Calibrated fiber-optic time distribution using dispersion-insensitive configuration

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***Abstract*—In this paper we propose and investigate a fiber-optic time dissemination configuration, which is insensitive to fiber chromatic dispersion and its slope thanks to implementing additional feedforward compensated channel. This approach, despite requiring additional slice of spectrum, simplifies the link calibration substantially. Good link calibration accuracy is confirmed experimentally proving that such approach is suitable for accurate time dissemination.**

Keywords—time transfer, fiber optic, chromatic dispersion, calibration

I. Introduction

Time dissemination requires accurate knowledge of the propagation delay introduced by the dissemination link. This delay must be kept constant during the link operation and its value is determined through the process of the link calibration.

One of the delay corrections that need to be determined in a fiber-optic time dissemination link is related to the chromatic dispersion of the fiber. This is related to the difference of the laser wavelengths used to propagate the forward and backward signals, which are necessary to stabilize the propagation delay of the link (see Fig. 1a). Determining this chromatic dispersion correction requires an extra calibration step where the wavelength of one of the lasers (usually the forward one) is varied when the stabilization loop is temporarily opened [1]. This step must be repeated if, due to any reasons, the length of the fiber changes substantially. Calibration of such link may pose a level of difficulty, especially for users unfamiliar with metrological applications.

In this paper we investigate the modified link configuration (Fig. 1b) containing additional forward laser (λ_C), which allows zeroing the chromatic dispersion correction. To get such a result it is necessary to place λ_C close to the middle between λ_A and λ_B, while the exact value depends on the spectral characteristics of the lasers used (mostly their residual frequency chirping) and the second order dispersion of the fiber installed in the link. An important feature of the solution discussed is that it is possible to set the correct wavelength of the λ_C during initial calibration of the link terminals, which does not need any further user adjustment after the link installation.

II. System Pre-calibration

The system pre-calibration is performed by its manufacturer and its purpose is twofold: determination of the inherent asymmetry related to the optical and electronic circuits (hardware) installed in the local and remote terminals (1) and finding the correct value of λ_C assuring compensation of the chromatic dispersion asymmetry (2).

The first pre-calibration phase can be easily performed using a short patchcord (about 1 m long) to connect the local and remote modules. Measurement of the propagation delay to the system output τ_{DELAY} and the round-trip propagation delay T_{RT} (both are measured with respect to the system reference point) allows finding the hardware asymmetry, which equals to:

$$\Delta\tau_T = 2\tau_{DELAY} - T_{RT}. \quad (1)$$

This asymmetry can be further absorbed into the PPS advancing block, so after this phase of system calibration its delay equals exactly to one half of the round-trip delay.

The second phase, related to setting λ_C, can in principle be done with an optical spectrum analyzer. This requires three accurate wavelength measurements and taking into account the correction related to the fiber dispersion slope S:

$$\Delta\lambda_S \approx \frac{S}{D}\Delta\lambda^2, \quad (2)$$

where D is the fiber dispersion coefficient and $\Delta\lambda$ is half the difference between λ_A and λ_B. Using this approach it is, however, impossible to take the chirp (see Fig. 2 for an example) of the lasers into account the, making it unsuitable

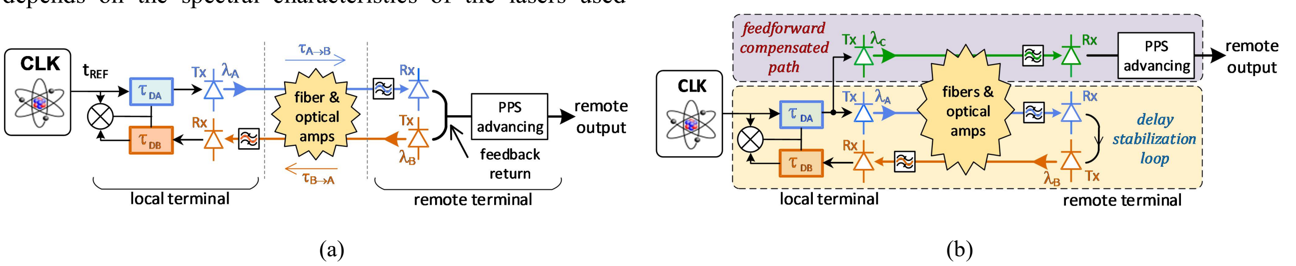

Fig. 1. Fiber optic time transfer link with stabilized propagation delay: basic configuration (a) and dispersion-insensitive configuration with additional forward laser (b).

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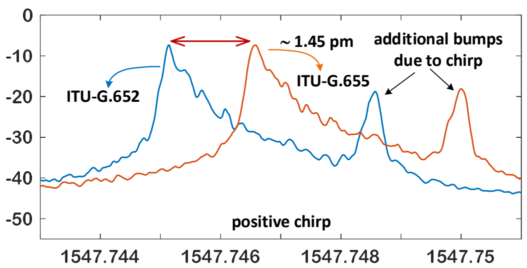

Fig. 2. Spectrum of the laser modulated by an external electroabsorptive modulator showing its chirp. Red and blue colors are used to show the optimal placement of the laser wavelength for two fiber types, showing different dispersion and dispersion slope.

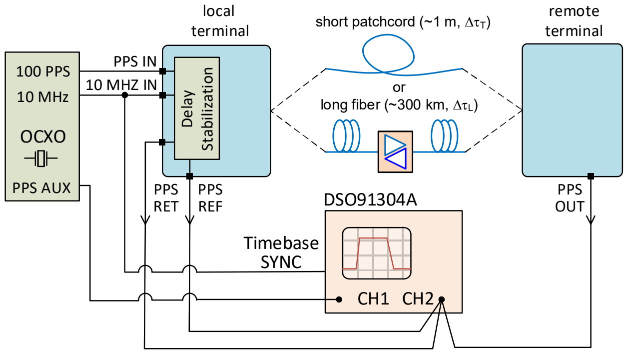

Fig. 3. Measurement setup used for the system calibration.

for an accurate time transfer/dissemination.

To remove the abovementioned difficulty we propose to use the another approach where a calibration setup based on a long piece of fiber (a few hundred km), equipped with necessary optical bi-directional amplifiers (OBA), is used. This setup is shown in Fig. 3.

Fiber			G.652	G.655
calibration @ 300 km		M	1486549870±8	
verification	150 km	E	743644870±4	744194870±4
		M	743644870±8	744194869±8
			Δ = 0±9	**Δ = +1±9**
	50 km	E	248414870±4	248629870±4
		M	248414870±8	248629871±8
			Δ = 0±9	**Δ = -1±9**
			Impact of fiber type	
	300 km	M	1486549878±8 Δ = -7±11	1486549866±8 Δ = +4±11

E - estimated M - measured
quantities in [ps]

Fig. 4. Results of system calibration and its verification for two different fiber lengths and fiber types.

Using the setup from Fig. 3 the round-trip delay us measured first, which value is independent on the λ_C wavelength (the round-trip delay involves only lasers λ_A and λ_B – see Fig. 1b). Then the λ_C is adjusted to get the τ_{DELAY} equal exactly to one half of T_{RT}. This way of the system calibration takes naturally all fiber-relates effects into account, i.e. dispersion slope and lasers chirp.

III. Experimental Results

The system calibrated using 300 km long fiber was then tested at two different lengths of 150 km and 50 km. Two different fiber types, namely G.652 (with standard dispersion) and G.655 (with reduced dispersion) were used. The results are collected in Fig. 4 and shows good agreement between the estimated and measured values of the propagation delay.

IV. Conclusion

Proposed scheme of chromatic-dispersion insensitive configuration simplifies the process of link calibration and allows high level of time dissemination accuracy. The calibration verification results are similar to those obtained in 2-laser delay-stabilized configurations, like e.g. ELSTAB [3].

References

[1] Ł. Śliwczyński et al., "Calibrated optical time transfer of UTC(k) for supervision of telecom networks," Metrologia, vol. 56, 015006, 2019, 10.1088/1681-7575/AAEF57.

[2] F. Zuo et al., „Multiple-node time synchronization over hybrid star and bus fiber network without requiring link calibration," Journal of Lightwave Technology, vol. 39, 2021, doi: 10.1109/JLT.2020.3043340

[3] P. Krehlik at al., "ELSTAB- fiber optic time and frequency distribution technology - a general characterization and fundamental limits," IEEE Trans. Ultrason. Ferroel. Freq. Contr., vol. 63, pp. 993-1004, 2016.