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IMPLEMENTATION OF ON-BOARD DATA MANAGEMENT IN VERY HIGH RESOLUTION EARTH OBSERVATION SPACECRAFT

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Abstract

As Earth Observation missions are becoming increasingly more demanding in terms of spatial and spectral resolutions (0.5m to 5m in 8 to 200 channels), accompanying requirements for on-board payload data handling are becoming more stringent as well. As a result, an increasing demand for the management of high data rates and large data volumes is generated. A limiting factor remains however the downlink capacity, which can be overcome by introducing innovative technologies in both transmitter systems and on-board data pre-processing and compression.

In this paper, an advanced and innovative architecture for spaceborne high-speed payload data management subsystems is presented. In order to cope with all existing requirements with respect to data volumes/rates and redundancy concepts, the design applies a modular approach. Based on OHB-System's experience with Payload Data Handling Systems (PDHS) for the synthetic aperture radar system of SAR-Lupe and for the optical payloads of MSRS and KOMPSAT II, several concepts will be presented. The main constituents of these PDHSs can be classified into the following items: Data Processing, Compression, Storage, Channel Coding and Encryption, and Transmission.

A presentation of the entire data chain is given, beginning with the output of the imaging sensor and ending at the downlink signal. Investigation of this chain yields the conclusion that using the IEEE 1355 space wire standard to provide scaleable redundancy and performance has distinct advantages. Every module of the data management chain features compression, evaluation, truncation, storage, formatting, encryption and downlink of data. The entire system also includes the complete ground test equipment for verification of the PDHS as a stand-alone unit, for tests at subsystem level and for complete system tests during spacecraft AIV.

The complete data management chain can reach a performance of more than 10Gbit/s input rate and an output rate of 740Mbit/s using dual polarisation techniques at X-Band. Only low power consumption and 40 kg of mass in a redundant configuration is required to obtain this performance.

1 OVERVIEW

Future missions for high resolution (spatial, spectral and radiometric) Earth observation will have significant increased performance requirements for onboard data processing. High performance of data storage and downlink is already required for typical missions today. The following presents a modular system architecture as being used for Kompsat II, SAR-Lupe, and MSRS but also other projects running at OHB-System.

Data rates can easily reach 70 up to 1.800 Mbit/s per spectral channel for a ground resolution of about 5 to 1 meter at only 10 bit spectral resolution. Assuming 5 meter ground resolution and a scene size of 50x700km, one would have to store already 84 Gbit per spectral channel on-board the satellite. For 12 channel that aims into a storage capacity of 1.008Gbit, which is demanding in terms of power issues. Assuming further a down-link capacity of 500 Mbit/s (actual technology) one would need 1 hour for the downlink. This short example shows, that high speed data processing on-board the spacecraft is necessary to reduce the data amount to the really needed information part. One example for this pre-processing is data compression, other examples are data evaluation and truncation to the area of interest.

A modular design is desired to provide maximum flexibility in order to insert other processing elements into the processing chain. For example there might be the need to truncate data in front of the compression or the data storage is not required as the mission wishes online downlink only (GEO applications). Further, programmatic aspects can lead to a separation of the processing chain into different manufactures.

A scaleable design is desired to easily adapt the processing chain to different numbers of spectral channels or missions requiring high redundant design. But it leads to a cost effective design. However, for very dedicated missions one can still combine elements of the processing chain like compression, storage and channel coding. This combination would give an optimised mass & power budget. The system architecture for a modular scalable high speed processing chain is given in Figure 1.

The Camera Unit itself is not part of the processing chain and shown for overview purposes. The Camera Unit contains the detectors and provides finally the A/D converted digital signal stream as input for the processing chain.

The processing chain consists of:

1) Data Pre-processing Unit
2) Data Storage Unit
3) Channel Coding Unit

A Space Wire standard can be integrated to facilitate the construction as the backbone of the payload data system to which all kind of different blocks can be connected. The Space Wire standard specifies the physical interconnection media and data communication protocols to enable the reliable sending of data at high-speed (between 2 Mbit/s and 400 Mbit/s) from one unit to another. It promote compatibility between the data handling equipment and subsystems. Space Wire links are full-duplexed, point-to-point, serial data communication links. The Space Wire is able to support many different processing architectures using the point-to-point links and Space Wire routing switches. An architecture can be tuned to the different mission requirements and specifications.

The EGSE dedicated to the processing chain has also to provide a modular & scaleable design under cost effectiveness. The EGSE is designed to support a wide range of test on unit level as well as on chain level. Furthermore it is used to verify the data output of the X-Band transmitter.

Moreover the Space Security System offers all the functionality and performance required for reliable and secure missions of today and tomorrow. The system performs all the tasks from key management, authentication, real-time encryption and decryption. These tasks provide protection of all satellite and ground links up to level SECRET. Secured links are from the On-board Computer TMTC function (incl. Inter-Satellite-Links) and from the payload data handling to ground.

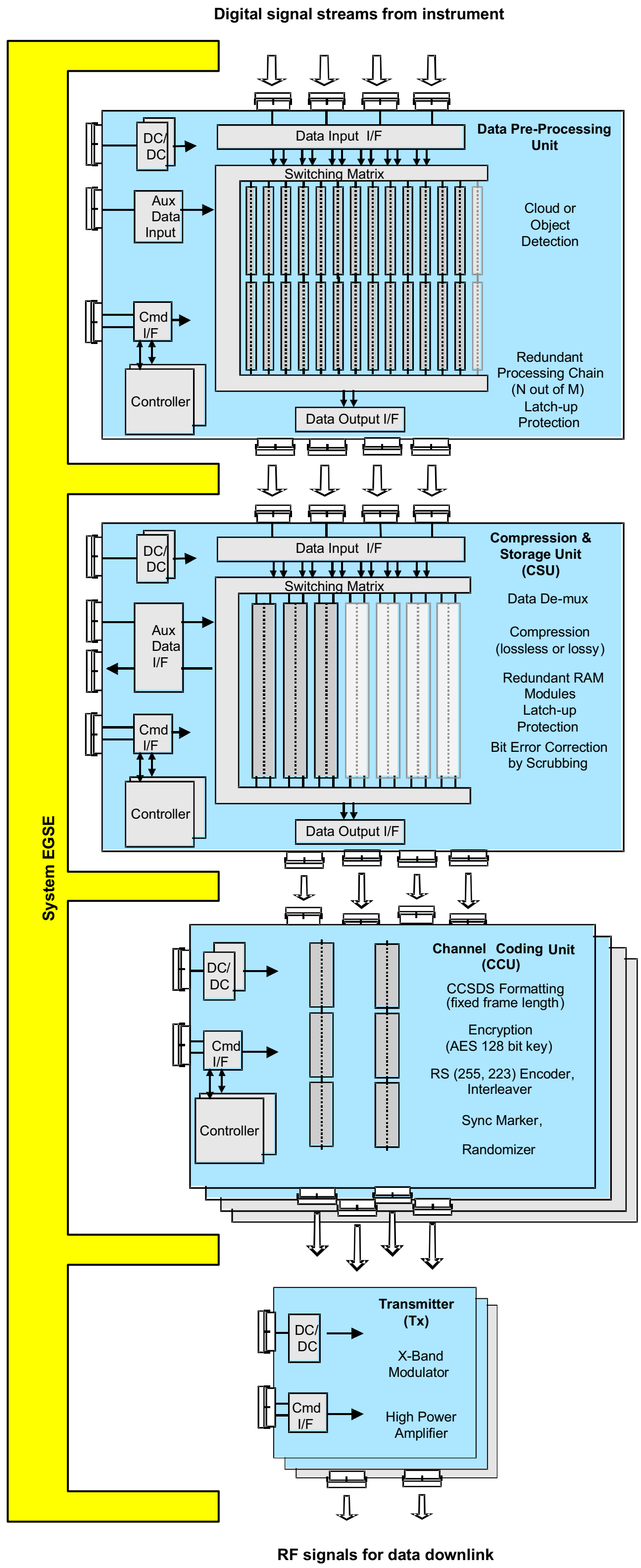

Figure 1: PDHS Architecture

2 HIGH-PERFORMANCE PAYLOAD DATA HANDLING SYSTEM

The presented PDHS is designed modular serving high-end performances as well as less demanding applications for small satellite limitations.

2.1 Pre-Processing

Applications for data pre-processing are for example autonomous object/event detection using a wide field sensor. After on-line detection of events, the selected area will be investigated in more detail using a high resolution sensor steered automatically to the area of the event by the spacecraft itself. This technology is used for example for an autonomous fire detection system studied by OHB-System. The information regarding the location of the fire is provided within 5 minutes in order to enable fire fighting in the early stage.

Another example is the online detection of clouds and the resulting selection of cloud-free scenes, e.g. by re-pointing of the spacecraft or instrument mirror. This processing must be performed in real time to close the high precision control loop. Data pre-processing is mainly performed in order to decrease the data volume for downlink issues.

An example of the core technology used for pre-processing is the VSOP board based on DSP or LEON-3 processors. Figure 2 shows the DSP-Board equipped with commercial components and Figure 3 the VSOP Block diagram.

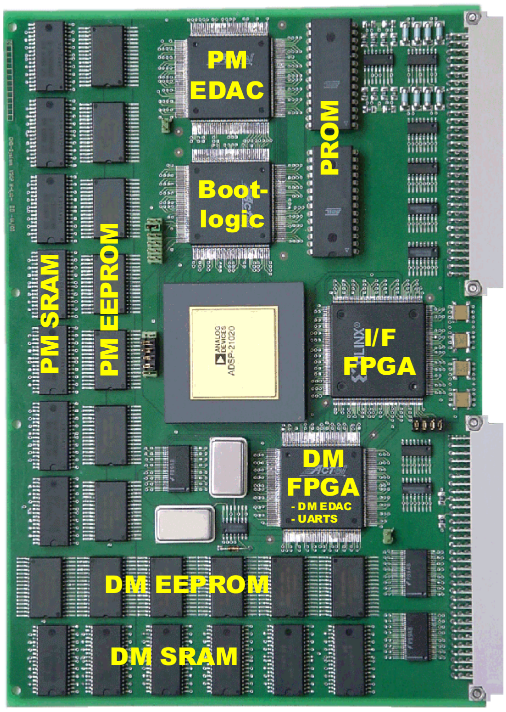

Figure 2: VSOP Board Layout with Commercial Components

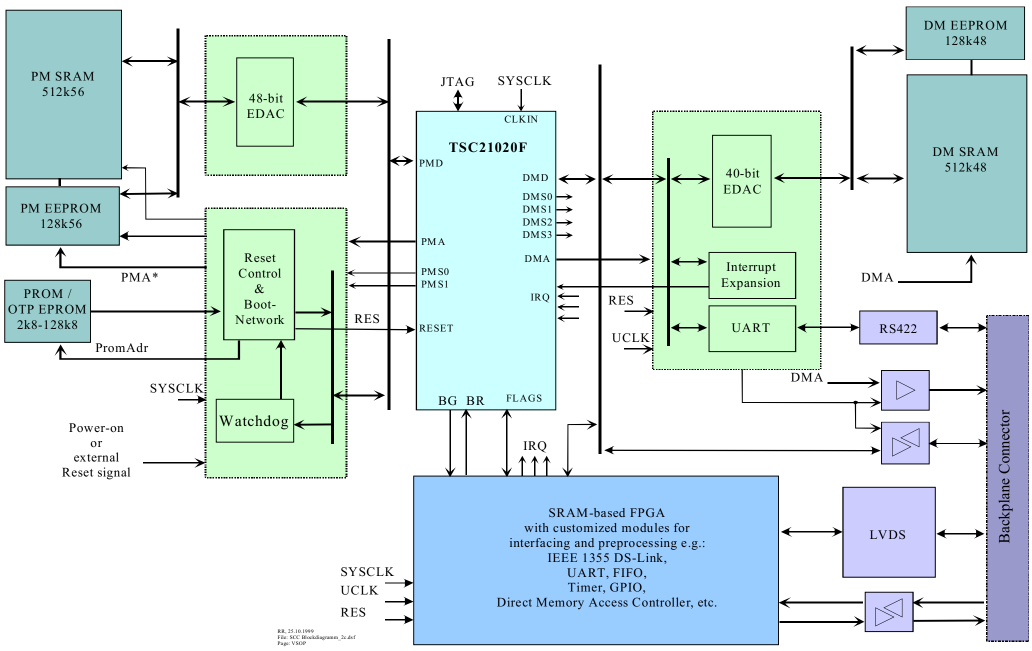

Figure 3: VSOP Block diagram

The VSOP provides 30 MFLOPS sustained and 45 MFLOPS peak performance at 15MIPS. A set of VSOP boards can easily be interconnected to form a multiprocessor architecture for dedicated applications. For high performance the implementation based on LEON-3 processor as IP-cores on FPGAs or ASICs provides performances from 20-35 MFLOPS at 25-45 MIPS.

2.1.1 Compression & Storage Unit

The CSU consists of parallel compression & memory modules to cope with very high input data rates. Image data compression e.g. according to standard algorithms is classically performed in a processing pipeline before the mass data storage. This requires high rate on-line processing capability for the compression and also a considerable amount of data buffering in the compression, because the compression algorithm is performed on image tiles. The new approach of our design is to combine mass data storage and compression into one module. This saves significantly storage and interface overhead in the compression and in particular it allows for operational variation of the compression task: it can be performed either quasi-online using a small part of the mass memory as intermediate tile buffer or completely offline. By such, the compression task is completely decoupled from the incoming data rate and peak power may be adapted to the operational needs of an individual mission. Our implementation performs lossless and lossy compression using JPEG 2000 algorithm with 650 Mbps per module. The modules have a scalable storage capacity of 32-128 Gbit. A CSU with 16 modules would cover a total sensor input data rate of up to 10 Gbps and a storage capacity of up to 2 Tbit EOL memory.

The scaling to the very high sensor data rate and memory capacity is done by utilisation of several CMMs, which are used in parallel. All modules are setup and controlled by a central unit controller, which also provides the interfaces to the spacecraft. Due to its high integration level our approach significantly reduces the required power figure.

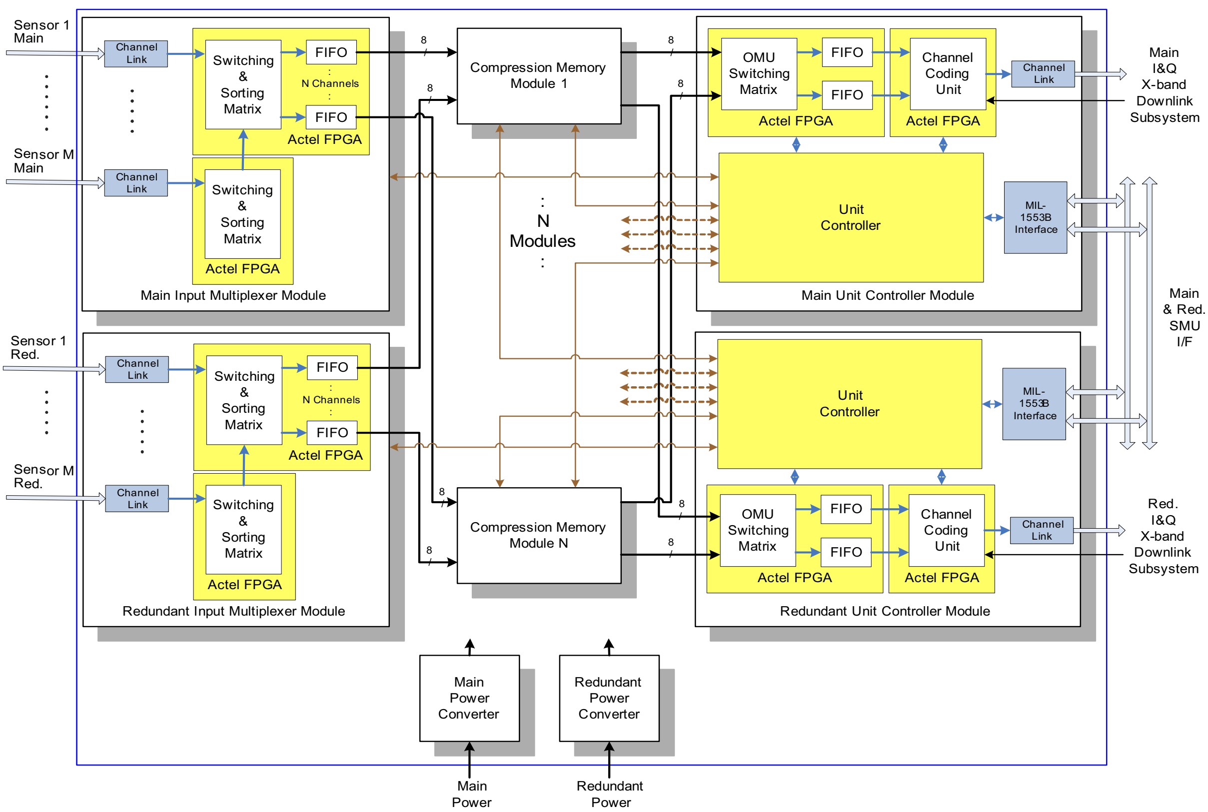

Figure 4: CSU System Block Diagram

The proposed basic implementations have the heritage from the Framing Camera Data Processing Unit (DPU) designed for JPL's DAWN mission. This unit provides the complete image processing and compression (JPEG2000), including a 8 Gbit mass memory plus a LEON-2 based controller with MIL-STD 1553B interface. The flight model of a DPU is shown in Figure 5.

Figure 5: DAWN Framing Camera DPU

2.1.2 Channel Coding Unit

The next generation of the PDHS includes the channel coding function combined within the Compression & Storage Unit. A separate channel coding unit is also available for specific applications. The Channel Coding Unit performs encryption of a high speed data stream together with telemetry channel coding according to recommendations of the consultative Committee for Space Data Systems (CCSDS).

The Channel Coding Unit is a high speed data processing unit that operates on two independent input data streams. The maximum input data rate per pipeline channel equals 2x216 Mbit/s, the output data rate is 2x250 Mbit/s constant. For the data on both data streams the CCU features:

Encryption: The Data will be encrypted (on demand) in the IDEA standard with 128 bit key length in real-time. IDEA is a world-wide available symmetric encryption standard and has not been cracked up-to-now. T-Des, AES or costumer specific encryption can be used if desired. The encryption itself is performed by dedicated hardware (data encryption module, DEM).

Reed-Solomon encoding: Behind the encryption the data stream will be Reed-Solomon (RS) en-coded. From code blocks of 223 bytes 32 check symbols are generated to provide error detection and correction capability for up to 16 Byte errors. Five of theses RS-encoders are available in parallel for every data stream and are operated in a byte-by-byte time multiplexed manner (interleaving). By this burst errors equal to 80 symbol (640 bit) duration can be corrected.

Header generation: The data is subdivided into packets of equal length, each packet owns a header information. Most of the header information is provided to the CCU via an external interface and the CCU collects and inserts this information into the data stream in real time.

ASM insertion: Each packet is provided with an asynchronous synchronisation marker, a fixed identifier that leads every packet.

Randomiser: All data except for the ASM are randomised in order to provide sufficient 1-0 transitions for transmission.

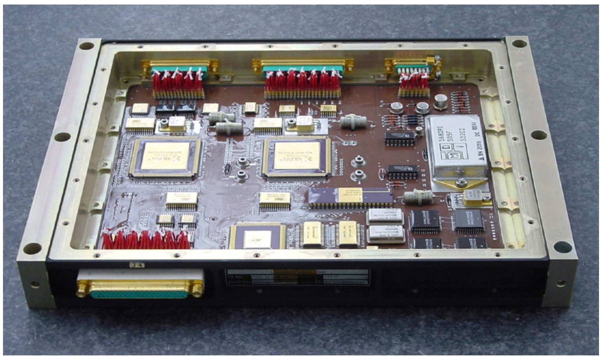

Figure 6: Channel Coding Unit Core Layout

The CCU is controlled via a redundant bi-directional serial interface for command and control. The interface standard is RS422. It can be mounted together to form a combined case. Since no electrical interconnection exists between the cases, there is no single point of failure for the combined unit.

The CCU provides fast, CCSDS compatible and redundant 128bit Reed-Solomon coding with real-time IDEA encryption for 2x250 Mbit/s output data rate.

2.1.3 Transmitter

For the payload data downlink of current X-band transmitter with a total data rate of up to 500 Mbit/s for single polarization channel (either QPSK or 8 PSK) were considered. Due to the ITU bandwidth limitations of 375 MHz, we propose a concept based on dual polarization channels that can handle up to 1000 Mbit/s. A third transmitter is used for redundancy of one of the other two.

2.1.4 EGSE

The EGSE is a high-speed data test system for advanced high-speed data processing chains including downlink subsystems onboard of earth observation satellites. The EGSE is designed to support the tests demanded by the various test and integration levels:

1. Single Unit tests: the EGSE acts as unit tester for the processing chain elements like Pre-processing Unit, Data Storage Unit and Channel Coding Unit but also the analogue X-Band Transmitter.
2. Sub-system test: the EGSE allows the test of the entire processing chain.
3. System tests: the EGSE provides interfaces to the spacecraft system EGSE in order to support the complete spacecraft test after integration of all assemblies.

Figure 7 shows a version of the complete integrated test system where all components are located in three 19'' racks.

The EGSE provides stimulus serial data interfaces and accepts 8 bit parallel data at rates of up to 2x250 Mbit/s for testing the digital Channel Coding Unit. Furthermore the EGSE generates stimulus 8 bit telemetry data streams synchronously to a input clock provides by a high data rate QPSK X-Band Transmitter at rates of up to 2x320 Mbit/s. A integrated X-Band Receiver provides at its out-put serial data and clocks, separate for I- and Q-Channel, to the Channel Decoding Unit (CDU).

The data can be written to a PC for evaluation purposes or send to a Bit Error Tester. The EGSE provides a com-plete Bit Error Test-Set, which is selectable via the Selec-tor-Unit of the CDU. The EGSE is completed with meas-urement equipment to evaluate signal parameters and qualities for high speed digital signals as well as RF sig-nals up to 18 GHz.

The functional block diagram of the test set-up is pre-sented in Figure 9. The Bit Error Test is one of the most important tests to verify the performance of the processing chain in combination with the transmitter. All operations and modes are commanded and controlled by a man ma-chine interface which is connected to the CDU via a built-in LAN interface. This LAN interface provides a complete access of a higher priority test system to the EGSE work-ing as a front-end test system to the spacecraft payload. The CDU of the EGSE is a high-speed data ingest sys-tem.

Figure 7: EGSE Assembly

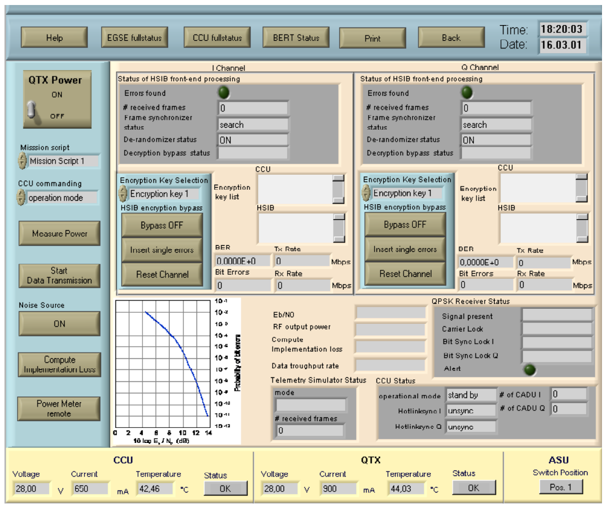

Figure 8: Bit Error Test Setup – MMI Mask

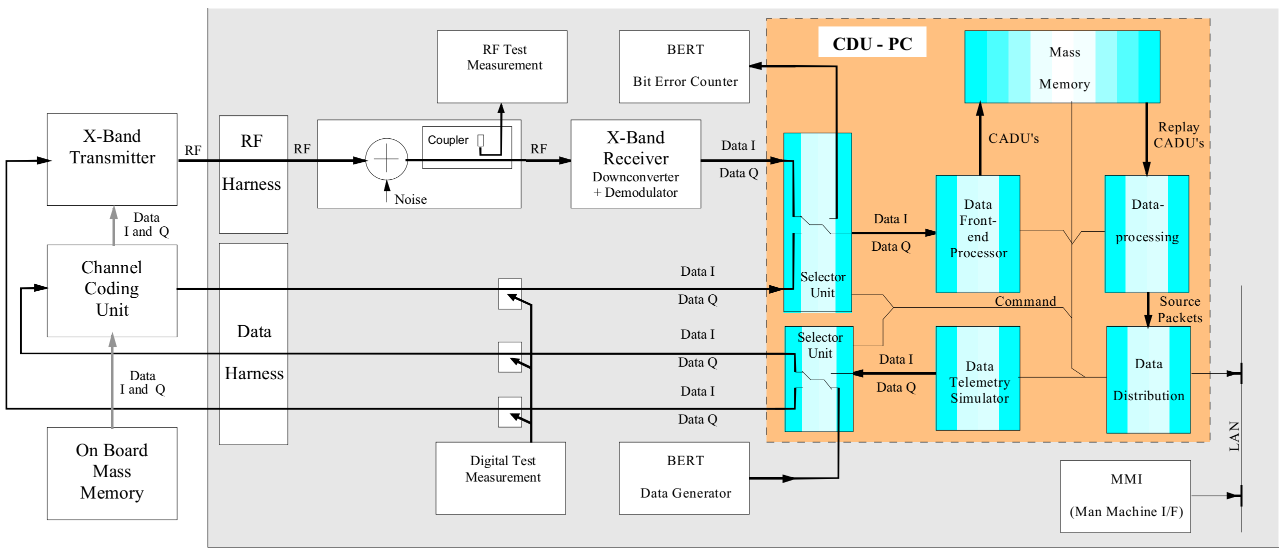

Figure 9: Functional Block diagram of the EGSE and Interfaces to the Units and Test

3 CONCLUSION

OHB System provides an advanced on-board data handling chain include a Security System as an adequate solution for future Earth Observation applications and services. The Payload Data Handling System features high performance in data compression, data evaluation und truncation as well as data storage, data formatting (CCSDS), data encryption and downlink.

The units of the processing chain are:

- DSP boards for high performance controlling and pre-processing.
- Compression and Storage Unit (CSU) for high speed and capacity storage.
- Channel-Coding Unit (CCU) for high speed image data processing and formatting.
- EGSE & SCOE for high-speed sub-units check-out and system tests.

On the other hand the security System provide all the tasks from key management, authentication, real-time encryption and decryption to provide protection of all satellite and ground links up to level Secret. The Secured links are from on-board Computer TMTC function and from the payload data handling to ground.

Seven elements of importance to the cryptographic processes are on the satellite:

- TMTC External Authentication Unit for integrity protection on segment layer,
- Satellite Management Unit Crypto Board (SCB) for key negotiation with EC-DH for two sets of encryption and authentication keys,
- Channel Coding Unit (CCU) as a part of the Payload Data Handling System for high speed image data processing and formatting,

and on the ground segment the corresponding counter parts:

- TMTC Segment Authentication Server to generate and verify signatures,
- Ground Crypto Unit (GCU) for established authenticated connection with SCB and real-time symmetric encryption and decryption,
- Channel Decoding Unit (CDU) for real-time decryption and CCSDS type decoder, and the
- µProcessor based SmartCards for secure key storage and mutual authentication.

4 REFERENCES

[1] MSRS, KOMPSAT-2, SAR-Lupe on OHB-System AG, Website: *http://www.ohb-system.de*