# Opto-VLSI-based Tuneable Photonic RF Filter

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***Abstract*—A tuneable photonic RF filter structure is proposed, and simulated. The structure comprises a reconfigurable Opto-VLSI processor, arrayed waveguide gratings, a fiber array, and high-dispersion fibres. The processor has the ability to generate positive and negative weights for realising arbitrary responses. The proof-of-concept of the tunable photonic RF signal processor is also experimentally demonstrated.**

***Keywords*— Optical signal processing, tuneable filter, liquid crystal devices, reconfigurable architecture and photonic switching system.**

## I. INTRODUCTION

Photonic-based radio frequency (RF) filter have the advantages of immunity to electromagnetic interference, flexibility, broadband capability and light weight compared to RF filter implemented using electronic circuit. These advantages open new opportunities in a wide range of potential applications especially when high selectivity, resolution, wide tunability, and fast reconfigurability characteristics are required [1].

Several tunable photonic RF filter structures have been proposed and demonstrated [1-6], where filter reconfigurability is achieved by adjusting the tap weights through optical attenuation via MEMS switches [2], using variable optical attenuators (VOAs) [4], or employing Fibre Bragg Gratings (FBG) [5] that can be tuned either thermally or mechanically. However, in order to achieve high-resolution reconfigurable photonic RF signal processors that are able to synthesise arbitrary transfer characteristics, extensive research and development are still required [6].

In this paper, the principle of a reconfigurable photonic RF filter is discussed. The structure employs a broadband optical source, a pair of Arrayed Waveguide Gratings (AWG), an Opto-VLSI processor, a pair of high-dispersion fibres, and a balanced photodetector to synthesise arbitrary frequency responses through optical beam steering and multicasting as well as true-time delay generation.

## II. PHOTONIC RF FILTER STRUCTURE

The structure of the photonic RF filteris shown in Fig. 1. A broadband light source of amplified spontaneous emission (ASE) is externally modulated by the RF signal through an electro-optic modulator (EOM). The modulated light is routed via a circulator into an N-channel arrayed waveguide grating (AWG 1) that slices the ASE into different RF-modulated wavebands, which are routed to a fiber array of N fibre pairs. Each fiber pair consists of an upper fiber (connected to an output port of AWG 1) and a lower fiber (connected to a corresponding port of AWG 2). A lens array is used to convert the divergent beams from the upper optical fibers into collimated beams.

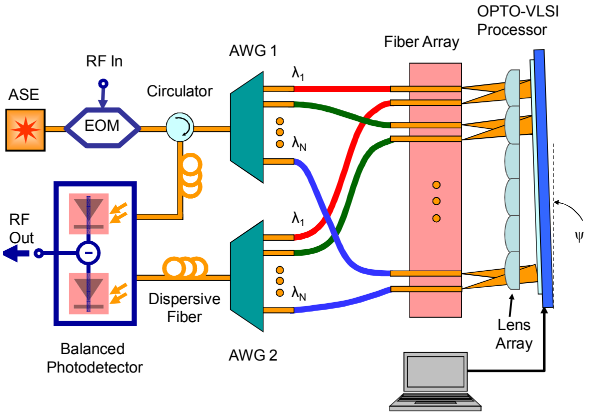


**Fig. 1.** Proposed reconfigurable photonic RF filter

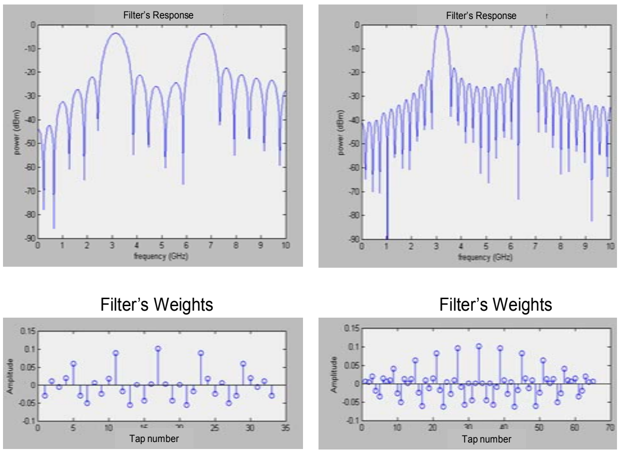
By employing an appropriate hologram into the Opto-VLSI processor, the collimated beam is appropriately steered and coupled with arbitrary attenuation (or weight) to either the upper fiber (for positive weights) or to the lower port (for negative weights). The wavelengths from the lower ports are multiplexed via AWG 2 and delayed by a high dispersion fiber, while the remaining wavelengths, which are steered and coupled back into the upper fibers, are multiplexed by AWG 1 and reach another similar high dispersion fiber via the circulator. The two multiplexed WDM signals are detected by a pair of balanced photodiodes which generate delayed versions of the input RF signal with positive and negative weights that are controlled by the phase holograms uploaded onto the Opto-VLSI processor, thus realising an arbitrary transfer function.

## III. SIMULATED RESULT

The response of the Photonic RF signal processor shown in Fig. 1 can be expressed as

$$H(\omega) = \sum_{k=0}^{N-1} a_k e^{-j\cdot\omega\cdot k\cdot T} - \sum_{k=0}^{N-1} b_k e^{-j\cdot\omega\cdot k\cdot T} \qquad (1)$$

where $N$ is the number of the taps, $a_k$ is the weight associated with the optical intensity of the $k^{th}$ waveband, $\lambda_k$, coupled into the $k^{th}$ upper optical fibre and detected by the upper photodetector. $b_k$ is the weight associated with the optical intensity of the $k^{th}$ waveband, $\lambda_k$, coupled into the $k^{th}$ lower optical fibre and detected by the lower photodetector.



(a) (b)

**Fig. 2.** Examples of filter responses and weights synthesising passbands at 3.1 GHz and 6.7 GHz. (a) 32-waveband (steering only) filter structure, and (b) 32-waveband filter with multicasting.

A computer algorithm has been developed to optimise the tap weights, $a_k$, and $b_k$ that synthesise a specific frequency response and generate the appropriate phase holograms to be uploaded into the Opto-VLSI processor. Fig 2(a) shows simulated 32-waveband dual passband filter response, where only steering holograms are used to generate the filter's 32 weights. Fig 2(b) shows simulated 32-waveband dual passband filter response, where multicasting holograms are used to generate the filter's 64 weights (each waveband is multicast to both of the corresponding fiber pair). It is obvious that weight levels in both Fig. 2(a) and Fig. 2(b) are close in magnitude. However, a much improved filter shape factor is seen when multicasting is employed.

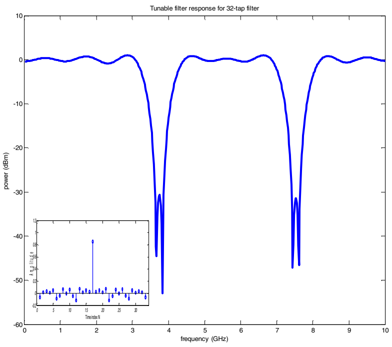


**Fig. 3.** Notch-filter response and weights (inset) of a 32-tap filter structure with notch frequencies at 3.75 GHz and at 7.5 GHz.

Fig. 3 show examples of notch filter responses and their corresponding weights where the notch frequencies are selected at 3.75 GHz to 7.5 GHz.

## IV. EXPERIMENTAL RESULTS

To demonstrate the principle of the photonic RF filter, 5 taps were used. Figures 4(a) shows the phase holograms applied to the Opto-VLSI processor to generate a constant time-delay increment with variable filter weights. For each pixel block, an optimum phase hologram was appropriately uploaded, so that the power level of the specific waveband was attenuated to an appropriate intensity. Figure 4(b) shows the wavebands measured by the OSA, and Fig. 4(c) shows the corresponding filter response, where the solid lines denotes the experimental results, which matches with the simulation results shown in dashed lines.

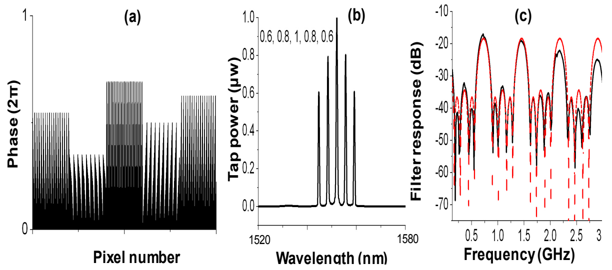


**Fig. 4.** RF filter tuning via tap weight control. (a), phase hologram applied to Opto-VLSI processor; (b) selected RF-modulated wavebands using the corresponding phase holograms (c) measured (solid line) and simulated (dashed line) filter response.

The filter response exhibit a free-spectral range (FSR) of about 722 MHz, and this is in good agreement with the specified dispersion coefficient of the HDF used in the experiments. The time delay increment, which is the product of the waveband separation and dispersion coefficient of the HDF, was 1.38 ns.and 3.60 nm, respectively.

## V. CONCLUSIONS

The principle of a reconfigurable photonic RF filter has been proposed and demonstrated. Simulation and experimental results show that arbitrary tap weights can be generated using optimised steering and multicasting phase holograms uploaded onto the Opto-VLSI processor. The experiments described in this paper demonstrate the principle of the reconfigurable photonic RF filter. Finally, it is important to note that by employing a two-dimensional 20mm×20mm Opto-VLSI processor, a 512-tap can practically be realised using 128-channel AWGs.

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