

THE SELECTION AND USE OF PRECISE FREQUENCY AND TIME SYSTEMS

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Abstract

The ITU-R has authorized the creation of a handbook, "The Selection and Use of Precise Frequency and Time Systems." This handbook is designed for use by the beginner in the field and for undeveloped countries that wish to establish a national laboratory or calibration laboratory. The lack of such a handbook is serious, so the ITU has decided to generate one. The editor, Richard L. Sydnor, and the assistant editor, David Allan, have selected authors for the various chapters from experts in the field and have correlated the work and generated the various drafts for the final version.

The chapters and their authors are:

Preface and Forward	H. G. Kimball, ITU
Glossary	CCIR and ISO
Chapter 1 Introduction and Basic Concepts	Claude Audoin, Laboratoire de l'Horloge Atomique, France
Chapter 2A Local Frequency and Time Sources	Andreas Bauch, Physikalische-Technische Bundesanstalt, Germany
Chapter 2B Steering References	Roger Beehler, NIST
Chapter 3 Characterization: Frequency Domain, Time Domain, Environment	Laurent-Guy Bernier, Observatoire de Neuchâtel, Switzerland
Chapter 4 Measurement Techniques (Metrology)	Fred Walls, NIST
Chapter 5 Characteristics of Various Frequency Standards	Richard Sydnor, Jet Propulsion Laboratory
Chapter 6 Time Scales	Claudine Thomas, BIPM, France Patrizia Tavella ¹
Chapter 7 Uses of Frequency Sources	Sigfrido Leschiutta ^{1,2} Franco Cordara ¹ ¹ Istituto Elettronico Nazionale, Italy ² Politecnico di Torino, Italy
Chapter 8 Operational Experience, Problems, Pitfalls	Richard Sydnor, Jet Propulsion Laboratory Michel Granveaud, Observatoire de Paris, France
Chapter 9 Future Prospects	Richard Sydnor, Jet Propulsion Laboratory
Chapter 10 Conclusions	Leonard Cutler, Hewlett-Packard Donald Sullivan, NIST

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INTRODUCTION

The International Telecommunications Union — Radio (ITU-R) has decided that, in view of the fact that no handbook or general reference book covering the field of precise frequency standards exists, and that the need for such a book is critical for the developing countries and for students of the field, one should be generated. The authors were selected by the editors and have graciously donated their time and expertise to the completion of the book. Without their efforts and cooperation this work could not have been completed. Each chapter includes a list of references for those wishing to explore the topics of the chapter in detail. The book is now in the hands of the ITU-R for translation into several languages and will soon be available.

PREFACE, FORWARD, AND GLOSSARY

Mr. H.G. Kimball, the past chairman of the ITU-R, wrote the preface explaining the reason for publishing the book. The editors have written the forward giving a general description of the book and its contents, and where to find different topics. The glossary of terms used in the time and frequency field is based on the glossary that was originally generated by the CCIR (now the ITU-R) with additional definitions from ISO where there are differences or omissions.

CHAPTER DESCRIPTIONS

Chapter 1: Introduction and Basic Concepts

A historical background of the development of atomic frequency standards is given. The physics underlying commercially available atomic frequency standards are described and the means of applying them to frequency standards are outlined. The criteria which determine the performance of the various standards are discussed. In addition, quartz crystal oscillators are described because of their use in all the frequency standards. Every atomic frequency standard includes a quartz crystal oscillator and a certain amount of the performance of the frequency standard is due to the performance of the quartz crystal oscillator. Since this book is not designed to teach people how to design new frequency standards, but rather in how to use them, only commercially available precise frequency standards are covered, i.e., cesium beams, rubidium gas cells, hydrogen masers, and, of course, quartz oscillators.

Chapter 2A: Local Frequency and Time Sources

The actual implementation block diagrams and critical design parameters of the frequency standards based on the physics concepts of Chapter 1 are described and the use of the quartz crystal oscillator in each is outlined. Cesium, rubidium, hydrogen masers, and quartz crystal oscillators are covered in detail. Passive and active standards are covered.

Chapter 2B: Steering References

A complete listing of all the possible references that are available for syntonizing local frequency standards and for synchronizing local time standards to UTC coordinating with the SI second are given. Advantages and disadvantages of each are given, as well as the relative cost and complexity of operation of each of them.

Chapter 3: Characterization: Frequency Domain, Time Domain, Environment

Complete descriptions of the various measures of frequency and time stability, as used in the frequency and time field as well as those used in the communications field, written from a communications point of view, are presented. Cross-references are given to relate the communications point of view with the conventional frequency and time point of view. High-noise oscillators and low-noise oscillators are covered, as are the effects of frequency multiplication, and multiplicative and additive noise. This chapter covers true variance, $\sigma_y(\tau)$, Mod $\sigma_y(\tau)$, $S_\phi(f)$, $L(f)$, $S_x(f)$, TIE, structure functions, the Hadamard variance, and the high-pass variance.

Chapter 4: Measurement Technology (Metrology)

Measurement techniques for determining the characteristics of the frequency source are discussed in detail. Actual hardware examples of each technique are given, as well as things to be careful about. This is an updated and condensed version of some of the tutorials that have been given in the past.

Chapter 5: Characteristics of Various Frequency Sources

The actual performance in the time domain and frequency domain of available frequency sources are given. Systematic effects are included, giving the sensitivity of the different sources to environmental conditions and aging.

Chapter 6: Time Scales

The different time scales are defined and discussed, including TAI (International Atomic Time), UTC (Coordinated Universal Time), ET (Ephemeris Time), and UT# (the different Universal Times). A discussion of the means of generating time scales and examples of each are given, including the algorithms used by NIST and BIPM. The availability of documents for coordinating a local time scale with the BIPM are given, with examples of each.

Chapter 7: Uses of Frequency Sources

The many uses for frequency sources are described with specific examples described in detail.

Chapter 8: Operational Experience, Problems, Pitfalls

The real world operation of frequency sources with *caveats* about things that may degrade their performance. Reliability of the different sources is discussed and data are given for some standards.

Chapter 9: Future Prospects

Likely changes to expected in the future with the continual improvement of frequency sources and new technology are discussed.

Chapter 10: Conclusions

A wrap-up of the contents of the handbook and its use.

SUMMARY

The final draft was submitted to the ITU-R and is due to be published at the end of 1996.

APPENDIX: TABLE OF CONTENTS

Preface

Foreward

Glossary

Chapter 1 Introduction and Basic Concepts

 1.1 Historical Sketch

 1.2 Basic Principles of Frequency Standards

 1.2.1 Quartz Crystal Frequency Standards

 1.2.2 Atomic Frequency Standards

 1.2.2.1 Spectroscopic Properties of Interest

 1.2.2.2 Passive and Active Atomic Frequency Standards

 1.3 Basic Metrology Concepts

 1.3.1 Frequency Stability

 1.3.1.1 Definition

 1.3.1.2 Quartz Crystal Oscillators

 1.3.1.2.1 Random Frequency Fluctuations

 1.3.1.2.2 Systematic Effects

 1.3.1.3 Atomic Frequency Standards

 1.3.1.3.1 Short Term Frequency Stability

 1.3.1.3.2 Medium Term Frequency Stability

 1.3.1.3.2.1 Medium Term Frequency Stability in Passive Frequency Standards

 1.3.1.3.2.2 Medium Term Frequency Stability in Active Frequency Standards

 1.3.1.3.2.3 Long Term Frequency Stability

 1.3.2 Accuracy

 1.3.2.1 Residual Frequency Offsets

 1.3.2.2 Definition

 1.3.2.3 Primary and Secondary Frequency Standards

 1.3.3 Reproducibility, Resetability

 1.3.4 References

Chapter 2A Local Frequency and Time Sources

 2A.1 Introduction Chapter 2 Available Frequency and Time Sources

 2A.2 Quartz Crystal Frequency Standards

 2A.2.1 Basic Principles

 2A.2.2 The Resonator

 2A.3 The Rubidium Gas Cell Frequency Standard

 2A.4 The Hydrogen Maser

 2A.5 The Cesium Beam Frequency Standard

 2A.6 References

Chapter 2B Steering References

 2B.1 Introduction

 2B.2 Factors to be Considered in the Selection and Use of Alternative Time-and-Frequency Dissemination Services and Techniques

 2B.3 Comparisons of Alternative Sources and Dissemination Techniques for Precise Time-and-Frequency References

 2B.4 Additional Techniques Relating to the Use of the Various Alternative Services, Systems, and Techniques

 2B.5 Bibliography Related to Time-and-Frequency Steering Techniques

**Table 2B.1 Characteristics of Some Potential Sources and Dissemination Techniques
for Precise Time-and-Frequency Reference Information**

**Table 2B.2 Additional Information Relating to the Practical Use of Various Alternative
Sources of Time-and Frequency Signals**

Chapter 3 Characterisation: Frequency Domain, Time Domain, Environment

3.1 Introduction

3.2 Model of the Oscillator

- 3.2.1 The Phasor Model and the Analytic Signal
- 3.2.2 The Low Noise Oscillator
- 3.2.3 Spectrum of the Low-Noise Oscillator
- 3.2.4 The High Noise Oscillator
- 3.2.5 Spectrum of the High Noise Oscillator
- 3.2.6 Effect of Frequency Multiplication
- 3.2.7 Demodulation of the Noise Processes
- 3.2.8 Standard Definition of Noise Processes
 - 3.2.8.1 Amplitude and Phase Noise Processes
 - 3.2.8.2 Time Error Process
 - 3.2.8.3 Instantaneous Frequency Process
- 3.2.9. Multiplicative and Additive Noise
 - 3.2.9.1 Multiplicative Noise
 - 3.2.9.2 Additive Noise
- 3.2.10 Polynomial Model

3.3 Characterisation: Definitions Methods

- 3.3.1 Spectral Domain
 - 3.3.1.1 Basic Definitions
 - 3.3.1.2 Spectral Purity Concepts
- 3.3.2 Time Domain
 - 3.3.2.1 Introduction
 - 3.3.2.2 Basic Concepts
 - 3.3.2.2.1 Model of the Frequency Counter
 - 3.3.2.2.2 Moving Average Operator
 - 3.3.2.2.3 Increment Operator
 - 3.3.2.3 Basic Time Domain Measurements
 - 3.3.2.3.1 The True Variance
 - 3.3.2.3.2 The Classical Allan Variance
 - 3.3.2.3.3 The Modified Allan Variance
 - 3.3.2.3.4 The Time Interval Error
 - 3.3.2.3.5 The Time Variance
 - 3.3.2.3.6 Other Time Domain Measurements
 - 3.3.2.3.7 The Multi-variance Analysis
 - 3.3.2.4 Pitfalls
 - 3.3.2.4.1 Effect of Zero-Crossing Detection
 - 3.3.2.4.2 Effect of Dead-Time
 - 3.3.2.4.3 Effect of System Bandwidth
 - 3.3.2.4.4 Truncation Effects
 - 3.3.2.5 Algorithms
 - 3.3.2.5.1 Frequency Averaging by Phase Sampling
 - 3.3.2.5.2 Computation of Classical Allan Variance
 - 3.3.2.5.3 Computation of Modified Allan Variance
 - 3.3.2.5.4 Summary
 - 3.3.2.6 Applications
 - 3.3.2.7 Conversion between Time & Frequency Domains
- 3.3.3. Environmental
 - 3.3.3.1 Definitions

3.3.3.2 Pitfalls

3.4 A Bridge to Next Chapter

3.5 Appendix: Random Processes

3.5.1 Introduction

3.5.2 Definition of a Random Process

3.5.3 Stationary Random Processes

3.5.4 Non-Stationary Random Processes

3.5.5 Auto-Correlation Function

3.5.6 Power Spectral Density

3.5.7 Linear Filtering of Random Processes

3.6. References

Chapter 4 Measurement Techniques (Metrology)

4.0 Introduction

4.1 Direct Measurements of Time (Phase) and Frequency

4.1.1 Direct Measurements of Time (phase)

4.1.2 Direct Measurements of Frequency

4.2 Heterodyne Measurements of Frequency and Phase (Time)

4.2.1 Heterodyne Measurements of Phase (Time)

4.2.2 Heterodyne Measurements of Frequency

4.2.3 Heterodyne Measurements of PM Noise

4.2.4 Dual Mixer Time Measurements Systems

4.2.5 Picket Fence Based Measurement Systems

4.2.6 Digital Techniques for Frequency and PM measurements

4.2.7 Three-Cornered Hat Measurements

4.2.8 Cross-Correlation Measurement Systems

4.3 Single-Oscillator Measurements of Frequency and PM Noise

4.3.1 Delay-Line Measurements of Frequency and PM Noise

4.4 Measurements of AM Noise

4.5 References

Chapter 5 Characteristics of Various Frequency Standards

5.1 Definitions and Discussion: Measures and Implications

5.1.1 The Characterisation of Random Processes

5.1.1.1 $L(f)$, $S_4(\tau)$

5.1.1.2 $\sigma_y(\tau)$, $\text{mod}\sigma_y(\tau)$, $\sigma_z(\tau)$

5.1.2 Systematic Effects

5.1.2.1 Environmental Effects

5.1.2.1.1 Temperature

5.1.2.1.2 Humidity

5.1.2.1.3 Barometric Pressure

5.1.2.1.4 Magnetic Field

5.1.2.1.5 Power Line Voltage, Noise, and Interruptions

5.1.2.1.6 Acceleration, Vibration, and Shock

5.1.2.1.7 Ageing

5.1.2.1.8 Drift

5.2 Characteristics of Various Frequency Standards

5.3 References

Chapter 6 Time Scales

6.1. Introduction

6.1.1. Universal Time

6.1.2. Ephemeris Time

6.1.3. International Atomic Time

6.1.4. Coordinated Universal Time

- 6.2. Time scales in general relativity
 - 6.2.1. Coordinate systems in general relativity
 - 6.2.2. The 1991 IAU Resolution A4
 - 6.2.2.1. Recommendation I
 - 6.2.2.2. Recommendation II
 - 6.2.2.3. Recommendation III
 - 6.2.2.4. Recommendation IV
 - 6.2.3. International Atomic Time
 - 6.2.4. Other coordinate time scales
- 6.3. Generation of time scales
 - 6.3.1. Expected qualities
 - 6.3.1.1. Reliability
 - 6.3.1.2. Stability
 - 6.3.1.3. Accuracy
 - 6.3.1.4. Delay of access
 - 6.3.2. Timing data
 - 6.3.2.1. General form of timing data
 - 6.3.2.2. Comparison of clocks located on the same site
 - 6.3.2.3. Comparison of clocks located on remote sites
 - 6.3.2.4. Smoothing of data measurement noise
 - 6.3.3. Stability algorithm
 - 6.3.3.1. Definition of an average time scale
 - 6.3.3.2. Length of the basic interval of computation
 - 6.3.3.2.1. Update of TA every interval of duration T
 - 6.3.3.2.2. Update of TA when the interval of duration nT is ended
 - 6.3.3.3. Weighting procedure
 - 6.3.3.3.1. General ideas
 - 6.3.3.3.2. Weighting procedure in AT1(NIST)
 - 6.3.3.3.3. Weighting procedure in ALGOS(BIPM)
 - 6.3.3.4. Frequency prediction
 - 6.3.3.4.1. General ideas
 - 6.3.3.4.2. Frequency prediction in AT1(NIST)
 - 6.3.3.4.3. Frequency prediction in AOSLG(BIPM)
 - 6.3.3.5. Accuracy of the scale interval of a time scale
 - 6.3.5. Examples
 - 6.3.5.1. Stability of some independent time scales
 - 6.3.5.2. Steering of some local representations of UTC
- 6.4. Dissemination of time scales
- 6.5. Conclusions
- 6.6. References

Chapter 7 Uses of Frequency Sources

- 7.1 Uses of Frequency Sources in Science and Technology
- 7.2 Metrology
 - 7.2.1 Accuracy Comparison between the Standard of Time and Those of the Other Basic Quantities
 - 7.2.2 Relations between the Unit of Time and Other Units
- 7.3 Fundamental and Applied Physics
 - 7.3.1 g, Acceleration Due to Gravity
 - 7.3.2 GM, Gravitational Constant Times Earth Mass
 - 7.3.3 The Gravitational Field of the Earth
 - 7.3.4 Very Large Baseline Interferometry (VLBI) and Quasi-VLBI
- 7.4 Positioning and Navigation
 - 7.4.1 Conical Navigation
 - 7.4.2 Circular or Spherical Navigation
 - 7.4.3 Hyperbolic Navigation

- 7.4.4 Hyperbola, Hyperboloid and their Properties
- 7.4.5 Accuracy Requirements for the Frequency Standards used in Navigation Systems
- 7.5 Telecommunications
 - 7.5.1 Analogue Systems
 - 7.5.2 Digital Systems
- 7.6 Other Applications
 - 7.6.1 Automotive Applications
 - 7.6.2 Electrical Power Systems and Compressed Gas Dispatching
 - 7.6.3 Instrumentation
 - 7.6.4 Doppler Radar
- 7.7 References

Chapter 8 Operational Experience, Problems, Pitfalls

- 8.0 Overview
- 8.1 Frequency and Time Tools
 - 8.1.1 Choice of a Reference
 - 8.1.1.1 Assessing What is Needed
 - 8.1.1.2 Steered versus Free-running Clock
 - 8.1.2 Tools for Operational Use
 - 8.1.2.1 F/T System Stability
 - 8.1.2.1.1 Measurement Noise
 - 8.1.2.1.2 Measuring Clock Performance
 - 8.1.2.2 System Reliability
 - 8.1.2.2.1 Failure Rates
 - 8.1.2.2.2 Problems in Dealing with Errors
 - 8.1.2.3 System Accuracy
 - 8.1.2.4 Practical Hardware Problems
- 8.2 Data and Examples from Operational Experience
 - 8.2.1 Frequency and Time Standards
 - 8.2.2 Examples of Problems
 - 8.2.3 Frequency and Time Comparisons
 - 8.2.3.1 Is Linear Regression Best?
 - 8.2.3.2 Problem with Cycle Ambiguity
 - 8.2.4 Other Data, System Set-up, and Processing Ideas and Problems
 - 8.2.4.1 Models versus Reality
 - 8.2.4.2 Data Formats
 - 8.2.4.3 Retrieving and Storing Data
 - 8.2.4.4 Installation Concerns
 - 8.2.4.5 Care and Replacement
- 8.3 Conclusion
- 8.4 References

Chapter 9 Future Prospects

- 9.1 Introduction
- 9.2 General Overview
- 9.3 Gas Cell Devices
- 9.4 Caesium Beam Standards
- 9.5 Hydrogen Masers
- 9.6 Trapped Ion Standards
- 9.7 Caesium Fountain
- 9.8 Quartz Oscillators
- 9.9 Oscillator Stabilised to GPS
- 9.10 Oscillator Stabilised with Cooled Sapphire Resonator
- 9.11 Optical Frequency Standards
- 9.12 Summary

Chapter 10 Conclusions

- 10.1 General Observations
- 10.2 Clocks and Oscillators
- 10.3 Measurement Methods and Characterisation
- 10.4 Time Scales, Coordination, and Dissemination
- 10.5 Realities

Questions and Answers

JAMES CAMPARO (AEROSPACE CORP.): How are you people going to get copies of this to us?

RICHARD SYDNOR: Okay, I have a few copies here for people who are really interested. They are draft copies, there might be a few typos here and there and that sort of thing. If anyone wants to leave their name with me, I will contact you as soon as it's published and give you addresses and actual prices so that you can order copies.

JAMES CAMPARO: Would that be for both handbooks?

RICHARD SYDNOR: It's the same location for both handbooks, but I will give you information on this one. And then if you write to the address, they'll send you a catalog.

GERRIT de JONG (NMi VAN SWINDEN LAB, NETHERLANDS): The other handbook is not yet ready, so it's only this handbook.

JAMES CAMPARO: So you were referring to the one coming out in December?

GERRIT de JONG: No, only the manuscripts will be finished. So it will take maybe half a year or longer.

JOHN VIG (ARL): It sounds like there's a lot of good reference information in this book. Is there any chance that we could get at least some of it on the Web? Both Frequency Control and the PTI now have a Web site.

RICHARD SYDNOR: Well, we have a copyright problem. It belongs to ITU. It would be a good idea. I can make a couple inquiries to find out. The price is quite reasonable, \$30 or so for a technical book that's 200 and some odd pages full of information; and a lot of references if you wanted to delve deeper there into any of the topics.

JOHN VIG: I know that at least the contributions by government authors are not copyrighted.

RICHARD SYDNOR: Yes, but there are a lot of foreign authors, you know, some of the primary authors are from Europe. It's an international book, it's not a US book.