MAINTENANCE OF UTC(MIKE) IN FINLAND BY USING A DELAY GENERATOR AS A MICRO STEPPER

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ABSTRACT

Local time in the Centre for Metrology and Accreditation is derived from our master clock, a hydrogen maser. An often occurring phenomenon in hydrogen masers is a small, approximately constant frequency drift. As a consequence, the time error of a hydrogen maser typically follows a parabola. To compensate for this, a programmable delay generator is used to produce an opposite function. Thus, a local time UTC(k) is frequently a combination of master clock time and a programmable delay. In the Centre for Metrology and Accreditation we follow this approach. The delay generator is computer controlled to generate a parabolic delay d: $d(t) = a+bt+ct^2$, where c is aging factor in ns/day^2 (which is essentially stable), b is rate correction in ns/day, a is constant in ns, and t is time in days from start ($MJD\text{-}MJD_0$).

The aging factor c of our master clock is less than 3 ps/day^2, equivalent to df/f < 1x10^{-16}/day. The produced time UTC(MIKE) is compared to UTC via dedicated time and frequency receivers. Calculation of the parameters a, b and c, predicting the behaviour of the master clock, is the key problem of accurate time keeping. To maintain the time difference UTC-UTC(MIKE) within ±10 ns, as published in Circular-T, elaborate calculations with supporting data from other atomic clocks in the laboratory are required. Since October 1, 2009 up to the end of March 2009 UTC-UTC(MIKE) has stayed within ± 9 ns, which at the moment seems to be the tightest range of all the participating laboratories.

INTRODUCTION

Centre for Metrology and Accreditation (MIKES) maintains the UTC time in Finland. UTC(MIKE) has been reported by BIPM since April 2004 (from MJD 53464). MIKES has altogether five atomic clocks, two Cs clocks and three masers, of which two are active and one is passive. Each clock is placed in a separate, temperature controlled cabinet. The cabinets are located below ground in a temperature and humidity controlled laboratory. The power supply is a stable 230 V uninterruptible power supply (UPS) with a local direct current battery back-up.

The master clock (MC), Kvarz CH1-75A, is our most stable hydrogen maser. The tick of the MC initiates the time difference measurements and drives the delay generator. A commercial delay generator (SRS DG645) with 5 ps time resolution produces the UTC(MIKE), which in turn supplies time to two GPS time and frequency receivers (GTR50 and Legacy-E GPS/GLO). The time resolution of the delay adjustment is one minute. Due to the GPS PPP time link, BIPM publishes our REFPGS results in "PPP" section with 18 other laboratories instead of the conventional "corrected GPS data" section.

The steered delay d is a parabola: $d(t) = a + bt + ct^2$, where a is constant in ns, b is rate in ns/day and c is aging in ps/day^2. The problem is to define all the parameters in a way that makes the UTC(MIKE) an optimal estimate of UTC. We try to optimize both the rate and value of UTC-UTC(MIKE) difference. Our results since October 2009 are shown in Fig. 1. The rate has been all the time within ± 0.35 ns/d and time deviation within ≈ ± 5 ns.

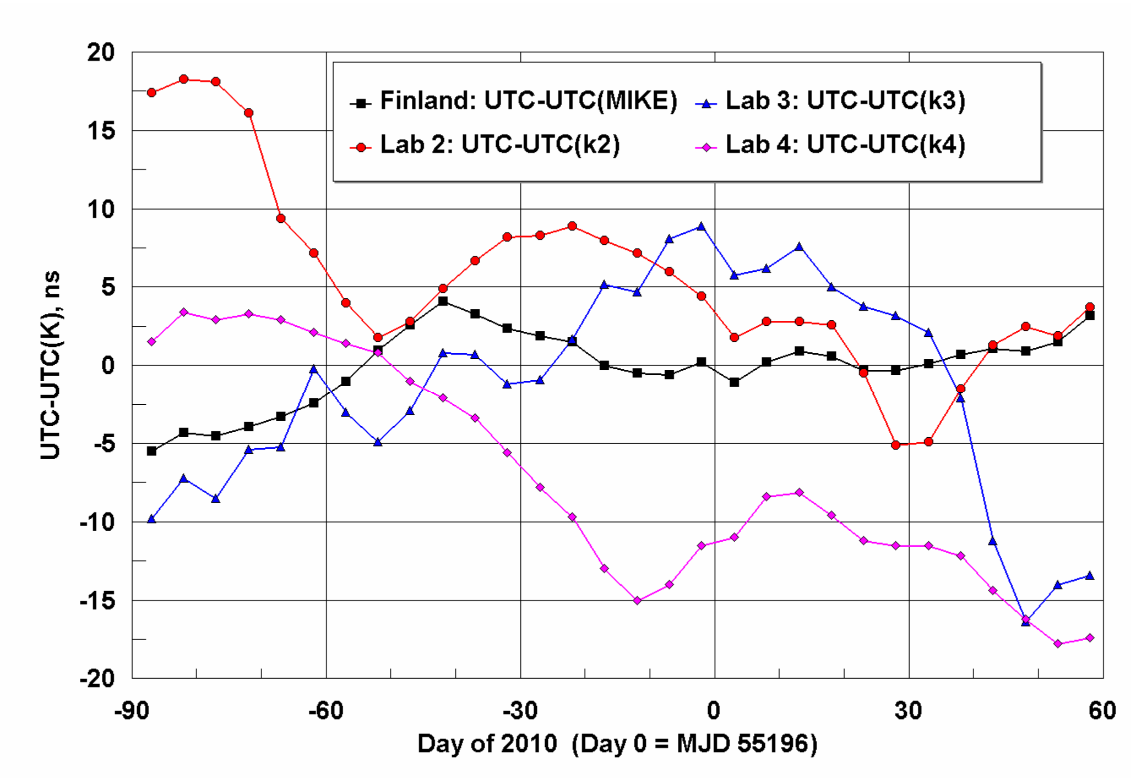

Fig. 1. The UTC estimates UTC-UTC(k) of MIKE and three other PPP laboratories

Calibration of time and frequency receivers at MIKES is achieved through clock comparison with SP (The national metrology institute of Sweden), where a two-way satellite transfer link is available. We have done several time comparisons since 1972. The latest comparison was within the framework of the Euromet project 860. The results of this comparison lead us to believe that UTC(MIKE) is within +/- 2 ns of corrected UTC(SP) [1].

ENVIRONMENTAL STABILITY OF CLOCKS AND RECEIVERS

The laboratory building of MIKES was completed in 2005. The building has excellent environmental conditions for the maintenance of different metrological quantities. The input air of the laboratories is conditioned in two levels (make-up machines and laboratory group machines, 41 air conditioning machines total). The incoming air is first standardized by humidifying it to saturation and then cooling it down to ≈ 9 °C to reach 100% relative humidity. When air is reheated to 23 °C it produces very stable relative humidity of ≈ 41 %. In addition, some of the laboratory racks have their own temperature condition machines, e.g. racks for the atomic clocks. The building stands on solid rock and is thus vibrationally stable. The power for the building is provided by two 1 MVA transformers, first for the "dirty" power (air conditioning machines, lighting, cleaning etc.) and the second for "clean" power (computers, laboratory devices). In addition, a diesel generator and an UPS system provide the essential devices with power in case of power grid failure, a rare occasion. The building and the positions of the three FT laboratories are depicted in Fig. 2. In Figs. 3 and 4 show the temperature and relative humidity history of the atomic clock cabinets of MIKES over a time period of five months from Oct. 2009 to Feb. 2010.

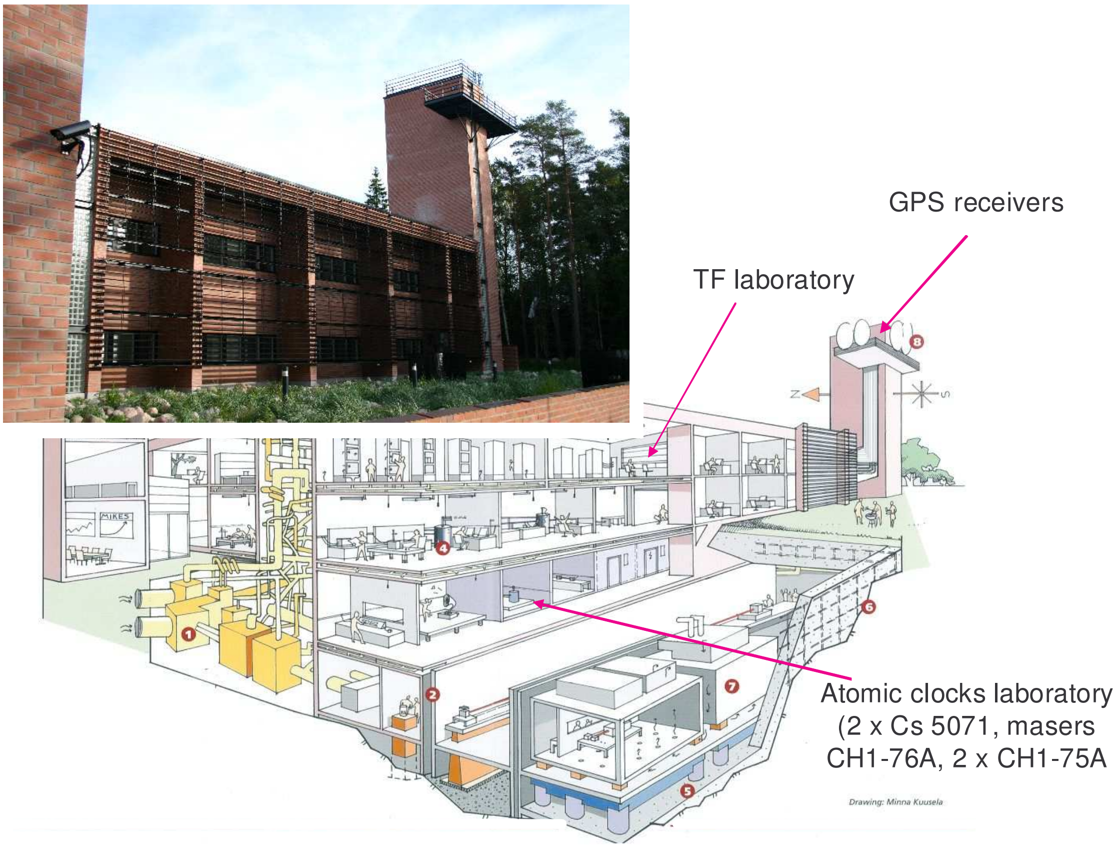

Fig. 2. MIKES building and the positions of time and frequency laboratories

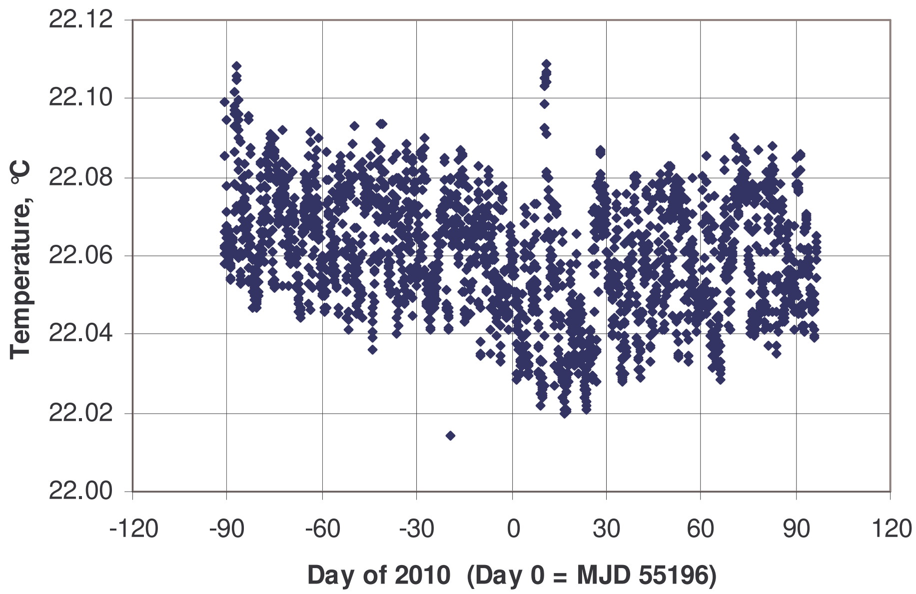

Fig. 3. The temperature of incoming air for the atomic clocks

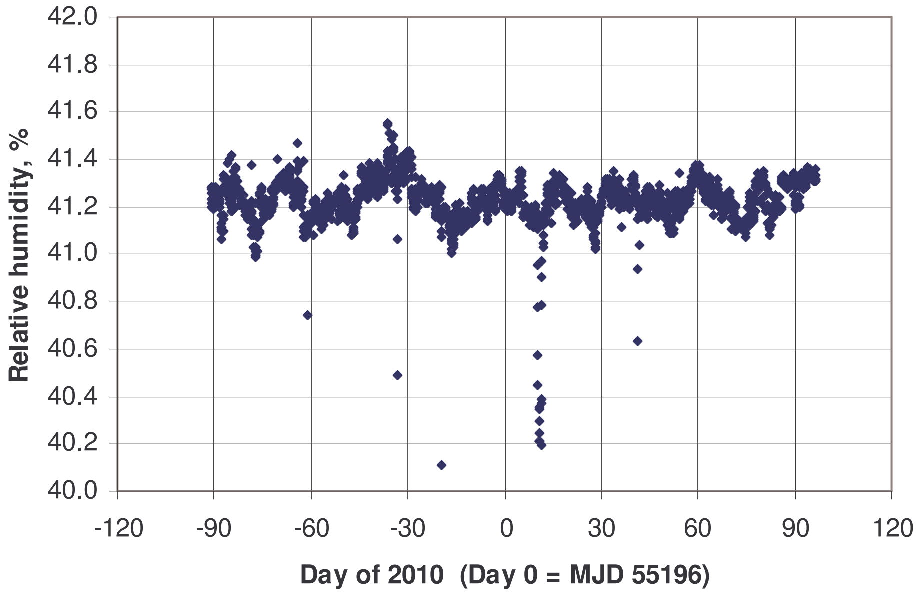

Fig. 4. The relative humidity of incoming air for the atomic clocks

Time and frequency receivers are located in the receiver room of the tower of MIKES, where the ambient conditions are maintained by a separate air conditioning machine without humidity control. Antennas of the receivers are located on top of the tower. There is no temperature stabilization for them or the exposed parts of the antenna cables. Figs. 5 and 6 show the temperature of the receiver room and the outdoor temperature over a time period of five months from Oct. 2009 to Feb. 2010, covering the relatively harsh Finnish winter.

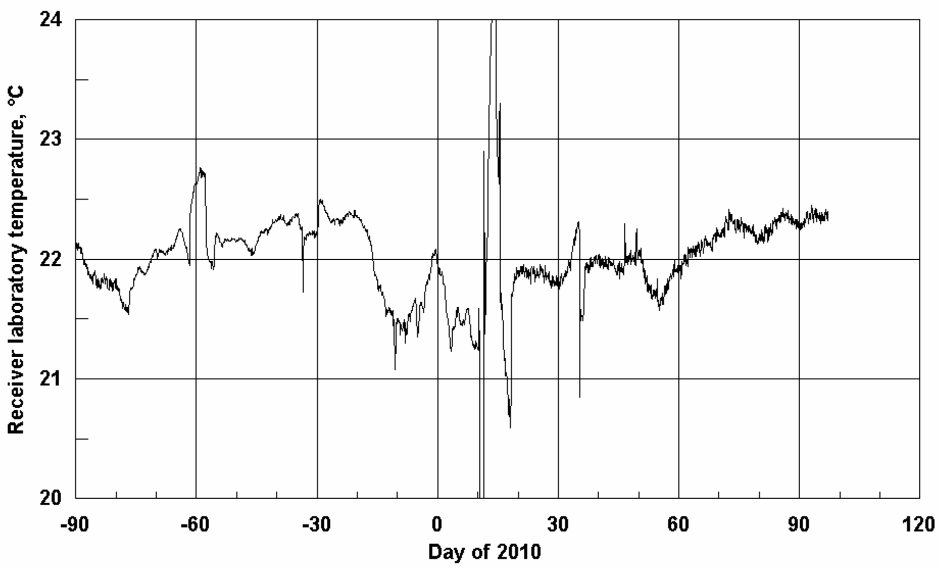

Fig. 5. The temperature of the receiver room of MIKES

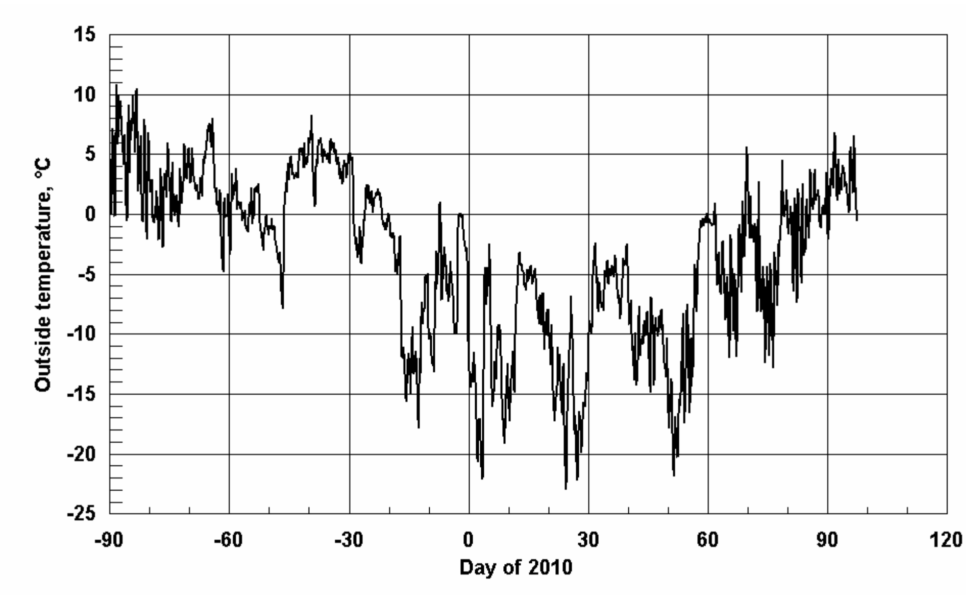

Fig. 6. The outside temperature

MASTER CLOCK STABILITY

Our master clock has been an active hydrogen maser since 2005. The current master clock has been in operation since March 2008. Its aging factor was low even immediately after commissioning and it has decreased, see Fig. 7. Since August 2009 aging has been around 1 ps/day^2, equivalent to df/f ≈ $2 \cdot 10^{-17}$ per day. This value is approximately ten times better than the specifications given by Kvarz, the supplier of our H-masers [2], [5].

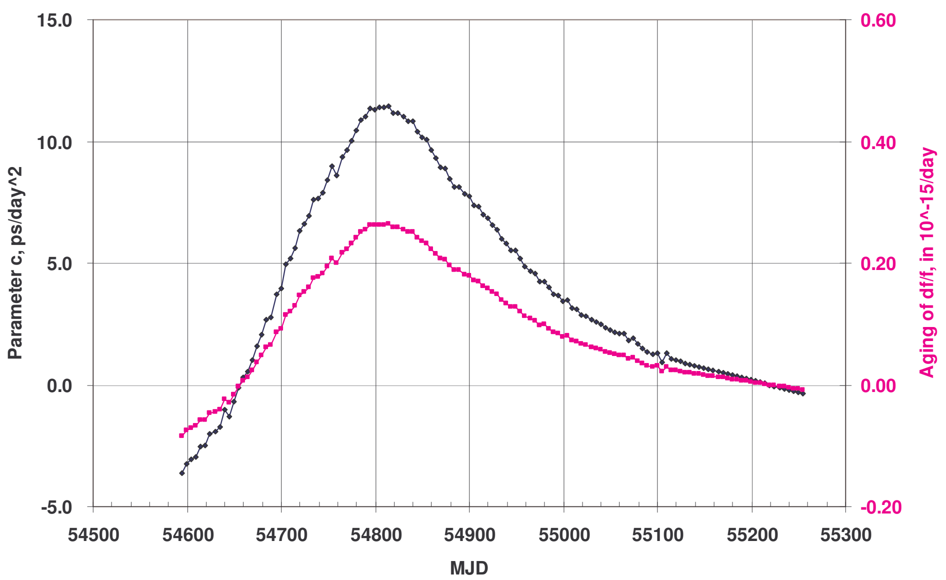

Fig. 7. Stability of master clock

At this stability level even the calculation of the parameters *b* and *c* with an accuracy that produces a meaningful correction is difficult. For example, if we want to know the rate *b* within +/- 10 ps/day, we need at least 6 months UTC-UTC(MIKE) data, provided that the aging keeps very low. Assuming that the rate is known, we need only 2 months of data to check that the aging parameter *c* is less than 1 ps/day^2.

When controlling UTC-UTC(MIKE), the key problem is to forecast the behaviour of MC. The time period that has to be forecasted when a new Circular-T becomes available is typically two weeks to the past and four weeks to the future.

All the means at our disposal to control the stability of MC are used, especially if the last point UTC-UT(MIKE) is an outlier. REFGPS values and data from the rest of atomic clocks is used. Linear and parabolic regressions are used to extrapolate UTC-UTC(MC) data. Our experience from parabolic regression in the case of noisy data is that the optimal regression solution easily overestimates the aging parameter *c*.

The residual standard deviation (RSD) of UTC-UTC(MC) data has been 048 ns during the last 5 months. The only problem at the moment is the "embedded" IGST reference time, but we hope that some organization will start publishing it shortly. The short term residual noise of PPP data seems to be low, about 10 ps, $\tau \approx 1$ h. At present, in order to improve the 048 ns RSD factor, we collect PPP data also from other timing labs. By comparing UTC-UTC(lab) to corresponding PPP data of the above-mentioned labs, we can improve our time keeping slightly. Hopefully this phase can soon be abandoned.

STABILITY OF TIME AND FREQUENCY RECEIVERS

GPS receivers are sensitive to the temperature. E.g. the temperature coefficient of our Legacy CV receiver is around 5 ns/°C and that of its active antenna around 0.1 ns/°C. The temperature stability in the receiver room during the last year was about 1 °C peak-to-peak, short term air conditioning problems excluded. The new receiver, GTR50, has an internal thermostat to keep the receiver part stable. Probably GTR50 and its antenna is less susceptible to temperature variations than Legacy-E, a subject of further studies for us.

The long term (years) stability of GPS-receivers is an open question. Our experience from our older GPS timing receivers [6] points out drifts of 10 to 50 ns/a. Therefore scheduled calibrations of timing receivers are absolutely necessary. For short term stability one development task is to improve temperature stability of the receiver room and to provide elementary stabilization of the antenna temperatures.

STABILITY OF CABLES AND DISTRIBUTION AMPLIFIERS

Euromet 828 supplementary Cable Delay comparison pointed out that the measurement of timing delay of common coaxial cables is not trivial, even in national calibration labs [3], [4]. Typical variation of the results was 0.3 %. For example, the scatter of the results on 36 m cable was 4 ns peak-to-peak. Reason for the unsatisfactory results relates to delay dispersion and frequency dependent attenuation in coaxial cables. Therefore different measuring methods produce different results. When coaxial cables are connected to pps distribution amplifier, the sum of separately measured delays in cables and distribution amplifiers differs easily 0.5 ns from the delay of the whole. This is caused by different pulse responses of cables and amplifiers.

We have done only preliminary studies on stability of cablings. As a first approximation the effects of varying temperatures inside building are not significant, but air pressure variation seems to cause even 0.2 ns peak-to-peak delay changes for the full length of cables (≈ 50 m).

One of the major goals is distribution of UTC(MIKE) correctly between different points inside the building. The only working method for cable delay calibration seems to be a portable rubidium clock and time interval counter. After repeating this calibration three times, we believe that UTC(MIKE) is available within ± 0.3 ns both in receiver tower and in the time laboratory of the second floor.

Fig. 8 shows the principle of cabling for the maintenance of time at MIKES. The times given in the table are clock time differences from UTC(MIKE) at the beginning of March, 2010.

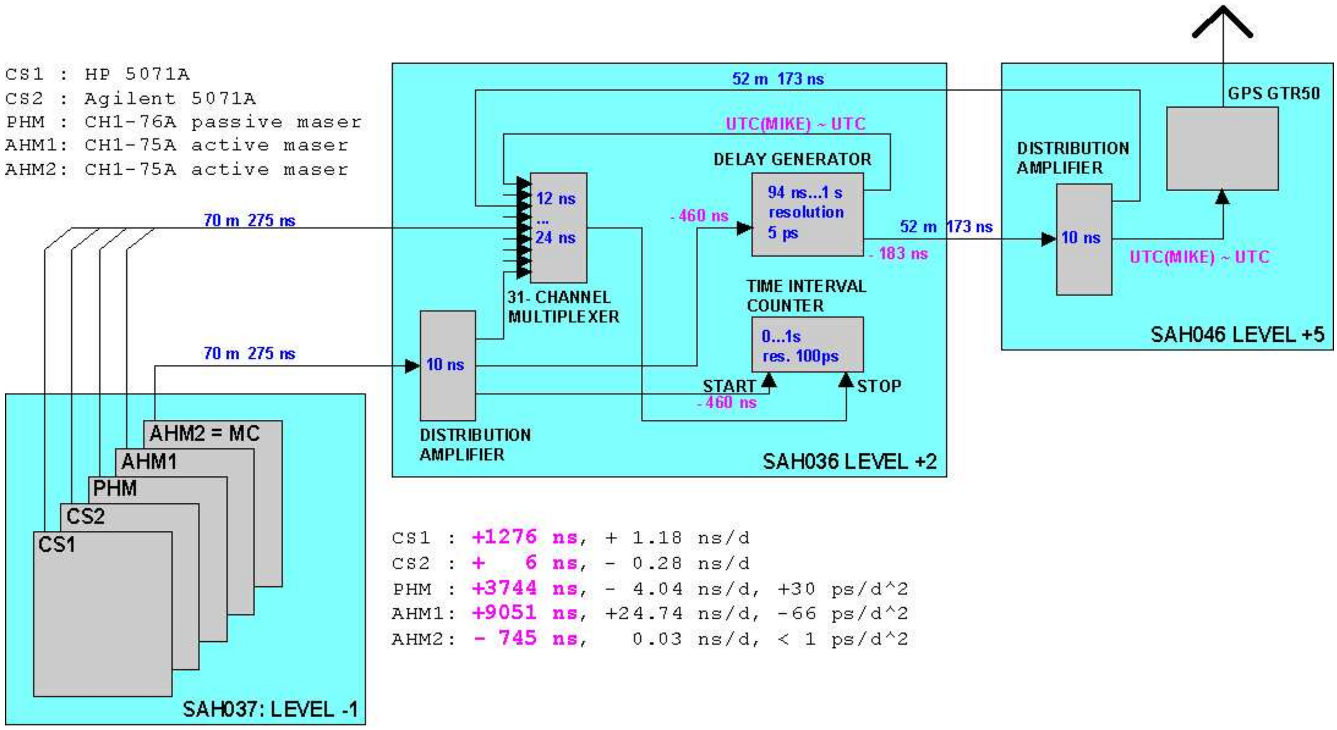

Fig. 8. The maintenance of time at MIKES

CONCLUSIONS

Time keeping at nanosecond level is very complicated matter. When a micro stepper is used, regular adjustments of MC are not needed. When MC stays intact, its stability is better. Temperature effects to receivers and antennas cause problems, when one has to estimate the behaviour of MC using disturbed data. Our masers are sensitive to ambient conditions. Therefore we have stabilized the conditions extremely carefully. In addition, cabling causes some minor problems. The delay itself is quite stable but the result of delay measurement is method dependent. When all those facts are in control, it helps to calculate 45 days extrapolation to UTC-UTC(MIKE), i.e. to set the microstepper parameters.

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