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LETTER

An ultra-wideband injection-locked frequency divider with a multi-order resonator and the passive injection-boosted technique

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Abstract This paper presents an ultra-wideband injection-locked frequency divider (ILFD) design which is applicable to a multi-applications system. A transformer-based multi-order resonator is utilized in the ILFD to attain a flat phase response. The passive injection-boosted technique is proposed to increase the injection signal amplitude and thus widen the locking range. With the injection-boosted technique and the multi-order resonator, the proposed ILFD demonstrates a measured locking range of 50 GHz, covering 48 GHz to 98 GHz. The divider designed in a 40-nm process consumes a DC power of 11.2 mW excluding buffers and occupies a core size of 0.38×0.63 mm^2.

Keywords: injection-locked frequency divider, ultra-wideband, passive injection-boosted technique, multi-order resonator, locking range

Classification: Microwave and millimeter wave devices, circuits, and hardware

1. Introduction

The applications in the millimeter-wave regime commonly require that the RF front-end works in a wide band [1, 2, 3, 4, 5, 6, 7, 8]. For example, the IEEE 802.11ad standard covers from 57 GHz to 63 GHz, and the bandwidth requirement of the automotive radars in the 77-GHz band is 4 GHz. The frequency synthesizer is one of the most critical blocks in a wireless system since it, meanwhile, serves the Rx and Tx chain. A phase-locked loop (PLL) based frequency synthesizer diagram is presented in Fig. 1(a). Usually, the voltage-controlled oscillator (VCO) and the millimeter-wave frequency divider need to work in high frequencies and a wide band. Recently, some wideband VCOs [9, 10, 11] and multi-mode VCOs [12, 13, 14, 15, 16, 17] have been demonstrated with ultra-wide tuning bands. For example, [9] exhibits a wideband VCO with a 39.5% relative tuning range. The VCO in [10] realizes a tuning range of 42 GHz. The multi-mode VCO in [12] demonstrates a 32.6-GHz bandwidth. The above results imply the possibility of a multi-band system with a single frequency synthesizer. The frequency synthesizer in Fig. 1(b) using the dual-mode VCO is possible to cover more than one application in a standalone system. Accordingly, the first stage divider, i.e., the mm-wave divider, is expected to realize an ultra-wideband locking range (LR) to cover the two tuning bands of the dual-mode VCO.

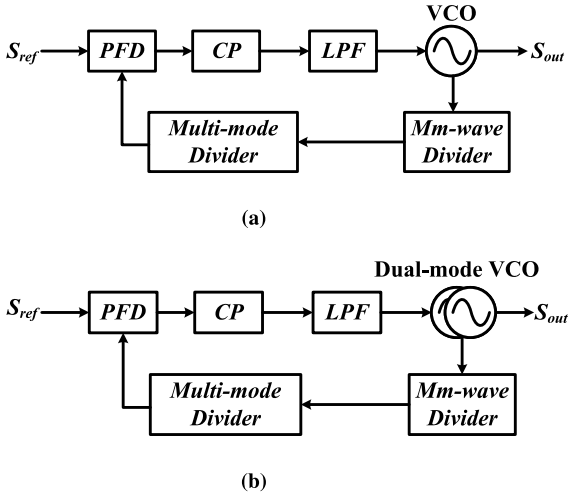

Fig. 1 The PLL architectures with the (a) single-mode VCO, (b) dual-mode VCO.

It is well known that the injection-locked frequency dividers (ILFDs) with the highest operation frequencies are the more suitable choice for the mm-wave divider compared with static dividers and miller dividers. Nevertheless, the traditional injection-locked divider has a narrow operation bandwidth. Much research [18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28] has been conducted to enhance the LR of the injection-locked frequency dividers and multipliers. [18] reduces the Q value of the tank to attain a flat phase response. [19] proposes the frequency-tracking technique achieving 39% fractional bandwidth. [20] using the current-synthesis technique realizes a LR from 26.1 GHz to 38.2 GHz. In [23], the design employing the transformer-based high-order resonator exhibits a LR from 32.4 to 61.9 GHz. [26, 27, 28] prove the effectiveness of the transformer coupling resonator.

However, there are less discussion and methods about the injection boosting technique, and the presented LRs are not enough to cover multiple applications. In this paper, a passive injection-boosted technique is proposed, which widens the LR by 14 GHz. Besides, the proposed divider uses a transformer-based 4th-order resonator to get a flatter phase response. With the above techniques, our circuit has a measured LR from 48 GHz to 98 GHz, which makes it possible to cover multiple applications using one frequency synthesizer. We note that the earlier work is presented in a

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$$\text{FoM (GHz/mW)} = \frac{\text{Locking Range (GHz)}}{\text{DC Power (mW)}} \quad (21)$$

4. Conclusions

This paper proposes an ultra-wideband ILFD using the passive injection-boosted technique and the high-order resonator. First, the pole frequencies of the transformer-based 4th-order resonator are analyzed in detail. Then, the passive injection-boosted technique is demonstrated to offer a significant injection amplitude gain, which enhances the LR by about 14 GHz. The measurement results demonstrate a LR of 50 GHz, from 48 GHz to 98 GHz. This work makes it possible that one frequency synthesizer covers multiple applications with the proposed divider design.

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