Software-defined microwave photonic filter with high reconfigurable resolution

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Abstract

We present an arbitrary-shaped microwave photonic filter based on stimulated Brillouin scattering in the fiber. The filter bandwidth, center frequency, and amplitude response can all be software-defined with a resolution in the order of MHz.

I. INTRODUCTION

As a key component in microwave photonics, the microwave photonic filter (MPF) has been studied intensively and has shown its prominent superiority in functionality and flexibility [1]. The realization of the MPF can be roughly categorized into two main approaches: the optical delay based incoherent structure and the optical filter based coherent structure. For both approaches, the research trend is always to increase the flexibility while decreasing the cost.

Stimulated Brillouin scattering (SBS) is a common optical nonlinear effect in the optical fiber with a natural linewidth of only 10 to 30~MHz, which can be used for realizing high-resolution MPFs. However, in the previous schemes, the control precision of the SBS-based filter is limited due to the low pump control precision [2, 3].

In this paper, we review our work on realizing an ultra-high-resolution software-defined MPF adopting the SBS effect in the optical fiber. By using an IQ modulator (IQM) with carrier suppressed single sideband modulation (CS-SSB), the filter response can be controlled with a resolution in the order of MHz [4]. An alternative solution is to use a directly-modulated laser (DML) which has similar performance but is more cost efficient with lower system complexity [5].

II. PRINCIPLE

Since the SBS gain is directly related to the power spectrum of the pump, the key to high-precision control of the Brillouin-based filter lies in precisely generating and controlling the pump spectrum. We employ two key techniques to ensure this: the high-resolution digital pump generation and the filter response correction based on the measurement-feedback-adjustment [6].

The pump generation method for the IQM approach is shown in Fig. 1. We first precisely define the target pump spectral shape in the frequency domain through a digital signal processor (DSP) by software. Then we obtain the corresponding time domain signal by using inverse Fourier transform and accurately generate this electrical waveform with a digital-analog converter (DAC). The designed electrical signal modulates a CW light with an IQM acting as the pump wave and finally gives rise to the SBS effect functioning as an optical filter. Similarly, a DML can be used as the Brillouin pump with a well-designed modulation current. the DML spectrum will be broadened to different profiles according to the amplitude of the current through the chirp effect.

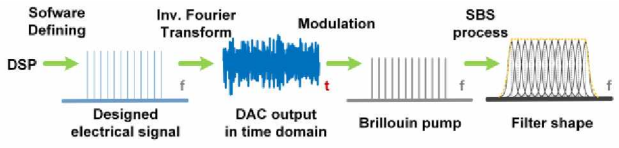

Fig. 1. The principle of the software-defined MPF.

Due to the non-ideal factors in the filtering system, the designed pump wave cannot result in an ideal filter response. In order to adjust the filter response accurately, a feedback correction is required to digitally control the amplitude of each pump frequency component according to the measured SBS gain shape. In general, after 3-10 iterations of the precise feedback, we can obtain the stable pump waveform for the arbitrary-shaped filter and this pump waveform can be stored for the future use.

III. EXPERIMENT AND RESULTS

We implement the high-resolution MPF adopting both the IQM-based and the DML-based pump as shown in Fig. 3. For the IQM-based approach, a 10-GS/s DAC is used to generate a multi-tone pump waveform, which is modulated on the light with CS-SSB modulation in an IQ modulator so that each frequency component of the pump can be precisely adjusted. After boosted to a high power level, the modulated light is sent into a 12.5-km single mode fiber (SMF) acting as the Brillouin pump. In addition, the multi-stage Brillouin amplification structure can be used for improving the pump efficiency and obtaining higher filter rejection ratio. A delayed orthogonal swept pump can be adopted to realize a polarization insensitive filter [4]. For the DML-based approach, a DML is driven by a well-designed current waveform generated with a 1-GS/s DAC instead of the independent external cavity laser (ECL) and the IQ modulator with peripheral devices. It is evident that the

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DML approach has a lower system complexity and a lower requirement for the DAC sampling rate.

In the probe branch, a swept signal generated by an electrical vector network analyzer (EVNA) acts as the probe. After the suppression of the upper sideband by a band-stop filter (BSF), it is sent to the fiber and is amplified once sweeping within the SBS gain region. The probe is then detected by a photodiode (PD) and is sent to the EVNA for measuring the system response. The SBS gain spectra (i.e. the filter responses) are obtained by comparing the results when the SBS pump is on and off.

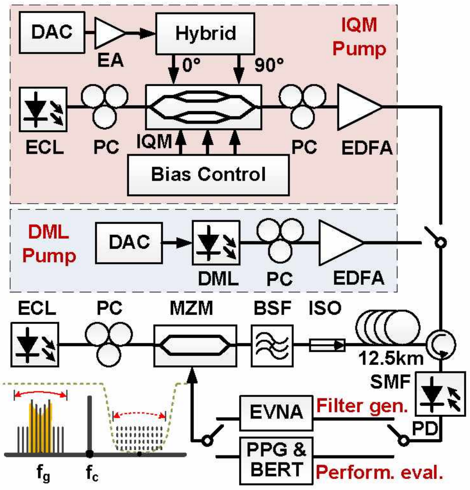

Fig. 2. The experimental setup.

The IQM approach has very high control precision. By tuning the frequency of the designed pump waveform, the center frequency of the MPF can be tuned with a resolution of ~1 MHz. By changing the number of the electrical spectral lines, the filter bandwidth can be changed with a step of ~20 MHz. More precise adjustment can also be realized by slightly altering the position of the pump lines at both edges. The filter bandwidth ranges from ~20 MHz to several GHz. Moreover, the filter response can also be defined precisely. This is the distinguished advantage of the proposed MPF against other approaches. By generating

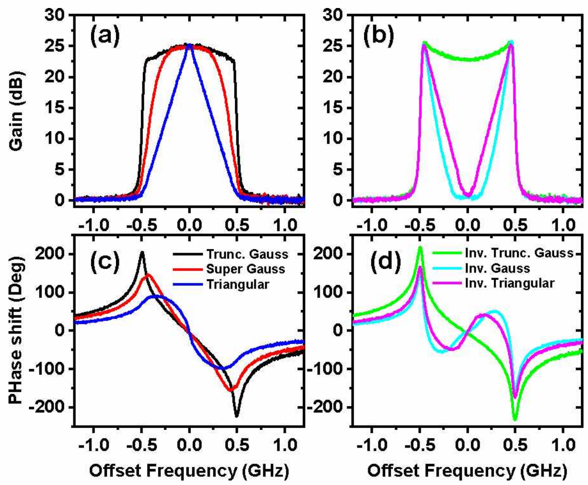

Fig. 3. The (a, c) amplitude and (b, d) the corresponding phase responses of polarization insensitive arbitrary-shaped MPFs with the IQM approach.

different pump spectra and applying the feedback compensation according to the targeted filter shapes, the final MPF shapes are obtained as shown in Fig. 3, including truncated-Gaussian, triangular, inverse triangular etc. The corresponding phase responses vary according to the amplitude responses.

Whereas the DML-based approach greatly reduces the requirement for the system complexity but maintains similar control precision. We compare the rectangular filter generated by DML approach with the IQM approach as shown in Fig. 4. The DML approach results in similar passband ripple and slightly less steep edges which lead to smaller phase variation at two filter edges. For most of the applications, this minor shape degradation is acceptable. Further noise measurement also indicates that the two approaches have similar performance when amplifying a real signal.

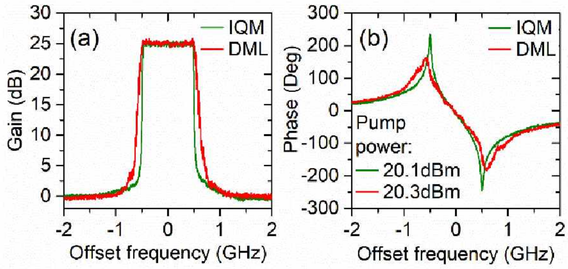

Fig. 4. The (a) amplitude and (b) phase response comparison of the rectangular filters between DML and IQM approach.

Taken together, the two approaches have their own suitable application scenarios. If there is a high requirement for the filter control precision and accuracy, more sophisticated DML approach should be selected. If the application is more sensitive to the cost or volume, a simple DML approach can be a good choice without sacrificing too much performance.

IV. Conclusions

We have realized a software-defined arbitrary-shaped microwave photonic filter based on SBS effect in the optical fiber. The high-resolution control of the filter shape, bandwidth and center frequency have been realized with both IQM and DML approaches. The multi-dimensional filter flexibility provides precise optical processing approach in microwave photonic fields and makes it a promising MPF solution.

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