Chapter 6
Optimization-Based Design of RF-VCOs with Tapered Inductors

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ABSTRACT
Voltage-Controlled Oscillators (VCOs) are widely used in wireless transceivers. Due to the stringent specifications regarding phase-noise, LC-VCOs are usually adopted. The need for maximizing phase-noise as well as minimizing the power consumption makes imperative the adoption of optimization-based design methodologies. For the optimization of the LC-VCO characteristics, special attention must be paid to the integrated inductor design, since its quality factor may have a strong influence in the LC-VCO phase-noise. Furthermore, designers must ensure that the higher limit of VCO operating frequency is sufficiently below the inductor resonant frequency. In this chapter, a study on the influence of the quality factor of the inductors on the LC-VCO overall behavior is presented. Then, optimization of integrated inductors by exploring the inductor geometric layout is presented. Finally, results obtained for the design of an LC-VCO in 130nm Technology using a previously optimized inductor are presented.

INTRODUCTION
The rapid development of CMOS technology during the last decades has made possible the implementation of ever more complex wireless communication systems. This evolution is mainly based on three vectors, i.e., the availability of devices with shrinking dimensions, with capacity for working at higher frequencies and operating with lower supply voltages. Although recent technologies are offering devices with extremely reduced dimensions, they present new non-ideal effects...
that must be taken into account when designing the analog/RF part of the wireless communication systems. Among these system’s several components, Voltage controlled oscillators (VCOs) are widely used. Due to the stringent specifications regarding phase-noise, LC-VCOs are usually adopted. The need for maximizing phase-noise as well as minimizing the power consumption makes imperative the adoption of optimization-based design methodologies. For the optimization of LC-VCOs, however, designers must consider the particular specificity of the several elements comprising the oscillator, such as the integrated inductor, the varactors and Mosfet transistors. As will be shown in this chapter, special attention must be paid to the integrated inductor design. Integrated inductors for RF applications usually show poor quality factor leading to severe degradation of the LC-VCO phase noise. Furthermore, designers must guarantee that the operating frequency of the VCO is sufficiently below the inductor resonant frequency as a way of guaranteeing the expected behavior of the VCO for all the envisaged tuning range. Currently, integrated inductor design functionalities on available EDA tools are confined to a set of predefined solutions offered by each specific technology. The set of available design solutions, however, is quite limited, forcing designers to exploring new design solutions using very lengthy electromagnetic simulations, making impractical the possibility for optimizing the inductor design. To overcome this limitation significant effort has been employed in investigating inductor models as well as new geometrical topologies, such as tapered inductors, as a way of improving their performance. Previous attempts at modeling integrated inductors have concentrated on the simple \( \pi \) model. Recently, in (Passos, Fino, & Moreno, 2013), new equations for the evaluation of the \( \pi \) model lumped element values were proposed, guaranteeing accurate results for tapered or fixed width inductors, for frequencies up to 10GHz. Since none of these models, has yet been integrated into current EDA tools, designers usually perform the design of the LC-VCO in two separate phases. First the inductors are designed by integrating the adopted model in an optimization kernel. Then, the design of overall LC-VCO is performed, taking into account the characterization of the inductor previously designed. In this work the EKV 2.6 MOSFET model is considered for the characterization of the LC-VCO active elements. The use of a fully model-based-optimization methodologies offers the designer the possibility for designing the overall circuit in an efficient way and using only Matlab.

This chapter is organized as follows: Section 2 deals with LC-VCO characteristics and stresses the influence of the inductor quality factor on the LC-VCO phase-noise. In section 3 a detailed description of the inductor model is presented and results obtaining using this model in the optimization-based design of three inductors are shown. In Section 4 the LC-VCO design methodology is described in detail and several working examples are presented. Finally, future research directions as well as conclusions are driven.

**LC-VCO CHARACTERIZATION**

At high frequency applications, LC-VCO topologies are usually preferred to other configurations, such as relaxation or ring oscillators (Herzel, Erzgraber, & Weger, 2001). These VCO topologies are based on the concept of providing a negative resistance in order to compensate the resonator losses. This technique allows to achieve high oscillation amplitude, thus increasing the phase noise performance. Among several different LC oscillator topologies, the CMOS cross-coupled LC-VCO, such as the double switch oscillator, depicted in Figure 1, is widely used due to its better noise performance as well as improved rise and fall time symmetry (Hajimiri & Lee, 1999). In this topology the negative resistance is controlled by the tail current source, represented by transistor Mb in Figure 1. The introduction of