Temperature Stability Assessment of GaN Power Amplifiers with Matching Tantalum Capacitors

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Introduction

Wide band gap GaN and SiC devices are expected to experience high levels of growth in applications ranging from power conversion to RF transistors and MMICs. End users recognize the advantages of GaN technology as an ability to operate under higher currents and voltages. RF GaN market is expected to grow at 22.9 % CAGR over 2017-2023, boosted by implementation of 5G networks. [1]

During the past years, the wide band semiconductors have reported achievement of >1000 V BDV that opens new challenges for high power industrial applications such as electric traction systems in trams, trolley buses or high-speed trains etc.

Decoupling and BIAS matching tantalum capacitors are used due to its stability of capacitance value over wide temperature range, stable capacitance with BIAS, no piezo noise sensitivity at small, low profile case sizes. They are not prone to wear out associated with Aluminum electrolytic capacitors and exhibit high reliability & stability across temperature, voltage and time.

GaN Power Amplifiers with matching Tantalum Capacitors

GaN RF Power Amplifiers

Requirements for the best linearity of RF GaN power amplifiers, as one of the key parameters, can be achieved by two ways:

1] use of optimum output impedance of the optimum linearity, this could however limit the output power and decrease efficiency.

Or 2] use optimum output impedance for maximum power output and define the working linearity region by the proper BIAS point setting and optimization. This requires a proper design of BIASing circuits and its stability in wide operating conditions. [1]. Tantalum capacitors in number of referenced designs are used to keep the working point within the high linearity region.

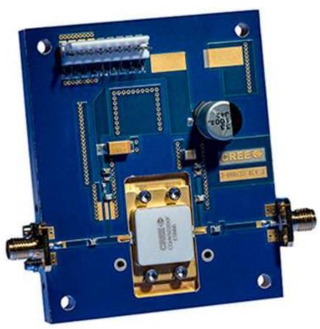

Fig.1. RF GaN Power Amplifier; image credit: Cree

RF GaN reference designs with tantalum capacitors:

- **Nitronex NPTB00004 GaN 28V, 5W RF Power Amplifier for CW, pulsed, WiMAX, W-CDMA, LTE,** DC to 6 GHz. 10μF 16V gate decoupling capacitors.

- **Qorvo QPD1008** 125W, 50V, DC – 3.2 GHz, GaN RF 10μF 16V gate BIAS decoupling capacitors. The other Qorvo designs:
  QPD1008L DC - 3.2 GHz, 125 Watt, 50V GaN RF Power Transistor
  QPD1009 DC - 4 GHz, 15 Watt, 50V GaN RF Transistor
  QPD1010 DC - 4 GHz, 10 Watt, 50V GaN RF Transistor
  QPD1015L DC - 3.7 GHz, 65 Watt, 50V GaN RF Power Transistor

- **Cree / Wolfspeed CGHV50200F** 200W, 4400 - 5000 MHz, 50-Ohm Input/Output Matched, GaN HEMT with 10μF 16V capacitors
  The other Cree references:
  CGH40006P 6 W, RF Power GaN HEMT
  CGH40010 10 W, DC - 6 GHz, RF Power GaN HEMT
  CGH40025 25 W, RF Power GaN HEMT
  CGH40045 45 W RF Power GaN HEMT
  CGH55030F1 / CGH55030P1 30W, 5500-5800 MHz, 28V, GaN HEMT for WiMAX

GaN High Power PFC Compliant Systems

The main power supplies used in telecom, server, and industrial power supply unit (PSU) systems convert AC line power to an isolated constant DC voltage output suitable for the loads the power: typically, 1 kW to 5 kW 12V for server PSUs, 48V for telecom rectifiers, and 24V for industrial PSUs. These systems require a front-end power factor correction (PFC) circuit to shape the input current of the power supply, so as to meet the power factor and current total harmonic distortion (THD) norms defined in IEC61000-2-3.

Requirements for PFC to meet >80 % standards calls for very-high efficiency over wide operating ranges of input and output. This need has generated interest in bridgeless PFC topologies that push the efficiency above 99%. [3]

Capacitors are among the critical components that in case of SC failure may cause a fatal error. Tantalum capacitors are providing high capacitance efficiency in small dimensions with stable electrical parameter over its long lifetime:

- **Texas Instrument TIDA 00961 GaN 12V, 1.5kW for telecom, servers and industrial power supplies** 100μF 16 V, 220μF 16 V tantalum capacitors for bulk 12V line stabilization [1], 4.7μF 10V on 3.3V output stabilization.
- **Texas Instrument LMG3410 600V 12A Integrated GaN Power Stage for solar power, battery chargers** with 33μF 16V as 5V output capacitor.

GaN Hi Point of Low Controller

TI half-bridge point-of-load 80V 10A GaN controller LMG5200 evaluation board implements the 48-V to 1-V converter as a single-stage hard-switched half-bridge with current-doubler rectifier. This topology efficiently supports a high step-down ratio while providing significant output current and fast transient response.

GaN offers superior switching performance to traditional silicon MOSFETs due to its lack of reverse-recovery effect and reduced input and output capacitance. By using a GaN module, this application achieves high efficiency while operating in a hard-switched configuration.

Four low ESR B case 150μF 6.3V polymer tantalum capacitors are used as high efficient, high power filtering output small size capacitors.

GaN Board Temperature Stability Assessment

GaN board selection

QORVO QPD1008 has been selected as a typical representative board with input tantalum capacitors subjected to a temperature stability measurement at RICE, University of West Bohemia. The QPD1008 is a 125 W (P3dB) wideband unmatched discrete GaN on SiC HEMT which operates from DC to 3.2 GHz with a 50 V supply rail. The device is in an industry standard air cavity package and is ideally suited for military and civilian radar, land mobile and military radio communications, avionics, and test instrumentation. The device can support pulsed, CW, and linear operation. [2]

In measurement set up, this transistor was connected in the test board as an amplifier for frequency range from 0.96 GHz to 1.215 GHz. The aim was to observe an influence of the C2 capacitor on the transistor behaviour for different ambient temperature level. The C2 capacitor is tantalum capacitor (10 μF/16 V) recommended by the manufacturer in its reference datasheet – see Fig. 3 and Fig. 4.

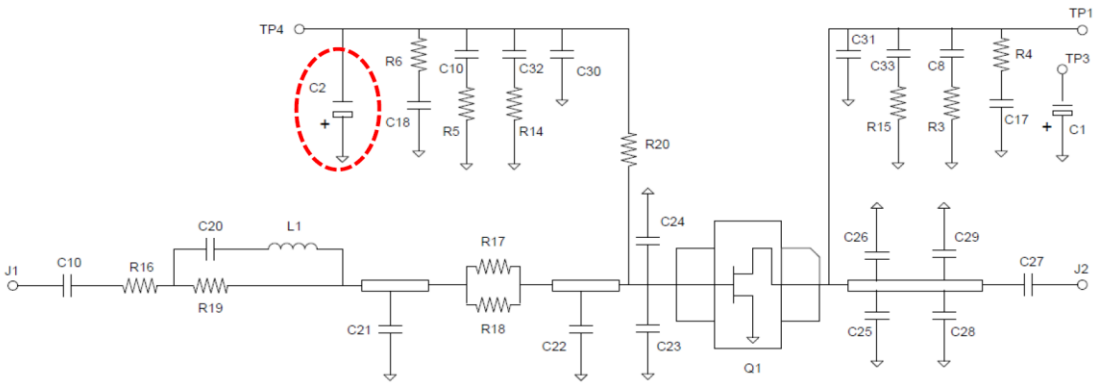

Fig. 3: Circuit diagram of GaN QPD1008 connection as an amplifier for frequency range from 0.96 GHz to 1.215 GHz

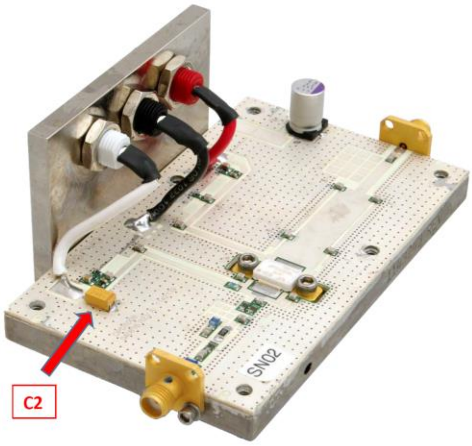

Fig. 4: GaN QPD1008 evaluation test board with C2 tantalum capacitor

Measurement Setup

The measurement was performed at standard conditions within the referenced datasheet operating conditions recommendations:

Bias and voltage setup: according to datasheet
Input signal: sin wave, frequency of 1 GHz, power of 15 dBm
Ambient temperature: -30 °C; +25 °C and +70 °C
Measurement equipment:

- Spectrum analyser Agilent N9320B
- Oscilloscope Tektronix MSO4104B

Spectrum analyser was connected to the test board output via the 30 dB attenuator. C2 tantalum capacitor waveforms were measured by oscilloscope and compared at different temperatures. The test board was inserted into the climatic chamber. Before the measurement, the test board was conditioned at least 30 minutes at the desired temperature (-30 °C, +25 °C and +70 °C). Spectrum of output signal was measured and compared.

Measurement Results

Figure 5, 6 and 7 presents measured waveforms and its FFT analyses on C2 tantalum capacitor position at temperatures: -30 °C, 25 °C and +70 °C. Spectrums of the output signals of GaN test boards – see figure 8.

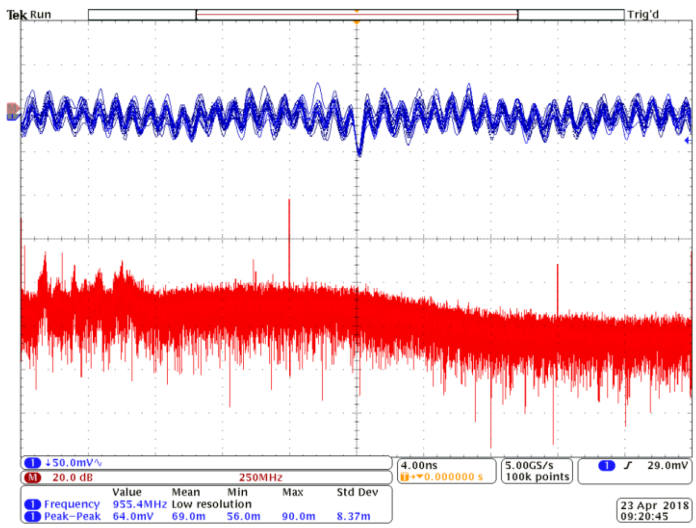

Fig. 5: Waveform on C2 tantalum capacitor at -30 °C and its FFT analysis

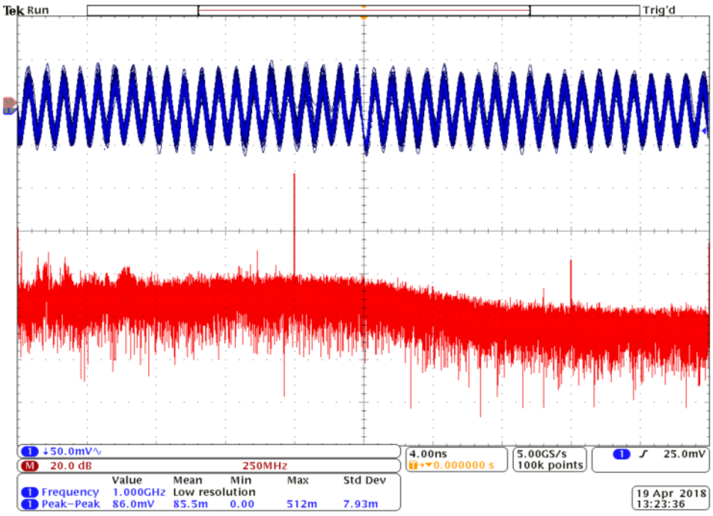

Fig. 6: Waveform on C2 tantalum capacitor at +25 °C and its FFT analysis

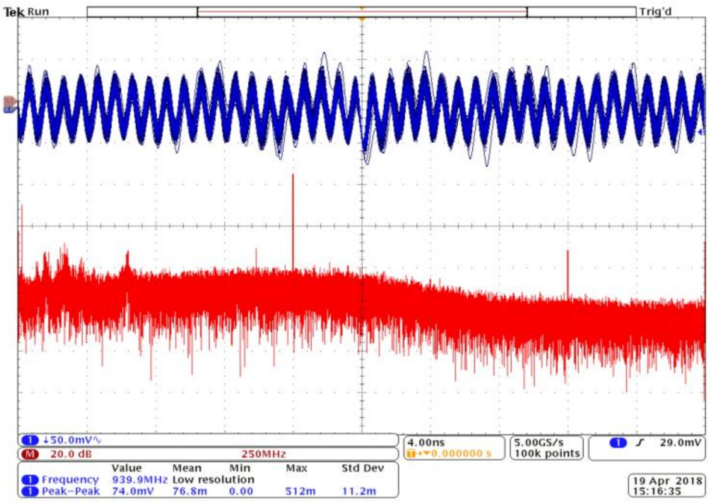

Fig.7. Waveform on C2 tantalum capacitor at +70 °C and its FFT analysis – tantalum capacitor.

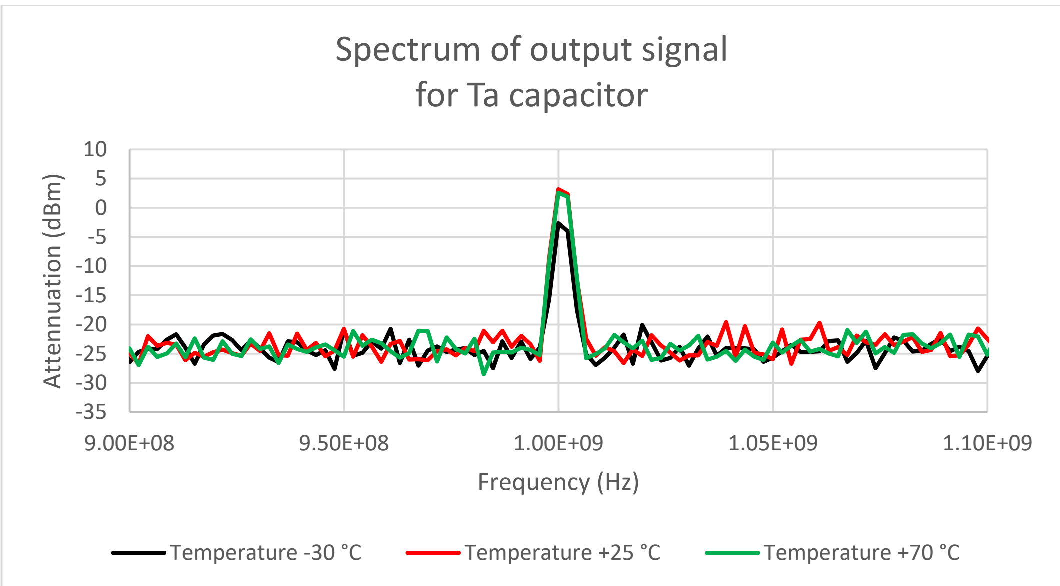

Fig. 8. Spectrums of the GaN test board output signals for different temperatures.

Measurement Summary

There are practically no measurable differences in output signal stability of the tested RF amplifier board at +25 °C and +70 °C temperatures. Some output signal drop about 5 dBm test frequency attenuation is visible in the measured spectrums at ambient temperature of -30 °C. Nevertheless, such shift within 5 dBm can still be considered as a very good stability performance of the tested GaN RF power amplifier at the referenced conditions.

Conclusions

Rate of improvements of conventional MOSFETs has levered off, as their performance is now close to its theoretical limits as determined by the underlying fundamental physics of these materials and processes.

GaN is featuring a higher critical electric field strength than silicon that is resulting in a smaller size for a given on-resistance and breakdown voltage than a silicon semiconductor. GaN also offers extremely fast switching speed and excellent reverse-recovery performance, critical for low-loss, high-efficiency performance.

The above feature pose GaN as an ideal choice for RF systems and the upcoming fast growing 5G networks development as well as growing market of high power ~1 kV industrial applications such as renewable energy, EV/HEV vehicles, power traction systems, servers etc. GaN advantages can bring also new applications that have not been possible to make within such small size and simplified architecture so far such as the 48-V to 1-V single-stage hard-switched converter.

Stability at wide temperature range and harsh conditions are one of the design challenge for number of industrial applications. Linearity, efficiency, stability and high-power outputs are mostly driven of a good impedance matching and stable gate BIAS working point setting. Tantalum capacitors have been the favourite solution for BIAS decoupling circuits in the latest GaN power amplifiers.

The reference measurement on GaN RF power amplifier Qorvo QPD 1008 with tantalum 10 µF 16 V decoupling capacitor confirmed its very good stability at whole temperature range from -30 °C to +70 °C.

References

[1] Texas Instrument TIDA 00961 GaN 12V, 1.5KW design-in note; January 2018; http://www.ti.com/lit/ug/tidudt3/tidudt3.pdf

[2] Markos.A.,Z.; “Efficiency Enhancement of Linear GaN RF Power Amplifiers Using the Doherty Technique”; 2009; Kassel university press GmbH; ISBN online: 978-3-89958-623-7

[3] Qorvo QPD1008 125W, 50V, DC – 3.2 GHz, GaN datasheet; https://www.qorvo.com/products/p/QPD1008