THE EUROPA SEISMIC PACKAGE (ESP): 2. MEETING THE ENVIRONMENTAL CHALLENGE. S. Kedar[1], W. T. Pike[2], I. M. Standley[3], S. B. Calcutt[4], N. Bowles[4], B. Blaes[1], Farokh Irom[1], M. Mojarradi[1], S. D. Vance[1], B. G. Bills[1], [1]Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109, CA [2]Dept. of Electrical and Electronic Engineering, Imperial College, London, UK, [3]Standley Technology Consulting, Claremont, CA, [4]Dept. of Physics, Oxford University, UK. sharon.kedar@jpl.nasa.gov

Introduction: NASA is currently studying a potential Europa lander mission, and instrumentation must be ready within 3-4 years. In a companion paper [1] we summarized the requirements that would enable a seismic system to provide a probe of the habitability of Europa and introduced a candidate broadband instrument capable of delivering those requirements, the SP microseismometer built around a micromachined silicon suspension and delivered for the InSight mission to Mars. Here we outline an approach for adapting this design without any compromise in performance to provide a Europa Seismic Package (ESP) that overcomes the three significant challenges in the environmental conditions, specifically gravity, temperature and radiation.

Gravity for ESP: The change in gravity from 3.7 m/s^2 to 1.3 m/s^2 will result in a different offset of the sensor's suspended proof mass for the vertical axis. This requires minor modification of the sensor-die design with the reduced deflection allowing an increased range of tilt for deployment with no compromise in performance. As tailoring the suspension for the higher offset of Mars has already been achieved in the SP sensor die, we assess this to be a low risk development for ESP.

Temperature for ESP: The seismometer sensor head has to be mechanically coupled to the surface of Europa and so is expected to operate at close to ambient temperatures (fig. 1). Day-night temperatures on Europa's surface span 80-125 K up to 45° latitude [2, 3] and may reach as low as 50 K in shadowed regions. Temperatures on more distant ocean worlds such as Enceladus can dip to around 30 K [4]. Hence to adapt SP to ESP requires a reduction in the minimum operational temperature from 210 K to 80 K. Both this drop and the variation in temperature can affect the performance of the microseismometer.

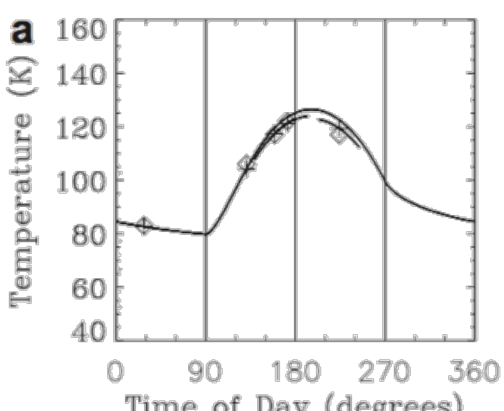

Figure 1: The Europa temperature diurnal profile [2]

The SP sensor's mechanical functionality has already demonstrated in liquid nitrogen at 77K and the lower temperature has the beneficial effect of reducing the suspension's thermodynamic noise floor with the root of absolute temperature, an improvement of up to 30% depending on the thermal coupling to the Europa ambient. Hence we plan to avoid using any sensor-head heating for operation. The variability in temperature is more challenging due to the unwanted thermal contribution of the seismic output through the thermal coefficient of the suspension's Young's modulus. This contribution affects the vertical component of the seismic output for those frequencies unattenuated by the thermal isolation of the sensor die, below ~10 mHz. For Mars we successfully balanced thermal elasticity and expansion coefficients in SP to minimise the overall thermal sensitivity of the vertical axis. This sensitivity is reduced by more than 3 in the lower Europa gravity. Depending on the tilt range required for deployment for ESP we can implement either:

- identical three-axis sensors without thermal compensation deployable over a full 4π solid angle and use die-temperature decorrelation to minimise the thermal contribution, or
- adjusted compensation for the specified tilt range for the vertical-axis sensor, as for the SP.

We achieved a thermal time constant of 2000s for SP to attenuate the unwanted thermal contribution at seismic frequencies above 10 mHz. We will reduce the thermal conductance of the pathways on the sensor die to further increase this attenuation.

Radiation for ESP: Europa sets the most stringent requirements for radiation [5,6]. The total dose depends on the cruise duration, configuration and approach, but is dominated by the lander location, and surface-mission duration. The SP is able to achieve its full performance with the majority of the components located away from the sensor head on the SP's feedback board within the warm electronics box of the InSight lander. This board is connected through a 2 m tether to the proximity electronics on a single hybrid within each sensor head. This distributed electronics scheme allows for optimum protection of the components from the Mars environment, with only the proximity electronics

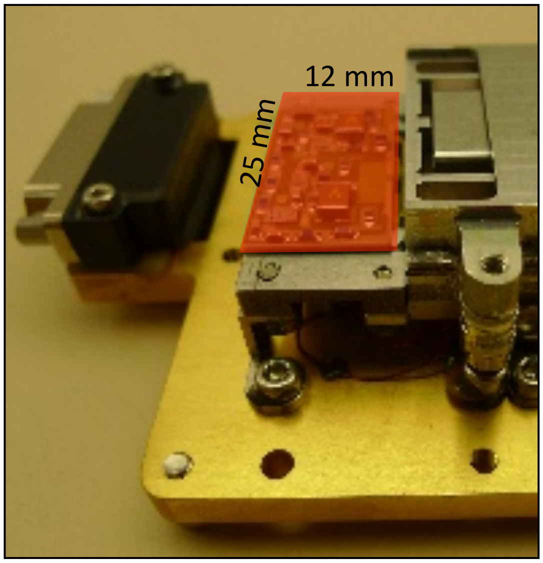

Figure 2: The SP proximity electronics hybrid (shaded red) is likely to see the highest radiation dose, but can be spot shielded with an additional mass of ~40 g.

substantially exposed. We anticipate an analogous approach on the Europa lander, with a shielded, thermally insulated vault available within the lander body as a shared facility for all the payload electronics, reducing the total dose to below 100 krad. For ESP's more exposed sensor-head electronics we have a working assumption of a maximum a total dose of 300 krad. This corresponds to the worst-case scenario of the higher radiation received on the trailing side of Europa, shielded under 8 mm of Al during a 30-day mission, including a margin of 2.

The SP electronics design has to be adapted to this radiation environment through a combination of swap-in of flight-qualified radiation-hard parts and additional localized 8-mm Al shielding for the proximity electronics. A preliminary radiation review of all the microelectronic components used in SP indicates that there are alternatives available for all parts that do not currently meet our assumed Europa radiation requirements already, with no predicted compromise in performance. Spot shielding of the proximity electronic components outside the vault comes with a minimal additional mass due to the small area of the SP's front-end hybrid (fig. 2).

In addition to the high sensitivity and broad frequency response, a seismic system placed on Europa will be required to have the ability to observe a wide range of surface displacements [1]. 24-bit (~140dB) ADCs are the standard in all terrestrial seismic recording systems, and are used on InSight. This high dynamic range is crucial when placing a first seismometer on a planetary body whose range of seismicity and seismic amplitudes are unknown, and even more so for a short-lived mission such as the Europa Lander. This ADC will be located beyond the feedback electronics in the shielded vault and we have identified a candidate design that delivers our performance while meeting our assumed radiation requirements.

Testing ESP: We have already developed cold-test facilities to validate the performance of the SP down to 200K at the sub-1ng/rtHz level, and we are extending the range down to 80K to simulate Europa surface temperatures. As the SPs can operate in tilted configurations to simulate Mars gravity on Earth, we can similarly provide complete performance validation under Europa temperature and gravity simultaneously. We have also developed rapid swap-in procedures to identify any performance degradation from the introduction of radiation-hard components.

Conclusions: Europa confronts any instrument designer with formidable challenges. We have outlined a low risk path to adapt InSight's SP broadband microseismometer for the Europa gravity, temperature and radiation environment, identifying specific solutions that meet these challenges. In particular, the distribution of electronics on SP already minimizes the shielding required for the most exposed components on Europa.

The development of the SP itself has already demonstrated much of the testing required to validate this pathway, including the ability to determine performance at reduced gravity and temperature with radiation-hard space-qualified parts.

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