TP44200SG-LLC240-EVB

240 W LLC Resonant Converter Evaluation Board Using

Tagore Technology's Superior GaN HEMT (TP44200SG)

User Manual

Rev-2.0

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About this document

Objective and Purpose

This application note describes Tagore Technology's 240 W LLC Resonant Converter Evaluation Board (TP44200SG-LLC240-EVB) using its 180 mΩ superior GaN HEMT TP44200SG. The user will be able to perform a complete evaluation of the EVB by following the procedures outlined in this document and all the necessary supporting information (circuit schematics, BOM, layout, key operating waveforms, etc.) is provided to facilitate a quick adaption to a production design.

Intended audience

This application note is intended for Tagore Technology's customers and partners using its 180 mΩ superior GaN HEMT TP44200SG.

Revision History

Document version	Date of release	Description of changes
Rev 1.0	09-Dec-2022	First release
Rev 2.0	30-Aug-2023	Design Rev-2, all sections rearranged and revised

Contents

1 Introduction

The **TP44200SG-LLC240-EVB** is a highly efficient Half-Bridge (HB) LLC resonant converter evaluation board utilizing the advantages of Tagore Technology's Superior GaN HEMT **TP44200SG**. The EVB provides Galvanic isolation to deliver 240 W at 20 V_{dc} output from input dc voltage in the range between 380 V_{dc} to 400 V_{dc}, which is the typical output voltage of PFC ac-dc converters. Tagore Technology's "Enhancement Mode High Electron Mobility GaN Transistors (E-HEMTs) with ESD protection" parts have very low output capacitance (C_{OSS}), gate charge (Q_G) and reverse recovery charge (Q_{rr}) is completely absent. Leveraging these advantages, the resonant converter is designed to switch at high frequency. This resulted in reduced magnetics size, and higher efficiency compared to similar power converters using Si MOSFETs. The peak efficiency obtained is > 97 %, which helps in meeting the stringent requirements of various standards.

Figure 1-1: Photograph of TP44200SG-LLC240-EVB.

Lower loss allows the GaN HEMTs to operate continuously without any external heatsink reducing volume and weight of the EVB. The TP44200SG parts are Surface Mount Devices (SMDs) which come in small QFN 5 mm X 7 mm package. This enables the layout design to be compact, improves EMI due to lower voltage oscillations during switching and makes the assembly process cheaper. Thus, the LLC EVB has a small form factor increasing the power density. This is a compact, cost-effective LLC solution dedicated to SMPS applications such as EV battery chargers, data center servers, laptop adapters, and industrial power supply. For a full system testing, this EVB can be used in conjunction with the 240W Totem-Pole PFC converter Eval board: TP44100SG-TPPFC240-EVB.

1.1 Working Principle

The functional block diagram of the EVB shown in Figure 1-2. The Half-Bridge is realized using Tagore Technology's superior GaN HEMT TP44200SG. It is followed by a resonant tank consisting of a resonant inductor (L_r), the LLC transformer with magnetizing inductance (L_m), and a resonant capacitor (C_r), connected in series. The GaN HEMT-based HB LLC resonant dc-dc converter is controlled by Onsemi's

NCP13992 IC. The GaN FET TP44200SG has very low output capacitance C_{OSS}. As a result, a very small transformer magnetizing current (I_m) is needed to achieve zero-voltage-switching for the switching devices. Thus, the switching loss is reduced, improving the efficiency of the LLC converter. The secondary of the transformer has a center tap arrangement. The transformer output voltage is rectified using two Synchronous Rectifier (SR) MOSFETs to further enhance the power conversion efficiency. The SR controller IC MP6924GS drives both the SR FETs.

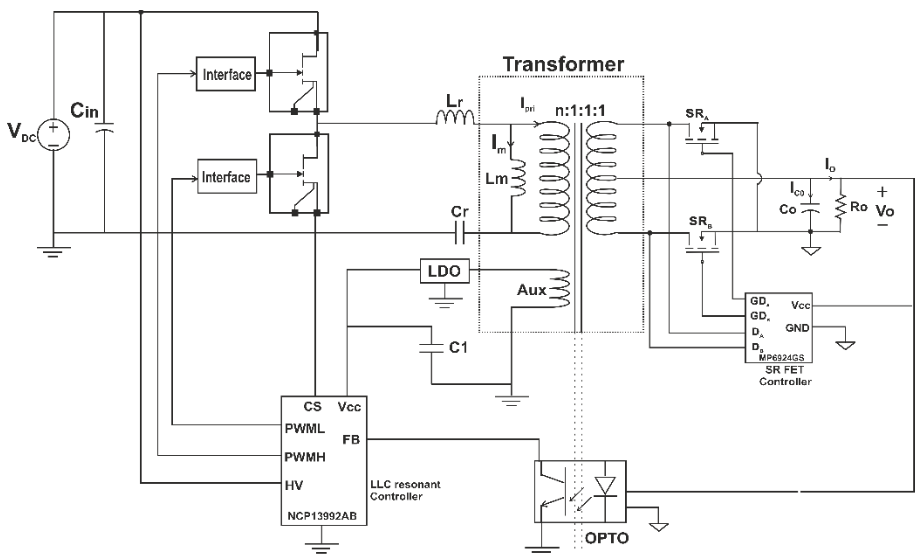


Figure 1-2: Functional block diagram of EVB.

The initial bias supply for the LLC controller IC is developed through the HV pin of the controller by charging bias supply capacitor C1 as shown in Figure 1-2. Once the voltage across the bias supply capacitor C1 reaches UVLO threshold, and the dc bus voltage reaches the brown-out threshold, the controller releases the Low-Side (LS) PWM pulses for a finite period. This allows the bootstrap voltage for the High-Side (HS) driver to be developed. Once the HS supply exceeds the UVLO threshold of the HS driver, the HS PWM pulses are released. The controller initiates the start-up sequence, the transformer aux winding gets power, and strengthens the controller bias supply. At this point, the initial bias supply through the HV pin cuts off. The output voltage feedback is taken to the controller IC through an optocoupler for achieving galvanic isolation between input and output sides of the EVB. The LLC controller IC releases PWM of 0 − 12 V, while GaN HEMTs needs 0 – 6 V. So, a level-down-shifter/interface circuit is used between gate terminal of GaN HEMT and controller PWM output. The interface circuit is shown in Figure 1-3. For further details, please refer to the datasheet of TP44200SG.

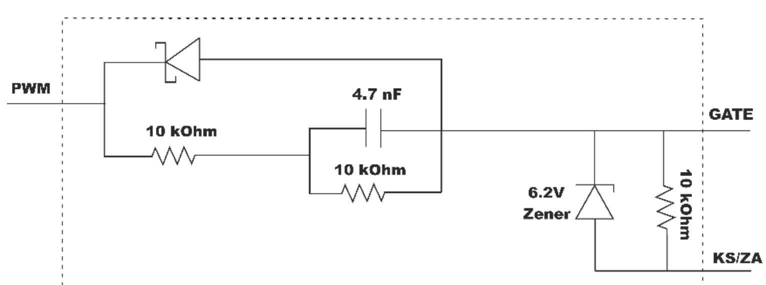
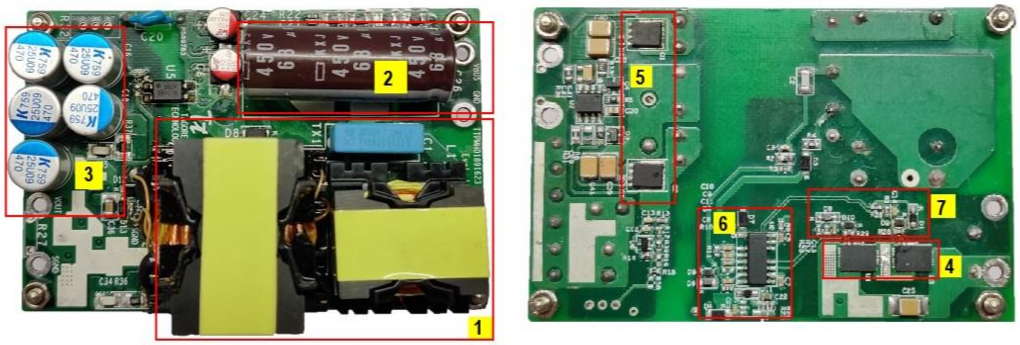


Figure 1-3: Interface Circuit

2 Physical Details and Specifications Of EVB

Photographs of both the top and the bottom sides of the LLC EVB are shown in **Error! Reference source not found.**, with key components identified.



1	Resonant Tank
2	Input Filter Capacitor
3	Output Filter Capacitors
4	GaN Devices
5	SR MOSFETs
6	Controller
7	Si MOSFETs & Drive Ckt.
8	Gate Interface Circuits

Top Side Bottom Side

Figure 2-1: Top (Left) and Bottom (Right) views of the EVB with key circuit blocks identified.

2.1 Dimension Measurements

Table 2-1 : Mechanical Dimensions

Mechanical Dimensions	Value	Unit
Length of EVB PCB	93.62	mm
Width of EVB PCB	61.29	mm
Thickness of EVB PCB	1.6	mm
Height of tallest component on Top Side	37	mm
Height of tallest component on Bottom Side	3.8	mm
Gross Volume of EVB PCB	243.29	cc

2.2 Technical Data

Table 2-2 : Key Technical Specifications

PARAMETER	TEST CONDITIONS	MIN	NOM	MAX	UNIT
Input Voltage		380	390	400	V_{dc}
Output voltage		19.5	20	20.5	V_{dc}
Output current				12	A
Output voltage ripple	Peak -to- Peak	300	350	400	mV
Output power			240		W
Efficiency	V_{dc} = 400V, full load.		96.78		%
Switching frequency	V_{dc} = 400V, full load.	220	250	260	kHz

3 Operating Procedure

3.1 List Of Instruments and Hardware Items Required

For testing the Eval Board, following list of instruments and hardware items are required:

- TP44200SG-LLC240-EVB
- dc Power Source: 380 V_{dc} to 400 V_{dc}, 1 A (min.)
- Load: Electronic Load or Rheostat (20 V_{dc} (min.), 240 W)
- Observation Instruments:
  - Power Meter: 400 V_{dc} min., 1 A min, 250 W
  - Digital Multimeters for measuring voltages and currents (400 V_{dc}, 12 A)
  - Digital Storage Oscilloscope (DSO) (Preferably with 4 Channels, BW ≥ 300 MHz)
  - High Voltage Probe (min. 500 V) compatible with the DSO
  - Current Clamp Probes (min. 15 A) compatible with the DSO
- Wires and cables for making electrical connections.

3.2 Operating Procedure Steps

- Ensure that the dc Power Source is turned off and output voltage of the EVB is zero. Then connect the input power terminals of the EVB to the output terminals of the dc power source in appropriate polarity. (Optional: Connect a power meter in between the EVB input and dc power supply).
- Set electronic load value to 0 A in constant current mode and ensure loading is disabled. Connect the output terminals of the EVB to the electronic load in correct polarity.
- Connect voltage, current probes from DSO to the desired observation points.
- Set the output of the dc power source to 0 V and then switch it on. Gradually increase the dc output to 390 V_{dc}. Observe that the EVB output voltage will rise to 20 V_{dc} and maintain the same value indicating that the EVB startup is complete.
- Enable the electronic load and then gradually increase the loading to the desired value not exceeding the maximum output power rating of the EVB.

4 Experimental Results

4.1 Efficiency

Efficiency measurement test is done by measuring the input power using a digital power meter, while the output voltage and currents were measured by digital multimeter and the electronic load respectively. Measured efficiency of the EVB at 400 V_{dc} input voltage for different output load currents is shown in Figure 4-1.

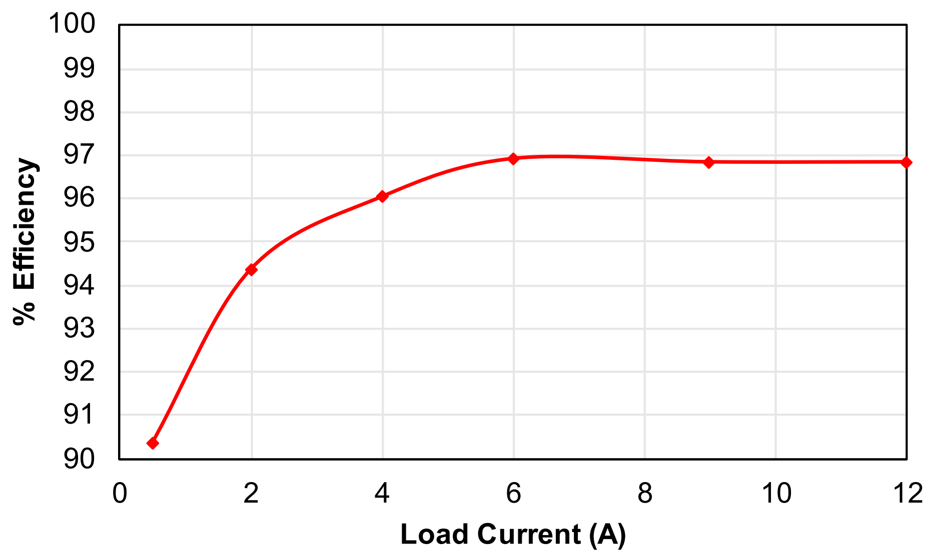


Figure 4-1: Efficiency vs Output current plot at 400 V_{dc} input voltage.

4.2 Load Regulation

The load regulation is within 20.2 V ~ 20.1 V in the complete load range and 400 V_{dc} input voltage.

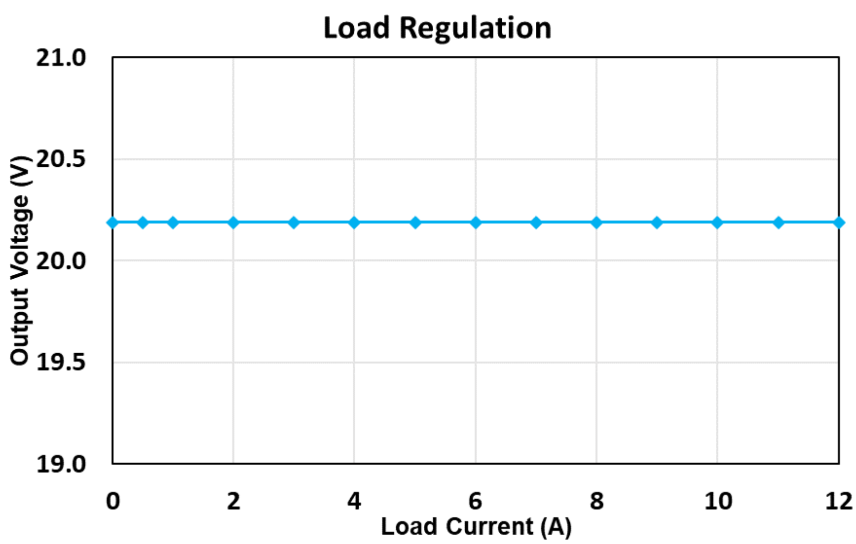


Figure 4-2: Load Regulation vs Output current plot at 400 V_{dc} input voltage.

4.3 Electrical Waveforms

Typical switching waveforms of the Half bridge stage in the LLC resonant converter at full load and 400 V_{dc} input voltage is shown in Figure 4-3.

Figure 4-3: Channel 1(Blue): HB switching node (200 V/div); Channel 2(Red): Gate voltage of the Low side GaN device (5 V/div); Channel 3(Green): Load current (10 A/div); time: 1 µs/div.

The EVB works in burst mode at no load or very light load. Typical switching waveforms of the Half bridge stage in the LLC resonant converter at no load and 400 V_{dc} input voltage is shown in Figure 4-4.

Figure 4-4: Channel 1(Blue): HB switching node (100 V/div); Channel 2(Red): Gate voltage of the Low side GaN device (5 V/div); Channel 3(Green): Load current (1 A/div); Channel 4(Orange): Output Voltage (5 V/div); time: 50 ms/div.

Output voltage transient waveforms during step changes in Load (0 to 200 W and vice-versa) is shown in Figure 4-5.

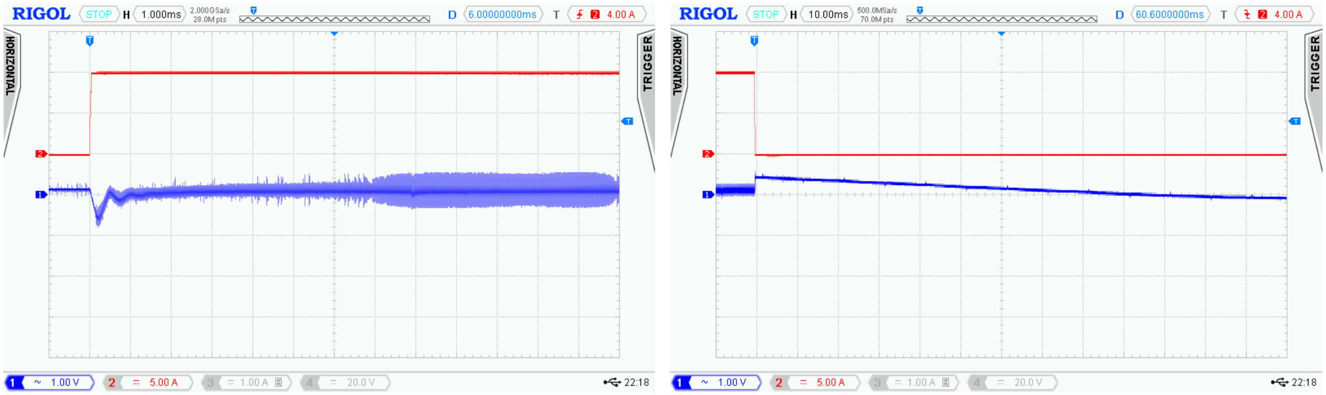


Figure 4-5:Output voltage transients (1 V/div.) due to step change in Load. (Left) 0 to 200 W; (Right) 200 W to 0W.

Waveforms of Switch node voltage of the Half-Bridge LLC stage along with input voltage and current, and output voltage during startup at no load is shown in Figure 4-6.

Figure 4-6: Startup waveforms using front end PFC. Channel 1(Blue): Input voltage (200 V/div); Channel 2(Red): Input Current (1 A/div); Channel 3(Green): LLC HB switch node voltage (200 V/div); Channel 4(Orange): Output voltage (20 V/div); time: 50 ms/div.

5 PCB Layout

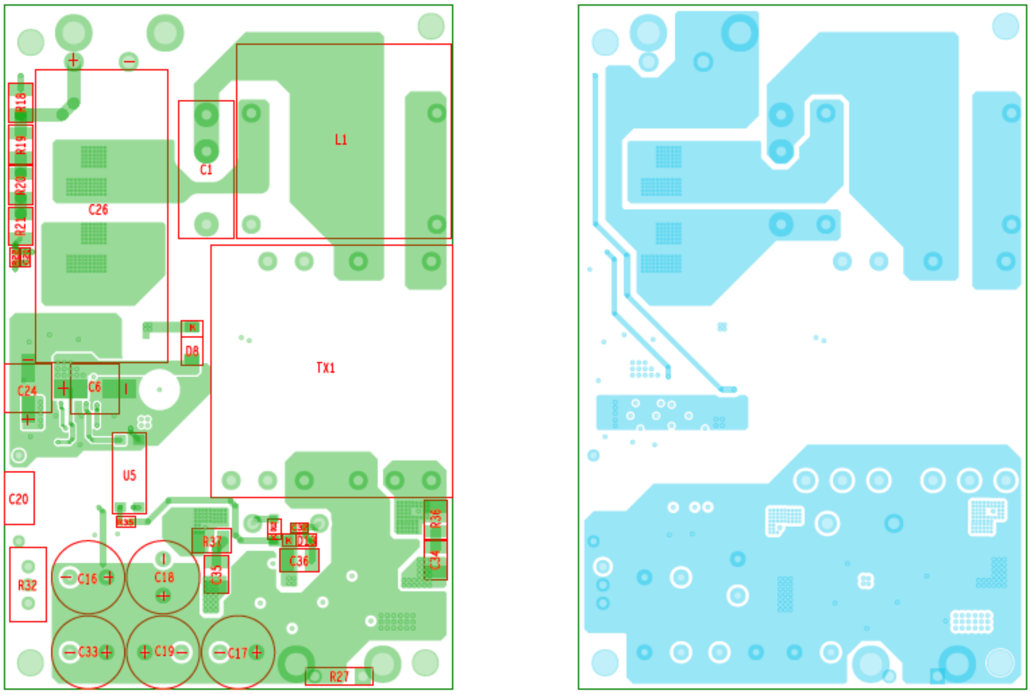


Figure 5-1: Top Layer (Left), Mid Layer 1 (Right).

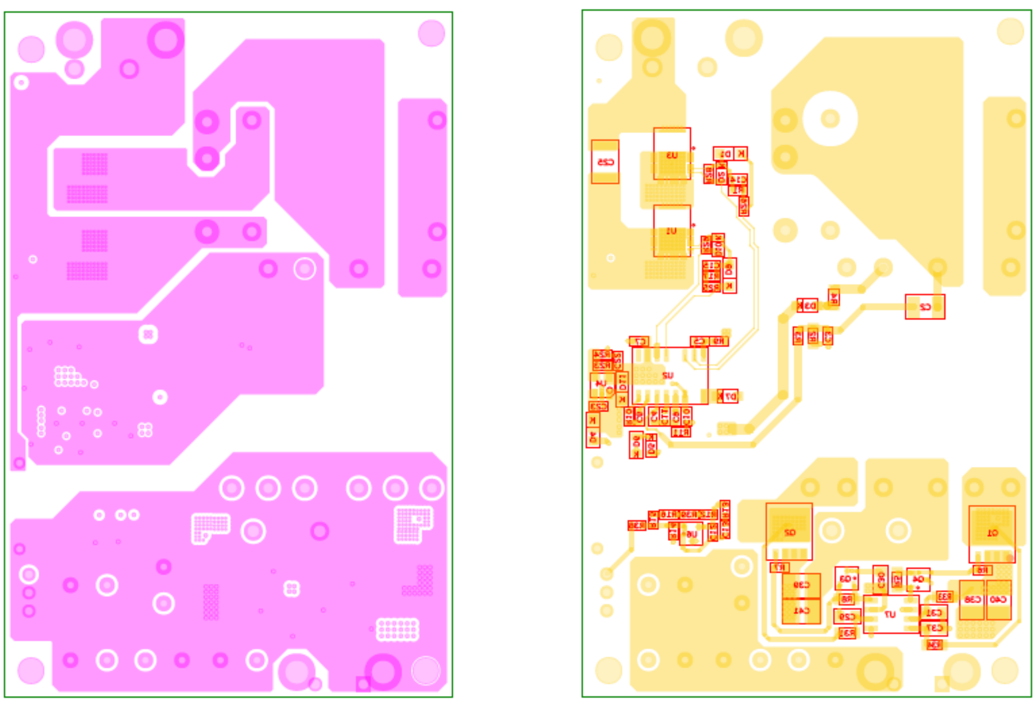


Figure 5-2: Mid Layer 2 (Left), Bottom Layer (Right).

6 Bill Of Materials

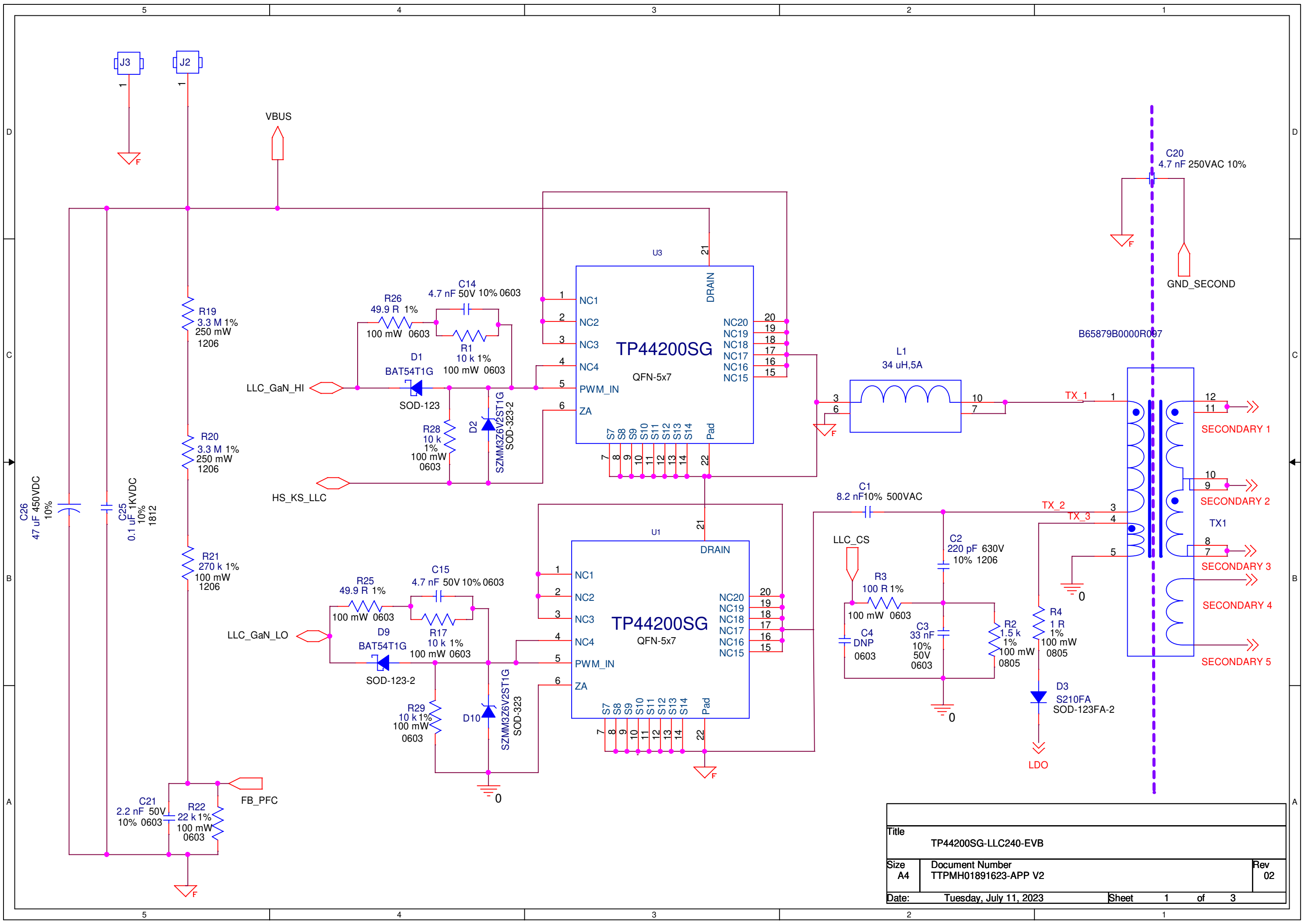
Table 6-1: Bill of Materials (BOM)

240 W CHARGER LLC BOM								
Sl #	**Qty**	**Reference**	**Description**	**Value**	**Rating**	**Package**	**Part Number**	**Manufacturer**
1	1	C1	Film Capacitor, 10%	8.2 nF	500 V	15 mm Pitch	B32671L0822J000	EPCOS / TDK
2	1	C2	MLCC, C0G, 10%	220 pF	630 V	1206	Standard Part	
3	1	C3	MLCC, X7R, 10%	33 nF	50 V	0603	Standard Part	
4	1	C4		DNP		0603		
5	2	C5, C7	MLCC, X5R, 10%	1 µF	50 V	0603	Standard Part	
6	2	C6, C24	MLCC, X7R, 20%	47 µF	35 V		865080543009	Wurth Elektronik
7	2	C8, C9	MLCC, X7R, 20%	10 nF	50 V	0603	Standard Part	
8	1	C10	MLCC, X7R, 10%	100 nF	50 V	0603	Standard Part	
9	4	C11, C12, C14, C15	MLCC, X7R, 10%	4.7 nF	50 V	0603	Standard Part	
10	1	C13	MLCC, X7R, 10%	47 nF	50 V	0603	Standard Part	
11	5	C16, C17, C18, C19, C33	Polymer Capacitor	470 µF	25 V	TH	A759MS477M1EAAE20	Kemet
12	1	C20	Ceramic Cap., 10%	4.7 nF	250 V	TH	DE2B3SA681KN3AT02F	Murata Electronics
13	1	C21	MLCC, C0G, 5%	2.2 nF	50 V	0603	Standard Part	
14	1	C22	MLCC, X5R, 10%	6.8 µF	25 V	0603	Standard Part	
15	2	C23, C32	MLCC, X7R, 10%	0.1 µF	50 V	0603	Standard Part	
16	1	C25	MLCC, X7R, 10%	0.1 µF	1 kV	1812	Standard Part	
17	1	C26	Electrolytic Capacitor	47 µF	450 V	TH	EKXJ451ELL470ML25S	United Chemi-Con
18	2	C29, C37		DNP		0805		
19	1	C30	MLCC, X7R, 20%	1 µF	50 V	0805	Standard Part	
20	1	C31	MLCC, C0G, 5%	1 nF	50 V	0805	Standard Part	
21	2	C34, C35	MLCC, X7R, 10%	47 pF	630 V	1206	Standard Part	
22	1	C36	MLCC, X5R, 20%	10 µF	50 V	1206	Standard Part	
23	4	C38, C39, C40, C41	MLCC, X7R, 5%	0.1 µF	100 V	0805	Standard Part	
24	3	D1, D9, D11	Schottky Diode	30 V	400 mW	SOD-123	BAT54T1G	Onsemi
25	2	D2, D10	Zener Diode	6.2 V	300 mW	SOD-323-2	SZMM3Z6V2ST1G	Onsemi
26	2	D3, D12	Schottky Diode	100 V	2 A	SOD-123FA	S210FA	Onsemi
27	1	D4	Zener Diode	36 V	200 mW	SOD-123-2	Standard Part	
28	1	D5	Zener Diode	4.3 V	300 mW	SOD-323	Standard Part	
29	1	D6	Zener Diode	15 V	400 mW	SOD-323F-2	D3Z15BF-7	Diode Inc.
30	1	D7	Diode	1000 V	1 A	SOD-123FA	US1MFA	Onsemi
31	1	D8	Diode	600 V	1 A	DO-214-2	ES1JAF	Onsemi
32	1	D13	Zener Diode	24 V	500 mW	SOD-123-2	BZT52C24-TP	Micro Commercial Co.
33	1	L1	Inductor	34 µH	5A		Custom	Tagore Technology
34	2	Q1, Q2	N-Channel MOSFET		150 V	TDSON-8	FDMS8D8N15C	Onsemi
35	2	Q3, Q4	PNP Transistor		20 V	SOT-23-3	NSS20200LT1G	Onsemi
36	6	R1, R10, R11, R17, R28, R29	Resistor, 1%	10 kΩ	100 mW	0603	Standard Part	
37	1	R2	Resistor, 1%	1.5 kΩ	100 mW	0805	Standard Part	
38	1	R3	Resistor, 1%	100 Ω	100 mW	0603	Standard Part	
39	1	R4	Resistor, 1%	1 Ω	100 mW	0805	Standard Part	
40	2	R5, R8	Resistor, 1%	3.9 Ω	100 mW	0805	Standard Part	
41	2	R6, R7	Resistor, 1%	20 kΩ	100 mW	0603	Standard Part	
42	1	R9	Resistor, 1%	2.7 Ω	100 mW	0603	Standard Part	
43	1	R12	Resistor, 1%	1 kΩ	100 mW	0603	Standard Part	
44	1	R13	Resistor, 1%	5.6 kΩ	100 mW	0603	Standard Part	
45	1	R14	Resistor, 1%	2.4 kΩ/ 2.3 kΩ	100 mW	0603	Standard Part	

240 W CHARGER LLC BOM								
Sl #	Qty	Reference	Description	Value	Rating	Package	Part Number	Manufacturer
46	1	R15	Resistor, 1%	300 Ω	100 mW	0603	Standard Part	
47	1	R16	Resistor, 1%	16 kΩ	100 mW	0603	Standard Part	
48	1	R18	Resistor, 1%	2.7 kΩ	250 mW	1206	Standard Part	
49	2	R19, R20	Resistor, 1%	3.3 MΩ	250 mW	1206	Standard Part	
50	1	R21	Resistor, 1%	270 kΩ	250 mW	1206	Standard Part	
51	1	R22	Resistor, 1%	22 kΩ	100 mW	0603	Standard Part	
52	1	R23	Resistor, 1%	90.9 kΩ	100 mW	0603	Standard Part	
53	1	R24	Resistor, 1%	9.1 kΩ	100 mW	0603	Standard Part	
54	2	R25, R26	Resistor, 1%	49.9 Ω	100 mW	0603	Standard Part	
55	1	R27		DNP		TH		
56	1	R39	Resistor, 1%	1.5 kΩ	100 mW	0603	Standard Part	
57	2	R31, R34	Resistor, 1%	1 kΩ	100 mW	0805	Standard Part	
58	1	R32	POT			TH		
59	1	R33	Resistor, 1%	27 kΩ	100 mW	0805	Standard Part	
60	2	R35, R38		DNP		0603		
61	2	R36, R37	Resistor, 1%	22 Ω	250 mW	1206	Standard Part	
62	1	TX1	Transformer			PQ-32-30	Custom	Tagore Technology
63	2	U1, U3	GaN HEMT, 180 mΩ		650 V	QFN-5x7	TP44200SG	Tagore Technology
64	1	U2	LLC Controller			SOIC-16	NCP13992ABDR2G	Onsemi
65	1	U4	Adj. Voltage Regulator		200 mA	SOT-23-5	AP2205-W5-7	Diode Inc.
66	1	U5	Optocoupler			SMD-4	FOD817CSD	Onsemi
67	1	U6	Voltage Regulator	36 V		SOT-23	LM431SBCM32X	Onsemi
68	1	U7	SRFET Controller			SOIC-8	MP6924GS	Monolithic Power Systems
69	1	PCB					TTPMH01891623	Tagore Technology

7 Schematic Diagram

The electrical schematic diagram of the EVB is provided in this section.



J3
J2
VBUS
C20
4.7 nF 250VAC 10%
GND_SECOND
U3
TP44200SG
QFN-5x7
DRAIN
NC1
NC2
NC3
NC4
PWM_IN
ZA
NC20
NC19
NC18
NC17
NC16
NC15
S7 S8 S9 S10 S11 S12 S13 S14 Pad
R26
49.9 R 1%
100 mW 0603
C14
4.7 nF 50V 10% 0603
R1
10 k 1%
100 mW 0603
D1
BAT54T1G
SOD-123
LLC_GaN_HI
R28
10 k
1%
100 mW
0603
D2
SZMM3Z6V2ST1G
SOD-323-2
HS_KS_LLC
R19
3.3 M 1%
250 mW
1206
R20
3.3 M 1%
250 mW
1206
R21
270 k 1%
100 mW
1206
C26
47 uF 450VDC
10%
C25
0.1 uF 1KVDC
10%
1812
L1
34 uH,5A
B65879B0000R097
TX_1
TX_2
TX_3
TX1
SECONDARY 1
SECONDARY 2
SECONDARY 3
SECONDARY 4
SECONDARY 5
C1
8.2 nF10% 500VAC
LLC_CS
R3
100 R 1%
100 mW 0603
C2
220 pF 630V
10% 1206
C4
DNP
0603
C3
33 nF
10%
50V
0603
R2
1.5 k
1%
100 mW
0805
R4
1 R
1%
100 mW
0805
D3
S210FA
SOD-123FA-2
LDO
U1
TP44200SG
QFN-5x7
R25
49.9 R 1%
100 mW 0603
C15
4.7 nF 50V 10% 0603
R17
10 k 1%
100 mW 0603
D9
BAT54T1G
SOD-123-2
LLC_GaN_LO
R29
10 k 1%
100 mW
0603
D10
SZMM3Z6V2ST1G
SOD-323
C21
2.2 nF 50V
10% 0603
R22
22 k 1%
100 mW
0603
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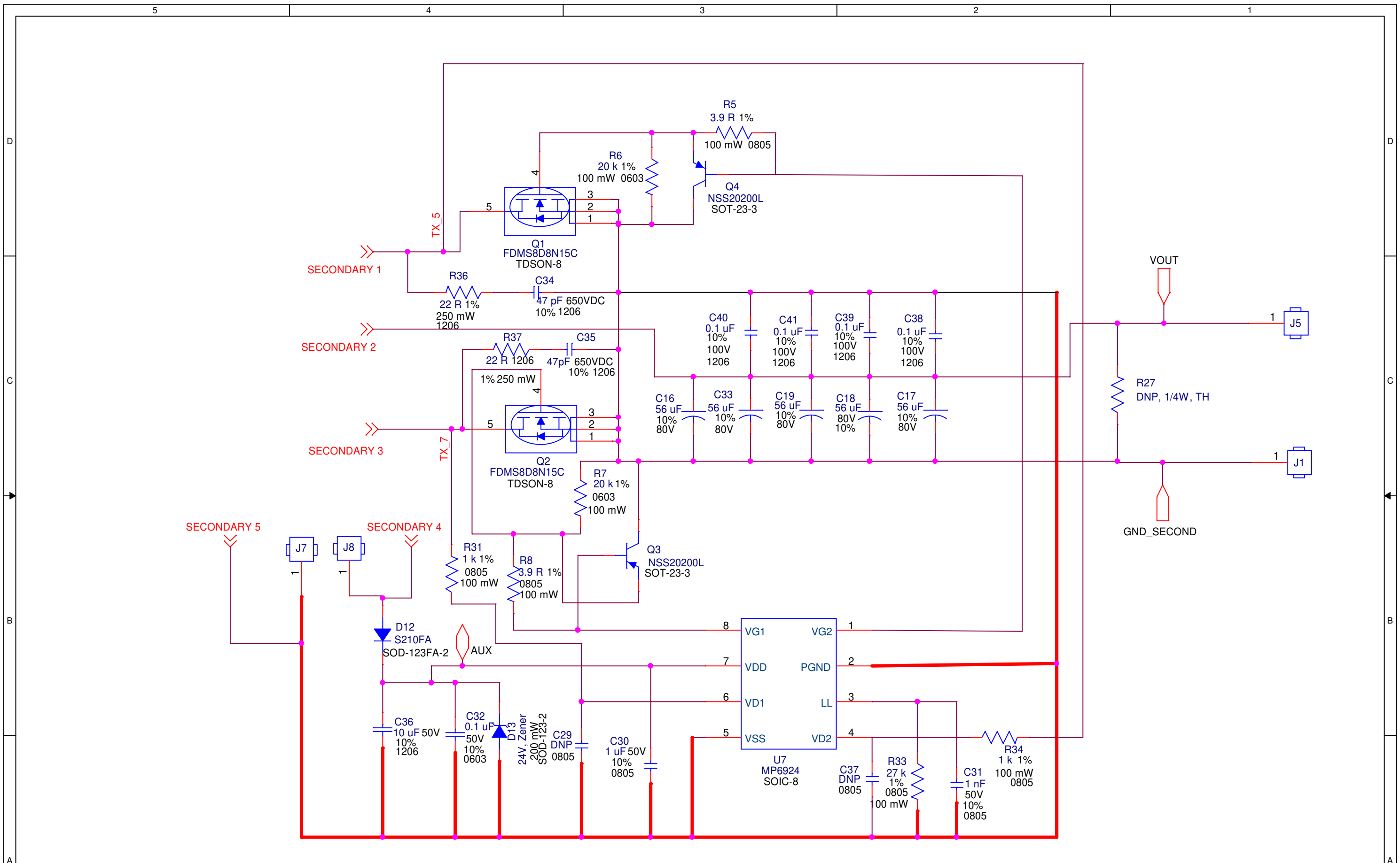

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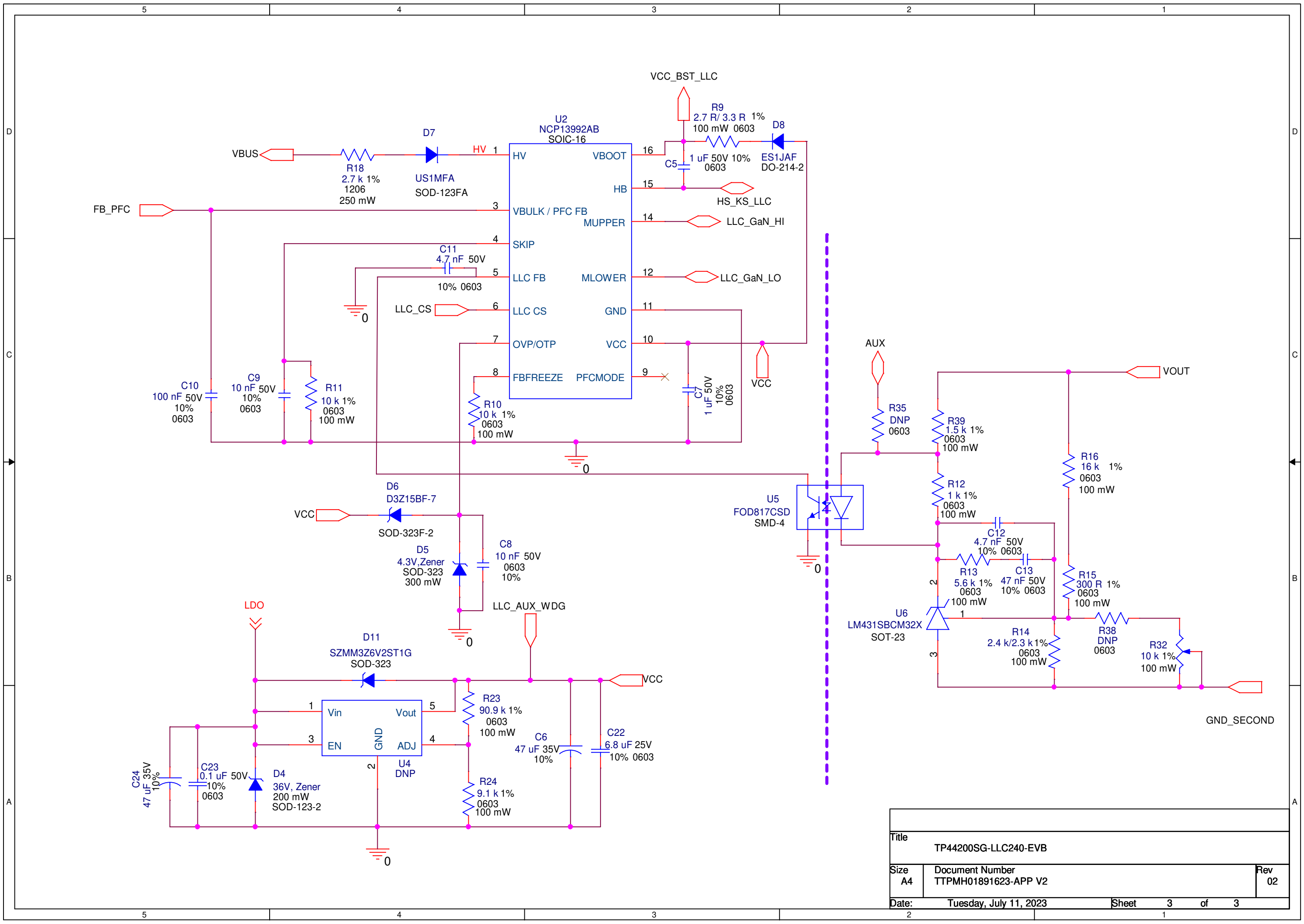

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