PhLEXSAT - A Very High Throughput Photo-Digital Communication Satellite Payload

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Abstract — Photonic components offer an advantage of minimizing the size, weight and power consumption (Swap) of a satellite communication payload. This paper presents how this can be utilized in Increasing the capacity of Very High Throughput Satellites (VHTS) while reducing the cost at the same time. Photonics is capable of offering a limitless bandwidth in THz range at the band around 1550 nm while offering high data rates and frequencies with almost lossless propagation in an optical fibre.

However, at present only a few demonstrations of photonic devices in non-critical equipment with limited degree of integration can be found in the satcom industry as we as in literature. With the advancement of the photonic technology, it is now possible to develop Tbps-like software defined photonic payload.

PhLEXSAT project, funded under the European Union H2020, is led by DAS Photonics in cooperation with MDA UK, Eutelsat, Axenic, HHI Fraunhofer and Argotech.

Keywords— *Digital Signal Processing, Photonics, Satellite Communication, VHTS, Terabit*

I. Introduction

This paper presents a space-based photo-digital communication payload called PhLEXSAT. PhLEXSAT is a THz range communication system that will use novel optical devices for space-based systems which are currently under design and development stage. The architecture presented incorporates advanced broadband photonic ADC and photonic DAC with digital processing firmware with a high degree of miniaturization and power-consumption efficiency. The architecture is suitable for future Terabit per second satellites. The two main components of the photonic sampler architecture presented are Mach-Zehnder interferometer (MZI) modulators PIC and high-linear photodetector (HL-PD) PIC. The frequency clock used for the photonic sampler is a space-grade pulsed laser.

II. Mission Scenario

This section presents one of the several mission scenarios in which the photonic electronic channelizer (PhLEXSAT) is capable of providing a substantial benefit over currently available satellite telecom payloads in terms of throughput.

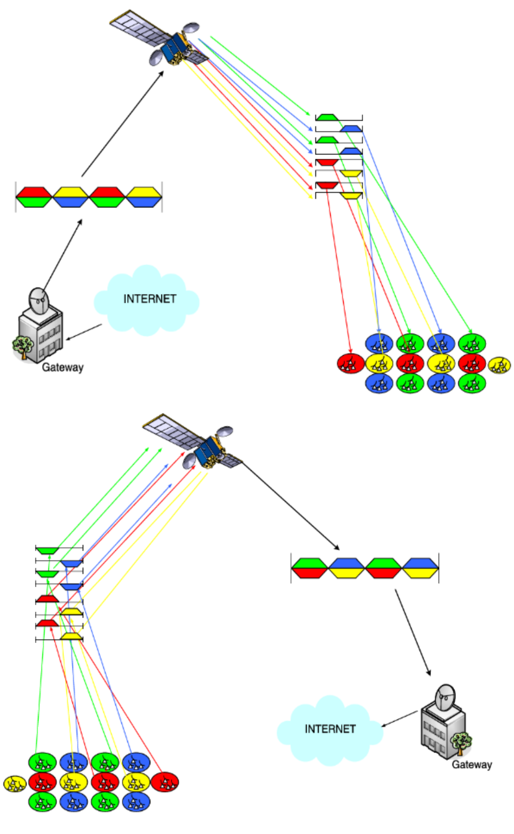

Figure 1 Illustration of HTS forward (top) and return (bottom) link

The forward link provides connectivity from the gateway to a user terminal and the return link provides connectivity from a user terminal to the gateway. An illustration of both links is depicted in Fig. 1.

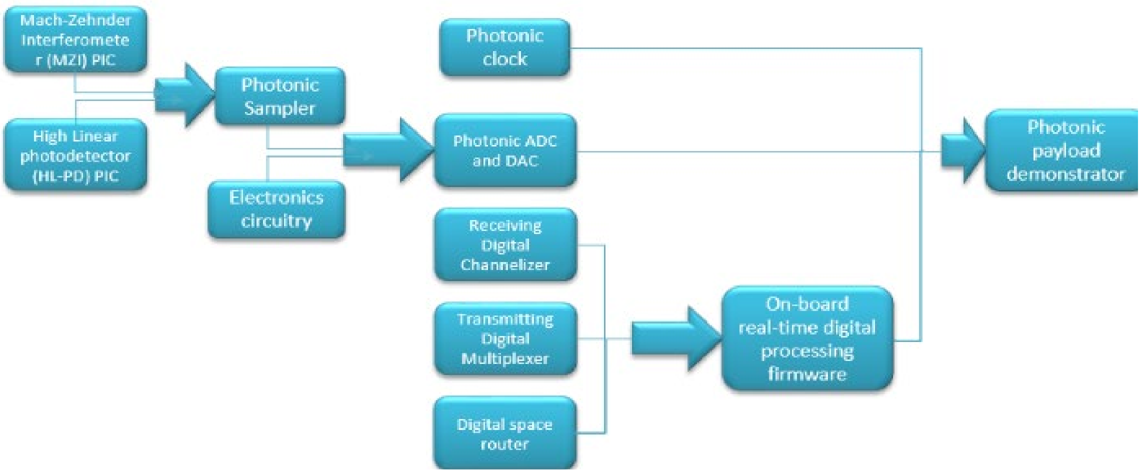

Figure 2: Block diagram of the PhLEXSAT demonstrator

While designing the system architecture, one of the main objectives was to reduce the Size, Weight and Power (SWaP) of the payload in comparison to the presently available systems using photonics solution. Very High Throughput Satellite (VHTS) has been considered for this purpose which would otherwise require a large number of RF units. Photonic solution can offers a reduction in SWaP and in turn an attractive mission price.

In order to achieve the Tbps capacity, it is important to gain access to as much as possible frequency spectrum, instead of being limited to Ka- or Ku-band where current HTS systems operate. It is therefore proposed to take advantage of the available ITU FSS frequency bands in Q-, V- and W-band.

III. Payload Concept

Following are the summary of the frequency plan and user beams and gateways information for the selected baseline reference mission:

- Target capacity : 1 Tbps
- Forward Uplink: V-Band (42.5 – 43.5, 47.2 – 50.2 and 50.4 – 51.4 GHz) and W-Band (81 – 86 GHz)
- Forward Downlink: Ka-Band (17.3 – 20.2 GHz)
- Return Uplink: Ka-Band (27.5 – 30 GHz)
- Return Downlink: Q-Band (37.5 – 42.5 GHz) and W-Band (71 – 76 GHz)
- Number of GWs: 13 using dual polarization in the forward uplink (total aggregated forward uplink bandwidth 260 GHz) and single polarization in the return downlink (total aggregated return downlink bandwidth of 130 GHz)
- Number of user beams: 500 with 500 MHz allocated bandwidth per user in the forward uplink (total aggregated forward uplink bandwidth of 250 GHz) and 250 MHz allocated bandwidth per user in the return uplink (total aggregated return uplink bandwidth of 125 GHz).

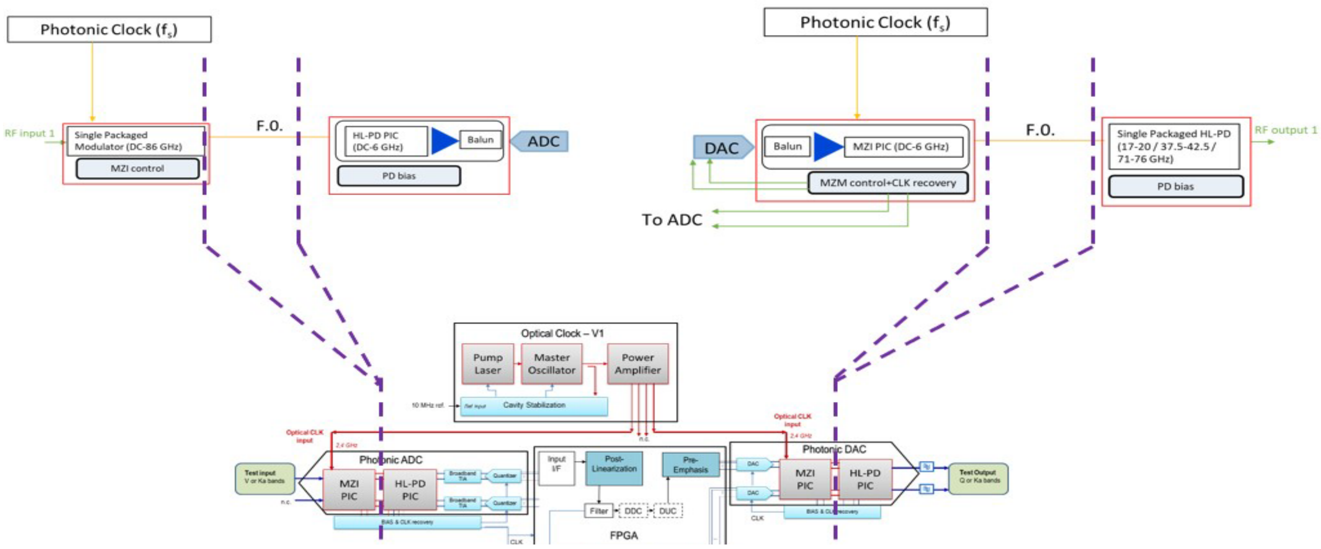

Figure 3: PhLEXSAT demonstrator architecture

Block diagram of the PhLEXSAT demonstrator is shown in Fig. 2 and the PhLEXSAT demonstrator architecture is shown in Fig. 3.

IV. PhLEXSAT System Specification

The demonstrator consists of one Photonic ADC and one Photonic DAC synchronized by an optical clock at around 4 to 6 GHz. RF signals at Ka/V/W band will be injected to the Photonic ADC. The samples routed to the post-linearization and digital filter stages will be analysed either digitally to measure the fundamental parameters of SFDR and ENOB as well as routed to an external low speed DAC to evaluate the filter and linearization functionalities.

A. Scalability and Flexibility and SWaP

PhLEXSAT ADC and DAC targets to achieve:

- Reduced SWaP due to the integration of PIC-based optoelectronic devices in a single packaged module.
- Multi-carrier integration in the same package in order to be used as a standard ADC with the only difference of (1) having much higher analog bandwidth and (2) with optical clock instead of electrical.
- An ultra-compact (150 grams), low power consumption (<4W) frequency stabilized optical clock able to feed 4 dual ADC/DAC with size, mass and footprint smaller than the standard MLOs.

For the Photonic DAC, a digital signal will be stored in a memory and transmitted to the DAC at Ka/Q/V frequencies. The typical DAC parameters such as SNR, distortion and ENOB will be measured in RF with laboratory equipment.

Finally, a set of bypass test RF to RF will be carried out in order to demonstrate the complete functionality.

B. Demonstrator mass and power

Estimated mass and power of the demonstrator up to TRL 5 (not the full scale flight model) of the PhLEXSAT payload are 2.4 kg and 23.95 W respectively.

C. Functional and performance requirements of the demonstrator

For the payload demonstrator the aim is to reach TRL5 and the requirements mentioned in this section are applicable to demonstrator only. Following are the other important functional and performance requirements for the PhLEXSAT system parameters:

- Input RF power: < 1 W (TBC)
- Output RF power: < 1 W (TBC)
- Input SNR (min): 10 – 30 dB
- Number of ADC outputs: 8 GTH lanes
- Number of DAC inputs: 8 GTH lanes
- Channelizer/ Router frequency granularity: - 2.5 MHz (TBC)
- Out of band rejection: > 40 dB (TBC)
- Operating modes: Fixed gain mode and Automatic level control mode
- Error Vector Magnitude (EVM): 0.37% (TBC)
- Equivalent Number of Bits (ENOB): 7.5 bits up to 52 GHz (V-band) as minimum in the subsampled 1 GHz bandwidth
- Dynamic Range (SFDR): 50 - 60 dB

V. Effect of environments on the PhLEXSAT payload

A. Radiation Environment

SPENVIS (SPace ENVironment Information System), which is a WWW interface to models of the space environment, has been used to simulate and estimate the radiation levels for PhLEXSAT on the mission scenario selected. The effect of radiation depends on the mission profiles like height of the orbit, position, longitude, range, and lifetime durations in years. In this study, the inputs considered for the simulation were:

- Orbit: GEO
- Longitude: 7 degree East
- Mission operation lifetime: 15 years

Based on the analysis the PhLEXSAT equipment is will withstand a Total Ionising Dose (TID) of 150 krad at 9 krad/h maximum and a Total Non-Ionising Dose (TNID) the following levels:

- Energy 60 MeV
- Fluency 5E10 p/cm2
- Flux 1E8 p/cm2/s

B. Thermal Environment

PhLEXSAT will be functional in the following thermal environment:

Operating
Cold: -10°C and Hot: +65°C

Non-operating
Cold: -35°C and Hot: +85°C

Cold start: -25°C

VI. Conclusions and future work

The consortium has presented the suitability of an optical payload for the mission scenario of very high throughput satellites.

A brief description of the demonstrator architecture has been identified. Next steps include designing and breadboarding iteration on the optical clock, breadboarding of photonic sampler, under lab evaluation of high-speed data converters.

Final goal of this project is to build the photonic payload demonstrator with contribution by all the consortium members. To accomplish that the consortium is going through several intermediate phases of developing the components of the photonic payload like Mach-Zehnder Interferometer, High Linear photodetector, channelizer, router, multiplexer Photonic ADC, DAC and clock with required specification and performance.

ACKNOWLEDGMENT

The PhLEXSAT project is funded under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004253.

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