STABILITY OF THE PROPAGATION DELAY IN THE TIME REFERENCE SIGNAL FIBER OPTIC TRANSMISSION

Marcin Lipiński, Przemysław Krehlik, Łukasz Śliwczynski, Andrzej Wolczko

Abstract – To find out what is the possible precision in the F-O (Fiber Optic) transmission of the time reference 1PPS (Pulse Per Second) some hardware experimental works have been done. Basing on the simplex structure of such transmission link the main sources of the propagation delay instability were checked and qualified. Then the Two-Way-Transmission over the optical fiber structure was assembled and the time-delay difference for different temperatures of the medium distance F-O (Fiber-Optic) link was measured. As the result some important practical conclusions and remarks on how to develop the precise Two-Way-Transmission optical link for the time reference signals comparison are drawn.

Index Terms – Time Reference Comparison, Fiber-Optic transmission.

I. INTRODUCTION

First experimental works in FO reference time and frequency signals developed in 2005 transmission proved the usefulness of the specialized fiber links in the precise comparison of these signals between distant laboratories [1]. However, only the general usefulness and some parametric advantages over the Common-View GPS method were stated.

In the paper the results of some basic experimental research results on the specialized F-O link are presented. Especially the most important phenomena and factors which determine the possible obtainable precision in such links are indicated. Next the configuration of Two-Way link specialized to the atomic time reference signals differential comparison was assembled and its basic time-delay difference stability with variable fiber temperature was estimated.

II. BASIC MEASUREMENTS

To establish what are the main sources of the time-delay instabilities in the specialized F-O link, the basic hardware experiment was assembled. Thermal dependences of time-delay in all system components were examined as well as the influence of received signal level on the time-delay in the receiving circuitry was tested.

At first the thermal features of the optical singlemode fibers were tested. Even though there are some simulation as well as experimental data reported [2, 3, 4] the hardware measurements were carried out.

The schematic diagram of fiber time-delay thermal dependence test set is shown in Figure 1. In all experimental measurement a modified 1PPS signal called xPPS served as the time specific transmitted signal.

As the result the calculated thermal coefficients of the propagation delay-time $\theta_{\text{FIB}}$ in three different fibers presented in Table 1.

Table1. Fiber propagation delay-time thermal coefficients.

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>L [m]</th>
<th>$t_{AV}$ [µs]</th>
<th>$\lambda$ [nm]</th>
<th>$\theta_{\text{FIB}}$ [ps/°C⋅km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMF-28 Corning</td>
<td>12 660</td>
<td>$\approx$61.92</td>
<td>1554.94</td>
<td>$+37.796$</td>
</tr>
<tr>
<td>SMF-DS Lucent</td>
<td>20 051</td>
<td>$\approx$98.30</td>
<td>1554.94</td>
<td>$+37.965$</td>
</tr>
<tr>
<td>LEAF Corning</td>
<td>20 059</td>
<td>$\approx$98.12</td>
<td>1554.94</td>
<td>$+38.666$</td>
</tr>
</tbody>
</table>

The above table shows that the thermal time-delay coefficient $\theta_{\text{FIB}}$ have almost the same values irrespective on the fiber type. Moreover, in the most popular SM-28 Corning Glass singlemode Dispersion Zero fiber the value of $\theta_{\text{FIB}}$ does not also depend on the transmitted light wavelength. The latter suggests the best choice of the operating wavelength in the third transmission window.

Next the F-O transmitter as well as the F-O receiver time-delay thermal behavior were examined. The test set was similar to that of the Figure 1 but the fiber spool was replaced by the F-O attenuator and the photodiode by the whole receiver. Tested component was placed into refrigerator chamber to vary its temperature and at the same time all other components of the simplex link were operating at the constant room temperature. All measurements were done by the carefully stabilized
wavelength on $\lambda = 1554.94$ nm and in the received signal level of the range from $-13$ dBm to $-2$ dBm. The brief results obtained are shown in Table 2.

Table 2. F-O transmitters and F-O receivers time-delay thermal coefficients.

<table>
<thead>
<tr>
<th>Component</th>
<th>$\theta [\text{ps/}^\circ \text{C}]$</th>
</tr>
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<tbody>
<tr>
<td>Tx-N1</td>
<td>+0.202</td>
</tr>
<tr>
<td>Tx-N2</td>
<td>+0.196</td>
</tr>
<tr>
<td>Rx-o1</td>
<td>-0.459±0.129</td>
</tr>
<tr>
<td>Rx-o2</td>
<td>-0.721±0.1</td>
</tr>
</tbody>
</table>

The thermal coefficients $\theta$ of the receivers were visibly dependent on the received signal level. Nevertheless both in the transmitter and the receiver thermal instability of their delay-time values may be in practice neglected especially when both components operate in the air-conditioned and temperature-stabilized laboratories.

In contrary to the above a quite important seems to be the received signal level effect on the delay-time of the receiver. The measurement results of both Rx-o1 and Rx-o2 are shown in Figure 2.

![Figure 2.](image)

Figure 2. The input level effect on the receiver delay-time.

III. TWO-WAY ASSEMBLY AND MEASUREMENTS

Next the Two-Way experimental link was assembled and some important measurement were provided. The schematic diagram of Two-Way link is shown in Figure 3.

![Figure 3.](image)

Figure 3. Two-Way experimental link.

The individual xPPS pulse rising slope propagates in the counter-directions through the fiber. As the result the delay-time difference statistics between the rising slope of counter-propagating pulse was collected. The temperature of the fiber varied in the range of $+2^\circ\text{C} \pm 22^\circ\text{C}$ thus introducing to the link the one-way delay-time variation in the range of approximately 21 ns±26 ns. The fiber used was 32 720 m length (SMF-28 12 660 m + LEAF 20060 m).

In the experiment some technical parameters should be checked. One of the key parameter seemed to be the wavelengths of counter-propagating signals. To avoid the variation of the delay times first assumption was that wavelengths emitted by both lasers should be as close as possible. Nevertheless the experiment showed that in such condition some drastic excessive noise occurs in the receiver. The noise was resulting from the received and back-reflected and/or back-scattered light mixing on the receiver photodiode. The first decision was to avoid all back-reflecting FC-PC connectors along the fiber by using the APC connectors, but all was in vain. The point was the back-scattered (Rayleigh) light. The solution chosen was to slightly detune the lasers. The spectra of the light at the receiver Rx-o2 input is shown in figure 4.

![Figure 4.](image)

Figure 4. Spectra of the received signal.

The received light signal wavelength is $\lambda_1 = 1554.293$ nm and on $\lambda_2 = 1554.864$ nm line the back-scattered signal as well as the product of the Brillouin effect in form of the pair of lines in the vicinity are visible. Keeping the laser de-tuned to this extent the overlapping of the both lasers spectra pedestals is small enough, thus the previously mentioned excessive noise was not observed any longer.

At last the time delay difference changes as the result of the fiber temperature was measured. Results are presented in Table 3.

Table 1. Delay-time dependence on the temperature of the fiber in Two-Way F-O link.

<table>
<thead>
<tr>
<th>Oscilloscope</th>
<th>$\Delta t_{\text{HV1}} - \Delta t_{\text{HV2}}$ [ps]</th>
<th>Receiver level [\mu W]</th>
<th>$\sigma$ [ps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP54845A</td>
<td>+2±13</td>
<td>300</td>
<td>11</td>
</tr>
<tr>
<td>HP83480A</td>
<td>-2.3±6.4</td>
<td>250</td>
<td>15.9</td>
</tr>
</tbody>
</table>

The results were collected on two different oscilloscopes: 1.5 GHz HP54845A and 20 GHz HP83480A as the statistics in form of the histograms. The example of the histogram is shown in Figure 5. The statistics collecting times were 12 min 15 s for HP54845A and 22 min for HP83480A.
IV. COMMENTS AND CONCLUSION

In the presented experiment some new research was done and a complex of the substantial phenomena in the proposed F-O application field was examined as well as the technical investigations were carried out.

As the conclusion of the paper it should be stated that:

- The key factor influencing the precision of the atomic time reference comparison in distant laboratories is the thermal dependence of the fiber delay-time;
- in Two-Way F-O link in which all transmitting and receiving equipment operates at stable laboratory temperatures the influence of the external temperature of the fiber may be dramatically reduced;
- the maximum obtainable precision of the time reference signal comparison offered in this configuration at the distances between laboratories up to 30 km is better than 10 ps.

ACKNOWLEDGEMENTS

The results presented in the paper were obtained during the realization of the Ministry of Science and Higher Education grant number R0203303.

REFERENCES


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