Differential LC VCO with Enhanced Tank Structure and LC Filtering Techniques in InGaP/GaAs HBT Technology

InGaP/GaAs HBT 공정을 이용하여 향상된 탱크 구조와 LC 필터링 기술을 적용한 차동 LC 전압 제어 발진기 설계

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Abstract

This paper presents the InGaP/GaAs HBT differential LC VCO with low phase noise performance for adaptive feedback interference cancellation system(AF-ICS). The VCO is verified with enhanced tank structure including filtering technique. The output tuning range for proposed VCO using asymmetric inductor and symmetric capacitors withlow pass filtering technique is 207 MHz. The output powers are −6.68 including balun and cable loss. The phase noise of this VCO at 10 kHz, 100 kHz and 1 MHz are −102.02 dBc/Hz, −112.04 dBc/Hz and −130.40 dBc/Hz. The VCO is designed within total size of 0.9×0.9 mm^2.

요 약

본 논문은 InGaP/GaAs HBT 공정을 통해 제작한 적응성궤환 잡음제거시스템용 낮은 위상잡음을 갖는 LC 차동 전압제어 발진기를 제안합니다. 전압제어 발진기는 필터링 기술을 포함한 향상된 공진 탱크 구조를 갖습니다. 비대칭 인덕터 대칭 캐패시터 구조로 제안된 전압제어 발진기의 출력 가변 범위는 207 MHz입니다. 출력 전력은 balun과 케이블 손실을 포함하여 −6.68 dBm입니다. 10 kHz, 100 kHz, 1 MHz에서의 위상잡음은 각각 −102.02, −112.04 그리고 −130.4 dBc/Hz입니다. 이 전압제어 발진기는 총 0.9×0.9 mm^2 면적 내에 집적화되었습니다.

Key words : Symmetrical And Asymmetrical Inductance Tank Structures, Monolithic Microwave Integrated Circuit (MMIC), Heterodyne Bipolar Transistor(HBT), Differential LC VCO, Phase Noise, Cross Coupled Configuration

Ⅰ. Introduction

To complete the predominant radio frequency communication systems, integrated voltage controlled oscillators(VCOs) are very important parts in every communication system blocks. Nowadays differential topology is one of most common techniques to improve the phase noise of the integrated LC VCOs. Thus, common building block in RF integrated circuit is differential pair of bipolar transistors[1].

This differential structure offers high loop gain making it common method to design differential voltage controlled oscillator(VCO) in RFICs. For hybrid VCO design, the traditional Colpitts LC topology is used to avoid the additional complexity that is like in a differential VCO design. For this reason, we could use just

「This research work has been supported by Nano IP/SoC Promotion Group of Seoul R&BD Program in 2006.」

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· 논 문 번 호 : 20061103-10S

· 수정완료일자 : 2007년 1월 29일

limited differential topology and modeling information[1].

An integrated VCO circuit offers reduced size and enhanced performance. Besides, verified varactor diodes through proposed paper are used to tune the reference frequency. In addition to capacitive coupling feedback, a fully differential topology allows to reduce $1/f$ noise [2].

Additional LC filtering technique is used in front of buffer to enhance the phase noise and compensate output power[1].

In section II, the main design methods like SCAIT structure performance and noise filtering technique and application theory are introduced. Section III presents the measured result from the proposed VCO as numerical data for works mentioned in section II. Finally Conclusion will be outlined for this paper.

Ⅱ. Circuit Design Method and Analysis

The Adaptive Feedback-Interference Cancellation System(AF-ICS) Theory is main application of this design. The AF-ICS consists of four typical blocks like adaptive status monitoring control system, adaptive detector, cancellation signal generator and signal divider. The adaptive detector which is designed by RF analog system removes the signal feedback to receiver and consists of cancellation signal detector and error signal detector. The signal cancellation detector works as a signal coupler, and the error signal detector works as a sampler for necessary error signal. The cancellation signal generator consists of delay line, phase shifter and attenuator. It makes the identical signal with sane amplitude and anti-phase to cancel the feedback signal. The adaptive status monitoring control system consists of amplitude phase comparer and digital signal processing blocks. Fig. 1 shows the block diagram of the AF-ICS[3].

To make the cancellation of the adaptive feedback signal, AF-ICS requires a precise signal source. Therefore, this LC VCO with low phase noise using noise frequency filtering technique is definitely required in

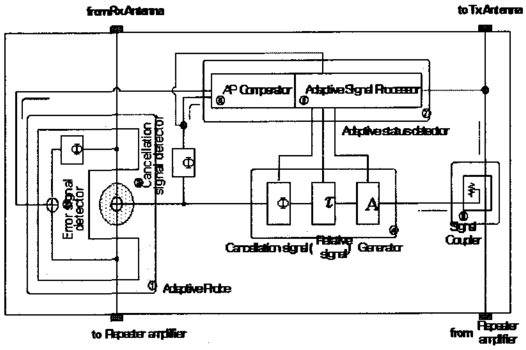


Fig. 1. Block diagram of the adaptive feedback interference cancellation system.

these applications. The differential cross-coupled topology with asymmetric inductance and symmetric capacitance tank circuit is applied to achieve low phase noise.

The next section described the other methodology that was used in order to ensure the VCOs have low phase noise performances; asymmetrical and symmetrical tank structure will be described. The device that is used in this design is InGaP/GaAs HBT. The equivalent circuit of it is shown in Fig. 2.

In modern circuit design, the differential topology is generally used to get common mode noise reduction. That's why the differential topology is widely used instead of single-ended even though it requires more elements to design. Also the 1/f noise can be reduced

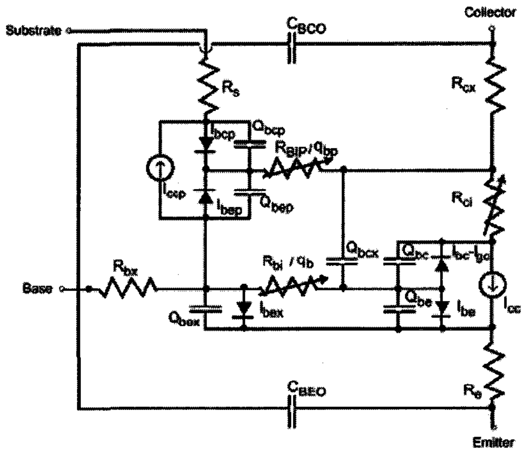


Fig. 2. HBT equivalent circuit for VBIC.

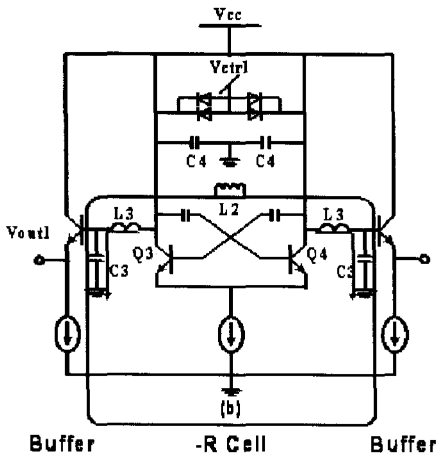


Fig. 3. Circuit schematics of the differential LC VCO proposed SCAIT.

by using cross-coupled capacitance feedback technology[2].

Phase noise of oscillator is originated primarily through two mechanisms, distinguished by the path into which the noise is injected[4]. The VCO includes both a feedback oscillation signal path and a frequency control path. This paper treats of the phase noise reduction in these paths using specific frequency filtering technique and enhanced tank structure.

The designed VCO in Fig. 3 consists of asymmetric tank structure. In previous work[2], the both of inductance and capacitance values are considered asymmetrically. It reduces redundant space that makes comparable performance about conventional symmetric tank structure. But the oscillated wave form of core stage has a little distortion in head room. The problem came from asymmetric capacitor structure in resonator tank. Therefore the distortion and a little loss in headroom are eliminated with enhanced tank using symmetric capacitance in asymmetric tank structure.

The noise frequency filtering structure short noise frequencies around supply voltage and feedback noise to ground.

LC low pass noise frequency filtering technique: To reduce phase noise of the VCO, noise filtering technique is used with LC low pass filter between the core and buffer stages shown as Fig. 3 like a L3 and C3.

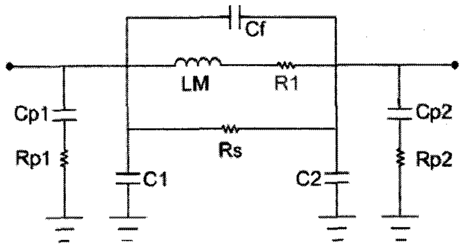


Fig. 4. Equivalent circuit of the spiral inductor.
LM : Main inductance of the spiral inductor
C1 : Capacitance of input shunt capacitor
C2 : Capacitance of output shunt capacitor
Cf : Series capacitance due to coupling
R1 : Series resistance of the spiral inductor

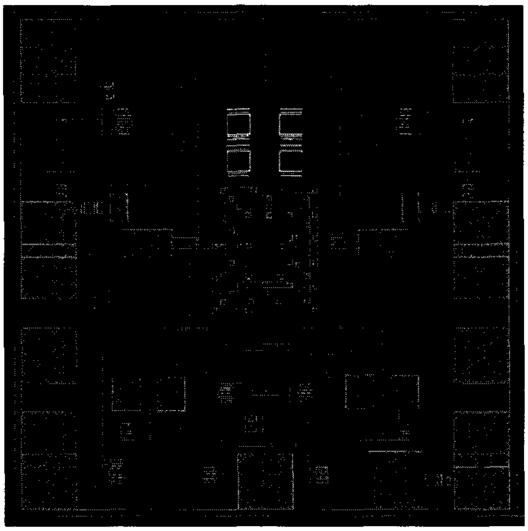
The capacitive filtering technique is based on filtering theory. Because of this VCO design based on active component, which it required to dismiss of other high order harmonics. To remove harmonics, low pass filtering is one of most basic theory. In design, low pass filtered noise frequencies go through ground following the arrow, so enhance phase noise performance can be obtained[1].

To get a high Q value, the capacitance of the resonator is required to be higher than inductance. So, the inductor needs to be with a low parasitic series resistance. Fig. 4 describes the equivalent circuit of spiral inductor. The R1 that is series resistance of the spiral inductor is dominant factor of the inductor Q-value. Proposed VCO is modified to decrease this series resistance for low phase noise performance.

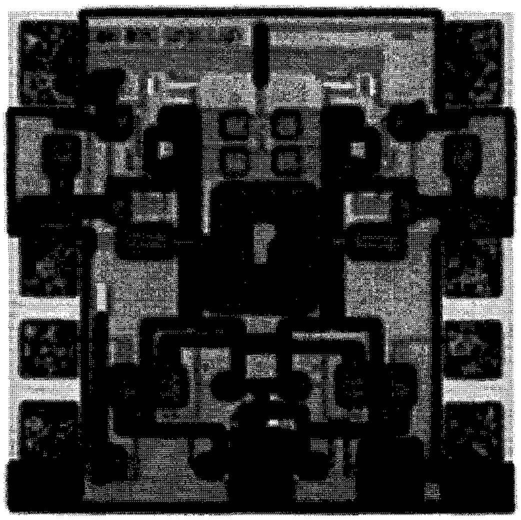
Simulation for this design is based on Agilent Advanced Design System 2004A using Knowledge-on InGaP/GaAs HBT process library. The schematic of this design is verified with checking rule of Knowledge-on process design kit. The outer conditions like a wire bonding inductance and PCB connection loss were considered in final simulation.

Ⅲ. Measurement Results

The designed VCO with proposed theory is fabricated and measured. The final chip size of VCO is under 1×1 mm^2. This is fabricated by using commercial InGaP/



(a) Layout of 0.9×0.9 mm²



(b) Fabricated chip in of 0.9×0.9 mm²

Fig. 5. Layout and microphotograph of the differential LC VCO.

GaAs HBT process which shows a cut-off frequency(f_T) of 50 GHz and maximum oscillation frequency(f_{MAX}) of 80 GHz. Fig. 4 shows final layout and fabricated chip of SCAIT-VCO design.

The differential output of the SCAIT-VCO is measured using balun to make differential signal as single one like Fig. 6. Output power of fundamental harmonic is −6.68 dBm and difference with second harmonic is 28.44 dBc.

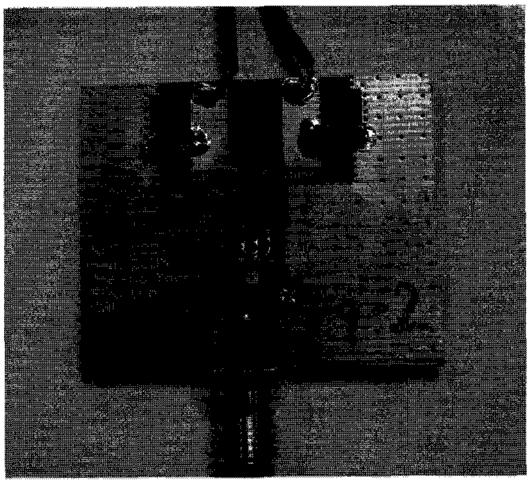


Fig. 6. Top view of VCO test board.

Measured phase noise is −112.04 dBc/Hz at offset frequency 100 kHz. Also, the phase noise at 1 MHz offset is −130.40 dBc/Hz at 1 MHz offset, when supplying control voltage is 0 V. The measured results have a little difference with simulation results. There's a little frequency shifting and decrease of output power. In this LC VCO, enhanced tank with SCAIT structure shows low phase noise performance which is better than previous work[2].

Table 1 summarizes the measurement results of the proposed LC VCO. Fig. 7 and 8 show output spectrum and phase noise characteristic which are obtained through power spectrum analyzer.

In order to compare the VCO performance with other VCOs in terms of different frequencies and power di-

Table 1. Summary of the measurement results.

Items		Unit	Simulation	Measurement
Oscillation Frequency		GHz	1.624	1.619
Output Power		dBm	−1.945	−6.68
Tuning range(0∼3 V)		MHz	138	207
Supply Voltage		V	5	5
Current Consumption		mA	14.8	15
Phase Noise	@100 kHz	dBc/Hz	−109.0	−112.04
	@ 1 MHz		−129	−130.40
Chip Size		mm²	0.9×0.9	0.9×0.9

Table 2. Summary of VCO performance from recently published literature.

Ref.	Type	Freq [GHz]	Tuning Range [MHz]	Phase Noise [dBc/Hz] @100 kHz	Figure of Merit
[5]	CMOS	2.6	-	−99	−177.7
[7]	InGaP HBT	1.46	260	−104	−170.3
[8]	0.5um bipolar	1.9	100	−103	−172.5
[9]	SiGe HBT	2.02	470	−86	−157.3
[10]	SiGe HBT	2.5	120	−107	−168.7
[11]	SiGe HBT	1.476	150	−100	−166.8
[12]	CMOS	1.9	160	−98	−171.8
This work	InGaP HBT	1.619	207	−112.04	−177.5

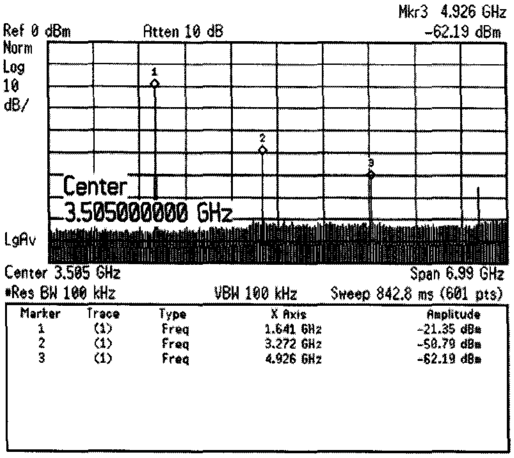


Fig. 7. Output spectrum with harmonic suppression.

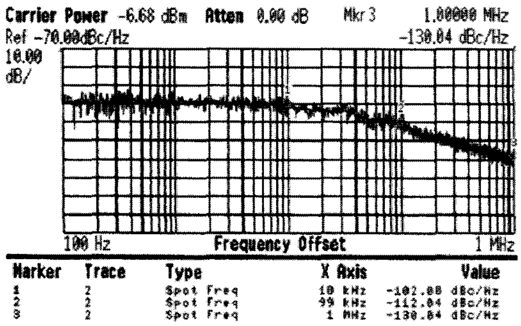


Fig. 8. Phase noise of SCAIT-VCO at low tuning voltage.

ssipations, a widely used figure-of-merit(FOM) is defined as

$$FOM = L(\Delta f_m) - 2\log\left(\frac{f_0}{f_m}\right) + 10\log\left(\frac{P_{diss}}{1mW}\right) \quad (1)$$

where L is the measured phase noise, f_0 is the oscillation frequency, f_m is the frequency offset, and P_{diss} is the dissipation power of the VCO. In this work, we achieved a FOM of −177.5(SCAIT-VCO) which is quite comparable to the previously published one. Table 2 summarized the VCO performance from recently published literature.

Ⅳ. Conclusion

In this paper, LC-VCO with noise frequency filtering technique and enhanced tank(symmetric capacitance and asymmetric inductance) is proposed. At this point, the VCO has two kinds of enhanced point to get optimum phase noise characteristic. It has a low phase noise performance base on oscillated signal compensation which is suppressed with symmetric capacitor structure and harmonic noise frequency filtering techniques. Furthermore, the phase noise was obtained using inductor with high Q-factor in LC tank, thereby obtaining wider tuning range than that of the symmetric structure. Also, it has a wider tuning range than the symmetric tank structure. Therefore, such technique can be applied in any other VCO topology to enhance phase noise characteristic.

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