Ice-Embedded Transceivers for Europa Cryobot Communications

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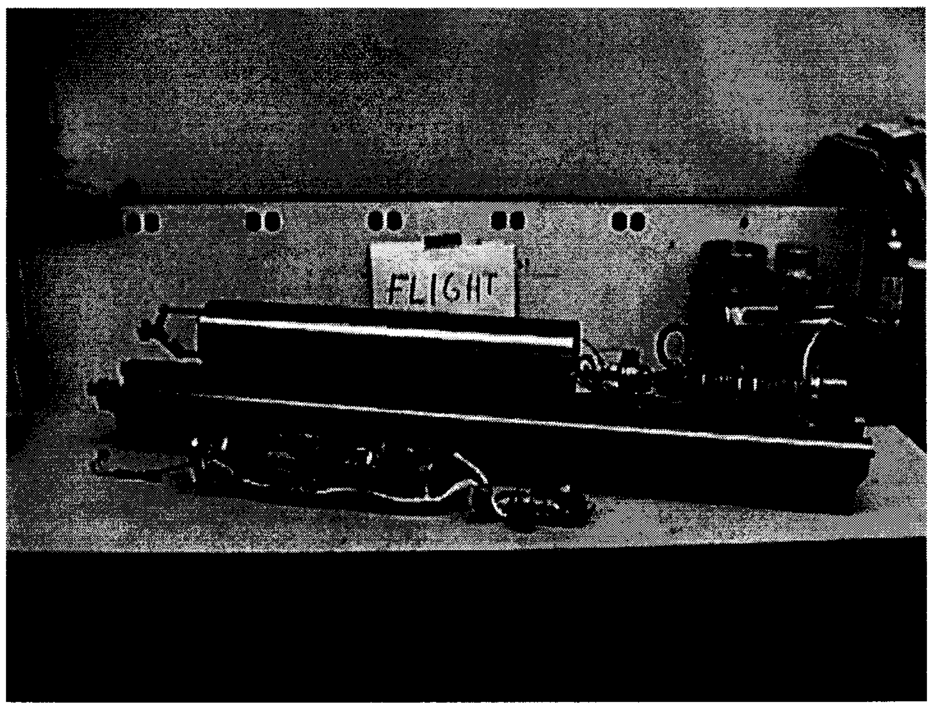
Europa Exploration

- Exploration of Europa is motivated by the potential for finding life.
  - This moon of Jupiter is covered with frozen water ice that shows cracks and melt zone of undetermined age.
  - The next Jovian moon, Io, has active volcanism driven by tidal forces.
  - The potential for Europan liquid water ocean under the ice has fueled speculation about how to reach and explore such an ocean for life.
- A unique exploration problem
  - Landing on Europa, deep in Jupiter's gravity well, is difficult.
  - Once there, the target are is several kilometers away under solid ice.

"Ice Rafts" on surface of Europa. From Galileo spacecraft, NASA/Caltech-JPL

Cryobot Exploration

- JPL design studies have developed an exploration concept.
  - The good stuff is at the bottom, under the ice. A cryobot is an autonomous robot that melts through the ice. It is equipped with in-situ science instruments for investigating the ice and the ocean.
  - Design and development of cryobots is underway at JPL for possible use on Europa, the poles of Mars, and Earth polar regions.
  - Several field tests have proven the cryobot design can get through the ice.



The Europa Communication Problem

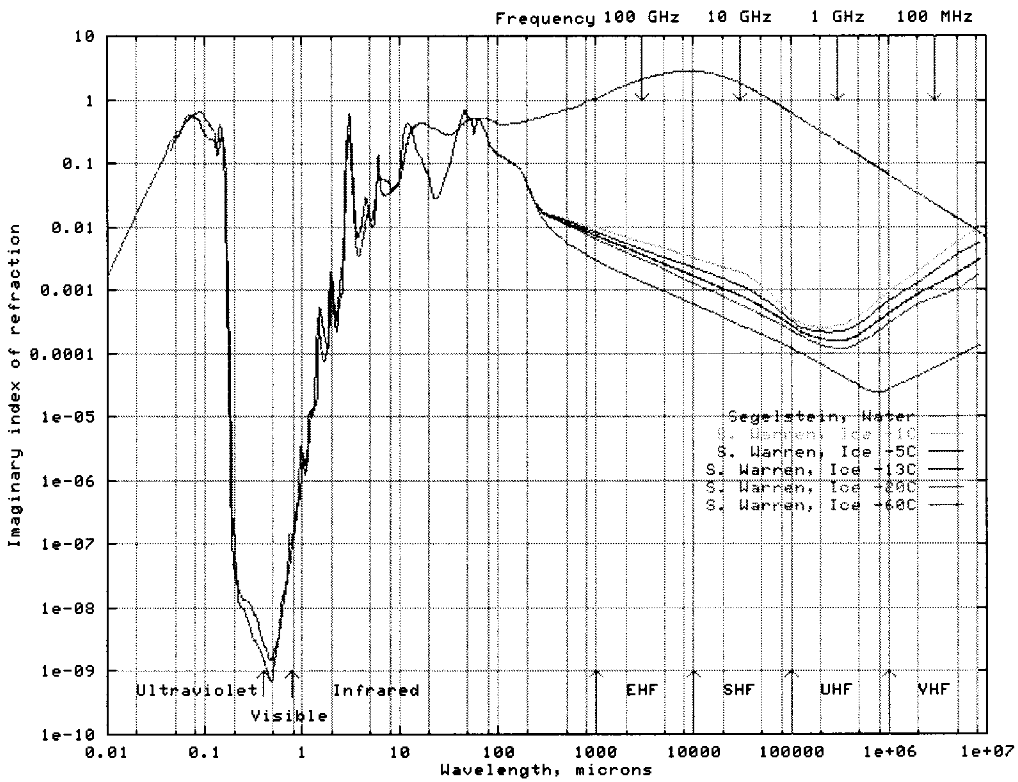
- Among the many challenges of cryobot exploration of Europan oceans, the communications system combines several difficulties.
  - Getting to the ocean is a big problem. So is getting the data back out. Current cryobot experiments use tethers for power and communication.
  - Evidence support strong tides on Europa. The surface may flex 10's of meters per revolution (3.5 days).
  - The ice thickness is still being debated. A communications design must be prepared for many kilometers, with the possibility of more distance.
  - The inner Jovian system is bathed in radiation from particles trapped in the Jovian magnetosphere. Even on the Europan surface, the radiation is concern for the electronics that will send the data back to Earth.
- A cryobot mission is not short duration.
  - The time to melt through to the ocean is measured in days or months. The communications must provide support during the melt phase and at the ocean.
  - Communications must survive several Europa orbits.

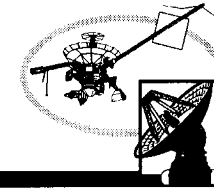
Lake Vostok study

- This communication study was originally done for JPL's Lake Vostok/Europa design study. The communications problems have many similarities:
  - Lake Vostok, Antartica, is a fresh-water lake roughly the size of Lake Ontario. It is covered by a slow-moving glacier 4 km thick.
  - Speculation abounds concerning the possibility and nature of life in Lake Vostok. This led to design studies on contamination-free exploration concepts.
  - A sample return was deemed infeasible, only data comes out.
- The design study identified the main communications tradeoff as tethers versus transceivers. Both can be deployed from the back of a cryobot during descent.
  - Tethers are reliable for slow-moving ice, can also carry power, and have very large bandwidth. However; they have strict length limits, are risky in moving ice, and can involve a lot of mass.
  - Transceivers can transmit through ice at certain frequencies. They were explored as a design option for the study.

Optical Properties of Ice

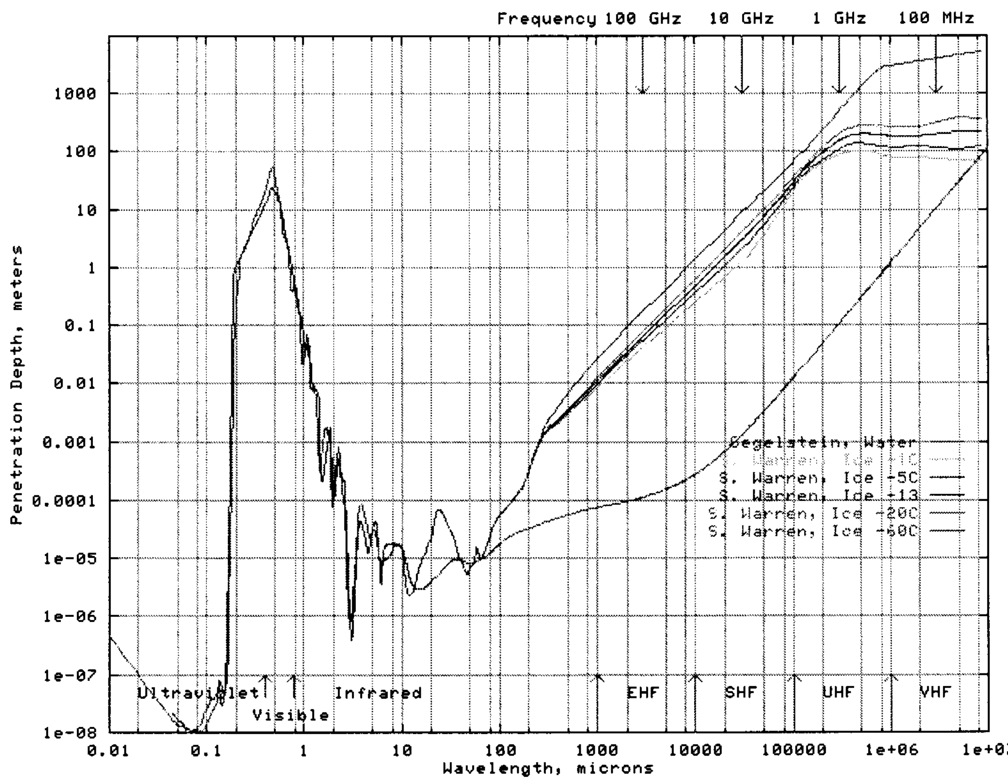
- Water ice has dielectric properties that make it semi-transparent at optical and radio frequencies. This is the basis of radio-glaciology.





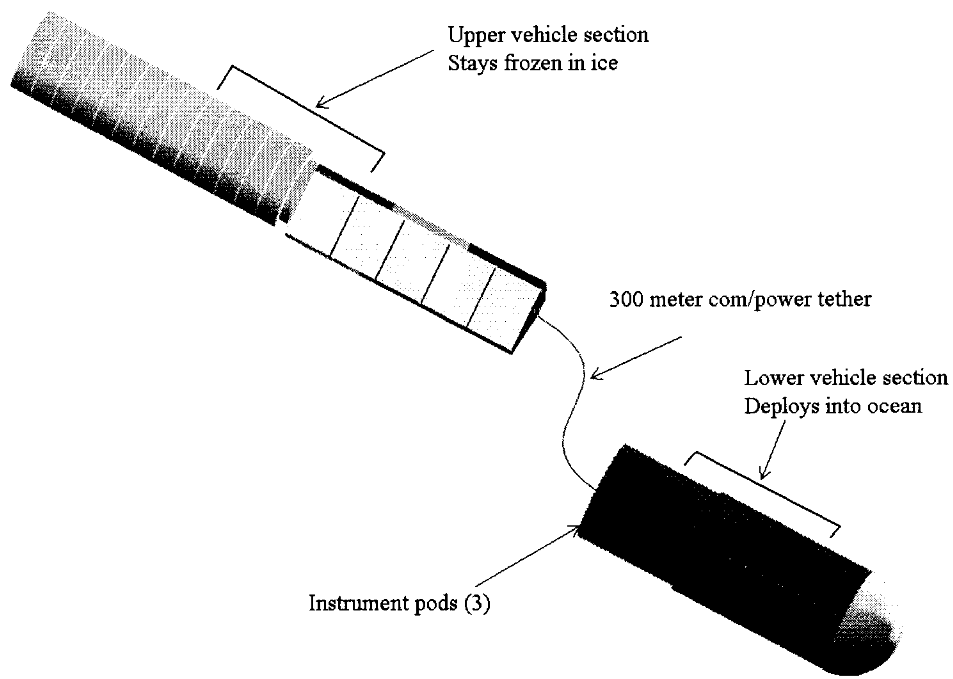
Radio transmission through Ice

- Electro-magnetic penetration depth favors longer wavelengths.
- Antenna size and data rates favor shorter wavelengths.
- Water ice displays a tradeoff point around 1 GHz.



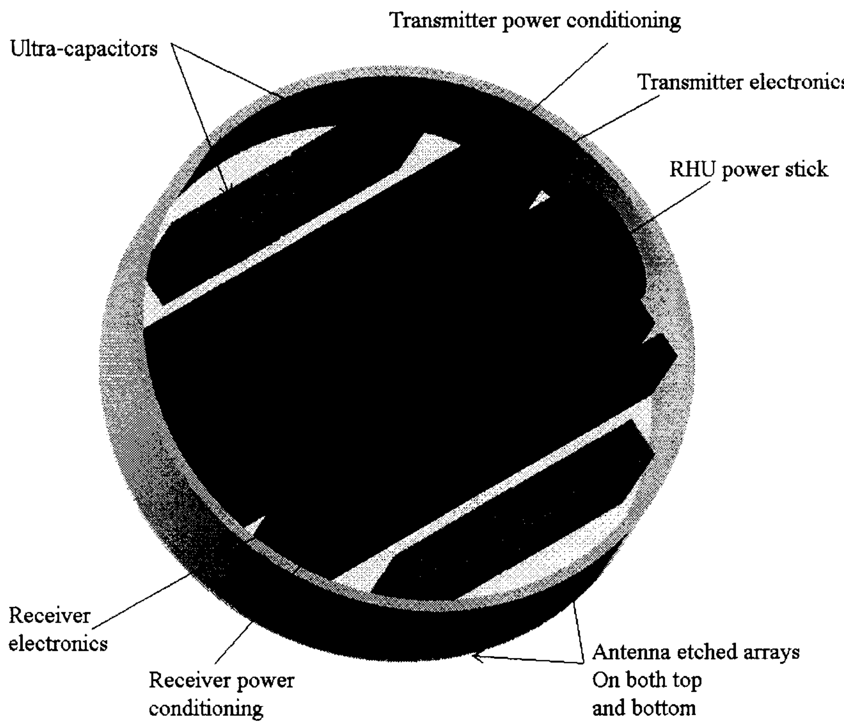
Transceiver concept

- Transceivers the size of a large hockey puck are stacked in the back of the cryobot and deployed at intervals during descent.
  - Not affected by tidal disruptions. Tethers could be snapped.
  - Spacing can be changed to increase total distance with some degradation to data rate. Tethers must be sized for a maximum length.
  - At the ocean, the cryobot proceeds forward on a 300 meter tether. The tether connects to an anchor left in the ice which also contains the first transceiver.



Transceiver concept (cont.)

- Each transceiver is autonomous, with it's own power supply. A failure of one transceiver can be bridged by adjacent transceivers, at much reduced data rates.
- Transceivers could use current patch antenna technology, but require miniaturized radio-isotope power units.

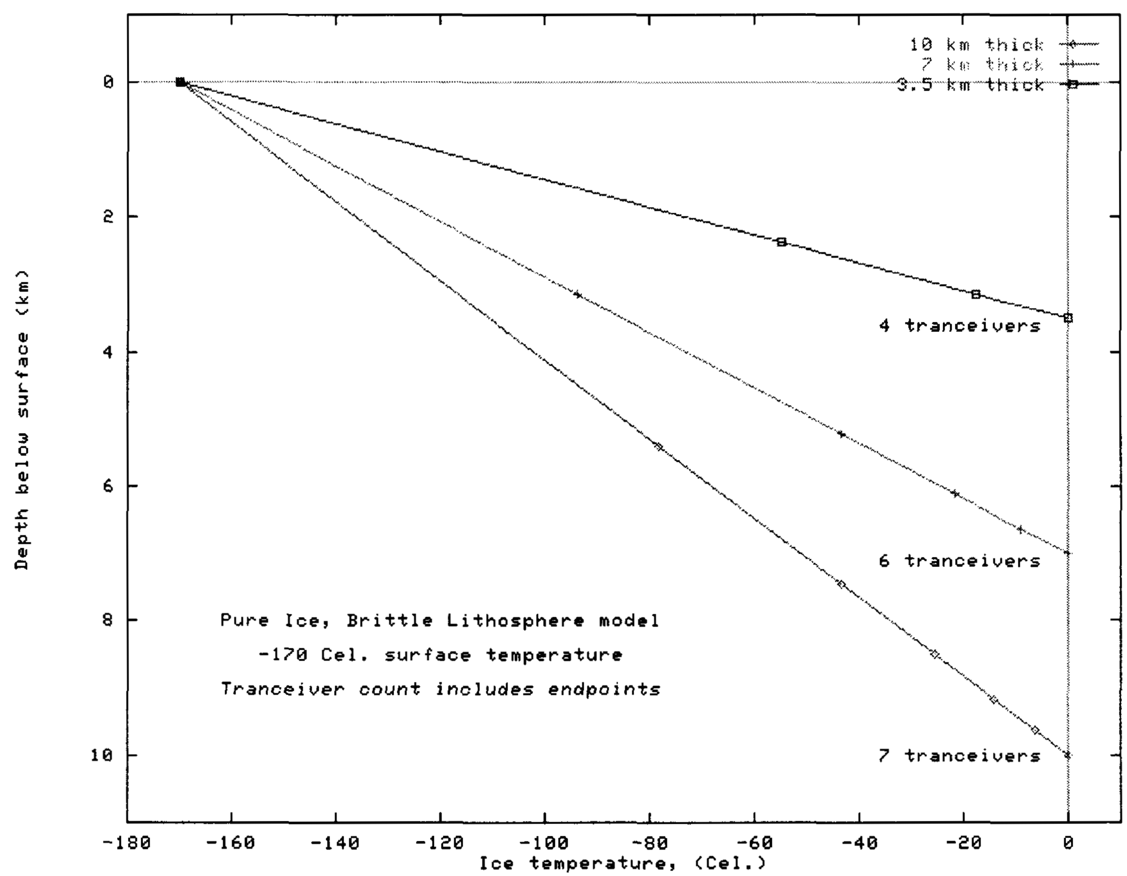


Communication Link Margin

- We identified the 1 GHz patch antennas designed for MUSEs-C as a viable antenna. The link margin analysis assumed:
  - 400 mWatt power supply. Capacitors used for data bursts.
  - Receiver & transmitter efficiencies of 25%.
  - Target data rate of 10 KHz.
  - Various assumptions about distance, ice temperature, and ice impurities.
- The transceiver spacing depends most heavily on the temperature profile and salt impurities.
  - Research turned up references for the variation of ice permittivity [Stephen G. Warren, "Optical constants of ice from the ultraviolet to the microwave",] and with salinity [Matzler, C. and Wegmuller, U "Dielectric properties of freshwater ice at microwave frequencies"].
  - Europa's temperature profile is still under debate, but appear to be bounded between a uniform brittle lithosphere, or a thicker and more complex convecting sublayer [Pappalardo et al., "Geological Evidence for solid-state convection in Europa's ice shell".]
  - Combining equation from several sources led to development of a computer model for determining transceiver spacing.

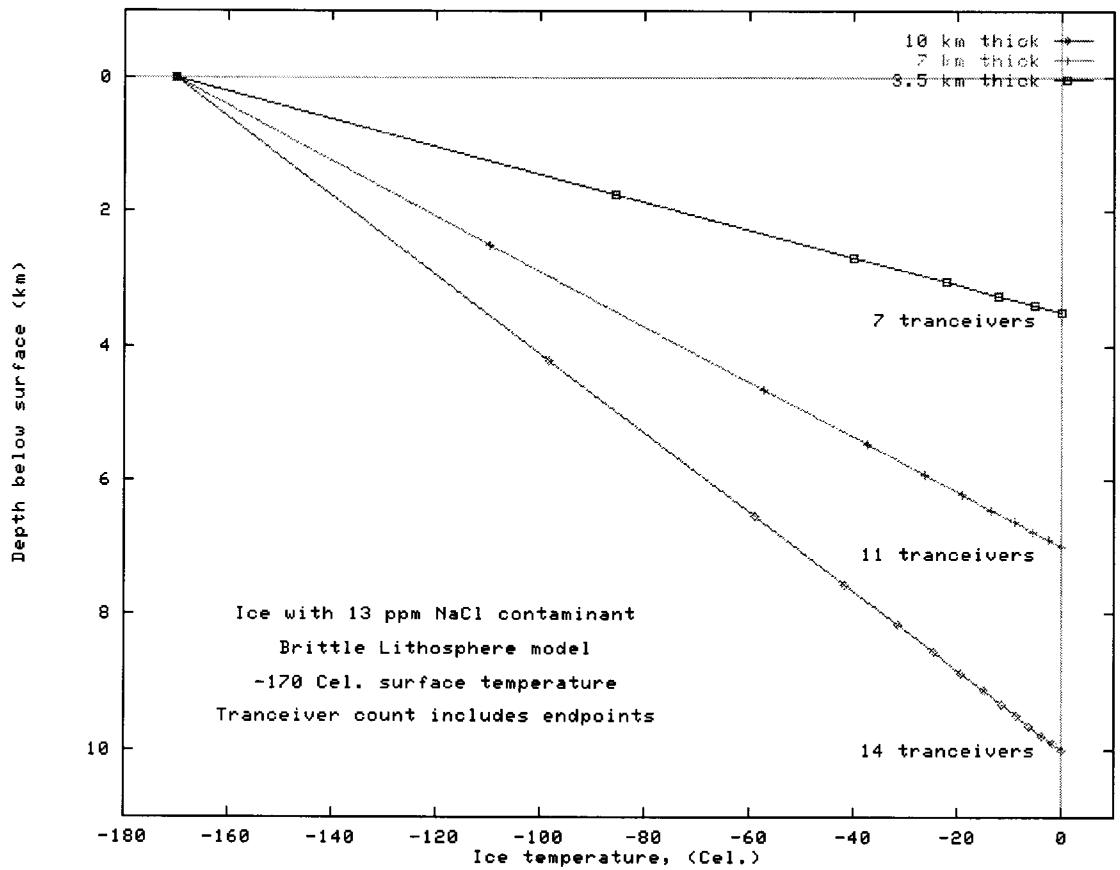
Pure Brittle lithosphere

- The best case scenario. Only 7 transceivers needed.
- Transceivers are most effective where ice is coldest, which is also the riskiest place of tethers. At water boundary, tethers are safer and more effective.



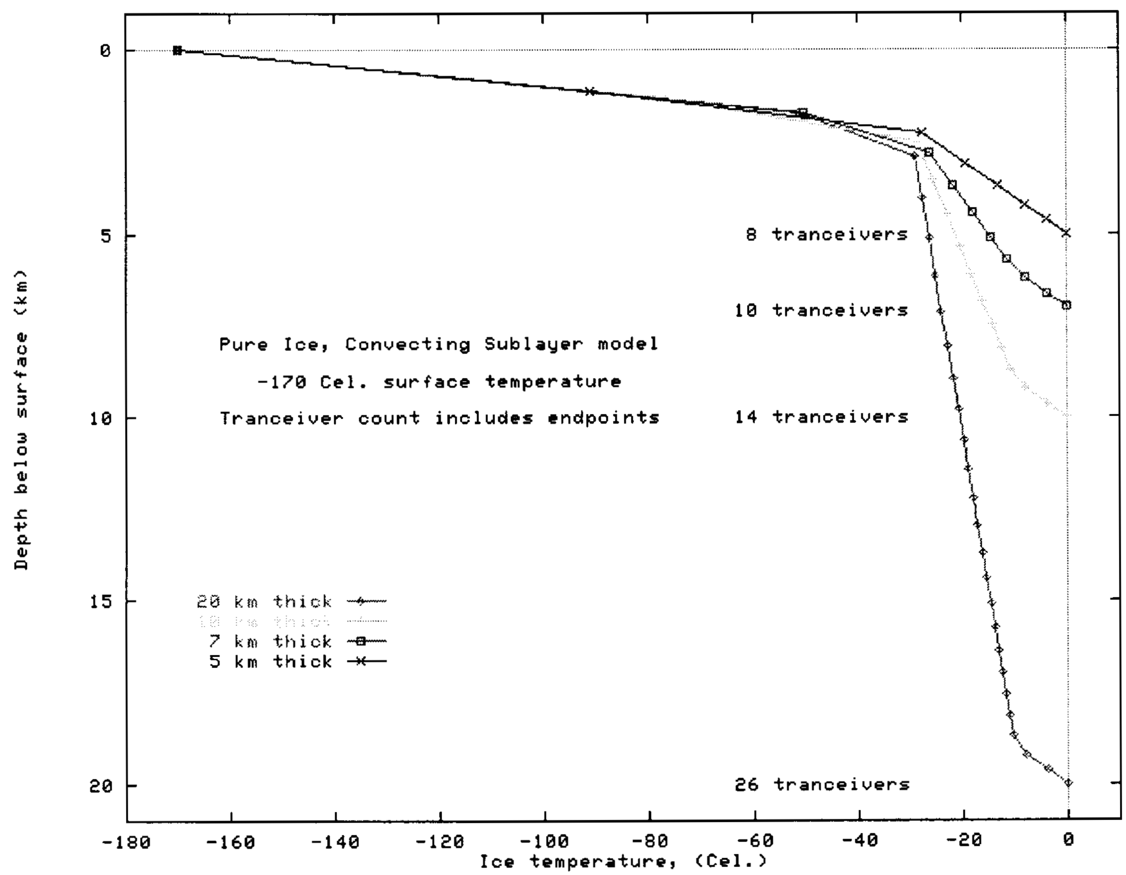
Salty Brittle lithosphere

- Next best scenario. Introduction of 13 ppm salt into model increases the required transceivers from 7 to 14.
- If conditions are less saline or not as deep as the design point, the spacing can be adjusted to provide a higher data rate.



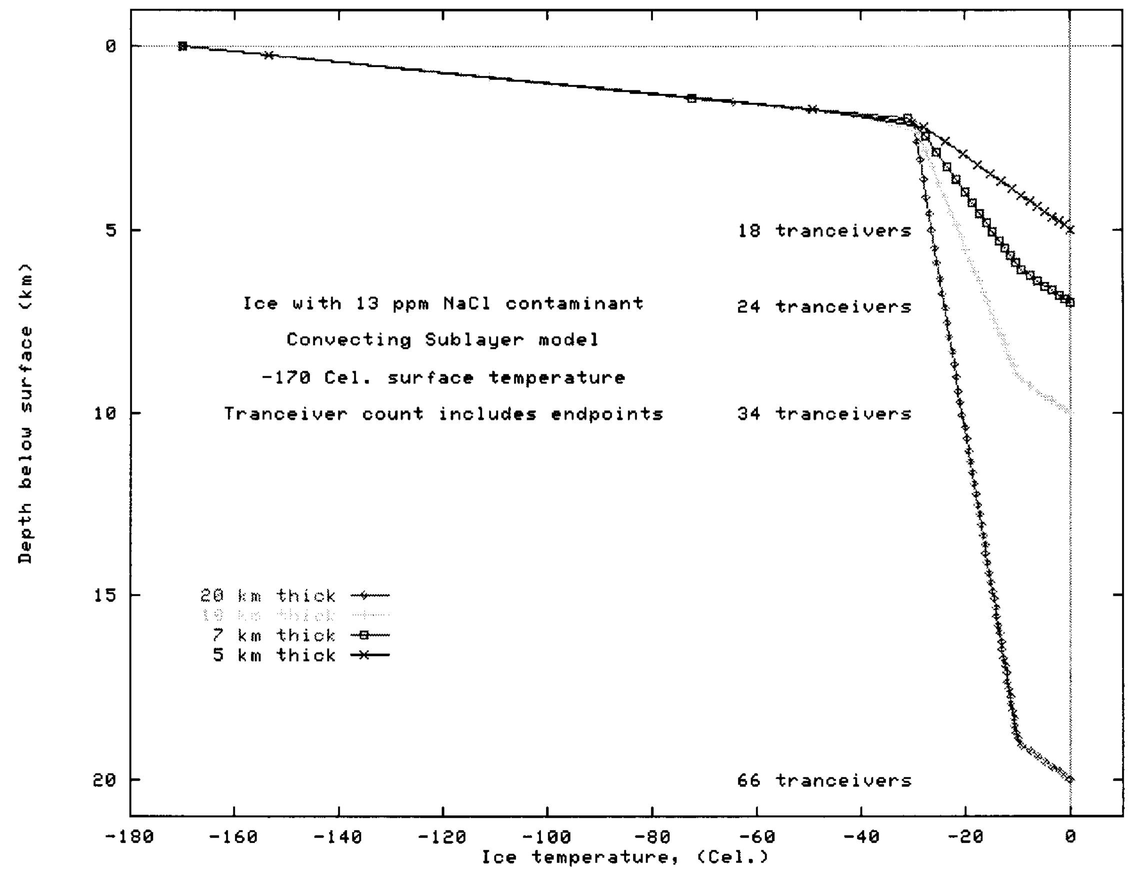
Pure Convecting sublayer

- The convecting sublayer model complicates the temperature profile.
- This crust model is thicker, and most of the distance is now “warm” ice.
- The factors increase the maximum transceiver count to 26.



Salty Convecting sublayer

- This is the worst case. Introduction of 13 ppm salt into convecting lithospher model increases the maximum required transceivers from 26 to 66.
- For this case, the mass of 66 transceivers may begin to approach the mass of a 20-km armored fiber optic cable that could survive Europan conditions.



Conclusions

- A simplified link margin analysis supports the concept of using small transceivers to send data through the ice crust of Europa.
- Number of transceivers varies strongly with:
  - Thermal model for the Europan crust.
  - Brine contaminants in the ice.
- If the Europa crust has more than 15 parts per million of salt contaminant, the number of transceivers may be prohibitive. Options:
  - A combined transceiver/tether approach using transceivers in cold, brittle ice. The tether would run through the kilometers of warm ice in the convecting sublayer model.
  - Given a fixed number of transceivers, adjust the data rate of temperature profile and salinity found at the landing site.