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# 3kW High-Efficiency CCM Bridgeless Totem Pole PFC Reference Design using GaN E-HEMTs

Reference Design  
Technical Manual



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## 1. Introduction

This application note highlights the motivation, operating principle, and design considerations of Bridgeless Totem Pole PFC (BTPPFC) using GaN Enhancement-mode HEMTs (E-HEMTs). The design of a 3kW BTPPFC example using GaN Systems' 650V GaN E-HEMTs is presented in detail.

## 2. Why a GaN-based bridgeless PFC?

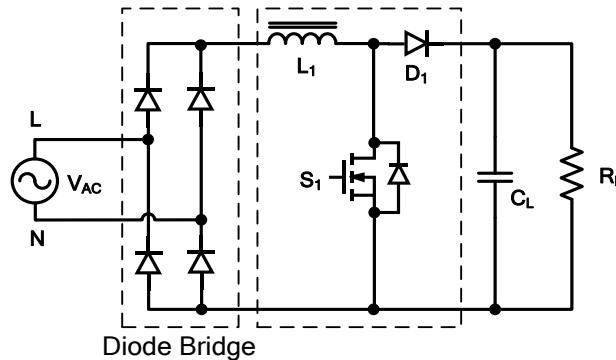


Figure 1. Conventional boost PFC circuit

A conventional PFC circuit is shown in Figure 1. It consists of a full bridge rectifier and a boost pre-regulator. The boost stage can be Continuous Conduction Mode (CCM) or Discontinuous Conduction Mode/Critical Conduction Mode (DCM/CrCM) with zero/valley voltage switching for improved efficiency.

However, a large portion of system loss is in the diode bridge and can not be avoided even with zero voltage switching on the Boost stage. This inherently limits the peak efficiency of the conventional PFC circuit. A rectifier diode has a typical 1V forward voltage drop, and there are two diodes in the current path, which could account for 2% of total efficiency loss. A well-designed PFC stage can achieve an efficiency of approximately 97 to 98%, but an efficiency higher than 98% becomes very challenging for standard PFC due to the fixed diode bridge loss.

For example, the 80PLUS Titanium efficiency standard demands a half-load efficiency of 94% at low line and 96% at high line. Considering the typical DC/DC stage efficiency is about 97.5%, to meet the 80PLUS Titanium standard, the PFC stage efficiency needs to be >98.5% [1].

In a bridgeless PFC, the diode losses can be eliminated, allowing for efficiencies of 99% or higher to meet the highest efficiency standards. Various bridgeless PFC topologies have been proposed to overcome the high diode bridge losses [2]. Among all the bridgeless PFC topologies, the popular 2-phase bridgeless PFC and BTPPFC will be illustrated and compared.

## 2.1. 2 Phase Bridgeless PFC

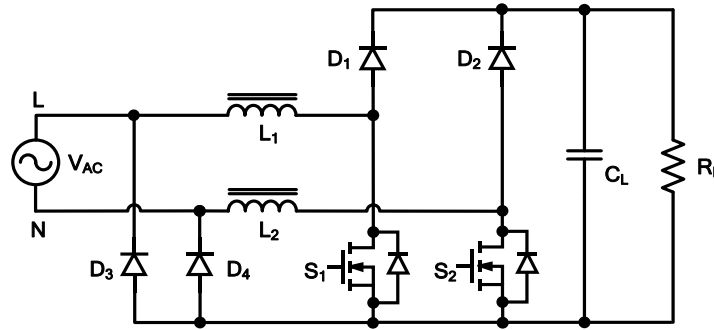


Figure 2. Two-phase bridgeless PFC

The topology of the 2-phase bridgeless PFC is shown in Figure 2. This topology is essentially two boost legs, with each one taking control during each half of the AC cycle.  $S_1/S_2$  are typically super junction MOSFETs, and  $D_1/D_2$  can be diodes or for higher efficiency, SiC diodes. It has, in the past years, been the popular bridgeless PFC topology on the market, because it is easy to implement using conventional Si MOSFETs with control similar to a standard PFC circuit, and efficiency is improved as it eliminates one diode from the current path. However, it comes with the following drawbacks:

- **Low power density and component utilization:** The part count is doubled, and each boost stage only works during a one-half cycle, which reduces the power density and adds to the BOM cost.
- **Additional return diodes:** for EMI purposes, diodes  $D_3/D_4$  are needed to provide a current return path and reference DC-link ground to  $N$  to reduce the common-mode noise [2].
- **$D_1/D_2$  needs to be fast SiC diodes:** These SiC diodes have a higher  $V_F$  (conduction loss) and relatively higher cost than AC rectifier diodes.
- **Complicated current sensing circuit:**  $S_1/S_2$  body diodes and  $D_3/D_4$  share the return current.
- **No bidirectional capability:** This PFC topology cannot be utilized in applications that require bidirectional power flow between AC and DC ends. Due to the aforementioned high reverse recovery loss  $D_1/D_2$ , can not be replaced by MOSFETs.

## 2.2. Bridgeless Totem Pole PFC

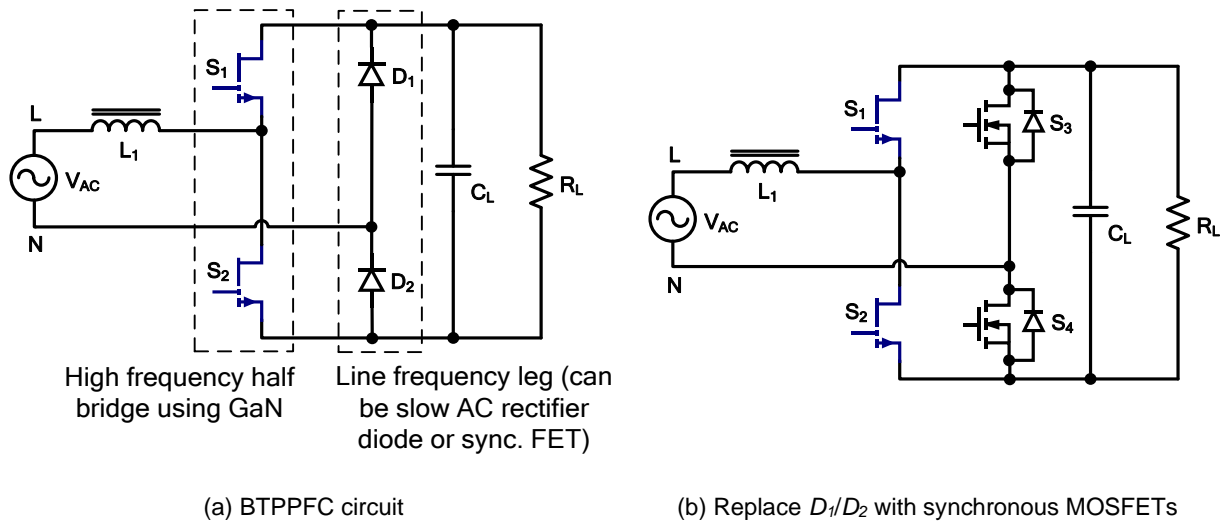


Figure 3. A BTPPFC circuit using GaN E-HEMTs

Figure shows the topologies of a BTPPFC. It can be considered a conventional boost PFC in which one half of the diode bridge is replaced by active switches  $S_1$  and  $S_2$  in a half-bridge configuration, hence the name “totem pole”. The diode  $D_1/D_2$  forms the slow 50/60Hz line frequency leg, which can either be slow AC rectifier diodes or can be replaced by low- $R_{ds(on)}$  synchronous MOSFETs for improved efficiency, as shown in Figure 3.(b).

The BTPPFC overcomes many issues which existed in the previous two-phase bridgeless PFC, and has the following advantages:

- **Improved efficiency:** The main current only flows through two switches at a time.  $S_1/S_2$  are driven synchronously with complementary PWM signals, and the  $S_3/S_4$  on the slow line frequency legs can be low  $R_{ds(on)}$  Si MOSFETs to further reduce the conduction loss.
- **Lower part counts, higher power density, and lower BOM cost.** It is a simpler circuit that uses fewer parts: It needs only one inductor, and neither SiC diodes nor AC return diodes are required.
- **Bidirectional power flow.** The BTPPFC is inherently capable of bidirectional operation. It is ideal for applications that require power flow in both directions, e.g., Energy Storage System (ESS) and onboard bidirectional battery chargers (OBBC).

### 2.3. Zero $Q_{rr}$ GaN for CCM BTPPFC

The BTPPFC has been proposed before, but its application has been minimal until recently. The major challenge is the poor reverse recovery performance of conventional silicon MOSFETs in the half-bridge configuration. It makes CCM operation impractical due to the excess  $Q_{rr}$  loss at turn-on. To avoid body diode conduction, BTPPFC with silicon MOSFETs must work in CrCM/DCM modes, which is only suitable for lower power and has more complicated control. Usually, a multi-phase interleaved configuration is used to achieve a higher power level and increases the current ripple, which again adds cost and complexity.

The absence of a body diode (zero  $Q_{rr}$ ) and the fast switching speed of GaN make GaN E-HEMTs an ideal fit for CCM hard switching half-bridge power stage. As can be seen in Figure (a)  $Q_{rr}$  measured using standard test methods include both  $Q_{rr}$  of the high side body diode and  $Q_{oss}$  of the MOSFET, though  $Q_{rr}$  usually dominates for Si MOSFETs. By contrast, GaN E-HEMTs exhibit significantly lower hard turn-on loss as there is only  $Q_{oss}$  loss - the loss induced at hard switching device during turn-on due to the output capacitance charging current of the free-wheeling switch.

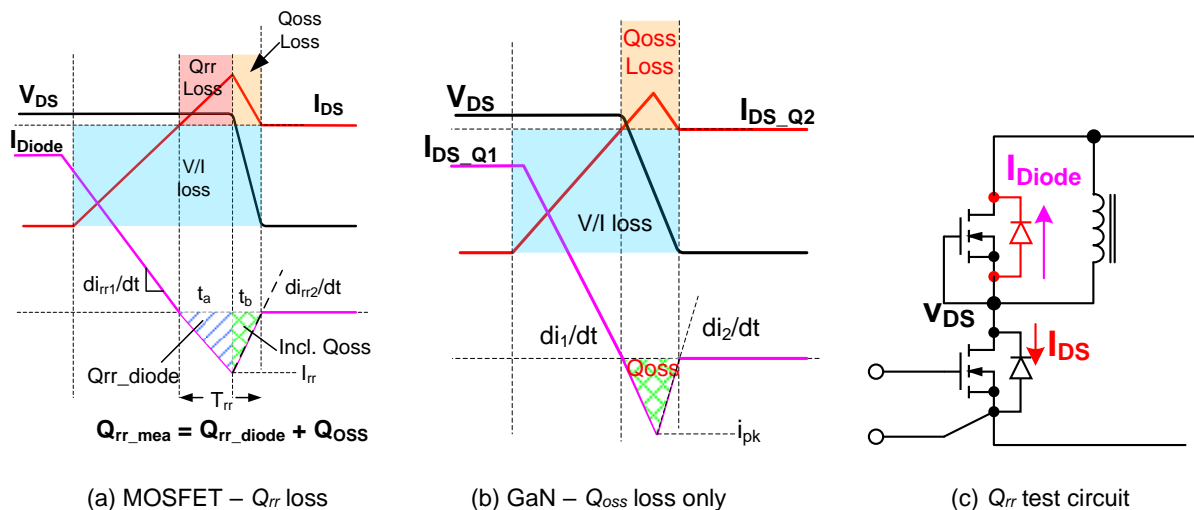


Figure 4. Hard turn-on loss breakdown (MOSFET vs. GaN)

Table compares the switch-on loss caused by  $Q_{rr}$  (or  $Q_{oss}$  for GaN) between a silicon MOSFET and a GaN E-HEMT from GaN Systems. GaN has zero  $Q_{rr}$ , and its output capacitance charge can be more than an order of magnitude smaller than 650 V silicon MOSFETs. Even compared to CoolMOS CFD with an ultra-fast body diode, GaN shows a much superior reverse recovery performance. Assuming a CCM BTPPFC operating at 65 kHz, GaN dissipates 2.5 W switching loss due to the  $Q_{oss}$  loss at turn-on, while a similar CoolMOS CFD7 has about 68.7 W at switch-on because of the  $Q_{rr}$  alone! This excellent hard switching performance makes GaN HEMT the perfect candidate for CCM BTPPFC design.

Table 1.  $Q_{rr}/Q_{oss}$  Loss Comparison (650 V GaN HEMT vs Si CoolMOS)

	Si CoolMOS CFD7 w/ Fast Body Diode	GaN HEMT	Unit
	IPW65R029CFD7	GS66516B	
$R_{DS(ON)}$ Typ.	24	25	mΩ
$Q_{rr}$	1600	0	nC
$Q_{oss}$ @ $V_{DS}=400V$	1012	134	nC
Turn-on loss due to $Q_{RR}/Q_{OSS}@F_{SW}=65kHz$	68.7	2.5	W

## 2.4. Basic operating principle

The BTPPFC operates in two modes depending on the polarity of input AC voltage, as shown in Figure 5.

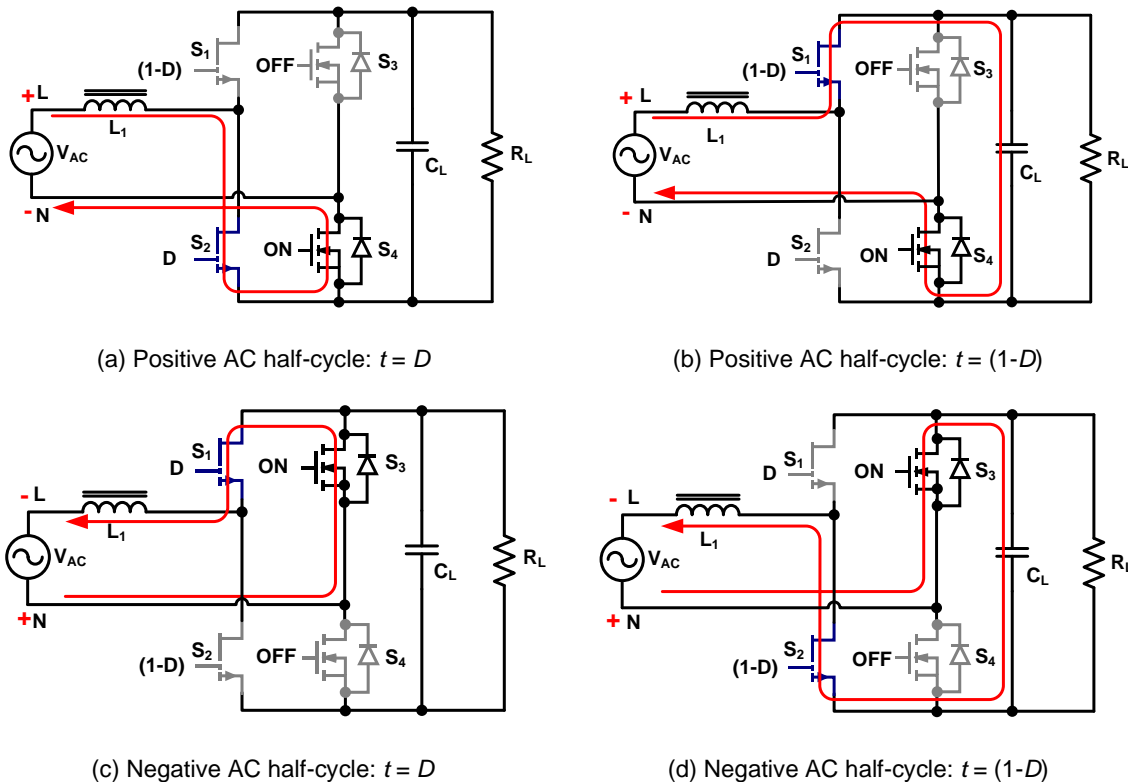


Figure 5. Current flows in TPPFC during positive and negative AC half-cycles

1. During the positive half cycle (line > neutral):  $S_2$  is the main switch, and  $S_1$  is driven with a complementary PWM signal.  $S_1/S_2$  and  $L_1$  form the boost DC/DC stage. During this positive half cycle, half-bridge leg  $S_4$  is turned on, and  $S_3$  is always inactive. When the main switch



$S_2$  is turned on, current flows from  $L_1 \rightarrow S_2 \rightarrow S_4$  and back to  $N$ . During the period of  $(1-D)$  when  $S_2$  is turned off,  $S_1$  is turned on, and current flows through  $S_1$  and back to  $N$  via  $S_4$ . The DC bus ground VDC- is tied to  $N$  potential as  $S_4$  is conducting all the time.

- During the negative half cycle (neutral > line): the operation in the negative half cycle is similar, except the role of top and bottom switches are swapped. Now,  $S_1$  becomes the main switch, and  $S_2$  is free-wheeling, and  $S_3$  is turned on, and  $S_4$  is inactive.

### 3. Design example

A 3 kW CCM BTPPFC reference design is provided to demonstrate the performance of GaN HEMTs, as shown in Figure 6. The detailed design specifications are shown in Table 2.

Table 2. 3 kW BTPPFC design specification

Parameter	Value
Input Voltage ( $V_{in}$ )	90-264 V <sub>rms</sub>
Output Voltage ( $V_{out}$ )	400 V
Maximum Output Power	3 kW (1.5kW for low line)
Switching Frequency	65 kHz
Line Frequency	50/60 Hz
Output voltage ripple	≤5%
Inductor current ripple	≤20%

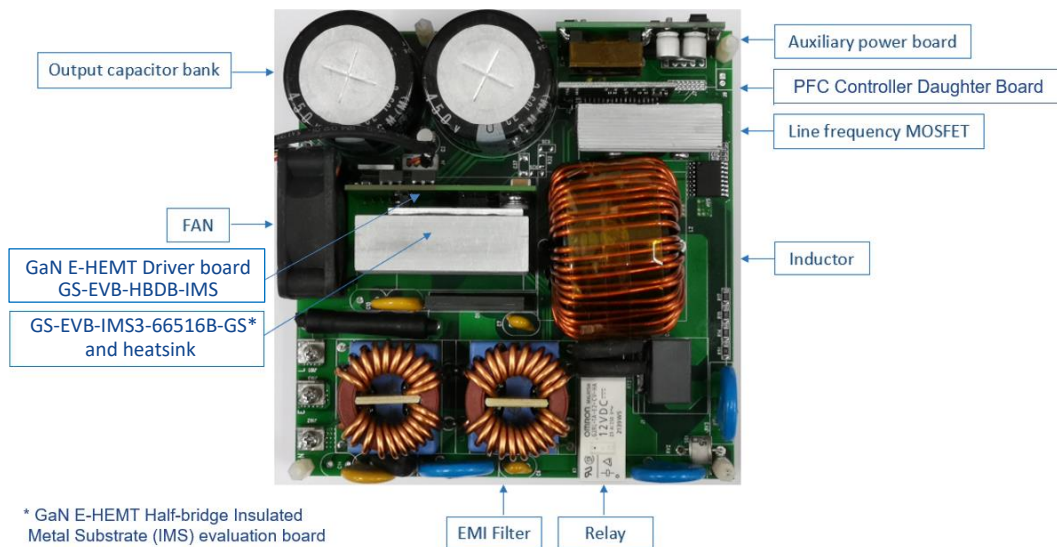


Figure 6. The 3 kW CCM BTPPFC reference design

### 3.1. System Block Diagram

The BTPPFC reference design block diagram is shown in Figure 7. The reference design consists of four sub-assemblies;

- 1) **Motherboard:** This board consists of an EMI filter, a start-up circuit, the line frequency Si MOSFETs and their gate drive circuits, and voltage and current sensing circuits. The IXFH80N65X2 devices from IXYS were chosen as the line-frequency switches.
- 2) **PFC Controller Daughter Board:** This control board uses the UCD3138 PFC control chip from Texas Instruments (Infineon 1EDB7275F). The PFC controller Daughter Board includes current, input line voltage, and output voltage sampling pins as inputs. The outputs are 4 PWM pins, of which two are applied to the GaN E-HEMT driver board, and the other two are applied to the line frequency Si MOSFETs.
- 3) **GaN E-HEMT Driver Board (GS-EVB-HBDB-IMS):** This board uses the SiLabs SI8271 isolated gate drive IC to drive the GaN Half-bridge IMS board (GS-EVB-IMS3-66516B-GS).
- 4) **GS-EVB-IMS3-66516B-GS:** Evaluation board from GaN Systems, which is a Half-Bridge Insulated Metal Substrate (IMS) board that uses high switching speed GS66516B GaN E-HEMT's [3]. The design details of this evaluation board can be found on the GaN Systems website at [4].

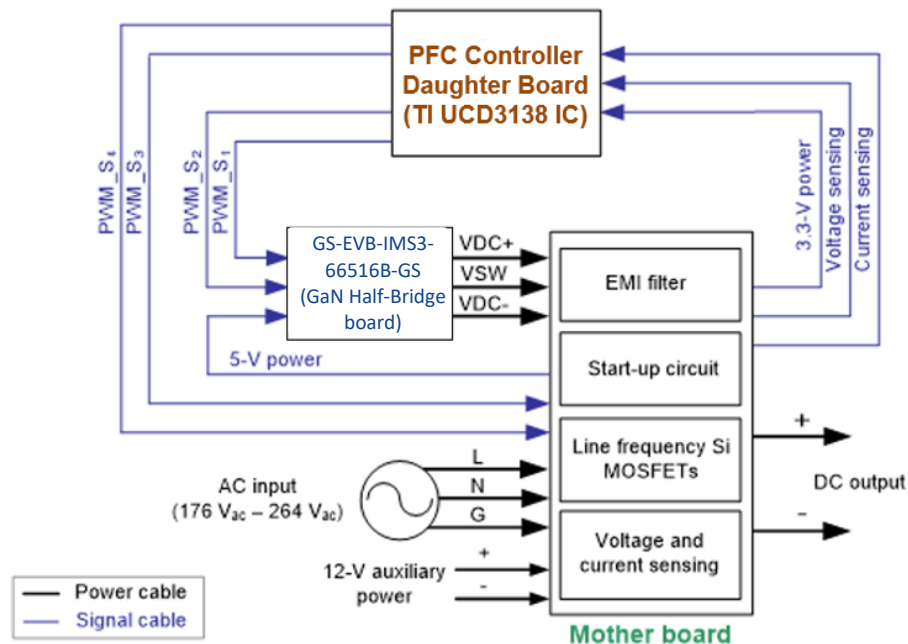


Figure 7. System block diagram

- 5) Auxillary power board: This board is a flyback dc-dc converter. It offers power for all control circuits, transistor driver and fan cooling. The board's input is 400V bus voltage, and output is 12V for fan and driver, 7V for the control circuit, and an isolated 9V for driving the high-side Si MOSFET.

### 3.2. Control scheme

The average current control is employed. The voltage and current loop control are similar to conventional boost PFC converter. The measured signals are DC output voltage  $V_{dc}$ , inductor current  $i_L$ , and input voltage  $V_{acL}$  and  $V_{acN}$ . The inductor current is measured by a high bandwidth hall sensor IC. The overall control block diagram is shown in Figure 8. A relay is applied to achieve the soft-start function. The AC polarity detection is performed by measuring the voltage  $V_{acL}$  and  $V_{acN}$ . The power reference is generated from the output voltage  $V_{dc}$  loop. The input current reference can be obtained by multiplying the power reference with the rectified AC input voltage and divided by the square of input AC RMS voltage. The output from the current loop drives the PWM modulator to generate the gate signals. Therefore, the line current can be tracked to the input voltage waveform, as shown in Figure 9.

Overvoltage, Undervoltage, and overcurrent protection have been implemented for the input and output of the PFC converter. <10uS reacting time of grid overcurrent protection is enabled by the 1MHz bandwidth hall sensor.

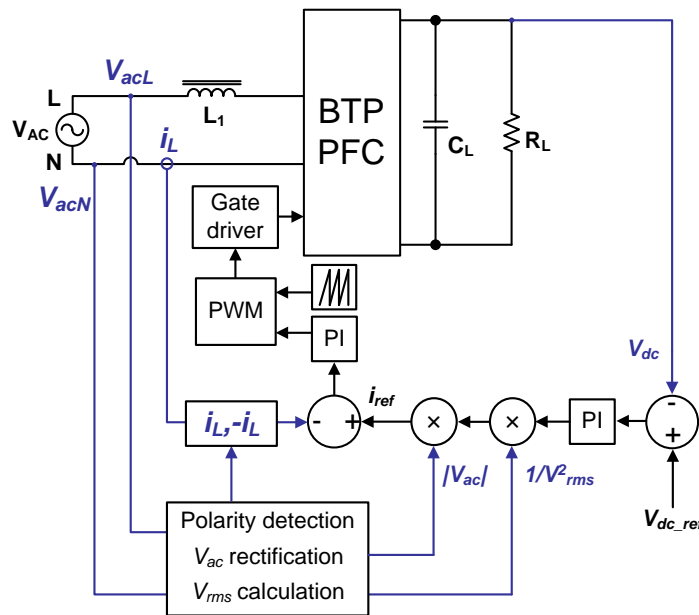


Figure 8. Control block diagram

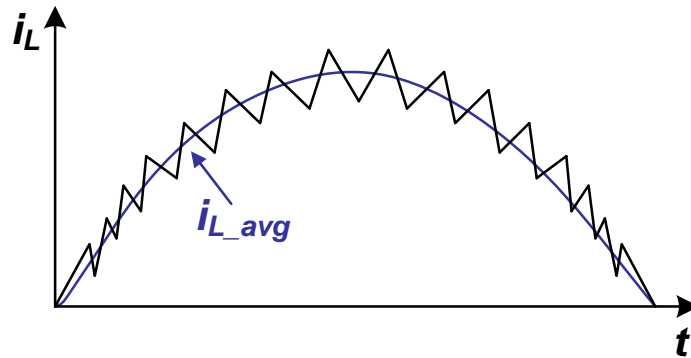


Figure 9. The average current mode control scheme

## 4. Test Results

The measured efficiency curve is shown in Figure 10. The peak efficiency reaches 99.05% at 1.5 kW, 230 V<sub>ac</sub> (the aux loss includes the auxiliary power, and fan cooling loss). The power factor under different loads is shown in Figure 11. The converter input and output waveform under the full load is shown in Figure 12. The converter full-load start-up waveform is shown in Figure 13.

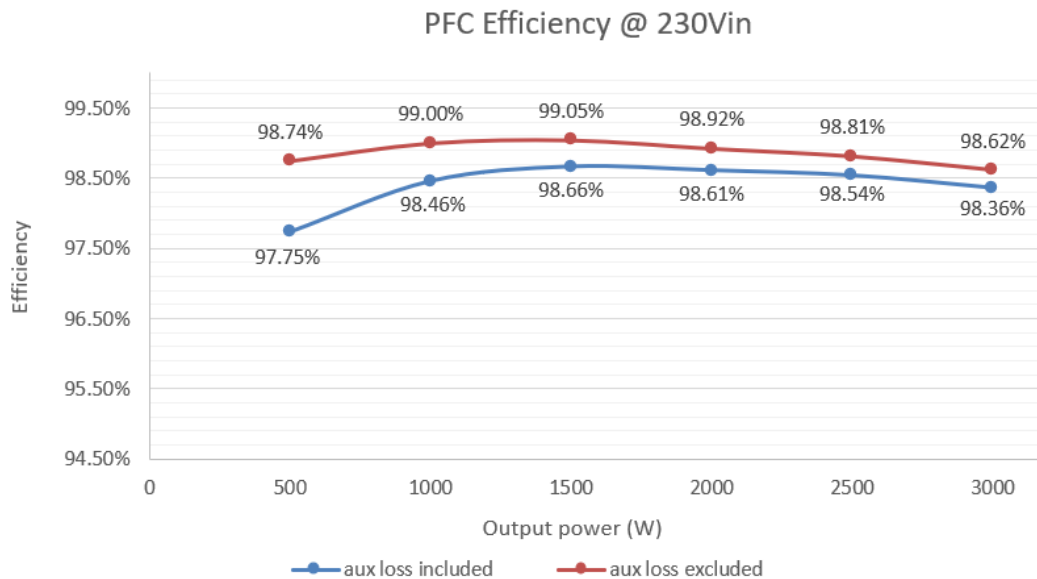


Figure. 10. Efficiency at 230 V<sub>ac</sub>

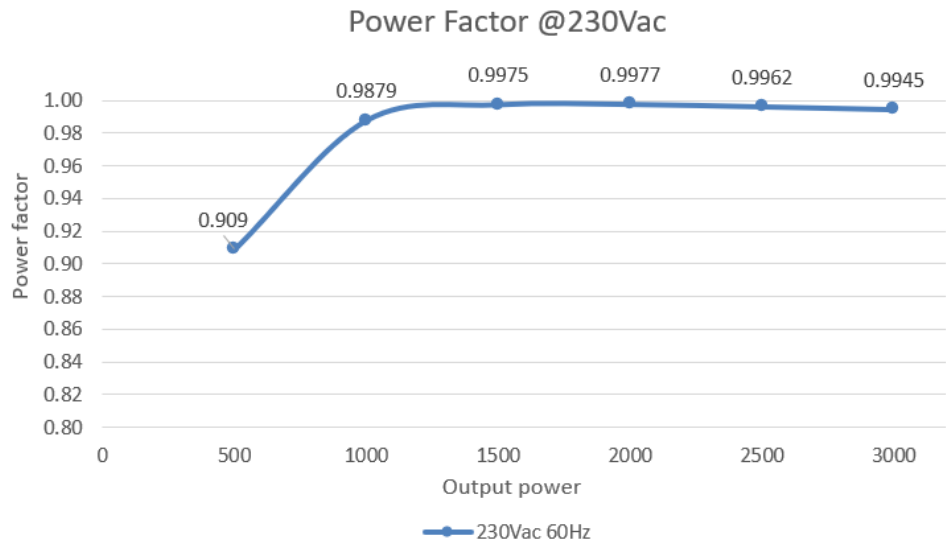


Figure 11. Power factor at 230 V<sub>ac</sub>, 60 Hz

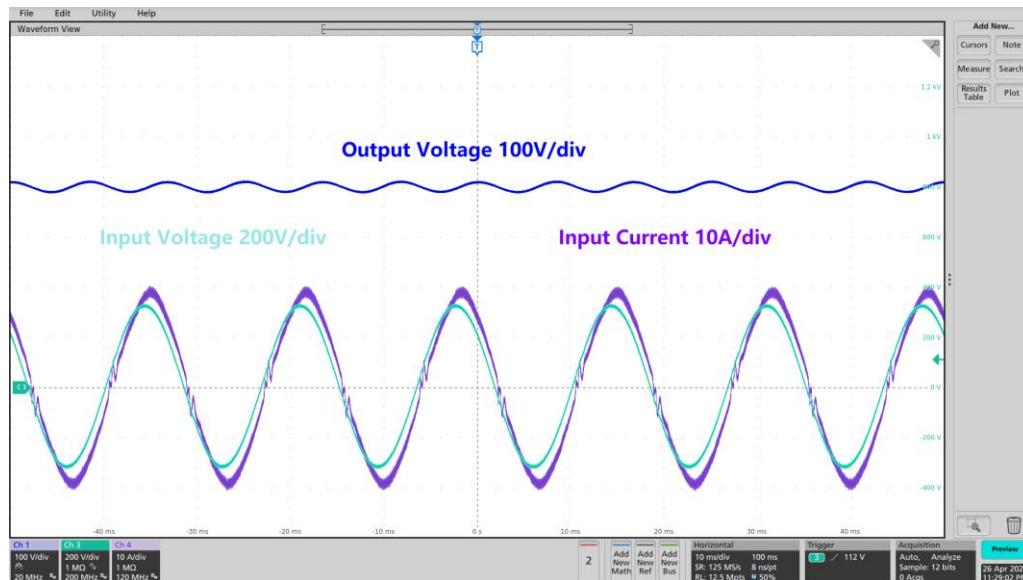


Figure 12. Converter Input and output waveform at 230 V<sub>ac</sub>, 400 V<sub>dc</sub>, and 7.5 A<sub>dc</sub>.

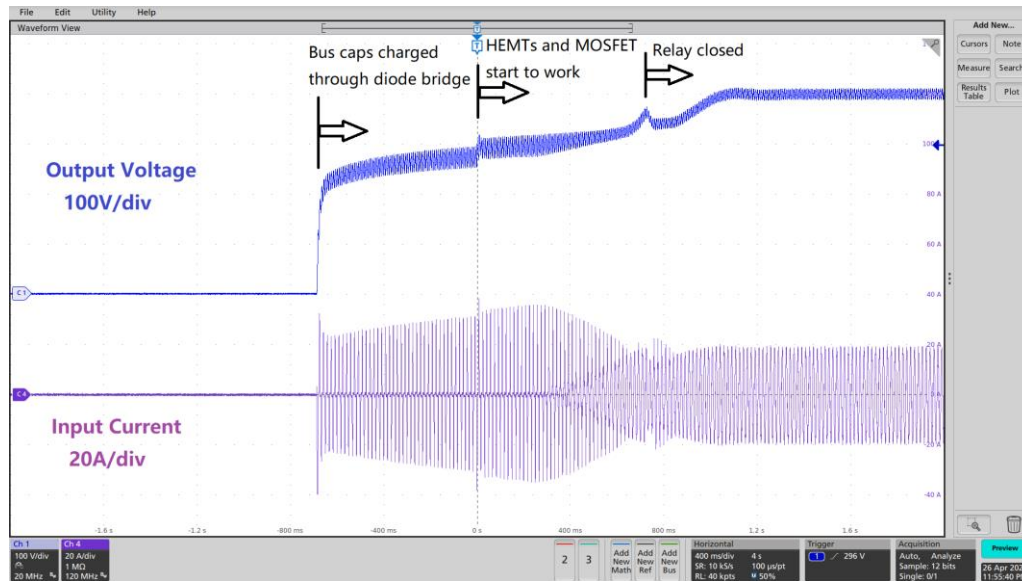


Figure 13. Converter 3kW full load start-up waveform

The thermal images was taken at 230 V<sub>ac</sub>, 400 V<sub>dc</sub>, and 7.5 A<sub>dc</sub> with a fan, and the ambient temperature was 25 °C. As shown in Figure 14 and 15, the boost inductor temperature is 49.4 °C, the temperatures on the MOSFET, and GaN E-HEMT are 55.5 °C and 57.2 °C, respectively.

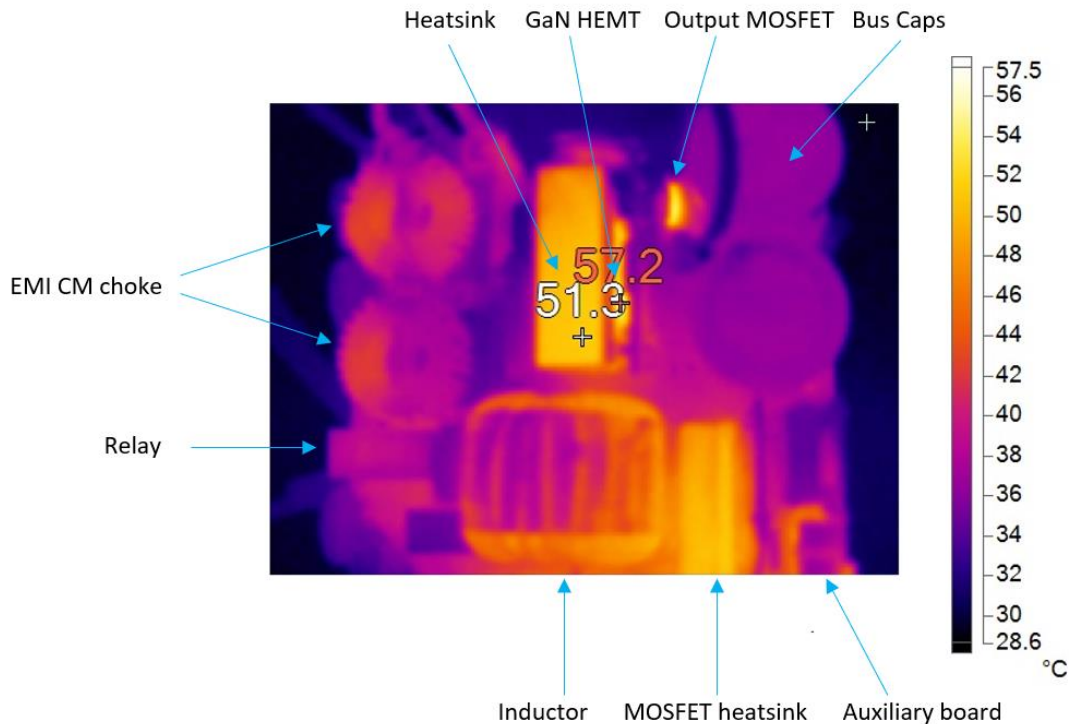


Figure 14. Temperature of GaN HEMTs and its heatsink



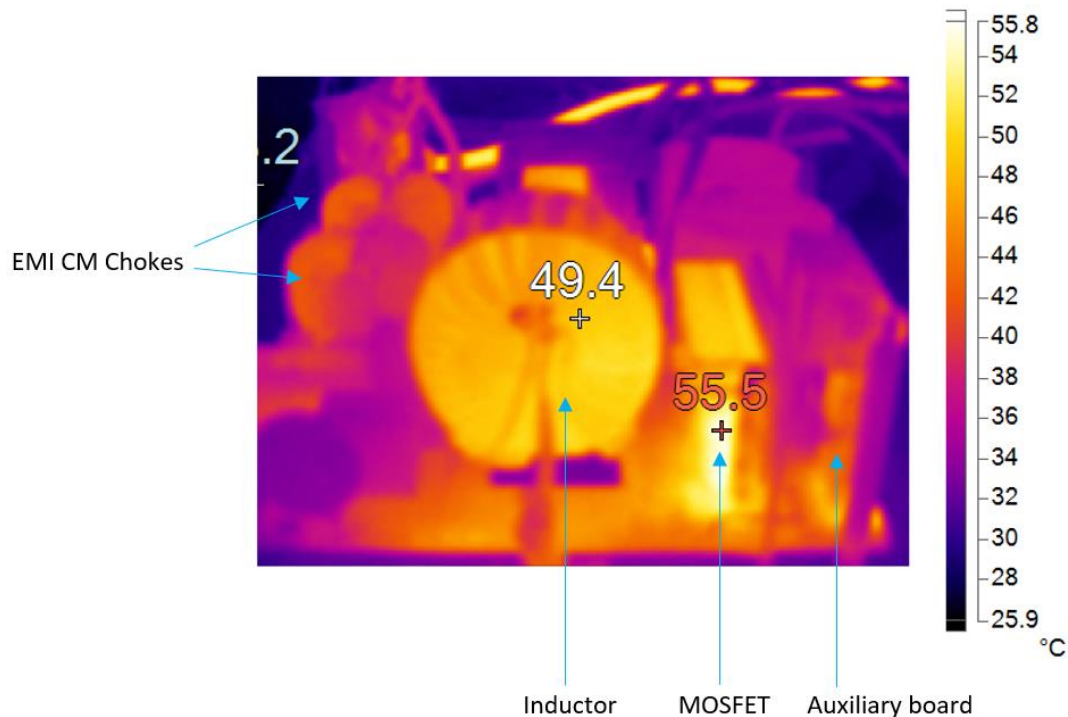


Figure 15. Temperature of the boost inductor and Si MOSFET

## 5. Applications

The scope of applications for this 3 kW GaN E-HEMT-based BTPPFC includes, but is not limited to following,

1. The unidirectional or bidirectional onboard battery charger in electrified vehicles. The BTPPFC is a promising bidirectional PFC candidate to achieve the bidirectional power flow from grid to vehicle (G2V) and from vehicle to grid (V2G).

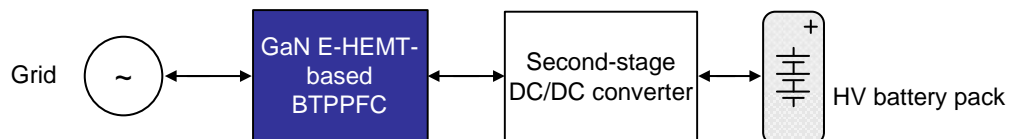


Figure 16. Electrified vehicle onboard bidirectional battery charger system

2. Energy storage systems. The BTPPFC can realize the bidirectional interconnection between the grid and an energy storage system to better utilize the harvested energy and optimize the overall design.

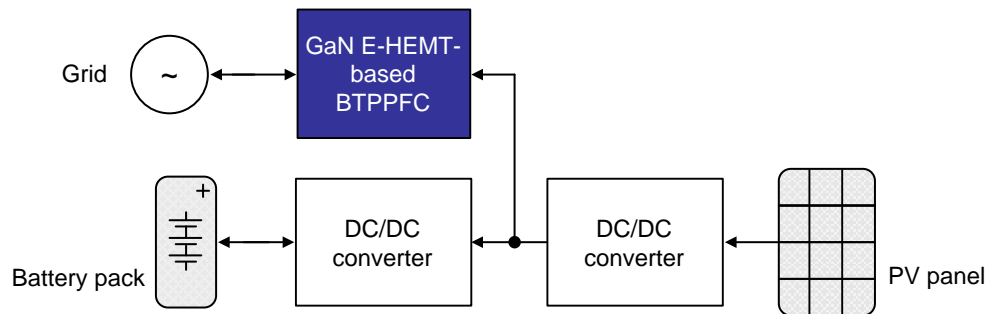


Figure 17. Energy storage system

3. Telecom applications. The BTPPFC can also be applied to the telecom applications to increase efficiency, reduce system size, and reduce system BOM cost.

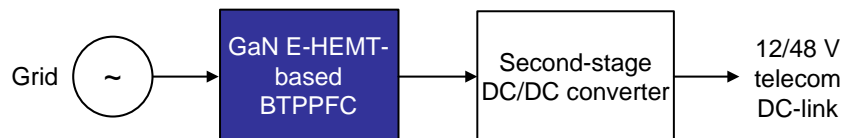


Figure 18. Telecom application

## 6. Conclusion

This technical manual presents the motivation, operating principle, and design considerations of a BTPPFC using GaN E-HEMTs. A 3 kW BTPPFC reference design using GaN Systems 650 V GaN E-HEMT is provided. The test results, as well as the thermal performance, are presented. GaN Systems' E-HEMTs have advantages in the CCM BTPPFC design in terms of power density, efficiency, and performance. Several possible application examples based on the BTPPFC are also given.



## 7. Appendix A – Schematics

### 7.1. Motherboard Schematics

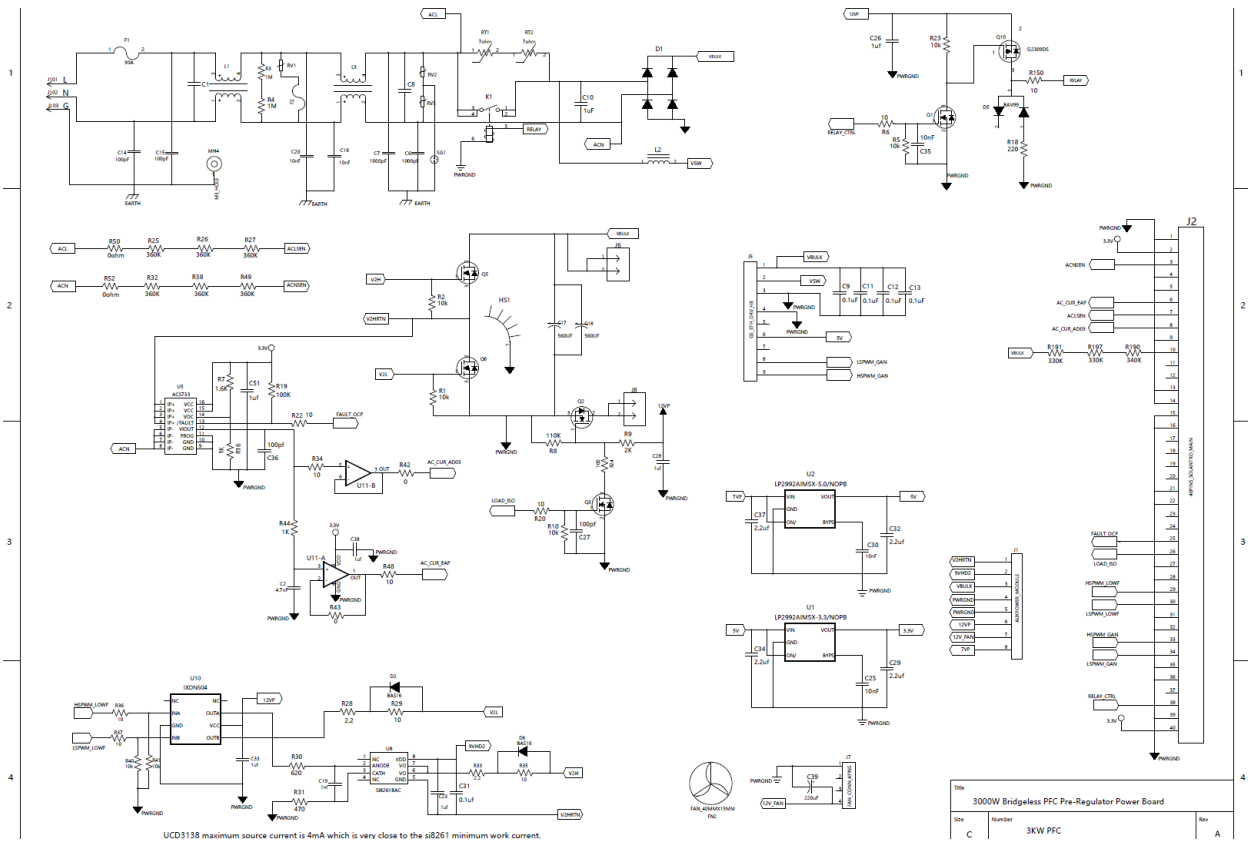


Figure. 19. Motherboard schematic page 1

## 7.2. PFC Controller Daughter Board Schematic

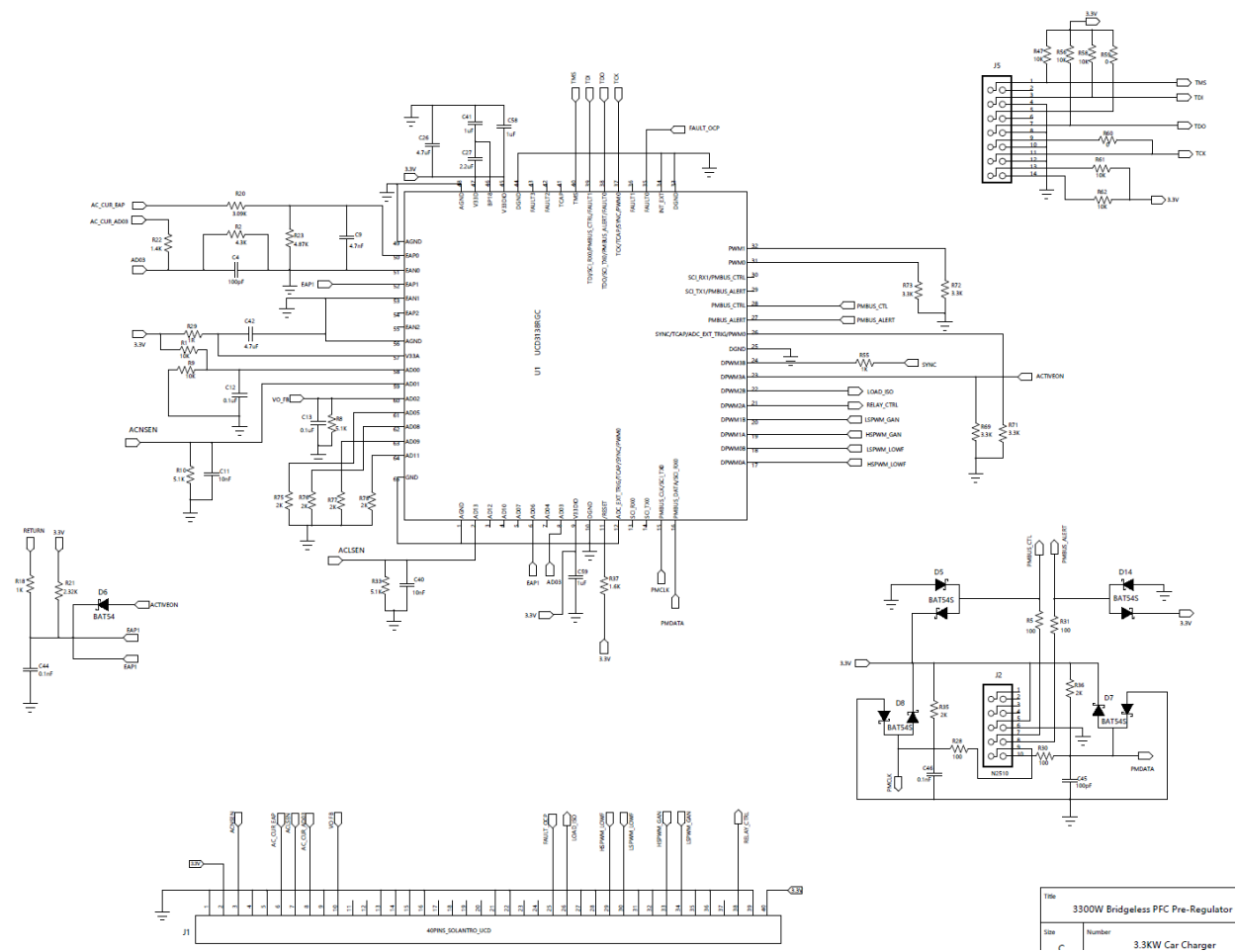


Figure. 20. The PFC Controller Daughter Board schematic

### 7.3. GaN E-HEMT Driver Board GS-EVB-HBDB-IMS schematic

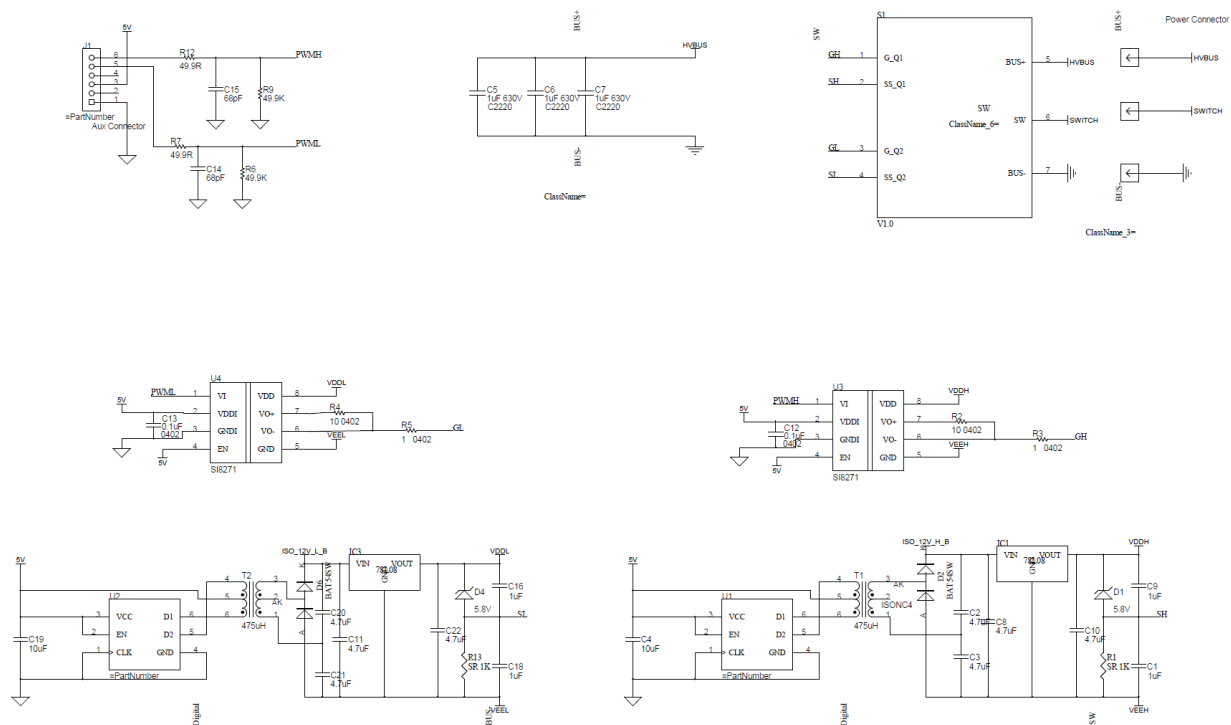


Figure. 21. GaN E-HEMT Driver Board GS-EVB-HBDB-IMS schematic

#### 7.4. Auxiliary power Board schematic

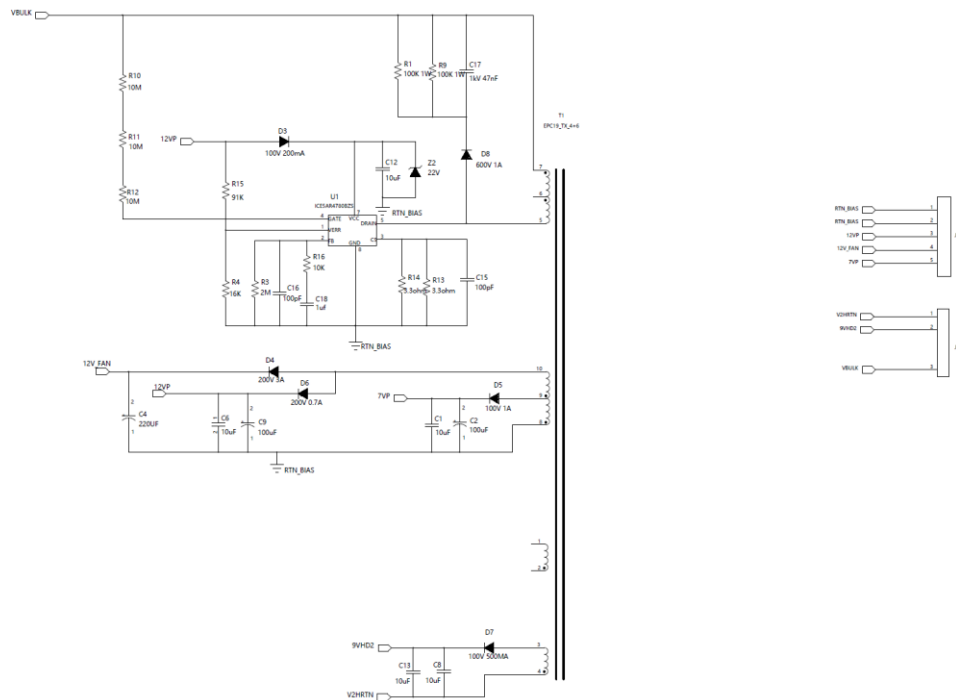


Figure 22. Auxiliary power Board schematic

## 7.5. GS-EVB-IMS3-66516B-GS GaN E-HEMT IMS3 Board Schematic

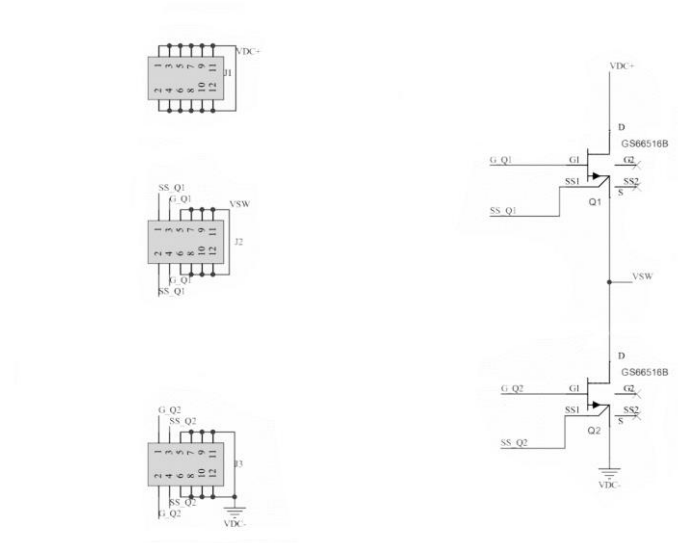


Figure 23. GaN E-HEMT IMS3 Board schematic

## 8. Appendix B – Layout

### 8.1. PCB Layout - Motherboard

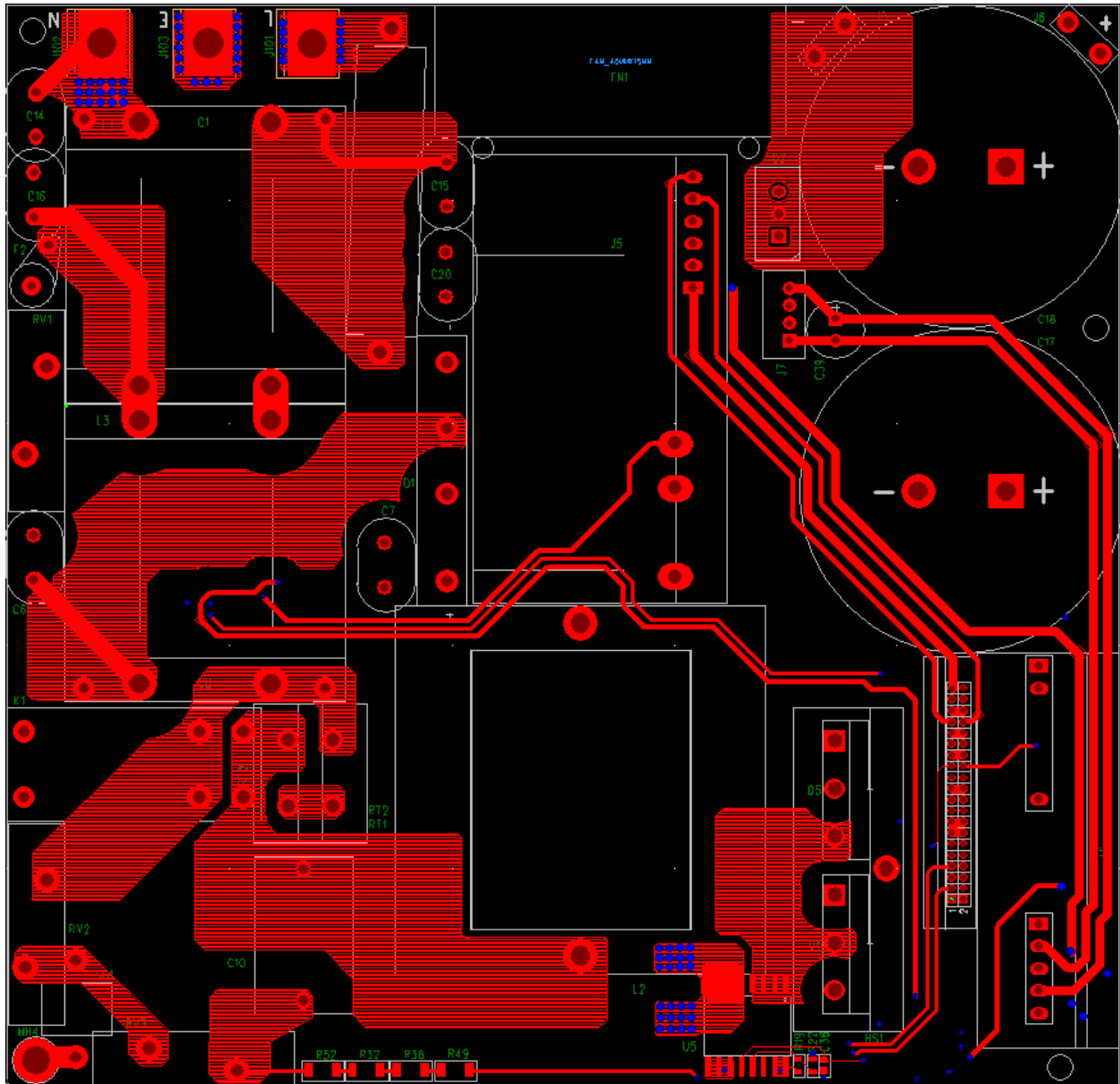


Figure 24. Motherboard PCB layout

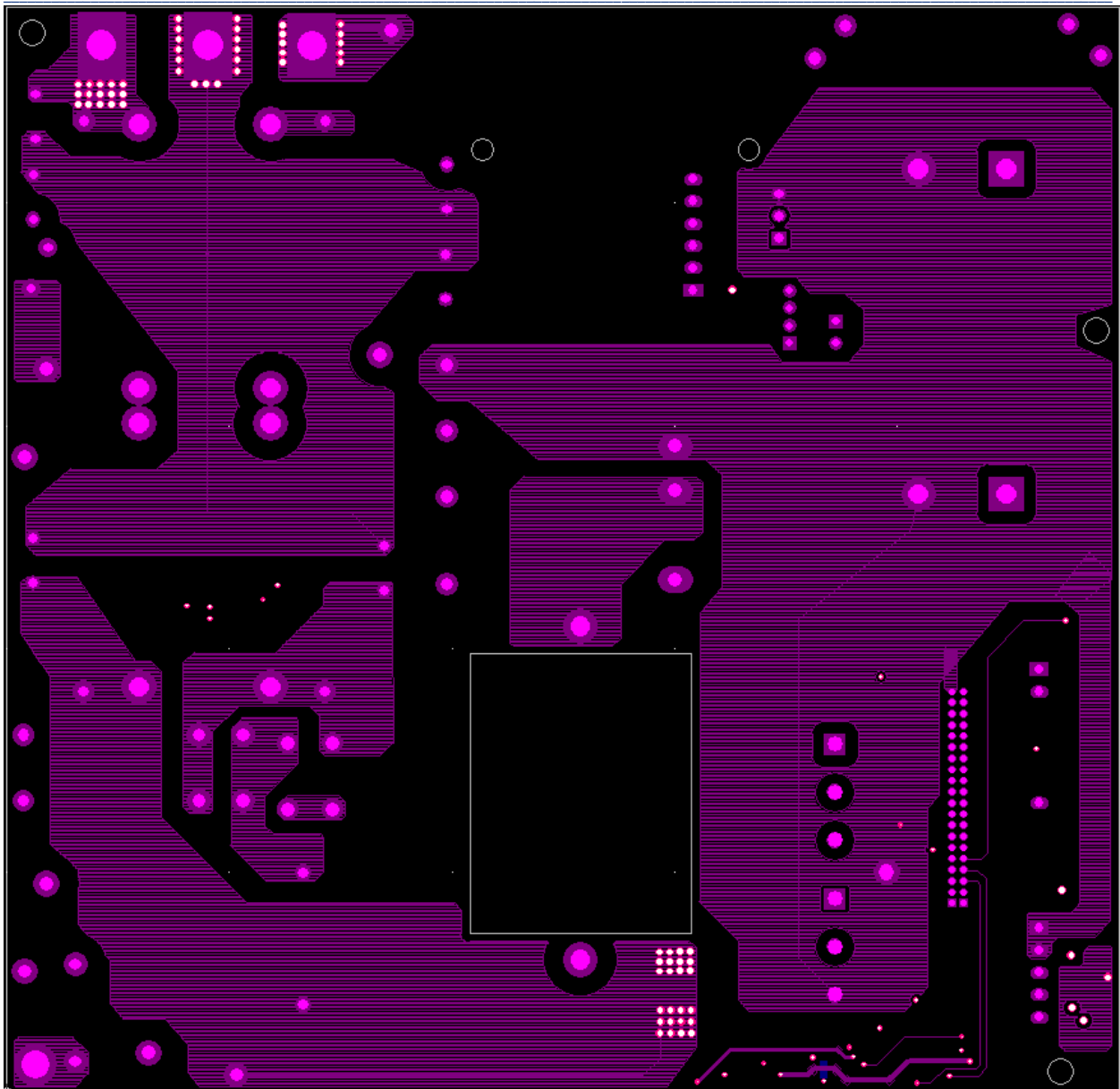


Figure 25. Motherboard PCB layout mid layer 1

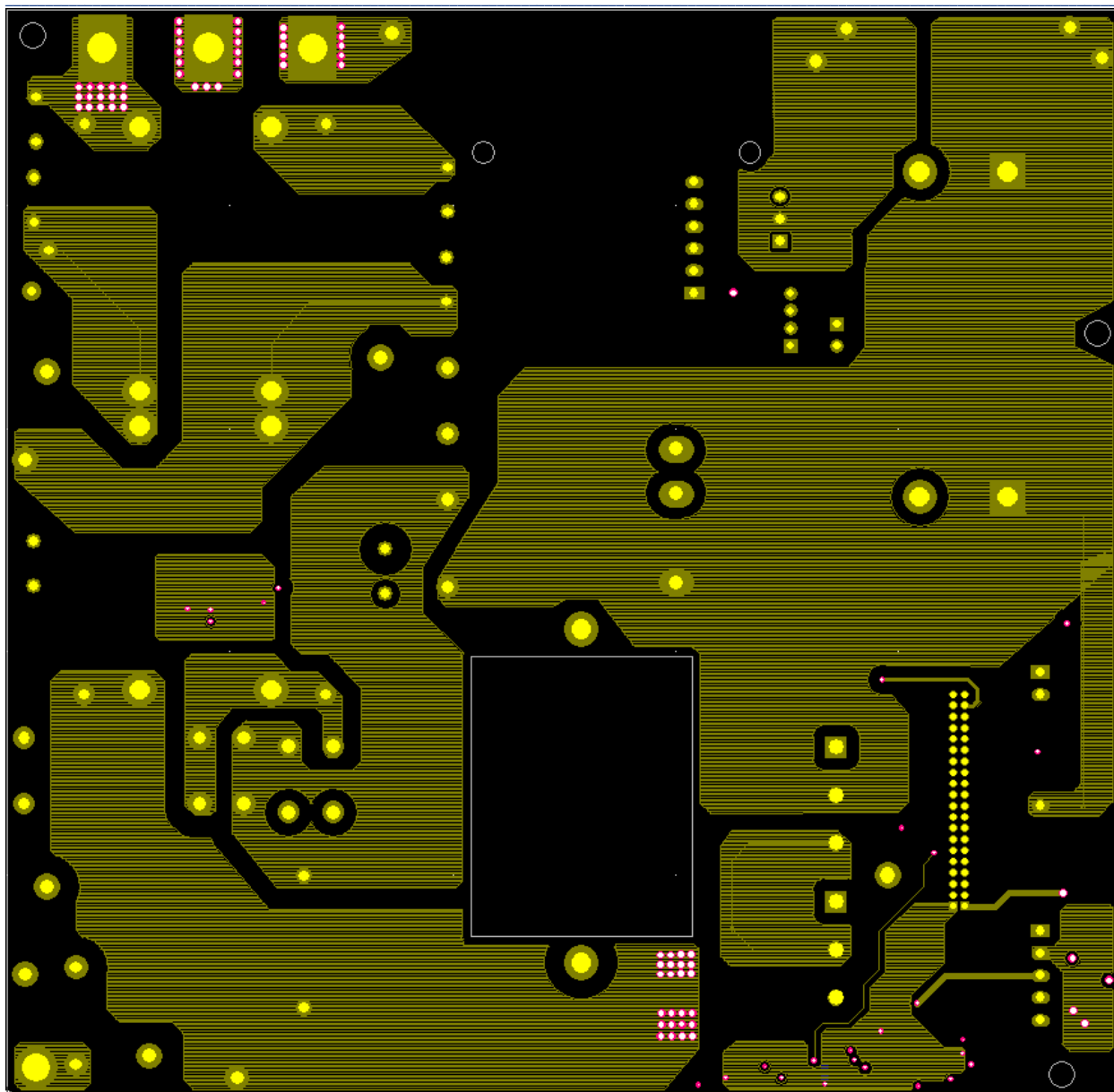


Figure 26. Motherboard PCB layout mid layer 2

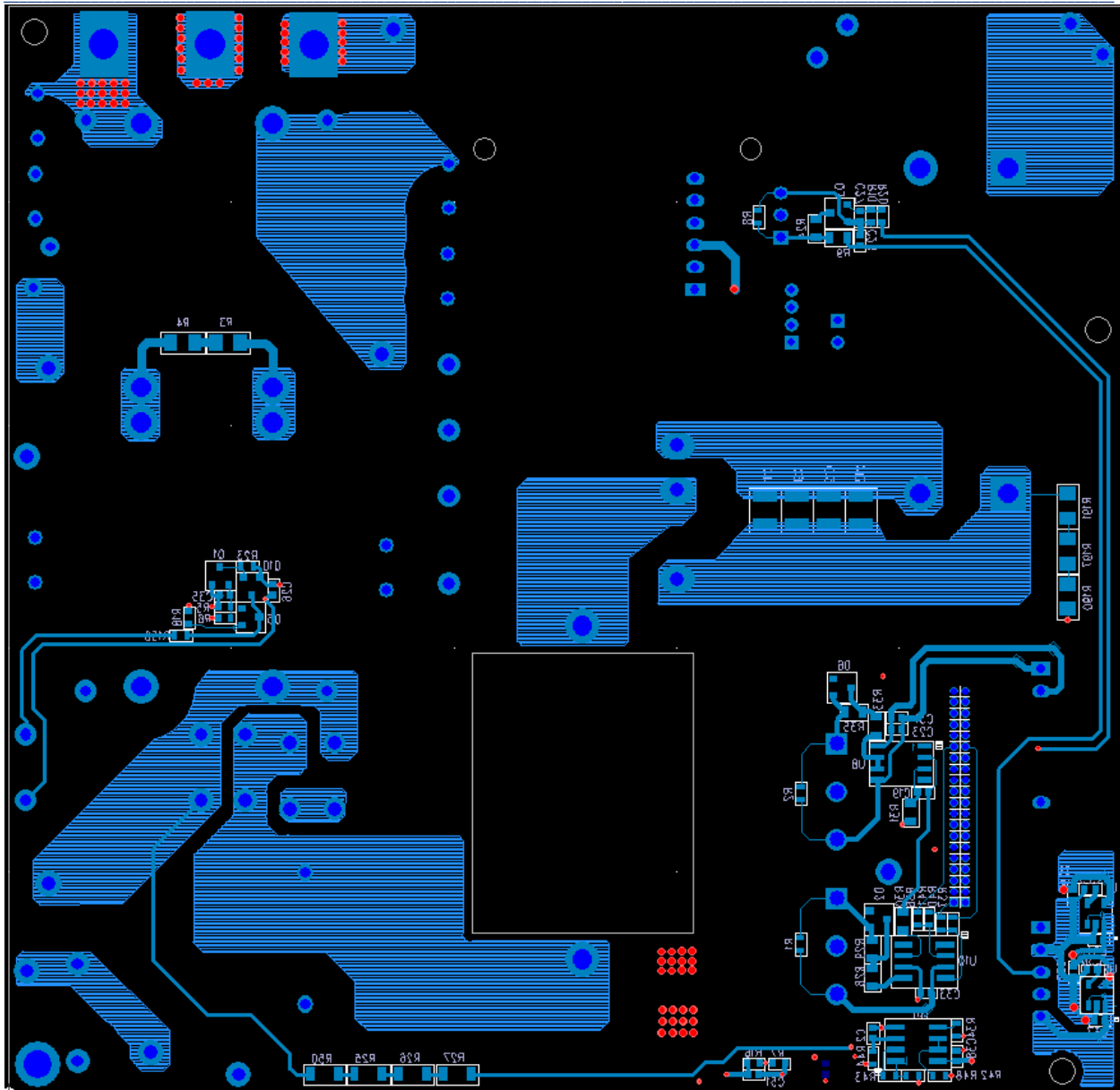


Figure 27. Motherboard PCB layout: bottom layer



## 8.2. PCB layout – PCB Controller Daughter board

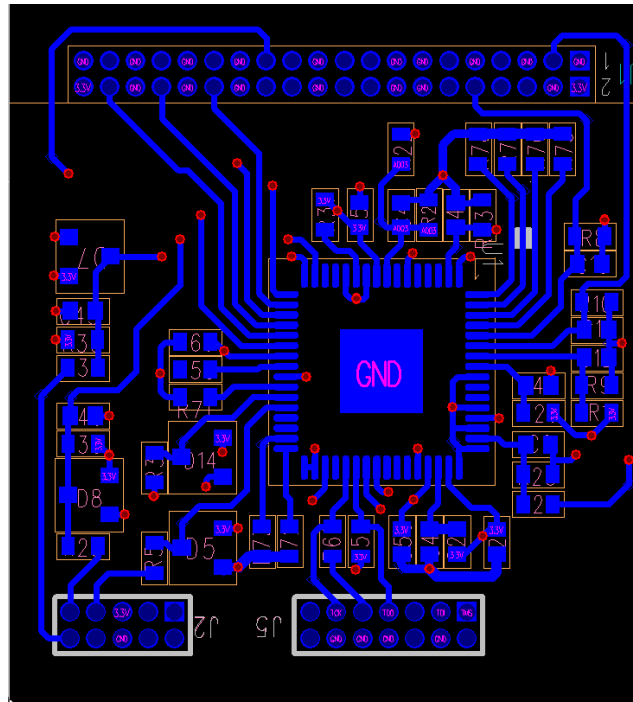


Figure 28. PFC Controller Daughter Board PCB layout: top layer

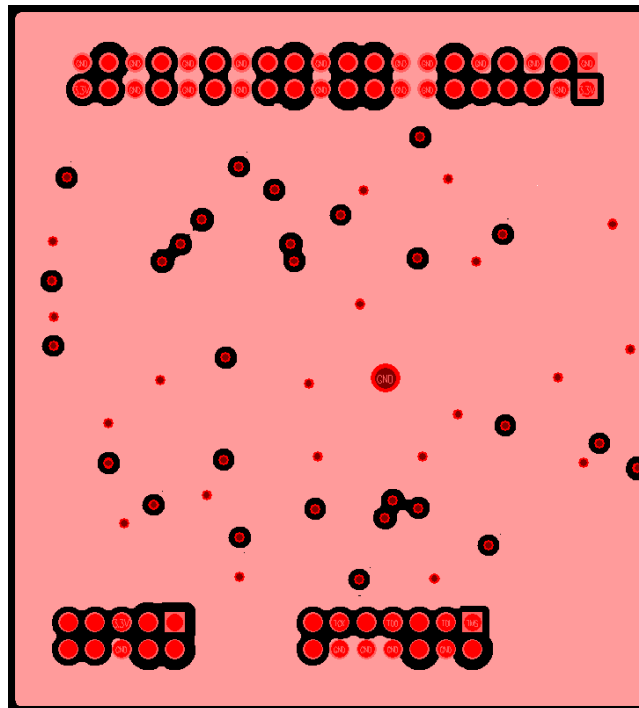


Figure 29. PFC Controller Daughter Board PCB layout: mid layer 1

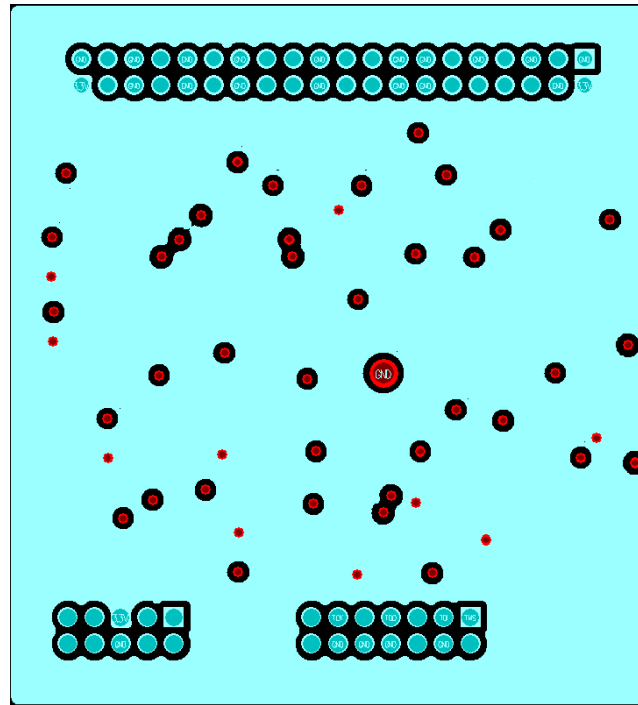


Figure 30. PFC Controller Daughter Board PCB layout: mid layer 2

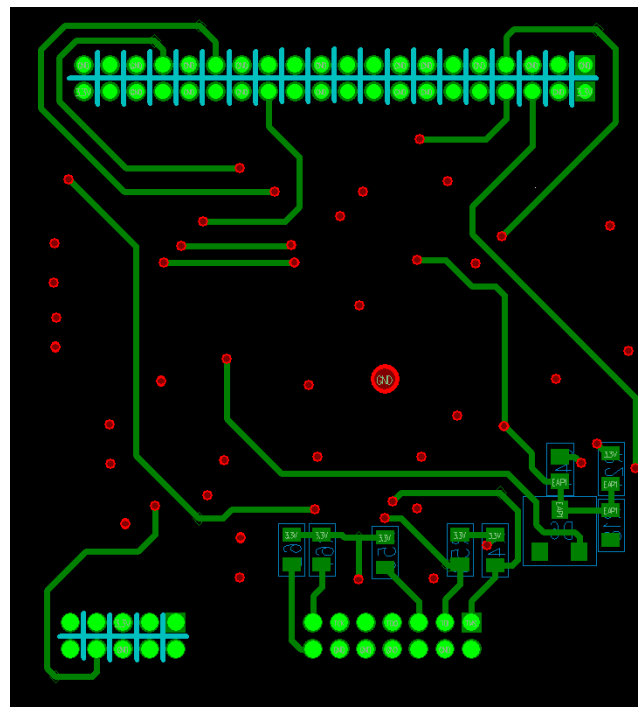


Figure 31. PFC Controller Daughter Board PCB layout: bottom layer

### 8.3. PCB layout - GaN E-HEMT Driver Board GS-EVB-HBDB-IMS

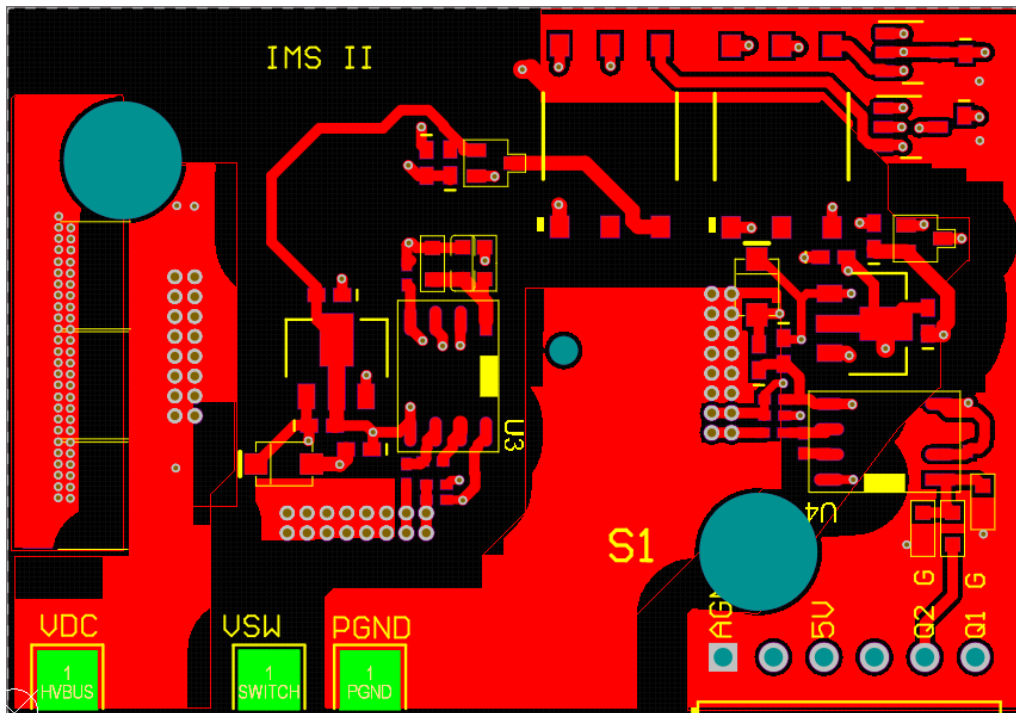


Figure 32. GaN E-HEMT Driver board GS-EVB-HBDB-IMS PCB layout: top layer

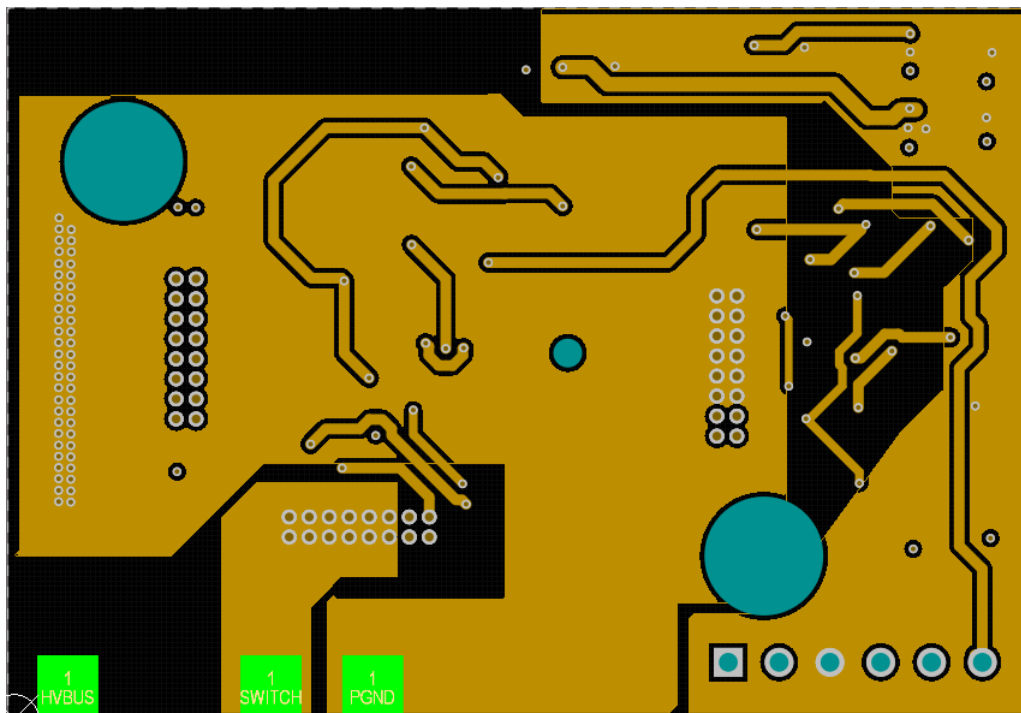


Figure 33. GaN E-HEMT Driver board GS-EVB-HBDB-IMS PCB layout: mid layer 1

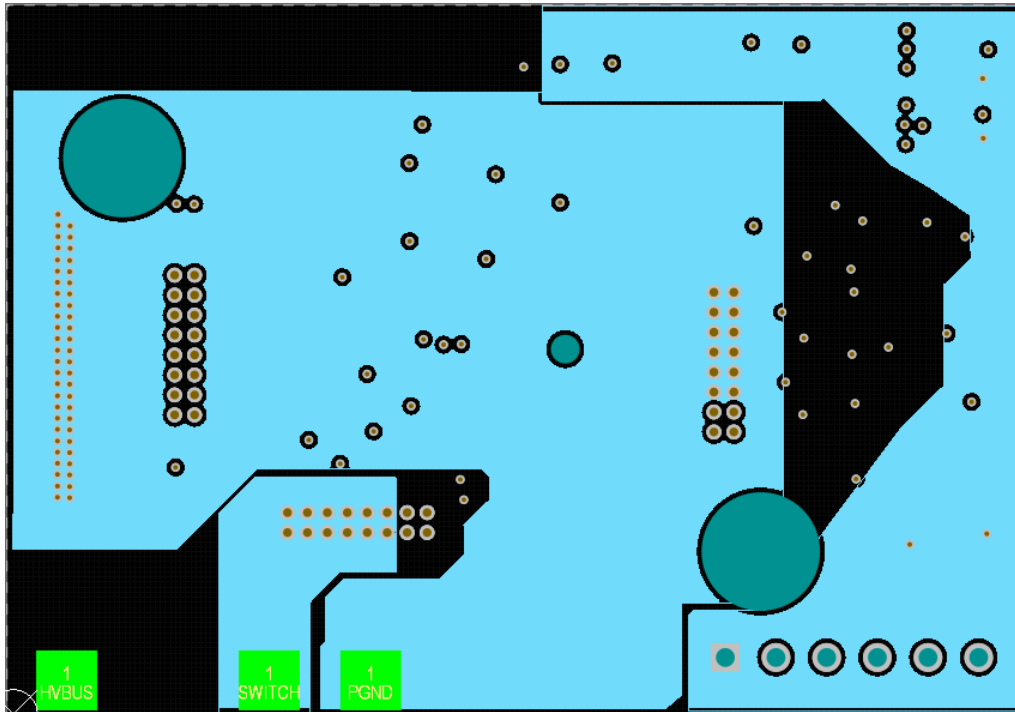


Figure 34. GaN E-HEMT Driver board PCB GS-EVB-HBDB-IMS layout: mid layer 2

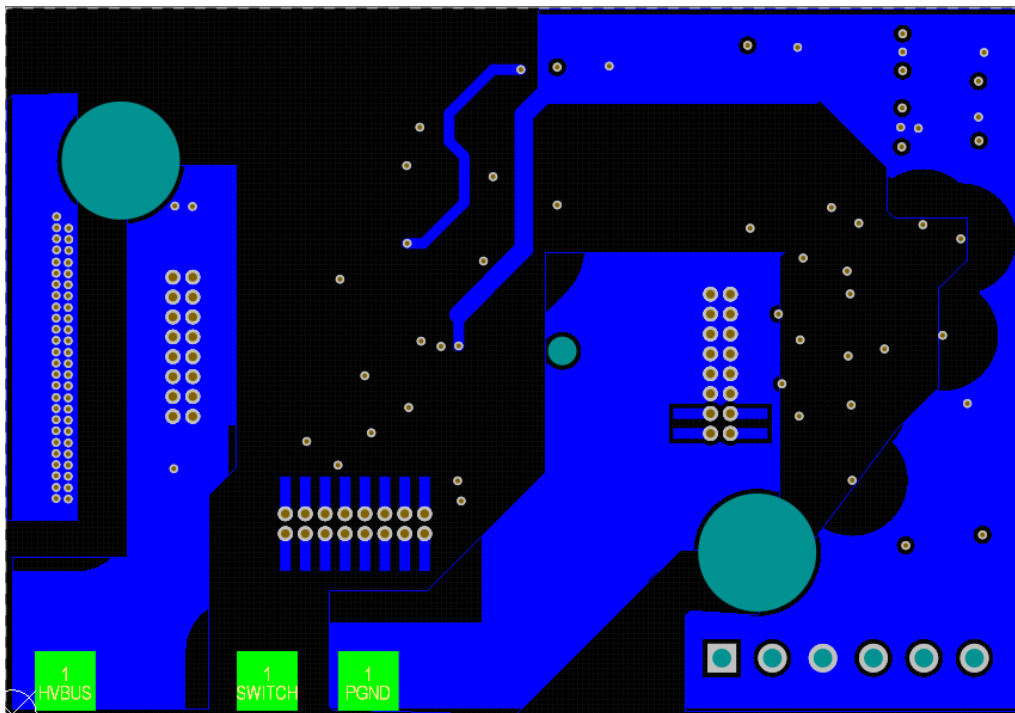


Figure 35. GaN E-HEMT Driver board PCB GS-EVB-HBDB-IMS layout: bottom layer

## 8.4. PCB layout - Auxiliary Power Board

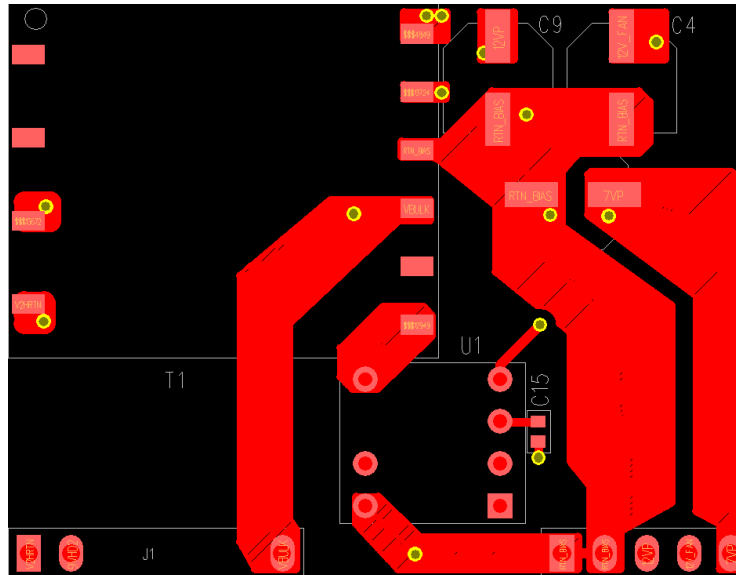


Figure 36. Auxiliary power PCB layout: top layer

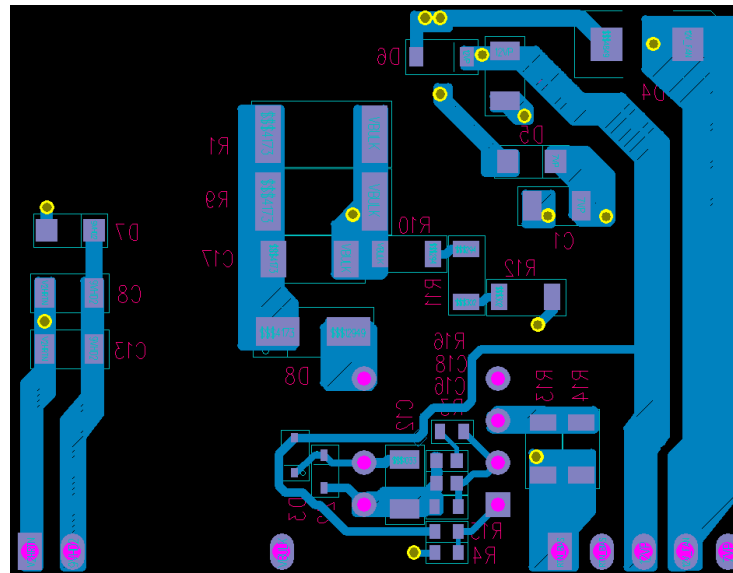


Figure 37. Auxiliary power PCB layout: bottom layer

## 8.5. PCB layout – GS-EVB-IMS3-66516B-GS GaN E-HEMT IMS3 Board

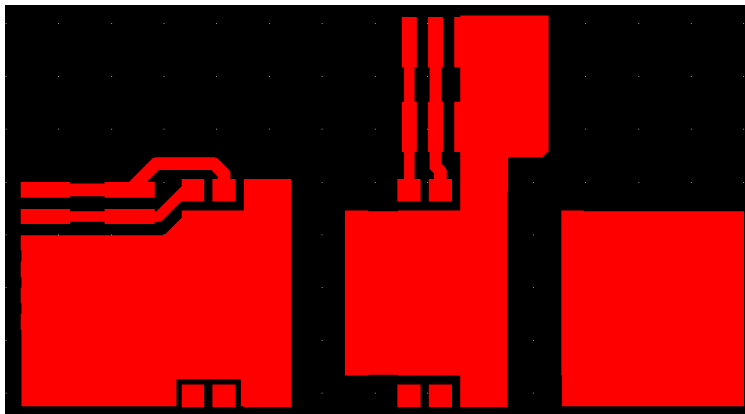


Figure 38. GaN E-HEMT IMS3 PCB layout: Top layer

## 9. Appendix C – List of Materials

### 9.1. List of materials - Motherboard

Table 3. Motherboard list of materials

Ref_Des	Part Number	Description
U5	ACS733KLATR-40AB-T	SMD SOIC16 CURRENT SENSOR ACS733
D2	BAS16-7-F,BAS16	Diode 75V 200mA SOT23-3
D6	BAS16-7-F,BAS16	Diode 75V 200mA SOT23-3
D5	BAV99-7-F,BAV99	DIODE 75V 300mA SOT23
C29	10V_2.2UF_X7R	CAP 0603 10V 2.2uF X7R
C32	10V_2.2UF_X7R	CAP 0603 10V 2.2uF X7R
C37	10V_2.2UF_X7R	CAP 0603 10V 2.2uF X7R
C34	10V_2.2UF_X7R	CAP 0603 10V 2.2uF X7R
C23	25V_1UF_X7R	CAP 0603 25V 1uF X7R
C26	25V_1UF_X7R	CAP 0603 25V 1uF X7R
C28	25V_1UF_X7R	CAP 0603 25V 1uF X7R
C33	25V_1UF_X7R	CAP 0603 25V 1uF X7R
C51	25V_1UF_X7R	CAP 0603 25V 1uF X7R
C31	50V_0.1UF_X7R	CAP 0603 50V 0.1uF X7R
C27	50V_100PF_X7R	CAP 0603 50V 100pF X7R
C35	50V_10nF_X7R	CAP 0603 50V 10nF X7R
C36	50V_100PF_X7R	CAP 0603 50V 100pF X7R
C25	50V_10NF_X7R	CAP 0603 50V 10nF X7R
C30	50V_10NF_X7R	CAP 0603 50V 10nF X7R
C19	50V_1NF_X7R	CAP 0603 50V 1nF X7R
C9	650V_0.1UF_X7R	CAP SMD 1210 650V 0.1UF X7R
C11	650V_0.1UF_X7R	CAP SMD 1210 650V 0.1UF X7R
C12	650V_0.1UF_X7R	CAP SMD 1210 650V 0.1UF X7R
C13	650V_0.1UF_X7R	CAP SMD 1210 650V 0.1UF X7R
C17	LGM2W561MELC35	CAP AL TH 450V 560UF 35Dx35H
C18	LGM2W561MELC35	CAP AL TH 450V 560UF 35Dx35H
C39	16V_220UF_D6.3	CAP TH 16V 220uF D6.3mmX11mm
C1	CAP_X2_2.2UF_HORIZONTAL	CAP TH X2 310V 2.2UF
C8	CAP_X2_2.2UF_HORIZONTAL	CAP TH X2 310V 2.2UF
C14	CAP_Y2_100PF	CAP Y2 440VAC 100pF Y5S
C15	CAP_Y2_100PF	CAP Y2 440VAC 100pF Y5S
C16	CAP_Y2_10NF	CAP Y2 440VAC 10nF Y5U

Table 3. Motherboard list of materials (Continued)

Ref_Des	Part Number	Description
C20	CAP_Y2_10NF	CAP Y2 440VAC 10nF Y5U
L1	CM_CHOKE_1	CM CHOKE LONG LEAD HORIZONTAL
L3	CM_CHOKE_1	CM CHOKE LONG LEAD HORIZONTAL
J7	FAN_CONN_4PINS	CON 4PIN 2.0PITCH
F1	FUSE_250V_30A,30A	FUSE 250V AC 30A Fast Axial Lead
F2	FUSE_3.5A	FUSE 250V AC 3.5A TIME LAG
SG1	GASTUBE_2500V	GASTUBE 2500V TH
D1	GB025-12N01	DIODE BRIDGE 1PH 1200V SIP
L2	PI160694V1	Power inductor
Q2	IPP65R045C7_TO220	N MOSFET TO220
U10	IXDN604SIA,IXDN604	IC 4A Dual Output Drive SO8
U1	LP2992AIM5X-3.3/NOPB	LDO 3.3V 150mA SOT23-5
U2	LP2992AIM5X-5.0/NOPB	LDO 5V 150mA SOT23-5
C10	MKPX2,1uF	Capacitor, OS CON, vvV, zzmiliohm, [temp], 20%
Q5	IXFH80N65X2	MOS N-ch 650V 80A TO247
Q6	IXFH80N65X2	MOS N-ch 650V 80A TO247
Q1	SN7002N	N MOS 60V 0.2A SOT-23
Q3	SN7002N	N MOS 60V 0.2A SOT-23
RV1	MOV_560V	MOV_560V_20MM
RV2	MOV_560V	MOV_560V_20MM
RV3	MOV_560V	MOV_560V_20MM
RT1	SL22 7R010	NTC 7ohm D22mm 100J
RT2	SL22 7R010	NTC 7ohm D22mm 100J
K1	G2RL-1A-E2-CV-HA DC12	G2RL-1A-E2-CV-HA DC12
R1	10K_1/10W_1%	RES 0603 10k 1/10W
R2	10K_1/10W_1%	RES 0603 10k 1/10W
R5	10K_1/10W_1%	RES 0603 10k 1/10W
R10	10K_1/10W_1%	RES 0603 10k 1/10W
R23	10K_1/10W_1%	RES 0603 10k 1/10W
R40	10K_1/10W_1%	RES 0603 10k 1/10W
R41	10K_1/10W_1%	RES 0603 10k 1/10W
R6	10_1/10W	RES 0603 10ohm 1/10W 1%
R20	10_1/10W	RES 0603 10ohm 1/10W 1%



Table 3. Motherboard list of materials (Continued)

Ref_Des	Part Number	Description
R22	10_1/10W	RES 0603 10ohm 1/10W 1%
R36	10_1/10W	RES 0603 10ohm 1/10W 1%
R37	10_1/10W	RES 0603 10ohm 1/10W 1%
R150	10_1/10W	RES 0603 10ohm 1/10W 1%
R8	110K_1/10W	RES 0603 110k 1/10
R7	1K_1/10W	RES 0603 1k 1/10W
R16	1K_1/10W	RES 0603 1k 1/10W
R19	100K_1/10W	RES 0603 100k 1/10W
R18	220_1/10W	RES 0603 220 1/10W
R24	100_1/8W	RES 0805 100 1/8W
R29	10_1/8W	RES 0805 10 1/8W
R35	10_1/8W	RES 0805 10 1/8W
R28	2.2_1/8W	RES 0805 2.2 1/8W
R33	2.2_1/8W	RES 0805 2.2 1/8W
R9	2K_1/8W	RES 0805 2K 1/8W
R31	470_1/8W	RES 0805 470 1/8W
R30	620_1/8W	RES 0805 620 1/8W
R3	1M_1/4W	RES 1206 1M 1/4W
R4	1M_1/4W	RES 1206 1M 1/4W
R191	330K_0.25W_1%	Resistor, Metal Film, 1/4 watt, 1%
R197	330K_0.25W_1%	Resistor, Metal Film, 1/4 watt, 1%
R190	340K_1/4W_1%	RES 1206 340k 1/4 watt 1%
R25	360K_1/4W	RES 1206 360k 1/4W
R26	360K_1/4W	RES 1206 360k 1/4W
R27	360K_1/4W	RES 1206 360k 1/4W
R32	360K_1/4W	RES 1206 360k 1/4W
R38	360K_1/4W	RES 1206 360k 1/4W
R49	360K_1/4W	RES 1206 360k 1/4W
R50	00HM,0ohm	RES SMD 1206 0ohm
R51	00HM,0ohm	RES SMD 1206 0ohm
U8	SI8261BAC	ISOLATED DRIVE SO8
Q10	SI2309CDS-T1-E3	MOSFET, P-ch, -60V, -1.25A, 550 milliohms
R44	1K_1/10W_1%	RES 0603 1k 1/10W
R43	0_1/10W_1%	RES 0603 0 1/10W
R48	10_1/10W_1%	RES 0603 10 1/10W
R34	10_1/10W_1%	RES 0603 10 1/10W
R42	0_1/10W_1%	RES 0603 0 1/10W
C2	50V_4.7NF_X7R	CAP 0603 50V 4.7nF X7R
C38	50V_1uF_X7R	CAP 0603 50V 1uF X7R

## 9.2. List of Materials - PFC Controller Card

Table 4. PFC Controller card list of materials

Ref-Des	Part Number	Description
C44	C0603,0.1nF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C46	C0603,0.1nF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C12	C0603,0.1uF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C13	C0603,0.1uF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C45	C0603,100pF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C4	C0603,100pF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C11	C0603,10nF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C40	C0603,10nF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C41	C0603,1uF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C58	C0603,1uF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C59	C0603,1uF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C27	C0603,2.2uF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C9	C0603,4.7nF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C26	C0603,4.7uF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
C42	C0603,4.7uF	Capacitor, Ceramic, Low Inductance, vvV, [temp], [tol]
D6	D-BAT54,BAT54	Diode, Schottky, 200-mA, 30-V
D5	D-BAT54S,BAT54S	Diode, Dual Schottky, 200-mA, 30-V
D7	D-BAT54S,BAT54S	Diode, Dual Schottky, 200-mA, 30-V
D8	D-BAT54S,BAT54S	Diode, Dual Schottky, 200-mA, 30-V
D14	D-BAT54S,BAT54S	Diode, Dual Schottky, 200-mA, 30-V
R59	R0603_1%,0	Resistor, Chip, 1/16W, 1%
R60	R0603_1%,0	Resistor, Chip, 1/16W, 1%
R22	R0603_1%,1.4K	Resistor, Chip, 1/16W, 1%
R37	R0603_1%,1.6K	Resistor, Chip, 1/16W, 1%
R5	R0603_1%,100	Resistor, Chip, 1/16W, 1%
R28	R0603_1%,100	Resistor, Chip, 1/16W, 1%
R30	R0603_1%,100	Resistor, Chip, 1/16W, 1%
R31	R0603_1%,100	Resistor, Chip, 1/16W, 1%
R1	R0603_1%,10K	Resistor, Chip, 1/16W, 1%
R9	R0603_1%,10K	Resistor, Chip, 1/16W, 1%
R47	R0603_1%,10K	Resistor, Chip, 1/16W, 1%
R56	R0603_1%,10K	Resistor, Chip, 1/16W, 1%
R58	R0603_1%,10K	Resistor, Chip, 1/16W, 1%
R61	R0603_1%,10K	Resistor, Chip, 1/16W, 1%
R62	R0603_1%,10K	Resistor, Chip, 1/16W, 1%
R18	R0603_1%,1K	Resistor, Chip, 1/16W, 1%
R55	R0603_1%,1K	Resistor, Chip, 1/16W, 1%

Table 4. PFC Controller card list of materials(Continued)

Ref-Des	Part Number	Description
R55	R0603_1%,1K	Resistor, Chip, 1/16W, 1%
R29	R0603_1%,1R	Resistor, Chip, 1/16W, 1%
R21	R0603_1%,2.32K	Resistor, Chip, 1/16W, 1%
R35	R0603_1%,2K	Resistor, Chip, 1/16W, 1%
R36	R0603_1%,2K	Resistor, Chip, 1/16W, 1%
R75	R0603_1%,2K	Resistor, Chip, 1/16W, 1%
R76	R0603_1%,2K	Resistor, Chip, 1/16W, 1%
R77	R0603_1%,2K	Resistor, Chip, 1/16W, 1%
R78	R0603_1%,2K	Resistor, Chip, 1/16W, 1%
R20	R0603_1%,3.09K	Resistor, Chip, 1/16W, 1%
R2	R0603_1%,4.3K	Resistor, Chip, 1/16W, 1%
R69	R0603_1%,3.3K	Resistor, Chip, 1/16W, 1%
R70	R0603_1%,3.3K	Resistor, Chip, 1/16W, 1%
R71	R0603_1%,3.3K	Resistor, Chip, 1/16W, 1%
R72	R0603_1%,3.3K	Resistor, Chip, 1/16W, 1%
R73	R0603_1%,3.3K	Resistor, Chip, 1/16W, 1%
R23	R0603_1%,4.87K	Resistor, Chip, 1/16W, 1%
R8	R0603_1%,5.1K	Resistor, Chip, 1/16W, 1%
R10	R0603_1%,5.1K	Resistor, Chip, 1/16W, 1%
R33	R0603_1%,5.1K	Resistor, Chip, 1/16W, 1%
U1	UCD3138RGC,UCD3138RGC (1EDB7275F Infineon)	IC, Digital Power Controller

### 9.3. List of Materials - GaN E-HEMT Driver Board GS-EVB-HBDB-IMS

Table 5. GaN E-HEMT Driver Board GS-EVB-HBDB-IMS list of materials

Ref_Des	Part Number	Description
C1, C9, C16, C18	1uF	CAP, CERM, 1uF, 35 V,0402
C2, C3, C8, C10, C11, C20, C21, C22	4.7uF	CAP, CERM, 4.7uF, 35 V,0402
C4, C19	10uF	CAP, CERM, 10uF, 50 V,0402
C5, C6, C7	1uF_630V_2220	CAP CER 1UF 630V X7R 2220
C12, C13	0.1uF_0402	CAP, CER, 0.1uF, X7R, 0402
C14	68pF	CAP, CERM, 68 pF, 50 V, 0402
C15	68pF	CAP, CERM, 68 pF, 50 V, 0402
D1, D4	5.8V Zener	Zener, 5.8V, 500 mW, SOD-123
D2, D6	BAT54SW	D-SOT323_BAT
IC1, IC3	IC-78L08	LDO 8V
R1, R13	1K_0402	RES 1K
R2, R4	10_0402	RES, 1%, 0402
R3, R5	1_0402	RES, 1%, 0402
R7, R12	49.9ohm	RES, 49.9, 1%, 0.063 W, 0402
R6,R9	49.9kohm	RES,49.9k,1%, 0.063 W, 0402
T1, T2	760390014	Transformer, 475uH, SMT
U1, U2	SN6505BDBVR	1 A, 420 kHz Transformer Driver
U3, U4	SI8271	IC ISOL GATE DRIVER SINGLE

### 9.4. List of Materials - Auxiliary Power Board

Table 5. Auxiliary power board list of materials

Ref_Des	Part Number	Description
C18	0603_25V_1UF	CAP 0603 25V 1uF X7R
C4	16V_220UF_D6.3	CAP AL SMD 25V 220UF
C2	25V_100UF	CAP AL SMD 25V 100UF D6.3
C9	25V_100UF	CAP AL SMD 25V 100UF D6.3
C16	0603_50V_100PF	CAP SMD 0603 50V 100pF
C1	1206_25V_10UF	CAP SMD 1206 25V 10UF
C6	1206_25V_10UF	CAP SMD 1206 25V 10UF
C8	1206_25V_10UF	CAP SMD 1206 25V 10UF
C12	1206_25V_10UF	CAP SMD 1206 25V 10UF
C13	1206_25V_10UF	CAP SMD 1206 25V 10UF
C17	1808_1KV_0.047UF	CAP SMD 1808 1kV 0.047uF
J3	CONN_5PINS	
J1	CON_7PINS	
D4	ES3DB	DIODE SMD SMA 200V 3A
D8	ES1J	DIODE SMA 600V 1A ES1J
D5	SS1FH10	DIODE SMF 100V 1A
D7	ES07B	DIODE SMF 100V 500MA
D6	RF071MM2STR	DIODE SOD-123 200V 700mA
D3	BAV19WS-7-F	DIODE SOD323 100V 200mA
T1	EPC19_TX_4+6	

U1	ICE5AR4780BZS	IC Coolset
R4	0603_16K	RES 0603 16k 1/10W
R15	0603_91K	RES 0603 91k 1/10
R13	1206_3.3OHM	RES SMD 1206 3.3ohm 1/4W
R14	1206_3.3OHM	RES SMD 1206 3.3ohm 1/4W
R16	0603_10K	RES_0603_10K_1/10W
R10	1206_10MOHM	RES 1206 10Mohm 1/4W
R11	1206_10MOHM	RES 1206 10Mohm 1/4W
R12	1206_10MOHM	RES 1206 10Mohm 1/4W
R1	2512_100K_1W	RES SMD 2512 1W 100Kohm
R9	2512_100K_1W	RES SMD 2512 1W 100Kohm
Z2	SOD323F_22V	ZENER SOD323F 22V 500mW

## 9.5. List of Materials - GS-EVB-IMS3-66516B-GS GaN E-HEMT IMS3 Board

Table 6. GS-EVB-IMS3-66516B-GS GaN E-HEMT IMS3 board list of materials

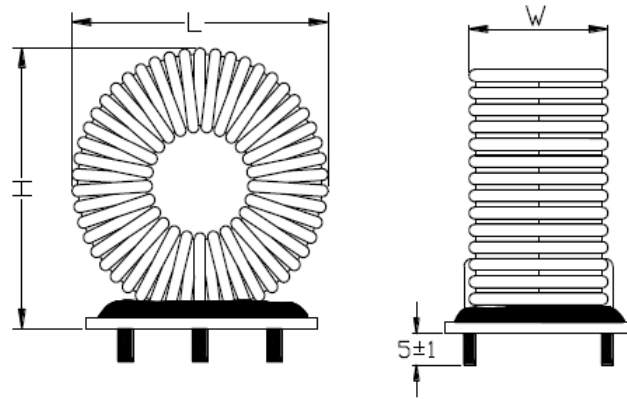
Ref_Des	Part Number	Description
J1, J2, J3	FTS-106-02-X-DV	CONN HEADER SMD 12POS 1.27MM
Q1, Q2	GS66516B	GAN TRANS E-MODE 650V 60A

P/N: PI160694V1

### Inductance Solution

$I_{rms}$	13 A
$I_{peak}$	18.382 A
$L @ 0 \text{ A}$	$526.338\mu\text{H} \pm 10\%$
$L @ 13 \text{ A}$	$284.61\mu\text{H} \text{ ( } H=94.63\text{Oe )}$
$L @ 18.382 \text{ A}$	$200.04\mu\text{H} \text{ ( } H=133.81\text{Oe )}$
Core Loss	$0.3790738 \text{ W}$
Copper Loss	$5.655\text{W}$
Total Loss	$6.033592 \text{ W}$

### Inductance View



### Inductance Size:

L×W×H  
 L: 50  
 W: 40  
 H: 51

### Inductance View



Figure 39. Specification of L2 inductor (PI160694V1) on the mother board

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References

- [1] Z. Ye, A. Aguilar, Y. Bolurian, and B. Daugherty, “GaN FET-Based High CCM Totem-Pole Bridgeless PFC,” 2014/2015 Texas Instruments Power Supply Design Seminar, [Online]. Available: [http://edu.21ic.com/uploads/down/edu/2015/1447033762\\_2508.pdf](http://edu.21ic.com/uploads/down/edu/2015/1447033762_2508.pdf)
- [2] L. Huber, Y. Jang, and M. M. Jovanovic, “Performance evaluation of bridgeless PFC boost rectifiers,” *IEEE Transactions on Power Electronics*, vol. 23, no. 3, pp. 1381-1390, May 2008.
- [3] GaN Systems, GS66516B bottom-side cooled 650 V E-mode GaN transistor datasheet, 2020, [Online]. Available: <https://gansystems.com/wp-content/uploads/2020/04/GS66516B-DS-Rev-200402.pdf>
- [4] GS66516BHB-EVBIMS22: GaN Systems, High Power IMS 2 Evaluation Platform [Online]. Available: [https://gansystems.com/wp-content/uploads/2020/05/GSP665x-EVBIMS2\\_Technical-Manual\\_Rev\\_200514.pdf](https://gansystems.com/wp-content/uploads/2020/05/GSP665x-EVBIMS2_Technical-Manual_Rev_200514.pdf)

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