Multi-wavelength Space Multiplexing Photonic A/D Converters

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Abstract—**A multi-wavelength space multiplexing photonic A/D converters is proposed which combines the WDM and space division multiplexing and enables higher sampling rate with the low loss and completely passive demultiplexing feature. The key technologies and progress are discussed.**

Index Terms—Photonic analog-to-digital converter, Optical sampling, Radio frequency photonics

I. Introduction

Electronic analog-to-digital converters (EADCs) has become a bottleneck since it has difficulty reaching the high sampling speeds with suitable resolution for many current and potential applications such as radar, high-performance communication, electronic instrumentation and so on [1]. Photonic ADCs (PADCs) have been proposed as a promising technology to implement high bandwidth A/D since photonic technology can offer many attractive advantages such as ultrastable and high speed optical sampling pulses, high bandwidth, nearly lossless signal remoting [1]-[3]. The photonic sampling and electronic quantizing PADC, which performs the sampling in the optical domain at high sampling rates and parallel quantizing at lower signal processing rates, has attract much interest since it takes the advantage of the short pulse widths and low jitter of mode-locked laser and adopted relative mature optical and electronic technology. The architecture based on Time division multiplexing (TDM) or Wavelength Division Multiplexing (WDM) techniques respectively has been proposed [3]-[5]. The TDM approach requires several high speed optical switch and precise synchronization between each stage. The WDM approach has a low loss and completely passive demultiplexing features, but its sampling rate is limited by the available spectral bandwidth and repetition rate of mode-locked lasers. Here, we present a multi-wavelength space multiplexing photonic A/D converters which holds the advantages of WDM approach, and can reach higher sampling rate by combining the WDM and space division multiplexing (SDM). The key technologies needed are discussed. A multi-wavelength space multiplexing PADC with sampling rate exceeding 150Gs/s is designed and some experiment results are also given.

This work was supported in part by 863 Project under Grant 2007AA01Z275 and 2006AA01Z242, National Science Foundation of China (NSFC) under Grant 90704002 and 60507013, Dawn Program for Excellent Scholars by the Shanghai Municipal Education Commission.

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II. System Architecture

The multi-wavelength space multiplexing photonic A/D architecture is shown in Fig. 1. The multiple wavelength interweaved pulse generator (MWPG) is used to generate multiple wavelength interweaved optical pulse train. The space multiplexed sampling module (SMSM) is used to sample the RF analog signal by time interleaving method based on space division multiplexing, where the pulse train from MWPG is split into several paths by a coupler, and the RF signal is sampled by electro-optic modulators (EOM) on each path at different sampling position, seeing Fig.1. The sample position of the pulse train on eachpath is adjusted by optical delay lines. The sampling pulse train on each path is demultiplexed to different wavelength channel. On each channel, the sampling optical signal is detected by a photo detector (PD) and quantized by a "slow speed" electronic A/D. The quantized data on each channel are combined to obtain the last digitized result of the RF analog signal.

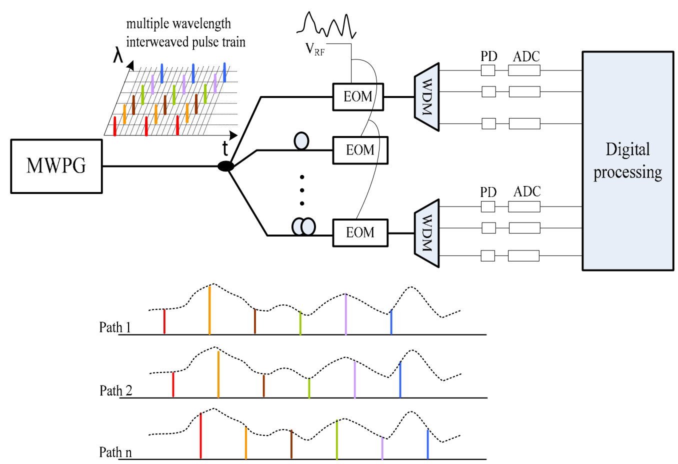


Fig. 1 The architecture of the multi-wavelength space multiplexing photonic ADC

III. The Generation of Multiple Wavelength Interweaved Sampling Clock

Several method has been proposed to generate the multiple wavelength interweaved sampling clock [6]-[8]. Spectral slicing of single broad bandwidth laser is a relatively cost-effective and mature one among them. Unfortunately, broadband lasers with high repetition rate are still not

978-1-4244-4785-5/09/$25.00 ©2009 IEEE

commercially available. There are two ways to solve the problem. One is to use super continuum generation to broaden the bandwidth of mode-locked picosecond fiber laser with gigahertz repetition rate [9]. The other is to increase the repetition rate of broadband mode-locked femtosecond fiber laser by optical time division multiplexing (OTDM). We take the second way and have presented a simple approach to generate high-repetition-rate time-wavelength interweaved sampling clock using commercially available broadband mode-locked femtosecond fiber laser and low cost optical passive devices.

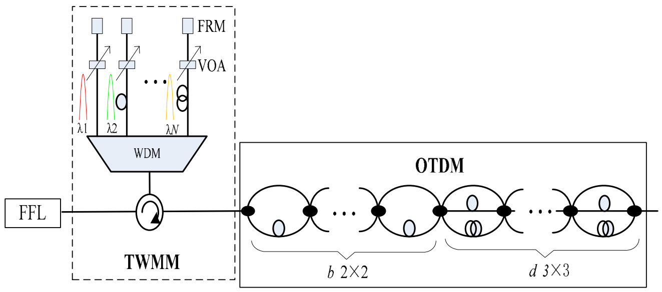
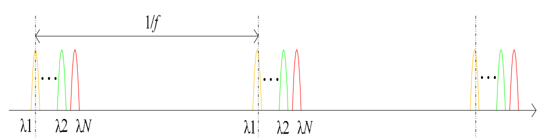
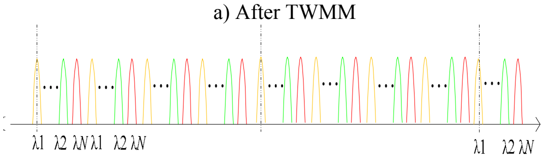


Fig. 2 The architecture of the multiple wavelength interweaved pulse generator
FRM: Faraday rotate mirror, VOA: variable optical attenuator

Fig. 2 shows the structure of the MWPG proposed. Pulses from a mode-locked broadband femtosecond fiber laser at the repetition rate of f are inputted to a time and wavelength mapping module (TWMM), which spectrally slices each input pulse from femtosecond fiber laser into N pulses of different wavelengths and maps the sliced pulses to different time positions with appropriate FDLs, so as to form a pulse train as shown in Fig. 3 a). The pulse train is then directed to an OTDM module with multiple factor of M. The interval of the output clock as shown in Fig. 3 b) is $1/(f \times N \times M)$. The OTDM module consists of several cascaded 2×2 and/or 3×3 optical fiber couplers. Hence appropriate M can be obtained flexibly by selecting the stage of 2×2 and 3×3 optical fiber couplers. The optical power loss of the OTDM module consists only of the excess loss of each coupler and the insertion loss of the last coupler.



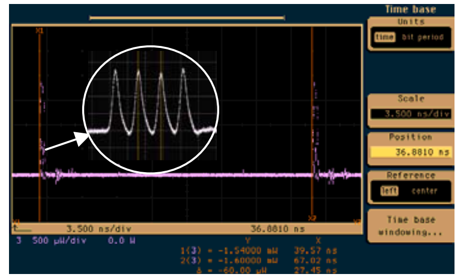
a) After TWMM



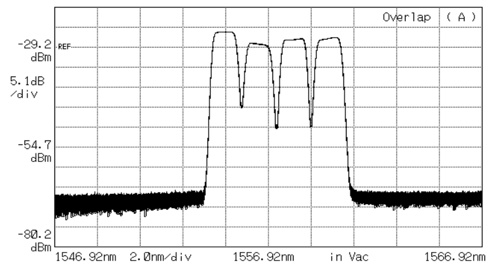
b) After OTDM

Fig. 3 The pulse train a) after TWMM, b) after OTDM

An OTDM module with M=54 is implemented using a 2×2 multiplexer and three 3×3 multiplexers. The three output optical pulse trains of the last 3×3 coupler can be inputted directly into three spatial path of SMSM to make the best use of optical power. The optical power loss of the OTDM module for each pulse train is around 6 dB.

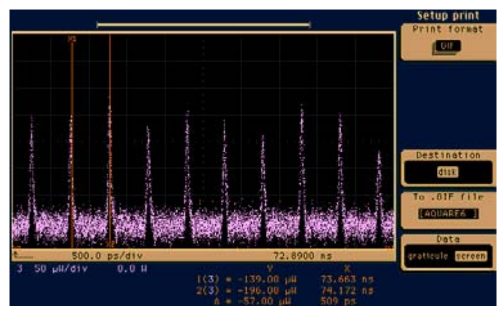


a) Measured pulse train

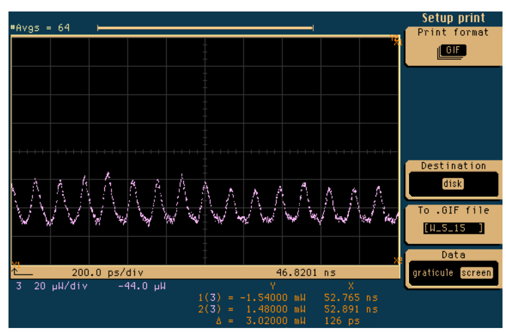


b) Spectrum

Fig. 4 Measured pulse train and its spectrum after TWMM



a) For one of 4 WDM channels



b) time-wavelength interweaved sampling clock of 4 wavelengths

Fig. 5 Measured pulse train after OTDM

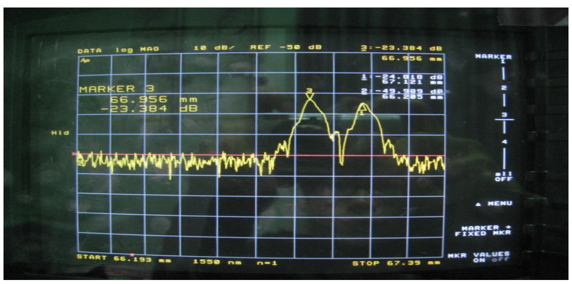
Fig. 4 shows the pulse train and its spectrum after the 4 channel TWMM when the WDM used has channel spacing of 200GHz and 3dB bandwidth of approximate 1.2nm, and the mode-locked femtosecond fiber laser with 70fs pulse width at a repetition rate of 36.44MHz and 45nm full width at half maximum (FWHM) is adopted. The time-wavelength interweaved sampling clock of 4 wavelengths is Fig. 5.

The theoretical sampling rate will exceed 150Gs/s when all available wavelength channels in above configuration are configured. Higher repetition can be obtained by using more wavelengths or OTDM stages or spatial path, or all of them.

IV. PRECISE FIBRE DELAY CONTROL

The accuracy of the time interval of the sampling clocks depends on the precision of delay control in the TW MM, OTDM, and the alignment precision in time interleaving sampling based on space division multiplexing also relays on the precision of delay adjustment on the each path of SMSM. Delay precision around 2ps can be reached by relatively easy manipulation [11] , see Fig 6(a), and sub-picosecond delay precision can be obtained by a manual mechanical fiber stretcher and/or the thermal fiber micro-stretching technique [10], see Fig 6(b).

a) Using the method in ref[10], 1.5ps



b) Using the method in ref[11], 0.7ps

Fig.6 The results of precise delay control using the method in ref[10] and the method in ref[11]

V. CONCLUSIONS

A multi-wavelength space multiplexing photonic A/D converter which combines the WDM and space division multiplexing and permits higher sampling rate has been presented. The approach to generate high repetition rate time-wavelength interweaved sampling clock and the precise fiber delay control technique are discussed. The design of a multi-wavelength space multiplexing PADC more than 150Gs/s under full configuration is given. Generation of about 8Gs/s multi-wavelength interweaved pulse train is demonstrated with a 4 channels WDM and a 54 time OTDM.

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