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Programmable Microwave Transversal Filter using Acousto-Optic Tunable Filtering

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ABSTRACT

Electronically programmable, broadband analog Radio Frequency (RF) transversal filter architecture is proposed and implemented using an Acousto-Optic Tunable Filter and a Chirped Fiber Bragg Grating. Proof-of-concept filter two-tap notch filters are demonstrated with a tunable range of 2-8 GHz and notch depth of 35 dB.

Keywords: Acousto-optical Signal Processing, (070.1170) Analog Signal Processing, (070.6020) Signal Processing.

1. INTRODUCTION

Applications, such as in electronic warfare, radar, and multibeam adaptive antenna systems for commercial and military communications, involve filtering operations in a changing signal processing environment. Hence there is a need for electronically programmable RF transversal filters that can be adapt to the changing environment conditions. When the mentioned applications require signal processing capabilities over broad bandwidths (tens of GHz), photonic-based RF systems provide an excellent option [1]. Over the years a number of photonic techniques have been proposed to implement transversal RF filters [2–14]. This paper presents detailed design and experimental demonstration of the proposed optimized and compact AOTF based analog RF filter design. The rest of the paper describes the theory and demonstration of the proposed retroreflective analog RF filter.

2. AOTF BASED RADIO FREQUENCY TRANSVERSAL FILTER

The design of the proposed bulk AOTF device based RF transversal filter is shown in Fig. 1. Signal from a broadband light source is intensity modulated using a high-speed Mach-Zehnder interferometeric waveguide modulator (MZWM) by the RF signal that needs to be filtered. The modulated light is fed to the AOTF device through an optical circulator (C1) and a Polarization Controller (PC) and a fiber grin lens FL_1. The light entering the AOTF forms the Gaussian minimum beam waist at the center of the device. The angle θ that the incident light makes with the AOTF surface normal is adjusted so that it satisfies Bragg diffraction condition for the C-band (e.g., 1530-1562 nm). The device diffracts light when fed by RF drive signal(s) to produce vertical or s-polarized Bragg diffracted beam which is coupled into a second fiber lens FL_2. FL_2 is placed at a distance from AOTF such that it captures the maximum diffracted light (using the self-imaging effect [15]). The coupled light into FL_2 passes through a CFBG that has a linearly varying grating period along its physical length. Thus the different wavelengths within the AOTF diffracted broadband light develop differential time delays between themselves. The reflected and relatively delayed wavelengths trace their paths backwards through FL_2 and the AOTF to undergo a second Bragg diffraction. The double-diffracted p-polarized light is then coupled into FL_1. The AOTF diffracted light forms a spectral Sinc squared function about a central Bragg-matched wavelength. With multiple RF drive frequencies, multiple sinc squared functions are obtained along the optical spectrum. The double-pass Bragg diffraction squeezes the spectral function even more [16,17] and the resulting spectral functions or lobes are narrow enough to allow them to be approximated by unit impulse function for RF filter design. The height of the impulse functions or the filter tap coefficients can be varied by varying the strength of the AOTF RF drive signals. Thus through the CFBG reflection-mode operation, wavelength difference between the impulses translates into time difference between filter taps, i.e., $\tau = \Delta\lambda\, D_{cg}$ where D_{cg} is the CFBG dispersion constant.

In filter design the weights of the filter can be both positive and negative. In intensity-based optics however, negative numbers cannot be represented directly. The proposed filter design therefore utilizes a unique design where the even odd wavelengths of the diffracted broadband light and hence the even and odd weights are separated. A Wavelength Division Multiplexed (WDM) Interleaver (I) device is used to spatially split the spectrum into odd and even wavelengths [11].

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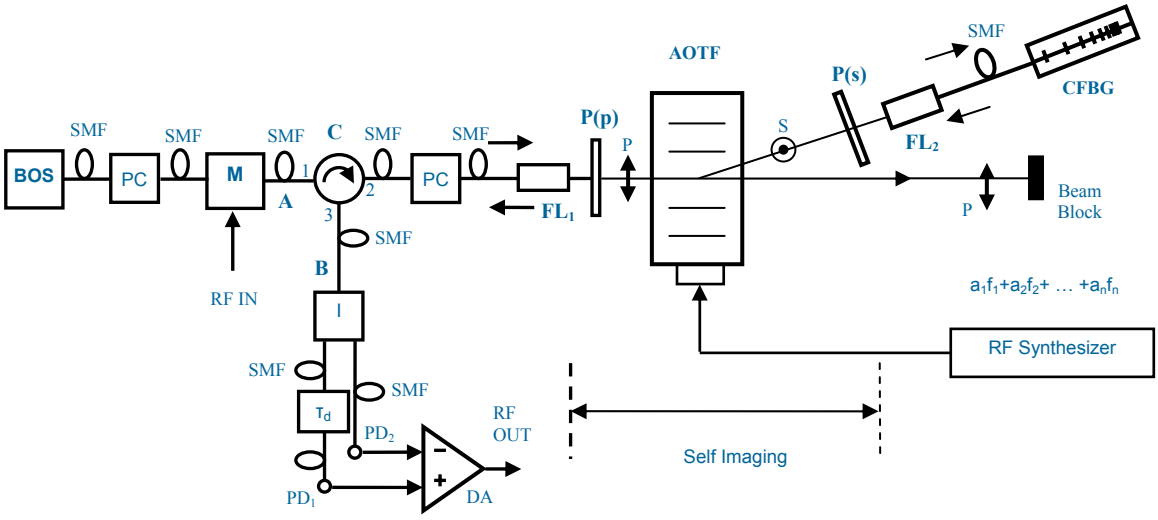


Fig. 1. Proposed retro-reflective design programmable broadband RF transversal filter using compact CFBG fiber-optics and an AOTF.

The even wavelengths and odd wavelengths are used for positive and negative tap coefficients, respectively. The fixed time delay of τ_d between the odd and even wavelengths is compensated by adding a fixed fiber delay of τ_d to the even wavelength channels before entering the photodetector PD_1 whereas the odd wavelengths are directly detected by PD_2. Finally, RF signals from PD_1 and PD_2 are subtracted electronically by the RF Differential Amplifier (DA) to implement both the positive and negative filter coefficients and hence to produce the desired filtered RF output.

3. EXPERIMENTAL RESULTS

The design shown in Fig. 1 is implemented using a collinear Tellurium Dioxide (TeO_2) AOTF from Crystal-Tech/ Nuonics with a 1520–1640 nm operation band. Two-tap and four-tap RF filters are implemented such that their tap weights are only positive and therefore the experimental setup contains a single PD whereas the interleaver I and differential amplifier DA are not deployed. The AOTF is set for an incident Bragg angle of 1.5° and driven by a 47.4 MHz RF signal with a 45 mW power which corresponds to a 50% diffraction efficiency for a 1544 nm test wavelength. An erbium-doped fiber amplifier (EDFA) broadband optical source is used for implementation of the RF notch filters. At the 1544 nm test wavelength, the total fiber-in to fiber-out (port A to port B, see Fig. 1) RF filter optical loss is 8.47 dB. The minimum beam waist distance z_0 for FL_1 and FL_2 is 6 cm, The deployed CFBG has a D_{cg} of 35.2 ps/nm. The deployed output RF amplifier restricts the output RF spectrum between 2 and 8 GHz. Thus the broadband optical signal from the EDFA is intensity modulated using a MZWM driven by a 2–8 GHz broadband RF signal from a Hewlett Packard network analyzer. For two-tap notch filter operation, the AOTF is fed by two independent RF drive signals. The first two-tap filter is implemented by feeding the AOTF by RF signals at frequencies of 47.35 and 47.2 MHz where as for the second two-tap filter the fed RF frequencies are 47.27 and 47.2 MHz. The wavelength difference or spacing $\Delta\lambda$ between diffracted spectral lobes for the two filter examples is 4.6 nm and 2.1 nm, respectively. Also the lobes in both examples have a 3 dB spectral width of 0.75 nm which gives the criteria for defining the maximum attainable tunable frequency for the notch filter design. The filter coefficient time delays τ of 161.92 ps and 73.9ps, generated through $\Delta\lambda$ of 4.6 nm and 2.1 nm, respectively, lead to notch frequencies of 3.09 GHz and 6.75 GHZ as seen by the HP network analyzer trace in Fig. 2(a) and Fig. 2(b). The figures besides showing the tunability of the implemented 2-tap notch RF filter also give a comparison of the ideal theoretical filter responses against the experimental results. Results show a reasonably close match between ideal theory and experimentally measured filter responses.

Future work relates to implementation of Fig. 3 hybrid analog-digital control RF transversal filter which would combining the DMD^{TM}-based digital design to the current AOTF-based analog design for versatility and enhanced performance [18,19]. Its aim would be to combine the benefits of the digital design, e.g., repeatability and provision

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large number of filter taps, and the benefits of the analog design, e.g. near- continuous resolution controls for filter tap weights and time delay selection and fast response time.

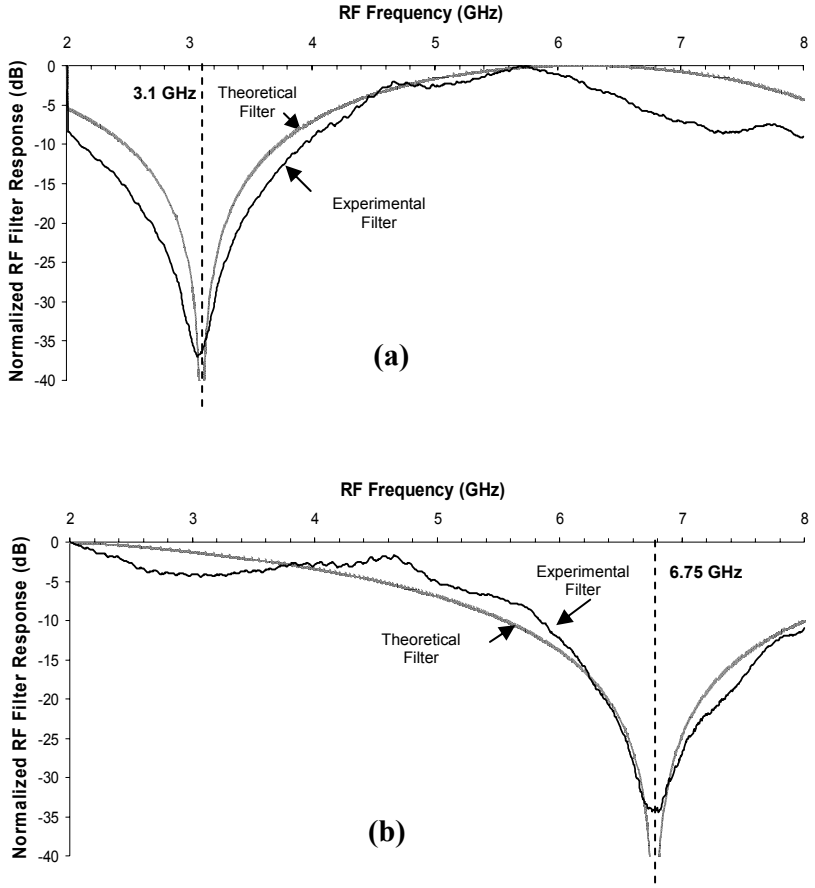


Fig. 2. Normalized frequency domain impulse response H(f) of the demonstrated RF notch filter with the null frequency set at (a) 3.09 GHz and (b) 6.75 GHz.

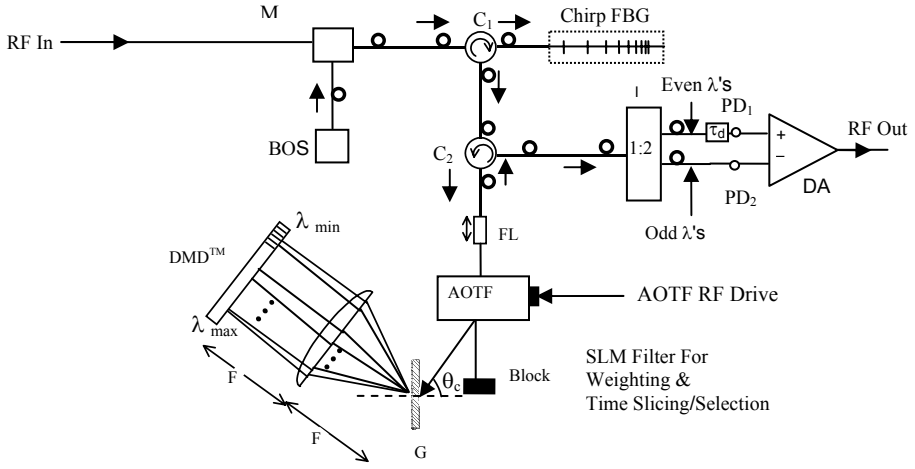


Fig. 3. Normalized frequency domain impulse response H(f) of the demonstrated RF notch filter with the null frequency set at (a) 3.09 GHz and (b) 6.75 GHz.

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4. CONCLUSION

A compact, fast reset time and near-continuous resolution RF transversal filter design is demonstrated for RF applications requiring adaptive filtering. The design is based on an optical retro-reflective architecture using AOTF double-pass Bragg diffraction for spectral filter weight control and a compact 1 cm long CFBG for inter-weight time delay control. Results using an infrared band TeO2 AOTF successfully demonstrate a basic two-tap agile RF notch filter. The filter successfully demonstrated the programmability of the weighting and time delay controls .

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