

OCEAN WORLDS SIGNALS THROUGH THE ICE (STI) TECHNOLOGY – FIBER OPTIC AND FREE-SPACE COMMUNICATION DEVELOPMENTS. K. L. Craft¹, E. Asenath-Smith², R. F. Coker¹, C. R. German³, M. V. Jakuba³, A. Lakey¹, R. R. Lien^{1,4}, R. D. Lorenz¹, A. Mahapatra⁵, C. McCarthy⁶, S. O’Riordan⁵, G. W. Patterson¹, A. R. Rhoden⁷, H. Sequeira¹, M. Silvia³, V. Singh⁶, R. Stilwell¹, and M. E. Walker⁸, ¹Johns Hopkins University Applied Physics Laboratory (Kate.Craft@jhuapl.edu), ²US Army Corps ERDC/CRREL, ³Woods Hole Oceanographic Institution, ⁴University of Oregon, ⁵Linden Photonics, Inc., ⁶Lamont-Doherty Earth Observatory, ⁷Southwest Research Institute, Boulder, ⁸Planetary Science Institute.

Introduction: Ocean worlds, such as Europa and Enceladus, present some of the best potential habitats for life in our solar system. To one day access and explore the oceans or water pockets within their ice shells, has many challenges. A successful mission will need to penetrate the ice shell to distances of km to 10s of km over a few years, survive tidal stressing, potential faults, salts and other potentially corrosive chemistries, all while maintaining communication with the surface. Here we present development progress by our ocean world STI team for **robust fiber optic and free space communication technology to provide data transmission rates adequate to achieve science and exploration objectives, critical for any future mission to access an ocean world’s subsurface.**

Our developments build on previous studies of cryobot concepts that explored the use of optical communication tethers with coupled radio frequency (RF) relay devices to enable communication between a descending probe and a surface lander (e.g. [1 - 4]). Fiber optic tethers would face shearing challenges from potential fault motion in the ice shell and chemical degradation, while the RF relays must remain thermally stable in extreme cold and high pressure environments, while transmitting under constrained power and form factor limits. RF and other forms of free space communication (optical, acoustic) would be constrained by the composition and thermal conditions of the ice.

Approach: Recent developments by our STI team over the last year include: (1) further characterization of the performance of optical tethers under Europa-like shearing conditions, initial soak and freeze-in tests, and adhesion test developments; (2) thermo-mechanical design of a housing for an RF relay module; (3) acoustic free space transmission feasibility study, and (4) modeling of tidal stress and potential induced fault slip and strain on tethers crossing faults throughout a tidal cycle.

Optical Tethers. Shear testing characterized the robustness and transmission performance of optical tethers previously used for ocean submersible exploration under Europa temperatures (260K to 95K) and potential stress levels and loading velocities (5e-7 to 3e-4 m/s) [5]. These tethers were the 1) Strong Tether Fiber Optic Cable (STFOC) and 2) High Strength STFOC (Linden Photonics, Inc.). Test set-up embedded the tethers into pure water ice blocks and then sheared them under applied force in a three-block double direct

shear configuration. Results showed the tethers continued to transmit data, with only low transmission reduction (<10 dB) and minor damage to the outer tether jackets at the coldest temperatures. Similar shear tests are currently underway with new loose tube tether designs, other strength members, and additional jacket materials (e.g., non-kink STFOC; Hytrel® outer jacket).

Additional tests under way will characterize performance of the tethers during long cold (~100K) soaks in ice of various chemistries [6]. The tethers must transmit data over a mission lifetime of at least 2 years and it is important to characterize any degradation in performance over time due to the extreme cold and potentially caustic chemistries in the ice.

Tests are also being performed to characterize any change in performance due to pressures placed on the tether during the refreezing of the ice behind the cryobot as it descends. Figure 1 shows the test cylinder being used to freeze in tethers and measure transmission performance.

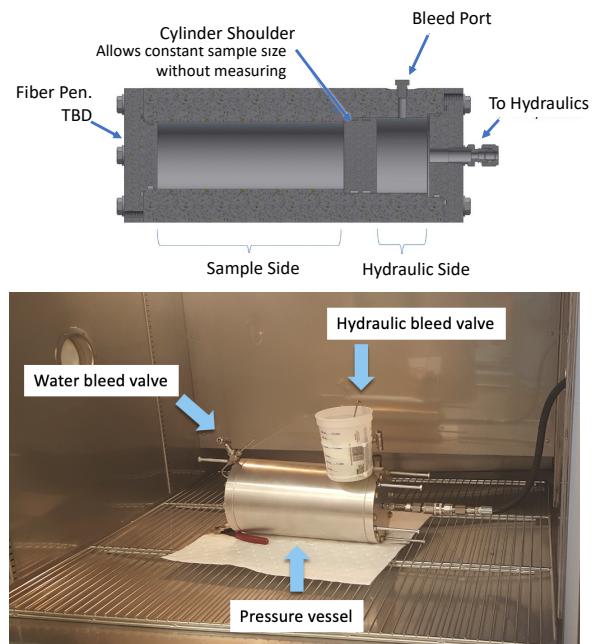


Figure 1. Test cylinder to simulate the freeze-in process that will occur around a tether as it is deployed behind a cryobot descending in the ice. Tests will characterize signal transmission under various freeze-in pressures to simulate deployment at a range of depths in the ice shell.

Tether jacket materials will also be tested to improve our understanding of adhesion of various material classes to ice under the Europa conditions. Peel tests will occur in shear and tensile delamination modes and results will inform the expected transfer of strain from potential fault movement in the ice shell. Initial test developments include methods to grow ice in adhesion to tether jacket materials (Figure 2), and facility set-up.

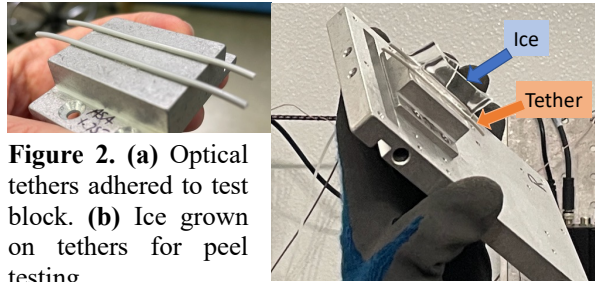


Figure 2. (a) Optical tethers adhered to test block. (b) Ice grown on tethers for peel testing

RF relay. Building off our initial evaluation of a potential RF antenna design and performance for RF communication in a modeled Europa-like environment [7], we are working to consider thermal and mechanical considerations for such a relay module. Initially, the volume available for housing and deploying RF relay modules at Europa was based on constraints in current cryobot concept studies (e.g. [1,4]), however these studies optimized cryobot diameters for melt-through efficiency, while not thoroughly addressing thermo-mechanical constraints for a relay module. Constraints include reliable performance over a lifetime of several years in temperatures that range from $<80\text{K}$ to $>200\text{K}$, under large hydrostatic pressures, and in the presence of periodic (tidal) or rapid (fracturing) forcing.

Modeling is underway to evaluate the thermo-mechanical characteristics of potential RF module housing design for performance in a Europa or Enceladus ice-shell. The current design is a primary titanium pressure vessel with two mated independent antenna pressure vessels. The primary vessel will house the electronics modules, batteries, heating elements and

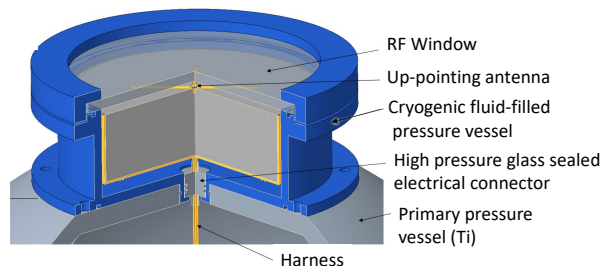


Figure 3. Top of initial pressure vessel design for an RF relay module concept showing the upper antenna housing that incorporates previous STI team antenna design work [7], submersible design experience (WHOI), and considers thermal and mechanical needs for function in an ocean world ice shell.

thermal insulation material, while the two exterior cryogenic fluid-filled vessels will house the up- and down-pointing RF antennas. Figure 3 shows the current design for the antenna housing and connection to the primary vessel, made by glass sealed electrical connectors. Thermo-mechanical modeling will inform on if modifications to the design are needed and then we will manufacture two RF module mock-ups for loading and thermal tests that will be conducted over a range of temperatures representing deployment at multiple depths in an ocean world ice shell.

Free-space acoustic feasibility. A study is under way to explore the feasibility for using acoustic signals through Europa's ice shell. The modeled acoustic properties of the ice (mainly attenuation length and ambient noise) were initially based on those measured by the South Pole Acoustic Test Setup (SPATS) for ice [8,9]. Transmission distances were then calculated as a result of input power and signal-to-noise ratio.

Ice shell stress and fault modeling. Prior analytic and numerical modeling by the STI team has estimated the tidal stress with depth in Europa's ice shell, building off of [10], and constrained resulting potential fault slip strain hazards throughout a tidal cycle [11,12]. Fault model results show that fault motion varies dependent on location on Europa, fault angle and orientation, and Europa's orbital location (i.e. true anomaly). These models predict the thermal and deformational conditions that communication technologies may encounter at deployment and inform our tether and RF module designs and development tests to ensure survival and successful data transmission.

Summary: Cryobot communication hardware will face risks due to ocean worlds' challenging thermal regimes, chemistries, and tidal motions. Our STI work begins to address the thermo-mechanical challenges in order to ensure a successful communication architecture and enable the discovery of life on another world.

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