

Characterization of 720 and 940 MHz Oscillators with Chip Antenna for Wireless Sensors from Room Temperature to 200 and 250 °C

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Abstract — Oscillators that operate at 720 and 940 MHz and characterized over a temperature range of 25 °C to 200 °C and 250 °C, respectively, are presented. The oscillators are designed on alumina substrates with typical integrated circuit fabrication techniques. Cree SiC MESFETs, thin film metal-insulator-metal capacitors and spiral inductors, and Johanson miniature chip antennas make-up the circuits. The output power and phase noise are presented as a function of temperature and frequency.

Index Terms — MESFETS, chip antennas, oscillators SiC alumina.

I. INTRODUCTION

The need for electronics that operate at high temperatures is growing in both commercial and government applications. The automobile industry uses a variety of electronics that operate at high temperatures including power brake (140 °C), on-engine (150 °C) and exhaust sensors (850 °C) [1]. The oil and natural gas industry require high temperature wireless sensors for drilling and monitoring wells up to 360°C [2]. NASA's planned missions to Venus will require electronic systems for probes and robotic landers on the surface that could reach as high as 500 °C [3]. Mechanisms for exploring the atmosphere of Venus may consist of small airplanes, but sophisticated electronics will be required to navigate the vessel in temperatures up to 320 °C [4].

NASA Glenn Research Center is developing high temperature electronics for wireless sensing applications [5, 6]. Oscillators that incorporate a capacitive pressure sensor have been developed [7]. The pressure was varied and the oscillation frequency shifted according to the change in capacitance at 300 °C. The oscillator/pressure sensor was coupled to a square ring antenna, which radiated its power over a distance of one meter.

In this paper, two oscillators that operate over a temperature range of 25 to over 200 °C are presented. Both oscillators utilize a miniature chip antenna that radiates to a receive antenna 1.7 m away. The miniature chip antenna greatly reduces the overall size of the circuit,

making it much more applicable for miniaturized wireless sensor applications that operate at high temperatures.

II. DESIGN AND FABRICATION

The oscillators are based on a conventional Clapp oscillator design, which is shown in Fig. 1. The values of C_T , C_1 , C_2 and L_T are given in Table 1 for both the 720 and 940 MHz designs. The method of design is illustrated in [6].

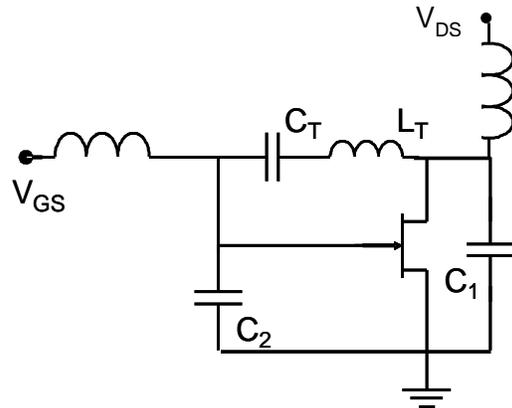


Figure 1: Schematic of Clapp oscillator.

Table 1. Passive component values.

| Oscillator | C_T (pF) | C_1 (pF) | C_2 (pF) | L_T (nH) |
|------------|------------|------------|------------|------------|
| 720 MHz | 10 | 4 | 4 | 8.5 |
| 940 MHz | 5 | 10 | 10 | 10.5 |

Figures 2 and 3 are photographs of the fabricated oscillators. The oscillators are fabricated on 99.9 % alumina substrates that are 500 μm thick and have a dielectric constant of 9.9. A Cree SiC MESFET, model number CRF24010D, is used in both oscillators with thin film metal-insulator-metal (MIM) capacitors and spiral inductors. The metallization of the underlying first metal of the MIMs is Cr/Au (25/500 nm). A 1.6 μm thick silicon dioxide layer is used as the insulator; the dielectric

constant of the silicon dioxide is approximately 4.3. The top electrode metallization is Ti/Au (25 nm/1.7 μm) and finally a third layer of 1.7 μm Au, for a total metal thickness of 3.9 μm , is used to decrease the resistive losses. The thin film spiral inductor has 1.5 turns for the 720 MHz design and 1.9 turns for the 940 MHz design, which results in an inductance of 8.5 and 10.5 nH, respectively, according to Sonnet simulations. The miniature chip antennas, model number 0920AT50A080, were provided by Johanson Technology. The antennas resonate at approximately 920 MHz, which matched well the 940 MHz oscillator design, thus no matching circuit required. To better match the chip antenna to the 720 MHz design, a 2 pF chip capacitor was placed in series with the input of the antenna to resonate with the series inductance of the antenna. Wire bonds were used to connect the drain, gate and source of the transistor to DC bias pads.

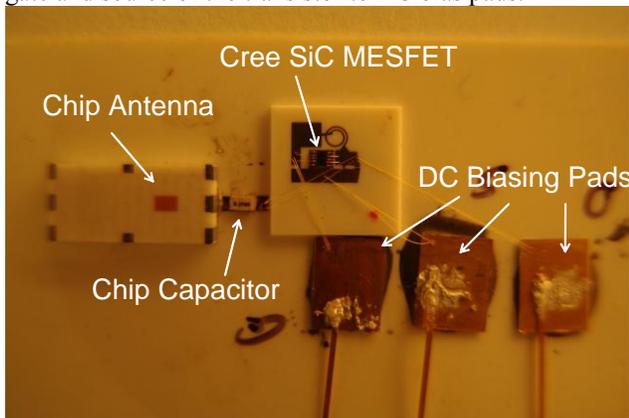


Figure 2: Photograph of 720 MHz circuit.

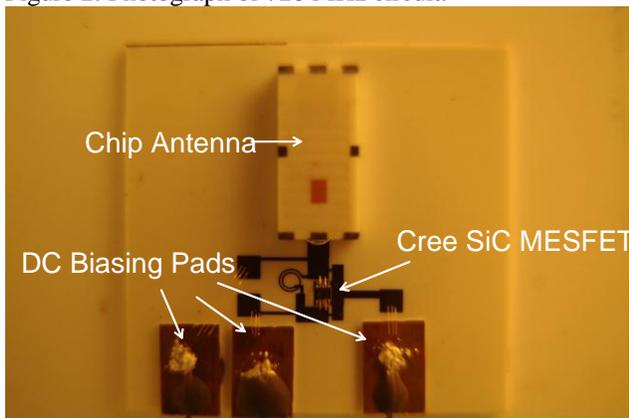


Figure 3: Photograph of 940 MHz circuit.

III. OSCILLATOR CHARACTERIZATION

The oscillators were characterized in an anechoic chamber. All of the test equipment is outside the room to eliminate interference from the equipment. The oscillators are clamped to a ceramic heater that is placed on a rotational stage so that a 180° radiation pattern can be measured. A wideband horn is used as the receive antenna

and has a gain of 2.3 and 4.0 dBi at 720 and 940 MHz, respectively. The oscillators with chip antennas are separated from the receive antenna by 1.7 m. Between the oscillator and ceramic heater are four, 500 μm thick alumina wafers to minimize the effects the heating element in the ceramic heater has on the circuits. A thermocouple is placed on the circuit substrate near the oscillator to accurately record the temperature of the circuit. The temperature of the ceramic heater is varied with a Labview controlled power source. An Agilent E4440A spectrum analyzer is used to record the spectrum and phase noise at temperature increments of 25 °C starting at room temperature and ending when the oscillator fails. Before each measurement, the temperature is held constant with the oscillator operating for 10 minutes to assure thermal equilibrium is reached. The gate voltage was varied as the temperature is varied to keep the drain current constant at 100 mA for both designs. For the 720 MHz circuit, the drain voltage is 6 V, and for the 940 MHz design, the drain voltage is 8.8 V.

The measured spectrum for the 720 MHz design at 25 and 200 °C is shown in Fig. 4. It is seen that the frequency of oscillation and transmitted power decrease with temperature. The oscillation frequency decreases from 726.2 MHz at 25 °C to 720 MHz at 200 °C, which is less than a 1% change. The transmitted power decreases from -22.1 dBm at 25 °C to -27.9 dBm at 175 °C, which is only a decrease of 3 dBm, but it decreases to -34.4 dBm at 200 °C. Just beyond 200 °C, the 720 MHz oscillator seizes to operate. Figure 5 shows the frequency and transmitted power received at every temperature setting.

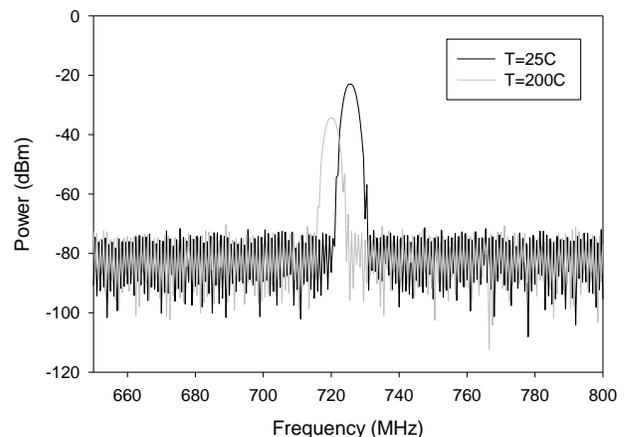


Figure 4: Measured spectrum for the 720 MHz circuit at 25 and 200 °C.

Figure 6 displays the spectrum at 25°C and 250°C for the 940 MHz oscillator design. The figure shows the oscillation frequency and transmitted power decrease similar to the 720 MHz design. The frequency decreases from 940.2 MHz at 25°C to 932.2 MHz at 250°C, which is less than a 1% change. The transmitted power decreases

from -27.6 dBm at 25°C to -32.9 dBm at 175°C. Beyond this, the power decreases more rapidly to -41.7 dB at 250°C. Just above 250 °C the 940 MHz oscillator seizes operation. Figure 7 shows the frequency and transmitted power received at every temperature setting.

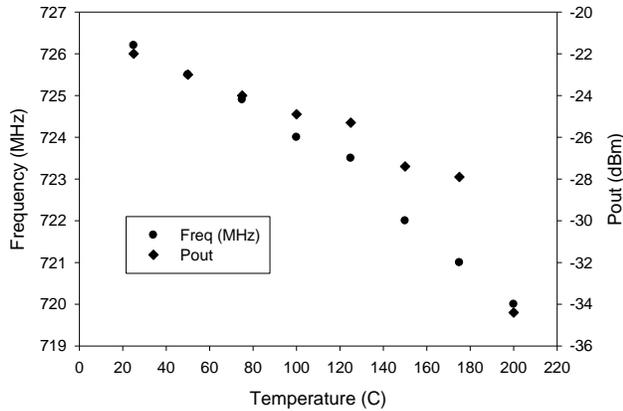


Figure 5: Measured received power and frequency for the 720 MHz circuit as a function of temperature.

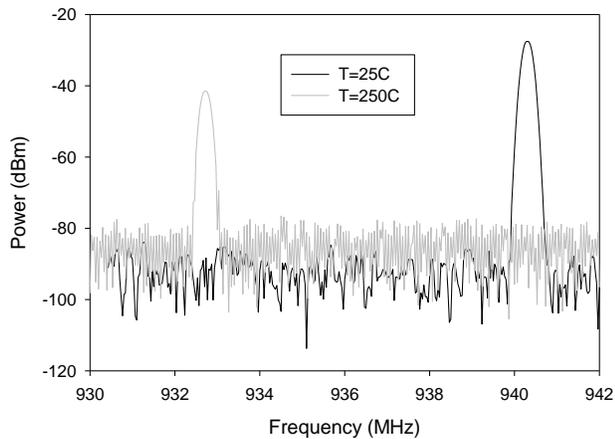


Figure 6: Measured spectrum of the 940 MHz circuit at 25 and 250 °C.

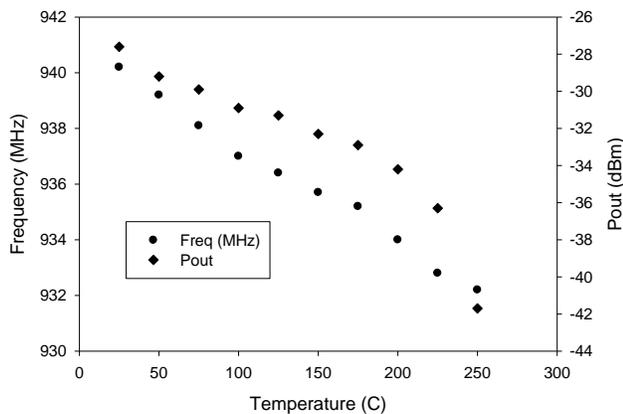


Figure 7: Measured received power and frequency for the 940 MHz circuit as a function of temperature.

The measured phase noise of the 940 MHz design at 25 and 250 °C is shown in Fig. 8. The phase noise increases at higher temperatures far from the carrier frequency, which is expected. Figure 9 shows the phase noise at 100 kHz offset over the temperature range from 25 to 250 °C. The phase noise increases as temperature increases, which is expected. The 720 MHz circuit had similar phase noise characteristics.

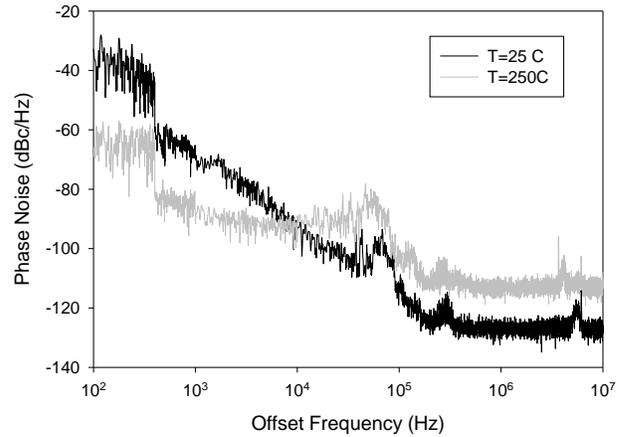


Figure 8: Measured phase noise of the 940 MHz circuit at 25 and 250 °C.

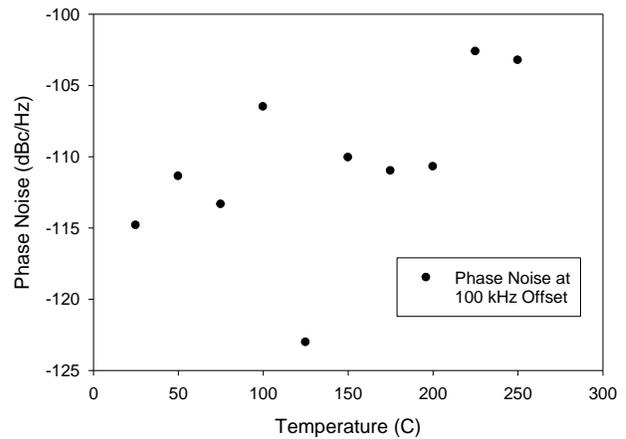


Figure 9: Measured phase noise of the 940 MHz circuit at 100 kHz offset frequency as a function of temperature.

The measured radiation patterns of the two oscillator designs are shown in Figs. 10 and 11. Both graphs clearly demonstrate how the transmitted power decreases as temperature increases. More important, the radiation patterns for both designs change very little over the temperature ranges.

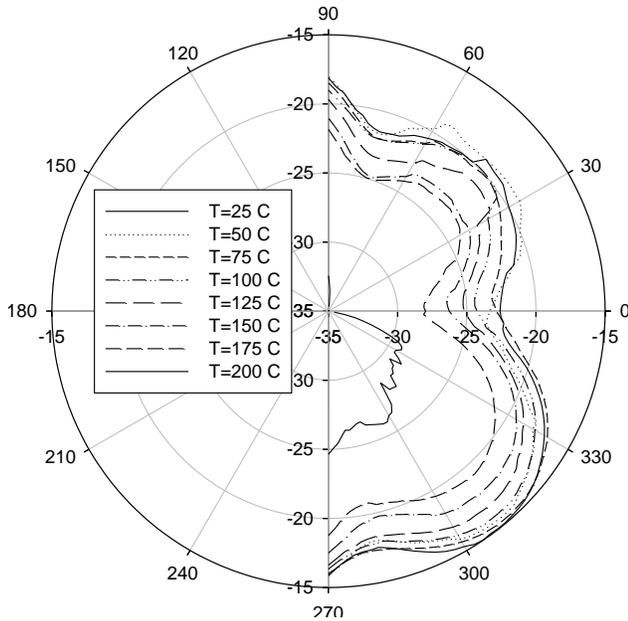


Figure 10: Measured radiation pattern of the 720 MHz circuit as a function of temperature.

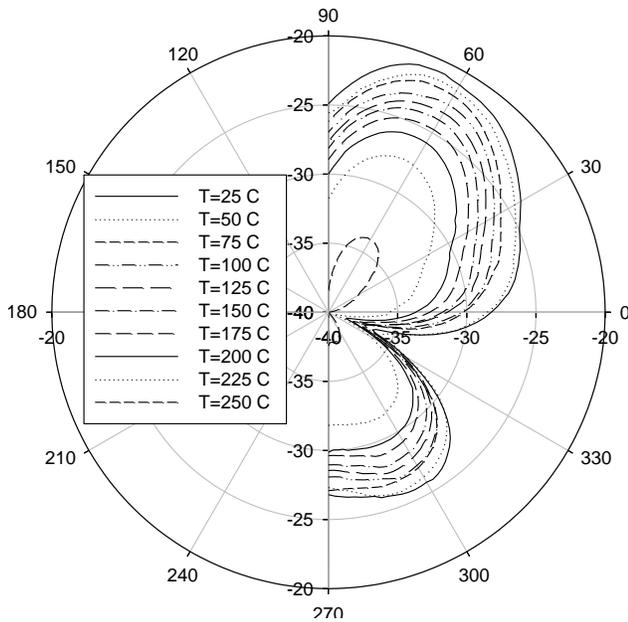


Figure 11: Measured radiation pattern of the 940 MHz circuit as a function of temperature.

IV. CONCLUSIONS

Oscillators that utilize miniature chip antennas have been presented. They were operated at 720 and 940 MHz over a temperature range from 25 to 200 and 250°C,

respectively. Both designs have a frequency shift less than 1% over their designated temperature ranges. The transmitted power varies little until the oscillators reach the temperature just before they stop operation, then the power decreases significantly. Radiation patterns demonstrate that there is no significant change in the radiation patterns and that the chip antennas may be used to at least 250 °C. The circuits and their characteristics demonstrate that the technology permits wireless sensors operating through 250 °C by replacing the MIM capacitor, C_T , by a capacitive pressure sensor as was done in [7].

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