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An Approach for Geostationary Satellite Mode Management

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Abstract: In each mission phase, a satellite is characterized by a well-defined set of modes. They define a clear configuration of the spacecraft subsystems and have specific operational implications. In this paper, we present an approach for geostationary earth observation satellite mode management during both the Launch and Early Orbit phase and the full operational phase. It draws on a real space mission project currently carried out at OHB System AG. The configurations of the Attitude and Orbit Control System are also analyzed, their operational meaning and the relationship with the satellite modes. It is also explained how on-board autonomy requirements play a relevant role in the satellite mode definition and management. Geostationary satellites can usually be operated in a quasi real-time fashion, therefore a limited level of on-board autonomy can be sufficient. However, they can be characterized by high availability requirements and have a need for ground operation reduction, which can lead to an increased level of on-board autonomy in satellite mode management.

Keywords: Mission Control and Operations, Spacecraft Mode Management, Autonomous Systems, Man-in-the-loop Systems, Launch and Early Orbit Phase, Geostationary Orbit, Attitude and Orbit Control System

1. INTRODUCTION

Starting from the launch phase up to its disposal, and in each mission phase, a satellite is characterized by a well-defined set of modes, whose definition and operational implication are a relevant step in any space mission design and spacecraft manufacturing. This is actually a system engineering discipline and has to take into account the complete life-cycle of a satellite, especially its operational constraints and requirements. A satellite mode can be regarded as a clearly identified configuration of both satellite platform and payload hardware and software. Every satellite mode has operational implications, meaning that each satellite mode allows a specific set of operations in order to fulfill operational objectives and requirements, see Eickhoff (2012). Initialization of a mode (at satellite, subsystem, instrument or unit level) includes the configuration of the necessary hardware and software, the periodic transmission of telemetry packets, the periodic acquisition of telemetry parameters, and the activation of all the automatic processes required to achieve the mode, monitor its health status, and stay within in a stable manner.

Another important topic is the definition of the autonomy level for spacecraft mode transitions, which impacts the overall spacecraft design and the mission operational concept. Spacecraft on-board autonomy is a matter of degree and is continuously increasing, see Jonsson et al. (2007). The ECSS-E-ST-70-11C (2008) defines four levels of autonomy. Spacecraft can be endowed with a specific level of on-board autonomy, which determines the distribution of responsibilities and the corresponding capabilities of the ground station versus the spacecraft. From an operational point of view, on-board autonomy can be actually regarded as migration of functionality from the ground segment to the flight segment, see Grant et al. (2006). In this respect, Esteve et al. (2012) account for some key-factors, that is to say mission type, mission objectives and priorities, type of the spacecraft orbit, spacecraft ground visibility profile, operations concepts, and communication constraints. Its traditional notion as predefined explicit behaviors can fulfill the needs for satellites operating in a predictable environment. However, this approach is not adequate for spacecraft operating in unpredictable contexts, which feature deep space exploration systems or critical operational phases such as automated spacecraft docking. Further drivers for rich on-board autonomy are the overall improvement of the spacecraft availability and reliability, and the reduction of costs in ground segment operations, which can address long-term planning instead of day-to-day procedures, see van der Ha (2003).

This paper focuses on the mode management approach for a geostationary earth observation satellite system during the Launch and Early Orbit Phase (LEOP) and when the satellite has reached the Geostationary Orbit (GEO). It draws on a real space mission project currently carried

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out at OHB System AG. Such space mission will provide Europe with an operational satellite system able to support accurate prediction of meteorological phenomena and the monitoring of climate and air composition through operational applications. As a rule, geostationary satellites have continuous ground visibility with very small communication delay. If needed, they can be operated in a quasi real-time fashion, therefore a limited level of on-board autonomy can be sufficient. However, due to their mission objectives, they may have very high availability requirements, as loss of service has economical consequences. They may also have a need for reduction in ground operation intervention. These factors can imply increasing the on-board autonomy. Thus, we have two extreme cases, either the ground operators drive the complete satellite mode transition down to each reconfigurable HW or SW unit by executing a step-by-step procedure and uploading the related telecommands, or the ground operators send a telecommand to trigger a mode transition with the satellite converting it into a series of on-board operations for the spacecraft subsystem reconfiguration. Some satellite mode transition can be implemented with the former approach, others with the latter. In the solution hereafter proposed, satellite mode transitions triggered by critical on-board detected failures are autonomously managed by the On-board Software (OBSW). As for nominal ground operations, the first approach is basically preferred with some very few exceptions.

This paper also shows the link between the satellite and the Attitude and Orbit Control System (AOCS) modes during the LEOP and GEO phases. It has been organized as follows. Section 2 provides the operational meaning of the satellite, AOCS, and payload modes. Section 3 describes the approach for satellite mode transition, in particular it distinguishes between the man-in-the-loop mode transitions and the ones carried out autonomously by the spacecraft. Section 4 shows how the satellite and AOCS mode change during the LEOP phase up to the transition into the GEO orbit. Section 5 focuses on satellite and AOCS mode management during the GEO phase. Finally, section 6 concludes the paper.

2. SATELLITE MODE DEFINITIONS

Modes are conceived at satellite, AOCS, and payload level. The following satellite modes can be defined (see Fig. 1):

- The satellite is in Launch Mode (LAM) from the moment of transfer of power provision from ground to the on-board batteries, until satellite separation from the launcher. During LAM, the satellite batteries are powered, the S-band receivers are on, one S-band transmitter is on, and the satellite communication buses are initialized. After having enabled all the analog and digital acquisition/commanding lines, the On-board Computer (OBC) waits for the separation signal to start the separation sequence. Survival thermal control functionality is also guaranteed.
- At detection of launcher separation by the OBC, the satellite enters automatically the Sun Acquisition Mode (SAQ) and executes the separation sequence. Solar panels are oriented towards a specific reference position (the platform has a solar-array driving mechanism), and the Sun pointing has to be reached and maintained. The SAQ can be also entered upon a Ground TC.
- In Nominal Mode (NOM), the satellite along its payload is fully operational. The satellite is three-axes stabilized ensuring the required high pointing accuracy of +Z face (see Fig. 2) towards the Earth in order to provide mission product data and services, once configured, in a autonomous way.
- The Yaw Flip Mode (YFM) is required at each equinox to avoid direct Sun illumination of the satellite −Y face due to thermal reasons (the only radiator is placed on the −Y face). The satellite will rotate around the Z axis thanks to its reaction wheels.
- In Stand-by Mode (SBM), the satellite acts as an in-orbit spare not used for any operational service but able to become operational within a short time frame. Full health and safety activities are maintained, including continuous real time monitoring. Thrusters are disabled via the latch valves system.
- The satellite enters the Safe Mode under critical on-board anomaly detection, which cannot be autonomously recovered or which, though recovered, could present a risk later on if normal operations are continued. Return to normal operations is completely carried out under ground control.

The operational concept of a typical spacecraft includes one or more safe mode configurations that represent the ultimate reaction to spacecraft severe anomalies. In safe mode, the communication link to ground, a specific power supply profile, and thermal survival functions for relevant equipment are maintained, whereas all nonessential on-board units/subsystems are powered off, some subsystems/units can be switched to redundant hardware parts, and the spacecraft is (automatically) oriented to a particular attitude with respect to the Earth or the Sun, see Tipaldi and Bruenjes (2015). Safe mode has to be carefully conceived in terms of spacecraft configuration, observability, and commandability (for instance, OBSW dump and patch functions).

The payload modes shall be compatible with the primary satellite modes. We can identify the following payload basic modes:

- In Survival Mode, the payload is off, however the satellite platform enables the protection devices, such as the survival thermal lines.
- In Stand-by mode, the payload is on and some basic monitoring and power lines are activated.
- In Wait Mode, the payload is ready to operate. AOCS *a-priori* compensation for the scanning movement of the payload is activated, see Gimenez et al. (2005).
- In Operational mode, the instrument is fully operable and provides science data.

The management of payload modes is under direct Ground control (which means that mode transition TCs are directly routed to the payload). The spacecraft switches automatically payload modes in defined failure cases, such as during the transition into safe mode.

In the same way, the AOCS modes shall be compatible with the primary satellite mode. The following AOCS modes are defined: