A compact autonomous melting probe for subsurface sensor deployment

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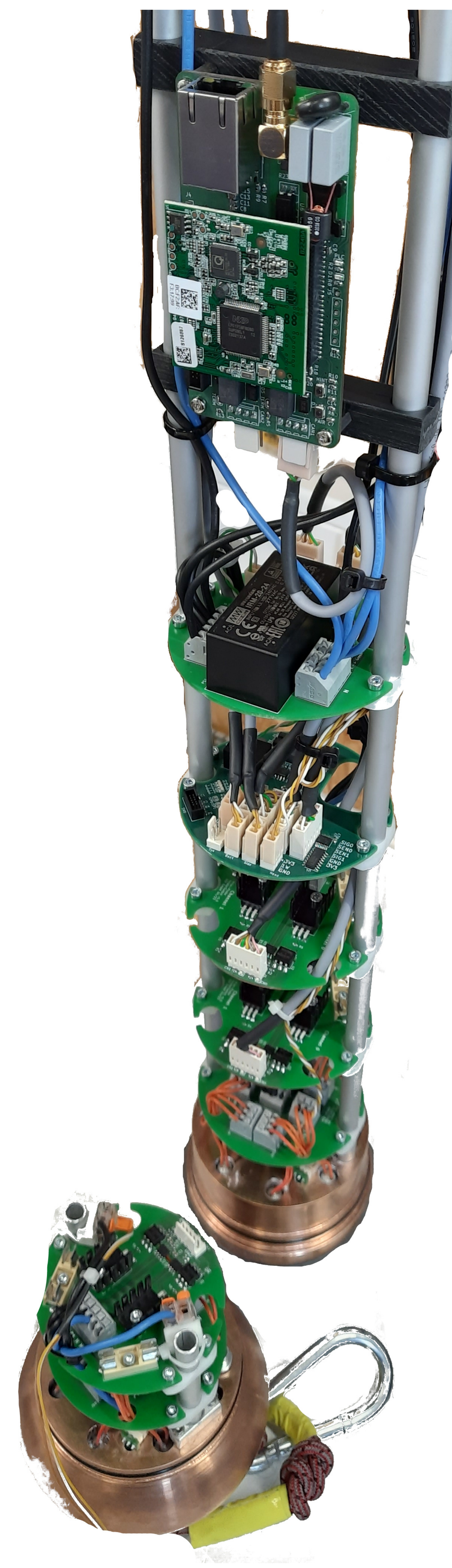
Autonomous access to ice layers up to 100 meters in depth is increasingly important for a range of scientific applications, including glaciology, climate studies, and astrophysics. Compact melting probes represent a promising solution for the deployment of sensors in and beneath the ice, particularly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



System Design

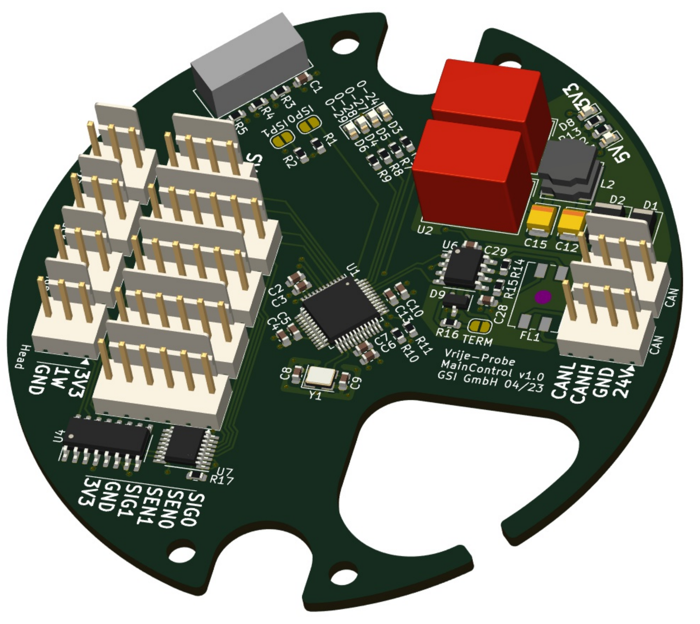
The probe is designed according to the special needs of the RNO-G project regarding diameter and depth of the hole, but is adaptable if needed. For easy use and maintenance, the design is simple and straight forward with as few parts and functions as possible to reach the target depth. After setup, the probe will melt autonomously to the target depth and hold position and orientation once reached.

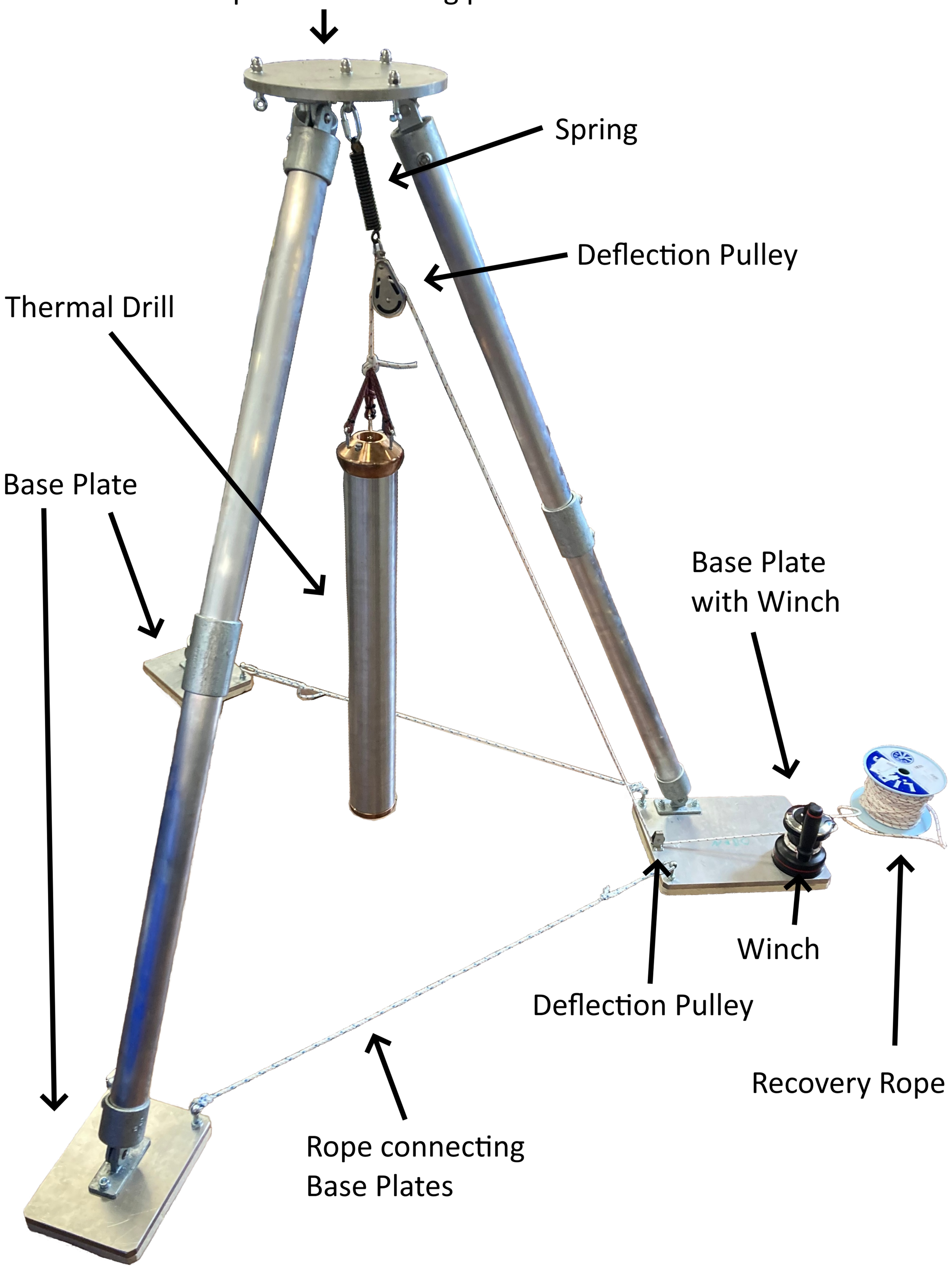
For holes up to 100m passive orientation control using a cone support at the back of the probe is sufficient to keep the probe upright. To maintain an upright position while melting, the back of the probe is build wider than the tip and keept at lower temperatures, resulting in a theoraticaly slightly slower melting speed of the back. The main part of the probes mass will be carried by the wider back keeping the probe upright, resting mainly on the small ledge melted by the cone support at the back.
This design also simplifies the recovery of the probe after a mission, as only the back will touch the ice.

The probe is build with three heating sections. The most heating power is installed in the tip and will heat up to about 90°C during downward melting operation. The back heats up to about 60°C, melting only the small ledge to keep the probe upright. The tube section is also heated to prevent freezing to the sides of the hole and keept at 5-10°C.

Technical Specifications

Dimensions (Diameter x length)	125 mm x 920 mm
Weight	11.8 kg
External Power Supply	240V AC 50 Hz
Internal Power Supply	24 V DC
Heating Power	6.6 kW
Design Power	3.0 kW
Design Depth	30m
Melt velocity	3.0 m/h
Internal Communication	CAN
Surface Communication	PowerLAN





Monitoring for System Awareness

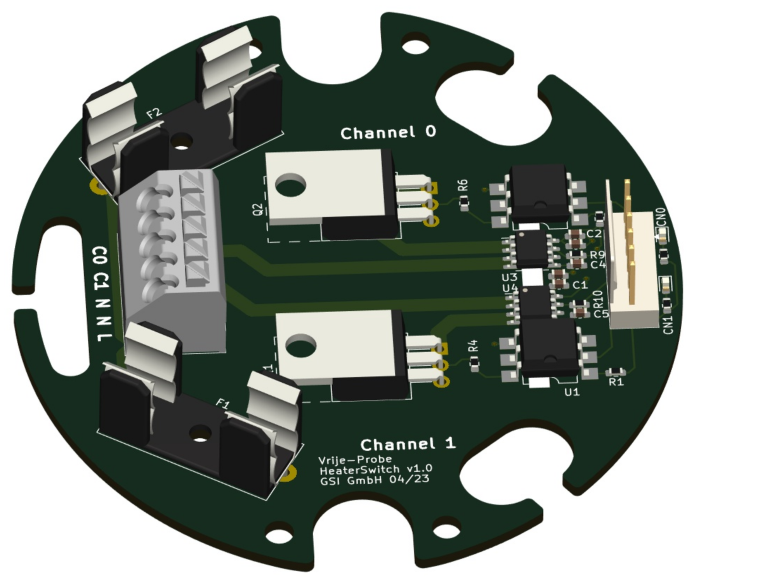
All three heating sections are build with separate and individually switchable channels to maintain temperature. A microcontroller is used to control the temperature of the sections while maintaining a configurable power level to adapt to different power supplies.

All channels are monitored for temperature, voltage and current to detect and identify faults reliable and fast.
The communication between probe and surface station is also monitored at both side, enabling rescue operations of the probe even in the case of complete communication loss, assuming the power supply is still connected and active.

The operator will be informed of the probe status by a three level (Info, Warning, Alarm) message system. If a fault is detected, the system tries to isolate the identified channel or sensor to maintain operational state, even with reduced heating power if neccessary. A successfully identified and isolated error will issue a warning to the operator. An alarm is only issued if further maintained operation might result in a fatal loss of the probe.

Power Consideration

Reaching a depth of 30m in a single operation and day requires a melting speed of about 3.0 m/h, assuming a melting duration of 10 hours.
A speed of 3.0 m/h requires about 2,350 W heating power at the tip (3,000 W installed in 4 channels) and 1,000 W at the cone support (2,000 W installed in 2 channels).
The tube also requires heating to prevent it from freezing to the sides of the hole, additional 1,600 W (2 channels) are installed in the tube, heating the tube to 5-10°C in short power bursts.
To operate the probe with a maximum heating power of 6,600 W powered by a generator with 3.0 kW output, the controller distributes the power as needed to the sections.



Demonstration at RNO-G

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 mostly autonomously after setup, reaching target depths and optionally remaining embedded in the ice as a long-term sensor node with surface communication. [1]

Need a probe?

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Do not hesitate to contact us.
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References:
[1] 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