	92.8 °C
Bx2	Max	37.5 °C
	Min	29.2 °C
	Average	34.1 °C
Bx3	Max	45.1 °C
	Min	24.1 °C
	Average	37.2 °C
Sp1		42.9 °C
Sp2		52.7 °C
Sp3		27.0 °C
Sp4		23.5 °C

2.4 Key Waveforms

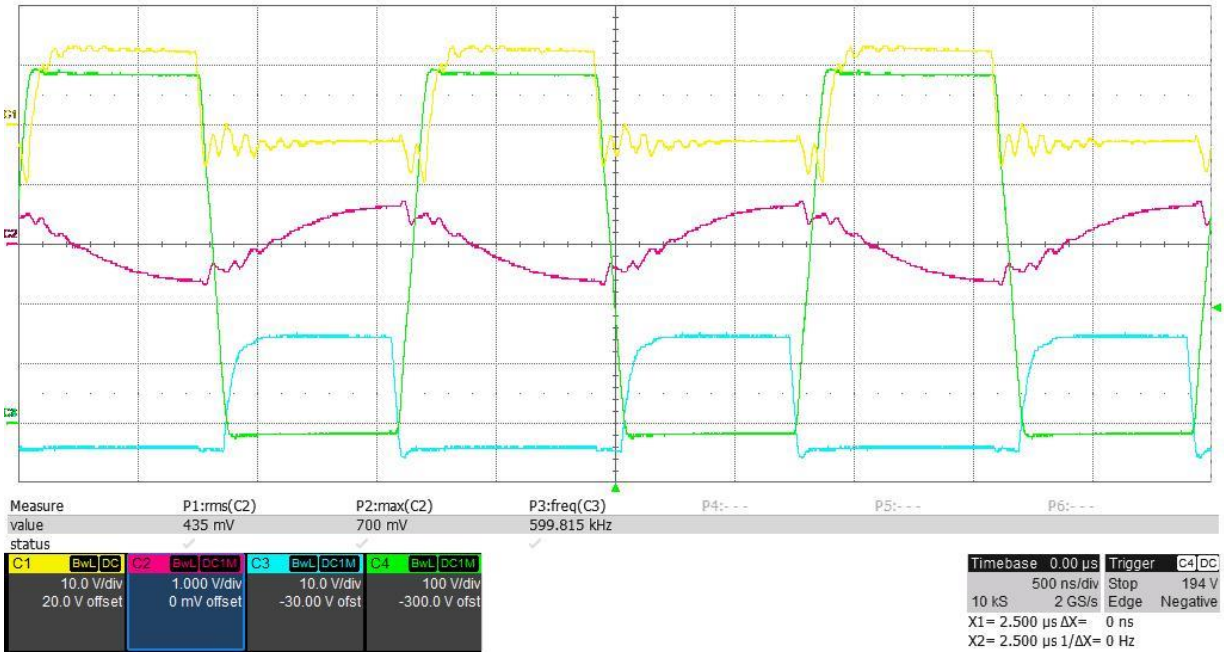
2.4.1 Soft-switching waveforms at 374.788Vin, 280.056Vout/1315.1W, Eff=97.323%: C1: Q101_VGS, C2: Ipri measured with Rogowski Coil with 100mV/A scale, C3: Q105_VGS, C4: Q105_VDS.



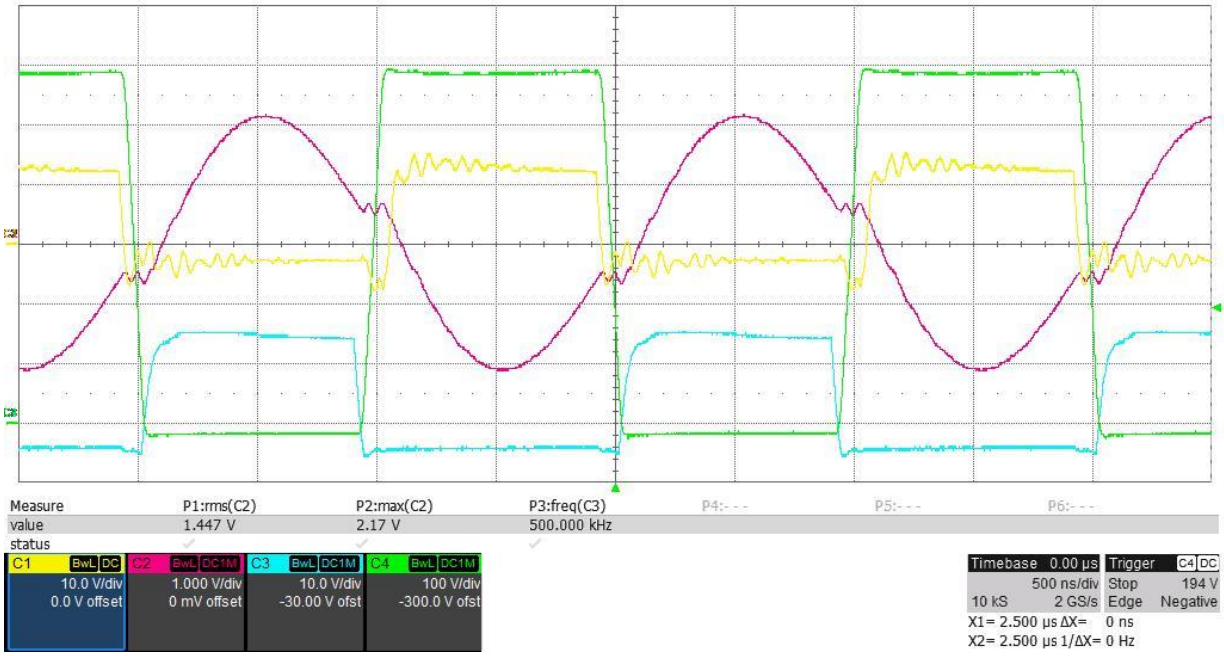
2.4.2 Soft-switching waveforms at 388.456Vin, 280.016Vout/6592.7W, Eff=96.348%: C1: Q101_VGS, C2: Ipri measured with Rogowski Coil with 100mV/A scale, C3: Q105_VGS, C4: Q105_VDS.



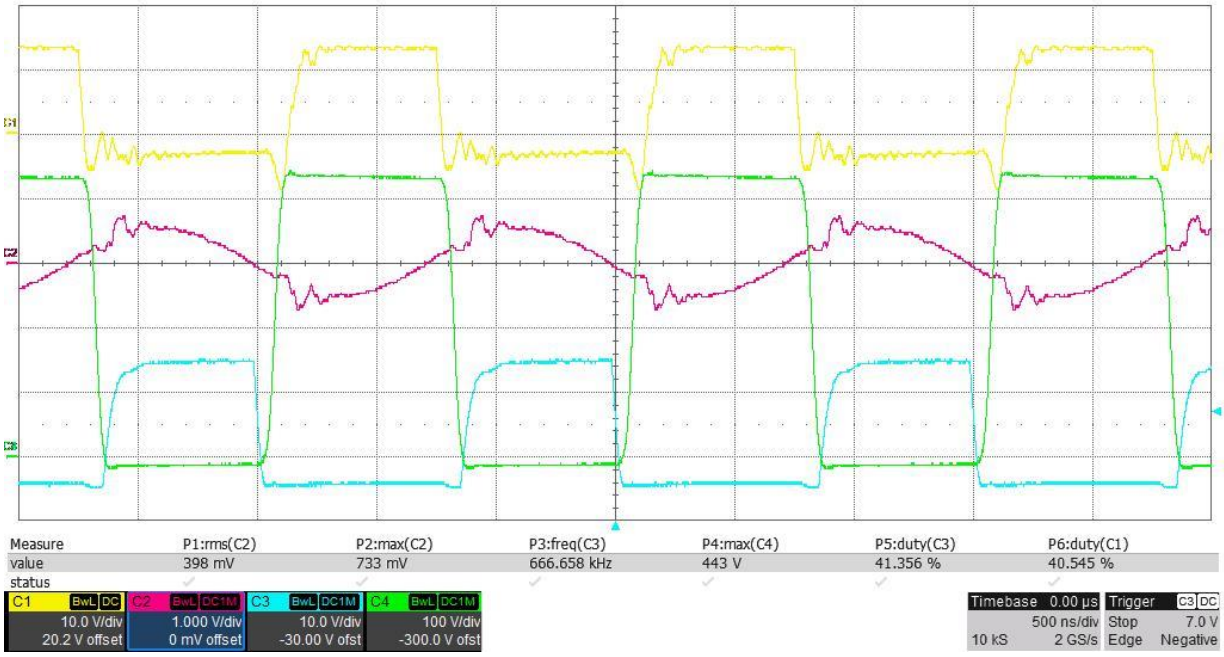
2.4.3 Soft-switching waveforms at 566.799Vin, 420.150Vout/1323.6W, Eff=95.322%: C1: Q101_VGS, C2: Ipri measured with Rogowski Coil with 100mV/A scale, C3: Q105_VGS, C4: Q105_VDS.



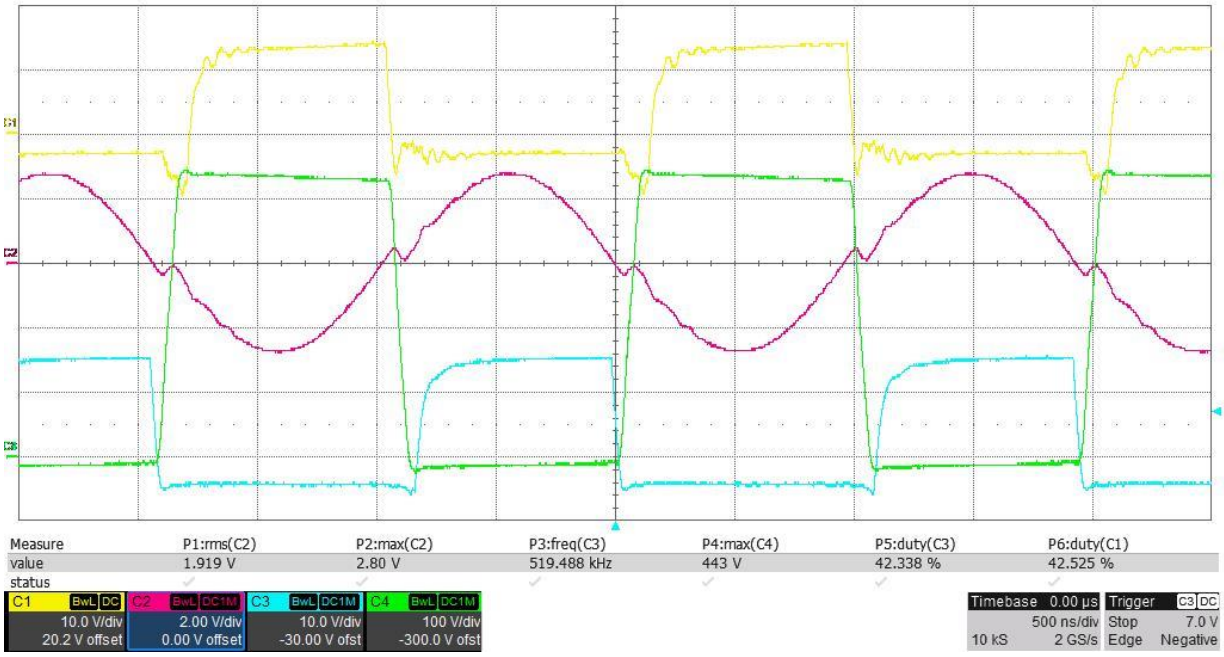
2.4.4 Soft-switching waveforms at 569.161Vin, 420.012Vout/6613.7W, Eff=97.696%: C1: Q101_VGS, C2: Ipri measured with Rogowski Coil with 100mV/A scale, C3: Q105_VGS, C4: Q105_VDS.



2.4.5 Soft-switching waveforms at 567.476Vin, 420.047Vout/1332.9W, Eff=93.927%: C1: Q107_VGS, C2: Isec measured with Rogowski Coil with 100mV/A scale, C3: Q103_VGS, C4: Q103_VDS.



2.4.6 Soft-switching waveforms at 568.323Vin, 420.010Vout/6584.1W, 97.888%: C1: Q107_VGS, C2: Isec measured with Rogowski Coil with 100mV/A scale, C3: Q103_VGS, C4: Q103_VDS.



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