Photonic Tunable RF Filter with Reconfiguration Capabilities based on Arrayed Waveguide Gratings and Fiber Dispersion

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Abstract — **A novel photonic microwave filter architecture based on the use of laser arrays and the periodicity of NxN arrayed waveguide gratings (AWG) optical response is proposed. Independent filter response coarse and fine tuning as well as reshaping of each filter response have been experimentally demonstrated showing an excellent agreement with theory.**

I. Introduction

Photonic transversal RF filters have attracted a lot of interest due to their interesting features as high dynamic range, high compactness and fast reconfiguration and tuning requirements. Several configurations have been proposed employing a variety of fiber-optic devices as highly dispersive fibers [1], fiber gratings [2-4], fiber-optic prisms [5] or arrayed waveguide gratings (AWG) [6]. Photonic microwave filters benefit from low loss and size of optical fiber devices and cables as well as from immunity to electro-magnetic interference (EMI).

In this paper, a novel architecture based on the use of multi-wavelength lasers (MWL) and NxN arrayed waveguide gratings is proposed and experimentally demonstrated. The proposed filter architecture relies on the use of the periodicity of the AWG spectral response which allows to implement a very flexible and spectrally efficient filter architecture by combining wavelength division multiplexing (WDM) and wavelength-selective delays. The same operation principle was recently proposed by the authors to implement a beamforming network [7].

II. Filter description

Fig. 1 shows the proposed architecture. It employs an optical delay line (ODL) based on one single NxN AWG in a loop-back configuration (feedback between input and output ports) [7] where, unlike previous proposals [6], the delay is implemented using simultaneously fiber dispersion and multiple wavelengths with a separation amongst them equal to the Free-Spectral Range (FSR_{AWG}) of the AWG. In this scheme, the optical carriers are simultaneously amplitude modulated by the RF/microwave electrical signal using an external modulator and launched to the AWG-based ODL. When multiple simultaneous wavelengths with a separation amongst them equal to the FSR_{AWG} are launched into the delay line common input port, they are routed to the same AWG output port passing through a certain length of fiber (e.g. L_1). Each wavelength is delayed differently due to wavelength dependent fiber chromatic dispersion and fed back into the symmetric input port. Then, the AWG focuses the delayed WDM signal into the common output port where it is photodetected. In this way, microwave filter with multiple taps are obtained with only one AWG.

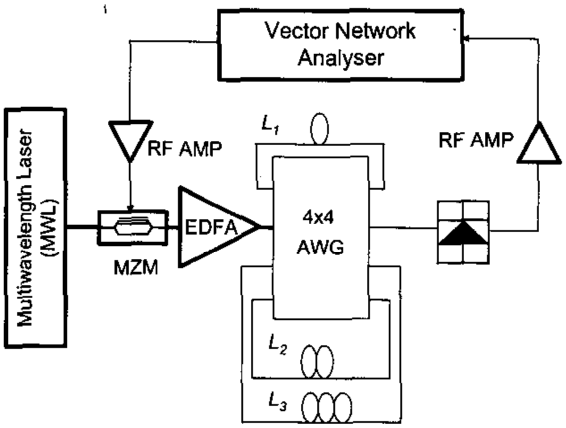

Fig. 1 Photonic RF filter architecture

In order to select the filter response a multiwavelength source with the ability to switch among different sets of simultaneous optical carriers with a frequency spacing equal to FSR_{AWG} is required. This source can be implemented, for instance, using several multi-wavelength lasers (MWL) [8] and switching among them or by simultaneously tuning all the wavelengths of each set. Moreover, since AWGs can route several sets of wavelengths at the same time, more than one microwave filter can be obtained simultaneously if several sets of wavelengths are used together (obtaining a parallel filter) [9].

III. Filter Response Tuning Capability

The proposed architecture presents independent coarse and fine tuning capabilities. If the optical carriers are simultaneously shifted by an integer multiple of the AWG channel spacing (CS_{AWG}) to adjacent channels of the AWG, as shown schematically in Fig. 2, then they are routed to a different output port passing through a different length of fiber (e.g. L_2). In this way, a coarse tuning of the filter response can be achieved, by varying the total dispersion value of the optical path. Since this coarse tuning capability depends on the total fiber path length, the desired filter responses can be independently designed with high accuracy by specifying the optical fedback path lengths. It is important to point out that the proposed solution for the coarse tuning of the filter is not restricted to the use of a set of broad-range tunable lasers as previously proposed solutions [1-2] reducing considerably the overall cost of the filter since fixed MWL can be employed.

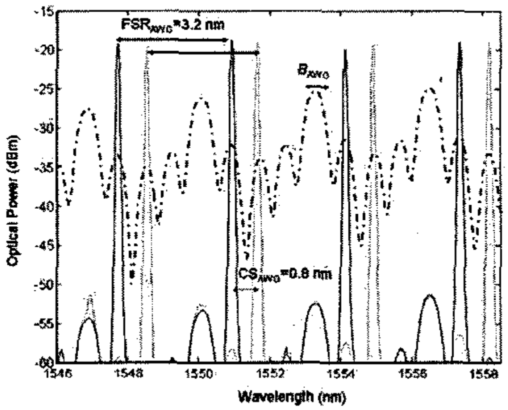

Fig 2. Optical power at the photodetector input, corresponding to a four taps filter with 3.2 nm wavelength spacing (solid line). The dashed-dotted line corresponds to the 4x4 AWG in loop-back configuration optical response obtained with a broadband ASE source. The highest pass-bands correspond to the direct path (common input port to common output port).

Once a certain filter response is synthesized by selecting the corresponding fed-back path, it is possible to introduce dynamic fine tuning capabilities if the MWL presents slight wavelength spacing reconfiguration capabilities to adjust, for instance, the frequency of a notch in a certain frequency interval. This additional fine tuning capability is practically limited by the bandwidth of the AWG pass bands, BW_{AWG} as well as by the source tuning range.

IV. Filter Response Reshaping Capability

In addition to the tuning capabilities, the filter response of the proposed architecture can be independently reconfigurated by windowing the filter impulse response. It can be achieve by means of the variation of the laser output power. It is well known from digital filter design theory [10] that the shape of the transfer function of a discrete time transversal filter can be reconfigured changing the weights (i.e. apodisating) of the time samples of the impulse response. Apodisation using appropriate windowing functions usually results in the reduction of the filter secondary sidelobes, finesse and contrast ratio.

An alternative coarse method for reconfiguring the shape of the filter response is by changing the number of signal samples or taps (i.e. WDM signals). It changes the number of nulls between main lobes and the shape of the filter response but do not change the filter FSR.

IV. Experimental Results

In order to show the reconfiguration and tuning capabilities of the proposed filter architecture different experiments have been carried out employing the setup of Figure 1. The laser array was implemented using two narrow-tuning distributed-feedback (DFB) lasers and two wide-tuning external cavity lasers (ECL), which output wavelengths were combined using a standard 4:1 fiber optic coupler. A 40 Gb/s Mach-Zehnder modulator (MZM) with 30 GHz -3dB bandwidth was employed as external modulator. An Erbium-doped fiber amplifier (EDFA) was used to compensate for the ODL optical losses. Two RF amplifiers were used to boost the RF signal from/to a vector network analyzer used to measure the filter response.

A. Filter tuning capability

Fig. 3 shows the experimental results which confirm the coarse tuning capabilities of the proposed architecture. Measurements for three fiber path lengths are provided (L_1= 2.1 km, L_2=25.07 km and L_3=27.17 km). Solid lines correspond to theoretical results and dotted lines are the experimental results. An excellent agreement between theoretical and experimental results can be observed.

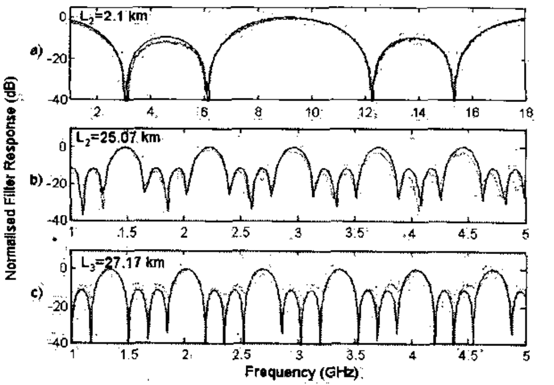

Fig. 3 Normalised photonic microwave filter responses showing coarse tuning capabilities. a) Response 1 (L_1=2.1 km); b) Response 2 (L_2=25.07 km); c) Response 3 (L_3=27.17 km). Solid lines are theoretical values and the dotted ones experimental.

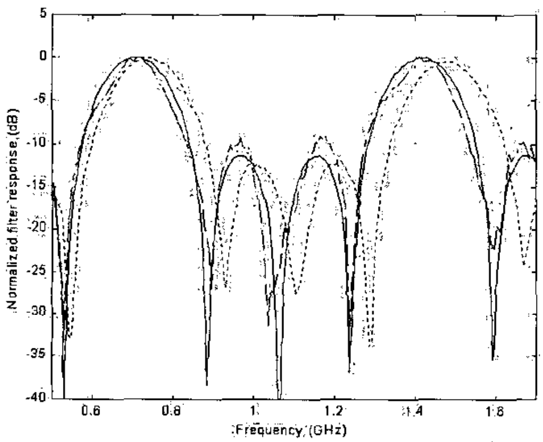

Fig. 4 Filter fine tuning capabilities. Dashed and short-dashed lines are the experimentally filter responses for υ=3.2 nm and υ=3.35 nm, respectively. The solid line is the theoretical response for υ=3.2 nm.

Fig. 4 shows the experimental results obtained to demonstrate the fine tuning capabilities of the filter, achieved by slight variations of the separation between optical carriers, υ. The exact wavelengths of the MWL were λ_1=1547.747 nm, λ_2=1550.947 nm, λ_3=1554.147 nm, and λ_4=1557.347 nm. The solid line corresponds to the theoretical calculation for this uniform four taps filter with υ=400 GHz (3.2 nm), passing through a delay element consisting on a 25 km fiber coil (L_1). The dashed line corresponds to the experimental results. A good agreement between theory and experiments may be observed. By setting υ=417.24 GHz (3.35 nm) the resonances of the filter response shift to higher frequencies, as may be observed in Fig. 4 (short-dashed line). The corresponding theoretical calculation has been omitted for the sake of clarity. The filter free-spectral range (FSR) obtained experimentally is 739.6 MHz, which agrees very well with the theoretical calculation (739.52 MHz). This measurements shows the fine tuning capability of the proposed filter architecture using optical sources with a very small tuning range.

B. Filter reshaping capabilities

The reconfiguration of the shape of the filter response by means of changes on the number of taps (WDM signals) is demonstrated in the experimental results shown in Fig. 5. Solid lines correspond to theoretical results and the dotted lines are the experimental results. Both show again a good agreement with theory. Experimental results for 4, 3 and 2 taps filter (from top to bottom) are in very good agreement with theoretical predictions. As can be seen from Fig. 5, the number of nulls between two main lobes is N-1, being N the number of taps.

Moreover, as mentioned in Section IV, the filter response may be easily reshaped by windowing the amplitudes of the optical carriers [2,4]. This allows to change the value of fundamental filter response parameters as filter finesse and contrast ratio. The experimental demonstration of the filter response reshaping capabilities by windowing is shown in Fig. 6.

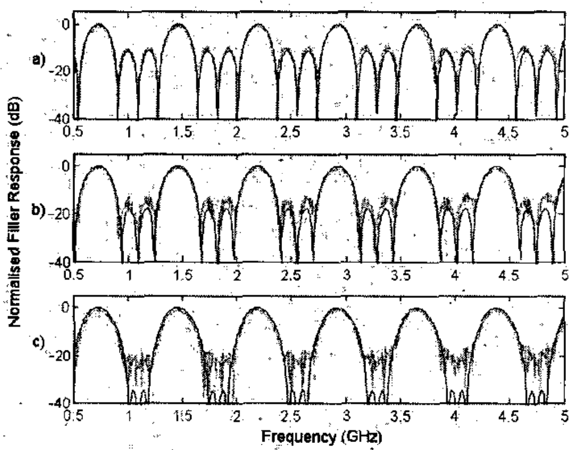

Fig. 5 Normalised filter response (4 taps) with MWL optical power weighting. The solid line shows the theoretical calculations and the dashed line the experimental results. a) Uniform weighting (1, 1, 1, 1); b) Arbitrary weighting (0.63, 1, 1, 0.63); c) Hanning weighting (0.38, 1, 1, 0.38).

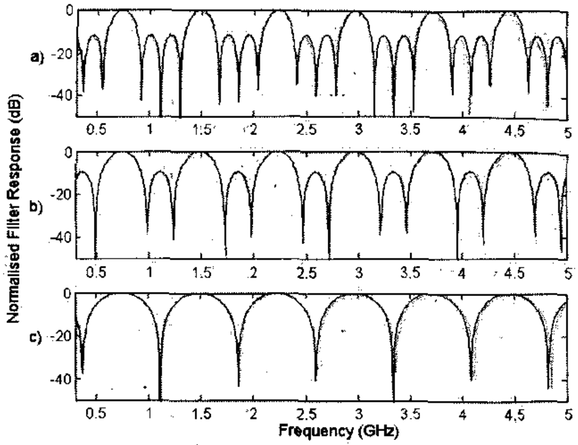

Fig. 6 Normalised filter response (uniform window) as a function of the number of filter taps (optical carriers). The solid line shows the theoretical calculations and the dashed line the experimental results. a) 4 taps; b) 3 taps; c) 2 taps.

V. CONCLUSION

A novel tunable photonic RF filter architecture based on the use of laser arrays and NxN arrayed waveguide gratings has been proposed. The architecture exploits the periodicity of the AWG spectral response. Filter coarse and fine tuning are achieved by changing the absolute delay path and wavelength spacing, respectively. Independent coarse and fine tuning as well as reshaping of individual filter responses have been experimentally demonstrated showing an excellent agreement with theory. Finally, the proposed architecture does not require of the use of tunable optical sources over a huge optical margin unlike [1]-[2] which reduces the system cost.

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