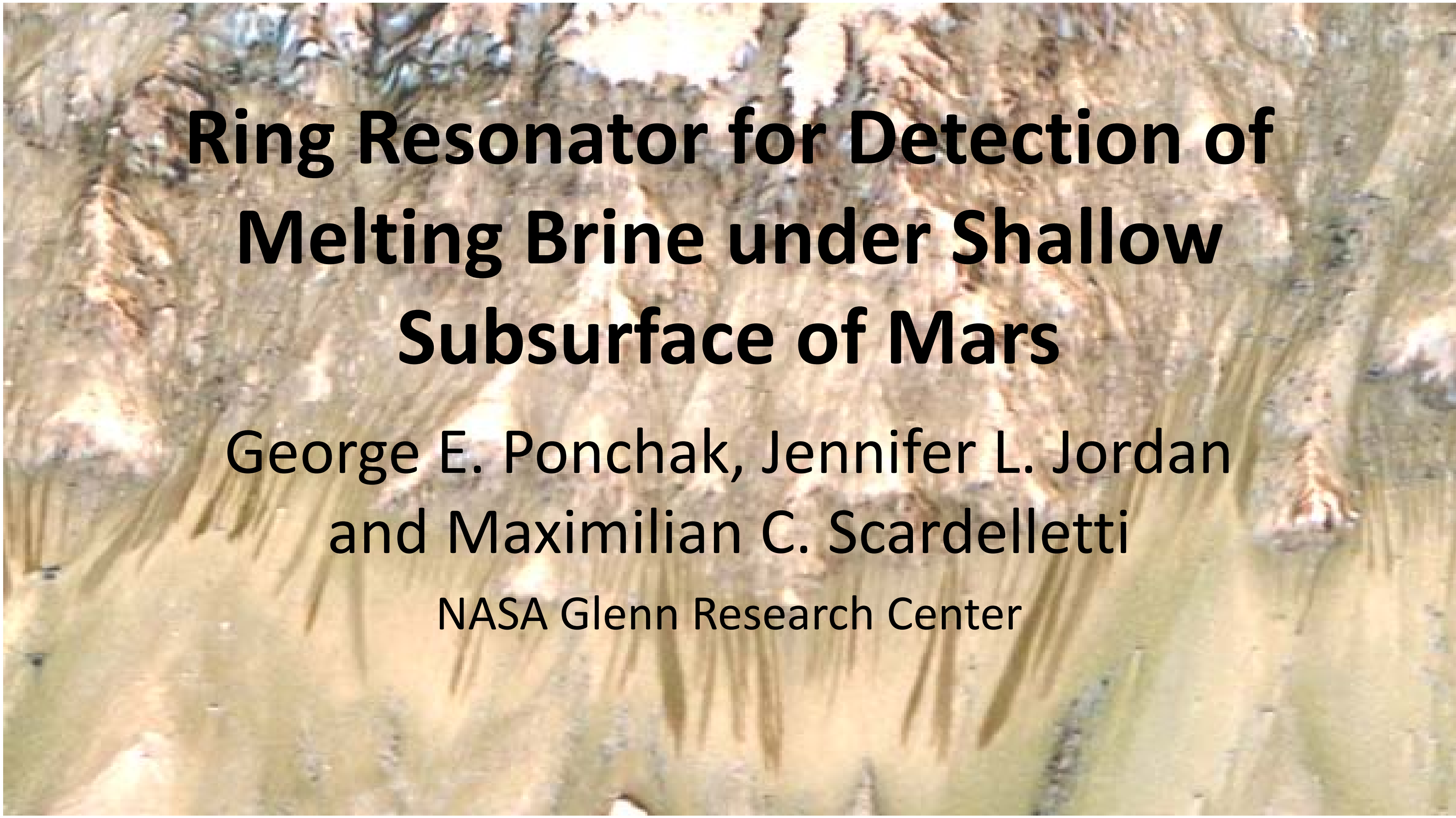

Ring Resonator for Detection of Melting Brine under Shallow Subsurface of Mars

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Introduction

Photo from Mars Phoenix Lander. Is this frozen brine in the Mars shallow subsurface?

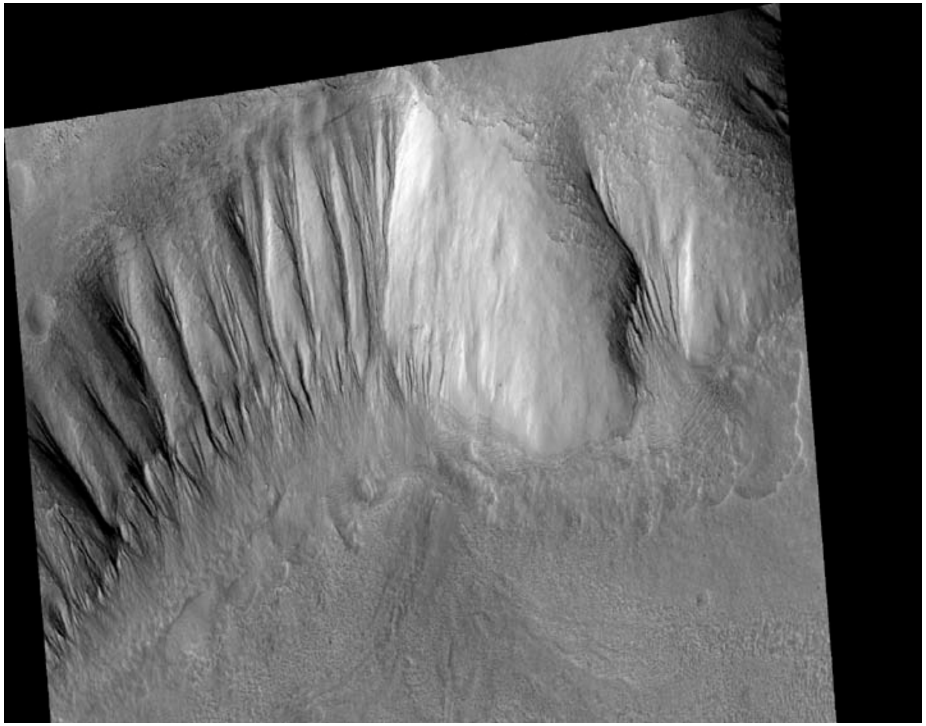


Image from Mars Reconnaissance Orbiter. Is flowing brine causing gullies on Mars?

Introduction

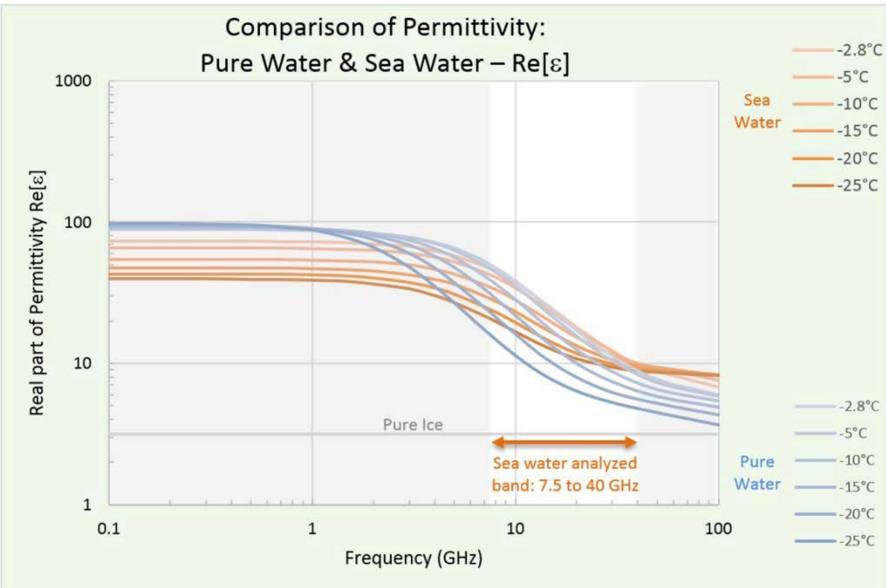
- The Phoenix Mars Scout mission discovered perchlorate salts in the Martian soil.
  - Perchlorate salts absorb water present in the soil or atmosphere through deliquescence.
- Thermal and Electrical Conductivity Probe (TECP) data of the Martian soil during the Phoenix mission showed an increase in the real part of permittivity every Martian night, and it was hypothesized that this is due to absorption of water from the atmosphere by the soil or salts in the soil.
- It has been hypothesized that freeze-thaw cycles cause the formation of brine pockets in saline soils.
- Further analysis of the TECP data showed an increase in permittivity during the day, possibly due to the melting of the frozen brine.
- Raman spectroscopy conducted in a Mars simulation chamber demonstrated that liquid brine can form in the Mars shallow subsurface if salts are deposited on frozen water.

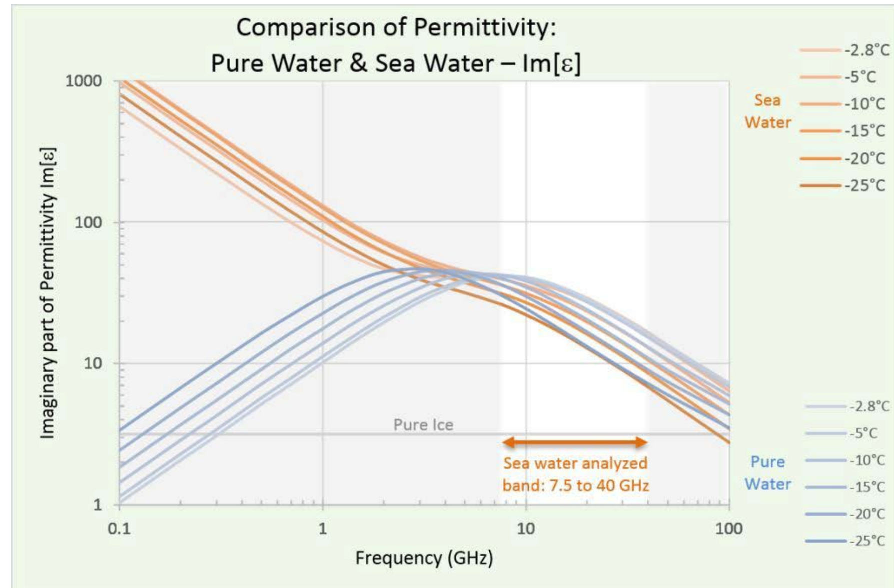
Introduction

To prove the hypothesis that frozen brine melts and flows during the day:

- We need a method to detect the melting of frozen brine in the Mars shallow subsurface during the Mars day.
- Ideally, the measurement will not require inserting probes into the surface.

Background





- The real and imaginary relative permittivity (ε_r'-jε_r'') of pure water and brine varies with frequency and temperature, but ε_r'-jε_r'' of ice is nearly constant and a factor 10 to 100 smaller.
- Measurements of ε_r'-jε_r'' can be used to detect the phase change from solid to liquid water or brine.

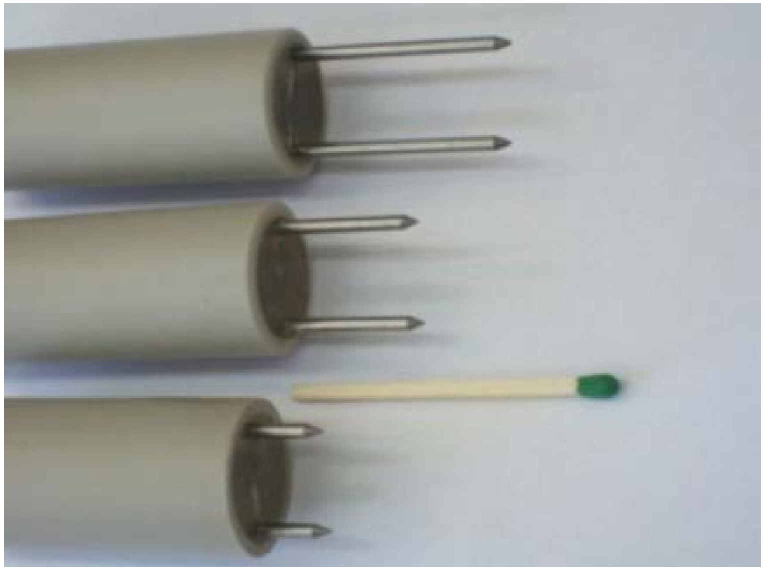
"The Dielectric Properties of Brine in Sea Ice at Microwave Frequencies," A. Stogryn and G. J. Desargant, IEEE Transactions on Antennas and Propagation, Vol. AP-33, No. 5, May 1985. Figures made by Dr. Durval Zandonadi Jr.

Background

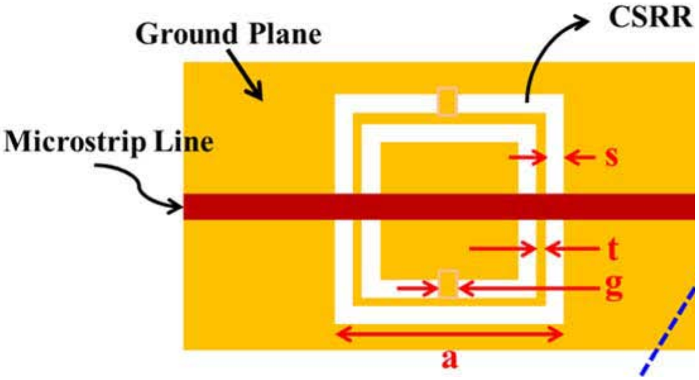
- The relative permittivity of Mars soil was measured to be 2.5 to 2.8.
- The relative permittivity of sandy loam through clay was measured to be 2.6 to 3.
- The relative permittivity of dry sand was measured to be 2.45
- Thus, sand and earth soils may be used to simulate Mars soil.

State of the Art

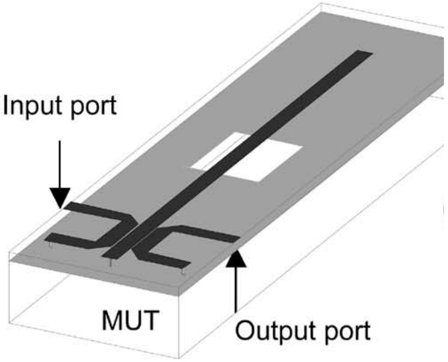
Sensors in the literature rely on the soil interacting with electromagnetic fields generated by open ended transmission lines or resonators.



W. Skierucha and A. Wilczek, “A FDR sensor for measuring complex soil dielectric permittivity in the 10-500 MHz frequency range,” *Sensors*, Vol. 10, 2010, pp. 3314-3329.



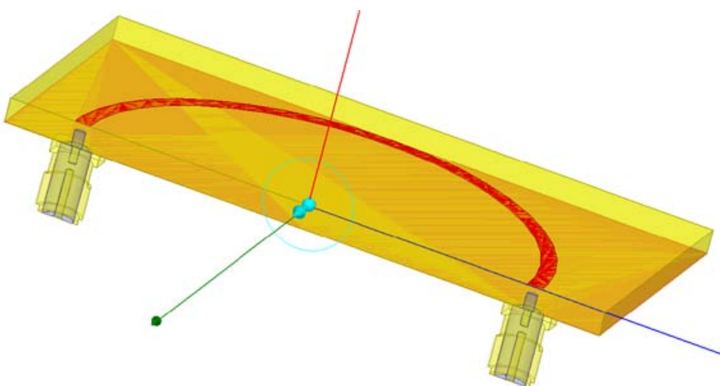
C.-S. Lee and C.-L. Yang, “Complementary split-ring resonators for measuring dielectric constants and loss tangents,” *IEEE Micro. and Wireless Comp. Lett.*, Vol. 24, No. 8, pp. 563-565, Aug. 2014.

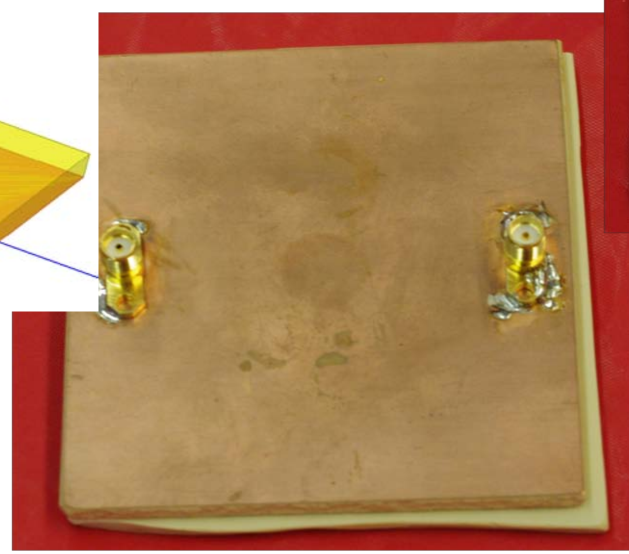


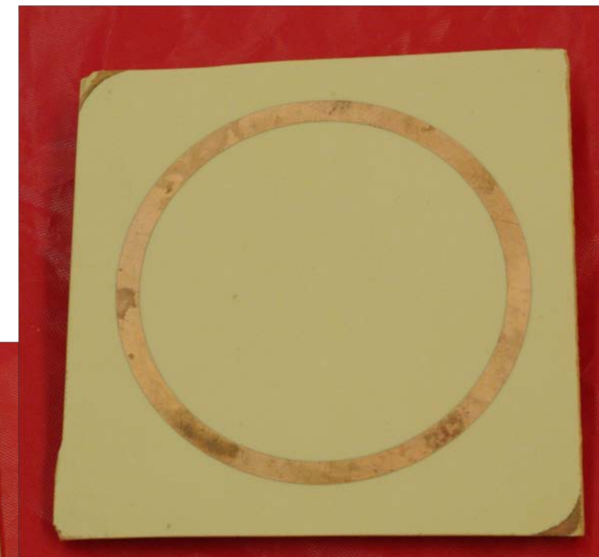
E. Fratticcioli, M. Dionigi and R. Sorrentino, “A simple and low-cost measurement system for the complex permittivity characterization of materials,” *IEEE Trans. Instru. And Measur.*, Vol. 53, No. 4, pp. 1071-1077, Aug. 2004.

Ring Resonator Design

3.15 mm thick substrate
3.7 mm wide microstrip, 64.7 mm diameter ring
0.5 mm coupling gap between connector and microstrip
0.76 mm thick TMM 10i superstrate



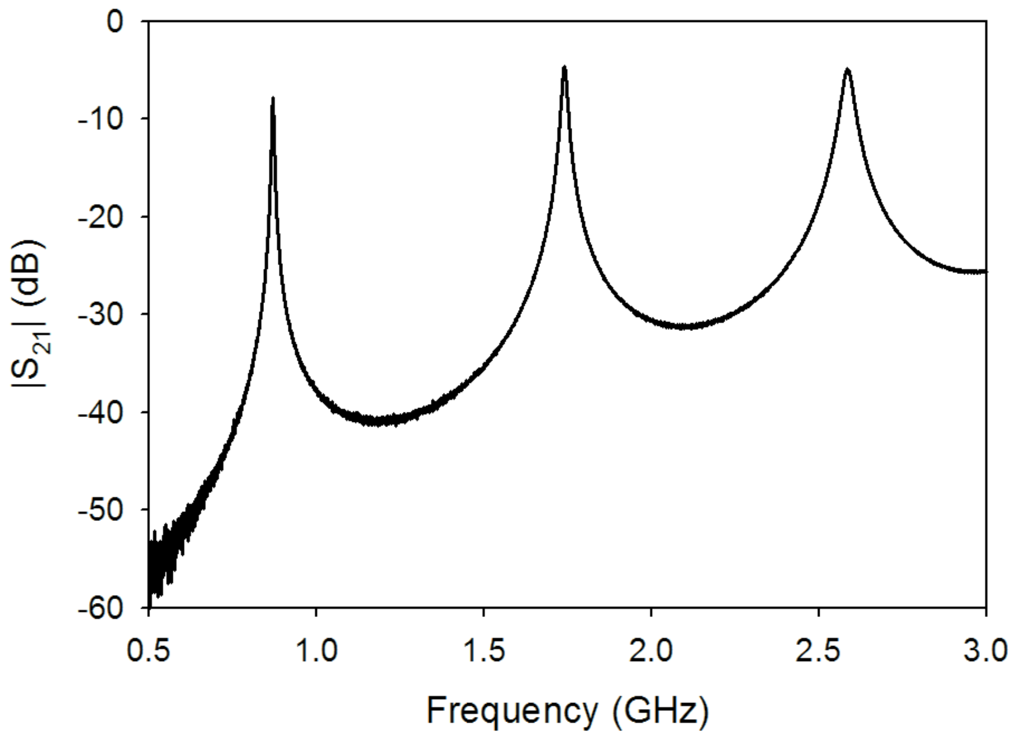




Based on K. Sarabandi and E. S. Li, "Microstrip ring resonator for soil moisture measurements," *IEEE Trans. Geoscience and Remote Sensing,* Vol. 35, No. 5, pp. 1223-1231, Sept. 1997.

Resonator Characteristics

- Theoretically, the ring resonator has an infinite number of resonances.
- We looked at only the first three resonances.
- The resonant frequency and the quality factor (Q) of the resonance depend on $\varepsilon_r' - j\varepsilon_r''$ of the sample.



$$\frac{f_n}{f_{n,air}} = \frac{\sqrt{\varepsilon'_{eff,air}}}{\mathrm{Re}\sqrt{\varepsilon'_{eff}}} \qquad Q_{d,n} = \frac{Q_n Q_{n,air}}{Q_{n,air} - Q_n}$$

Measurement Setup

•The sensor is placed on dry sand with a thin layer of ice buried in the shallow subsurface.
•A thermocouple measures the temperature of the sand under the ice.
•A scale weighs the sample to monitor any evaporation and to determine the moisture content.

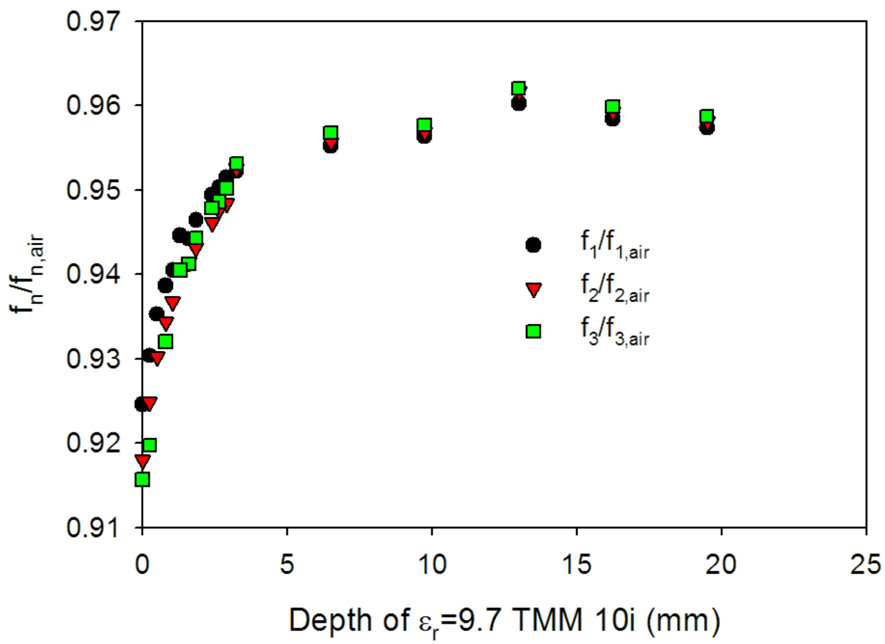
Control Tests

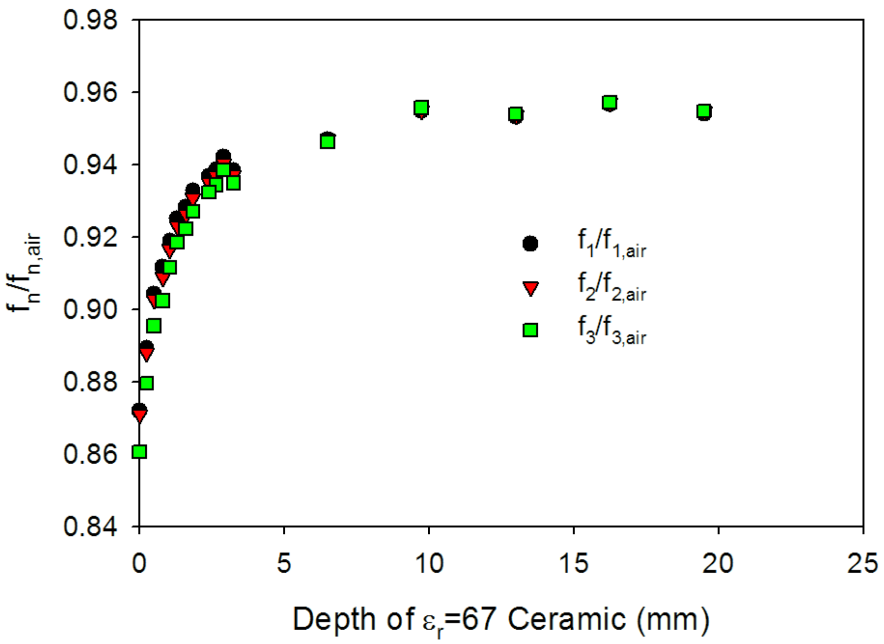
- Because the thickness and uniformity of ice layers are difficult to control, a series of control tests were conducted first.
- Use RT/Duroid with a permittivity of 2.2 as a simulant for dry sand.
- Use TMM10i (ε_r'=9.8) as a simulant for moist sand.
- Use ceramic (ε_r'=67.5) as a simulant for water.
- Use 2.5 mm thick layer of DI water in a cavity.
- Use 2.5 mm thick layer of brine in a cavity.
- NOTE: TMM10i and the ceramic have a very low loss tangent (very small ε_r'') so the measured Q is indeterminate.

ε_r'=2.2 Duroid
Sample
ε_r'=2.2 Duroid
ε_r'=2.2 Duroid
ε_r'=2.2 Duroid

Control Tests

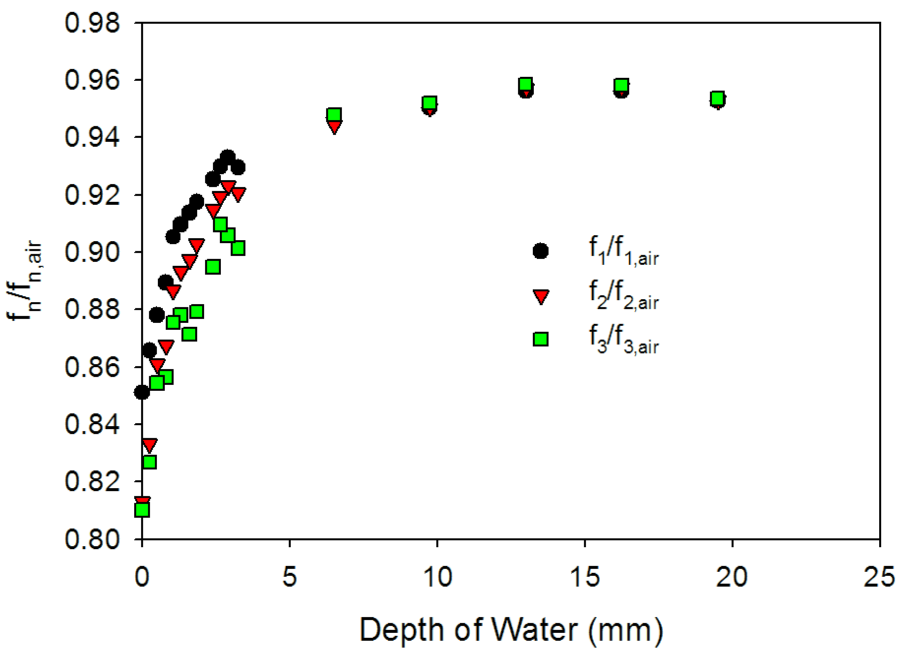
•The variation in the resonant frequency is greater for the higher permittivity ceramic than for the TMM 10i.
•There is very little difference in variation for the first three resonances.
•In both cases, the maximum depth that the SAMPLE may be detected is 10 mm.

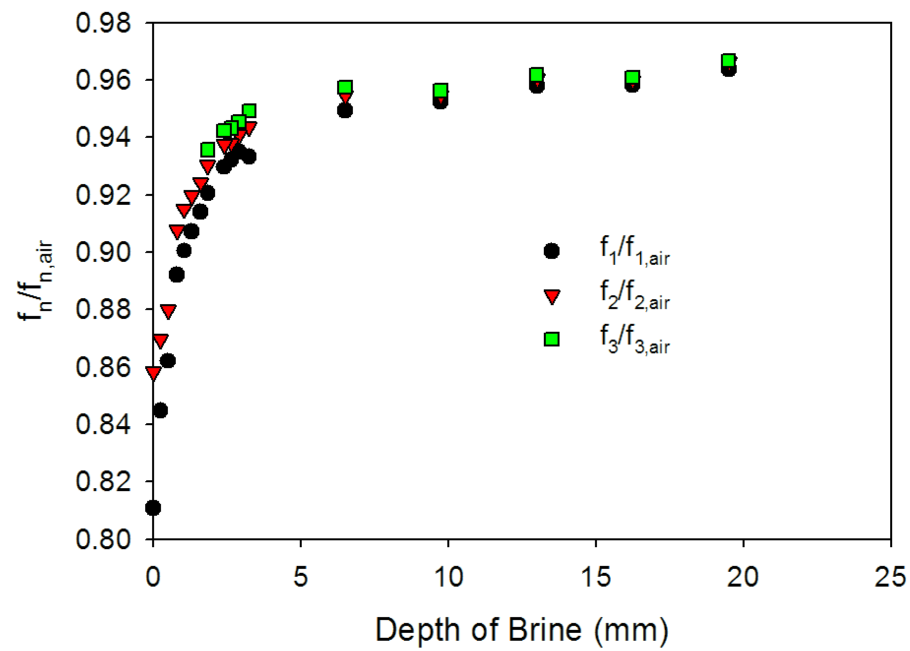




Control Tests

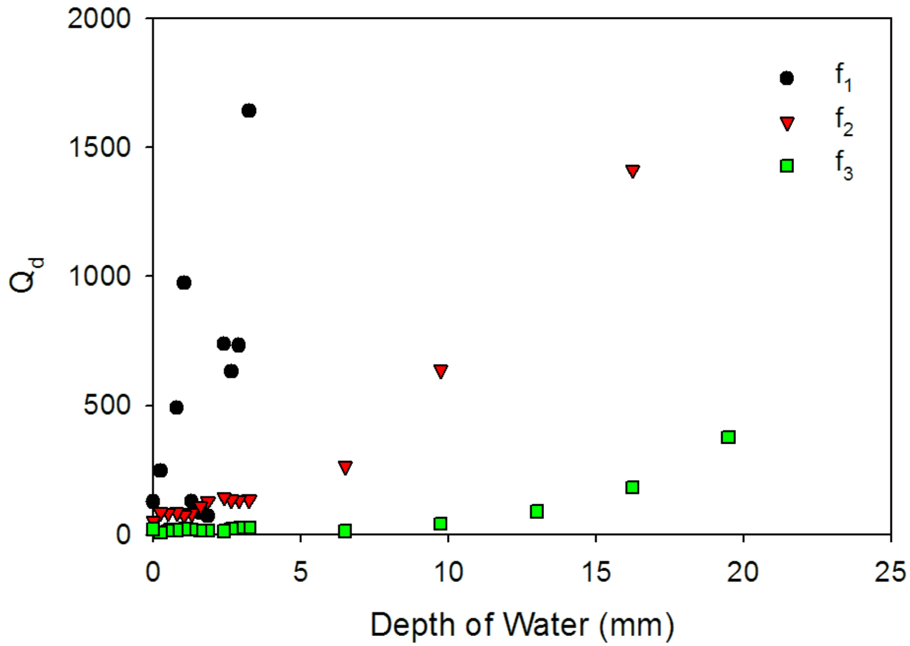
- The variation in resonant frequency is slightly greater than for the ceramic sample, but it is similar.
- The variation in the resonant frequency for DI water and brine is very similar.
- The maximum depth that the sample may be detected is 10 mm.

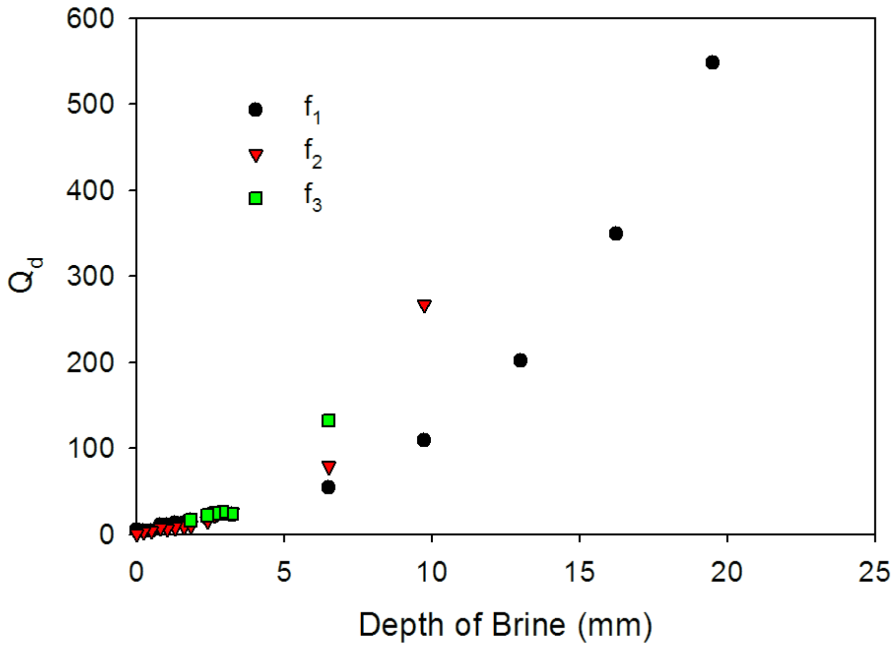




Control Tests

- There is a measureable difference in Q for the three resonant frequencies.
- There is a significant decrease in Q if the sample is near the surface.
- The maximum depth that the sample can be detected is 20 mm or slightly greater.



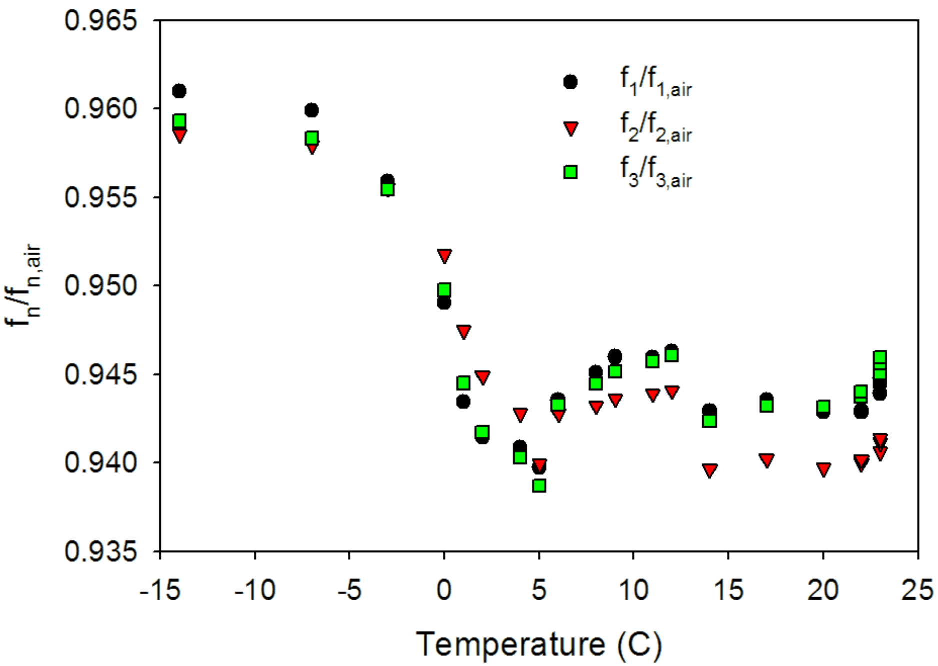


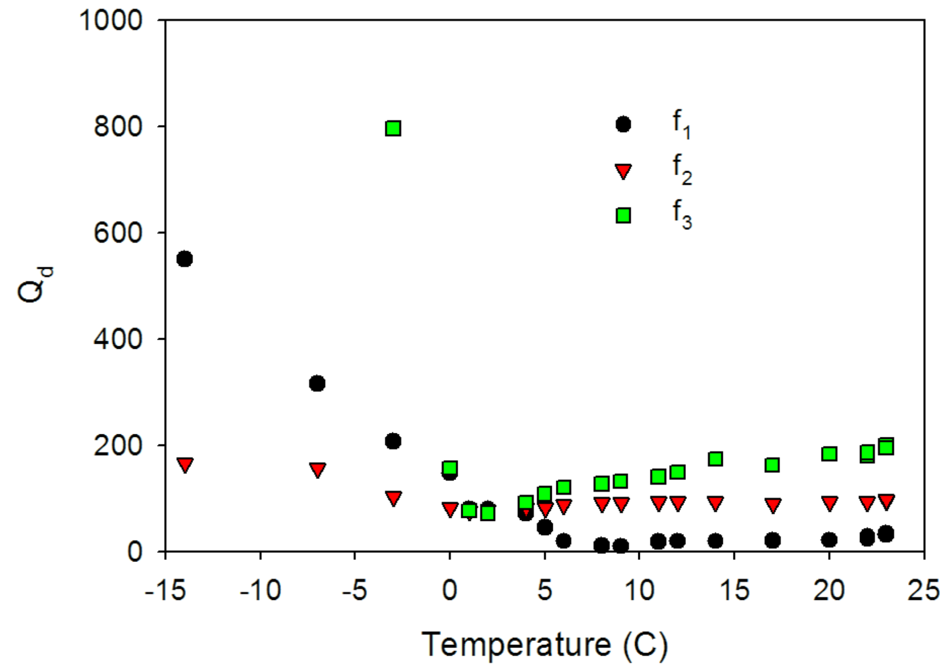
Melting Ice Tests

- Sand was cooled before the setup.
- Layer of ice was placed on cooled sand and buried under cooled sand.
- The volume of sand is not large so the temperature is not uniform throughout the sand.
- Condensation formed on the sand surface.

Melting Buried Ice, 7.5 mm Deep

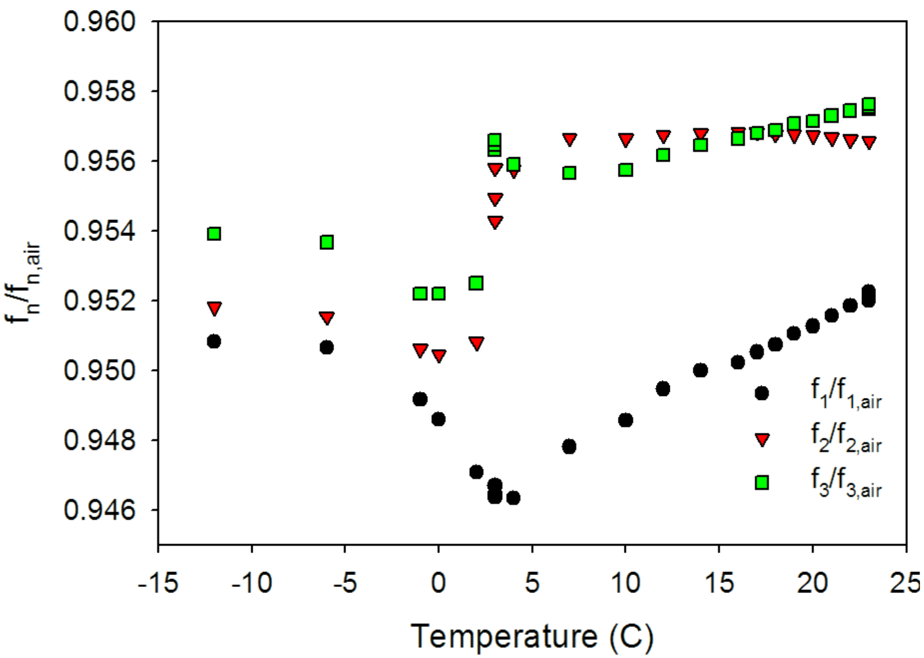
- There is a measurable change in resonant frequency when the ice melts.
- BUT, the actual change in resonant frequency is small.
- The decrease in Q when the ice melts is significant.

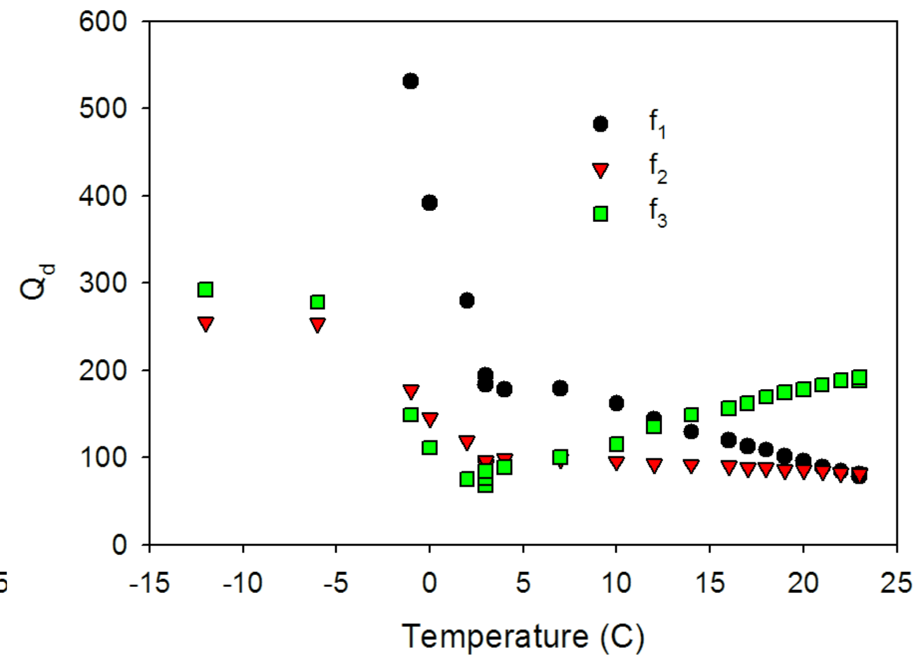




Melting Buried Ice, 15 mm Deep

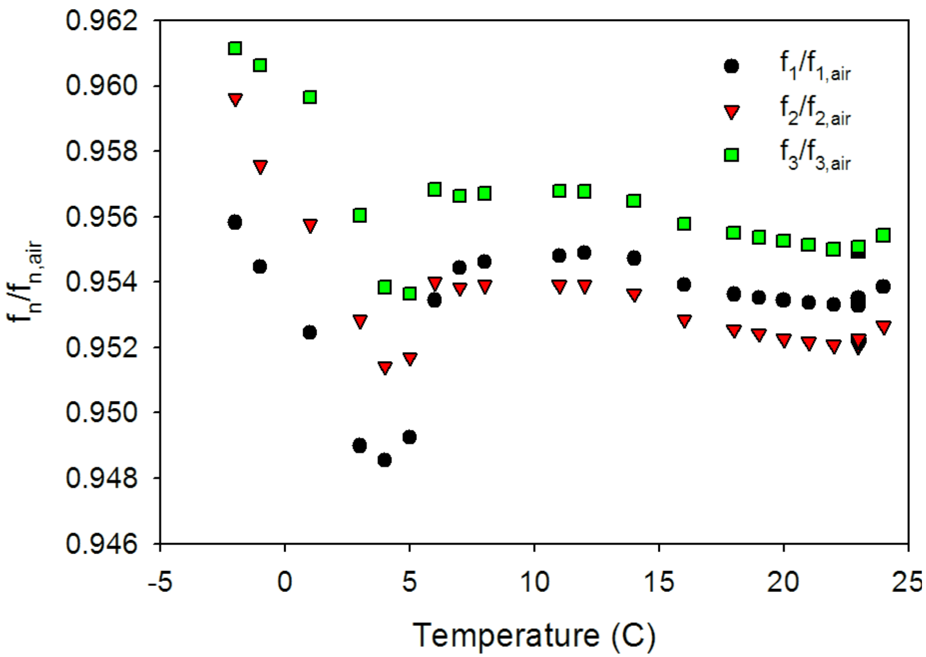
- There is a measurable change in resonant frequency when the ice melts.
- BUT, the actual change in resonant frequency is small.
- Note the resonant frequency returns to the pre-melt value as the thin layer of water disperses in the sand.
- The decrease in Q when the ice melts is significant.

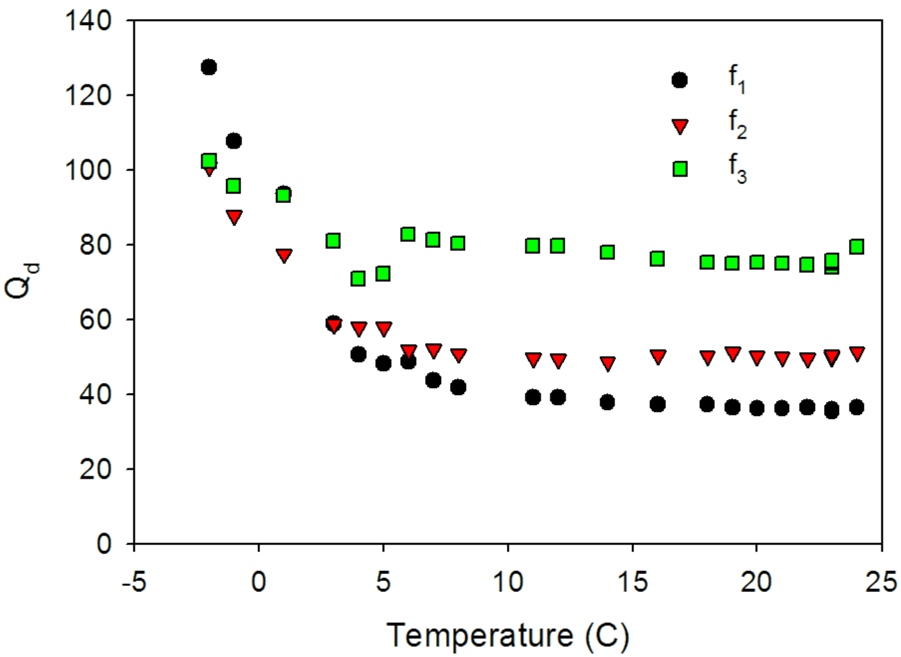




Melting Buried Brine, 7.5 mm Deep

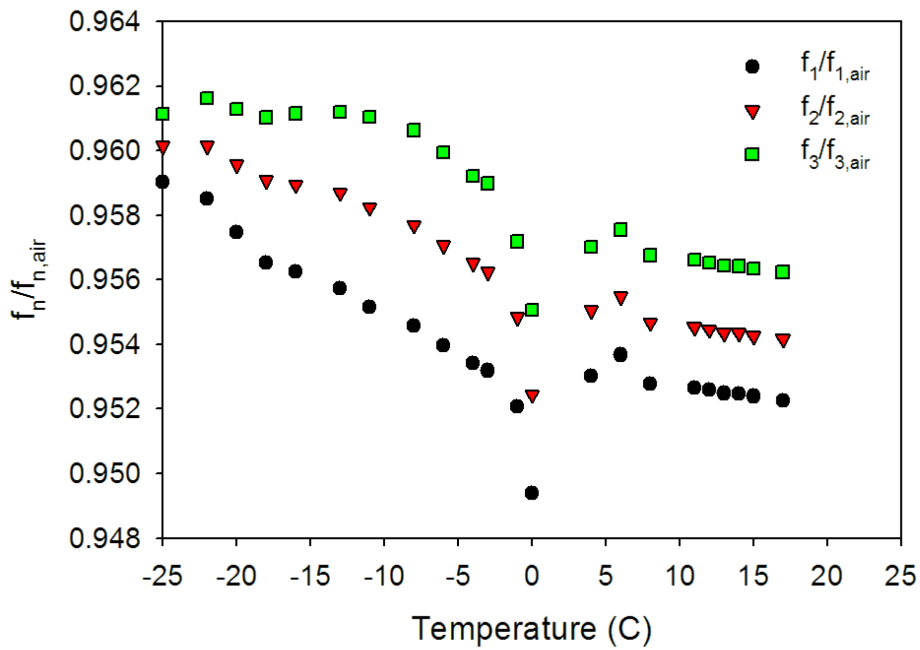
- There is a measurable change in resonant frequency when the ice melts.
- BUT, the actual change in resonant frequency is small.
- There is an obvious variation in the shift in resonant frequency with the resonance harmonic.
- The decrease in Q when the ice melts is significant.

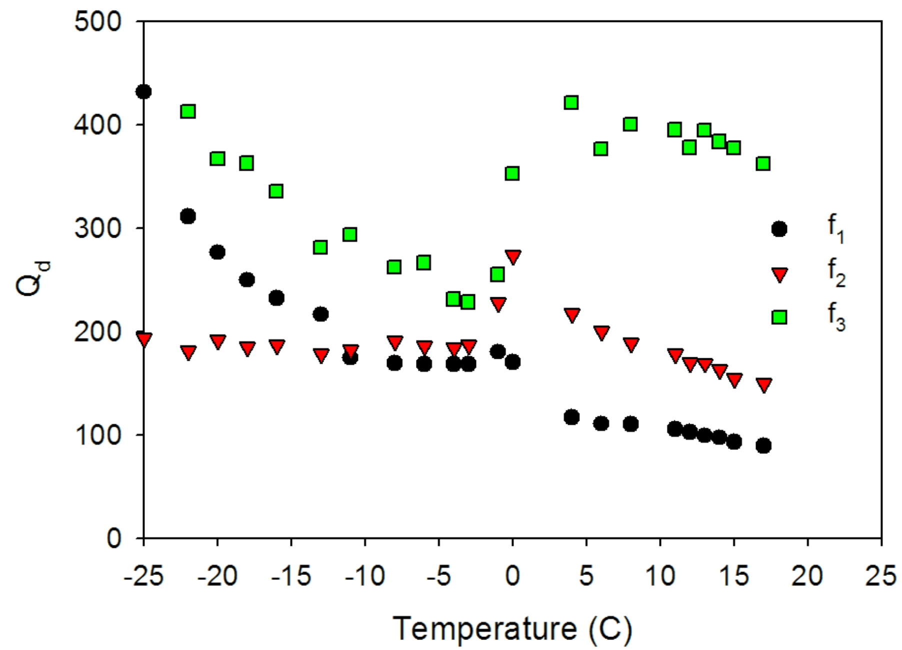




Melting Buried Brine, 15 mm Deep

- There is a measurable change in resonant frequency when the ice melts.
- BUT, the actual change in resonant frequency is small.
- There is an obvious variation in the shift in resonant frequency with the resonance harmonic.
- The decrease in Q when the ice melts is significant, but the second harmonic characteristic is different.





Implementation

•Brine Sensor would be placed on arm of the rover as part of a suite of sensors.
•Arm would need to hold the sensor over the surface.
•Because the sensor is sensitive to movement (height variations cause a shift in resonant frequency), it may be best to place the sensor on the surface and hold it down with the arm.
•The sensor requires a simple transceiver that only requires a magnitude measurement.

Acknowledgements

- This work was funded by a NASA MATISSE project.
- The project PI is Prof. Nilton Renno, The University of Michigan.

- The suite of sensors developed under the project are the brine sensor, an optical microscope, a radiometer, a saltation sensor and an electric field probe.