

# Preface

Voltage-controlled oscillators (VCOs) and frequency dividers are two of the key building blocks in phase-locked loops (PLLs) and frequency synthesizers, not only to generate clean LO signals for frequency conversion in wireless transceivers but also to generate accurate high-frequency clock signals for wireline systems. As the system applications continue to demand higher and higher performance in terms of higher frequency, wider bandwidth, lower phase noise, and lower power consumption, the design of these building blocks becomes more and more challenging, in particular in aggressively scaled low-voltage CMOS processes for low cost and high system-on-chip integration.

Many years ago, we published a book entitled “Low-Voltage CMOS RF Frequency Synthesizers” to discuss and summarize various inductor-based design techniques for low-voltage high-performance frequency synthesizers. The main focus was on low-voltage and low-power designs for narrow-band applications, in which integrated inductors play a critical role. However, due to their high-Q and narrow-band characteristics, these design techniques have limited applications in recently emerging multi-band multi-mode and software-defined radios. Fortunately, transformer-based design techniques have recently been developed and emerged as potential replacement of integrated inductors for more features and even better performance. However, to the best of our knowledge, there has still been no book aiming to introduce transformer-based low-voltage and wideband CMOS VCOs and frequency dividers.

As continuation and complementary to our previous book and intended for engineers, managers, researchers, and students who are working on or interested in CMOS radio frequency or mm-Wave integrated circuits and systems, this book presents in-depth description and discussion of transformer-based design techniques that enable CMOS oscillators and frequency dividers to achieve ultra-wide frequency tuning range and ultra-wide frequency locking range while maintaining state-of-the-art performance in terms of high operation frequency, low supply voltage, good phase noise, and low power consumption. In addition to the design, simulation, and characterization of integrated transformers for different

applications, this book will also discuss their unique characteristics and features that enable performance improvement, such as passive coupling or multiple impedance peaks, which have not been covered in any of the existing books. Finally, to illustrate the usefulness of these transformer-based design techniques, design consideration and optimization of various CMOS oscillators and frequency dividers for different applications together with their measured performance are elaborated, focusing on not only ultra-low supply voltage but also ultra-wide frequency tuning range and locking range at very high frequencies.

More specifically, detailed description and discussion of the following selected designs will be included in the book.

1. A transformer-feedback VCO (TF-VCO) features high swing and low phase noise even at a supply voltage below the device threshold voltage. Fabricated in a 0.18- $\mu\text{m}$  CMOS process, a 1.4-GHz PMOS TF-VCO achieves an FoM of 190 at 0.35-V supply voltage, and a 3.8-GHz NMOS TF-VCO achieves an FoM of 193 at 0.5-V supply voltage.
2. A quadrature VCO using transformer coupling (TC-QVCO) eliminates both noise and power consumption by active coupling devices in existing QVCOs while exhibiting all advantages in the TF-VCO. Fabricated in a 0.18- $\mu\text{m}$  CMOS process, a 17-GHz TC-QVCO achieves an FoM of 187.6 and a phase error of  $1.4^\circ$  at 1-V supply voltage.
3. A transformer-based dual-mode VCO achieves a wide frequency tuning range exploiting the two impedance peaks of a transformer tank. Fabricated in a 0.13- $\mu\text{m}$  CMOS process, the 2.7-to-4.3 GHz and 8.4-to-12.4 GHz dual-mode QVCO achieves average  $\text{FoM}_T$  of 195 and 203 in the two bands, respectively.
4. A magnetically tuned multi-mode VCO (MT-VCO) measures ultra-wide frequency tuning range around 70 GHz by changing the coupling coefficient of the transformer. Fabricated in a 65-nm CMOS process, the 57.1-to-90.1 GHz MT-VCO achieves an average  $\text{FoM}_T$  of 188.2 at 1-V supply.
5. Transformer-feedback injection-locked frequency dividers (TF-ILFDs) feature quadrature outputs with enhanced output swing even with low supply and low power. Fabricated in a 0.18- $\mu\text{m}$  CMOS process, a 18.1-GHz TF-ILFD with differential outputs achieves 21.6 % locking range when consumes 2.75–4.35 mW at 0.5-V supply, and a 17.5-GHz TF-ILFD with quadrature outputs achieves 27.8 % locking range when consuming 11.4–13.6 mW at a 0.6-V supply.
6. A self-frequency-tracking injection-locked frequency divider (SFT-ILFD) utilizing transformer to generate the injection current with frequency-dependent phase shift to extend the locking range. Fabricated in a 65-nm CMOS process, a 62.9-GHz SFT-ILFD achieves 29 % locking range while consuming 1.9 mW at a 0.8-V supply voltage.

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