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# Extending Leeson's Equation

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**Abstract:** Oscillator phase noise is one of the key limitations in several fields of electronics. Electronic oscillator phase noise is usually described by the Leeson's equation. Since the latter is frequently misinterpreted and misused, a complete derivation of the Leeson's equation in modern form is given first. Second, effects of flicker noise and active-device bias are accounted for. Next the complete spectrum of an electronic oscillator is derived extending the result of the Leeson's equation into a Lorentzian spectral line. Finally the spectrum of more complex oscillators including delay lines is calculated, like opto-electronic oscillators.

**Keywords:** phase noise; Leeson's equation; oscillator bias; Lorentzian line; opto-electronic oscillator

# Razširitev Leesonove Enačbe

**Izvleček:** Slovene version of the abstract in case of Slovene authors or a copy of the English version of the abstract

**Ključne besede:** Slovene keywords in case of Slovene authors or a copy of English keywords

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## Introduction

The purpose of the introduction is to provide background and place the study in a broader context. It has to describe the purpose of the work and its importance. The current state of the art should be reviewed carefully including all the key references. Controversial or diverging hypotheses must not be ignored. A short description of the aim of the presented work and main highlights should be presented. The introduction may be concluded with the outline of the paper. Keep the introduction understandable to a wide range of readers who may not be intimately familiar with the topic of the paper.

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Materials and methods should be described with sufficient detail to allow others to replicate and build on published results. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited. Give the name and version of any software used and make clear whether computer code used is available. Chapter name may be adapted to the topic of the manuscript or split into more chapters if it benefits the readability of the manuscript.

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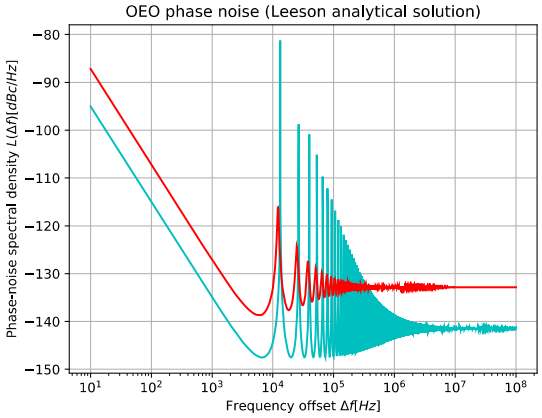


Figure 1: Black and White images must have a resolution of at least 600 dpi and a maximum width of 80 mm.

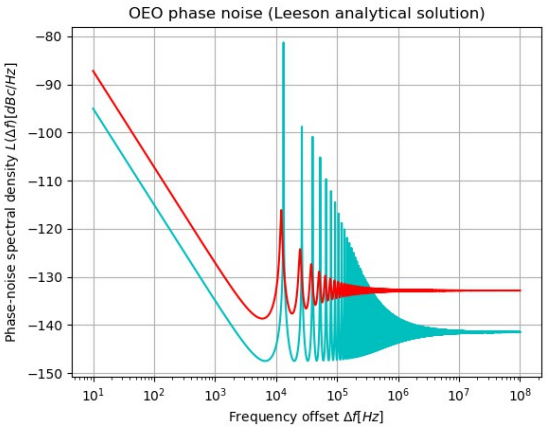


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Figure 3: Images combining Black and White part and a Grayscale or Color part must have a resolution of at least 600 dpi and a maximum width of 80 mm.

Figures and tables should be placed as close as possible to the text where they are first referenced.

Table 1: Parameters and their values.

| Parameter | Value |
|---|---|
| $R_1$ | 10 □ |
| C | 15.3 µF |

## *Equations*

Equations should have a reference number on the right side. The reference number should be enclosed in parentheses. To reference an equation from the text, quote its reference number enclosed in brackets, e.g. see equation Error: Reference source not found. Equations may be typed using the Microsoft equation editor (e.g. Eq. Error: Reference source not found) or the MathType equation editor (e.g. Eq. Error: Reference source not found).

$$L(\Delta f)=\frac{1}{2}\left[1+\left(\frac{f_0}{2Q_L\Delta f}\right)^2\right]\frac{k_B T F}{P_0} \qquad (1)$$

$$L(\Delta f)=\frac{1}{2}\left[1+\left(\frac{f_0}{2Q_L\Delta f}\right)^2\right]\frac{k_B T_0 F}{P_0}\left(1+\frac{f_c}{|\Delta f|}\right)$$

$$L(\Delta f)=\frac{1}{2}\left[1+\left(\frac{f_0}{2Q_L\Delta f}\right)^2\right]\frac{k_B T_0 F}{P_0}\left(1+\frac{f_c}{|\Delta f|}\right) \qquad (2)$$

$$\log L(\Delta f)_{\mathrm{dBc/Hz}}=10\log_{10}\frac{1}{2}\left[1+\left(\frac{f_0}{2Q_L\Delta f}\right)^2\right]\frac{k_B T_0 F}{P_0}\left(1+\frac{f_c}{|\Delta f|}\right)\cdot 1\mathrm{Hz}$$

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Define abbreviations the first time they are mentioned in the abstract, text; also the first time they are mentioned in a table or figure.

Keywords are not capitalized.

All websites need to be referenced as does unpublished data or personal communications.

Capitalize words such as Group, Section, Method, etc. if followed by a number, e.g. "In Group 4, five samples..."

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Write 1990s rather than with an apostrophe (1990’s) or just 90s.

The measurement mL: the L is always a capital.

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## Supplementary material

Supplementary material available on the publishers web page contains:

Measurement data shown in Figs 3, 5, and 6.

A video demonstration of the experiment.

Source code for the microprocessor on module A.

## Acknowledgments

Acknowledgments (if any) should appear as a separate section before the list of references.

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## References

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