A Novel RF Photonics Band-Pass Filter

Sana Mansoori, Lam Anh Bui, Arnan Mitchell

Australian Photonics CRC,

School of Electrical and Computer Engineering, RMIT University,

GPO Box 2476V, Melbourne VIC 3001, Australia.

Abstract — **A novel photonically implemented RF band-pass filter, using a comb-laser and a fiber dispersive medium is presented. Positive and negative taps are achieved by driving two Mach-Zehnder modulators with opposing quadrature biases.**

I. INTRODUCTION

There has been considerable interest in the optically implemented RF filters over recent years. These systems overcome the limitations of conventional digital RF filtering techniques by providing high sampling rates. This allows processing of RF signals in the GHz region. Photonic implementations also take advantage of the low loss, large time-bandwidth product and electromagnetic immunity inherent in optical structures.

Incoherent realisations of such optical systems have been of particular interest in order to avoid the problems associated with optical interference. Numerous techniques for implementing transversal filters in the optical domain have been proposed [1-3]. Most of these realise low-pass transversal filters. The reason being that in such incoherent systems, the coefficients are determined by the intensity of optical signal, restricting the coefficients to positive values.

FIR band-pass filters can only be realised if a method of obtaining negative coefficients is devised. A few all-optical approaches have been demonstrated for realising negative coefficients. These realisations exploit the cross gain modulation in laser media. Coppinger et al obtained negative coefficients by using saturation modulation of a semiconductor optical amplifier (SOA) [4]. Another implementation [5] utilises the carrier depletion effect in a distribution feedback (DFB) laser and the cross gain modulation in semiconductor amplifiers. The above techniques, however, have been demonstrated for two tap band-pass filters. Although they have the advantage of being all-optical, extending the concept to higher order filter is not trivial.

An optoelectronic implementation which could be readily extended to higher order band-pass filters has been demonstrated [6]. The technique uses separate structures for positive and negative coefficients. The outputs of the two structures are then differentially detected. The optical structures use an array of laser to provide the taps for the filter, which can be cumbersome and costly.

In this paper we propose an optoelectronic method of obtaining a real band-pass transversal filter. The method uses a single broadband comb source to provide the filter taps and two intensity modulators driven at opposing quadrature points to provide the positive and negative coefficients.

This paper is organized in the following manner. Section II describes the principle of operation of the proposed band-pass filter. The experimental procedure and results, along with a comparison with simulations are presented in Section III. In Section IV, methods of improving the system operation and of obtaining both tunability and reconfigurabilty are discussed. Finally, the conclusions are summarized in Section V.

II. THEORY OF OPERATION

A low pass filter with impulse response $h(t)$ can be transformed to a band-pass filter by multiplying the impulse response with a sinusoid at frequency ω_0. This introduces negative taps in the band-pass filter impulse response. The frequency response of the band–pass filter will have a similar shape to the low-pass filter but a centre frequency of ω_0. Its impulse response will have the same *envelope* of the low-pass filter but with alternating positive and negative coefficients.

In this work we obtain a band-pass filter using this concept. Starting with a low-pass filter *h(t)*, a band-pass filter impulse response can be obtained as

$$h_{BP}(t) = h(t) - h(t - t_0) \qquad (1)$$

This impulse response has the same envelop as *h(t)*, but has alternating positive and negative coefficients. The frequency response $H_{BP}(\omega)$ of this band pass filter is equivalent to the low-pass filter response $H(\omega)$ shifted to frequency $\omega_0 = \pi / t_0$.

To realize this idea, we propose the structure shown in Fig. 1. The optical carrier in this implementation is provided by a comb-laser. Its spectrum consists of multiple equally spaced longitudinal modes. The optical signal is split into two arms. The upper path is modulated with the RF signal to be filtered and the lower arm is modulated with the same RF signal with a 180° phase-offset. A time delay is also introduced to the RF signal in the lower arm as illustrated in Fig. 1. The modulated optical signals are then combined before traveling through a dispersive medium. The filtered RF signal is then recovered using a photodetector.

If the lower arm is removed from the structure in Fig 1, it realises a low-pass filter. The comb-laser longitudinal modes constitue the filter taps. The RF signal is modulated onto each of these taps. When traveling through the dispersive medium each wavelength will experience a different delay. The output of the medium is therefore a collection of various delayed modulated optical signals corresponding to various modes of the comb-laser. Finally, the photodetector converts these modulated optical signals to a sum of delayed RF signals. The overall effect of the above operation is a low-pass transversal filtering. The impulse response *h(t)* being equal to the power spectrum of the comb-laser.

When the lower arm is included in the structure, it introduces the negative coefficient that transform the frequency response of the transversal filter from a low-pass to a band-pass. The 180° phase-offset provides the negative of *h(t)* and the time shift provides the delay t_0 to define the band-pass filter center frequency. The overall result in this case is a band-pass filter with impulse response $h_{BP}(t)$ defined in Equation (1).

II. EXPERIMENTAL VERIFICATION

In order to verify the theory developed in Section II, the experiment set up as depicted in Fig. 2 has been used. The optical source is an Anritsu AF5A211P2 comb-laser driven at 195 mA. This laser outputs multiple longitudal modes in the range of 1532nm to 1544nm wavelength with the mode spacing of 0.3nm. The output of the comb-laser is then split equally between two arms by a 50:50 fibre coupler. The optical wavelengths in the two arms are then modulated by a separate Mach-Zehnder Modulator (MZM).

In order to achieve positive and negative taps, the upper arm and the lower arm are modulated with the same link gain and at 180° phase difference. This is attained as

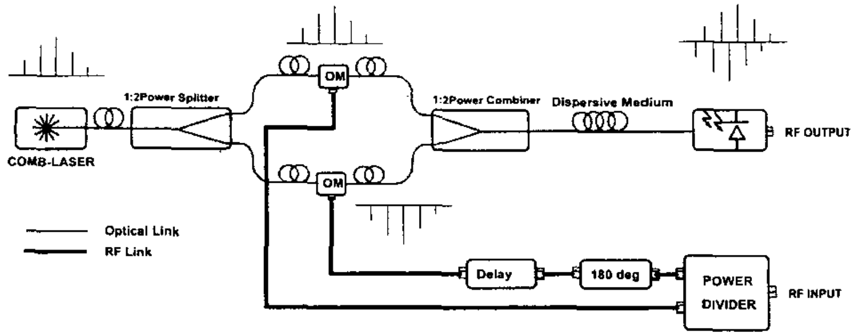


Fig. 1 Band-pass Filter Implementation Concept

follows. First, both MZMs are biased at positive slope quadrature. To obtain zero phase shift between the two arms, a carefully prepared length of optical single mode fiber is used to compensate for the path difference between them. Next, the link-gain in both arms is measured to verify that they are identical. Since identical MZMs were used the link gain were found to be almost equal. Finally, the 180° phase difference is achieved by biasing the upper arm MZM at positive slope quadrature and adjusting the bias of the lower MZM to give negative slope quadrature. The true time delay mechanical phase-shifter (KDI/Triangle PV-18) is adjusted to 61.9ps in order to obtain equally spaced alternating positive and negative taps, as shown in Figure 2.

The two arms are combined together using another 50:50 fibre coupler. The output of the 50:50 fibre coupler is then lauched into a 24.3 km length of SM fiber.

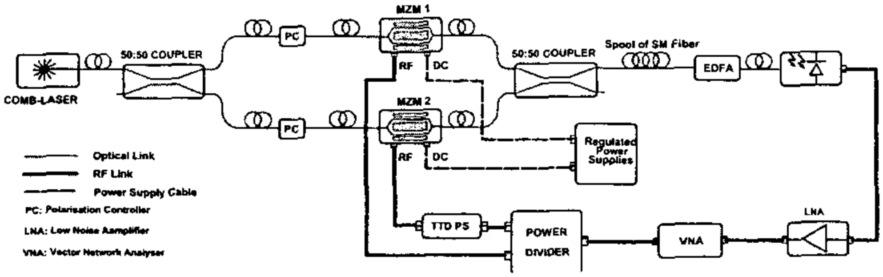
The output of the SM fiber is a collection of alternating positive and negative delayed RF signals. The differential time delay between these taps is 61.9ps which correspondes to half the comb-laser mode spacing.

The transfer function of the filter is measured using a Wiltron 37347A vector network analyzer. Fig. 3a) presents the filter impulse response, which shows the alternating positive and negative taps equally spaced at 61.9ps. Fig. 3b) depicts the filter magnitude response. The dotted trace shows the theoretical results obtained from the simulations and the solid trace shows the experimental results. It can be seen that the real band-pass response is obvious with no DC component. Reasonable agreement between the measurement and calculation is obtained. The centre frequencies of the pass band coincide for both the simulations and the experimental results at 8.5GHz corresponding to t_0=58.8ns tap spacing.

IV. DISCUSSION

It is worth noting that the preliminary results presented in Section III exhibits some variation from the simulations. The side lobes for the experimental result are higher than the simulations. The transfer function obtained on the network analyzer showed some time variation. This has been attributed to a low level of coherent interference between the upper and lower arms in the structure. Methods of eliminating the effect of coherence in the structure are being investigated. Improved results will be presented at the conference.

It would be advantageous to make the demonstrated band-pass filter tunable and reconfigurable. Tuning of the filter pass-band could be achieved by using a tunable comb-laser. By varying the spacing between the longitudinal modes, hence the filter tap's spacing, the free spectral range (FSR) could be adjusted. To reconfigure the pass-band of the filter, a tunable optical filter can be employed to shape the comb-laser spectrum and thus obtain the required filter impulse response. The Acousto-optic tunable filter (AOTF) [7] is a suitable candidate for this purpose. Implementations of this sort are currently under investigation.



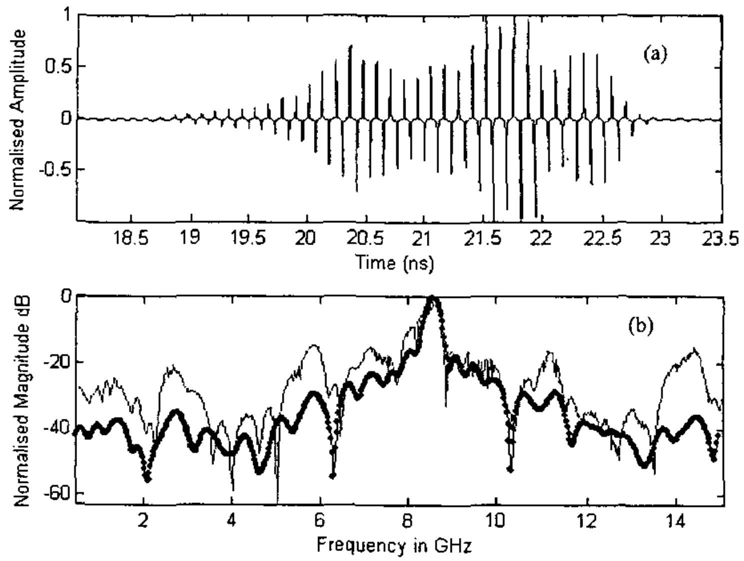


Fig.3 Theoretical (dotted) and measured (solid) band-pass filter magnitude response

V. CONCLUSIONS

A novel photonic Band-pass RF transversal filter employing a comb-laser and a length of single mode fibre as the dispersive medium has been proposed and demonstrated. The experimental results compare well with the simulations and thus the concept is validated. It has been proposed that the overall band-pass filter transfer function could be tuned by using a tunable comb-laser. Reconfigurabilty of the filter transfer function could be achieved by using an AOTF after the comb-laser.

REFERENCES

[1] D. Hunter and R. A. Miansian, "Tunable microwave fiber-optic bandpass filter," *IEEE Photonics Technology Letters*, vol. 11, pp. 874-876, 1999.

[2] D. Pastor and J. Capmany, "Fibre optic tunable transversal filter using laser array and linearly chirped fibre array," *Electronics Letters*, vol. 34, pp. 1684-1685, 1998.

[3] M. Y. Frankel and R. D. Esman, "Fiber-optic tunable microwave transversal filter," *IEEE Photonics Technology Letters*, vol. 7, pp. 191-193, 1995.

[4] F. Coppinger, S. Yegnannarayanan, P. D. Trinh, and N. Jalali, "All-optical RF filter using amplitude inversion in a semiconductor optical amplifier," *IEEE Transactions on Microwave Theory and Techniques*, vol. 45, pp. 1473-1477, 1997.

[5] S. Li, K. S. Chiang, W. A. Gambling, Y. Liu, L. Zhang, and I. Bennion, "A novel tunable all-optical incoherent negative-tap fiber-optic transversal filter based on a DFB laser diode and fiber Bragg gratings," *IEEE Photonics Technology Letters*, vol. 12, pp. 1207-1209, 2000.

[6] J. Capmany, J. Cascon, J. L. Martin, S. Sales, D. pastor, and J. Marti, "Synthesis of fiber-optic delay line filters," *Journal of Lightwave Technology*, vol. 13, pp. 2003-2012, 1995.

[7] H. Mendis, A. Mitchell, I. Belski, M. Austin, and O. A. Peverini, "Design, realisation and analysis of an apodised, film-loaded acousto-optic tunable filter," *Applied Physic B*, vol. 73, pp. 489-493, 2001.