# High Temperature Performance of a SiC MESFET Based Oscillator

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***Abstract* — A hybrid, UHF-Band differential oscillator based on 10 W SiC RF Power Metal Semiconductor Field Effect Transistor (MESFET) has been designed, fabricated and characterized through 475 °C. The circuit is fabricated on an alumina substrate with thin film spiral inductors, chip capacitors, chip resistors, and wire bonds for all crossovers and interconnects. The oscillator delivers 15.7 dBm at 515 MHz into a 50 Ω load at 125 °C with a DC to RF conversion efficiency of 2.8 %. After tuning the load impedance, the oscillator delivers 18.8 dBm at 610 MHz at 200 °C with a DC to RF conversion efficiency of 5.8 %. Finally, by tuning the load and bias conditions, the oscillator delivers 4.9 dBm at 453 MHz at 475 °C.**

***Index Terms* — oscillators, wide-bandgap, SiC, High Temperature.**

## I. Introduction

The need for sensors and wireless communications to those sensors is increasing rapidly for many applications. A subset of those applications with great potential in the commercial marketplace is sensors and sensor systems that operate at high temperatures (500 °C and above). For example, telemetry during mining and oil drilling, automobile engine and brake sensors, and aircraft engine sensors must operate at high temperatures to enable systems with increased efficiency and decreased pollution [1]-[3]. Wide bandgap semiconductor devices offer potential for high temperature, RF operation [4]-[5], which is required for wireless transmission from the sensor to a cooler part of the system.

A critical part of a wireless system is the local oscillator that generates the RF signal that is modulated by the sensor and transmitted to the receiver. The frequency bands of interest for these applications are the UHF Industrial, Scientific and Medical (ISM) bands. There have been several reported results of X-Band oscillators based on GaN operating at room temperature [6]-[8] and one NMOS SiC based ring oscillator operating at 625 kHz and 300 °C [9]. In this paper, we report for the first time a SiC MESFET based oscillator operating in the UHF band at temperatures from 30 to 475 °C.

## II. Circuit Description

The active device used is a Cree SiC MESFET, part number CRF24010, designed for power amplifier applications around 2 GHz. This device is capable of 17 dB of gain and 41 dBm of output power at 1.95 GHz when cooled with a heat sink and fan. The DC current-voltage (I-V) characteristics are measured, without a heat sink, at drain voltages up to 20 V and are shown in Fig 1.

A free-running, balanced oscillator is designed using two cross-coupled discrete MESFETs. The circuit is laid out with 1.5 μm thick gold metallization on an alumina substrate. The tank is an L-C circuit consisting of a 1½-turn spiral inductor and a 3.0-pF chip capacitor. A 10-Ω chip resistor is placed in series with the gate bias to prevent common-mode oscillations. Gold wire bonds are used for crossovers and to connect to the top surfaces of the devices. 50-pF chip capacitors are used for DC blocking in the feedback loop. The RF output is measured with a signal-ground wafer probe. A circuit schematic is shown in Fig. 2, while a photograph of the assembled circuit is shown in Fig. 3.

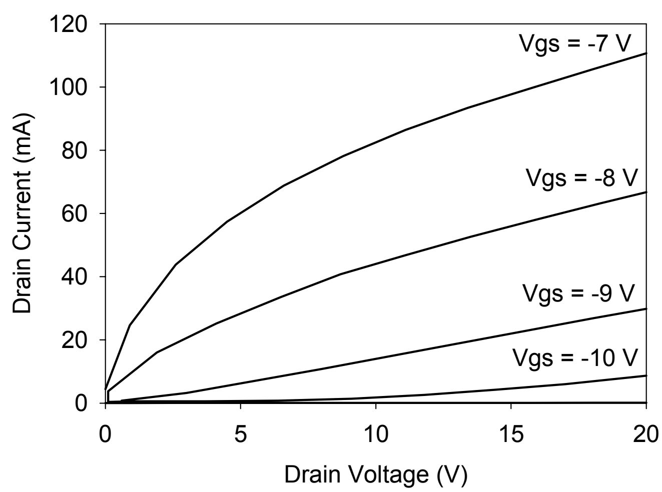


Fig. 1. DC current-voltage relationship of SiC MESFET at gate voltages of –7, -8, -9, and –10 V.

All measurements are performed using needle probes for DC bias and RF ground-signal probes for RF signals. A specially designed probe station is used for high-temperature RF measurements. The system includes a ceramic disk heater on an insulated heater chuck and heat-shielded microwave probes and cables [10]. During test, the alumina substrate rests directly on the ceramic heater and the temperature is measured on top of the alumina circuit. Thus, the temperatures reported here are the carrier or base plate temperature seen by the SiC transistors.

## III. Results

Because there are no reliable high temperature models for the MESFET, the oscillator will be operated at high temperature with the same DC bias point used at room temperature. To determine an optimal room temperature bias point, the output of the oscillator is fed directly into the 50 Ω termination of the spectrum analyzer. With the drain voltage set at 6.0 V, the drain current is varied (by adjusting the gate bias) from 100 mA to 230 mA and the center frequency, efficiency, and output power are recorded at each operating point. The results are shown in Fig. 4. The center frequency varies between 517 and 529 MHz across the range of drain currents. Efficiencies above 11 % are measured when the drain current is between 180 and 220 mA, and a maximum output power of 22.0 dBm is obtained at a drain current of 218 mA.

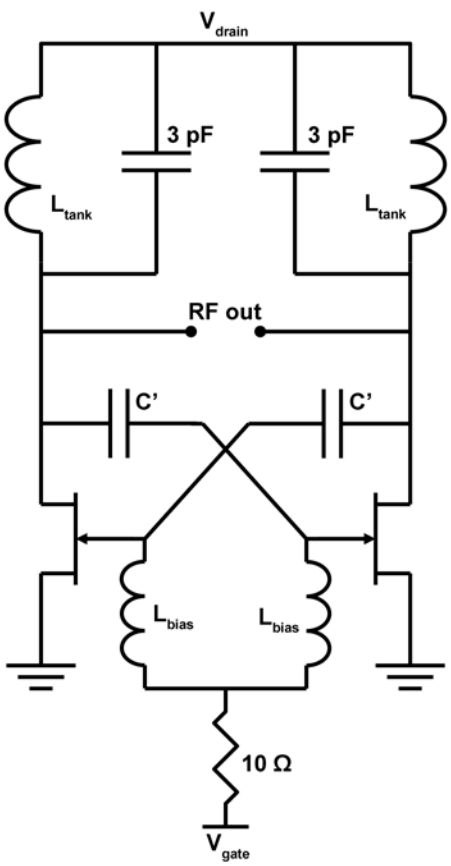


Fig. 2. Schematic diagram of MESFET-based oscillator circuit. The L-C tank circuit is shown at the top of the diagram, while the differential RF output is in the middle.

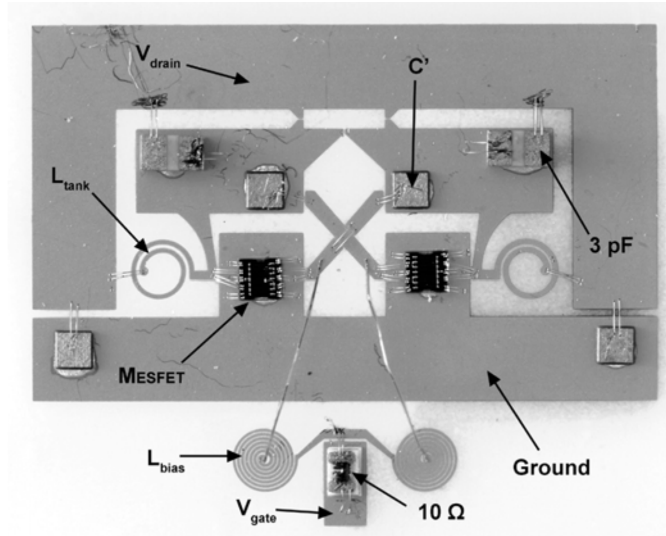


Fig. 3. Photograph of the assembled oscillator circuit.

Based on the results shown in Fig. 4, a drain bias of 6.0 V and 180 mA is chosen to maximize efficiency at a low drain current to minimize the self-heating of the active devices. It is also noted that the drain voltage is set very low to minimize self-heating, and that if DC power dissipation was not a concern, higher output power could be obtained. The current through each transistor is held to only 90 mA at this bias point. At this operating point, the room-temperature output power is 21.1 dBm, the efficiency is 11.8 %, and the center frequency is 526.8 MHz. The oscillator's spectrum is recorded in Fig. 5. The higher-order harmonics are shown to all be more than 40 dB below the output power of the fundamental frequency.

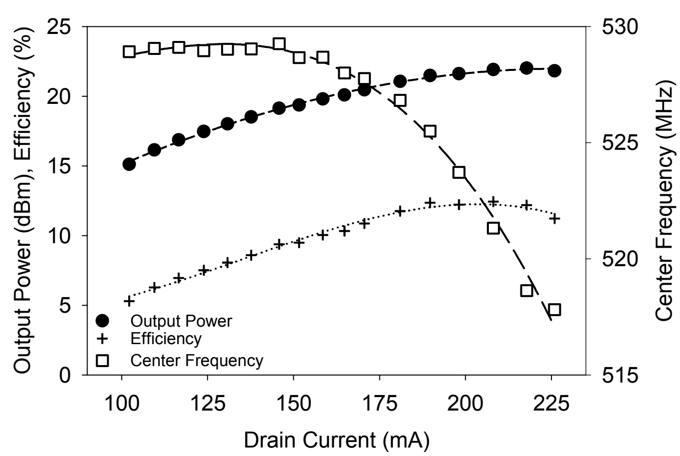


Fig. 4. Change in center frequency and oscillator efficiency as the drain current is varied from 70 to 270 mA. The drain voltage is held constant at 6.0 V.

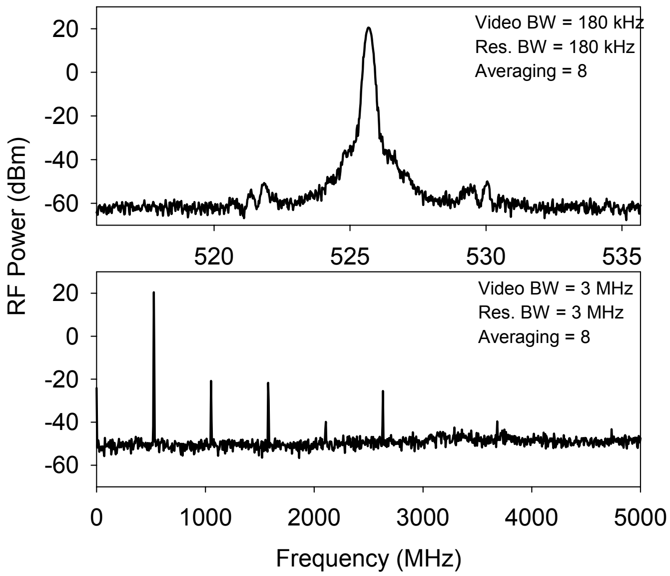


Fig. 5. RF spectrum of the oscillator at room temperature into a 50 Ω load.

The oscillator's phase noise is also measured at room temperature. A low power reference signal is injected into the circuit at the oscillator's fundamental frequency to lock the circuit long enough to complete a phase noise measurement. For this circuit, a reference signal power of -29 dBm at 526 MHz is sufficient to lock the oscillation frequency. A phase noise plot is shown in Fig. 6 and indicates phase noise values of –106 dBc/Hz at 1 kHz offset and –110 dBc/Hz at 100 kHz offset.

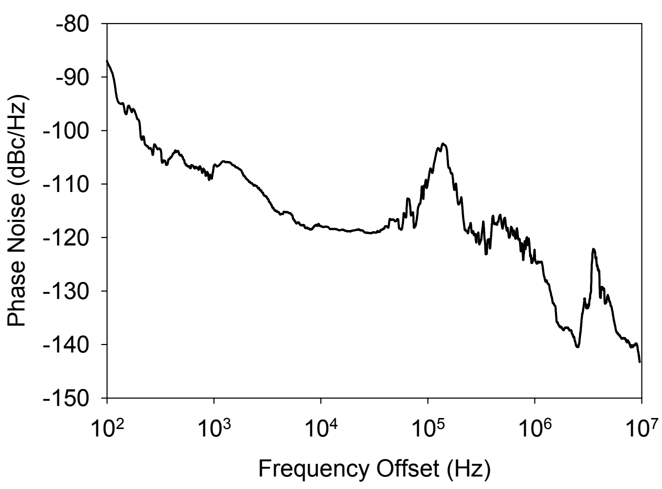


Fig. 6. Phase noise of the oscillator at room temperature into a 50 Ω load.

The substrate is then heated using a ceramic disk heater on an insulated wafer chuck. The circuit is supplied a constant drain bas of 6.0 V and 180 mA during the heating cycle. The center frequency, output power, and phase noise are measured in 25 °C intervals from 25 °C (room temperature) to 100 °C. The circuit failed to oscillate at this fixed bias point at temperatures above 105 °C.

The results show that the output power drops from 21.1 dBm at room temperature to 13.9 dBm at 100 °C, the efficiency drops from 11.8 % to 2.3 %, and the center frequency shifts downwards from 527 to 512 MHz. The center frequency and output power are plotted as a function of temperature in Fig. 7.

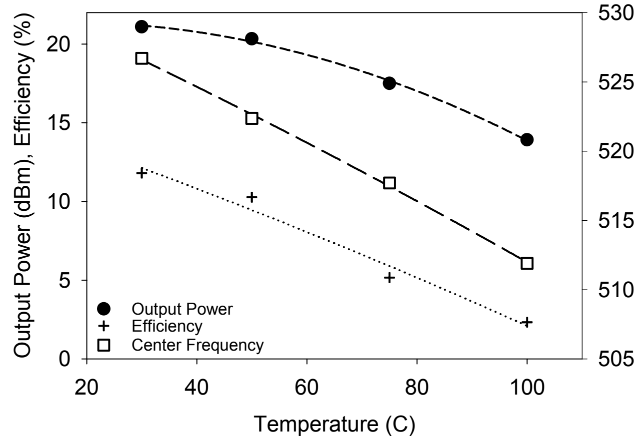


Fig. 7. Center frequency and RF power measured into a 50 Ω load at 30, 50, 75 and 100 °C.

By changing the circuit's bias point, oscillation is achievable at 125 °C. Raising the drain voltage to 7.0 V and current to 189 mA, an output power of 15.7 dBm was measured at 514.8 MHz, for an efficiency of 2.8 %. The authors were unable to force oscillation at any bias point above 125 °C into a 50 Ω termination.

The measurement system was then modified by adding a single stub tuner at the input of the spectrum analyzer. The stub position and circuit bias points were tuned to achieve maximum room temperature efficiency. The best efficiency was found with the drain biased at 6.0 V and 220 mA and the tuner set at $115 + j40\ \Omega$. This is not the impedance seen at the circuit, however, because of the length of coaxial cable and the RF probe between the tuner and the oscillator. At this operating point, the circuit is measured to have a center frequency of 610.9 MHz, an output power of 24.7 dBm, and an efficiency of 22.4 % at room temperature.

The circuit was again heated and continued to oscillate at this fixed operating point to 200 °C. At 200 °C, the circuit was measured to have a center frequency of 610.4 MHz, an output power of 18.8 dBm, and an efficiency of 5.8 %. The change in output power, efficiency, and center frequency across the temperature range is shown in Fig. 8.

Above 200 °C, adjustments can be made to the tuner position and the gate and drain biases to continue to produce oscillations. The authors were able to create a 4.9 dBm, 453 MHz signal with the substrate temperature at 475 °C. The spectrum of this signal is shown in Fig. 9.

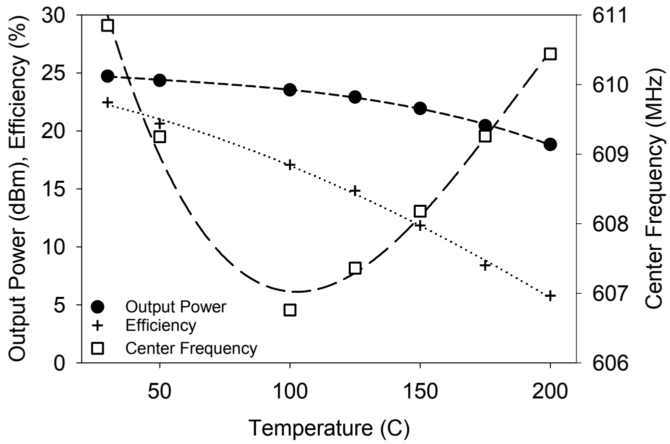


Fig. 8. Changes in center frequency and output power as a function of temperature through 200 °C.

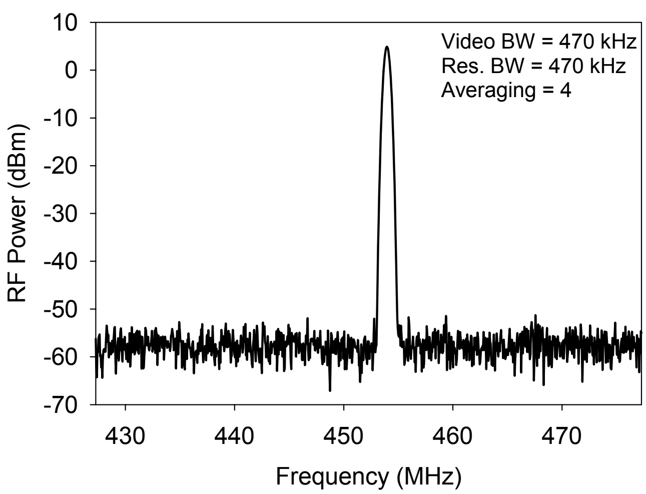


Fig. 9. Spectrum of 453 MHz signal measured at a substrate temperature 475 °C. The drain is biased with 7.85 V and 111 mA. The output power is 4.9 dBm.

## IV. Conclusion

A high-temperature oscillator circuit has been demonstrated. Oscillation into a 50 Ω load was achieved at temperatures up to 125 °C at 515 MHz. After tuning the load impedance, oscillations were measured to 200 °C around 610 MHz. By tuning both the bias point and load impedance, oscillations were measured through 475 °C.

These results indicate that the MESFETs used in this experiment have enough high-frequency gain at elevated temperatures to be used for RF signal generation. The L-C tank circuit as implemented, however, does not maintain a sufficient quality factor to be useful in high temperature designs.


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