Spectrum sliced microwave photonic signal processing

Xiaoke Yi, and Robert A. Minasian
School of Electrical and Information Engineering, University of Sydney, NSW 2006, Australia
Phone: +612 93512110, Fax: +612 93513847, Email: xiaokeyi@usyd.edu.au

Abstract
Recent new developments in spectrum sliced photonic signal processors, which address the challenges of dispersion induced distortion and noise mitigation are presented, together with a novel multi-tap filter with insensitivity to the operating optical wavelength.

Introduction
Photonic signal processing offers the prospect of high time-bandwidth processing of signals directly in the optical domain, to solve the limitations of electronic approaches. The most direct implementation involves using a multi-wavelength source applied to a dispersive medium structure, such as an optical fiber [1].Spectrum slicing of a broadband light source has been proposed as a low-cost solution and scalable approach for realizing multiple taps [2]. Spectrum slicing microwave photonic filters have been reported by using different slicing techniques such as array waveguide gratings (AWGs), and fiber Bragg gratings (FBGs) [1]. The exploitation of their applications requires systematic investigations of the filter performance at high frequency.

In this paper, we focus particularly on recent new developments in spectrum sliced photonic signal processors that can address important performance issues. We investigate the dispersion induced RF distortion based on a general model for spectrum sliced microwave photonic filter design. We also describe a novel noise mitigation strategy based on the characteristic of the relative-intensity noise (RIN) in spectrum sliced photonic signal processors. Finally we present a spectrum sliced photonic signal processor structure that can achieve multi-tap characteristics, high frequency operation, and insensitivity to the operating optical wavelength.

2. Dispersion induced RF distortion
The principal issue that makes the design of spectrum sliced microwave photonic filters more complex, is that the finite width of the spectral slice illuminates a region of the dispersive medium and this causes a complex interaction in the response, which results in an RF degradation in the frequency response of the processor that is beyond the well-known carrier suppression effect [3][4]. This can cause important effects in the characteristics of the filter.

The dispersion induced distortion has been investigated based on a general model for spectrum sliced microwave photonic filters which is applicable to arbitrary variable time delay characteristics and to both double sideband and single sideband modulation formats [4]. Due to the effect of dispersion and the non-negligible sliced spectrum bandwidth, the filter coefficient is complex and modulation frequency dependent, thus its amplitude and phase character will respectively contribute to the RF decay [4]. Therefore spectrum sliced microwave photonic filters experience an additional dispersion induced RF degradation that relates to the optical spectrum character of the sliced spectrum.

Fig. 1 shows the relationship between the slicing bandwidth defined as the bandwidth between the –3dB down points of the slice, and the corresponding RF operational bandwidth where the filter response drops by 3 dB relative to its low frequency level, for different group delay slopes of the dispersive delay line. It can be seen that spectrum sliced photonic filters can operate to high frequencies if small spectrum slice bandwidths are used in conjunction with low group delay slope dispersive elements as shown in the results obtained by using FBGs with super-Gaussian apodization as the slicing element. The dashed lines in Fig.1 show the RF operational bandwidth for a dispersion value of 211.3ps/nm, for different slicing shapes, which show that the rectangular shape slicing gives a higher bandwidth performance in comparison to AWG Gaussian shape slicing. These results provide data for designing the slicing filter so as to meet a specified high frequency operational range requirement.

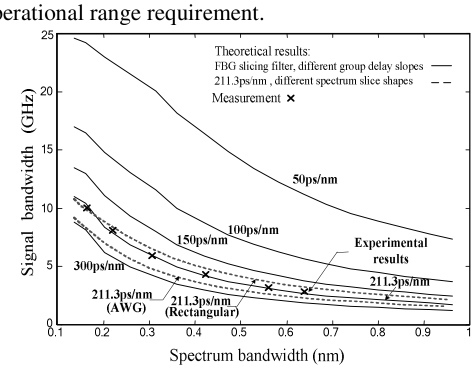

Fig1. Relationship between the sliced spectrum bandwidth and the corresponding RF operational bandwidth

2. Noise mitigation design strategy
The noise characteristics of spectrum sliced microwave photonic filters are significant issues because spectrum sliced sources have “thermal-like” properties [5], and consequently they have excess intensity noise. This very high excess noise level in fact sets the dominant limitation to the performance of spectrum sliced filters [6]. Hence, if spectrum sliced filters are to be used in

practice, highly effective methods to suppress the excess intensity noise will be required.

An effective noise mitigation design strategy that is low cost and is applicable to multi-tap, high frequency spectrum sliced microwave photonic filters, is based on making the spectral slice bandwidths narrower than the modulation frequency, and making the spacing between slices larger than the photodetector bandwidth [7]. This design ensures that the noise is low at the filter passband in high-frequency spectrum sliced microwave photonic signal processors, and achieves significant levels of noise mitigation.

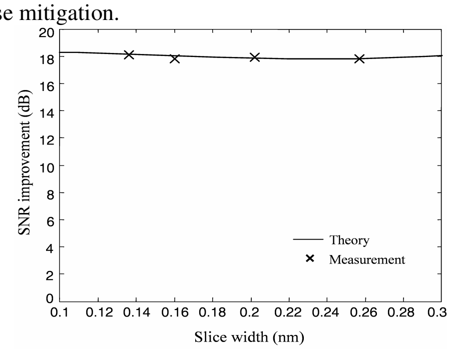

Fig. 2. SNR improvement of a filter at the center frequency of 6.3 GHz, using a designed slice width of 0.016 nm, relative to the use of a range of other typical slice widths.

The design strategy exploits the frequency behaviour of the RIN. The modulation frequency is chosen to be larger than the optical spectral bandwidth. In that case, the modulation waveform is not constant on the scale of the coherence time of the sliced source, and RIN exhibits a frequency-dependent character which is determined by the autocorrelation of the power spectral density of the source. For a finite slice width, the autocorrelation overlap diminishes rapidly at higher frequencies, and this causes a roll-off effect in the RIN at high frequencies. Hence the design strategy comprises choosing the spectral slice bandwidths to be narrower than the modulation frequency. This ensures the noise is low at the filter passband in high frequency microwave photonic signal processors.

However, the amount of noise mitigation that can be obtained in practice is limited by the phenomenon of modulation-induced noise translation in spectrum sliced photonic signal processors [7]. The power of this translated noise increases with the square of the modulation index. Hence, even if the filter is designed to be in the low-RIN region of the spectrum slice frequency-dependent characteristic, once modulation signal is applied, translated noise appears at the modulation frequency. Fig. 2 shows the SNR improvement of a filter at the center frequency of 6.3 GHz, using a designed slice width of 0.016 nm, relative to the use of a range of other typical slice widths. An increase in SNR of 18 dB relative to the use of other slice widths can be seen.

3. High frequency photonic signal processor

A novel spectrum sliced optical delay line signal processor that is particularly simple, and which can work to high frequency, while exhibiting good tolerance to the source wavelength is presented in Fig.3 [8]. It is based on an amplitude-modulated single sliced source and a novel sinusoidal group delay line structure. This introduces tailored phase shifts to the carrier and sidebands of the amplitude-modulated spectrum sliced signal. The sinusoidal delay line functions as a multiple-tap transversal delay line and enables the filter to integrate the tap weights and delays in one unit.

The filter can work to high microwave and millimeter-wave frequencies, because the free spectral range (FSR) of the microwave photonic filter is only determined by the oscillation frequency of the sinusoidal delay line. Through a design that makes the slice width to be equal to or multiple times the oscillation frequency of the sinusoidal group delay line, the filter weights are only determined by the product of the oscillation frequency and time amplitude of the sinusoidal group delay, and are independent of the optical carrier wavelength. This insensitivity to operating optical wavelength is advantageous because it shows the filter is robust to changes in environmental conditions, such as temperature changes that can cause shifts in the central frequency of the sliced source and delay line, and it also provides a flexible design capability. Moreover, for filter operation with a specified FSR, the filter weights can be designed by designing the time amplitude of the sinusoidal delay line.

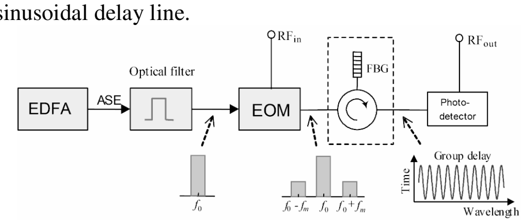

Fig. 3. Structure of the new microwave photonic filter.

Conclusion

Recent new developments in wideband signal processing based on spectrum slicing technique have been presented. These comprise the quantitative analysis of dispersion induced RF distortion and a novel noise mitigation technique, which provide data for designing spectrum sliced photonic filter operation at high frequencies with low noise, and a novel spectrum sliced optical delay line signal processor which can work to high frequency, while exhibiting good tolerance to the source wavelength.

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