REENGINEERING A TRADITONAL SPACECRAFT CONTROL CENTER

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ABSTRACT

Deutsche Telekom is operating various communication satellites since 1989. The SCC (spacecraft control center) is located near Frankfurt / Germany. The entire system is based on antenna/RF equipment, baseband and computer software packages running on a computer network of different machines.

Due to increased maintenance effort the old baseband system needed to be replaced. This also had effects to the computer system, especially to the M&C. The aim was to design the entire system in a way that the operation effort in costs aspects and human intervention are minimized.

This paper shows the successful real world project of reengineering a traditional spacecraft control center (SCC). It is shown how a fifteen year old hardware (baseband system) and software design was replaced by a modern concept during normal operations.

The new software packages execute all necessary tasks for spacecraft- and ground station control. The Monitor and Control System (M&C) is a database driven design (FRAMTEC, from CAM Germany).

KEY WORDS

Satellite Control Center, Reengineering, Baseband and Real - Time Data Processing

INTRODUCTION

The original SCC was designed in 1985 to provide the following features:

(1) Simultaneous and continuous operation for up to four satellites
(2) Ku-Band telemetry, telecommand and Ranging for these satellites
(3) Network interconnection to SCC and ground station at Weilheim (S-, Ku-Band)
(4) Computer-based system for remote monitoring and control of the whole SCC equipment
(5) Attitude and orbit determination and prediction (integrated Flight Dynamic System)
(6) High reliability and availability of the SCC equipment (system availability design 99.95%)
(7) Ease of operations, automatic control of routine functions for both SCC and satellite control.

Some equipment manufacturers does no longer exist and the maintenance costs increased dramatically, related hardware and software components had to be replaced by a modern system.

THE OLD GROUND CONTROL SYSTEM

The Satellite Control Center of Deutsche Telekom is composed of

(1) main and emergency control room
(2) the main computers including the Twisted Pair Ethernet Local Area Network (LAN)
(3) the Analysis and Offline System
(4) the Flight Dynamic System (FDS)
(5) the baseband equipment installed in the central building
(6) the antenna buildings for DFS and TV-Sat with RF-equipment and the antennas.
(7) the remote ground stations at DLR sites

The system configuration of the Satellite Control Center is shown in figure 1:

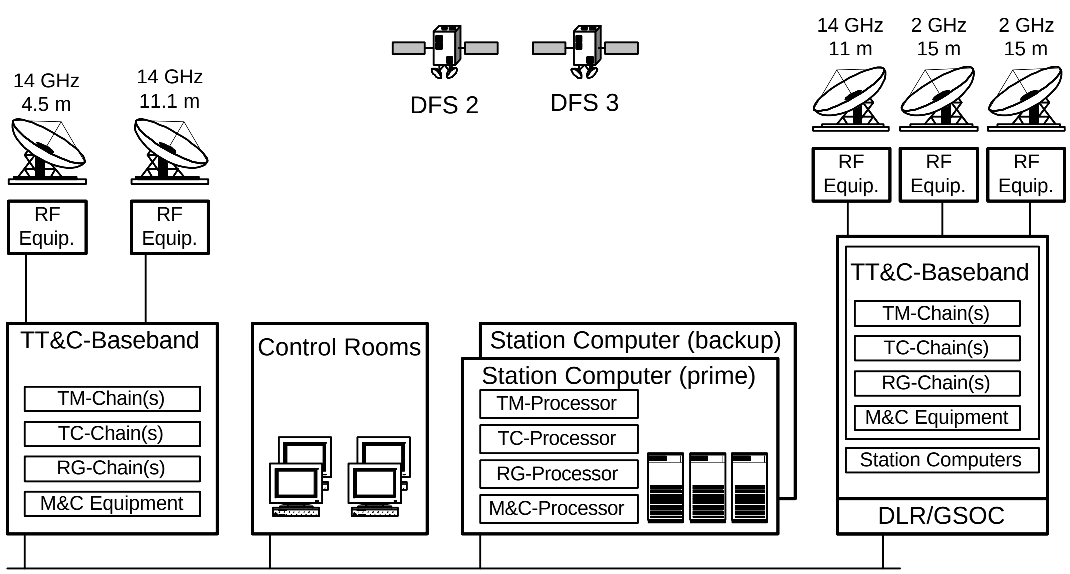

Figure 1: System overview

COMPUTER SYSTEMS HARDWARE DESIGN AND NETWORKING

The computer system is based on a midsize cluster system and workstations running OpenVMS on Compaq hardware. The FDS uses hardware from Hewlett Packard. The workstations are used for processing and display primary real-time data. Figure 2 shows the diagram of the computer systems.

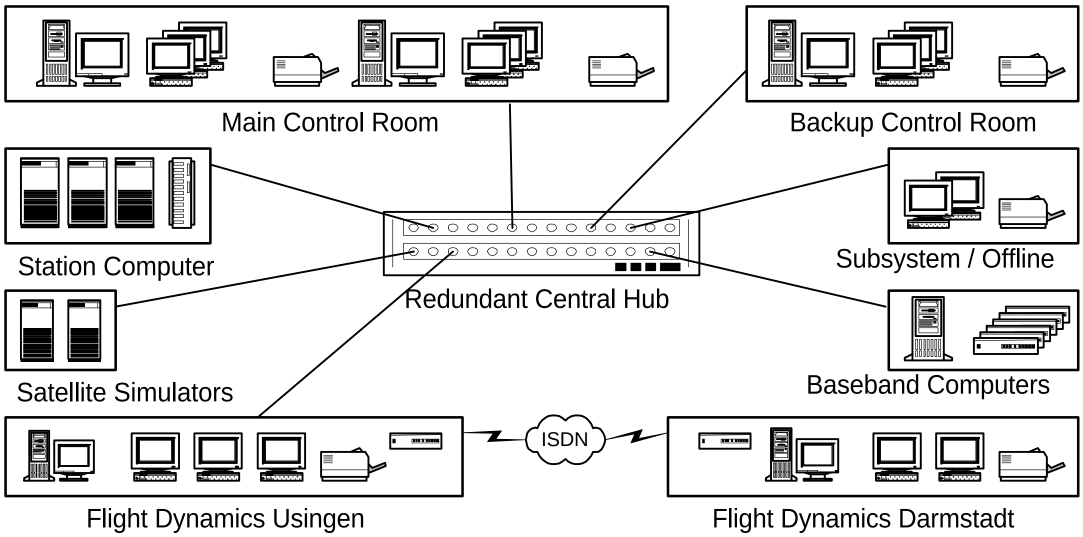

Figure 2. Diagram of computer systems

Data communications links are installed between Telekom SCC, DLR GSOC (German Space Operation Center) and the DLR Weilheim ground station. Data communications are performed by ISDN (Integrated Services Digital Network) and leased lines.

BASEBAND EQUIPMENT, RF EQUIPMENT AND ANTENNAS

The old baseband equipment is located in the main station building. The equipment is organized in chains for the functions of receiving telemetry, sending telecommands and performance of ranging:

(1) Telemetry (TM) Equipment consists of six chains. Each TM-chain is composed of a 70 MHz Receiver, a PSK-Demodulator, a Bit-Synchronizer, a PCM-Preprocessor and a front-end processor.
(2) Telecommand (TC) Equipment consists of six chains. Each TC-chain is composed of a front-end Processor, a TC-Controller, a PSK-Modulator and a 70 MHz Phase Modulator.
(3) Ranging (RNG) Equipment consists of two ranging systems. The ranging systems are interfaced to the LAN via front-end Processors.
(4) The Time-and Frequency System is based on a rubidium frequency standard .
(5) The front-end Processors (FEP) have several functions: converting, time-tagging and sending the real-time data from the baseband via the LAN to the main computers and to monitor and control the devices in the associated chains. The front-end processors are PDP-11 computers (running RSX 11 M) from DEC.

(6) The two Monitor and Control Processors (MCP) have two functions. First to connect the equipment inside the antenna building (e.g. ACUs, amplifiers). Second, the MCP collects all monitoring data from the baseband and sent only new information to the station computer.
(7) The RF equipment is installed in a antenna building. The four high frequency groups include up-/down-converters, high power amplifiers, low noise amplifiers and ranging converters.
(8) Two TT&C antennas are used. The antenna sizes are 4.5m and 11m.

PROBLEMS (CHALLENGES)

During the last five years of operating problems increased with spare parts supply. These complications led to the decision to exchange the old hardware, except RF equipment and antennas.

In a first step in 1996 the entire VAX/VMS computer hardware was replaced by Compaq Alpha/AXP computers running OpenVMS. In the second step the old baseband equipment was replaced by a modern COTS solution. Different suppliers from around the world were asked to provide new system components, e.g. a new baseband system including the overall M&C system.

The cost drivers for the new system were identified:

(1) Not widely known European (ESA) TM, TC and RNG standards from the early eighties
(2) Interfacing with existing real-time system (e.g. RF equipment) and control center software which should not be impacted (e.g. TM and TC processing software)
(3) New HMI development

THE NEW SYSTEM

CAM (Gilching, Germany) was selected as main contractor. The new baseband hardware is based on a COTS solution under Microsoft Windows NT © and also the new M&C system is widely based on a COTS/MOTS solution. The new system, i.e. the exchanged components, are composed of:

(1) three new baseband units
(2) a new switch matrix
(3) a new time and frequency system
(4) two new interface computers to the existing RF equipment
(5) new interface software to the existing real-time system (TM / TC / RNG)
(6) new M&C system with an integrated modern Human Machine Interface (HMI)

The baseband units are COTS products running Windows NT delivered by the main contractor. Two new PCs were added to control the RF equipment and antennas which all remains unchanged. A new switch matrix has been integrated - controlled by the new PCs. As a new time and frequency system (TFS) a redundant GPS receiver was selected. The time synchronization of all computers was simplified by a GPS based Network time server.

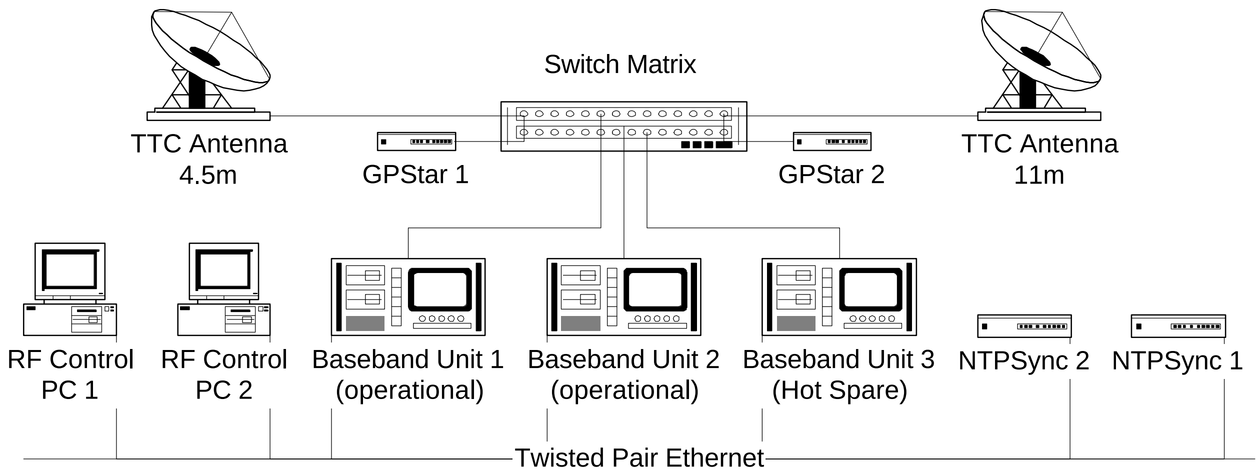

Figure 3: The new baseband system

MAINTENANCE ASPECTS

The new hardware has no user serviceable parts. Maintenance and repair activities are reduced to identify and replace faulty boards and send them to the manufacturer for repairing.

The new highly integrated equipment reduces the number of boxes and the amount of rack space from seventy single boxes in eight racks to ten boxes in three racks. (single units: TM: 30, TC: 18; RNG: 14; TFS: 4; Control Processors: 4; switch-matrixes: 2).

SOFTWARE DESIGN

The entire operation of the SCC is based on the software installed on various computers. The software is divided into parts on the main cluster computers (routing, archiving, logging, etc.), parts on the workstations (TM / TC) and parts on various PCs (HMI, for visualization purposes).

The Cluster Software is the heart of the system. All incoming data are time-tagged, stored and routed to the other systems. The main operational software provides functionality for TC, RNG, M&C and data archiving. The workstation software in conjunction with the HMI provides the graphical user interface. There exist no fixed configuration. If needed, any software (except the HMI, running only on the PCs) can run on each workstation. In addition a dedicated workstation is designed as an emergency system. The aim was to leave the real-time processing software unchanged, i.e. only modify the interfaces to the new baseband system and to replace the complete M&C system.

THE NEW MONITOR AND CONTROL SYSTEM

The M&C system was replaced completely. The new baseband system, the new TFS, the existing untouched RF equipment and the monitoring of the entire computer system has been integrated.

Monitoring and Control is performed at the SCC from the control rooms by two operators. The operators can monitor and control the complete data flow through the system from antenna to the SCC. The M&C of the ground station is divided into subsystems and devices as follows:

(1) Antennas, antenna control units, High frequency groups (at Usingen and Weilheim)
(2) Switching matrixes
(3) Baseband equipment: Telemetry chains, Telecommand chains, Ranging chains
(4) Time and frequency system
(5) Computer systems

The M&C information is reduced to four different levels:

(1) Level 4: system level referring to the overall ground configuration and status
(2) Level 3: satellite level referring to configuration and
(3) Level 2: chain level referring to subsystem status and function
(4) Level 1: low device level referring to basic parameters and to bits and bytes

These classifications are mapped to the ground station monitoring and control functions. The entire ground system can be operated using a few mouse-clicks on the graphical Windows NT screens.

ACTUAL PROJECT REQUIREMENTS FOR THE M&C SYSTEM

The following project requirements have to be fulfilled by the M&C system:

(1) Reduce time and costs for implementation; this is an implicit requirement resulting from the number of deliverable items and the time remaining for the development itself. Also reducing the costs is an implicit requirement, since space mission budgets are constantly decreasing.
(2) Increase the functionality; since the cost for resources (memory and CPU power) did decrease nearly daily it should not be a problem to integrate also resource intensive functionality into the systems such as parameter history, trend limits, direct replay of telemetry etc..
(3) Make use of proven software, i.e. to avoid as far as possible the development of new project specific software components.
(4) Modern Human-Machine-Interfacing including line- and symbol plots for representation the current state of the monitored / controlled domain also in a graphical manner.
(5) Quick and easy configuration by the users themselves; this point reflects not only the implementation of derived parameters and the (re-)definition of complex structured data packets but also modification of the display views.
(6) TM, TC and M&C shall be used in identical manner. This is a logical consequence, since processing of monitor data is nearly the same as processing telemetry data and the generation / transmission of control information to the ground station is also nearly the same as commanding a space craft with the exception that “keep alive messaging” is in general not necessary for M&C systems.

FRAMTEC

The monitor and control software is based on a COTS product named FRAMTEC (Framework for Advanced Monitoring, Telemetry and Control). This software is also used by different agencies such as DLR Oberpaffenhofen, Germany and EUMETSAT Darmstadt, Germany.

FRAMTEC was selected due to the high flexibility of the decommutation and the parameter processing rules. Another reason was that all interfaces to other components within the Telekom SCC environment have been available.

FRAMTEC is a kernel system for processing telemetry and monitoring data and for generation of control information, e.g. for the configuration of the baseband units. This tool was developed between CAM and DLR (Deutsche Forschungsanstalt für Luft- und Raumfahrt) which is a Joint Venture partner with Deutsche Telekom.. The development based on the experience gained in a wide range of commercial, scientific and manned space missions.

The basic idea of FRAMTEC is that the user can configure applications easily and fully almost without software modifications. The processing rules of the parameters and the layout of the data packets are described within the process database. Even the recognition of incoming data packets can be handled within the process database.

The standard processing of parameters can be defined in a straight forward manner: A wide range of standard process functions for bit/byte extraction, transformation into the engineering unit, limit checking, adaptive processing, event generation, etc. are available.

The handling of special processing, e.g. processing of derived parameters, is simple using the integrated interpreter functionality: a C/C++ like source code is written directly into the process database. This code is semi compiled during the database load operation and executed in real-time by the integrated virtual machine. Additionally user hooks are available to link user-written functions directly to the application – if necessary.

For the definition and handling the data packets complete functionality is available, such as for processing fixed positions or processing multiplexed positions with reference to multiplexer tables. The definition of sub-frames is supported to avoid multiple definition of the same parts of data packets or to interpret the contents of an incoming data packet or part of it dynamically according to the values and states of other parameters.

Control packets to be transmitted as configuration information are specified within the process database in a similar manner. Functionality for administrations of control packets (modifying, sending, loading form disk, saving to disk) is supported. The transmission of control packets is performed on operator request or also after detection of specific events.

This flexibility allows the definition of vehicle and equipment independent decommutation and parameter processing rules in a quick and comfortable manner. The representation of parameter values as well as the modification and transmission of control information is performed using a modern, Windows-based, human-machine-interface (HMI).

COMPONENTS OF FRAMTEC

As can be seen by the name “framework”, FRAMTEC consists not only of a single program performing the related operations but it consists of multiple components / products working together to satisfy all the relevant requirements in a modern, comfortable and safe manner. The figure below shows the relationships between these components. Figure 4 shows the FRAMTEC components:

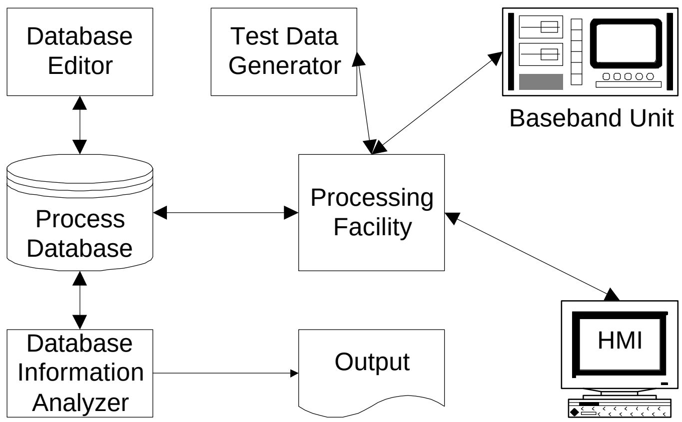

Figure 4: Components of FRAMTEC

The process database contains all information about the processing information as well as the information about control packets structures. The process database is maintained by the FRAMTEC Data Base Editor (FDBE) and loaded into the processing facility during the startup phase. This tool (FDBE) is based on the commercial product MS ACCESS © .

Before loading a new or modified process database into an operational system, it is essential to perform various checks and analyzes to detect any faults.

The processing facility is the on-line kernel of FRAMTEC – received monitor data packets are identified and related to the description within the process database processed, i.e. the parameter information - originally a sequence of bits - is gained, converted into engineering units (volts, temperatures, etc.) and made visible to the operator using the integrated HMI. Inputs given by the operator are processed and the appropriate action is performed; this includes also the modification / construction of control information and sending them to the equipment to be controlled.
In many projects appropriate M&C systems have to be configured without direct connection to the related hardware facilities because they are not yet available or otherwise in use, i.e. there are only limited possibilities to perform any tests with the original equipment. For this reason a test-data can be replayed or generated to perform tests previous to connect to the operational equipment. The usage of this tool reduces the time necessary for integration and test with the original equipment.

The modern Windows-based HMI (in multiple instances) is used to provide display information (in alphanumerical and also in graphical manner) to the operating personnel and to receive inputs to configure the system. Due to access to the archive, it is possible to show data of the latest history, e.g. in form of line-plots, even if the HMI was currently started. The definition of the display masks is not part of the application. The views can be configured without modifying the software by the user itself. Since the HMI is connected to the processing facility using the TCP/IP protocol, M&C can be performed not only on-site, but also from any other place, e.g. from the home office.

MONITORING AND CONTROL PHILOSOPHY

The ground segment display formats represent the ground station in a hierarchical structure.

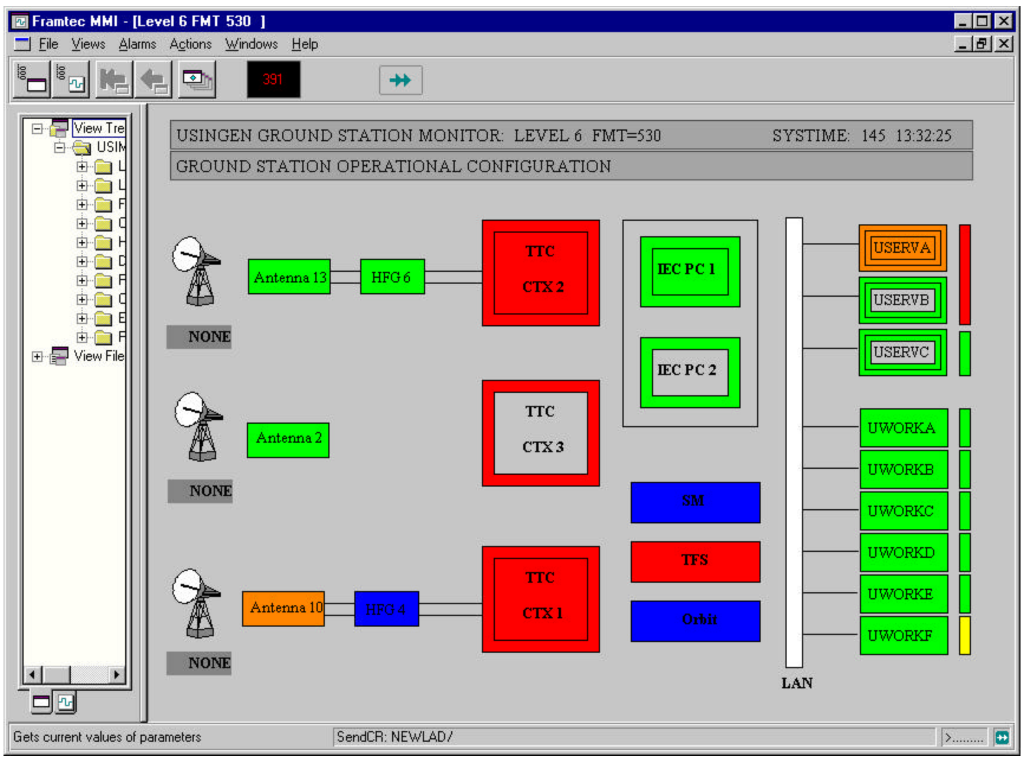

Figure 4. Typical display “system overview” (in emergency state)

The status of any system, subsystem or device is represented by color coded graphical symbols:

(1) Green: fully operational
(2) Yellow: soft-limits reached, but still operational
(3) Red: hard-limits reached , not operational
(4) Orange: device is switched to local or a task of a computer is crashed
(5) Blue: communication alert

This representation allows the operator or subsystem engineer to select the desired information from top to bottom or vice versa. The higher level monitoring display formats contain all relevant information, the lower level display formats show the details. The monitoring display formats are driven by the referenced monitoring parameters and derived parameters according to the display format descriptions. The following figures show typical ground station system monitoring screens.

REENGINEERING ASPECTS

Due to the fact, that the complete integration and testing has to be performed during normal operation of the existing satellites – without disturbing these operations (as far as possible) – the project has been structured in various phases:

(1) Integration of TM and TC processing using the existing S/C specific software components as far as possible – only the interfaces to the baseband equipment have been changed
(2) Integration of the new PCs controlling the unchanged RF equipment (e.g. ACUs)
(3) Integration of the new time and frequency system
(4) Integration of the new overall M&C system

One main restriction was, that it must be always possible to switch back to the old system in case of any anomalies to continue the operation of the spacecrafts in a save manner. This was achieved by:

(1) Joint testing the single components – ever under the premises to reduce the impacts for the normal S/C operations, i.e. test could only be performed during restricted time intervals, after an exactly planning of these test and successfully performed "pretests".
(2) The switching of telemetry and telecommand processing was achieved by patching a few cables in the main building
(3) The integration of the both PCs controlling the RF equipment was more complicated: The existing RF equipment is controlled via an IEC bus and only one controller can act as master at a time. For this reason specific switches had been integrated into the system, to switch the four IEC busses from the old to the new system and vice versa.

Using this mechanism it was always possible to switch between the new and the old environment and to operate the S/C in safe manner.

As already mentioned, the handover of the parts of the new system has been performed in single phases and each one after intensive testing the new components. A great advantage was that all the tests concerning any operational behavior have been performed together by both parties.

Due to the high flexibility of FRAMTEC and the easy manner to modify the behavior of the processing and generation of control information this projects could be completed successfully.

CONCLUSION

The reengineering process showed full success. During the project it was shown that FRAMTEC was able to fulfill the requirements. The hardware was delivered in late September 2000. The acceptance test was successful performed in March 2001. The use of a COTS product reduced substantially the project development time.

FRAMTEC offers a wide flexibility not only for space related missions but also for nearly every application which needs high performance parameter processing without writing new code for any new application.