

Scientific Instruments

— and —

Phase Noise and Frequency Stability in 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

home page <http://rubiola.org>

Spring 2024

Oscillators – and – Scientific Instruments – Preliminary program, Spring 2024

	No	Contents	Learning material & documentation project: Enrico's lecture notes on https://rubiola.org and the following refs
Part 1: General Instruments (Phase noise and frequency stability & Scientific Instruments)	1	Introduction to the course. Quantum noise, thermal noise, shot noise.	E. O. Göbel. U. Siegner, <i>The New International System of Units (SI)</i> , Wiley-VCH 2019
	2	Flicker noise. Rothe-Dahlke model. Guarding & shielding. Noise temperature, noise factor and noise figure.	Various documents, to be listed later. A book project: E. Rubiola, <i>Phase Noise</i> .
	3	Friis formula. Noise Equivalent Power (NEP). Analog meets digital. Noise, errors and artifacts in ADCs and DACs.	A. Yariv, <i>Optical Electronic in modern communications</i> , Oxford. Saleh-Teich <i>Photonics</i> , Wiley. C. E. Calosso, E. Rubiola, Phase Noise and Jitter in Digital Electronics, arXiv:1701.00094.
	4	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 the applications
	5	Spectrum analyzer. Lock-in amplifiers. Time-to-digital and frequency-to-digital converters.	A book project about TDC, FDC and related statistics. 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, arXiv:2201.07109. A book project: E. Rubiola, <i>Phase Noise</i> U. L. Rohde, E. Rubiola, J. C. Whitaker, <i>Microwave and wireless synthesizers</i> , Wiley 2021 (Ch.2)
	7	Allan variance (cont.). Experimental methods for the measurement of oscillators.	E. Rubiola, F. Vernotte, arXiv:2201.07109. U. L. Rohde, E. Rubiola, J. C. Whitaker, <i>Microwave and wireless synthesizers</i> , Wiley 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> . A few articles by E. Rubiola. C. E. Calosso, E. Rubiola, Phase Noise and Jitter in Digital Electronics, arXiv:1701.00094.
	9	The Leeson effect. i.e., the origin of noise in oscillators and lasers	E. Rubiola, <i>Phase noise and frequency stability in oscillators</i> , Cambridge 2010
	10	The Pound Drever Hall frequency control for the stabilization of RF/microwave oscillators and lasers.	A book project: E. Rubiola, <i>The Pound Drever Hall Frequency Control</i> Eric D. Black ED, An introduction to Pound–Drever–Hall..., <i>Am J Phys</i> 69(1) January 2001
Part 3: The New SI (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 BIPM 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.	BIPM, The International System of Units 9 th ed, 2019. E. O. Göbel. U. Siegner, <i>The New International System of Units (SI)</i> , Wiley-VCH 2019
	14	Quantum electrical standards and practical electrical references.	BIPM, The International System of Units 9 th ed, 2019. E. O. Göbel. U. Siegner, <i>The New International System of Units (SI)</i> , Wiley-VCH 2019
	15	Temperature, fundamental and practical stuff. (Skip the mole). Candela and radiometric/photometric units (quite short). Goodbye.	BIPM, The International System of Units 9 th ed, 2019. E. O. Göbel. U. Siegner, <i>The New International System of Units (SI)</i> , Wiley-VCH 2019

Origin and Purposes

The contents originates from

- My tutorials at int'l conferences and my lectures as a guest scientist 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](mailto:doctorat@ubfc.fr)

(replace [dot] and [at] as appropriate, and remove spaces)

They are instructed to accept everybody

Learning Material

home page <http://rubiola.org>

Course #1

News
Enrico's Noise Chart - Enrico's Chart (Zenodo) - Companion article
Publications
• Books
• Open literature
• Journal articles
• Selected conferences
• Seminars & tutorials
EFTS
Open lectures
• Course #1 (3×7.5 H) 1: Instruments 2: Oscillators & noise 3: The new SI
• Course #2 (10 H) Scientific publication
Oscillator noise support material for my book (Cambridge, 2008-2014)
Affiliations
Links



Enrico Rubiola
home page

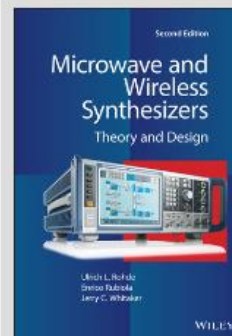
<http://rubiola.org>
also <http://rubiola.net>

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replace "at" = "@" and "dot" = "."

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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

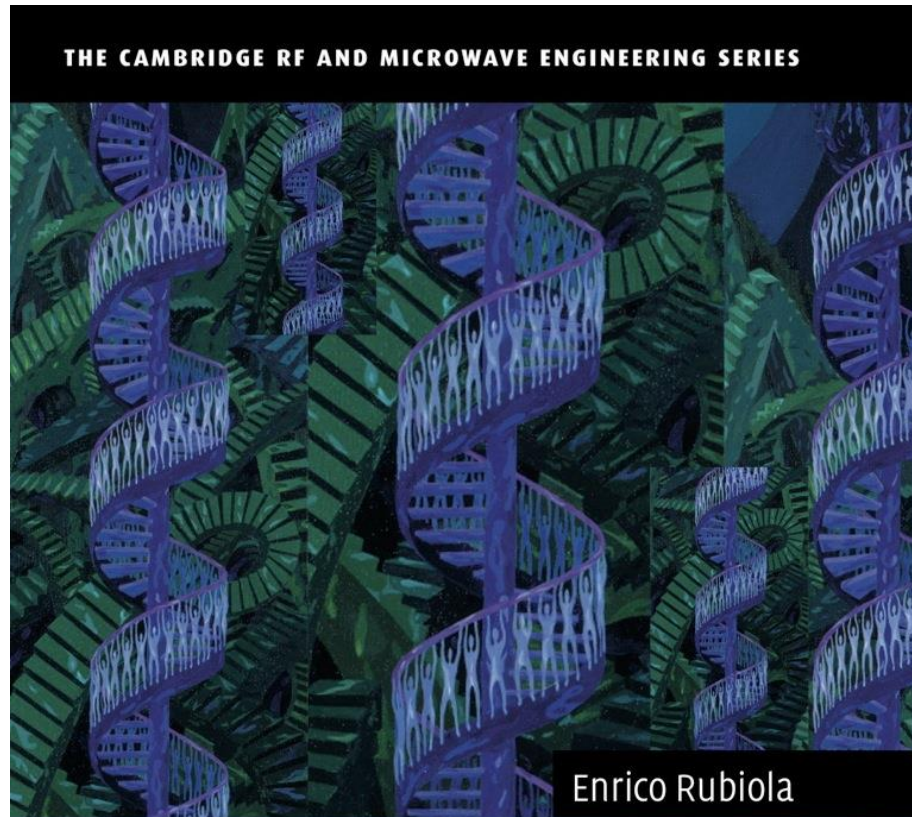
E. Rubiola
Phase noise metrology
Book project

book project:

**Phase Noise
Metrology**

Phase Noise and Frequency Stability in Oscillators

5



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 Leeson 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

Downloads

- [The Enrico's chart of Phase Noise and Two-Sample Variances](#)
- [The Companion of Enrico's Chart for Phase Noise and Two-Sample Variances](#)
- Ch. 2 of Microwave and Wireless Synthesizers, [draft updated version](#) (limited circulation, only for review purposes)
- Various articles [here](#)

European Frequency and Time Seminar

Full week crash course,
with lectures and labs

With some good luck,
there will be a real
seminar with lab
sessions, and online
lectures too

2024 EFTS Week Schedule – Preliminary							
Time	Mon, July 1	Tue, July 2	Wed, July 3	Thu, July 4	Fri, July 5	Colors	
8:15	7:30–8:30 Registration	Coffee	Coffee	Coffee	Coffee	Logistics & events Lectures	
8:30 – 9:20	8:30 Introduction to TF Y. Le Coq SYRTE & FIRST-TF	Relativity Frédéric Meynadier BIPM, Int'l	Navigation & GNSS Carsten Rieck, RISE, SE	Synchronization over Digital Networks K. Teichel, PTB, DE	8:30–11:30 Laboratory	Labs / computer Welcome & Closing	
9:20 – 10:10	Introduction to Oscillators E. Rubiola, FEMTO, FR	Intro Atomic Clocks G. Miletì, LTF, CH	FS Combs J. Kronjäger, PTB, DE	Small Clocks C. Affolderbach, LTF, CH		3. SDR, GPS & PRN (9:30-11:30) 4. GPS RX & RINEX 5. Atomic clock 6. Resonators	Contents By color
10:10 – 10:40	Coffee & cookies	Coffee & cookies	Coffee & cookies	Coffee & cookies			Chapter 1 General & Applications Enrico Rubiola
10:40 – 11:30	Phase Noise E. Rubiola, FEMTO, FR	Stabilized Lasers C. Lacroûte, FEMTO	Satellite Synch Carsten Rieck, RISE, SE	Optical Clocks Rachel Godun, NPL, UK			Chapter 2 Meas & Oscillators Enrico Rubiola
11:30 – 12:20	Variances F. Vernotte, FEMTO, FR	Free-space links Sascha Schediwy Univ. W. Australia	Cold Atoms C. Lacroûte, FEMTO	Invited #2 Attosecond pulses TBD	11:30 Quick coffee 11:45-12:30 Historical Perspective F. Vernotte, FEMTO		Chapter 3 Atomic Clocks Gaetano Miletì
12:20 – 13:50	Lunch	Lunch	Lunch	Lunch	12:30–12:45 Closing	Chapter 4 Timing & Transfer Francois Vernotte	
13:50 – 14:40	Digital Controls C.E.Calosso, INRiM	Atomic Clock Physics G. Miletì, LTF, CH	Optical fiber links J. Kronjäger, PTB, DE	Clock Synchronization Security K. Teichel, PTB, DE	12:45–14:15 Lunch		
14:40 – 15:30	Quartz Oscillators Bernd Neubig Axtal Consulting, DE	Atomic Time Scales Frédéric Meynadier BIPM, Int'l	Coffee	Coffee	14:15–16:15 Visit, Observatory or FEMTO-ST	Laboratories Y.Gruson, J.M.Friedt, E.Rubiola	
15:30 – 16:00	Coffee	Coffee	15:10–17:10 Laboratory 1, 3 & 4 (Noise, SDR, RINEX)	15:00–18:00 Laboratory 3. SDR, GPS & PRN 5. Atomic clock 6. Resonators			
16:00 – 18:00	Laboratory 1. PM/AM noise, 2. Data Analysis	Laboratory 1. PM/AM noise, 2. Data Analysis			Visit at the Museum of Time, and Drink	Go to the pier	You are free
18:00 – 19	Posters, beer and chips at the TF Department (ethanol-free drinks too)	(free time)	Lecture auditorium Jules Haag				
19 – 20							
20 – 21:30	Dinner on your own	Dinner on your own	Dinner on your own	Social Dinner Boat on the river 19:30 (boat leaves at 19:45)			
21:20 – 24	Backup for the Astronomy session, depending on weather	Astronomy depending on weather	Last chance for the Astronomy session, depending on weather				

Updated
January 17, 2024