

# An Ultra Low Phase Noise W-Band GaAs-Based PHEMT MMIC CPW VCO

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**Abstract** — A W-band voltage control oscillator (VCO) using 0.1- $\mu\text{m}$  AlGaAs/InGaAs/GaAs PHEMT MMIC technology with ultra low phase noise is presented. This VCO demonstrated an operation frequency centered at 97 GHz with a tuning range of 2 GHz and an output power of 1 mW. The measured single side-band phase noise is  $-88$  dBc/Hz at 1MHz offset. To the best of our knowledge, this phase noise performance is not only the best among the previously reported results for HEMT MMIC VCO at this frequency, but also rivals those for most VCOs using HBTs.

## I. INTRODUCTION

Oscillators are important components in communication systems. In the past, most high frequency oscillators are based on IMPATT and Gunn diodes. Though they demonstrated good power performance, the special processes are not compatible with other MMIC components. With the MMIC technologies advanced in the recent years, millimeter-wave MMIC oscillators operated at W-band frequencies implemented based on HEMT and HBT devices were reported [1]-[7]. HEMT devices have the advantages of higher gain for high frequency operation and therefore quite a few MMIC VCO were reported [1]-[5]. On the other hand, HBTs has inherent low device  $1/f$  noise characteristics, oscillators based on InP-based HBT to achieve low phase noise performance [6]-[7].

In this paper, a low phase noise W-band MMIC HEMT VCO is presented. This VCO demonstrated an operation frequency centered at 97 GHz with 2-GHz tuning range and 1-mW output power. The most significant feature of this VCO is that the measured phase noise is  $-88$  dBc/Hz at 1-MHz offset. Table I summarizes the previously reported performances and features of MMIC VCOs in W-band. It can be observed that the phase noise performance reported in this paper is not only the best among the previously reported W-band HEMT VCOs, but also rivals those of most HBT-based VCOs except the one in [8], which reported a superior phase noise performance of  $-95$  dBc/Hz for 1-MHz offset at 104 GHz.

## II. DEVICE CHARACTERISTICS AND MMIC PROCESS

The HEMT device used in this design is TRW 0.1- $\mu\text{m}$  high linearity AlGaAs/InGaAs/GaAs PHEMT MMIC process. The HEMT device has a typical unit current gain cutoff frequency ( $f_T$ ) of higher than 100 GHz and maximum oscillation frequency ( $f_{max}$ ) of greater than 250 GHz at 2-V drain bias, with a peak dc transconductance ( $G_m$ ) of 600 mS/mm. The gate-drain breakdown voltage is 6 V, and the drain current at peak transconductance ( $I_{d,spk}$ ) at 2-V drain-source voltage is 600 mA/mm. This MMIC process also includes thin-film resistors, MIM capacitors, spiral inductors, and air-bridges. The wafer is thinned to 4-mil for the gold plating of the backside and reactive ion etching via holes are supported.

## III. VCO DESIGN

The W-band oscillator circuit schematic diagram and photograph are shown in Fig. 1. The chip size is 1.5 mm  $\times$  1 mm. The HEMT device used in this design is TRW 0.1- $\mu\text{m}$  high linearity AlGaAs/InGaAs/GaAs PHEMT MMIC process. A HEMT device with four-finger 80- $\mu\text{m}$  gatewidth is employed and grounded coplanar waveguide (GCPW) is used as the transmission medium in this design. Two transmission lines connected to two source terminals and one transmission line to gate are dedicated to decide the operation frequency and form the positive feedback. Via holes are placed on the ground metals to suppress the undesired parallel plate modes of the GCPWs. In addition, airbridges are used at each discontinuity to suppress the undesired slot mode excitation. All the passive structures were characterized by a full-wave EM analysis to eliminate the uncertainty of passive element models.

## IV. MEASURED RESULTS

This VCO was measured via on-wafer probing and the output signal was monitored through the spectrum analyzer by using a sub-harmonic mixer to down-convert the W-band RF signal to IF band. By tuning the gate

voltage from  $-0.3$  to  $0.4$  V, the frequency and the power of the output signals were read from the spectrum analyzer. Fig. 2 shows the oscillation frequency and output power as functions of gate voltage for  $V_d = 4$  V. The tuning range is about 2 GHz centered at 97 GHz and the average output is  $-1$  dBm. The phase noise is directly estimated from the spectrum analyzer as shown in the spectrum plot of Fig. 3, which indicates the phase noise to be  $-88$  dBc/Hz at 1-MHz offset. This is not only the best phase noise result among the previously reported W-band HEMT VCOs [1]-[5], but also rivals those of the HBT-based VCOs [6]-[7].

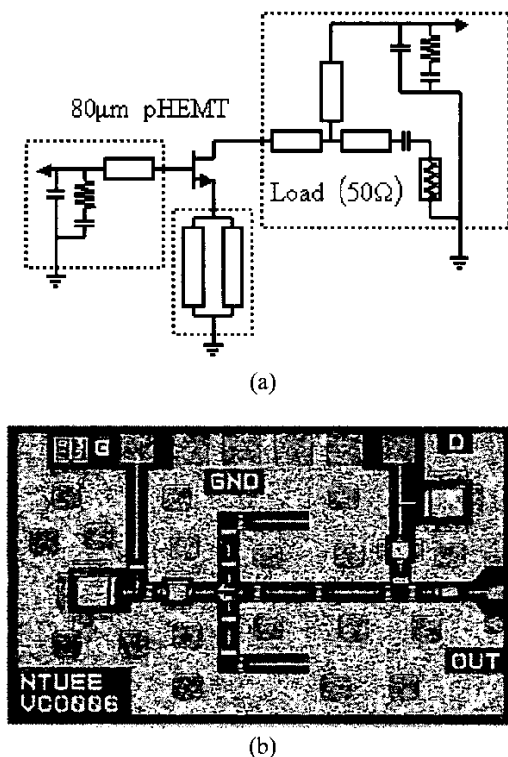


Fig. 1. The (a) circuit schematic diagram, (b) chip photograph (chip size  $1.5 \text{ mm} \times 1 \text{ mm}$ ), of the W-band MMIC CPW VCO.

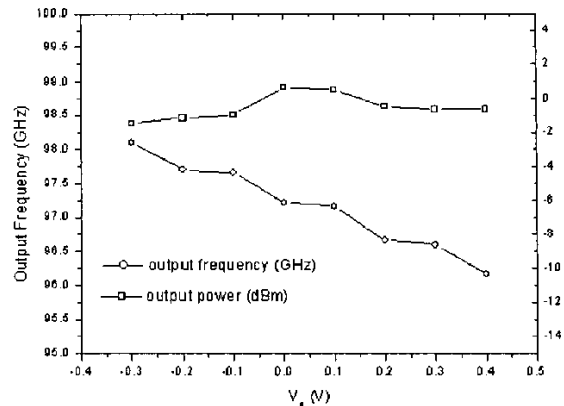


Fig. 2. The measured oscillation frequency and output power as functions of gate voltage for  $V_d = 4$  V.

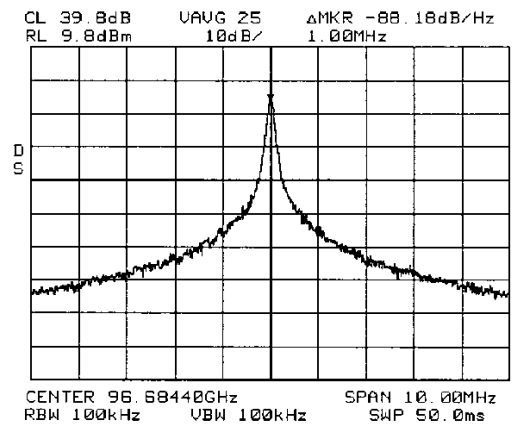


Fig. 3. The measured spectrum plot of the W-band MMIC CPW VCO. The VCO oscillates at 96.7 GHz with phase noise of  $-88$  dBc/Hz at 1-MHz offset.

## V. DISCUSSIONS

Although this W-band GCPW VCO utilized the same HEMT device ( $0.1\text{-}\mu\text{m}$  GaAs-based PHEMT MMIC process provided by TRW) and a similar circuit architecture as the W-band microstrip-line VCO reported in [1], the phase noise performance is significantly different from each other. The reason is described briefly as the following.

The phase noise of an oscillator is related to two noise sources, which are the up-converted low-frequency noise and the multiplied noise near by the carrier frequency [9]. The up-converted low-frequency noise is due to the nonlinearity of the transistor that can be treated as a mixer. The power incident into the gate  $P_i$ , and the feedback

power out of the matching circuit  $P_f$  can be analyzed via the harmonic balance (HB) analysis by defining a feedback loop of the gate and drain of the PHEMT device. It is observed that there is a trade off between output power and phase noise. On the other hand, the multiplied noise near by the carrier frequency is related to the open loop quality factor  $Q$ , which is a function of the angular frequency derivatives of the magnitude and phase of the open loop gain [9]. One can conclude that the phase noise will be improved as  $Q$  increases.

Comparing the microstrip-line VCO reported in [1] with this CPW VCO the  $Q$ -factors are similar in both designs and therefore the up-converted low-frequency noise power will dominate the phase noise performance. Since the small signal open loop gain of the microstrip-line VCO is higher than that of this CPW VCO, the microstrip-line VCO operated at a higher saturation condition and cause higher  $P_f$  with a higher near carrier noise power. Due to a lower  $P_f$ , the CPW VCO exhibits a better phase noise performance but lower output power.

## VI. CONCLUSION

In this paper, an ultra low phase noise W-band MMIC CPW VCO using GaAs-based HEMT is presented. The measured tuning range of this VCO is 2 GHz with an average output power of -1 dBm over its tuning range. A phase noise of -88 dBc/Hz at 1-MHz offset was achieved, which is the best result among the previously published VCOs in this frequency regime.

## ACKNOWLEDGEMENT

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TABLE I  
THE PREVIOUSLY REPORTED PERFORMANCE AND FEATURES OF W-BAND MMIC

Author	Huei Wang et al., [1]	K. Bangert et al., [2]	S. Kudszus et al., [3]	H. J. Siweris et al., [4]	V. Radisic et al., [5]	K. W. Kobayashi et al., [6]	Y. Baeyens et al., [7]	Uchida, K. [8]	This work
Device	0.1 $\mu$ m PHEMT	0.15 $\mu$ m PHEMT	0.15 $\mu$ m PHEMT	0.12 $\mu$ m HEMT	0.1 $\mu$ m AlInAs/GalnAs/InP HEMT	InP-HBT	InP-HBT	InGaP/InGaAs HBT	0.1 $\mu$ m PHEMT
Approach	Negative resistance	Negative resistance	Negative resistance	Feedback	Negative resistance	Push-Push 2 <sup>nd</sup> harmonic	Differential	Negative resistance	Negative resistance
Freq. (GHz)	90.5 (power) 92 (low noise)	94	94	77	80	108	94	104	97
Tuning Range	800 MHz (low noise) 600 MHz (power)	8 GHz (electrical) 18 GHz (removing airbridge)	4.5 GHz	2 GHz	7 GHz (Varactor-tune)	2.73 GHz (Varactor-tune)	13 GHz		2 GHz
Output power (dBm)	7.6 (low noise) 8.8 (power)	7.78	2 (max.)	7.5	12.5	0.92	-3	-3.4	0.7
1 MHz offset phase noise (dBc/Hz)	-68.2	-67	-71	-78	-	-88	-85	-95	-88

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