BIPM Capacity Building & Knowledge Transfer Programme
2024 BIPM - TÜBİTAK UME Project Placement

REPORT

Project Name	Time and frequency measurements. Application of the atomic clocks in modern technology
Description	Fundamental principles of atomic clock, and its application in technology. Time and frequency-related measurements
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Motivation & Introduction

Time is one of the most crucial quantities in science. The unit of time is measured with high accuracy based on the frequency of the hyperfine energy levels of the cesium-133 atom. Consequently, it is more convenient and reliable to redefine other SI units through the concept of time. Atomic clocks are employed as extremely precise tools for timekeeping and other applications.
Currently, Coordinated Universal Time (UTC) serves as the global standard for precise timekeeping, maintained by the time laboratories of National Metrology Institutes (NMIs) or Designated Institutes (DIs). These laboratories hold primary frequency standards and contribute their time data to the Bureau International des Poids et Mesures (BIPM) to establish UTC.
Furthermore, time-related measurements play a critical role in science, metrology, high-speed communication, secure communication, navigation systems, and other fields. This research aims to investigate the definition of the time unit, time and frequency-related calibration, and establish a National Time standard.

Research

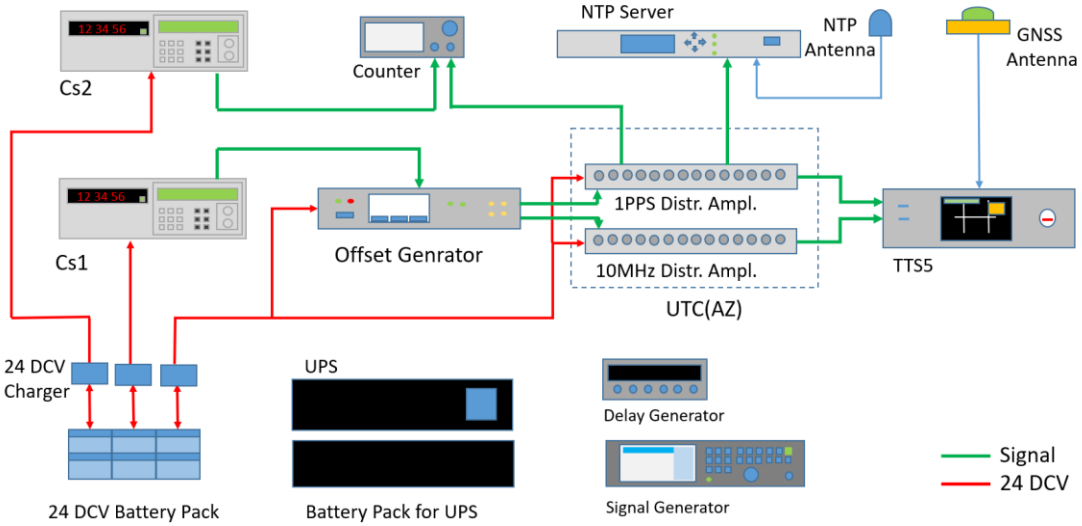
Atomic clocks are one application of the fundamental properties of atoms. Specific atoms are selected based on their quantum states, and a quartz oscillator is locked to the frequency of the hyperfine energy transition of these atoms. This allows the oscillator to

generate one second or 1 Hz. Cesium atomic clocks achieve accuracy levels between E-13 and E-14, meaning a one-second deviation would occur only after at least one million years.

In time metrology, three primary types of measurements are conducted: frequency measurements, time interval measurements, and count measurements. Each type has its own specific methods. The differences between direct frequency measurement and phase measurement techniques are also examined. Throughout the project, these measurements were conducted, and the results were analyzed. Sources of uncertainty, as well as uncertainty calculations and budget estimations, were assessed in accordance with international standards.

The project also explored the principles and physics underlying atomic clocks, frequency counters, and optical clocks. Atomic clocks have numerous critical applications across science, metrology, navigation, and communication. In scientific research, atomic clocks have been used to refine fundamental constants, test fundamental physics theories, detect gravitational waves, and more. Time synchronization, time transfer, and unified standards for time (T), frequency (F), and length (L) are key applications in metrology. In addition, atomic clocks are essential for positioning systems and secure communication networks.

One of the most important applications of atomic clocks is establishing Coordinated Universal Time (UTC). Currently, around 90 laboratories with more than 550 atomic clocks worldwide contribute to UTC. The primary objectives of this project are to investigate time metrology and its applications. Scheme 1 illustrates the implementation of this project's results at the Time and Frequency Laboratory of the Azerbaijan Metrology Institute (AzMİ).



Scheme 1. AzMİ Time Scale System

Here, Cs1 is the primary atomic clock, and Cs2 is the cesium-based backup atomic clock. The offset generator will be used to adjust frequency, while distribution amplifiers will provide high-accuracy 1 pps and 10 MHz signals as UTC(AZ). The frequency counter will monitor the time deviation of Cs2. The TTS5 system will determine the difference between UTC(AZ) and UTC, and then send this information to the BIPM. The NTP server system will manage time dissemination services.
These systems and equipment will enable the establishment of Azerbaijan National Time, support time dissemination, provide limited calibration capabilities, and facilitate scientific research.

Conclusions and Future Work

As a result of the experimental and theoretical research conducted at TÜBİTAK UME, I gained valuable experience and knowledge in UTC formation, time services, and limited calibration measurements.
Currently, the Azerbaijan Metrology Institute has all the necessary equipment except for cesium atomic clocks for implementing the Time Scale System. The Time and Frequency Laboratory is expected to be prepared soon for UTC contributions, time dissemination, and calibration. Once the laboratory is fully operational, initial results will be published.

Acknowledgments

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