On Board Processing Payload

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Abstract

In this article the SDR ASIC designed by SatixFy for a Regenerative processor payload will be presented, combined with the reasoning to use a regenerative processor in modern UHTS and LEO constellations both from a technical and commercial points of view.

A regenerative payload provides improved performance, reduced latency, support of mesh connection, simplified implementation for Non-GEO constellations, and better usability in comparison to basic bent-pipe designs. On the other hand, it may require more processing power on board and guarantee future-proof design. Namely ensuring that communication protocols required by the users are supported along the whole life cycle of the satellite.

With the introduction of a software defined radio ASIC, which is able to support large bandwidth in both uplink and downlink directions, the implementation of a future proof regenerative payload is closer than ever. In this article the SDR ASIC designed by Satixfy for a payload will be presented, including the Radiation Hardening aspects of the design.

1. Introduction

Modern satellite systems such as LEO constellations and GEO UHTS bring the promise of higher capacity and lower cost per Mbps. However, these come at a cost in multiple areas that need to be addressed in a different way than in past systems. The immense amount of information to be transferred between the users and gateways possess a challenge on gateway cost, location, efficiencies in GEO and furthermore in LEO constellations. This paper demonstrates that a regenerative on-board processing payload provides a good solution and that modern silicon and communications technologies mitigate concerns such as future proofing and power consumption.

2. The Gateway link and associated challenges

Modern UHTS satellites and LEO constellation will provide data service to the users at rates in the order of magnitude of 1Tbps. Gateway sizing is derived from the gateway link budget. As demonstrated in [3] and shown in Table 1, a typical bent pipe GEO forward link is planned to provide 2.6 b/Hz on beam peak and 2 b/Hz averaged over the beam @ Es/No at peak of ~9.5dB. The return link is worse and is typically ~1-1.5 b/Hz (1.2b/Hz on average). In the LEO case a similar assumption is taken, taking into account a much bigger dynamic range variation due to the movement of the satellites to and from the remote user.

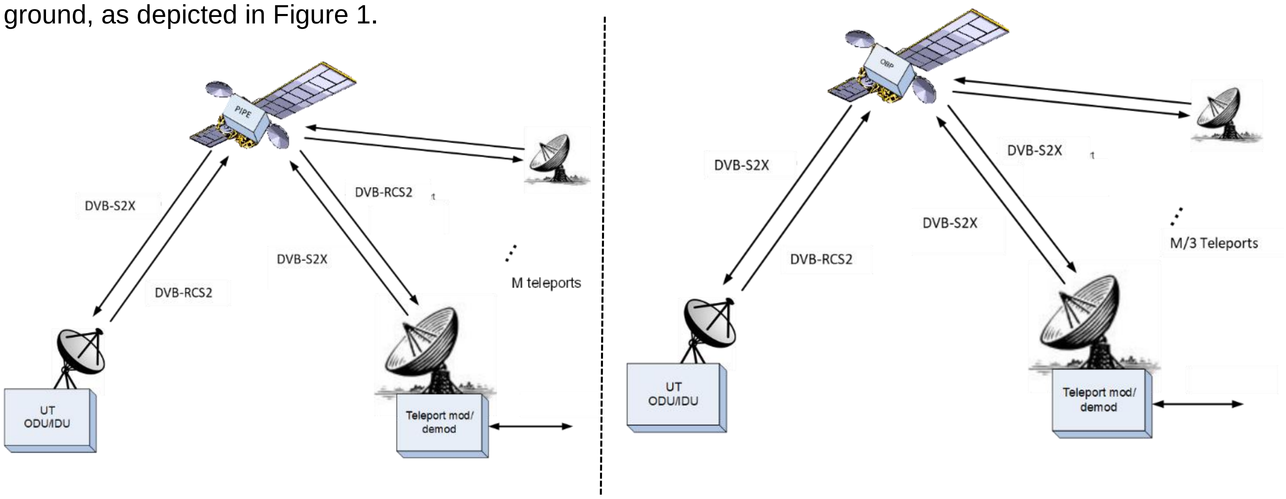
In the case of bent pipe implementation, the GW link has the same efficiency as the user link which is on average 2 b/Hz. In such a bent pipe system the GW link efficiency is the same as the user link and the GW capacity is limited by the total bandwidth availability in the Ka or Q/V bands. A 1Tbps satellite will require 500 GHz of total GW capacity. Using 2.5 GHz with 2 polarizations in Ka band will require 100 separate GW locations. For the return channel, carriers are typical MF-TDMA based and 1-10MHz in size. Assuming 1:4 (modern network ratio) requires 250Gbps in the return link. Using an average 5MHz carrier results in (@1.2b/Hz, 20% RO) 50,000 carriers. In the case of LEO bent pipe the complexity increases as you need for every coverage interest area around the globe a GW in the line of sight of the satellite. When covering AERO and maritime paths this mandates GWs locations and associated backhaul in the oceans.

Table 1: Typical Forward Link Budget for Ka HTS over 500MHz channel and Clear-Sky conditions

		Bent Pipe PL	**Regenerative PL**
Uplink	**EIRPe [dBW]**	73	73
	Frequency [GHz]	29.5	29.5
	Free Space Loss [dB]	213.2	213.2
	G/Ts [dB/K]	19.3	19.3
	Es/No	21.5	21.5
Downlink	**Average EIRPd**	60	NA
	Frequency [GHz]	19.7	
	Free Space Loss [dB]	209.7	
	G/Te [dB/K]	17.5	
	Es/No	9.7	
Total	**Es/No**	9.4	21.5
Bit/Hz		2.63	5.9

3. Decoupling the links

Regenerative processing on the payload de-couples the user and GW links. Modulation and demodulation are done in the payload instead of on the ground. The GW link now stands on its own taking advantage of the large antennas both on the ground and on the satellite and the path loss between the satellite and the ground, as depicted in Figure 1.



Bent Pipe *Regenerative Processing*

Figure 1: Protocols Used in Bent-Pipe and Regenerative Processing Payloads

Link budget calculations show that for the GW link, on average, an improvement of 10dB can be achieved in the Es/No compared to a bent pipe link. Looking at the DVB-S2X QEF table we can see that an improvement of ~12 dB can double link efficiency. In our case the efficiency will increase from 2 b/Hz on average to 6 b/Hz (double of the peak) or a x3 increase. 500 GHz of forward link capacity will translate to 33 GW locations instead of 100. The impact on the return link will be even greater. The smaller MF-TDMA will be demodulated in the payload and aggregated into a single high rate SCPC return carrier with much better efficiency. The efficiency factor here will be x5. 100 carriers of 5 MHz will translate to a single 500 MHz carrier decreasing the complexity of the GW hardware on the return channel.

On the LEO front we gain twofold. A similar gain to GEO will be achieved from improved GW link efficiency on the forward and return links. A major additional advantage is routing capacity on the satellite. Once data has been demodulated on the satellite, we can route this data to different destinations. This opens the use of Inter-Satellite Links (ISL). Data flow within the constellation can now be routed over high rate optical or RF links between satellites on the same plane or between planes and determine the ultimate GW destination for the traffic. Satellites that service AERO and Maritime traffic will route the traffic through ISLs to the appropriate land GW according to least cost routing or regulatory requirements.

An additional benefit of regenerative payload is a single-hop mesh connectivity between standard terminals. In bent pipe systems mesh connectivity between standard terminals is dual-hop with an interconnection done through the GW. In GEO, the delay associated is prohibitive for delay sensitive applications like voice and other.

4. The commercial implications

The de-coupling of the GW and user link translates to commercial implications:

- Link capacity is almost linear to GW hardware costs. Reducing the number of required links x3 will reduce the cost by almost the same amount on the forward link
- Return link are typically MF-TDMA based, the receivers for these are more complicated and costlier and carries are small. Return link saving will be x5 due to efficiency and at least double that due to the reduced complexity (SCPC vs. MF-TDMA)
- Total GW hardware saving when aggregating both forward and return is >x3 (x3 FL, x5 RL, 1:4 ratio). So a $500M hub will now cost $150M, a saving of $350M.
- GW real estate comprises of teleport hosting space and landing rights. The number of GW sites required for UHTS or LEO surpass current HTS requirements so existing players will need to establish new locations and new players will have to acquire and install tens or even hundreds of sites.

5. Concerns related to regenerative payload

The majority of traditional satellite payloads have been bent pipe. The most common concerns when analyzing regenerative payload have been: future proofing, power consumption and cost.

(a) Future proofing – waveforms change, and different equipment vendors keep a “closed garden” system approach where there is no compatibility between the physical layer implementations. The solution for that is using standards and Software Defined Radio (SDR) architecture in the payload. SDR allows to manipulate the parameters of the waveform including frame structure, Modulation, Coding, Constellations and much more.

(b) Power consumption – Space qualified solid-state solutions often relied on older geometries and process nodes which consumed significant power. Space devices need to meet harsh requirements in resistance to Latch-up, Single Even Upsets and aggregated effects of Ionizing radiation. Silicon on Isolators (SoI) technology has proven as the most capable of handling these requirements. Modern SoI geometries such as 28nm, 22nm and 12nm have both inherent immunity and good power consumption/performance ratio. Gigabits of data can be processed with just a few watts.

(c) Cost – Silicon costs are derived from quantities. The volume generated by LEO constellations will help to split the NRE costs between a much larger number of chips and reduce the current cost by a scale of magnitude.

(d) LEO satellites are targeted to have a shorter life cycle and be replaced over time. Many LEO orbits are also less susceptible to radiation. This makes it easier to take advantage of technology developments in the future and implement them.

A possible way to ensure future proof payload is by splitting the air interface functionalities into two parts:

- A specific part, which includes such functions as encoding, decoding and modulation. This part is implemented in the ground segment.
- A generic part, which includes basic signal processing functions common to many waveforms, such as pulse shaping and filtering. This part is implemented on-board the satellite.

A high-speed link transferring generic waveform description to the payload, connects those two parts. Thus, a new air interface, including new coding and modulation would, affect only the ground segment, while the space segment, which is still regenerative, remains unchanged.

Payload complexity affects both cost and processing power consumption. It can be mitigated by locating various functionalities at the ground segment. Examples of such solutions are:

- Baseband frame routing: a fully regenerative payload would include a full set of functionalities through the whole set of protocols, including routing and queuing. Off loading higher layers functionalities to the ground segments would highly reduce the payload complexity. In the proposed baseband frame routing scheme, the packet created by the gateway is ready to be sent as-is from the payload to the destination without any modification, except perhaps a routing label.
- Control Gateway: A regenerative satellite payload would need to act as a hub for the terminals in its coverage area. This activity involves medium access control (MAC) activities, that can be off-loaded to the ground by creating a specific control gateway that would perform the necessary control functionality for a cell or a group of cells. This solution would require a specific control channel from the Control Gateway to the satellite, but would drastically reduce the computing power necessary at the payload.

6. Payload architecture

The proposed payload architecture is shown in Figure 2. It includes a digital beam former + channelizer capable of generating multiple beams (tens to hundreds) and dividing the spectrum according to the demand and a regenerative processor including a multitude of SDR modulators/demodulators.

Depending on the required capacity, the on-board processor will be made of multiple instantiations of a generic processor chip which will be connected to each other and between themselves using high speed SERDES interfaces. Traffic can be routed between User/GW/ISL beams on demand.

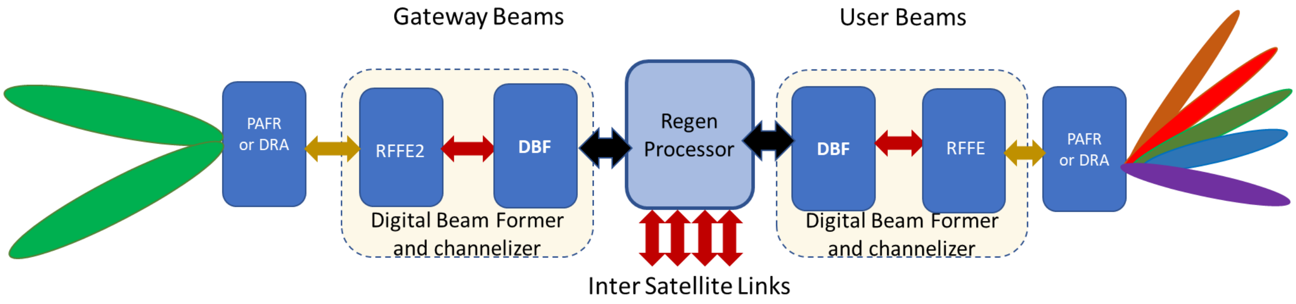


Figure 2: Proposed Payload Architecture

7. SX-4000 ASIC, Regen Processor building blocks

SatixFy is developing the SX-4000 Regenerative ASIC. The SX-4000 is a Rad Hard by design chip aimed to be used in GEO/MEO/LEO orbits to build a regenerative processor. The block diagram and architecture of the SX-4000 is given in Figure 2.

SX-4000 will feature the following characteristics:

- Software Defined Radio Architecture
- Multiple wide band (>500MHz) DVB-S2X modulators
- Multiple wide band DVB-S2X demodulators
- Multiple burst RCS2 demodulators
- Beam hopping support (Super Frame)
- Complete DVB-S2X M range from 256 APSK to Very Low SNR support
- High speed and low speed interfaces
- DSP and CPU

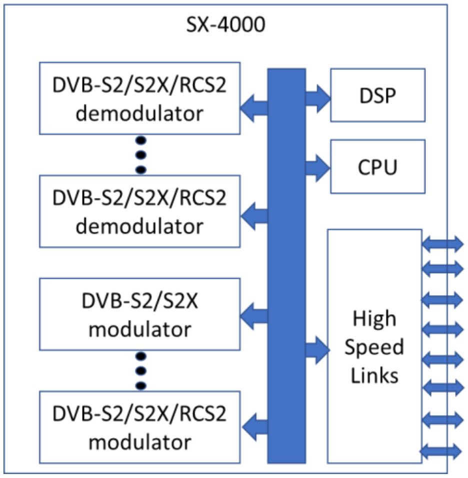


Figure 3: SX-4000 Architecture

8. Traffic Engineering and power

Analyzing the LEO case presented in [3] we had 198 satellites ([3] have looked at an example of 198 satellites, Walker constellation, 11 planes, 18 satellites per plane). To generate a 1 Tbps of total forward link capacity, each satellite needs to process ~5 Gbps of data. Using the average 2bps/Hz we will use 2.5 GHz of spectrum which can operate in 5 modulators of 500 MHz or any other equivalent combination. On the GW link we will need only 1 GHz as the efficiency factor is 5bps/Hz, or 2 modulators of 500 MHz. The total power for 7x 500 MHz modulators in modern silicon geometries is only a few watts.

9. Radiation Hardening

GEO and some of the inclined nGSO orbits are the most challenging from a radiation aspect. SatixFy's design for the SX-4000 meets the most stringent criteria by using the most appropriate silicon process (Silicon on Insulators) and by implementing Rad Hard by design techniques such as hardened library cells, majority voting cells and other industry common practice techniques. The SX is designed to perform in the following radiation environment:

- TID > 100KRad
- SEUth> 30MeV*cm2/mg
- SEL > 60MeV*cm2/mg

10. Summary

Modern VHTS GEO satellites and LEO constellation can benefit immensely from a regenerative processing payload. SatixFy's SX4000 Rad Hard regenerative ASIC, currently under design will enable saving cost, increasing efficiency and perform flexible capacity allocation using beam hopping without compromising satellite power consumption and future readiness due to advanced silicon process node and Software Defined Radio architecture.

References

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