Test Report: PMP23461
GaN-based 4kW Bi-directional CLLLC Converter Reference Design

Description

The PMP23461 reference design is a 4kW, bidirectional, CLLLC converter. The design employs a full-bridge CLLLC converter with synchronous rectification. The CLLLC utilizes both frequency and phase modulation to regulate the output across the required regulation range. The design uses a single processing core inside a TMS320F28388D microcontroller to control CLLLC. Synchronous rectification is implemented by the same microcontroller with Rogowski coil current sensors. High density is achieved through the use of high-speed GaN switches (LMG3522). The CLLLC runs with a variable frequency from 250kHz to 800kHz.

Resources

PMP23461	Design Folder
TLV365-Q1, LMG3522R030-Q1	Product Folder
TMS320F280039C-Q1, TMS320F28388D	Product Folder

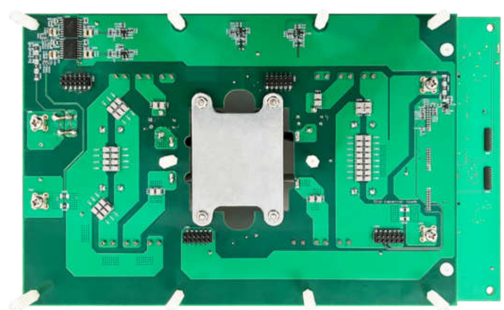
Features

- 4kW, bidirectional, CLLLC converter
- Peak system efficiency of 96.5% with an open-frame power density of 2kW/L
- In-built frequency response analyzer (SFRA) for verification and design of control loops

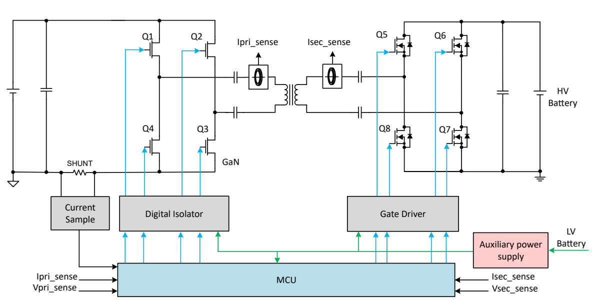
Applications

- Onboard charger
- Secondary voltage sense
- Secondary current sense

Top of Board



Bottom of Board



Block Diagram

1 Test Prerequisites

This chapter describes the functional parameters of CLLLC converters and the required test equipments.

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	MIN	TYP	MAX	UNITS
V_{in}	380	400	450	V
I_{in}			12	A
V_{out}	250	350	400	V
I_{out}	1		12	A
Switching Frequency	250	500	800	kHz

1.2 Required Equipment

- DC source: Chroma 62150H-1000
- DC source: GW Instek GPS-3303C
- DC load: Chroma 63208E-600-560
- Multimeter: Fluke 287C
- Oscilloscope: Tektronix DPO3054
- Electrical thermography: Fluke TiS55
- Vector Network Analyzer: OMICRON Bode100

1.3 Considerations

PMP23461 is a re-design of PMP22650/TIDM02013 CLLLC power stage. PMP23461 has four GaN daughter card, one Interposer, one MCU card and Main board. Using GaN daughter card enables customer quick replace failure switches. Most components of two reference design are the same, except for operational amplifier used in current sensing circuit.

The GaN card is LMG3522EVM-042, you can apply for extra boards. There are three options for MCU card. You can use F280039C EVM or F28P65X EVM or F28388D EVM.

For design guide, please refer to TIDM-02013.

1.4 Dimensions

The board total dimensions are 250mm (length) × 160mm (width) × 50mm (height).

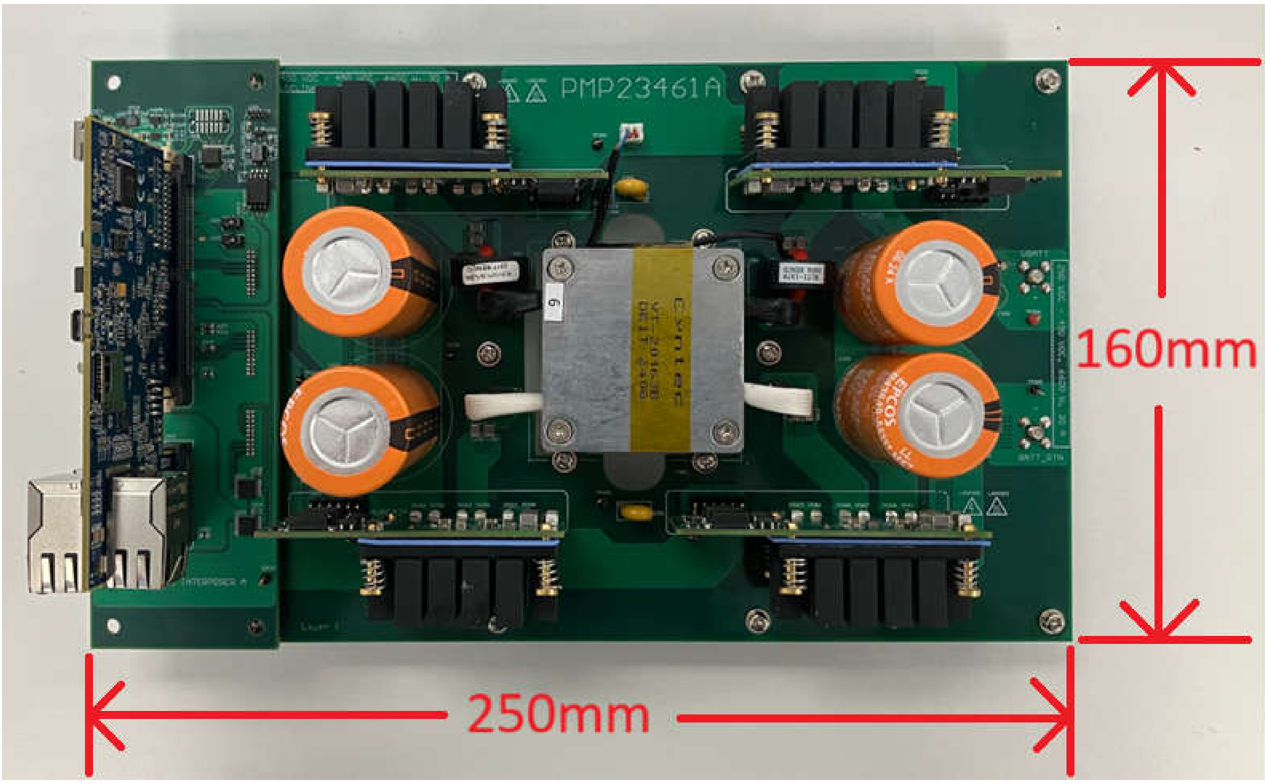


Figure 1-1. Dimensions

2 Testing and Results

2.1 Efficiency Graphs

Efficiency is shown in Figure 2-1.

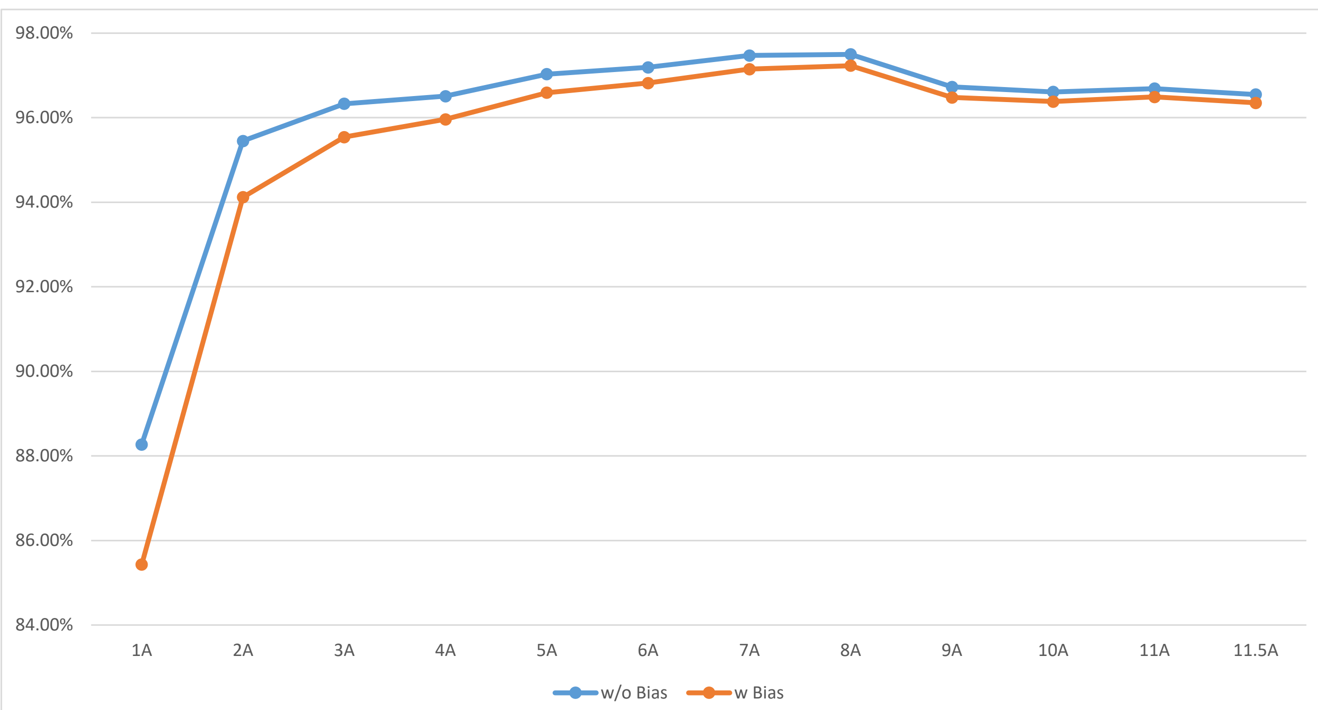


Figure 2-1. Efficiency Graph at 400V_{in}, 350V_{out}

2.2 Efficiency Data

Efficiency data is shown in Table 2-1.

Table 2-1. Efficiency at 400V_{in},350V_{out}

V_{out}(350)/V	I_{out}	P_{out}/W	V_{in}/V	I_{in}/A	P_{in}/W	Vbias/V	Ibias/A	Pbias/W	Eff no bias/%	Eff with bias/%
353.07	1	353.07	399.99	1	399.99	5.1	2.61	13.311	88.27%	85.43%
353.137	2	706.274	399.95	1.85	739.9075	5.1	2.06	10.506	95.45%	94.12%
353.15	3	1059.45	399.93	2.75	1099.8075	5.1	1.78	9.078	96.33%	95.54%
353.19	4	1412.76	399.95	3.66	1463.817	5.1	1.65	8.415	96.51%	95.96%
353.16	5	1765.8	399.96	4.55	1819.818	5.1	1.64	8.364	97.03%	96.59%
353.1	6	2118.6	399.97	5.45	2179.8365	5.1	1.63	8.313	97.19%	96.82%
353.08	7	2471.56	399.96	6.34	2535.7464	5.1	1.62	8.262	97.47%	97.15%
352.93	8	2823.44	399.96	7.24	2895.7104	5.1	1.61	8.211	97.50%	97.23%
351.62	9	3164.58	399.95	8.18	3271.591	5.1	1.68	8.568	96.73%	96.48%
351.59	10	3515.9	399.94	9.1	3639.454	5.1	1.68	8.568	96.61%	96.38%
351.55	11	3867.05	399.93	10	3999.3	5.1	1.67	8.517	96.69%	96.49%
351.55	11.5	4042.825	399.93	10.47	4187.2671	5.1	1.67	8.517	96.55%	96.35%

2.3 Current Sense

Two Rogowski coils are added to monitor the current, one at primary resonant tank, one at secondary tank, as shown in Block Diagram.

The output signal of Rogowski coil is a differential waveform of current, So we need add an integral circuit to restore the current signal. After that, using an amplifying circuit to adjust the amplitude of current signal, as Figure 2-2shows. R327 and C337 forms a basic integral circuit, then an inverting amplifier circuit using TLV365 provides a gain of 1.825 to the signal. Finally we can get the waveforms as Figure 2-3, Figure 2-4, and Figure 2-5 shows.

CH1: CLLLC_IPRIM_TANK signal

CH3: Primary resonant tank current

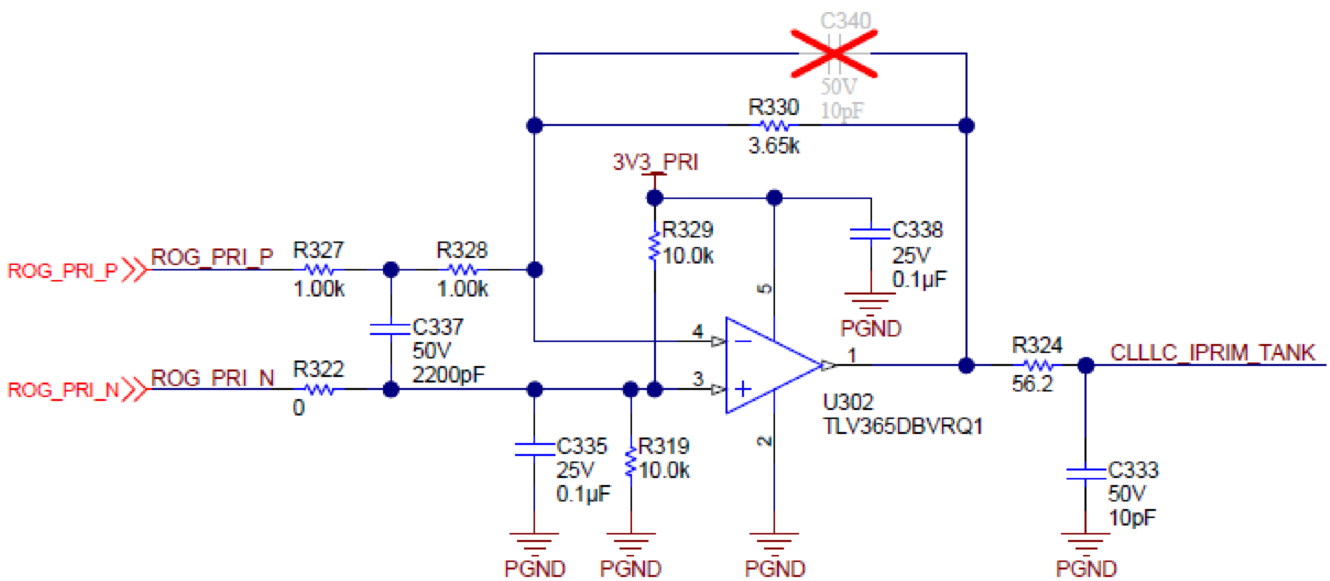


Figure 2-2. Current Sensing Circuit

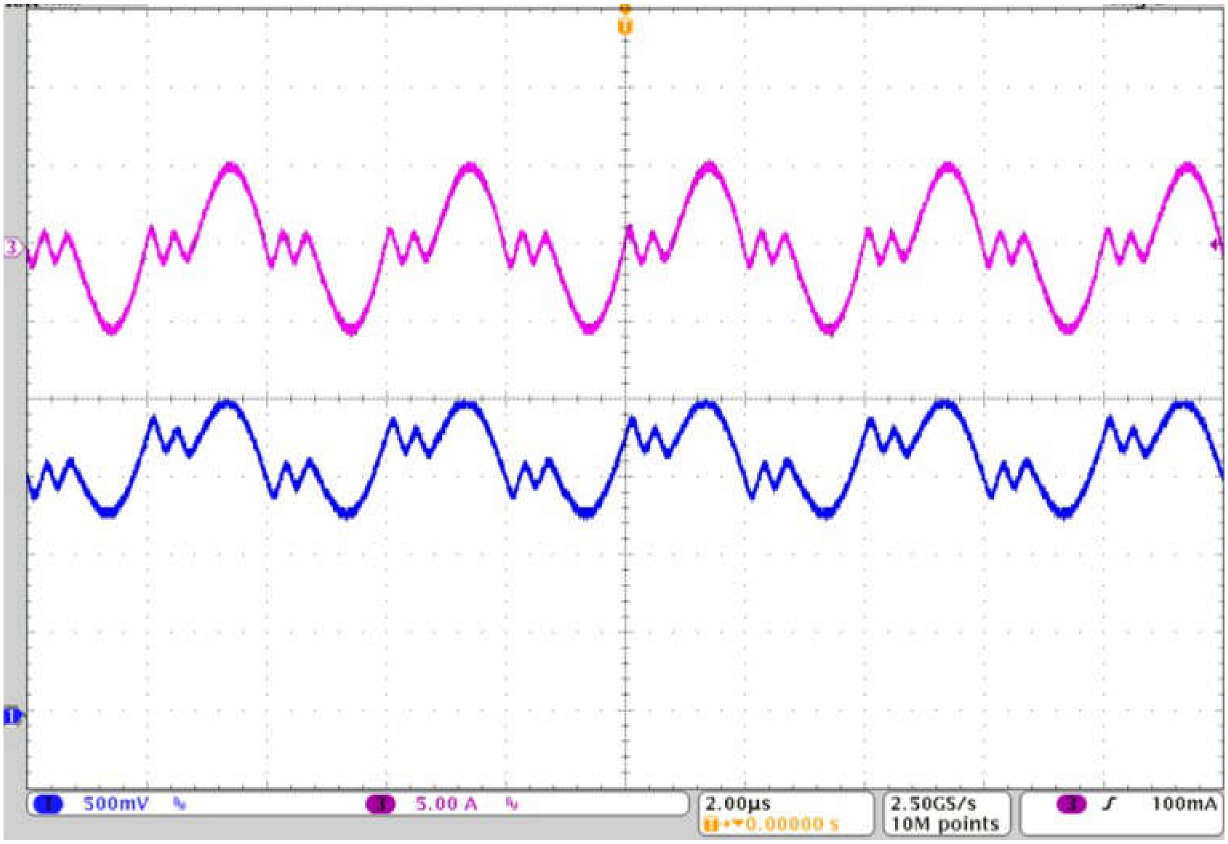


Figure 2-3. CLLLC_IPRIM_TANK Signal at 250kHz

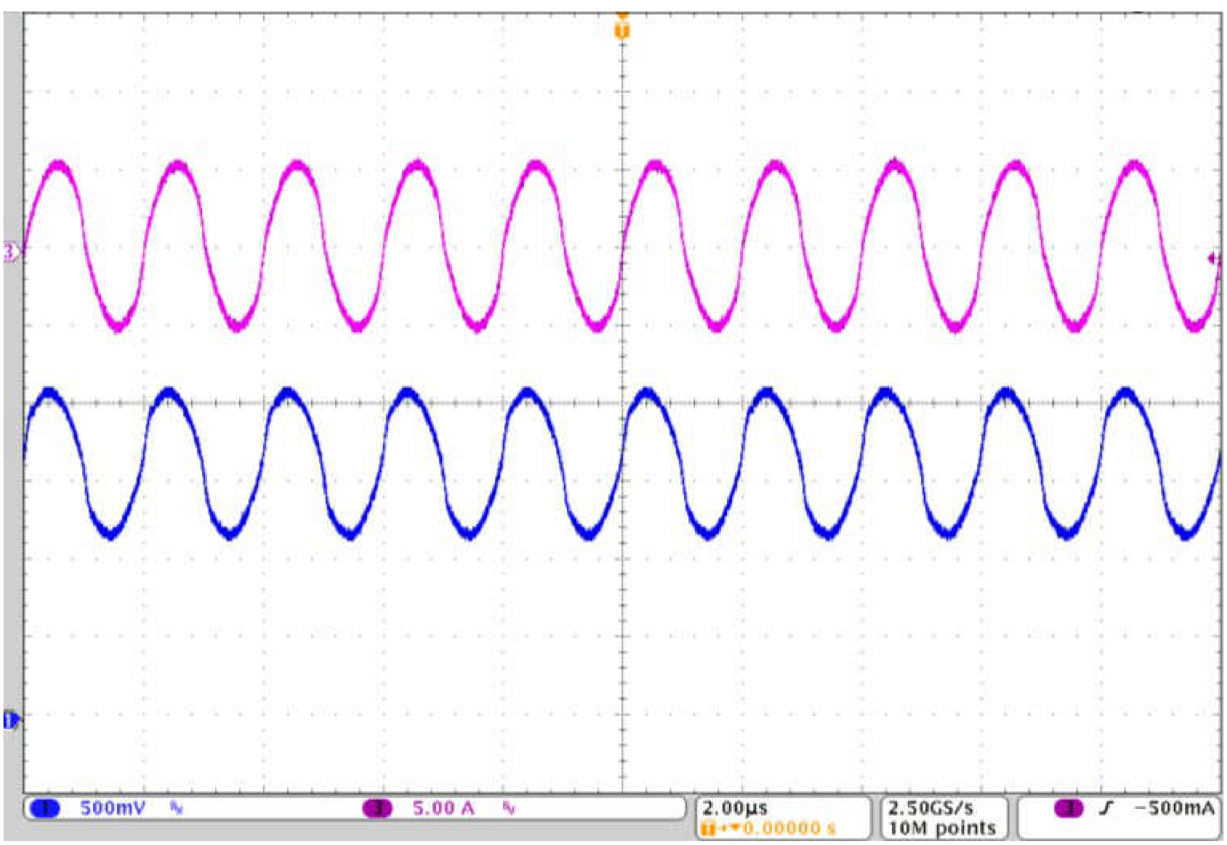


Figure 2-4. CLLLC_IPRIM_TANK Signal at 500kHz

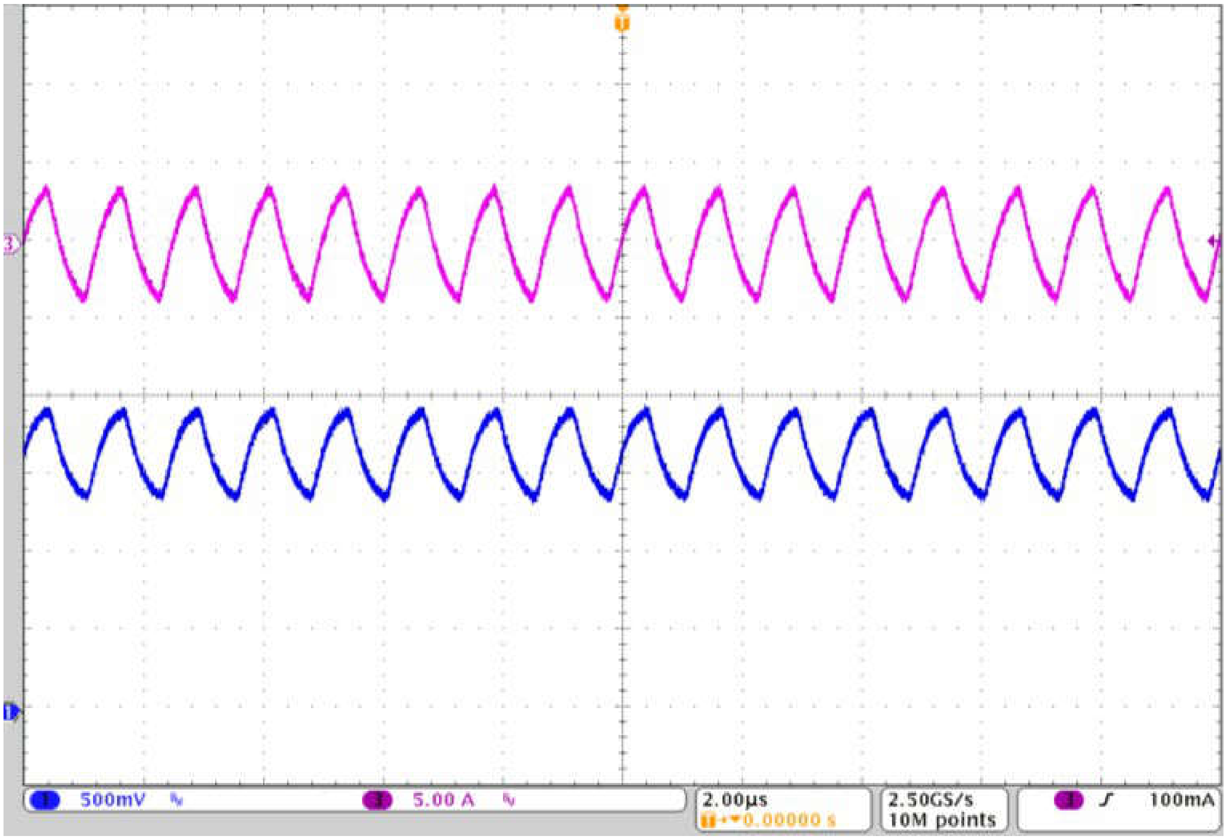


Figure 2-5. CLLLC_IPRIM_TANK Signal at 800kHz

2.4 Bode Plots

Bode plot are shown in Figure 2-6. The test condition is 400V_{in}, 350V_{out}, 11.5A I_{out}, room temperature. As shown in Figure 2-6, the gain margin is -15.79dB. The phase margin is 101.93º with 635Hz bandwidth.

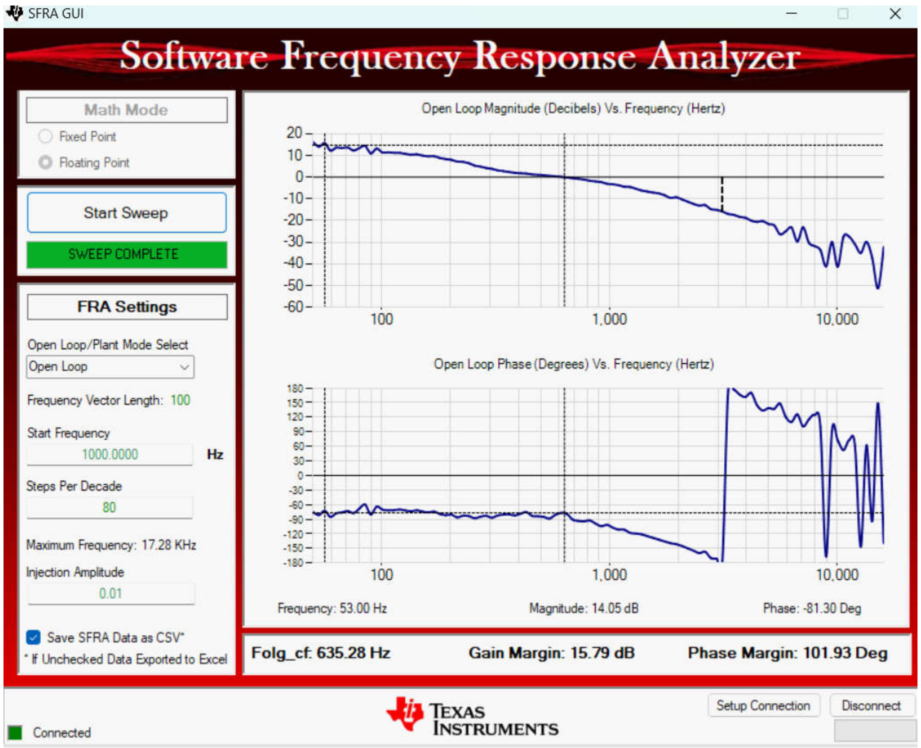


Figure 2-6. Bode Plot

3 Waveforms

3.1 Switching

Figure 3-1 shows CLLLC operation at 11.5A (4kW) under the following parameters:

- Traces
  - CH1: GaN Primary Switch Node Drain Voltage
  - CH2: GaN Secondary Switch Node Drain Voltage
  - CH3: Transformer Primary Current
  - CH4: Transformer Secondary Current
- Conditions
  - – V_{IN} = 400V
  - – V_{OUT} = 350V
  - – I_{OUT} = 11.5A

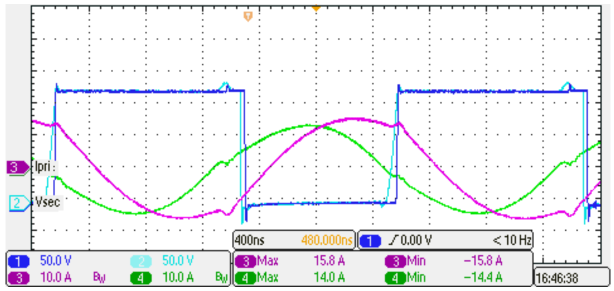


Figure 3-1. CLLLC Operation 11.5A (4kW)

Figure 3-2 shows CLLLC operation at 2A under the following parameters:

- Traces
  - C1: GaN Primary Switch Node Drain Voltage
  - C2: GaN Secondary Switch Node Drain Voltage
  - C3: Transformer Primary Current
  - C4: Transformer Secondary Current
- Conditions
  - V_{IN} = 400V
  - V_{OUT} = 350V
  - I_{OUT} = 2A

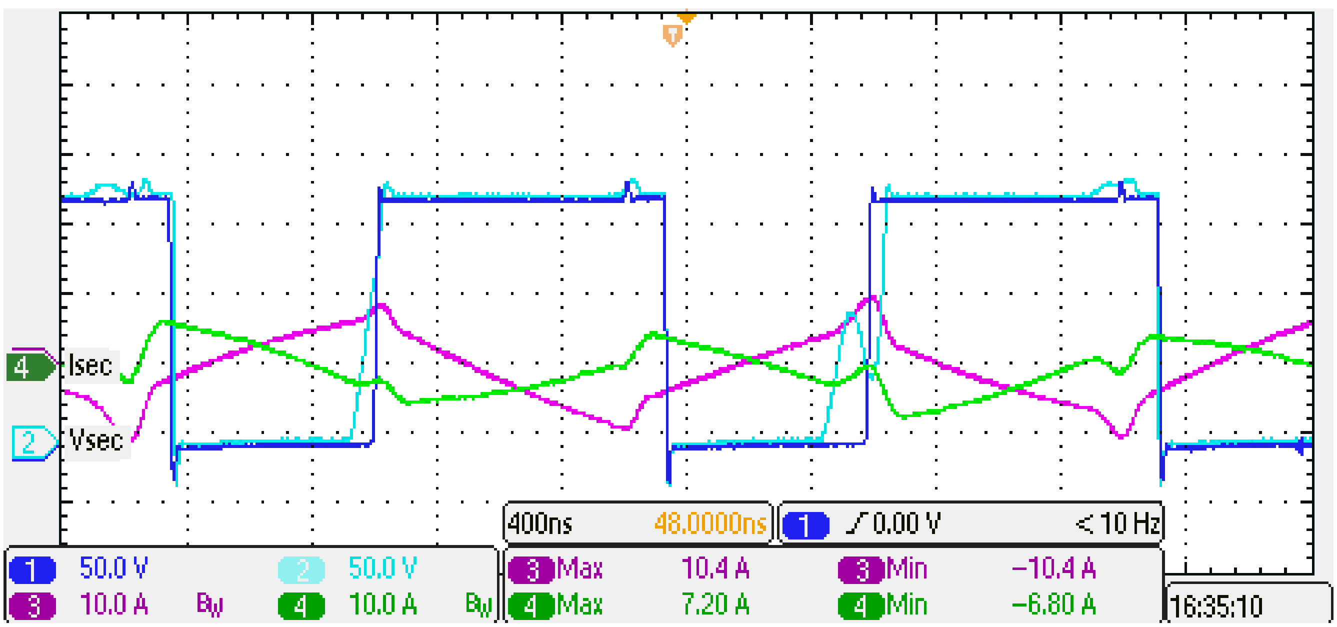


Figure 3-2. CLLLC Operation 2A

Trademarks

All trademarks are the property of their respective owners.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you fully indemnify TI and its representatives against any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale, TI's General Quality Guidelines, or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products. Unless TI explicitly designates a product as custom or customer-specified, TI products are standard, catalog, general purpose devices.

TI objects to and rejects any additional or different terms you may propose.