A Multi-PLL Approach to Low-Spur, Low-Jitter Frequency Synthesis for Millimeter-Wave Bands

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EXTENDED ABSTRACT

We present a novel local oscillator architecture for mmWave frequencies consisting of a pair of low-frequency PLLs driving a larger number of integer-N PLLs to be used in phased arrays or MIMO transceivers. It employs two fractional-N PLLs in the lower GHz range, each driven by its own crystal oscillator, with their RF outputs connected to a 2:1 multiplexer (MUX). The MUX output is connected to the input of a mmWave PLL array. By using a small loop bandwidth for the fractional-N and a large loop bandwidth for the integer-N mmWave PLLs, a low level of phase noise and spurious tones (spurs) is predicted. In this topology, the phase noise of the mmWave PLLs is reduced by noise averaging, whereas phase noise and spurs from the fractional-N PLLs are reduced by signal processing after downconversion of the signal to the baseband. The very low level of fractional spurs is achieved by an intelligent control of the MUX, resulting in spur positions much larger than the loop bandwidth.

In most wireless communication and radar systems, the LO frequency must be programmable in small steps. When using phase-locked loops (PLL) for frequency synthesis, a fractional-N PLL is, therefore, mandatory. The large frequency multiplication factor in a simple mmWave PLL results inevitably in an excessive PLL phase jitter at the PLL output. Combining at least two PLLs in a cascade may significantly reduce the jitter at the output of the high-frequency PLL [1].

Fig. 1 shows a block diagram of an exemplary local oscillator for the D-band. In consists of a pair of low-frequency fractional-N PLLs followed by a 2:1 MUX driving an array of integer-N mmWave PLLs. By selecting the proper fractional-N PLL using a 2:1 multiplexer, fractional spurs are shifted to significantly above the loop bandwidth.

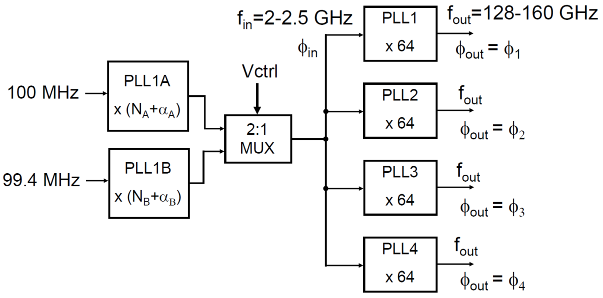

Fig. 1. Block diagram of an examplary LO design.

In millimeter-wave (mmWave) wideband transmission employing orthogonal frequency division multiplexing (OFDM), carrier phase noise is the primary limiting factor, as orthogonality is sensitive to phase noise. In OFDM systems, a few subcarriers are used as pilot tones to measure the phase noise for each symbol. This error is then subtracted in order to correct the remaining subcarriers. Known as common phase error (CPE) correction, this improves the SNR by reducing the LO phase noise. Intuitively, it is evident that this correction is more efficient for slow noise components than for fast noise. Therefore, the CPE correction can be modelled in the frequency domain by multiplying the phase noise spectrum of the downconverted signal by a high-pass filter [1]. Fig. 2 shows the resulting modelled phase noise spectrum for three different numbers of mmWave PLLs using a subcarrier spacing of 480 kHz. At large offsets, the phase noise of the mmWave VCO dominates the spectrum. With every doubling of n_{PLL} the phase noise is reduced by 3 dB. This results from phase noise averaging of the uncorrelated mmWave VCOs. At small offsets, the phase noise spectrum is much reduced by the baseband filtering associated with CPE correction.

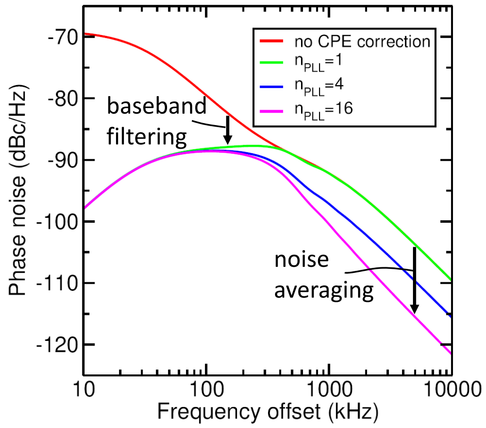

Fig. 2. Modelled phase noise spectrum of an OFDM system for 1, 4 and 16 mmWave PLLs after CPE correction with Δf_{car}=480 kHz. The upper curve is for $n_{\mathrm{PLL}} = 1$ without CPE correction.

REFERENCES

[1] F. Herzel, C. Carta and G. Fischer, "Phase jitter analysis of cascaded PLLs for millimeter wave applications," *2025 International Radar Conference (RADAR)*, Krakow, Poland, Oct. 2025, pp. 658-663, doi: 10.1109/RadarConf2559087.2025.11205138.