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Development of ETRI Satellite Simulator-*ARTSS*

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Abstract

Advanced Real-Time Satellite Simulator(ARTSS) has been developed to support the telemetry, tracking and command operations of the ETRI satellite control system and to provide satellite engineers a more powerful and informative satellite simulations tool on the desktop. To provide extensive simulation functions for a communication satellite system in the pre-operational and operational missions, ***ARTSS*** uses a geosynchronous orbit(GEO) satellite model consisting of the attitude and orbit control subsystem, the power subsystem, the thermal subsystem, the telemetry, command and ranging subsystem, and the communications payload subsystem. In this paper, the system features and functions are presented and the satellite subsystem models are explained in detail.

I. Background

ETRI has developed a real-time satellite simulator, ***ARTSS***, supporting both pre-operational and operational missions of a communication satellite, for last two years. Originally, this project was initiated as a part of the project: Development of the ground-based satellite control systems, which has also been carried out by ETRI. ***ARTSS*** was designed to simulate Koreasat and will be used primarily for the testing and validation of the ground operation control center facilities and flight-control procedures and strategies, as well as for the training of satellite operations personnel in both satellite and ground segment procedures.

II. System Description

System Environment

The following hardware and software environment is required to develop and operate ***ARTSS*** system.

Hardware Requirements
- Main Computer : VAX station 4000/60 with 32 MB main memory, 1GB HDD and color monitor
- 3-D Attitude and Orbital Motion Display: Two 486 IBM PCs with 17 inch color monitors
- System Interface: DECNET H/W and a terminal server supporting RS232C serial line

Software Requirements
- Operating System: VMS V5.5 or higher, DOS 6.0
- Graphic Software: XLib V11 or higher, OSF/MOTIF, MS Window
- System Interface: DECNET S/W
- Programming Language: VAX C, Visual C++

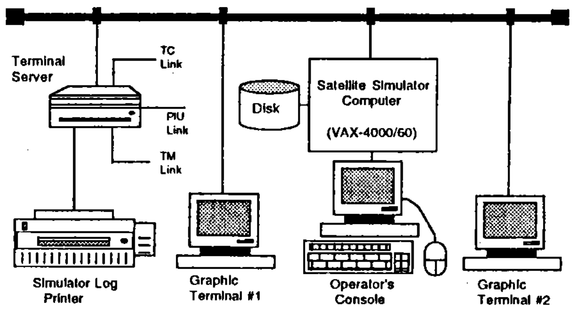

Fig.1 Hardware Configuration

Design Requirements and Concept

A prime requirement is that the simulator run efficiently in real-time to drive the Satellite Control Center(SCC) software; i.e., events in the simulator must occur on a time scale comparable to that of the real satellite. A further requirement is that the modeling be sufficiently detailed to give the user a good representation of the real satellite. In order to fulfill those purposes the simulator must be perceived by the SCC real-time monitoring and control computer as an in-orbit satellite. Thus the simulator is required to: 1) generate representative analog telemetry data and accurate digital telemetry data, 2) receive satellite control commands and react, via the telemetry data, in an appropriate and realistic manner, 3) provide satellite status information, 4) operate sufficiently closely to real-time to provide the telemetry and monitoring data at realistic intervals and rates, and 5) generate representative dynamic and orbital behavior in response to appropriate commands.

The design concept of ***ARTSS*** is based on the modular architecture, which allows the flexibility, the portability, and the independency of the system components. The system can be tailored and reconfigured very friendly by means of adding on the specialized and user supplied modules to the system components.

ARTSS may be divided into four functional blocks: the user interface block, the TTC interface block, the simulator kernel block, and the satellite and environment model block. Figure 2 shows the system functional block diagram. ***ARTSS*** simulates the satellite dynamics, sensors, attitude processing electronics(APE), and actuators including the processing of the telecommands and generation of telemetry data. Its external interfaces are the simulator user and TTC interfaces. Figure 3 shows the simulator's software structure and internal data and control flow.

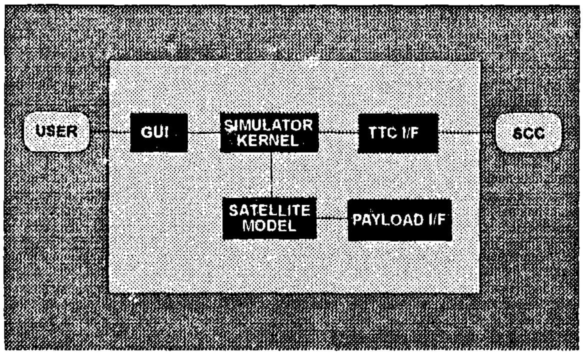

Fig.2 System Functional Block Diagram

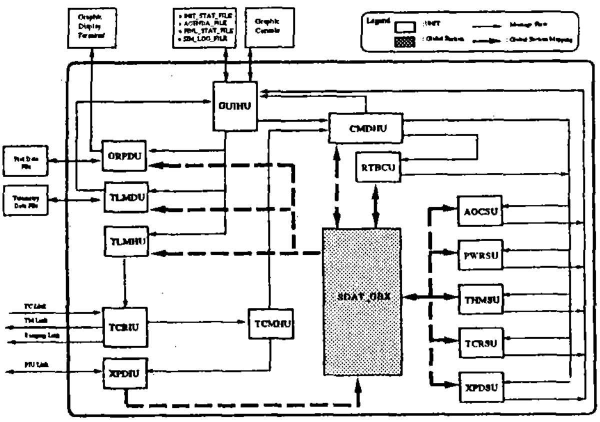

Fig.3 ***ARTSS*** Software Structure

User Interface Block

The graphic user interface(GUI) of ***ARTSS*** provides monitoring and control facilities for the simulator by acting as a layer between the user and the kernel of the simulator, to which it is coupled via service calls. Based on the OSF/Motif windows standard, it supports the simulator control and the satellite telecommanding as well as the simulation monitoring by means of alphanumeric representations, trend graphs, and 3-dimensional graphic visualization, in real-time. This block includes the GUI handling unit, the graphic display unit and the telemetry display unit. The user interfaces with ***ARTSS*** directly via VAX station 4000/60. The user is provided with the password necessary to login to the station and to start simulator. In the main console the following windows are provided(Fig. 4);

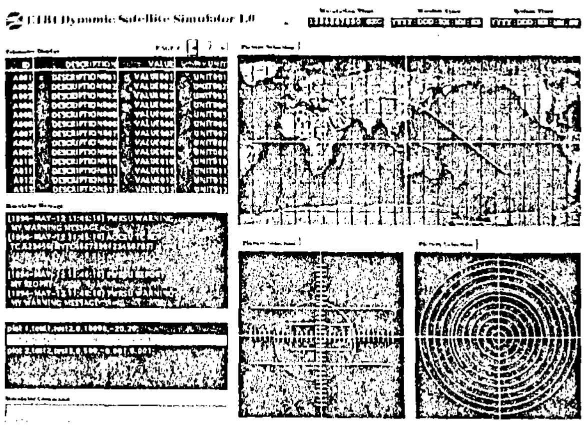

Fig.4 ***ARTSS*** GUI Console

Commander Window

A simulator control command is entered on a command line by the user. The facility checks the validity of the command syntax before actually sending the input command to the simulator kernel. Functions accessible from the user includes simulation control, telemetry modification, event file processing, and anomaly introduction.

Telemetry Display

This function allows for the visualization of telemetry variables, arranged in tables, in alphanumeric format. The user can define the layout and select key variables to be displayed.

Log Display

The simulation log keeps track of all significant events taking place during a simulation run.

Graph/Subsatellite Trajectory Display

This window can be used in dual purposes allowing the visualization of either simulation variables in graph format or subsatellite trajectories on the earth map, all real-time. In the graph mode, up to five trend curves can be selected.

Sensor View Window

This window can be used in dual modes. In the pre-operational mode, it displays the fields of view of the sun and horizon sensors and the state of satellite attitude with respect to earth, sun, and moon. In the operational mode, it displays the field of view of the earth sensor and the state of satellite attitude with respect to the earth.

Orbit Location/Stationkeeping Window

This window can also be used in dual purposes. It can be selected to display either the satellite location on the orbit or satellite pointing errors in east, west, north and south station keeping maneuvers.

Fig.5 3-D Attitude Dynamics Graphic Monitor

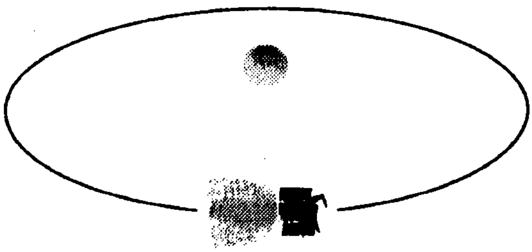

Fig.6 3-D Orbit Dynamics Graphic Monitor

Flight Dynamics Monitors

Two external auxiliary graphic monitors are used to visualize three dimensional satellite flight states in real-time. They are connected with the VAX station through RS232C interface.

3-D Attitude Monitor: This offers a 3-dimensional graphic animation of the satellite showing its attitude dynamically as calculated by the attitude dynamics model of the satellite(Fig.5)

3-D Orbit Monitor: This provides the graphic representation of the orbital state as calculated by the orbital dynamics model of the satellite.(Fig. 6)

TT&C Interface Block

This provides an interface between ***ARTSS*** and the SCC for supporting the mutual ground operations activities such as tracking, telemetering and telecommanding. All data between ***ARTSS*** and the SCC pass through the LAN, using DecNet protocol such as task-to-task transparent communication. The LAN connected to the external command source(SCC) is continuously monitored for commands. Alternatively, serial communication via serial links of DecServer to the LAN is possible between ***ARTSS*** and the SCC.

The satellite command signals from the SCC, which specify a command opcode and data word, are received by the LAN or serial link and forwarded to the telecommand handling unit in the simulator kernel block for decoding and further distribution.

Telemetry frames generated by the telemetry handling unit in the simulator kernel block are transmitted to the SCC via the LAN or serial link every two seconds. Prior to transmitting the frame, the incrementing frame counter is inserted. The simulator transmits telemetry only while the simulation is active. On the other hand, if the simulation is paused through the simulator control menu, telemetry transmission will be suspended.

Simulator Kernel Block

The real-time simulation kernel provides four simulation control functions consisting of simulation command processing, telemetry control, model control, and simulation data logging and recording. The command processing function receives, decodes, validates, and simulates execution of satellite commands sent to the simulator via GUI or TTC interface. Telemetry control function controls the format and content of the simulated telemetry data. ***ARTSS*** allows the centralized processing to efficiently control the distributed subsystem models of the satellite in real-time. In the normal mode, ***ARTSS*** generates and transmits telemetry frame every two seconds. In the dwell mode, maximum period for generation and transmission of the telemetry is 0.25 seconds. Therefore, each subsystem process basically runs with the period of 0.25 seconds except for attitude dynamics of which period is 0.01 seconds. Under peak loading conditions, the CPU load does not exceed 70 % of its CPU allocation for the program which must execute in real-time on the host computer. Communication method used by the simulator processes are VMS mailboxes.

Satellite Model Block

The satellite model block contains the satellite and environment models. This comprises attitude and orbit control subsystem model unit, power subsystem model unit, thermal subsystem model unit, TC&R subsystem model unit and payload subsystem model unit(Fig. 7). The models periodically output simulated telemetry data to the global data section. Telemetry is stored in the format in which it will appear in the telemetry frame(scaled raw values) and is forwarded to the telemetry handling unit for additional processing. The models accept satellite commands, anomaly requests, and live telemetry file inputs on their mailboxes and change their states as appropriate. The subsystems as follows;

Attitude and Orbit Control Subsystem

The AOCS unit supports two sequential mission modes. The first, pre-operational mode, operates from the time the satellite injection from its launch vehicle into the transfer orbit, throughout the transfer orbit, and until the initiation of the earth acquisition in the Geosynchronous orbit. The second, operational mode, operates at the Geosynchronous altitude from the onset of the initial earth acquisition throughout the mission life time of the satellite. The AOCS is designed to provide all necessary functions of the sensors and control equipments needed to maintain and monitor the satellite pointing requirements and control the required

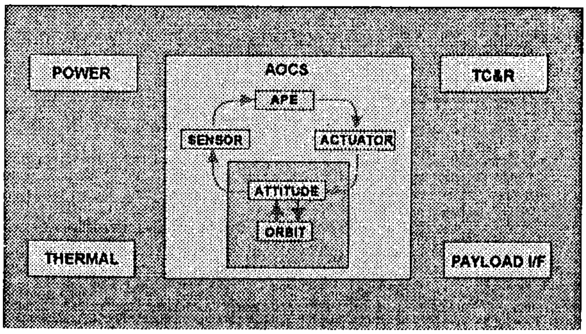

Fig.7 Satellite Model Block Diagram

maneuvers during all phases of satellite design life. The AOCS unit comprises satellite dynamics model(SDM), the sensor models, the attitude processing model(APE), and the actuator models.

Satellite Dynamics Model(SDM)

The SDM consists of the orbital and attitude dynamics. The orbital dynamics model includes the natural perturbations due to the sun and moon's attraction, the solar wind and the effect of mass distribution of the earth. The attitude dynamics model comprises kinematics and disturbance torques model.

Roll and pitch angles, as they are measured by reference to the satellite geocentric vector, are computed from the current attitude information. Disturbance torque model due to the thrust misalignment is included in the apogee kick motor(AKM) model. The SDM evolves the satellite Geocenter vector, but does not model the satellite's orientation with respect to any body other than the earth.

The SDM inputs torque from the roll/yaw torquer (RYT), pivot angle and rate from the pivot model(PVTM), and thruster torque and force. It calculates the combined torques acting on the satellite, modifies the state of the model based on the combined forces, and updates the satellite orbit.

Sensor Models

The sensor models process ephemeris data from the SDM and produce telemetry and attitude information to the Attitude Processing Electronics Model(APEM). The sensor models consist of the horizontal sensor assembly model(HSAM), the sun sensor assembly model(SSAM), the earth sensor assembly model(ESAM) and the rate measuring assembly model(RMAM).

The HSAM consists of two functionally independent bolometer telescope assemblies containing thermistor bolometer detectors with optics and processing electronic circuitry in an integral assembly and rotated about the spin axis by 45 degrees with respect to each other. The HSAM is used to determine time lags between the command eye pulses (CEPs) generated by the SSA and the earth crossing envelops(ECEs) produced by two bolometer telescope assemblies of the HSA.

The SSAM consists of redundant detector assemblies and associated electronics used to determine sun angle with respect to the spin axis of satellite on transfer orbit and the phasing of a satellite reference axis with respect to the sun.

The ESAM determines roll and pitch errors of satellite with respect to the earth center during operational mode which is most of satellite's life time. The ESAM measures roll and pitch attitude by scanning the fields of view of two pencil beam bolometers across the earth in an east/west direction and looking for the difference in radiation between the earth and space.

The RMAM models the roll RMA and the yaw RMA each of which contains two gyros. The model inputs yaw and roll rates from the SDM, adds a gyro drift rate and integrates these to give delta roll and yaw angles. The model outputs the delta roll and yaw rates to the APEM.

Attitude Processing Electronics Model(APEM)

The APEM models all the preoperational and operational mode attitude control subsystem(ACS) functions of the satellite attitude processing electronics. The modes are relevant to transfer and Geosynchronous orbits, respectively. The APEM accepts satellite commands, anomaly requests, and sensor data as input and produces telemetry and actuator demands as output. Inputs to the APEM consist of commands routed by the command execution unit, angle and rate information produced by the HSAM, SSAM, ESAM and RMAM, and anomaly settings generated by the user at the APEM menu.

In the operational mode, roll and pitch angles are input from the ESAM and roll and yaw angles are input from the RMAM. The APEM inputs satellite commands, sensor data, and anomaly settings, modifies and updates its operating state accordingly, and produces telemetry and actuator commands. Actuator commands are output to the RYT, momentum wheel assembly and pivot model(MWA&PVTM) and thrusters.

Actuator Models

The actuator models consist of RYT, MWA&PVT, combined propulsion system(CPS), and AKM models. Actuator models produce forces and torques corresponding to commands from APE and ground control center and output them to the SDM.

The RYTM provides a magnetic dipole moment such that its interaction with the earth's magnetic field will create control torques. When energized, the RYTM provides a magnetic dipole moment. The polarity of the dipole moment depends on the polarity of the applied voltage. The RYT has a constant torque capacity. The outputs of the RYTM function consist of telemetry and torques sent to the SDM.

In the MWA&PVTM, there are two MWAs on the satellite, each attached to its own PVT. The MWA provides angular momentum storage and electrical torque capability about the spin axis of the MWA rotor. The MWAM contains an inertia wheel storage which is driven by a motor to a speed which is commandable from the ground or from the APE. The MWAM includes the wheel speed feedback necessary to achieve the demanded speed. The MWAM outputs speed demands to MWA dynamics model in SDM. The PVTM uses a stepper motor to incrementally position the spin axis(momentum vector) of the MWA and provides on-orbit attitude trim of the roll axis.

The CPS consists of the rocket engine assembly(REA) and the electrothermal hydrazine thruster(EHT) models. They provide forces and torques to the SDM according to commands from the APE and the ground control center. Forces and torques produced by each thrusters, REAs and EHTs, are stored in the TF table. In the REAM, the REAs are used in either a pulse mode and/or steady-state (continuous firing) mode, depending on the demand. The total torque on the satellite resulting from the REA firing is calculated. The tank pressure is not modeled and the REA torque variation with pressure is not modeled. The model includes an 11 second back-up timer which, unless reset, terminates a ground commanded thruster firing after 11 seconds. The torque for each thruster is obtained from the torque-force table(TF table). The total torque is evaluated by summing torques from all thrusters presently firing and passed to the SDM. The outputs of the REAM function consist of telemetry and torque data sent to the SDM. In the EHTM, the EHTs(thruster 13,14,15, and 16) are used in steady-state mode for the primary north/south stationkeeping maneuvers. The EHTs can only be fired in either even (14/16) or odd (13/15) pairs. It is necessary to enable the appropriate pairs of EHTs prior to initiating firing of these thrusters. The enable/disable thruster command is executed via an EHT control assembly (ECA).

Power Subsystem model

The primary function of the power subsystem is to provide the unregulated power required to operate the satellite for the its life time in orbit. The power subsystem simulates functions of solar array, solar array drive, battery, battery charge regulator, power supply electronics, and battery pull-up assembly. In the preoperational mode, the solar array is stowed and partially operational. In the operational mode, i.e. Geosynchronous orbit mode, the power subsystem has four phases. Firstly, when the satellite is operating in eclipse, the power subsystem discharges the battery to supply the required power and, during daytime, recharges it with the power generated by the solar array. Secondly, the power subsystem keeps trickle charge for maintaining the battery in full charge except for EHT firing mode. Thirdly, the battery repeats deep discharge and pull-up to recondition for preparing eclipse season. Fourthly, there is a peak time in the power consumption. During this phase(EHT firing mode), the battery is disconnected from the solar array and supplies the power to the EHT. Only the solar array supplies power to the unregulated bus. During the EHT fire, it is necessary to prevent the power fluctuation. The model outputs telemetry data to the global data section.

Thermal Subsystem

The thermal subsystem model simulates the switching status of the heaters and calculates the node temperatures on the satellite in accordance with the sun angles. The model outputs telemetry data to the global data section. Most of thermal commands fall into the category of enabling or disabling heaters and heater control units.

Telemetry, Command and Ranging(TC&R) *Subsystem*

The TC&R subsystem is modeled to simulate only the switching status of the TC&R subsystem of the satellite. Telecommand reception & distribution and telemetry generation & transmission functions are included in the simulator kernel block.

Communications Payload Subsystem

The key feature of the communcations payload subsystem model is capable of interfacing the real hardware transponder to ***ARTSS***. In this case, the model collects telemetry data directly from the hardware transponder and passes them to the global data section.

III. Conclusions

The real-time satellite simulator, ***ARTSS***, presented above was developed to support the ground operation activities of the satellite control center such as mission preparation and execution and to offer the satellite engineers with a powerful and easy-to-use satellite simulation tool. For these purposes, ***ARTSS*** was designed to provide easy-accessible-interfaces and a variety of subsystem models of GEO communication satellite. The user-friendly menu driven GUI is provided with lots of informative monitoring and control facilities for simulator. Another key feature of ***ARTSS*** is that the system provides a real communication payload subsystem by interfacing with a real hardware transponder.

The future goal for ETRI satellite simulator is to develop the general purpose satellite simulation tool supporting low earth orbit(LEO) satellite missions as well as GEO satellite missions.

Acknowledgments

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