

PMP20289 RevA

Test Report

- **400V – 12V/500W high frequency LLC series resonant converter**
- **350kHz resonant frequency**
- **Around 500kHz switching frequency for 400V to 12V conversion**
- **Utilize TI GaN FETs as input switches**
- **Optimized LLC SR conduction with UCD7138/UCD3138A**
- **Achieve peak 96.8% efficiency**

Test Completion Date: May 27, 2016

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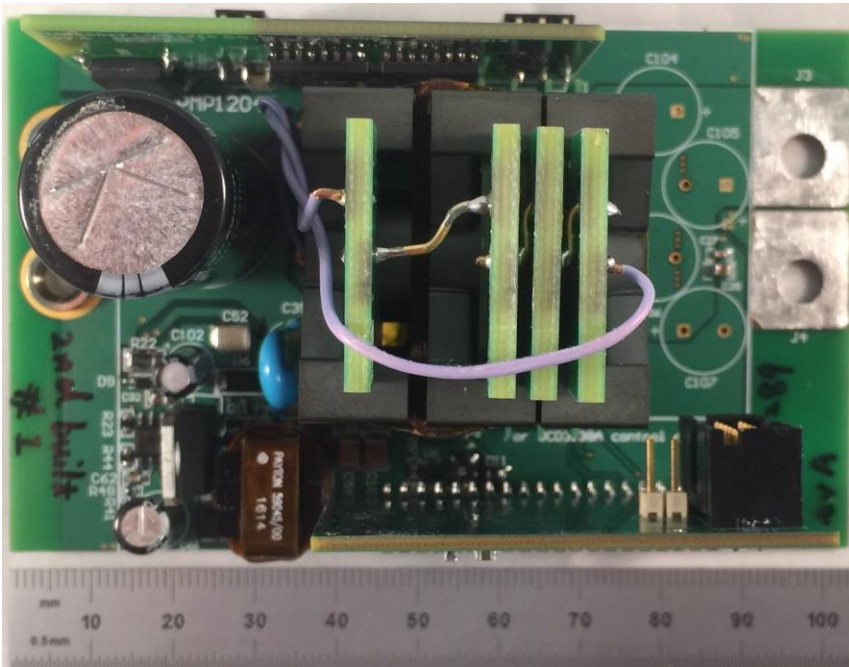
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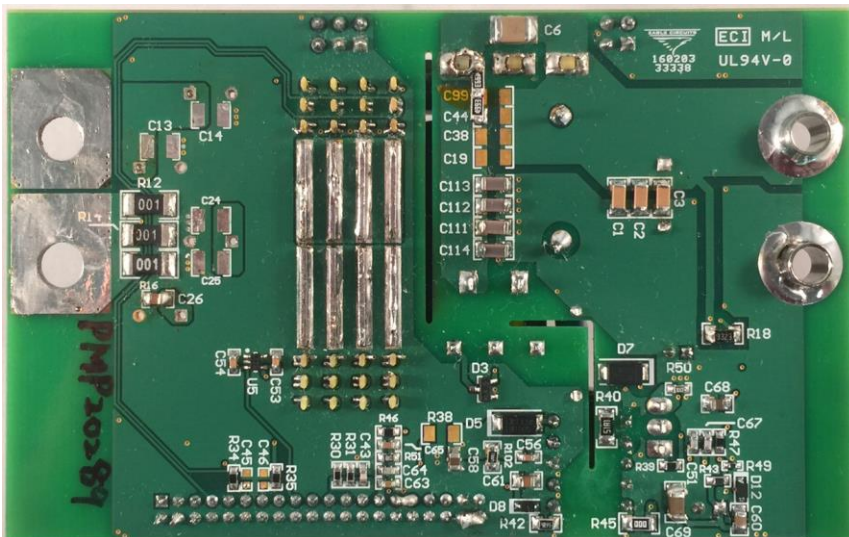
1. Board Photos

The photographs below show the detailed views of the PMP20289 Rev A board, which is built on PMP12047 Rev A PCB.

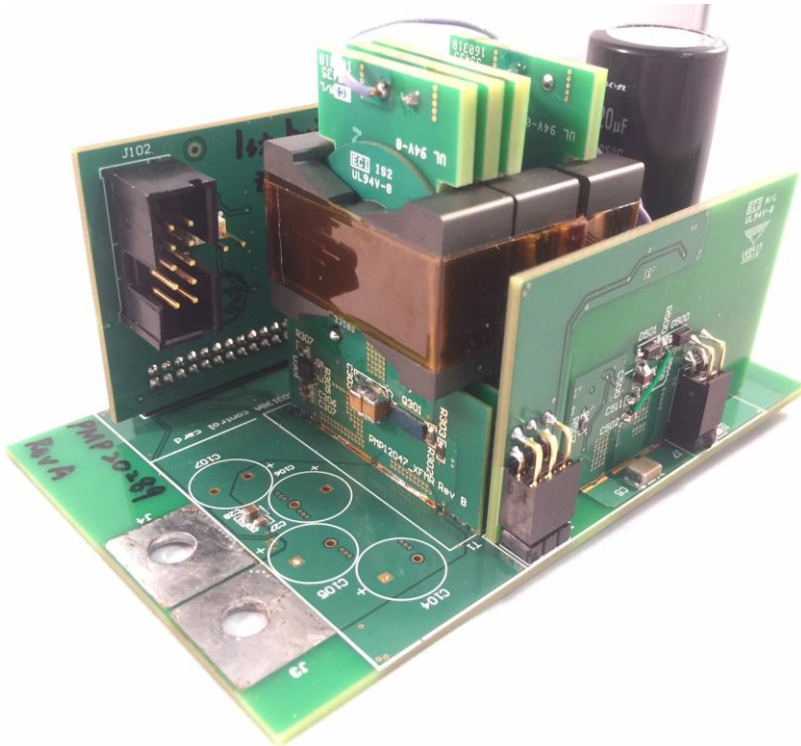
1.1 WHOLE BOARD TOP VIEW



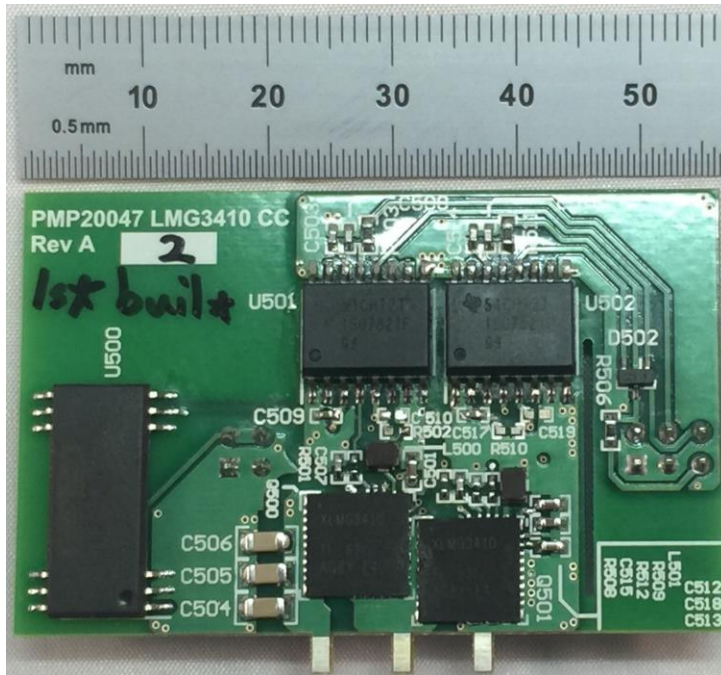
1.2 WHOLE BOARD BOTTOM VIEW



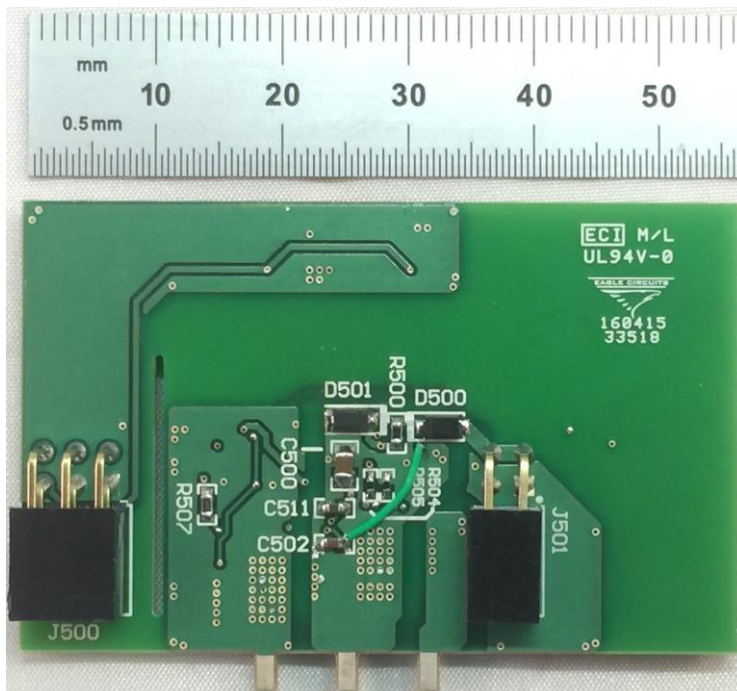
1.3 WHOLE BOARD SIDE VIEW



1.4 GAN CONTROL CARD TOP VIEW

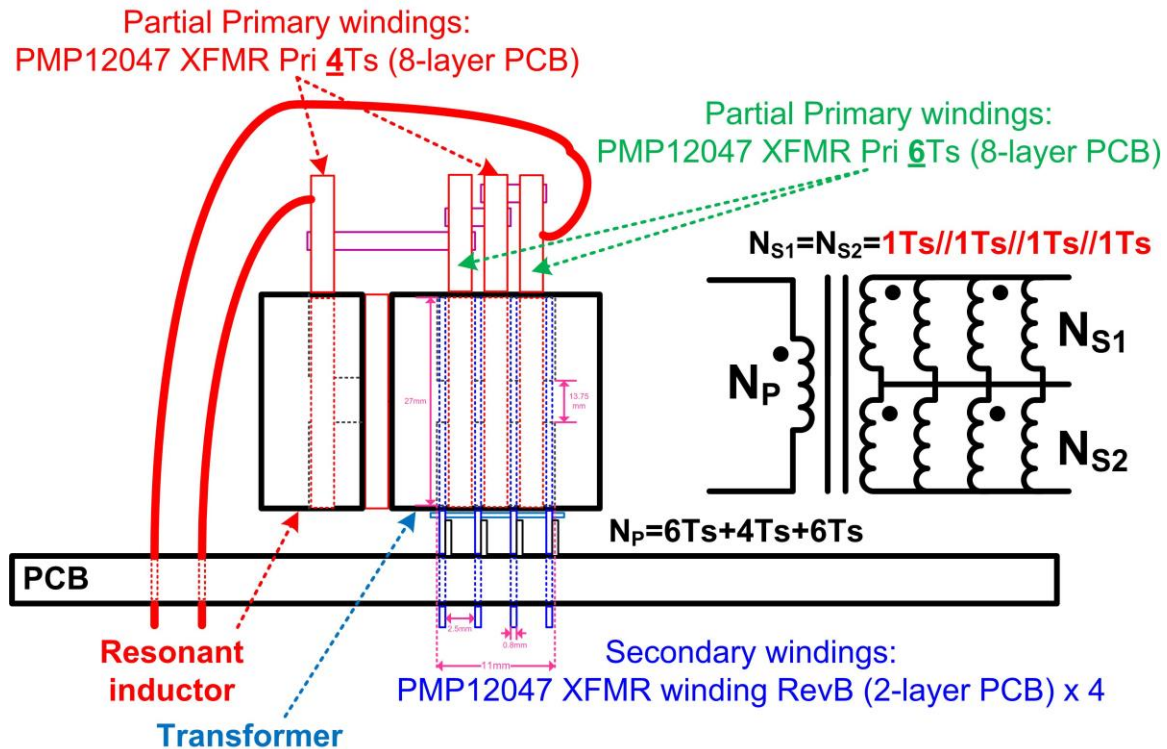


1.5 GAN CONTROL CARD BOTTOM VIEW

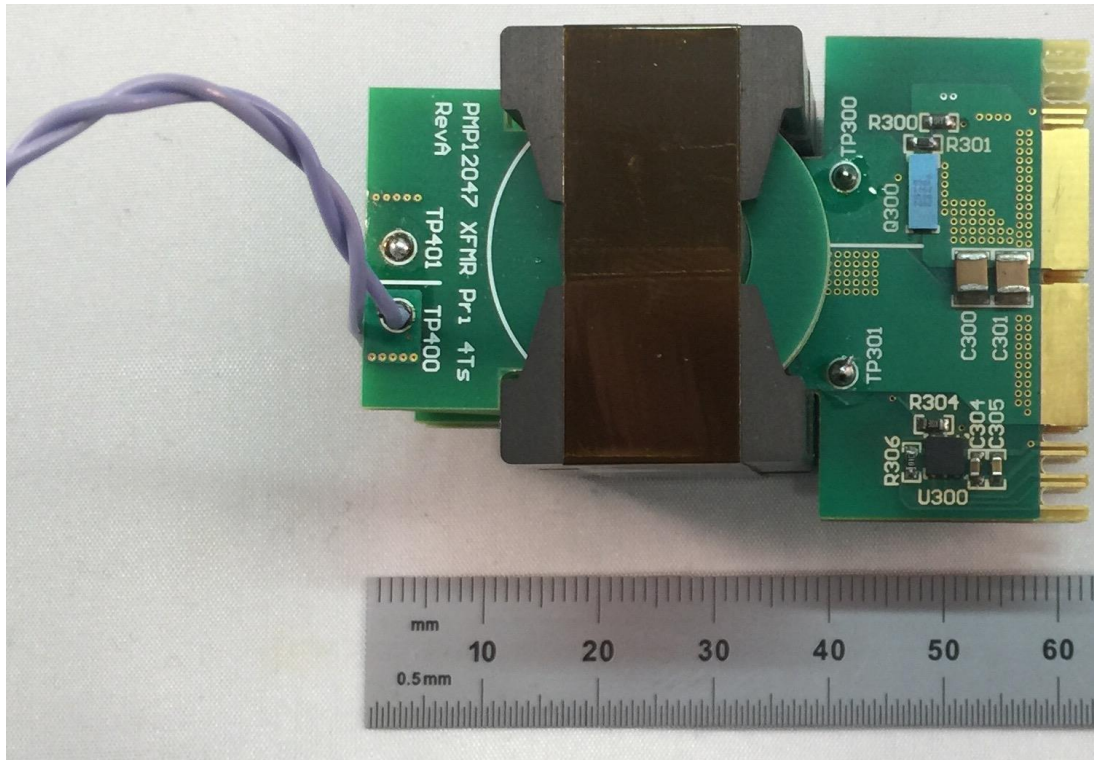


1.6 TRANSFORMER AND RESONANT INDUCTOR STRUCTURE

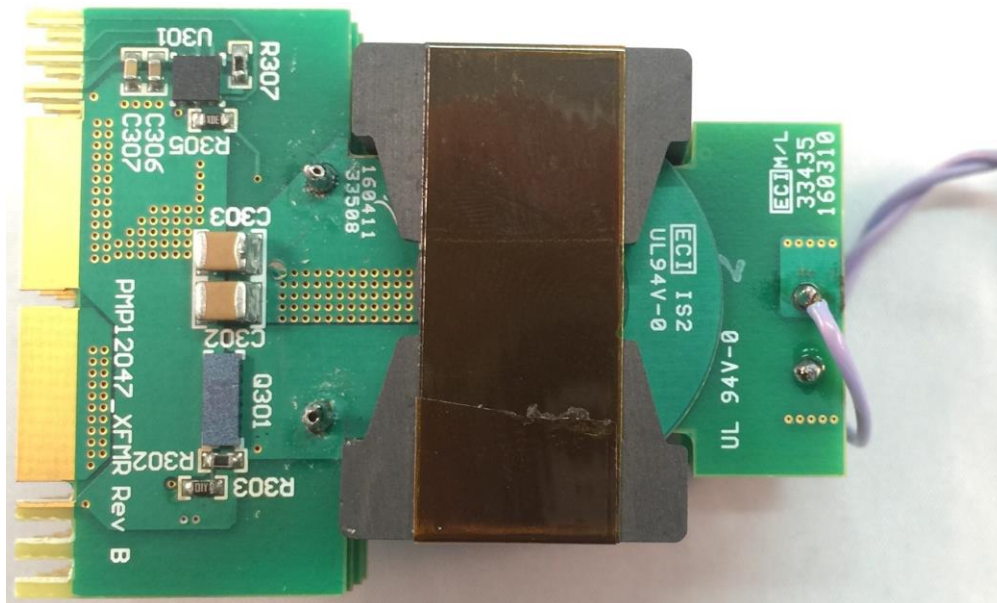
The LLC transformer and resonant inductor of PMP20289 consist of PQ3220 core with 3F35 core material, PMP12047_XFMR_Pri_4Ts_Rev_A PCB, PMP12047_XFMR_Pri_6Ts_Rev_A PCB, and PMP12047_XFMR_winding_Rev_B PCB. The transformer is gapped to have 67.5uH primary inductance (@400kHz measured frequency) and ~1.66uH (@400kHz measured frequency) leakage inductance. Air gap between resonant inductor and the transformer is also reserved to achieve ~2.05uH (@400kHz measured frequency) inductance on resonant inductor. Transformer and resonant inductor structures are shown in the figure below:



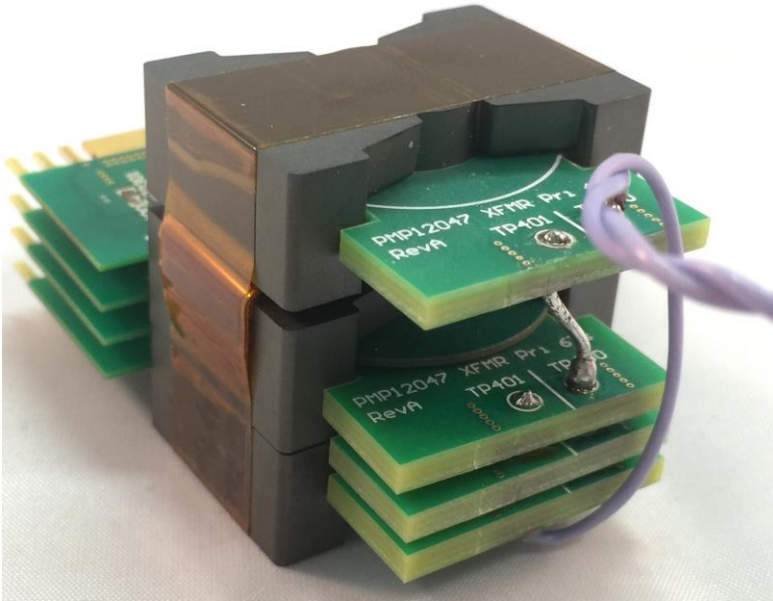
1.7 TRANSFORMER TOP VIEW



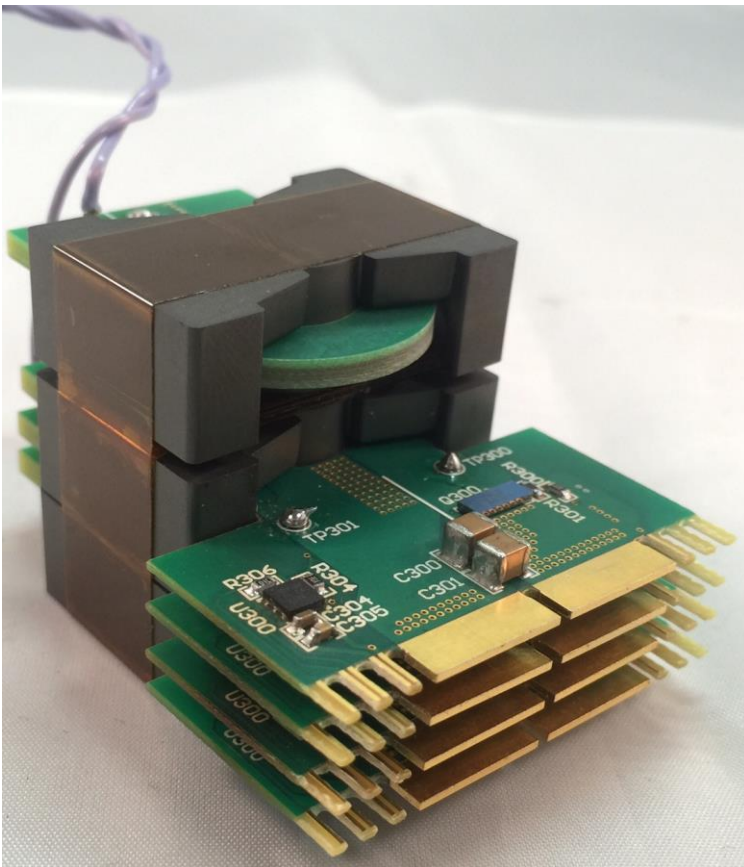
1.8 TRANSFORMER BOTTOM VIEW



1.8 TRANSFORMER SIDE VIEW

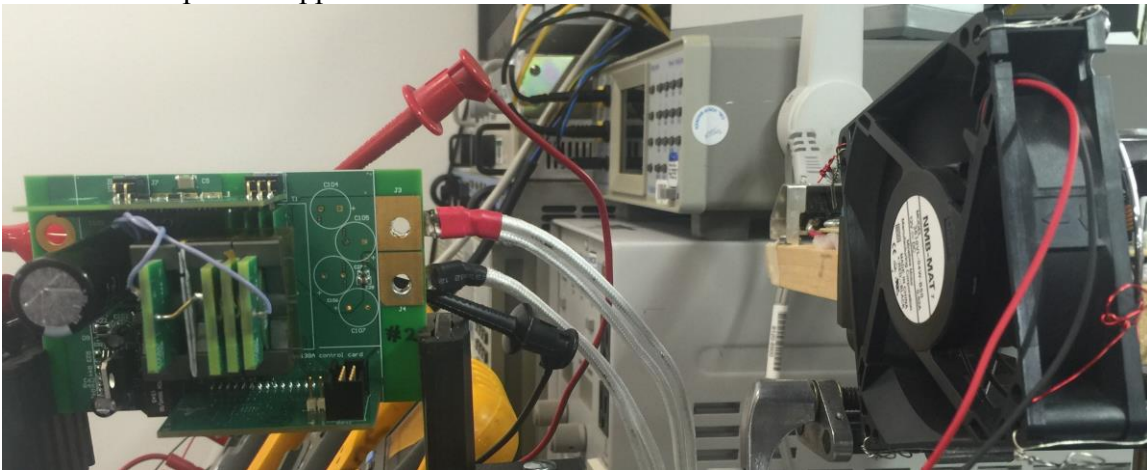


1.8 TRANSFORMER SIDE VIEW

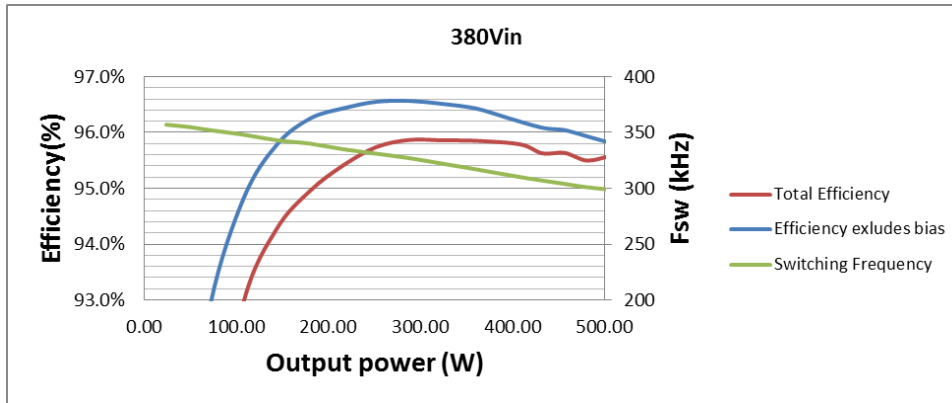


2. Efficiency

The efficiency curves are shown in the tables and graph below with the set up shown in the figure below. A 12V Fan (NMB Technologies Model # 3610VL-04W-B50) is applied to provide air cooling to the board. R18, R22, and D9 are removed for the efficiency measurement excluding bias supply power losses. 12V_P and 5V are supplied from external power supplies and not included in the measurement results.



2.1 EFFICIENCIES AND SWITCHING FREQUENCIES @ 380VIN



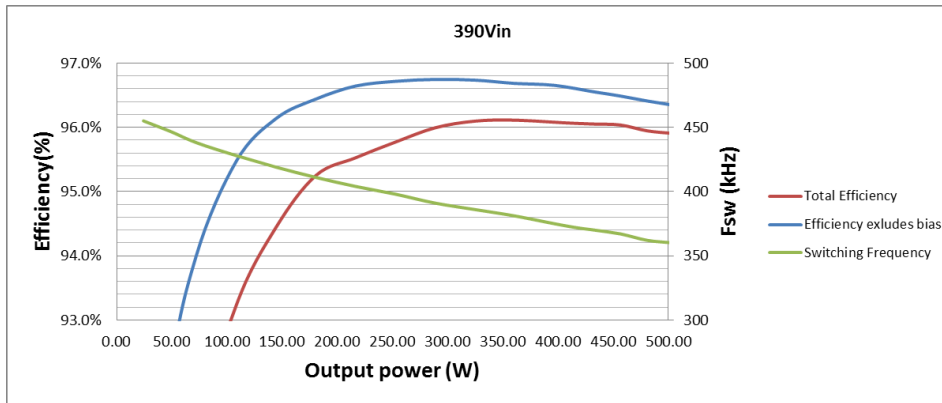
2.1.1 Efficiencies and switching frequencies data – Total Efficiency

Vin(V)	Iin(A)	Pin(W)	Vout(V)	Iout(mV)	Iout(A)	Pout(W)	Eff(%)	Fsw(kHz)
380	1.39	527.44	12.01	42.00	41.97	504.07	95.57%	299
380	1.32	503.12	12.02	40.00	39.97	480.47	95.50%	301
380	1.26	477.28	12.02	38.00	37.97	456.45	95.63%	304
380	1.19	452.20	12.02	36.00	35.98	432.42	95.63%	307
380	1.12	426.74	12.02	34.03	34.01	408.76	95.79%	310
380	0.99	376.20	12.02	30.02	30.00	360.59	95.85%	317
380	0.89	338.58	12.02	27.02	27.00	324.56	95.86%	322
380	0.79	300.96	12.02	24.02	24.00	288.52	95.87%	327
380	0.69	263.72	12.02	21.02	21.01	252.49	95.74%	331
380	0.60	226.86	12.02	18.02	18.01	216.45	95.41%	335
380	0.50	190.00	12.02	15.02	15.01	180.42	94.96%	340
380	0.40	153.14	12.02	12.02	12.01	144.38	94.28%	343
380	0.31	116.66	12.02	9.03	9.02	108.47	92.98%	348
380	0.21	80.56	12.02	6.03	6.03	72.43	89.91%	352
380	0.15	55.86	12.02	4.01	4.01	48.17	86.23%	355
380	0.08	31.92	12.02	2.02	2.02	24.26	76.01%	357
380	0.02	7.22	12.02	0.00	0.00	0.00	0.00%	360

2.1.2 Efficiencies and switching frequencies data –Efficiency Excludes Bias

Vin(V)	Iin(A)	Pin(W)	Vout(V)	Iout(mV)	Iout(A)	Pout(W)	Eff(%)
380	1.39	526.30	12.01	42.02	41.99	504.31	95.82%
380	1.32	500.84	12.02	40.00	39.97	480.47	95.93%
380	1.25	475.38	12.02	38.01	37.98	456.57	96.04%
380	1.19	450.30	12.02	36.02	36.00	432.66	96.08%
380	1.08	412.07	12.02	33.02	33.00	396.63	96.25%
380	0.98	374.07	12.02	30.03	30.01	360.71	96.43%
380	0.89	336.41	12.02	27.03	27.01	324.68	96.51%
380	0.79	298.91	12.02	24.03	24.01	288.64	96.57%
380	0.69	261.63	12.02	21.03	21.02	252.61	96.55%
380	0.59	224.58	12.02	18.03	18.02	216.57	96.43%
380	0.49	187.57	12.02	15.03	15.02	180.54	96.25%
380	0.40	150.86	12.02	12.03	12.02	144.50	95.78%
380	0.30	114.38	12.02	9.03	9.02	108.47	94.83%
380	0.21	77.94	12.02	6.03	6.03	72.43	92.93%
380	0.14	53.85	12.02	4.04	4.04	48.53	90.12%
380	0.08	29.41	12.03	2.02	2.02	24.28	82.56%
380	0.01	4.56	12.03	0.00	0.00	0.00	0.00%

2.2 EFFICIENCIES AND SWITCHING FREQUENCIES @ 390VIN



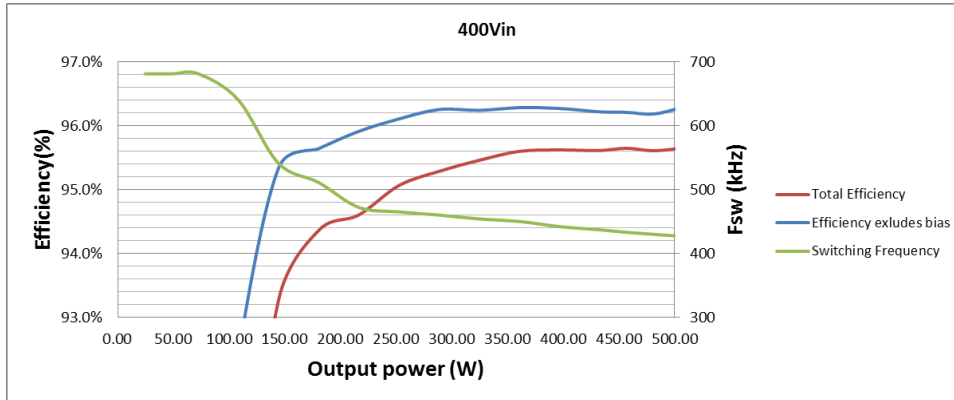
2.2.1 Efficiencies and switching frequencies data – Total Efficiency

Vin(V)	Iin(A)	Pin(W)	Vout(V)	Iout(mV)	Iout(A)	Pout(W)	Eff(%)	Fsw(kHz)
390	1.35	525.72	12.01	42.01	41.98	504.19	95.91%	360
390	1.29	501.15	12.02	40.03	40.00	480.83	95.95%	362
390	1.22	475.41	12.02	38.01	37.98	456.57	96.04%	367
390	1.16	450.45	12.02	36.02	36.00	432.66	96.05%	370
390	1.09	425.49	12.02	34.03	34.01	408.76	96.07%	373
390	0.96	375.18	12.02	30.02	30.00	360.59	96.11%	381
390	0.87	337.74	12.02	27.02	27.00	324.56	96.10%	386
390	0.77	300.69	12.02	24.03	24.01	288.64	95.99%	391
390	0.68	263.64	12.02	21.02	21.01	252.49	95.77%	398
390	0.58	226.59	12.02	18.02	18.01	216.45	95.53%	404
390	0.49	189.54	12.02	15.03	15.02	180.54	95.25%	411
390	0.39	152.88	12.02	12.02	12.01	144.38	94.44%	419
390	0.30	116.22	12.02	9.02	9.01	108.35	93.22%	428
390	0.20	79.56	12.02	6.03	6.03	72.43	91.04%	438
390	0.14	55.38	12.02	4.01	4.01	48.17	86.98%	447
390	0.08	31.20	12.02	2.02	2.02	24.26	77.77%	455
390	0.02	7.02	12.02	0.00	0.00	0.00	0.00%	469

2.2.2 Efficiencies and switching frequencies data –Efficiency Excludes Bias

Vin(V)	Iin(A)	Pin(W)	Vout(V)	Iout(mV)	Iout(A)	Pout(W)	Eff(%)
390	1.34	523.89	12.02	42.02	41.99	504.73	96.34%
390	1.28	498.73	12.02	40.03	40.00	480.83	96.41%
390	1.21	473.19	12.02	38.01	37.98	456.57	96.49%
390	1.15	448.11	12.02	36.02	36.00	432.66	96.55%
390	1.05	410.36	12.02	33.02	33.00	396.63	96.65%
390	0.96	372.96	12.02	30.02	30.00	360.59	96.68%
390	0.86	335.63	12.02	27.03	27.01	324.68	96.74%
390	0.77	298.35	12.02	24.03	24.01	288.64	96.75%
390	0.67	261.18	12.02	21.03	21.02	252.61	96.72%
390	0.57	224.09	12.02	18.03	18.02	216.57	96.64%
390	0.48	187.20	12.02	15.03	15.02	180.54	96.44%
390	0.39	150.31	12.02	12.03	12.02	144.50	96.14%
390	0.29	113.61	12.02	9.03	9.02	108.47	95.47%
390	0.20	76.67	12.02	6.00	6.00	72.07	94.00%
390	0.13	52.38	12.02	4.01	4.01	48.17	91.96%
390	0.07	28.35	12.03	2.02	2.02	24.28	85.65%
390	0.10	37.83	12.03	0.00	0.00	0.00	0.00%

2.3 EFFICIENCIES AND SWITCHING FREQUENCIES @ 400VIN



2.3.1 Efficiencies and switching frequencies data – Total Efficiency

Vin(V)	Iin(A)	Pin(W)	Vout(V)	Iout(mV)	Iout(A)	Pout(W)	Eff(%)	Fsw(kHz)
400	1.32	527.60	12.02	42.01	41.98	504.61	95.64%	427
400	1.26	502.80	12.02	40.02	39.99	480.71	95.61%	430
400	1.19	477.60	12.02	38.03	38.00	456.81	95.65%	433
400	1.13	452.40	12.02	36.01	35.99	432.54	95.61%	437
400	1.04	414.80	12.02	33.02	33.00	396.63	95.62%	442
400	0.94	377.20	12.02	30.02	30.00	360.59	95.60%	450
400	0.85	340.00	12.02	27.02	27.00	324.56	95.46%	454
400	0.76	302.80	12.02	24.02	24.00	288.52	95.28%	460
400	0.66	265.60	12.02	21.02	21.01	252.49	95.06%	465
400	0.57	228.80	12.02	18.02	18.01	216.45	94.60%	472
400	0.48	191.20	12.02	15.02	15.01	180.42	94.36%	511
400	0.39	154.80	12.02	12.02	12.01	144.38	93.27%	541
400	0.31	122.00	12.02	9.02	9.01	108.35	88.81%	640
400	0.21	85.72	12.03	6.03	6.03	72.49	84.57%	681
400	0.15	60.44	12.03	4.04	4.04	48.57	80.36%	681
400	0.09	34.44	12.03	2.05	2.05	24.64	71.56%	681
400	0.01	3.76	12.03	0.00	0.00	0.00	0.00%	bus

2.3.2 Efficiencies and switching frequencies data –Efficiency Excludes Bias

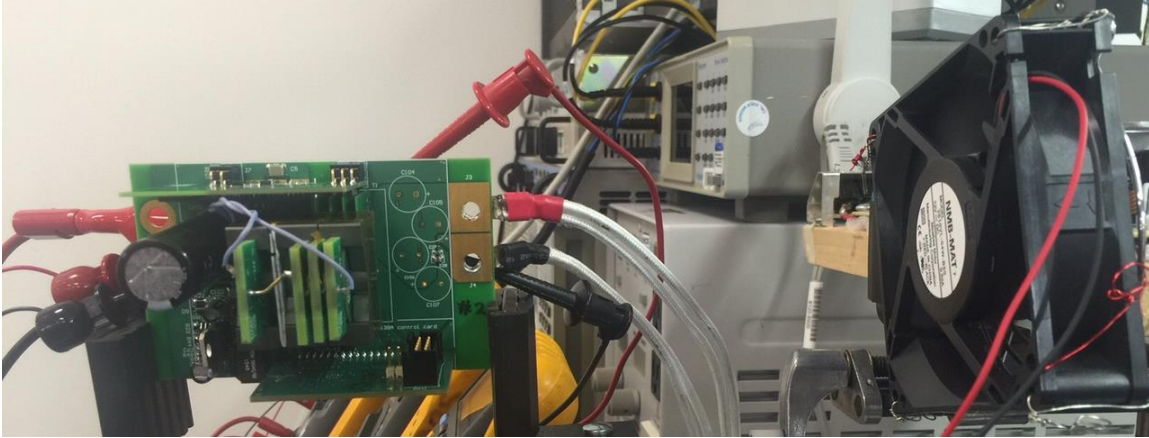
Vin(V)	Iin(A)	Pin(W)	Vout(V)	Iout(mV)	Iout(A)	Pout(W)	Eff(%)
400	1.31	524.40	12.02	42.03	42.00	504.85	96.27%
400	1.25	499.92	12.02	40.03	40.00	480.83	96.18%
400	1.19	474.56	12.02	38.01	37.98	456.57	96.21%
400	1.12	449.68	12.02	36.02	36.00	432.66	96.22%
400	1.03	412.00	12.02	33.02	33.00	396.63	96.27%
400	0.94	374.52	12.02	30.02	30.00	360.59	96.28%
400	0.84	337.24	12.02	27.02	27.00	324.56	96.24%
400	0.75	299.88	12.02	24.03	24.01	288.64	96.25%
400	0.66	262.72	12.02	21.02	21.01	252.49	96.10%
400	0.56	225.68	12.02	18.02	18.01	216.45	95.91%
400	0.47	188.64	12.02	15.02	15.01	180.42	95.64%
400	0.38	151.56	12.03	12.02	12.01	144.50	95.34%
400	0.29	117.32	12.03	9.02	9.01	108.44	92.43%
400	0.21	82.64	12.03	6.03	6.03	72.49	87.72%
400	0.14	57.08	12.03	4.01	4.01	48.21	84.46%
400	0.07	28.40	12.03	2.02	2.02	24.28	85.51%
400	0.02	7.60	12.01	0.00	0.00	0.00	0.00%

2.4 4 POINTS (10%, 20%, 50%, 100%) EFFICIENCY

380Vin		390Vin		400Vin	
10% efficiency	90.12%	10% efficiency	91.96%	10% efficiency	84.46%
20% efficiency	94.83%	20% efficiency	95.47%	20% efficiency	92.43%
50% efficiency	96.55%	50% efficiency	96.72%	50% efficiency	96.10%
100% efficiency	95.82%	100% efficiency	96.34%	100% efficiency	96.27%

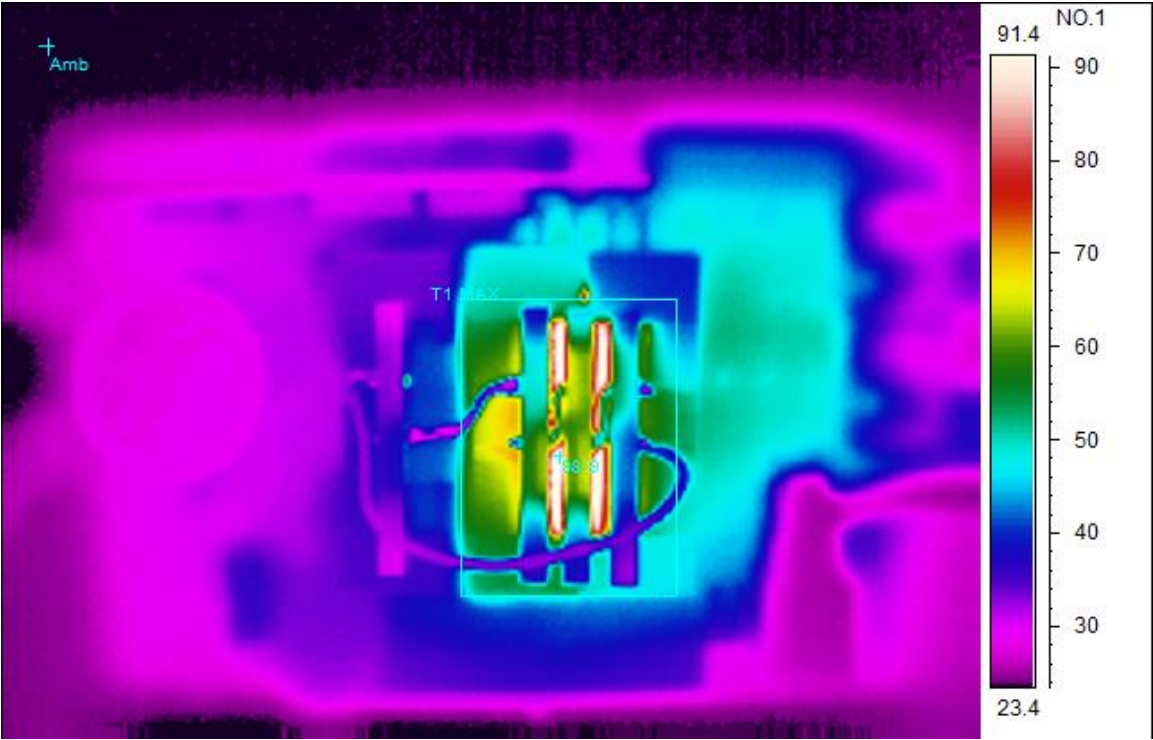
3. Thermal Performance

The efficiency curves are shown in the tables and graph below with the set up shown in the figure below. A 12V Fan (NMB Technologies Model # 3610VL-04W-B50) is applied to provide air cooling to the board.

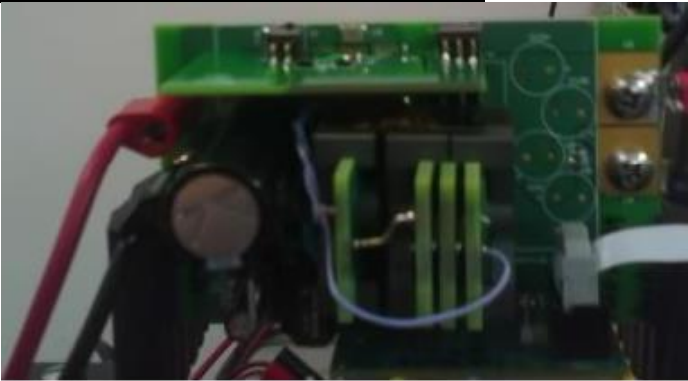


3.1 380VDC INPUT, 12V/42A OUTPUT

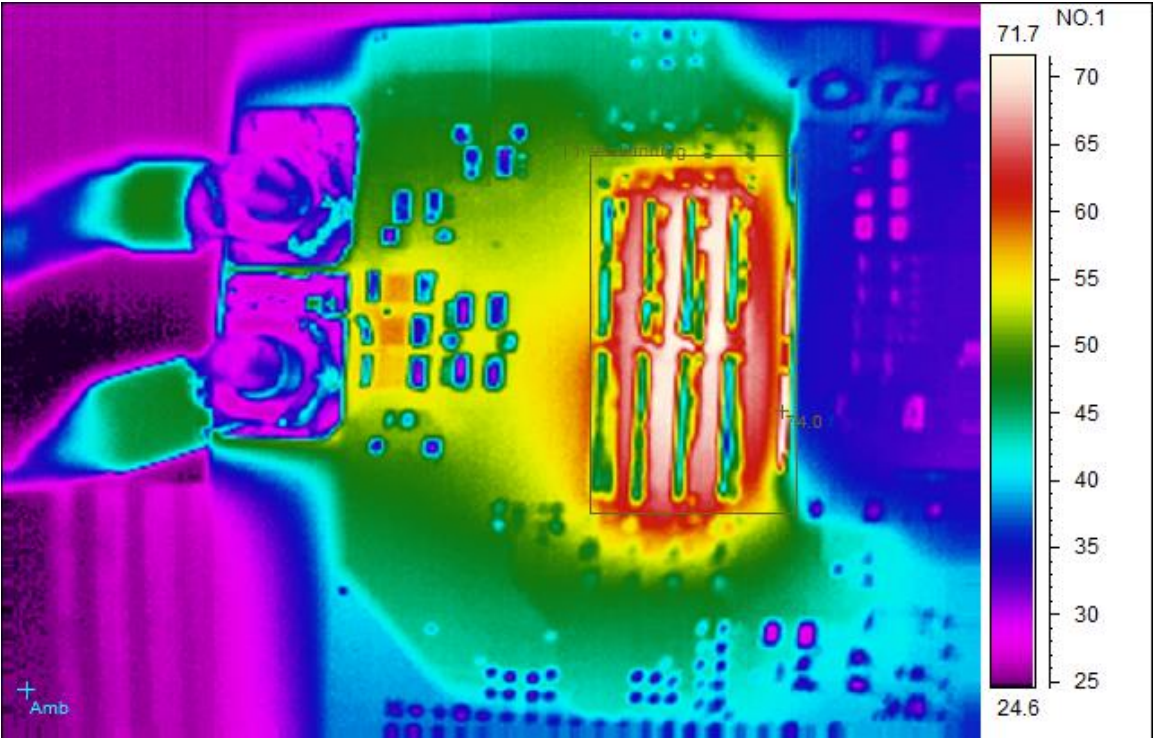
3.1.1 Top side



Spot analysis	Value
Amb Temperature	23.5°C
Area analysis	Value
T1 MAXMax	98.9°C



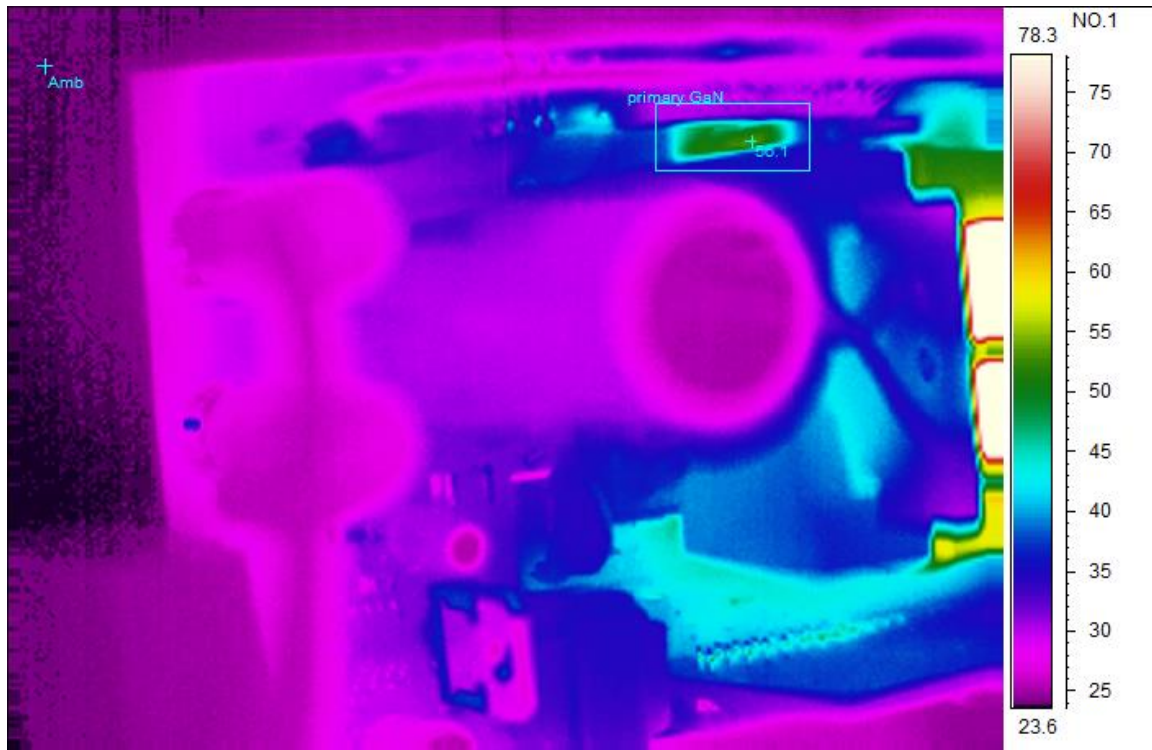
3.1.2 Bottom side



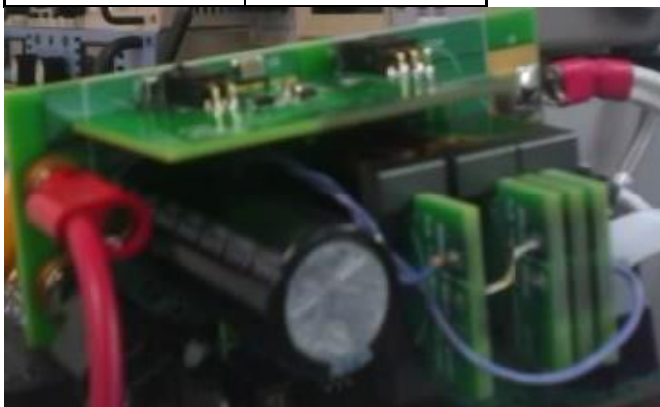
Spot analysis	Value
AmbTemperature	25.0°C
Area analysis	Value
T1 sec winding Max	74.0°C



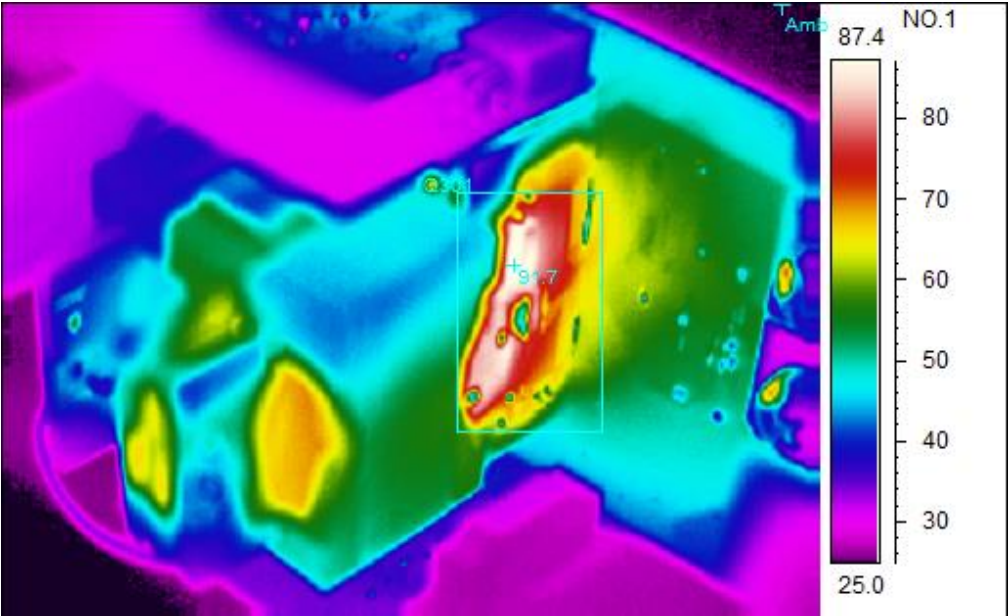
3.1.3 Primary GaNFET



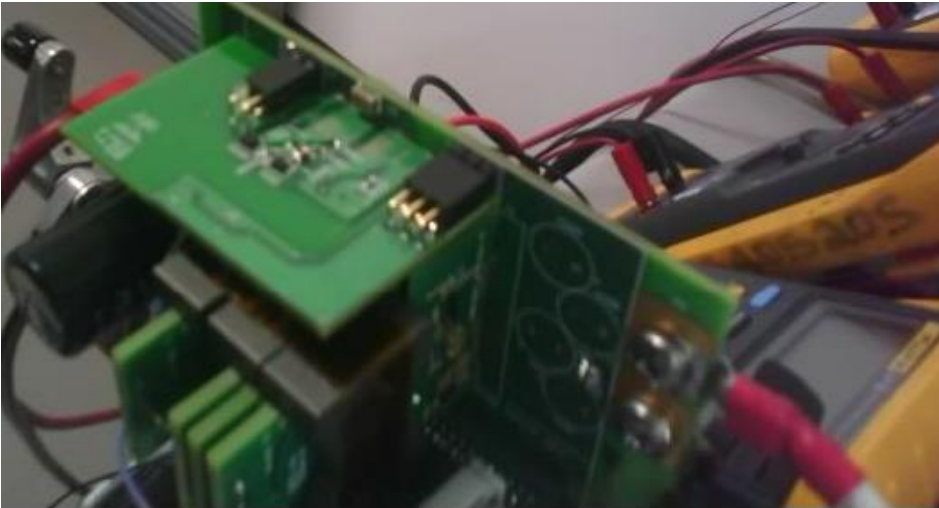
Spot analysis	Value
Amb Temperature	24.0°C
Area analysis	Value
primary GaNMax	56.1°C



3.1.4 Transformer PCB windings

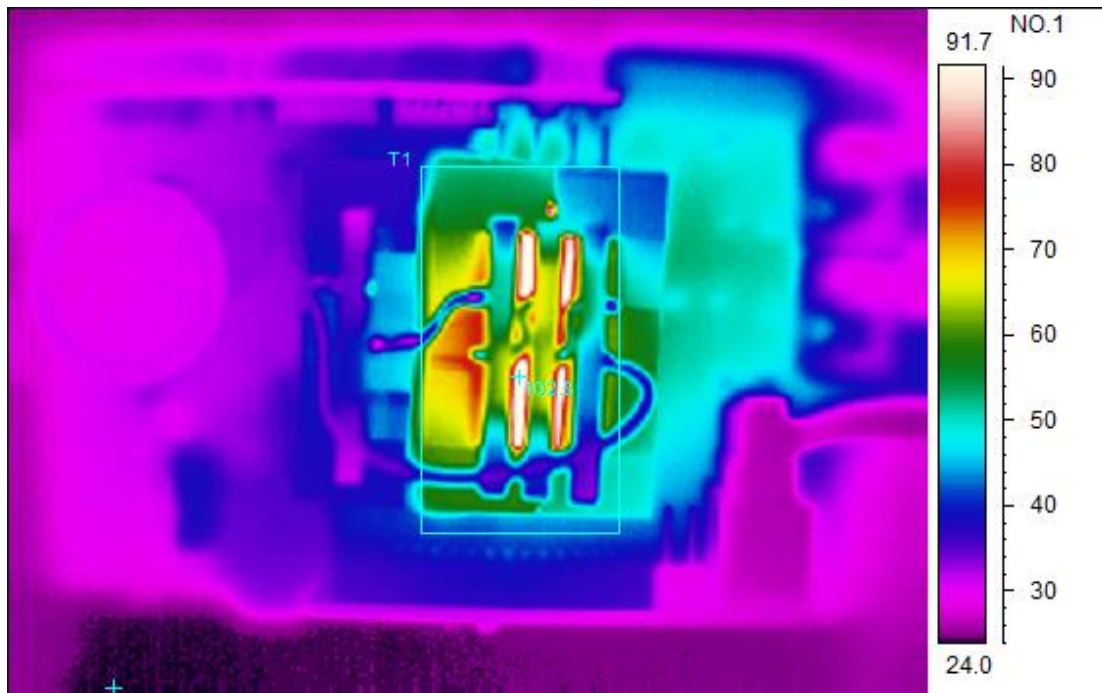


Spot analysis	Value
Amb Temperature	25.2°C
Area analysis	Value
Q301Max	91.7°C

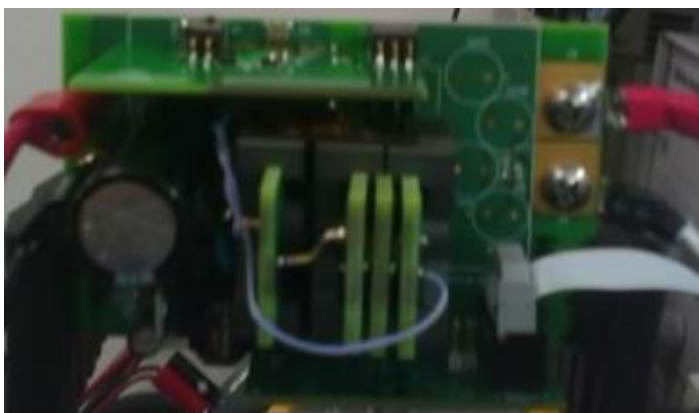


3.2 390VDC INPUT, 12V/42A OUTPUT

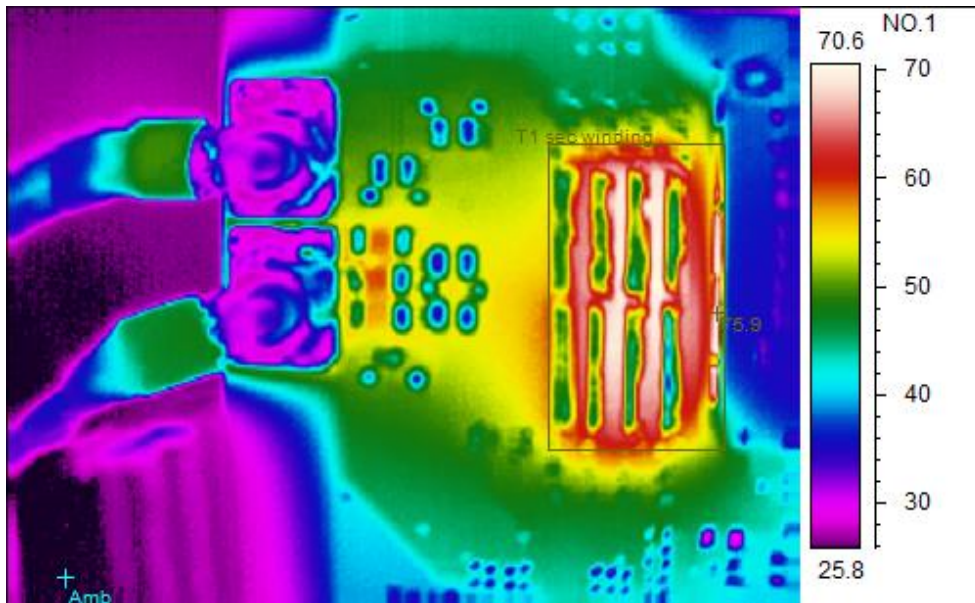
3.2.1 Top side



Spot analysis	Value
Amb Temperature	24.3°C
Area analysis	Value
T1Max	102.8°C



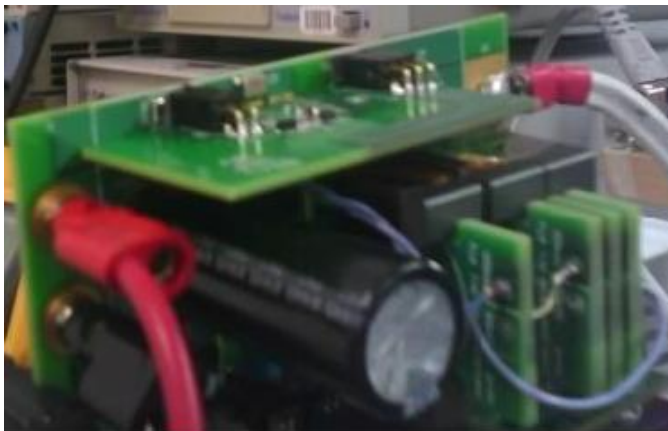
3.2.2 Bottom side



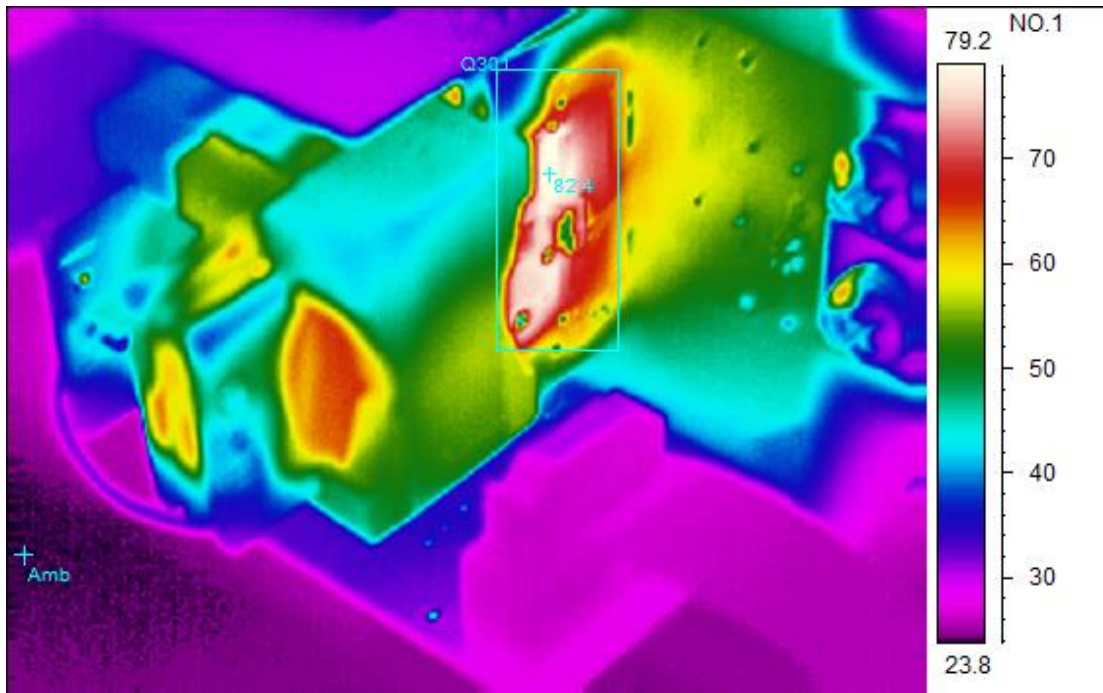
Spot analysis	Value
Amb Temperature	25.9°C
Area analysis	Value
T1 sec windingMax	75.9°C



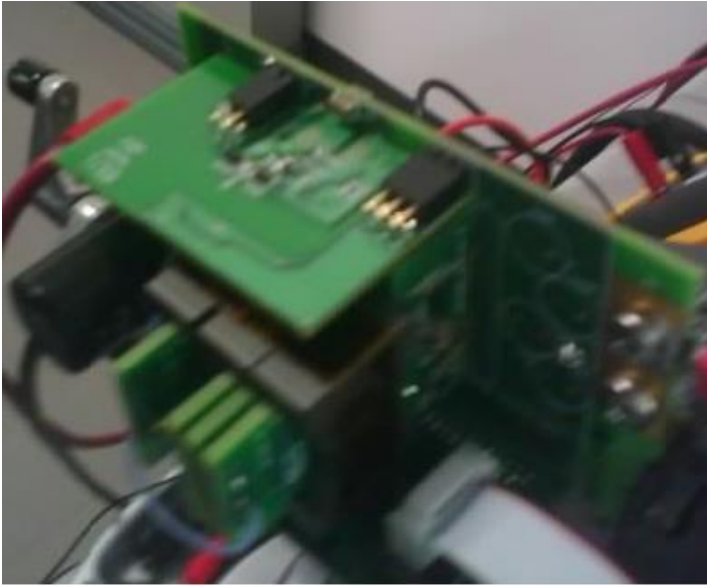
Spot analysis	Value
Amb Temperature	24.8°C
Area analysis	Value
Primary GaNMax	59.7°C



3.2.4 Transformer PCB windings

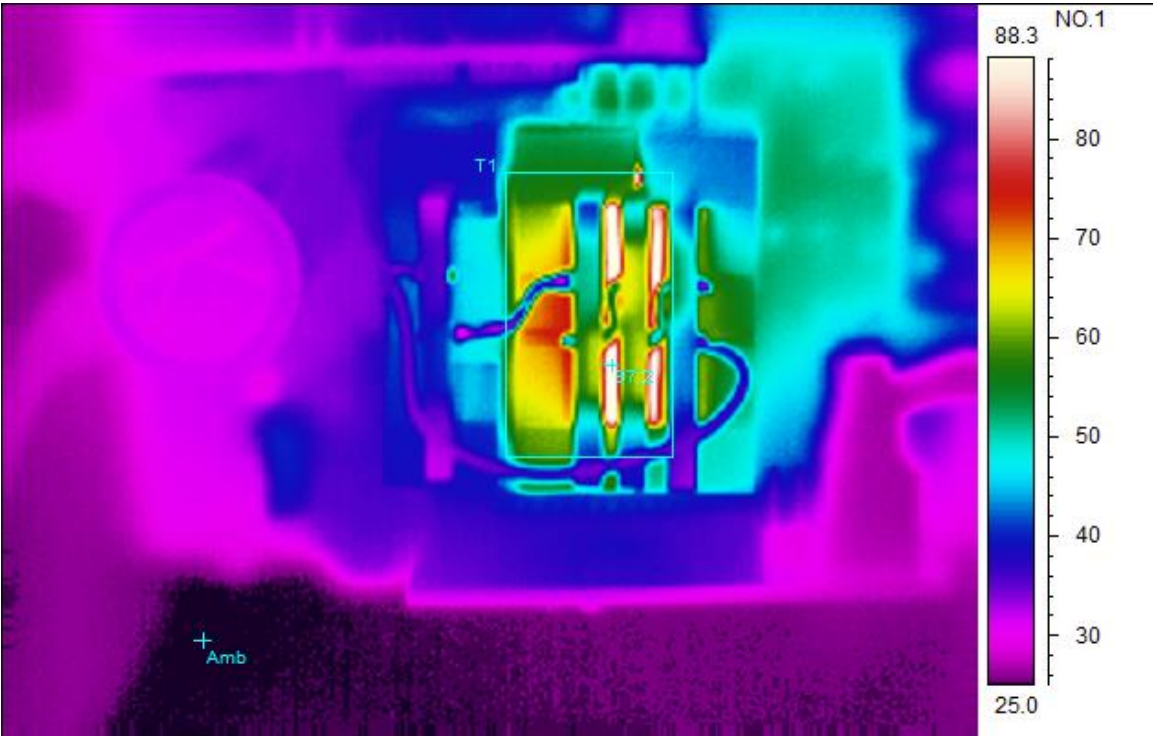


Spot analysis	Value
Amb Temperature	24.1°C
Area analysis	Value
Q301Max	82.4°C

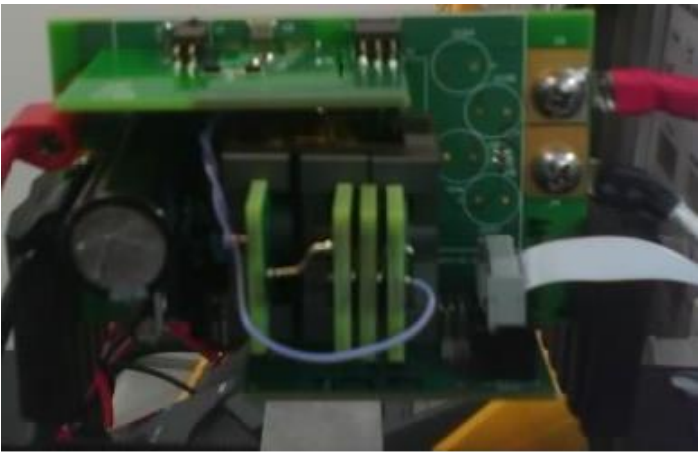


3.3 400VDC INPUT, 12V/42A OUTPUT

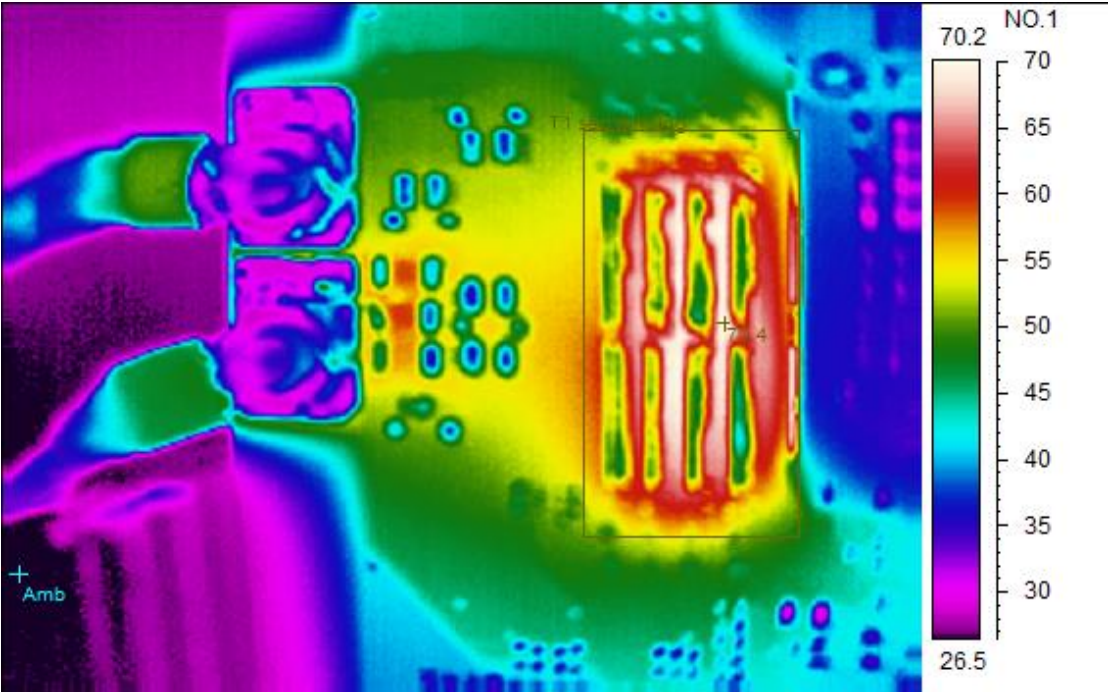
3.3.1 Top side



Spot analysis	Value
Amb Temperature	24.8°C
Area analysis	Value
T1Max	97.2°C



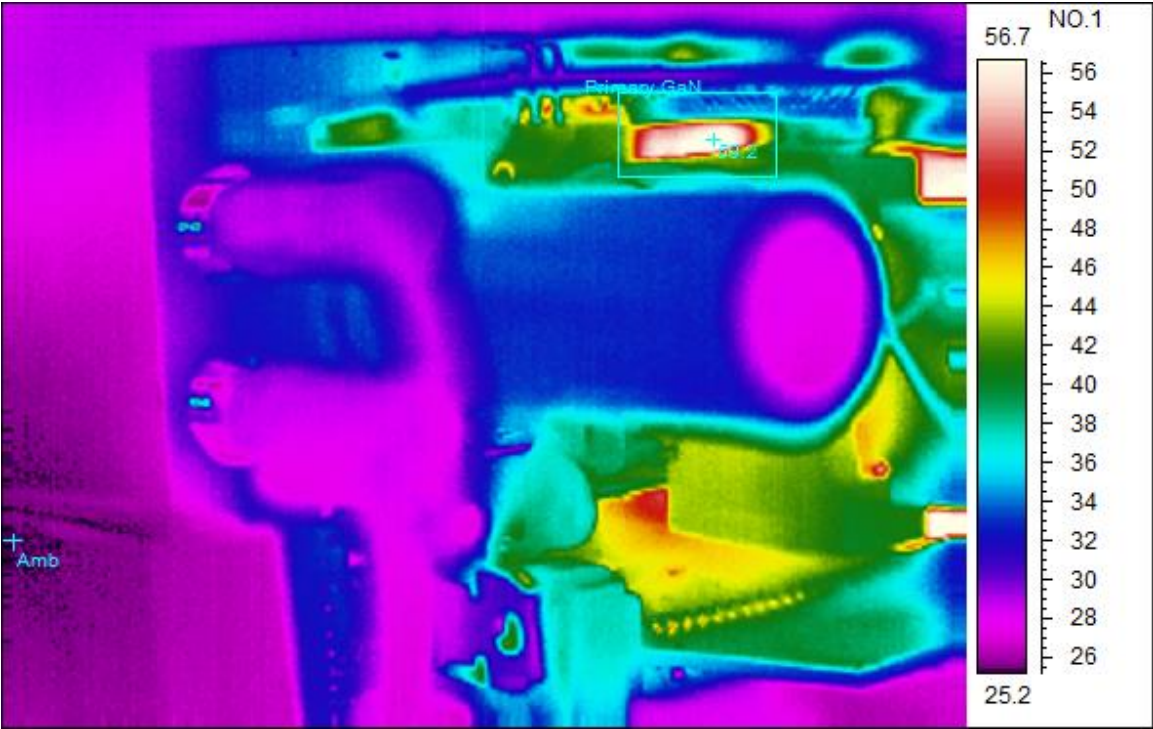
3.3.2 Bottom side



Spot analysis	Value
Amb Temperature	26.4°C
Area analysis	Value
T1 sec windingMax	70.4°C



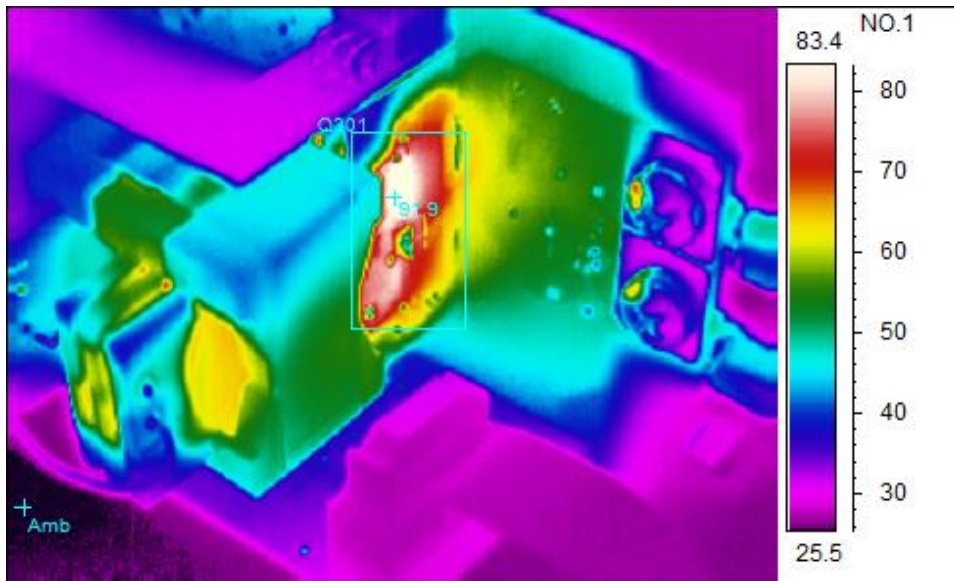
3.3.3 Primary GaNFET



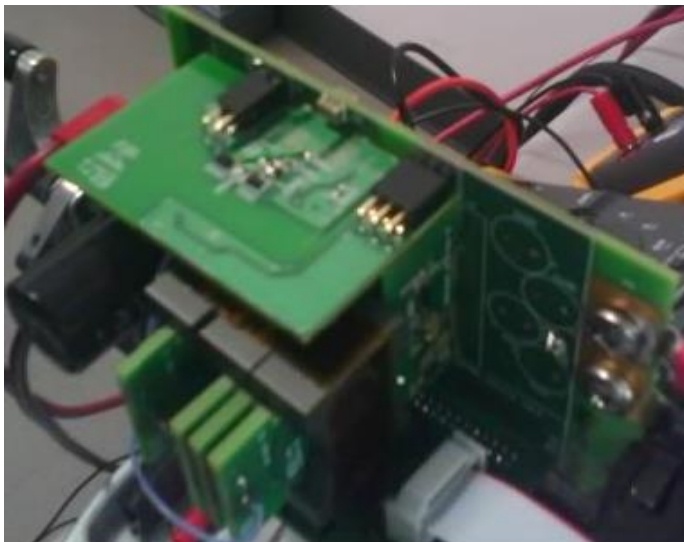
Spot analysis	Value
Amb Temperature	25.5°C
Area analysis	Value
Primary GaNMax	59.2°C



3.3.4 Transformer PCB windings

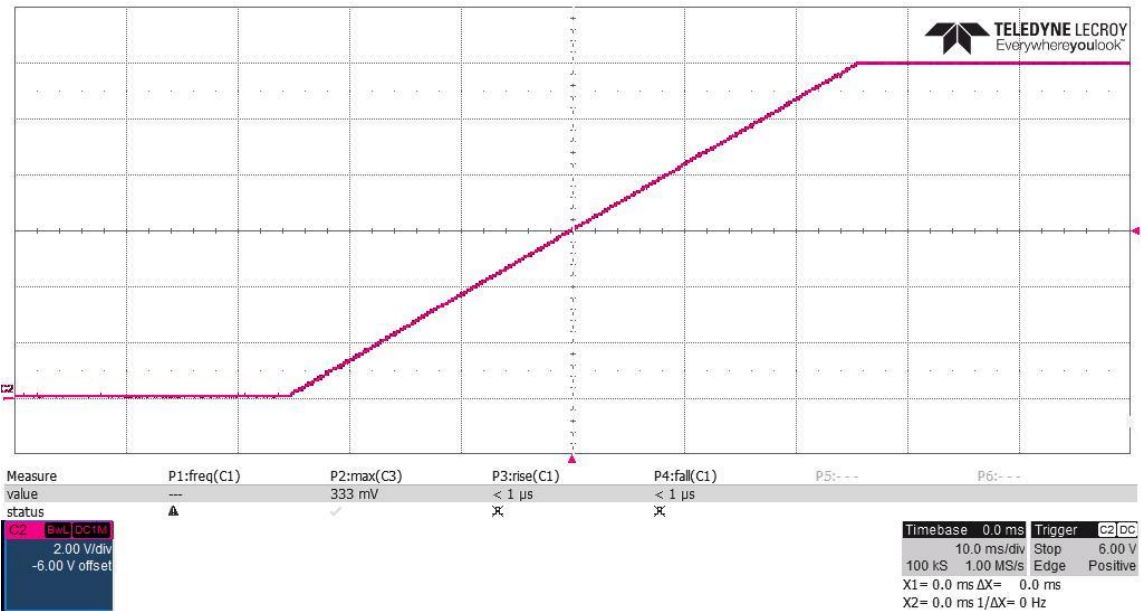


Spot analysis	Value
Amb Temperature	25.5°C
Area analysis	Value
Q301Max	91.9°C

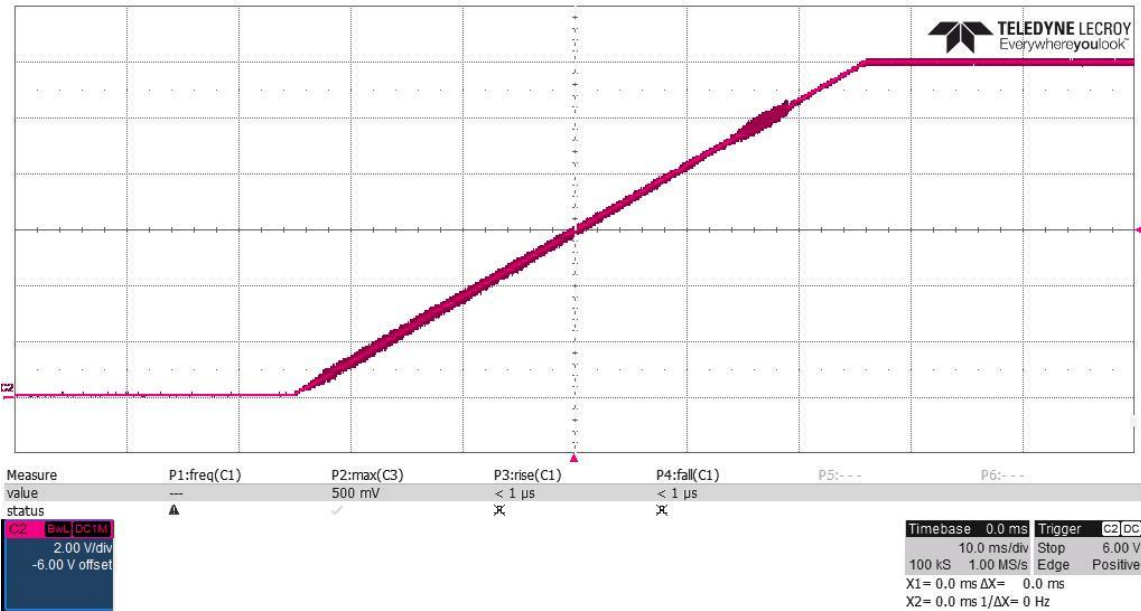


4. StartUp Transient

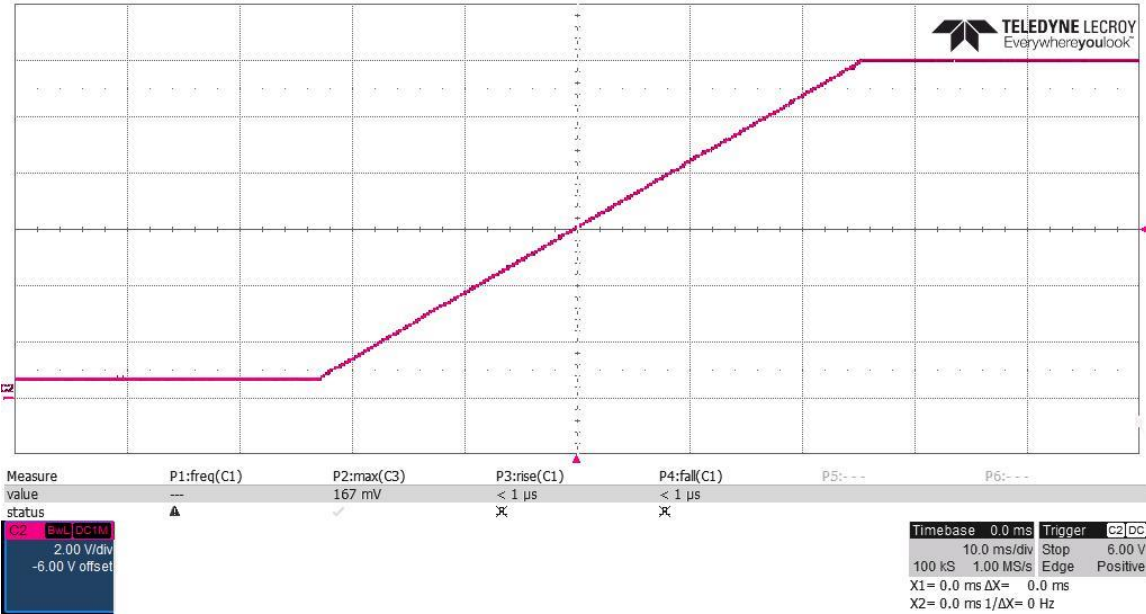
4.1 380VDC INPUT, 12V NO LOAD



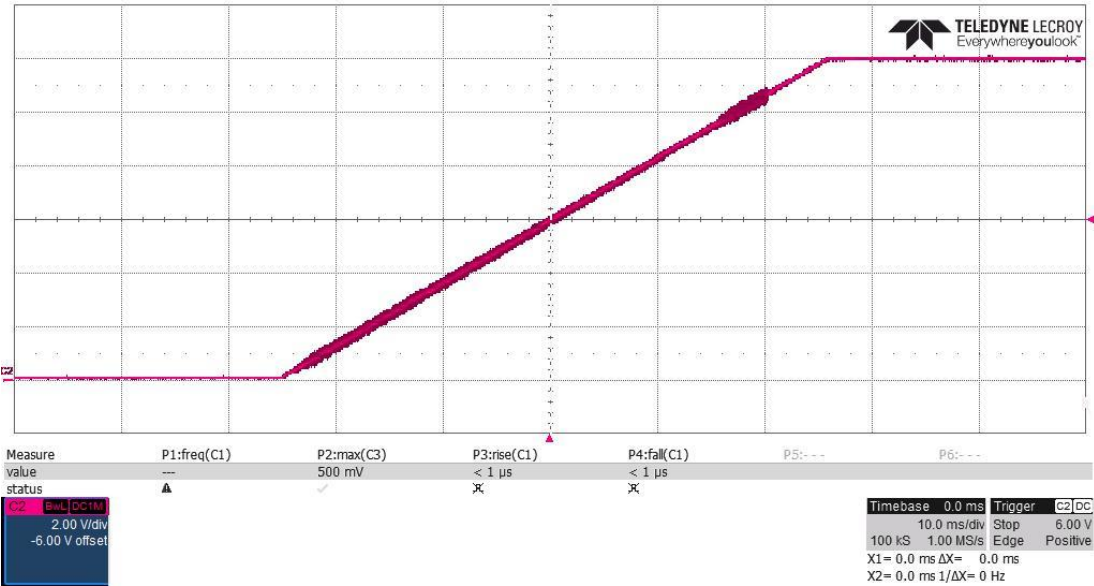
4.2 380VDC INPUT, 12V/42A



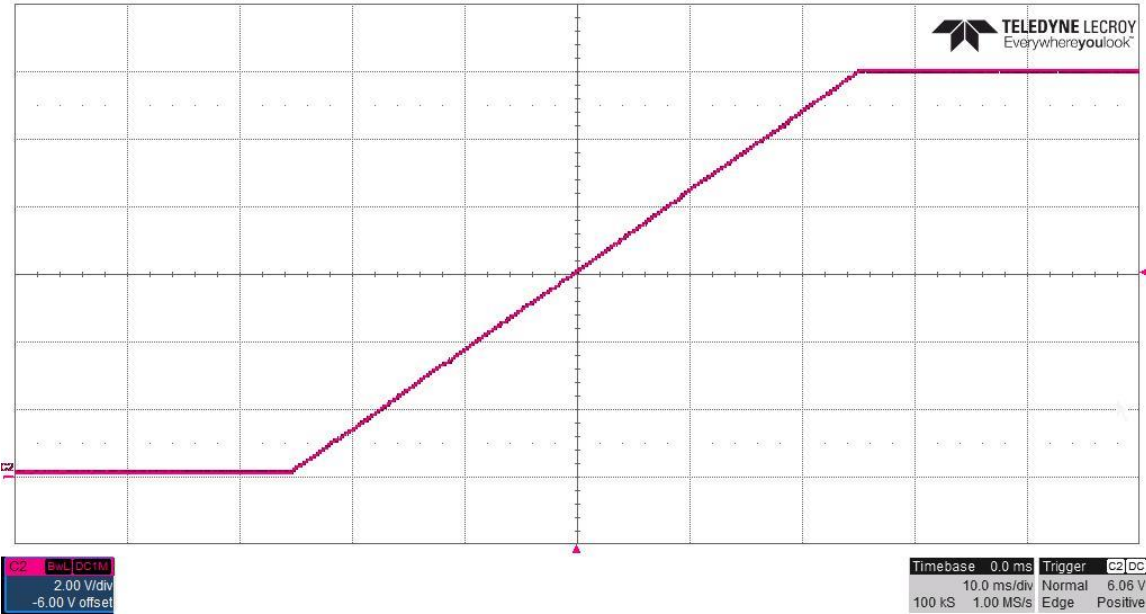
4.3 390VDC INPUT, 12V NO LOAD



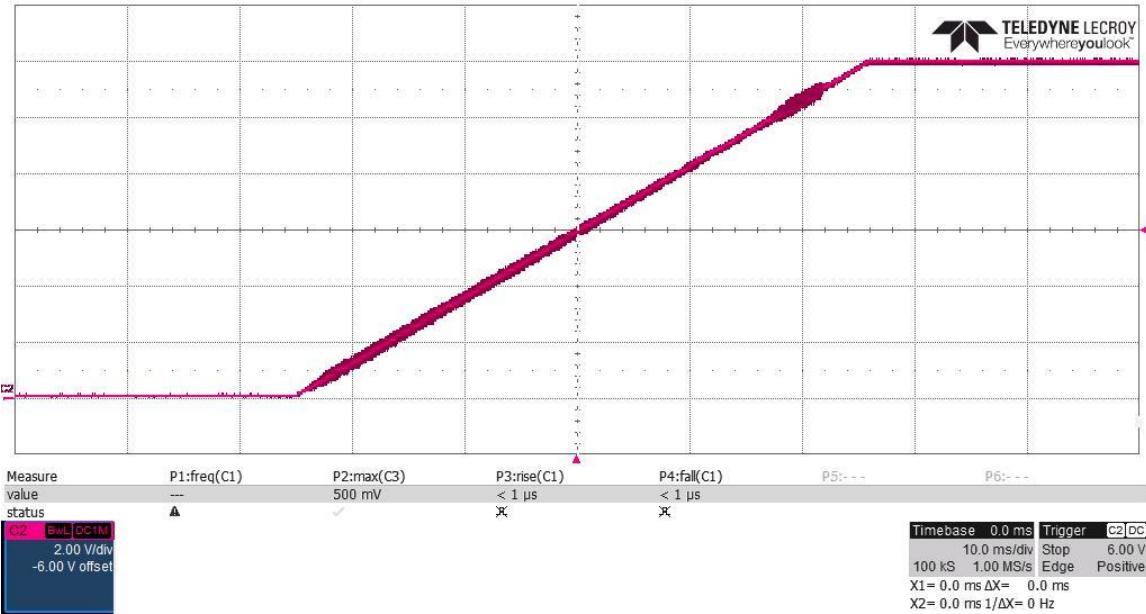
4.4 390VDC INPUT, 12V/42A



4.5 400VDC INPUT, 12V NO LOAD

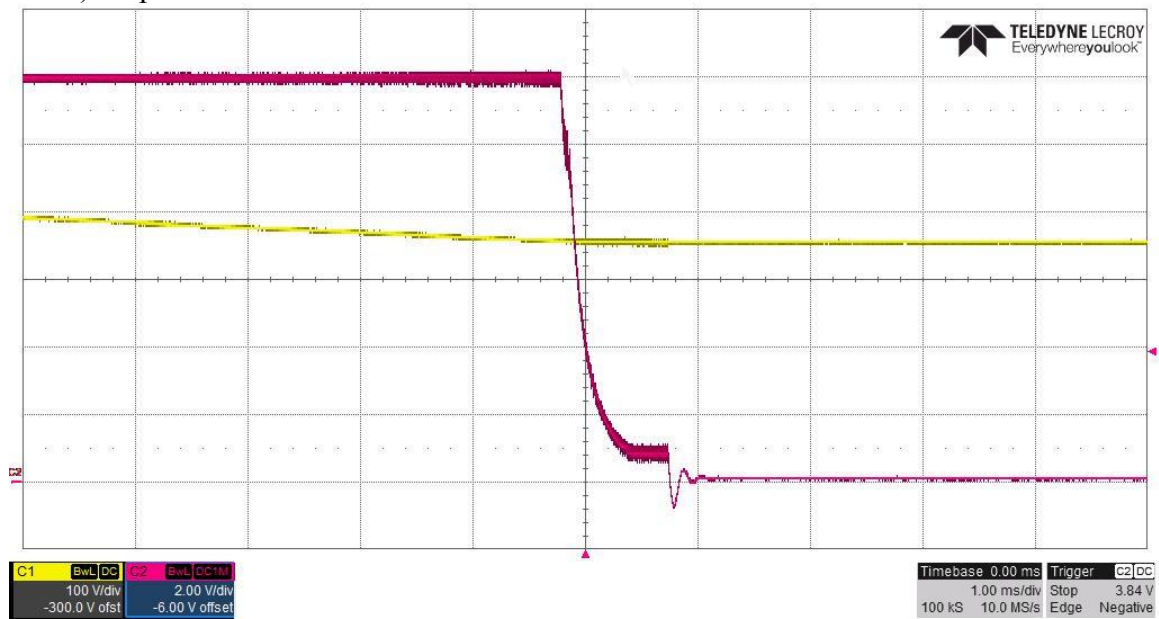


4.6 400VDC INPUT, 12V/42A



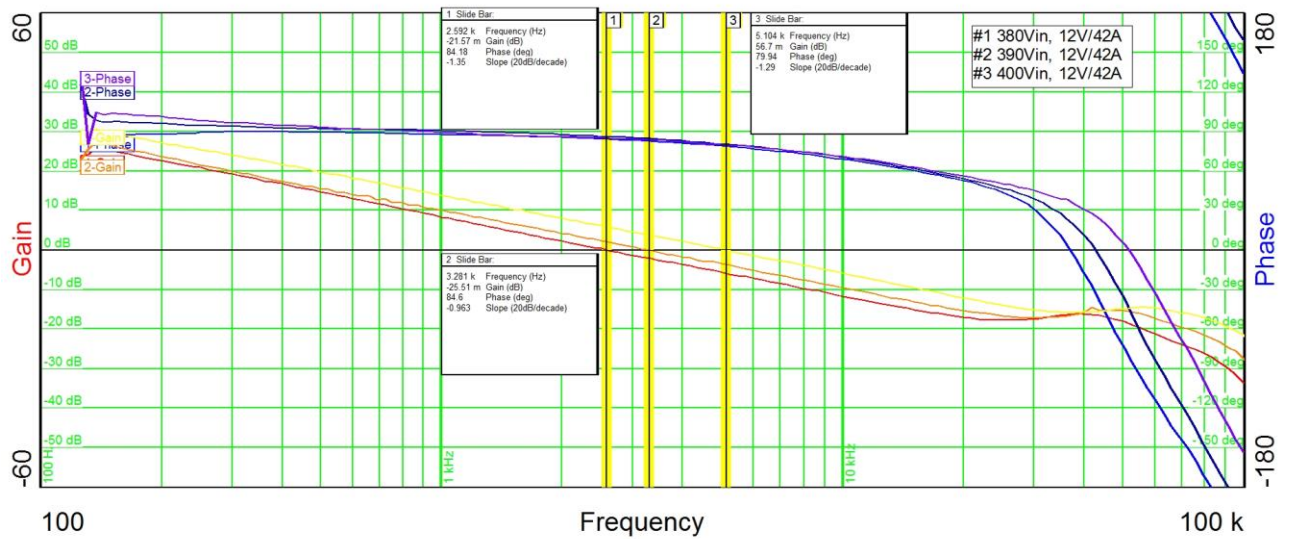
5. Turn Off Transient

Turn off transient is shown in the plot below, where CH1 is the input voltage and CH2 is the output voltage. It was with 390V_{DC} input and 12V/42A (constant current mode) output.



6. Frequency Response

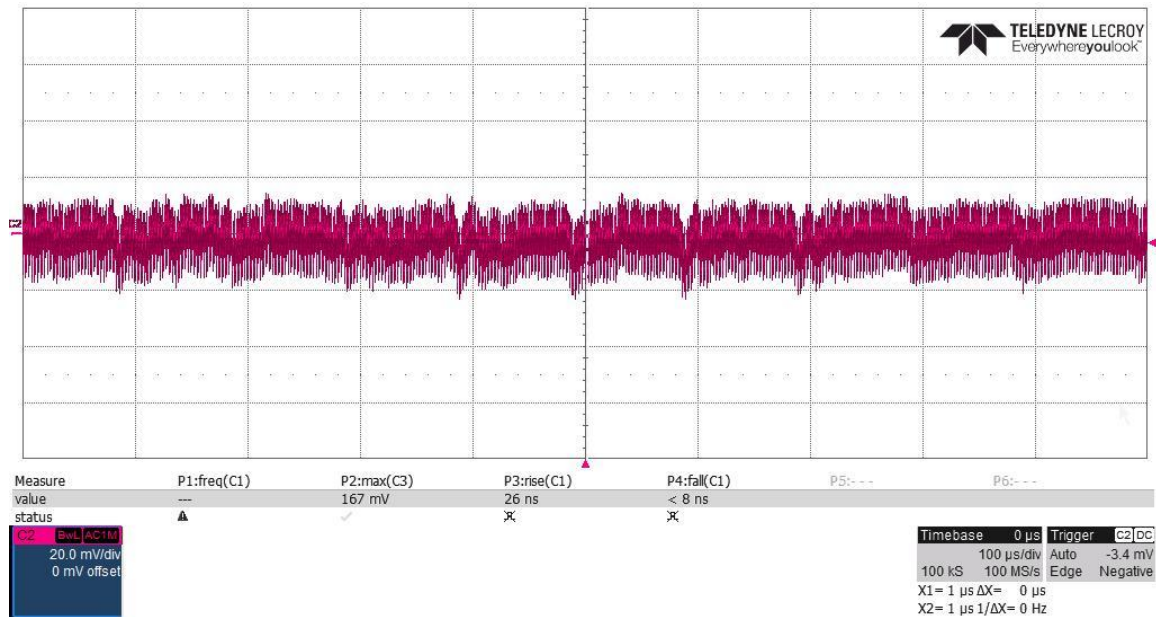
Frequency responses during full load operation (12V/42A at output) are shown in the plots below. Curve #1 is with 380VDC input. Curve #2 is with 390VDC input. Curve #3 is with 400VDC input.



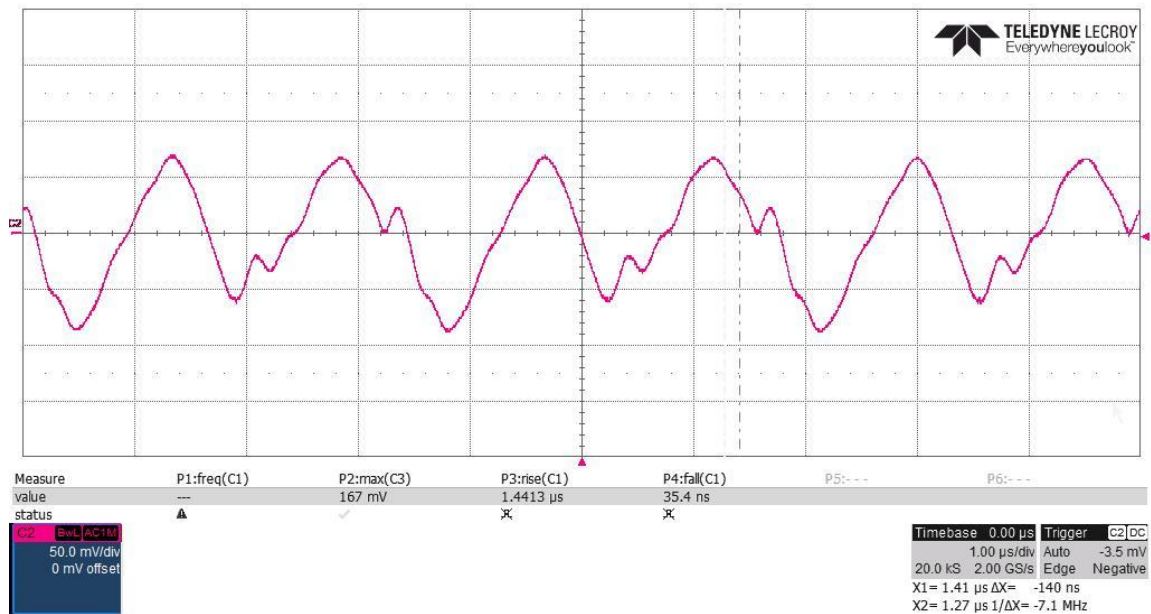
7. Ripples and Noises

The output ripple voltages (in AC level) are shown in the plots below.

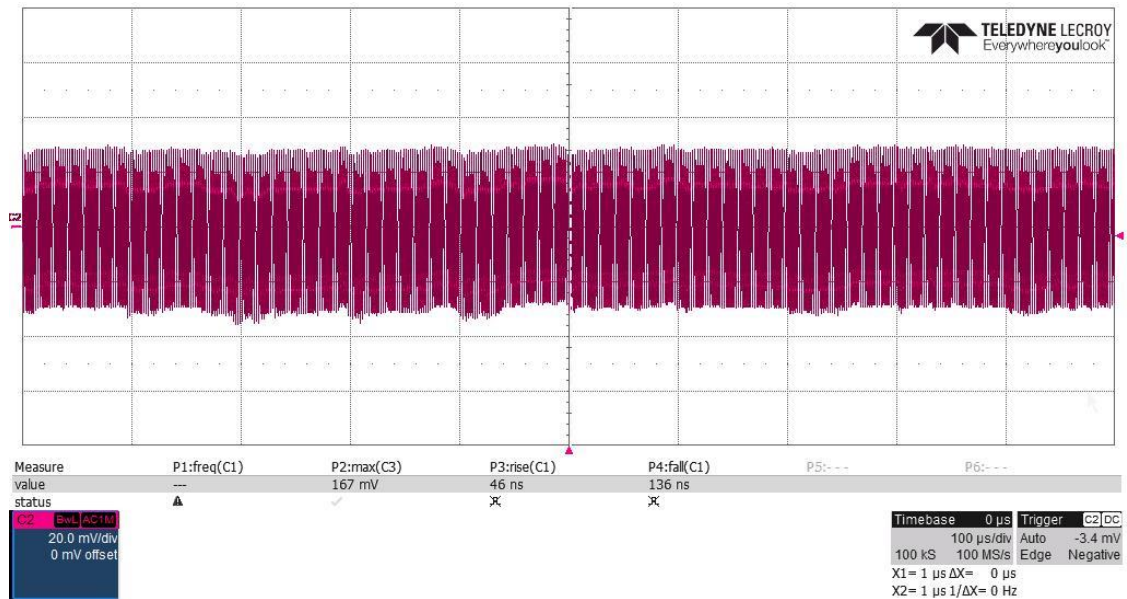
7.1 380VDC INPUT, 12V NO LOAD



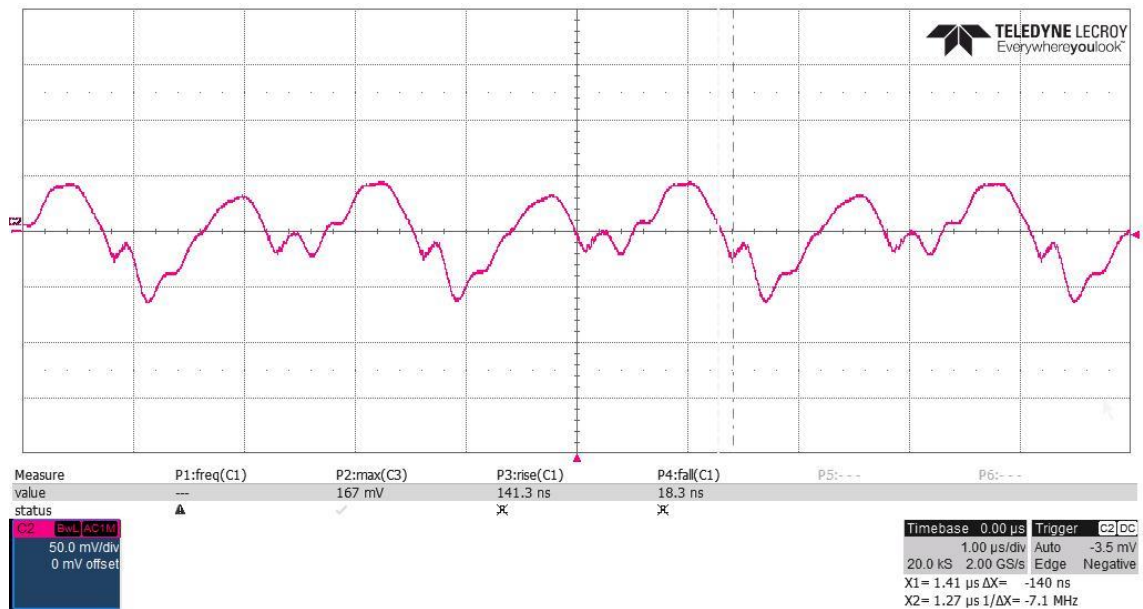
7.2 380VDC INPUT, 12V/42A



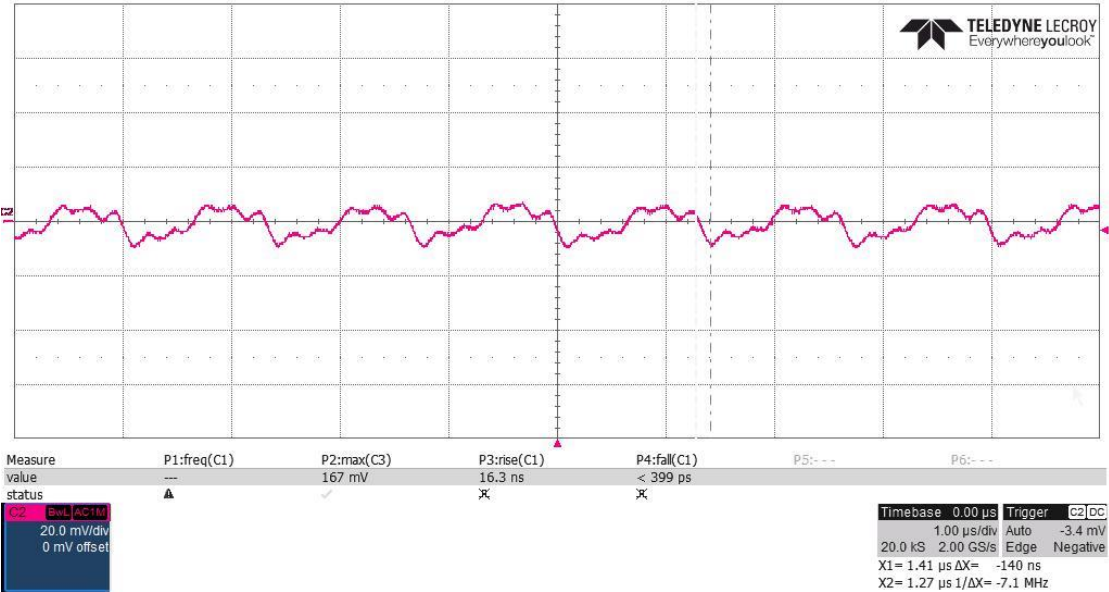
7.3 390VDC INPUT, 12V NO LOAD



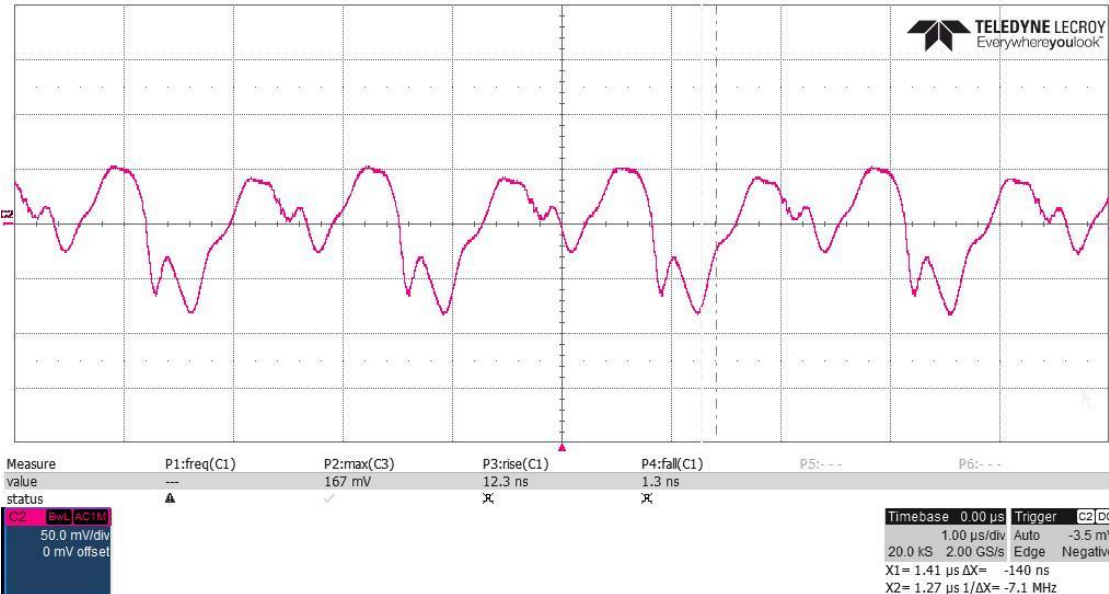
7.4 390VDC INPUT, 12V/42A



7.5 400VDC INPUT, 12V NO LOAD



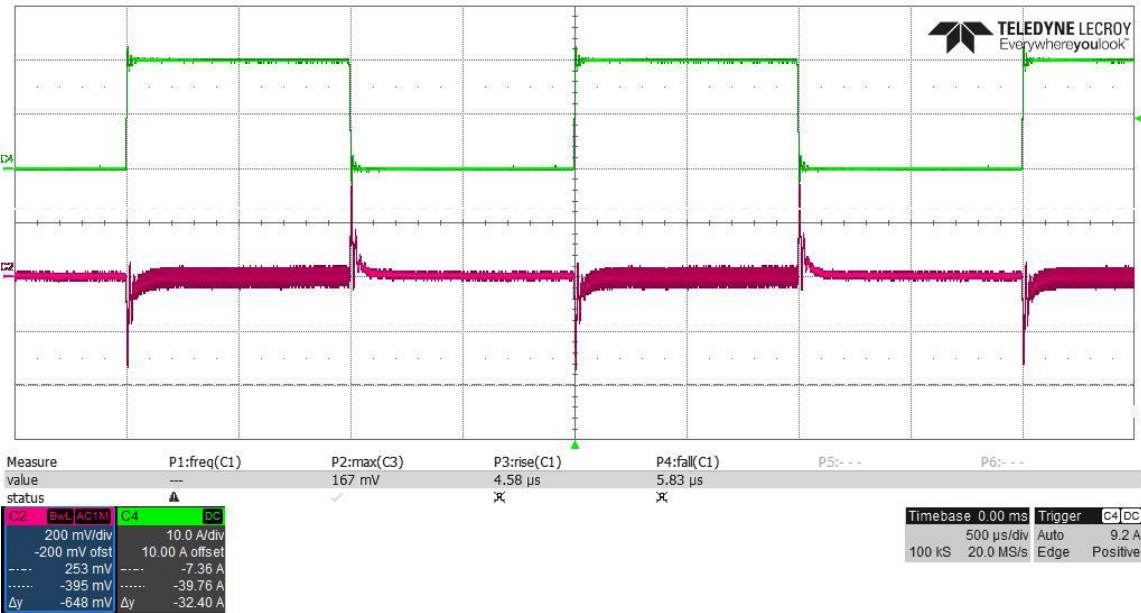
7.6 400VDC INPUT, 12V/42A



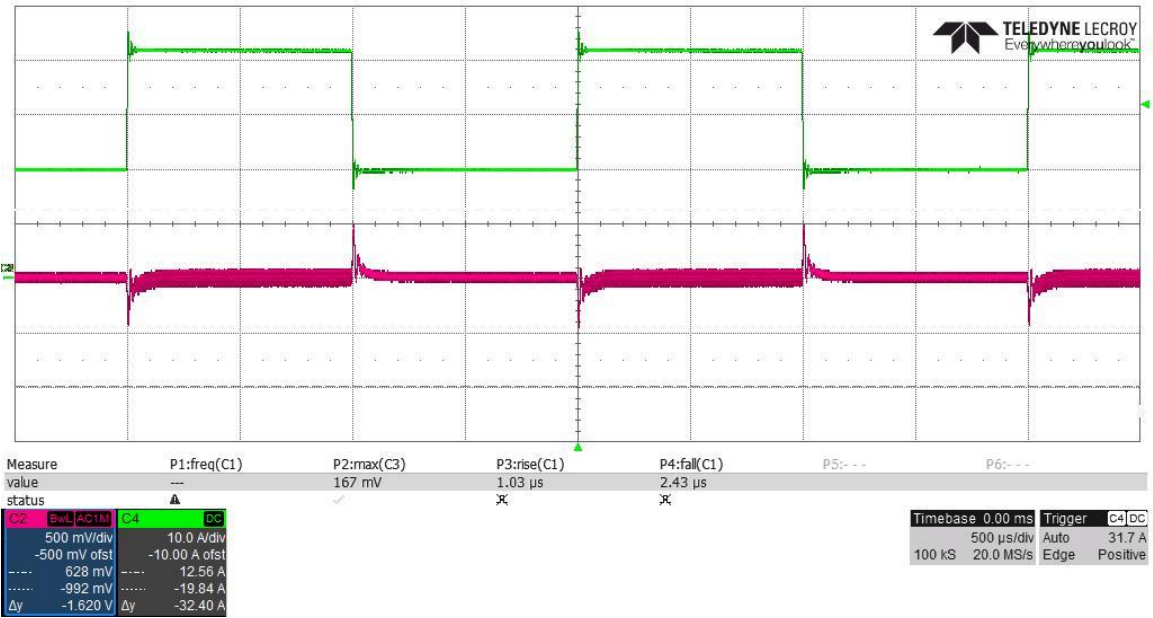
8. Dynamic Response

Transient responses are shown in the plots below, where CH2 is the output voltage at AC level and CH3 is the output current.

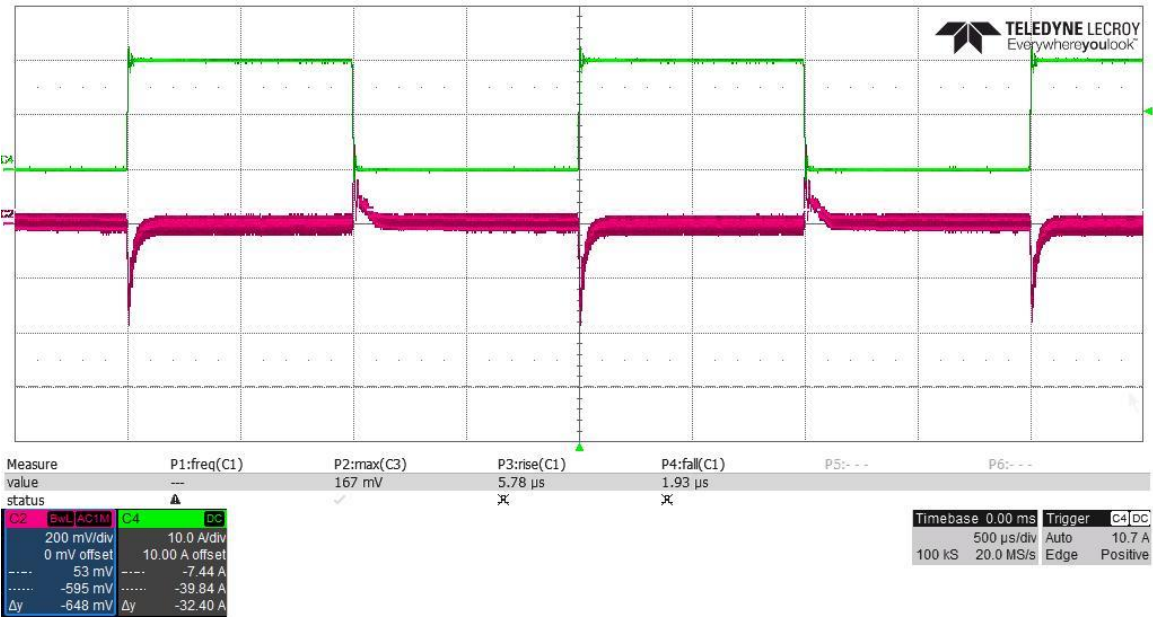
8.1 380VDC INPUT, 0.1AOUT TO 20AOUT



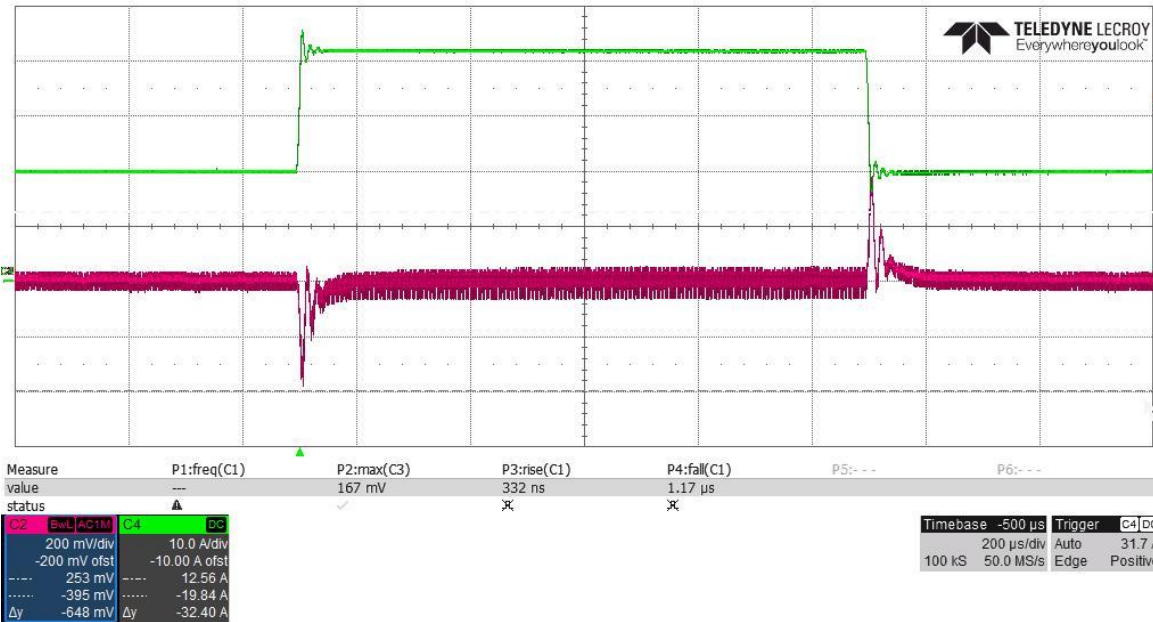
8.2 380VDC INPUT, 20AOUT TO 42AOUT



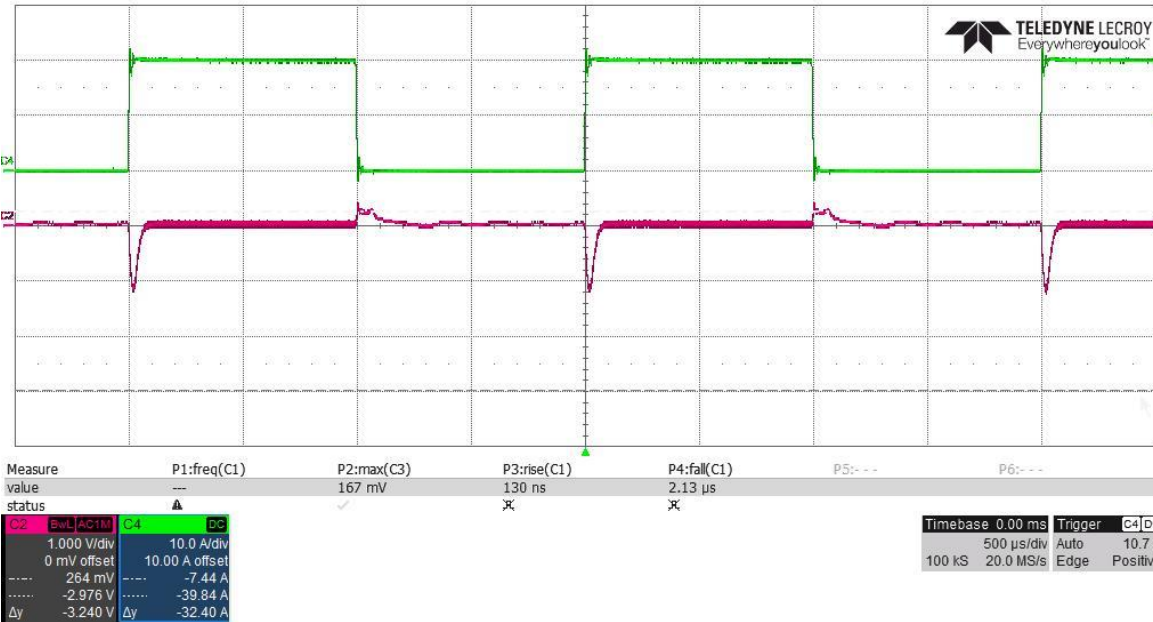
8.3 390VDC INPUT, 0.1AOUT TO 20AOUT



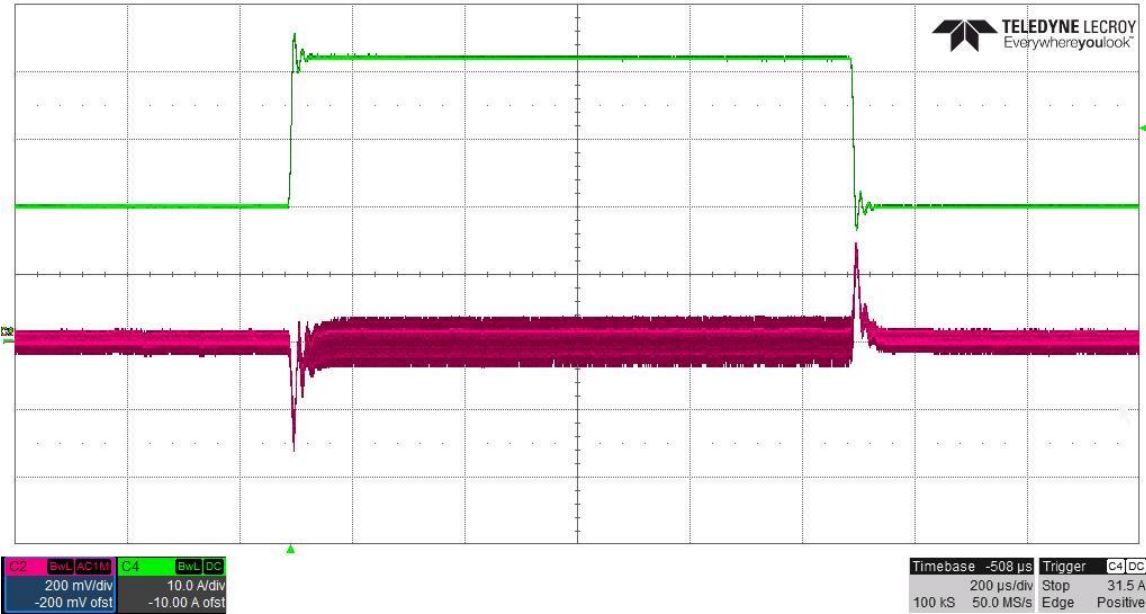
8.4 390VDC INPUT, 20AOUT TO 42AOUT



8.5 400VDC INPUT, 0.1AOUT TO 20AOUT

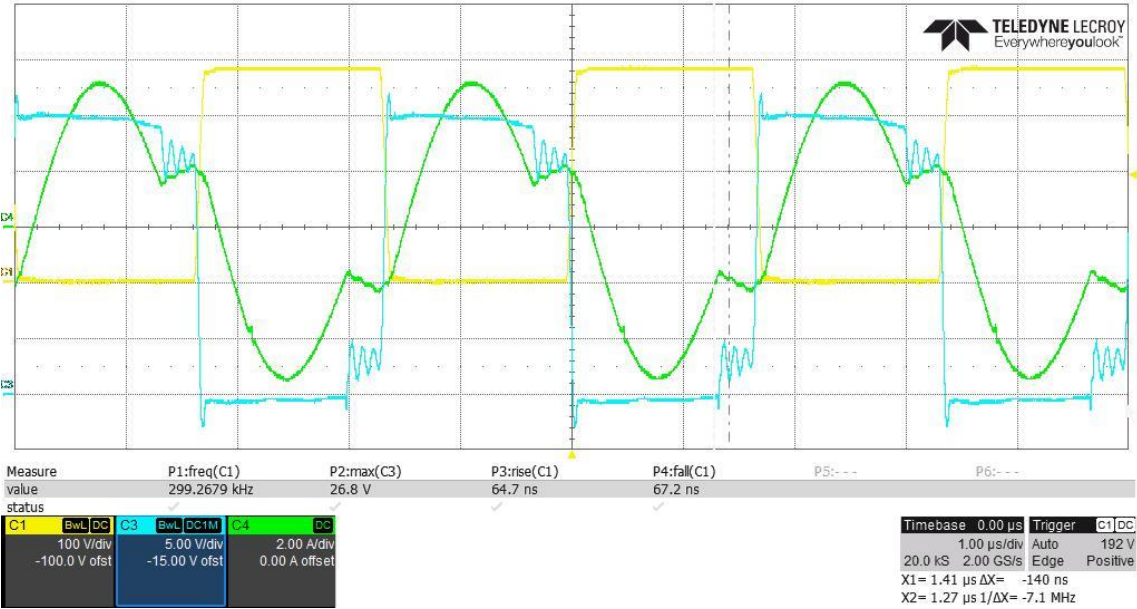


8.6 400VDC INPUT, 20AOUT TO 42AOUT

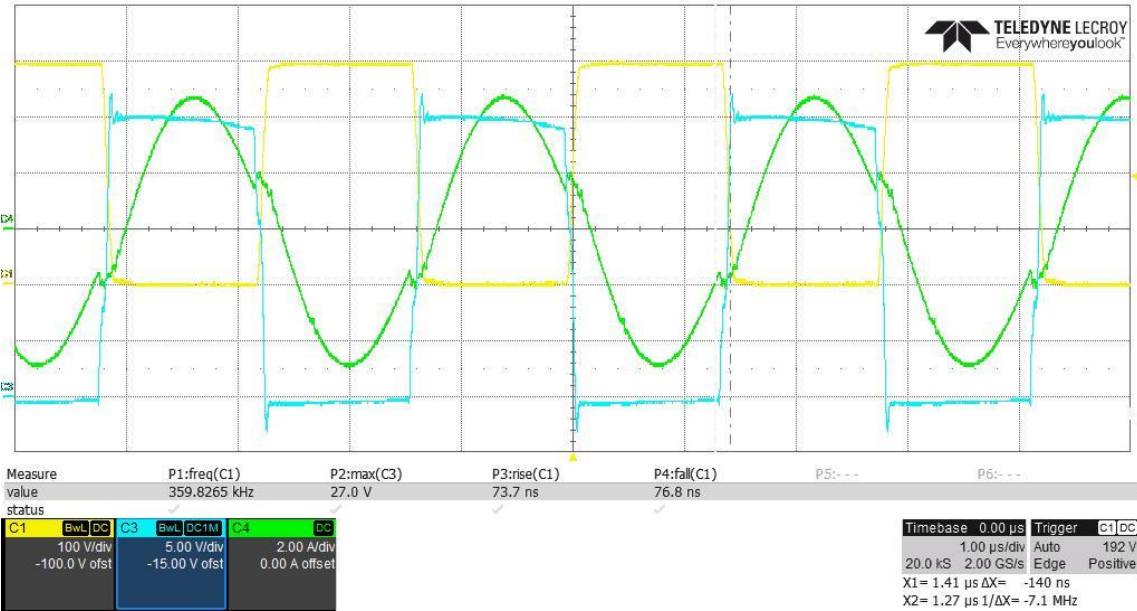


9. Key Waveforms

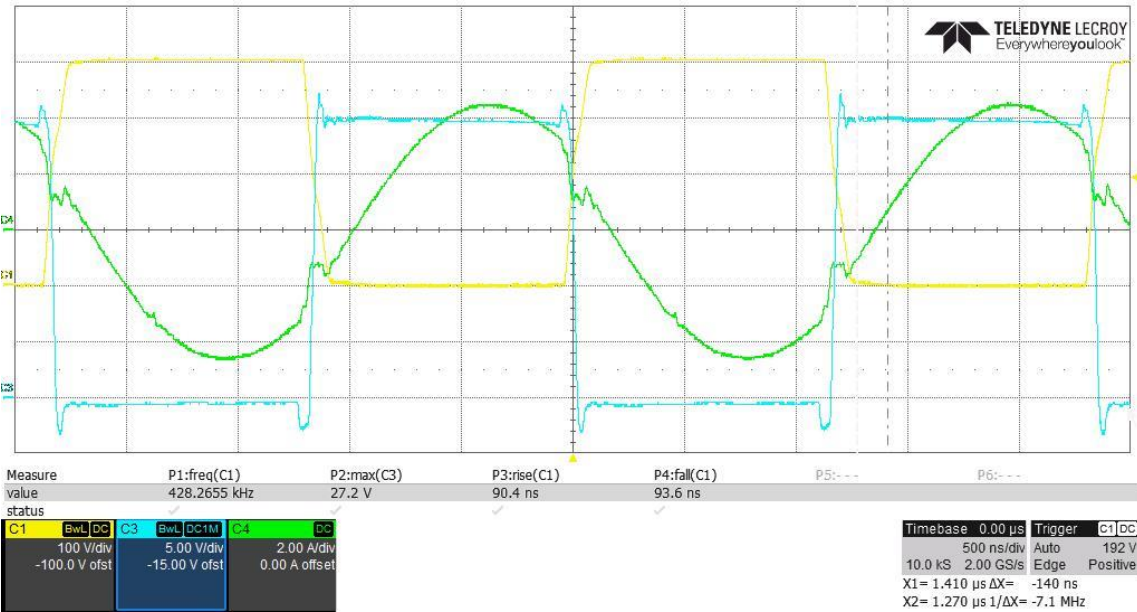
9.1 V_{DS_Q501} (PRIMARY GANFET), V_{DS_Q301} (SECONDARY SR FET) @ 380VIN, 12/42A



9.2 V_{DS_Q501} (PRIMARY GANFET), V_{DS_Q301} (SECONDARY SR FET) @ 390VIN, 12/42A



9.3 V_{DS_Q501} (PRIMARY GANFET), V_{DS_Q301} (SECONDARY SR FET) @ 400VIN, 12/42A



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