Test Report: PMP40988

Variable Frequency, ZVS, GaN-Based 5-kW Two-Phase Totem-Pole PFC Reference Design

Description

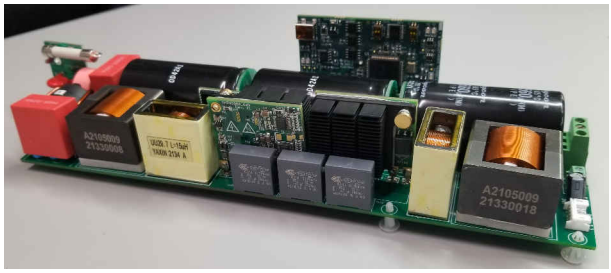
This reference design is a high-density and high-efficiency, 5-kW power factor correction (PFC) converter implemented with TI's high-performance GaN power switches. A peak system efficiency of 99% with an open-frame power density of 120 W/in^3 was measured. The power stage uses a two-phase totem pole PFC in a brand new topology and control mechanism. The new control method operates with variable frequency and maintains zero voltage switching (ZVS) over all operating conditions. The control is implemented with a TMS320F280049C high-performance microcontroller. The operating frequency range of the converter is approximately between 100 kHz and 800 kHz.

Features

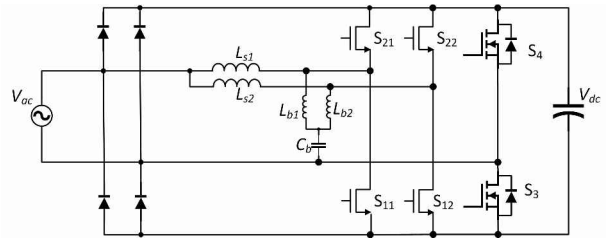
- 99% Efficiency
- Phase shedding
- 5-kW, 20-ms hold up
- Power Density: 120 W/in^3
- Density without hold up: 180 W/in^3

Applications

- Merchant network and server PSU
- Merchant telecom rectifiers
- Industrial AC-DC



Board Photo



Simplified Schematic

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
AC Input	230 Vac–277 Vac
Output voltage	400 V
Maximum Output Power	5 kW

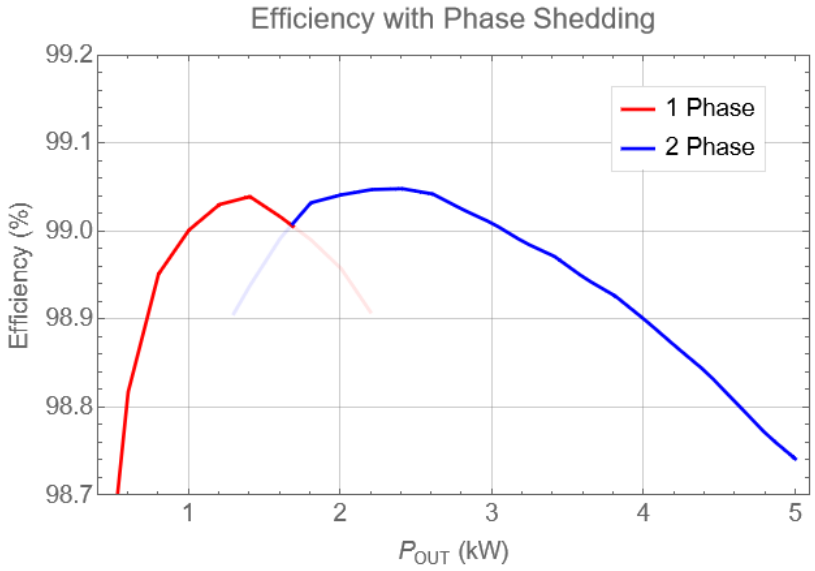
1.2 Dimensions

38 mm × 65 mm × 263 mm

2 Test Results

2.1 Efficiency Graphs

Efficiency is shown in the following figure. The enhanced efficiency at lighter loads is enhanced by turning off one of the phases. This, along with the high-efficiency enabled by the GaN switches and the ZVS control, enables a flat efficiency over a wide operating range.

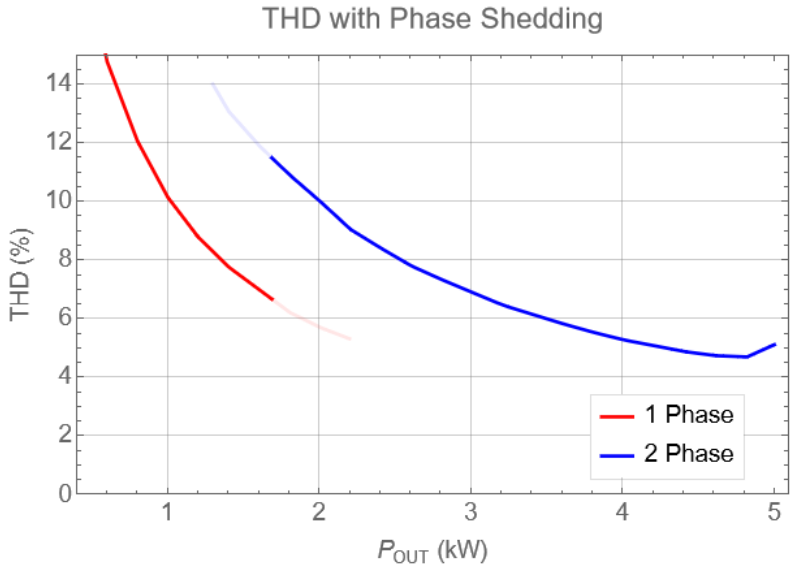


V_{IN} = 230 V_{RMS}

V_{OUT} = 400 V

Figure 2-1. Efficiency Graph

2.2 THD



V_{IN} = 230 V_{RMS}

V_{OUT} = 400 V

Figure 2-2. THD Graph

2.3 Data

Power, efficiency, and THD data is provided in the following table.

Table 2-1. Power, Efficiency, and THD Data

Phases	V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	V_{BIAS} (V)	I_{BIAS} (A)	P_{IN} (W)	P_{OUT} (W)	P_{BIAS} (W)	Efficiency (%)	THD (%)
1	230.1	2.0	401.6	1.0	11.9	0.25	409.6	403.4	3.0	98.48	19.88
1	230.0	2.8	401.6	1.5	11.9	0.22	611.6	604.3	2.7	98.82	14.76
1	230.0	3.6	401.6	2.0	11.9	0.21	812.8	804.3	2.5	98.95	12.05
1	229.9	4.5	401.5	2.5	11.9	0.21	1015.0	1004.8	2.5	99.00	10.13
1	229.8	5.4	401.5	3.0	11.9	0.20	1217.4	1205.6	2.4	99.03	8.77
1	229.8	6.2	401.6	3.5	11.9	0.19	1420.3	1406.7	2.3	99.04	7.75
1	229.7	7.1	401.6	4.0	11.9	0.19	1623.7	1607.7	2.2	99.02	6.98
1	229.7	8.0	401.6	4.5	11.9	0.18	1827.0	1808.5	2.2	98.99	6.21
1	229.6	8.9	401.6	5.0	12.0	0.18	2029.8	2008.6	2.1	98.96	5.69
1	229.6	9.8	401.5	5.5	12.0	0.17	2233.2	2208.8	2.1	98.91	5.29
1	229.5	10.7	401.5	6.0	12.0	0.17	2437.7	2410.0	2.0	98.87	4.88
2	230.0	3.7	401.6	2.0	11.9	0.38	815.5	804.0	4.5	98.60	20.56
2	229.9	4.6	401.7	2.5	11.9	0.35	1017.6	1004.9	4.2	98.75	16.70
2	229.8	5.4	401.6	3.0	11.9	0.33	1219.4	1205.7	3.9	98.88	14.83
2	229.8	6.3	401.6	3.5	11.9	0.32	1421.7	1406.6	3.8	98.94	13.06
2	229.7	7.2	401.6	4.0	11.9	0.31	1624.1	1607.7	3.6	98.99	11.89
2	229.7	8.0	401.6	4.5	11.9	0.30	1826.1	1808.4	3.5	99.03	10.89
2	229.6	8.9	401.6	5.0	11.9	0.29	2027.9	2008.4	3.4	99.04	10.00
2	229.6	9.8	401.7	5.5	11.9	0.28	2230.6	2209.3	3.4	99.05	9.04
2	229.5	10.7	401.6	6.0	11.9	0.27	2433.8	2410.6	3.3	99.05	8.39
2	229.4	11.6	401.7	6.5	11.9	0.27	2636.8	2611.6	3.2	99.04	7.79
2	229.4	12.4	401.7	7.0	11.9	0.26	2839.9	2812.2	3.1	99.02	7.32
2	229.3	13.3	401.7	7.5	11.9	0.25	3042.8	3012.6	3.0	99.01	6.88
2	229.3	14.2	401.7	8.0	11.9	0.25	3246.5	3213.6	3.0	98.99	6.45
2	229.2	15.1	401.6	8.5	11.9	0.24	3449.6	3414.1	2.9	98.97	6.13
2	229.1	16.0	401.7	9.0	11.9	0.24	3653.6	3615.1	2.9	98.95	5.81
2	229.0	16.9	401.6	9.5	11.9	0.24	3856.3	3814.8	2.8	98.93	5.52
2	228.9	17.8	401.7	10.0	11.9	0.23	4061.2	4016.5	2.8	98.90	5.26
2	228.8	18.7	401.7	10.5	11.9	0.23	4265.7	4217.4	2.7	98.87	5.06
2	228.8	19.6	401.7	11.0	11.9	0.22	4470.4	4418.5	2.7	98.84	4.86
2	228.8	20.5	401.8	11.5	11.9	0.22	4676.1	4620.1	2.6	98.80	4.73
2	228.7	21.4	401.8	12.0	11.9	0.22	4881.7	4821.5	2.6	98.77	4.69
2	228.7	22.3	401.8	12.5	11.9	0.21	5086.8	5022.6	2.5	98.74	5.16

2.4 Thermal Performance

The thermal image is shown in the following figure. The test conditions occurred at 230-V input, 400-V output, and a 5-kW load. The worst-case observed temperature is 40.7 °C.

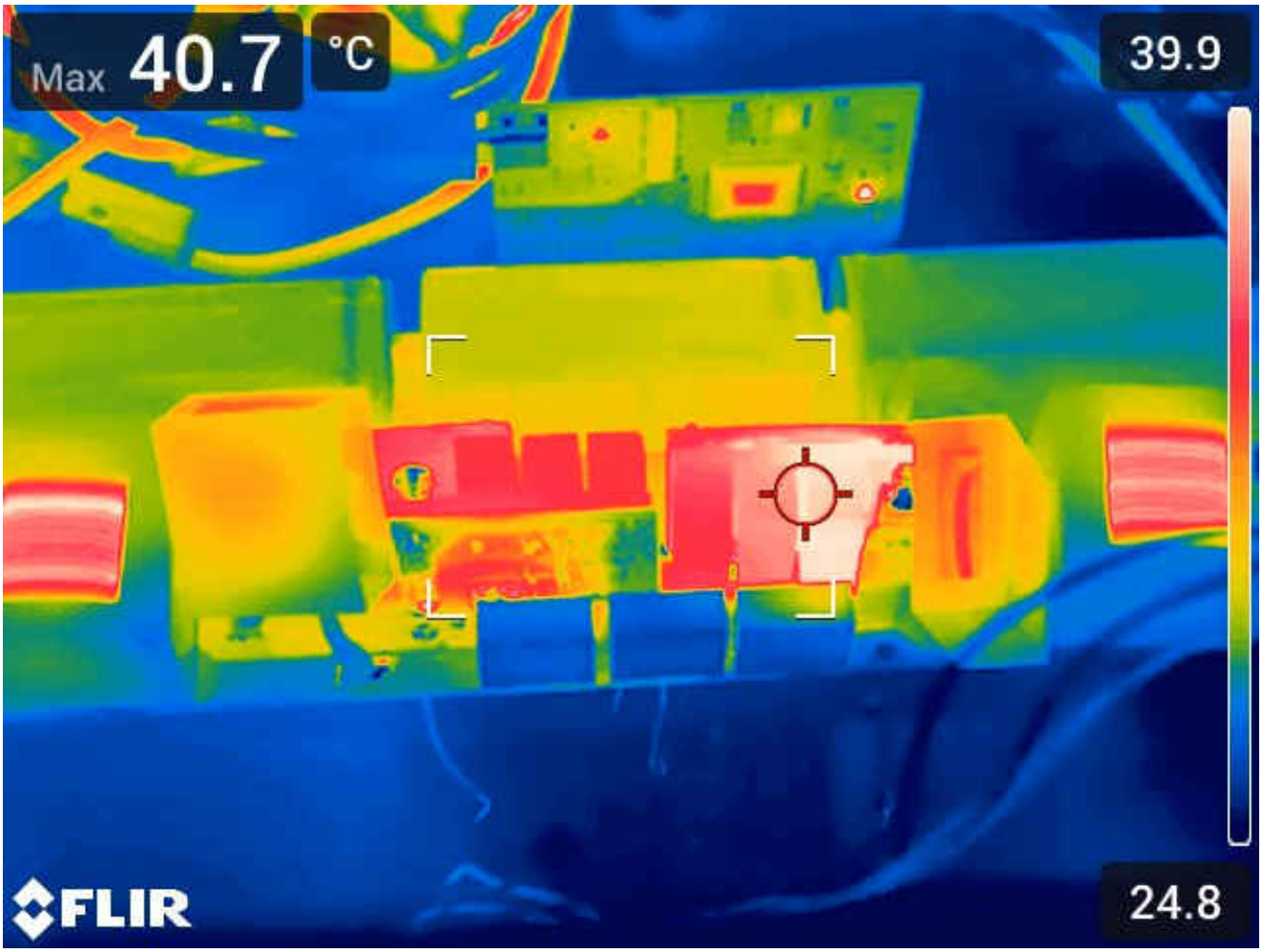


Figure 2-3. Thermal Image

The GaN FET thermal solution is illustrated in the following images.

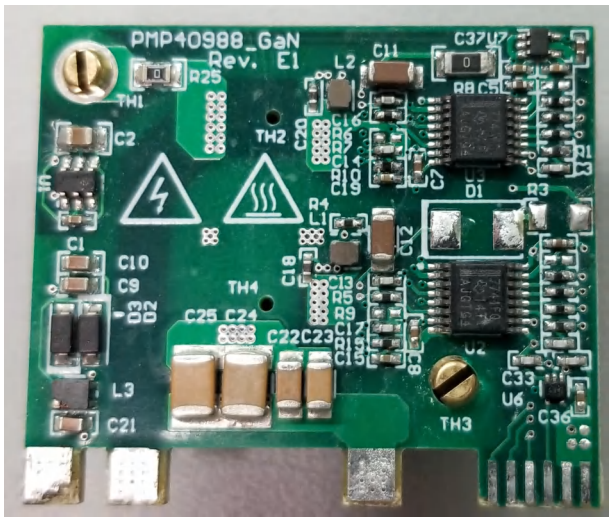


Figure 2-4. GaN Card - Bottom View

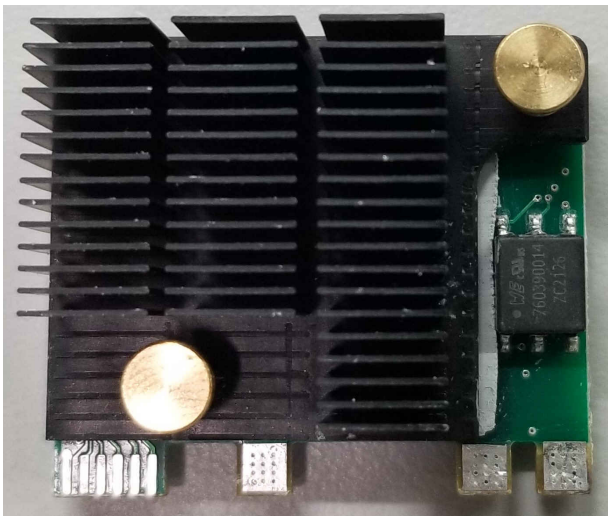


Figure 2-5. GaN Card - Top View

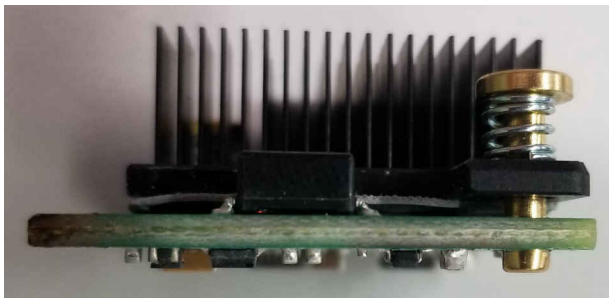


Figure 2-6. GaN Card - Side View

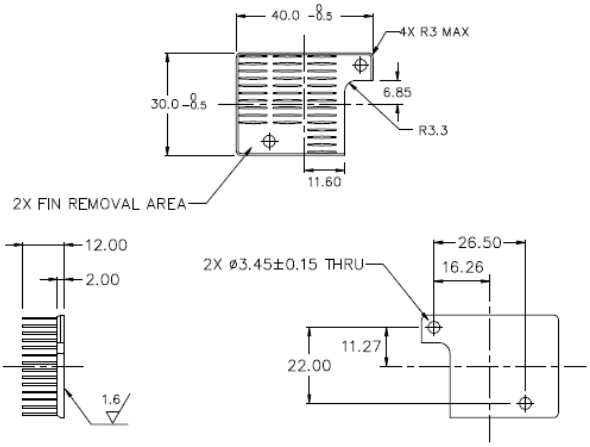


Figure 2-7. GaN Card - Heat Sink

3 Waveforms

3.1 Switching Waveforms

Switching behavior is shown in the following figures. Test conditions for these waveforms occur at:

- V_{IN}: 230 V
- V_{OUT}: 400 V
- I_{OUT}: 10 A

Note

Several operating points are illustrated to demonstrate the topology and controls ability to maintain ZVS when the input voltage is both above and below ½ V_{OUT}.

- CH1 - V_{SW} Phase 1
- CH2 - V_{SW} Phase 2
- CH2 - I_{SW} Phase 1
- CH4 - I_{SW} Phase 2

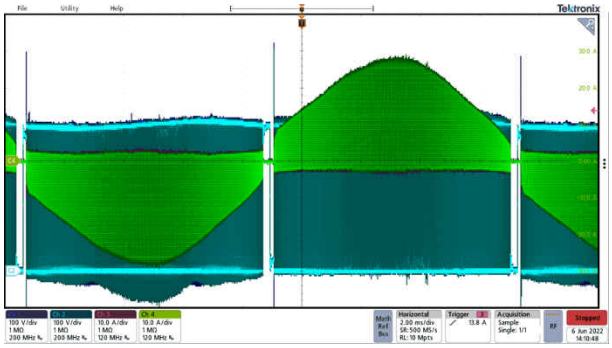


Figure 3-1. Entire Waveform

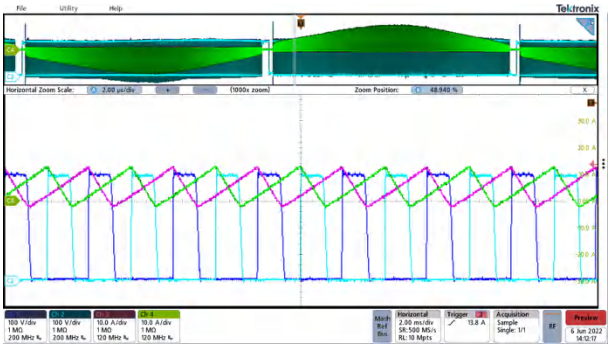


Figure 3-2. V_{IN} < ½ V_{OUT}

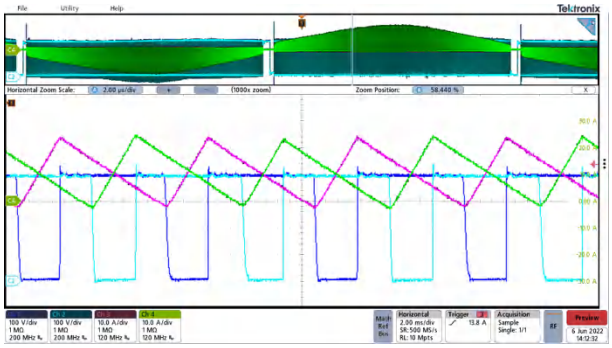


Figure 3-3. V_{IN} > ½ V_{OUT}

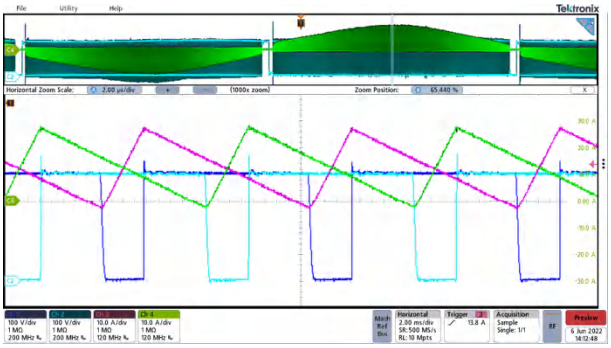


Figure 3-4. V_{IN} > ½ V_{OUT}

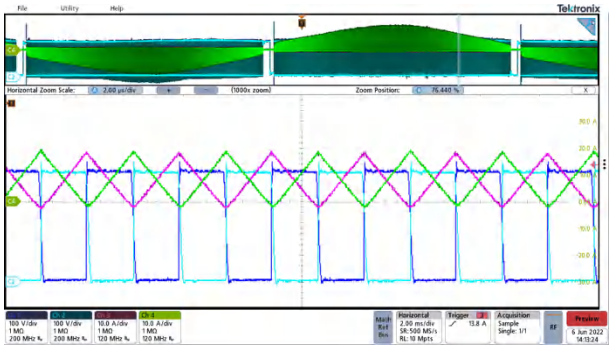


Figure 3-5. V_{IN} = ½ V_{OUT}

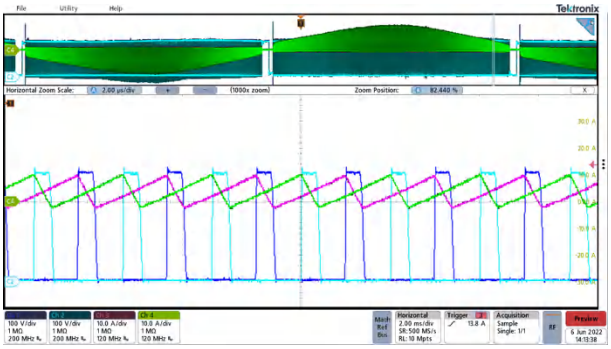


Figure 3-6. V_{IN} < ½ V_{OUT}

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