Radiation Hardened by Design of LC-VCO in 28 nm FDSOI process with Auxiliary Varactor pair

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1. Introduction

Wireless communication systems deployed in radiation-prone environments such as space missions, nuclear power plants, and high-energy physics instrumentation require highly reliable and radiation-tolerant integrated circuits [1]. Among the critical building blocks of RF transceivers, the Voltage-Controlled Oscillator (VCO) plays a fundamental role in frequency synthesis, carrier generation, and phase-locked loop (PLL) operation. Therefore, maintaining stable oscillation frequency and low phase noise under radiation exposure is essential for system reliability.

In harsh radiation environments, semiconductor devices are subject to Total Ionizing Dose (TID) effects caused by high-energy photons or particles interacting with the oxide layers of MOS devices. The generated electron–hole pairs (ehps) lead to charge trapping in the oxide [2] and at the oxide–semiconductor interface. In LC-VCOs, this phenomenon results in the degradation of transconductance and bias current. Consequently, radiation exposure induces oscillation frequency drift, phase-noise degradation, and potential instability in conventional oscillator topologies.

To address these challenges, Radiation-Hardened-by-Design (RHBD) techniques offer a circuit-level solution that enhances robustness without requiring specialized fabrication processes. In this work, an RHBD LC-VCO architecture implemented in a Samsung 28 nm FDSOI process is proposed. The design incorporates an auxiliary varactor pair symmetrically connected to the conventional LC tank to compensate for radiation-induced capacitance variations. By stabilizing the overall effective capacitance under TID exposure, the proposed topology minimizes frequency drift across wide dose ranges.

The effectiveness of the proposed design is validated through temperature testing, demonstrating significantly improved frequency stability compared to a conventional LC-VCO structure. This approach provides a scalable and practical solution for radiation-tolerant RF systems intended for space and nuclear instrumentation applications.

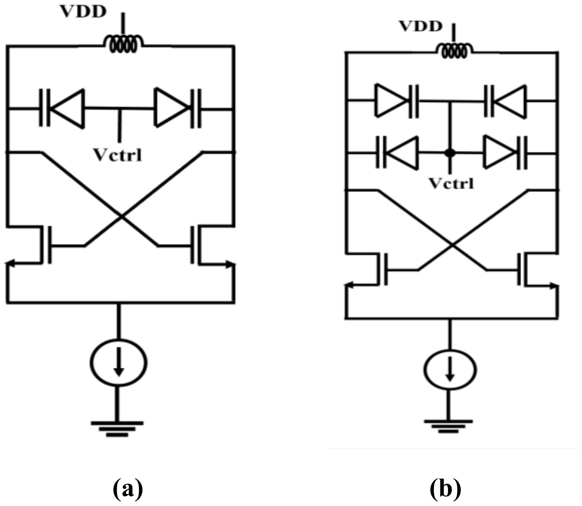


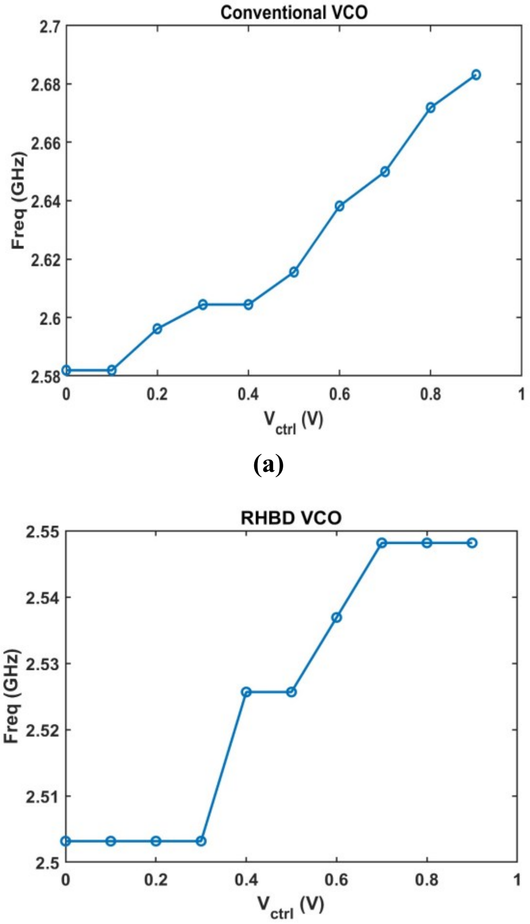
Fig. 1 . **(a)** Conventional LC-VCO **(b)** Proposed RHBD LC-VCO with auxiliary varactor pair

2. Proposed RHBD LC-VCO

Figure 1(a) shows the conventional cross-coupled LC-VCO topology, while Fig. 1(b) presents the proposed Radiation-Hardened-by-Design (RHBD) LC-VCO incorporating an auxiliary varactor pair. The conventional LC-VCO consists of a differential LC tank formed by an inductor and voltage-controlled varactors, a cross-coupled NMOS pair that provides the necessary negative resistance to compensate for tank losses, and a tail current source that sets the bias current [3]. The oscillation frequency is determined by the resonance condition of the LC tank and can be expressed as ,

$$f_0 = \frac{1}{2\pi\sqrt{LC_{tank}}}$$

Where C_{tank} includes the varactor capacitance and parasitic components. In this structure, any variation in varactor capacitance directly translates into a change in oscillation frequency. Environmental perturbations such as temperature-dependent transistor parameters and



(a)

(b)

Fig. 2 . Measured oscillation frequency of the **(a)** Conventional VCO versus control voltage **(b)** Proposed RHBD LC-VCO with auxiliary varactor pair

passive component variations therefore result in frequency drift. Fig. 2 shows the measured oscillation frequency versus control voltage of the conventional and proposed RHBD VCO.

Under Total Ionizing Dose (TID) exposure, degradation in transistor parameters leads to a reduction in transconductance and a shift in device bias conditions. Therefore, the common-mode output voltage of the differential VCO core decreases. Since the varactor capacitance is voltage-dependent [4], any change in the common-mode voltage modifies the effective bias across the varactors, resulting in a variation of the tank capacitance [5]. Because the oscillation frequency is determined by the resonance condition , a change in the effective capacitance directly translates into a frequency shift.
To enhance robustness against such variations, the proposed RHBD architecture introduces an auxiliary varactor pair symmetrically connected to the LC tank, as shown in Fig.1(b). The auxiliary varactors are placed in parallel with the primary tuning varactors while preserving the differential symmetry of the oscillator core.

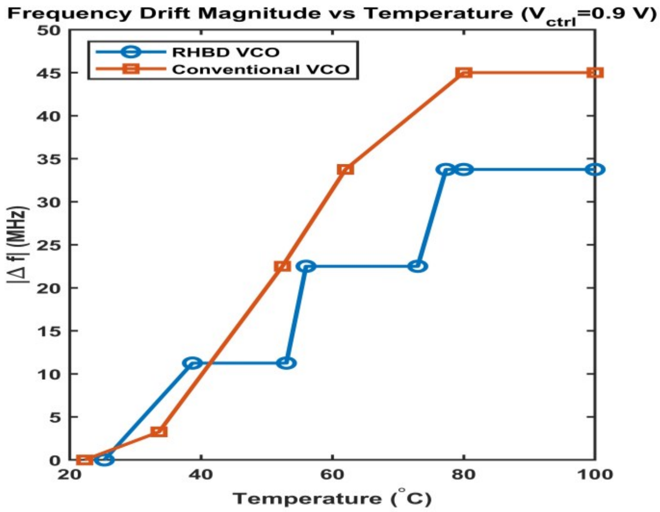


Fig. 3. Comparison of the measured frequency drift magnitude versus temperature of conventional and proposed LC-VCO

In the proposed RHBD architecture, the auxiliary varactor pair is symmetrically introduced to stabilize the effective tank capacitance against such common-mode voltage variations. By increasing the total controlled capacitance and distributing the voltage dependence across multiple varactor elements, the relative capacitance variation caused by common-mode shifts is reduced. Consequently, the oscillation frequency exhibits improved stability under TID-induced bias perturbations.

3. High Temperature Test Results

Fig. 3 shows the magnitude of frequency drift as a function of temperature at for both the RHBD and conventional VCOs, where the drift is referenced to the lowest-temperature operating point. As temperature increases, both designs exhibit increasing frequency deviation due to temperature-dependent transistor and passive component variations. However, the RHBD VCO consistently demonstrates a smaller frequency drift across the entire temperature range, reaching approximately 34 MHz at high temperature compared to about 45 MHz for the conventional VCO. This corresponds to a reduction of roughly 25–30% in temperature-induced frequency variation, clearly indicating that the RHBD architecture provides improved robustness against thermal effects.

3. Conclusions

This work presented a Radiation-Hardened-by-Design (RHBD) LC-VCO architecture incorporating an auxiliary varactor pair to enhance frequency stability against environmental variations. By increasing and symmetrically distributing effective tank capacitance, the proposed design reduces the sensitivity of the oscillation frequency to bias-dependent capacitance changes. Chip measurement results demonstrate improved robustness compared to the conventional topology, including reduced frequency sensitivity to control voltage and approximately 25–30% lower temperature-induced frequency drift. Since temperature variation induces changes in transistor bias conditions and varactor capacitance similar to those caused by TID effects, the observed improvement in temperature stability indirectly validates the effectiveness of the proposed RHBD technique against TID-induced performance degradation. These results confirm that the auxiliary varactor configuration effectively stabilizes the LC tank without significantly increasing circuit complexity.

As future work, irradiation testing will be performed to experimentally evaluate the Total Ionizing Dose (TID) tolerance of the proposed RHBD VCO. The detailed radiation characterization results will be presented at the conference.

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