

# GS66508T-EVBDB2/GS66516T-EVBDB2 GaN E-HEMT Daughter Board and GS665MB-EVB Evaluation Platform

## User's Guide

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### DANGER!

This evaluation kit is designed for engineering evaluation in a controlled lab environment and **should be handled by qualified personnel ONLY**. High voltage will be exposed on the board during the test and even brief contact during operation may result in severe injury or death.

Never leave the board operating unattended. After it is de-energized, always wait until all capacitors are discharged before touching the board.



### CAUTION

This product contains parts that are susceptible to damage by electrostatic discharge (ESD). Always follow ESD prevention procedures when handling the product.

## Overview

The GS665XXT-EVBDB2 daughter board evaluation kit consists of two GaN Systems 650V GaN Enhancement-mode HEMTs (E-HEMTs) and all necessary circuits including half bridge gate drivers, isolated power supplies and an optional heatsink to form a functional half bridge power stage. It allows users to easily evaluate the GaN E-HEMT performance in any half bridge-based topology, either with the universal mother board (P/N: GS665MB-EVB) or users' own system design for quick prototyping.

## Features

- Serves as a reference design and evaluation tool as well as deployment-ready solution for easy in-system evaluation.
- Vertical mount style with height of 35mm, which fits in majority of 1U design and allows evaluation of GaN E-HEMT in traditional through-hole type power supply board.
- Current shunt position for switching characterization testing
- Universal form factor and footprint for all products

The daughter board and universal mother board ordering part numbers are below:

Table 1 Ordering part numbers

| Part Number     | GaN E-HEMT P/N: | Description                                                                   |
|-----------------|-----------------|-------------------------------------------------------------------------------|
| GS66508T-EVBDB2 | GS66508T        | GaN E-HEMT top side cooled 650V/30A, 50mΩ, Broadcom isolated driver ACPL-P346 |
| GS66516T-EVBDB2 | GS66516T        | GaN E-HEMT top side cooled 650V/60A, 25mΩ, Broadcom isolated driver ACPL-P346 |
| GS665MB-EVB     | GS665MB-EVB     | Universal 650V Mother Board                                                   |

## Control and Power I/Os

The daughter board GS665XXT-EVBDB2 circuit diagram is shown in Figure 1. The control logic inputs on 2x3 pin header J1 are listed below:

Table 2 Control pins

| Pin  | Description                                                                                                                                                                                                                                                                                        |
|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ENA  | Enable input. Internally pulled up to V <sub>CC</sub> . A low logic disables all PWM gate drive outputs.                                                                                                                                                                                           |
| VCC  | Auxillary power supply input for logic circuit and gate driver. The daughter board has 2 isolated 5V to 10V DC/DC power supplies (split +6V / -4V) for top and bottom E-HEMTs                                                                                                                      |
| VDRV | Optional 9V gate drive power input. This pin allows users to supply separate gate drive power supply. By default V <sub>DRV</sub> is connected to V <sub>CC</sub> on the daughter board via a 0 ohm jumper FB1. If bootstrap mode is used for high side gate drive, connect V <sub>DRV</sub> to 9V |
| PWMH | High side PWM logic input for top switch Q1. It is compatible with 3.3V and 5V                                                                                                                                                                                                                     |
| PWML | Low side PWM logic input for bottom switch Q2. It is compatible with 3.3V and 5V                                                                                                                                                                                                                   |
| 0V   | Logic inputs and gate drive power supply ground return.                                                                                                                                                                                                                                            |

### Power pins

- VDC+: Input DC Bus voltage
- VSW: Switching node output
- VDC-: Input DC bus voltage ground return. Note that control ground 0V is isolated from VDC-.

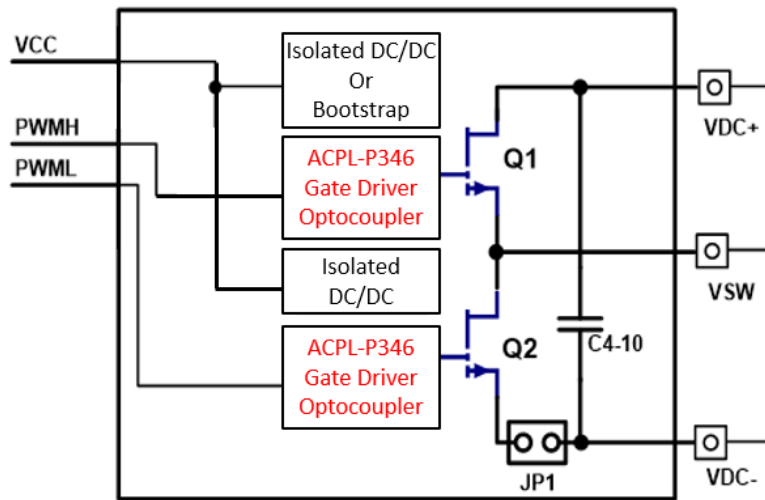


Figure 1 GS66508T/6516T-EVBDB2 Evaluation Board Block Diagram

## GS66508T/GS66516T-EVBDB2 half bridge daughter board

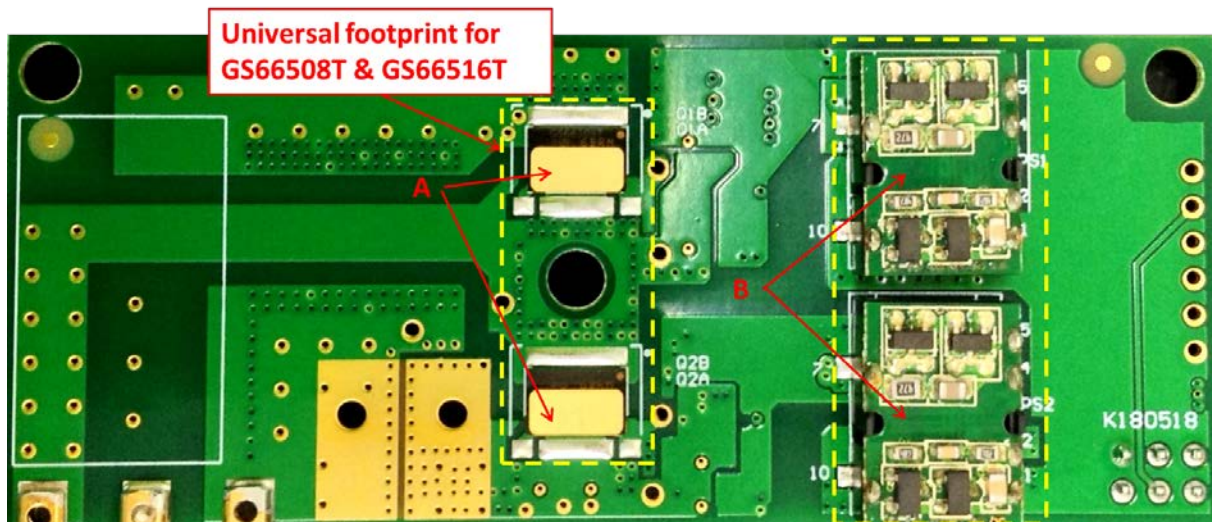


Figure 2 GS66508T/GS66516T-EVBDB2 bottom side (without heatsink)

- 2x GaN Systems 650V E-HEMT GS66508T (30A/50mΩ) or GS66516T (60A/25 mΩ). The PCB footprints are universal and compatible for both packages
- 5V to 10V (split into +6V/-4V) isolated DC/DC gate drive power supply

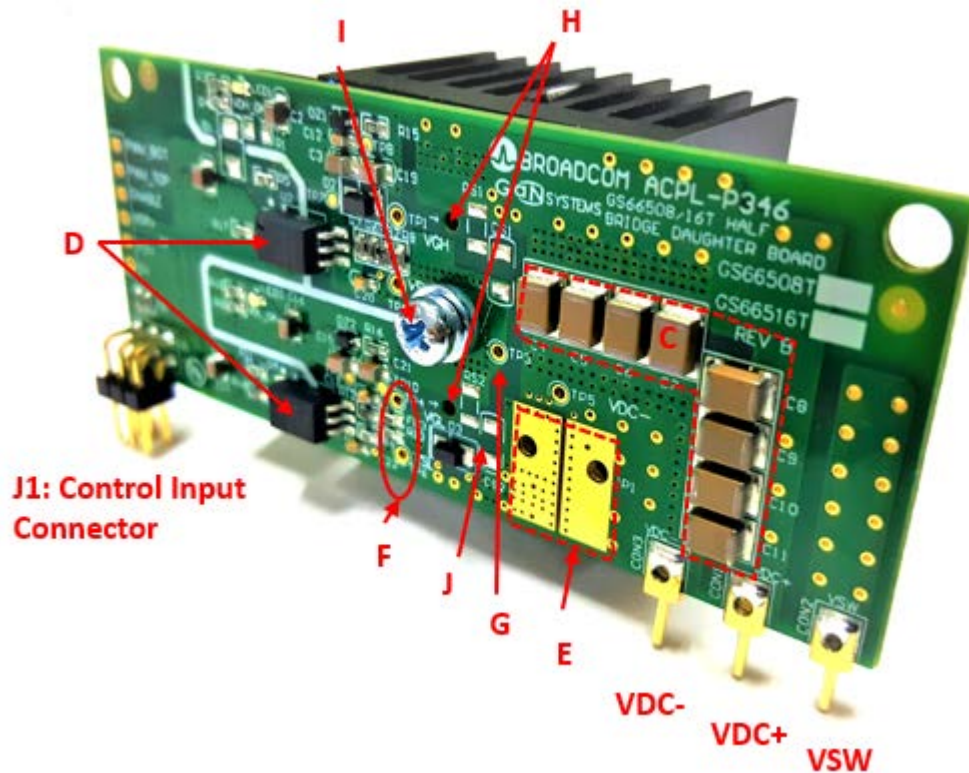


Figure 3 GS66508T/GS66516T-EVBDB2 top side

- C. Decoupling capacitors C4-C11
- D. Isolated gate driver
- E. Optional current shunt position JP1.
- F. Test points for bottom Q2 V<sub>GS</sub>.
- G. Recommended probing positions for Q2 V<sub>DS</sub>.
- H. Holes for temperature monitoring of Q1/Q2
- I. M3 mounting screw for heatsink
- J. (Optional) RC snubber circuit

## GaN E-HEMTs

This daughter board includes two GaN Systems E-HEMTs: either two GS66508T (650V/30A, 50mΩ) or two GS66516T (650V/60A, 25mΩ) in a GaNPX® top-side cooled package. The thermal pad on top of the device is internally connected to the source. Electrical insulation will be needed for heatsink attachment. The GaNPX® T-package also features a dual symmetrical gate for easier paralleling and PCB layout.

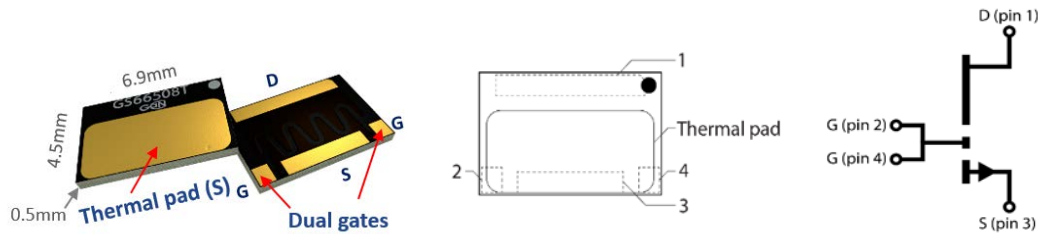


Figure 4 Package outline of GaNPX® T Package

## Gate drive power supply

- A bipolar gate drive bias with +6V and -4V for turning off is chosen for this design for more robust gate drive and better noise immunity.
- 5V to +10V isolated DC/DC converters are used for gate drive. The 10V is then split into +6V and -4V bias by using a 6V Zener diode
- By default, the gate drive supply input  $V_{DRV}$  is tied to  $V_{CC} +5V$  via a 0Ω jumper (FB1). Remove FB1 if separate gate drive input voltage is to be used.

## Gate driver circuit

- The half bridge evaluation boards use two Broadcom gate drive optocouplers (ACPL-P346) to drive the GaN transistors directly. The ACPL-P346 gate driver optocoupler is used to isolate and drive the GaN transistor, operating at high DC bus voltage. It has a rail-to-rail output with maximum output current of 2.5A to provide fast switching high voltage and driving current to turn the GaN device on and off efficiently and reliably. The drive output is separated by a diode and a 10Ω gate resistor is used to limit the current for sourcing and a 2Ω gate resistor for sinking.
- The ACPL-P346 has a propagation delay of less than 110 ns and typical rise and fall times of approximately 8 ns. The very high Common Mode Rejection (CMR) of 100kV/us (min) isolates high transient noise during the high frequency operation and prevents erroneous outputs. It can provide isolation certified by UL 1577 for up to  $V_{ISO}$  3750V<sub>RMS</sub>/min and IEC 60747-5-5 for working voltage,  $V_{IORM}$  up to 891 V<sub>PEAK</sub>.
- The GaN E-HEMT switching speed and slew rate can be directly controlled by the gate resistors. By default the turn-on gate resistors, R6/R12, are 10Ω and turn-off gate resistors, R7/R14, are 2Ω. The user can adjust the values of gate resistors to fine tune the turn-on and turn-off speed.
- FB2/FB3 are footprints for optional ferrite bead. By default they are populated with 0Ω jumpers. If gate oscillation is observed, it is recommended to replace them with ferrite bead with  $Z=10-20\Omega@100MHz$ .

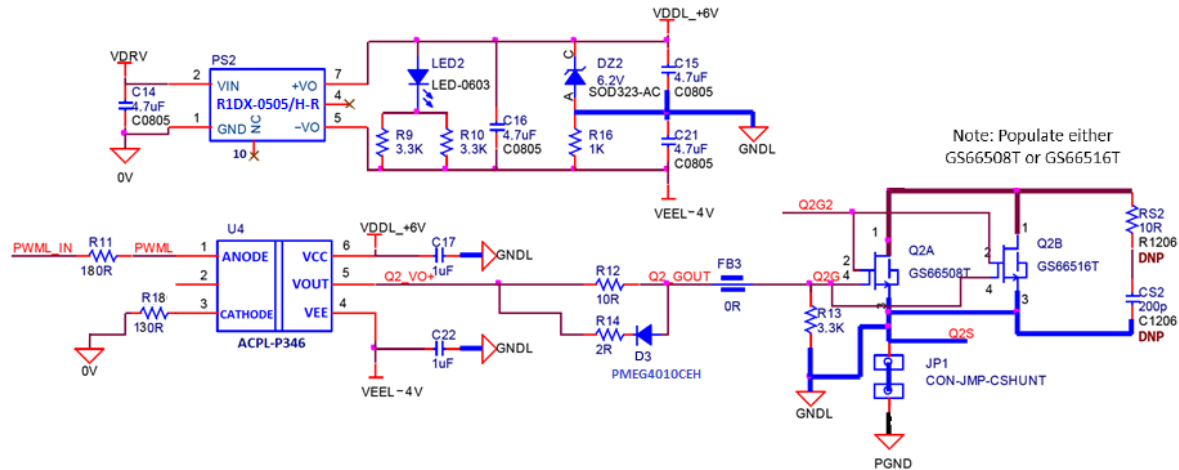


Figure 5 Gate bias and driver circuit

### RC Snubber

RS1/CS1 and RS2/CS2 are place holders to allow user to experiment with the RC snubber circuit, which is not populated. At high frequency operation the power dissipation for RS1/RS2 needs to be closely watched and CS1/CS2 should be sized correctly. It is recommended to start with 33-47 pF and 10-20  $\Omega$ .

### Current shunt JP1

- The board provides an optional current shunt position JP1 between the source of Q2 and power ground return. This allows drain current measurement for switching characterization test such as Eon/Eoff measurement.
- The JP1 footprint is compatible with T&M Research SDN series coaxial current shunt (recommended P/N: SDN-414-10, 2GHz B/W, 0.1 $\Omega$ )
- If current shunt is not used JP1 must be shorted. JP1 affects the power loop inductance and its inductance should be kept as low as possible. Use a copper foil or jumper with low inductance.

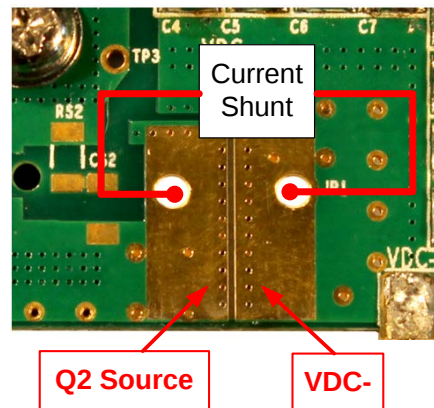


Figure 6 Recommended probe connection with current shunt



#### CAUTION

Check JP1 before the first time use. To complete the circuit, JP1 needs to be either shorted or a current shunt must be inserted before powering up.

#### Measurement with current shunt

1. When measuring VSW with current shunt, ensure all channel probe grounds and current shunt BNC output case are all referenced to the source end of Q2 before the current shunt. The recommended setup of probes is shown as below.
2. The output of coaxial current shunt can be connected to oscilloscope via 50Ω termination impedance to reduce the ringing.
3. The measured current is inverted and can be scaled by using:  $I_d = V_{id}/R_{sense}$ .

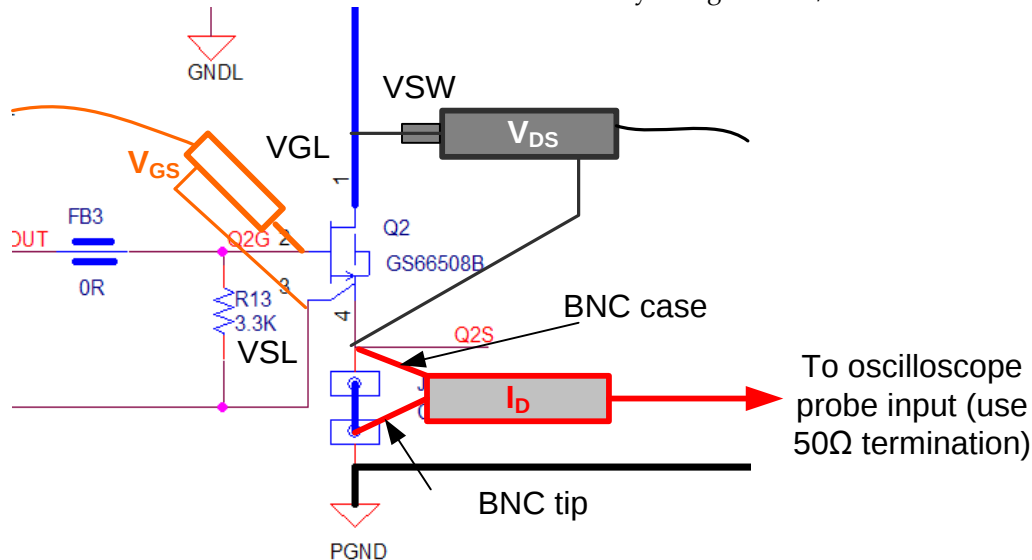


Figure 7 Recommended probe connection with current shunt

#### Thermal design

1. The GS66508T and GS66516T E-HEMTs have a thermal pad on the top side for improved heat dissipation. Instead of relying solely on the PCB for cooling, heat can be transferred to a heatsink directly from the top of the E-HEMT, reducing the total thermal resistance.
2. A heatsink can be mounted to the board using a M3 screw with lock washer and nylon insulated bushing. A Thermal Interface Material (TIM) is needed to provide electrical insulation and conformance to the thermal pad surface. The daughter board evaluation kit supplies with a 35x35mm heatsink with M3 tapped hole. Other heatsinks can also be used to fit users' system design.
3. **Care should be taken during the assembly of the heatsink to avoid PCB bending and mechanical stress to the GaN E-HEMT.** We recommend to limit the torque of M3 mounting screw to <1 in-lb (0.1Nm) for GS66508T and <2 in-lb (0.2Nm) for GS66516T, which translates to about ~50psi pressure on each device.



#### WARNING

Over-torquing the heatsink may create excess mechanical stress and could result in device failure. Always follow the maximum torque spec and attach the heatsink carefully to avoid any PCB bending or high pressing force on the devices.

4. The E-HEMT case temperature, can be monitored using an IR camera or a thermocouple through two drilled holes from the top side as shown below:

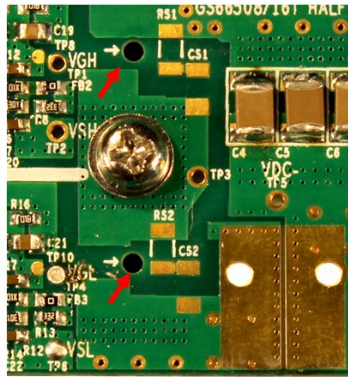


Figure 8 Location for case temperature monitoring



#### CAUTION

There is no on-board over-temperature protection. Monitor the E-HEMT temperature closely during the test. Never operate the board with device temperature exceeding  $T_{J\_MAX}$  (150°C)

5. The TIM we use on this assembly is Berguist® SilPad 1500ST, the measured total thermal resistance can be found in Figure 9. Compared to a bottom-cooled design, the top-side cooled package eliminates the PCB thermal resistance and significantly improve the thermal performance. Thermal grease is typically not needed on the assembly. If thermal grease is applied, use non-conductive and non-capacitive type thermal grease.
6. Forced air cooling is recommended for power testing.

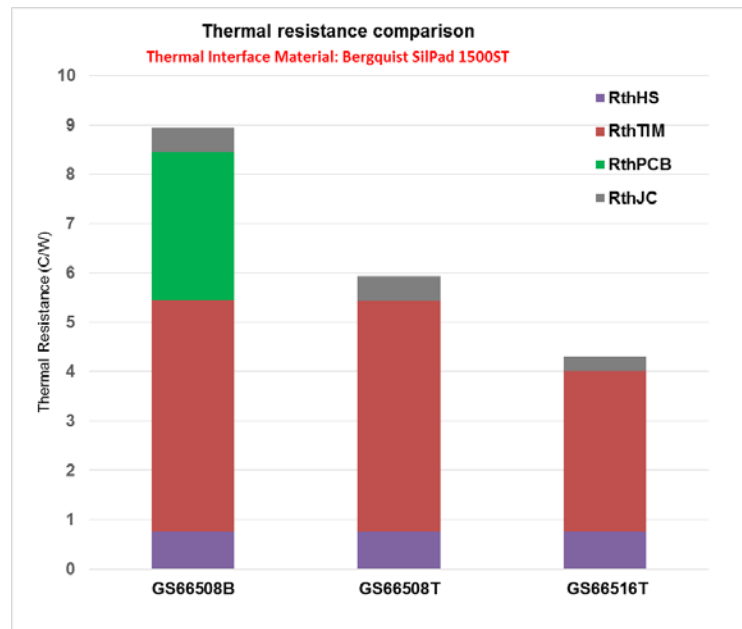


Figure 9 Evaluation board thermal resistance comparison

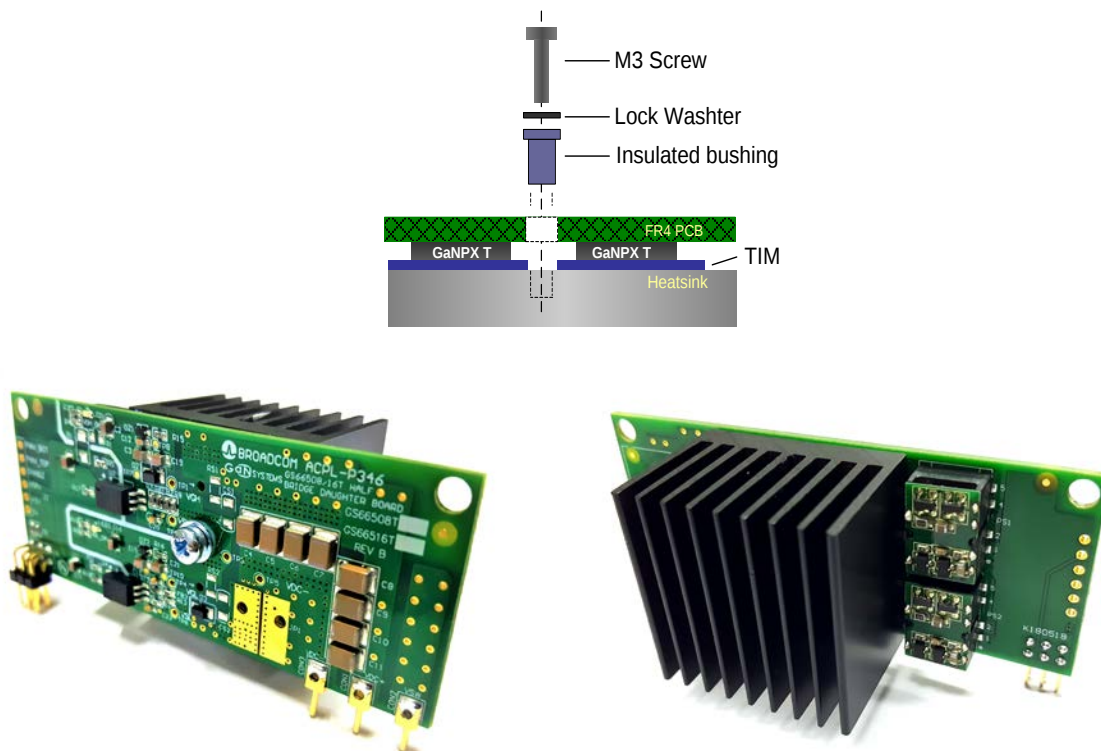


Figure 10: The daughter board assembly with heatsink attached

## Using GS665XT-EVBDB2 with universal mother board GS665MB-EVB

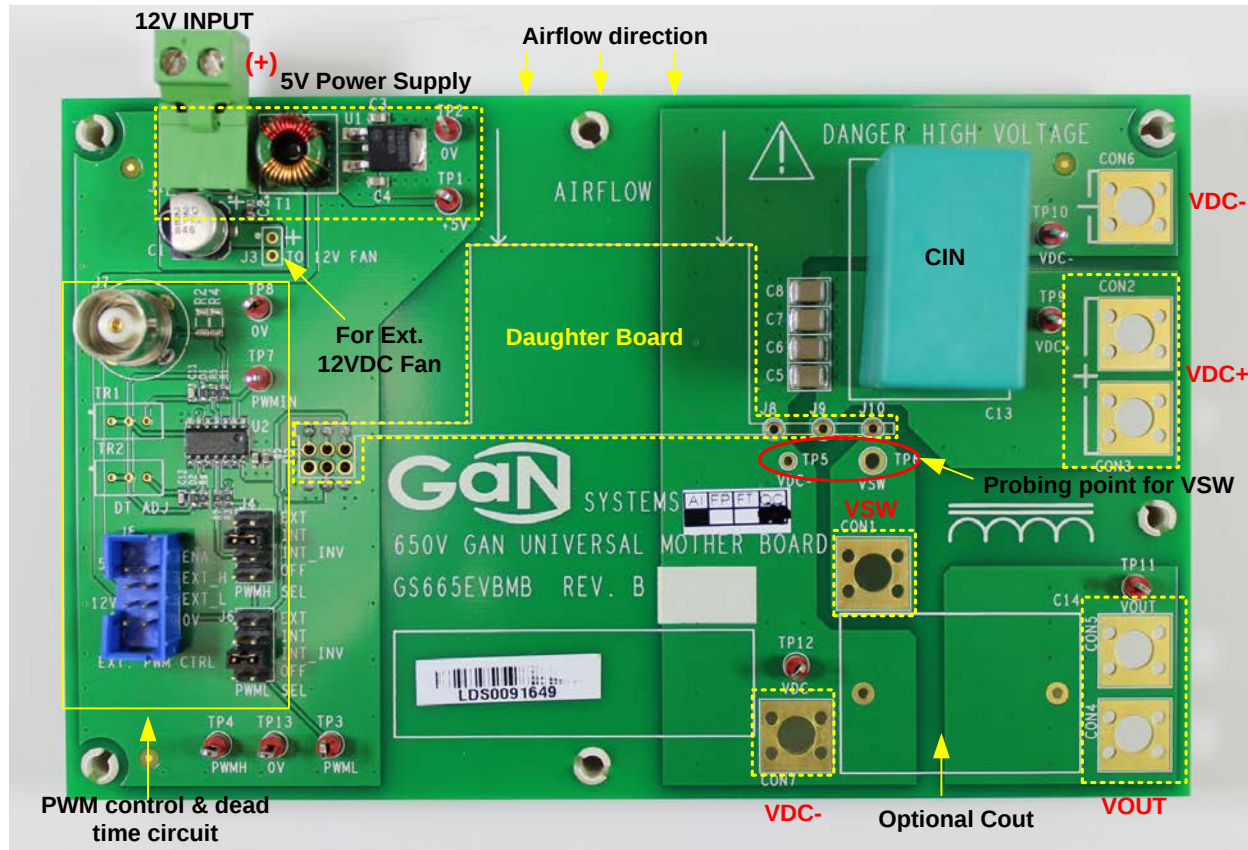


Figure 11: 650V universal mother board GS665MB-EVB

GaN Systems provides a universal 650V mother board (ordering part number: GS665MB-EVB, sold separately) that can be used as the basic evaluation platform for all the daughter boards.

The universal 650V mother board evaluation kit includes following items:

1. Mother board GS665MB-EVB
2. 12VDC Fan

### 12V input

The board can be powered by 9-12V on J1. On-board voltage regulator creates to 5V for daughter board and control logic circuits. J3 is used for external 12VDC fan.

## PWM control circuit

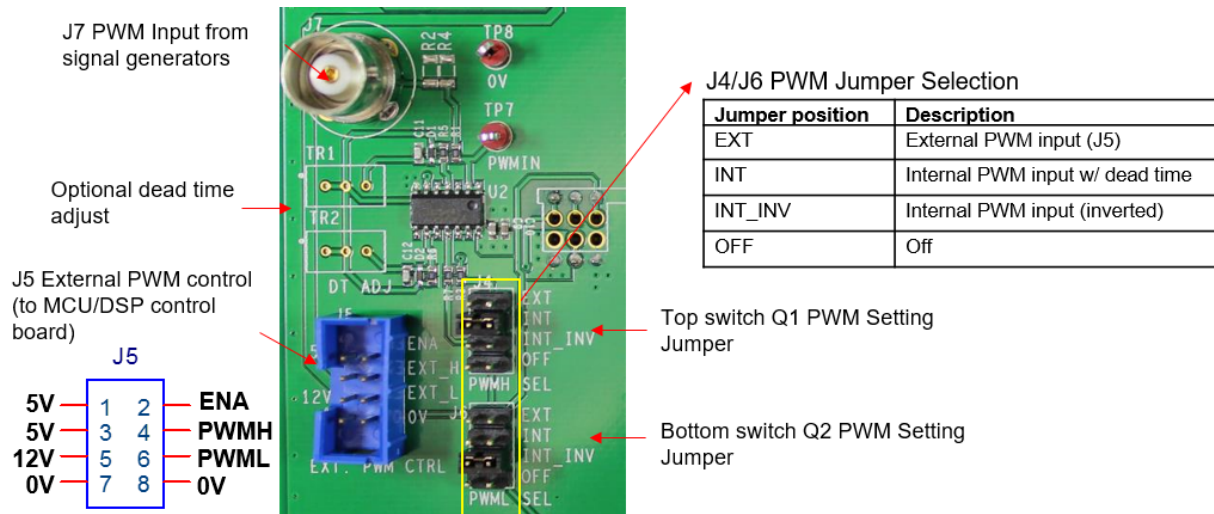


Figure 12 PWM control input and dead time circuit

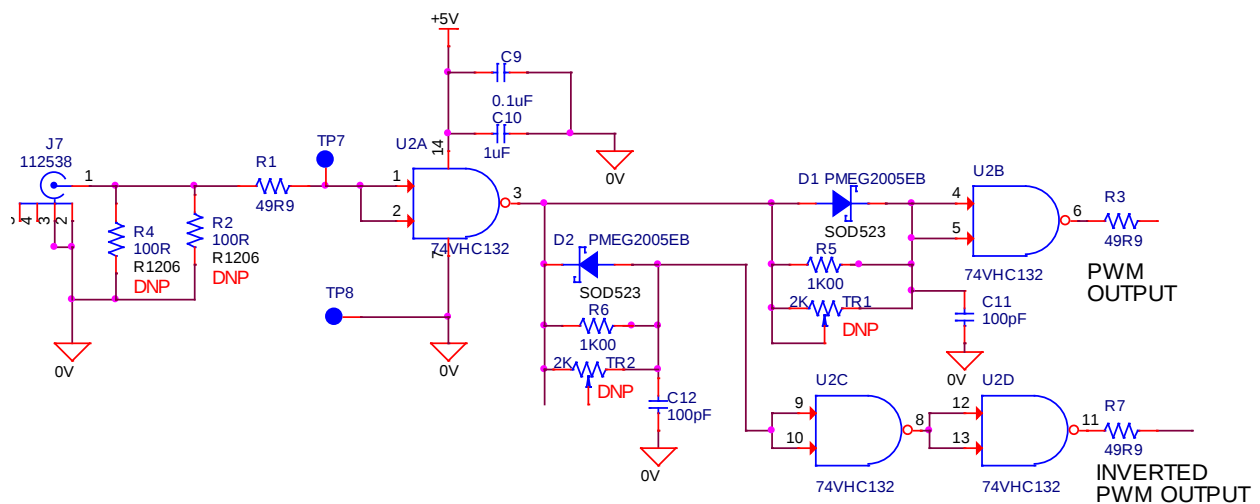


Figure 13 On board dead time generation circuit

The top and bottom switches PWM inputs can be individually controlled by two jumpers J4 and J6. Users can choose between a pair of complementary on-board internal PWM signals (non-inverted and inverted, controlled by J7 input) with dead time or external high/low side drive signals from J5 (users' own control board).

An on-board dead time generation circuit is included on the mother board. Dead time is controlled by two RC delay circuits, R6/C12 and R5/C11. The default dead time is set to about 100ns. Additionally two potentiometers locations are provided (TR1/TR2, not included) to allow fine adjustment of the dead time if needed.


**WARNING**

ALWAYS double check the jumper setting and PWM gate drive signals before applying power. Incorrect PWM inputs or jumper settings may cause device failures

### Test points

Test points are designed in groups/pairs to facilitate probing:

| Test points  | Name         | Description                                               |
|--------------|--------------|-----------------------------------------------------------|
| TP1/TP2      | +5V/0V       | 5V bias power                                             |
| TP7/TP8      | PWMIN/0V     | PWM input signal from J7                                  |
| TP4/TP3/TP13 | PWMH/PWML/0V | High/low side gate signals to daughter board              |
| TP9/TP10     | VDC+/VDC-    | DC bus voltage                                            |
| TP11/TP12    | VOUT/VDC-    | Output voltage                                            |
| TP6/TP5      | VSW/VDC-     | Switching node output voltage (for HV oscilloscope probe) |

### Power connections

CON1-CON7 mounting pads are designed to be compatible with following mounting terminals:

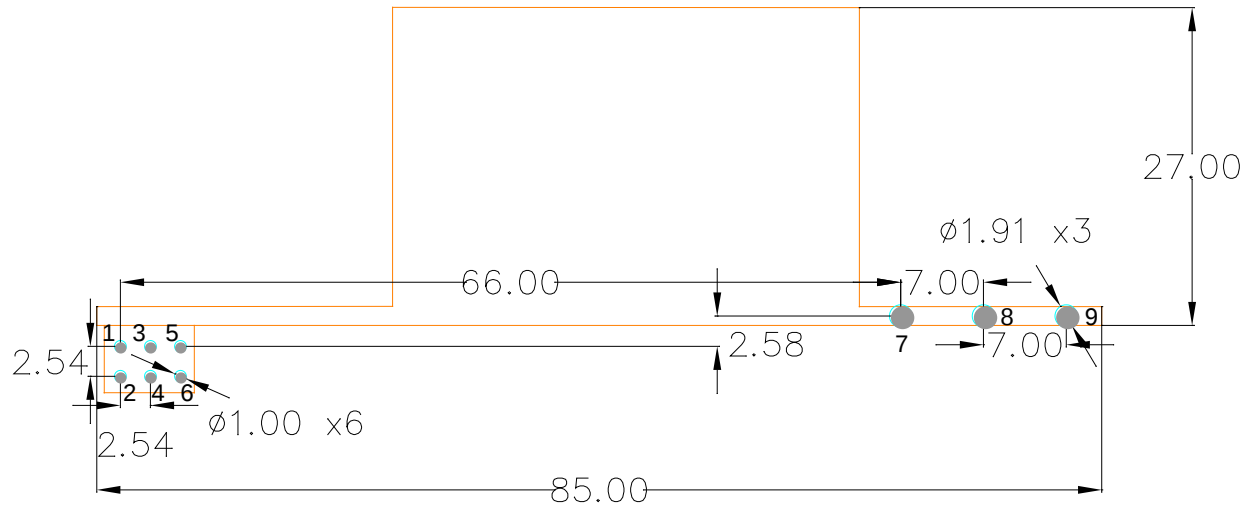
- #10-32 Screw mount,
- Banana Jack PCB mount (Keystone P/N: 575-4), or
- PC Mount Screw Terminal (Keystone P/N: 8191)

### Output passives (L and C14)

An external power inductor (not included) can be connected between VSW (CON1) and VOUT (CON4/5) or VDC+ (CON2/3) for double pulse test. Users can choose the inductor size to meet their test requirements. It is generally recommended to select a power inductor with low inter-winding capacitance to obtain best switching performance. For the double pulse testing we use 2x 60uH/40A inductor (CWS, P/N: HF467-600M-40AV) in series. C14 is designed to accommodate a film capacitor as output filter.

## Using GS665XXT-EVBDB2 in system

The daughter board allows users to easily evaluate the GaN performance in their own systems. Refer to the footprint drawing of GS665XXT-EVBDB2 as shown below:



1. All units are in mm.
2. Pin 1-6: Dia. 1mm
3. Pin 7-9: 1.91mm (75mil) mounting hole for Mill-max Receptacle P/N: 0312-0-15-15-34-27-10-0.

Figure 14 Recommended footprint drawing of daughter board GS665XXT-EVBDB2

## Double pulse test mode

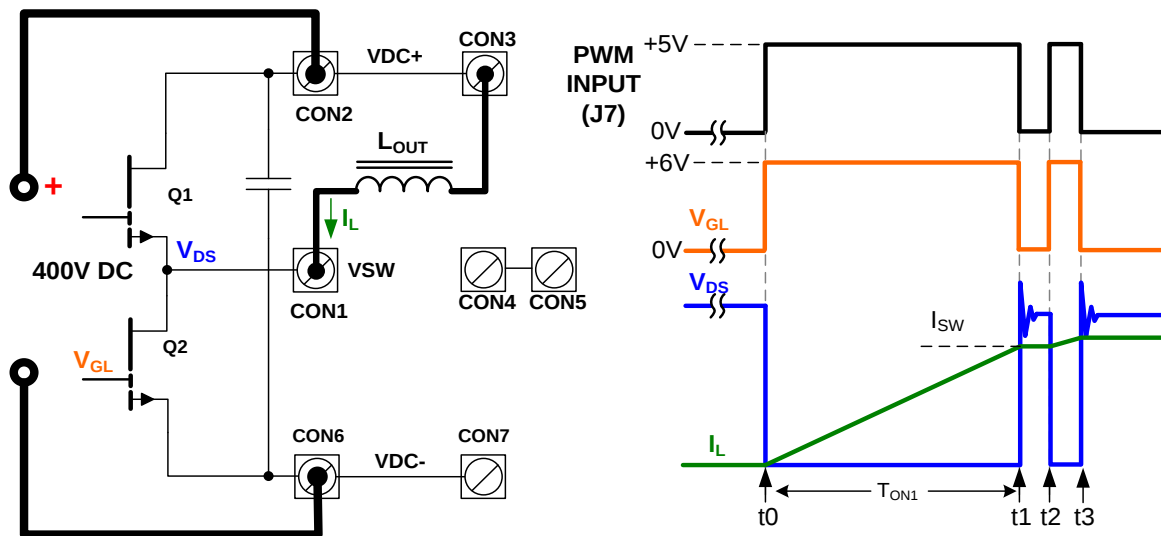


Figure 15 Double pulse test setup

Double pulse test allows easy evaluation of device switching performance at high voltage/current without the need of actually running at high power. It can also be used for switching loss (Eon/Eoff) measurement and other switching characterization parameter test.

The circuit configuration and operating principle can be found in Figure 14:

1. The output inductor is connected to the VDC+.
2. At  $t_0$  when Q2 is switched on, the inductor current starts to ramp up until  $t_1$ . The period of first pulse  $T_{ON1}$  defines the switching current  $I_{SW} = (V_{DS} \cdot T_{ON1}) / L$ .
3.  $t_1$ - $t_2$  is the free wheeling period when the inductor current  $I_L$  forces Q1 to conduct in reverse.
4.  $t_1$  (turn-off) and  $t_2$  (turn-on) are of interest for this test as they are the hard switching transients for the half bridge circuit when Q2 is under high switching stress.
5. The second pulse  $t_2$ - $t_3$  is kept short to limit the peak inductor current at  $t_3$ .

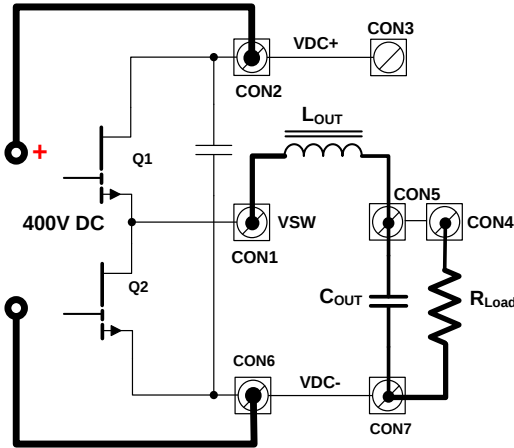
The double pulse signal can be generated using programmable signal generator or microcontroller/DSP board. As this test involves high switching stress and high current, it is recommended to set the double pulse test gate signal as single trigger mode or use long repetition period (for example >50-100ms) to void excess stress to the switches. Q1 can be kept off during the test or driven synchronously (J4 set to OFF or INT\_INV) and Q2 is set to INT (or EXT position if PWM signal is from J5).



### WARNING

Limit the maximum switching test current to 30A for GS66508T (60A for GS66516T) and ensure maximum drain voltage, including ringing, is kept below 650V for pulse testing. Exceeding this limit may cause damage to the devices.

## Buck/Standard half bridge mode



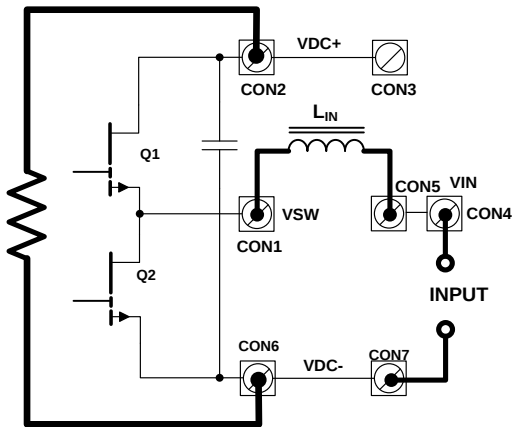
This standard half bridge configuration can be used in the following circuits :

- Synchronous Buck DC/DC
- Single phase half bridge inverter
- ZVS half bridge LLC
- Phase leg for full bridge DC/DC or
- Phase leg for a 3-phase motor drive

Jumper setting:

- J4 (Q1): INT
- J6 (Q2): INT\_INV

## Boost mode



When the output becomes the input and the load is attached between VDC+ and VDC-, the board is converted into a boost mode circuit and can be used for:

- Synchronous Boost DC/DC
- Totem pole bridgeless PFC

Jumper setting:

- J4 (Q1): INT\_INV
- J6 (Q2): INT

## Quick Start procedure – Double pulse test

Follow the instructions below to quickly get started with your evaluation of GaN E-HEMT.

Equipment and components you will need:

- Four-channel oscilloscope with 500MHz bandwidth or higher
- high bandwidth (500MHz or higher) passive probe
- high bandwidth (500MHz) high voltage probe (>600V)
- AC/DC current probe for inductor current measurement
- 12V DC power supply
- Signal generator capable of creating testing pulses
- High voltage power supply (0-400VDC) with current limit.
- External power inductor (recommend toroid inductor 50-200uH)

1. Check the JP1 on daughter board GS665XXT-EVBDB2. Use a copper foil and solder to short JP1.
2. Install GS665XXT-EVBDB2 on the mother board. Press all the way down until you feel a click.  
Connect probe between VGL and VSL for gate voltage measurement.
3. Set up the mother board:
  - a. Connect 12VDC bias supply to J1.
  - b. Connect PWM input gate signal (0-5V) to J7. If it is generated from a signal generator ensure the output mode is high-Z mode.
  - c. Set J4 to OFF position and J7 to INT.
  - d. Set High voltage (HV) DC supply voltage to 0V and ensure the output is OFF. Connect HV supply to **CON2** and **CON6**.
  - e. Use HV probe between TP6 and TP5 for Vds measurement.
  - f. Connect external inductor between **CON1** and **CON3**. Use current probe to measure inductor current IL.
4. Set up and check PWM gate signal:
  - a. Turn-on 12VDC power.
  - b. Check the 2 LEDs on the daughter board. They should be turned on indicating the isolated 9V is present.
  - c. Set up signal generator to create the waveforms as shown in Figure 14. Use equation  $I_{sw} = (V_{DS} * T_{ON1}) / L$  to calculate the pulse width of the first pulse and ensure the  $I_{sw\_max}$  is  $\leq 30A$  at 400VDC.
  - d. Set the operation mode to either single trigger or Burst mode with repetition period of 100ms.
  - e. Turn on the PWM output and check on the oscilloscope to make sure the VGL waveform is present and matches the PWM input.
5. Power-on:
  - a. Turn on the output of the HV supply. Start with low voltage and slowly ramp the voltage up until it reaches 400VDC. During the ramping period closely observe the the voltage and current waveforms on the oscilloscope.
6. Power-off:
  - a. After the test is complete, slowly ramp down the HV supply voltage to 0V and turn off the output. Then turn off the 12V bias supply and signal generator output.

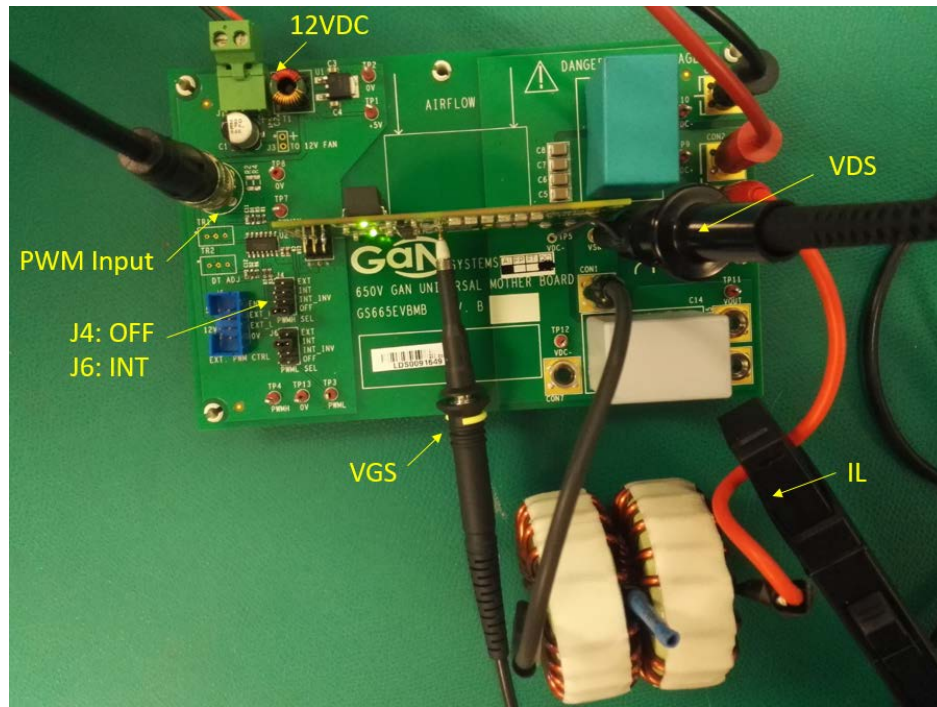


Figure 16 Double pulse test setup example

## Test results

Double Pulse test ( $V_{DS}=400V$ ,  $I_{MAX} = 30A$ ,  $L=120\mu H$ ,  $R_{G(ON)}=10\Omega$ ,  $R_{G(OFF)}=2\Omega$ ,  $V_{GS}=+6/-4V$ )

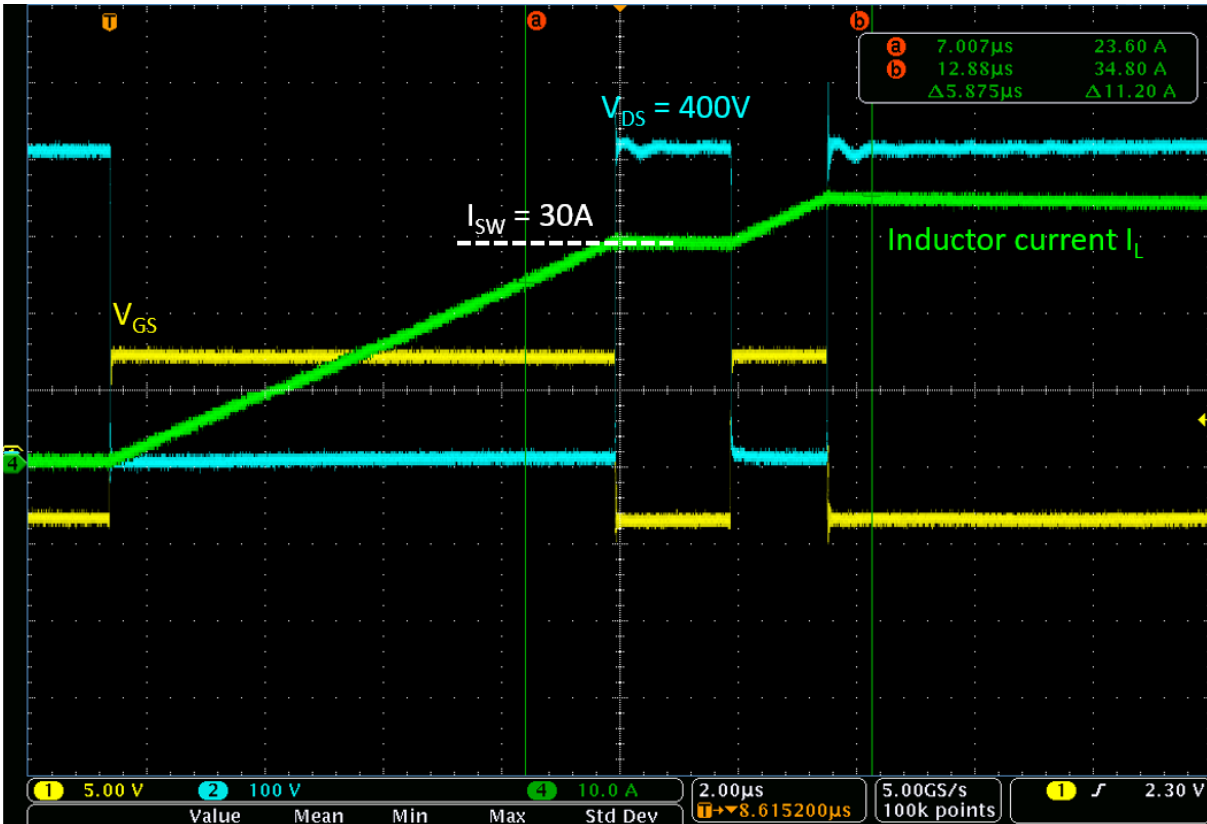
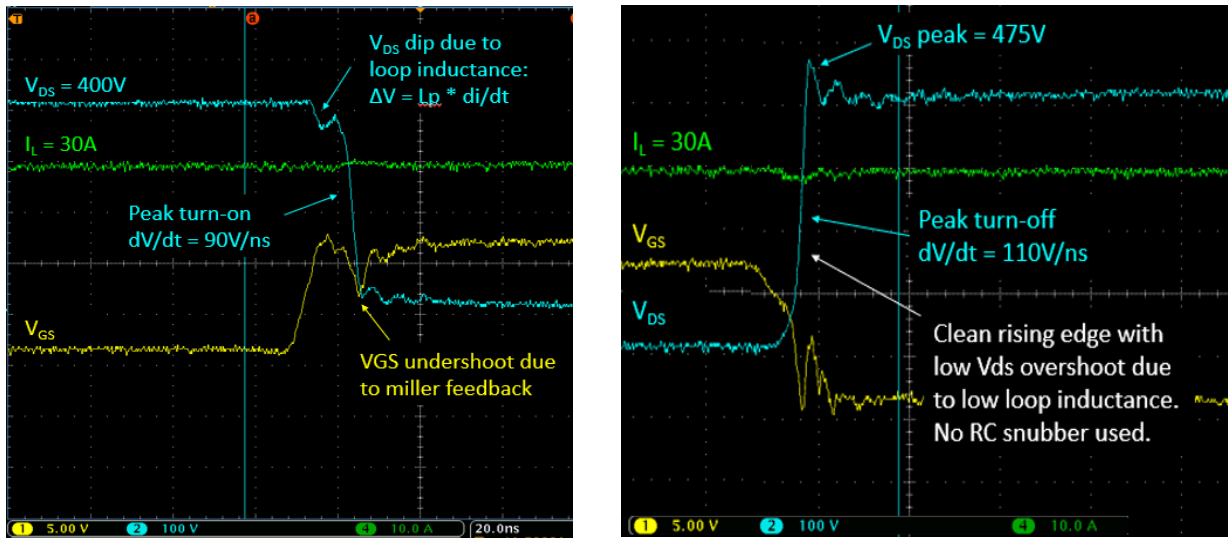


Figure 17 400V/30A double pulse test waveform (GS66508T)

Figure 17 shows the hard switching on waveforms at 400V/30A. A  $V_{ds}$  dip can be seen due to the rising drain current ( $dI/dt$  in the power loop  $\Delta V = L_p \times dI/dt$ , where  $L_p$  is the total power loop inductance). After the drain current reaches the inductor current, the  $V_{ds}$  starts to fall. The  $V_{gs}$  undershoot spike is caused by the miller feedback via  $C_{gd}$  under negative  $dv/dt$ .

Due to the low gate charge and small  $R_{G(OFF)}$ , GaN E-HEMT gate has limited control on the turn-off  $dV/dt$ . Instead the  $V_{ds}$  rise time is determined by how fast the turn-off current charges switching node capacitance ( $C_{oss}$ ).

The low  $C_{oss}$  of GaN E-HEMT and low parasitic inductance of GaNPX® package together with optimized PCB layout, enables a fast and clean turn-off  $V_{ds}$  waveform with only 50V the turn-off  $V_{ds}$  overshoot at  $dV/dt > 100V/ns$ . The measured rise time is 3.9ns at 400V and 30A hard turn-off.



a) Hard switching turn-on 400V/30A

b) Hard switching turn-off 400V/30A

Figure 18 Double pulse test switching transient waveforms (GS66508T)

### Switching Loss energy ( $E_{on}/E_{off}$ ) measurement

A T&M search coaxial current shunt (SDN-414-10, 0.1 $\Omega$ ) is installed for switching loss measurement as shown below.

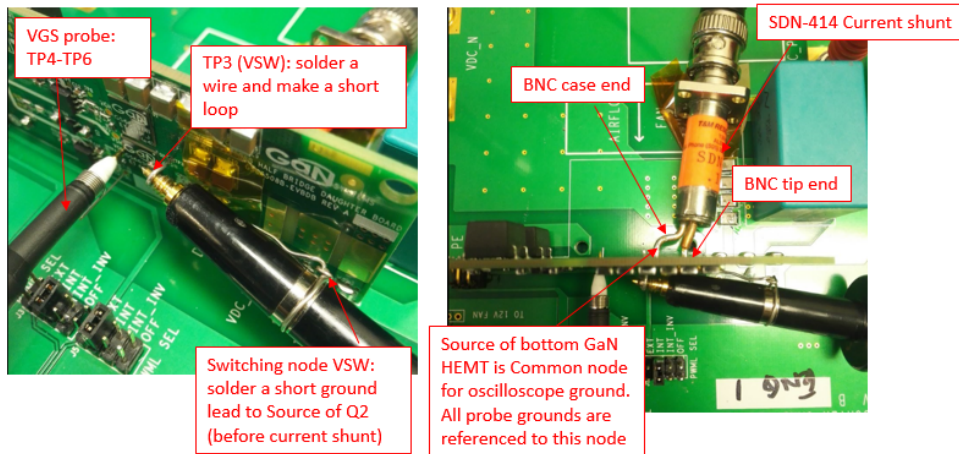


Figure 19  $E_{on}/E_{off}$  measurement probe connection with current shunt

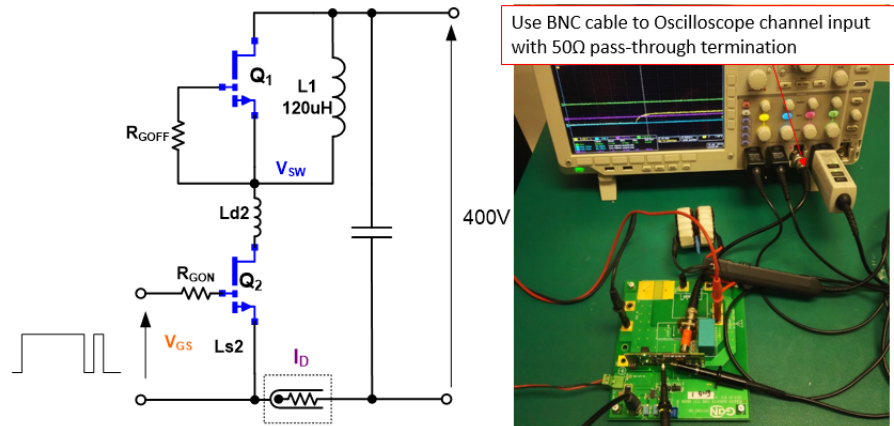


Figure 20 Eon/Eoff measurement and test bench setup

The switching energy can be calculated from the measured switching waveform  $P_{sw} = V_{ds} \cdot I_d$ . The integral of the  $P_{sw}$  during switching period is the measured switching loss. The channel deskewing is critical for measurement accuracy. It is recommended to manually deskew  $I_d$  against  $V_{ds}$  as shown in Figure 21. The drain current spike is caused by charging the high side switch  $C_{oss}$  ( $Q_{oss}$  loss).

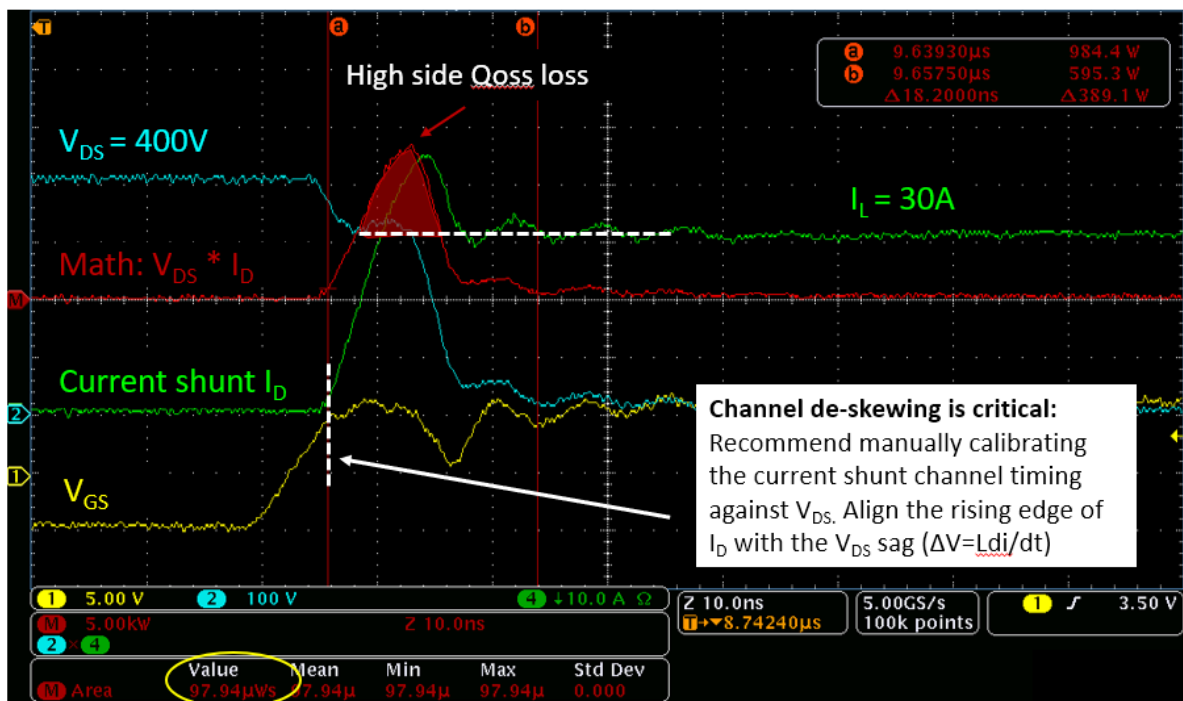


Figure 21 Turn-on switching loss measurement ( $E_{on}=98\mu J$ , 400V/30A,  $T_J=25^\circ C$ )

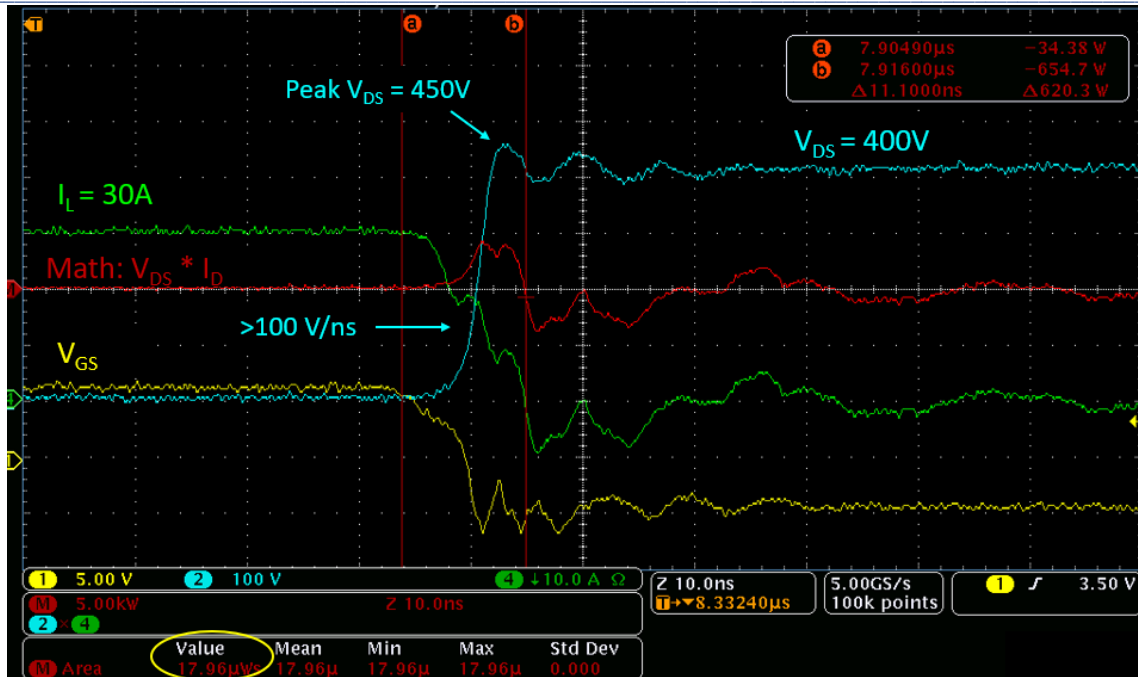


Figure 22 Turn-off switching loss measurement ( $E_{off}=18\mu J$ , 400V/30A,  $T_J=25^\circ C$ )

The switching loss measurements with drain current from 0 to 30A for GS66508T or up to 60A for GS66516T can be found in Figure 23. The turn-on loss dominates the overall hard switching loss.  $E_{on}$  at 0A is the  $Q_{oss}$  loss caused by the  $C_{oss}$  at high side switch.

### GS66508T Switching Loss Measurement

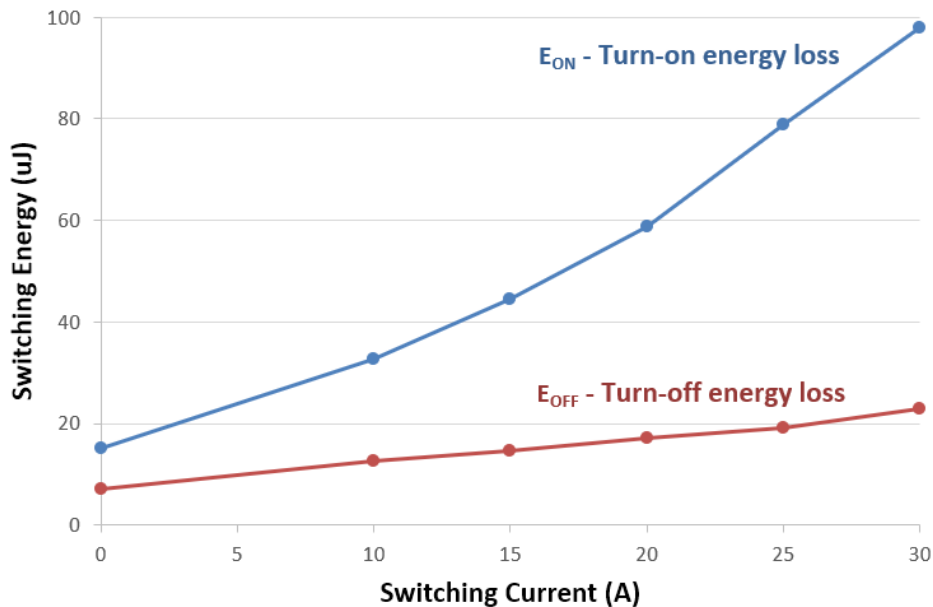


Figure 23 GS66508T Switching Loss Measurement ( $V_{DS} = 400V$ ,  $T_J=25^\circ C$ )

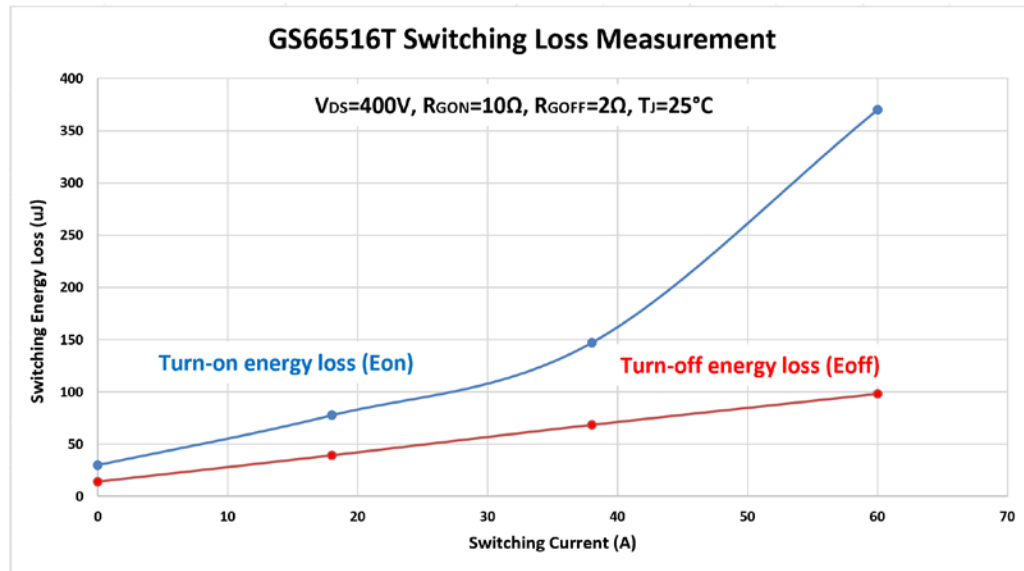


Figure 24 GS66516T Switching Loss Measurement ( $V_{DS} = 400V$ ,  $T_J=25^\circ C$ )

#### Synchronous Buck Test ( $L=120\mu H$ , $V_{IN}=400V$ , $V_{OUT}=200V$ , $D=50\%$ , $FSW=100\text{ kHz}$ , $POUT=0-2.4kW$ )

To test the efficiency of GaN transistor in hard switching operation, the board is connected as DC-DC converter in synchronous buck configuration. The converter is operated at high frequency 100 kHz. A very high conversion efficiency of more than 98.4% is achieved using 650V E-HEMT GS66508T (30A/50mΩ) and GS66516T (60A/25mΩ) transistor and gate drive optocoupler, ACPL-P346 at 100 kHz.

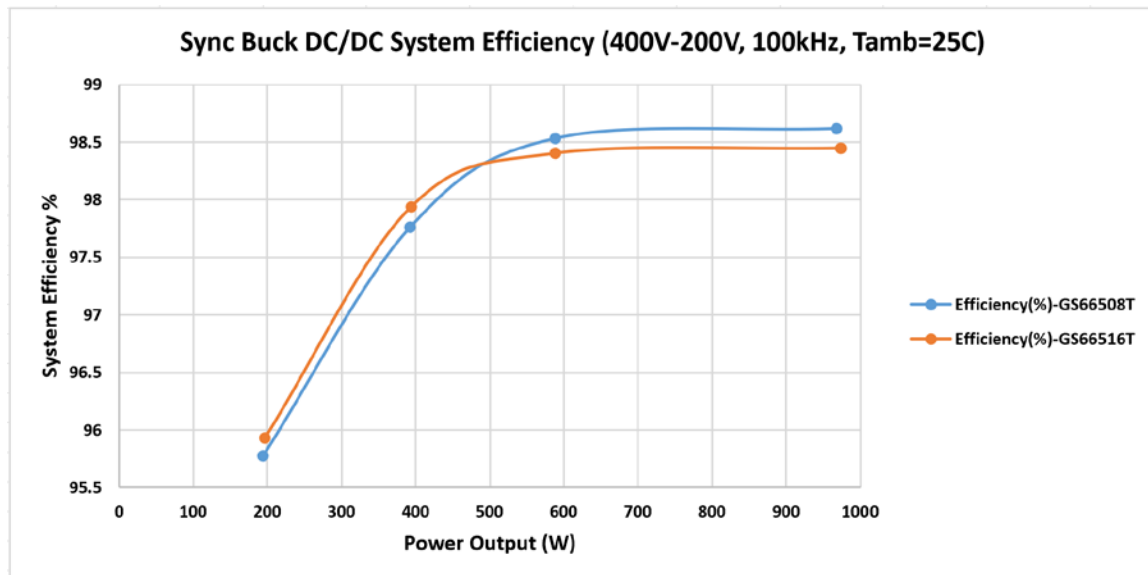


Figure 25 Synchronous Buck Efficiency and thermal measurement

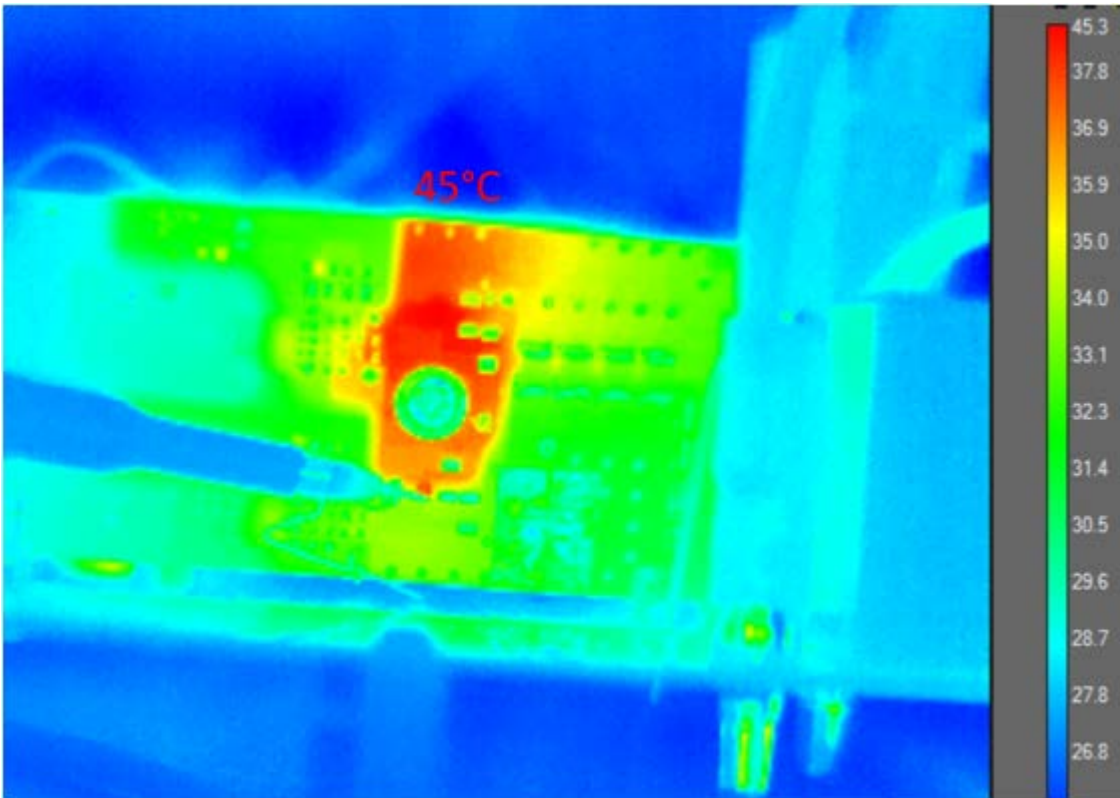
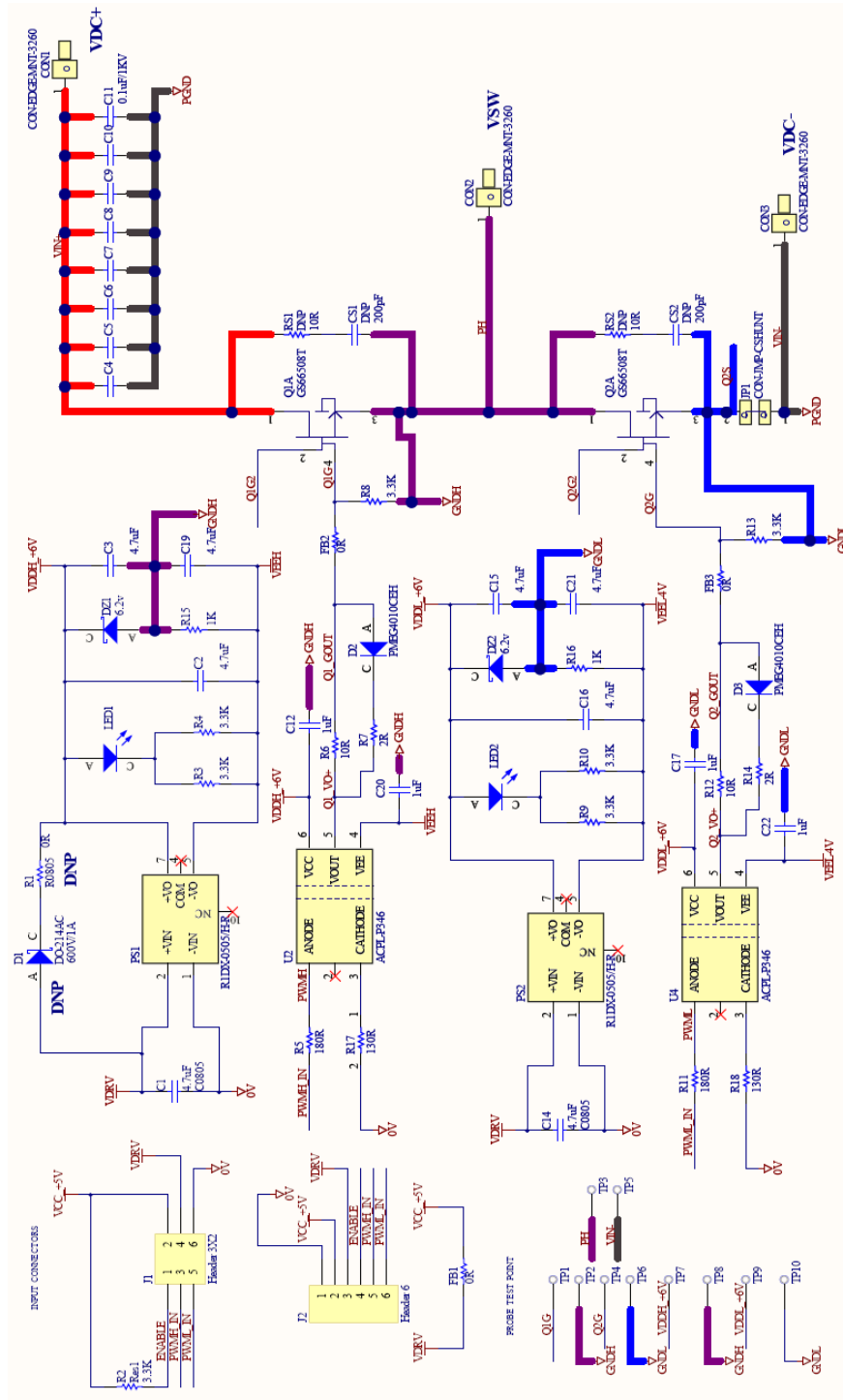


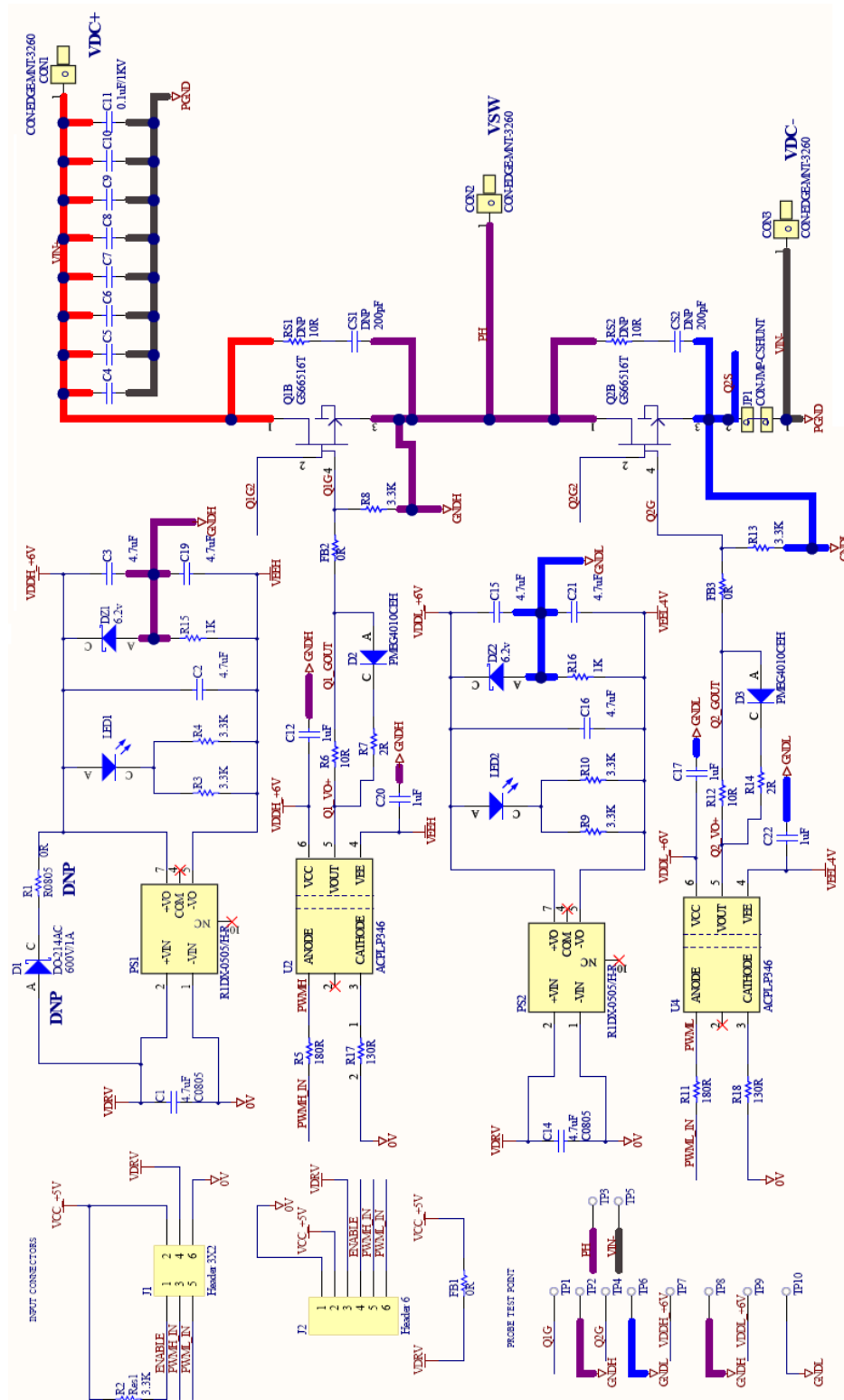
Figure 26 Thermal image (GS66508T, Pout=1kW)

## Appendix A: GS66508T/GS66516T-EVBDB2 with Isolated Gate Driver

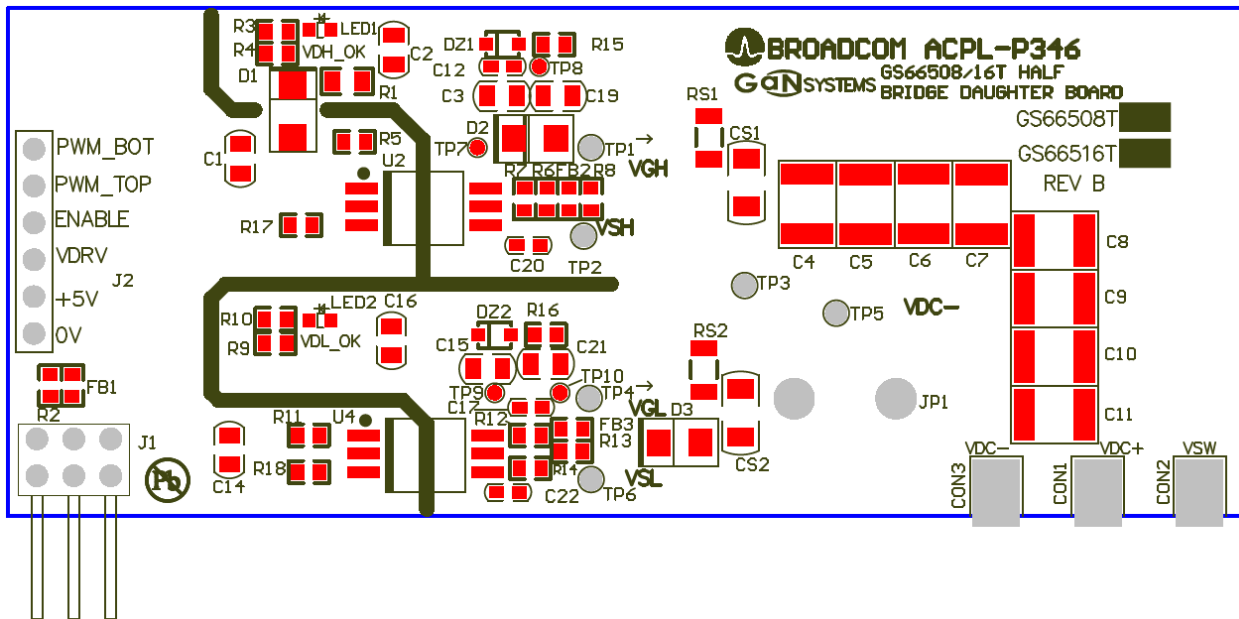
### Circuit schematics-GS66508T-EVBDB2



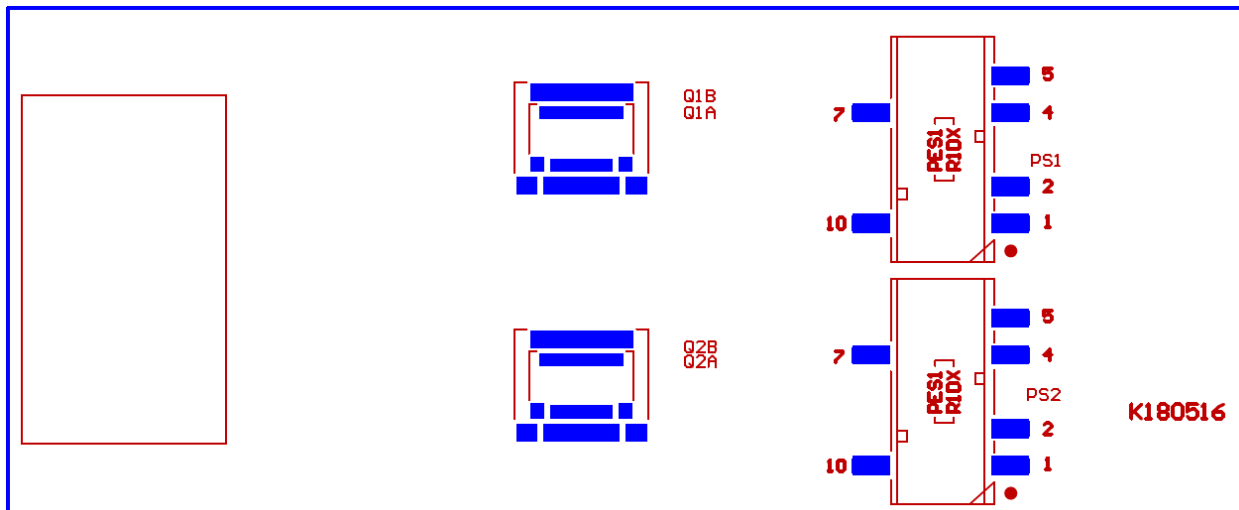
Circuit schematics-GS66516T-EVBDB2



Assembly Drawing (Top)

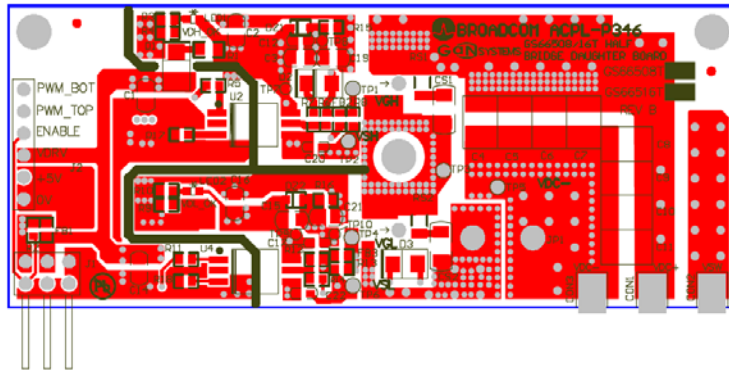


Assembly Drawing (Bottom)

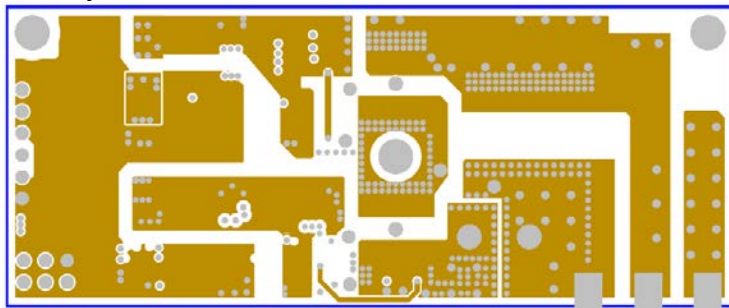


## PCB layout

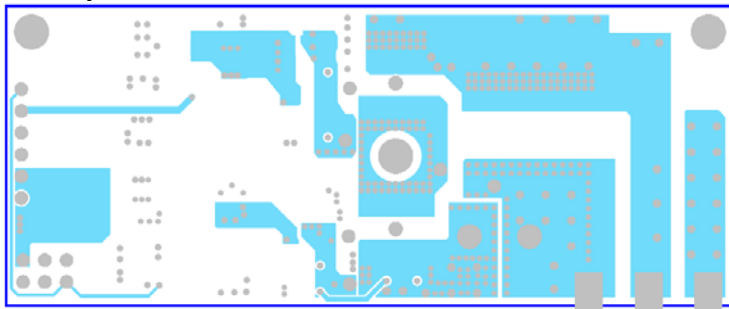
### Top Layer



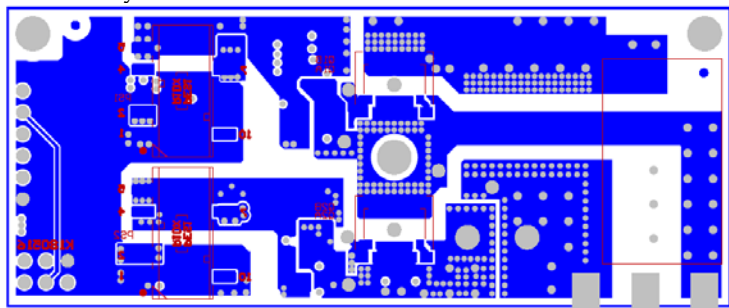
### Mid Layer 1



### Mid Layer 2



### Bottom Layer



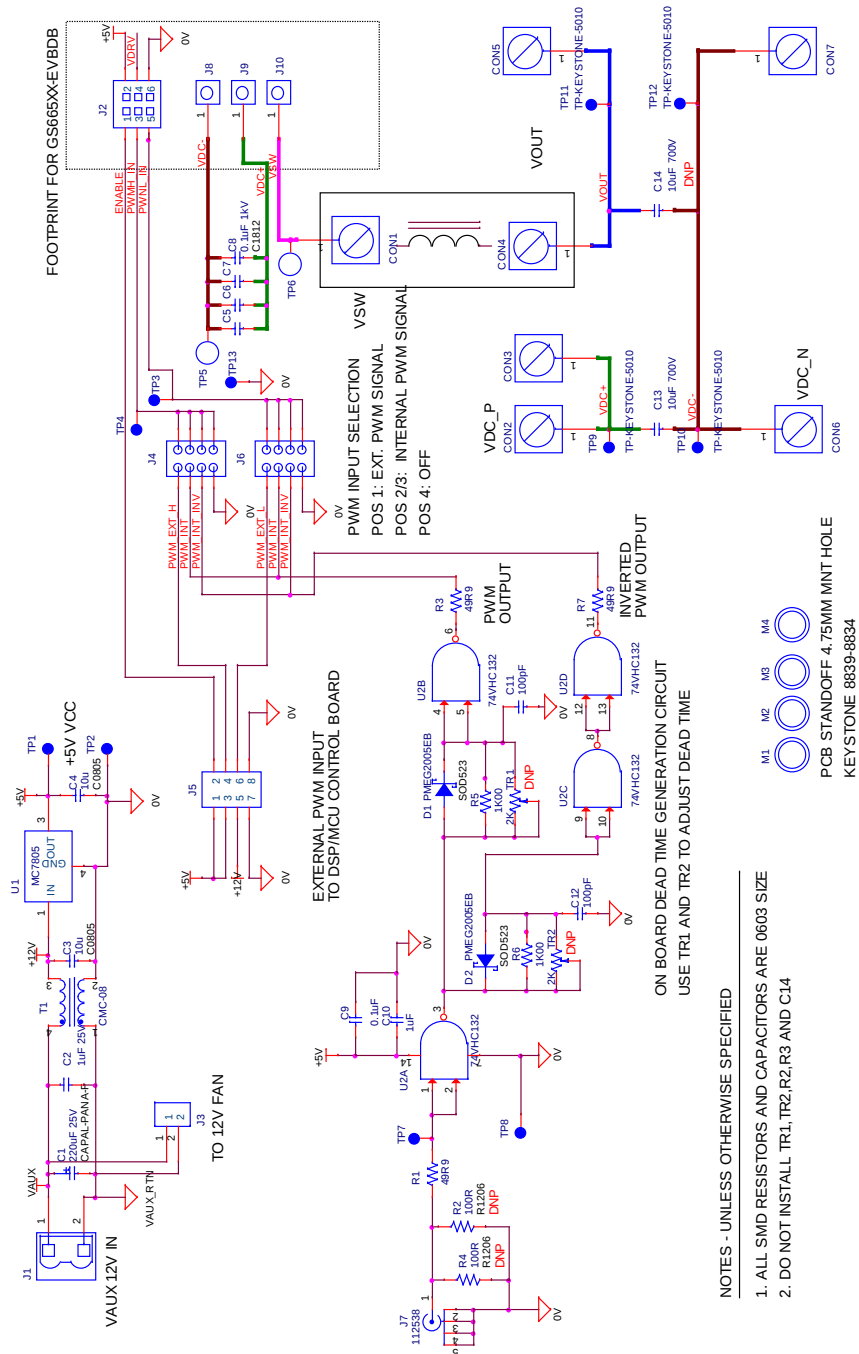
## 650V GaN E-HEMT Evaluation Board User's Guide

### Bill of Materials

| S.NO | Designator                   | Value             | Description                                                                                           | Manufacturer     | Part number                            | Qty | Remarks  |
|------|------------------------------|-------------------|-------------------------------------------------------------------------------------------------------|------------------|----------------------------------------|-----|----------|
| 1    | PCB                          |                   | PCB bare 4-layer 2oz Cu.                                                                              |                  |                                        | 1   |          |
| 2    | CON1,CON2,CON3               | CON-EDGE-MNT-3260 | CONN PC PIN EDGE MNT                                                                                  | Mill-Max         | 3620-2-32-15-00-00-08-0                | 3   |          |
| 3    | CS1, CS2                     |                   | CAP, CER, 200pF, 630V, 1206                                                                           | KEMET            | C1206C201FBGACTU                       | 0   | No Mount |
| 4    | C1,C2,C3,C14,C15,C16,C19,C21 | 4.7uF             | CAP, CER, 4.7UF, 25V, +/-10%, X7R, 0805                                                               | TDK              | C2012X5R1E475K125AB / MC0805X475K250CT | 8   |          |
| 5    | C4,C5,C6,C7,C8,C9,C10,C11    | 0.1uF 1kV         | CAP, CER, 0.1UF,1KV, +/-10%, X7R, 1812                                                                | KEMET            | C1812C104KDRACU / C1812V104KDRACU      | 8   |          |
| 6    | C12,C17,C20,C22              | 1uF               | CAP, CER, 1UF, 25V, +/-10%, X7R, 0603                                                                 | KEMET            | C0603C105K3RACTU / TMK107B7105KA-T     | 4   |          |
| 7    | DZ1,DZ2                      | 6.2V zener        | DIODE ZENER 6.2V 200MW SOD323                                                                         | Vishay           | BZX384C6V2-E3-08 / BZX384-C6V2         | 2   |          |
| 8    | D1                           | 600V 1A           | DIODE ULTRAFAST 600V 1A SMA                                                                           | Fairchild        | ES1J                                   | 0   | No Mount |
| 9    | FB1,FB2,FB3                  | OR                | RES, OR JUMPER, 1%, 0603                                                                              | Yageo            | RC0603FR-070RL/ MC0603SAF0000T5E       | 3   |          |
| 10   | JP1                          | CON-JMP-CSHUNT    | CURRENT SHUNT JUMPER                                                                                  |                  |                                        | 0   | No Mount |
| 11   | J1                           | CON-HDR-2X3       | CONN 3PIN DUAL ROW, 0.1" PITCH, R/A                                                                   | SAMTEC           | TSW-103-08-G-D-RA                      | 1   |          |
| 12   | J2                           | CON-6POS          |                                                                                                       |                  |                                        | 0   | No Mount |
| 13   | LED1, LED2                   | LED-SMD-0603      | LED, GREEN, SMD 0603                                                                                  | UTEON            | LTST-C191KGKT                          | 2   |          |
| 14   | PS1, PS2                     | R1DX-0505/H-R     | ISO. DC/DC 5-10V, 1W                                                                                  | RECOM            |                                        | 2   |          |
| 15   | Q1A, Q2A                     | GS66508T          | GaN E-HEMT 650V/30A TOP COOL                                                                          | GaN Systems      | GS66508T                               | 2   |          |
| 16   | Q1B, Q2B                     | GS66516T          | GaN E-HEMT 650V/60A TOP COOL                                                                          | GaN Systems      | GS66516T                               | 2   |          |
| 17   | RS1, RS2                     | 10R               | RES, 10R, 1%, 1206                                                                                    | generic          |                                        | 0   | No Mount |
| 18   | R1                           | OR                | RES, OR, 1%, 0805                                                                                     | generic          | generic                                | 0   | No Mount |
| 19   | R2,R3,R4,R8,R9,R10,R13       | 3K3               | RES, 3.3K, 1%,1/10W, 0603                                                                             | Multicomp        | MCWR06X3301FTL                         | 7   |          |
| 20   | R6,R12                       | 10R               | RES, 10R, 1%,1/10W, 0603                                                                              | Boums            | CRO603-FX-10R0ELF                      | 2   |          |
| 21   | R5,R11                       | 180R              | RES, 180R, 1%,1/10W, 0603                                                                             | Walsin           | WR06X1800FTL                           | 2   |          |
| 22   | R7,R14                       | 2R                | RES, 2R, 1%,1/10W, 0603                                                                               | Walsin           | WR06W2R00FTL                           | 2   |          |
| 23   | R15,R16                      | 1K0               | RES, 1K, 1%,1/10W, 0603                                                                               | Yageo            | RC0603FR-101KL                         | 2   |          |
| 24   | R17,R18                      | 130R              | RES, 130R, 1%,1/10W, 0603                                                                             | Yageo            | RC0603FR-07130RL                       | 2   |          |
| 25   | TP1,TP2,TP3,TP4,TP5,TP6      | CON-TP-1POS       | Probe test point                                                                                      |                  |                                        | 0   | No Mount |
| 26   | TP7,TP8,TP9,TP10             | CON-TP-1POS       | Probe test point                                                                                      |                  |                                        | 0   | No Mount |
| 27   | U2,U4                        | ACPL-P346         | Optocoupler                                                                                           | Broadcom         | ACPL-P346-000E                         | 2   |          |
| 28   | D2, D3                       | PMEG4010CEH       | DIODE PMEG4010CEH SBD SOD123F                                                                         | NXP              | PMEG4010CEH / PMEG4010EH               | 2   |          |
| 29   |                              |                   | heatsink, 35x35mmx25.4mm, customized                                                                  | Shenzhen Mingzhi | PY16-Q20-1                             | 1   |          |
| 30   |                              | 81.58.336         | M3 screw w/ insulated sleeve( Machine Screw, Spring Washer, M3, 8 mm, Steel, Zinc, Pan Head Pozidriv) | ETTINGER         | 81.58.336                              | 1   |          |
| 31   |                              | WS0330A           | Washer shoulder M3 NYLON                                                                              | Essentra         | WS0330A                                | 1   |          |
| 32   |                              |                   | Electrically insulated Thermal pad                                                                    | Bergquist        | SILPAD 1500ST                          | 1   |          |
|      |                              |                   |                                                                                                       |                  |                                        | 63  |          |

## Appendix B - GS665MB-EVB – 650V Universal Motheboard

## Circuit schematics



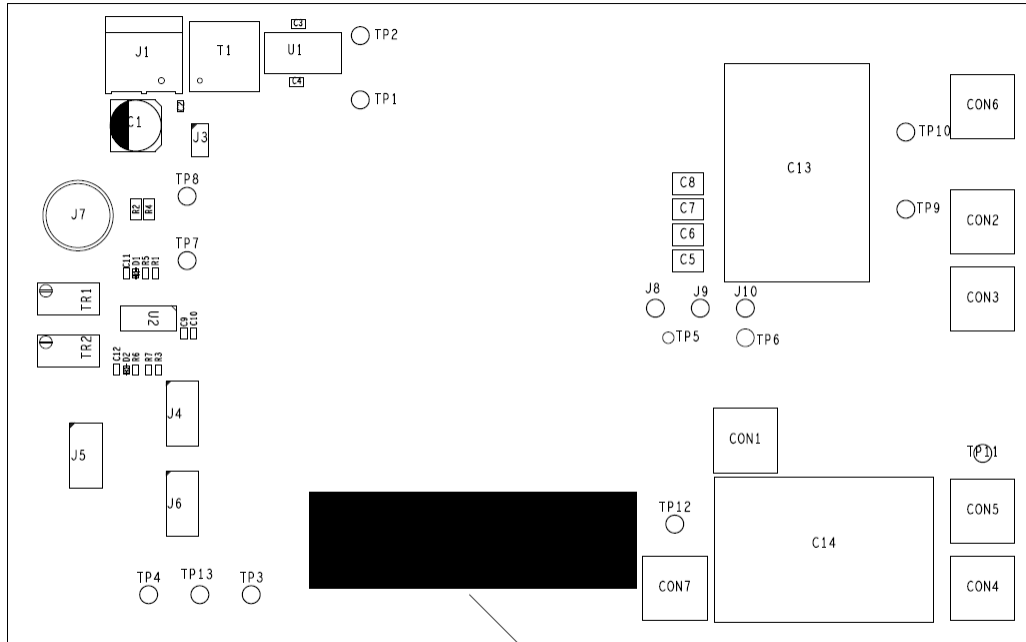
NOTES - UNLESS OTHERWISE SPECIFIED

1. ALL SMD RESISTORS AND CAPACITORS ARE 0603 SIZE
2. DO NOT INSTALL TR1, TR2, R2, R3 AND C14

## Assembly drawing

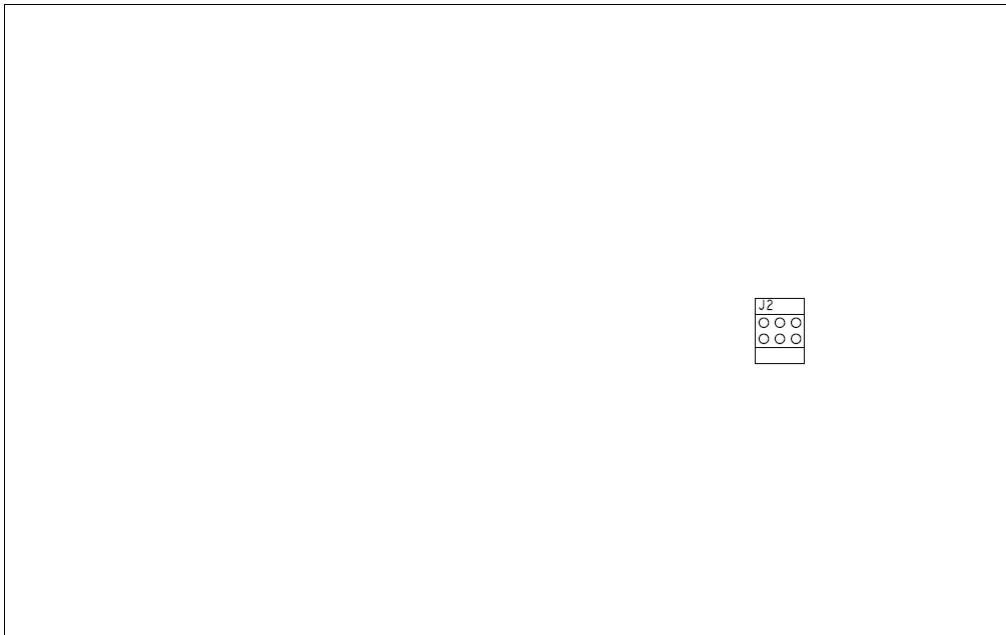
### Assembly Top

TOP COMPONENT SIDE



SUGGESTED LOCATION FOR S/N LABEL

### Assembly Bottom



**Bill of Materials**

| GaN SYSTEMS 650V GaN UNIVERSAL MOTHER BOARD |                                                 |                                                             |                         |                 |                         |                                                                 |
|---------------------------------------------|-------------------------------------------------|-------------------------------------------------------------|-------------------------|-----------------|-------------------------|-----------------------------------------------------------------|
| BOARD PIN: <b>GS665EVBMB</b>                |                                                 |                                                             |                         |                 |                         |                                                                 |
| Revision <b>B1</b>                          |                                                 |                                                             |                         |                 |                         |                                                                 |
| Last Update <b>6/30/2016</b>                |                                                 |                                                             |                         |                 |                         |                                                                 |
| Quantity                                    | Reference                                       | Description                                                 | Value                   | Manufacturer    | Part number             | Assembly Note                                                   |
| 1                                           | PCB                                             | PCB bare 2-layer 2oz Cu.                                    |                         |                 |                         |                                                                 |
| 1                                           | CON1,CON2,CON3,CON4,C7                          | TERMINAL SCREW VERTICAL PC MNT                              | CON-10-32-SCRWMMNT      | KEYSTONE        | 8191                    | DO NOT INSTALL                                                  |
| 2                                           | 1 C1                                            | CAP ALUM 220UF 20% 25V SMD                                  | 220UF 25V               | Parasonic       | EEE-FK1E221P            |                                                                 |
| 3                                           | 1 C2,C10                                        | GENERIC 1UF/25V, 10% X7R SMD 0603                           | 1uF                     | TAIYO YUDEN     | TMK107B7105KA-T         |                                                                 |
| 4                                           | 2 C3,C4                                         | GENERIC 10UF/25V, 10% SMD 0805                              | 10uF                    | TAIYO YUDEN     | TMK2128BJ106KG-T        |                                                                 |
| 5                                           | 4 C5,C6,C7,C8                                   | GENERIC 0.1uF/1000V, SMD 1812                               | 0.1uF 1kV               | KEMET           | C1812C104KDRAC7800      |                                                                 |
| 6                                           | 1 C9                                            | GENERIC 0.1uF/25V, 10% X7R SMD 0603                         | 0.1uF                   | TAIYO YUDEN     | TMJ107BB 7104KAHT       |                                                                 |
| 7                                           | 2 C11,C12                                       | GENERIC 100PF/25V 5% NP0 SMD 0603                           | 100pF                   | KEMET           | C0603C101J3GACTU        |                                                                 |
| 8                                           | 1 C13,C14                                       | CAP FILM 10UF/600VDC 5%, 27.5MM LEAD                        | 10uF 700V               | KEMET           | C4AEHBU5100A11J         | DO NOT INSTALL C14                                              |
| 9                                           | 2 D1,D2                                         | DIODE SCHOTTKY 20V 500MA SOD523                             | PMEG2005EB              | NXP             | PMEG2005EB.115          |                                                                 |
| 10                                          | 1 J1                                            | TERM BLOCK HDR 2POS R/A 5.08MM                              | CON-TERM-BLK-2POS-RA    | TE CONNECTIVITY | 796638-2                |                                                                 |
| 11                                          | 1 J1-PLUG                                       | TERM BLOCK BLUG 2POS 5.08MM                                 | CON-CONNECTIVITY        | TE CONNECTIVITY | 796634-2                |                                                                 |
| 12                                          | 1 J2                                            | CONN RCPT 6POS, 100 DBL STR PCB                             | CON-RCPT-2X3-BOT        | HARWIN          | M20-7850342             | MOUNT FROM BOTTOM SIDE<br>CONNECTOR FOR 12V FAN, DO NOT INSTALL |
| 13                                          | 1 J3                                            | CONN RCPT 8POS DUAL VERT PCB                                | CON-2POS                |                 |                         |                                                                 |
| 14                                          | 2 J4,J6                                         | CONN HEADER 8POS DUAL VERT PCB                              | CON-JMP-4POS            | HARWIN          | M20-9880445             |                                                                 |
| 15                                          | 1 J5                                            | CONN 8-POS, DUAL ROW 2.54MM                                 | CON-HDR-4X2             | AMPHENOL        | 75869-132LF             |                                                                 |
| 16                                          | 1 J7                                            | CONN BNC JACK STR 50 OHM PCB                                | 112538                  | AMPHENOL        | 112538                  |                                                                 |
| 17                                          | 3 J8,J9,J10                                     | CONN RECEPT PIN .032-.046" .075"                            | CON-RCPT-EDGE MNT       | MILLMAX         | 0312-0-15-15-34-27-10-0 | MATING SOCKET FOR MILLMAX<br>EDGE MNT PIN                       |
| 18                                          | 3 R1,R3,R7                                      | generic 1% smd 0603                                         | 49R9                    | VISHAY DALE     | CRCW060349R9FKEA        |                                                                 |
| 19                                          | 2 R2,R4                                         | generic 1% smd 1206                                         | 100R                    |                 |                         | DO NOT INSTALL                                                  |
| 20                                          | 2 R5,R6                                         | generic 1% smd 0603                                         | 1K00                    | VISHAY DALE     | CRCW06031K00FKEA        |                                                                 |
| 21                                          | TP1,TP2,TP3,TP4,TP7,TP8,TP9,TP10,TP11,TP12,TP13 | TEST POINT PCB                                              | TP-KEYSTONE-5010        | KEYSTONE        | 5010                    |                                                                 |
| 22                                          | 2 TR1,TR2                                       | COMM MODE CHOKE 5.2A TH                                     | 2K                      | RECOM           | CMC-08                  | DO NOT INSTALL                                                  |
| 23                                          | 1 T1                                            | IC REG LDO 5V 1A DPAK                                       | CMC-08                  | ON SEMI         | MC7805BDBTRKG           |                                                                 |
| 24                                          | 1 U1                                            | 1 IC GATE NAND 4CH 2-INP 14-SOIC                            | MC7805                  | FAIRCHILD       | 74VHC132MX              |                                                                 |
| 25                                          | 1 U2                                            | PCB STANDOFF NYLON STACKABLE 4.75MM MECH-STD/OFF-KEYSTONE-8 | 74VHC132                |                 |                         | PCB SPACER, INSTALL FROM<br>BOTTOM SIDE                         |
| Off the board components:                   |                                                 |                                                             |                         |                 |                         |                                                                 |
| 26                                          | 6 M1,M2,M3,M4,M5,M6                             | PCB STANDOFF NYLON STACKABLE 4.75MM MECH-STD/OFF-KEYSTONE-8 | MECH-STD/OFF-KEYSTONE-8 | KEYSTONE        | 8833                    | SUPPLY LOOSE, DO NOT INSTALL<br>ON THE ASSEMBLY                 |
| 27                                          | 1 FAN                                           | FAN AXIAL 38X20MM 12VDC WIRE                                |                         | SUNON FANS      | PMD1238PKB1-A (2)GN     | INSTALL ON J4 "INT" POSITION AND<br>J6 "INT INV" POSITION       |
| 28                                          | 2 JUMPER                                        | JUMPER SHUNT GENERIC                                        |                         | TE CONNECTIVITY | 382811-8                |                                                                 |

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