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# EVALUATION OF OSCILLATOR PHASE NOISE SUBJECT TO RELIABILITY

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*Abstract* - **This paper systematically investigates the hot carrier (HC) and soft-breakdown (SBD) induced performance degradations in CMOS voltage-controlled oscillators. After the MOSFET device RF parameter degradations due to HC and SBD effects are experimentally evaluated, the HC and SBD induced performance degradations of a differential 5-stage ring oscillator and a cross-coupled LC oscillator are evaluated for the first time for 0.16 µm technology, focusing on phase noise. Two design techniques are proposed to improve the oscillator performance. The SpectraRF and BERT simulation results verified the effectiveness of the proposed design techniques.**

***Keywords -*** **circuit reliability, hot carrier, MOSFETs, oxide breakdown, voltage controlled oscillators**

## I. INTRODUCTION

In recent years, the wireless communications have been experiencing an exploding development. The service quality and the functionality are much better than before. Currently, people are working on system-on-a-chip that will make the transceiver even smaller and cheaper. However, with the continuous increase of the working frequency and the continuous decrease of the transistor sizes, the CMOS technology has to face many challenges. One of them is the reliability. Hot carrier (HC) and oxide breakdown are two important issues in reliability. They could degrade the device and circuit performance greatly [1][2], and cannot be ignored.

Voltage controlled oscillator (VCO) is a very important block in phase locked loop (PLL) based frequency synthesizer. The VCO phase noise dominates other noise sources in PLL. It mainly determines the selectivity of the receiver. In this paper, two kinds of VCOs are studied in terms of performance degradation due to HC and SBD effects, including ring oscillator and cross-coupled LC oscillator.

In section 2, the experimental facts of hot carrier and soft breakdown (SBD) effects on MOSFETs are shown. In section 3 and section 4, the phase noise performance degradations of the ring oscillator and cross-coupled LC oscillator due to HC and SBD effects are studied. And in section 5, some techniques for improving the VCO phase noise performance are be proposed and verified.

## II. MOSFETS PERFORMANCE DEGRADATIONS

With the continuous decrease of MOSFET sizes, the electric fields in both channel and silicon have been increasing that cause the hot carrier (HC) effects. With the gate oxide thickness is becoming thinner, the soft breakdown (SBD) effect takes place often. Both HC and SBD effects cause the MOSFET parameters shift, and in turn degrade the circuit performance.

To evaluate the MOSFET device parameter degradations due to HC and SBD effects, the accelerated stress test was performed. The 0.16 µm CMOS technology wafers were stressed, and the aged device parameters were extracted from the experiment. For fresh device, the channel width is 50 µm, the oxide thickness is 2.4 nm, and the threshold voltage is about 0.4 V. The wafer is probed with the Cascade 12000 probe station and Agilent 4156B precision semiconductor Parameter Analyzer for DC measurements, while the RF experiments up to 50 GHz are carried out using Agilent 8510C network Analyzer. The device parameter degradations are shown in Fig. 1, including degradations of threshold voltage, mobility, transconductance, cut-off frequency and drain current.

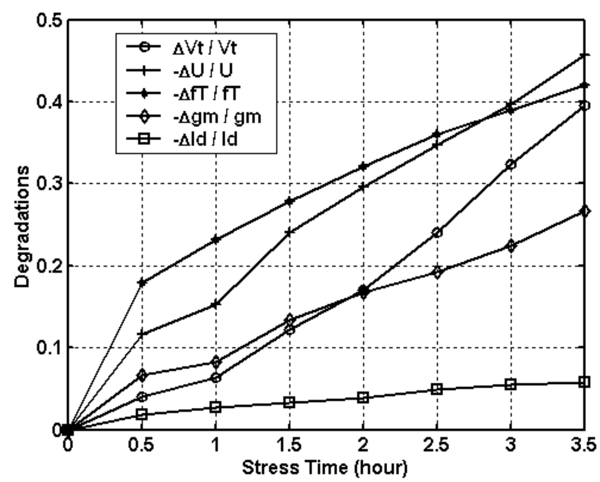

Fig. 1 Measured MOSFET parameter degradations

From Fig.1, after 3.5-hour stress, the threshold voltage increases about 40%, and the mobility, transconductance, drain current and the cut-off frequency decrease about 45%, 27%, 7% and 45%, respectively.

The S-parameter degradations are shown in Fig.2 to Fig.4. S11 degradation is shown in Fig.2. Shown in Fig.2 is the S21 degradation. And HC and SBD effects on S22 are shown in Fig.4. In RF circuits, the S11, S21 and S22 represent the input matching, gain and output matching properties, respectively.

With the DC and RF parameters are degraded so significantly, it is anticipated that the RF circuit performance would be degraded accordingly.

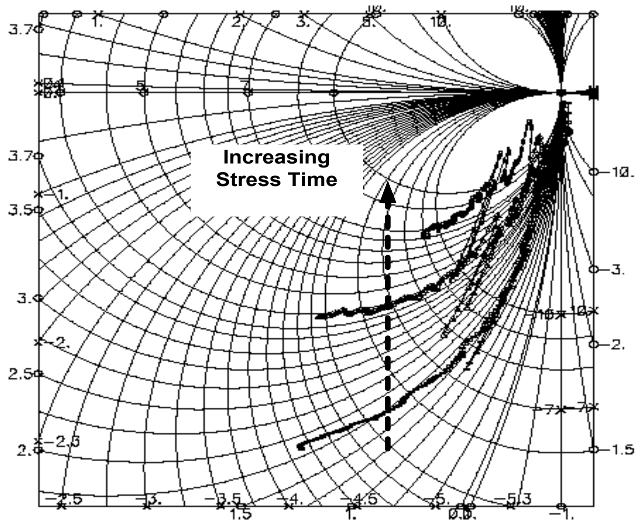


Fig. 2 Measured S11 degradation

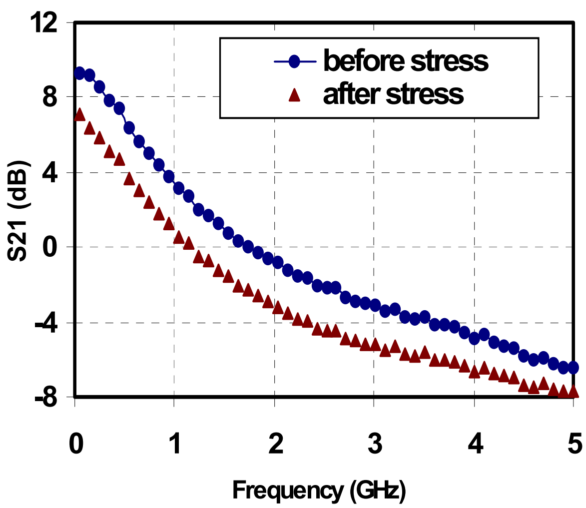


Fig.3 Measured S21 degradation

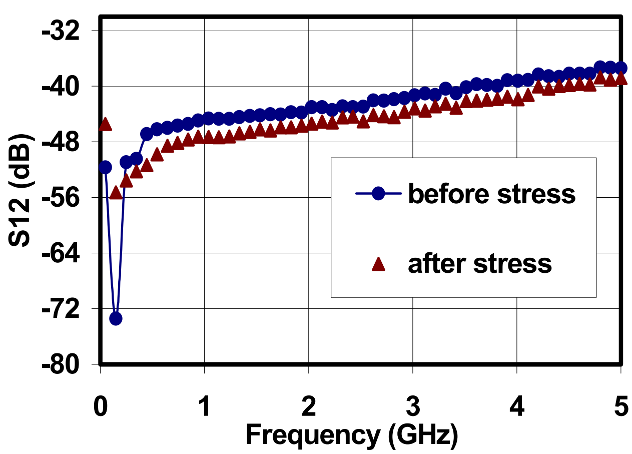


Fig.4 Measured S12 degradation

III. RING VCO PHASE NOISE DEGRADATION

In order to evaluate the degradation of VCO phase noise due to HC and SBD effects, a 5-stage ring VCO composed of 5 fully differential delay stages is examined. As shown in Fig. 5, each delay cell consists of NMOS differential pairs with PMOS resistive loads. The gate voltage $V_g$ is controlled carefully by a replica biasing circuit so that the PMOS transistors are working in the linear region and the voltage swing is kept constant.

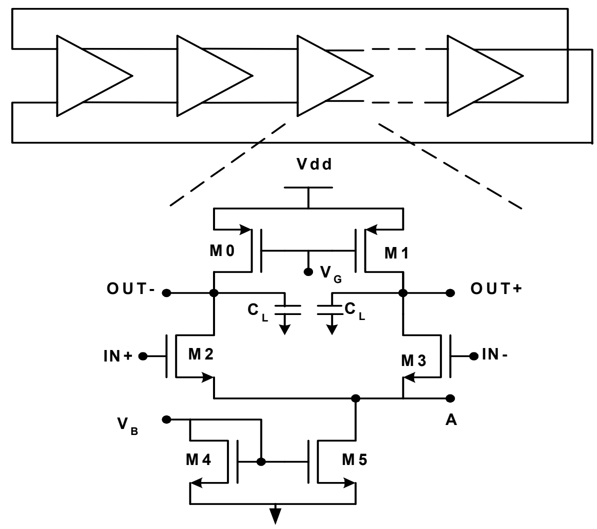


Fig. 5 Schematic of the ring VCO

The control circuit is shown in Fig. 6. The control signal, in a PLL, is from the output of the loop filter.

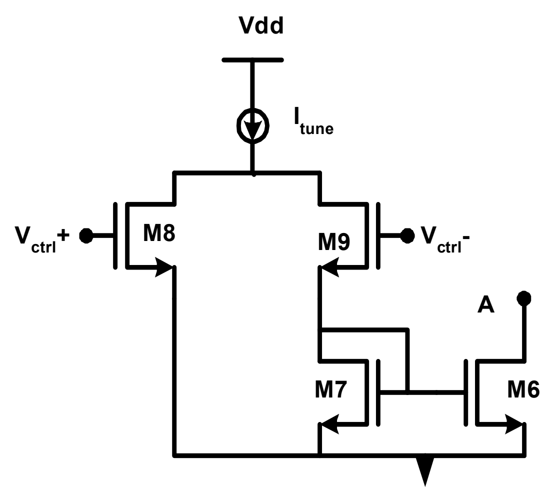


Fig. 6 A control circuit

In this work, the 0.16 µm CMOS technology wafers were stressed, and the aged device parameters were extracted, which in turn were used to evaluate the VCO circuit performance degradation incorporating with BERT and SpectraRF simulators.

The VCO phase noise degradation due to HC and SBD effects is shown in Fig. 7.

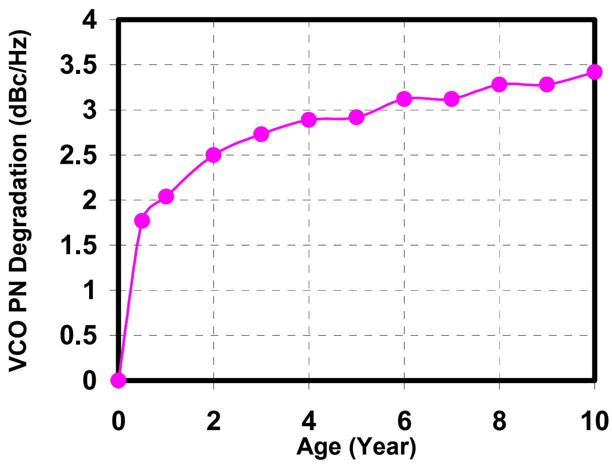


Fig. 7 VCO phase noise degradation

It is shown in Fig.7 that the VCO phase noise is degraded dramatically in the first two years, and then the degradation slows down. For a 10-year period, the total VCO phase noise degradation is about 3.5 dB. The degradation is so significant that the receiver selectivity would be degraded accordingly.

## IV. LC VCO Phase Noise Degradation

The ring VCO phase noise degradation due to HC and SBD effects were studied in section 3. Usually ring VCO is not used widely in wireless communications because its phase noise is relatively high, and it is very difficult for it to meet the more stringent phase noise requirement for most wireless communication systems. The most widely used VCOs are some LC oscillators. Shown in Fig. 8 is a typical cross-coupled LC oscillator.

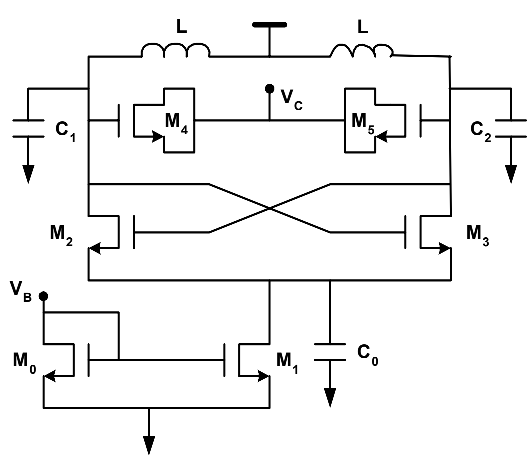


Fig. 8 Schematic of cross-coupled LC oscillator

In Fig.8, transistor M0 and M1 form the current source and provide the bias current for the oscillator. M2 and M3 are differential pair, and cross-coupled each other. M4 and M5 are varactors used to provide the tuning range in terms of control voltage Vc. The two inductors and capacitance C1 and C2 form the resonator. The phase noise in LC feedback oscillators is usually captured by Leeson's proportionality [3]

$$L(\omega_m) \propto \frac{1}{V_0^2} \cdot \frac{kT}{C} \cdot \frac{\omega_0}{Q} \cdot \frac{1}{\omega_0^2} \tag{1}$$

In this equation, phase noise is given as Kt/C noise that is shaped in frequency by the LC tank and normalized to the power in the oscillation amplitude. Phase noise is scaled by a circuit specific noise factor F, the constant of proportionality that comprises noise contributions from various circuit elements. Being circuit specific, the noise factor needs to be identified for each oscillator topology in terms of device sizes, current, and other circuit parameters.

It has been shown in section 2 that the MOSFET parameters will drift after stress due to HC and SBD effects. In the LC oscillator, if the device parameters are changed, both the phase noise and the amplitude will change too [4].

Using the proposed methodology, the HC and SBD effects on LC oscillator is evaluated. The simulation results are shown in Fig. 9.

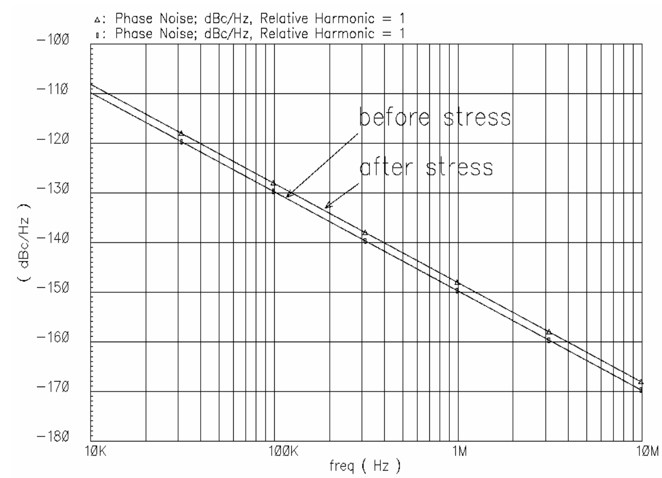


Fig. 9 Phase noise degradation for LC oscillator

From Fig. 9, after stress, the phase noise of the cross-coupled LC oscillator increases by about 2 dB.

## V. Techniques To Reduce VCO Phase Noise

From section 3 and 4, it is obvious that the HC and SBD can degrade VCO phase noise significantly. To reduce HC and SBD effects, some techniques are proposed in this section.

The first technique to reduce HC and SBD effects is the cascode structure. The cause of HC effect is the high voltage drop between the drain and the source of the transistor in the

VCO circuit. Another transistor can be cascaded with the transistor in the circuit to share the original $V_{ds}$. In this way, the $V_{ds}$ for each transistor is much lowered, and the HC effect is also reduced. The cascode structure is applied to the ring VCO, and shown in Fig.10. And the phase noise degradation for the cascode VCO is shown in Fig.11. It is seen that the improvement is obvious.

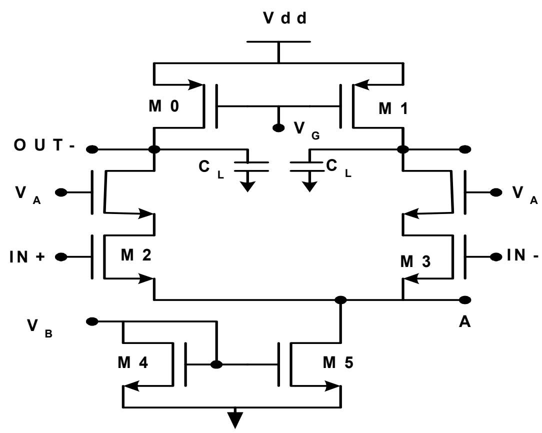


Fig.10 Schematic of cascode VCO

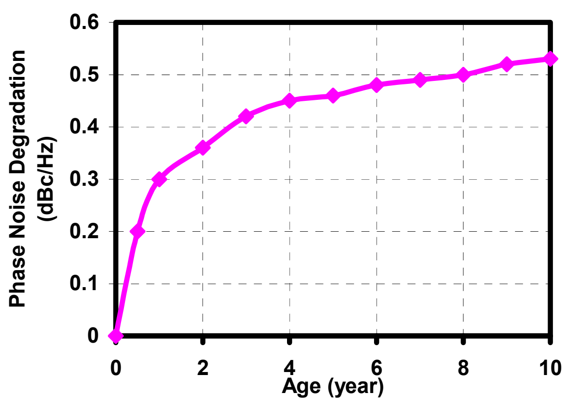


Fig. 11 Phase noise degradation for cascode VCO

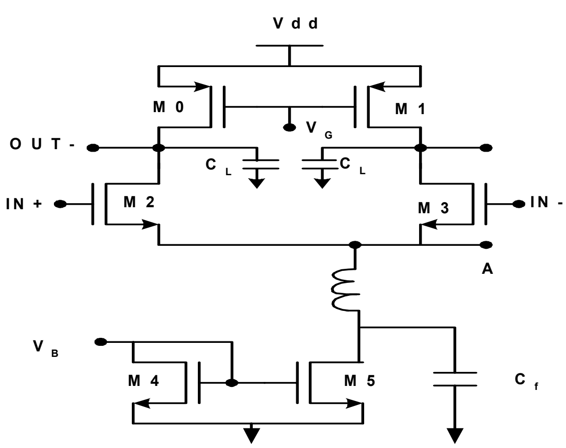


Fig.11 Schematic of the VCO with noise filter

Another technique to reduce the VCO phase noise is to use a filter to reduce the noise contribution of the current source [5]. The schematic of the VCO using the filtering technique is shown in Fig.12. And the phase noise degradation is shown in Fig.13.

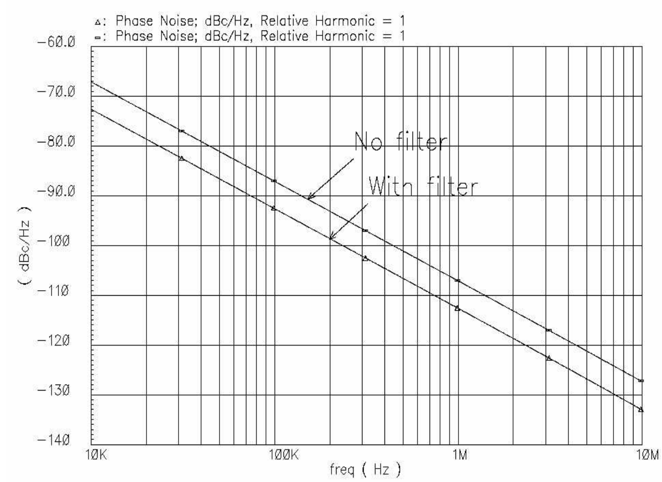


Fig.12 Phase noise degradation for VCO with noise filter

From Fig.12, the improvement from using noise filter is also significant.

## SUMMARY

HC and SBD effects on MOSFET devices were evaluated experimentally. VCO phase noise performance degradations due to HC and SBD effects have been evaluated on ring VCO and LC oscillators. Two design techniques to improve the VCO phase noise performance have been proposed and verified.

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