TerraSAR-X Ultra Stable Oscillator Temperature Drift Compensation

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After 15 years of successful radar operations in space, the German SAR satellite TerraSAR-X (TSX) showed peculiarities in the frequency of the Ultra Stable Oscillator (USO) since 1st of Nov. 2022 13:56 UTC. In the bistatic configuration with TanDEM-X the oscillator frequency can be monitored very precisely. The difference frequency between both systems in the analog-to-digital converter sampling frequencies Δf_{ADC} (which is derived from the USO frequencies) is monitored continuously because it is an important parameter for the bistatic processing. The measurements used to be very stable due to the excellent quality of the USOs. However, from that point in time on there was a high variability, even affecting the quality of processed products. This variation could be traced back to frequency variations on TSX and the telemetry of the USO box clearly indicated an issue. In Figure 1 on the left the current consumption of the USO box is shown in blue. A peak of the current shortly before 14:00 UTC is visible, followed by a strong fluctuation afterwards.

The current consumption of the USO box comprises both the actual oscillator and the internal heating circuitry as it is an oven-controlled crystal oscillator (OCXO). The power consumption for the heating is dominating. The current measurements indicated a failure of the internal temperature regulation circuitry. However, it is technically not possible to switch off the temperature regulation independent of the oscillator. As a solution, the whole USO box was brought to a different (increased) temperature level by raising the ambient temperature via an external heater in order to decrease the stress for the internal heating circuitry and improve the temperature stability of the USO by external heating. On the right of Figure 1 the temperature of the USO box is shown in red. After the heater is switched on around 15:00 UTC, the temperature is increasing and in a similar fashion the current fluctuation is decreasing.

The increased temperature level initially led to very stable Δf_{ADC} measurements during the first day as shown on the very left side of Figure 2. However, a higher variability was experienced afterwards. Those fluctuations are not random, but the frequency is fairly stable within a data take. The bistatic TanDEM-X mission could cope with this USO behavior due to the inherent synchronization signal exchange within each bistatic acquisition. Nevertheless, the geolocation accuracy is affected. Even though the distortion is low and does not violate the mission requirements, there is a degradation compared to the very high precision provided during the complete mission lifetime [1].

The observed frequency variation is highly correlated with the temperature of the USO box. Unfortunately, a frequency estimate can only be generated for bistatic acquisitions and is not available for processing monostatic acquisitions.

A detailed analysis of the frequency vs. temperature correlation and the whole ground segment revealed the possibility to consider a temperature variant sampling frequency in the processing. This requires the derivation of compensation laws, the forwarding of the temperature telemetry for processing and an update of the operational processors for both, the monostatic (TerraSAR-X Multimode SAR Processor, TMSP) and the bistatic (Integrated TanDEM-X Processor, ITP) missions.

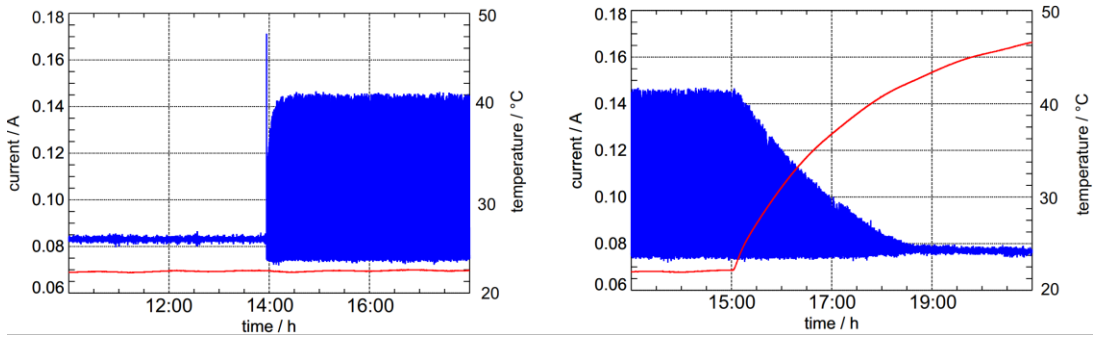

Figure 1 Current (blue) and temperature (red) of the redundant USO of TSX. On the left the failure around 14:00 UTC on the 1st of Nov. 2022 is visible, when the current starts to fluctuate strongly after an initial peak. On the right the intended increase of the temperature of the USO is visible which leads to a significant decrease of the current fluctuation. The external heater was switched on around 15:00 UTC on the 8th of Nov. 2022.

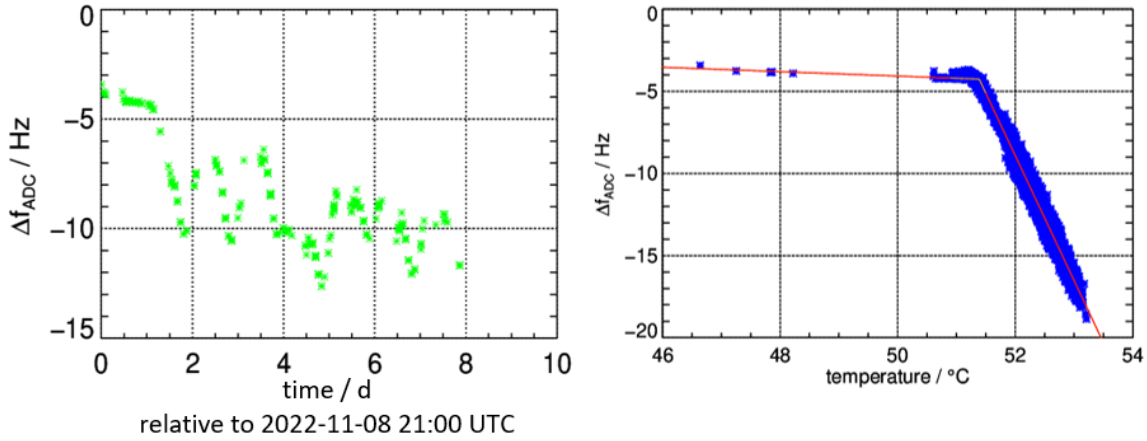

Figure 2 Measured Δf_{ADC} frequency after the external heater was switched on. A relatively stable phase at the beginning is followed by a variation which shows a high correlation with the temperature of the USO box (left). Sectionally linear fit for the temperature dependency of the Δf_{ADC}. Blue points represent measurements (form bistatic TanDEM-X mission data takes). The red lines are the linear fits over restricted pre-defined temperature intervals (right).

The oscillator and sampling frequencies show a linear dependency on the temperature of the USO box over certain temperature ranges. On the right of Figure 2 the sectionally linear fit of Δf_{ADC} versus temperature is depicted in red. The fit is derived from Δf_{ADC} measurements provided by bistatic acquisitions as shown in blue. The Δf_{ADC} measurements vary over a range of approximately 15 Hz over the considered temperature range. Applying the linear fit during processing of the data takes, the frequency can be estimated with a standard deviation below 1 Hz which is the same order of magnitude of the frequency knowledge before the anomaly [2], [3].

In conclusion, we will show at the workshop how we can maintain the excellent performance of TSX despite the new challenges the ageing instrument poses.

[1] T. Fritz et al., “TerraSAR-X basic product specification document,” DLR Public Document TD-GS-PS-3302, Tech. Rep. 1.9, 2013, available at: https://sss.terrasar-x.dlr.de/docs/TX-GS-DD-3302.pdf

[2] U. Balss, H. Breit, T. Fritz, U. Steinbrecher, C. Gisinger and M. Eineder, "Analysis of internal timings and clock rates of TerraSAR-X," *2014 IEEE IGARSS*, Quebec City, QC, Canada, 2014, pp. 2671-2674.

[3] U. Balss, C. Gisinger, M. Eineder, “Measurements on the Absolute 2-D and 3-D Localization Accuracy of TerraSAR-X,”. Remote Sensing. 2018; 10(4):656.