Microelectronics Journal 43 (2012) 1016–1022

Contents lists available at SciVerse ScienceDirect

Microelectronics Journal

journal homepage: www.elsevier.com/locate/mejo

A low power low phase noise dual-band multiphase VCO

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ARTICLE INFO

Article history:
Received 15 October 2011
Received in revised form
18 July 2012
Accepted 27 July 2012
Available online 19 August 2012

Keywords:
Dualband
VCO
Quadrature
Low power
Low phase noise

ABSTRACT

This paper presents a low-power low-phase noise multiphase VCO that operates in 2.5 GHz and 5.0 GHz frequency bands. The dual-band multiphase VCO uses the frequency doubling method to generate the higher band signals from the lower band signals, and it shows excellent phase noise performance compared to other dual-band multiphase VCOs presented in literature. The VCO has been implemented in 0.18 μm CMOS technology, and its frequency is tunable from 2.23 GHz to 2.68 GHz and from 4.46 GHz to 5.36 GHz. The measured phase difference between the *I*/*Q* signals is 90.0°/88.9° for the two frequency bands respectively. The phase noise figure-of-merits (FOMs) for the two frequency bands are −189.4 dB and −185.1 dB.

1. Introduction

Due to the increasing demand for low power multi-band transceivers, the design of low power multi-band quadrature VCOs becomes more important but yet remains challenging. The most commonly adopted method was to use switched inductor or capacitor [1,2], but the parasitic of the switched elements inevitably degraded the quality factor of the LC tank. Shin et al. [3] showed a dual-band quadrature VCO realized by using frequency dividers, mixers and notch filters, but the increased circuitry complexity made this design unattractive.

In general, the operation in the higher frequency band imposes more challenges on the tuning range and phase noise performance than in the lower band due to the decreased loaded quality factor of the LC tank at high frequency. Therefore, by keeping the oscillator operating at a relatively low frequency can help to improve the phase noise performance. Jia et al. [4] introduced a method for realizing dual-band VCO by using frequency doublers, but the design was limited to signal-ended mode operation for the higher band. Hsieh et al. [5] discussed a 15/30 GHz dual-band multiphase VCO using frequency doubler. However, due to the signal loss along the coplanar strip line in the rotary traveling-wave oscillator, the circuit required a large power to start-up and sustain the VCO oscillation, which degraded the phase noise FOM.

This paper presents a dual-band multiphase VCO that can cover the most popular industrial, scientific and medical (ISM) frequency bands, such as Blue Tooth (2.40–2.48 GHz), IEEE 802.11$_{b,g}$ (2.40–2.48 GHz for Europe and USA), IEEE 802.11$_{a}$ (5.15–5.25 GHz/5.25–5.35 GHz) and HiperLAN (5.15–5.30 GHz). Because the targeted upper band frequency is about twice the lower band frequency, the upper band signal can be generated by multiplying the lower band frequency by two. The series cross-coupled VCOs are implemented for the 2.4 GHz band operation. Since the signals are coupled actively, and because of the series-coupling topology, the low-power operation can be achieved. The frequency doublers are adopted to convert the lower band signal to the upper band signal. Power-down scheme is also implemented, such that the frequency doubler switches off when the system is working in the lower band. In this proposed design, the same LC tank is used for both bands operations, thus eliminating the disadvantages brought by selecting of smaller LC tank for upper band operation. Furthermore, compared to the conventional dual-band multiphase VCO designs in [1,2], the proposed design can provide eight-phase signals rather than four-phase signals in the lower band. This makes the circuit suitable for more applications, such as to be used in the clock and data recovery (CDR) circuits with quarter-rate sampling [6] or 1/8-rate sampling [7] topology.

2. Architecture

The architecture of the dual-band multiphase VCO is illustrated in Fig. 1. It consists of an eight-phase VCO and four frequency doublers. Transmission gates are used for band selection. The eight-phase VCO oscillates in the 2.5 GHz band and the frequency doublers convert the signals from the 2.5 GHz band to the higher 5.0 GHz frequency band. In such a way, the frequency

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http://dx.doi.org/10.1016/j.mejo.2012.07.019

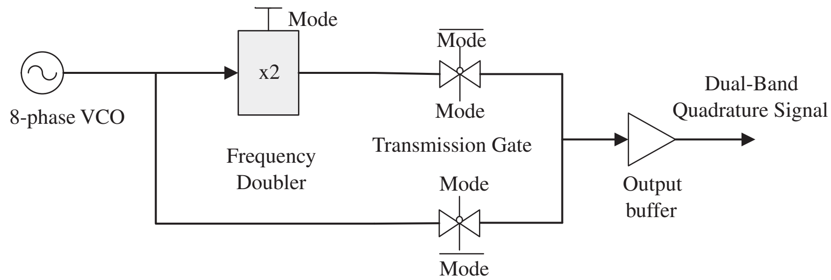

Fig. 1. Architecture of proposed dual-band VCO.

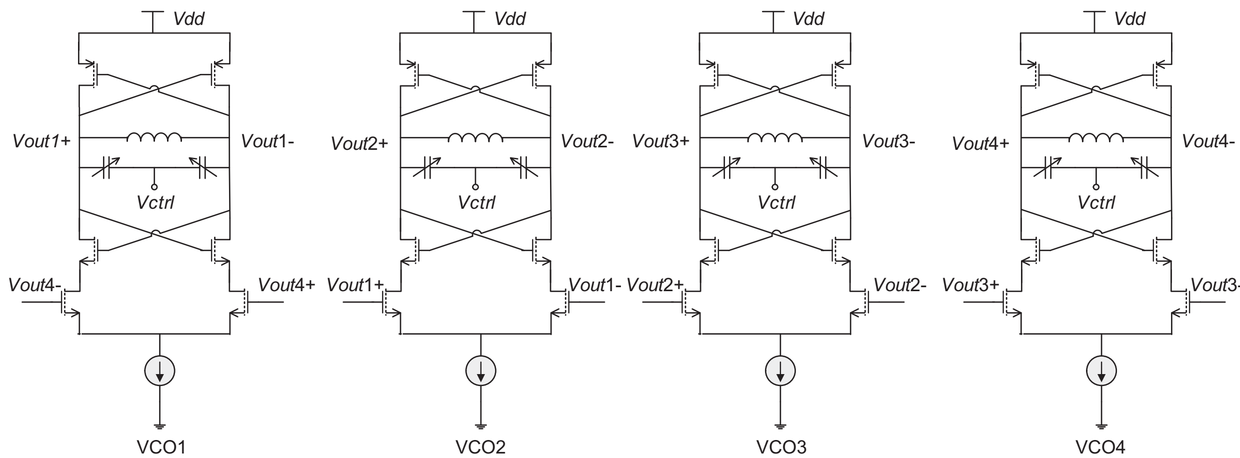

Fig. 2. Series-coupled eight-phase VCO.

tuning range and the phase noise performance in the upper band can be maintained comparable as that in the lower band, and the design constraints imposed on the upper band operation are greatly relaxed. Open-drain NMOS transistors are used as the output buffer for measurement.

3. Lower band operation

Fig. 2 shows the structure of the eight-phase VCO. It is composed of four differential VCOs connected in a cross-coupled closed loop. The total phase shift across the closed loop is 180°, so the output signals from any two adjacent VCOs have 45° phase difference. If we take the phase of v_{out1+} as the 0° reference, we can obtain the phases of v_{out2+}, v_{out3+} and v_{out4+} as 45°, 90°, and 135° respectively, and the phases of v_{out1-}, v_{out2-}, v_{out3-} and v_{out4-} as 180°, 215°, 270°, and 315° respectively.

The series-coupling topology is adopted in this design for its advantage of low power consumption and good phase noise performance [8]. The phase error is independent of the coupling strength; therefore the phase noise performance can be optimized by reducing the coupling strength without sacrificing the phase accuracy. Furthermore, in most VCOs, the phase noise in the $1/f^3$ region is dominated by the $1/f$ noise of the tail current. In the series-coupled VCO topology, the effect is significantly reduced due to the degeneration provided by the cascaded structure that reduces the noise current that can reach the tank. Besides the flicker noise of the tail transistor, other main phase noise contributors include the thermal noise from the LC-tank parasitic resistor, the transistor channel thermal noise and transistor gate noise. Because of the up-conversion effect, the flicker noise will contribute to the phase noise in the $1/f^3$ region, while the thermal noise and gate noise are up-converted to $1/f^2$ noise.

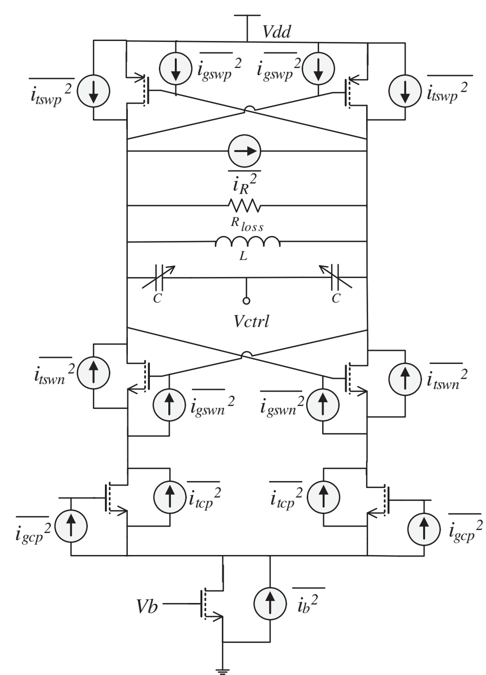

Fig. 3. Equivalent noise circuit of the series VCO.

An equivalent noise model for the designed VCO is depicted in Fig. 3, where $\overline{i_b^2}$ is the flicker noise of the tail transistor, which is proportional to $K/C_{ox}WLf$, where K is the flicker noise coefficient, W and L are the channel width and length respectively, and C_{ox} is the gate-oxide capacitance; $\overline{i_{gcp}^2}$, $\overline{i_{gswn}^2}$ and $\overline{i_{gswp}^2}$ are the gate noises of the coupling transistor, and the N/PMOS switching pairs respectively, which are proportional to $8kT\delta C_{gs}\varepsilon l$, where k is the