The Leeson Effect

PM and AM noise, and frequency stability in oscillators

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Simply stated, an oscillator consists of a loop in which a resonator sets the oscillation frequency and an amplifier compensates for the resonator loss. The oscillation amplitude is set by clipping or other gain-saturation mechanism, usually in the amplifier. When phase noise is introduced in the loop, the oscillator converts it to frequency noise through a process of time-domain integration. The consequence is that the oscillator phase fluctuation diverges in the long run. This phenomenon was originally referred as the "Leeson model" after a short article published by D. B. Leeson [1]. On my side, I prefer the term "Leeson effect" in order to emphasize that it is far more general than a simple model [2].

The first part of this tutorial explains the phase-to-frequency conversion mechanism as a general phenomenon inherent in the feedback, following an heuristic approach based on physical insight. There follow the relationships between the noise of the internal components (sustaining amplifier, resonator, etc.) and the phase noise at the oscillator output, or equivalently the frequency stability.

The second part is the analysis of the phase noise spectra found in the data-sheet of commercial oscillators: dielectric-resonator oscillator (DRO), whispering gallery oscillator (WGO), 5–100 MHz quartz crystal oscillators, opto-electronic oscillator (OEO). The analysis gives information on the most relevant design parameters, like the quality factor Q and the driving power of the resonator, and the flicker noise of the sustaining amplifier.

The last part shows the derivation of the oscillator phase noise formulae from the elementary properties of the resonator. Interestingly, the amplitude non-linearity, necessary for the oscillation amplitude to be stable, splits the resonator relaxation time into two time constants. The approach shown in this last part is general. It applies to all oscillators, including quartz, RLC, microwave cavity, delay-line, laser, etc.

This tutorial updates on the earlier editions, and also on the book [2] by including the AM noise and the impact of AM noise on phase noise [3].

References

[1] D. B. Leeson, A simple model for feed back oscillator noise spectrum, Proc. IEEE 54(2) pp. 329–330, Feb. 1966.

[2] E. Rubiola, *Phase noise and frequency stability in oscillators*, Cambridge 2008 & 2010.

[3] E. Rubiola, R. Brendel, A generalization of the Leeson effect, April 2010 (48 pages). arXiv:1004.5539 [physics.ins-det].