

# Part I

## Theoretical Background on Oscillators and Time References

In this Part I, the theoretical concepts are discussed, needed to build and to better understand the principles behind time references. Some of the introduced concepts are rather basic, others are more advanced. Depending on the experience and background of the reader, some parts of this elaborate theoretical introduction can be skipped. However, in Part II of this thesis, where different oscillator implementations are discussed, this theory will extensively be used. Evidently, where applicable, the used formulas and principles are referenced.

In Chap. 2 the basic principles are discussed to obtain a time reference. Starting from the state space description of an autonomous system, the minimum requirements or components of an oscillator are derived. Afterwards, different categories of oscillators and their properties are discussed. Commonly used parameters to characterize an oscillator, such as the Q factor, are introduced.

The next chapter, Chap. 3, focuses on oscillator noise. Different noise sources are identified. Afterwards, an overview is given of the different noise theories developed over the years. Starting from the basic noise model of Leeson, the Linear Time-Variant noise theory of Hajimiri is explained after which also several non-linear theories are briefly introduced. Finally, the relation between the phase noise spectrum and the jitter of the oscillator output is discussed.

The last chapter in this part, Chap. 4, focuses on the most important properties of an oscillator for Wireless Sensor Networks: the long-term frequency stability. In practice, this corresponds to the process, temperature, and supply voltage (PVT) dependency of the output frequency. The quality of the available components in standard CMOS is discussed and their linearity and temperature behavior is analyzed. Finally, an overview is given of different integrated oscillator topologies. The trade-offs between the different design parameters are discussed, starting from the state of the art found in the literature.