CURRENT STATUS AND PERFORMANCE

Onboard Galileo Atomic Clocks

The European Commission and the European Space Agency have approved the Galileo GNSS programme. Two experimental satellites will be launched in late 2005 or early 2006. Atomic clocks are critical for satellite navigation. After more than ten years of development and an overall budget of â‚¬ 30M, two onboard clock technologies have been qualified. The author considers their current status and performance.

Galileo is a joint initiative of the European Commission and the European Space Agency (ESA) for building a state-of-the-art global navigation satellite system (GNSS). Galileo will provide a highly accurate, guaranteed global positioning service under civilian control and will be interoperable with GPS and GLONASS. The final Galileo system will consist of thirty satellites, 27 operational and three active spares, stationed on three circular Medium Earth Orbits at an altitude of 23,222km, with an inclination of 56Âº to the equator.

GSTB-V2
Atomic clocks are critical for GNSS. The Rubidium Atomic Frequency Standard (RAFS) and Passive Hydrogen Maser (PHM) are the projected onboard clock technologies for Galileo. Every satellite will embark two RAFSs and two PHMs; dual technology is necessary to ensure reliability (technology diversity) and satellite lifetime of twelve years. The development of RAFS and PHM are based on studies done by the Observatory of NeuchÃ¢tel late1980s and by Temex NeuchÃ¢tel Time (TNT) since 1995. The studies are supported by ESA. The activities related to Galileo System Test Bed (GSTB-V2) experimental satellite and implementation of the In Orbit Validation Phase are in progress. Two experimental satellites with a lifetime of three years will be launched in late 2005 or early 2006 aiming at:

- securing Galileo frequency filings
- testing some critical technologies, such as the atomic clocks
- experimenting with Galileo signals
- characterising Medium Earth Orbits environment.

Nine flight model clocks are being produced for the GSTB-V2 experiment: six RAFSs and three PHMs. Prior to launch, both types of clocks are subject to electronic tests and shock and vibration tests.

RAFS Milestones
The development of RAFS technology began at TNT in 1997. In 2000 one RAFS1 Engineering Model was completed. Updated RAFS1 development began in June 2000 and was completed in early 2002. These activities included:

- improvement of clock stability with insertion of thermally regulated base-plate to better than 4*10-14 at 10â€™000 sec
- review of electronics package layout and components
- manufacture of five Engineering Qualification Models for lifetime qualification
- manufacture of one Qualification Model.

In addition to the vibration and qualification tests, two radiation tests were carried out at CNES in Toulouse. The first, which simulated Galileo orbit (four cycles of 3rad per day during one week), showed no frequency radiation sensitivity. The other test, which simulated the total dose over the duration of the mission (30 krad, continuous radiation at 400 rad/h during three days) showed no electronic failure or performance degradation, although the drift of the crystal oscillator needed compensation; subsequent models have been modified accordingly.
RAFS2, initiated at the end of 2001 and completed at the beginning of 2003 with the delivery of an Engineering Model, is the baseline unit for development of the flight models for GSTB-V2. Two main objectives were achieved:

- further optimisation of the physics package to reduce flicker floor to better than 3*10-14 (drift removed: 2*10-14 /day)
- inclusion of a DC/DC converter and the satellite TT&C interface compatible with new ESA requirements.

PHM Milestones
The space hydrogen maser will be Galileoâ€™s master clock. The first maser development for navigation applications, kicked off in 1998, was initiated by the development of an active maser at Observatory of NeuchÃ¢tel. However, the Galileo definition phase showed that the active maser was too heavy and too voluminous, whilst its excellent frequency stability was not required. Therefore, in 2000, development was re-orientated towards building a PHM. The development of the PHM Engineering Model was completed in early 2003. Since June

2003 the instrument has been continuously tested to assess long-term performance and early identification of reliability and lifetime problems. Manufacturing for future flight production began in January 2003. The instrument was redesigned by Temex NeuchÃ¢tel Time to increase compactness and ease assembly, integration and on-satellite testing by the inclusion of an external vacuum envelope. Main efforts focus on repeatable and reliable manufacturing. Two technological models, one structural and one Engineering Qualification Model were built. In addition, five Qualification Models are being manufactured for life demonstration. One Proto-Flight Model (Figure 5) is completing proto-qualification testing and is now integrated in the GSTB-V2 satellite. A second Flight Model is about to be delivered.

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