TDINV3000W050B: 3000 W Single Phase Inverter Evaluation Board

1 Introduction

The TDINV3000W050B 3000W inverter kit provides an easy way to evaluate the performance advantages of GaN power FETs in various inverter applications, such as solar and uninterruptible power supplies (UPS). The kit provides the main features of a single-phase inverter in a proven, functional configuration, operating at or above 50kHz. At the core of the inverter are four TP65H050G4WS 50mΩ GaN FETs configured as a full bridge. These are tightly coupled to gate-drive circuits on a board which also includes flexible microcontroller options and convenient communication connection to a personal computer (PC). The switch-mode power signals are filtered to provide a pure sinusoidal output. For more information and the complete design files, please visit https://www.transphormusa.com

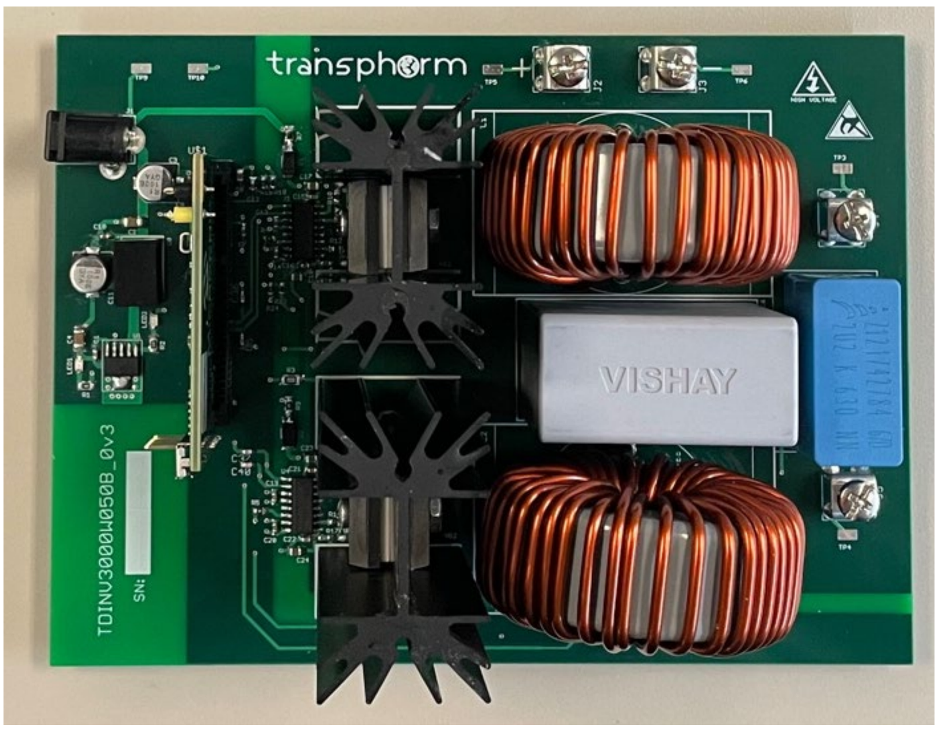

Figure 1. TDINV3000W050B 3kW Single Phase Inverter Evaluation Board

The TDINV3000W050B is for evaluation only, which is intended to demonstrate GaN FET technology and is for demonstration purposes, and no guarantees are made for standards compliance.

There are areas of this evaluation board that have exposed access to hazardous high voltage levels. Exercise caution to avoid contact with those voltages. Also note that the evaluation board may retain high voltage temporarily after input power has been removed. Exercise caution when handling.

When testing converters on an evaluation board, ensure adequate cooling. Apply cooling air with a fan blowing across the converter or across a heatsink attached to the converter. Monitor the converter temperature to ensure it does not exceed the maximum rated per the datasheet specification.

The control portion of the circuit is designed around the DSP Modules from Microchip. The source code is available along with related support information directly from Microchip. In addition to this general resource, Transphorm provides original firmware which comes loaded in flash memory on the microcontroller. The source code, configured as a complete project, is available at https://www.transphormusa.com. This project is a convenient starting point for further developments. The microcontroller itself resides on a small, removable control card, supplied by Microchip, so that different dsPIC33CK devices may be used if desired. The schematic for the TDINV3000W050B circuit board is provided at the end of this user guide document, as well in the design files.

1.1 TDINV3000W050B Kit

- TDINV3000W050B single-phase inverter assembly
- Microchip dsPIC33 plug in module card (MA330048)
- 12V power supply with U.S. adaptor

1.2 TDINV3000W050B Specifications

- Input voltage: $0V_{DC}$ - $400V_{DC}$
- Output voltage: V_{DC} / $\sqrt{2}V_{RMS}$ at 50/60Hz, the output frequency may be changed in the software; as delivered it is 60Hz
- Output power: up to 3000W
- Auxiliary supply voltage: $12V_{CC}$
- PWM frequency: 50kHz
- Power dissipation: The power dissipation in the GaN FET is limited by the maximum junction temperature. Refer to the TP65H050G4WS datasheet

2 Circuit Description

Refer to Figure 2 for a block diagram of the inverter circuit. A detailed schematic is available in the design files. The TDINV3000W050B inverter is a simple full-bridge structure. The two half-bridges are driven with pulse-width modulated (PWM) command signals to create a sinusoidal varying output. The output filter largely removes the switching frequency, leaving the 50/60Hz fundamental sinusoid. The high-frequency (50kHz+) PWM signals are generated by the Microchip microcontroller and connected directly to high speed, high voltage gate drivers. A connection for external communication to the microcontroller is provided by an isolated USB interface. Except for the high-voltage supply for the power stage, all required voltages for the control circuitry are derived from one 12V input.

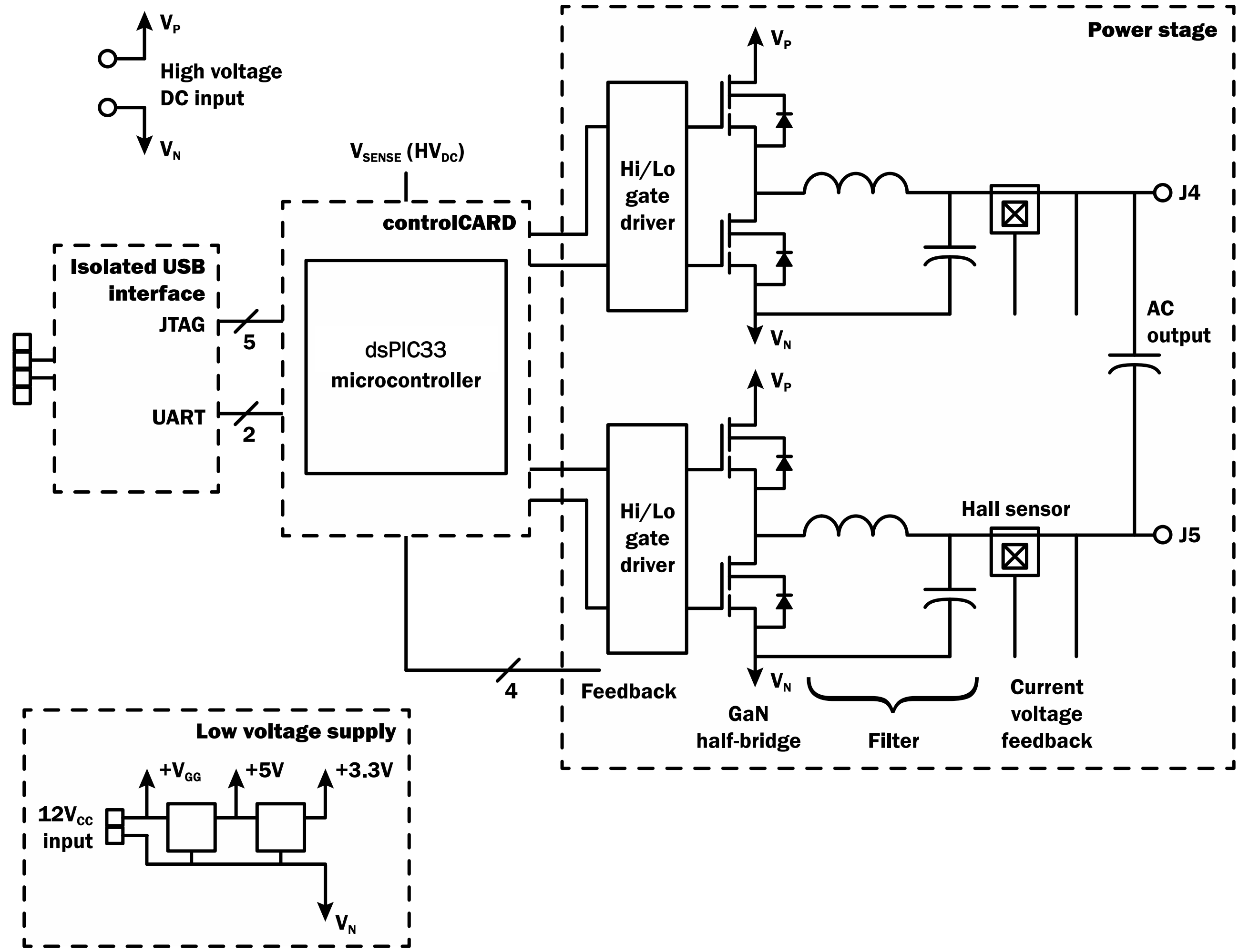

Figure 2. Circuit Block Diagram

The inverter takes advantage of diode-free operation, in which the freewheeling current is carried by the GaN FETs themselves due to their bi-directional capability, without the need of additional freewheeling diodes. For minimum conduction loss, the gates of the FETs are enhanced while they carry the freewheeling current. The high-side Vgs1 and low-side Vgs2 waveforms are therefore pairs of non-overlapping pulses, as illustrated in Figure 3 below, where A is the dead time and B is the duty cycle.

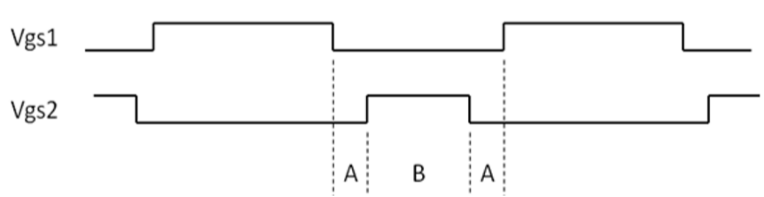

Figure 3. Gate-Drive Pulse

2.1 Gate Drivers

High-voltage integrated drivers supply the gate-drive signals for the high and low-side GaN FETs. These are 2500V isolation drivers (Silicon Labs Si82xx family), specifically chosen for high-speed operation without automatic dead time insertion. The dead time between turn-off of one GaN FET in a half-bridge and turn-on of its mate is set in the firmware.

2.2 Dead Time Control

The required form of the gate-drive signals is shown in Figure 3. The times marked A are the dead times when neither transistor is driven on. The dead time must be greater than zero to avoid shoot-through currents. The Si82xx gate drive chip ensures a minimum dead time based on the value of resistor R4 and R5, connected to the DT pin. The efficiency performance for the evaluation board is to design the dead time at around 260ns, which can be further optimized by the users to apply to different switching frequencies and power levels.

2.3 Output Filter

A simple filter on the output (L1, L2) attenuates the switching frequency, producing a clean sinusoidal waveform for output connections in terminals J4 and J5. The filter inductors and capacitors used on the demo board were chosen to provide the optional combination of benefits: low loss, good attenuation of the switching frequency, and small size. Consult the schematic and/or bill of materials to verify values; but in general, the cutoff frequency will be around 5kHz - 10kHz to accommodate 100Hz switching. The inductors have powder cores with relatively low permeability (60-90) and soft saturation characteristics. The inductors and/or capacitors can be changed to evaluate different filter designs.

2.4 Current Sensing

Hall sensors U5 and U6 provide linear current feedback to the microcontroller. These signals are used to control output power flow, to protect against over current. Note that these are placed at an intermediate point of the output filter. Refer to the bill of materials on page 8 to confirm the sensor part numbers, but typical would be the MCS1802GS-40-P sensor, which has a ±40A range (100mV/A). These parts are pin-compatible with ±5A and ±30A versions of MCS1802GS, should lower ranges be desired. Note also that resistor dividers scale the 5V outputs to the 3V range of the A/D for the microcontroller.

2.5 Communication

Communication between the microcontroller and a computer is accomplished with a mini USB cable to a JTAG microcontroller interface.

2.6 Control Card

The microcontroller resides on a removable card, which inserts in a Samtec 60 pin socket on the inverter PCB. The socket can accept many of the DSPIC series control cards from Microchip. The Microchip dsPIC33 PIM control card (MA330048) supplied with the kit provides capability to experiment with a wide variety of modulation and control algorithms. It comes loaded with firmware to allow immediate, out-of-the-box, operation. Should the user wish to use an alternative microcontroller family, an appropriate control card can be designed to insert into the Samtec 60 pin socket.

2.7 Heatsink

The two TO-247 GaN FETs on each half-bridge are mounted on a common heatsink. The heatsink is adequate for 3000W operation with forced air flow. Even higher efficiency at high power may be achieved by minimizing the temperature rise. This may be accomplished with stronger airflow. Alternately the heatsinks could be replaced with larger and more effective ones.

3 Demonstration

Power for the AC output is derived from the high-voltage DC input. This will typically be a DC power supply with output voltage up to 400V_{DC}. A 22µF, low ESR film capacitor is provided as a bypass capacitor for the high voltage supply, along with several lower valued ceramic capacitors in parallel. This is not intended to provide significant energy storage. It is assumed that the power supply or preceding DC-DC stage contains adequate output capacitance.

The control, communication, and gate-drive circuits are all powered from a single 12V input (V_{CC}). The wall-plug adaptor provided generates the appropriate voltage (typically 12V) and power level.

Note that all signals on the board are referenced to the negative terminals of the high and low voltage supplies, which are tied together on the PCB. The heatsinks are also connected to the negative terminals of the supplies.

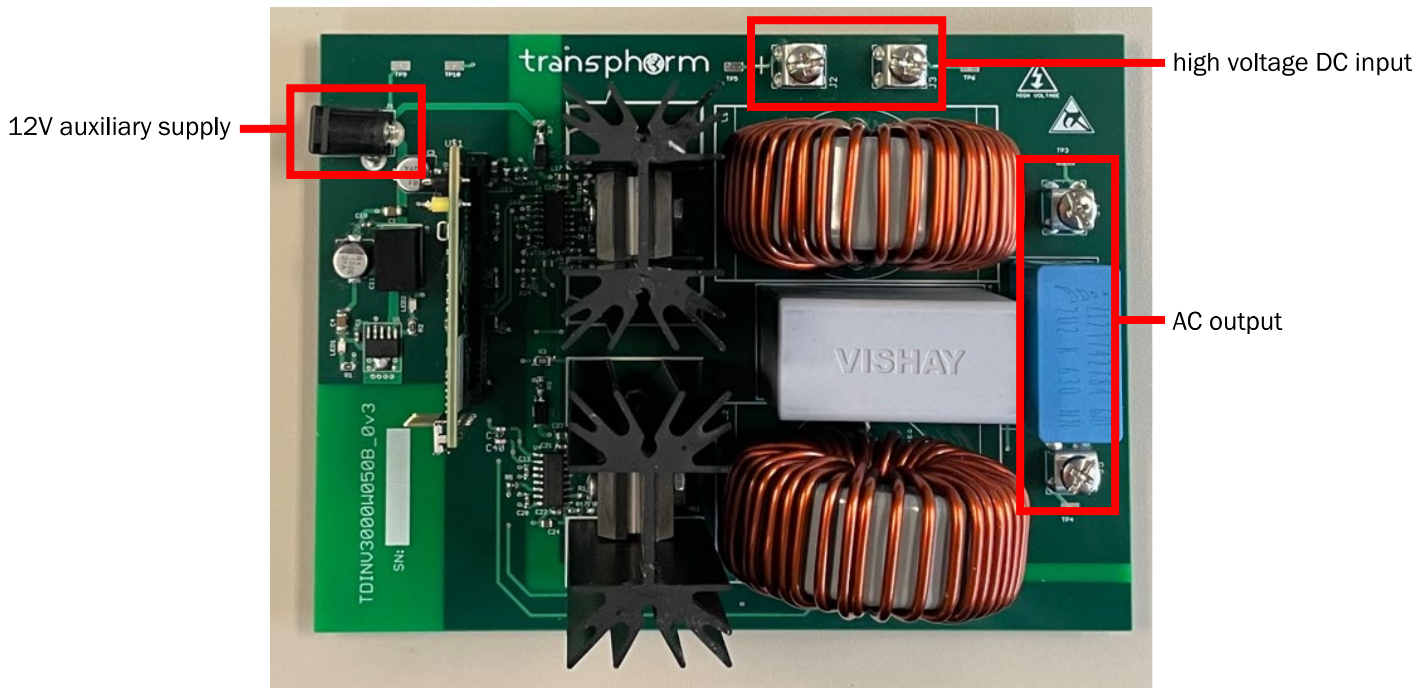

Figure 4. Connections

3.1 Power On

- Refer to Figure 4. Insert the microcontroller card to the 60-pin socket before applying any power to the board
- Before turning on the supply, connect the high-voltage power supply to the +/- inputs (J2 and J3). Do not apply too much force to the J2 and J3 connectors, as excessive force may bend and/or crack the PCB

- If a load is to be used, connect the load to the output terminals (J4 and J5). Do not apply too much force to the J4 and J5 connectors, as excessive force may bend and/or crack the PCB
- Insert the V_{CC} (12V) plug to jack J1. LED1 should illuminate, indicating power is applied to the 5V and 3.3V regulators. Depending on the specific control card used, one or more LEDs on the control card will also illuminate, indicating power is applied. A flashing LED indicates the firmware is executing
- To use the pre-loaded firmware, no computer connection is required. If a computer connection is required for code modification, connect the USB cable from the computer to the USB connector on the microcontroller
- Turn on the high-voltage DC power. The input high-voltage supply may be raised gradually while the output AC voltage also gradually increases by 0.707 times

3.2 Power Off

- Switch off input high-voltage DC supply
- Power off 12V auxiliary supply

3.3 Test Overview

Figure 5 shows typical waveforms. The negative terminal of the high-voltage supply is a convenient reference for the oscilloscope measurements, provided there are not multiple connections to earth ground.

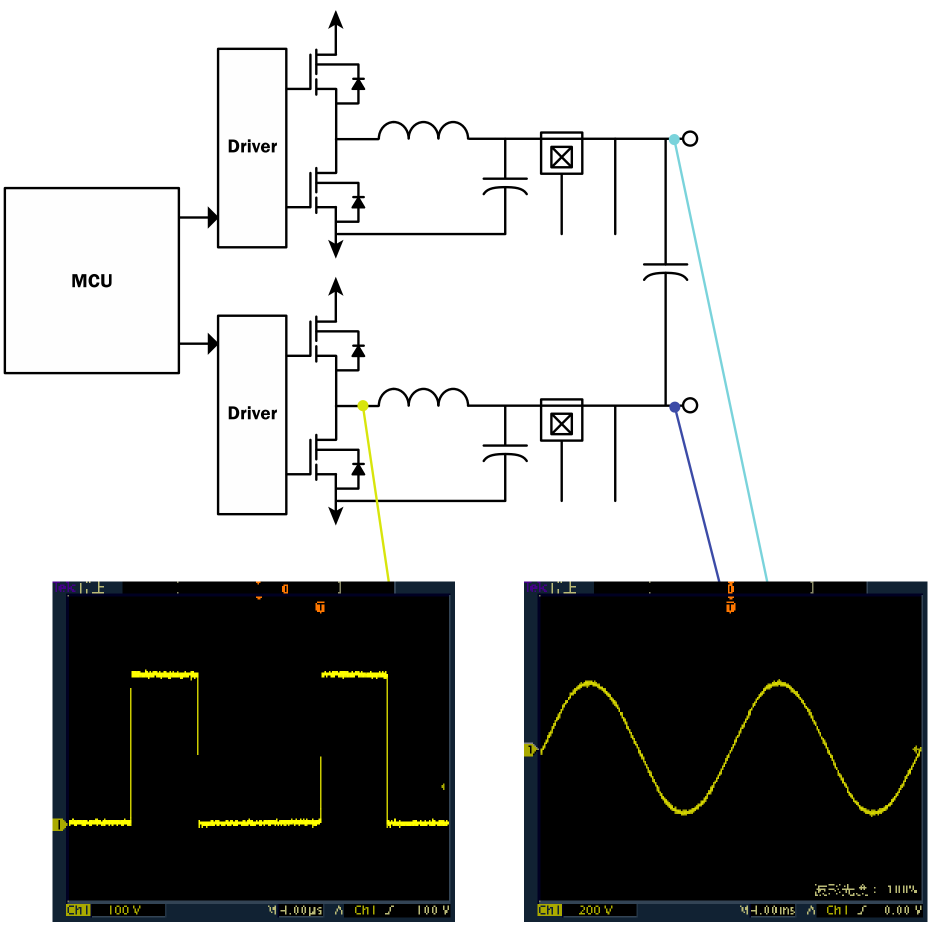

Figure 5. Typical Waveforms

3.4 Efficiency

Typical efficiency results are shown in Figure 6. These data points correspond to efficiency measurements made in still air with 30 minutes' dwell at each power level. Input power from the $400V_{DC}$ source and output power to a resistive load were measured with a Yokogawa WT1800 power analyzer.

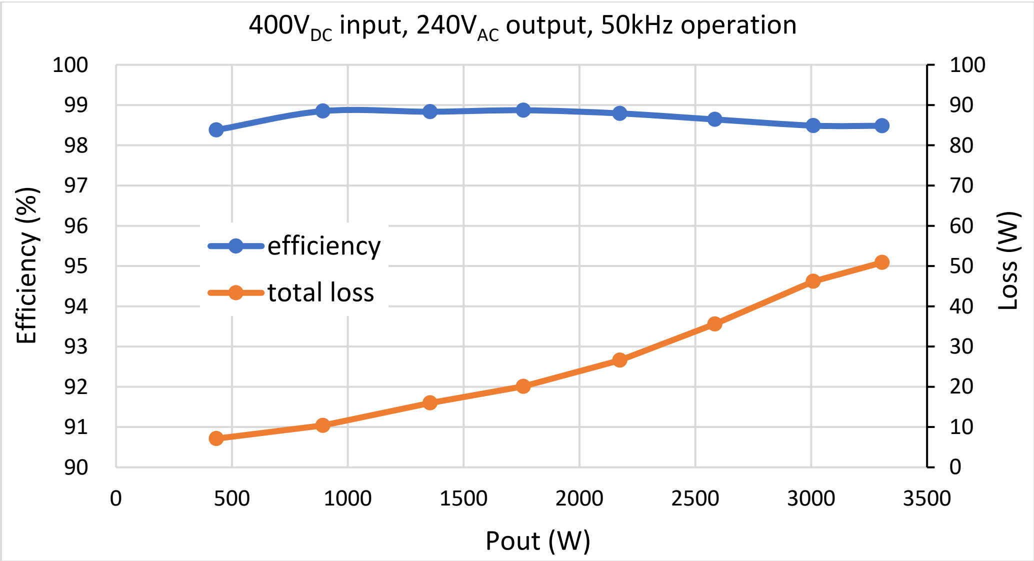

Figure 6. Typical Efficiency

3.5 Protection

The TDINV3000W050B evaluation board supports user-defined current limit thresholds in both the positive- and negative-going directions. The current limit is 30A.

3.6 Probing

The board has eight other test point locations for probing: V_{CC}, V_{DD}, SN1, SN2, GS1, GS2, and GND. To minimize inductance during measurement, the tip and the ground of the probe should be directly attached to the sensing points to minimize the sensing loop. For safe, reliable, and accurate measurement, a scope probe tip may be directly soldered to the low-side FET drain and a short ground wire soldered to the low-side FET source. See Figure 7 for an alternative that does not require soldering the probe tip.

Figure 7. High-Voltage Signal Probing Method

4 Design Details

See Figures 8 and 9 for a detailed circuit schematic and Figure 10, 11 and 12 for the PCB layout. The parts list can be found in Table 1.

Table 1. Bill Of Materials

No.	Designator	Device	Value	Qty.	Manufacturer	Part Number
1	R1	R-US_R0805	1kΩ	1	Panasonic	ERJ-6GEYJ102V
2	R2	R-US_R0805	348Ω	1	Panasonic	ERJ-6ENF3480V
3	R3	R-US_R1206	0Ω	1	Panasonic	ERJ-8GEY0R00V
4	R4, R5	R-US_R0603	150kΩ	2	Yageo	RC0603FR-07150KL
5	R7, R9	R-US_R0805	10Ω	2	Panasonic	ERJ-6GEYJ100V
6	R10, R12, R14, R16	R-US_R0603	35Ω	4	TE Connectivity	RP73PF1J34R8BTDF
7	R11, R13, R15, R17	R-US_R0603	10kΩ	4	Panasonic	ERJ-3GEYJ103V
8	R18, R23	R-US_R0603	5.23kΩ	2	Panasonic	ERJ-3EKF5231V
9	R19, R24	R-US_R0603	10.2kΩ	2	Panasonic	ERJ-3EKF1022V
10	R20, R22	R-US_R0603	0Ω	2	Panasonic	ERJ-3GEY0R00V
11	R21, R25	R-US_R0603	100kΩ	2	Panasonic	ERJ-3GEYJ104V
12	R28, R29, R30, R31	R-US_R1206	680kΩ	4	Panasonic	ERJ-P08J684V
13	R32	R-US_R1206	9.09kΩ	1	Panasonic	ERJ-8ENF9091V
14	R33, R34, R35, R36, R37, R38, R39, R40	R-US_R1206	1.6MΩ	8	Panasonic	ERJ-8ENF1604V
15	R41, R43, R44, R51	R-US_R1206	10kΩ	4	Yageo	RC1206FR-0710KL
16	R42	R-US_R1206	220Ω	1	Yageo	RC1206JR-07220RL
17	R45, R46, R48, R49	R-US_R1210	10Ω	4	Yageo	AC1210FR-0710RL
18	RSN1, RSN2, RSN3, RSN4, RSN5, RSN6, RSN7, RSN8		open	8		
19	C1, C10, C13, C14, C15, C16, C19, C20, C21, C22, C25, C27	C-USC0603	0.1uF / 25V	12	AVX	06033C104JAT2A
20	C2	C-USC1206	22uF / 25V	1	Samsung Electronics	CL31A226KAHNNNE
21	C3, C11	PANASONICFPV	100uF / 25V	2	Panasonic	EEE-FPE101XAP
22	C4	C-USC1206	10uF / 25V	1	AVX	CL31A106KAHNNNE
23	C5, C36, C37, C40	C-USC0603	10pF / 25V	4	Kemet	C0603C100J3HAC7867
24	C6	MKP1848622454P4	22uF / 450V	1	Vishay	MKP1848625454P4
25	C7, C12	C-USC0805	1nF / 25V	2	CUI Inc.	06033D102KAT2A
26	C8, C9	C-USC0805	0.1uF / 25V	2	AVX	08053C104KAT2A
27	C17, C18, C23, C24	C-EUC0805	10uF / 16V	4	Kemet	C0805C106M4PACTU
28	C26, C28	C-USC0603	open	2		
29	C29, C30	C-EUC1206	220pF / 16V	2	Wurth Electronics	885012008014
30	C31, C32	C-EUC1206	100nF / 50V	2	Samsung Electronics	CL31F104MBCNNNC
31	C33	C-USC0603	100pF / 10V	1	Wurth Electronics	885012006008
32	C34, C35, C38, C39	C-EUC1206	10nF / 630V	4	Murata	GRM31BR72J103KW01L
33	C42	B32674D6225K	2uF / 630V	1	Epcos	B32674D6225K
34	C43, C44		open	2		
35	CSN1, CSN2, CSN3, CSN4		open	4		
36	L1, L2		330uH	2	MPS	P11055
37	FB1, FB2, FB3, FB4	R-US_R0603	120Ω	4	Murata	BLM18KG121TH1D
38	D1, D2	DIODE-DO-214AC	600V / 1.7V_F	2	Fairchild	ES1J
39	LED1, LED2	LEDCHIP-LED0805	LED	2	Rohm	SML-211UTT86

40	U1	TPS79533	LDO	1	TI	TPS79533DCQR
41	U3, U4	SI8274	driver	2	SiLabs	SI8274GB1-IS1R
42	U5, U6	MCS1802GS-40-P	current sense IC	2	MPS	MCS1802GS-40-P
43	U7	OP_JC	OPA	1	Texas Instruments	OPA2350UA/2K5
44	U8	V7805-500	Regulator	1	CUI Inc.	102-1709-ND
45	Q1, Q2, Q3, Q4	TP65H050G4WS	GaN FET	4	Transphorm	TP65H050G4WS
46	J1	PJ-002AH	plug	1	CUI Inc.	PJ-002AH
47	J2, J3, J4, J5	KEYSTONE_7691	test pin	4	Keystone	7691
48	U$1	MECF-30-01-L-DV-WT	connector	1	Samtec Inc	MECF-30-01-L-DV-WT
49	HS1, HS2	529802B02500G_PINS	heatsink	2	Aavid Thermalloy	530002B02500G
50	between TP65H050G4WS (Q1, Q3) and heatsink		thermal pad	2	Aavid Thermalloy	4169G
51	screw on TP65H050G4WS to heatsink		screw	2	B&F	PMSSS 440 0063 PH
52	place under PCB		bumper cylindrical	5	3M	SJ-5003
53	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10		test point	10		

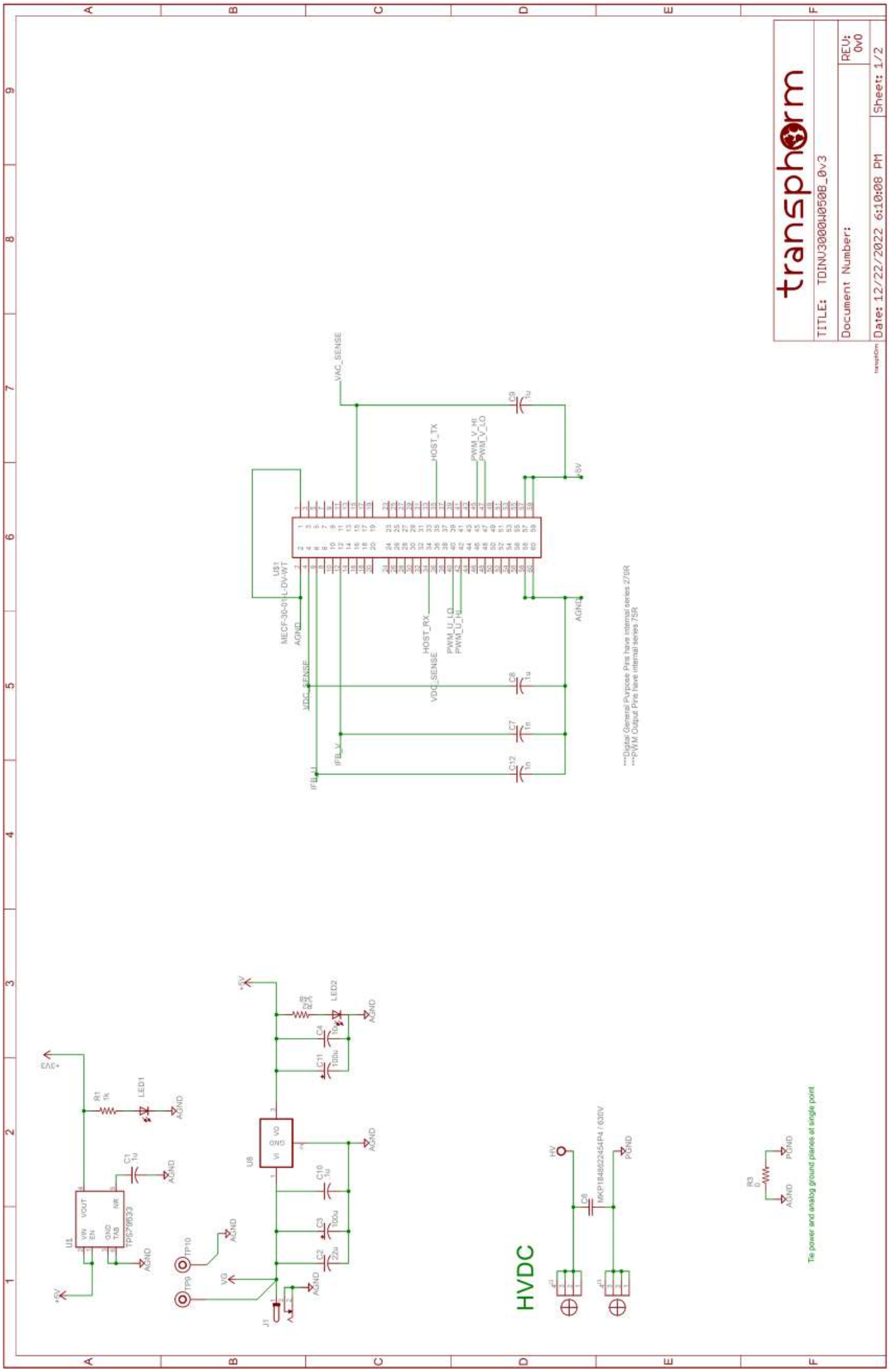

Figure 8. EVB Circuit A

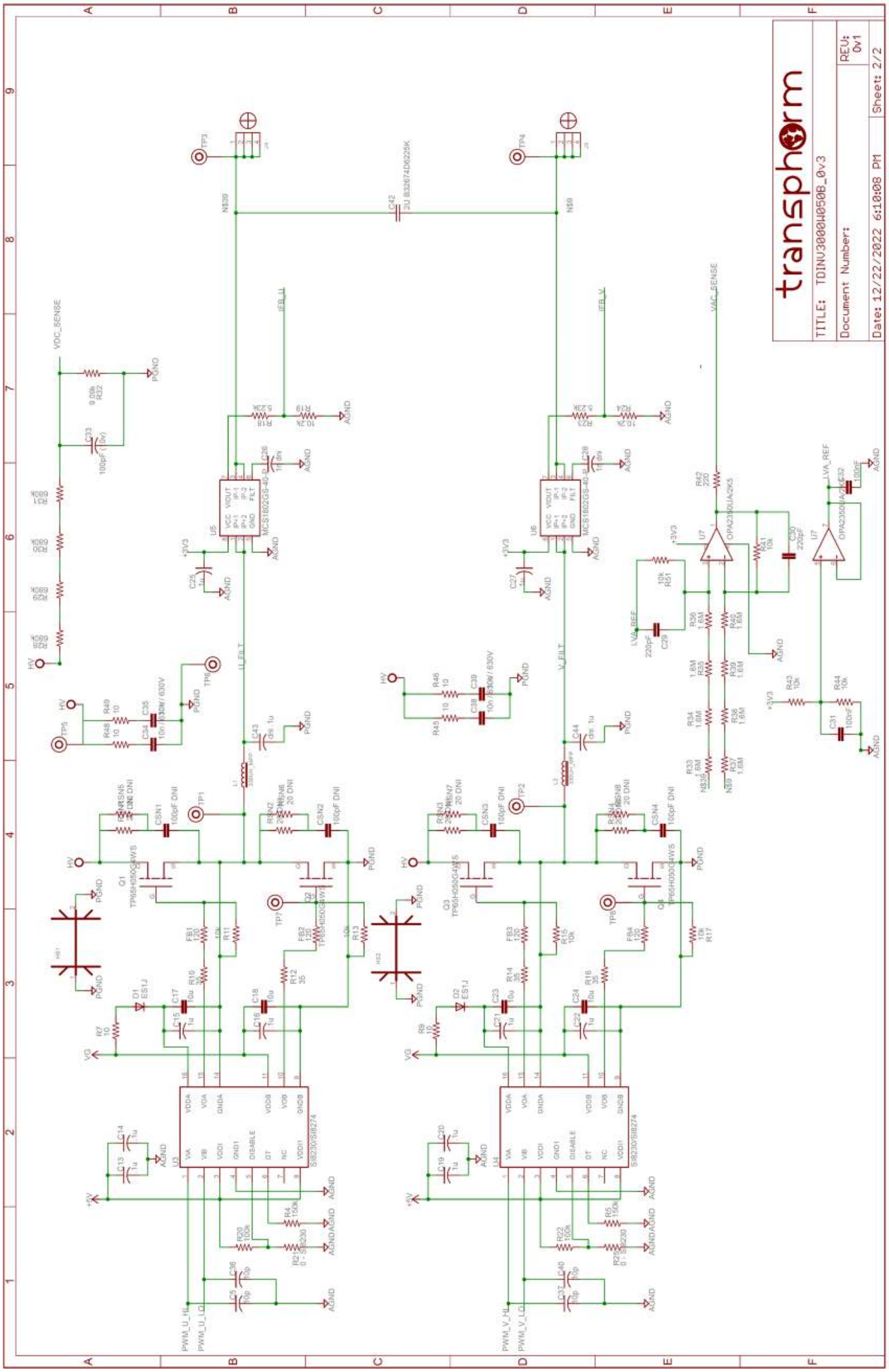

Figure 9. EVB Circuit B

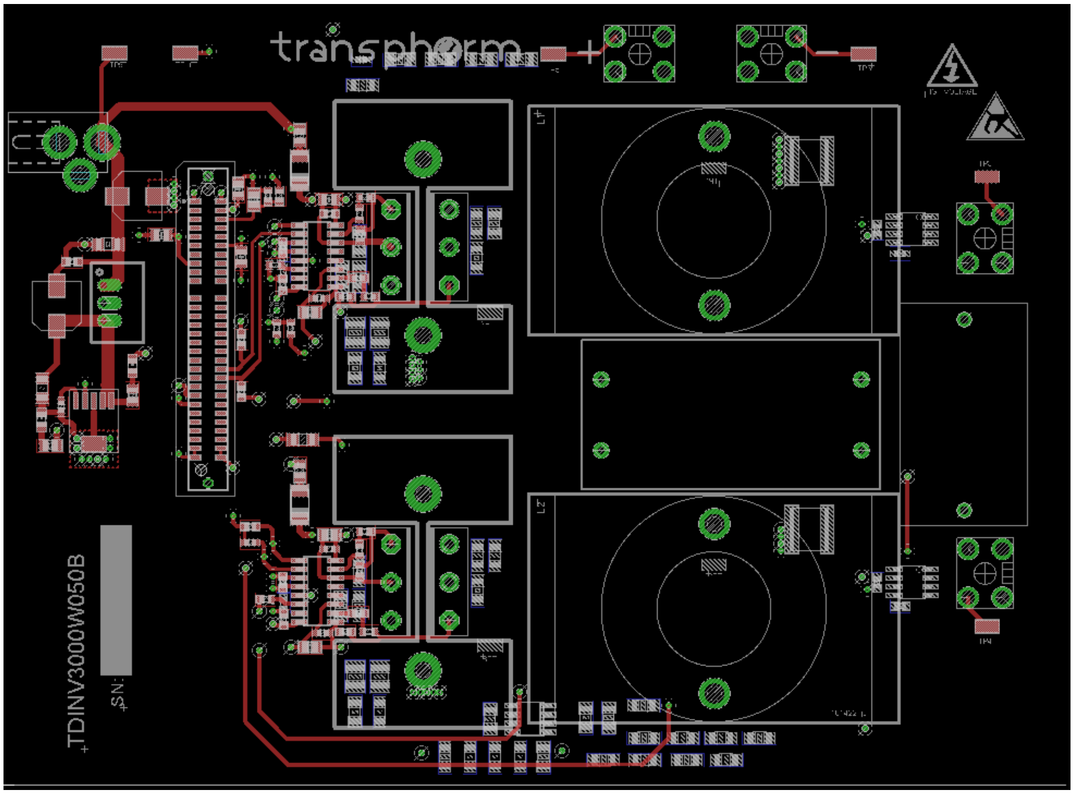

Figure 10. PCB Top Layout

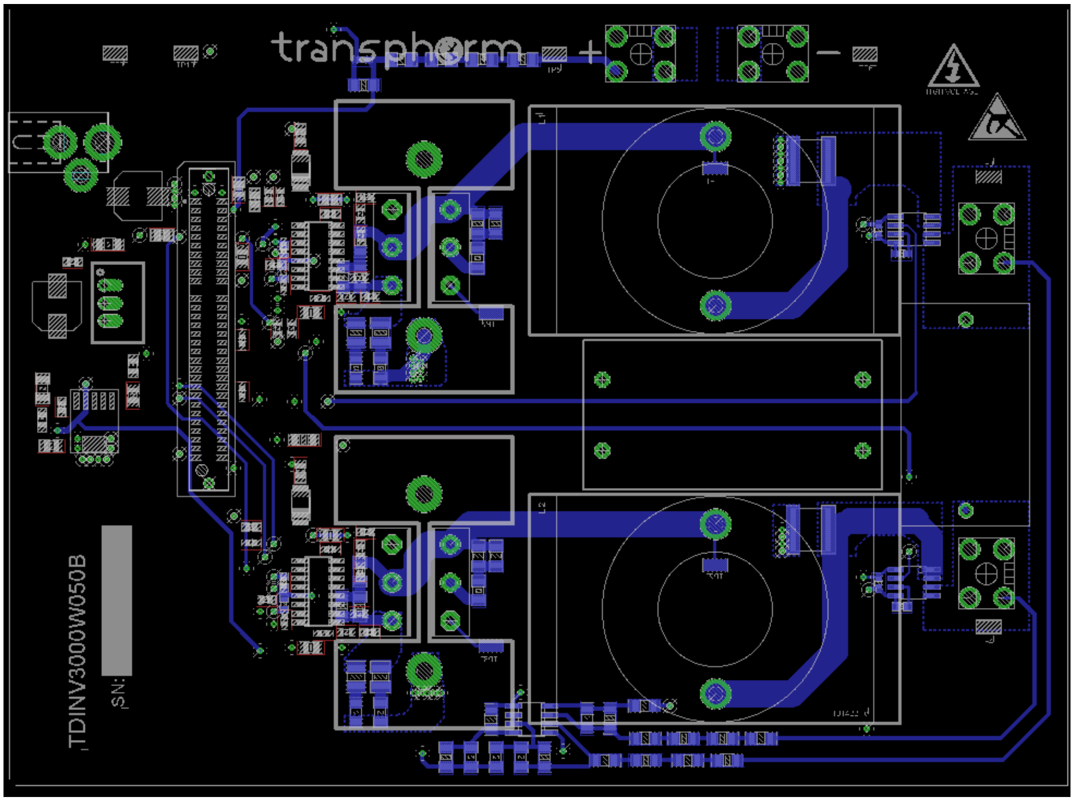

Figure 11. PCB Bottom Layout

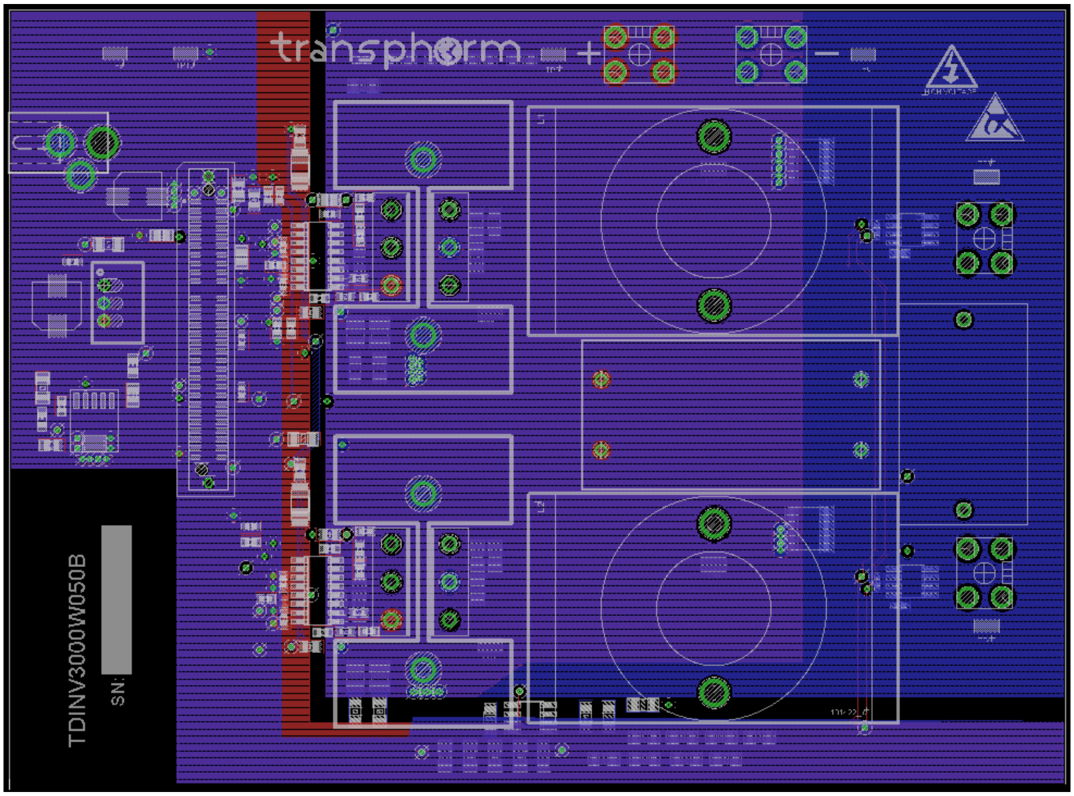

Figure 12. PCB Complete layout