

## GS65011-EVBEZ

# GaN E-HEMT EZ Drive® Open Loop Boost Evaluation Board

## Technical Manual



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**DANGER!**

Electrical Shock Hazard - Hazardous high voltage may be present on the board during the test and even brief contact during operation may result in severe injury or death. Follow all locally approved safety procedures when working around high voltage.

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

**This board should be handled by qualified personnel ONLY.**



PCB surface can become hot. Contact may cause burns. Do not touch!

**CAUTION:**

This product contains parts that are susceptible to damage by electrostatic discharge (ESD) or exposure to voltages in excess of the specified voltage. Always follow ESD prevention procedures when handling the product. Avoid applying excessive voltages to the power supply terminals or signal inputs or outputs

## Introduction

The GS65011-EVBEZ Evaluation Board (EVB) is an open loop Boost converter and was designed to help customers evaluate GaN Systems’ EZDrive® solution with a GaN Systems’ E-HEMT.

The EZDrive® circuit is a low-cost, easy way to implement a GaN driving circuit using a standard MOSFET controller with integrated driver. The EZDrive® circuit provides design control for the optimization of efficiency and EMI. It is adaptable to any power level, any frequency, and any LLC and PFC controller.

The board is populated with GaN Systems’ GS-065-011-1-L, a 5×6 mm PDFN package Enhancement-Mode High Electron Mobility Transistor (E-HEMT).

## Evaluation Board Contents and Requirements

### Kit Contents

The GS65011-EVBEZ includes the following hardware.

**Table 1 • GS65011-EVBEZ Evaluation Kit Contents**

Quantity	Description
1	GS65011-EVBEZ GaN E-HEMT evaluation board assembly

### Hardware Requirements

In order to evaluate the performance of the evaluation board, the following equipment is required:

- High speed digital oscilloscope
- DC load (power resistor or electrical load)
- High voltage DC power supply
- Low voltage DC power supply
- DC test leads

## Evaluation Board Assembly Overview

The EVB is assembled with the EZDrive® circuit and one GS-065-011-1-L GaN E-HEMT. Headers are included for power connections. A probe connector and vias are included for waveform measurements.

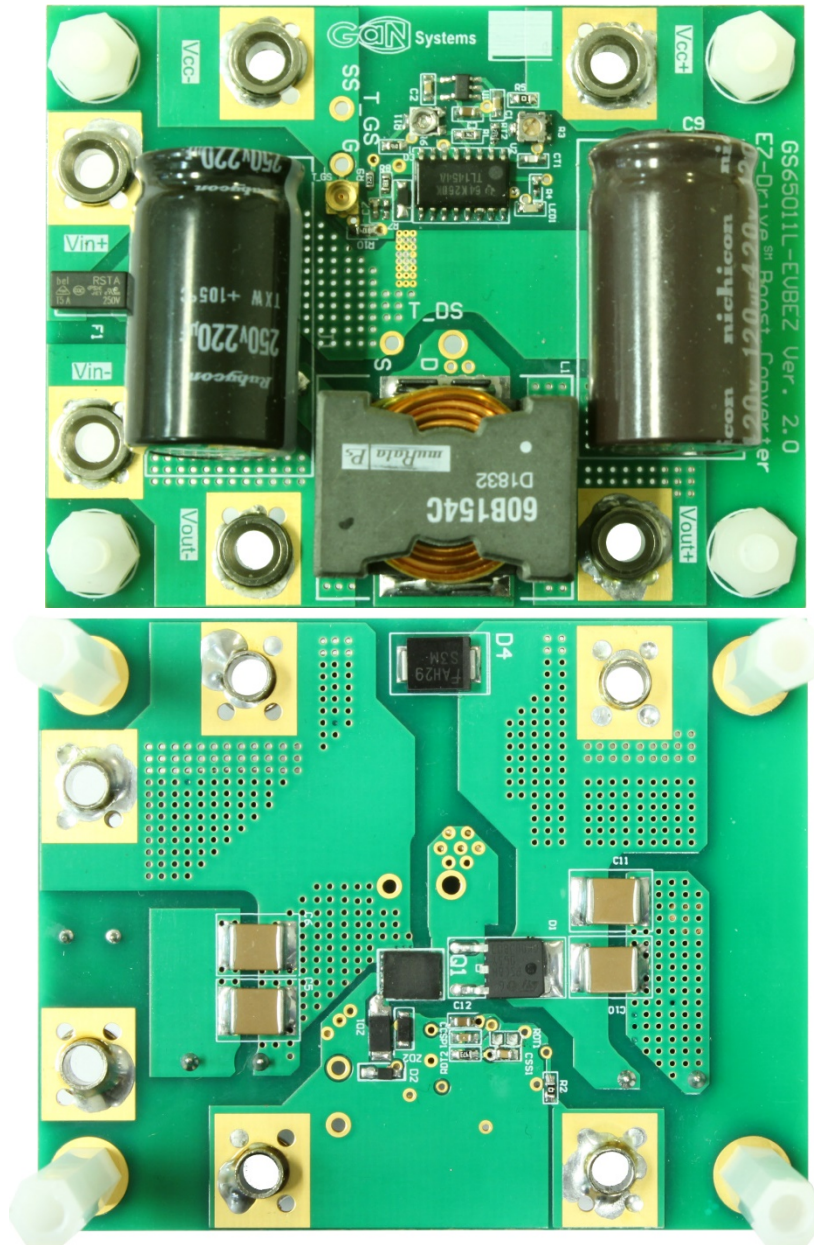


Figure 1 • GS65011-EVBZ Evaluation Board Assembly

## Block Diagram and Schematic

The block diagram and schematic of the evaluation board are provided in Figures 2 and 3.

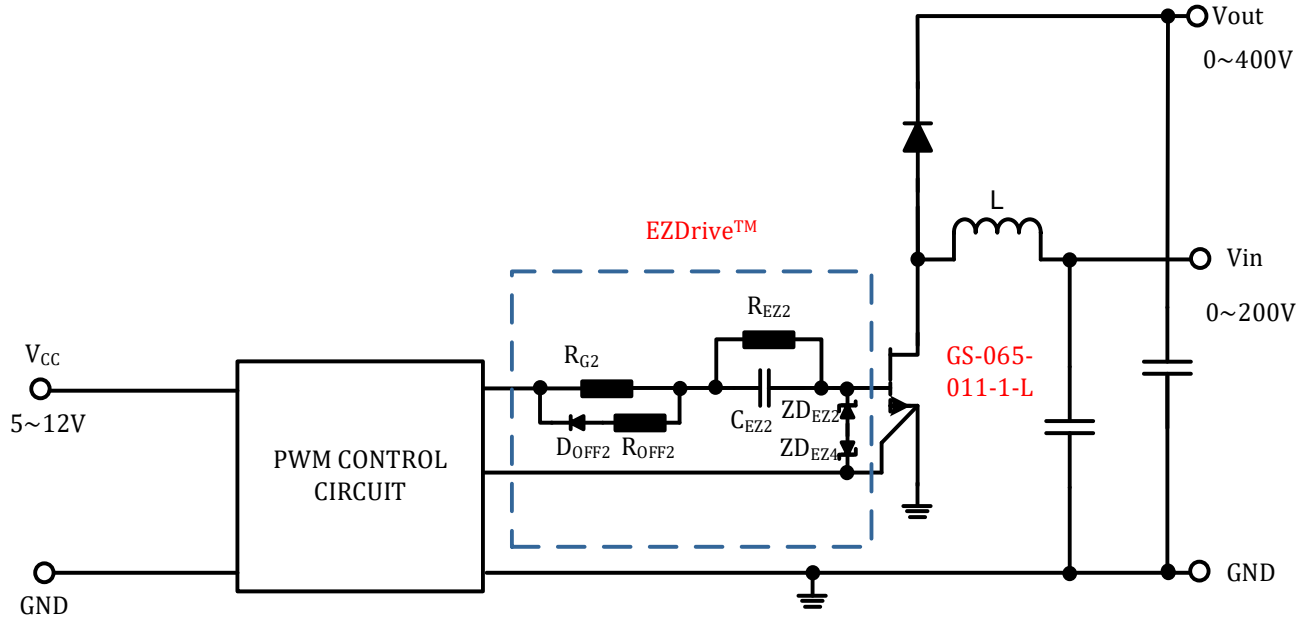


Figure 2 • GS65011-EVBEZ Block Diagram

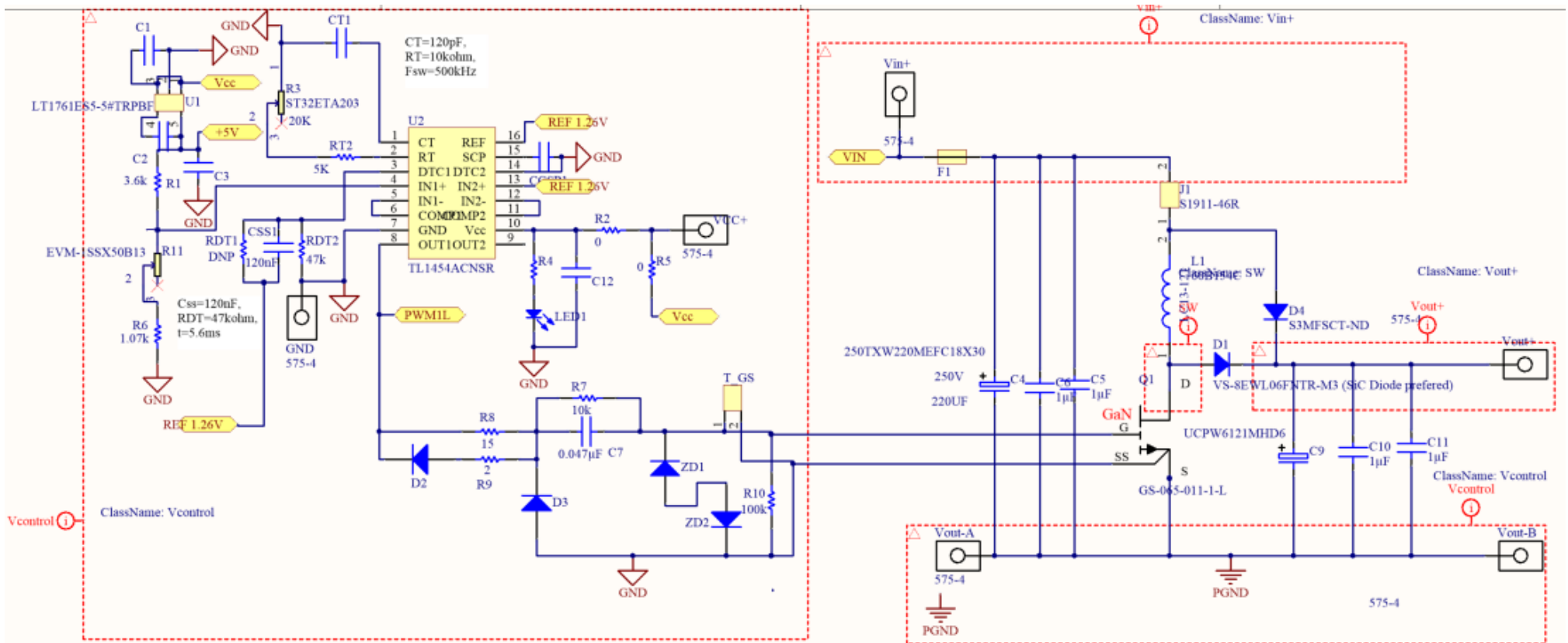


Figure 3 • GS65011-EVBZ Schematic

## Circuit Description

The GS65011-EVBEZ EVB is a GaN-based open-loop DC/DC Boost converter. It is assembled with the EZDrive® GaN driving circuit, a Si MOSFET PWM controller (TL1454ACNSR) and a 650V 5×6 mm PDFN package GaN E-HEMT, (GS-065-011-1-L). The PWM control signal is generated internally by the PWM controller, U2.

The EZDrive® uses a Si MOSFET controller to drive a GaN HEMT which has a lower threshold voltage than a Si MOSFET. The EZDrive® circuit is shown in the dotted box in **Figure 2**. It is a low-cost, low component-count circuit composed of two Zener diodes, one capacitor, three resistors and one diode.

$Z_{DEZ1}$ ,  $Z_{DEZ2}$  clamp the positive and negative gate drive voltages.  $C_{EZ}$  holds a negative voltage for GaN E-HEMT turn-off.  $R_{EZ}$  sets the minimum driving current required to keep the GaN E-HEMT fully turned on.  $R_G$  controls the turn-on speed and  $R_{OFF}$  controls the turn-off speed.

The two operation modes for EZDrive® are:

- **Mode 1:** Assuming the  $V_{CC}$  of the controller is 12V and the controller output is ON, the driving voltage on the GaN E-HEMT is clamped to 6V by Zener diode  $Z_{DEZ}$ . The rest of the  $V_{CC}$ , 6V, is stored across the capacitor  $C_{EZ}$ .
- **Mode 2:** The voltage stored in  $C_{EZ}$  is applied to the gate in reverse, allowing the GaN E-HEMT to be turned off quickly.

This circuit converts the Si MOSFET PWM controller's output voltage to the proper voltage thresholds for driving GaN Systems' E-HEMTs.



## Cautionary Notes

A Boost converter's output voltage is higher than the input voltage,  $V_{IN}$ . When operating at a high duty cycle and low load/no load operating conditions, the output voltage will rise and has the potential of damaging the GaN device. To avoid an overvoltage on the GaN device, two actions are recommended.

First, **always apply a load at the output voltage,  $V_{OUT}$ .**

Secondly, pre-set the PWM signal before applying power to  $V_{IN}$ . **Figure 4** shows the block diagram of PWM signal generation inside the TL1454ACNSR.



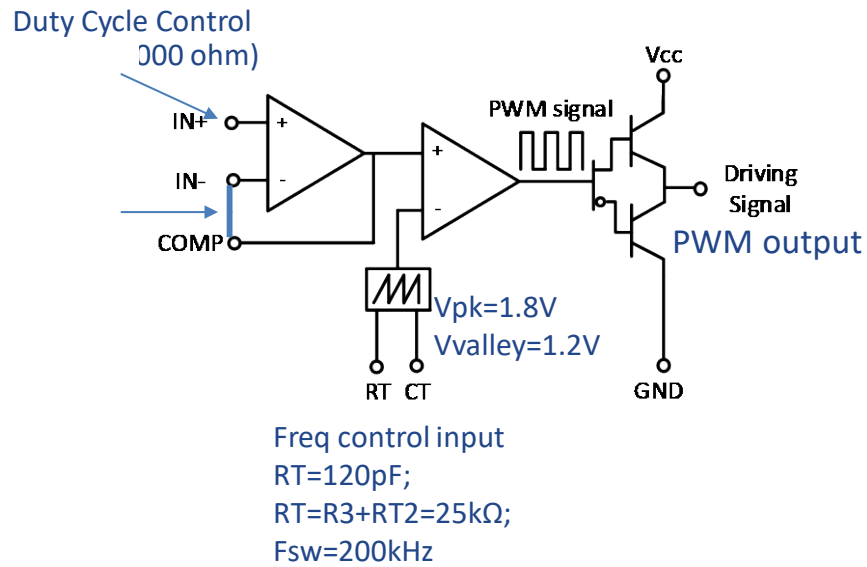


Figure 4 • GS65011-EVBEZ PWM signal adjustment diagram

The PWM signal is adjusted by tuning the controller’s peripheral resistors, R11 and R3. Use the Table 1 to set the duty cycle with R11. Use Table 2 to set the switching frequency with R3. Select the appropriate values according to your own specifications and requirements. **For a safe start up, 10% duty cycle and frequency 250kHz is recommended.**

Table 1 • PWM Duty Cycle Setting up table

	R11 (Ω)	IN1+ (V)	Duty Cycle
Case 1	1000	1.83	0 %
Case 2	850	1.74	10 %
Case 3	500	1.52	47 %
Case 4	0	1.15	100 %

Table 2 • PWM Frequency Setting up table

	fsw_MIN	fsw	fsw_MAX
R3 (kΩ)	20	5	0
CT (pF)	120	120	120
fsw (kHz)	200	500	900



## Quick Start Guide

This chapter will guide the user through the evaluation board overview, hardware operation, test setup and test results.

### Evaluation Board Overview

The evaluation board contains:

- Connectors for both high voltage ( $0\text{Vdc} < V_{\text{IN}} < 200\text{Vdc}$ ) and low voltage ( $5\text{Vdc} < V_{\text{CC}} < 12\text{Vdc}$ ) power supplies
- Connector for the output load
- User-friendly probe connector and vias for  $V_{\text{GS}}$ ,  $V_{\text{DS}}$  measurement and other performance verification
- The jumper for current sensing

The operating specifications of the evaluation board are as follows:

- The recommended input voltage operating range is  $0\text{ V} < V_{\text{IN}} < 200\text{ V}$ . (The maximum input voltage is limited by the output voltage of the Boost converter, which is further subject to operating mode, the duty cycle and the load value.)
- Frequency of operation of 200 kHz - 900 kHz.
- The maximum load current depends on die temperature and is further subject to switching frequency and operating voltage. Forced air cooling or heat sinking can increase current rating.

## Evaluation Test Setup

Figure 5 shows the test setup for the GS65011-EVBEZ evaluation board. Make sure that the specified safety precautions mentioned in “Safety Precautions” on page 2 are followed.

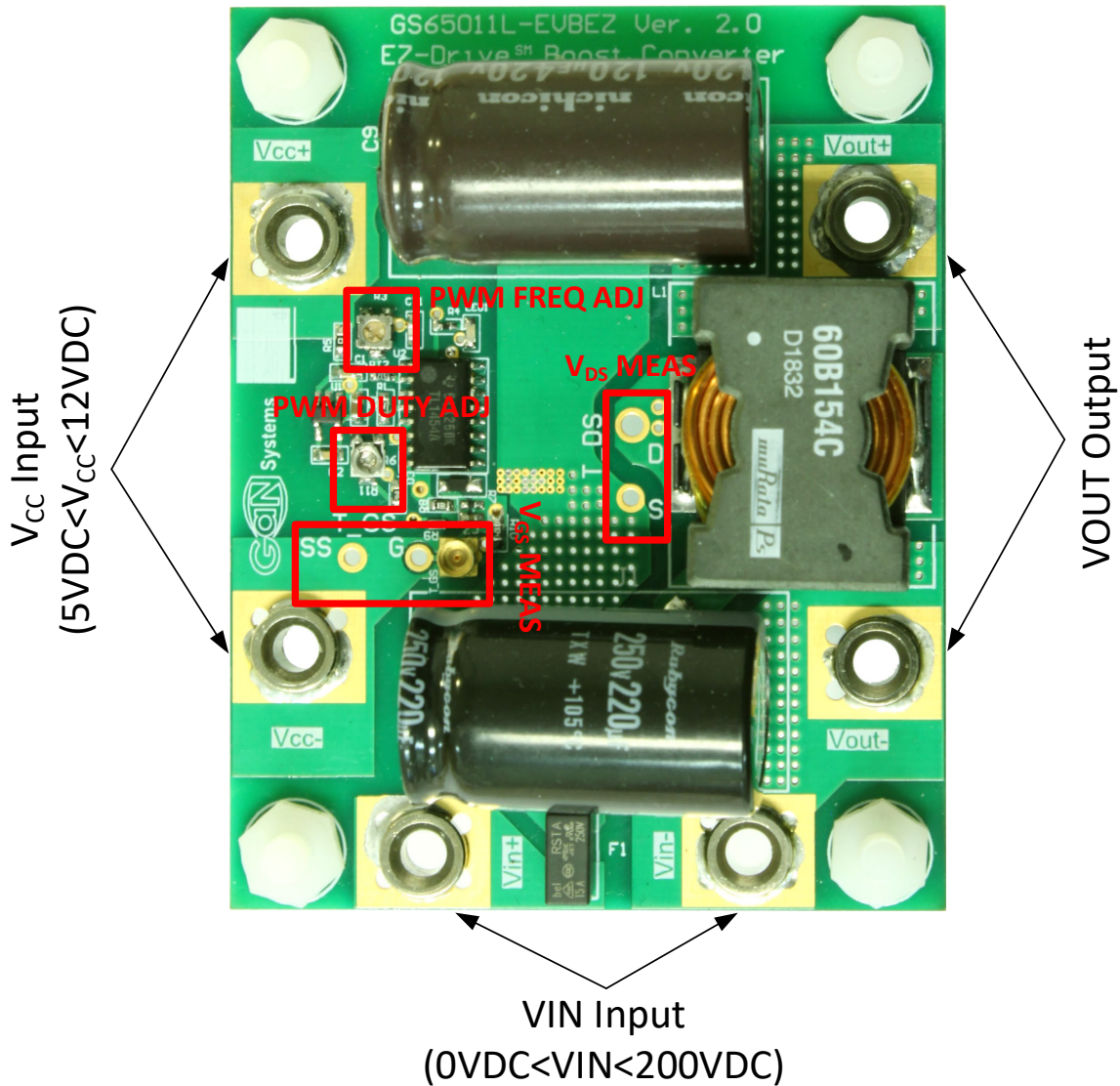


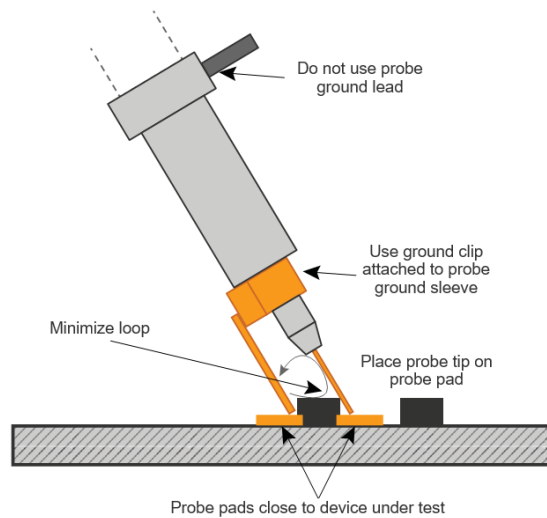
Figure 5 • GS65011-EVBEZ Test Setup

## Hardware Operation

The general guidelines for operating the evaluation board are listed in this section. Follow the steps to configure the hardware properly.

- 1) Always connect a load (E-load) to Vout+ and Vout-.
- 2) Pre-set the PWM frequency and the duty cycle (by tuning R3 and R11), according to the PWM signal look-up tables. Start with 10% duty cycle and frequency 250kHz.
- 3) Apply  $V_{CC}$  ( $5V_{DC} < V_{CC} < 12V_{DC}$ ) to Vcc+ and Vcc-, use T\_GS (MMCX JACK) or G/SS (VIAS) for  $V_{GS}$  monitoring
- 4) Check the  $V_{GS}$  waveform and fine-tune the PWM frequency (by tuning R3) and duty cycle (by tuning R11)
- 5) For taking an efficiency measurement, add a current meter and use Vin+ and Vin- for  $V_{IN}$  and use Vout+ and Vout- for  $V_{OUT}$  measurement.
- 6) Apply  $V_{DC}$  to Vin+ and Vin- and sweep the voltage from low (0V) to max. Monitor the output voltage and device temperature. Make sure  $V_{OUT}$  is lower than 400V, and the GaN device temperature is lower than 150°C. Note: the maximum input voltage is limited by the output voltage of the Boost converter, which is dependent on the operating mode, the duty cycle and the load value.
- 7) After testing, turn off  $V_{IN}$  first, then  $V_{CC}$  across Vcc+ and Vcc- last.

**Note:** When measuring the high frequency content switch node, care must be taken to avoid long ground leads. Measure the switch node by placing the oscilloscope probe tip through the Drain via and Source via (designed for this purpose). See **Figure 6** for proper probe technique and **Figure 5** for the location of  $V_{GS}$  and  $V_{DS}$  measure vias. Use a high voltage passive/differential probe for the  $V_{DS}$  measurement.



**Figure 6 • Proper Oscilloscope Probe Measurement Technique**

**Note:** A jumper is placed between the  $V_{in+}$  signal and the inductor (beneath the input capacitor C4) The jumper can be replaced by a loop of jumper wire to take the inductor current measurement.

**Figure 7** shows the jumper location. **Figure 8** shows how to replace the jumper with a loop of jumper wire to take the current measurement with a current probe. The jumper wire loop and the current probe are not included in the Evaluation Kit.

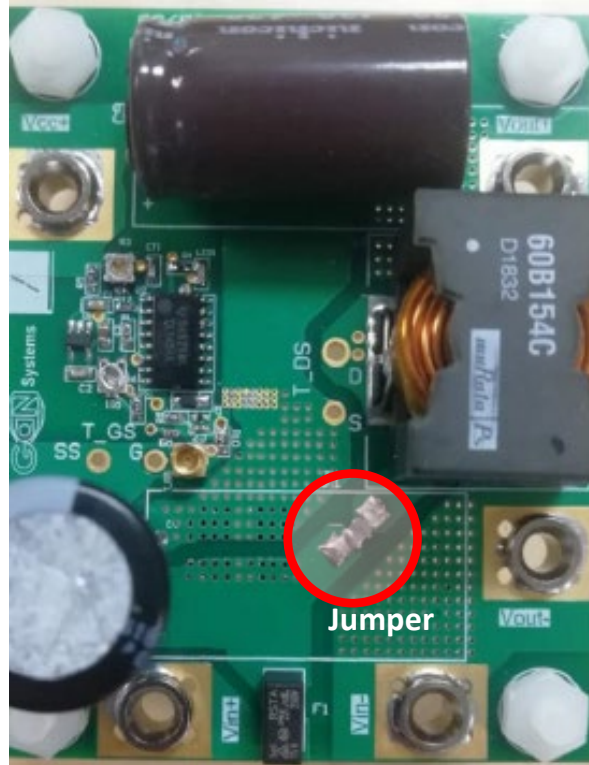


Figure 7 • Current Sensing Jumper Location

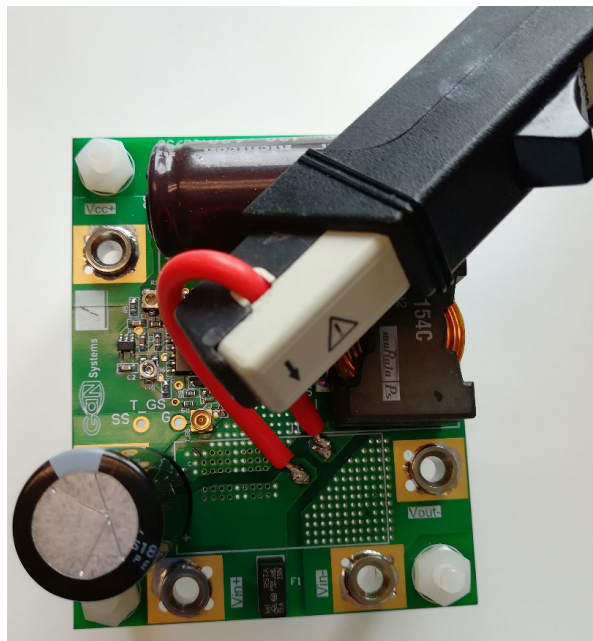
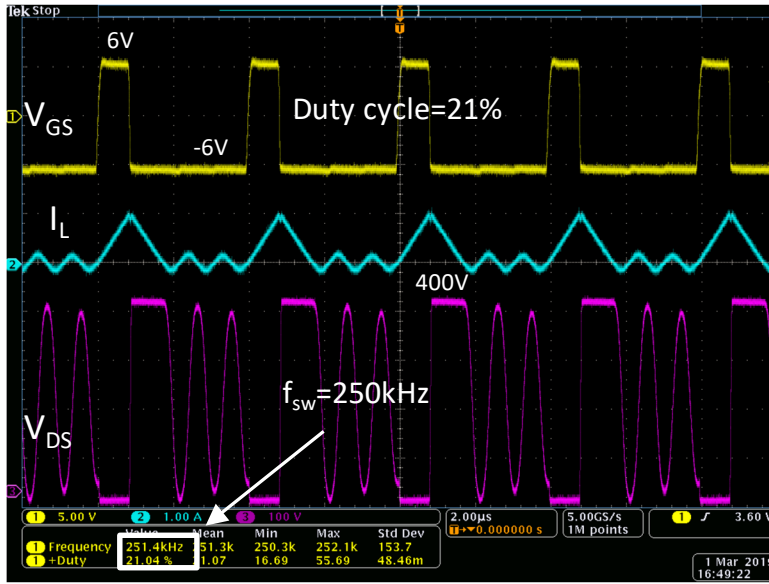


Figure 8 • Inductor Current Probe Insert Example

## Evaluation Results

The evaluation results are shown in Figures 7 through 10.

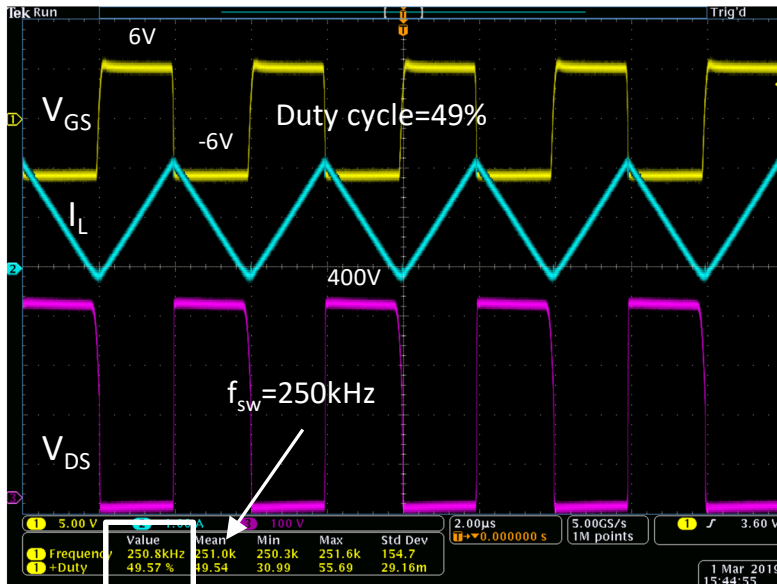
Figure 7 • Test Results at half load



$P_{OUT}$	Half load (100W)
$V_{IN}$	200V
$V_{OUT}$	400V
Duty cycle	21%
$f_{sw}$	250kHz
Efficiency	96%

Test conditions:  $V_{IN}$ =200V;  $V_{OUT}$ =400V;  $I_{OUT}$ =0.25A;  $P_{OUT}$ =100W (half load);  $f_{sw}$ =250kHz

Figure 8 • Test Results at full load

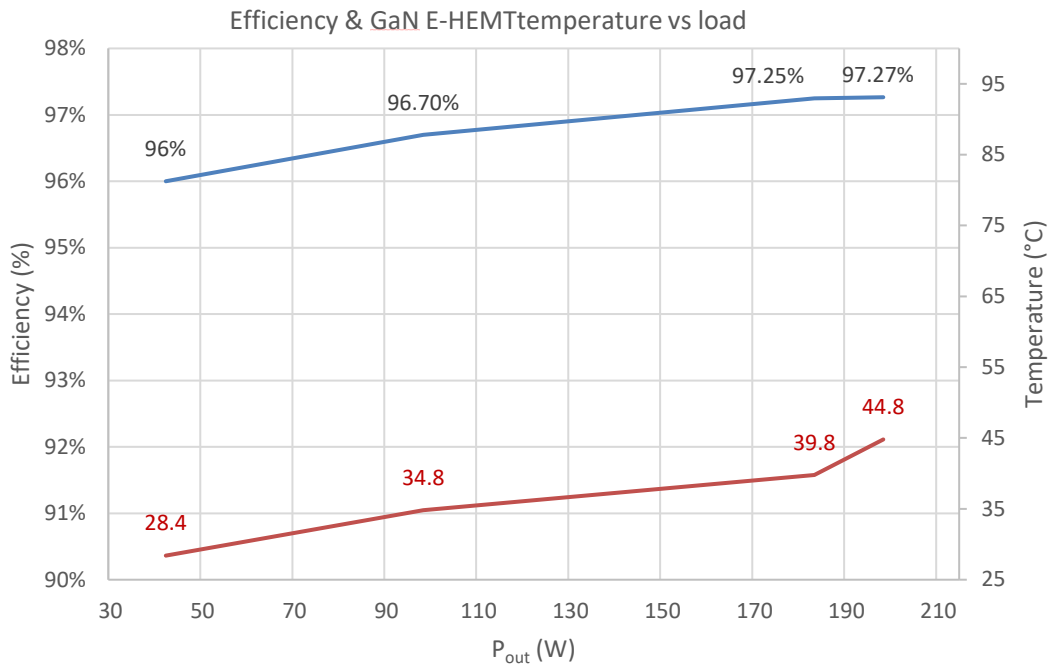


$P_{OUT}$	Full load (200W)
$V_{IN}$	200V
$V_{OUT}$	400V
Duty cycle	49%
$f_{sw}$	250kHz
Efficiency	97.3%

Test conditions:  $V_{IN}$ =200V;  $V_{OUT}$ =400V;  $I_{OUT}$ =0.5A;  $P_{OUT}$ =200W (full load);  $f_{sw}$ =250kHz

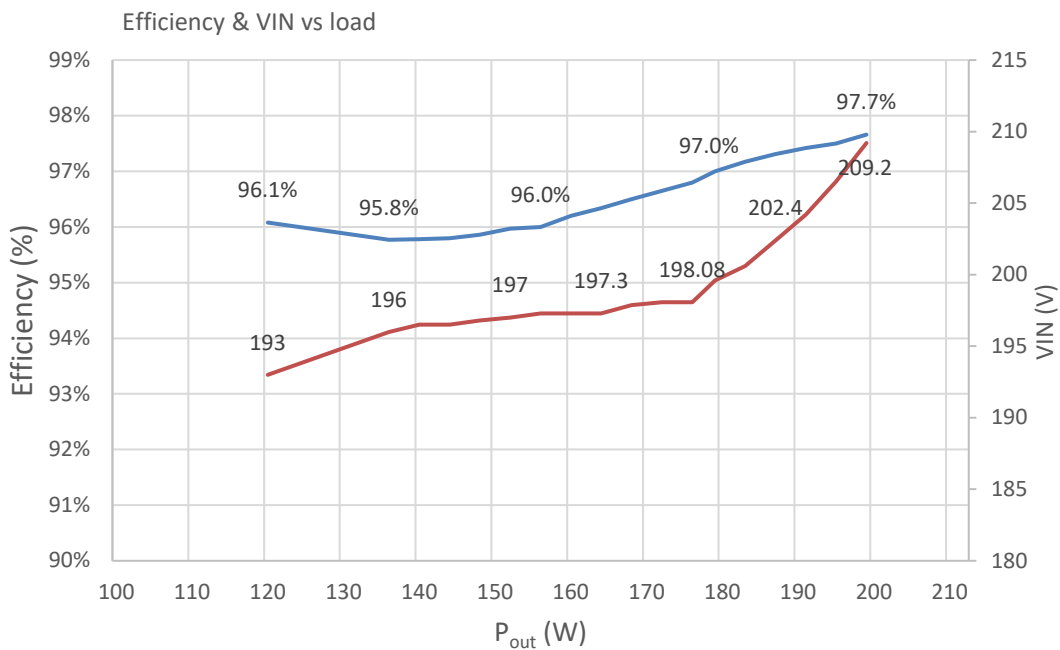


**Figure 9 • Efficiency & GaN E-HEMT temperature vs load**



Test conditions:  $V_{IN}=200V$ ,  $V_{OUT}=400V$ ,  $f_{sw}=250kHz$

**Figure 10 • Efficiency &  $V_{IN}$  vs load**



Test conditions: Duty cycle=40.8%,  $V_{OUT}=400V$ ,  $f_{sw}=250kHz$



## Thermal Considerations

The EVB includes one GS-065-011-1-L GaN E-HEMT. Although the electrical performance surpasses that for traditional silicon devices, their relatively smaller size does magnify the thermal management requirements. The evaluation board is intended for bench evaluation under low ambient temperature and with convection cooling. The addition of heat-sinking and forced air cooling can significantly increase the current rating of these devices, but care must be taken to not exceed the absolute maximum junction temperature of +150 °C.

Note: The EVB does not include any on-board current or thermal protection.

The thermal performance of the EVB is shown in **Figure 10** and **Figure 11**. Infrared thermography was performed under the following conditions, with a fan on at room-ambient temperature:

- $V_{IN} = 200V$
- $V_{OUT} = 400V$
- $I_{OUT} = 0.5A$
- $f_{sw} = 250\text{ KHz}$

**Figure 11 • Thermal imaging with an external fan ( $T_{MAX} = 44.8^{\circ}C$ )**



## Technical Resources

This document and additional technical resources are available for download from [www.gansystems.com](http://www.gansystems.com).

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## GS65011-EVBEZ Revision History Table

Revision #	Changes from Previous	Owner
190603	First version	Yajie Qiu
190621	Changed from EZDriveSM to EZDriveTM and made editing changes	J. Ajersch
200526	Changed from EZDrive™ to EZDrive®. Changed from “User Guide” to “Technical Manual”	K. Song J. Ajersch