

# ESA Investigates Galileo Clock Anomalies



As first reported last November, anomalies have been noted in the atomic clocks serving Europe's Galileo satellites. Highly accurate timing is core to satellite navigation. Each Galileo carries four atomic clocks to ensure strong, quadruple redundancy of the timing subsystem: two Rubidium Atomic Frequency Standard (RAFS) clocks and two Passive Hydrogen Maser (PHM) clocks. The current Galileo constellation consists of 18 satellites in orbit, adding up to a total of 36 RAFS clocks and 36 PHM clocks in orbit.

## RAFS clocks

In recent months a total of three RAFS clocks have undergone unexpected failure on Galileo satellites – all on Full Operational Capability (FOC) satellites, the latest Galileo model. These FOC RAFS clock failures all seem to have a consistent signature, linked to probable short circuits, and possibly a particular test procedure performed on the ground, with investigations continuing to identify a root cause.

No RAFS clock failures have occurred aboard the four Galileo In Orbit Validation (IOV) satellites, the original Galileo model. In addition the RAFS clock on ESA's very first test navigation satellite, GIOVE-A launched in 2005, has been checked, and was reactivated successfully. Ongoing investigations on the ground have identified potential weaknesses in the RAFS clock design, but no root cause is yet established.

## PHM clocks

In the past two years, there have been five PHM clock failures on the IOV satellites and one PHM clock failure on the FOC satellites. These failures are better understood, linked to two apparent causes: one is a low margin on a particular parameter. The second is related to the fact that when some healthy PHM clocks are turned off for long periods, they do not restart due to a change in clock characteristics in orbit. To date one PHM clock has failed due to the first mechanism, and five due to the second mechanism.

## Corrective actions

For the remaining 33 RAFS clocks working in orbit, the risk of failure is believed to be lower due to different testing scenarios on the ground. In addition, new operational measures have been put in place to further mitigate the risk. All these measures have no impact on Galileo's overall performance.

While investigations by ESA and its industrial partners are continuing, there is consensus that some refurbishment is required on the remaining RAFS clocks still to be launched on the eight Galileo satellites currently being constructed or tested.

For the remaining 30 PHM clocks working in orbit, operational procedures are being studied to significantly reduce the risk of future failure. These measures are currently being validated, ahead of their planned introduction in a few weeks. A plan to refurbish the remaining PHM clocks still to be launched is currently being finalised. For procurement of future PHM clocks, design modification is being considered to significantly increase operating margins and avoid the problems experienced to date.

## Looking forward

Overall, three out of four IOV satellites have experienced clock anomalies, and two out of 14 FOC satellites.

As ESA Director General Jan Woerner commented during his [18 January press briefing](#), no individual Galileo satellite has experienced more than two clock failures, so the robust quadruple redundancy designed into the system means all 18 members of the constellation remain operational.

Similarly, Galileo's Initial Services, [which began on 16 December](#), have been unaffected by these anomalies.

The impact of RAFS and PHM clock refurbishment onto Galileo's launch schedule is under study, but at this point ESA is confident it will resolve the issue and remains committed to launch the next four Galileo FOC satellites before the end of this year.