

A Compact Autonomous Melting Probe for Subsurface Sensor Deployment

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Autonomous access to ice layers up to 100 meters in depth is increasingly important for a range of scientific applications, including glaciology, climate studies, and astrophysics. Compact melting probes represent a promising solution for the deployment of sensors in and beneath the ice, particularly in remote environments where conventional drilling is logistically challenging.

The system presented here was developed within the framework of the Radio Neutrino Observatory Greenland (RNO-G) and built on behalf of the collaboration. Its primary purpose was to autonomously create reference holes for detector stations during expeditions to Greenland. At RNO-G, near-surface calibration transmit antennas are typically installed in shallow, hand-dug holes (~2 m deep) in the absence of a suitable tool to create deeper installation holes with adequate effort. At two stations (21 and 23), these near-surface calibration transmit antennas were instead installed in augered boreholes between 10 and 20 m depth, allowing a more favorable transmit-receive angle between the log-periodic dipole antennas (LPDAs) and vertically polarized (Vpol) receiver antennas on the power string.

The melting probe enables the creation of these deeper boreholes in an automated, efficient, and logistically lightweight manner. Following the improved results, it is envisioned to install near-surface pulsers at such depths (~20 m deep) for future RNO-G stations, using a melting system such as the one presented here.

Its successful use by the RNO-G team has demonstrated the feasibility of replacing traditional augering techniques with autonomous melting systems for future deployments.

While the RNO-G deployment served as a specific use case, the broader objective of the project lies in advancing autonomous melting probe technology for general sensor delivery in icy environments. The compact probe can operate fully autonomously after setup, reaching target depths and optionally remaining embedded in the ice as a long-term sensor node with surface communication.

This contribution details the design and control logic of the system, as well as power considerations and operational autonomy. Field results from Greenland include performance metrics such as melt rate, energy consumption, and mission reliability, highlighting the system's suitability for scientific deployments in polar and alpine ice.

References

S. Agarwal, et al., (2025) Instrument design and performance of the first seven stations of RNO-G, JINST 20 P04015, <https://doi.org/10.1088/1748-0221/20/04/P04015>

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