

## TDHBG2500P100: 2.5kW Half-bridge Evaluation Board

### Introduction

The TDHBG2500P100 half-bridge evaluation board provides the elements of a simple buck or boost converter for basic study of switching characteristics and efficiency achievable with Transphorm's 650V GaN FETs. In either buck or boost mode the circuit can be configured for synchronous rectification. Jumpers allow use of a single logic input or separate hi/lo inputs. The high-voltage input and output can operate at up to 400Vdc, with a power output of up to 2.5kW. The inductor provided is intended for efficient operation at 100kHz, although other inductors and other frequencies may be easily used.

The TDHBG2500P100-KIT is for evaluation purposes only.



Figure 1. TDHBG2500P100 half-bridge evaluation board

## Warnings



## TDHGB2500P100 input/output specifications

### High-voltage input/output: 400Vdc max

Auxiliary supply (J1): 10V min, 18V max

Logic inputs: nominal 0V-5V

Pulse-generation circuit:  $V_{lo} < 1.5V$ ,  $V_{hi} > 3.0V$

Direct connection to gate driver:  $V_{lo} < 0.8V$ ,  $V_{hi} > 2.0V$

SMA coaxial connectors

Switching frequency: configuration-dependent

Lower limit determined by peak inductor current

Upper limit determined by desired dead-time and power dissipation

Power dissipation in the GaN FET is limited by the maximum junction temperature. Refer to the [TPH3212PS datasheet](#).

## Circuit description

The circuit comprises a simple half-bridge featuring two TPH3212PS GaN FETs, as indicated in the block diagram of Figure 2. Two high-voltage ports are provided which can serve as either input or output, depending on the configuration—boost or buck. In either case one FET acts as the active power switch while the other carries the freewheeling current. The latter device may be enhanced, as a synchronous rectifier, or not. With GaN FETs the reverse recovery charge is low and there is no need for additional freewheeling diodes. Two input connectors are provided which can be connected to sources of logic-level command signals for the hi/lo gate driver. Both inputs may be driven by off-board signal sources; or alternatively, a single signal source may be connected to an on-board pulse-generator circuit which generates the two non-overlapping pulses. Jumpers determine how the input signals are used.

An inductor is provided as a starting point for investigation. This is a 440µH toroid intended to demonstrate a reasonable compromise between size and efficiency for power up to 2.5kW at a switching frequency of 100kHz.

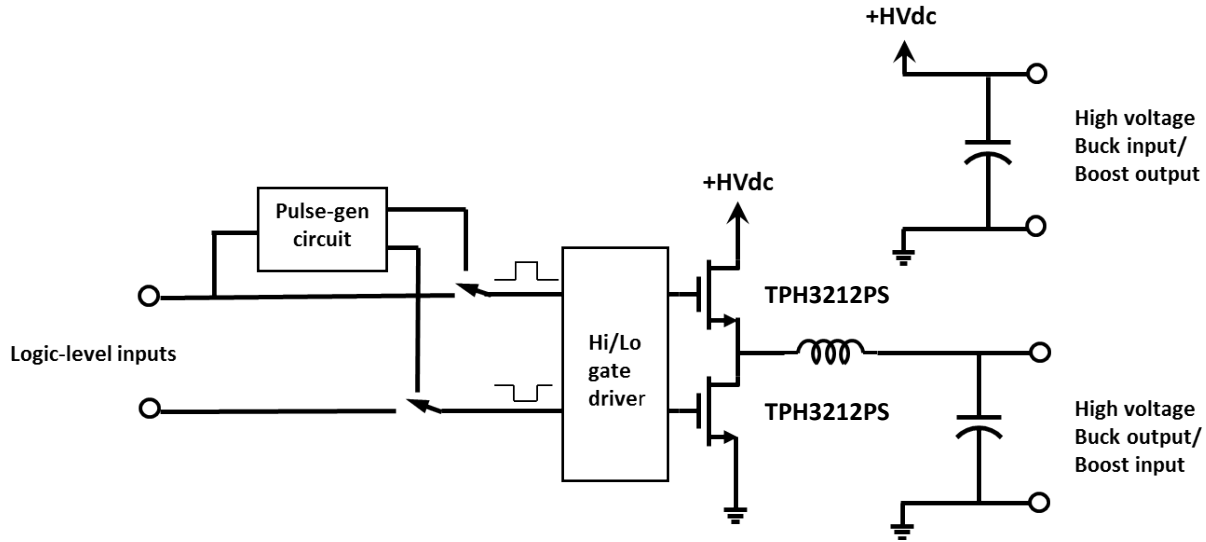


Figure 2. Functional block diagram

## Using the board

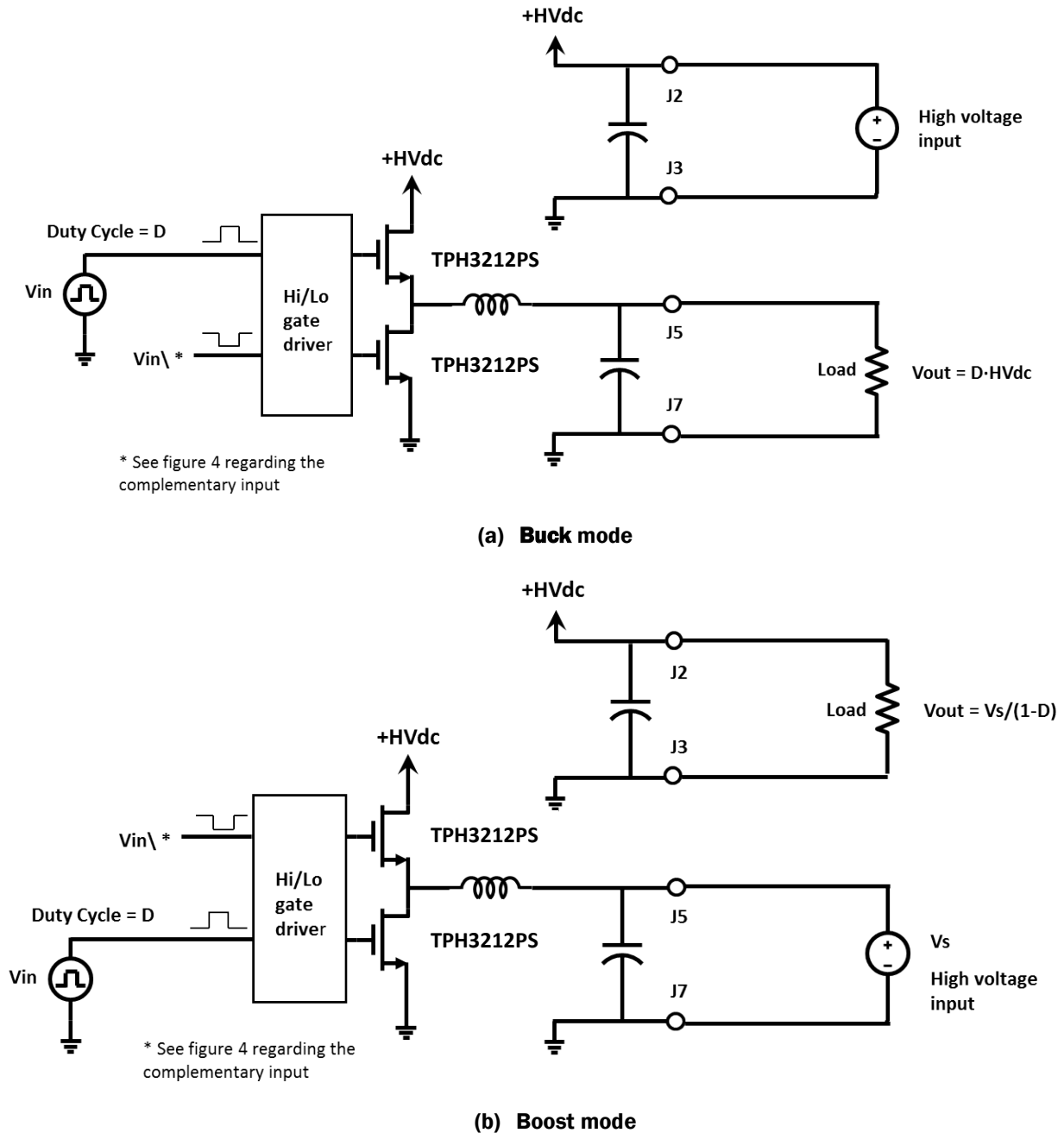
The board can be used for evaluation of basic switching functionality in a variety of circuit configurations. It is not a complete circuit, but rather a building block. It can be used in steady-state DC/DC converter mode with output power up to 2.5kW.

When operating the board at high power (>1000W), an external fan should be used to cool the heatsink.

## Configurations

Figure 3 shows the basic power connections for buck and boost modes. For buck mode, the HVdc input (terminals J2, J3) is connected to the high-voltage supply and the output is taken from terminals J5 and J7. For boost mode, the connections are reversed.

Note that in boost mode a load must be connected. The load current affects the output voltage up to the transition from DCM to CCM. In buck mode the load may be an open circuit.



**Figure 3. Supply and load connections for buck (a) and boost (b) configurations**

Figure 4 shows possible configurations for the gate-drive signals. In Figure 4(a), a single input from an external signal source is used together with the on-board pulse generation circuit. J4 is used, J6 is left open circuit. Jumpers JP1 and JP2 are in the top position, as shown. If the high-side transistor is to be the active switch (e.g. buck mode), then the duty cycle of the input source should simply be set to the desired duty cycle (D). If the low-side transistor is to be the active switch (e.g. boost mode) the duty cycle of the input source should be set to (1-D), where D is the desired duty cycle of the low-side switch. This configuration results in synchronous rectification. If it is desired to let the device carrying the freewheeling current act as a diode, then the appropriate jumper should be placed so that the pull-down resistor is connected to the driver. Figure 4(b) shows a buck-mode

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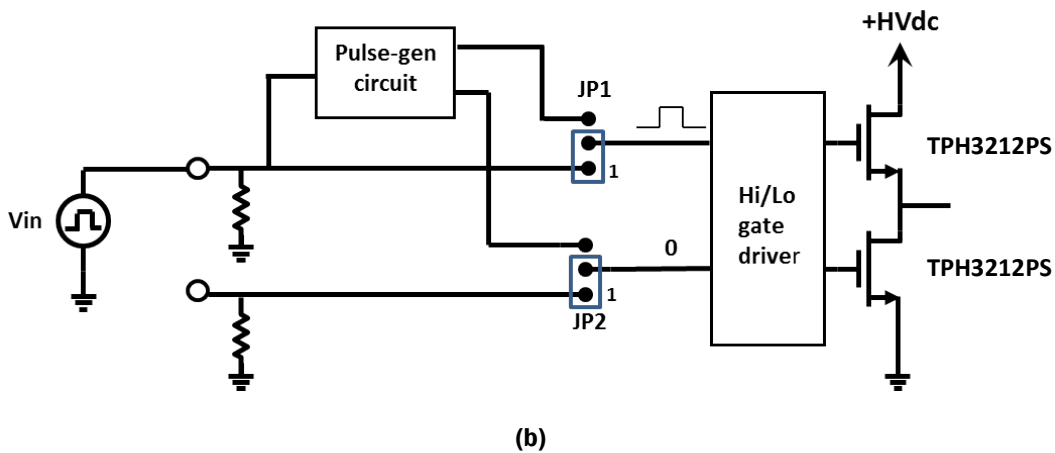
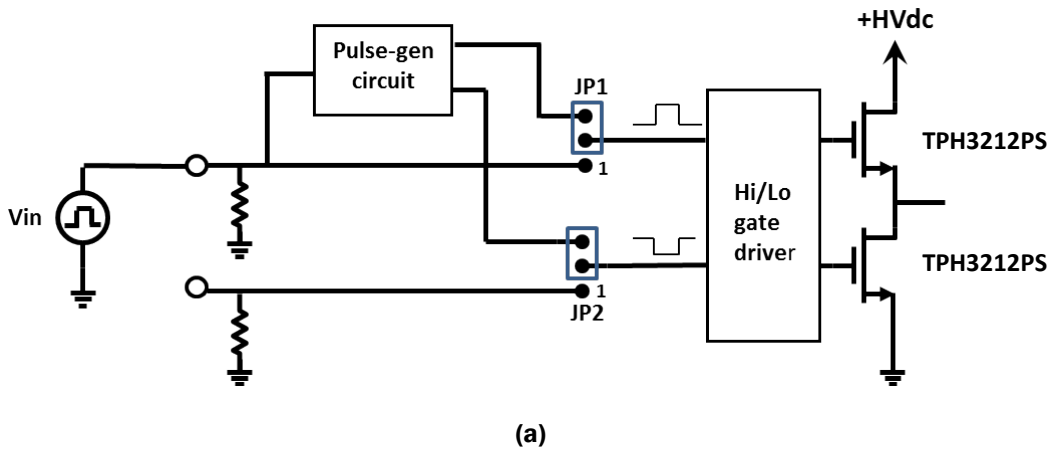
configuration where the low-side device is not enhanced. Finally, Figure 4(c) shows use of two external signal sources as inputs to the gate driver.

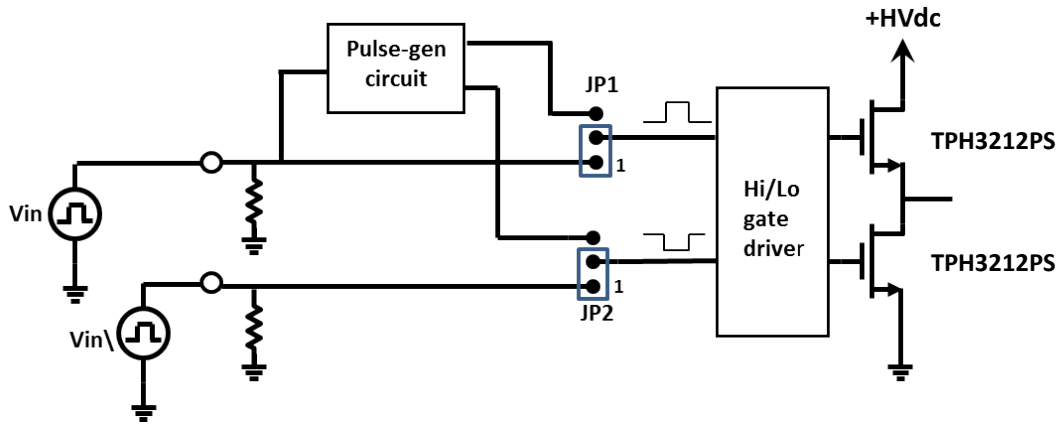
For any configuration, an auxiliary supply voltage of 10V-18V must be supplied at connector J1.

Pull-down resistors R5 and R6 have a value of 4.99k. If a 50Ω signal source is used and 50Ω termination is desired, then R5 and R6 may be replaced (or paralleled) with 1206 size 50Ω resistors.

## Boost mode/buck mode operation

For buck mode operation, with input voltage of 400V and output voltage of 48V; 50A max output current is achievable at 2500W with duty cycle of 12%. A typical 400V<sub>in</sub> - 200V<sub>out</sub> buck operation with 50% duty cycle, 6.5A max output current is seen at 2500W. On the other hand, for 200V<sub>in</sub> - 400V<sub>out</sub> boost mode operation at 2.5kW, 12.5A max output current can be reached with a duty cycle of 50%. Thermal cooling must be enforced for high current switching at all times.



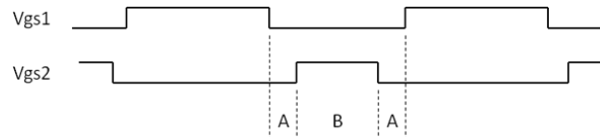


(c)

**Figure 4. Input configurations**  
 (a) using a single source for either buck or boost mode  
 (b) buck mode without synchronous rectification  
 (c) using two signal sources

## Dead time control

The required form of the gate-drive signals is shown in Figure 5. 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 Si8230BB gate drive chip ensures a minimum dead time based on the value of resistor R7, connected to the DT input. The dead time in ns is equal to the resistance in k $\Omega$  x 10, so the default value of 12k corresponds to 120ns. This will add to any dead time already present in the input signals. The on-board pulse generator circuit; for example, creates dead times of about 60ns. The resulting dead time at the gate pins of Q1 and Q2 is about 240ns. Either shorting or removing R7 will reduce the dead time to 60ns.



**Figure 5. Non-overlapping gate pulses**

## Design details

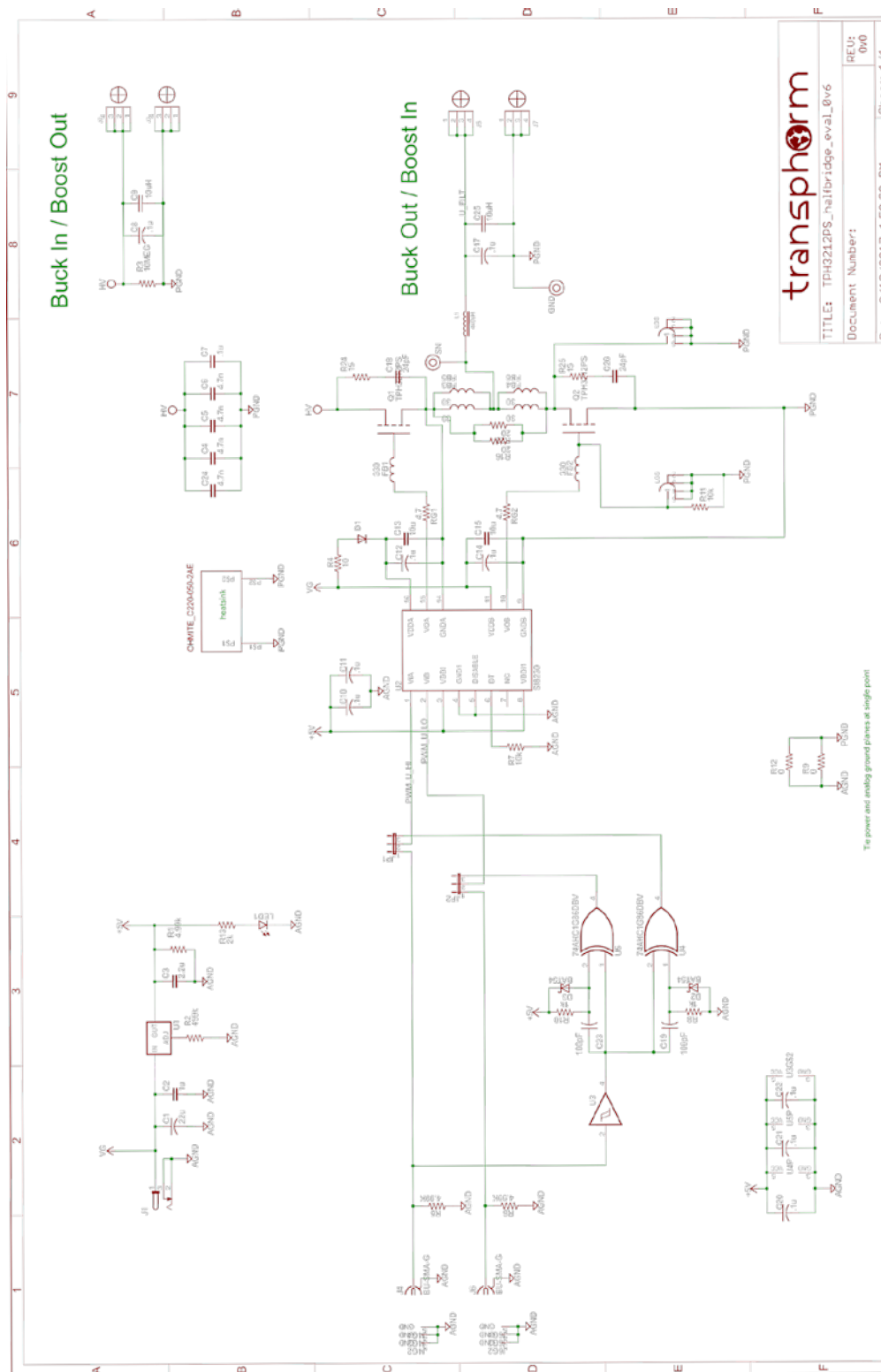
See Figure 6 for a detailed circuit schematic and Figure 7 for the PCB layers (also included in the [design files](#)). The parts list can be found in Table 1.

**Table 1. TDHBG2500P100 half-bridge evaluation board bill of materials (BOM)**

| Designator         | Qty | Value        | Description    | Package  | Part Number      | Manufacturer      |
|--------------------|-----|--------------|----------------|----------|------------------|-------------------|
| U3                 | 1   |              | 74LVC1G17DBV   | SOT23-5  | SN74LVC1G17DBVR  | Texas Instruments |
| D1, D4, D5         | 3   |              | DIODE-DO-214AC | DO-214AC | ES1J             | Fairchild         |
| FB1, FB2           | 2   | 300 $\Omega$ | FB0603         | 603      | MMZ1608S301ATA00 | TDK               |
| FB3, FB4, FB5, FB6 | 2   | 30 $\Omega$  | FB0805         | 805      | BLM21SN300SZ1D   | Murata            |
| JP1, JP2           | 2   |              | JP2E           | JP2      | 68001-403HLF     | FCI               |

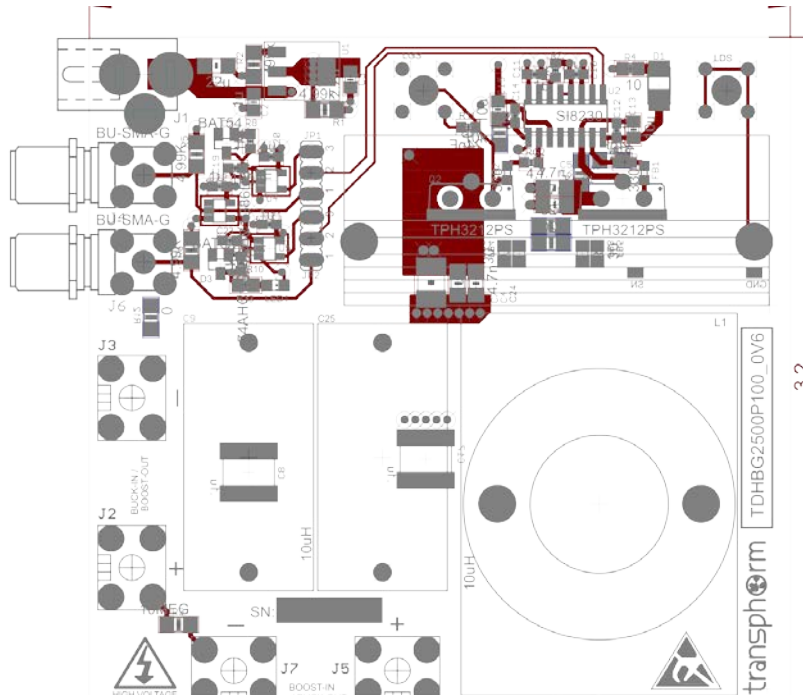
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| Designator                        | Qty | Value  | Description                              | Package       | Part Number              | Manufacturer      |
|-----------------------------------|-----|--------|------------------------------------------|---------------|--------------------------|-------------------|
| J2, J3, J5, J7                    | 4   |        | KEYSTONE_7691                            | KEYSTONE_7691 | 7691                     | Keystone          |
| LED1, LED2, LED3                  | 3   |        | LEDCHIP-LED0805                          | CHIP-LED0805  | SML-211UTT86             | Rohm              |
| U1                                | 1   |        | LT3082                                   | SOT223-3      | LT3082EST#PBF            | Linear Technology |
| J1                                | 1   |        | PJ-002AH                                 | PJ-002AH      | PJ-002AH                 | CUI               |
| LDS, LGS                          | 2   |        | TEKTRONIX-PCB                            | TEKTRONIX-PCB | 131-4353-00              | Tektronix         |
| C7                                | 1   | 0.1µF  | C-EUC1812                                | C1812         | C1812V104KDRACU          | Kemet             |
| C10, C11, C12, C14, C20, C21, C22 | 7   | 0.1µF  | C-USC0603                                | C0603         | 06033C104JAT2A           | AVX               |
| C8, C16, C17                      | 3   | 0.1µF  | C-USC2225K                               | C2225K        | VJ2225Y104KXGAT          | Vishay            |
| R15                               | 1   | 0Ω     | R-US_R0603                               | R0603         | RC0603FR-070RL           | Yageo             |
| R16, R23                          | 2   | 20Ω    | R-US_R1206                               | R1206         | RNCP1206FTD20R0          | Stackpole         |
| R9, R12                           | 2   | 0Ω     | R-US_R1206                               | R1206         | ERJ-8GEYOR00V            | Panasonic         |
| R4                                | 1   | 10Ω    | R-US_R0805                               | R0805         | ERJ-P06J100V             | Panasonic         |
| R14                               | 1   | 100kΩ  | R-US_R0603                               | R0603         | ESR03EZPJ104             | Rohm              |
| C19, C23                          | 2   | 100pF  | C-USC0603                                | C0603         | 06035A101FAT2A           | AVX               |
| R3                                | 1   | 10MΩ   | R-US_R1206                               | R1206         | HVC1206T1005JET          | Stackpole         |
| R7, R11                           | 2   | 10kΩ   | R-US_R0603                               | R0603         | ERJ-3GEYJ103V            | Panasonic         |
| C13, C15                          | 2   | 10µF   | C-EUC0805                                | C0805         | C0805C106M4PACTU         | Kemet             |
| R8, R10                           | 2   | 1kΩ    | R-US_R0603                               | R0603         | RC0603FR-071KL           | Yageo             |
| C2                                | 1   | 1µF    | C-EUC0805                                | C0805         | CC0805ZRY5V8BB105        | Yageo             |
| C3                                | 1   | 2.2µF  | C-EUC0805                                | C0805         | C2012X5R1E225K125AC      | TDK               |
| C1                                | 1   | 22µF   | C-USC1206                                | C1206         | CL31A226MOCLNNC          | Samsung           |
| R13                               | 1   | 2kΩ    | R-US_R0805                               | R0805         | RC0805FR-072KL           | Yageo             |
| C4, C5, C6, C24                   | 4   | 4.7nF  | C-EUC1206                                | C1206         | C1206C472KDRACU          | Kemet             |
| R1, R5, R6                        | 6   | 4.99kΩ | R-US_R1206                               | R1206         | RMCF1206FT4K99           | Stackpole         |
| R17, R18, R19, R20, R21, R22      | 6   | 560kΩ  | R-US_R0805                               | R0805         | ESR10EZPJ564             | Rohm              |
| R2                                | 1   | 499kΩ  | R-US_R1206                               | R1206         | RMCF1206FT499K           | Stackpole         |
| C9, C18                           | 2   | 10µH   | 10uH                                     | EPCOS_B32674  | B32794D2106K             | Epcos             |
| U4, U5                            | 2   |        | 74AHC1G86DBV                             | SOT23-5       | SN74AHC1G86DBVR          | Texas Instruments |
| D2, D3                            | 2   |        | BAT54                                    | SOT23         | BAT54W                   | NXP               |
| J4, J6                            | 2   |        | BU-SMA-G                                 | BU-SMA-G      | 5-1814832-1              | TE Connectivity   |
| U\$3                              | 1   | 460µH  | Inductor                                 |               | CWS-1MP-12640            | CWS               |
| HS1                               | 1   |        | HEATSINKC220-050-2AE                     |               | C220-050-2AE             | Ohmite            |
| U2                                | 1   |        | SI8230                                   | SOIC16N       | SI8230BB-D-IS            | SiLabs            |
| Q1, Q2                            | 2   | 72mΩ   | TPH_TO220VERT_TRI                        | TO-220        | TPH3212PS                | Transphorm        |
|                                   | 2   |        | Thermal pad between TPH3212 and heatsink |               | SP2000-0.015-00-54       | Bergquist         |
|                                   | 2   |        | 4-40 screw                               |               | 9900                     | Keystone          |
|                                   | 2   |        | Nylon washer shoulder                    |               | 3049                     | Keystone          |
|                                   | 1   | 12V    | Adaptor                                  |               | TRG10R120-11E03-Level-VI | Cincon            |
|                                   | 4   |        | Bumper cylin 0.312" dia blk              |               | SJ61A1                   | 3M                |

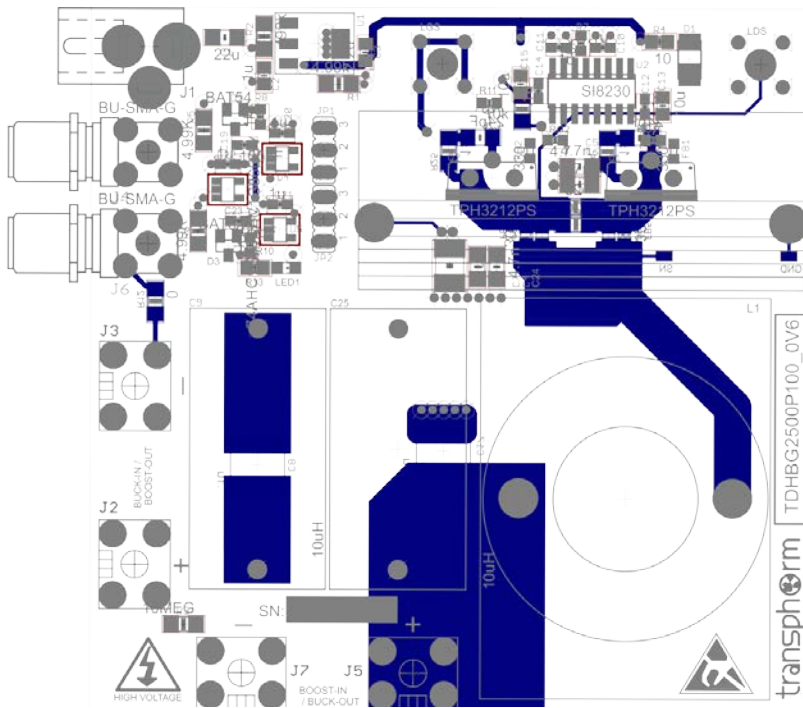


**Figure 6. Detailed circuit schematic**

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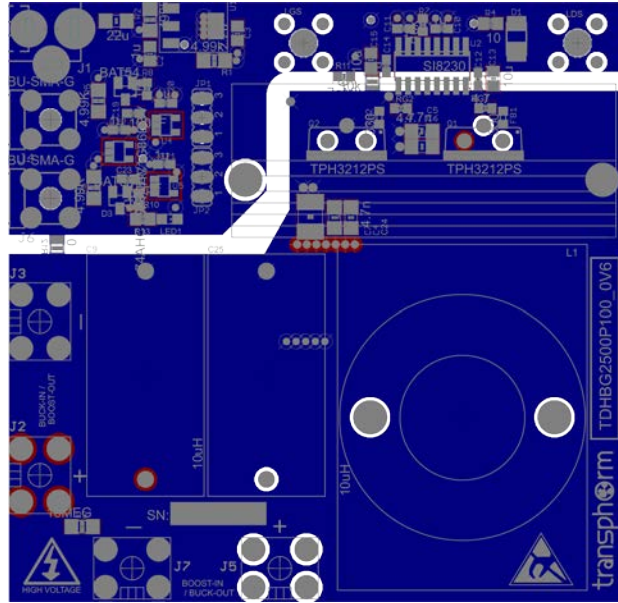


(a) PCB top layer



(b) PCB bottom layer

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(c) PCB inner layer 2 (ground plane) + inner layer 3 (power plane)

Figure 7. PCB layers

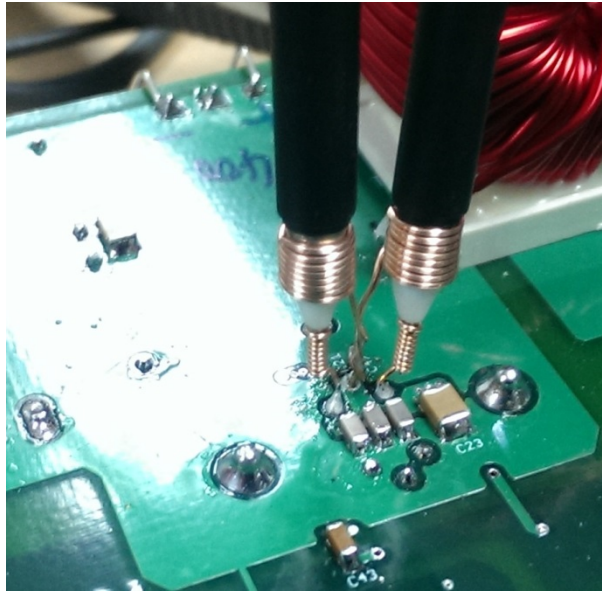
## Probing

Plated through-holes labeled test points (LGS and LDS) are provided for probing the low-side gate pulse and half-bridge switching node waveform. In order 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 8 for an alternative that does not require soldering the probe tip.

## WARNINGS:

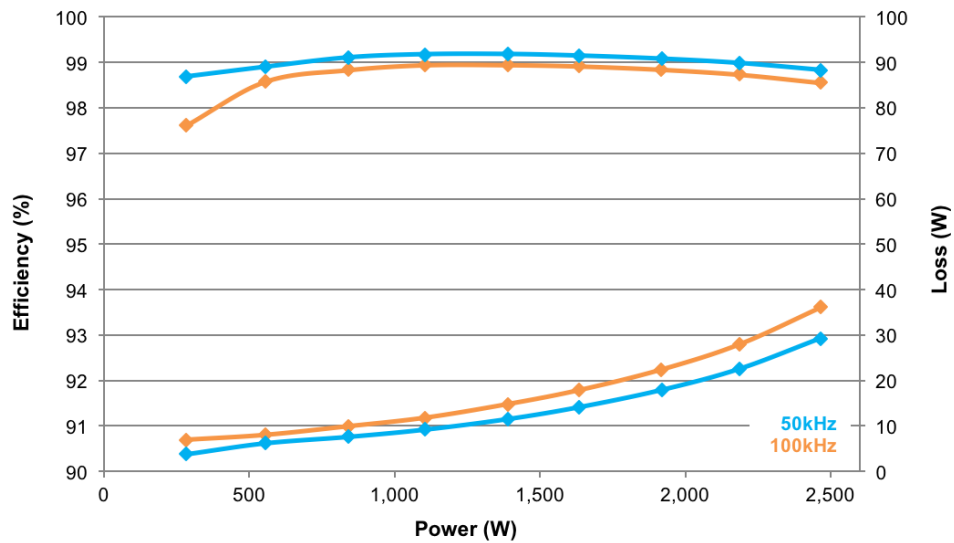
There is no specific protection against over-current or over-voltage on this board.

If the on-board pulse generation circuit is used in boost mode, a zero input corresponds to 100% duty cycle for the active low-side switch.



**Figure 8. Low-inductance probing of fast, high-voltage signals**

Efficiency has been measured for this circuit in boost mode with 200Vdc in and 400Vdc out, switching at 50kHz and 100kHz (Figure 9).



**Figure 9. Efficiency for a boost 200V:400V converter**



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