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Time Domain Modeling of InSight/SEIS VBB and SP Frequency Calibrations on Earth and on Mars

R. Widmer-Schnidrig[(1,2)], E. Wielandt[(2)]
N. Verdier[(3)] , Ph. Lognonné[(4)], T. Pike[(5)] and the SEIS team

(1) Black Forest Observatory (BFO), (2) Stuttgart University
(3) CNES Toulouse, (4) IPGP Paris, (5) Imperial College, London

InSight

Universität Stuttgart

Fig. 1

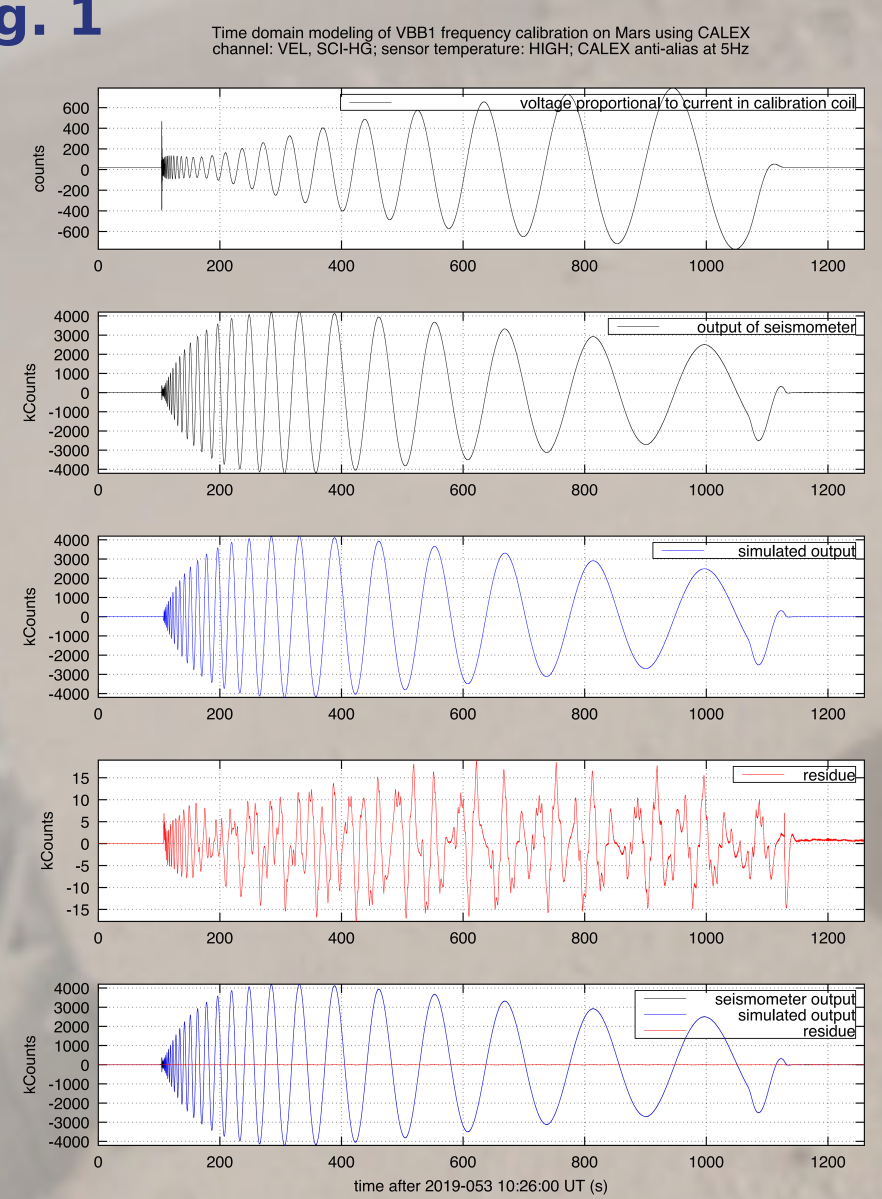

Fig. 1 Modeling of a voice coil calibration of sensor VBB1, VELocity high-gain channel. In the five panels is shown (top-to-bottom) (1) the input current to the calibration coil, (2) the measured seismometer rsponse, (3) the synthetic response, (4) the residue: difference between traces (2) and (3) and finally (5), a combined plot of the traces from panels 2,3 and 4. The syntetic trace can reproduce the data well: the rms-amplitude of the residue is only 0.5% of the total signal. Note the low back-ground noise level on Mars at end of traces. The residue is signal generated and points to imperfections of the linear model.

Fig. 2

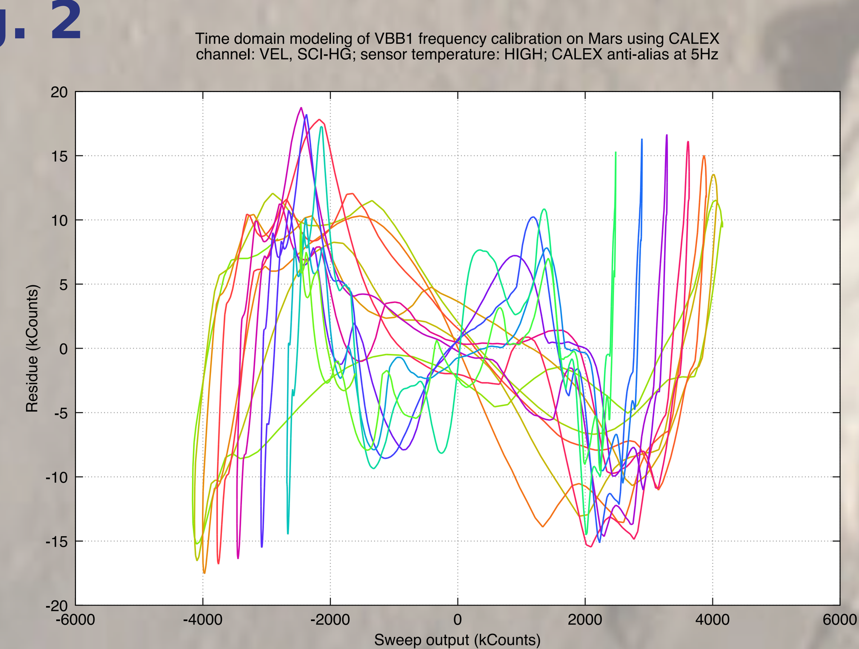

Fig. 2 Analysis of residue from Fig. 1: the residue is ploted against the output signal. Progression in time is color coded. A polynomial up to order five with dominant odd order terms is needed to model this non-linear behaviour.

Introduction

Inertial seismometers such as the VBB and SP sensors in the InSight/SEIS instrument package (Lognonné et al, 2018) convert ground motion into an electrical signal. The sensitivity of the seismometers is frequency dependent and in order to estimate this frequency dependence each of the six seismometer components of SEIS is equipped with calibration coils. An electrical current flowing through the calibration coil exerts a force on the seismometer proof mass similar to a ground acceleration. A calibration experiment then consists in injecting a known electrical current in the coil (input) and recording the response of the seismometer (output). By modeling the transfer function between input and output the frequency response of the seismometer can be estimated.

Ideally a seismometer behave as a linear system. However real-life mechanical and electrical components exhibit also a small non-linear response. On this poster we evaluate the linear part of the VBB and SP instrument response and inspect the residues for evidence of a non-linear component to the response.

The VBB calibration signal consists of a down-sweep from 5Hz to 5mHz and thus only allows a characterization of the VBBs in this band. Furthermore the time-domain amplitude of the initial, high frequency response is small such that this part of the transfer function will be ill constrained if estimated with a least-squares procedure. On this poster we ignore the high frequency roll-off and model only the response in the pass-band and the low-frequency corner. We use impulse-invariant recursive Schüssler-filters for the modeling in the time domain (Wielandt & Forbriger, 2016).

Fig. 3

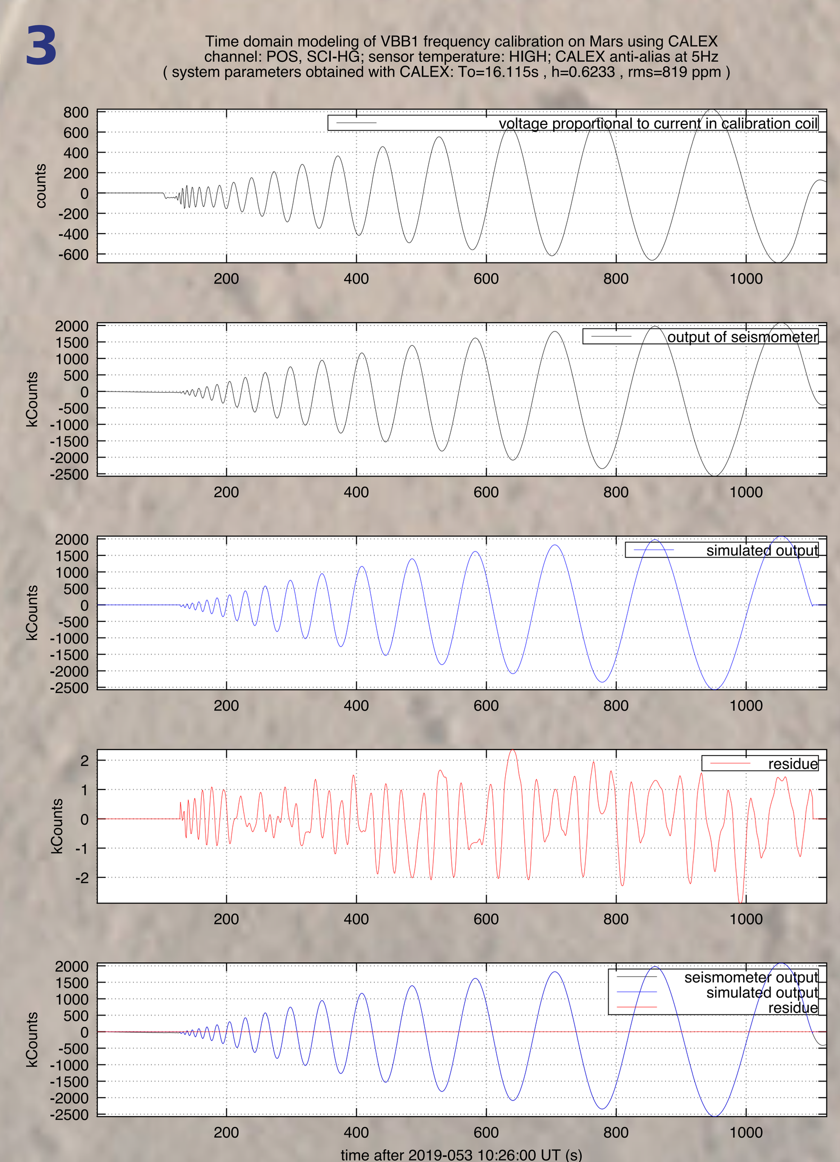

Fig. 3 Same as fig. 1 but for the POSition channel of VBB1. Here the rms amplitude of the residue is even smaller and only 0.1% of the total signal. Clearly the residue is signal generated and points to imperfections of the linear model.

Fig. 4

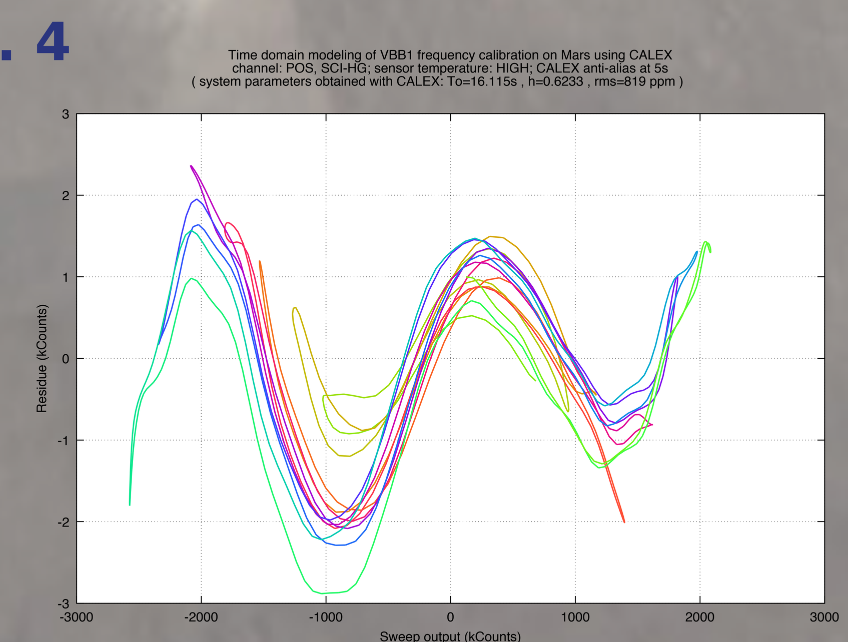

Fig. 4 Same as fig. 2 but now for the VBB1-POS signal from fig. 3 above. This is also a non-linear signal distortion with odd symmetry.

Fig. 5

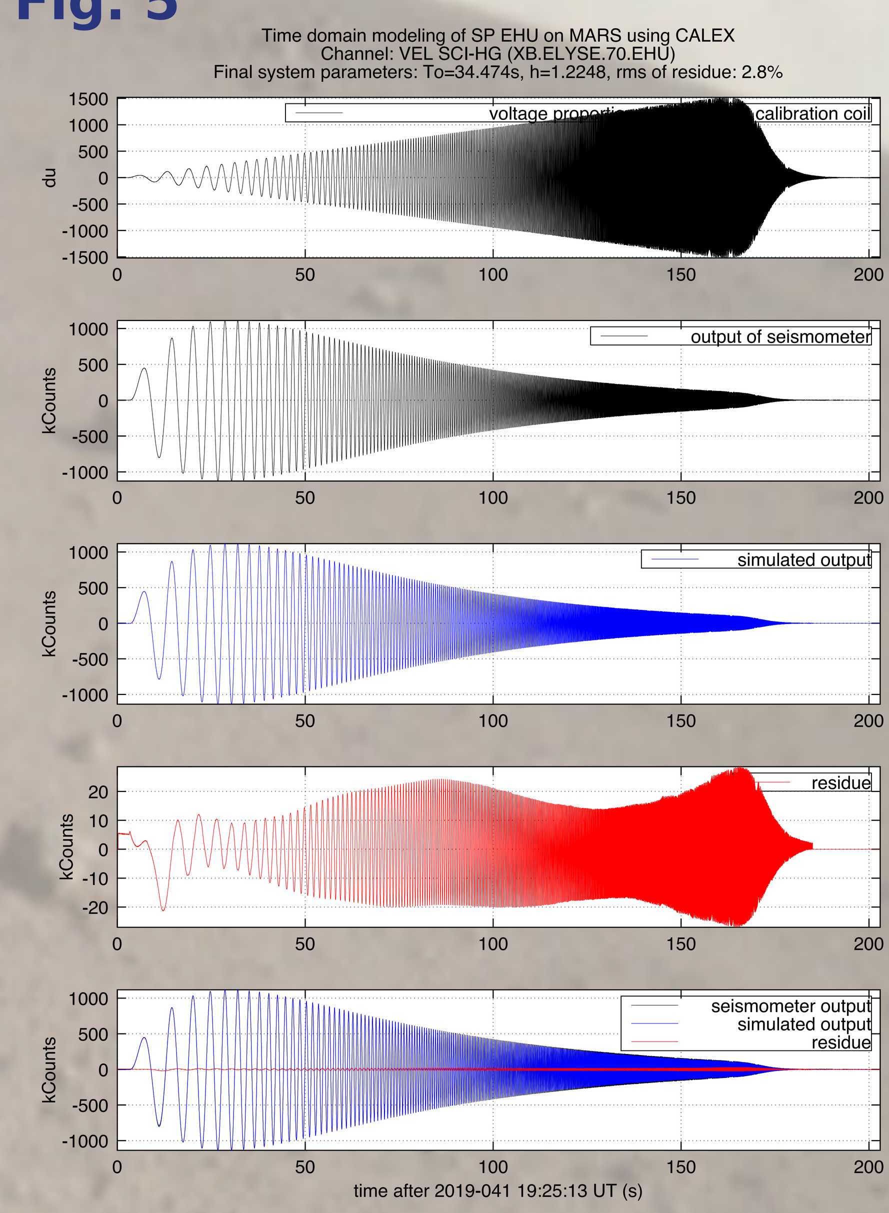

Fig. 5 Same as fig. 1 but for the vertical component SP1 channel. The rms-amplitude of the residue is 2%. The dominant structure of the residue does not point to a non-linear distortion but to an unmodeled linear component. The ~90 degree phase shift points to an unidentified inductance or capacitance. Our best model is an overdamped second order system with corner period T=34.47s and damping h=1.224 . It is unfortunate that the voice coil sweep starts with a period of 8 seconds - too short to reliably estimate the coner period To.

Conclusions

We have evaluated all calibrations of the SP and VBB seismometers (both VEL and POS channels). Both VBB and SP sensor calibrations can be modeled with a simple second order system with only three free parameters: gain, *A*, corner period, T_o, and fraction of critical damping, *h*.

VBB calibrations conducted at -54C, -45C and -35C reveal no temperature dependence of the (linear part of the) transfer function.

The residues obtained in modeling the sweep calibrations conducted on Mars are large compared to the seismic background noise and are correlated with the input signal. This indicates that a linear model is insufficient to fully describe the seismometer response.

All three VBBs show a small non-linear distortion with odd symmetry. This is true both for the VEL and POS channels. Frequency calibrations of the SEIS flight unit conducted in 2017 at CNES in Toulouse (not shown) did not reveal any non-linear response presumably because the CNES vault is too contaminated by antropogenic noise.

For the SP1 seismometer (fig. 5) the residue is dominated by a signal approx. 90° out of phase with the linear model prediction: an (as yet unidentified) unmodeled inductance or capacitance could be generating such a residue.

At this time we are unable to identify the culprit of the VBB non-linearities: both mechanical and electronic components may be responsible. Since the calibration current has not been measured and we only know the digital input to the D/A-converter, the non-linearity may also originate from the D/A-converter. Detailed experiments with the flight spare conducted in a seismically quiet vault may lead to a better understanding

References

Lognonné, Ph. et al., SEIS: Insight’s Seismic Experiment for Internal Structure of Mars. Space Sci. Rev. (2019).
Wielandt, E. and Forbriger, T. (2016): Linux version of program CALEX. open source software. URL: https://git.scc.kit.edu/Seitosh/software-for-seismometry-linux/tree/master/software/calex (visited on 09/18/2017).

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