Pulsed RF Operation of Microsemi GaN RF Power Transistors

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ABSTRACT

This paper explains the pulsed RF operation of Microsemi pulsed GaN HEMT RF power transistors using as an example the 1011GN-700ELM 1030MHz Mode-S Enhanced Message Length (ELM) avionics device. General descriptions are presented detailing both the pulsed gate bias operation and the bias sequencing operation of the "pulser" circuit used on the Microsemi evaluation test fixtures. This pulser circuit is also successfully implemented on all Microsemi pulsed common source class AB GaN device evaluation test fixtures for both pulsed avionics system and radar systems, from L-Band through C-Band and can be extended up to X-Band and Ku Band. A general description of the 1011GN-700ELM RF input and output circuit board design is also provided. Finally, 1011GN-700ELM pulsed RF device performance will be presented demonstrating the use of the pulser circuit in a test fixture.

PULSER CIRCUIT: PULSED GATE BIAS AND BIAS SEQUENCE

Figure 1 below shows the block diagram of a typical MICROSEMI GaN evaluation test fixture. It consists of a pulser circuit and a GaN RF power transistor circuit. The GaN RF circuitry consists of the GaN RF Power transistor device, RF input & output matching networks, gate & drain bias feeds and associated circuit components.

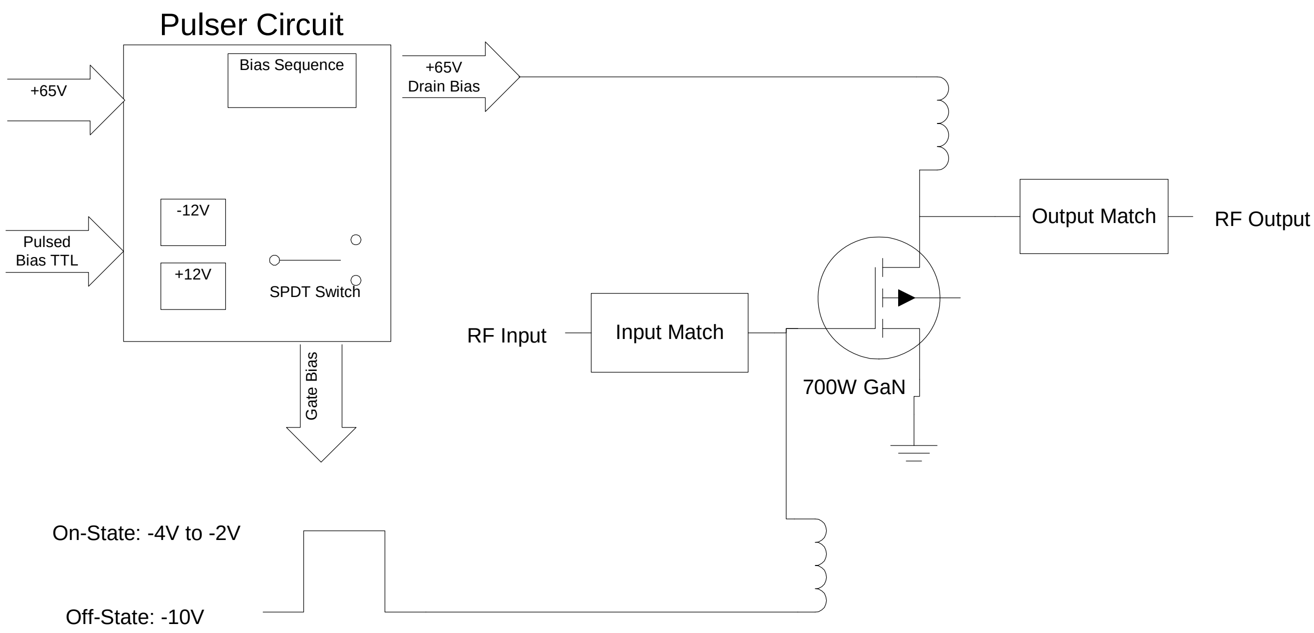


Figure 1 – Typical Microsemi GaN RF power transistor evaluation test circuit block diagram

The pulser circuit implements three essential operational functions:

[1] Generate negative pulsed gate bias ON (-4V to -2V) and OFF (-10V) voltages

[2] Improve efficiency and thermal performance operating in pulsed gate bias mode

[3] Apply Vdd DC bias subsequent to pinching off the enhancement mode device gate

The pulser circuit has as inputs: +65Vdc and a pulsed bias TTL signal. DC to DC conversion on the pulser circuit generates both +12Vdc and -12Vdc from the +65Vdc Input. All active devices in the pulser circuit are powered by +12V. The -12V is used to supply the necessary negative pulsed gate bias for the GaN common source, class AB configured, RF power transistor device. The pulser circuit uses a high speed switch (ADG419) that switches between an OFF state of -10V and a variable (adjustable) ON state voltage of -4V to -2V. The pulsed bias TTL line controls the SPDT switch input. The resultant SPDT switch output is a negative pulsed gate voltage which is used to bias the gate of the GaN device between OFF and ON states.

In the case of the 1011GN-700ELM device, the on-state voltage is adjusted such that the device Idq is set to 1A peak. Thus, this technique of pulse biasing ON and OFF the gate allows the average Idq of the device to be reduced from the peak Idq by the duty cycle of the pulse train. The very desirable benefits that result for pulsed RF operation are improved efficiency and a greatly reduced quiescent device heat dissipation.

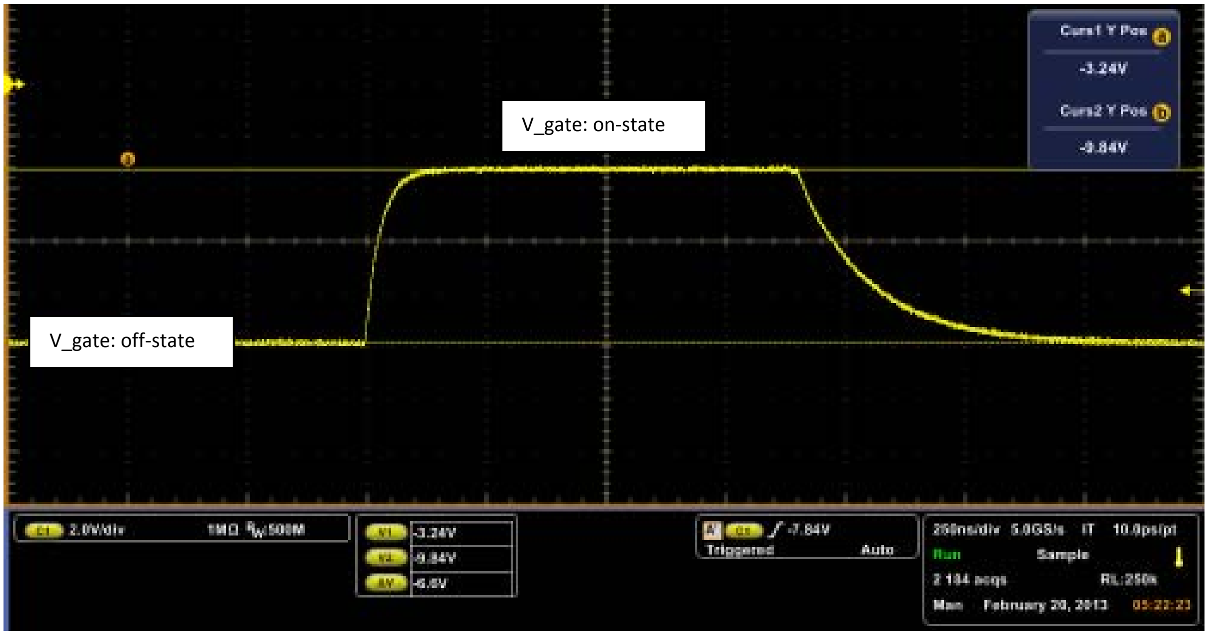


Figure 2 – Typical negative Vgs gate OFF (-12V) to ON (-3.2V) pulsing

Figure 2 shows the typical negative pulsed gate voltage applied to the 1011GN-700ELM device. It shows an ON state of -3.2V and OFF state of -10V. One key parameter to note is the pulse rise time of around 100ns. This fast rise time allows for minimal lag between the DC bias ON pulse and the RF input pulse. In other words, the Idq reaches its quiescent level at Vgs=-3.2V in the minimum time before the RF pulse is applied to the gate input in the transistor common source class AB configuration.

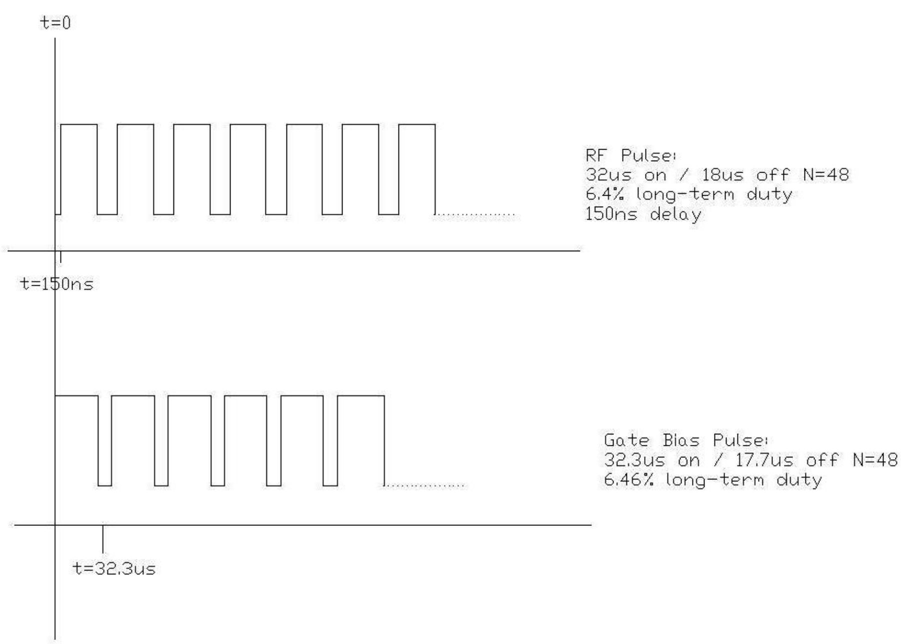


Figure 3 – Typical Mode-S ELM RF Pulsing

Shown in Figure 3 above are typical RF and gate bias pulse signal timing for the 1011GN-700ELM Mode-S ELM pulsing. The RF pulse input has a 150ns lag time relative to the gate bias pulse turn ON and, correspondingly, the RF pulse has approximately a 150ns lead time relative to the gate bias pulse turn OFF. This allows the RF pulse to experience the same Idq from beginning to end but when the RF pulse is not present the gate pulsing circuit turns off the Idq, improving efficiency and power dissipation.

Since the GaN HEMT is a depletion-mode device, it is imperative that the gate is pinched off before the drain voltage is applied to avoid damage. The pulser circuit is design such that it successfully applies the negative pulsed gate voltage to the GaN device before the drain Vdd voltage is applied. After the +65Vdc input is applied to the pulser circuit, DC to DC conversion takes place to create the +12Vdc and -12Vdc, both of which are used to generate the negative pulsed gate voltage. When completion of this DC to DC conversion is detected, a P-Channel MOSFET then safely switches ON the transistor drain voltage Vdd.

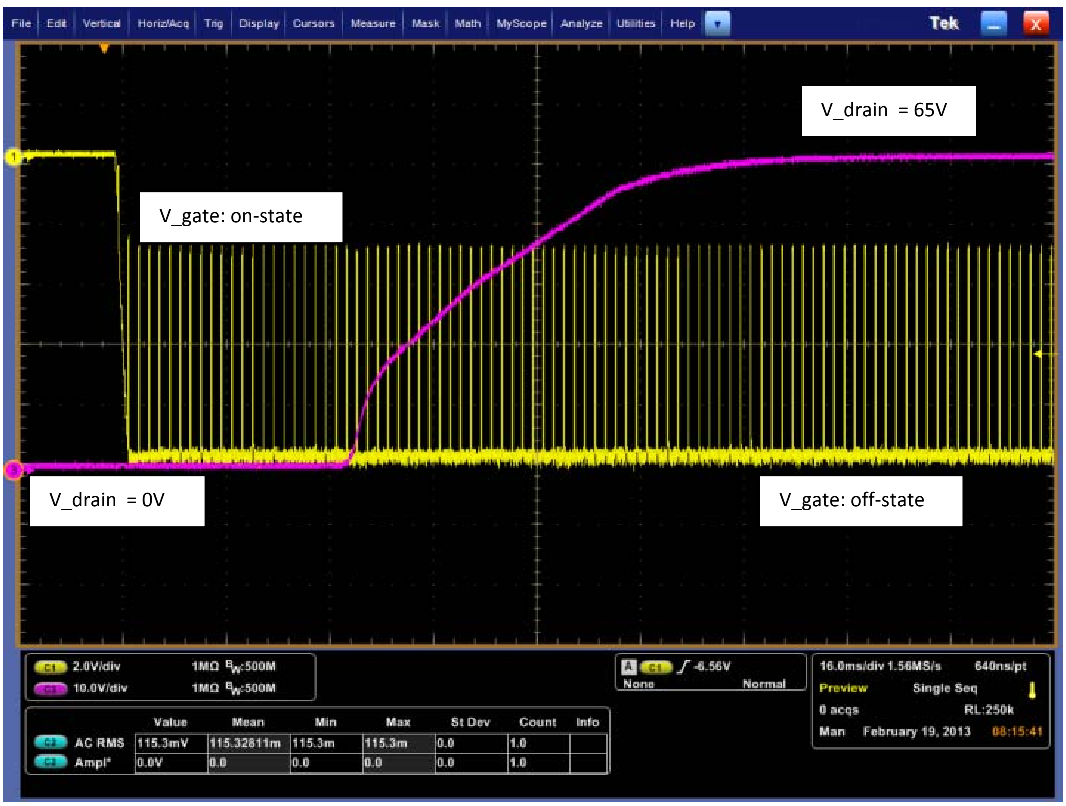


Figure 4 – Typical pulsed GaN RF power transistor Vdd drain bias sequencing timing

Consider the screen shot of Figure 4 showing the turn-on sequence of the GaN transistor device bias scheme. The pulsed gate voltage is generated first and the drain voltage turns on 35ms later. The slow rise time of the drain voltage is due to the charging of the charge storage capacitor on the drain bias feed.

GaN HEMT RF CIRCUIT

As will be explained by considering Figure 5 below, most of the design methods and techniques used on other high-power device technologies can be applied to the GaN HEMT RF power transistor circuit. Quarter-wave length bias feeds are used in the gate and drain. The gate bias feed uses a low-value series resistor to suppress oscillations while minimizing the change in Vgs as the gate starts to draw current when the device is driven into saturation. To achieve a more compact circuit topology, shunt capacitors are employed on the bias feeds to shorten the quarter wavelength circuit. An RC filter circuit is also used on the drain feed to suppress pulse ripple. Shunt capacitors are used on the input matching network to further reduce circuit size.

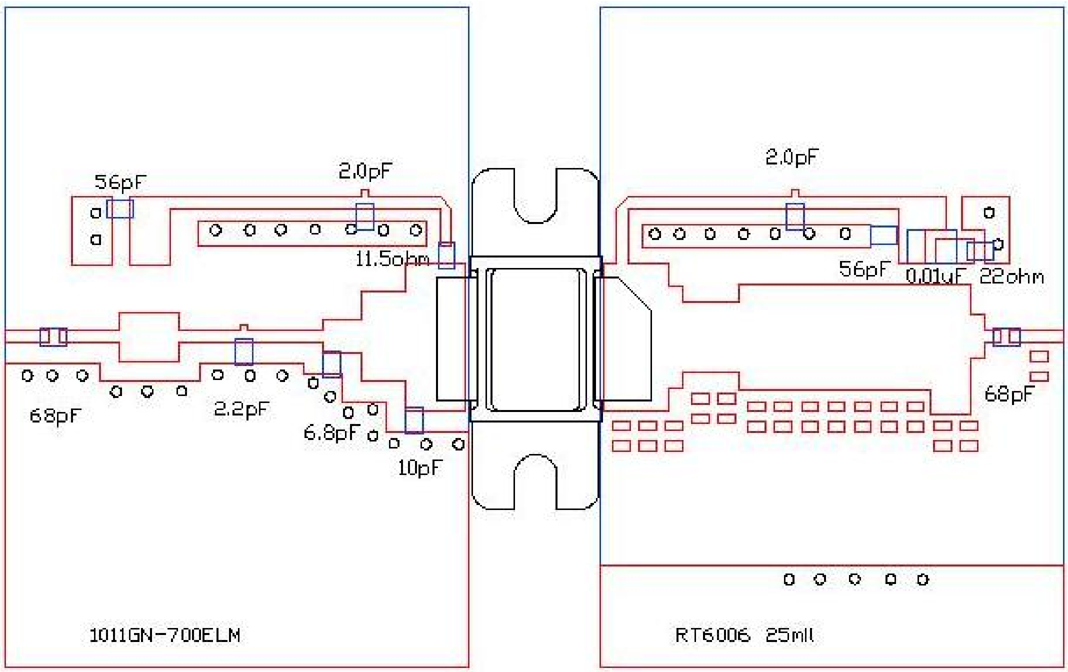


Figure 5 – 1011GN-700ELM Evaluation Test Fixture RF Circuits

RF PERFORMANCE

As far as test equipment "power-up" sequencing to evaluate a Microsemi GaN evaluation device in a Microsemi test fixture the simple procedure is:

[1] Turn OFF the pulsed RF input, the +65V power supply, and the TTL gate bias control signal
[2] Connect the RF input and the RF output cables to the test fixture
[3] Connect the gate bias TTL control signal to the TTL test fixture input
[4] Connect the power supply to the +65Vdc test fixture input
[5] Turn on the TTL gate pulsing signal
[6] Turn ON the +65V
[7] Turn on the pulsed RF input signal

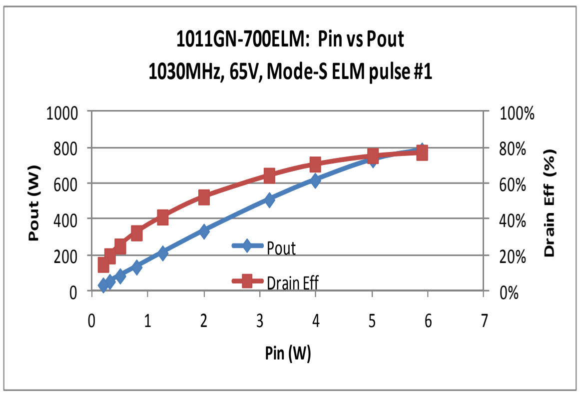
Some of the key highlights of the 1011GN-700ELM device performance include:

- Over 700W Pout
- 70% drain efficiency
- Over 20dB gain
- Fast rise/fall times

The features and functions of the pulser circuit make the Microsemi GaN HEMTs more suitable for pulsed RF applications by improving efficiency and heat dissipation and *it is very easy to use*.

DYNAMIC RANGE PERFORMANCE

The charts of Figure 6 below, show the dynamic range the 1011GN-700ELM GaN transistor device which is able to deliver over 700W Pout at over 70% drain efficiency and greater than 20dB gain. Impressively, proper biasing gives very flat 1011GN-700ELM RF gain for output power levels from 20W to 700W.



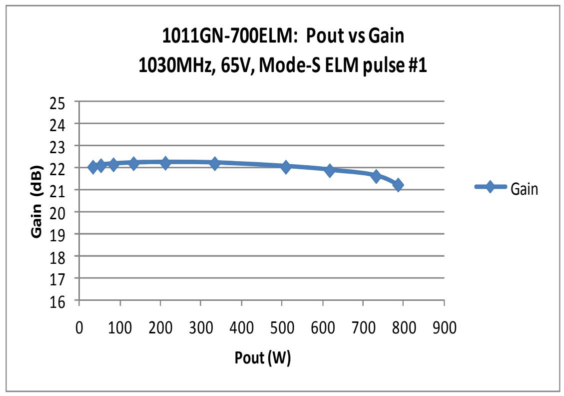


Figure 6 – 1011GN-700ELM typical performance

PULSE CHARACTERISTICS

Figure 7 following, illustrates the 1011GN-700ELM <25ns rise and fall times for a short 0.5us pulse width at 1% duty cycle and the heavier pulsing of the ELM burst: quantity 48 32us ON/18us OFF burst pulses repeated every 24ms (burst duty cycle = 64% & long term duty cycle LTD=6.4%).

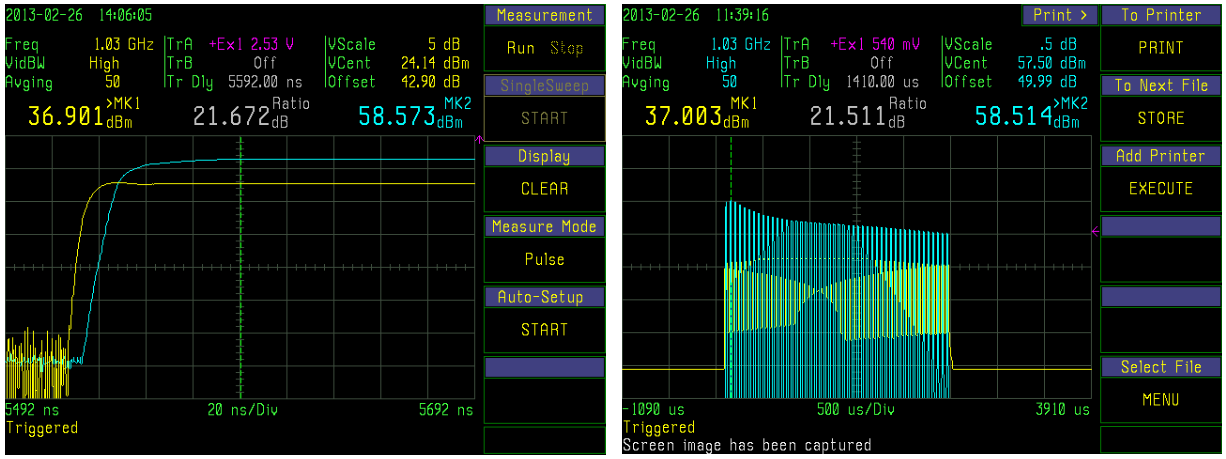
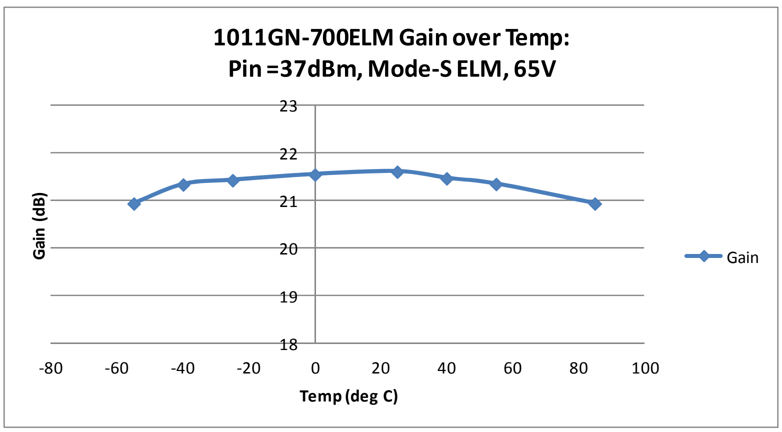


Figure 7 – 1011GN-700ELM short pulse & ELM long pulse rise time performance



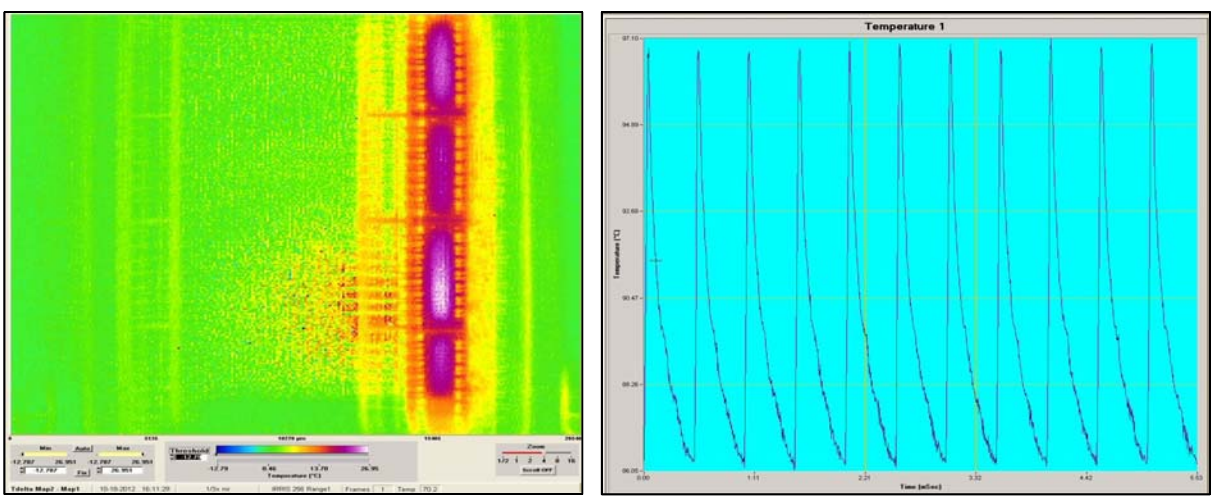


Figure 8 – Typical 1011GN-700ELM over temperature performance

PERFORMANCE OVER TEMP AND IR SCAN

Figure 8 demonstrates that at the rated output power (1dB compressed), the gain drops 0.7dB going hot and 0.3dB going cold. Over temperature gain variation may increase when operated in the linear region. However, over temperature and over output power gain variation can be reduced by slight adjustments of the gate bias voltage which controls Idq. Microsemi test fixtures do not implement temperature compensation allowing product developers to use their own proprietary methods if necessary. The transient thermal measurement shows a peak hot spot temperature rise of 97 deg C. This translates to a thermal resistance of 0.2 C/W.

CONCLUSION

This paper describes the operation of the pulser circuit that supplies a negative pulsed gate bias and the proper bias sequence to Microsemi GaN HEMT RF power transistors. It also provides some general discussions on RF circuit considerations. Typical RF performance curves are provided for the Microsemi 1011GN-700ELM L-band avionics GaN device, including over temperature and IR scan measurements. The pulser circuit is used on all Microsemi GaN HEMT RF power transistor test fixtures to properly bias for pulsed RF operation Microsemi pulsed GaN RF power transistors and pallets from 10W to over 1000W, from L-Band and S-Band to C-Band and beyond.