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# **Small Satellites, Big Opportunities**: Emerging FPGA Trends for Next-Generation CubeSat Communications

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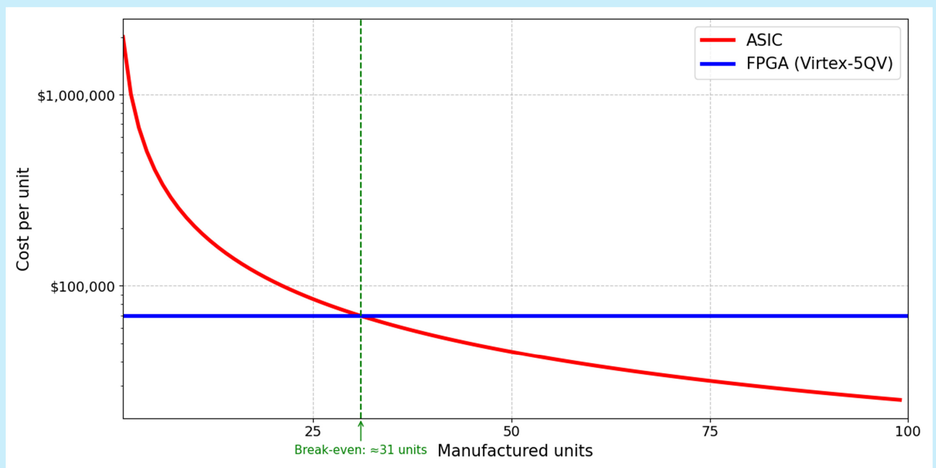
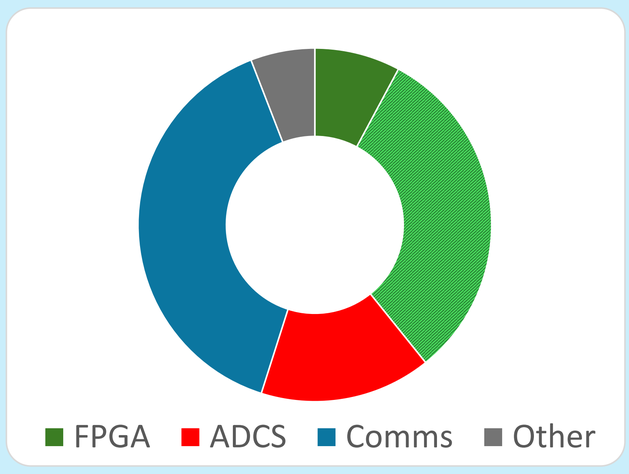



***Cost comparison between FPGA and ASIC***




***Power consumption by satellite subsystems***[1]

## FPGAs in Communications Satellites

The growing significance of small satellites in space missions motivates the definition of streamlined CubeSat platforms that emphasizes **cost-effective** and **flexible communication** solutions. Central to this effort is the **use of FPGAs**, chosen for their capacity to integrate **commercial off-the-shelf** components while meeting stringent performance and reliability demands. By capitalizing on FPGA-based architectures, both **rapid prototyping** and **reconfiguration capabilities** can be achieved for **on-the-fly protocol updates**, a critical requirement for satellite communications under tight power and volume constraints.

These advantages of FPGAs can be seen in the adjacent figures, which show the **cost difference** between COTS FPGA and custom hardware on-boad computer, which is very relevant for small or test missions, and the **power consumption** of FPGA compared to the rest of the satellite components, reaffirming the importance of reconfigurability to reduce power consumption at non-critical or idle moments.

Due to its importance in communication satellites, a study of **new useful techniques** implemented **in FPGAs** is needed, including advances in **signal processing**, **radiation-tolerant** sistems and **reconfigurability**. Through this work, we **aim to advance the knowledge base** for next-generation CubeSat communication systems, ultimately **fostering more resilient, versatile, and scalable satellite networks**.

## Radiation-tolerant

Because satellites orbit outside the atmosphere, they **face radiation**, mostly **from protons, electrons and ions**. This radiation causes Single-event upsets (SEU), **affecting flip-flops, latches, registers and the internal configuration** of the FPGA.

The first approaches to the problem resulted in the implementation of **rad-had devices**, **Triple Modular Redundancy (TMR)** or thermal and power monitoring of the logic cells to shut them down in case of radiation peaks.

Currently, novel techniques are being developed, such as **Parity-based Dual modular redundancy (DMR)**[2], which reduces the need of redundancy in the system while providing similar performance, and **quantum-based error correction algorithms,** which make the system more robust and resilient.

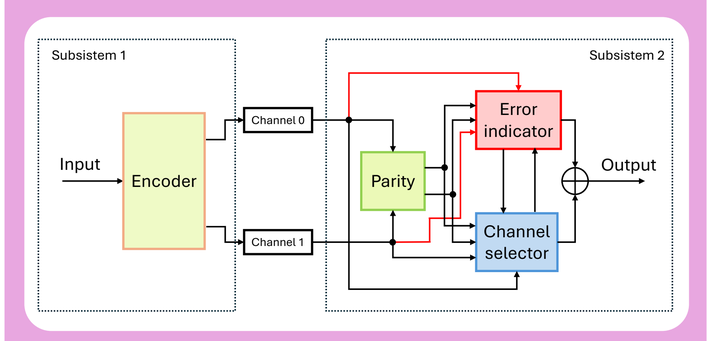
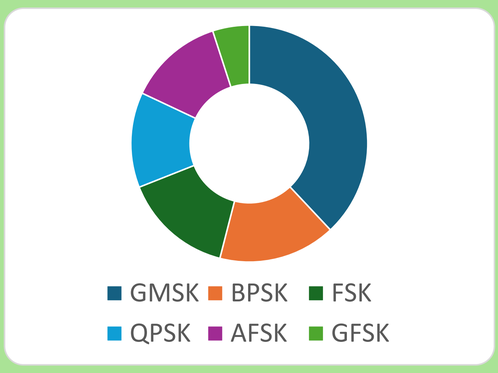
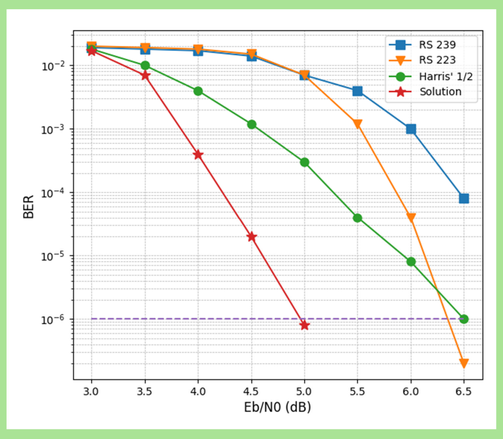



***Diagram of the DMR module***[2]

## Communications




***Modulation used in CubeSats missions***[1]




***Comparison of energy efficiency per bit in ISL***[3]

The **communications section of a satellite is vital** for a successful mission, as it **allows remote control and error correction** on-the-fly. That is why, being so critical, it is preferred to implement what is already known to work. Nevertheless, improvements can be acomplished without changing modulation. We present here two solutions which have arise regarding **Inter-satellite links (ISL)**[3] and **QPSK** in **5G**[4]**.**

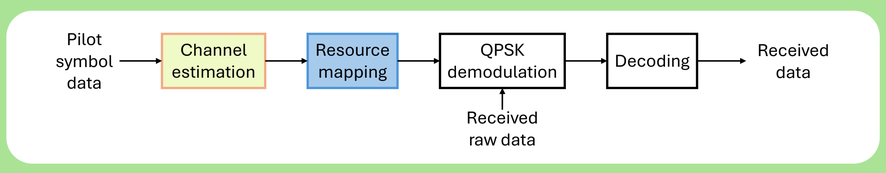
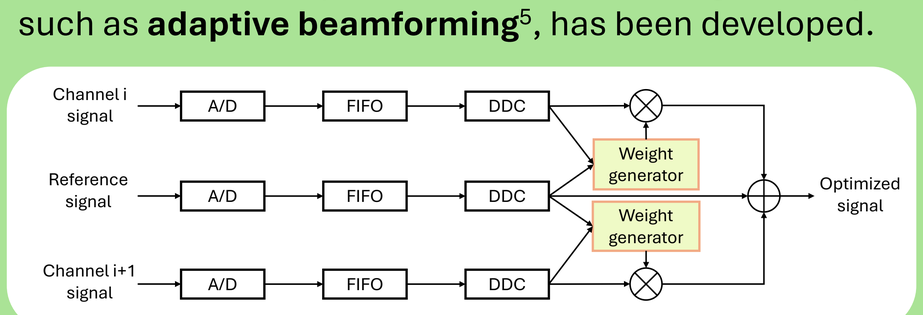



***Illustration of the channel estimation receiver***[4]

At the same time, **dynamic antenna steering techniques**, such as **adaptive beamforming**[5], has been developed.



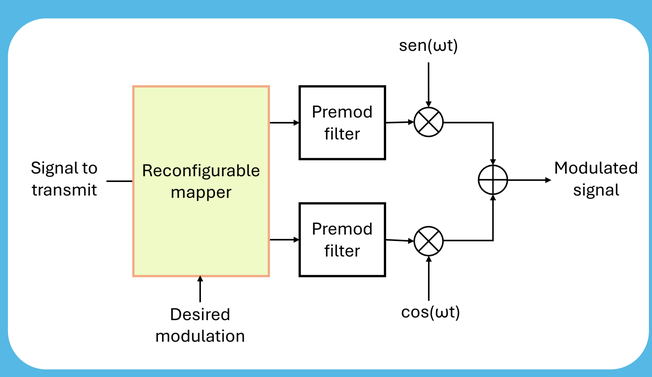

***Realization of the Adaptive Digital Beamforming***[5]

## Reconfigurability

The **reconfigurability** of the space platform **offers** many **advantages** for satellite missions. On the one hand, it facilitates **on-the-fly error management**. On the other, we can **extend mission lifetime** by updating protocols to new standards as they emerge.

Although it is **not an easy task** to fully implement reconfigurability algorithms in the communication modules, within the framework of the ESA mission GOMX-5, a **fully reconfigurable** and **error-resilient** TT&C module was developed and validated[6].

Regarding **broadband connectivity**, reconfigurability is the most efficient way to implement high bitrate communications using the minimum bandwidth in modulations such as **QAM** while **reducing power consumption**[7].




***Representation of the reconfigurable Transmitter for broadband***[7]

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