PAPER *Special Section on Analog Circuits and Their Application Technologies*

A 20-GHz Differential Push-Push VCO for 60-GHz Frequency Synthesizer toward 256 QAM Wireless Transmission in 65-nm CMOS

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SUMMARY This paper present a 20-GHz differential push-push voltage controlled oscillator (VCO) for 60-GHz frequency synthesizer. The 20-GHz VCO consists of a 10-GHz in-phase injection-coupled QVCO (IPIC-QVCO) with tail-filter and a differential output push-push doubler for 20-GHz output. The VCO fabricated in 65-nm CMOS technology, it achieves tuning range of 3 GHz from 17.5 GHz to 20.4 GHz with a phase noise of −113.8 dBc/Hz at 1 MHz offset. The core oscillator consumes up to 71 mW power and a FoM of −180.2 dBc/Hz is achieved.

key words: *CMOS, push-push VCO, injection locking oscillator, low phase noise, 256 QAM transceiver*

1. Introduction

The demand for high speed wireless communication shows explosive growth due to the increasing using of wireless device for HD video and multimedia transmission. Higher bandwidth and more complex modulation schemes are introduced to satisfy such high speed demand. One promising solution is to utilize 57–66 GHz available band. Recently, increasing higher data rate wireless communication using a 60-GHz CMOS direct conversion transceiver for IEEE 802.15.3c, IEEE 802.11ad/ay have been reported [1]–[4]. In the above transceivers, a 60-GHz local oscillator with quadrature output is necessary, moreover a phase noise of at least −96 dBc/Hz at 1MHz offset is required for local oscillator in order to utilizing 64 QAM modulation scheme [3]. To further satisfy higher speed demand and improve data rate, the wireless system should satisfy the phase noise and SNR requirement for more complex modulation scheme such as 256-QAM to realize 56.32 Gbps at 60 GHz.

In IEEE 802.11ad standard, the requirement of transmitter error vector magnitude (TX EVM) is below −26 dB to support 64 QAM. EVM requirement is proportional to QAM modulation order M when M is high. TX EVM is estimated to be below −32 dB to support 256 QAM. TX EVM can be shown as the equation below [5]:

$$\text{TX EVM} = \sqrt{\frac{1}{SNR^2} + \varphi^2_{\text{RMS,eff}}} \qquad (1)$$

where SNR is TX signal-to-noise ratio, and $\varphi^2_{\text{RMS,eff}}$ is integrated phase noise of local oscillator. TX SNR usually depends on the backoff of output power, and the phase noise sometimes has a dominant influence on TX EVM. For demodulation, a decision-directed PLL can be used for symbol-timing recovery to cancel low-offset phase noise, and finally relax phase noise requirement. With an optimum tracking bandwidth f_{TRACK} of carrier recovery loop, the effective integrated phase noise can be shown as below [5], [6]:

$$\varphi^2_{\text{RMS,eff}} = 2\int_0^{B/2} \mathcal{L}(f)\left(1-\frac{1}{1+\left(\frac{f}{f_{\text{TRACK}}}\right)^4}\right) df \qquad (2)$$

$\mathcal{L}(f)$ is the phase noise of the carrier. For IEEE 802.11ad, the optimum tracking bandwidth f_{TRACK} is 458.6 kHz. Keeping 3 dB margin, the effective integrated phase noise is −35 dB and resulting a phase noise requirement of 256 QAM for IEEE 80.211ad/WiGig to be less than −102dBc/Hz at 1 MHz offset.

As shown in Fig. 1 conventionally, the quadrature 60-GHz LO generation can be summarized as following methods. In Fig. 1 (a), Ref. [7] proposed a QPLL with in-phase injection-coupled QVCO (IPIC-QVCO) directly oscillat-

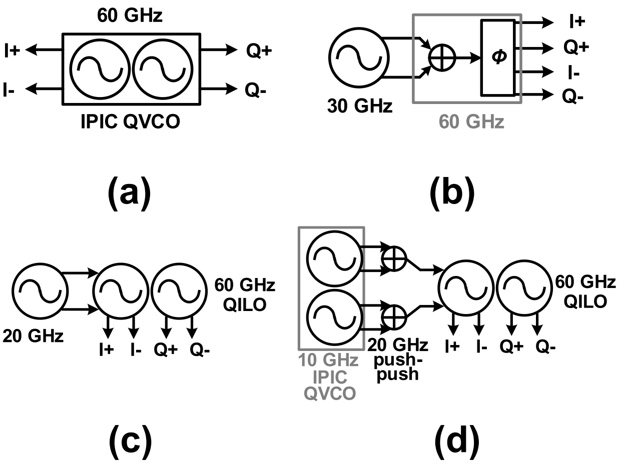

Fig. 1 Conventional 60 GHz quadrature LO generation approaches. (a) 60 GHz IPIC-QVCO (b) 30 GHz VCO + push-push + polyphase filter (c) 20 GHz VCO + 60 GHz QILO (d) 60-GHz QILO using proposed 10-GHz IPIC-QVCO based 20-GHz push-push VCO

Manuscript received October 17, 2016.
Manuscript revised January 26, 2017.

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DOI: 10.1587/transele.E100.C.568

ing at its fundamental frequency of 60 GHz, unfortunately, degradation of LC tank quality factor at millimeter-wave frequency degrades out-of-band phase noise, makes it hard to reach phase noise requirement of 256 QAM. He reports the best phase noise performance to be −91.5 dBc/Hz at 1MHz offset, which supports up to 16-QAM modulation scheme. As shown in Fig. 1 (b), an alternative solution [8] is by employing 30 GHz differential VCO in push-push to generate 60 GHz signal and followed by a polyphase filter to generate quadrature output. However, due to polyphase filter, the resulting large I/Q mismatch makes it inapplicable for complex modulation scheme such as 16-QAM. Figure 1 (c) shows sub-harmonic injection based quadrature injection locked oscillator (QILO). QILO is preferred and frequently used [1]–[5], [9] because of its better phase noise performance, thus 64 QAM can be supported. The reported state-of-art 60-GHz QILO achieves −96dBc/Hz at 1MHz offset, and its corresponding transceiver using 64-QAM modulation scheme achieves highest speed of 42Gb/s as well. However, as information shows explosive growth, there is still demand and improvement of phase noise to reach requirement of 256 QAM. In order to target 256 QAM and realize a phase noise of −102dBc/Hz at 1 MHz offset, Fig. 1 (d) 60-GHz QILO using proposed 10-GHz IPIC-QVCO based 20-GHz push-push VCO can be employed. Due to optimum tank quality factor at 10-GHz, this architecture can improve phase noise performance compared with Fig. 1 (c) 60-GHz QILO using 20-GHz VCO.

In this paper, a 17.5-to-20.5 GHz, −113.8 dBc/H@ 1MHz 20-GHz push-push VCO with 10-GHz IPIC-QVCO with tail filter is proposed and implemented. As shown in Fig. 2, by using proposed 20-GHz VCO in a 20-GHz PLL as sub-harmonic injection to 60-GHz QILO [13], the estimated phase noise at 60 GHz is −104 dBc/Hz at 1MHz offset.

This paper organizes as followed. In Sect. 2, analyses include proposed frequency synthesizer for best phase noise achievement at 60 GHz, 10-GHz IPIC-QVCO with tail filters, 20-GHz differential push-push VCO are introduced. Section 3 explains VCO measurement results. Finally conclusion is drawn for this work.

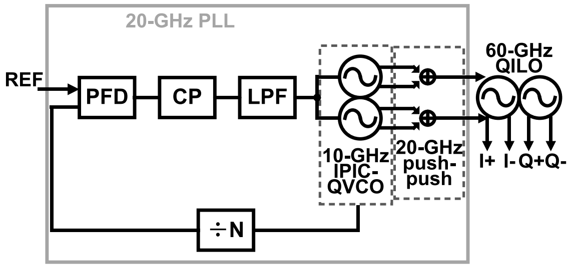

Fig. 2 60-GHz QILO using proposed 20-GHz push-push VCO in a 20-GHz PLL.

2. Analysis and Design of VCO

2.1 Design Consideration for Low-Phase-Noise 60-GHz Frequency Synthesizer

Figure 2 shows 60-GHz frequency synthesizer architecture using proposed 20-GHz VCO. There are 2 benefits by employing this architecture. First, the PLL divider N chain can be designed low-frequency and low-power. Second the phase noise will be improved because sub-harmonic 10-GHz QVCO provides phase noise improvement than 20-GHz VCO. Conventionally, 60-GHz quadrature LO in [1]–[5], [9] use a cross-coupled 20-GHz VCO, and the phase noise achieved at 20-GHz is −106 dBc/Hz@1MHz, resulting a phase noise at 60 GHz is −96 dBc/Hz@1MHz. According to Ref. [10], the switched capacitor can be optimized by keeping the same frequency turning range and the same capacitor to transistor size ratio. The inductor quality factor can be adjusted peaking at higher frequency by employing smaller inductor. As shown in Fig. 3, the oscillator overall tank quality factor has an optimum value with different inductor sizes and fixed switched capacitor. The frequency range from 3 GHz to 15 GHz is found to have the best overall tank quality factor. Thus the conventional sub-harmonic injection locked oscillator at 60 GHz can be improved by running fundamental oscillation frequency at range of 3–15 GHz. Considering 60 GHz sub-harmonic frequencies, such as 30 GHz, 20 GHz, 15 GHz, 12 GHz and 10 GHz. For 30 GHz and 20 GHz VCO, the intrinsic tank Q-factor is too low to obtain high phase noise. For 15 GHz, 12 GHz and 10 GHz, VCO needs very high output power to inject into 60 GHz oscillator, the injection locking range will be narrow. In order to obtain both high tank Q-factor and wide locking range, a push-push 20-GHz VCO using 10-GHz QVCO with optimum tank quality factor is proposed. With optimum tank quality factor, a better phase noise performance can be realized using VCO running at 10 GHz instead of at 20 GHz.

Previous work in [13] proposed a tunable second harmonic resonator based 20-GHz VCO shown in Fig. 4. Even

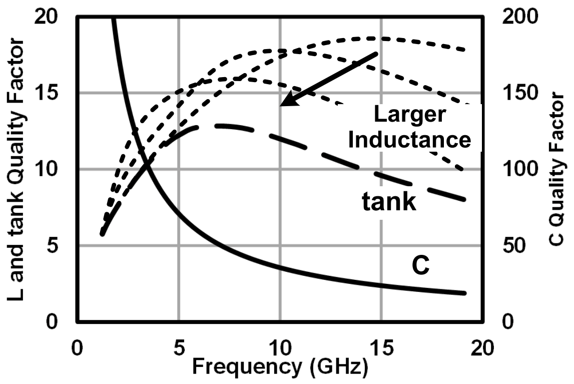

Fig. 3 Quality factor of inductor, capacitor and overall tank for 65-nm CMOS technology presented in [10].