The National System for Distribution of Reference Optical Carrier - first link evaluation

Krzysztof Turza, Artur Binczewski, Wojbor Bogacki
Poznan Supercomputing and Networking Center (PSNC)
Poznań, Poland
kturza@man.poznan.pl

Przemysław Krehlik, Łukasz Śliwczyński
Faculty of Computer Science, Electronics and Telecommunications
AGH University of Science and Technology
Krakow, Poland
krehlik@agh.edu.pl

***Summary* — In the paper the authors present the result of evaluation of the first optical fiber connection realized within the NLPQT (National Laboratory for Photonics and Quantum Technologies) project dedicated to the distribution of optical carrier signals coming from Polish optical clocks. The target network will connect major research centers in Poland and will also enable pan-European cooperation through implementation of cross-border connections. Under the project, there has been designed and manufactured an own ultra-stable laser distribution system. The results obtained during this preliminary evaluation show that the proposed system meets the requirements of phase stabilized distribution of the ultrastable optical frequency reference.**

Keywords—optical carrier; optical clock; frequency distribution; dark fiber; optical fiber

I. INTRODUCTION

Ultra-stable frequency signals are widely used in many fields, in particular in telecommunications (synchronization) or navigation (e.g. GPS system). The generation of frequency signals using optical cavities currently allows short-term stability that is about four orders of magnitude better compared to hydrogen masers [1] and, using optical frequency combs, makes it possible to use signals not only in the optical domain but also in the radio frequency domain. One of the main objectives of the NLPQT project [2] is to implement a nationwide distribution network of ultrastable laser signals that can be related to the optical atomic clock deployed at KL FAMO (National Laboratory for Atomic and Optical Physics) in Torun [3]. Wide availability of this type of signals seems to be a necessity due to the expected redefinition of the second in the SI system [4]. The realization of the aforementioned project will not only enable nationwide access to the ultra-stable frequency signal but, through the designed international connections, will enable pan-European international cooperation.

II. DESCRIPTION OF THE EVALUATED SYSTEM

The evaluated system was implemented on a fiber-optic line between Torun and Poznan using dedicated fibers (dark fibers) of PIONIER National and Research and Education Network (see Fig. 1) [5]. In order to make the measurement results independent from the quality of the reference signal in two distant locations, the measurement was organized as a loop: Torun-Poznan-Torun. The total length of the tested connection is a bit over 600 km. For the stabilization of the reference signal we use two laser stations (transmitter and receiver) manufactured and developed by PSNC. In these devices we implemented dedicated algorithm to control polarization changes in order to minimize the occurrence of so-called cycle slips. Moreover, a mechanism of automatic signal relocking after connection restoration (e.g. after a period of optical fiber failure) was also included. The effectiveness of both mechanisms was verified during ongoing experiments.

Fig. 1. National optical carrier signal distribution system as part of the NLPQT project based on dedicated optical fibres of the PIONER network.

To amplify the optical signal, bidirectional EDFA amplifiers developed at the AGH University of Science and Technology have been used. An automatic amplification control system has been developed and implemented, allowing to work with ultra-narrow, unmodulated laser signals transmitted in this system. In addition, these amplifiers are

equipped with a management channel (in-fiber) to control their operation without the need for another external system. On the evaluated line, nine amplifiers were used.

III. Preliminary Results

In the evaluated link, spectrally ultranarrow laser light with a wavelength of 1542.14 nm is transmitted as a reference signal. Thanks to the direct beatnote of the transmitted and received signal in the tested loop, it is possible to perform an accurate measurement of the stabilisation efficiency of the transmission system developed. Figure 2 presents measurement of the effectiveness of the device stabilisation system with one millisecond and one second sampling times. Figure 3 shows the phase noise of the tested system in the tested link. The increased noise level at frequencies of several tens of Hz is due to the significant length of the tested line and thus the necessity of using a relatively narrow-bandwidth noise cancellation loop.

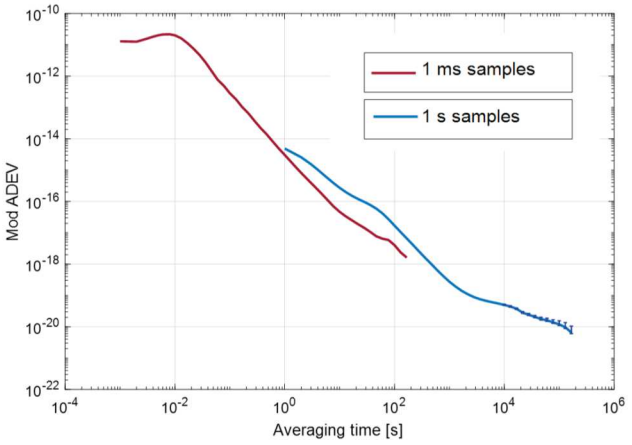

Fig. 2. Results of optical carrier transfer instability using the developed system.

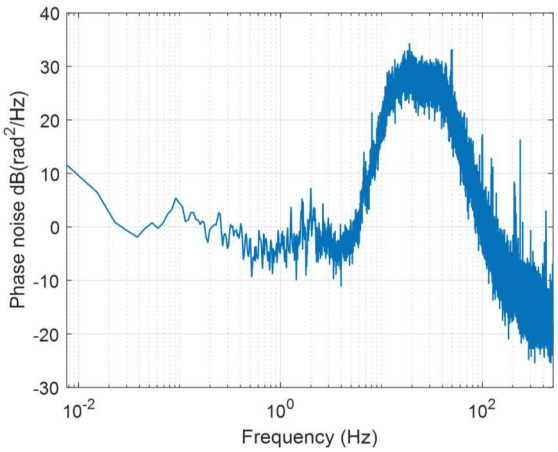

Fig. 3. Phase noise of the investigated system in a 600 km test link.

The tests confirmed the effectiveness of the implemented automatic polarisation control mechanism. This mechanism minimised the occurrence of cycle slips, which are the effect of fading of the beating signal (optical reference with signal returned to the local station). Also in the field test, the efficiency of automatic relocking of the system when the connection is restored was tested. Both of the above mechanisms guarantee continuous operation of the system without the need for "human intervention".

IV. Conclusions

The evaluation of the developed devices in real environmental conditions confirmed the effective operation of the implemented mechanisms for automatic transmission control and resilience to unexpected network events (including failures). Both mechanisms of automatic signal relocking and polarization control allowed to provide human-less operation of the system while at the same time guaranteeing its high quality. The tested 600 km line achieved long-term stability of the distributed signal at the level of 10^{-20} (for 10^5 s observation time). The verification of the developed algorithm for automatic gain optimization of individual optical amplifiers is currently in progress.

Acknowledgment

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References

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