# A Compact Ka-Band PHEMT MMIC Voltage Controlled Oscillator

Yu Wen[1,2], Sun Xiaowei[2], Qian Rong[2], and Zhang Yimen[1]

(1 *Microelectronics Institute, Xidian University, Xi'an* 710000, *China*)

(2 *Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, Shanghai* 200050, *China*)

**Abstract:** A compact Ka-band monolithic microwave integrated circuit (MMIC) voltage controlled oscillator (VCO) with wide tuning range and high output power, which is based on GaAs PHEMT process, is presented. A method is introduced to reduce the chip size and to increase the bandwidth of operation. The procedure to design a MMIC VCO is also described here. The measured oscillating frequency of the MMIC VCO is 36 ±1.2GHz and the output power is 10 ±1dBm. The fabricated MMIC chip size is 1.3mm ×1.0mm.

**Key words:** VCO; MMIC; Ka-band; active-biasing; PHEMT

**EEACC:** 1350H; 1230B; 2560S

**CLC number:** TN4 **Document code:** A **Article ID:** 0253-4177(2005)06-1111-05

## I Introduction

Oscillators are key components for microwave and millimeter-wave communication systems. In particular, VCOs for automotive radars have been studied in recent years[1~3]. Fundamental VCOs are preferred for automotive radars in view of cost, because their sizes are small and no multiplier is needed.

MMIC, recently find use in a variety of sensors, automotive, and other applications and systems. One-chip systems make essential the design of compact, high performance, wide-band fully integrated VCOs based on PHEMTs (pseudomorphic high electron-mobility transistors) epitaxial structure.

For a MMIC chip, its size is directly related to the cost, thus the smaller chip size is better. Another respect, for VCO, the wider the tuning range is, the wider its application area is. So a method for a designing a compact MMIC VCO with wide tuning range and high output power is presented in this paper. In order to reduce the chip size, active biasing technology may be chosen, and for achieving wide tuning range, the biasing inductor for the gate of the oscillating PHEMT should be optimized, at the same time a good DC bias line with as wide as possible a DC- to RF- frequency separation range is also a factor to increase the tuning range. As for the output power, maximum negative resistance is needed.

For verifying the method mentioned above, as well as for some other applications, a Ka-band MMIC VCO is designed by adopting this method and fabricated based on the GaAs PHEMT process. The measured oscillating frequency is 36 ±1.2GHz and the output power is 10 ±1dBm. The fabricated MMIC VCO chip size is 1.3mm × 1.0mm. The measured results show that this method of designing a compact Ka-band MMIC VCO with wide tuning range and high output power is

Yu Wen male, was born in 1966, associate professor. His research area is in design of microwave circuits, including MMIC design and MCM system integration. Email: yuwen@mail.sim.ac.cn

Received 5 December 2004, revised manuscript received 2 February 2005 

valid.

## 2 Designing method

Megej and Beilenhoff[5] reported that one important aspect of broadband VCO design is the DC-power supply to the oscillator transistors, and it is also one of the reasons for the bandwidth limitation of tunable oscillators. Usually, DC-biasing is provided by means of shortenning $\lambda/4$-long transmission lines with one blunt capacitor. These implementations require large chip area, which is generally much larger than that used by the active circuit itself. So we should mainly focus on the DC-bias lines to reduce the chip area. Generally speaking, transistor configuration with capacitive feedback in the source path has been used for VCO designing, and the basic schematic of this kind of VCO is shown in Fig. 1. In this case, we need three DC-bias lines for tuning voltage, and gate- and drain- voltage of the oscillating transistor ($T_{osc}$), respectively, thus the problems concerning DC-supply mentioned above are tripled. If the gate DC-bias line of the oscillating transistor is replaced with another

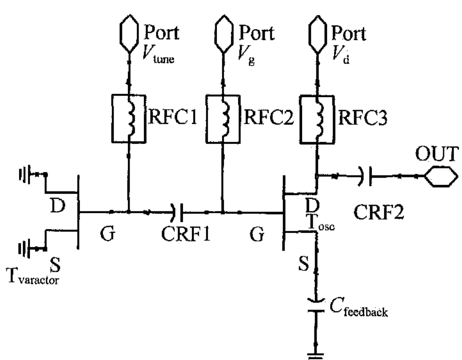


Fig. 1 Basic topology of VCO

transistor ($T_{bias}$), which is connected to the source of the oscillating transistor, as shown in Fig. 2, the VCO chip size will be reduced considerably since the area occupied by the transistor $T_{bias}$ is much less than what a DC-bias line needs. Of course the factor of the layout should also be considered. Though an inductor $L_g$ is needed to form the DC path for the transistor $T_{osc}$ and it needs some chip area, in the layout, as a whole, it can be placed in the unoccupied free space which cannot be used otherwise because of the DC-bias lines. These unoccupied free areas can be found out when designing the layout.

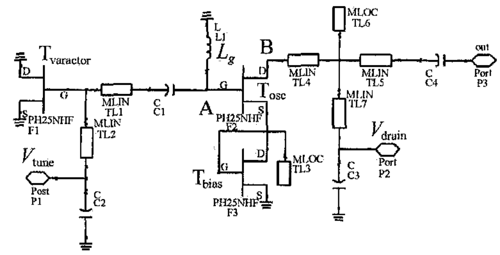


Fig. 2 Schematic of the designed MMIC VCO

The frequency tuning range of a VCO is mainly determined by the variation range of the input impedance of the oscillating PHEMT($T_{osc}$) in Fig. 2, so a large variation range of this input impedance is needed for a wide VCO tuning range. This input impedance comes from the left part of point A, i.e. a varactor ($T_{varactor}$), a tuning voltage bias line for the varactor, and an inductor ($L_g$) used for forming the DC path for the $T_{osc}$. Since the bias line is composed of a $\lambda/4$-long microstrip transmission line combined with a shunt capacitor, its effect can be ignored here. So the main factors influencing the input impedance are the capacitor $C_{tune}$ of the varactor and the inductor $L_g$, which are parallel. The impedance of the capacitor $C_{tune}$ combined in parallel with inductor the $L_g$ is $j\omega L_g/(1-\omega^2 L_g C_{tune})$, so if the maximum impedance variation range, which will lead to a maximum VCO tuning range, is needed, the inductor $L_g$ should be as large as possible. But the chip size will be increased considerably with a large inductor, and in another important respect, this inductor is also a leakage path for the oscillating signal. It will influence the output power obtained, so a trade-off must be made among these three factors: the impedance change range, the chip size, and the output power. By simulating with commercial CAD software, the optimum inductor value can be obtained.

The DC bias line is another limitation for the tuning range, since a $\lambda/4$-long microstrip transmission line combined with one shunt capacitor can only have a limited frequency separation range for a DC- and RF- signal, so some effort should be paid to design the bias line in order to obtain a separation range as wide as possible. Adopting two shunt capacitors is a good way.

As for the high output power, the first factor, also the most important factor, is the power handling ability of the oscillating transistor, so a fitful transistor with enough power handling ability should be chosen first, then a maximum negative resistance "look" to the left of point B should be obtained. Those are the main points.

From what is described above, a method to design a compact MMIC VCO with large tuning range and high output power may include such aspects as follows. First, for a compact design, a transistor connecting to the source of the oscillating transistor should be used to replace the gate DC-bias line of the oscillating transistor. Then, for a wide tuning range, an optimized inductor $L_g$ should be chosen and the DC-bias lines should be designed to have as large a DC- and RF- path separation as possible. Finally, for achieving high output power, the oscillating transistor should have enough power handling ability, and maximum negative resistance should be designed.

## 3 Designing procedure

Generally speaking, a MMIC VCO can be designed by such a procedure as follows.

(1) All three transistors will be chosen according to the VCO performance, in general, PHEMT with more fingers and a longer gate width will provide more output power. The PHEMT used as the varactor should have a $C_{max}/C_{min}$ ratio as large as possible;

(2) The DC-bias lines design. It is very important from the tuning range point of view; the separation of DC- and RF-paths will be fulfilled in a frequency range as large as possible. For practical application, a DC-bias line with two shunt capacitors in parallel is very good;

(3) $L_g$ optimization for inductor. The most important thing is the trade-off among the tuning range, the chip area and the output power, which has been analyzed above;

(4) Obtaining maximum negative resistance at point B in Fig. 4. This can lead to maximum output power, but the VCO tuning range will be decreased, so there is another trade-off between the output power and the tuning range;

(5) Output matching;

(6) Small signal analysis. After the five steps above, small signal *S*-parameter analysis is performed to this single port network and the oscillating frequency can be obtained preliminarily through this analysis. Rough adjustments should be done to achieve the oscillating frequency point and frequency tuning range needed;

(7) Large signal analysis. After having finished the small signal analysis, harmonic balance (HB) analysis will proceed. By means of this kind of large signal analysis, the ultimate oscillating frequency, its output power, and its phase noise can be obtained. Adjusting the related circuit structure parameters, mainly the lengths of some microstrips, the designer can make the design fulfill the required performance.

## 4 Design and measurement for VCO

In order to validate the method for designing a compact MMIC VCO with wide tuning range and high output power described above, and also for some other applications, a 36 GHz MMIC VCO is designed and fabricated based on GaAs PHEMT process. The schematic of the designed and fabricated VCO is shown in Fig. 2. It is a capacitive feedback negative resistance type oscillator circuit with active biasing technique. The negative resistance is obtained by means of the feedback capacitor connected in series to the source of the oscillating transistor (a 4 ×30μm PHEMT). Here the feedback capacitor is implemented with an open microstrip stub, and the oscillating transistor has an active bias at its source, the PHEMT $T_{bias}$ (2 ×30μm) acts as the current source for the oscillating transistor $T_{osc}$. The varactor $T_{varactor}$ is a 4 ×30μm PHEMT with both its source and drain connected to the ground.

Measurement is performed by putting the MMIC VCO chip directly on the board of the probe station. There are two capacitors (100pF and 1μF respectively) connected in parallel to each DC supply line, which are used to bypass the undesired RF signals. The oscillating curve is displayed on a MS288C spectrum analyzer. The measurement results are shown in Fig. 3 and Fig. 4. The operation condition for this MMIC VCO measurement is $V_d$ = 3.0V, $I_{ds}$ = 18mA. Figure 3 shows a typical oscillating signal with oscillating frequency of 36.825GHz, and Figure 4 shows the measured oscillating frequency and the associated output power tuning curves. It shows that the MMIC VCO designed has a tuning range of 2.4GHz around 36.0GHz with an output power of about 10dBm. The chip size of the fabricated MMIC VCO is 1.3mm ×1mm. The phase noise of the fabricated MMIC VCO is - 80dBc/Hz @100kHz. The phase noise is not very good, but it can be adopted in practical application. The main reason to this not very good phase noise is that the $Q$ factor of the LC tank is very poor.

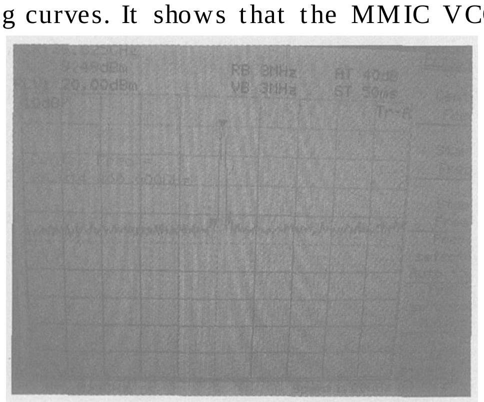

Fig. 3 Typical oscillating waveform

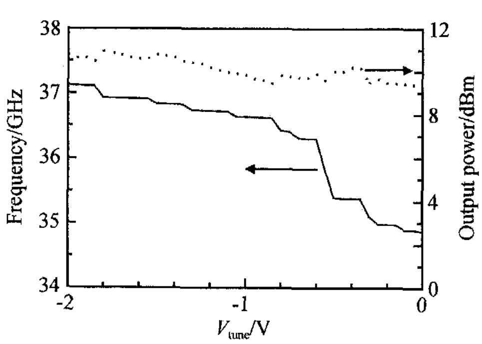


Fig. 4 Oscillating frequency and output power tuning curves

## 5 Conclusion

A compact 36GHz MMIC VCO with 2.4GHz tuning range and with about 10dBm output power is presented in this paper. This MMIC VCO is based on GaAs PHEMT process and has been designed by adopting the method for designing a compact MMIC VCO with wide tuning range and high output power. An active biasing technology, an optimized inductor, delicately designed DC-bias lines, and a maximum negative resistance are the main factors for designing a compact and wide tuning range MMIC VCO with high output power. The measurement results of the fabricated Ka-band VCO validate this method.

### References

[1] Welthof A, Siweris H J, Tischer H, et al. A 38/76GHz automotive radar chip set fabricated by a low cost PHEMT technology. IEEE MTT-S Int Microwave Symp Dig, 2002: 1855

[2] Priestly N, Newsome K, Dale I. A gunn diode based surface mount 77GHz oscillator for automotive applications. IEEE MMT-S Int Microwave Symp Dig, 2002: 1863

[3] Camiade M, Domnesque D, Alleaume P F, et al. Full MMIC millimeter wave front-end for a 76.5GHz adaptive cruise control car radar. IEEE MTT-S Int Symp Dig, 1999: 1489

[4] Zhang D X, Sturzebecher D, Daryoush A S, et al. Comparison of the phase noise perfomance of HEMT and HBT based oscillators. IEEE Int Symp Dig, 1995: 697

[5] Megej A, Beilenhoff K. Active biasing technique for compact wide-band voltage controlled oscillators. Institut für Hochfrequenztechnik TUD, 2003: 20

# 紧凑型 Ka 波段 PHEMT 微波单片集成 VCO

余　稳[1,2]　孙晓玮[2]　钱　蓉[2]　张义门[1]

(1 西安电子科技大学微电子研究所, 西安　710000)

(2 中国科学院上海微系统与信息技术研究所, 上海　200050)

**摘要**: 设计并流片制作了基于 GaAs PHEMT 工艺的 Ka 波段微波单片集成压控振荡器(MMIC VCO). 该 VCO 具有紧凑、宽电调谐带宽及高输出功率的特点. 提出了缩小芯片面积及增大调谐带宽的方法,同时还给出了设计 MMIC VCO 的基本步骤. 该方法设计并流片制做的 MMIC VCO 的测量结果为:振荡频率为 36 ±1. 2 GHz ,输出功率为 10 ±1dBm ,芯片面积为 1. 3mm ×1. 0mm.

**关键词**: 电压控制振荡器; 微波单片集成电路; Ka 波段; 有源偏置; PHEMT

**EEACC:** 1350H; 1230B; 2560S

**中图分类号**: TN4　　**文献标识码**: A　　**文章编号**: 0253-4177(2005)06-1111-05

余　稳　男,1966 年出生,副教授,主要研究方向为微波电路的设计,包括微波单片集成电路设计和 MCM 系统集成. Email:yuwen@mail.sim.ac.cn

2004-12-05 收到,2005-02-02 定稿