DWE Calibration Report

This document gives a summary report on the DWE-TUSO performance during in-flight check-outs and pre-launch tests and provides a description of the final DWE calibration.

Tests at Unit Level

The DWE-TUSO aboard Huygens is the QFS model. It was selected for flight, because during pre-launch unit level tests, it showed a better performance regarding frequency stability, the primary DWE concern, than the flight model.
The accuracy of the nominal USO output frequency was specified to be better than 10^{-8}. At S-Band, this corresponds to a range of $\pm$20 Hz around the nominal 2040 MHz. Using the thermal vacuum (TV) test campaign, performed 1995 at USO level prior to the integration of the USOs into the Cassini/Huygens radio system, we were able to find a mean offset level (at S-Band) of +9.2 Hz for the TUSO-QFS. This value was measured using a frequency reference with a significantly higher stability than that of the USOs. The random variation of this number was about $\pm$0.6 Hz. It can, however, not be excluded that frequency reference used during the unit level TV tests had an additional systematic error of similar magnitude due to aging, retrace errors and temperature effects (information given by USO manufacturer). Retrace effects may have also had an impact on the TUSO offset during the cruise to Saturn, whereas aging effects are unlikely due to the relatively short total operation time.
From one particular test of the TV test campaign at unit level, we were able to reconstruct the temperature dependence of the TUSO-QFS output frequency, albeit with only four measurement points. This dependence is displayed in Fig. 1. As the TUSO environmental temperature

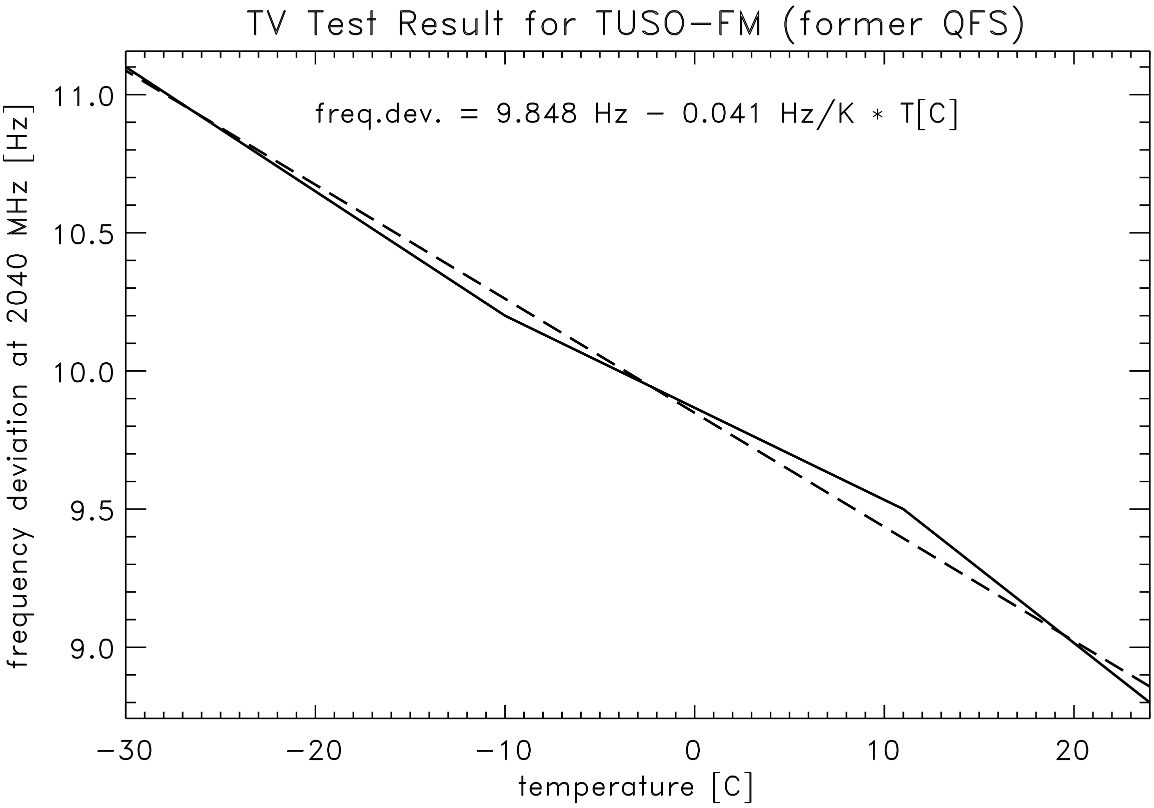

Figure 1: Temperature dependence of TUSO output frequency. Solid line: measurements, dashed line: linear regression.

during the mission at Titan, displayed by the TUSO box temperature parameter (see Health Report in the DOCUMENT directory), decreased by $\sim$10 K over the descent, the TUSO output frequency may have increased by $\sim$0.4 Hz. Taking into account the unknown accuracy of TUSO box temperature parameter and the smallness of the frequency increase (0.4 Hz corresponds to $\sim$12 cm/s zonal speed), it was decided to neglect this effect.

In-Flight Tests

DWE participated in 13 (out of 16) in-flight checkouts of the Huygens Probe and measured the frequency residuals between transmitter (TUSO) and receiver (RUSO). It has been shown for the originally planned DWE (frequency measurement aboard Cassini; see thesis in the DOCUMENT directory) that the exact values of the TUSO and RUSO output frequencies were negligible. The result depended primarily on the offset frequency between transmitter and receiver only. As transmitter (Huygens) and receiver (Cassini) did not move with respect to each other during the cruise to Saturn, the expected value of this offset was 0. A summary of the measurements is shown in Fig. 2.

Three features of this plot are noteworthy:

1) The behavior was remarkably similar in all checkouts.

2) The mean frequency (white solid line) displays an oscillation. It stems from an oscillation of the original frequency measurements (black dot cloud). The oscillation frequency was stable at 0.367 Hz in all checkouts, whereas its amplitude, plotted as the vertical extend of the black dot cloud, varied during a checkout. The oscillation frequency is an alias of the USO servo frequency of 135.633 Hz. This frequency oscillation was observed before the launch already, albeit with a rather small amplitude of $\sim$6 Hz peak-to-peak (p-p). The increase of the amplitude after the mating of Huygens to Cassini, however, remained a puzzle. The same behavior was observed also in tests of the Huygens receiver aboard Cassini (Probe relay tests, PRT), which involved a simulated Huygens signal from Earth instead of the real Huygens signal. These tests were performed between 2000 and 2003 after the discovery of a flaw in the signal decoding. From these tests, we concluded that the most likely reason for this effect is a spurious signal from the receiver itself (probably from the RUSO), which is detected by the receiver and mixed with the actual signal. This effect is thus produced in the receiver and not a characteristic of the transmitted signal. This result led to the conclusion that this effect has no impact on the frequency measurements obtained by Earth-based telescopes.

3) Upon closer inspection of this anomaly, we realized that the amplitude of the frequency oscillation was correlated to a drift of the mean frequency. This correlation is displayed in Fig. 3. The maximum frequency oscillation amplitude seen during a checkout or PRT was $\sim$30 Hz p-p. Within this range, all results, with the exception of the first checkout F1 (which was probably an exception anyway regarding environmental conditions), are consistent. The correlation has a random error of 0.65 Hz, which marks about the accuracy of the frequency measurement for this measurement scenario. A systematic trend of the TUSO-RUSO offset is not visible, which is an indication for negligible aging and retrace effects of the USOs.

Offset Calibration during Surface Phase

As mentioned in the section above, the actual offset from the nominal 2040 MHz of TUSO and RUSO was negligible for the Cassini-based DWE. The crucial parameter for calibration was the residual frequency between RUSO and TUSO only, which was measured in every checkout. For the Earth-based DWE, the situation was different. The residual frequency between the TUSO and an H-maser driven radio antenna tuned to 2040 MHz (plus expected Doppler shift) has never been measured. As the accuracy of the radio antennas is a few magnitude better than that of the USOs, we needed to know the offset of the TUSO to high accuracy.

This was achieved using the DWE measurement itself. When Huygens is at rest on the surface of Titan, all velocities necessary to calculate the Doppler shift are known to high accuracy. The only constraint for this kind of calibration is that the result should be consistent with the pre-launch measurements mentioned above, i.e. the +9.2-Hz-offset found from the evaluation of unit level TV tests.

The TUSO frequency deviation from the nominal 2040 MHz obtained by this method is +10.0 Hz. Considering the accuracy of the +9.2 Hz (see first section of this report), this result is in agreement with the pre-launch findings. The result, of course, depends on the assumed observation geometry. A shift of 0.1° in longitude would modify it by 0.44 Hz, a shift of 0.1° in latitude by 0.16 Hz. The landing site found by DWE by integration of the zonal speed and applying the latitude profile obtained by the descent imager (DISR) is, however, consistent with the landing site found by a comparison of a Cassini radar image with the DISR images (deviations: 0.03° in longitude, 0.02° in latitude). It is therefore justified to assume that the actual transmitter carrier frequency was $2,040,000,010$ Hz.

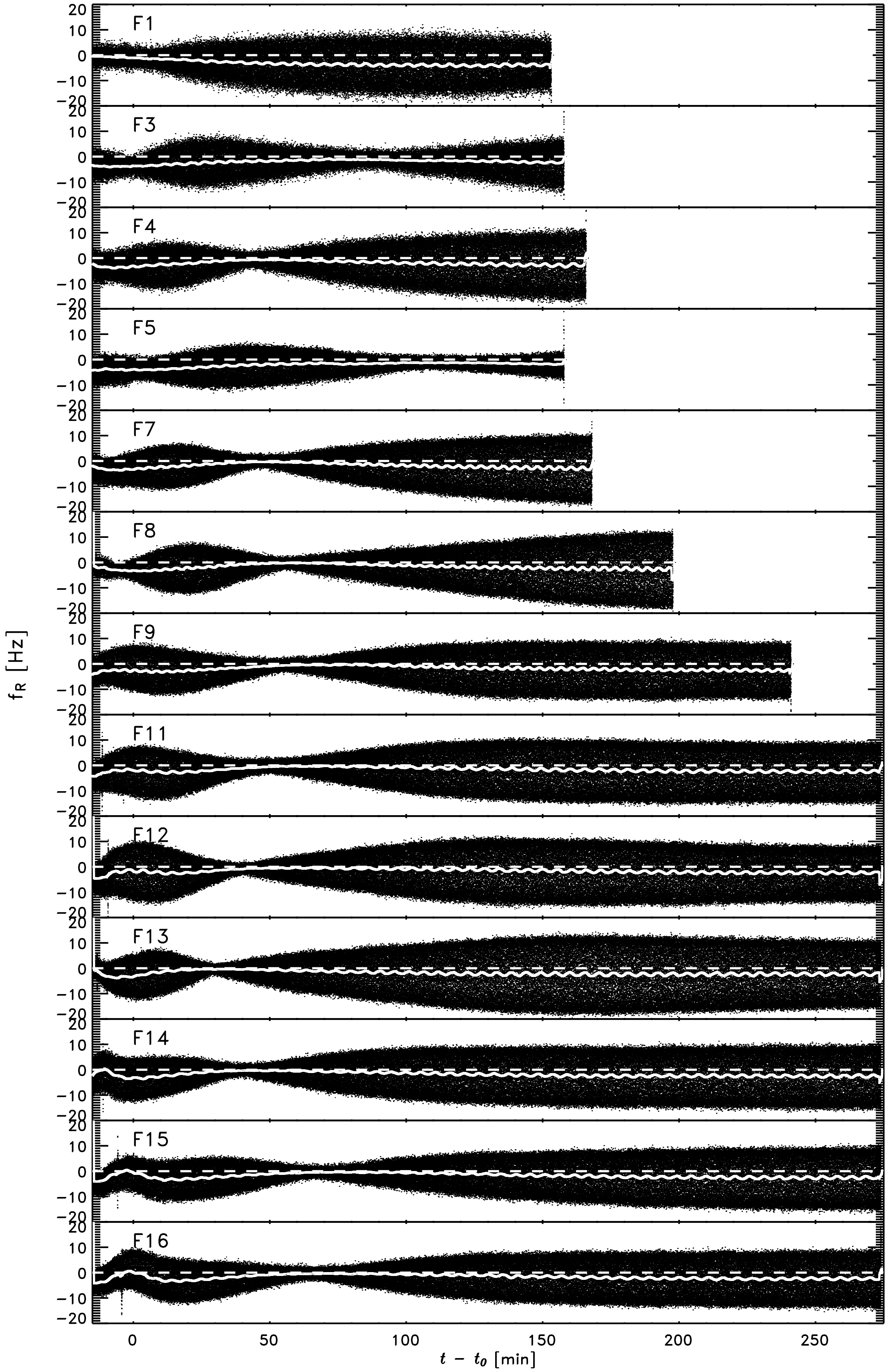

Figure 2: Summary of in-flight checkout results.

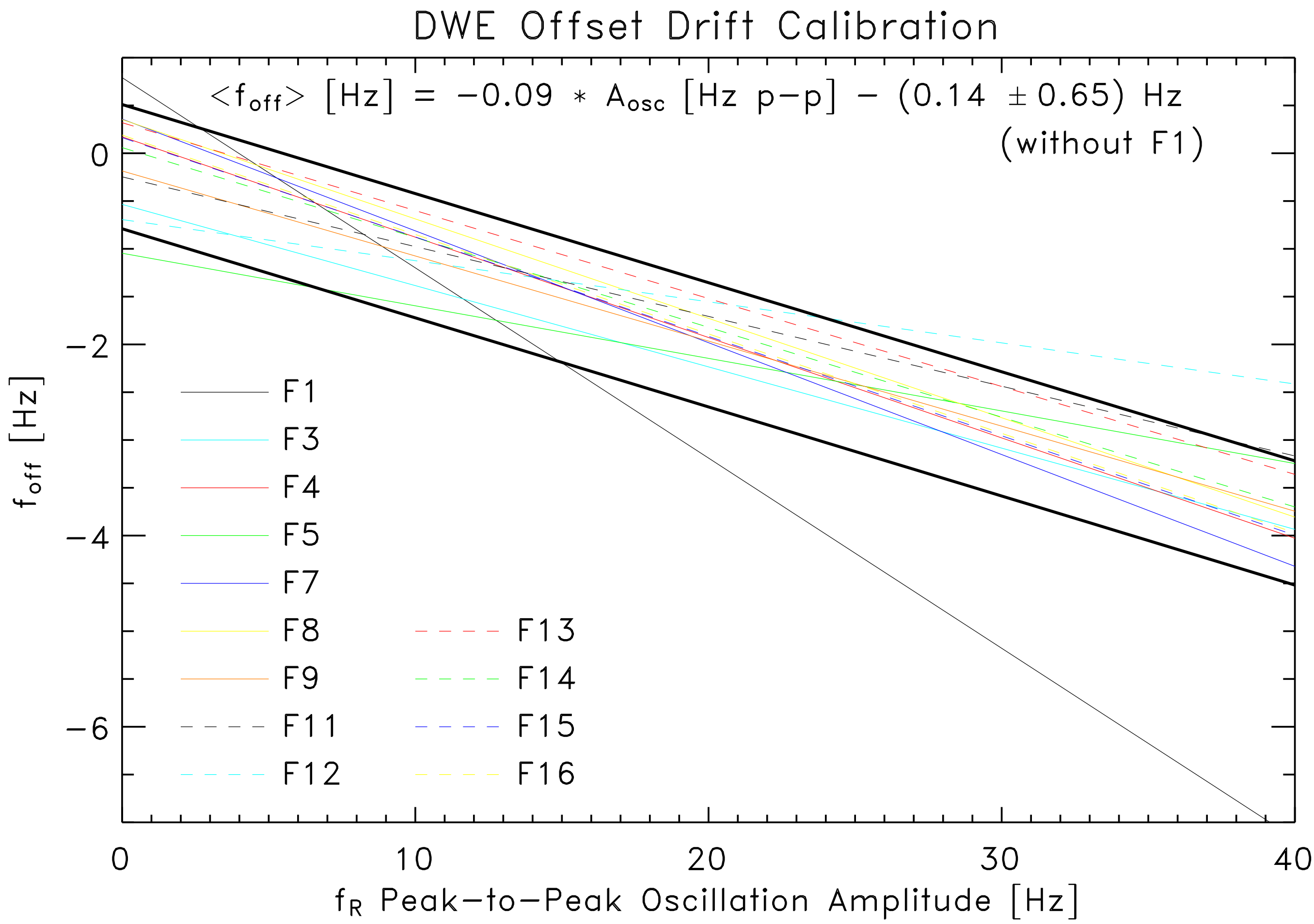

Figure 3: Correlation of frequency oscillation amplitude and frequency drift.