RAMSES AND MAXUS-8 - USING AN ECSS AND CCSDS COMPLIANT CONTROL SYSTEM IN SOUNDING ROCKETS TO PROCESS PCM DATA

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ABSTRACT

We here present a use case where RAMSES (Rocket And Multi-Satellite EMCS Software) will be used to issue telecommands and handle PCM data from the control systems and microgravity experiments onboard the MAXUS-8 sounding rocket. RAMSES is an IP based CCSDS (Consultative Committee for Space Data Systems) and ECSS (European Cooperation for Space Standardization) compliant general control system developed at Swedish Space Corporation for both sounding rockets and satellites.

1. INTRODUCTION

1.1. The MAXUS sounding rocket programme

The MAXUS sounding rocket programme is a joint venture between Astrium and SSC (Swedish Space Corporation). The MAXUS-8 sounding rocket with DLR, Kayser Threde and SAAB Space as sub-contractors is due for launch from Esrange Space Center outside Kiruna in Sweden in late 2009, preliminary in November. This upcoming launch will be the eighth in a series of successful sounding rocket micro-gravity campaigns using the MAXUS platform. The MAXUS programme has proven to be a reliable environment for high-quality microgravity experiments.

The payload on MAXUS-8 will consist of four independent experiments that can be accessed on ground via an umbilical connection up to one hour before launch. A single-stage propellant rocket, Castor IV B, will make sure that MAXUS-8, with a nominal payload mass of up to 785 kg, will be able to reach an apogee of approximately 700 km. The microgravity conditions suited for the onboard experiments will last up to 14 minutes. The flight will be under control of the onboard Guidance Control System by means of thrust vector control. An inter-stage adapter connects the rocket motor to the payload and encloses the re-entry cone. This interstage adapter contains the separation unit, the ignition and thrust termination control and a radar transponder. The parachute system that is used for land recovery ensures a payload landing speed of less than 10 m/s.

1.2. The XRMON-diff experiment

The XRMON module that was developed by SSC under contract from ESA during the MASER-11 campaign uses X-ray radioscopy to perform state-of-the-art in-situ experimental investigations of fundamentals in solidification of metal and other important phenomena in the fields of material processing. The aim of the upcoming microgravity X-ray radioscopy experiment XRMON-diff, that will be performed onboard MAXUS-8, is to study the diffusion between different metal alloys. The samples that are in physical contact will be heated until they melt in the XRMON furnaces. The diffusion process occurring under the microgravity conditions will be investigated through the means of X-ray radiography. The experiment will be controlled and monitored in real-time from ground by the SSC EGSE equipment using RAMSES and mission specific software. The resulting data is also archived onboard for later extraction and analysis after the retrieval of the MAXUS-8 payload.

1.3. RAMSES - Rocket And Multi-Satellite EMCS Software

RAMSES (Rocket And Multi-Satellite EMCS Software) [1] is a general mission control system for sounding rockets and multi-satellites, developed at SSC on the basis of more than 30 years experience. RAMSES is today used at SSC to test and verify software and hardware functionality during development and integration of spacecrafts prior to launch as well as to control and monitor spacecrafts after launch. RAMSES includes support for the CCSDS (Consultative Committee for Space Data Systems) and ECSS (European Cooperation for Space Standardization) standards. Since RAMSES is not limited to these standards it may actually be used in a wide range of space missions and by virtually any space organization.

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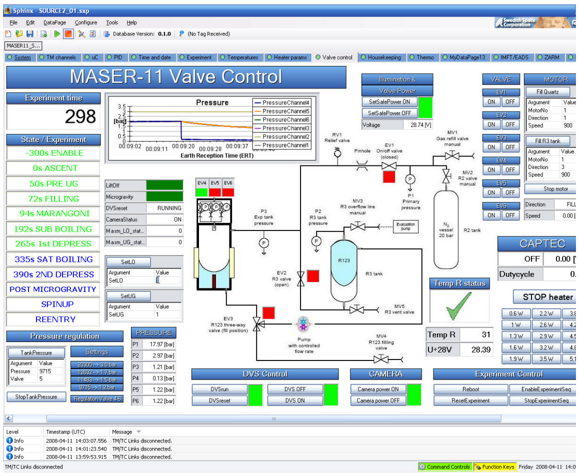

Figure 1. MASER-11 Telemetry Monitoring in RAMSES

The main concept of the RAMSES system is its open and scalable network architecture with a core consisting of several GUI oriented application nodes. The nodes run on a dedicated LAN sharing the network traffic through IP multicasting. It is a flexible and cost-effective system aimed to be used for several types of spacecraft constellations; sounding rockets, single satellite missions and multi satellite missions. The RAMSES system is easy-configurable and provides for a fast and straightforward setup. The RAMSES system core offers complete TM/TC functionality whereupon customized applications can easily be added and integrated to provide project specific functionality.

The functionality supported by the RAMSES core includes:

- **Monitoring**, in which all TM and TC data, regardless of source, can be extracted, calibrated, subjected to a range of monitor checks, further processed through the ECSS standardized SPEL language and displayed (Fig. 1)
- **Commanding**, where control messages (telecommands) are prepared, validated, sent for transmission, verified, logged and, in case of scheduled telecommands, supervised
- **Control Procedure Execution**, that through the ECSS standardized PLUTO language automates the execution of test, verification and flight procedures
- **Performance Evaluation**, to evaluate spacecraft performance, such as real-time graphs and telemetry display
- **Time Correlation**, that maps the spacecraft elapsed time to UTC and vice versa.
- **Data Distribution**, that gives the ability to service external requests for data being distributed on-line or off-line
- **Data Archive**, to create, manage and maintain the mission archive, for access internally by other control system elements or for external access through data distribution
- **Operational Database**, a repository for all data (spacecraft, ground segment) defining the mission specific characteristics of the element subjected MCS processing functions
- **Supervision**, to monitor the status of the system, the traffic on the network and all executing applications in both real-time and by managing mission archive contents

The RAMSES system has been successfully used in the FOTON-M3 mission, the sounding rocket campaign MASER-11 and is presently being used in the multi-satellite PRISMA project.

1.4. CCSDS and ECSS protocol standards

The Consultative Committee for Space Data Systems, CCSDS, was founded 1982 by the worlds major space agencies. The main purpose of the organization is to develop recommendations for space data- and information-system standards, with the goal to enhance governmental and commercial interoperability and cross-support while also reducing risk, development time, and project costs.

The European Cooperation for Space Standardization, ECSS, was started officially in 1993 by the European space industries and agencies as an initiative to develop a coherent, single set of user-friendly standards for use in all European space activities.

The CCSDS standardization area of interest for the ground segment includes Space Link and Coding Services that cover the recommendations for Telemetry and Telecommand Links. The transfer of telemetry and telecommands is in these recommendations packet oriented. The main idea of the packet telemetry concept is to facilitate multiple application processes on-board the spacecraft to produce and receive units of data as best suits each application process. It hence allows for the on-board data system to transmit data units over a space-to-ground communications channel in a manner that makes it possible for the ground system to recover the individual data units and in sequence provide them to instruments or other sub-systems. To accomplish these functions CCSDS defines two data structures: Telemetry Space Packets [2] and Telemetry Transfer Frames [3]. EMCS on ground is through this packet telemetry concept also able to in a similar manner directly address the on-board application processes utilizing the CCSDS defined Telecommand Space Packets [2] and Telecommand Transfer Frames [4].

The Telemetry Space Packet consists of a fixed packet primary header and packet data field that contain an optional secondary header and a payload data field that is under control of the on-board application process (Figure 2). The space packet primary header contains an application process identifier that is used to forward the packet to the correct on-ground instrument or sub-system. This header also contains such information as length, sequence count and other characteristics of the packet.

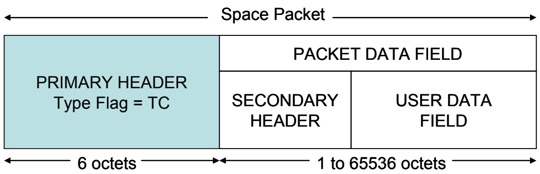

Figure 2. CCSDS Space Packet

The Telecommand Space Packet is virtually identical to the Telemetry Space Packet with an application process identifier, that in this case is used to forward the packet to the correct on-board application process, as well as length, sequence count and other characteristics of the telecommand packet.

ECSS does further specify the format of the payload data field in both the CCSDS Telemetry and Telecommand Space Packets by introducing the concept of Packet Utilization Standard, PUS [5], describing the content and usage of the aforementioned CCSDS Space Packet secondary header, here called data field header (Fig. 3). In this manner ECSS introduces several

Data Field Header

Spare	PUS Version Number	Spare	Service Type	Service Subtype	Packet Sub-counter	Desti-nation ID	Time	Padding
1	3	4	8	8	8	*	*	n

Size (bits) * mission specific size and format

Figure 3. ECSS Data Field Header

services such as: telecommand verification, housekeeping and diagnostic data reporting, parameter statistics reporting, event reporting, time management, on-board scheduling etc.

The purpose of Telemetry and Telecommand Transfer Frames as specified by CCSDS is to reliably transport the Space Packets between the EMCS and the spacecraft by utilizing a range of delivery options, such as multiplexing by using a concept of virtual channels.

The following sections will describe how RAMSES and the XRMON-diff module on-board MAXUS-8 communicates through CCSDS Space Packets that carry telemetry payload data with ECSS PUS Headers transported in IRIG-06 [6] compliant PCM frames.

2. GROUND SEGMENT SETUP FOR XRMON

The SSC EGSE equipment used for the XRMON-diff experiment consists of an SSC TM/TC Rabbit Interface Module, an Ethernet LAN with connected PC equipment running RAMSES core applications and mission specific software. The Rabbit Interface Module connects the ground segment flight and test equipment from Kayser Threde, as well as the umbilical connection, with the RAMSES network. This interface module is a general front end equipment developed by SSC and used in a wide variety of environments: operationally as in the MAXUS-8 campaign as well as during test and verification of the PRISMA satellites.

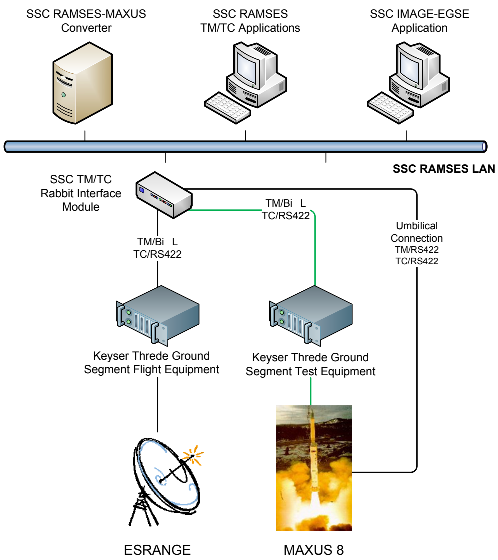

Figure 4. Ground segment setup for the XRMON-diff experiment

The RAMSES core applications that will be used for the XRMON-diff experiment are primarily:

- **Sphinx,** for monitoring telemetry from the experiment and also controlling the experiment through telecommanding
- **Anubis**, for archiving the telemetry data for later analysis.
- **Ankh**, to synchronize the RAMSES applications.

The mission specific software consists of two applications:

- **Maxus-to-RAMSES converter**, which extracts CCSDS compliant packets from the PCM frames, that has been encapsulated into RAMSES multicast packets by the TM/TC Rabbit Interface Module. This will be described in more detail further down.

- **Image reception software**, that receives and processes CCSDS compliant space packets containing radiographic images.

3. FROM MAXUS-8 TO GROUND

3.1. From XRMON to RAMSES

The radiographic data and telemetry data from the XRMON-diff experiment is encapsulated by software into separate CCSDS compliant Telemetry Space Packets and associated ECSS Data Field Header. The CCSDS Telemetry Space Packet headers contain valuable information such as the application id used to associate the data to correct on-board source, and a sequence count. The ECCS Data Field Header (Secondary Header in the CCSDS packet Data Field) contains the time when the data was sampled based on the onboard reference time. The time value is presented in the CCSDS standardized CUC (CCSDS Unsegmented Time Code) format [7]. The encapsulation of payload data into CCSDS Space Packets is performed by the actual XRMON module software and the resulting packets are forwarded to the

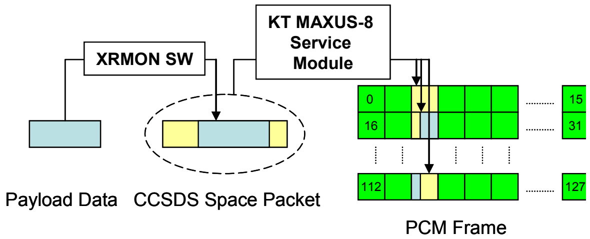

Figure 5. Encapsulation onboard of payload data

MAXUS-8 Service Module developed by Kayser Threde. The Space Packets are during flight fragmented and sent down to ground over a radio link in super-commutated time slots in each minor PCM frame (Fig. 5). Super-commutated time slots are allocated separately for the radiographic data and for the remaining XRMON-diff telemetry respectively.

Table 1. PCM data details for payload telemetry

	Payload PCM Data Details
Bit rate	512 kbit/s
Coding	BiΦL
Words/frame	128
Frames/format	48
Bits/word	16
Sync	2 words + 1 ID word

The PCM data is received by the ground segment flight equipment developed by Kayser Threde. During test and verification, the same data is transferred directly from the XRMON-diff module to ground test equipment (also developed by Kayser Threde) over a RS422 connection. The complete telemetry PCM frames are forwarded to SSC EGSE equipment. Table 1 summarizes the details of the PCM data link between the MAXUS-8 Service Module and the ground system equipment.

The Kayser Threde Ground Segment Flight Equipment receives the PCM frames and forwards them to the SSC TM/TC Rabbit Interface Module. The SSC TM/TC Rabbit Interface Module encapsulates the complete PCM frames in RAMSES PCM Packets with RAMSES specific headers and transmits them as IP packets (Fig. 6) onto the RAMSES network on a dedicated multicast address and port. The afore-mentioned Maxus-to-

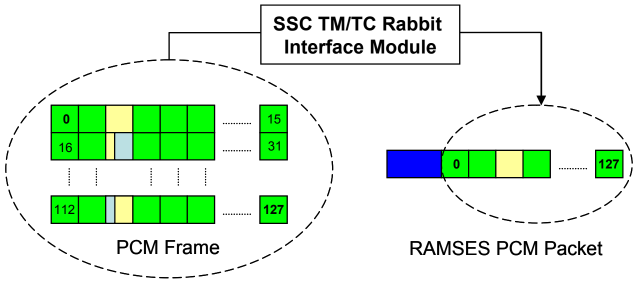

Figure 6. Encapsulation of PCM Frames into RAMSES PCM Packets

RAMSES converter receives these PCM frames in the multicast packets, and subsequently extracts and defragments the CCSDS Telemetry Space packets. The result it sent back out on the RAMSES network, now on another multicast address and port, with additional data in the RAMSES specific headers (Fig. 7). These packets can now be received and processed by the RAMSES core applications, e.g. Sphinx for monitoring of telemetry and Anubis for archiving, as well as by software developed specifically for this mission, the radiography image reception application.

Prior to launch, at the actual launch site, the SSC EGSE equipment interfaces the XRMON-diff module directly

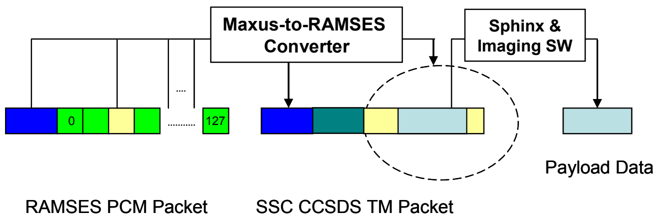

Figure 7. Extraction of CCSDS Space Packets and Payload Data

through an umbilical RS422 connection. The telecommands issued from the RAMSES Sphinx application are carried in CCSDS Space Packets within the RAMSES network to finally be converted by the TM/TC Rabbit Interface Module into a format recognized by the Kayser Threde TC Encoder that resides in the KT Ground Segment Flight and Test equipment. This data is transmitted by the TM/TC Rabbit Interface module over a serial link (Fig. 4).

3.2. The MAXUS-8 Motor and RAMSES

The description above is valid for the XRMON-diff data that is forwarded over a radio link dedicated for the payload telemetry, while the motor telemetry uses a separate radio link. SSC is responsible for the MAXUS-8 rocket systems and missions operations. RAMSES is used here as well, but the forwarded motor telemetry is in this case not encapsulated in CCSDS Space Packets on-board MAXUS-8. Instead the motor telemetry data, received by the Rabbit front end equipment in complete PCM frames, is encapsulated in IP multicast packets in a manner similar to the above-mentioned for XRMON-diff case. A MAXUS mission specific software application, PCMpand, then extracts the telemetry data from the encapsulated PCM frames and converts it into CCSDS Telemetry Space packets with RAMSES headers. Sphinx, Anubis and other RAMSES core applications are at this stage able to monitor and process the telemetry. Prior to launch an additional RAMSES Core application will be used for the motor telemetry, **Cheops**. This RAMSES application will execute control procedures written in the ECSS standardized PLUTO language [8] analyzing and verifying the functionality of the MAXUS-8 motor telemetry system.

4. SUMMARY

The use case described in this paper may be seen as an example how an ECSS and CCSDS protocol compliant ground control system, such as RAMSES, can be used to handle and process data transferred over a PCM link from sounding rockets. The data may be encapsulated in CCSDS Telemetry Space Packets with ECSS compliant content and transported over the downlink in PCM frames. This is however not a necessary requirement in order for the RAMSES system to be able to handle the data. The RAMSES system for example today handle motor telemetry by using dedicated front end equipment to encapsulate the PCM frames into IP multicast packets with RAMSES headers. A dedicated application subsequently captures the IP multicast packets, extracts the data directly from the PCM time slots and encapsulates the data on-ground into CCSDS compliant Telemetry Space Packets.

The RAMSES framework hence gives the user the choice to determine the level of PCM Frame data encapsulation; either ensuring compliance with CCSDS protocols or in addition conforming to the ECSS recommendations. The latter choice gives the user, through the additionally available ECSS PUS (Packet Utilization Standard) services, a wider range of possibilities for post-processing data within the RAMSES framework of core applications. RAMSES' open network architecture does also, together with its software libraries, empower the user to write its own mission specific applications. RAMSES gives the user the ability to handle fully CCSDS and ECSS compliant data in parallel with data carried over a PCM link if the need should arise. RAMSES as ground control system for sounding rockets may also be viewed as a strategic choice for an organization in its migration toward ECSS and CCSDS protocol compliance while at the same time retaining backward compatibility with its PCM legacy systems. For the Swedish Space Corporation this has been a cost-effective solution, since the RAMSES with small effort can be re-used between different satellite missions and rocket campaigns. The effort lies in updating the mission database and in some cases the development of mission specific applications with the support from existing RAMSES software libraries. In the MAXUS-8 case, for XRMON-diff experiment and and the motor telemetry system, the estimated cost is around 150 man-hours, a minor cost in the MAXUS-8 campaign.

5. REFERENCES

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