Traceability measurement results of accurate time and frequency in Bosnia and Herzegovina

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Abstract - **This paper presents the way of realization traceability measurement results of accurate time and frequency in Metrology Institute of Bosnia and Herzegovina (IMBIH). IMBIH will realize international traceability using GPS Common view t&f transfer technique. Also, by this paper, other existing t&f transfer techniques with characteristic measurement uncertainty, will be mentioned. Realization of international traceability is implemented through participation of 68 t&f laboratories all over the world, whose results contribute to calculation of reference UTC. Final result of reference UTC is provided by Bureau des Poids et Mesures (BIPM) using special algorithm. In the near future IMBIH will realize international traceability of measurement results, by participating in previously mentioned measurement system. In order to be a part of this system laboratory has to fulfill technical requirements defined by BIPM.**

Keywords – **traceability; ALGOS; common view; BIPM; measurement uncertainty.**

I. Introduction

Traceability in metrological sense is a *property of a measurement result* whereby the result can be *related to a reference* through documented *unbroken chain of calibrations*, each contributing to the *measurement uncertainty* [1].

Obviously the definition is very general, which makes slightly difficult to understand it properly. This tends to cause problems with application in the field laboratory. Certain fragments of the definition are described below:

- Property of measurement result: means that traceability should be an intrinsic quality of every results of measurement or data given by any measuring instruments used in the process of measurement;
- Related to a reference: describes a direct or indirect *link between values of the highest reference and the data measured in the field laboratory* i.e. by working standards, calibrated measuring instrument, etc.;
- Unbroken chain of calibrations: decribes *the way how traceability is provided* and what is a quality of the results at the end of the measuring process (a value with its uncertainty);
- Measurement uncertainty contribution requires metrology practice to *include the calibration measurements uncertainties into the total budget of any measurement which is placed below in the metrological traceability chain.*

The UTC is world-wide reference timescale. Its generation and dissemination is one of the main task of the BIPM Time Department. Physical realization of UTC do not exist. Instead, individual laboratories "k" realize an approximation to UTC, named UTC(k). The BIPM computes and publishes UTC – UTC(k) and its uncertainties in five day interval referenced to Modified Julian Dates (MJD) at 00:00:00 UTC in the monthly published Circular T. Calculation of UTC timescale is based on special algorithm called ALGOS used by BIPM. It is step by step algorithm. The link and the clock comparison data are filtered and cleaned from outliers [2]. Typical results of Circular T issued by BIPM are presented in Figure 1.

Today, realization of international traceability in time and frequency domain is based on differences between reference UTC and local realizations of UTC for all participants (t&f labs) in world measurement system. The second way to obtain traceability up to the highest metrology level is through other National Metrology Institute (NMI).

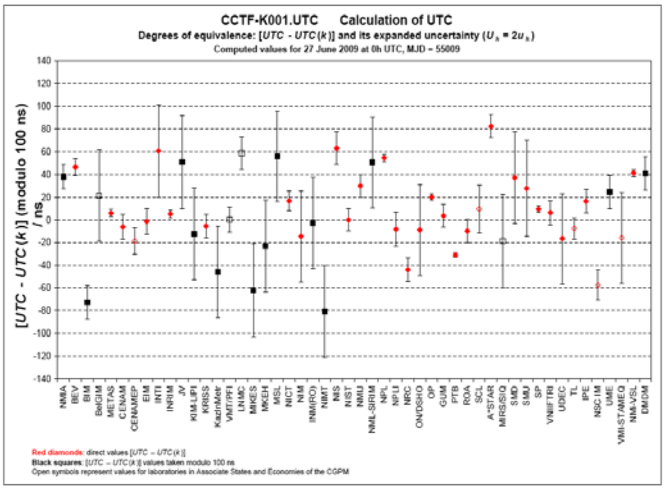
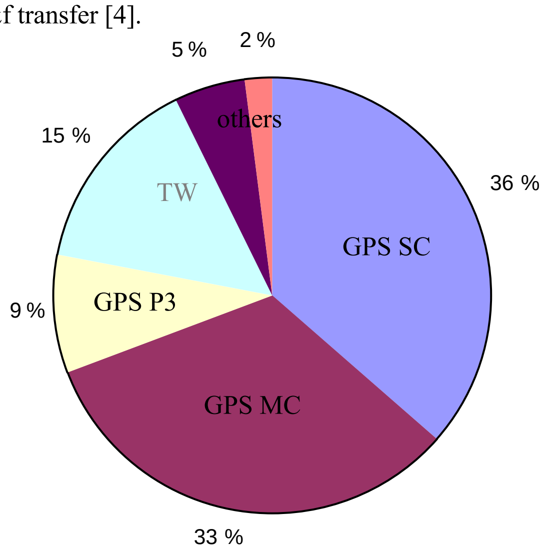


Figure 1. Graphical representation of time differences UTC-UTC(k) for all laboratories in international t&f measurement system (Circular T) [3]

II. TRACEABILTY USING US THE GLOBAL POSITIONING SYSTEM (GPS)

US GPS has become the dominant reference source for high accuracy time and frequency measurements. GPS consists of an orbiting constellation of at least 24 satellites and four should be visible at all times from any location on Earth. Time and frequency signals from GPS are referenced to local realization of UTC in United States Naval Observatory (USNO). Every satellite is equipped with two rubidium and two cesium clocks. Communication between laboratories and satellites are carried out by Pseudo Random Noise (PRN) codes which modulates carrier signal. PRN code enables recognition of each satellite in GPS constellation. Measurement data is comparing between atomic clocks at the GPS satellites and ground clocks in laboratories. There are several techniques usually used for mentioned comparisons, as one way, common view (CV), all in view (AV) GPS methods. Also, there is one non GPS technique, named Two way satellite time and frequency transfer (TWSTFT). Facilities which use in mentioned techniques, are operated in countinuous mode to allow the computation of phase and frequency differences of atomic clocks and timescales. GPS and TWSTFT techniques are used for frequency comparisons as well as for time transfer to realize reference UTC. Frequencies can be compared with an uncertainty in the 10^{-15} range with one day averaging and timescale differences can be compared at one nanosecond level. Contribution of different techniques is shown in Figure 1. As it presented, GPS techniques are the most widespread tools for t&f transfer [4].



TW: Two Way Satellite Time and Frequency Transfer
GPS SC: single-frequency single-channel C/A code GPS time transfer
GPS MC: single-frequency multi-channel C/A code GPS time transfer
GPS P3: dual-frequency multi-channel P3 code GPS time transfer
Others: GPS time observation and internal links

Figure 2. Techniques of time transfer used for clock comparison in UTC [4]

As shown on Figure 2, there are GPS sub-techniques which are characterized with specific types of GPS receivers. Depending of channel numbers of GPS receivers there are GPS SC and GPS MC techniques. Mentioned techniques use coarse and precise acquisition code respectively and that leads to typical precision: 10 ns for GPS SC and 1 ns for GPS MC. Principle of all t&f techniques is based on measurement one second time interval. Figure 3 presents fundamental measuring chain for measuring one second time interval consisted of: GPS satellite, GPS receiver, time interval counter and atomic clock. This technique is known as GPS one way. The second is defined as average value of pulse duration got from ground atomic clock and atomic clock situated in GPS satellite:

$$1\,[s] = \frac{N \times T_1 + N \times T_2}{2N} \qquad (1)$$

where:

N - number of pulses from ground and GPS atomic clocks
T_1, T_2 - duration of one second interval from both atomic clocks

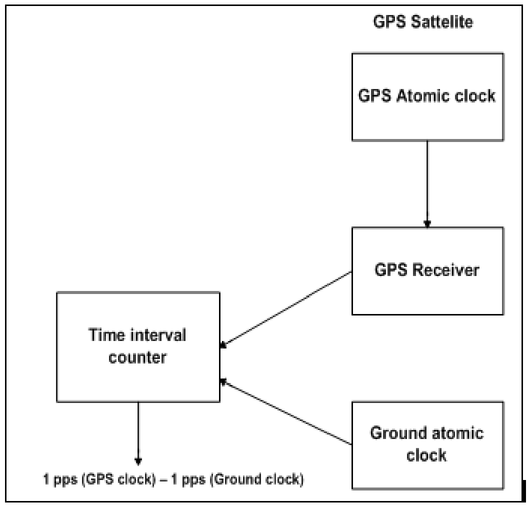


Figure 3. Technique for measuring time interval of 1 second

In this way, calculated 1[s] is distributed and maintained for long time period (one hour). After that, new value (corrected) of one second is distributed. This cycle is repeated at equal time intervals (i.e. 1 hour). In this way, atomic clock in national laboratory indirectly achieves international traceability up to reference UTC. Based on this technique, traceability chain is realized through differences (UTC(k) - GPS_{time}), ($UTC_{reference}$ - GPS_{time}) and ($UTC_{reference}$ - UTC(k)). Main sources which contribute to error related to mentioned differences are: signal delay in GPS receiver, signal propagation through troposphere and ionosphere and signal cable delay etc. Measurement uncertainty of mentioned technique is about 10^{-13}/day. There are other techniques (TWSTFT, GPS CV, GPS AV) characterized with lower measurement uncertainty used by NMIs all over the world.

III. PLANNED GPS TECHNIQUE TIME AND FREQUENCY TRANSFER IN IMBIH

Based on identification of national needs in B&H and role IMBIH at the international metrology level (achieving international traceability, participation in supplementary and key comparisons), it is necessary to choose t&f technique that satisfy two mentioned conditions. On the other hand, compromise between price and performance of t&f transfer techniques is realized. TWSTFT represent the most exact procedure to compare time scales of institutes which are far away from another. Advantages of mentioned technique are small measurement uncertainty and availability of the measurement results in quasi real time. Disadvantages are: sophisticated equipment required in each station (very high costs cca 100 000 euro) and transponder must be made available by the satellite operator (sometimes at great expense). It is possible to realize all GPS sub-technique with existing GPS t&f transfer equipment. In principle, distinctions between mentioned sub-techniques are: data format, processing time for measurement data, measurement uncertainties etc. For achieving the best measurement uncertainty combination of different techniques are used. Costs for t&f GPS transfer equipment are not so high as in the case of TWSTFT [5]. Typical measurement uncertainties for all t&f transfer techniques are presented in the Figure 4.

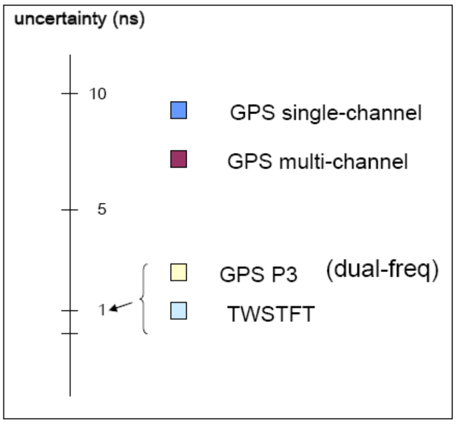


Figure 4. Typical measurement uncertainties for different t&f transfer techniques [6]

As it shown in the Figure 4, total measurement uncertainty consists of two parts: type A and type B. Type A is defined with statistical treatment of measurement data. In the second case, type B represents part of total measurement uncertainty that is not derived from statistical method (identification of signal delay of GPS receiver, propagation signal delay through ionosphere etc.). Based on previous explanation, IMBIH will realize GPS common view t&f transfer technique. The main reasons for implementation of mentioned technique are: lower price in comparison of TWSTFT equipment, very good total measurement uncertainty (lower than 10 ns).

CV allows the direct comparison of two clocks at remote locations. Setup of CV is illustrated in the Figure 5. In this technique, two stations, receive a one-way signal simultaneously from a single transmitter and measure the time difference between this received signal and their own local clock. The data are then exchange between stations in lab A-lab B and BIPM using standard ways (e-mail, FTP etc). Time difference between clocks in lab A and lab B is calculated by taking the difference between simultaneously UTC(labA) – GPS_{time} and UTC(labB) – GPS_{time} = Δt_B clock difference measurements.

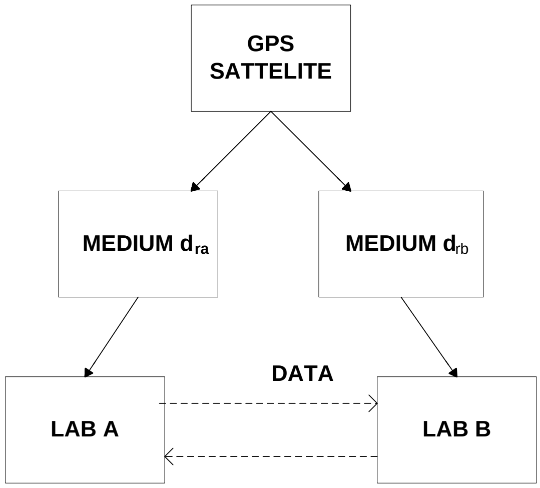


Figure 5. Common view setup [7]

Generally, one of these laboratories has primary realization of SI second. For the performance of time comparisons, a GPS receiver is synchronized with local realization of UTC in every laboratory. Mentioned differences for labA and labB can be expressed for as follows:

$$UTC\ (labA) - GPS_{time} = \Delta t_A \qquad (2)$$

$$UTC\ (labB) - GPS_{time} = \Delta t_B \qquad (3)$$

Each lab observes the time difference between its local realization of UTC and GPS time plus a propagation delay, which can be largely removed by using the one-way GPS time transfer procedures. By exchanging data files and performing a subtraction, the time difference between the two receiving stations is obtained and the GPS time drops out as indicated in equation as shown:

$$[UTC(labA) - UTC\ (labB)] = \Delta t_A - \Delta t_B \qquad (4)$$

It is important that the observations be made on the same satellite at the same time. Otherwise the stability of the GPS clock becomes a factor. This technique gives improved performance over the one-way technique because many errors are common mode and are therefore reduced.

Besides other t&f transfer techniques, GPS common-view technique has been used for many years by the BIPM as one of its main techniques for international time comparisons. The BIPM publish tracking schedules at its web site, so that observations between pairs of labs can be made simultaneously for the same satellite [7]. The accuracy of common-view time transfers is typically in the 1 to 10 ns range, with statistical uncertainty $u_A \approx 2.5$ ns and systematic uncertainty $u_B \approx 5$ ns. In cases of very long distance between two labs it is better to use all in view GPS method or TWSTFT, because the performance (total measurement uncertainty) of GPS CV settles down for long intercontinental baselines [7], [8].

International traceability of t&f measurements in B&H will be established using GPS CV as it shown in Figure 6.

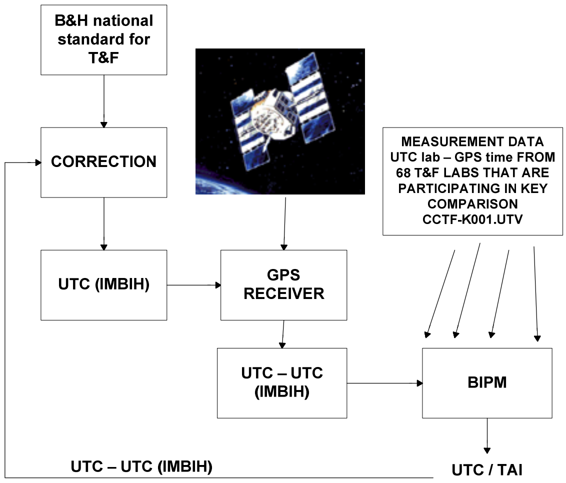


Figure 6. Potential international t&f traceability in B&H using GPS system

IV. ROLE OF THE BIPM IN ORGANIZING INTERNATIONAL TIME AND FREQUENCY MEASUREMENT SYSTEM

As it described before, BIPM is responsible to collect measurement data from all national laboratories which are contributing in calculation of reference UTC, and through its algorithm generates reference time. Over the years, the CIPM has set up a number of Consultative Committees. Among the tasks of these Committees are the detailed consideration of advances in physics that directly influence metrology, the preparation of recommendations for discussion at the CIPM, the identification, planning and execution of key comparisons of national measurement standards as CCTF-K001-UTC, and the provision of advice to the CIPM on the scientific work in the laboratories of the BIPM [9].

Activities of Consultative committee for time and frequency (CCTF) concern matters related to the definition and realization of the second, establishment and diffusion of International Atomic Time (TAI) and Coordinated Universal Time (UTC), and advice to the CIPM on matters related to time and time scales [10].

The main goals of International Committee for Measures and Weights (CIPM) Key Comparison CCTF-K001.UTC are to:

- Provide traceability to the international reference UTC through its local approximations UTC(k) maintained in national laboratories;
- Enable the broad dissemination of UTC by the participating laboratories located all around the world [9].

Through participation in mentioned Key comparison, IMBIH will obtain traceability to the SI second and other various related quantities. IMBIH's t&f laboratory should fulfill following conditions to contribute to the calculation of UTC at the BIPM:

- become a Member State of the BIPM or to an Associate of General Conference for Measures and Weights (CGPM);
- be equipped with atomic standards;
- has equipment adapted for time transfer, producing data in standard format as requested by the Consultative Committee for Time and Frequency (CCTF) and BIPM;
- has the capacity to report data to the BIPM on a continuous basis [11].

Institute of Metrology of Bosnia and Herzegovina (IMBIH) had signed International Committee for Weights and Measures Mutual Recognition Arrangement (CIPM MRA) on 15th June 2011. After that, B&H became Associate of General Conference for Measures and Weights (CGPM). As it mentioned before, that is one of the mandatory conditions that t&f laboratory must fulfill to participate in key comparison in time CCTF-K001.UTC. The objectives of mentioned arrangement are:

- to establish the degree of equivalence of national measurement standards maintained by NMIs;
- to provide mutual recognition of calibration and measurement certificates issued by NMIs;
- thereby to provide governments and other parties with a secure technical foundation for wider agreements related to international trade, commerce and regulatory affairs [12].

Based on previously described concept, t&f laboratory in B&H will establish international traceability of accurate time and frequency measurement results with capacity to measure:

- Time Scale Difference: local clock vs. UTC (IMBIH) and local clock vs. UTC;
- Frequency (generating standard frequencies 0.1 MHz, 1 MHz, 5 MHz, 10 MHz);
- Time Interval (period, rise/fall time, delay time, pulse width).

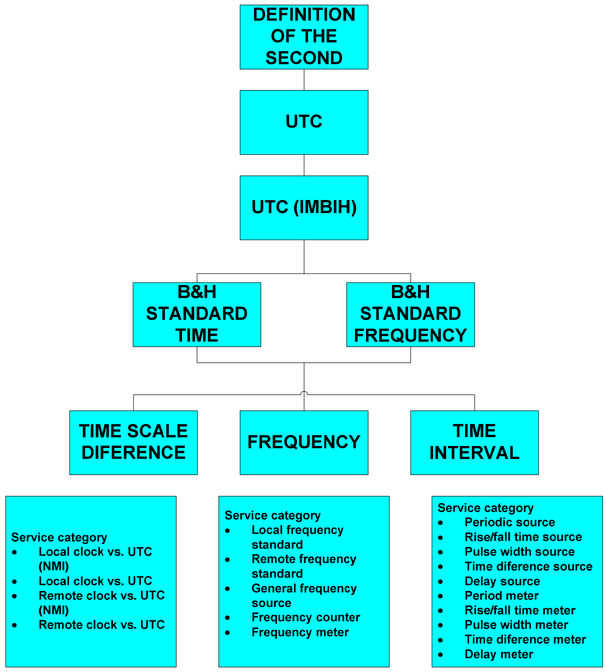


Figure 7. International traceability to SI second with CMCs in t&f domain respective to all classification services defined by BIPM

Figure 7 presents international traceability in time (frequency) to SI second with calibration and measurement capabilities (CMCs) respective to classification of all services defined by BIPM.

V. Conclusion

This paper presents detailed way of realization international traceability measurement results of accurate time and frequency in Metrology Institute of Bosnia and Herzegovina (IMBIH). As it shown, IMBIH will realize international traceability using GPS Common view time and frequency transfer technique. Also, by this paper other, existing t&f transfer techniques with characteristic measurement uncertainty, are mentioned. In this paper is also generally discussed about international traceability to SI second and technical requirements that one lab has to fulfill to participate in Key comparison CCTF-K001.UTC. By realizing all mentioned activities, Bosnia and Herzegovina will have international traceability of measurement results in time and frequency metrology area.

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