A SILICON SEISMIC PACKAGE (SSP) FOR PLANETARY GEOPHYSICS. W. T. Pike[1], S. Calcutt[2], I. M. Standley[3], A. G. Mukherjee[1], J. Temple[2], T. Warren[2], C. Charalambous[1], Huafeng Liu[1], A. Stott[1] and J. B. McClean[1], [1]Department of Electrical and Electronic Engineering, Imperial College London, SW7 2AZ, United Kingdom. [2]Atmospheric, Oceanic and Planetary Physics, Oxford University, OX1 3PU, United Kingdom. [3]Kinemetrics Inc., 222 Vista Ave., Pasadena CA 91107, USA. w.t.pike@imperial.ac.uk

As part of the seismic payload for the InSight mission to Mars, a three-axis set of microseismometers, known as SP, was successfully delivered for launch in 2016 [1]. The three micromachined sensors are shown in fig. 1 prior to integration. These sensors are micromachinined from single-crystal silicon by through-wafer deep reactive-ion etching to produce a suspension and proof mass with a fundamental vibrational mode of 6 Hz [2]. Bumpers formed by the reflow of solder balls in cavities formed during the through-wafer etching protect the suspension from damage. The motion of the proof mass is sensed capacitively between an array of parallel electrodes on the proof mass and a matching fixed array on a glass strip separated by a fixed gap from the proof mass. The proof-mass electrodes are protected from damage by shock and vibration through a protective surface dielectric. The seismometer is robust to high shock (> 1000 g) and vibration (> 30 g rms), and the sensor is functional down to 77K, allowing deployment under much harsher conditions than expected for InSight. In addition, all three axes of the microseismometer deliver full performance over a tilt range of ±15 degrees on Mars, allowing operation after deployment without levelling. The sensors are located in three separate packages with a total mass of 460g, including cabling. The sensors operate in feedback with a separate associated electronics board located on the InSight lander with the feedback automatically intiated on power on. The feedback electronics have a mass of 175g, giving a total mass of 635g for the three-axis SP delivery of packaged sensor heads, electronics board and associated connectors and cabling. The power requirement is 360 mW of which 30 mW is consumed in each sensor head.

25 mm

Figure 1 The microseismometer sensor set delivered for the InSight mission

The performance of the microseismometers was determined by coincidence testing with conventional broad-band seismometers with a noise floor at least an order of magnitude lower [3]. This allows the any loss of coherency to be attributed to the self-noise of the microseismometers, subject to minimization of any common environmentally induced terms in the signal. Fig. 2 shows the self noise of the vertical axis of the flight microseismometer determined after integration on the instrument assembly at CNES, Toulouse. Although the cleanroom environment at CNES prevents the determination of the noise at low and high frequencies, within the quiet seismic window from 0.1 to 1 Hz the self noise of the microseismometer is evident with a lower limit of 0.3 ng/rtHz, well below the InSight requirement of 1 ng/rtHz in this bandwidth. A noise model for the microseismometer based on measurements of the transducer gain, proof mass, resonance frequency, quality factor and electronics noise is also shown in fig. 2 and shows good agreement with the sensor-noise performance determined within the window at CNES. The sensor perfomance is limited in this window mainly by the fundamental thermodynamic limits set by losses from air damping of the suspension [4], in this case 0.25 ng/rtHz. The InSight microseismometers do not rely on vacuum to reduce the noise floor. The transfer function of the velocity output is flat to 30 s, with a selectable gain of either 24,000 or 4000 V/(m/s).

Following delivery, further development of microseismometer is being undertaken to further improve the performance. The performance target of the resulting silicon seismic package (SSP) is 2 to 4-fold reduction of the sensor noise within it's current bandwidth to 0.1 ng/rtHz. In addition, the aim is to extend the low frequency floor from 0.1 to 0.01 Hz (see fig. 2).

Three approaches are being pursued to reach this target while maintaining the overall sensor die size and avoiding any electronics redesign. First, the resonant frequency of the horizontal and vertical suspensions is being lowered from 6 to just over 3 Hz, improving

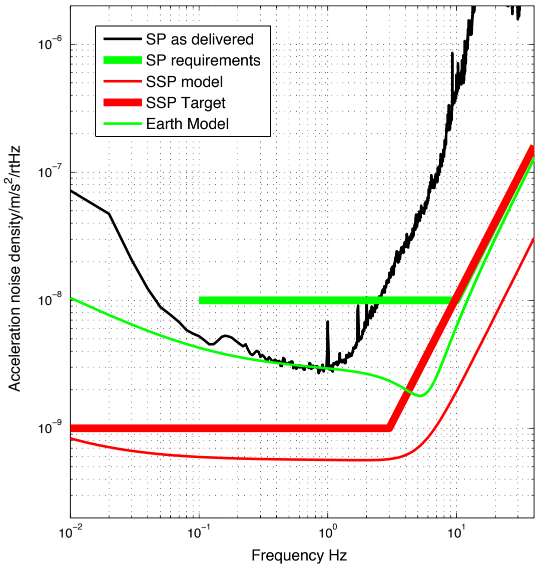

Figure 2 Noise performance of the delivered SP vertical microseismometer integrated into the InSight instrument assembly at CNES Toulouse (black), compared to the requirements (thick green) and instrument noise model (thin green). The target for SSP and corresponding noise model are shown in red.

the electronics displacement noise by a factor of 4 to 0.2 pm/rtHz. Secondly the proof mass will be increased by the addition of gold bar to the back of the proof mass. This is already implemented with the delivered sensors, but the considerable margins evident in shock and vibration testing indicate that there is scope for further mass addition, and there is certainly the area to accommodate further gold bar. Thirdly, the proof mass will be relieved to reduce the damping contribution from gas between proof mass the the glass strip of the displacement transducer. Noise modeling using updated parameters from the current development give the thin red line of fig. 2, indicating that such an improvement would be achievable, at least considering the known contributions to the sensor noise.

Both environmental and performance testing of the SSP sensors will allow validation of the target performance, with coherency testing in low-noise seismic vaults necessary to determine the noise floor across the entire target range from 0.01 Hz to 40 Hz. SSP has the potential to offer performance close to that of high-grade terrestrial seismometers but in a robust, compact package requiring simplified deployment such as passive drop off from a lander or rover.

Figure 3 Additional gold mass trim on the InSight microseismometers to increase the suspended mass and hence reduce the thermodynamic noise. For this sensor the mass is doubled.

References: [1] The mission is currently on hold, awaiting a new launch date. [2] Pike et al., IEEE Sensors 2014, pp1599-1602, 2014 [3] Barzilai et al., Rev. Sci. Instr., 69, pp 2766-2772, 1998 [4] Gabrielson, J. Vibration and Acoustics, 117 pp 405-410, 1995