INTEGRATED SATELLITE CONTROL CENTER

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ABSTRACT

Deutsche Telekom has been operating different flight models for several years. A Satellite Control Center (SCC) was designed and installed to support the operation of the satellite systems DFS Kopernikus and TV-Sat. The DFS Kopernikus system is composed of three flight models and the satellite system TV-Sat has one flight model.

The aim was to design an SCC and ground stations in a way, enabling the operation of satellites and groundstations by only two operators at the main control room. The operators are well trained but not scientifically educated. The high integrated SCC supports the operators with a state of the art man-machine-interface. Software executes all necessary tasks for spacecraft- and ground station control. Interaction in front of communication equipment is not necessary. The operation of satellites is a business with a high risk potential. This paper presents the design of a Satellite Control Center with high system availability.

KEYWORDS

Integrated Control Center, Satellite Operations, Remote Monitoring and Control, Flight Dynamic System

INTRODUCTION

The Satellite Control Center (SCC) of DBP Telekom is located near Usingen, about 50 km northwest of Frankfurt/Main. The system has been under operation since the launch of the first flight model DFS in June 1989. The Ku-Band acquisition of TV-Sat was performed in August 1989, the acquisition of DFS 2 in July 1990. In 1992 the system was expanded for the operation of DFS 3, which was launched in September 1992. The Launch and Early Orbit Phase (LEOP) was supported by Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR).

Besides the SCC the earth station also has communication facilities for Eutelsat satellites as well as for the Intelsat satellites over the Atlantic and Indian oceans. The SCC is composed of the spacecraft control facilities and the necessary ground stations at different locations. The SCC provides the following features:

- simultaneous and continuos operation for four satellites, with expansion capability for two further spacecraft
- Ku-Band telemetry at 11 GHz, Ku-Band telecommand for DFS at 14 GHz and for TV-Sat at 17 GHz
- ranging for one satellite at a time without interruption of telemetry reception
- network interconnection to Satellite Control Center and ground stations at Weilheim (S-, Ku-Band)
- computer-based system for remote monitoring and control of the whole SCC equipment
- attitude and orbit determination and prediction (integrated Flight Dynamic System)
- high reliability and availability of the SCC equipment (system availability design 99.95%)
- ease of operations, automatic control of routine functions for both SCC and satellite control.

The Satellite Control Center of DBP Telekom is composed of

- two control rooms
- the main computers
- the Analysis and Offline System
- the Flight Dynamic System
- the baseband equipment installed in the central building
- the antenna buildings for DFS and TV-Sat with RF-equipment and the antennas.
- the remote ground stations at DLR sites

The system configuration of the Satellite Control Center is shown in Figure 1.
As the system is distributed over several rooms a physically redundant Ethernet based Local Area Network (LAN) with standard communication protocols is used for interconnection of the equipment.

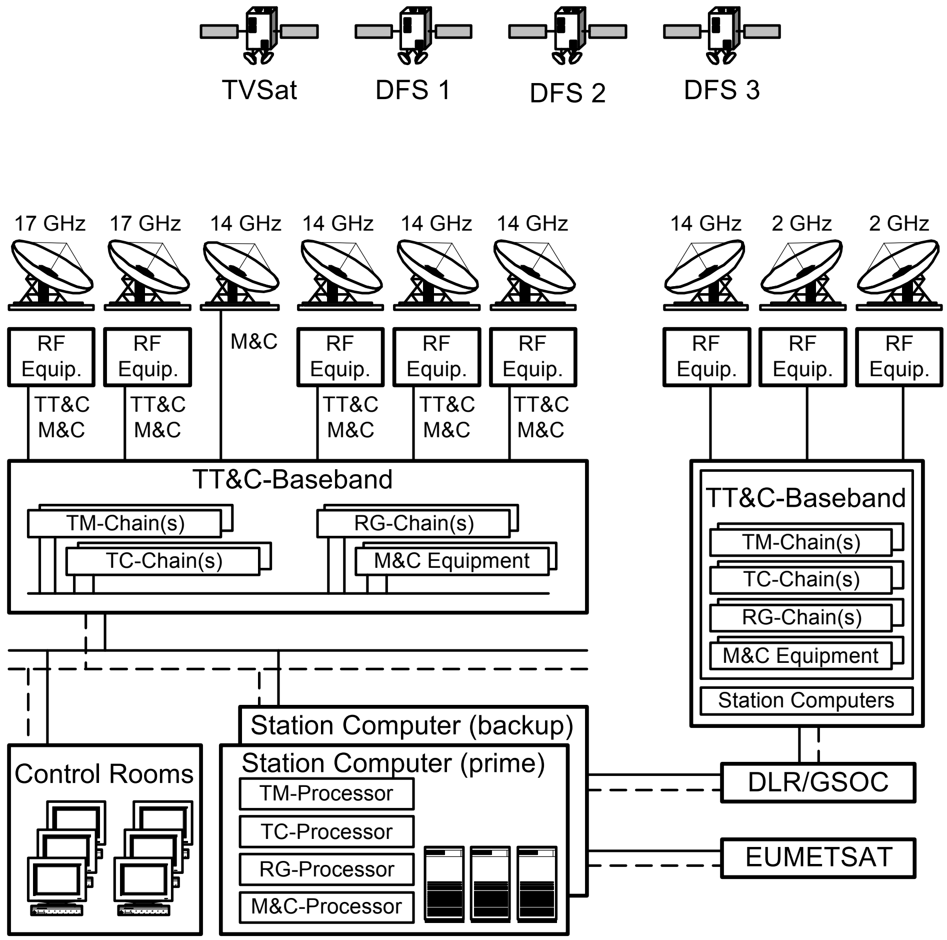

Figure 1. Configuration of the SCC

CONTROL ROOMS

The SCC has two control rooms. The larger (main) control room is used for the daily operations. The second (backup) control room is used for training, for offline analysis, for backup, software maintenance and integration purposes. The second control room is able to take over the workload of the main control room, if necessary.

The operator's system interface are the consoles. The main control room has two consoles. The backup control room one, separated from the main control room by foldable panels. Each console is equipped with 12 X11-Graphic Window terminals, which are grouped according to logical functions for comfortable operation.

The control rooms are designed in a way that two persons (normal shift) are able to see all information on the displays at any position inside the room. Alarms are indicated by colors and audible alarms. Graphical hardcopy devices (Postscript printers, color, black/white) are available for all displays. The communication equipment to the outer world e.g. fax, voice links and telephones are all located in the control rooms.

COMPUTER SYSTEMS HARDWARE DESIGN AND NETWORKING

The computer system is mainly based on Digital Equipment Corporation (DEC) hardware. The operating system is VMS. The system is equipped with a midsize Cluster system and workstation computers. The Flight Dynamic System uses workstations from Hewlett Packard (HP). The entire system runs 24 hours a day, 7 days a week. The following Figure 2 shows the diagram of the computer systems.

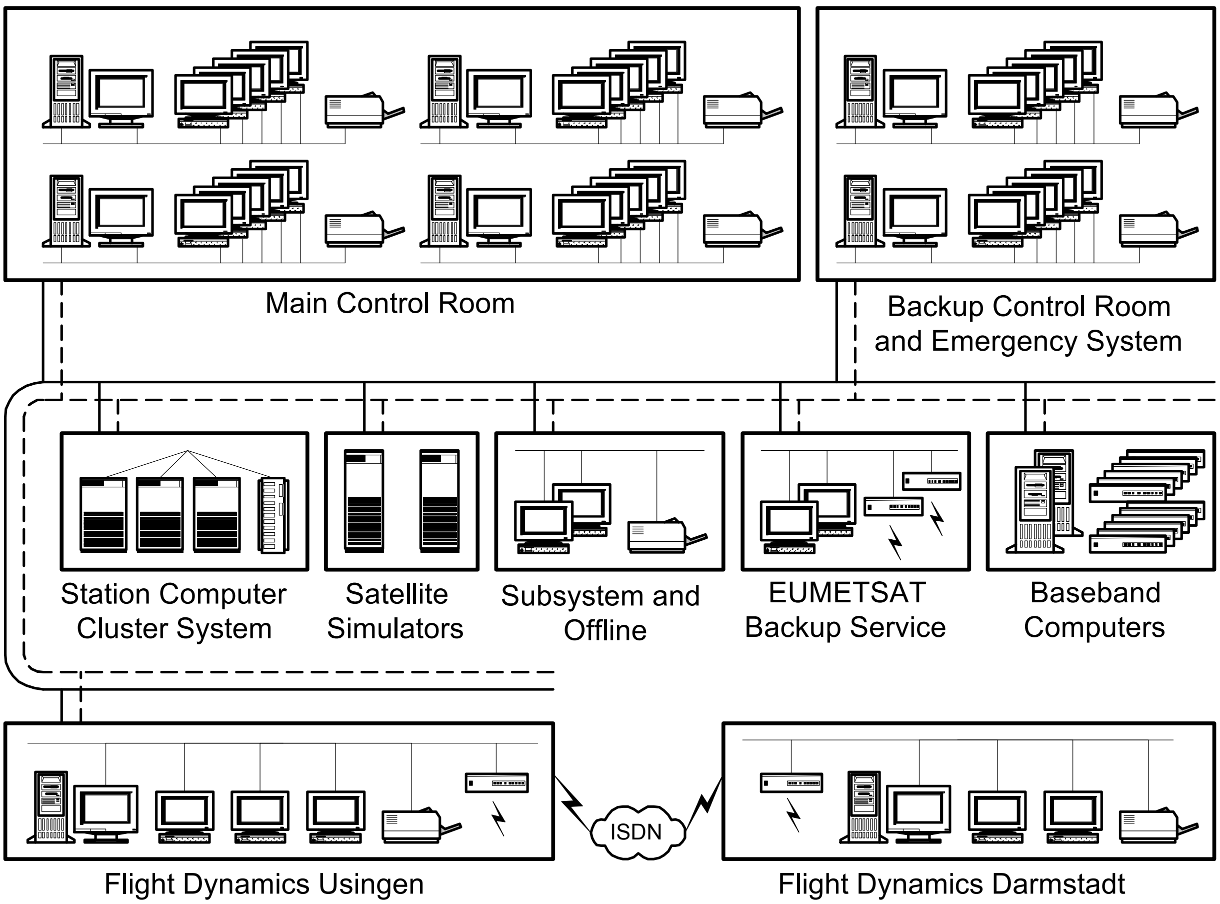

Figure 2. Diagram of computer systems

The main station computers (STC) are three VAX 8350 computers in a Cluster configuration with one starcoupler (CI-Cluster). The access to the discfarm is controlled by two redundant HSC storage controllers for common use of storage devices. Two VAX units in master/backup configuration process data in real time, the third unit is in standby as cold redundancy. For interconnection to other systems the LAN is used.

The workstations are used for processing and display primary realtime data. The processed output of the workstations is displayed by the X11-Window terminals.

Data communications links are installed between Telekom SCC, DLR GSOC (German Space Operation Center), DLR Weilheim (ground station) and EUMETSAT Control Center (Darmstadt). Data communications are performed by ISDN (Integrated Services Digital Network), X.25 service (for international links) and leased lines.

A redundant Local Area Network (LAN) with two physical Ethernet channels takes over the communications between all computers at the SCC. The redundancy switching of the LAN is performed by the STC and is transparent to the users. Two network protocols are used, DECNet (between DEC Computers) and TCP/IP between computers of different vendors. For external data communication Wide Area Network (WAN) routers are used. These routers perform also security checks for communications outside of Telekom SCC.

SOFTWARE DESIGN

The entire operation of the SCC is based on the software packages installed in the various computers. The software is divided into parts which run on the main cluster computers and parts which run on the workstations. The cluster system has software which is necessary to operate the groundstation and data that must be shared with others. The software running on the workstation is mainly software used to display parameters. The system is capable of commanding three satellites or commanding two satellites and ranging with a third one simultaneously.

The Cluster Software is the heart of the groundstation. All incoming data will be timetagged, stored and routed to the other systems. Special tasks which need to run only once in the system, are installed in the cluster system e.g. the telecommand system. The main operational software packages installed in the STC provide for telecommand, ranging, monitoring & control of the entire SCC and data archiving.

The Hot Backup System (HBK) software is based on the cluster configuration of the STC. It increases the reliability of the main computers. One machine is the active prime computer, a second is a hot standby processing all the same data in parallel with the prime. In the case a hardware or software error occurs (e.g. task crashed), the backup computer will take over within 30 seconds. The entire STC software runs on the backup system. In the transition phase switching from the crashed prime to the backup no data (e.g. telecommands) will be lost. The backup will proceed at the last complete step of the prime computer. The third cluster machine will become the new backup. Once running, the system works fully automatically.

The workstation software provides the graphical user interface to the system. There no fixed configuration exists. If needed, every software can be run on each workstation. The software installed in the workstations provides telemetry processing, offline analysis, flight dynamic, operation scheduler and the graphical display for entire SCC. The X11- Windows terminals display the processed data of the workstations.

A dedicated workstation is designed as an emergency system, used only if the main computers are not available. The software on this workstation is nearly the same as the software on the cluster system.

The Archiving and Offline Analysis System runs on workstations. The system stores and retrieves the telemetry, telecommand and monitoring data on disk and on tape. The offline software allows to simplify and unify analyzing and interpretation of stored data by print/plot software. All kinds of data can be graphically analyzed including data from any baseband device. The realtime data is present for 7 days on the discs at the STC, then the data is copied to tapes which will be saved for the lifetime of the satellites.

MONITOR AND CONTROL SYSTEM

Monitoring and Control (M&C) is performed at the SCC from the control rooms by two operators. In the framework of the communications components, operators can monitor and control the dataflow through the system from antenna to the SCC. The M&C of the ground station is divided into subsystems and devices as follows:

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

The M&C information is classified into six different levels:

- Level 1: ICD level referring to bits and bytes
- Level 2: low device level referring to basic parameters
- Level 3: high device level referring to device modes
- Level 4: chain level referring to chain status and function

- Level 5: satellite level referring to configuration and setup of up-and downlink of a S/C
- Level 6: system level referring to the overall ground operating system (GOS) configuration

These classifications are mapped to the ground station monitoring and control functions. The entire system, SCC and spacecraft, can be operated via character based terminals (e.g. VT340) or via a few mouse-clicks and graphical window terminals.

MONITORING

The ground segment display formats represent the ground station in a hierarchical structure (level 1 to 3 are alphanumeric, level 4 to 6 are graphic display formats). The operational condition of any system, subsystem or device is represented by color coded graphical symbols:

- Green: fully operational
- Yellow: soft-limits reached, but still operational
- Red: hard-limits reached , not operational
- Orange: device is switched to local or a task of a computer is crashed
- Light 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. For the basic Usingen ground station configuration there exist about 250 display formats. The monitoring display formats are driven by the referenced monitoring parameters and derived parameters according to the display format descriptions.

The monitoring of SCC computers and communication links are performed by monitoring-tasks on each node. These tasks send cyclical monitor information (e.g. stati of tasks, devices) to the monitor processor. It can be recognized whether a communication time-out arises from a node or from a link malfunction.

Figure 3 shows a typical groundstation monitoring system screen

CONTROL

The commanding of a spacecraft needs a concept which supports the accurate execution of time critical command sequences, whereby the controlling of a ground segment needs a powerful configuration instrument. The groundstation control concept differs from the telecommand concept.

The groundstation control processor is based sets of user definable databases. These databases contain the predefined configuration setup for all groundstation devices.

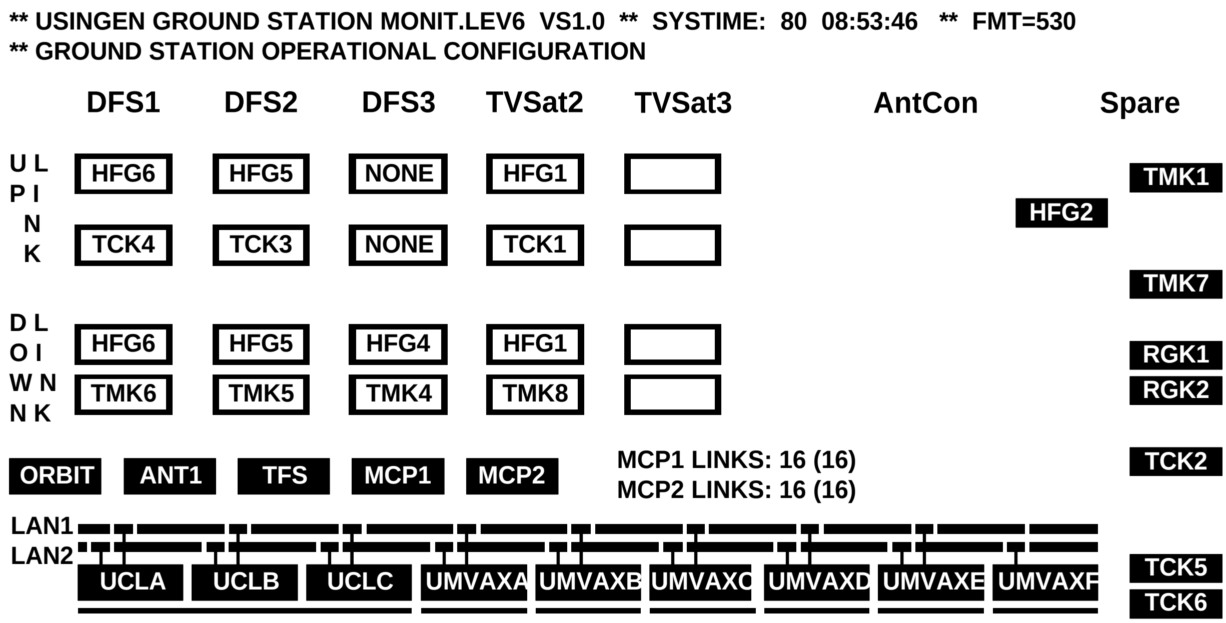

Figure 3. Typical display system screen layout

This data is the basis for sending control frames to the groundstation. The groundstation control is managed on three different stages described as follows:

- Interactive control via control display format allows the user control direct of the groundstation devices. The operator has the full control of the latest state and actual setup. The user selects the control display and values (e.g. “ON”, “OFF”, STANDBY”) and is supported by color coded realtime dialogue control prevalidation and immediate response presentation of devices. This feature is comfortable, effective and it requires almost no familiarization time

- Interactive Control via predefined Command Macros uses a definable and database administrated file which contains commands for the control processor. These commands allow setting of control parameters for every operational mode of a groundstation device and sending them to the groundstation.

- Automated Control via Control Scheduler executes predefined procedures of scheduled functions within the Ground Segment and the satellites.

SATELLITE SIMULATORS

The SCC is equipped with simulators for the satellites DFS and TV-Sat. The task of the simulator is to provide the most realistic model of the existing spacecraft including payload simulation, TT&C subsystem simulation and station keeping maneuver simulation. The output data of the simulator can be fed into the realtime satellite telemetry processor. Also the command system can send commands to be executed at the simulator.
The DFS simulator is composed of real satellite hardware (Attitude and Orbit Control System) and a software package for all other functions. The functions of the TV-Sat satellite are all simulated by software. The software of both simulators is written for VAX/VMS computers. The simulators are used mainly for training purposes.

THE FLIGHT DYNAMIC SYSTEM

The Flight Dynamic System (FDS) for Orbit Determination is integrated in the SCC. The system is normally configured to calculate orbit predictions automatically. The FDS will encompass all astrodynamical activities related to the day-to-day stationkeeping of the satellite throughout its operational lifetime, and finally its retirement at end of life. The system will be capable of supporting up to ten three-axis body-stabilized and spinning spacecraft during all mission phases, including LEOP, sun- and earth acquisition modes.

The FDS hardware is composed of five redundant HP 9000/700 workstations, with HP-UX UNIX as the operating system. Three workstations are located at the SCC in Usingen, two are at the FTZ facility in Darmstadt. Each workstation is equally configured and capable of performing all mission functions. The daily routine processing is done at Usingen. At each independent site, Darmstadt and Usingen, one server holds the data. If one server fails, the other server is able to service all workstations. The Ethernet LAN of the Flight Dynamic System is bridged to the existing SCC LAN. For the data communication between the sites two 64 Kbit/s ISDN links are used.

The Orbit Determination Process is initiated every three hours by the operators at the control room. This ranging measurement is under automatic control of the STC. The STC will collect the data from the antenna (angle) and the ranging subsystem. After a preprocessing done at the STC, the data will be copied to the FDS servers.

After receiving the new tracking data, the FDS will check and process the data to estimate a new orbit for each satellite. At the end of the processing the Kalman filter at the FDS will send back a status message to the STC. The entire process from collecting the data to the estimated new orbit is performed within 5 minutes and is completely monitored and displayed for each ranging passage and each satellite in the M&C system. The output of the FDS will be used for the station keeping of the satellites.

BASEBAND EQUIPMENT, RF EQUIPMENT AND ANTENNAS

The entire baseband equipment (excluding the RF-equipment) is located in one room at the main station building. The equipment is organized in chains for the functions of telemetry receiving, telecommand and ranging. The interface to the SCC LAN is managed by frontend processors. The RF signals are distributed to the RF equipment via a switch-matrix. The equipment inside the antenna buildings is connected via optical fiber links to the Monitoring and Control Processors (MCP, part of the baseband equipment) to the SCC LAN.

- The Telemetry (TM) Equipment is organized in six chains, four operational chains and two spares. Each TM-chain is composed of a 70 MHz Receiver, a PSK-Demodulator, a Bit-Synchronizer, a PCM-Preprocessor and a Frontend Processor.
- The Telecommand (TC) Equipment is also organized in six chains, three for DFS 1, DFS 2, DFS 3, one for TV-Sat, and two spares. Each TC-chain is composed of a Frontend Processor, a TC-Controller, a PSK-Modulator and a 70 MHz Phase Modulator.
- As Ranging (RG) Equipment with two equivalent ranging systems (RG-chains) are in use at the SCC. The ranging systems are interfaced to the LAN via Frontend Processors, in the same fashion as for the TM- and TC-chains.
- The Time-and Frequency System is based on a rubidium frequency standard with long term stability. The time information is linked via serial interfaces to the computers and baseband devices.
- The use of Frontend Processors (FEP) as LAN-communication units with two main functions, first converting, timetagging and sending the realtime data from the baseband via the LAN to the main computers and second to monitor and control the devices in the associated chains. The frontend processors are realtime PDP 11 computers (operating System RSX) from DEC. On startup the operating system and the application software is downloaded from the Monitor and Control Processors via the LAN.
- The two Monitor and Control Processors (MCP) have two main functions. First to connect the equipment inside the antenna building (e.g. high frequency groups, high power amplifiers). Second, the MCP collect all the monitoring data from the baseband equipment and only new information is sent to the STC to reduce the amount of data.

- The RF equipment is installed in two buildings close to the antennas. These four high frequency groups includes upconverters, high power amplifiers, low noise amplifiers, downconverters, converters for ranging calibration and the redundant devices.
- Five TT&C antennas are used, three for DFS satellites, two for TV-Sat. In principle each DFS (14 GHz) antenna can operate with each DFS satellite. Due to the size of one antenna (4.5 m dish), to meet the required accuracy, the angle tracking has to be performed by a communication antenna (18.5 m dish). One antenna (13m dish) is equipped for TV-Sat feeder link and for TT&C purposes (including angle tracking for orbit determination purposes). A second antenna only for TT&C purposes.

REDUNDANCY CONCEPT

The ground operating system is designed so as to avoid single point failures. The switching between the machines of the STC is performed automatically. If the entire STC is not available the startup, of the emergency system must be performed manually. The switching to the redundant LAN is also performed automatically and transparent to the user.
In the case that one (or two) baseband chains have an error, the switching to the redundant chains is performed by the operator at the control rooms.

The switching to the redundant RF equipment (e.g. up-converters) is performed automatically by the Remote Control Units (RCU) inside the antenna buildings. If this fails, it is also possible to switch via the STC or locally by hand inside the antenna buildings. Supposing an error occurs in one of the antenna or antennas subsystems, the remote antennas at the DLR Weilheim site will be used.

FUTURE ASPECTS

Today’s information technology world uses more and more powerful Reduced Instruction Set Computers (RISC). These new designs allow operational costs to be reduced significantly. The VAX type computers will be replaced by DEC Alpha AXP Computers. The functionality of the entire system will be the same but with more performance. The graphical user interface which was written for Deutsche Telekom will be replaced by a new system with more flexibility using commercial off the shelf tools.

Deutsche Telekom and DLR formed a joint venture to build a new Launch and Early Orbit Phase (LEOP) Ku-Band ground station. This station is able to support the next generation of Ku-Band only satellites (Payload and TT&C) in each phase of the mission. The new station will be integrated into the Telekom SCC M&C system. This station will be fully operational by the end of 1996. The joint venture gives both partners the unique opportunity to operate and support astronautical missions with two independent, although compatible Spacecraft Control Centers.