Fully Digital Electronics for Fiber-Link Frequency Transfer Implemented on Red Pitaya

A. C. Cárdenas-Olaya, C. E. Calosso
INRiM, Quantum Metrology & Nanotechnology, Turin, Italy

Abstract

This paper presents a digital instrumentation for frequency transfer on optical fiber links. The proposed system detects the phase and amplitude of the beatnotes at the two ends of the fiber for (actively or passively) compensating by the phase noise and the polarization rotation. The implementation is performed on Red Pitaya, an open source platform that integrates fast Analog-to-Digital and Digital-to-Analog converters with a Zynq System-on-Chip. The system features a detection bandwidth of 10 MHz, compatible with thousand kilometers links, that can be finely tuned for reaching an adequate Signal-to-Noise Ratio minimizing the generation of cycle slips.

1 Introduction

Fiber links have been demonstrated to be a suitable medium for optical frequency transfer featuring an stability of the order of $10^{-19} \div 10^{-21}$ [1]. However, mechanical stress, environmental factors and temperature fluctuations generate fiber length variations that degrade the frequency stability of the signal being transmitted. In order to compensate for such fiber noise, two techniques are widely used: the classical Doppler [2] and the more recent Two-Way [3]. The implementation of these techniques relies on the detection of the phase and the amplitude information contained in the beatnote between the received and the transmitted signals which is obtained through photo-detection at the local and the remote ends. There are three critical implementation requirements that may limit the adequate noise compensation and consequently the frequency transfer performance: First, the detection bandwidth that must be wide enough for extracting the phase information before it gets corrupted by the noise. In current applications, it is of the order of hundreds of kilo Hertz which limits implementations on long links because the phase can not be properly tracked. Second, additive noise is generated during the beatnote photo-detection, which is revealed as excess of noise in the measurement degrading the Signal-to-Noise Ratio (SNR) and leading to the generation of cycle slips. This effect is in general removed by reducing the detection bandwidth. And finally, the polarization rotation that should be maintained in order to avoid amplitude fluctuations on the detected beanote that could degrade the SNR.

In this work we present a fully digital instrument for frequency transfer over fiber link. The system provides the capability of finely tune the detection bandwidth from 10 MHz down to 1 kHz, allowing to reach the best tradeoff between the SNR and the detection bandwidth for minimizing the cycle slips rate. In addition, it implements the simplex algorithm, yielding a polarization control bandwidth up to 100 kHz.

A fiber emulator is implemented on the FPGA with the aim of studying the critical requirements (detection bandwidth, SNR, polarization) under different scenarios (noise typologies and levels), while taking advantage of the System-on-Chip (SoC) bandwidth for long term analysis. In particular for the evaluation of cycle slips whose rate in current implementations is one cycle slip per one or two minutes.

Preliminary results of the instrument are intended to be presented at the workshop.

2 Method

The proposed system, depicted in Fig. 1, was implemented on Red Pitaya [4]. The platform integrates a 14-bit, 125 MSps, dual channel Analog-to-Digital Converter (ADC), a 14-bit, 125 MSps, dual channel Digital-to-Analog Converter (DAC) and a SoC containing a FPGA and a Dual-core ARM processor.

The instrument subsamples directly the beatenote from the photo-detection and retrieves the phase (φ) and amplitude (α) information through an I/Q demodulator in a 10 MHz bandwidth which can be finely tuned down to 1 kHz. The phase, if actively compensated, is tracked by a servo that drives the Acousto-Optic Modulator (AOM) through a Numerically Controller Oscillator (NCO). The amplitude feeds a simplex algorithm that optimizes the polarization between the received and the transmitted signal for obtaining the maximum power on the beatnote.

A two-channel system is implemented on a single Red Pitaya which allows compensation and monitoring at each side. The useful data are stored in

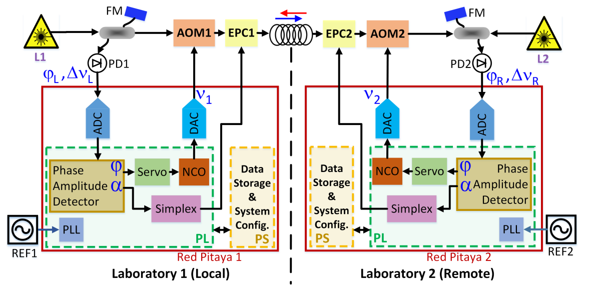

Figure 1: General scheme. PD: Photo-detector, FM: Faraday Mirror, EPC: External Polarization Controller, PL: Programmable Logic (FPGA), PS: Processing System (ARM processor).

memory and transferred to an external computer for post-processing.

Fig. 2 sketches the block diagram of one channel including the fiber emulator. The emulator generates the main noise sources involved in a setup for frequency transfer such as: fiber noise, photodetection noise and noise induced by the polarization. In addition, it is provided with the emulator of a polarization controller based on a four plates configuration. When the emulator is enabled, it acts on the NCO signal (DAC input) that instead of driving the AOM will be the instrument input, emulating the beatnote.

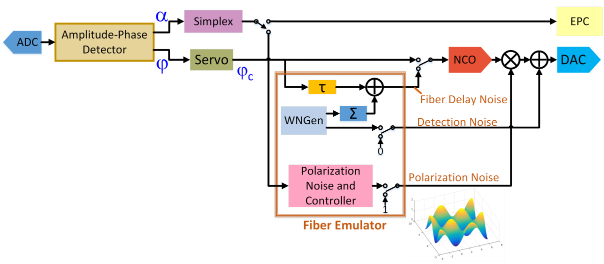

Figure 2: One channel system. τ: Fiber delay, WNGen: White Noise Generator, EPC: External Polarization Controller.

3 Conclusion

The proposed digital instrument is a compact solution that integrates different functionalities such as phase-meter, stability control and polarization control in a single platform.

The instrument is provided with the capability of applying different configurations of the two compensation techniques by properly setting the different blocks parameters, such as: the compensation action (open or close loop), compensation bandwidth (if any), the frequency of the beatnote detected that differs a factor of two from Doppler to Two-Way, the detection bandwidth, the data channels to be stored, etc.

References

[1] K. Predehl et al., *A 920-kilometer Optical Fiber Link for Frequency Metrology at the 19th Decimal Place*, Science, April 2012, **336(6080)**

[2] L.-S. Ma, P. Jungner, J. Ye and J. L. Hall, *Delivering the same optical frequency at two places: accurate cancellation of phase noise introduced by an optical fiber or other time-varying path*, Optics Letters, Nov. 1994, **19(21)**

[3] C. E. Calosso, E. Bertacco, D. Calonico, C. Clivati, G. A. Costanzo, M. Frittelli, F. Levi, A. Mura and A. Godone, *Frequency transfer via a two-way optical phase comparison on a multiplexed fiber network*, Optics Letters, March 2014, **39(5)**

[4] Red Pitaya, *Documentation and technical information*, `http://redpitaya.readthedocs.io/en/latest/`