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Hybrid Photonic Signal Processing for Radio Frequency Signals

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ABSTRACT

Photonics previously has been used in the all-analog and all-digital domain for processing of Radio Frequency (RF) Signals. This paper highlights recent work by the Riza group on a new hybrid analog-digital approach to RF signal processing and controls. Specifically, novels works will be described in the design of RF processing components such as fiber-optic attenuator, fiber-optic programmable delay lines, and optical transversal filters.

Keywords: Microwaves, Fiber-Optic Components, RF Signal Processing

1. INTRODUCTION

As the optical carrier is much higher than typical Radio Frequency (RF) signal, narrowband optical processing can be used to accomplish wide instantaneous bandwidth RF processing. Over the years, RF signal processing in the optical or photonic domain have been proposed for applications such as radar, wireless communications, electronic warfare, ultrasound, and astronomical antennas. Traditionally, processors proposed have been either all-digital in operations or all-analog in controls. By all-digital is implied that the optical devices implementing the processor operate in on-off binary modes such as a digital switched delay line or a transversal filter using a digital mode spatial light modulator (SLM). On the other hand, an all-analog processor uses optical devices or operations that have a smooth continuous nature over a given time/phase/amplitude grey-scale of the optical signal. Both approaches have their positives and limitations. For example, digital processing possesses intrinsic operational repeatability and efficient scaling while analog processing produces minimal processing noise due to quantization effects.

Highlighted and further enhanced in this paper is the concept of hybrid photonic signal processing that combines both analog and digital aspects of signal processing, both on a device level and interconnection level. To the best of the author's knowledge, the proposed scheme of hybrid designs is a first for photonic signal processing. The proposed scheme can be applied to both RF signals modulating optical carriers or un-modulated all-optical signals.

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2. HYBRID PHOTONIC SIGNAL PROCESSING

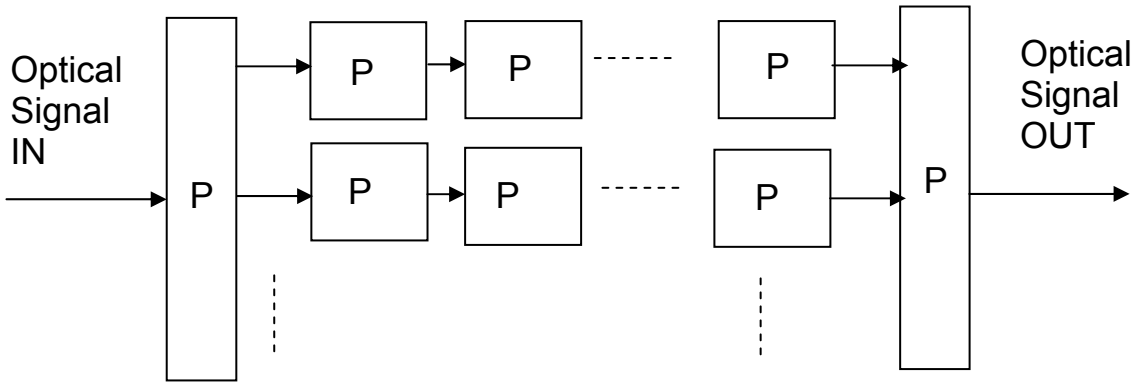
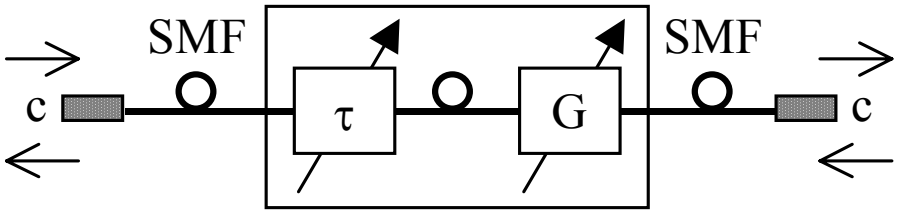


Fig.1. Proposed Hybrid Photonic Signal Processor. P: Analog or Digital Optical Processing Device or Module. Optical signal in can have RF modulation of analog, digital, or hybrid type.

Fig.1 highlights the basic concept of the proposed hybrid photonic signal processing theme. The overall system is shown to have one input and one output, although the same concept can be extended to Multiple Input Multiple Output (MIMO) systems. The optical signal may or may not have RF modulations impinged on the light carrier. The RF modulation formats can be analog, digital, or hybrid in nature, i.e., part analog and part digital. "P" stands for processor that can be either all-digital or all-analog in design.



Universal Processor Module

Fig.2 shows a universal processor module that is key to many signal processing operations.

To highlight the proposed hybrid designs, the sections to follow briefly describe designs and recent results from our proposed hybrid processors. Fig.2 shows a key universal processor module that is a cascade of a variable optical delay line and a variable optical attenuation control module. Hence, discussed next are two novel hybrid processor modules, one for optical loss/gain control and another for time delay control.

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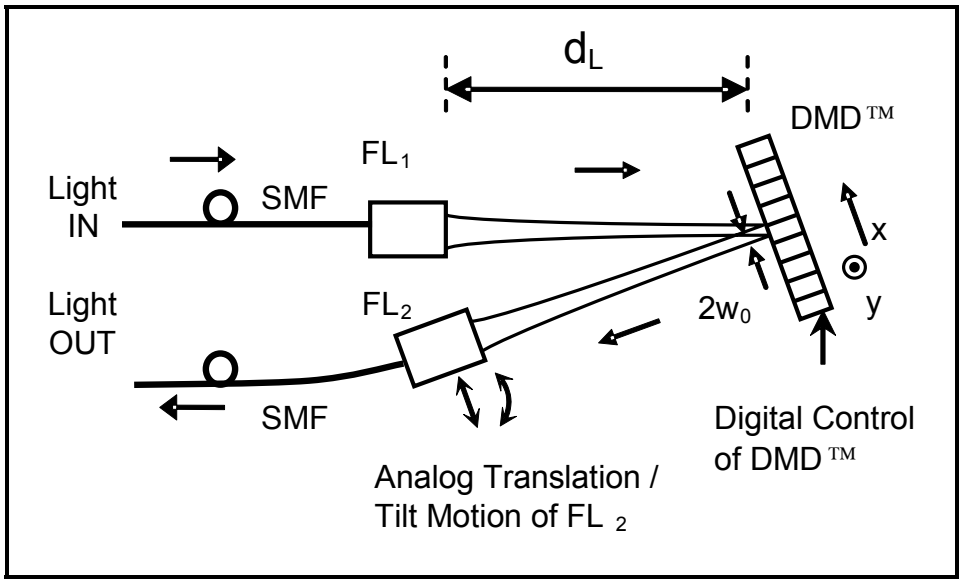


Fig.3 Proposed Hybrid Module for Variable Optical Loss/Gain Processing [2].

Fig.3 shows a recently demonstrated variable optical attenuator (VOA) module that implements hybrid processing. Specifically, powerful performance signal processing requires extremely precise control of signal strengths over a wide dynamic range with little loss penalty. In addition, Single Mode Fibers (SMFs) are ideal wires for flexible connections between the different processors that make the overall signal processing system. Hence, a SMF connected VOA with low loss and high dynamic range is extremely desirable. The Fig.3 design shows our proposed VOA that accomplishes this goal via hybrid analog-digital controls. Specifically, the Digital Micromirror Device (DMD) is all-digital in operations while the motion of the DMD and/or coupling fiber-optics is all-analog in nature. Using these hybrid methods, a very high 81 dB dynamic range has been measured. If effect, a 162 dB RF signal attenuation control can be implemented with the Fig.3 hybrid VOA module. This unprecedented VOA results is achieved by exploiting joint analog-digital operations of the optics and mechanics, a theme of the proposed hybrid technique.

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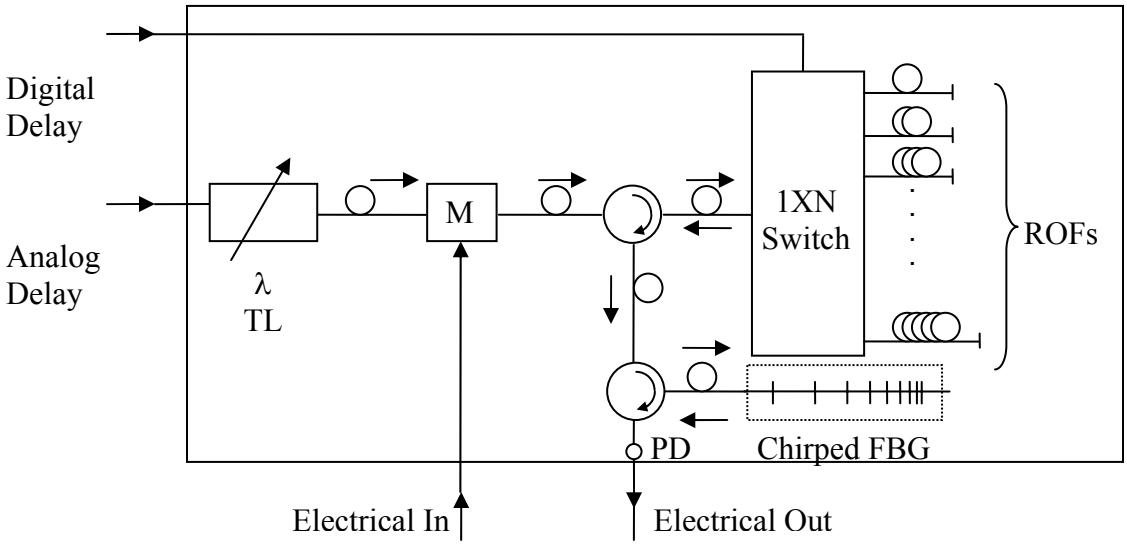


Fig.4. Proposed Hybrid Variable Optical Delay Line [3].

Another example of hybrid processor design is shown in Fig.4 that highlights a hybrid variable optical delay line. In this case, large delays are produced using digital operation of switching of optical paths while fine delays are produced by analog tuning of the laser wavelength. Such an approach deployed for an RF modulation has produced a near continuous RF delay control performance of over 16 bits (or 51,200 independent time delay settings) with a 25.6 ns time delay range with a 0.5 ps resolution. Hence the power of hybrid processing for delay operations is clear where both wide dynamic range and fine controls are delivered. Therefore, the operational bandwidth and signal-to-noise ratio (SNR) of a photonic signal processor can be greatly enhanced using a hybrid optical delay line.

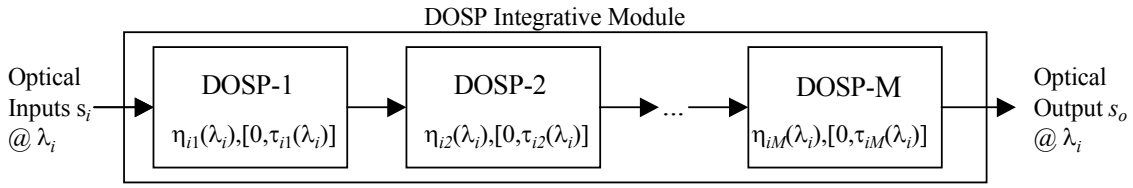


Fig.5. Example of Distributed Optical Signal Processing (DOSP) using Hybrid Techniques [4].

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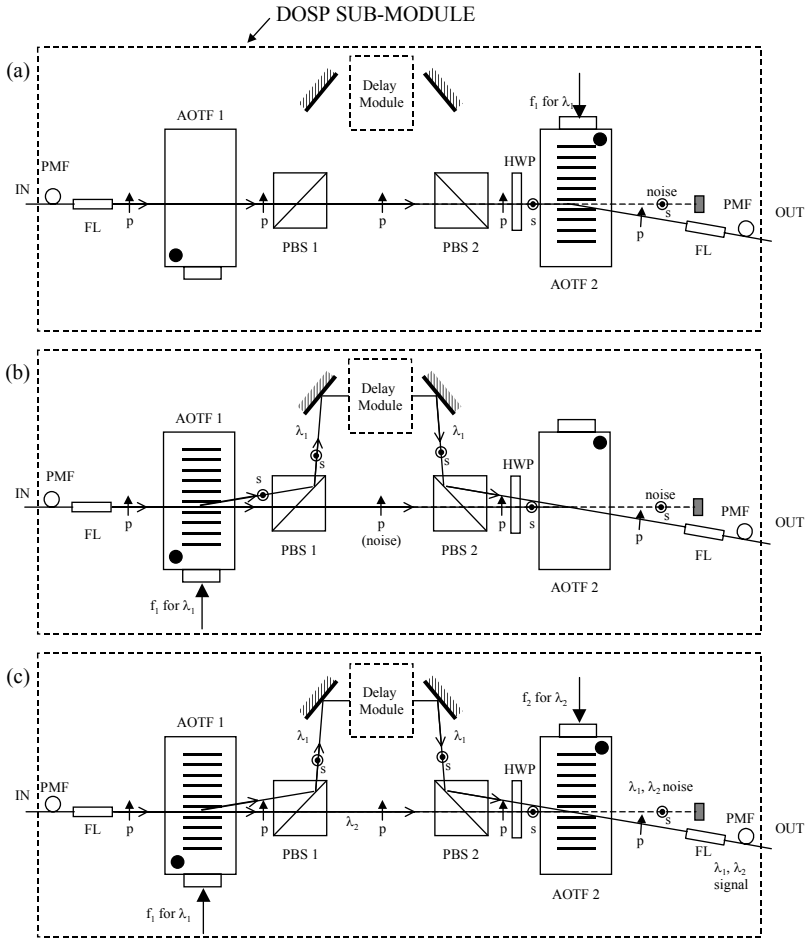


Fig.6. DOSP Module that implements Hybrid Processing. The module produces a digital delay operation but analog gain/loss controls [4].

Fig.5 and Fig.6 show another design for hybrid operations [4]. In this case, via digital operations of two AOTFs in Fig.6, a binary optical delay is realized while with analog operation of the chosen AOTF, gray-scale analog optical attenuation control is realized.

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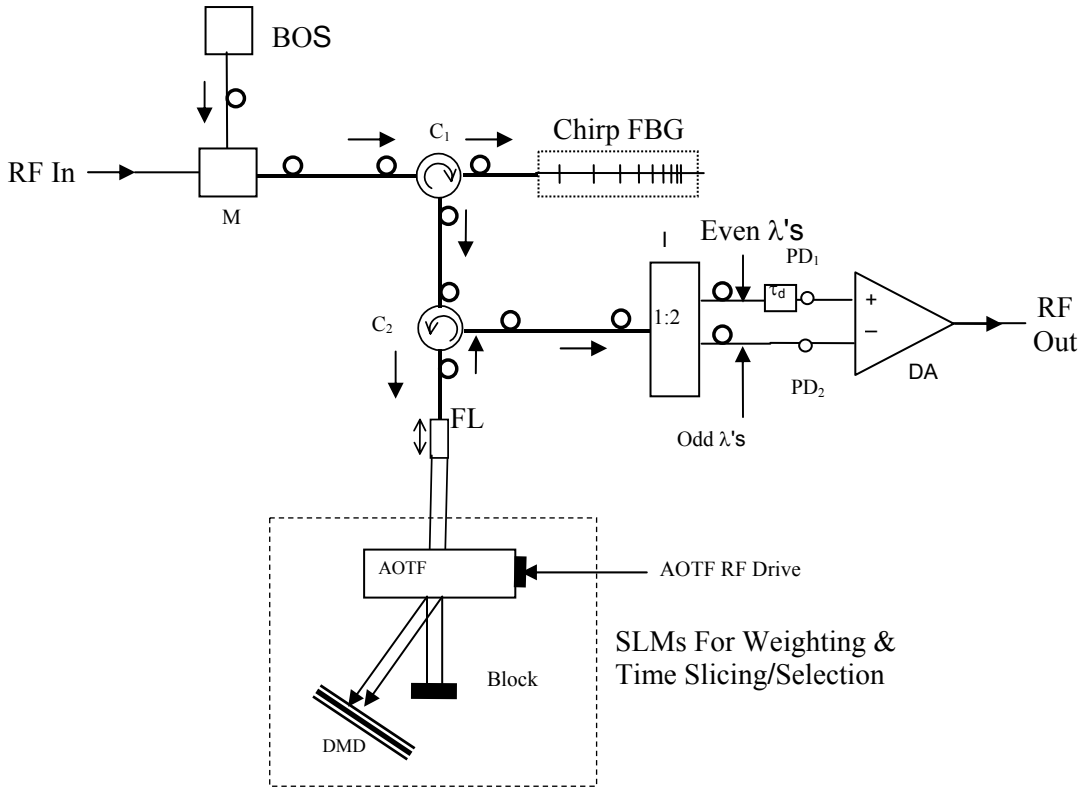


Fig.7. Proposed hybrid processor as a RF transversal filter. The DMD acts as a digital processor while the AOTF acts as the all-analog processing device.

Fig.7 shows a hybrid processor designed as an RF transversal filter. In this case, the DMD SLM acts as the all-digital RF filter [5] while the AOTF device acts as the all-analog part [6] of the serial or cascaded design hybrid processor. Both SLMs are operated in their specific independent digital and analog fashions to act as wavelength/time slicers and weighters to complete transversal filter processing.

3.CONCLUSION

Highlighted and proposed is the novel hybrid analog-digital technique for photonic signal processing. Applications for such as technique include all-optical to RF domain carriers. It is expected that the hybrid technique can yield higher performance signal processing versus all-digital or all-analog processing implementations. Future works relates to the demonstration of such next generation processors.

* also with Nuonics, Inc., Winter Park, FL, USA.

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