**Fostering the Innovation Potential of Research Infrastructures**

**INFRAINNOV-2-2016: Support to Technological Infrastructures**


# CLONETS – CLock NETwork Services
## Strategy and innovation for clock services over optical-fibre networks

**Grant Agreement Number: 731107**

# Deliverable D4.2

# Time and Frequency Training Blueprint
***Final***

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# Table of Contents

# 1 Executive Summary

This deliverable, D4.2 “Time and Frequency Training Blueprint”, provides an outline of the topics which may be included in a comprehensive training course in time and frequency metrology and its applications, organised into logical blocks of subjects and into three levels of competency, from entry level to advanced. It includes a detailed coverage of the optical-fibre time and frequency transfer methods which are the subject of CLONETS.

# 2 Introduction

## 2.1 Document content

The Training Blueprint is presented in section 3 of the document, in two parts:

- section 3.1: a visual concept map showing the logical training blocks and their arrangement into competency levels
- section 3.2: the detailed content of the training, block-by-block

## 2.2 List of acronyms and abbreviations

| | |
|---|---|
| CLONETS | CLock NETwork Services: Strategy and innovation for clock services over optical-fibre networks Project |
| EC | European Commission |
| EDFA | Erbium-Doped Fibre Amplifier |
| ELSTAB | Electronically Stabilized Fiber-Optic Time and Frequency Distribution System |
| EU | European Union |
| FDM | Frequency Division Multiplexing |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| H2020 | Horizon 2020 |
| IRU | Indefeasible Right of Use |
| NTP | Network Time Protocol |
| OSI | Open Systems Interconnection |
| PTP | Precision Time Protocol |
| REFIMEVE+ | Réseau Fibré Métrologique à Vocation Européenne (Metrological Fibre Network with European Perspective) |
| RF | Radio-frequency |
| SI | International System of Units |
| TAI | International Atomic Time |
| TDM | Time Division Multiplexing |
| TF | Time and Frequency |
| UT | Universal Time (different forms: UT0, UT1, UT2) |
| UTC | Coordinated Universal Time |
| WDM | Wavelength Division Multiplexing |

## 2.3 List of CLONETS project participants and abbreviations

| | |
|---|---|
| AGH/AGH-UST | Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie, Cracow, Poland |
| CESNET | CESNET, zájmové sdružení právnických osob, Prague, Czech Republic |
| CNRS* | Centre National de la Recherche Scientifique, Paris, France |
| INRIM | Istituto Nazionale di Ricerca Metrologica, Turin, Italy |
| GARR# | Gruppo per l'Armonizzazione delle Reti della Ricerca, Rome, Italy |
| Menlo | Menlo Systems GmbH, Martinsried, Germany |
| Muquans | Muquans, Talence, France |
| NPL | National Physical Laboratory, Teddington, United Kingdom |
| ObsParis¶ | Observatoire de Paris, Paris, France |
| OPTOKON | OPTOKON a.s., Jihlava, Czech Republic |
| Piktime Systems | Piktime Systems sp z o.o., Poznan, Poland |

| | |
|---|---|
| PSNC | Instytut Chemii Bioorganicznej Polskiej Akademii Nauk – Poznańskie Centrum Superkomputerowo-Sieciowe, Poznan, Poland |
| PTB | Physikalsch-Technische Bundesanstalt, Braunschweig, Germany |
| RENATER | Groupement d'interêt Public pour le Reseau National de Telecommunications pour la Technologie, l'Enseignement et la Recherche, Paris, France |
| Seven Solutions | Seven Solutions S.L., Granada, Spain |
| TOP-IX# | Consorzio TOrino Piemonte Internet eXchange, Turin, Italy |
| UCL | University College London, London, United Kingdom |
| UP13 | Université Paris 13, Villetaneuse, France |
| UPT AV CR (ISI) | Ustav Pristrojove Techniky AV, v.v.i., Brno, Czech Republic |

* linked third party to ObsParis
# third parties to INRIM
¶ coordinator

# 3 Time and frequency metrology training blueprint

## 3.1 Visual concept map

This Training Blueprint details content within the Time and Frequency domain, organised by technical level (Entry - Advanced). The target audience for the content listed within each technical level is as follows:

- **Entry** - General audience, policy makers, those who need a foundational knowledge of time, frequency and dissemination practices
- **Intermediate** – Industry professionals/end users/researchers moving into time and frequency; Industry/academic non-specialists new to time and frequency
- **Advanced** – Industry professionals/researchers working in the time and frequency domain seeking to gain specific advanced-level knowledge or practical know-how

The content within each technical level is organised into blocks. These blocks group related concepts, with each subsequent block building on the content in previous blocks. An overview of the blocks contained within each technical level, and a progressive learning pathway connecting them, is shown in the 'Visual Concept Map' given in Figure 1.

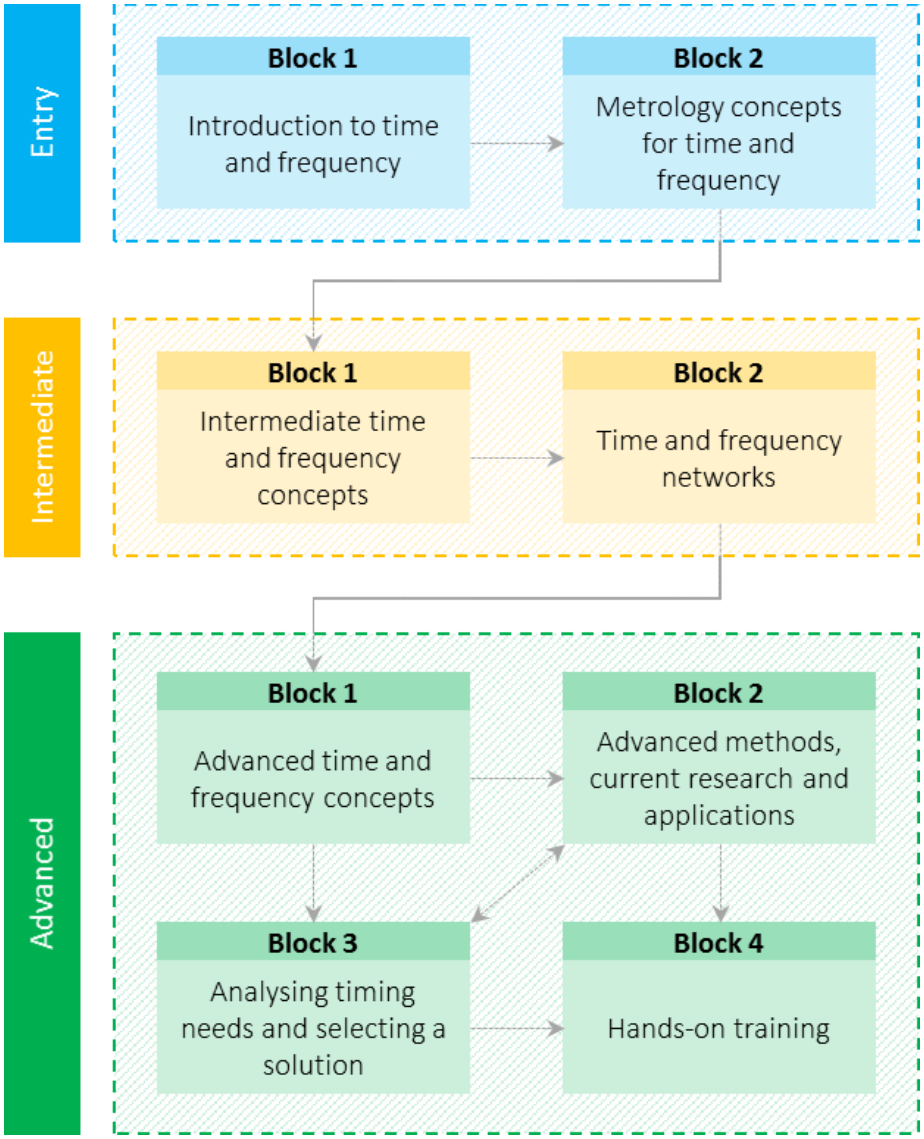


**Figure 1 . A 'Visual Concept Map' showing the content blocks within each technical level of the Training Blueprint. The grey arrows represent a progressive learning pathway. Note that learners could join this progressive pathway at any stage, provided that they possess the appropriate prerequisite knowledge.**

## 3.2 Detailed training blueprint

A detailed overview of the content within each of the blocks shown in Figure 1, together with the associated learning outcomes, is given in the following tables.

| | Content Covered | Learning Outcomes |
|---|---|---|
| Entry Level | ***Block 1: Introduction to time and frequency*** | |
| | → **Introduction to time and frequency**<br>– Historical perspectives<br>– The International system of Units<br>– Common SI prefixes for time and frequency<br>– Examples of events at different timescales<br>– Definition and realisation of the second<br>– Definition of frequency<br>– Hertz as the SI unit of frequency<br>→ **Clocks/frequency standards**<br>– Introduction to clocks<br>– History of clocks<br>– Types of clock<br>– Introduction to frequency measurement<br>– Introduction to frequency measurement equipment<br>→ **Introduction to timescales**<br>– Universal time (UT0, UT1, UT2)<br>– International atomic time (TAI)<br>– Coordinated universal time (UTC)<br>→ **Introduction to time and frequency dissemination**<br>– Why is dissemination needed? (Illustrated with selected examples)<br>– Summary of common dissemination techniques<br>– Important characteristics, advantages and disadvantages of different methods<br>→ **Overview of time and frequency applications/end users**<br>– Societal impact of time and frequency measurement and distribution<br>– E.g. Power grid, GPS/GNSS, etc. | → Be aware of historical developments in the field of time and frequency<br>→ Identify the second as the SI unit of time<br>→ Identify Hertz as the SI unit of frequency<br>→ Understand the role of atomic clocks as time and frequency standards<br>→ Be aware of different timescales and the differences between them<br>→ Understand the need for time and frequency dissemination<br>→ Be aware of common dissemination techniques and their defining characteristics<br>→ Understand the societal impact of time and frequency measurement and distribution<br>→ List examples of time and frequency end users |
| | ***Block 2: Metrology concepts for time and frequency*** | |
| | → **Introduction to metrology**<br>– Definition of metrology: The science of measurement and its application<br>– Wider role and importance of metrology in industry<br>→ **Metrological terms and definitions; introduction to:**<br>– Calibration<br>– Traceability<br>– Error and uncertainty<br>– Sensitivity<br>– Repeatability/Reproducibility<br>– Accuracy<br>– Stability<br>→ **Importance of metrology in time and frequency applications**<br>– Accuracy, stability, traceability and uncertainty<br>– Coordination of time and frequency | → Be aware of the field of metrology and its importance<br>→ Understand the concepts of calibration, traceability, uncertainty, accuracy and stability<br>→ Understand the terms accuracy, stability, traceability and uncertainty in relation to time and frequency applications |

Intermediate Level

***Block 1: Intermediate time and frequency concepts***

- **Brief recap of entry level concepts**
  - Time and frequency
  - Clocks/frequency standards
  - Timescales
  - Dissemination methods
- **More detailed exploration of clocks**
  - Principles of operation for quartz, rubidium, caesium, masers, optical clocks
  - Disciplined vs free running clocks
  - Performance issues and characteristics
  - Statistical tools to quantify stability and accuracy (e.g. Allen deviation)
  - Typical output signal formats
- **Time and frequency measurements**
  - General principles
  - Discussion of relevant equipment (Frequency counters, time interval counters, etc.)
  - Traceability
  - Typical uncertainties and related considerations
- **Time and frequency transfer and dissemination**
  - Detailed overview of current transfer/dissemination techniques (e.g. satellite methods (two way satellite transfer, GNSS), RF over fibre, optical frequency transfer over fibre)
  - Advantages and disadvantages of current methods

- Understand the principles of operation for quartz, rubidium, caesium, masers and optical clocks
- Understand the difference between disciplined and free running clocks
- Understand the issues that influence the performance of different types of clock
- Understand the statistical tools that can be used to quantify the stability and accuracy of clocks
- Be aware of different output signal formats
- Understand the general principles of time and frequency measurements
- Identify equipment used to measure time and frequency
- Understand different transfer/dissemination techniques and their associated advantages/disadvantages

***Block 2: Time and frequency networks***

- **Introduction to networks**
  - Overview of basic technology and operation
  - OSI layer network model
  - Network structure
  - Overview of basic technology and operation
  - Typical components (switches, amplifiers, etc.)
- **Types of network**
  - Wireless (including spoofing and jamming risks)
  - Copper
  - Fibre
- **Overview of key technologies on networks**
  - Network multiplexing with Wavelength Division Multiplexing (WDM), Time Division Multiplexing (TDM) and Frequency Division Multiplexing (FDM)
  - Data framing for bit transmission
- **Overview of networks currently in existence**
  - Owners/operators
  - Uses
  - Indefeasible Right of Use (IRU)
- **Time and frequency dissemination over packet based network networks**
  - Network time protocol (NTP)

- Understand the OSI layer network model
- Identify typical network components and related technologies on networks
- Be aware of different types of network and their typical characteristics
- Understand the differences between network time protocol (NTP) and precision time protocol (PTP) networks

| | | |
|---|---|---|
| | – Precision time protocol (PTP) and IEEE1588v2 standard<br>– Synchronous Ethernet and White rabbit<br>→ **High-performance time and frequency methods over fibre**<br>→ **Benefits of networks for time and frequency dissemination**<br>→ **Future plans** | |
| Advanced Level | ***Block 1: Advanced time and frequency concepts*** | |
| | *This 'Advanced topics in time and frequency' block can be used to cover selected topics from the 'Intermediate' section of this blueprint in more detail and technical complexity.*<br><br>*Given the advanced technical level of this block, the exact topics to be covered will depend upon the requirements of the audience in attendance.* | |
| | ***Block 2: Advanced methods, current research and applications*** | |
| | → **Measurement of absolute optical frequency**<br>– Optical frequency combs<br>– Applications<br>→ **Advanced optical time and frequency transfer methods**<br>– Physical layer features of fibre optic networks:<br>○ Fibre types<br>○ Routes<br>○ Optical vs. electro-optic regeneration<br>○ Optical amplification techniques<br>○ WDM, phase and group delay<br>○ Dispersion<br>○ Polarization<br>– Dealing with impairments in the context of time and frequency transfer:<br>○ Origins of fibre phase noise<br>○ Active noise compensation<br>○ Two-way transfer<br>○ Polarization effects<br>– RF-over-fibre vs. optical carrier methods:<br>○ Principles of operation<br>○ Performance limiting factors<br>○ Operational requirements<br>○ Compatibility with data networking<br>– Examples of implementations:<br>○ Commercially available instrumentation, e.g. Raman amplifier, EDFA, ELSTAB, REFIMEVE+<br>○ Experimental techniques based on published research<br>→ **Current research trends**<br>– Future redefinition of the second<br>– Optical clock comparisons | → Understand the principles of operation and applications of optical frequency combs<br>→ Identify current research trends in time and frequency<br>→ Understand potential applications of current research trends<br>→ Understand how traceability to UTC(k) sources can be established for selected applications |

| | |
|---|---|
| – Time and frequency system design<br>– Traceable, secure time transfer, e.g. for financial applications<br>– Sub-nanosecond time dissemination using white rabbit<br><br>→ **Overview of potential future applications**<br>– Smart grids<br>○ Phasor Measurement Units (PMU) in distribution networks<br>○ Applying White Rabbit to digital sensor technology<br>– Telecoms<br>– Quantum technologies<br>– Space technologies<br>– Earth sciences<br>– Radio astronomy<br><br>→ **Case study: achieving traceability to UTC(k) source**<br>– For commercial applications<br>– For standards laboratories | |
| ***Block 3: Analysing timing needs and selecting a solution*** | |
| → **How to assess needs**<br>– What factors should be considered? (Accuracy, stability, security concerns, etc.)<br><br>→ **Selecting an appropriate solution**<br>– What are the implications/challenges?<br>– What resources are required?<br>– What infrastructure exists/is required?<br>– What needs to be purchased?<br>– What are the running costs?<br>– Pros and cons of different potential solutions<br><br>→ **Group discussion/question and answer session** | → Understand what factors should be considered when assessing timing needs and how to assess them<br><br>→ Be able to select an appropriate solution according to meet timing needs |
| ***Block 4: Hands-on training*** | |
| *The activities within this 'Hands-on training' block should be tailored to meet the requirements of the audience in attendance.*<br><br>*Representative examples of topics that could be covered in this block are given below.* | |
| → **Example activities include**<br>– Laboratory based sessions covering a range of fibre technologies<br>– Setup and characterisation of a test White Rabbit link over fibre spools in the lab<br>– Calibration of fibre link delay<br>– Setup and characterisation of a WDM fibre link<br>– Clock calibration techniques, *e.g.* portable clock calibration<br>– Accuracy trials between PTP and NTP networks | → Use/calibrate relevant equipment |

# 4 Conclusion

This document provides a detailed outline of topics for a comprehensive course in time and frequency metrology, including the time and frequency transfer over optical fibre methods which are the basis of CLONETS.