

## **GSWP050W-EVBPA**

# **50W GaN E-HEMT Wireless Power Transfer Evaluation Board, Optimized for Class EF2 Amplifiers**

## **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 and devices 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, always connected to the load during the test on-going.

## Introduction to Magnetic Resonant Wireless Power Transfer

Recent technological advances in power semiconductors are enabling Wireless Power Transfer (WPT) as a technically and commercially viable option for charging and powering equipment across a wide range of markets, applications, and power levels.

Inductive charging has been in use for a number of years, however, it's burdened with limitations that restrict it to low power applications with tightly controlled alignment between the transmitter and receiver.

A more advantageous approach, magnetic resonant charging, addresses these shortcomings by using a high frequency oscillating magnetic field to transfer energy. The benefits that magnetic resonant charging offers include variable spacing between the transmitter and receiver, the ability to charge through materials such as a desk or an enclosure, one-to-many charging, ease of installation, suitability for high power levels, and fast charging. Table 1 provides a comparison between inductive charging and magnetic resonant charging.

GaN E-HEMTs are a key enabler of magnetic resonant charging because their extremely fast switching speeds, on the order of a few nanoseconds, result in very low switching losses. This allows them to operate efficiently at very high frequencies, such as the 6.78MHz that is commonly used for magnetic resonant charging.

**Table 1 A comparison of Inductive charging and Magnetic Resonant charging**

Charging technology	Inductive	Magnetic Resonant
Frequency range	80-300kHz	6.78MHz
Max transfer range	5mm	<b>50mm</b>
Multi-device	No	<b>Yes, at different power levels</b>
Spatial Freedom	Low	<b>High</b>
Power Range	Low & limited 30W max	<b>Broad &amp; versatile 50W to 20kW+</b>
Efficiency	Limited to 80%	<b>High: up to 95%</b>

A high-level block diagram of a resonant wireless power transfer system is shown in Figure 1. The transmit section is composed of a power amplifier, an impedance matching circuit and a transmit coil. High frequency energy is transferred wirelessly at 6.78MHz to the receive circuit which is comprised of a receive coil, an impedance matching circuit and a rectifier.

The GSWP050W-EVBPA evaluation board is designed to support and expedite the innovation of WPT systems by providing the Power Amplifier, the most challenging aspect of the system design.

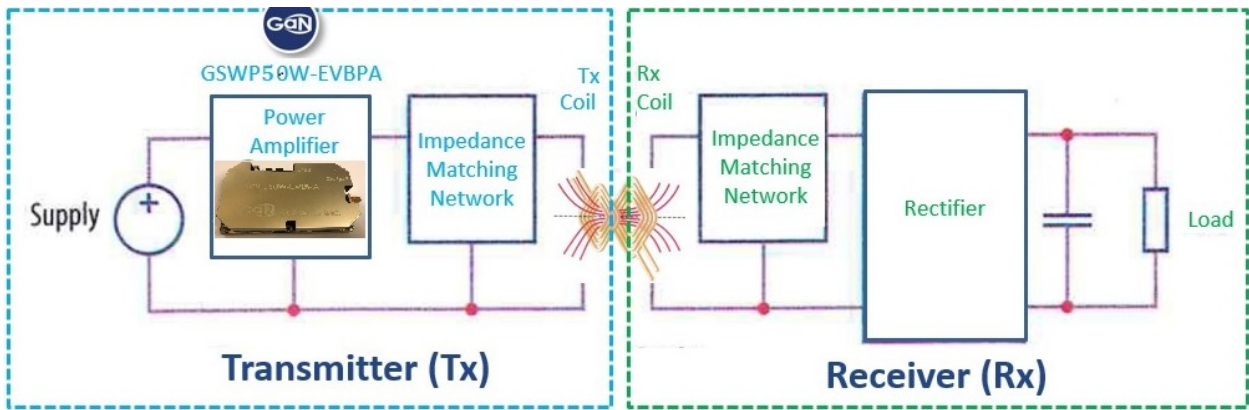


Figure 1 - A magnetic resonant wireless power transfer design.

## Evaluation board overview

The GSWP050W-EVBPA uses GaN Systems' GS61004B E-HEMTs in a 6.78MHz class EF2 power amplifier. The GS61004Bs are used with the integrated high-speed pSemi PE29102 gate driver in a push-pull configuration. The outputs of the PE29102 are capable of providing switching transition speeds in the nano-seconds range for hard switching applications.

This Technical Manual includes a circuit description, a quick-start guide and measurement results.

## Evaluation Kit Contents and Requirements

### Kit Contents

The GSWP050W-EVBPA includes the following hardware for evaluating the GaN E-HEMT 50W power amplifier.

Table 2 GSWP050W-EVBPA Evaluation Kit Contents

Quantity	Description
1	GaN E-HEMT GS61004B WPT PA evaluation board assembly
1	WPT PA heatplate
1	WPT PA EMC shield
2	2 pins DC cord

## Hardware Requirements

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

- DC power supply 50V/5A
- TEK scope with current probe TCM0030A
- Fluke 87 multimeter for input current
- 50dB 100W attenuator as load
- Spectrum analyzer
- Power meter
- Thermal meter

## Evaluation Board Assembly Overview

The evaluation board (EVB) is assembled with two GS61004B E-HEMT transistors and two PE29102 GaN E-HEMT drivers. Headers are included for monitoring the signal input, signal output, power connections and detection monitoring signals. Probe points are included for waveform measurements. Provision has been made for a single, suitable heatsink to be fastened against the two E-HEMTs, using the two holes in the center of the bottom heatplate.

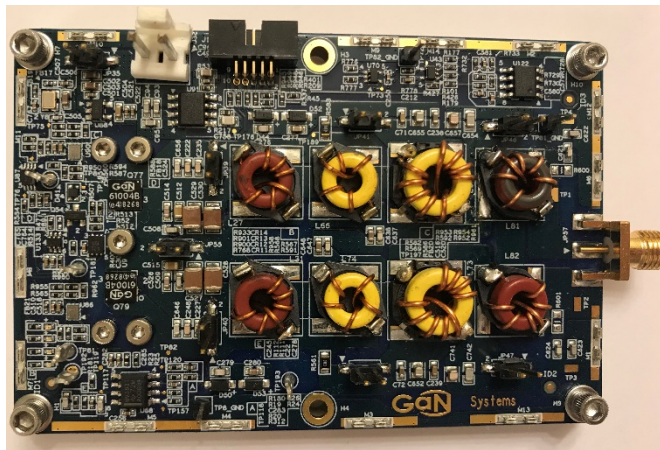
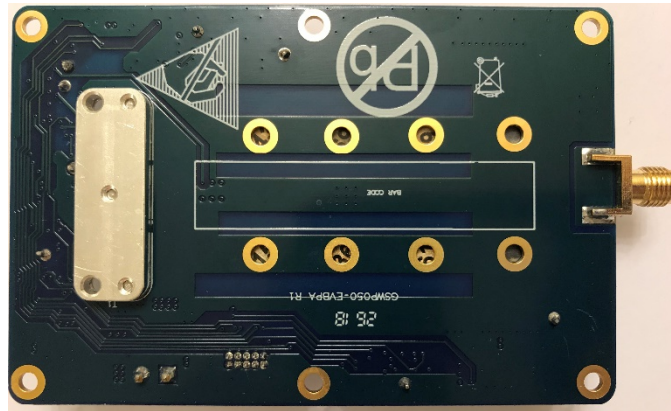
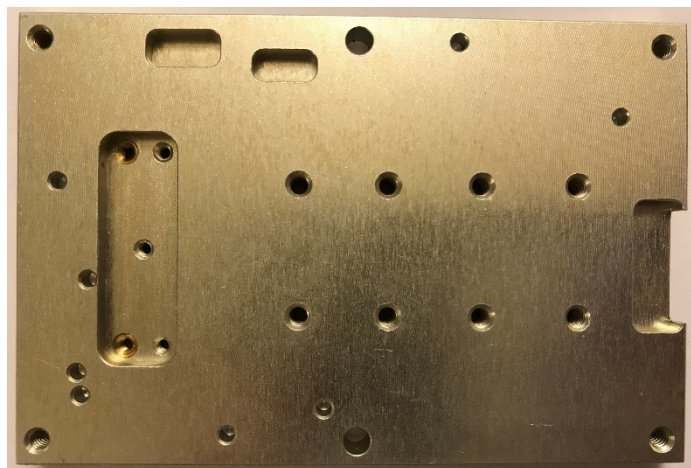


Figure 2 • Top side of GSWP050W-EVBPA Evaluation Board Assembly



**Figure 3 • Bottom side of GSWP050W-EVBPA Evaluation Board Assembly, showing copper coins**

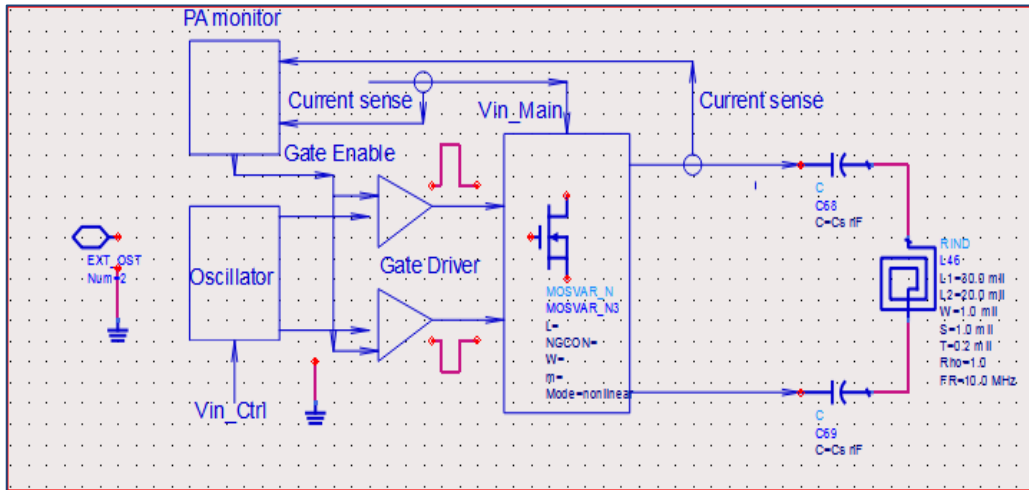


**Figure 4 • GSWP050W-EVBPA Evaluation Board heatplate**



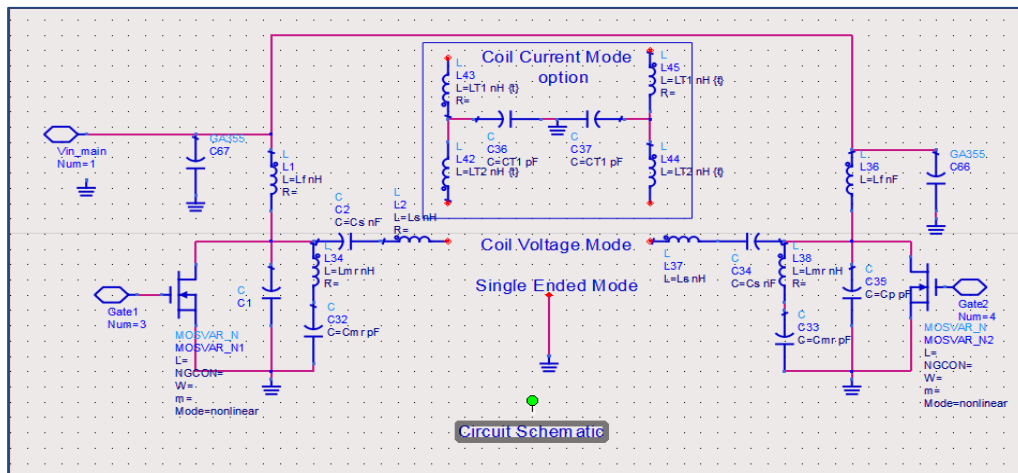
## Block Diagram

The block diagram of the evaluation board is provided in Figures 5 through 7.



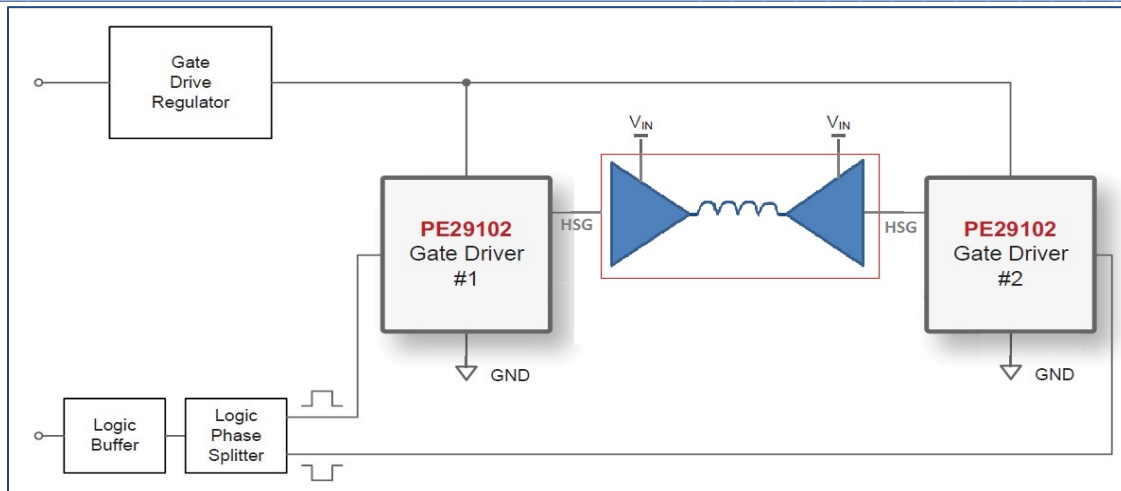
**Figure 5 • GSWP050W-EVBPA WPT Push-Pull EVB Block Diagram**

Note: The coil in Figure 5 is not included in the EVB.

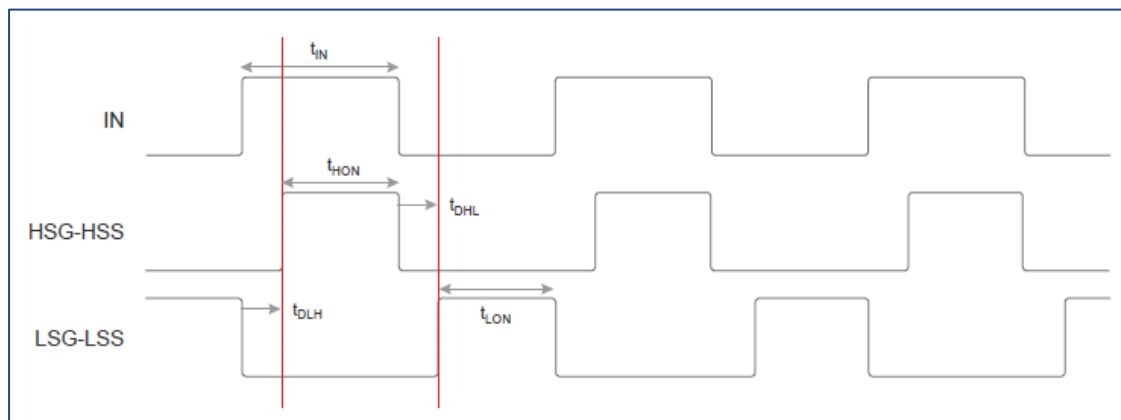


**Figure 6 • GSWP050W-EVBPA WPT Class EF2 PA Block Diagram**

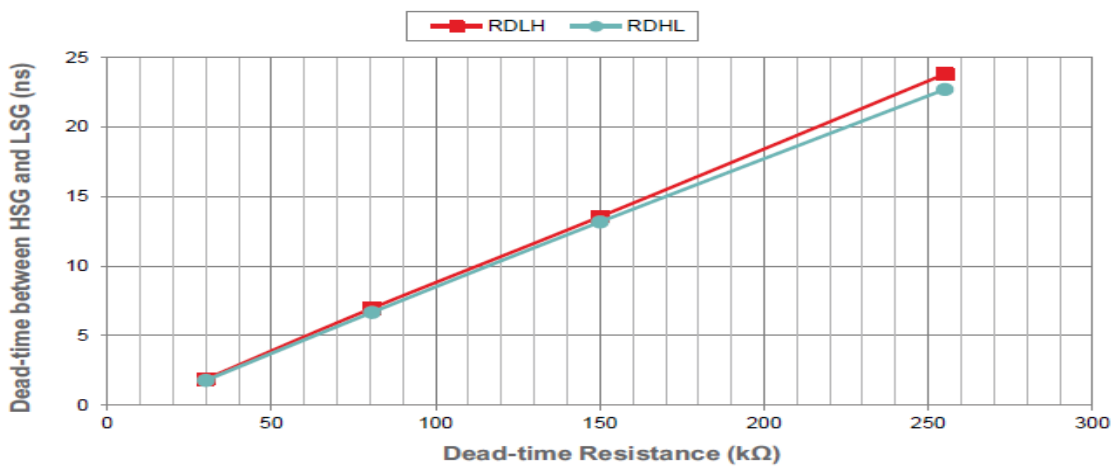
Note: The switch devices are GaN Systems' GS61004B E-HEMTs



**Figure 7 • GSWP050W-EVBPA WPT driver Block Diagram**



**Figure 8 • PE29102 Dead-time Waveforms and Duty Cycle Setting**



**Figure 9 • Dead Time vs Dead Time Resistor**



## Circuit Description

The Push-Pull circuit is comprised of two single ended PAs which share a common supply, however; the impedance matching is separated.

The high-side E-HEMTs are powered by a DC source, referred to as the HV supply. It is connected through J32. The voltage of this source not exceed 25V<sub>DC</sub>.

The low-voltage logic circuitry runs off a 3.3V<sub>DC</sub> voltage regulator, U88, which is powered from a +5V<sub>DC</sub> source connected through JP35. The +5V<sub>DC</sub> rail also feeds two PE29102 drivers U86 and U90, which are driven independently by U87, a common logic D-type flip/flop. U87 has a frequency divider configuration, which is driven by a crystal oscillator Y8 at a frequency of 13.56MHz. The two PE29102 gate drives are capable of 6V operation.

The PA can be configured to operate in a number of different modes, which include

- Push-pull configuration
- Single ended mode

Detailed operation procedures and setup for these alternative configurations are provided in the section titled “quick start guide”.

The PA includes an over-temperature protection circuit. Temperature sensor U9, placed close to the GS61004B E-HEMTs, monitors their temperature. In an over-temperature condition, the PE29102A driver will be disabled through U133 and stop driving the E-HEMTs. The design also includes circuitry to protect against over-current, and load mismatch.

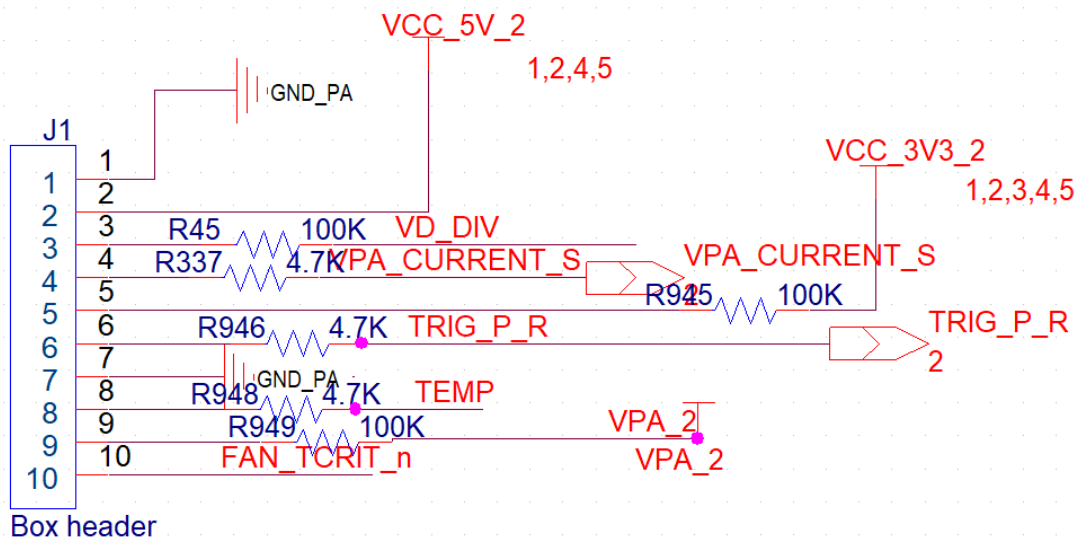
For convenience, test points are provided to monitor and measure the electrical signals. A description of the test points and diagram of their location is provided in Table 4.

The PA also includes a Micro Controller Unit (MCU) monitor interface header, J1. The signals available through J1 can be used to control the PA system for close loop in the WPT system. A definition of the signals available on header J1 is provided in Figure 10.

- Monitor signals on J1.
- Pin1: PA GND
- Pin2: 5V Input
- Pin3: output voltage detection
- Pin4: PA HV DC current
- Pin5: 3.3V DC
- Pin6: over voltage and current
- Pin7: PA ground
- Pin8: Temperature sensor voltage
- Pin9: PA HV DC input
- Pin10: Fan control enable

**Figure 10 • MCU interface definition. Signals on J1**

The PA connectivity is depicted in Figure 11 and includes the RF input and output, the DC biases and the MCU monitor interface.



**Figure 11 • Circuit Connectivity**

## Protection Circuit

The PA includes circuitry to protect against input DC overcurrent, device over temperature, output RF overvoltage and Voltage Standing Wave Ratio (VSWR) protection. The protection signals are combined by U133, a 3 inputs OR gate logic chip, and will shut the driver down under a fault condition.

Input DC overcurrent protection (OCP): U91 is the DC current sensor chip, which can handle a maximum of 10A. The output of the current sensor ship is a current sense signal that goes thru buffer OP U122 and is compared to a reference voltage. The reference voltage is set with R101 and R177. Upon an over current event, a signal is generated to signal OCP\_TRIG.

Overvoltage protection (OVP): The design includes overvoltage protection circuitry for both the high side and the low side. The high side voltage sensor is comprised of C276, C277, and two Schottky diodes; D52 and D44. C276/C277 form a voltage divider, the ratio of which can be changed. Two diodes rectify the RF signal to DC thru C278/C22 and R111 and the resulting voltage represents the high side output. The low side circuit is similar. It's comprised of C270, C280, and two diode D50, D53. These two voltage detection signals go to a two-channel comparator U68 and are combined with OR gate U70 into one overvoltage trigger, OVP\_TRIG.

The OVP and OCP go into a hard combine circuit D45, which is a dual diode in one. To generate an overcurrent / overvoltage protection trigger signal.

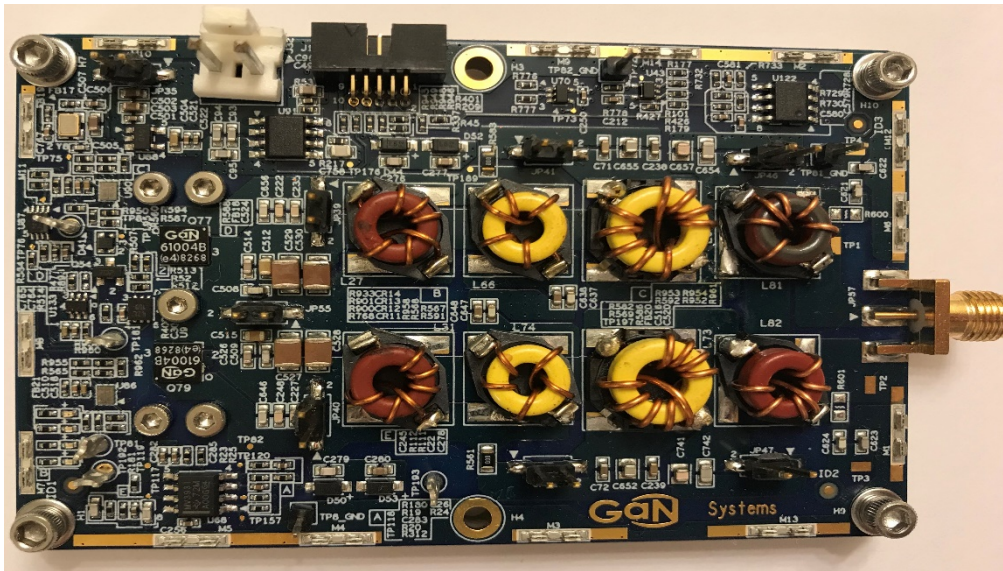


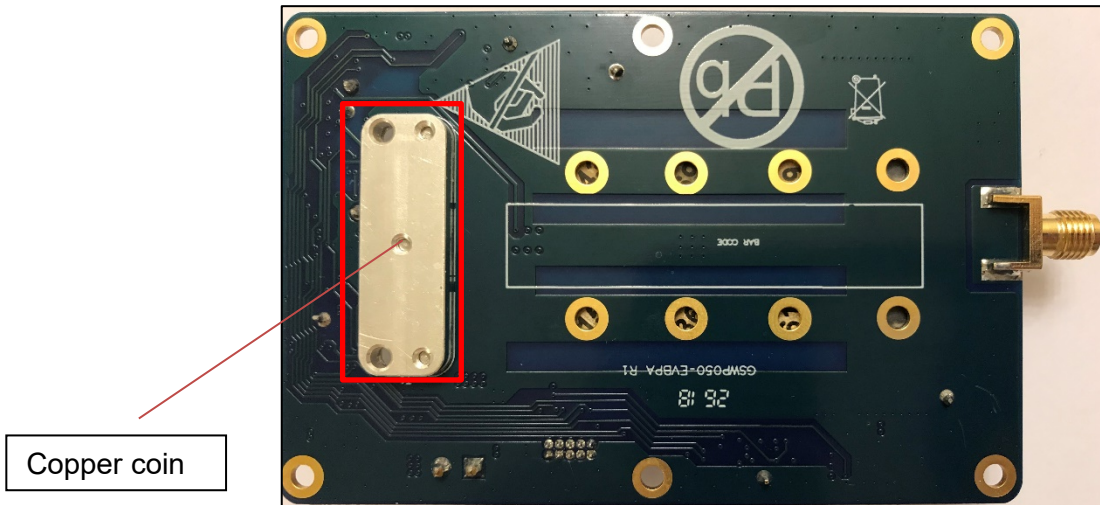
Figure 12 • Connectivity locations

## Thermal Management

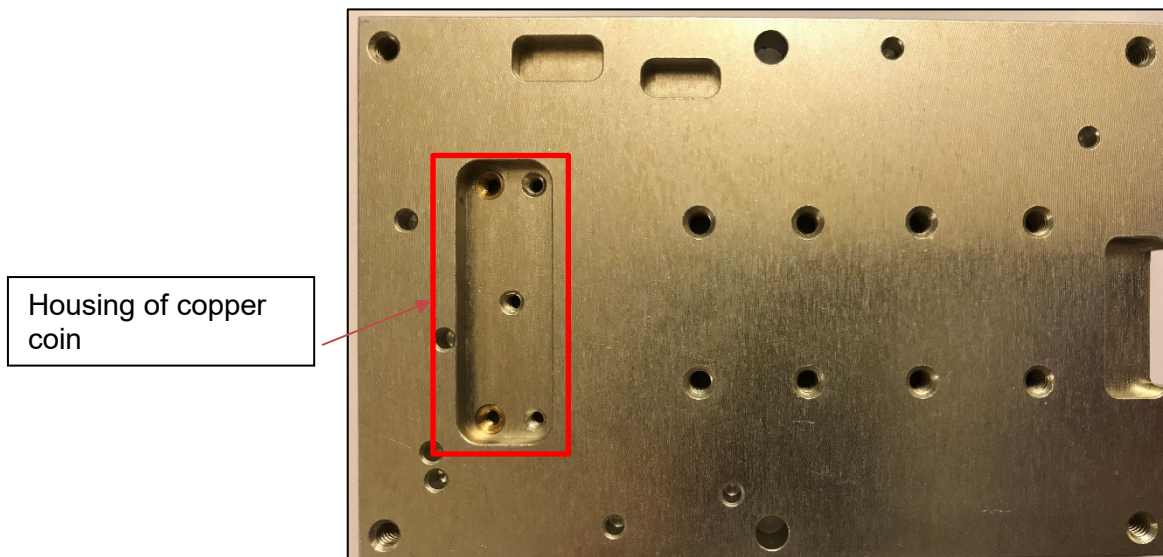
Thermal management of the GaN E-HEMTs in this RF power system is a critical aspect of the design. Maintaining low device temperatures through proper thermal management enhances the system reliability and extends the range of operating temperature.

The GS61004B are bottom-side cooled devices that use GaN<sub>PPX</sub>® packaging, designed for optimal thermal performance. For effective thermal management, a hole is cut out of the PCB to permit access to the copper coins. The two GS61004Bs' bottom side thermal pads are soldered directly onto the copper coin on the bottom side of the PCB and the Gate, Drain and Source signals are routed on the top side of the PCB. This set up provides an ultra-low thermal impedance from the die to the

copper coin.



PCB back side  
**Figure 13 • Copper coins soldered beneath PCB and devices top PCB**



**Figure 14 • Aluminum heatsink plate with housing for the copper coins**

## Quick Start Guide

The GSWP050W-EVBPA EVB is designed to as a platform for evaluating the GS61004B E-HEMTs in a Push-Pull Class EF2 PA for WPT. This chapter will guide the user through the evaluation board overview, PA operation, bench setup and test results.

## Evaluation Board Overview

### Kit Contents

The GSWP050W-EVBPA evaluation kit contains:

- Power Amplifier evaluation board assembly
- PA heatplate
- PA EMC shield
- 2 pins DC cord

### Evaluation board specifications

**Table 3:** EVB specifications:

PARAMETER	SPECS
Input Voltage range	25V <sub>DC</sub> max
Tx output power	50W
Tx efficiency (peak)	88%
Topology/Class	EF2
Frequency	6.78 MHz
Switching type	Push/Pull
GaN Systems part number	GS61004B
Number of GS devices	2
Optimized RL (load)	20Ω
Constant current mode	optional

The maximum operating specifications of the evaluation board are as follows:

- Maximum HV supply input operating voltage of 25V<sub>DC</sub>
- Maximum LV supply input operating voltage of 6V<sub>DC</sub>
- Frequency of operation of 6.78MHz.
- Maximum output power of 50W \*



Note: \* The maximum output power depends on the input voltage, as shown in Figures 21 and 24.

### Test points

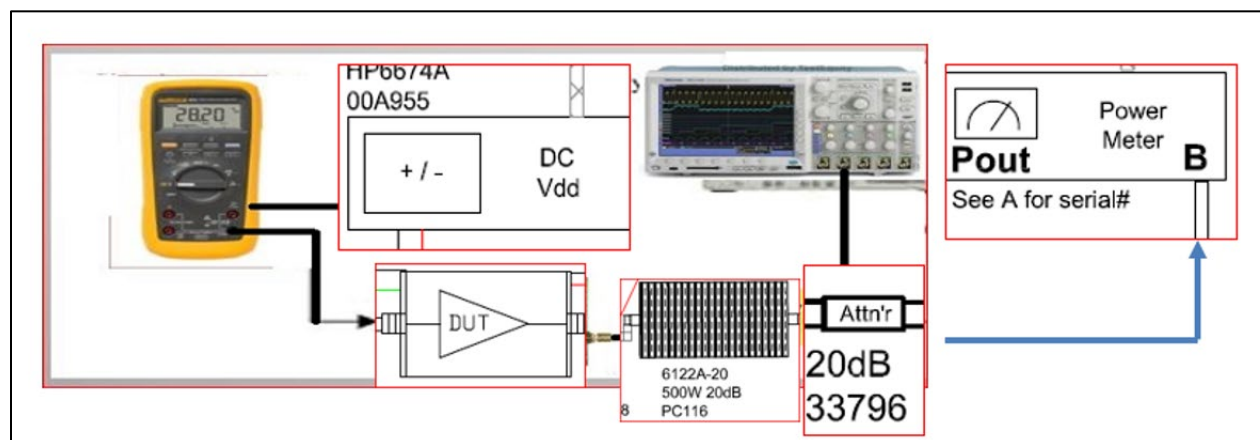
To monitor the performance of PA, test points are provided and as described in Table 4. All test points are available on the top side of the board, none are on the bottom side. The test points locations are silkscreened on the PCB.

**Table 4:** Test point description

Test point	Description	
TP197	U90 input (PE29102 driver)	
TP76	U6 input (PE29102 driver)	
TP8	Q77 Gate voltage	
TP81	Q76 Gate voltage	
TP189	Q77 Drain voltage	
TP82	Q76 Drain voltage	
TP176	25V DC current detection	

### Evaluation Bench Test Setup

The test bench setup for the GSWP050W-EVBPA EVB is shown in Figure 15. Ensure that the safety precautions mentioned on page 2 are followed.



**Figure 15 • Bench setup**

A recommended list equipment is provided below. Equipment with equivalent performance specifications can be substituted. In all cases, ensure that it is well calibration.



- DC power supply 50V/5A
- TEK scope with current probe TCM0030A
- Fluke 87 multimeter for input current
- 50dB 100W attenuator as load
- Spectrum analyzer: RIGOL DSA 815
- Power meter: GiGa 8542C
- Thermal meter, sensor is located at screw of copper coin

Note: The WPT test setup is normally a non-50 $\Omega$  system. If the PA is tested under a non-50 $\Omega$  system, the measurement results may not correlate with 50 $\Omega$  system due to the mismatch.

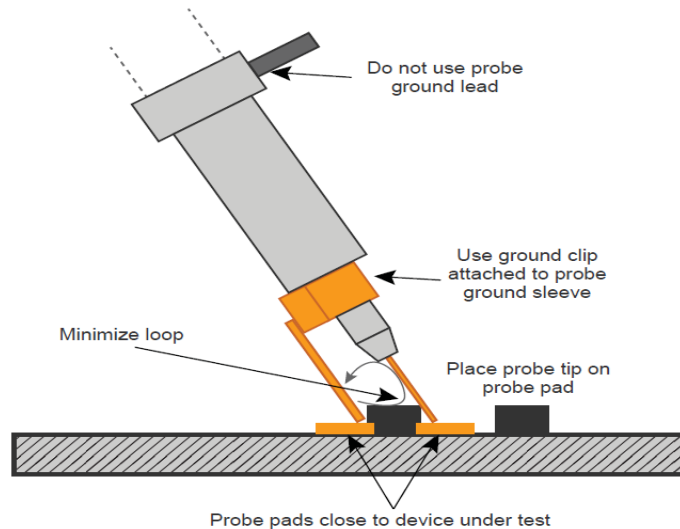
## Hardware Operation

The following steps provide a guideline for proper hardware operation and configuration.

- 1) First, set the current limit to 0.3A for the +5V<sub>DC</sub> supply feeding JP35.
- 2) Set the current limit to 1A for the HV DC supply feeding J32 at a voltage of between +10V<sub>DC</sub> and +10V<sub>DC</sub>.
- 3) Verify that all DC power supplies are turned off.
- 4) Make sure the load is connected to JP57.
- 5) Verify the Class EF2 waveform via test points TP8, TP81 with JP35 +5V<sub>DC</sub>.
- 6) Connect the V<sub>DD</sub> power supply to J32. Apply between 4V to +10V<sub>DC</sub> to J32. Read the output power at JP57.
- 7) Turn on the HV supply to the desired value. Do not exceed the absolute maximum voltage of +25V<sub>DC</sub>. Keep the JP35 +5V<sub>DC</sub> on.
- 8) To power the evaluation board down, reverse the steps above.

## Measurement Technique

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 at TP192 and TP193 (designed for this purpose) or to the closest ground screws. Refer to Figure 16 for the proper probe technique.



**Figure 16 • Proper oscilloscope probe measurement technique**

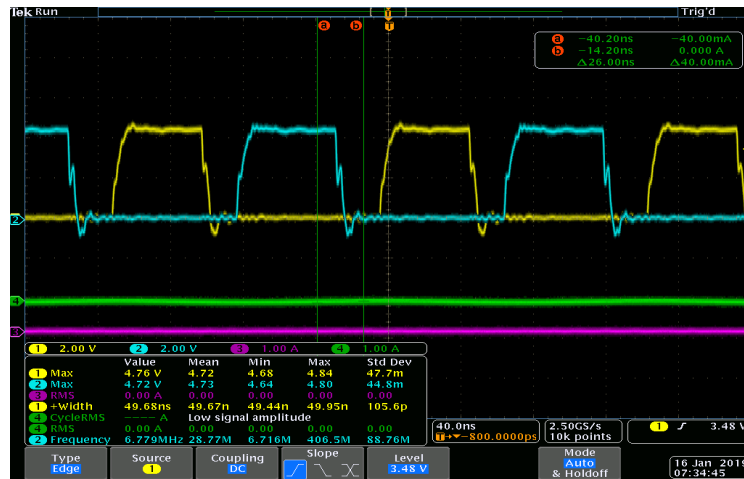
## PA Performance

### Power-on Procedure

- An additional heatsink may be required. The PA heatplate is provided with threaded hole locations that can be used to attach the heatsink to the heatplate with 4-40 screws. To ensure excellent thermal conduction, apply thermal grease to the PA / heatsink interface before screwing the units together. Enough thermal grease should be applied so that a small amount extrudes on all four sides as the screws are tightened. Wipe the assembly clean.
- Solder the wires with the SMA connector to JP57.
- Connector the load to JP57
- Plug the 5V<sub>DC</sub> supply into JP35. Pin 1: positive. Pin 2: negative. Turn the supply on and set the DC input voltage to 5V
- Plug the HV supply into J32. Pin 1: positive. Pin 2: negative. Turn the supply on and ramp the voltage from 0V to 10V.
- Monitor the test point voltage by comparing the power meter measurement to GaN Systems' test data which is available in Appendix A.
- If the measurements correlate, increase the HV supply to 20V<sub>DC</sub>.
- **IMPORTANT:** Ensure the 5V<sub>DC</sub> supply does not exceed 6V during testing.

## Evaluation Results

The evaluation results for performance are captured in Figures 17 through 21.



**Figure 17 • Oscilloscope Plot Showing Both GS61004B Gate Node Signals at TP8, TP81**

For a Class EF2 power amplifier topology, the optimal efficiency is achieved at a duty cycle of approximately 35%. At that operating point, the PA can work under very ZVS wide impedance range with high efficiency. The PA duty cycle is controlled by gate driver PE29102A. For a detailed time-delay design please refer to Figure 8 and Figure 9. The total resistor value of R955/R965 dominates the dead time of U86, and the delay time of U90 is controlled by R953/R952. Both two of PE29102A operate as high side mode, low side of chip is disable, and to reduce inductance thru shortened length of trace between gate of GS61004B and PE29102A, the pins of low side output of PE29102A are removed in the layout.

Typical waveforms at the devices Drain node are shown in Figure 18. Channel 1 is shown in yellow and channel 2 is shown in blue. At 25.0V<sub>DC</sub> input voltage, the output power is 50W .



**Figure 18 • Oscilloscope Plot Showing Both GS61004B Drain Node Signals**

The ratio of maximum Drain voltage and input DC voltage is 2.30 which is ideal for a class EF2 amplifier. This operating condition eliminates voltage stress on the transistors and has low second harmonics. The output current shown in green, is not a perfect sinewave due to high order harmonics on the output load.

Switch mode Power Amplifiers have a lot of harmonics at the output. One significant advantage of the Class EF2 topology is that it has a lower 2<sup>nd</sup> harmonic when compared to other PA topologies. This advantage results in a Class EF2 PA with much better EMI performance.

Figure 19 shows the spectrum of the PA at 50W output power. Compared to the fundamental frequency, the 2<sup>nd</sup> harmonic is -50.88dBc, the 3<sup>rd</sup> harmonic is -33.61dBc, and the 4<sup>th</sup> harmonic is -53.62dBc. This extremely low 2<sup>nd</sup> harmonic performance makes it much easier to filter out the PA's high order harmonic. This allows designers to meet EMI specifications and regulations without additional cost.

The PA's output power and efficiency are shown in Figure 20. This PA delivers 87% efficiency at 50W output power and 25V<sub>DC</sub> input voltage. This remarkable efficiency performance makes PA the best candidate of the WPT systems, and particularly advantageous for high power applications such as drone, autonomous robot and E-bike charging.

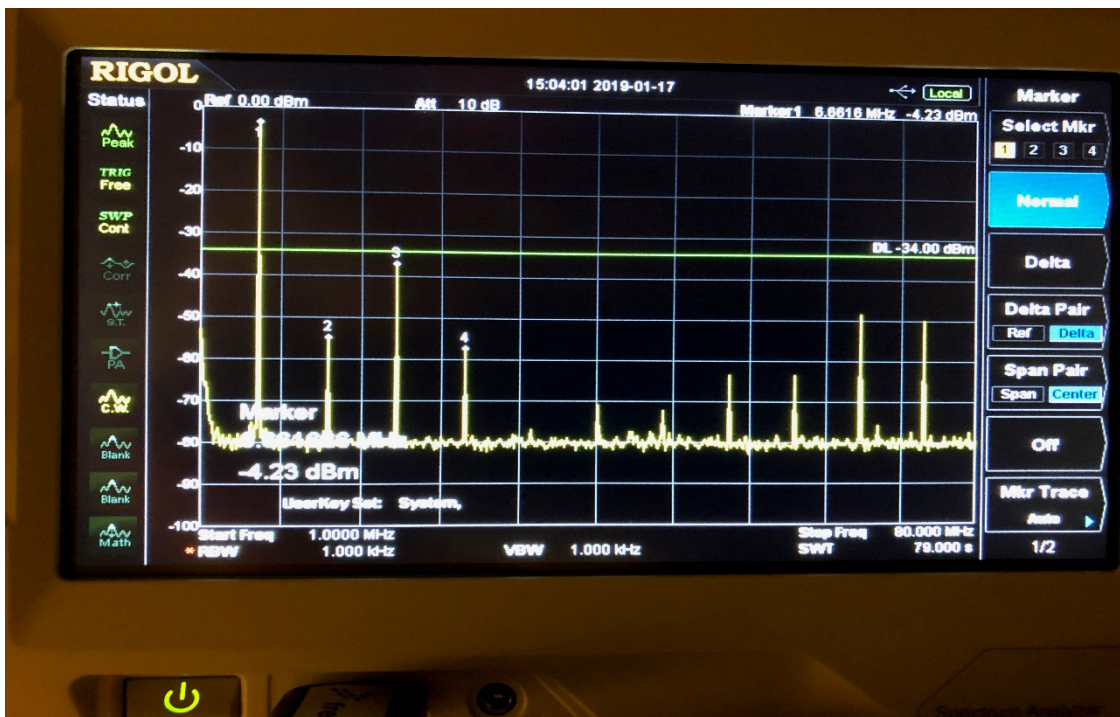
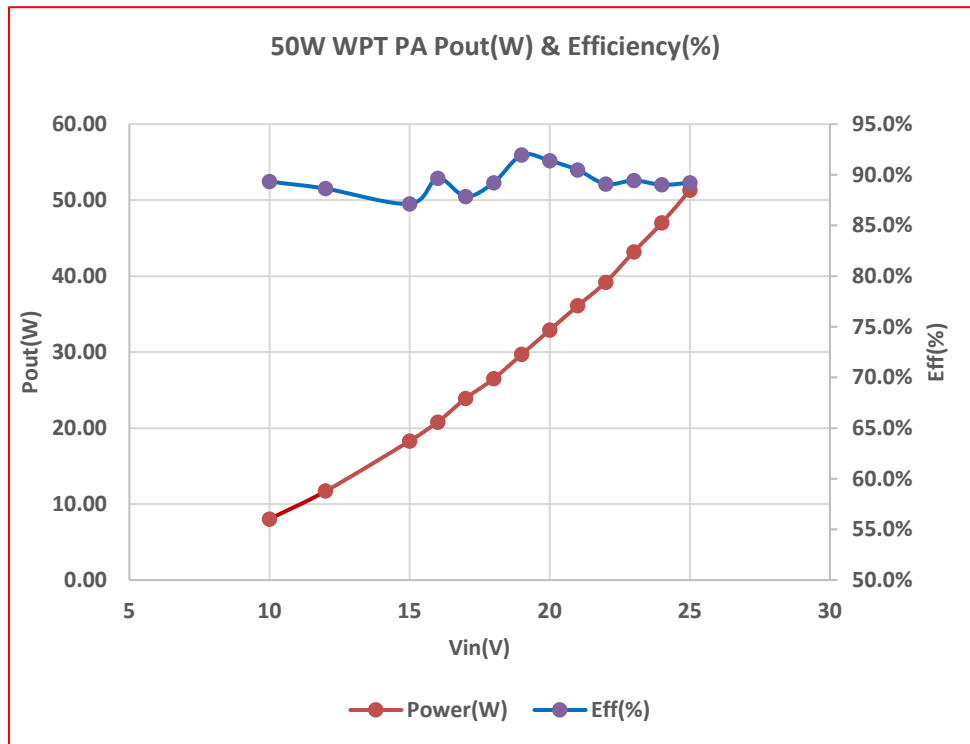


Figure 19 • Spectrum Plot of output terminal JP57 SMA after 49.66dB attenuation at 51.2W output power



**Figure 20 • Output power and efficiency of PA at JP57 SMA**

The PA's system reliability is optimized when the temperature rise of each device is kept to a minimum, including that of the GaN E-HEMTs. The GS61004Bs are especially well suited in this regard, for a number of reasons. First, they have very low switching losses which allows them to operate at high efficiency and a low temperature rise at 6.78MHz, the common frequency used for resonant wireless power transfer. Secondly, the bottom-side cooled GaN<sub>NPX</sub>® packaging provides an extremely low thermal impedance for efficient heat transfer to the heatsink, thereby drawing heat out of the device. This GaN based design is able to operate over a wide ambient temperature and with convection cooling, eliminating the need for cooling fans. These advantages support a PA design with excellent thermal performance up to 50W output power.

The temperature plot of the PA design was measured and captured with a SEEK thermal camera and is shown in Figure 21. The hottest devices are the first inductors, with the hottest inductor recording 40°C above ambient. The temperature rise of the GaN E-HEMTs, by comparison, is only 7°C. Because the GaN E-HEMTs run very cool, this allows operation over a very wide temperature range and extends operation to a higher power level while simultaneously simplifying the cooling system design and reducing the cost.

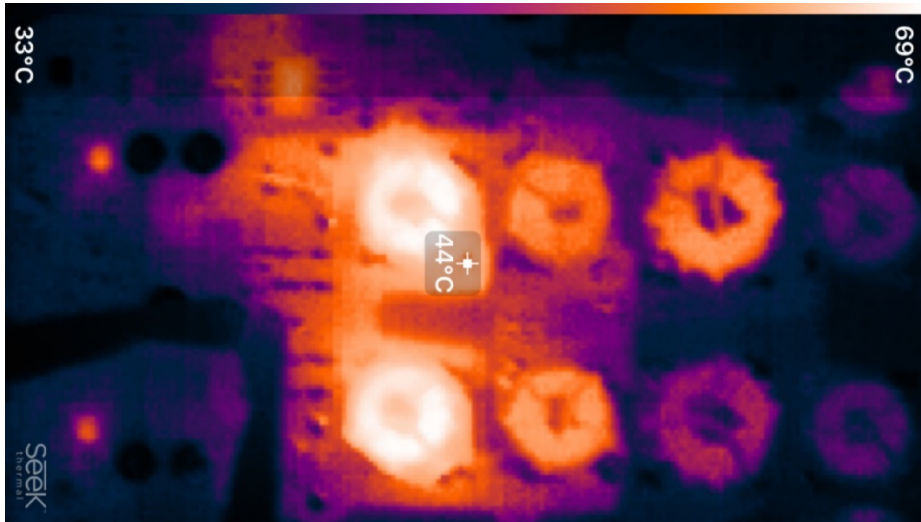


Figure 21 • Thermal measurement of PA at 50W output power

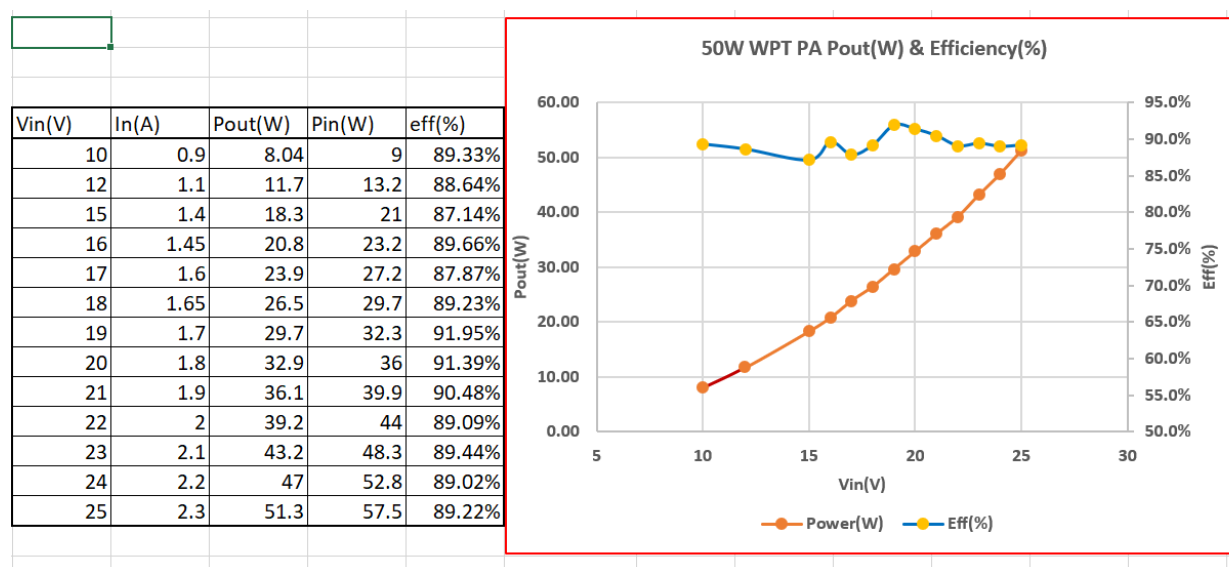


## Technical Resources

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

## Appendix A:

### Sample Test Data



**Evaluation Board/kit Important Notice**

GaN Systems Inc. (GaN Systems) provides the enclosed product(s) under the following **AS IS** conditions:

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This notice contains important safety information about temperatures and voltages. For further safety concerns, please contact a GaN Systems' application engineer.

In Canada:

GaN Systems Inc.  
1145 Innovation Drive Suite 101  
Ottawa, Ontario, Canada K2K 3G8  
T +1 613-686-1996

In Europe:

GaN Systems Ltd., German Branch  
Terminalstrasse Mitte 18,  
85356 München, Germany  
T +49 (0) 8165 9822 7260

In the United States:

GaN Systems Corp.  
2723 South State Street, Suite 150,  
Ann Arbor, MI. USA 48104  
T +1 248-609-7643

**[www.gansystems.com](http://www.gansystems.com)**

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