ICSO 2016

International Conference on Space Optics

Biarritz, France

18–21 October 2016

Edited by Bruno Cugny, Nikos Karafolas and Zoran Sodnik

Tunable and reconfigurable photonic Rf filtering for flexible payloads

M. A. Piqueras

M. Beltrán

J. García

P. Villalba

et al.

International Conference on Space Optics — ICSO 2016, edited by Bruno Cugny, Nikos Karafolas,
Zoran Sodnik, Proc. of SPIE Vol. 10562, 1056220 · © 2016 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2296226

TUNABLE AND RECONFIGURABLE PHOTONIC RF FILTERING FOR FLEXIBLE PAYLOADS

M. A. Piqueras, M. Beltrán, J. García, P. Villalba, O. Navasquillo
DAS Photonics, Camino de Vera s/n, Edificio 8F, 46022 Valencia, Spain
mapiqueras@dasphotonics.com

I. INTRODUCTION

The evolution of broadband communication satellites shows a clear trend towards an efficient use of the satellite and spectral resources. In this case the fact of having payloads capabilities enabling the dynamic allocation of bandwidth according with the dynamic needs of the traffic is of tremendous interest for future flexible telecom payloads although today's commercial tunable filters as such do not exist.

Photonic technologies for telecommunication satellites are gaining more and more significance with a remarkable progress in technological innovations. The inclusion of photonic technologies in Telecom payloads can lead to improvements in terms of bandwidth, re-configurability, as well as mass and power savings. For satellite operators the advantages that photonics can offer are also very interesting from a cost and flexibility point of view. Among the main functions to be implemented is the photonic filtering of RF signals, which exhibit more capabilities than its RF counterpart such as tunability and reconfigurability, which is of tremendous interest for future flexible telecom payloads.

Within the ESA TRP contract "Photonic RF Filtering" a filter able to provide central frequency tunability and passband bandwidth adjustability suitable for its use in telecom payloads as both stand-alone RF filter or as a module to be integrated in the future optical telecom payloads has been designed and manufactured.

II. BRILLOUIN-BASED PHOTONIC RF FILTERING

The photonic RF filter uses non-linear effects in the fiber to generate spectral regions with gain based on the Brillouin effect [1], [2]. In this kind of schemes, a pump signal is injected in the same fiber where the RF signal is present, though in counter-propagating direction. Due to Stimulated Brillouin Scattering (SBS) effect [3], a gain region is generated some GHz away from the pumping signal. The effect achieved is of active filtering, so the region to be filtered is actually amplified over the rest of the spectrum. SBS in optical fibers is a particularly interesting phenomenon to perform optical signal processing due to its low threshold power and narrow bandwidth.

The most appealing characteristic of SBS-based filters is its simply tuning and reconfiguration method. Tuning of this filter is as simple as varying the frequency of an electrical reference, whereas reconfiguration of the filter shape is achieved by changing the baseband waveform of the pump modulating signal. Then the filter shape is given by the convolution of the Brillouin gain spectrum and the pump spectrum.

III. PHOTONIC RF FILTERING IMPLEMENTATION

The architecture of the Photonic RF filtering demonstrator is shown in Fig. 1. The output of a continuous-wave laser is split into two branches. The lower branch is modulated by the RF input signal in an optical phase modulator to generate the Stokes signal. The upper branch is modulated in a Mach-Zehnder modulator to generate the optical pump signal, which counter-propagates then along the Stokes signal to generate Brillouin gain at the desired frequency. The filter has been implemented employing 900 m of highly non-linear fiber which exhibits an SBS frequency shift of 9.7 GHz and an SBS FWHM spectral width of < 24 MHz depending on the optical pump power.

The pump modulating signal is generated employing laboratory equipment controlled by a custom graphical user interface (GUI) software. A baseband signal generated from a digital-to-analog converter (DAC) is modulated in an RF synthesizer with IQ modulation to generate a fully reconfigurable electrical pump signal.

The tuning and reconfiguration capabilities of the photonic RF filter have been implemented as follows:

- The filter bandwidth is adjusted by modifying the number of tones as well as the frequency, amplitude, and phase of the tones of a multitoned baseband signal. The equivalent baseband response of the pump modulating signal can be digitally generated, modified and adjusted.
- The filter center frequency is adjusted by an RF synthesizer generating local oscillator (LO) frequencies of the center frequency minus the SBS frequency shift. For the SBS frequency shift of 9.7 GHz, the synthesizer should be able to be tuned within 1-3.05 GHz in order the filter gain is within the Ku-band

from 10.7 to 12.75 GHz. These frequencies are relatively low and can be addressed by a synthesizer chipset for a filter stand-alone system.

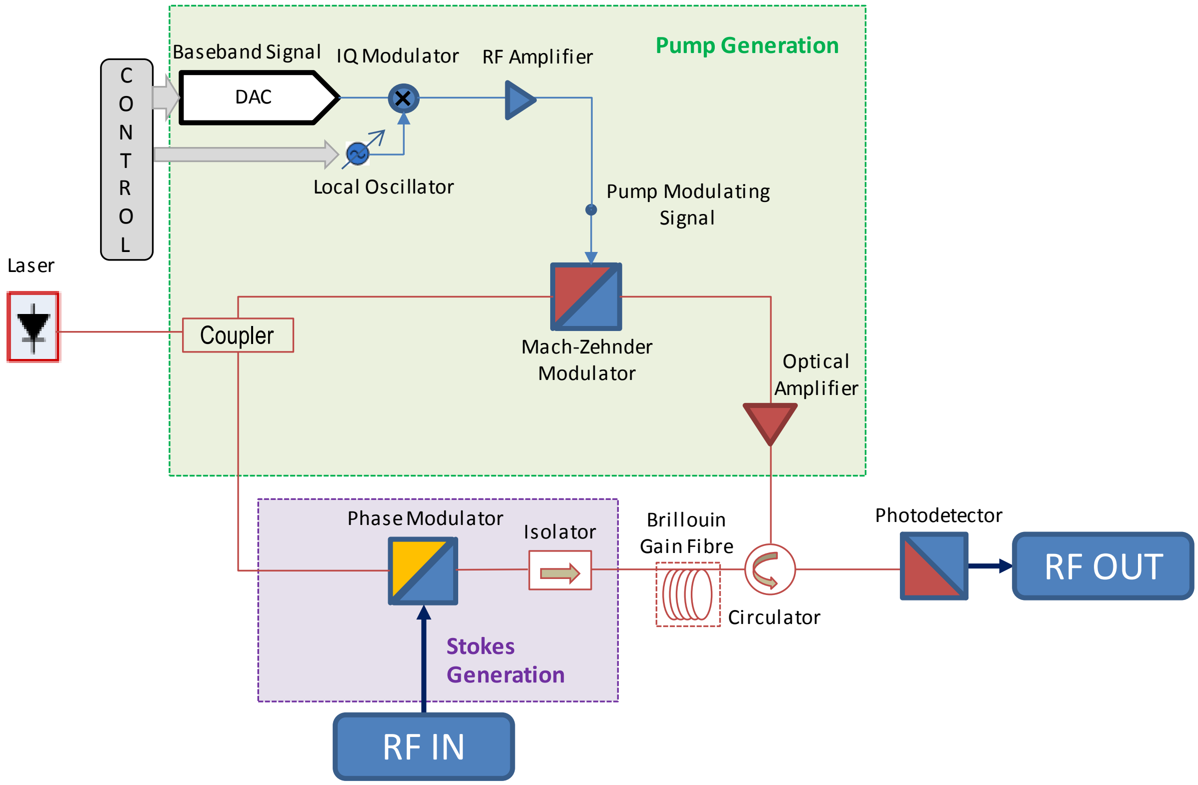

Fig. 1. Photonic RF filtering architecture

Fig. 2 shows a picture of the Photonic RF Filtering demonstrator. The structure of the demonstrator is composed of:

- One optoelectronic module, comprising the optical devices as well as control electronics. All components and devices are assembled in a printed circuit board with mechanical, electrical (RF, TM/TC and power supply), and optical interfaces. The module is operated through a custom GUI software.
- One Brillouin gain block, comprising the isolator, fiber, and circulator.
- One RF amplifier for pump signal generation.

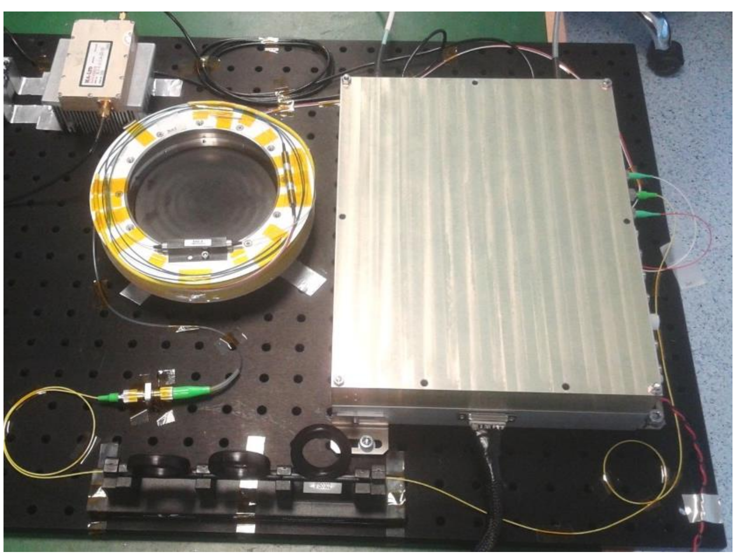

Fig. 2. Photonic RF filtering demonstrator

IV. BREADBOARD TEST RESULTS

The photonic RF filter has been tested employing an electrical network analyzer. The following parameters have been measured:

- Center frequency tuning in the Ku band
- Bandwidth adjustment from 36 MHz to 170 MHz.
- Return Loss
- Power handling
- Noise Figure
- Output Third-order Intercept Point (OIP3)
- Power consumption
- Center frequency, Insertion Loss, and Insertion Loss variation within the bandwidth (filter flatness) over the temperature

A. Center Frequency Tuning

Fig. 3 shows the tunability of the center frequency in all the operational frequency range of 2 GHz for the entire Ku-band, from 10.7 to 12.75 GHz. The LO frequency is tuned from 0.907 to 3.007 GHz with 100 MHz step.

From Fig. 3 it can be seen how the center frequency of the filter can be easily tuned by simply changing the frequency of a synthesizer.

In Fig. 3 it can also be seen that, in some cases, the shape of the filter changes depending on the center frequency. It is due to the ripple of the frequency response of the IQ modulators of the synthesizers (Fig. 1). The sensitivity of the filter response (RF-to-RF gain) respect to the optical pump power is around 7 dB/dB, so a difference in the amplitude of the pump tones of 0.1 dB result in 0.7 dB of ripple in the generated filter response which imposes stringent requirements of the RF section of the pump generation.

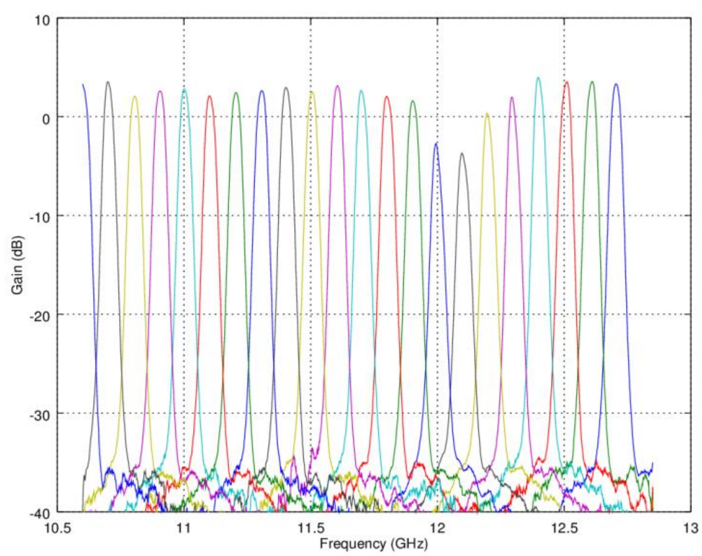

Fig. 3. Photonic RF filter gain response tuning within the entire Ku-band

B. Bandwidth Adjustment

The filter bandwidth has been adjusted to 36, 54, and 72 MHz optimizing the compliance with its corresponding mask of insertion loss variation and out-of-band rejection. Fig. 4, Fig. 5, and Fig. 6 show the gain and group delay response for the 36, 54, and 72 MHz bandwidth, respectively.

From Fig. 4, Fig. 5, and Fig. 6 it is verified that the filter bandwidth can be adjusted by reconfigurable electronics. Insertion loss variation of 0.4 dB in-band is shown. Larger bandwidths exhibit better shape factor addressing sharper requirements of the filter insertion loss. In cases in which the bandwidth is close to the fundamental Brillouin bandwidth (~19 MHz) the filter shape is dominated by the fundamental response. Out-of-band rejection close to 40 dB are achieved in all the cases. Regarding group delay variation, values close to 2 ns are achieved within the filter bandwidth.

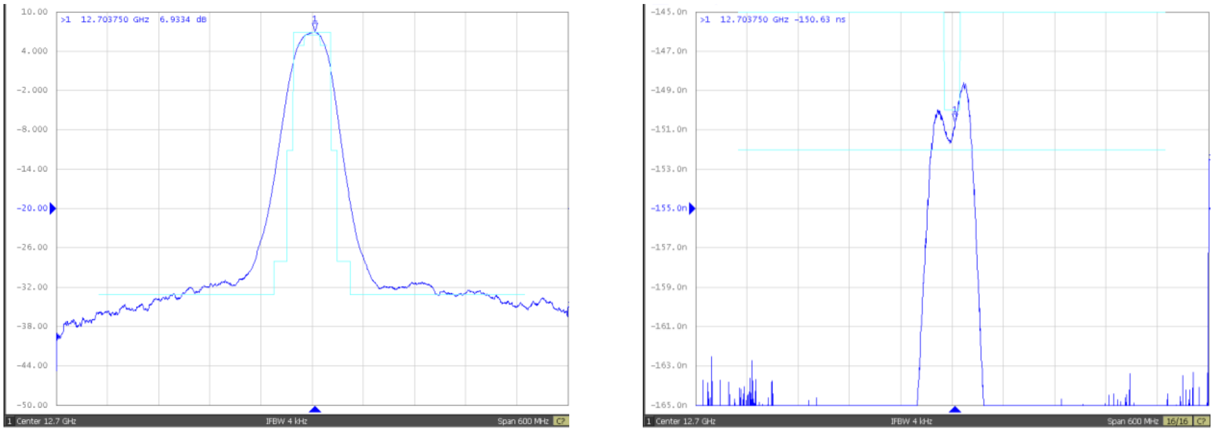

Fig. 4. Photonic RF filter response for 36 MHz bandwidth and corresponding mask. (Left) Amplitude. (Right): Group delay.

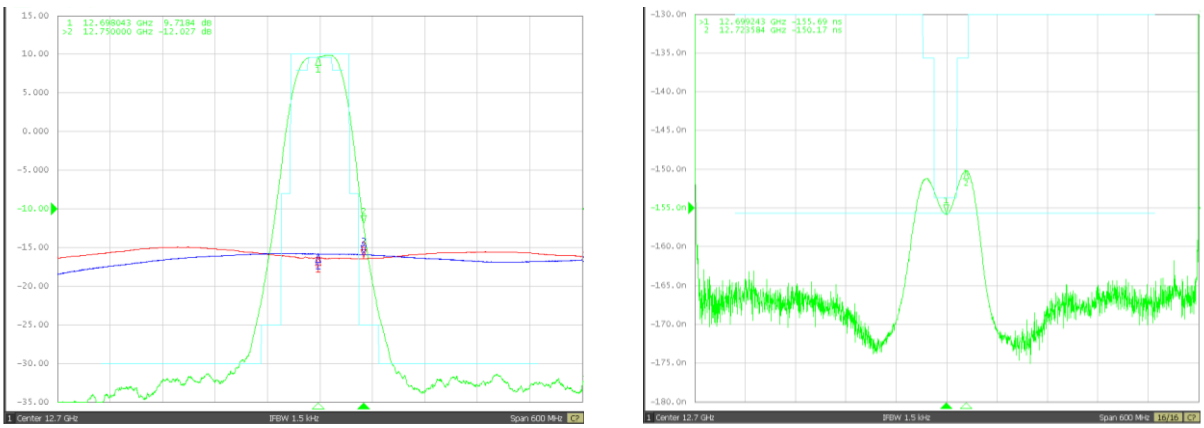

Fig. 5. Photonic RF filter response for 54 MHz bandwidth and corresponding mask. (Left) Amplitude. (Right): Group delay.

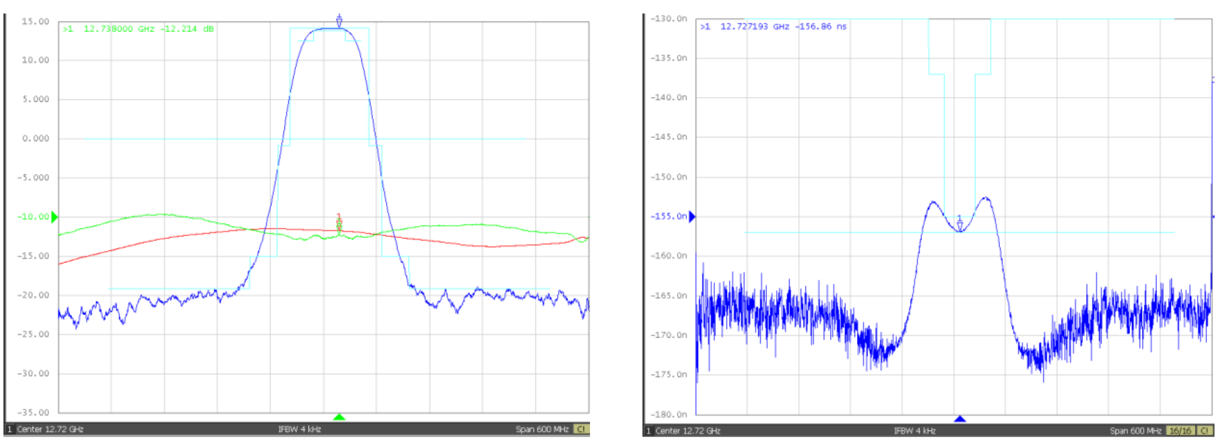

Fig. 6. Photonic RF filter response for 72 MHz bandwidth and corresponding mask. (Left) Amplitude. (Right): Group delay.

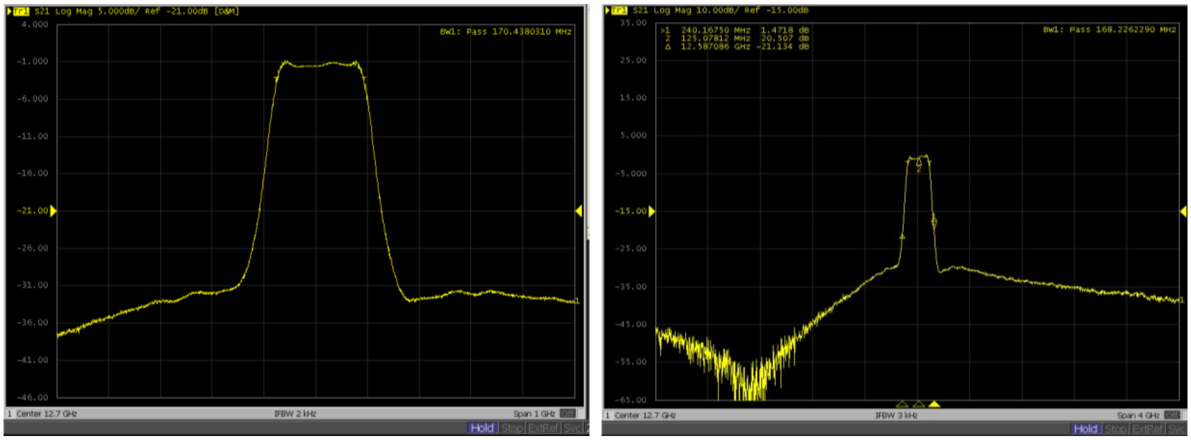

Fig. 7. Photonic RF filter response for 72 MHz bandwidth and corresponding mask. (Left) Amplitude. (Right): Group delay.

The filter was configured for 170 MHz bandwidth showing a shape factor lower than 1.4 (relation between the 3dB and 20 dB bandwidth) and out-of-band rejection larger than 30 dB in 4 GHz frequency range at Ku band. The results are shown in the Fig. 7.

C. Return Loss

Return loss is lower than -10 dB for the frequencies of interest, as shown in Fig. 6(Left).

D. Power Handling

Fig. 8 shows filter gain and group delay response as a function of RF input power. It can be seen that the filter has constant gain up to approximately -30 dBm. For higher input power the filter gain drops linearly with the input power and the filter bandwidth increases. The 1dB compression point has been tested to be -27 dBm. In addition, the saturation of the filter with more RF input power results in a better group delay ripple due to the compression effect and the effect of the filter bandwidth.

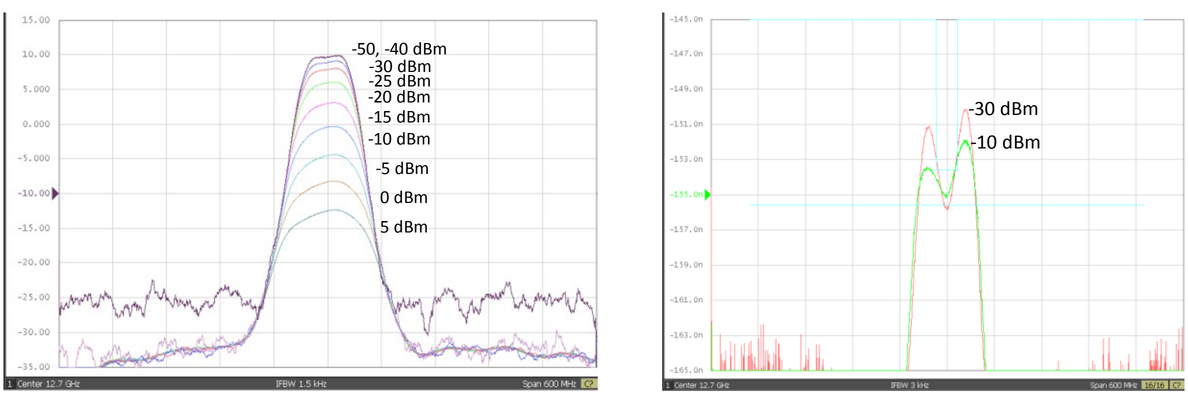

Fig. 8. Photonic RF filter response as a function of RF input power. (Left) Gain. (Right) Group delay

V. IMPLEMENTATION IN A PHOTONIC IMUX

One of the issues that difficult the integration of photonic filters in a photonic repeater which uses multi-frequency down-conversion is that each output of the optical switch might be carrying any wavelength. Thus, the filter has to be able to select its operating wavelength. Brillouin-based filters allow doing this. Multiple pump wavelength can be modulated by a separate LO, thus achieving parallel filtering of every channel, using a single fiber spool, as shown in Fig. 8.

In this option, there is one filter per channel and per beam. Each filter is configured by selecting one input wavelength for the pump signal that is equal to the wavelength of the RF channel selected by the switch. Besides, each filter sets an independent LO to select the desired channel.

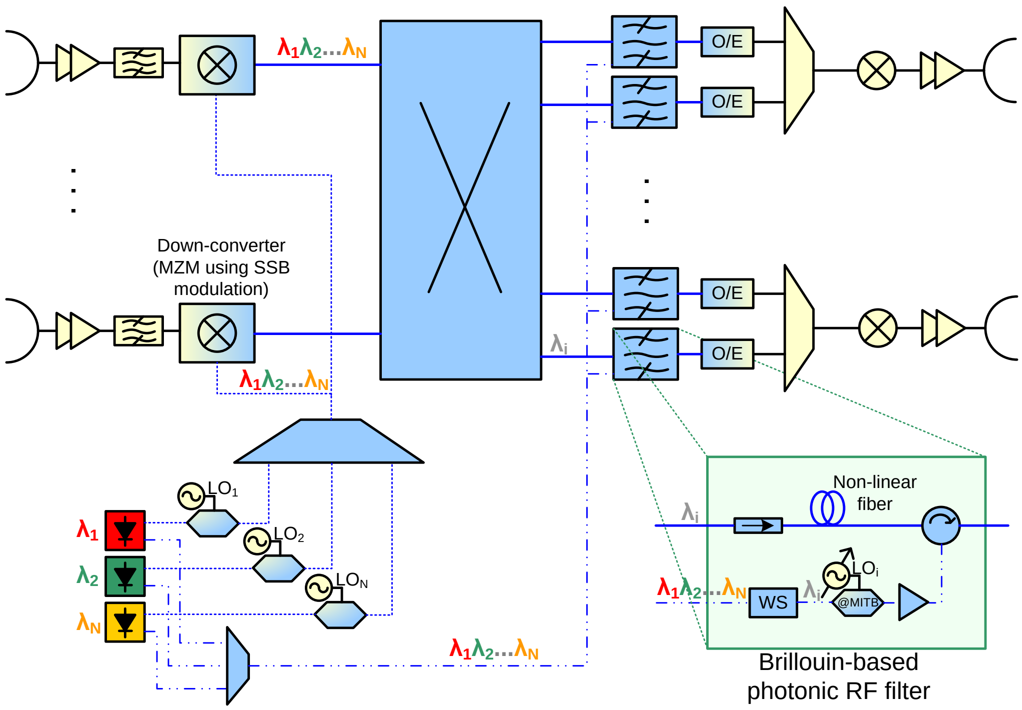

Fig. 8. Photonic payload architecture integrating Brillouin-based photonic RF filtering

VI. CONCLUSION

A photonic RF filter architecture suitable for its use in telecom payloads has been implemented and experimentally demonstrated. The designed filter has the capability of continuous tuning of its central frequency within the Ku band (10.7 to 12.75 GHz), although the same concept can be applied to Ka and Q/V bands. The filter bandwidth can be adjusted among the values from 36 to 170 MHz.

Other interesting characteristics of this filter is that multiple, simultaneous, independent filters can be implemented within the same non-linear fiber, which is of great interest for its use as a multi-channel filtering structure such as photonic IMUX with reconfigurable characteristics.

The optical solution of tunable and reconfigurable RF filter appeared as a promising alternative to the today's RF filters not only in future optical payloads but also in present telecom payloads as stand-alone filter.

ACKNOWLEDGEMENT

This work has been supported by the European Space Agency (ESA) under the TRP contract "Photonic RF Filtering".

REFERENCES

[1] X.S. Yao, "Brillouin Selective Sideband Amplification of Microwave Photonic Signals," *IEEE Photon. Technol. Lett.*, vol. 10, no. 1, pp. 138, January 1998.
[2] B. Vidal, J.L. Corral, J. Martí, "All-optical WDM multi-tap microwave filter with flat bandpass," *Opt. Express*, vol. 14, no. 2, pp. 581-586, January 2006.
[3] G. Agrawal, *Nonlinear fiber optics*, 5th ed., Academic Press, 2012.