An Approach to Generate Multi-wavelength Sampling Clock for Photonic A/D Converters

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Abstract

a approach to generate the time-wavelength interweaved sampling clock for photonic A/D converters is proposed. The generation of 7.87Gs/s time-wavelength interweaved sampling clock is demonstrated using 4 WDM channels and 54 time OTDM.

Introduction

In order to overcome the limitation of electronic analog-to-digital converters in ultra high speed applications such as high-performance communications, radar, electronic instrumentation, etc., photonic ADCs have been proposed as a promising alternative with the unique features of ultra stable and high-speed sampling, broad bandwidth, and nearly lossless signal remoting [1]-[2]. In many schemes studied so far, hybrid optical-electrical ADC is one of the most practically feasible methods [2]-[4]. Its key issue is the generation of multiple wavelength interweaved sampling clock. Spectral slicing of single broad bandwidth laser has been been proposed to generate such clock [5], which is relatively cost-effective and mature. Unfortunately, broadband lasers with high repetition rate are still not commercially available. Here, we present a simple approach to generate high-repetition-rate time-wavelength interweaved sampling clock using commercially available broadband femtosecond fiber laser and low cost optical passive devices. Architecture and experiment results are given.

System Architecture

The proposed architecture is shown in Fig. 1. Pulses from a mode-locked broadband femtosecond fiber laser at the repetition rate of f are input to a time and wavelength mapping module (TWMM), which spectrally slice each input pulse into N pulses of different wavelengths and map the sliced pulses to different time positions with appropriate FDLs, so as to form a pulse train as shown in Fig. 2 a). The pulse train is then sent to an OTDM module with multiple factor of M to generate the clock with the duration $1/(f \times N \times M)$ as shown in Fig. 2 b).

The OTDM module consists of b and d stages of 2×2 and 3×3 cascaded optical fiber couplers, respectively. Hence appropriate M (=2^b +3^d) can be obtain flexibly by selecting b and d. The fused-biconical 2×2 fiber couplers are placed before the 3×3 ones. In such arrangement, the optical power loss, IL_{OTDM} , of the OTDM module consists only of the excess loss of each coupler and the insertion loss of the last coupler. If the excess loss of each coupler is the same, we have:

$$IL_{OTDM} = \sum_{i=1}^{b} EL_i^{2\times2} + \sum_{i=1}^{d} EL_i^{3\times3} + IL^{l\times l} \tag{1}$$

where $EL_i^{2\times2}$ and $EL_i^{3\times3}$ are the excess loss of the 2×2 and 3×3 couplers, respectively; $IL^{l\times l}$ is the insertion loss of the last coupler (l=2 for 2×2 coupler and l=3 otherwise). In addition to provide flexibility in determining M, the use of 3×3 couplers can minimize the coupler stages [6].

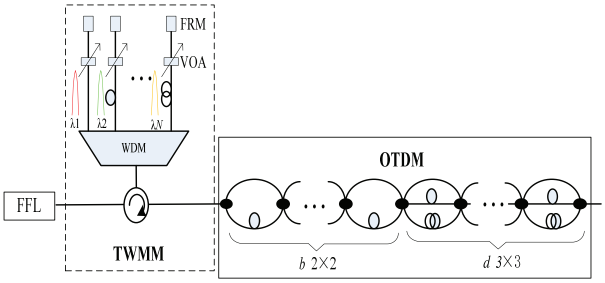
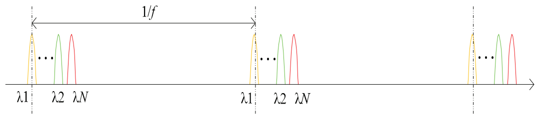
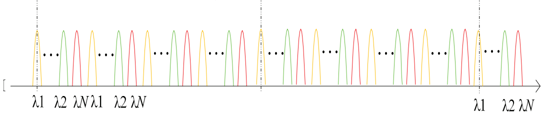


Fig. 1. The architecture of the multi-wavelength sampling clock generator. FRM: Faraday rotate mirror, VOA: variable optical attenuator



a) After TWMM



b) After OTDM

Fig. 2 The pulse train a) after TWMM, b) after OTDM

Experiment Results and Analysis

The mode-locked femtosecond fiber laser used in our experiment produces 70-fs pulses at a repetition rate of 36.44 MHz with average power of 40 mW. Its central wavelength is at 1560nm with 45 nm full width at half maximum (FWHM). The WDM used to configure the

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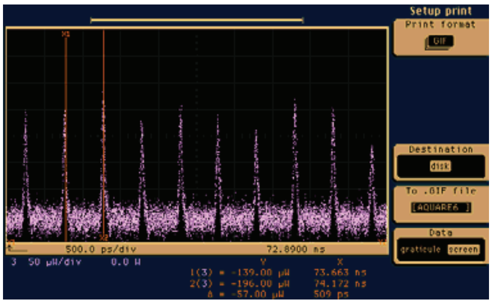
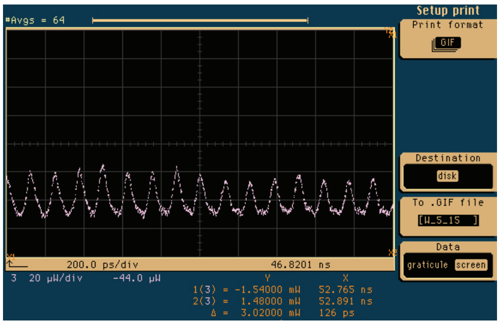
TWMM has channel spacing of 200GHz and 3dB bandwidth of approximate 1.2 nm. We used four wavelength channels at 1559.79nm, 1558.17nm, 1556.55nm, 1554.94nm, respectively, for demonstration. An OTDM module with M=54 is implemented using a 2 ×2 multiplexer and three 3x3 multiplexers. The typical excess loss of the 2x2 coupler is 0.15 dB and the typical insertion loss and the excess loss of the 3x3 coupler are around 5.1 dB and 0.3 dB, respectively. Hence, the optical power loss of the OTDM module is about 6.15dB according to equation (1). The accuracy of the time interval of the sampling clocks depends on the precision of FDLs. Delay precision around 2ps can be reached by relatively easy manipulation [7] and sub-picosecond precision can be obtained by the technique we developed [6].



```
3   50 µW/div     0.0 W
                  Y               X
     1(3) = -139.00 µW      73.663 ns
     2(3) = -196.00 µW      74.172 ns
        Δ = -57.00 µW       509 ps
```

a) For one of 4 WDM channels



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3   20 µW/div     -44.0 µW
                  Y                 X
     1(3) = -1.54000 mW     52.765 ns
     2(3) =  1.48000 mW     52.891 ns
        Δ =  3.02000 mW     126 ps
```

b) Time-wavelength interweaved sampling clock of 4 wavelengths

Fig. 3 Measured pulse train after OTDM

Fig. 3 a) shows the OTDM pulse output for one WDM channel. The sampling rate is 1.968 Gs/s, corresponding to a pulse duration of 1/(36.44×54)=0.508 ns. Fig. 3 b) is the time-wavelength interweaved sampling clock of 4 wavelengths. The sampling rate is 7.87 Gs/s. The pulse width is measured using autocorrelator to be approximately 5 ps. The average output power of the optical pulse train is -6.65dBm. Higher repetition rate up to 100 Gs/s can be obtained by using more wavelengths or OTDM stages, or both.

Conclusions

We presented a simple approach to generate high repetition rate time-wavelength interweaved sampling clock using commercially available mode-locked femtosecond fiber laser and optical wavelength/time division multiplexing (WDM/OTDM) techniques with low cost passive optical components by slicing the spectrum of a commercially available low-repetition-rate femtosecond fiber laser. Generation of 7.87Gs/s time and wavelength interleaved optical sampling clock is demonstrated using 4 WDM channels and 54 time OTDM. Such architecture can be used to produce higher sampling rate by using more wavelengths and/or OTDM stages.

Acknowledgement

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References

1. George .C.Valley, Optical Express, vol. 15, No. 5(2007), p. 1955-1982.
2. T. R. Clark, et al, IEEE Photonic Technol. Lett., 11(1999), p.1168-1170.
3. M. P. Fok, , et al, IEEE Photonics Technol. Lett., 16(2004), p.876-878.
4. F. X. Kartner, et al, 3rd OEEE International Conference on Group IV Photonics (2006), p.203-205.
5. Clark, T. R. , et al, IEEE International Topical Meeting on Microwave Photonics, 1999, Australia.
6. Xinwan Li, et al, Optical Express, Vol. 15, No.25(2007), p.16760-16766.
7. Xin Wang, et al, IEEE Sensors Journal, Vol. 8, Issue 7, (2008), pp. 1173-1179.