





Scientific Instruments - and -Phase Noise and Frequency Stability in Spring 2025 Feb 7, 2025 Last update Feb 7, Ler Oscillators

Lectures for PhD Students and Young Scientists

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Part 1: General

Part 2: Phase noise and oscillators

Part 3: The International System of Units SI

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Origin and Purposes

The contents originates from

- •My tutorials at int'l conferences and my lectures as a guest scientist in in other labs
- Long term interests in the foundation of metrology
- •Lab experience which does not fit elsewhere

Formally, a series of lectures for PhD students

In practice, open to everybody

No need to be a university student

Mandatory e-mail registration at

doctorat [at] ubfc [dot] fr

(replace [dot] and [at] as appropriate, and remove spaces) They are instructed to accept everybody



Oscillators – and – Scientific Instruments – Program, Spring 2025

| | No | Contents | Learning material & documentation project: Enrico's lecture notes on <u>https://rubiola.org</u> and the following refs | | |
|--|----|--|---|--|--|
| Part 1: General Instruments (Phase noise and frequency stability & Scientific Instruments) | 1 | Introduction to the course. Thermal noise, shot noise, quantum noise, flicker (1/f) noise. | E. O. Göbel. U. Siegner, The New International System of Units (SI), Wiley-VCH 2019 W. Nawrocki, Introduction to quantum metrology 2nd ed, Springer 2019 | | |
| | 2 | Noise temperature, noise factor, noise figure, Friis formula. Rothe-Dahlke model. Noise in photodetectors, noise equivalent power (NEP). Guarding and shielding. | Various documents, to be listed later. A book project: E. Rubiola, <i>Phase Noise</i> (see "Downloads" page) <u>A. Yariv, <i>Optical Electronic in modern communications</i>, Oxford. Saleh-Teich <i>Photonics</i>, Wiley.</u> | | |
| | 3 | Fourier analysis and cross spectrum method. A panorama of applications in numerous disciplines. | E. Rubiola, F. Vernotte, The cross-spectrum experimental method, arXiv:1003.0113 (Does not cover applications) | | |
| | 4 | Analog meets digital. ADCs and DACs. | <u>C. E. Calosso, E. Rubiola, Phase Noise and Jitter in Digital Electronics, arXiv:1701.00094.</u> Kester W (ed), Analog-Digital Conversion, Analog Devices 2004, ISBN 0-916550-27-3. ©AD, but free of charge pdf | | |
| | 5 | Lock-in amplifiers. Time-to-digital and frequency-to-digital converters. | A book project about TDC, FDC and related statistics (for now, only the slideshow is available) J. Kalisz, Review of methods for time interval measurements with picosecond resolution, <i>Metrologia</i> 41(1) p.17-32, 2004 | | |
| Part 2: Oscillators (Phase noise and frequency stability) | 6 | Clock signal, phase noise, and Allan variances | E. Rubiola, F. Vernotte, The Companion of Enrico's Chart, IEEE T MTT 71(7), 2023. A book project: E. Rubiola, <i>Phase Noise</i> (see "Downloads" page) U. L. Rohde, E. Rubiola, J. C. Whitaker, <i>Microwave and wireless synthesizers, W</i> iley 2021 (Ch.2) | | |
| | 7 | Allan variance (cont.). Experimental methods for the measurement of oscillators. | E. Rubiola, F. Vernotte, The Companion of Enrico's Chart, IEEE T MTT 71(7), 2023. U. L. Rohde, E. Rubiola, J. C. Whitaker, <i>Microwave and wireless synthesizers, W</i> iley 2021 (Ch.2) | | |
| | 8 | Bridge (interferometric method). Phase noise in amplifiers and components. PM/AM noise in digital systems (ADC, DAC, FPGA, DDS) | A book project: E. Rubiola, <i>Phase Noise</i> (see "Downloads" page) A few articles by E. Rubiola. <u>C. E. Calosso, E. Rubiola, Phase Noise and Jitter in Digital Electronics, arXiv:1701.00094.</u> | | |
| | 9 | The Leeson effect. i.e., the origin of noise in oscillators and lasers | E. Rubiola, Phase noise and frequency stability in oscillators, Cambridge 2010 | | |
| | 10 | The Pound Drever Hall frequency control for the stabilization of RF/microwave oscillators and lasers. | Eric D. Black ED, An introduction to Pound–Drever–Hall, Am J Phys 69(1) January 2001 A book project: E. Rubiola, The Pound Drever Hall Frequency Control (for now, only the slideshow is available) | | |
| Part 3: The New Sl scientific Instruments) | 11 | Uncertainty. International coordination of metrology. The new SI, in force May 20, 2019. | International Vocabulary of Metrology VIM and several BIPM documents about the coordination of Metrology. Everything is free on the <u>BIPM</u> web site. | | |
| | 12 | The SI units of time and length. | BIPM, The International System of Units 9 th ed, 2019. F. Riehle, <i>Frequency Standards</i> , Wiley-VCH 2004 | | |
| | 13 | The SI units of length (cont.) and mass. Introduction to electrical units. | <u>BIPM, The International System of Units 9th ed, 2019.</u> <u>E. O. Göbel. U. Siegner, The New International System of Units (SI), Wiley-VCH 2019</u> | | |
| | 14 | Quantum electrical standards and practical electrical references. | <u>BIPM, The International System of Units 9th ed, 2019.</u> E. O. Göbel, U. Siegner, The New International System of Units (SI), Wiley-VCH 2019 | | |

Learning Material

home page http://rubiola.org





Publications

Books



U. L. Rohde, E. Rubiola, J. C. Whitaker Microwave and wireless synthesizers John Wiley & Sons, Nov. 2020 **ISBN** 978-1-119-66600-4 Hardcover

E. Rubiola

Phase noise metrology Book project

book project: **Phase Noise** Metrology

E. Rubiola



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Enrico Rubiola home page

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This web site has no commercial purpose and pays full respect to your privacy No cookies, no counters, no IP collection, etc.

Downloads

Open access material

- <u>The Enrico's chart of Phase Noise and</u> <u>Two-Sample Variances</u>
- The Companion of Enrico's Chart for Phase Noise and Two-Sample Variances

Only for my students For review purposes, do not circulate

- Chapter 2 of Microwave and Wireless Synthesizers, <u>draft updated version</u>
- <u>Incremental notes on Phase noise</u>, based on the above updated Chapter 2
- Random parts of a <u>book project on Phase</u> <u>noise</u>. Items of the above notes move progressively here



Phase Noise and Frequency Stability in Oscillators

THE CAMBRIDGE RF AND MICROWAVE ENGINEERING SERIES



Phase Noise and Frequency Stability in Oscillators Cambridge University Press, November 2008 ISBN 978-0-521-88677-2 hardback ISBN 978-0-521-15328-7 paperback ISBN 978-1-139-23940-0 eBook ISBN 978-7-03-041231-7 Simplified Chinese

Contents

- Forewords (L. Maleki, D. B. Leeson)
- Phase noise and frequency stability
- Phase noise in semiconductors & amplifiers
- Heuristic approach to the Leson effect
- Phase noise and feedback theory
- Noise in delay-line oscillators and lasers
- Oscillator hacking
- Appendix



Microwave and Wireless Synthesizers

Microwave and Wireless Synthesizers Theory and Design



Ulrich L. Rohde Enrico Rubiola Jerry C. Whitaker

U. L. Rohde, E. Rubiola, J. C. Whitaker Microwave and Wireless Synthesizers John Wiley & Sons, April 2021 ISBN 978-1-119-66600-4,

Contents

- 1. Loop Fundamentals
- 2. Almost All About Phase Noise
- 3. Special Loops
- 4. Loop Components
- 5. Digital PLL Synthesizers
- 6. A High-Performance Hybrid Synthesizer
- 7. Appendices



European Frequency and Time Seminar

Every year

Full week crash course, with lectures and labs

2025 is already sold out

| 2025 EFTS Program — Preliminary | | | | | | | | | |
|---------------------------------|--|---|---|---|---|---|--|--|--|
| Time | Mon, June 30 | Tue, July 1 | Wed, July 2 🌓 | Thu, July 3 | Fri, July 4 | Colors | | | |
| 8:15 | 7:30–8:30 Registration | Coffee | Coffee | Coffee | Coffee | Logistics & events | | | |
| 8:30 - 9:20 | 8:30 Introduction to TF Luca Lorini SYRTE & FIRST-TF | Relativity Frédéric Meynadier BIPM, Int'l | FS Combs, basics Tara Fortier, NIST, USA | Synchronization over Digital Networks Martin Langer | 8:30–11:30 Laboratory | Labs / computer Welcome & Closing | | | |
| 9:20 - 10:10 | Introduction to Oscillators E. Rubiola, FEMTO, FR | Intro Atomic Clocks G. Mileti, LTF, CH | Small Clocks C. Affolderbach, LTF, CH | FS Combs, research Tara Fortier, NIST, USA | 3. SDR, GPS & PRN (9:30-11:30) | Contents By color Chapter 1 General & Applications Enrico Rubiola | | | |
| 10:10 - 10:40 | Coffee & cookies | Coffee & cookies | Coffee & cookies | Coffee & cookies | | | | | |
| 10:40 - 11:30 | Phase Noise E. Rubiola, FEMTO, FR | Atomic Time Scales F. Meynadier BIPM, Int'l | Satellite Synch P. Defraigne, ROB, BE | Optical Clocks Rachel Godun, NPL, UK | 5. Atomic clock 6. Resonators | | | | |
| 11:30 - 12:20 | Variances F. Vernotte, FEMTO, FR | Atomic Clock Physics G. Mileti, LTF, CH | Optical fiber links Cecilia Clivati, INRIM, IT | Time in power grids Mario Paolone, EPFL, CH | 11:30 Quick coffee 11:45-12:30 Historical Perspective | Chapter 2 Meas & Oscillators Enrico Rubiola | | | |
| | Lunch | | Lunch | Lunch | 12:30—12:45 Closing | Chapter 3 Atomic Clocks Gaetano Mileti | | | |
| 12:20 - 13:50 | | Lunch | | | 12:45 14:15 Lunch | | | | |
| 13:50 - 14:40 | Digital Controls C.E.Calosso, INRiM | Stabilized Lasers J. Gillot, FEMTO, FR (or C. Lacroute) | Cold Atoms M. Delehaye, FEMTO, FR | Clock Synchronization Security Martin Langer | 12:45–14:15 Lunch 14:15–16:15 Visit, Observatory or FEMTO-ST | Chapter 4 Timing & Transfer Francois Vernotte Laboratories | | | |
| 14:40 - 15:30 | Nicolas Vorobyev Navigation & GNSS | Navigation & GNSS | Coffee 15:10–17:10 | Coffee | | | | | |
| 15.20 16.00 | CNES, FR | P. Detraigne, ROB, BE | | 15:00-18:00 | | | | | |
| 16:00 - 18:00 | Laboratory 1. PM/AM noise, 2. Data Analysis | Laboratory 1. PM/AM noise, 2. Data Analysis | Laboratory 1, 3 & 4 (Noise, SDR, RINEX) | 3. SDR, GPS & PRN 5. Atomic clock 6. Resonators | You are free | E.Rubiola All lectures in Jules | | | |
| 18:00 – 19 | Science, beer and chips | | Visit at the | | | Haag auditorium | | | |
| 19 – 20 | at the TF Department (ethanol-free drinks too) | (free time) | Museum of Time, and Drink | Go to the pier | | Last update December 20, 2024 | | | |
| 20 21.20 | | | Dinner on your own | Social Dinner | | | | | |
| 20-21:30 | Dinner on your own | Dinner on your own | Dinner on your own | Social Diffiel | | December 20, 2024 | | | |

