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High-Power AIGaN/GaN FET-Based VCO Sources

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Abstract: The first report of multi-watt AlGaN/GaN FET-based voltage-controlled oscillators (VCO's) with high efficiency is presented. Varactor-tuned oscillators implemented using distributed networks oscillate at 3 GHz with high output power (2.7 w), high efficiency (27%), high supply voltage range (3.5 V to 30 V) and high tuning bandwidth (13%) over a control voltage range from 1 to 9 V. The measured output power and circuit efficiency are examined as a function of supply voltage. These results indicate high-power AlGaN/GaN-based VCO's may he used as high-efficiency sources for radio communications.

I. INTRODUCTION

Gallium nitride-based VCO's have exhibited comparable phase noise performance at microwave frequency to VCO's using GaAs technology [1]. With similar phase noise figures, GaN devices offer advantages for higher voltage and power operation up to 26 GHz as demonstrated by various organizations [2,3,4,5]. The higher power density, efficiency, and breakdown fields make GaN transistors ideal candidates for amplifier elements in power oscillators. Small size, single transistor die solutions, enabled by the higher power densities, simplifies assembly and packaging requirements.

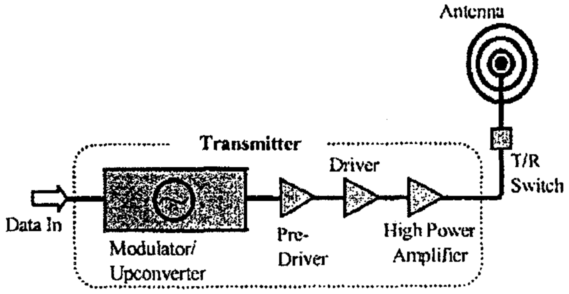

Fig. 1. **Generic transmitter architecture used in wireless infrastructure.**

High-power oscillators are commonly used for the modulator stage in wireless transmitters. A typical transmitter block diagram is shown in Fig. 1. A single high-power GaN VCO circuit could replace the modulator/upconverter, as well as the expensive drivers and high-power amplifier in the output stage.

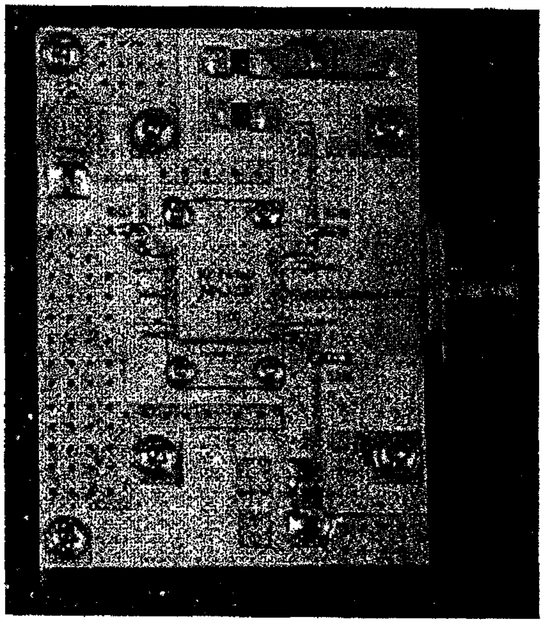

Fig. 2. Photograph of the AlGaN/GaN FET-based "CO mounted in test fixture.

This paper reports the first high-power GaN-based VCO's with high efficiency at 3 GHz. Output power as high as 2.7 watts, with 27% efficiency was measured with a high supply-voltage range (3.5 V to 30 V) and 13% tuning bandwidth. Transistors used were fabricated from undoped AlGaN/GaN heterostructures grown on semi-insulating SiC substrates.

Oscillators used for this study (Fig. 2) employed a common-gate design. The common-gate configuration is an ideal vehicle for evaluation of high-power oscillators, as it oscillates readily and is easily tuned.

Common-gate oscillators using GaAs FETs have been around for over twenty years [6]. Other possible oscillator configurations such as common-source, common-drain, and reverse-channel [7,8,9] have previously been demonstrated for GaAs FET oscillators.

The high-power VCO source was implemented using distributed networks. The GaN-based oscillator was constructed in an industry-standard metal-ceramic package. The design of oscillator has previously been published [1]. The packaged component was mounted in a test fixture for convenience. A picture of the completed assembly is shown in Fig. 2.

II. Oscillator Characteristics

A supply voltage of +15 V (V,,) was selected, which provided +13 V across the drain-source of the AlGaN/GaN FET. The measured drain current was 220 mA (Icc). The second harmonic was observed at -12 dBc. The frequency and output power are plotted versus control voltage in Fig. 3. The output power was about +28.7 dBm and essentially flat across the tuning range from +2 to +9 v.

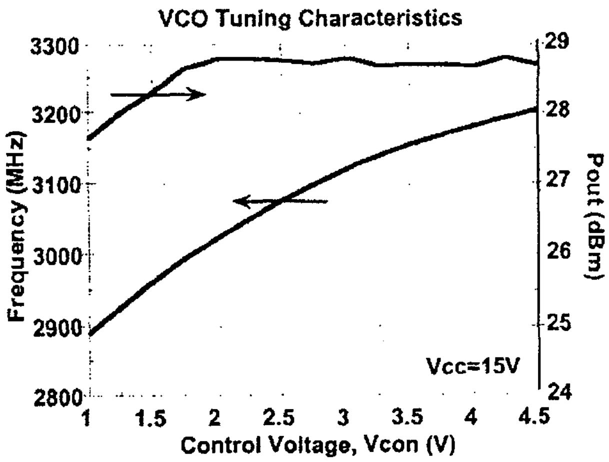

Fig. 3. Oscillation frequency and output power versus control voltage for GaN FET-based VCO.

A plot of the modulation sensitivity (Kv) and output power versus frequency is shown in Fig. 4. The measured Kv was 150 MHz/V to 50 MHz/V over 10% tuning bandwidth (+1.0 V to +4.5 V). The maximum observed tuning range was 380 MHz, or 13% bandwidth over the 1 V to 9 V range. When tested at V_{cc} = +20 V (V_{DS} = 18 V), a 10% tuning bandwidth was observed over a 1-V to 4.5-V range, with an output power exceeding 1.0 W. The output power was measured at the output of the fixture, and is not corrected for losses due to the transitions from the package to microstrip and from the microstrip to connector.

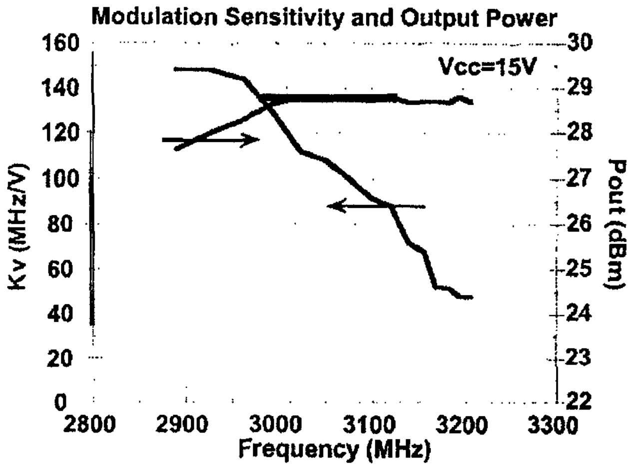

Fig. 4. Modulation sensitivity and output power of 3 GHz AlGaN/GaN FET-based VCO at Vcc = +15 V.

III. Phase Noise Performance

The phase noise at 3 GHz for a AlN-passivated GaN FET-based VCO was -80 dBc/Hz at 100 KHz offset. In Fig. 5, the phase noise is compared at 3

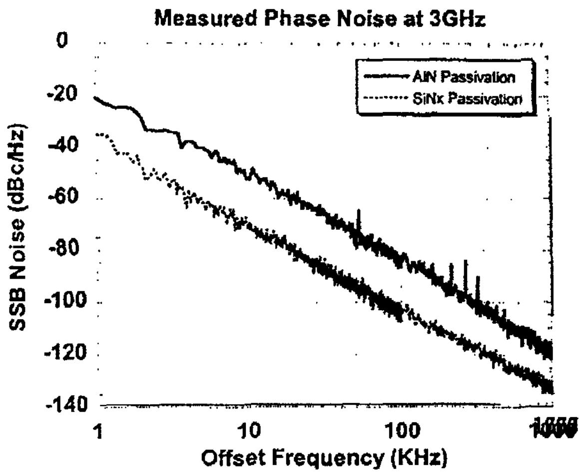

Fig. 5. Phase-noise performance of GaN-based VCO at 3 GHz with AlN (top curve) and SiN (bottom curve) passivation.

GHz to other oscillators [l] built using SiN-passivated GaN FETs.

The relatively poor phase noise performance is attributed to the non-optimized surface passivation applied to the GaN device. In this case, a low-temperature AlN passivation was deposited, most likely resulting in an amorphous film. The RF-to-dc dispersion (current slump) was improved by this passivation, but not eliminated. We surmise that the passivation did not totally cover the exposed regions between the source and drain, leading to non-uniform surface depletion effects in the 2-dimensional electron gas (2DEG). This would tend to spread out the 2DEG, increasing both the l/f and phase noise for the device.

As a comparison, Table I lists the phase noise results for another GaN-based oscillator on sapphire using silicon nitride for the passivation. In this case, the silicon nitride passivation nearly eliminated the RF to dc dispersion on this device, yielding RF power close to that predicted from the dc transfer characteristics. Oscillators utilizing this device yielded low phase noise, comparable to existing GaAs FET and HBT technologies [l].

TABLE I
SUMMARY OF GaN OSCILLATOR RESULTS USING TWO PASSIVATION TECHNIQUES

F_{osc}	Tuning BW	Substrate	P_{out}	Passivation	Phase Noise at 100 kHz	REF
(GHz)			(W)		(dBc/Hz)	
3.0	13%	SiC	2.7	Low-Temp. MBE AlN	-82	This work
6.0	10%	sapphire	0.5	SiN	-102 *	[1]

* Normalized to 3 GHz for comparison purposes.

IV. POWER SUPPLY DEPENDENCE

The output power and efficiency was studied versus supply voltage and the results are plotted in Fig. 6. The control voltage was maintained at +12 V (using two +6 V battery cells) and the supply voltage was increased from 0 V to 30 V. The oscillator begins to operate at +3.7 V (V_{cc}), which translates to a device voltage of 2.8 V (V_{cc}). The efficiency climbed from 18% at 5 V (V_{cc}) to 25% at +15 V, up to 27% at +20 V. Output power increased to 2.7 W at +27 V, with an associated efficiency of 26%. The device voltage at +27 V (V_{cc}) was +25 V (V_{DS}).

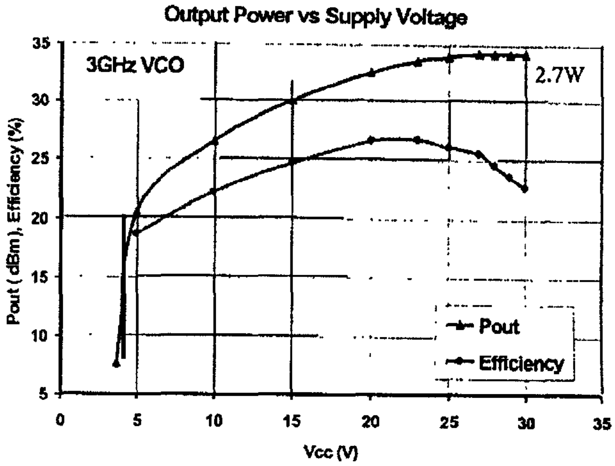

Fig. 6. Output power of GaN-based VCO versus supply voltage. The saturated output power is 2.7 W. The optimal efficiency of 27% occurs at V_{cc} = +20 V.

V. CONCLUSION

High-power (2.7 W) GaN FET-based VCO's with high efficiency (27%) have been demonstrated with 13% tuning bandwidth using a common-gate FET configuration. The device passivation is shown to play a critical role in achieving the desired phase noise for GaN-based oscillators. Proper passivation of the AlGaN/GaN heterostructure surface can allow good phase noise performance to be achieved, and can nearly eliminate RF-to-dc dispersion effects. These results suggest that highly efficient, tunable sources may be realized at microwave frequencies using GaN amplifier building blocks.

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REFERENCES

[l] J.B. Shealy, J.A. Smart, J.R. Shealy, "Low Phase Noise AlGaN/GaN FET-based voltage Controlled Oscillators (VCO's)," currently accepted for publication in *IEEE Microwave and Wireless Components Letters*, submitted Nov. 2000.

[2] Y. Wu, D. Kapolnek, J. Ibbetson, N. Zhang, P. Parikh, B. Keller, U.K. Mishra, "High Al-Content AlGaN/GaN HEMTs on SiC with Very High Performance," IEDM Digest, Pgs 925-927, Washington DC, Dec. 1999.
[3] HRL Laboratories, unpublished.
[4] CREE Inc., unpublished.
[5] B.M. Green, K. Chu, E. Chumbes, J. Smart, L. Eastman, J. Shealy, " The effect of surface passivation on the Microwave Characteristics of AlGaN/GaN HEMTs," *IEEE Electron Devices Lett., June 2000,* pp. 268-270.
[6] T. Rutlan, "GaAs FETs Rival Gunns In YIG-tuned Oscillators," *Microwaves,* Vol. 16, No. 7, pp. 42-48, July 1977.
[7] H. Abe, Y. Takayama, A. Higashisaki, R. Yamamoto, and M. Takeuchi, "A High Power Microwave GaAs FET Oscillator," *ISSCC Digest of Technical Papers,* pp. 164-165, February 1996.
[8] P.C. Wade, "Novel FET Power Oscillators," *Electronics Letters,* Vol. 14, No. 20, pp. 672-674, Sept 28, 1978.
[9] P. Wade, "X-Band Reverse Channel GaAs FET Power VCO," *Microwave Journal,* p. 92, April 1978.