Ocean World sampling and data communication through significant ice depths

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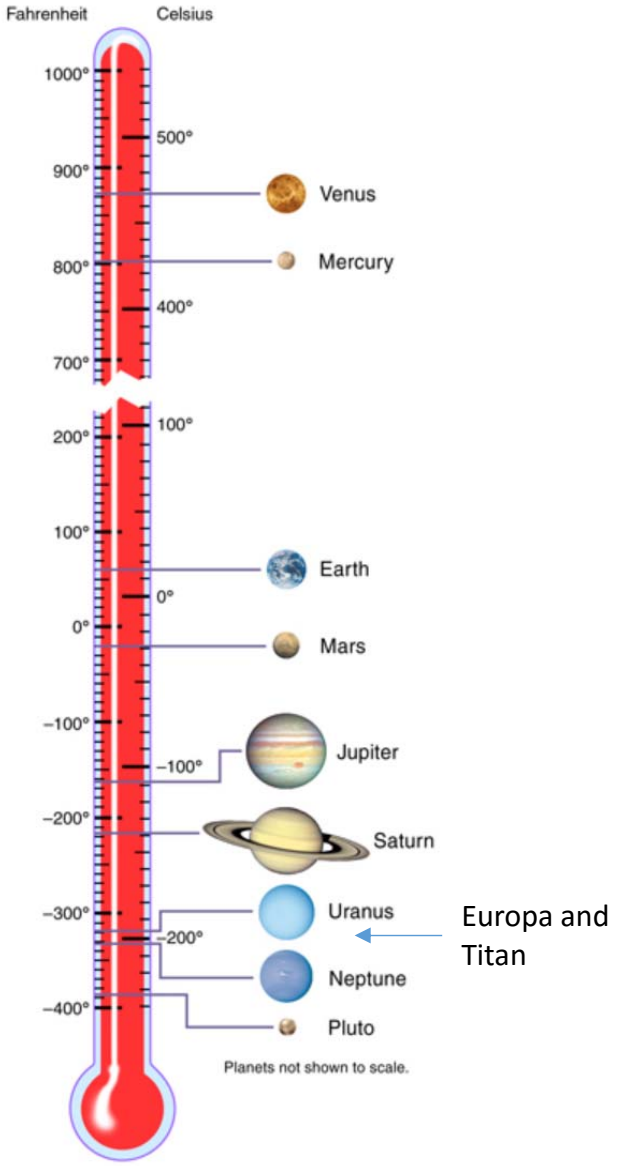
Outer Planets Assessment Group (OPAG)
Atlanta, GA Feb. 22 – 23, 2017
http://www.lpi.usra.edu/opag/meetings/feb2017/draft-agenda.pdf

Abstract

At our lab, we have developed and conceived various novel mechanisms that are driven by piezoelectric. At cryogenic temperatures, conventional piezoelectric materials lose most of their piezoelectric activity constraining their use for Ocean Worlds applications. Ferroelectric single crystals have been shown to have high piezoelectric coefficients at cryogenic temperatures. Using such materials for cryogenic temperature applications, we are developing actuators, drills and sample handling mechanisms and we have also conceived an approach for communicating over kilometers depth through ice. The details are presented in this poster.

Outline

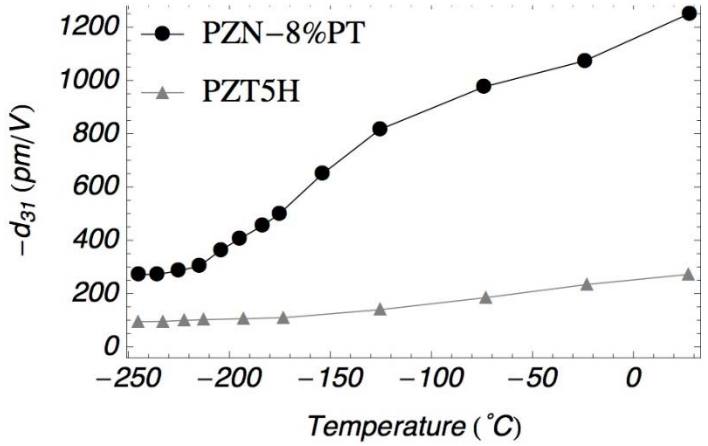
- Cryogenic temperature piezoelectric materials
- Piezoelectric driven devices
  - Sample conveyer
  - Linear inch-worm motors
  - Rotary motors
  - Piezoelectric hammer drills
  - Piezoelectric rotary hammer drills
  - Piezoelectric sonar
  - Piezoelectric acoustic communication
- Other NDEAA developments



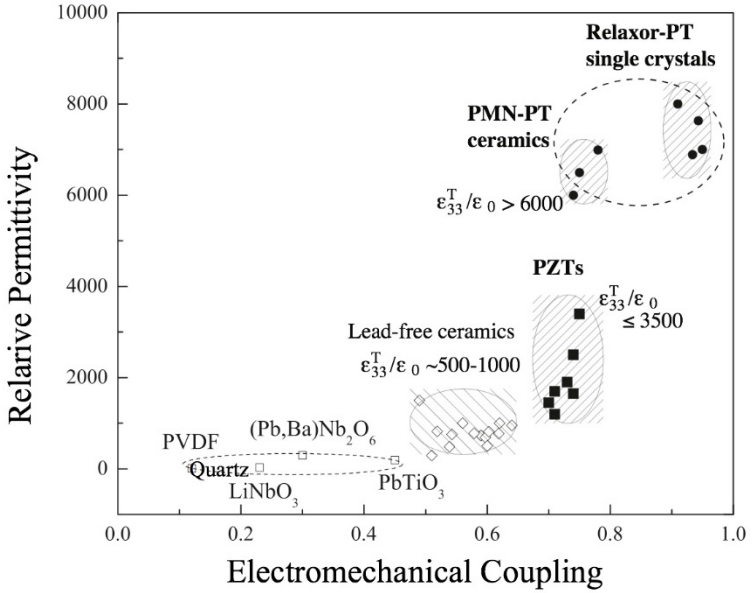
The temperature at various bodies in the Solar System

Piezoelectric transducers applicable at cryogenic temperatures

- Conventional piezoelectric materials, represented by PZT, lose most of their piezoelectric activity at cryogenic temperatures.
  - For example, the piezoelectric strain coefficient of soft PZT decreases from 760 pm/V (picometer per voltage) to 220 pm/V when the operating temperature decreases from 300K to 30K.

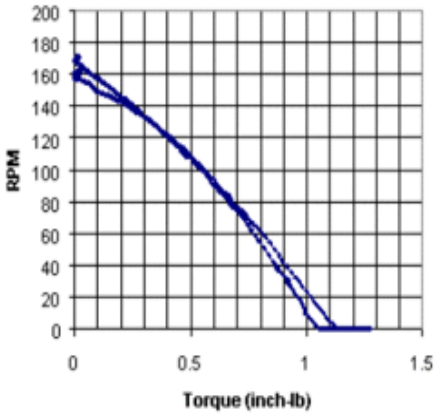


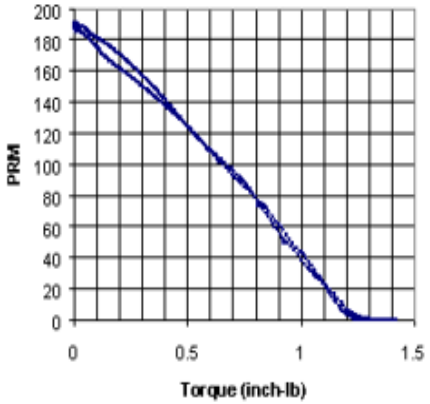
- Studies of relaxor-ferroeletric based single crystals have revealed their extremely high piezoelectric coefficient at cryogenic temperatures, e.g., d_{33} of single crystal piezoelectrics (PMN-PT or PZN-PT) at 30 K is almost equal to d_{33} of PZT-5A at room temperature, indicating great promise for cryogenic applications.
  - This high piezoelectric coefficient implies that similar acoustic sources for a transducer can be achieved by replacing conventional PZT material with relaxor-ferroelectric single crystal at cryogenic temperatures.



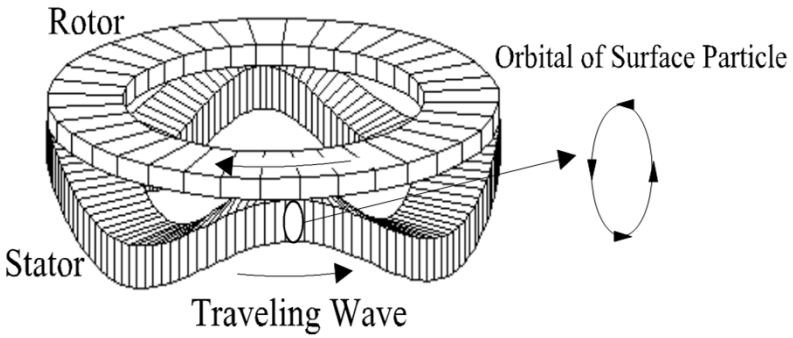
Rotary motors

Cryovac testing of the developed (traveling wave) piezoelectric motor





(a) Before test (b) After 231 temperature cycles
Temperature cyclic test

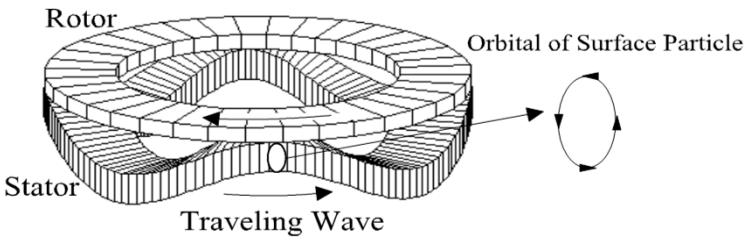


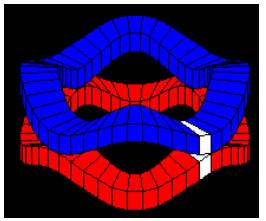
Principle of Operation of a Rotary Traveling Wave Motor.

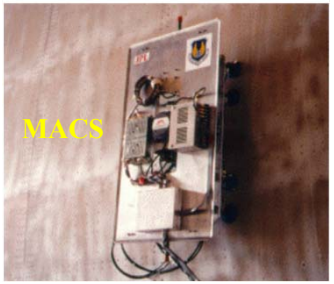
The developed motor survived a total exposure of 336 hours at cryovac test conditions of 65 hour at –80°C and 25-mTorr plus 271 hours at –150°C and 16-mTorr).

Ultrasonic motors (USM) advantages

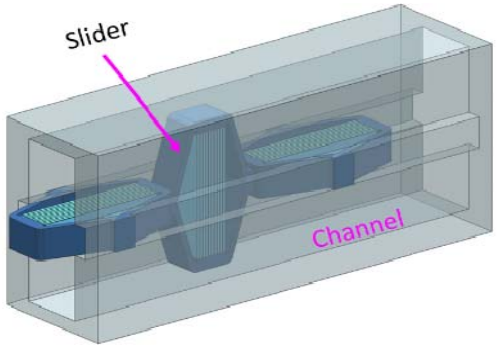
- Low speed and direct drive
- Order of magnitude higher torque density than electromagnetic motors
- Unique configurations: Pancake as well as annular shape for electronic packaging
- Lower cost, easy to miniaturize and to mass produce
- Inherently backdrivable (self braking)
- Not affected by magnetic field or radiation



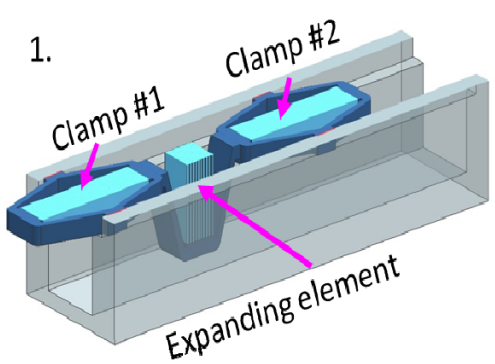


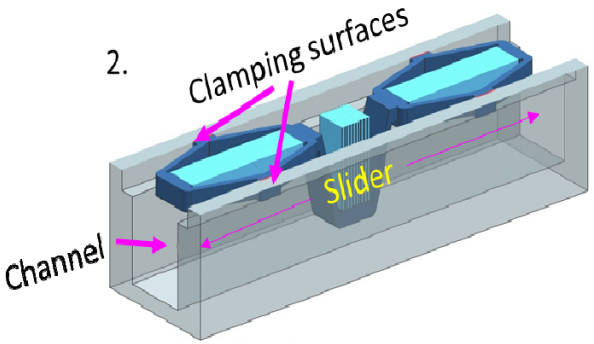


Linear motor



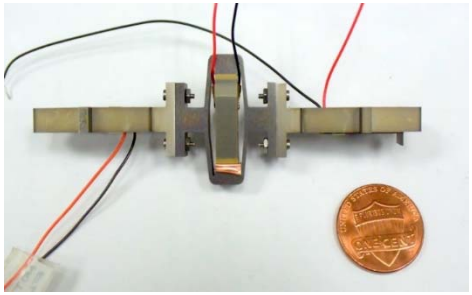
Configuration of a flextensional piezoelectric inch-worm motor.



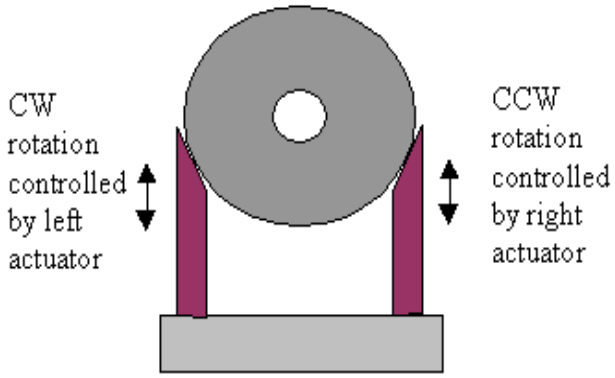


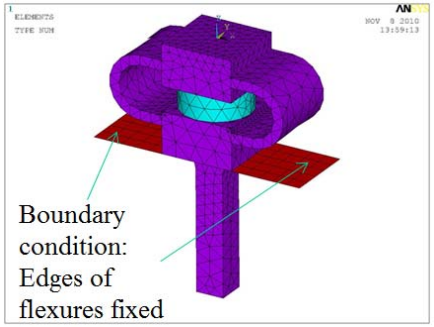
A step in the translation of the slider inside the channel that makes up the motor.

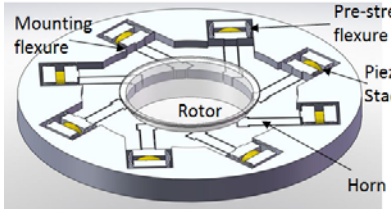
The fabricated piezoelectric inch-worm motor.



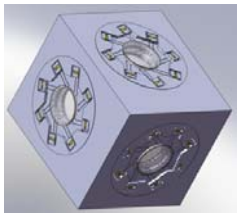
Piezo-Barth Motor

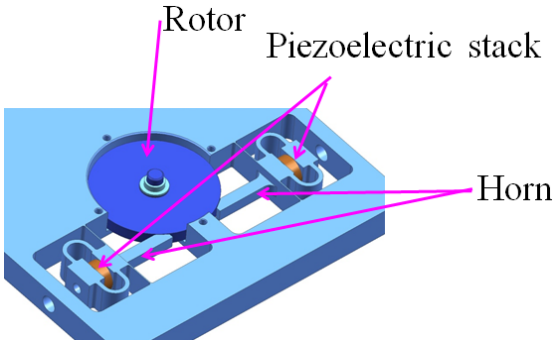


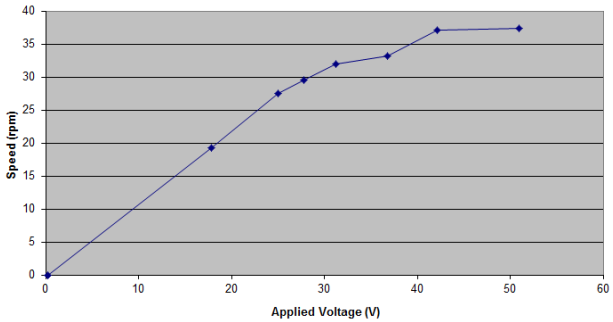




Unidirectional, bidirectional and 3D motor designs

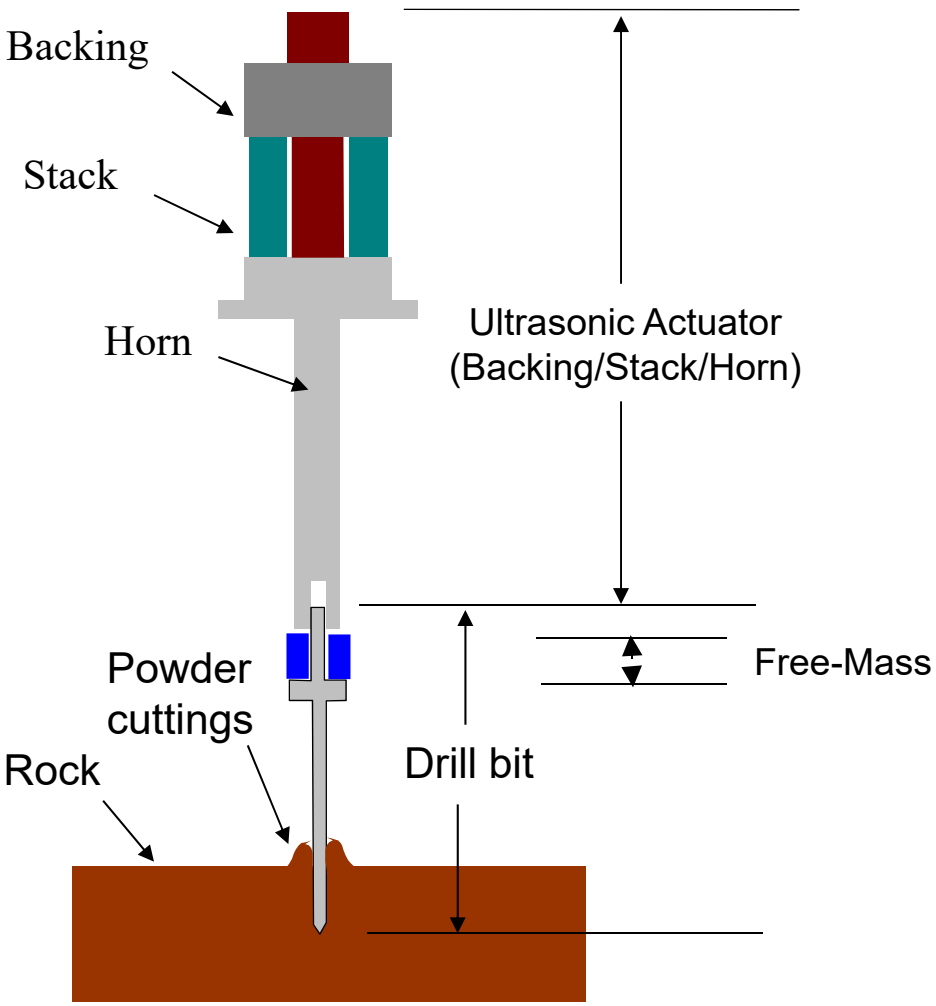




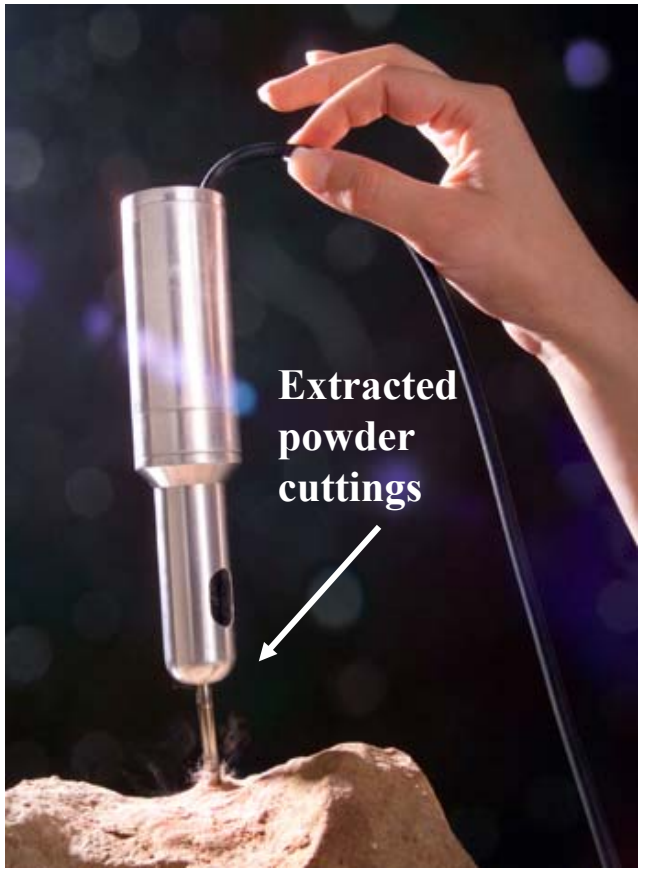


NTR REF: S. Sherrit, X. Bao, M. Badescu, Y. Bar-Cohen, P. Ostlund, P. Allen, and D. Geiyer, "Planar Rotary Piezoelectric Motor using Ultrasonic Horns," NTR Docket No. **47813**, (2010)

Ultrasonic/Sonic Driller/Corer (USDC)

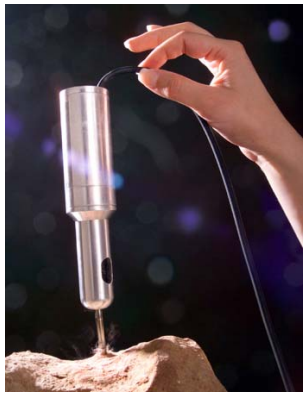


2000 R&D 100 award



USDC

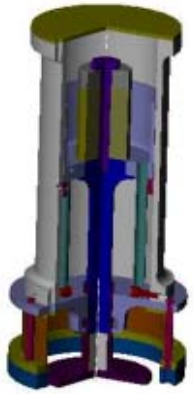
2000 R&D 100 award

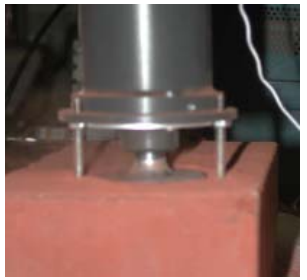


USDC

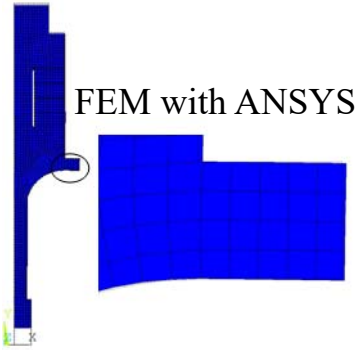
Packed soil penetrator

USDC anchor – operates forward and backward. Supported the steep terrain rover

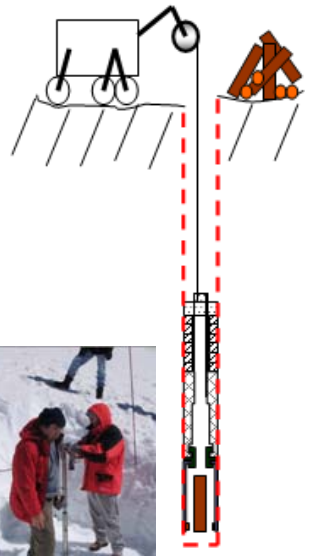




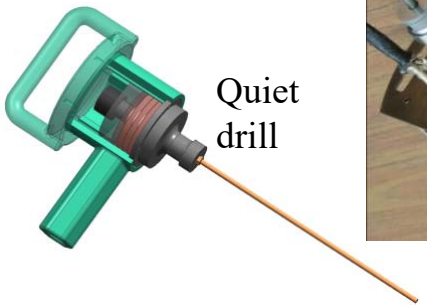
Ultrasonic Rock Abrasion Tool (URAT)



FEM with ANSYS



Gopher was field tested in Mt. Hood and Antarctica

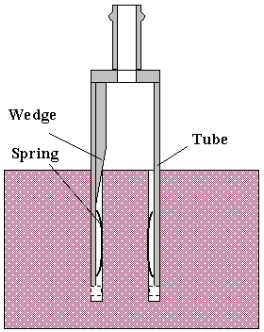


Quiet drill

High temperatures

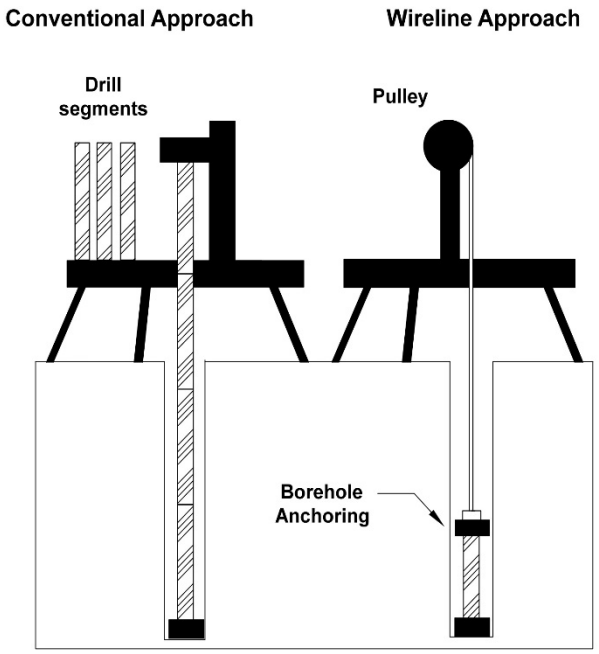
Low

Folded horn



All-in-one bit

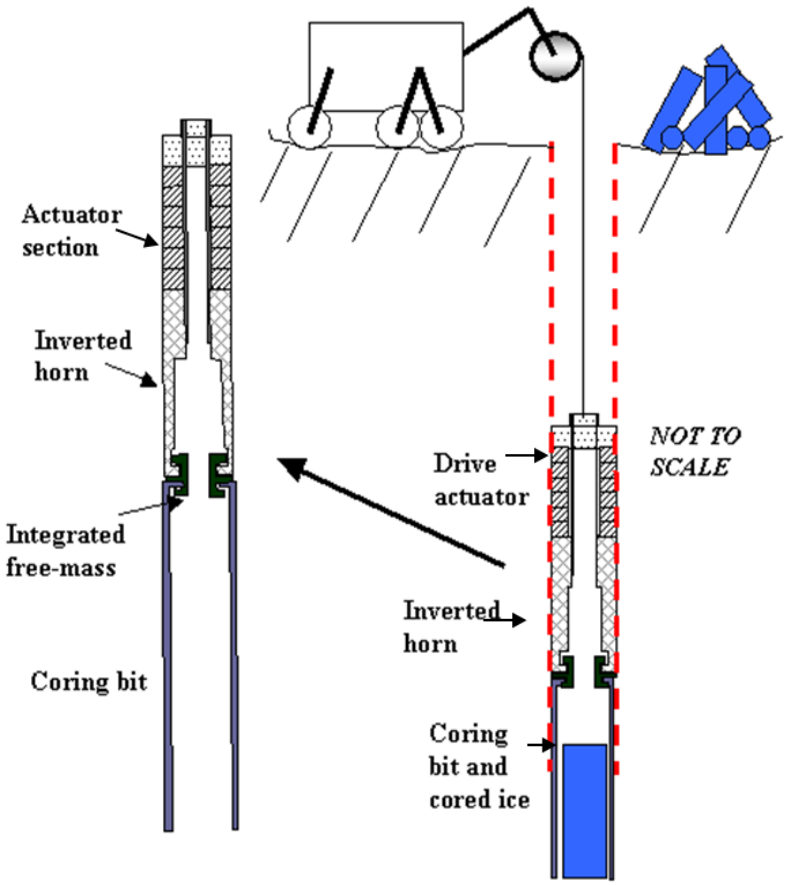
Wireline drill – reaching great depth



Rotary-hammer for efficient, dry drilling

- Piezoelectric actuator – hammers the bit and provides effective fracturing mechanism
- Electrical motors - provides cuttings removal via rotation, linear feed for weight on bit control, and anchoring

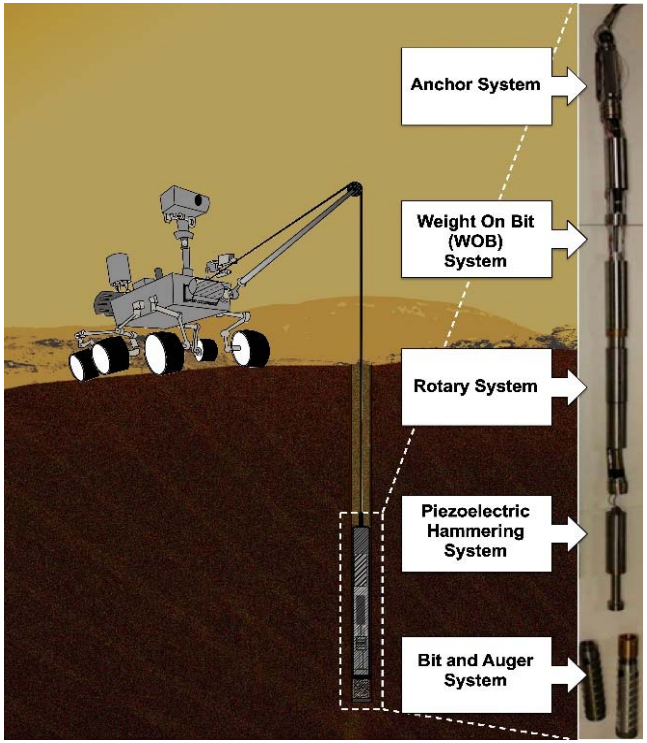
The U/S Ice-Gopher

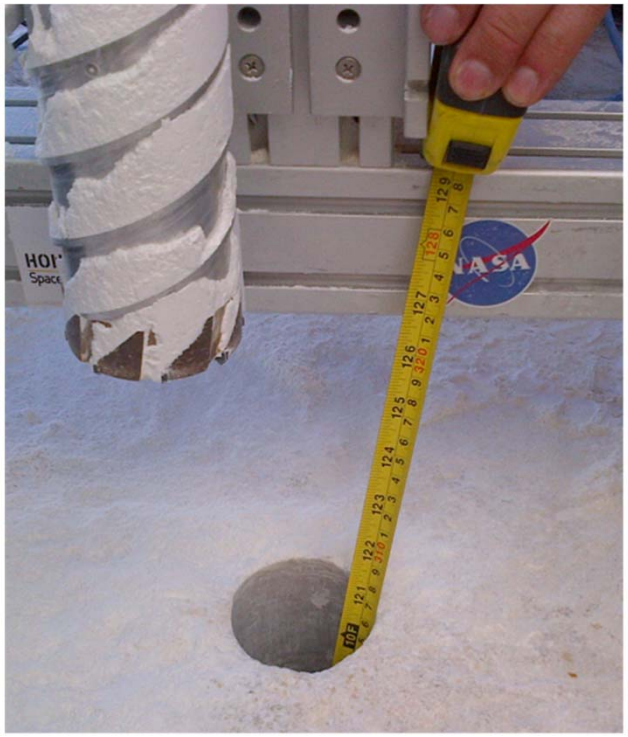


Sea ice drilled borehole entry

The gopher in the drilled hole

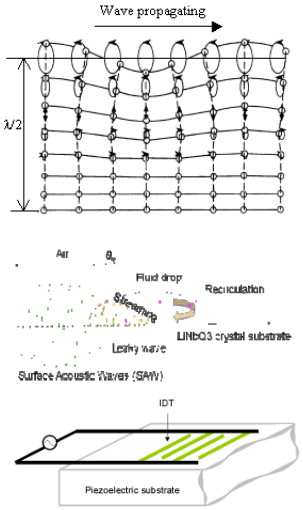
Field test (joint with Honeybee Robotics)

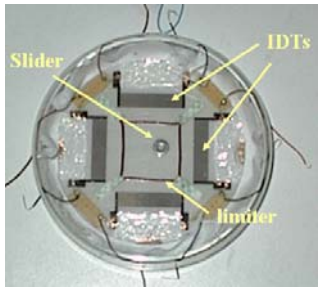




32 cores were extracted from a depth of 3.07 m

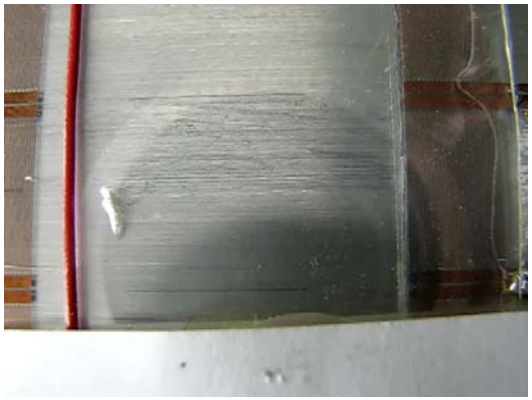
Beltless conveyer using Surface Acoustic Wave (SAW)

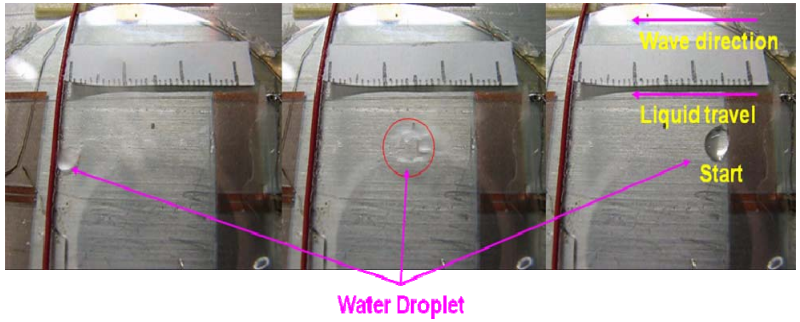




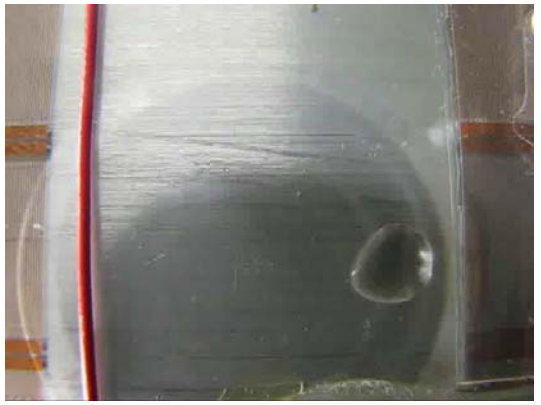
2D SAW motor

Snapshots from the travel of WCA 12 powder with 50% 7–8.5 μm particles.





Snapshots from the travel of water droplet (the travel direction here is from right to left).

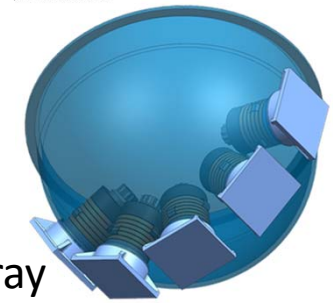


iSONAR - Acoustic analyzer of icy sub-surfaces of cold bodies in the solar system

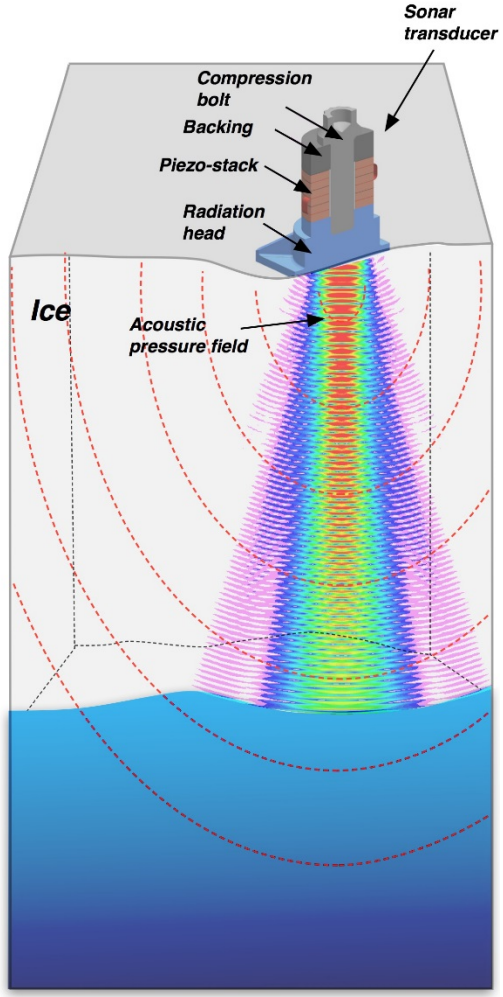
- An iSONAR is being proposed as an analyzer for exploring Europa's subsurface as well as the investigation of Titan lakes' architecture.

- A sonar probe emits acoustic waves, which are reflected from discontinuities and subsurface layer interfaces depending on the transmitted power and acoustic properties.

- The emitted waves are reflected by interfaces where contrast in acoustic impedance (sound speed times the density) occurs.



Sonar
transducer array



Wireless Acoustic System (WAcS) for communication through thick ice

Top surface asset (e.g., lander)

Ice

Transceiver N-1
- Acoustic link
- Comm. control
- Drive electronics
- Power

Transceiver N
- Acoustic link
- Comm. control
- Drive electronics
- Power

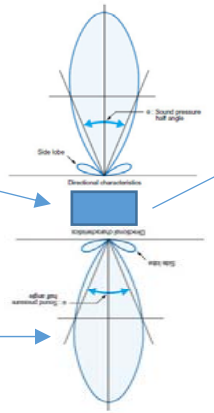
Penetrator with stack of deployable transceivers

Ocean

Ice surface

Lander

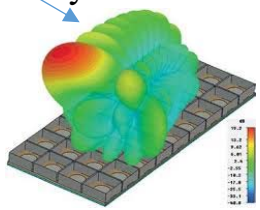
Acoustic transceiver



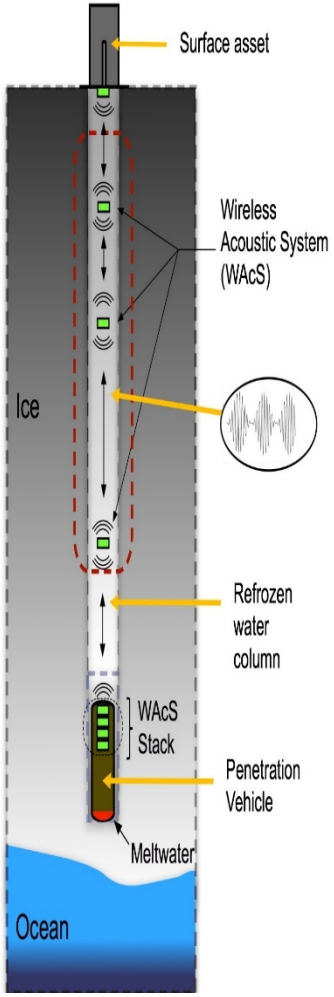
Transceivers

Directivity of the transmitted acoustic wave from a single transducer

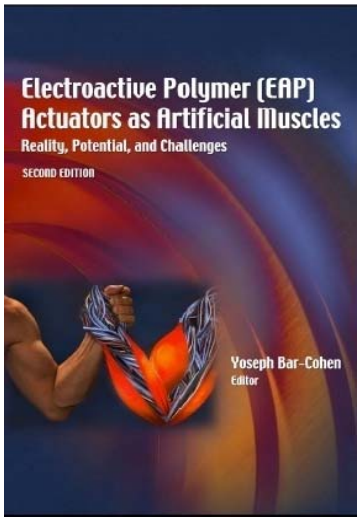
Transmitted acoustic field from a transducer array

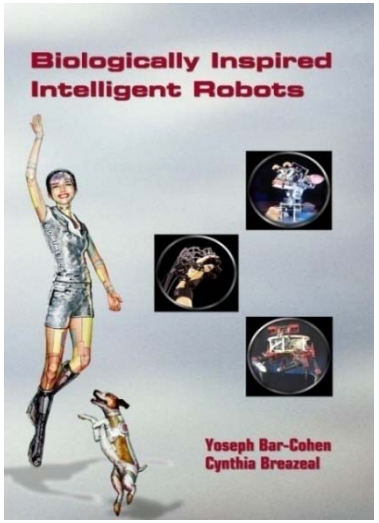


Cordless hydrothermal melting drill

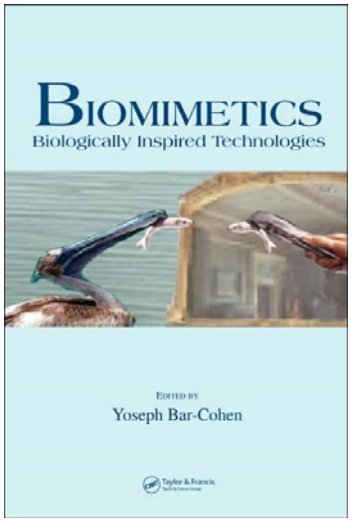


2000



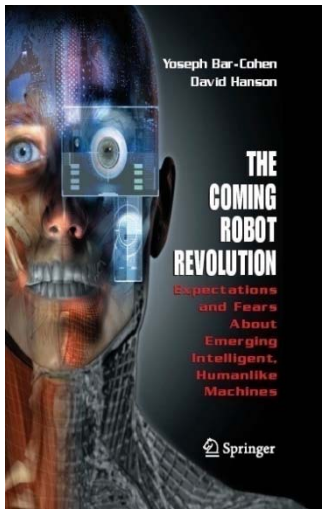


2003

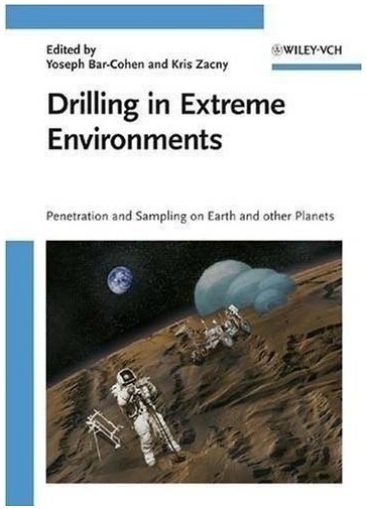


2005

1st Ed. (2001)
2nd Ed. (2004)



2009



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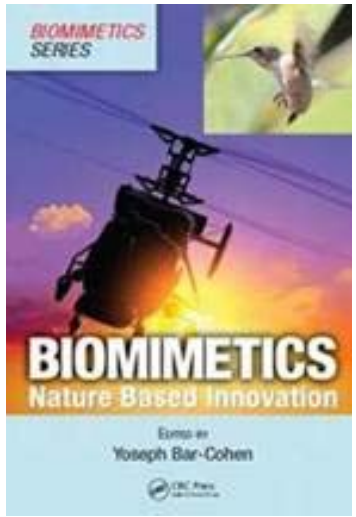
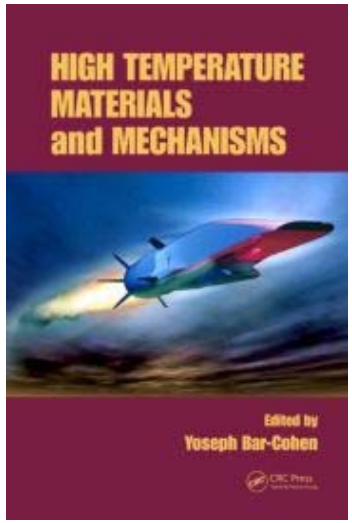
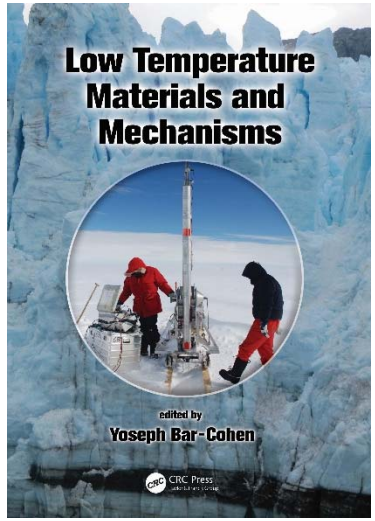


2011



2014



2016

http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm

Acknowledgement

Some of the research reported in this presentation was conducted at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA).

The clearance number is CL#17-0490, Jan. 26, 2017