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Galileo Spacecraft Modeling for Orbital Operations

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ABSTRACT

The Galileo Jupiter orbital mission using the Low Gain Antenna (LGA) requires a higher degree of spacecraft state knowledge than was originally anticipated. Key elements of the revised design include onboard buffering of science and engineering data and extensive processing of data prior to downlink. In order to prevent loss of data resulting from overflow of the buffers and to allow efficient use of the spacecraft resources, ground based models of the spacecraft processes will be implemented. These models will be integral tools in the development of satellite encounter sequences and the cruise/playback sequences where recorded data is retrieved.

Key Words: Aerospace, mission operations, sequence planning, spacecraft modeling

1.0 THE GALILEO PHASE II DESIGN

The Galileo Phase II redesign for Jovian orbital operations using the Low Gain Antenna (LGA) is driven by the need to match the high data acquisition rates with the low spacecraft data transmission capability. Many changes have been made to both the spacecraft and the ground data systems to optimize the effective data transmission rate. Spacecraft changes include extensive redesign of the Command and Data Subsystem (CDS) flight software, modifications to the Attitude and Articulation Control System (AACS) software and selected instrument flight software changes. Ground modifications include adding noise reduction equipment at selected DSN sites, intrasite and intersite antenna arraying capability, new receivers and signal acquisition equipment and extensive ground software changes to support new data transmission modes.

The changes to the flight system are numerous and constitute a significant redesign of the flight software. The primary modification to accommodate the low data rates was the switch from Time Division Multiplexed (TDM) telemetry modes to a packetized telemetry system based upon a highly optimized CCSDS packet definition. This allows a flexible, prioritized data transmission system, eliminating the inherent data redundancy of the TDM design.

Onboard data buffering is implemented to allow high rate data acquisition. Central to this design is the Data Memory System (DMS - tape recorder) which will hold 900 Mbits of data. This will be used to store high rate data (remote sensing and fields and particles science data) acquired during satellite encounters and relayed to the ground during the orbital cruise phase between encounters. For onboard data manipulation and real time data acquisition and storage, several buffers are implemented in solid state memory. The most important are the priority buffer, which holds priority engineering and Optical Navigation (OPNAV) data, and the multi-use buffer, which is used for the storage and manipulation of Real Time Science (RTS) and the playback of data from the DMS.

Extensive data editing and compression is implemented to reduce the number of bits transmitted to the ground. The CDS can select or deselect data sources based upon mission phase and can edit many of the data sources. Both lossy and lossless compression schemes have been implemented onboard. Lossy compression based upon the Integer Cosine Transform (ICT) algorithm has been implemented in the AACS software and is used to compress images and Plasma instrument (PWS) data sets. Compression ratios of 2:1 to 80:1 can be selected. Lossless compression using the Rice algorithms (Reference 1) has been implemented for selected science data sets, resulting in data compression ratios of 1.2:1 to 5:1.

2.0 SPACECRAFT DATA FLOW

Figure 1 illustrates the typical data flow within the flight system. As illustrated, the onboard data buffers form key elements of the design. Controlling the data input to the buffers and the data output to the downlink are key tasks for the flight sequences. If the aggregate data input rate exceeds the data transmission rate, the buffers will fill. Overfilling the buffers will result in discarding new data. However, if data acquisition is controlled such that the buffers empty, fill data is inserted on the downlink, lowering downlink efficiency. Maintaining the delicate balance of the buffer fill state will be a significant challenge for Phase II operations.

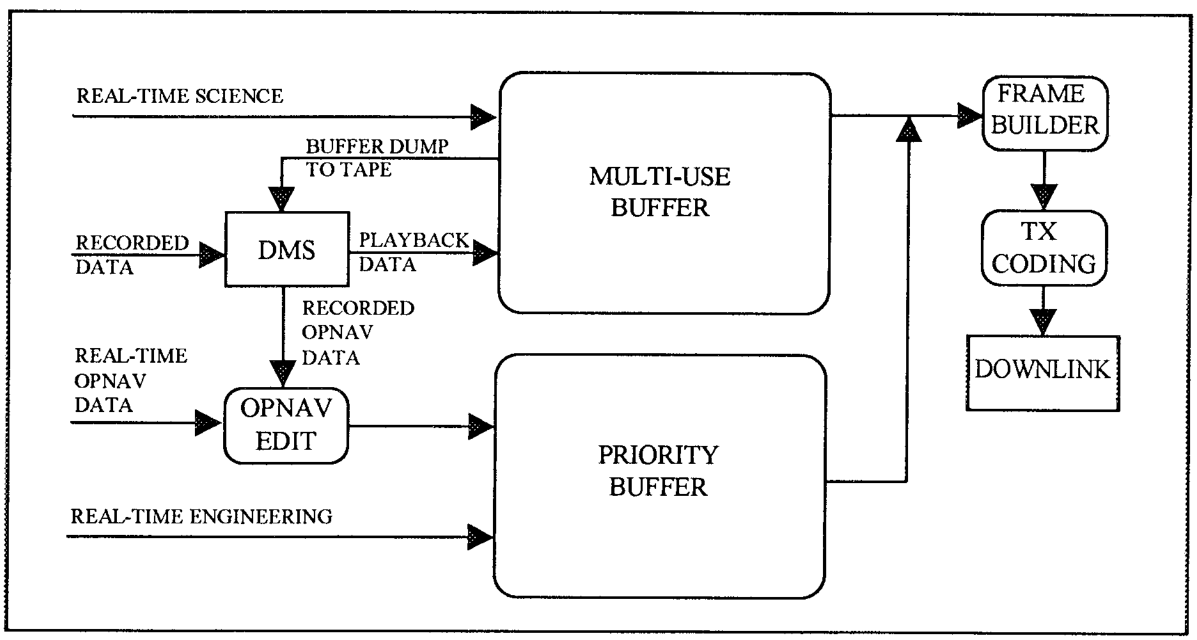

Figure 1 - Spacecraft Data Flow

The data input process has three constituent parts: the real time engineering (RTE) and OPNAV data, which is placed in the priority buffer, Real Time Science data (RTS) and the Playback data which is processed through the multi-use buffer. Real time data (RTE and RTS) is taken continuously and is controlled by the CDS. Data sources can be selected and deselected in accordance with planned observations and the data collection mode is controlled by the CDS telemetry command. Real time data acquisition and the downlink telemetry rate are controlled using the same command. This links the Real time data collection with the downlink telemetry rate via one of 90 selectable modes.

The OPNAV and Playback processes are independent of the real time data acquisition process, and are intermittent activities. OPNAV activities occur prior to encounters, and place certain restrictions on both the multi-use buffer (where the data is processed) and the priority buffer (where the data is stored for transmission). The Playback process for retrieving the recorded data is completely new for orbital operations. In playback, the CDS performs autonomous retrieval and processing of the data from the DMS, controlled by a special parameter set called the playback tables. These tables contain information on the format of the recorded data, lists the data to be retrieved and the editing and compression to be performed on the selected data. Playback data is placed in the multi-use buffer for processing. To control the filling of the multi-use buffer a set of buffer pointers have been implemented. When playback is active and the buffer fill state falls below the low watermark (i.e. the downlink rate exceeds the data acquisition rate, allowing the buffer to empty) the CDS will autonomously control the DMS to replay data into the multi-use buffer. When the buffer fill state exceeds the high watermark, the CDS commands the DMS to cease operation and processes the raw tape data into completed data packets. This process occurs simultaneously with real time data acquisition and is exclusive of all other record activities.

2.1 BUFFER MODELING

The buffer modeling task is necessary for the system to work. The highly interactive nature of the system and the statistical nature of the data compression algorithms necessitates an iterative approach to the design of spacecraft command sequences for orbital operations. With the number of independent variables that must be factored, and the accuracy with which they can be predicted, precise control of the buffer states will be difficult. Without ground based system models, the flight system could not be operated efficiently.

To control the buffer fill rate, many variables need to be controlled. On the output side, the commanded downlink data rate is varied in discrete steps over the course of a DSN track to closely match the data rate capability (Figure 2). These data rate changes must be predicted well in advance and scheduled in the sequence. Any change to equipment capabilities or link performance will affect the data rate capability and the output from the buffers.

On the buffer input, the various data sources must be controlled and the rates at which each source generates data must be predicted. This includes modeling which instruments are selected and deselected, the data editing algorithms and the target compression ratios. Each of these factors vary as a function of time. In addition, the compressibility of some of the sources is very data dependent, thus

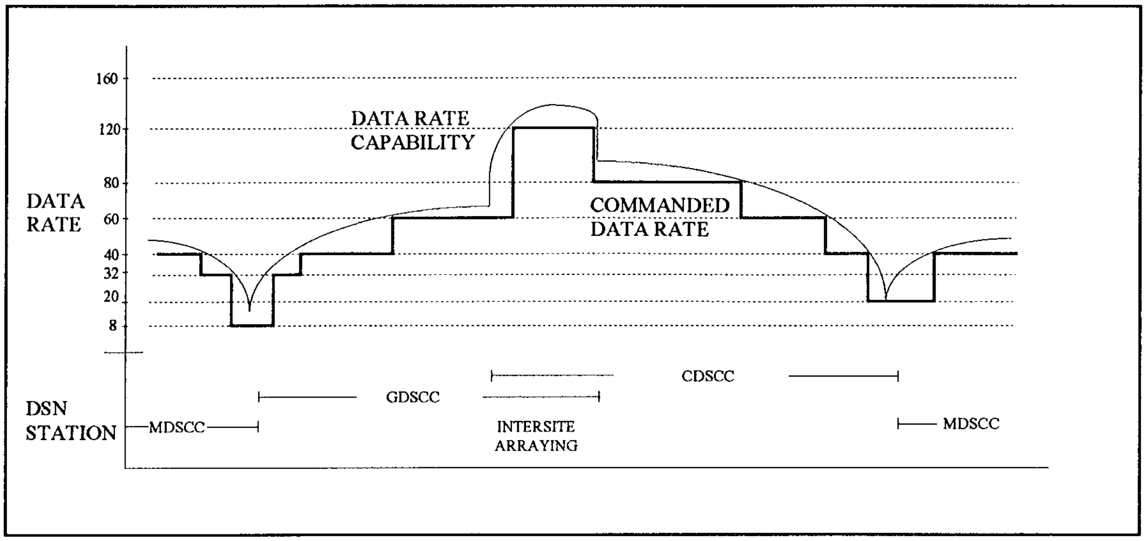

Figure 2 - Downlink Telemetry Rate Change Modeling

considerable variability in data volume is expected.

The priority buffer has only two input data sources; the real time engineering data and OPNAV data. The only significant restrictions on buffer state for the priority buffer is the requirement that the buffer be empty before initiating an OPNAV process. The current priority scheme essentially guarantees that if the downlink rate exceeds the engineering acquisition rate, this state is achieved.

The multi-use buffer requires significant modeling to predict its state. The modeling can essentially be broken down into two separate modeling regimes: the encounter phase, characterized by low downlink data rates and high rate RTS data acquisition with interspersed buffer dumps to tape, and the playback phase with higher downlink rates and with the Playback process active.

The bulk of the scientific data is gathered during satellite encounters. This includes the remote sensing and very high rate fields and particles instrument data which is recorded directly to tape at up to 806.4 Kbps, and the high rate RTS data, which is processed into the multi-use buffer. Typically, the desired RTS acquisition rate well exceeds the downlink rate, filling the buffer. To allow extended high rate data acquisition without overflowing the multi-use buffer the Buffer Dump to Tape function has been implemented. This is a sequence controlled activity wherein the CDS will transfer completed Virtual Channel Data Units (VCDUs - Memory Management Units) from the multi-use buffer to the DMS, freeing the buffer for continued data acquisition. Since buffer Dump to Tape is a sequence controlled activity, it can be scheduled to occur between other DMS activities. Buffer management during encounters consists of predicting RTS data acquisition rates and scheduling buffer dumps to tape when necessary to prevent buffer overflow and loss of data.

During the orbital cruise phase, data is retrieved from the DMS via the Playback process. Typically, the downlink data rate is higher than during encounters and the continuous RTS data acquisition is set to a lower rate. This allows the playback process to transfer data from the DMS into the multi-use buffer, process the data and prepare it for downlink. Since the replay of data from the DMS is controlled via the buffer high and low watermarks, the process is self-regulating. The modeling task for cruise consists of multiple parts: insuring that the high and low watermarks are properly set, insuring the RTS data acquisition is low enough to prevent data loss due to buffer overflow and modeling playback data editing and compression to recover all of the significant encounter data.

2.2 MODELING TOOLS

The Phase II ground system has two main tools for predicting and controlling the data flow on the spacecraft. They are: SEQGEN, the primary sequence generation tool of the Mission Sequence System (MSS) and MIRAGE, a newly developed tool for processing data rate predicts and producing buffer models. Supporting the generation of sequences and the modeling effort are a suite of tools to automate the process. New tools for Phase II are TLMGEN, which provides automated generation of spacecraft telemetry rate change commands based upon predicted capability and the Playback Table Editor which generates playback table entries based upon the DMS tape map and models playback data production based upon processing parameters selected. These tools, along with a host of existing science and mission design tools, provide data input into the modeling process and are used for optimizing data flow.

2.2.1 MIRAGE

The MIRAGE (Mission Integration, Real time Analysis and Graphical Editor) modeling tool is based upon an earlier multi-mission sequence planning tool developed by the Sequence Automation research group at JPL. Plan-It-II was developed on an UNIX platform using LISP, and specifically developed to be extensible for multiple missions. Plan-It-II provided the capability to simulate functionally the operations of a spacecraft, allow sequences to be staged through the model, and rapidly and interactively present the impacts of the sequence and any proposed changes on the spacecraft resources. The Galileo project adapted the core of Plan-It-II to model the Phase II design. Modifications include incorporating Galileo specific time standards and the Phase II functional design into the model, defining new input data types, providing new constraint checking algorithms and modifications to the user interface to more closely resemble familiar planning tools currently in use.

Mirage provides an interactive environment, displaying on-screen timelines of sequence activities and accompanying graphs showing the states of the spacecraft resources. It also provides an interface to the details of the science planning requests and allows the user to add, delete and modify these activities. This interaction allows the user to explore different approaches to a situation, varying parameters and displaying the results. This results in the rapid development of a viable sequence of data collection activities which the spacecraft can accommodate.

MIRAGE will be used early in the science sequence design process to analyze the effect of the science observations on spacecraft resources. Used primarily in the Orbit Activity Plan (OAP) level, it will determine if a planned set of Real-Time and recorded observations generate buffer overflow conditions, monitor the usage of the DMS and track the allocation of resources to the various science observations.

MIRAGE will also play an important role during sequence execution. Because of the uncertainties involved in the telecommunications link modeling and onboard data compression, the actual data flow may not proceed as predicted. Sequence tweaking, involving modification of one or more data acquisition or transmission parameters, will need to be modeled to determine the overall effect on the data flow. Integral to this process will be the MIRAGE analysis of the spacecraft resources.

2.2.2 SEQGEN

SEQGEN is an existing sequence development tool which takes the OAP level inputs and converts the activities into command sequences and playback parameter tables. SEQGEN is responsible for enforcing many of the sequencing rules and constraints checking for certain onboard data resources and downlink data transmission. For the Phase II mission, SEQGEN was modified to generate the playback table entries. These parameters, which are independent from the spacecraft sequence, instruct the CDS on how the recorded data will be processed. Integral to the generation of the Playback Table entries, the Playback Table Editor allows modification of the playback parameters, adjusting data selection, editing and compression for the recorded instrument data.

The output from SEQGEN can be routed to MIRAGE for modeling. This allows an iterative approach to the sequence generation process. In the early sequence design stages, an activity plan is produced and checked by MIRAGE for proper data flow. This product is refined into a working spacecraft sequence, again using MIRAGE modeling and the Playback Table Editor to adjust playback data parameters. Once the sequence is executing, sequence tweaks to optimize the data flow will be verified using MIRAGE before being sent to the spacecraft.

3.0 SUMMARY

This paper has presented the ground based modeling of the spacecraft processes for the orbital operations mission using the Galileo Low Gain Antenna. The redesign of the flight software requires a higher degree of spacecraft state knowledge than was originally anticipated. In order to optimize the data flow onboard the spacecraft and to the ground, interactive modeling of the data acquisition, buffering and transmission is required during the sequence design process and during sequence execution. These models have been developed concurrently with the flight software design, taking advantage of existing ground software where applicable and developing or adapting software for specific modeling and sequence generation functions.

4.0 ACKNOWLEDGMENTS

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5.0 REFERENCES

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