

Magneto-Inductive Communications for Ocean Worlds

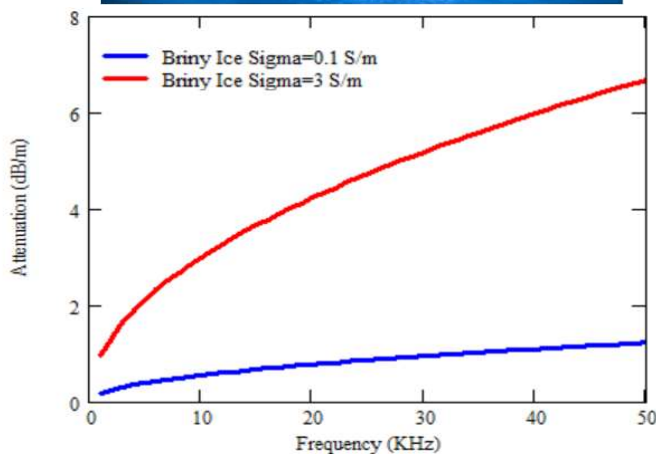
2020 NIAC Symposium
September 22nd - 24th, 2020

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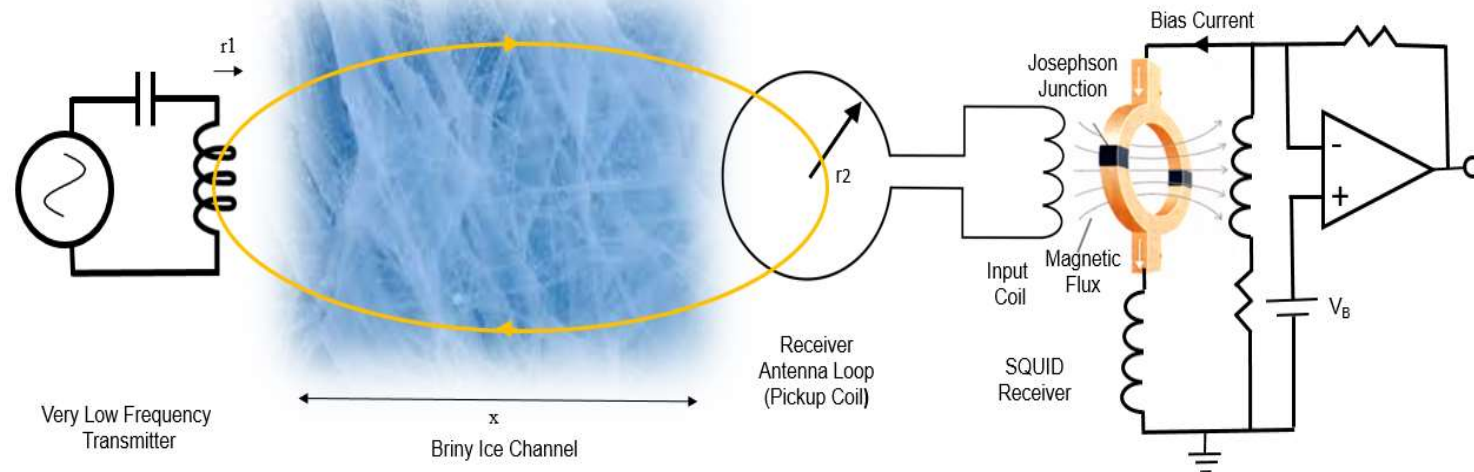
Innovation



Calculated attenuation of a conventional radio frequency signal propagating through a conductive medium at very low frequencies with electrical conductivity as a parameter. The situation worsens with increasing frequency and electrical conductivity.

- A mission to the under-ice ocean of Europa is one of the highest priority missions for NASA. The NASA Decadal Survey states: *“Europa’s probable ocean may be the best candidate in the solar system beyond Earth for a presently habitable environment.”*
- Concepts for a probe to melt through the 10 to 20 km thickness of briny ice to reach the buried ocean have been proposed. But how would such a probe communicate results?
- Conventional radio communications links cannot penetrate even if the Europa ice conductivity is the lowest estimated value, 0.1 S/m. The electric field attenuation exceeds 100 dB/km even at very low frequencies (<30 kHz).
- We have a promising solution based on a quasi-static magnetic field and a superconducting receiver.
- We propose a new concept, a “magneto-inductive” technology. But the magnetic field strength will degrade as *distance cubed* (independent of the medium so long as the medium is not magnetic) so a very sensitive receiver technology is needed to pick up the weak signal after penetrating several km of briny ice.
- We propose a superconducting quantum interference device (SQUID) based receiver and will investigate SQUID arrays to achieve a noise temperature (sensitivity) approaching the quantum limit (hf/k) and able to detect magnetic fields below 1 fT.

Approach

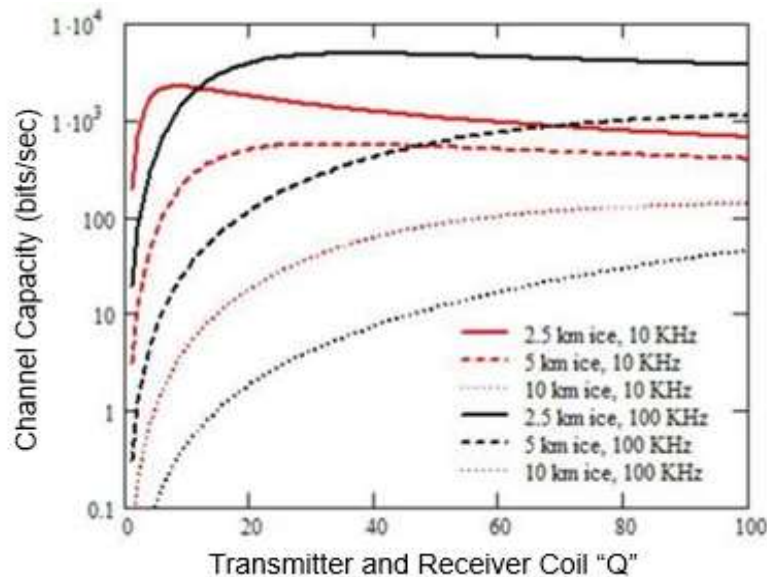


Magneto-inductive communications system through conductive medium of extent “x” employing SQUID-based receiver. When a SQUID (far right) is biased with a constant current, the voltage across it oscillates with increasing ϕ and period $\phi_0 (h/2e)$. SQUIDs can detect magnetic fields lower than one flux quantum $h/(2e) \approx 10^{-15}$ Wb, with 10^{-18} Wb reported in the literature. The output of the SQUID receiver interfaces with conventional modem and transmitter electronics.

- Magneto-inductive signals differ from electromagnetic signals because the electric field is suppressed. The magnetic field is a non-propagating quasi-static field that can penetrate a highly conductive medium. And, the magnetic field can be modulated to encode information hence it can be used for communications.
- Develop magneto-inductive communication system based on extremely high-sensitivity superconducting quantum interference device (SQUID) receiver and quasi-static magnetic field transmitter.
- Preliminary calculations indicate that we should achieve $\approx$ kbps with a modest transmitter and relatively small antennas (coils) using a SQUID-based receiver.
- Optimizing coupling of the input coil to the SQUID is critical to maximizing sensitivity.
- This study will complete that analysis and develop a magneto-inductive communications system design. Other applications include underground and underwater communications.

Approach

Preliminary calculations indicate that we can achieve a kbps or more with a modest transmitter and relatively small antennas (coils). The estimates below assume flux from the receive antenna (pick-up coil) can be efficiently coupled into the SQUID system, and a flux noise level of $2 \times 10^{-5} \Phi_0/\text{VHz}$. Additional assumptions include a 100 pH SQUID inductance and Transmit and Receive loop diameters of 0.5 m. Received power is proportional to loop Q but bandwidth is inversely proportional to Q so there will be an optimal capacity depending on range, etc. Going to higher frequencies requires commensurately higher Q coils which may be impractical. Lower frequencies result in poorer performance across all ice thicknesses.



Preliminary estimate of channel capacity through Europa briny ice.



Inside the Superconducting and Cryogenic Microwave Electronics Laboratory at NASA Glenn. The room is shielded from electric and magnetic fields for conducting extremely sensitive receiver measurements. The customized 4K closed-cycle refrigerator is equipped with a microwave transparent Beryllia radome in this photograph

Plan Forward

- Develop a link analysis tool, based on a modulated quasi-static magnetic field transmitter and SQUID-based receiver, for communications through a highly conductive medium.
- Optimizing coupling the magnetic field to the SQUID sensor (to maximize sensitivity).
- Actual SQUID system sensitivity, antenna design, system efficiency, potential magnetic interference from Jupiter, etc. still needs to be determined and the link model improved. A proof-of-concept is desirable (e.g. transmitting through equivalent attenuation using a metallic enclosure substitute).
- A COTS high temperature superconducting SQUID system is being procured. The intention is to validate the link equation. Communications through sea ice will be simulated by enclosing the transmitter in a shield and measuring magnetic field strength with the SQUID sensor. The link performance will be scaled to the actual link.
- Investigate alternative approaches (e.g. low temperature versus high temperature SQUIDs and possible advantages of an array of incommensurate SQUIDs). Arrays of SQUID loops of incommensurate area have demonstrated noise temperature (sensitivity) approaching the quantum limit.
- Begin investigating possible interference effects from the background magnetic field of Jupiter and possible effects of eddy currents induced in briny ice on reception signal quality.
- Collaborate with Yoseph Bar-Cohen (JPL) proposed project called “PRIME”(Probe using Radioisotopes for Icy Moons Exploration).

References

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