Data Reduction and Compression Session

Data Reduction and Compression Session

Introduction to CCSDS compression standards and implementations offered by ESA

Speakers: Lucana Santos Falcon (ESA), Roberto Camarero (ESA)

Using CCSDS image compression standard for SAR raw data compression in the H2020 EO-ALERT Project

Speaker: Enrico Magli (Politecnico di Torino)

Preliminary On-board Image Processing Solution for the H2020 EO-ALERT Project

Speakers: Mr Juan Ignacio Bravo (Deimos Space), Dr Murray Kerr (Deimos Space)

Image dequantization for hyperspectral lossy compression with convolutional neural networks

Speaker: Dr Diego Valsesia (Politecnico di Torino)

Solar Wind Analyzer - The Solar Orbiter milestone Towards On-board Intelligent decision making systems

Speaker: Dr Vito Fortunato (Planetek Italia s.r.l.)

From a hyperspectral/ multispectral on-board compressor to a Knowledge-based on-board processor: spaceOP3C HW/SW evolution

Speakers: Dr Leonardo Amoruso (Planetek Italia s.r.l.), Dr Michele Iacobellis (Planetek Italia s.r.l.)

On-Board Data Reduction Software in CHEOPS

Speaker: Dr Roland Ottensamer (University of Vienna)

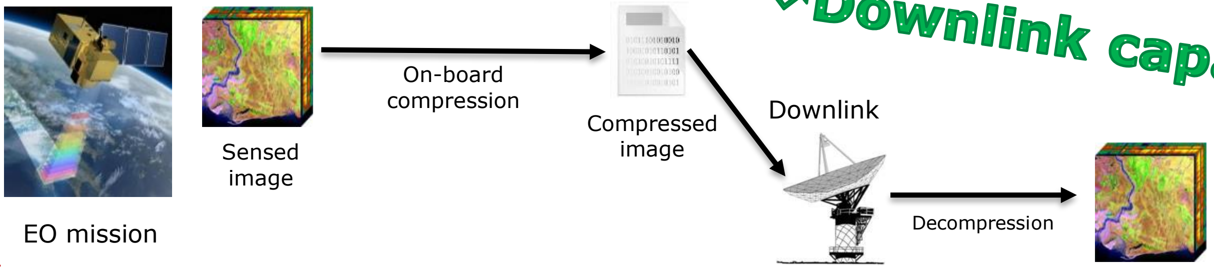
Introduction to CCSDS compression standards and implementations offered by ESA

Lucana Santos
Roberto Camarero

Introduction

1st complex on-board image processing ever?

→ Compression



⇗Downlink capacity⇗

⇧Duty cycle⇧

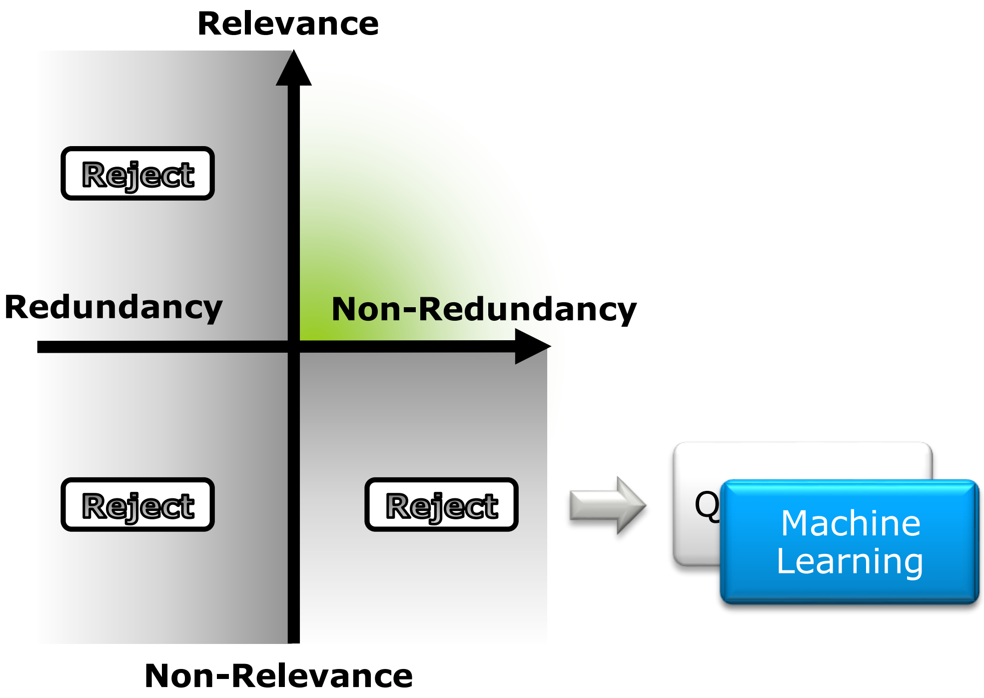
⇧Resolution⇧

⇗Dynamic Range⇗

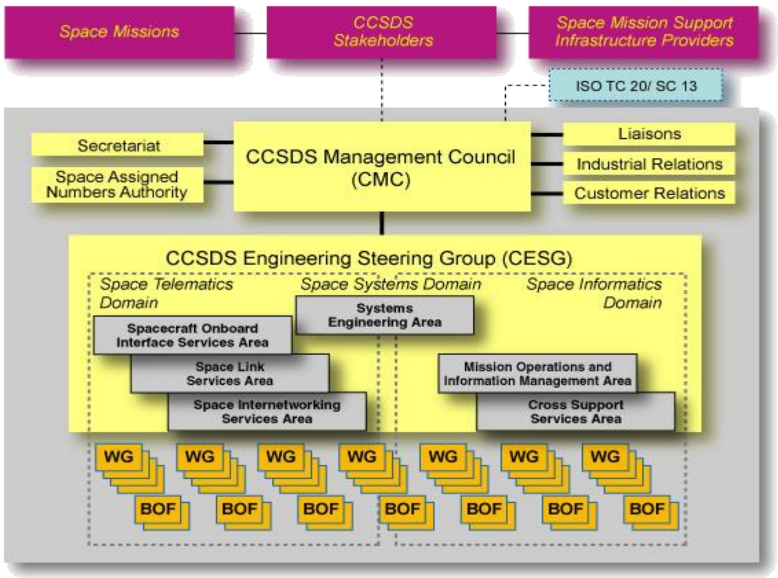
⇧Throughput⇧

⇧Downlink €€⇧

How is compression possible?



Introduction



Space Link Services Area (SLS)
AD: Gian Paolo Calzolari

→

Multispectral Hyperspectral Data Compression Working Group (SLS-MHDC)
Chair: Aaron Kiely

The challenge

Meet unique requirements of space missions and provide state-of-the-art performance

The goal

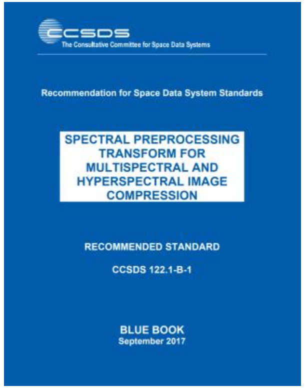
- Ease interoperability and adoption of compression
- Develop low-complexity high-throughput algorithms
- Ease efficient implementation on space-qualified HW

CCSDS compression standards

CCSDS algorithms (Consultative Committee for Space Data Systems)

CCSDS 122

- Lossless or lossy 2D compressor based on DWT

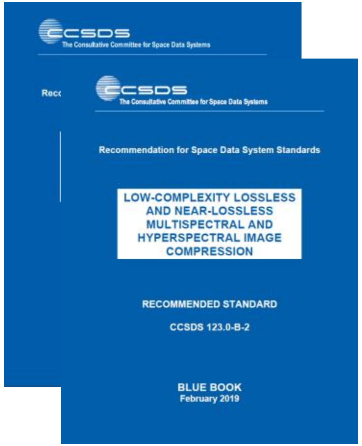


CCSDS 122.1

- Lossless or lossy 3D (1D+2D) compressor

CCSDS 121

- 1D Universal lossless based on Rice codes



CCSDS 123

- Multi/hyperspectral 3D predictive compressor

CCSDS compression standards

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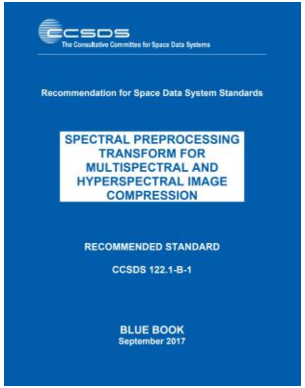

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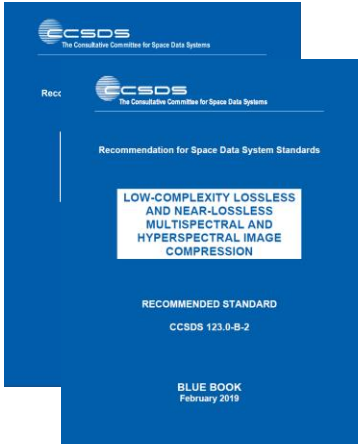


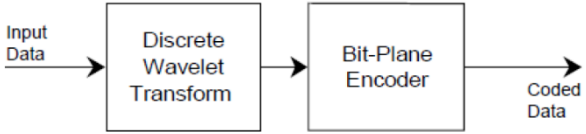
CCSDS 123

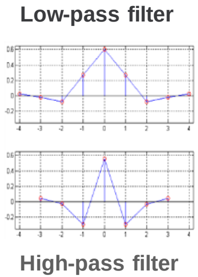
- Multi/hyperspectral 3D predictive compressor

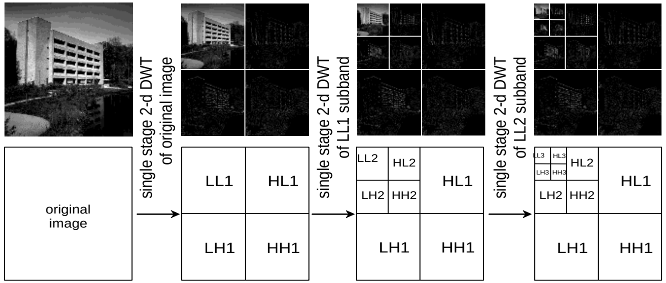
CCSDS 122.0

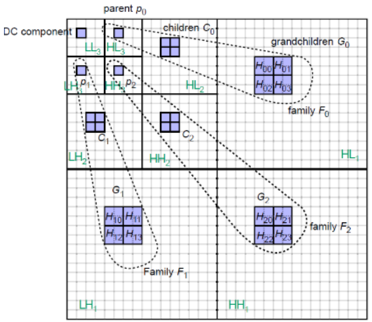
Image Data Compression : Lossy & Lossless

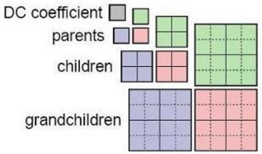
- Blue Book. Issue 1 - November 2005. Issue 2 - September 2017
- DWT + Bit-Plane Encoder
- Progressive lossy to lossless
- Fixed-rate or fixed quality
- Green Book CCSDS 120.1-G-2

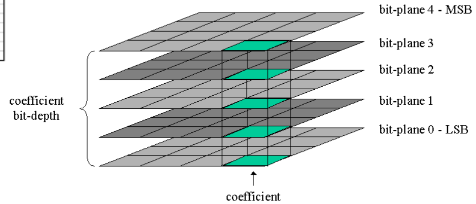












CCSDS compression standards

CCSDS algorithms (Consultative Committee for Space Data Systems)


CCSDS
The Consultative Committee for Space Data Systems
Recommendation for Space Data System Standards
IMAGE DATA COMPRESSION
RECOMMENDED STANDARD
CCSDS 122.0-B-2
BLUE BOOK
September 2017


CCSDS
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SPECTRAL PREPROCESSING TRANSFORM FOR MULTISPECTRAL AND HYPERSPECTRAL IMAGE COMPRESSION
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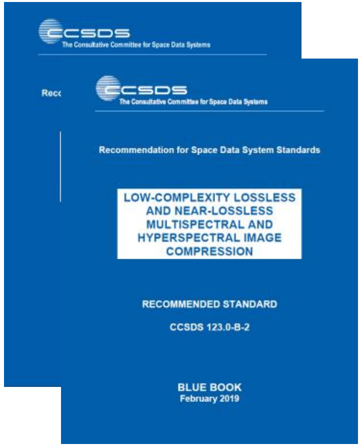
September 2017


CCSDS
The Consultative Committee for Space Data Systems
Recommendation for Space Data System Standards
LOSSLESS DATA COMPRESSION
RECOMMENDED STANDARD
CCSDS 121.0-B-2
BLUE BOOK
May 2012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BLUE BOOK
February 2019

CCSDS 122
- Lossless or lossy 2D compressor based on DWT

CCSDS 122.1
- Lossless or lossy 3D (1D+2D) compressor

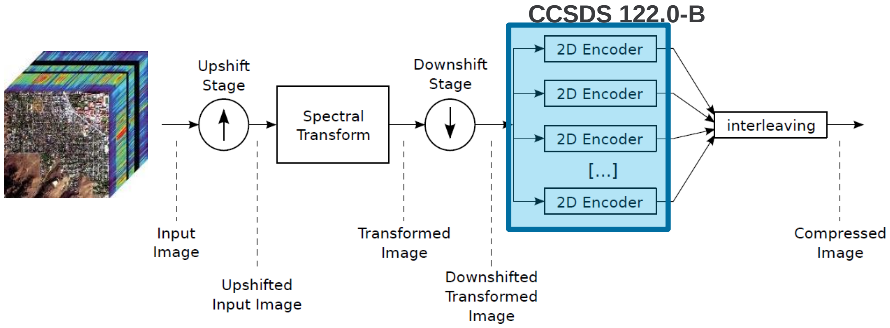
CCSDS 121
- 1D Universal lossless based on Rice codes

CCSDS 123
- Multi/hyperspectral 3D predictive compressor

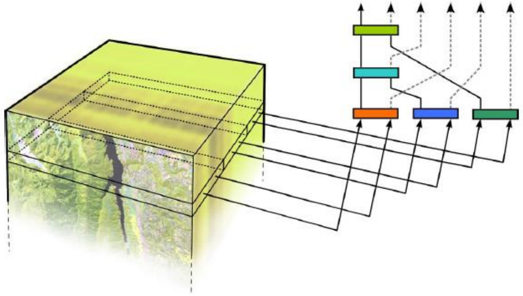
CCSDS 122.1

Spectral Pre-processing Transform For Multispectral & Hyperspectral Image Compression: Lossy & Lossless

- ✦ Spectral transform (1D) + 2D compressor (CCSDS 122.0-B)
- ✦ Blue Book. Issue 1. September 2017



POT



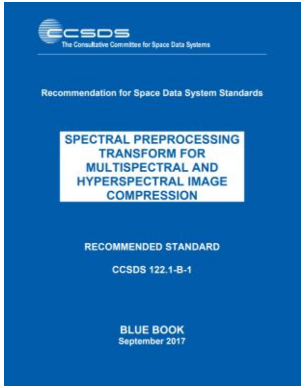
- ✦ 3 possible spectral transforms:
  - » 1D Wavelet transform (5/3 “lossless” DWT)
  - » ALT (Exogenous KLT): Pre-trained Fixed Arbitrary Linear Transform
  - » POT

CCSDS compression standards

CCSDS algorithms (Consultative Committee for Space Data Systems)

CCSDS 122

- Lossless or lossy 2D compressor based on DWT



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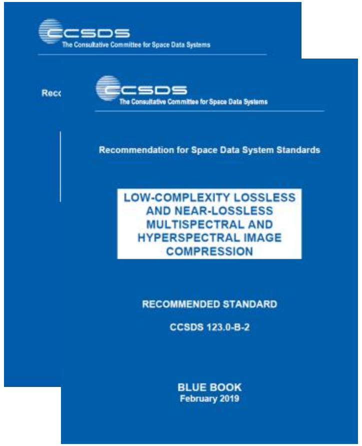
- Lossless or lossy 3D (1D+2D) compressor

CCSDS 121

- 1D Universal lossless based on Rice codes



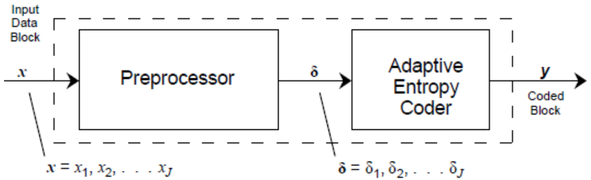
CCSDS 123

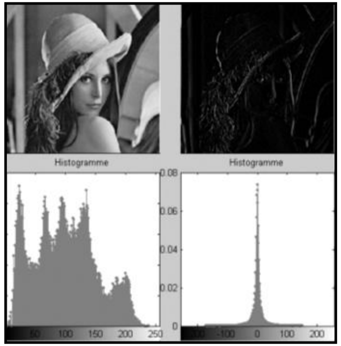
- Multi/hyperspectral 3D predictive compressor

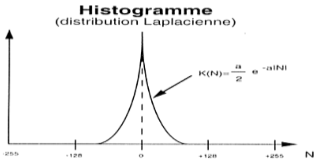
CCSDS 121.0

Lossless Data Compression

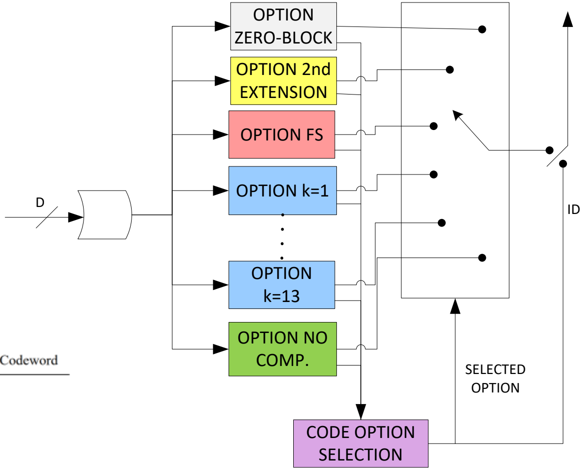
- Blue Book. Issue 1 - May 1997. Issue 2 – May 2012
- Lossless low-complexity predictive compressor
- Green Book CCSDS 120.0-G-3
- Different options for different distributions
- Low-Entropy options

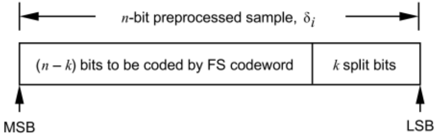


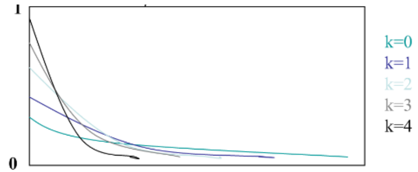




Preprocessed Sample Values, δ_i	FS Codeword
0	1
1	01
2	001
.	.
.	.
.	.
2^n–1	0000 . . . 00001 (2^n–1 zeros)





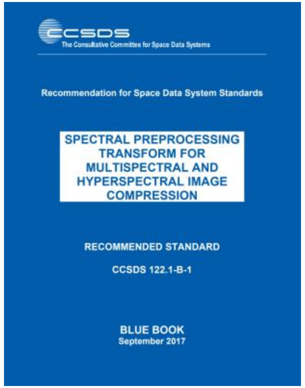


CCSDS compression standards

CCSDS algorithms (Consultative Committee for Space Data Systems)

CCSDS 122

- Lossless or lossy 2D compressor based on DWT

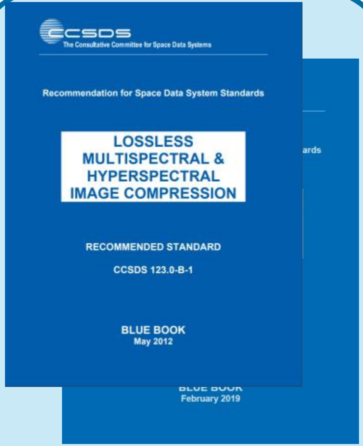


CCSDS 122.1

- Lossless or lossy 3D (1D+2D) compressor

CCSDS 121

- 1D Universal lossless based on Rice codes



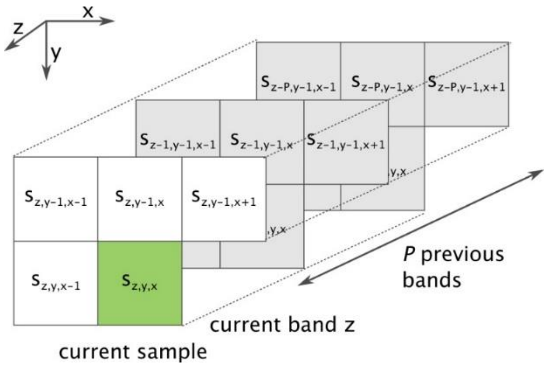
CCSDS 123

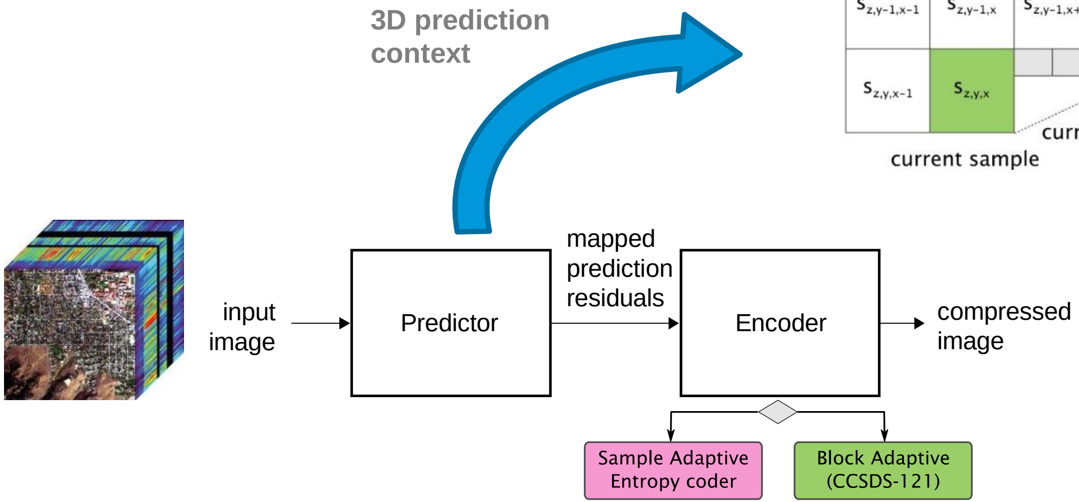
- Multi/hyperspectral compressor based on prediction.

CCSDS 123.0-B-1

Lossless Multispectral & Hyperspectral Image Compression

- Blue Book. Issue 1. May 2012
- Lossless low-complexity predictive compressor
- Based on Fast-Lossless (FL) algorithm (NASA)
  - » Sample adaptive encoder (FL) & Block-adaptive encoder (CCSDS 121.0-B)
- 3D predictor adaptively adjusts prediction weights
- Green Book CCSDS 120.2-G-1





CCDS compression standards

CCSDS algorithms (Consultative Committee for Space Data Systems)


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IMAGE DATA COMPRESSION
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CCSDS 122.0-B-2
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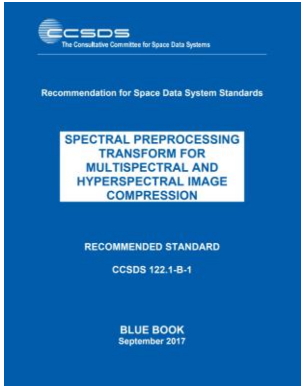
September 2017

CCSDS 122

- Lossless or lossy 2D compressor based on DWT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CCSDS 122.1

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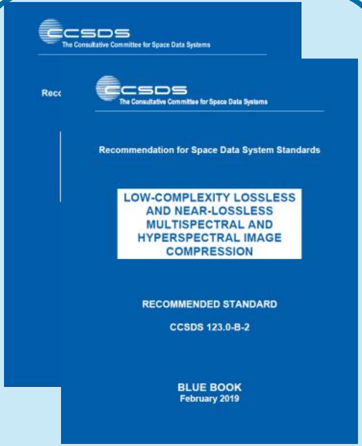
BLUE BOOK
May 2012

CCSDS 121

- 1D Universal lossless based on Rice codes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February 2019

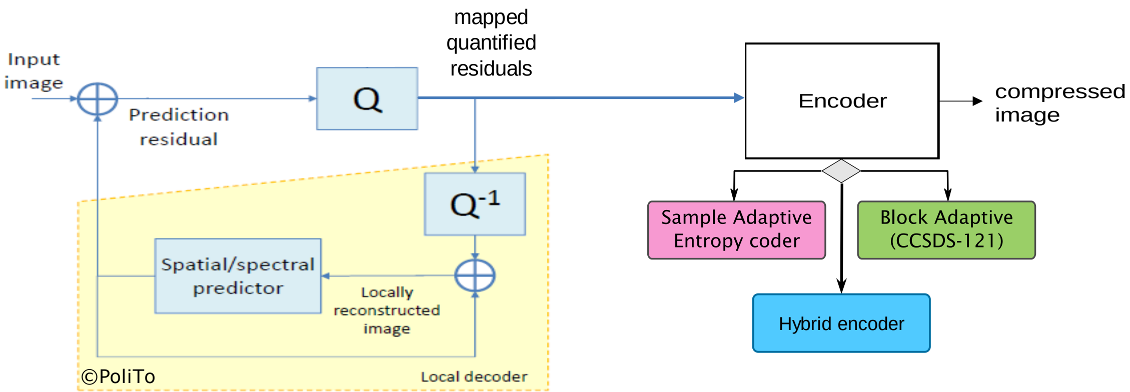
CCSDS 123

- Multi/hyperspectral 3D predictive compressor

CCSDS 123.0-B-2

Low-Complexity Near-Lossless Multispectral & Hyperspectral Image Compression

- Beyond lossless: **+ quantization + new entropy coder for low entropy**
- **Accurate quality control in pixel-by-pixel basis**
  - Bounded maximum and/or relative error
- Very low memory & computational resources (wrt CCSDS 122.1-B)
- Includes more efficient entropy coder for low bitrates



Pros and Cons of each standard

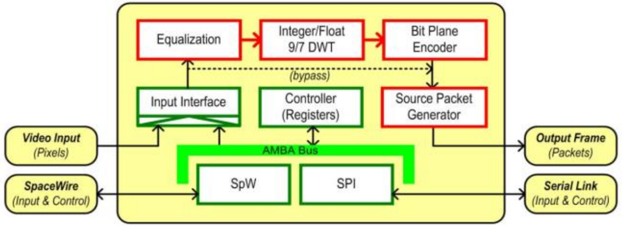
	Type of Data	Complexity	Throughput	Lossless efficiency	Lossy efficiency	Fixed-rate Fixed quality	Commercial counterpart	Relevant Space implementation
CCSDS 121.0-B-2	1D 32 bits	☺☺☺	☺☺☺	☺☺☺	--	Variable-rate Lossless	**JPEG-LS**	**SHyLoC ESA IP**
CCSDS 122.0-B-2	2D 16 bits(B-1) 32 bits(B-2)	😐	☺☺	☺☺	☺☺☺	Fixed-rate Coarse quality control	**JPEG2000**	**CWICOM ASIC**
CCSDS 122.1-B-1	3D 16 bits	☹/😐*	☺	☺☺	☺☺☺	Variable-rate Mechanism for rate allocation	**JPEG2000**	--
CCSDS 123.0-B-1	2D/3D 16 bits	☺☺	☺☺*	☺☺☺	--	Variable-rate Lossless	**JPEG-LS**	**SHyLoC ESA IP**
CCSDS 123.0-B-2	2D/3D 16 bits	☺	😐/☺*	☺☺☺	☺☺☺	Variable-rate **Precise quality control**	**JPEG2000**	--

* Mode-dependent

Implementations supported by ESA

CWICOM

CCSDS WAVELET IMAGE COMPRESSION MODULE



Key features

Lossless or lossy mode

Exact Fixed bit-rate

Equalization (non–uniformity correction)

CCSDS Source Packet formatting

No Eternal Memory. CQFP 256 ASIC

Bit accurate C reference software model

Budgets

60 Mpixels/s

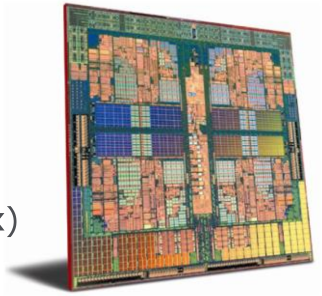
Up to 16 bits

Max width up to **3496 columns**

Max height unlimited (push-broom)

Compression **0.5 bpp to 10 bpp**

Power ~100 mW/Mpix/s max (**5-6W max**)



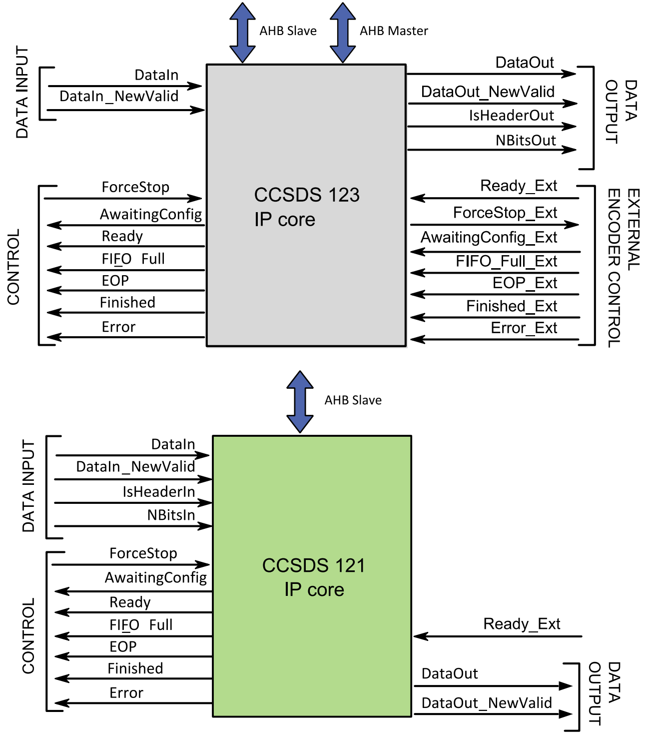
SHyLoC Compression IP Cores

- Implementation of **two lossless compression IP cores.**
- **Described** in VHDL.
- Compliant with:
  - **CCSDS 121**
  - **CCSDS123 lossless**
- Includes all configuration modes.
- Part of **ESA's IP core's Repository**.
- Developed by University of Las Palmas de Gran Canaria.
- Technology independent:

    One-time programmable FPGAs (Microsemi);

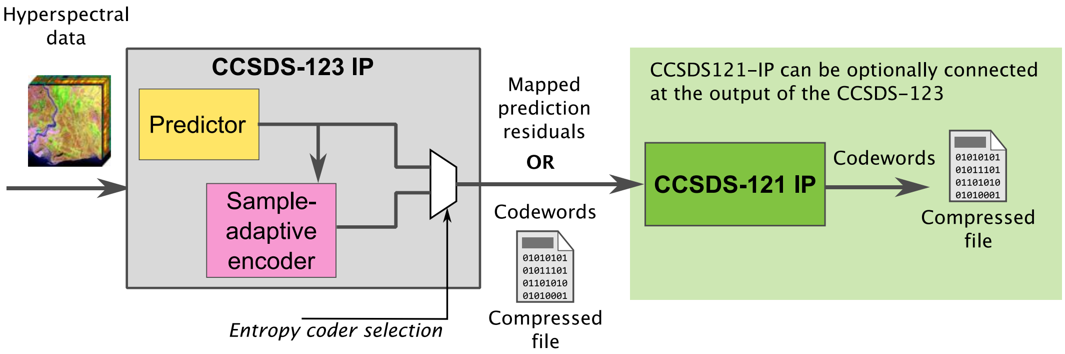
    Reconfigurable FPGAs (Virtex5);

    ASIC (DARE libraries)



SHyLoC IP Cores

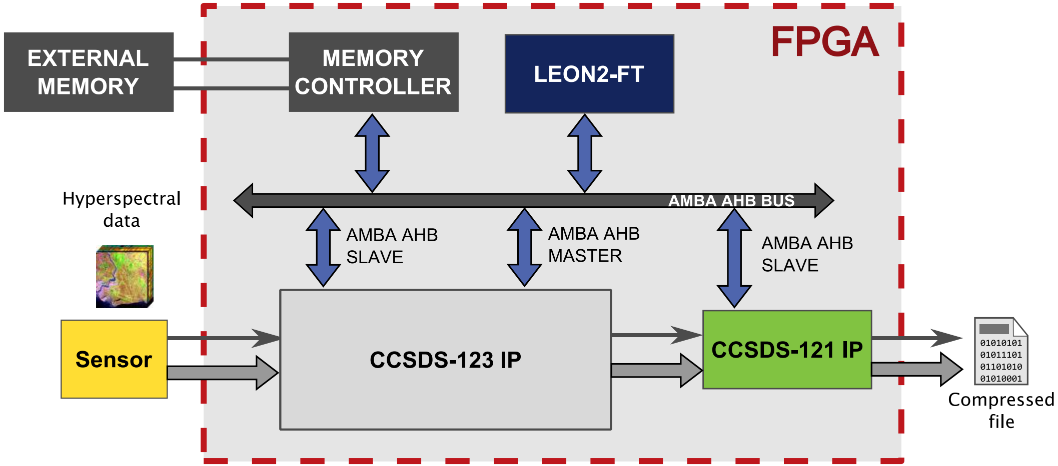
- The IP cores can be combined into a logical single entity.



- CCSDS 123 IP core:
  - High-performance lossless compression of multispectral and hyperspectral data.
  - Supports BSQ, BIP and BIL sample order.
  - Can be used as external pre-processor (predictor) for the CCSDS 121 IP core.
- CCSDS 121 IP core:
  - Universal lossless compressor based on Rice's coding.
  - Can be used as external entropy coder for the CCSDS 123 IP.

SHyLoC as HW accelerator

- Throughput up to 1 Gbps (~60 Msamples/s for 16-bit input) when implemented on a Virtex5 FX130.
- Include AMBA AHB interfaces.
- Compatible with GRLIB and LEON2-FT.



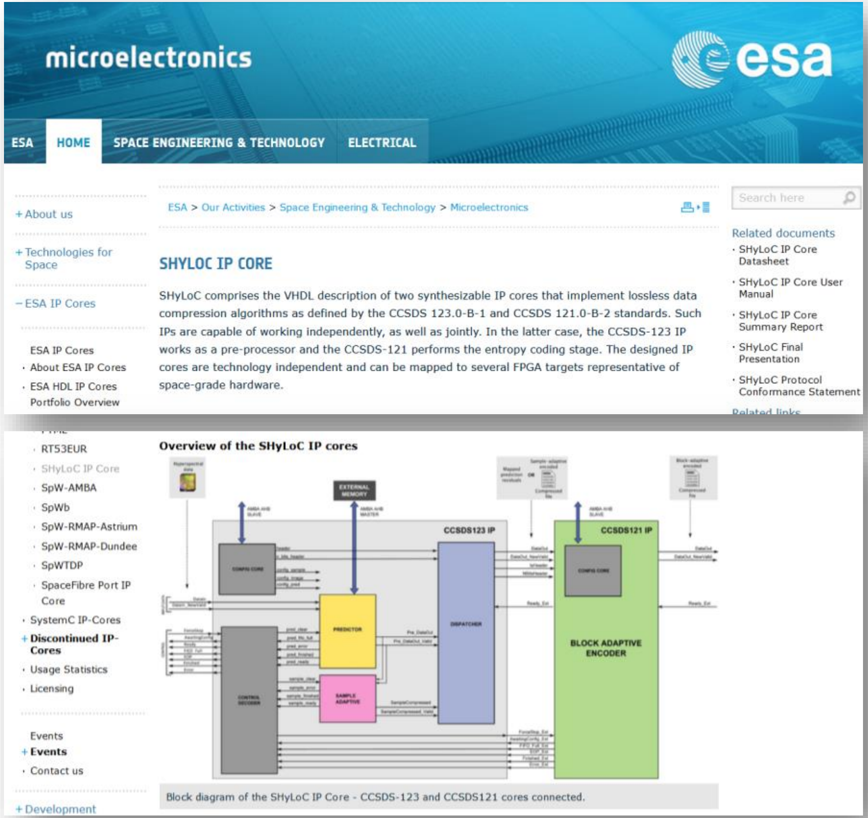
SHyLoC performance

- Compression performance in terms on data reduction depends on the CCSDS standards.
- Performance in terms of throughput, hardware resources and power consumption depends on the selected configuration and target device.

- Mapped to 7 different FPGA devices: Xilinx Virtex 5 & 5QR; Microsemi ProASIC3E, ProASIC3L, RTAX2000, RTAX4000 and RTG4
- Maximum throughput 140 Msamples/s in Virtex5 FX130, 80 Msamples/s in RTG4
- Low complexity: maximum 7% of LUTs Virtex5 FX130 and 13% Microsemi RTG4.
- On demonstrator (Virtex6), throughput of up to 1 Gbps.

SHyLoC availability

- Distributed by the ESA IP Core's service (https://www.esa.int/Our_Activities/Space_Engineering_Technology/Microelectronics/SHyLoC_IP_Core)
    - ESA/ESTEC maintains and distributes a small catalogue of IP Cores.
    - **The ESA IP Cores can be licensed for research and/or commercial use, under specific conditions to companies based in ESA members and participants states**
- Commercial version by Cobham Gaisler.



CONCLUSION

Compression is an **enabling technology** that **maximizes mission capacities** while **minimizing data rates and volumes and overall costs**

- Only major **drawback is complex and costly implementation in space HW**
  - Eased by **standardization** and “of-the-self” solutions (ESA IP and components)

CCSDS standards to **meet space missions requirements** providing **state-of-the-art performances**

- Large choice depending on:
  - Type of data: 1D, 2D or 3D
  - Type of compression: Lossless, lossy or near-lossless
  - Operating mode: fixed data rate (volume) or fixed quality
  - Memory and computing resources
- Widely available software & hardware implementations
- Large users community and literature