RF Transversal Filter Using an AOTF

S. Mansoori and A. Mitchell

***Abstract*—An acoustooptic tunable filter (AOTF) is employed in an optical system to obtain an independently tunable and reconfigurable radio-frequency transversal filter. Manipulating only the control signals of the AOTF modifies the transfer function of the filter. This letter demonstrates the experimental implementation of a two-tap version of the proposed filter. Avenues for increasing the number of taps are discussed.**

***Index Terms*—Acoustooptic tunable filter (AOTF), optical signal processing, transversal filters.**

I. Introduction

THE ADVANTAGES of radio-frequency (RF) signal transmission using optical fiber links have sparked increasing interest in using photonic-based systems to perform RF signal processing. The processing of signals in the photonic domain alleviates problems associated with frequency down conversion to base-band and the electronic bottleneck inherent in analog-to-digital conversion. Other attractive features include low and constant loss across the operation bandwidth and insensitivity to electromagnetic interference.

Among the photonic signal processing applications proposed, the transversal (or finite impulse response) filter has attracted the greatest attention. Transversal filters are used for microwave filtering applications for both notch filtering [1] and for more general RF amplitude and phase tailoring [2]. For a transversal filter, the output is given by

$$y[m] = \sum_{n=0}^{N-1} h[n]x[m - n\tau_s] \tag{1}$$

where N is the filter order and indicates the number of taps, $h[n]$ is the impulse response of the filter realized as the tap weights, τ_s is the sampling period or delay increment between the taps, and $x[n]$ is the input signal. Examining (1), the output of the transversal filter is equal to a sum of weighted, delayed versions of the input. Realizing such a filter optically involves finding a method of performing the weighting and delay operations in the optical domain.

Several techniques for implementing transversal filters in the optical domain have been proposed. These techniques mainly stem from two general concepts. In the first, a single tunable laser and an array of dispersive media is used to perform the tapping operation and provide the delay [3].

The second concept uses an array of tunable lasers as the tapping element and a single wide-band dispersive medium for the delay [4]. The authors of [4] specifically emphasize the importance of achieving tunabilty and reconfigurabilty simultaneously if these transversal filters are to meet their multiple potential applications. These proposed transversal filters either lack the flexibility of obtaining different weights and sampling periods independently or, in cases where these two parameters are addressed simultaneously, the design involves the control of a number of distinct devices, which can be expensive to implement.

A technique which is in the second category but requires configuration of only a single device was reported [5]. The method is based on the use of a multimode laser as the tapping element and a wide-band dispersive media. By varying the spacing between the modes, tunabilty is achieved.

Our work develops this idea by allowing for independent reconfiguration and tuning of the transfer function. In this letter, we propose an RF transversal filter that can be independently tuned and reconfigured by controlling a single optical device, namely an acoustooptic tunable filter (AOTF) [6]. A two-tap version of this proposed filter is demonstrated.

II. Overview

A. Operation of AOTF

An AOTF is an electronically tunable optical filter. Its operation is based on the so-called acoustooptic interaction, where the refractive index tensor of a medium is changed by the presence of an acoustic wave. The acoustic wave, therefore, produces a wavelength-selective single-tone grating in the optical medium that can be varied by simply varying the acoustic frequency.

Of particular interest to this investigation is the multiwavelength operation of the AOTF. In this case, two or more acoustic waves are applied to the device producing a multitone grating, which is the superposition of the single tone gratings produced by the individual acoustic waves, and consequently selects a number of optical wavelength simultaneously. RF signals are used to excite the acoustic waves in the AOTF. These RF signals control the operation of the device and are referred to as the control signals throughout this work.

The low weight, small size, fast tuning speed, and multiwavelength operation of the AOTF makes it a suitable candidate for optically realized transversal filter implementations. However, it does suffer from some limiting factors that can degrade the performance of the proposed transversal filter. The effect of these factors will be discussed in Section IV.

B. Proposed Transversal Filter Layout and Operation

The configuration of the proposed transversal filter is shown in Fig. 1. A broad-band optical source provides the optical carrier. Control signals applied to the AOTF select certain wavelengths from this broad-band optical carrier. These selected wavelengths constitute the transversal filter taps or the

Manuscript received October 2, 2003; revised November 19, 2003.

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Digital Object Identifier 10.1109/LPT.2004.823695

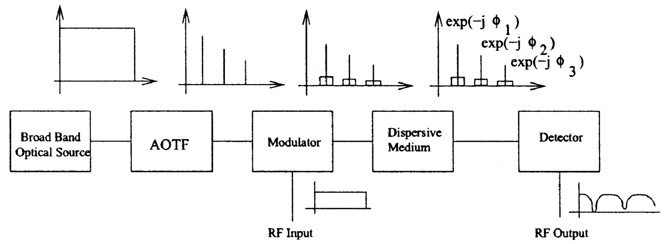

Fig. 1. Proposed filter layout.

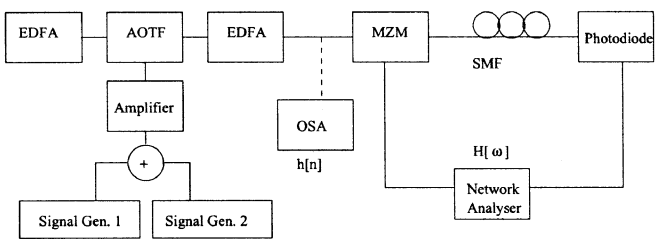

Fig. 2. Experimental setup.

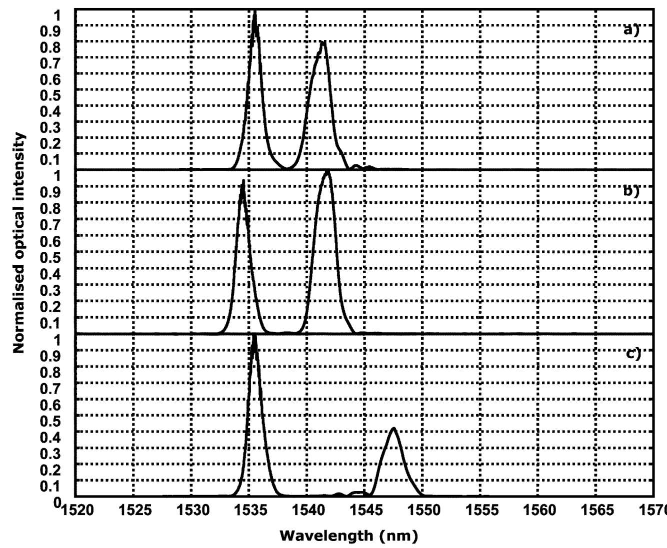

Fig. 3. Impulse response of the proposed transversal filter for three different tap spacings. (a) 5.8-nm tap spacing. (b) 7.2-nm tap spacing. (c) 12-nm tap spacing.

impulse response of the filter. Their amplitudes, which correspond to the tap weights, and their separation, which controls the time delay increment of the tap, can both be independently manipulated via the control signals applied to the AOTF.

These selected wavelengths are then intensity modulated with the RF signal (to be filtered) and pass through a dispersive medium. The optical carriers are then incident on a photodetector, which sums the RF signals vector ally. The output at this point is the filtered RF signal. The transfer function is approximately equal to the Fourier transform of the optical spectrum of the AOTF $h[n]$.

III. Experimental Work

The AOTF used in this work is a commercial bulk type AOTF with a tuning range of 1200–1700 nm and with a linewidth of approximately 2.4 at 1550 nm. Prior to implementing the proposed filter, the multiwavelength operation of the particular AOTF used in this experiment was studied to evaluate its coherent crosstalk behavior. The results showed that the intensity modulation induced on a −4-dBm optical signal caused by driving the AOTF with two RF signals simultaneously dropped significantly for separation of more than 100 kHz. To obtain distinct nonoverlapping taps, the separation between the taps should be greater than 2.5 nm (the AOTF linewidth). This corresponds to a control frequency separation of greater than 130 kHz. Therefore, the effect of crosstalk in this implementation would be minimal.

To verify the proposed filter concept, a two-tap version of the transversal filter was realized, as shown in Fig. 2. The amplified spontaneous emission from a high power erbium-doped fiber amplifier (EDFA) is used as a broad-band optical source. Two control signals were applied to the AOTF to select two optical wavelengths as the taps for the transversal filter. The optical signal was amplified through another EDFA. The impulse response of the transversal filter $h[n]$ was equal to the optical spectrum at this point. The selected wavelengths were intensity modulated with a 0.1- to 5-GHz RF signal using a Mach Zehnder modulator and then passed through a 4.5-km single-mode fiber (SMF) with dispersion equal to 17 ps/nm·km. The optical signal at the output of the fiber was detected using a broad-band PIN photodetector.

Referring to (1), the impulse response of the transversal filter $h[n]$ is equal to the optical spectrum at the output of the second EDFA. To demonstrate the tunabilty of the proposed filter, the impulse response of the filter for tap spacings of 5.8, 7.2, and 12 nm were measured on an optical spectrum analyzer and are shown as trace (a), (b), and (c), respectively, in Fig. 3. This was achieved by setting the two-signal generator to 85.1 and 85.4 MHz for Fig. 3(a), 85 and 85.4 MHz for Fig. 3(b), and 84.7 and 85.4 MHz for Fig. 3(c).

The transfer function of the transversal filter was measured on a network analyzer and is shown as the dotted line in Fig. 4. Also shown in Fig. 4, as the solid lines, are the transfer functions obtained by taking the Fourier transform of the three impulse responses. Good agreement is achieved. Note that the FSR of the transversal filter is reduced by increasing the spacing between the taps, which illustrates the tunabilty of the filter. For the particular tap spacings used in this experiment, the FSR (as defined in [5]) was calculated to be approximately 2.33, 1.9, and 1.12 GHz for tap spacings of 5.8, 7.2, and 12 nm, respectively.

The simulations show that the notch depths of the transfer function are affected by the uneven amplitude and linewidth of the taps. The experimental curves show deeper nulls at some points, which are attributed to the null being close to the noise floor.

IV. Discussion

The above experiment demonstrates that the transversal filter can be tuned easily by changing the spacing between control signals applied to the AOTF. Higher order filters can be obtained by increasing the number of control signals, and hence, the number of wavelength taps. Different filter shapes and apodizations could be realized by weighting the control signals accordingly. Two signal generators were used to control

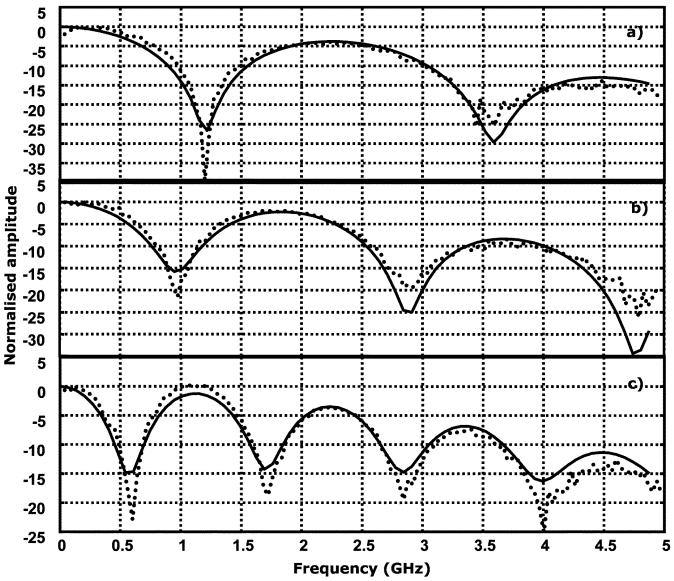

Fig. 4. Transfer function of the proposed transversal filter for three different tap spacings. (a) 5.8-nm tap spacing. (b) 7.2-nm tap spacing. (c) 12-nm tap spacing.

the AOTF, and hence, the transfer function of the transversal filter in this implementation. In a future implementation, this could be achieved with a single arbitrary signal generator or a digitally generated RF signal that contains the sum of the required RF control signals for the AOTF.

An issue is the efficiency of the device. The AOTF used in this work was a bulk type that requires approximately 1 W of RF power for 100% selection of each wavelength channel but has a maximum power rating of 2 W. This limits the number of taps for efficient operation of the device to two in this implementation. This can be alleviated in future implementations by using integrated AOTFs, which require less power (approximately 10 mW per channel) for efficient operation [7].

Another issue is the finite linewidth of the AOTF. The filter response in Fig. 4 exhibits significant amplitude degradation toward higher order frequencies. This is a direct result of the finite optical linewidth of the AOTF. Similarly, using integrated AOTF with narrower linewidth could improve the filter performance [8].

A more prominent limitation is associated with coherent crosstalk when implementing higher order filters. Using taps with equal spacing results in the accumulation of the coherence crosstalk at the difference frequency. A detailed study of this and other types of crosstalk in AOTF and methods of reducing their effects is in [9].

V. Conclusion

A novel photonic tunable RF transversal filter employing an AOTF and SMF as the dispersive medium has been proposed and demonstrated. The experimental results obtained compare well with the simulations and, thus, the concept is validated. It was shown that the overall transversal filter transfer function could be tuned and reconfigured by adjusting the control signals to the AOTF. The transversal filter could be extended to higher orders by increasing the number of control signals applied to the AOTF. Implementation of a higher order system involving an integrated AOTF is currently under investigation.

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