SILICON MONOLITHIC BALANCED OSCILLATORS USING ON-CHIP SUSPENDED ACTIVE RESONATORS

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Abstract

Silicon microwave monolithic balanced oscillators using suspended active resonators realized in a f_T=15 GHz BJT process are presented. These micro-machined oscillators feature lower power consumption and lower phase noise (∼5 dBc lower). Suspended active resonators tuned to self oscillate having an even simpler topology have also been demonstrated.

1 Introduction

Oscillators using resonators constructed from inductors and capacitors find wide application in electronic systems. In general integrated silicon oscillators for use at microwave frequencies can not use on-chip RF passive resonators since the on-chip resonators have excessive metal losses. In some cases these are so high that no oscillation can occur. Furthermore, on-chip resonators realized in silicon standard processes suffer significantly from shunt parasitics to substrate. Off-chip resonators play in practice an important role in achieving oscillator RF performance. Their use, however, tends to increase overall circuit size and cost. These various limitations can be overcome by using on-chip active resonators. Today most work on active inductors and resonators concerns GaAs [1, 2, 3]. The feasibility of realizing monolithic microwave oscillators on silicon has greatly increased with the emergence of high f_T silicon bipolar and SiGe technologies in recent years. Work has been reported in which an active inductor was used in realizing a tunable resonator tank circuit integrated with a HBT oscillator [4]. Silicon balanced oscillators using on-chip active resonators realized on ordinary silicon have been reported by the authors in [5].

Based on experienced gleaned in realizing suspended passive components and active resonators [6, 7], this paper describes the design, realization and characterization of novel silicon MMIC balanced oscillators using suspended active resonators realized by selective front side etch of silicon.

2 Oscillator Topology

Figure 1 shows the oscillator schematic using a balanced limiting amplifier and active resonator. The balanced limiting amplifier uses two transistors, T_3 and T_4, to provide DC feedback. T_3 and T_4 work actually as diodes, which automatically supply level shifting for the bases of T_1 and T_2, respectively. The oscillation frequency is estimated by

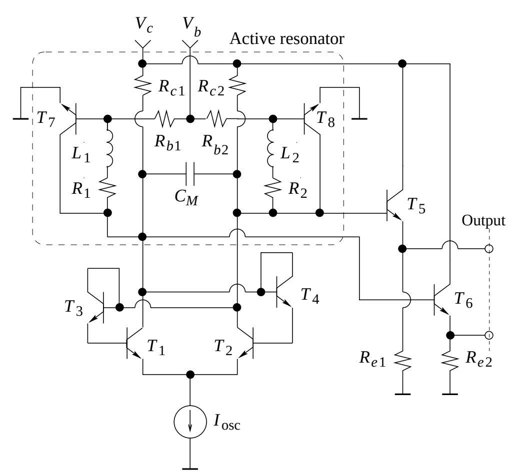

Figure 1: Balanced oscillator using active resonator

small signal analysis of the loop gain of the oscillator circuit as function of frequency. Harmonic balance simulation using Hewlett-Packard's Microwave and RF Design System (MDS) was utilized to carry out nonlinear analysis and design of the oscillator.

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The active resonators were designed to resonate at the frequency where the losses of the active inductors are zero. In order to enable oscillation, limiting amplifier must be designed to obtain negative output conductance ($-G_{LA}$), in other words, to provide enough loop gain. This can be achieved by properly choosing the scaling, feedback and biasing of the transistors in the limiting amplifier. Secondly, in order to have the oscillation frequency fall within the bandwidth of the active resonator for which the active inductors have minimum losses (or highest Q-factor) the output reactance of the limiting amplifier within this band should be as low as possible. In most cases the output impedance of a balanced limiting amplifier is capacitive. This output capacitance lowers the oscillation frequency to less than the designed resonant frequency.

The balanced output of the oscillators are transferred via emitter followers to the pads for measuring at the output. During simulation the 50 Ω load associated with the on-chip probes were taken into account.

2.1 Oscillators Using Suspended Active Resonators

Our study of active inductors on silicon [7] found that suspended active inductors consumed one fourth to one fifth of the current used by normal active inductors. This encouraged us to employ the suspended membrane technique in the integrated oscillator in order to reduce losses dissipated in the substrate as well as noise. A suspended active resonator was designed to replace the active resonators realized directly on ordinary silicon. Consequently, the suspended oscillator requires less power to build up and maintain the same loop gain for oscillation. Figure 2 and 3 are photo's of two oscillators designed at 2.3 GHz and 3.2 GHz, respectively.

2.2 Suspended Active Resonators Working as Oscillators

The suspended membrane structure by reducing substrate losses makes it easier to achieve output negative resistance from the active resonators. In contrast to the normal active resonators on silicon, we observed negative resistance from suspended active resonators with increasing supply current by tuning V_b. Oscillation was therefore built up without the use of the limiting amplifier to enhance loop gain. This undoubtly simplifies the topology and saves on integration area. The output power and phase noise, however, were found to be at the same level as that using the limiting amplifier. Apparently the removal of the the limiting amplifier as an extra noise source is compensated by the increased bias current required for the active resonator to oscillate.

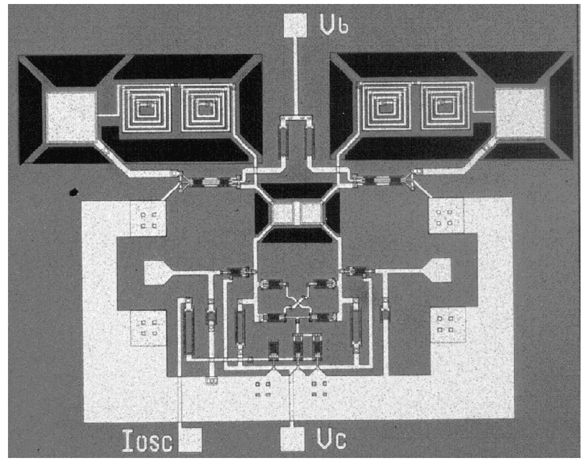

Figure 2: Photo of an 2 GHz oscillator using suspended active resonator

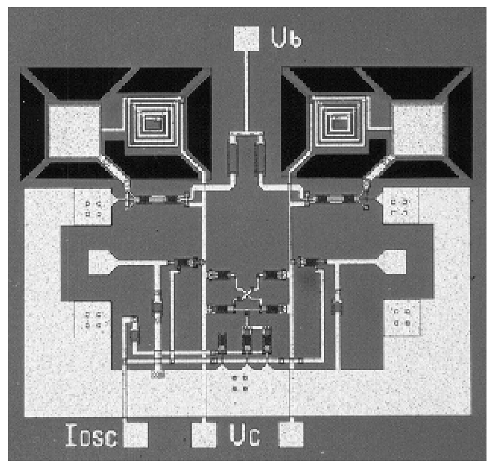

Figure 3: Photo of an 3 GHz oscillator using suspended active resonator

The measurement results are discussed in detail in the next section.

3 Oscillator On-Wafer Measurement

The suspended oscillators were fabricated in a compact $<$1.0x0.9 mm^2 area based on the DIMES-03 silicon bipolar process (f_T=15 GHz). As shown in Figure 2 and 3, the oscillator layout has three DC pads and two RF output pads, all for on-wafer measurement. The current flowing into the active resonator can be tuned by the voltage V_b. The pad I_{osc} is for the current source control and V_c is the voltage

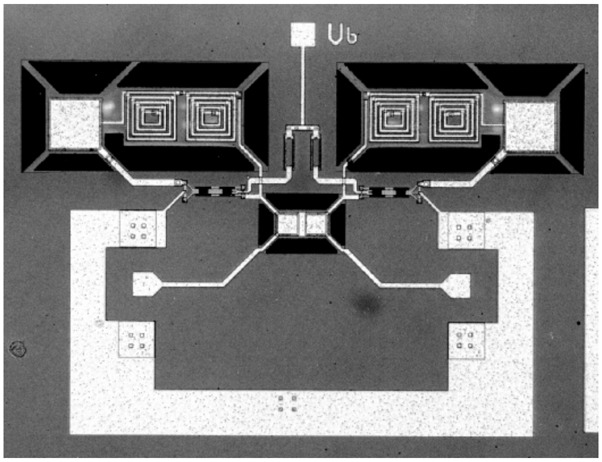

Figure 4: Photo of a suspended 2 GHz resonator

supply for the whole circuit. When measuring the RF output pads were probed by the Cascade Microtech ACP-40 probes and the outputs connected to a spectrum analyzer via a 180° hybrid. The measured spectrum of a suspended

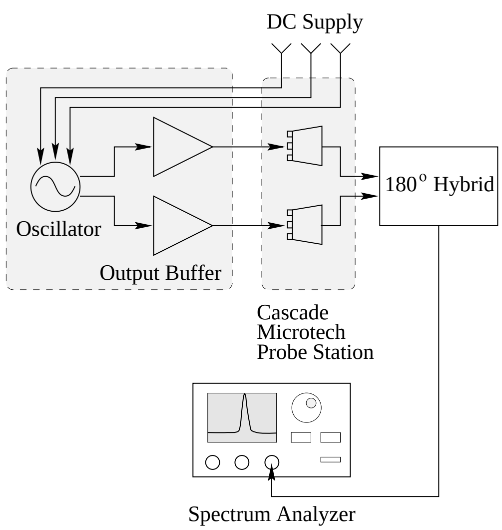

Figure 5: Oscillator on-chip measurement setup

2 GHz oscillator is given in Figure 7 as compared to the normal 2 GHz oscillator spectrum in Figure 6. The measured frequencies, output power, current consumption and phase noise of normal and suspended oscillators are given in Table 1. It can be seen that the suspended oscillator has not only lower phase noise, but also a much cleaner spectrum around the oscillation frequency than that of the normal oscillators. The spikes in Figure 6 are due to the rich oscillator parasitics noted for direct realization on silicon. The improvement in phase noise obtained from suspended oscillators is less than as expected. The noise contribution from the active resonator, compared to that from current consumption, is quite high. On the other hand, although the enhanced-Q of active inductors do improve the oscillator performance on silicon, the noise level outside the enhanced-Q bandwidth is higher than the normal noise floor. The shoulders outside the bandwidth are shown in Figure 8.

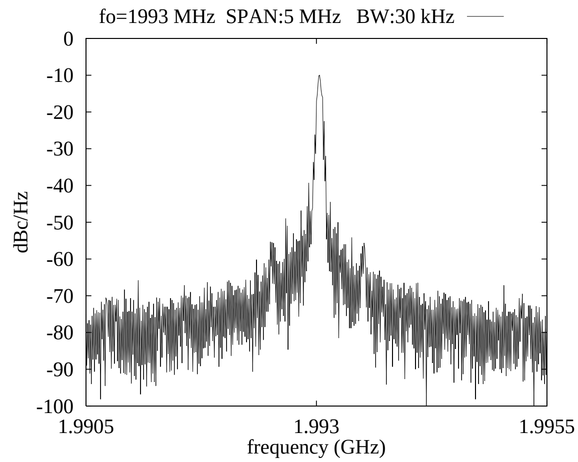

Figure 6: Spectrum of a normal 2 GHz oscillator

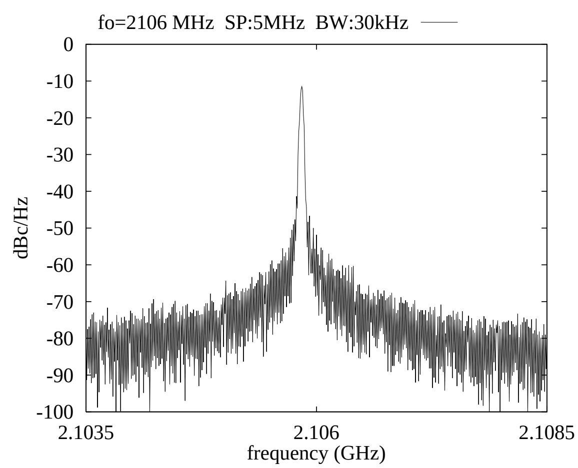

Figure 7: Spectrum of a suspended 2 GHz oscillator

For comparison the simulated phase noise curves for 2 GHz and 3 GHz are shown in Figure 9. This rough measurement of phase noise was carried out using HP8565E spectrum analyzer. The measured phase noise range of 2GHz and

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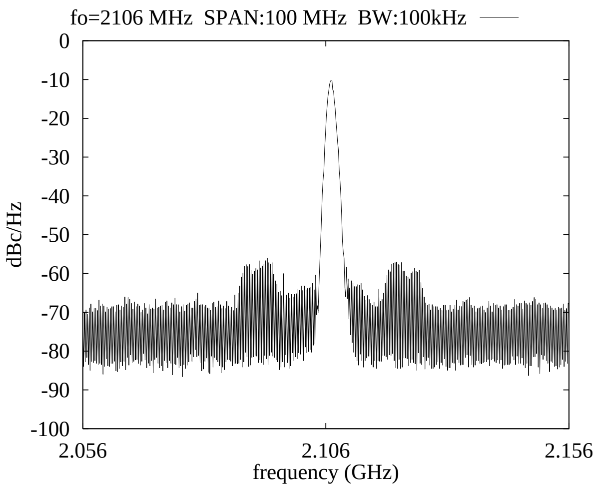

Figure 8: Oscillator Spectrum with an out of band shoulder

	f_o (GHz)	P_o (dBm)	current (mA)	phase noise at 1 MHz
designed	2.32	-8.4	–	-103 dBc
suspended	2.11	-11.5	6.9	-105 dBc
normal	1.99	-10.0	13.8	-100 dBc
designed	3.20	-9.0	–	-97 dBc
suspended	3.14	-13.0	8.7	-100 dBc
normal	2.98	-12.0	15.3	-95 dBc

Table 1: Results comparison

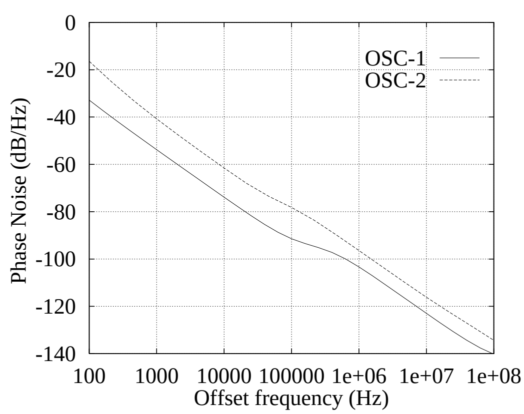

Figure 9: Simulated phase noise for two oscillators

3 GHz oscillators is -100.0∼-105.0 dB/Hz at 1 MHz offset from carrier, which is very close to the simulated phase noise figure.

4 Conclusions

Silicon MMIC balanced oscillators using suspended active resonators realized in a conventional bipolar process were realized. Better phase noise, cleaner spectrum and lower power consumption were obtain compared with those directly fabricated on ordinary silicon. Good agreement between simulation and measurement were obtained. The suspended active resonators working as an oscillator has a simpler topology and occupies a smaller integration area.

5 Acknowledgement

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