# K-Band Monolothic VCO Using PHEMT Technology

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## Abstract

***An appropriate nonlinear design methodology based on the optimisation of the load cycles is applied for a K-band MMIC VCO using 0.2 µm GaAlAs/GaInAs/GaAs Pseudomorphic HEMT technology. A tuning range over 13.5% bandwidth (22.5-25.8 GHz) is obtained, with a high sensitivity of 4.5 GHz/V. A constant output power of 6 dBm and a phase noise level less than - 85 dBc/Hz at 1 MHz offset from the carrier, were measured over the tuning range.***


## Introduction

Monolithically integrated high electron mobility transistors (HEMTs) offer a number of application benefits, including high operating frequency, low HF noise, high reliability, and compact size. These attributes are making HEMTs the active devices of choice in many millimeterwave applications. In fact, a monolithic 213 GHz quasi-optical oscillator using InP based HEMTs is reported in [1]. Moreover, a comparative study of the phase noise contribution of HEMT and HBT based oscillators demonstrates that a lower up-conversion factor can be achieved with HEMTs than with HBTs [2].

Using Pseudomorphic HEMT technology, we developed a fully monolithic K-band VCO which has a high tuning sensitivity needed for the frequency modulation and phase locked sources in communication systems.

An approriate nonlinear approach is used in the design of VCO's. This methodology is mainly based on the optimisation of the intrinsic load cycles which provides the best insight on the active device large signal behavior [3]. The first successful pass of this VCO design indicates the importance of a rigorous design methodology. This paper describes the design approach, the main features of the used technology, and the monolithic circuit performance.

## Oscillator Design

The schematic diagram of the VCO is shown in Figure 1. It is based on a 0,2µm Pseudomorphic HEMT under series feedback configuration, which is realized by means of capacitances $C_S$.

A tuning varactor diode has been included in the circuit connected to the gate side of the HEMT, which contributes to change the equivalent inductance of this circuit, and results in the variation of oscillation frequency. The frequency tuning range depends on the maximum available varactor capacitance ratio.

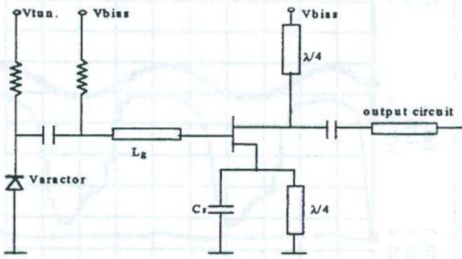


Fig.1 : schematic of VCO.

Generally, a small signal analysis is used to derive initial elements values of the circuit. A nonlinear analysis (usually harmonic balance) is then performed to optimise passive elements in order to get the desired performance (frequency, power and harmonics). However, the H.B. oscillator analysis presents some disadvantages, for exemple: the excessive computation time due to the numerous parameters to be optimised.

Therefore, to overcome the problem, we adopted a nonlinear design and optimisation procedure which is as follows: as a first step in the circuit design, classical small signal analysis is used to get the initial values of the feedback elements featuring a negative resistance at the drain terminal of the active HEMT over the desired oscillation frequency range. In the second step, the oscillator is transformed to a reflection amplifier and the optimisation of the intrinsic load cycle form allows to get optimum values of the passives feedback elements $L_g$ and $C_s$ for each varactor control voltage. The final values of $L_g$ and $C_s$ will be choiced among these optimum in order to have a near ideal load cycle form over the tuning voltage. The optimum load cycle should have a minimum

area (minimum reactive power), non distorted, and featuring the largest Ids and Vds swings. For the final values of $C_s$ and $L_g$, the voltage over current ratios are used to synthesize the output load in the final step.
The oscillator circuit is designed using the PML large signal models of HEMTs and varactor diodes, and simulated with the commercial microwave software HP-MDS.

## Fabrication

The circuit is fabricated using 0.2μm gate length Pseudomorphic HEMT GaAlAs/GaInAs/GaAs technology from Philips Microwave Limeil Foundry. The employed HEMT device with a finger width of 4*30μm has a unit current gain frequency ($f_t$) of 62 GHz, and the minimum noise figure of 0.9dB at 12GHz with an associated gain of 11.5dB. The technology further includes via-holes, epitaxial resistors and MIM capacitors. The substrate height is 100μm.
The varactor has an interdigitated fingers structure, with length fixed to 3μm, and width to 8*30μm . The varactor capacitance value varies from 0.76pF to 0.18pF by changing the bias voltage from 0 to 1.4V. Figure 2 shows a circuit layout. The chip size is 1.5mm * 2mm.

## Performance

The RF performances of the VCO were measured in a low insertion loss microstrip test fixture. Figure 3, shows the output spectrum at 22,7 GHz measured by means of a spectrum analyzer HP8700 series. The Figure 4, displays the variation of the output frequency as a function of the varactor voltage which is varied between 0.4 and 1.4V. We can notice that the results show good agreement with the design simulations.
The oscillator is tuneable over a range of 3 GHz. A high tuning sensitivity of about 4.5 GHz/V was achieved. The output power is nearly constant over the control voltage range with 6 dBm. The slightly difference observed between the measured and simulated output power is mainly due to unaccounted losses from the fixture transition and the cable.
The frequency pushing characteristics for drain and gate voltage are resumed in Table 1. The oscillation frequency decreases with Vgs and increases with Vds. This can be explained by the bias dependence of the HEMT equivalent circuit elements. The decrease of $f_{osc}$ with Vgs is mainly caused by the increase of $C_{gs}$. However, the increase of oscillation power with Vds which is greater than the knee voltage, is related to the ration increase of $g_m/g_{ds}$.

The measured phase noise at 1MHz offset from carrier is less than -85dBc/Hz, over the tuning range in spite of the very low varactor quality factor.
The performances of the present oscillator compare well with the published characteristics of other VCOs [4-10].

## Conclusion

Monolithic K-band wide tuning range VCO has been realized using 0,2μm Pseudomorphic HEMT technology. A tuning bandwidth of more than 3GHz and an excellent tuning sensitivity of 4.5GHz/V, with a constant output power of 6dBm have been achieved. The nonlinear design and the described optimisation procedure is an appropriate oscillator design methodology. The measured data which agree well with the design simulations show the first successful pass of this approach.


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Table1 : Performance of VCO.

| Performance | Unity | Value |
|---|---|---|
| Output power | dBm | 6 |
| Tuning bandwidth | GHz- % | 3.3 - 13.5 |
| Tuning sensitivity | GHz/V | 4.5 |
| Phase noise @ 1MHz | dBc/Hz | -85 |
| dc power consumption | mW | 54 |
| Efficiency | % | 7.5 |
| Freq. pushing drain bias | MHz/V | 153 |
| Power pushing drain bias | mW/V | 1.87 |
| Freq. pushing gate bias | MHz/V | 300 |

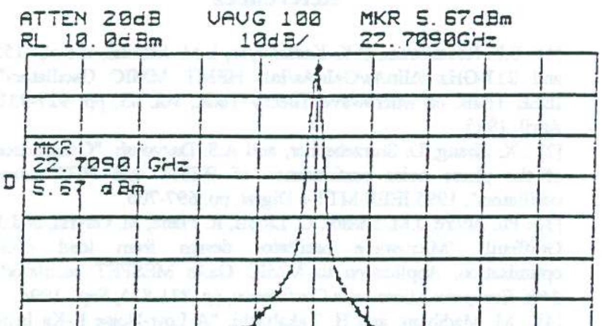


Fig.3 : Output spectrum of the K-band VCO

(Vds = 3V Ids = 18mA Vc = 0.6V)

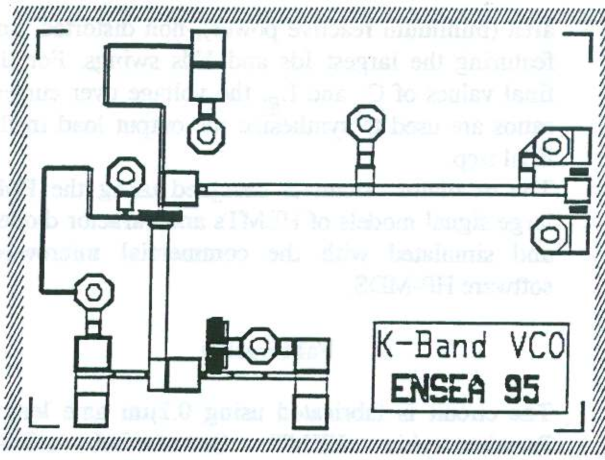


Fig.2 : Layout of the monolithic circuit chip.

(Vds = 3V Ids =18mA)

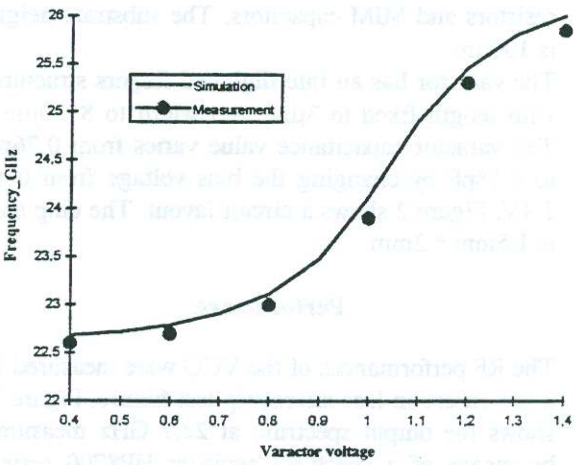


Fig.4-a : Oscillation frequency vs. control voltage

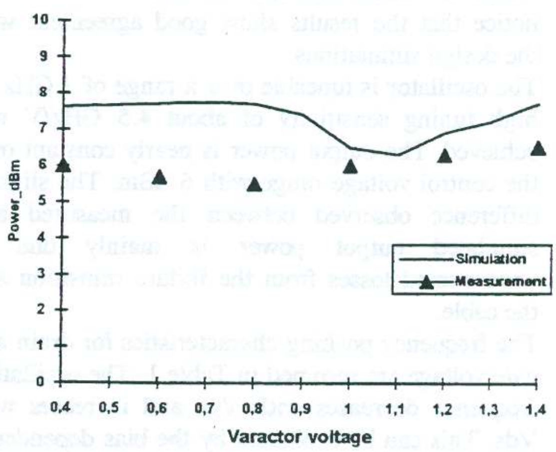


Fig.4-b : Output power vs. control voltage