INTRODUCTION

As part of the design and development phase of the European Galileo satellite navigation system, ESA created a Galileo System Test Bed (GSTB) programme of activities. The GSTB programme contains two major elements:

- GSTB-V1, a test bed for the Galileo navigation algorithms primarily using GPS data,
- GSTB-V2, a pair of custom-designed satellites: GIOVE-A built by Surrey Satellite Technology Limited (SSTL) and GIOVE-B being built by Galileo Industries SA.

The four major mission goals of the GIOVE satellites are:

- The launch of a satellite into a representative orbit, carrying a payload able to transmit at the filed frequencies in order to protect the GALILEO frequency filing, before the ITU in-service deadline expired in 2006;
- The validation and demonstration of key Galileo payload technologies currently under development within Europe;
- The measurement of the Galileo orbit radiation environment, providing data to verify existing models and for use in the design of the operational satellites;
- The provision of a representative signal in space to allow co-ordination to commence with other terrestrial and satellite systems and to allow signal performance measurements to be made and receivers to be tested in realistic conditions.

Through its work on a Geostationary Mini-Satellite Platform (GMP), SSTL was able to offer ESA a rapid development schedule for the GIOVE-A satellite. The contract for GIOVE-A was signed early in July 2003 for a delivery of the satellite in the second half of 2005. In 2006 GIOVE-A generated the first ever Galileo signal-in-space and thus began the process of securing the Galileo frequency filing.

BACKGROUND

2.1 SSTL’s Geostationary Mini-Satellite Platform

Early in 2000, under the British National Space Centre’s MOSAIC initiative for small satellite missions SSTL began to develop the Geostationary Mini-Satellite Platform (GMP). GMP is primarily targeted at telecommunications missions with a secondary aim of providing a platform for other applications and orbits with payload masses in the range of 80-250 kg and payload power requirements in the range 0.5 – 2.5 kW. The geostationary minisatellite platform is a hybrid design based on the existing SSTL enhanced microsatellite and minisatellite platforms, with a highly integrated modular avionics architecture, based largely on internally developed sub-systems and platform equipment. Figure 1 below shows a typical configuration for a GMP telecom mission in the geostationary orbit.
Two variants of the GMP are being developed by SSTL to take advantage of a set of different launch scenarios:

- **Geostationary Mini-Satellite Platform - Direct Injection Variant (GMP-D).**
  This variant relies on the upper stage of the launch vehicle to place the satellite directly into its operational orbit. The GMP-D is scalable and can accommodate a range of payloads of up to 2.5 kW with mission durations of up to 10 years. The low end, low cost version is tailored for smaller capacity payloads with shorter lifetime requirements.

- **Geostationary Mini-Satellite Platform - Transfer Variant (GMP-T).**
  This vehicle will attain its operational orbit by transferring from a geostationary transfer orbit using an apogee engine. It is designed to take advantage of a wide range of more traditional launch opportunities. This platform can accommodate the same size payloads as the larger version of the GMP-D but with additional external real-estate available for antennas.

### 2.2 Mini-Satellite Navigation System

In parallel with the definition phase of Galileo, SSTL studied the possibility of using the GMP as the basis of a mini-satellite navigation system (MSNS). A feasibility assessment was completed early in 2002 based upon the GMP platform carrying a dedicated navigation payload in the MEO orbit. A 12-satellite constellation was defined which, when combined with the GPS system, would provide a significant improvement in navigation performance for the users and would also provide a degree of independence from GPS. MSNS offered Europe the possibility of an “early entry” Galileo system at relatively low cost. As well as studying the embarking of regenerative payloads SSTL also looked at the possibility of embarking a transparent navigation transponder similar to the navigation payload carried by the Inmarsat-4 satellites and planned to be used for the EGNOS and WAAS augmentation systems. The accommodation of this payload on the GMP-D was proved to be feasible.

### 3 DESCRIPTION OF THE SATELLITE

#### 3.1 Payload

The GIOVE-A payload configuration is of a regenerative design, generating navigation signals on either E5a, E5b, E6 or E2L1E1 channels. A simplified block diagram of the navigation payload elements is shown in Figure 2.

The function of the regenerative navigation payload is to retrieve data uploaded to the satellite via the platform’s S-band RF system, generate the appropriate navigation messages, ranging signals and spreading codes and then modulate them onto one of the four navigation channels. The back-up payload shown, has SSTL substitute designs to replace any or all of ESA’s Customer Furnished Items (CFI) units comprising the signal generation chain, and is carried only as a mitigation against schedule risk should any of the CFI units not be available on time.

The payload configuration includes dual signal generation and up-conversion stages, one based on a SSTL design and the other on ESA furnished GALILEO payload equipment. Together with the switched transmitter stage, the payload provides the necessary redundancy for single channel transmissions, thereby fulfilling the primary mission requirements.

The navigation payload comprises the following main elements:

- **CFI Signal Generator Chains** – for the generation, storage and buffering of navigation data, ranging and spreading codes. The navigation signal generator provides control and programmability of the generation, content and format of the navigation messages and selection of the data rates, spreading and ranging codes. The navigation data is then modulated to generate the desired signal and upconverted to the final output frequency. For redundancy, two CFI chains are embarked.

- **SSTL Signal Generator Chain** – the 3rd signal generation chain for the generation of a navigation signal sufficient to fulfil the frequency filing protection requirements. As with the CFI signal generator chain, the SSTL chain performs the navigation message generation, modulation and upconversion.
• Transmit chain – provides switching, channel amplification, gain control, high power amplification and filtering of the navigation signal. Two transmit chains are employed, one for the upper band and the other for the lower. The transmit chains are configured so that they can be switched to provide redundancy in single-channel operation.

• Timekeeping system – contains two rubidium atomic frequency standards and a clock control unit containing a phase lock loop to generate the 10.23MHz output clock.

• Antenna – a single iso-flux L-band antenna with three inputs is used for transmission of the navigation signals. This antenna has been designed specifically for the GALILEO programme and provides an antenna pattern consistent with the frequency filing.

• Platform S-band TT&C transmitter and receiver – the regenerative navigation payload makes use of the platform TT&C receivers and transmitters to uplink, via the platform OBC, non-real time payload data which is then converted into the navigation messages by the payload processor, and to acknowledge correct receipt of the navigation data.
Figure 2. Payload design.
3.2 Platform

The GMP is designed to be tolerant of a single point failure in any of the subsystems. This platform architecture is given below in Figure 3.

A detailed definition of the platform is provided in [1]. The main characteristics of the platform are:

**Structure & Thermal** - the structure is designed to be modular with separate propulsion, avionics and payload bays for ease of AIT. The structural frame uses aluminium honeycomb and thermal control is achieved mainly passively with the north/south Y panels being used as radiator surfaces for the payload. The dimension of the satellite when stowed ready for launch is 1.3m x 1.3m x 1.8m.

**Power** – the power generation is via a pair of sun-tracking solar array wings populated with silicon cells. The GMP design makes use of elements of the Main Error Amplifier, BCRs, BDRs and PDMs flown on previous SSTL missions. The power subsystem provides a 28V unregulated bus (from the battery) and a 50V regulated bus. Power storage is via a Li-Ion battery.

**AOCS** – the AOCS makes use of the following hardware:

- **Sensors:** Earth Sensors, Sun Sensors, Gyros
- **Actuators:** Reaction Wheels, Thrusters, Torque Rods
- **Control:** On-Board Computer, AOCS Interface Module, Attitude Safety Module (ASM)

**OBDH** - the On-Board Computer (OBC) used by GMP is the SSTL OBC695 development that makes use of the single chip implementation of the ERC32 processor. This OBC provides the GMP with a high performance, rad-hard processor appropriate for the processing and lifetime demands of the SSTL GEO spacecraft. For GIOVE-A the OBC695 is embarked as a payload computer and the central OBC is SSTL’s OBC386 based on an Intel microprocessor.

The avionics architecture makes use of the SSTL open ‘plug ‘n’ play’ bus architecture provided by the use of the dual redundant Controller Area Network (CAN) bus.

**Comms** - the RF subsystem has SSTL-built S-band receivers and transmitters with antennas positioned for full 4π coverage. It is fully redundant and the receiver allows direct commanding of any equipment connected to the CAN bus.

**Propulsion** - for GMP-D, a monopropellant catalytically decomposed hydrazine system is being developed at SSTL. For GIOVE-A there is a much more limited requirement for delta-v than for a telecom mission so that the hydrazine system is replaced by a butane system using SSTL’s own resistojet thrusters whilst retaining much of the GMP hydrazine system.

The physical layout of the satellite is illustrated below.
Technology Centre (ESTEC) for the Environmental Test campaign.

The spacecraft has been integrated and tested in the three bays (Avionics Bay, Propulsion Bay and Payload Bay).

**Figure 5. Integration of the platform at SSTL.**

The ESA furnished navigation and timing payloads were delivered to SSTL between January and June 2005. These were integrated and tested in the payload bay with the SSTL payload elements and high-power transmit chains. The payload bay then underwent around three weeks of thermal cycling in SSTL’s thermal chamber. During this time the various payload modes and performance characteristics were tested. In parallel, in early June 2005, the Avionics Bay was integrated to the Propulsion Bay to form the complete platform. The platform then underwent just over a week of thermal cycling during which all the platform systems were exercised at extreme temperatures.

At the beginning of July, the platform and payload were finally brought together and integrated to form the complete GIOVE-A spacecraft. Following this the final major integration activity took place: the integration of the payload antenna.

**Figure 6. Integration of the payload antenna onto the GIOVE-A spacecraft at SSTL.**

Towards the end of July the spacecraft was shipped to the European Test Services (ETS) Facilities at ESTEC, Noordwijk, Netherlands, for the Environmental (EVT) campaign. The entire test campaign was performed at ESTEC, and comprised Thermal Vacuum and Balance testing, Acoustic, Vibration, Mass Properties, EMC and functional testing.

**Figure 7: GIOVE-A spacecraft being prepared for environmental testing at ESTEC**

The duration of the EVT campaign was a little over three months. After its successful completion the spacecraft was ready to ship to the launch site.

5 LAUNCH AND EARLY OPERATIONS

In December 2005 GIOVE-A was shipped to Baikonur and the launch campaign started. The launch vehicle was a Soyuz rocket with a Fregat upper stage to directly inject GIOVE-A into the Galileo orbit.

**Figure 8. Integration of GIOVE-A with the Fregat upper stage.**
The launch took place on 28th December. Within a few hours of the launch and two minutes after separation from the Fregat, the Guildford control centre established contact with the satellite, performed an initial checkout and initiated the deployment of the solar arrays within two hours and ahead of schedule. The next day the radiation monitoring payloads were activated. GIOVE-A was operating successfully in the Galileo orbit.

On the 12th January at around 1730 GMT the first Galileo signal-in-space was broadcast from the satellite and the signal received at both Chilbolton in the UK and Redu in Belgium. The quicklook print of the signal is reproduced below.

**Figure 9. Launch of GIOVE-A.**

Over the following week the platform commissioning was completed and the satellite was ready for payload operations.

### 6 Payload Operations

The navigation payload commissioning commenced on the 10th January with a complete checkout of the low-power equipment. These operations went to plan and the decision was taken on the 12th January to power on the high power equipment and to generate the first Galileo signal.

**Figure 10. Payload commissioning at RAL facility in Chilbolton, Hampshire.**

In the weeks following the initial signal all of the Galileo signals were exercised and the missions four major requirements have been fulfilled.

### 7 Summary and Conclusions

SSTL has demonstrated through this project that its low-cost rapid-response approach to satellite development can be applied to a higher class of mission than had previously been thought possible. SSTL’s development approach to microsatellites has now been applied to a much larger satellite in the half tonne class. The customer benefited from this in several significant ways:

- a satellite was procured for a very large saving when compared to a more traditional approach,
- the satellite was delivered on time,
- the satellite performed as planned and allowed the customer to achieve his major aims, particularly the in-orbit validation of the Galileo payload technology and the claiming of the rights to the frequencies.
8 REFERENCES


9 ACKNOWLEDGMENTS

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