Final characterization of InLambda delay standards for Supplementary Time Interval Comparison

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INTRODUCTION

The EURAMET Project #1288, started in 2013, was aimed to prepare travelling standards for a new Inter-Laboratory Comparison of Time Intervals planned as a Supplementary Comparison in the KCDB, as a response to negative experiences of EUROMET TF community with a cable delay measurement within the EUROMET Project #828 which showed that a cable delay is not well-defined measured quantity and its value is significantly dependent on the shape of signals used for cable delay measurements and the selected trigger levels (maximum difference of about 1 % of the measured cable delay).

Within this project, there were developed and studied two types of standards: the electronic based Time Interval Generator (TIGen) developed by AGH and GUM, characterized before – poster presentation during EFTF 2016, and the based on stabilized optical delay lines Time Interval standards developed and produced by InLambda Company in cooperation with MIRS/SIQ. Here, we present the final results of characterization of three InLambda standards: the assessment of the real accuracy of the generated time intervals, including short- and long-term stability and possible influence of systematic factors, as well as determination of the required repeatability and reproducibility conditions resulting in reduction of systematic effects to a single picoseconds (≤ 10 ps) level.

TRAVELLING STANDARDS UNDER CHARACTERISATION

Fig. 1 The set of three InLambda standards

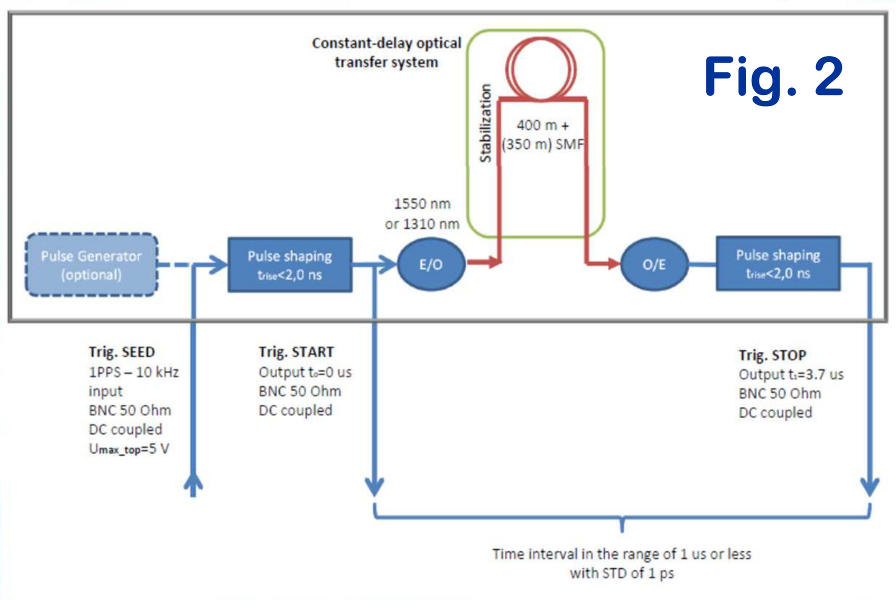
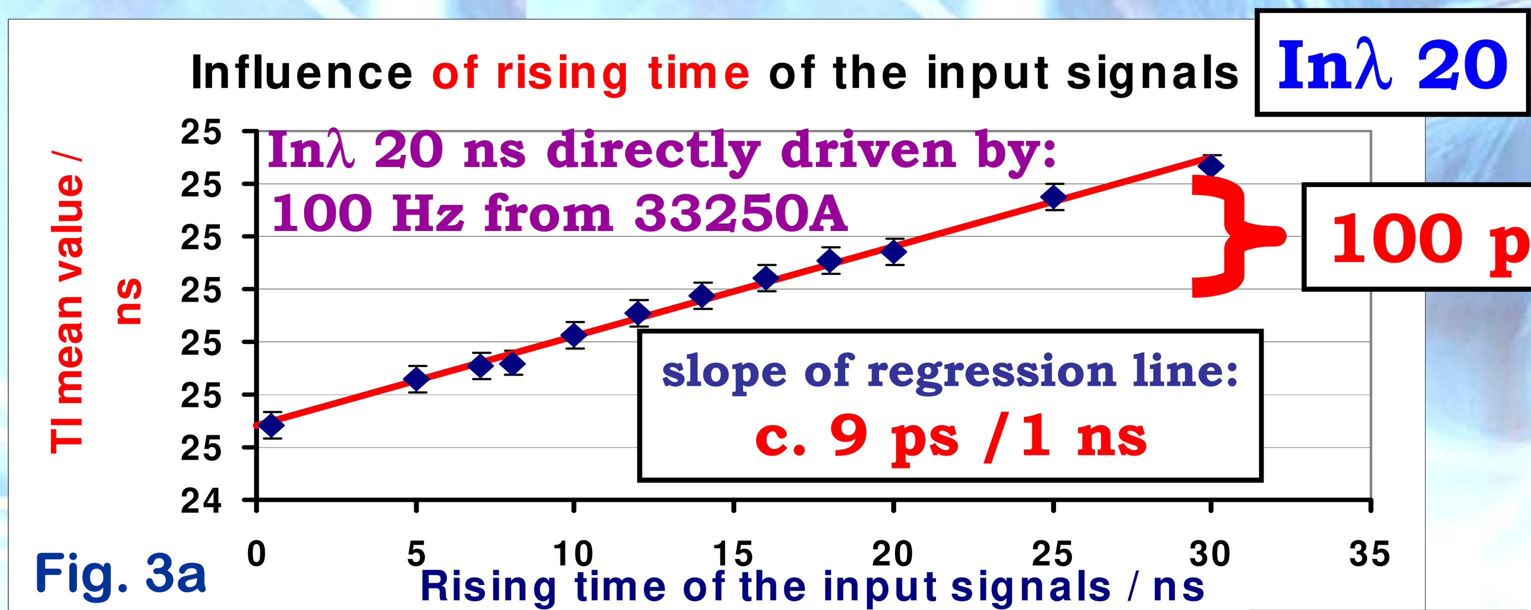


Fig. 2 The block scheme of operation of InLambda standards

The specially developed for TI comparison travelling InLambda standards (Fig. 1a and 1b) are based on stabilised optical delay lines maintained by internal temperature stabilization of the fibers at approximately 35 °C (Fig. 2). Each InLambda standard realizes a single value of time interval defined between START and STOP output pulses: c. 20 ns, c.100 ns or c. 300 ns appropriately. The outputs are precisely matched, so the parameters of output signals are closely the same. Together with very sharp slopes (rise time < 500 ps), it allows to minimize the undesirable effects of start/stop trigger errors and trigger level timing errors. InLambda standards require the external pulses (passed into the input) that are the flywheel of the output signals. The external input pulses should fulfill the special requirements verified below in order to achieve the required repeatability and reproducibility conditions. All signal inputs/outputs are BNC-female connectors. In the fixed external conditions, the observed long-term instability does not exceed 2 ps.

DEPENDENCE ON RISING TIME OF THE INPUT SIGNALS



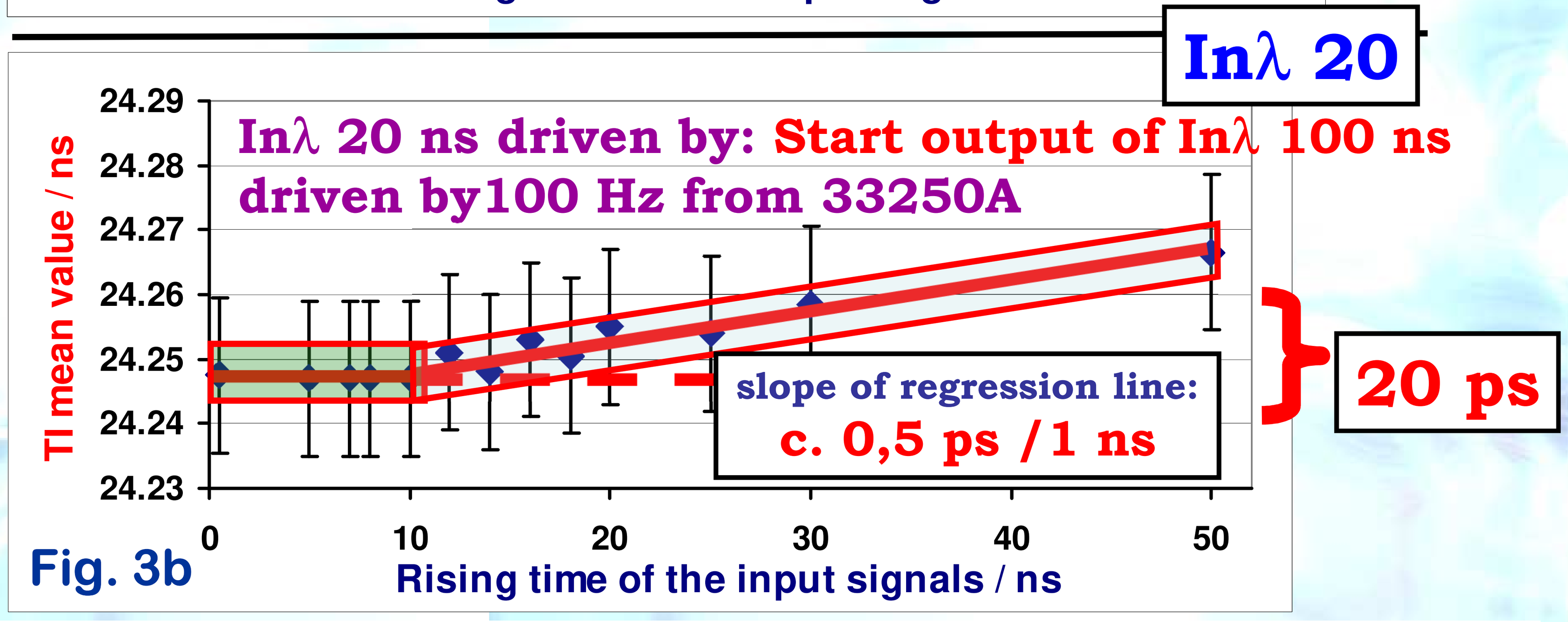
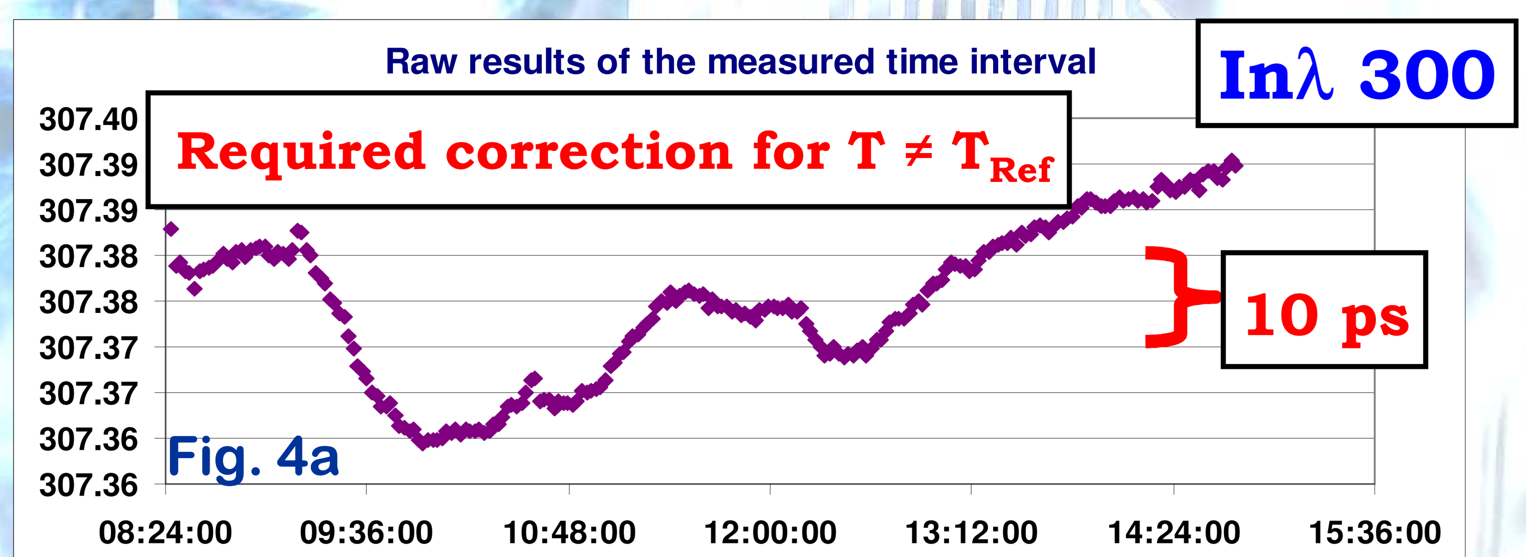


Fig. 3 The observed influence of rising time of the external input signals on the realized time interval – significantly reduced when using the output signal of the other InLambda standard as the input signal of the measured InLambda standard: the effect disappears for rising time <10 ns).

INFLUENCE OF AMBIENT TEMPERATURE



For Inλ 300: c. 2,5 ps / 1 K

For Inλ 100: c. 1,4 ps / 1 K

For Inλ 20: c. 0,6 ps / 1 K

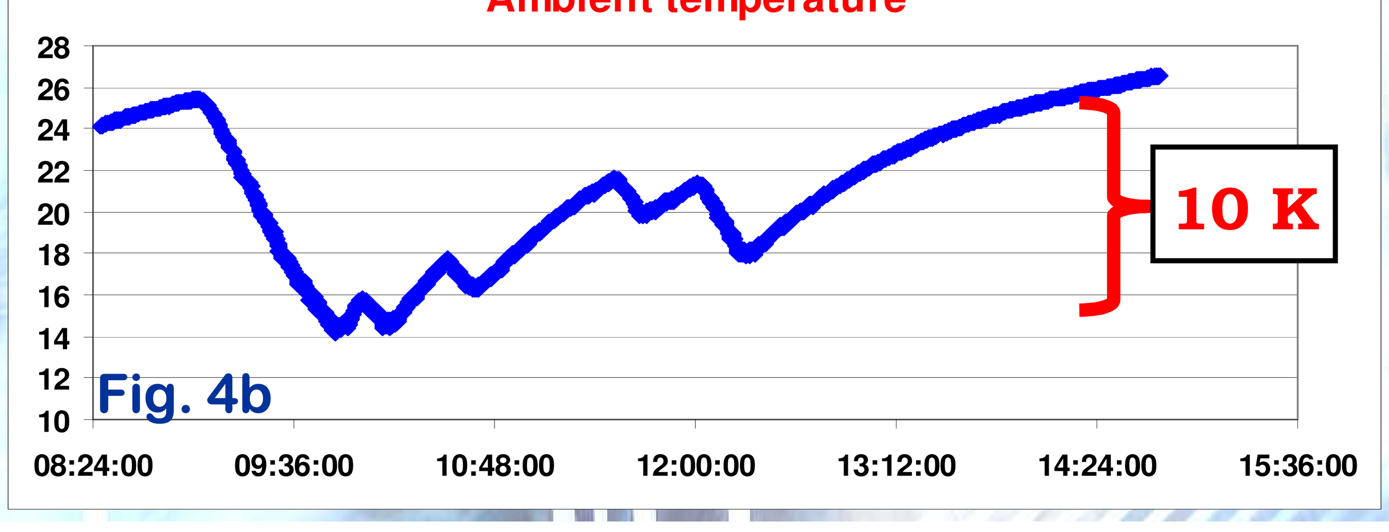
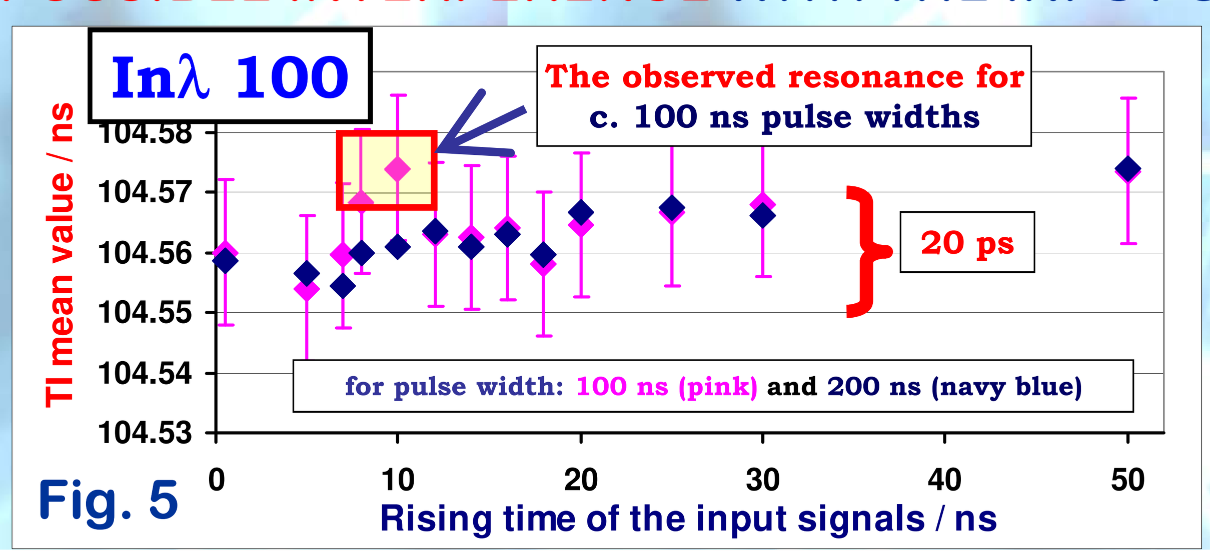


Fig. 4 The observed a small influence of ambient temperature on the realized time interval – probably caused by imperfection of temperature fiber stabilization (not to be omitted at more precise measurements).

POSSIBLE INTERFERENCE WITH THE INPUT SIGNALS



For Inλ 20: at pulse width approx. 20 ns

For Inλ 100: at pulse width approx. 100 ns

For Inλ 300: at pulse width approx. 300 ns

Fig. 5. For some combination of the pulse width and rising time of the input signals, there is possible an interference of the output signals with the input signals. The effect is observed for each standard when the input pulse widths are close to the realized time intervals.

REFERENCE VALUE AND DEGREE OF EQUIVALENCE

$$x_{Ref} = \frac{\sum_{i=1}^{N} \delta_i \frac{1}{u_i^2} x_i}{\sum_{i=1}^{N} \delta_i \frac{1}{u_i^2}} \qquad u_{wei} = \frac{1}{\sqrt{\sum_{i=1}^{N} \delta_i \frac{1}{u_i^2}}} \qquad \delta_i = \begin{cases} 1 & \text{for the „most reliable" results} \\ 0 & \text{for other results} \end{cases}$$

$$u_{Ref}^2 = u_{wei}^2 + u_{rep}^2 \qquad u_{rep} = 5\ \text{ps}$$

$u_{rep} = 5$ ps: evaluated based on observed experimentaly stability and reproducibility of TI

$$u^2(x_i - x_{Ref}) = u_i^2 + \underbrace{(1 - 2\delta_i)}_{=1 \text{ or } =-1} u_{wei}^2 + u_{rep}^2 \qquad E_i = \frac{x_i - x_{Ref}}{U(x_i - x_{Ref})}$$

The „most reliable" results = the results for which it is unambiguously stated that the residual non-linearities of TIC and other non-compensated systematic effects are included into uncertainties which are consistent with other results (omitting outliers).

DEPENDENCE ON THE INPUT SIGNALS FREQUENCY

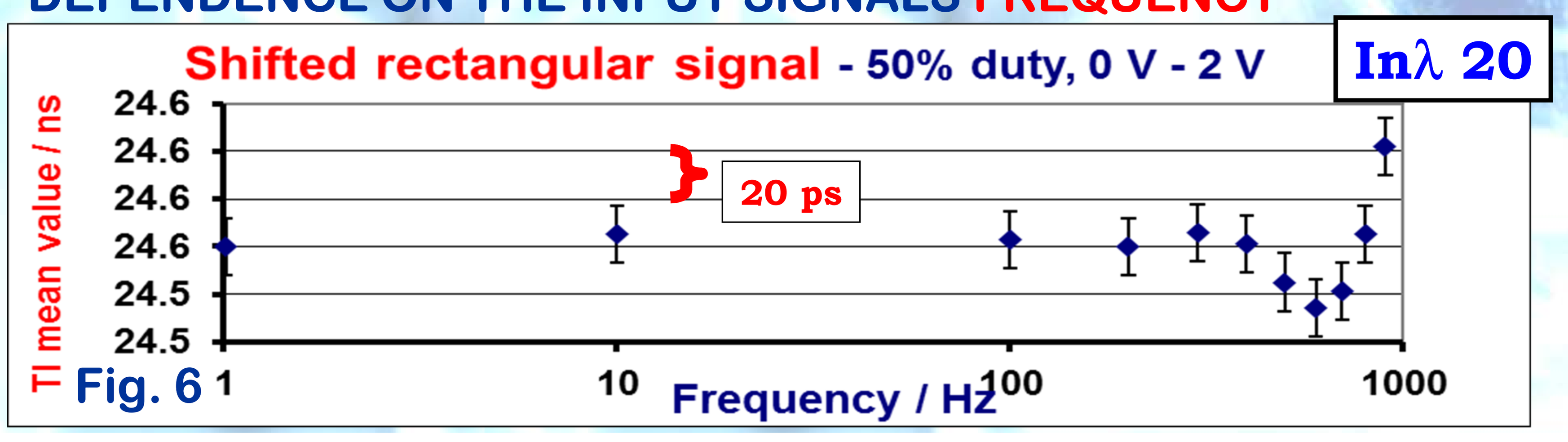


Fig. 6. For the shifted rectangular signals there is no observed change of the realized time interval up to about 200 Hz. For the fixed pulse width, the upper limit frequency will be changeable. (e.g. for 100 ns – c. 5 kHz, for 15 µs – c. 200 Hz).

CONCLUSIONS

InLambda standards are ready for Time Interval Supplementary Comparison:

- the required measurement conditions have been defined (the possible sources of errors have been recognized),
- good stability and reproducibility of generated Time Intervals,
- about 10 ps of assigned expanded uncertainty of the travelling standard.

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