ELECTROMAGNETIC COUPLING IN MARS SOIL SIMULANTS TO SUPPORT MARS ISRU WATER EXTRACTION

STUDENT: SHANTI GARMAN

Mars In-Situ Resource Utilization

- *In-situ* resource utilization (ISRU): Utilize a planet's extant materials to reduce mission mass and cost ($$)
- Water necessary to support life
- H_2O can be processed into H_2 and O_2
- Evidence of H_2O ice on Mars: Images from HiRISE camera aboard Mars Reconnaissance Orbiter (MRO)

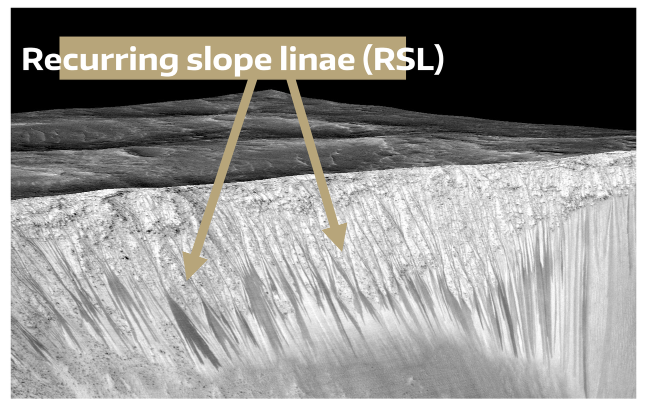


Image credit: NASA/JPL-Caltech/Univ. of Arizona

Credit: ISRO/ISSDC /Emily Lakdawalla

Image credit: NASA/JPL-Caltech/Univ. of Arizona

EM Coupling & Dielectric Heating

- Electromagnetic (EM) energy works to rotate dipoles in dielectric material
- Permittivity is complex and a function of frequency

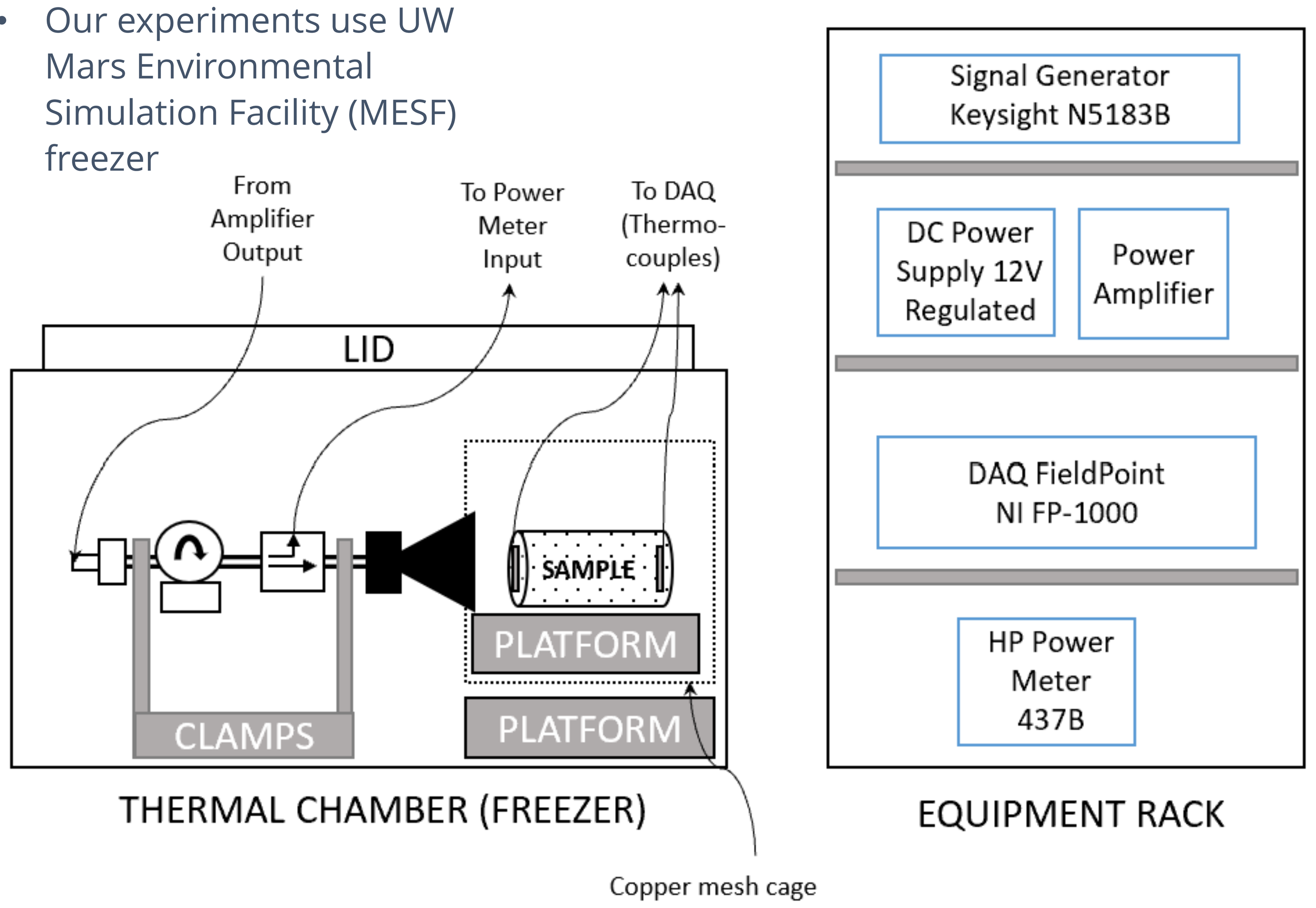
$$\varepsilon = \varepsilon' - j\varepsilon'' \rightarrow \varepsilon(\omega) = \varepsilon'(\omega) - j\varepsilon''(\omega)$$

- Imaginary part of complex permittivity contributes to loss → dielectric heating

$$Q_{\text{dielectric}} = \frac{1}{2} \cdot \omega\varepsilon'' E^2$$

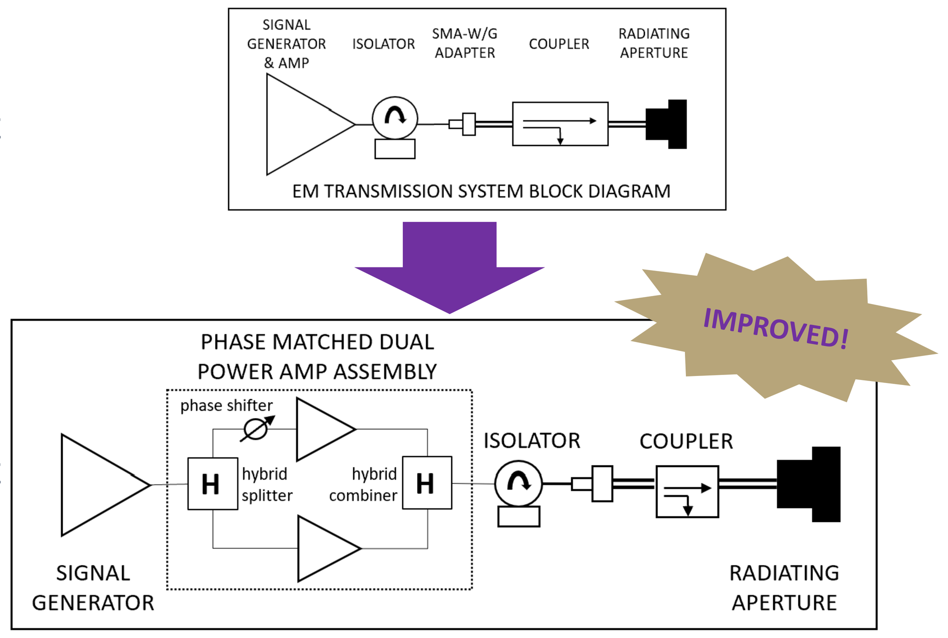
Experimental Setup

- Our experiments use UW Mars Environmental Simulation Facility (MESF) freezer



X-Band Transmission System

- Initial microwave transmission system
  - P_{out}=+31 dBm (~1.2-1.3 W)
  - Operating frequency range: 8-10 GHz
    - High end limited by amplifier frequency response
- Phase Matched Dual-Power Amplifier microwave transmission system
  - P_{out}=+34 dBm (~2.5 W)
  - Operating frequency range: 8-11 GHz
    - Improved amplifier operating bandwidth



Mars Soil Simulants

- Martian regolith (soil) simulants developed by NASA for scientific research include:
  - Mars Mojave Simulant (MMS)
  - JSC-Rocknest
- Only MMS used in this study
- Mass of MMS samples measures approx. 29.5g
- Sample holders
  - Inner dimensions: 11.0 cm³
  - Inner rectangular cavity:
    - Rmax Thermasheath-3 polyisocyanurate rigid foam
  - Front and rear windows:
    - Laird Eccostock polyethylene foam
    - Low dielectric loss (ε=*1.06-j0.001*) to reduce unwanted reflections

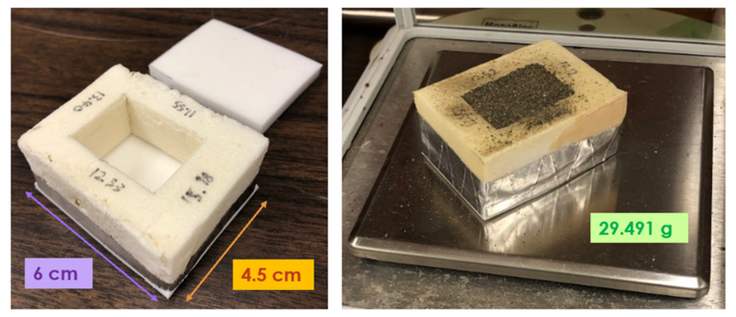
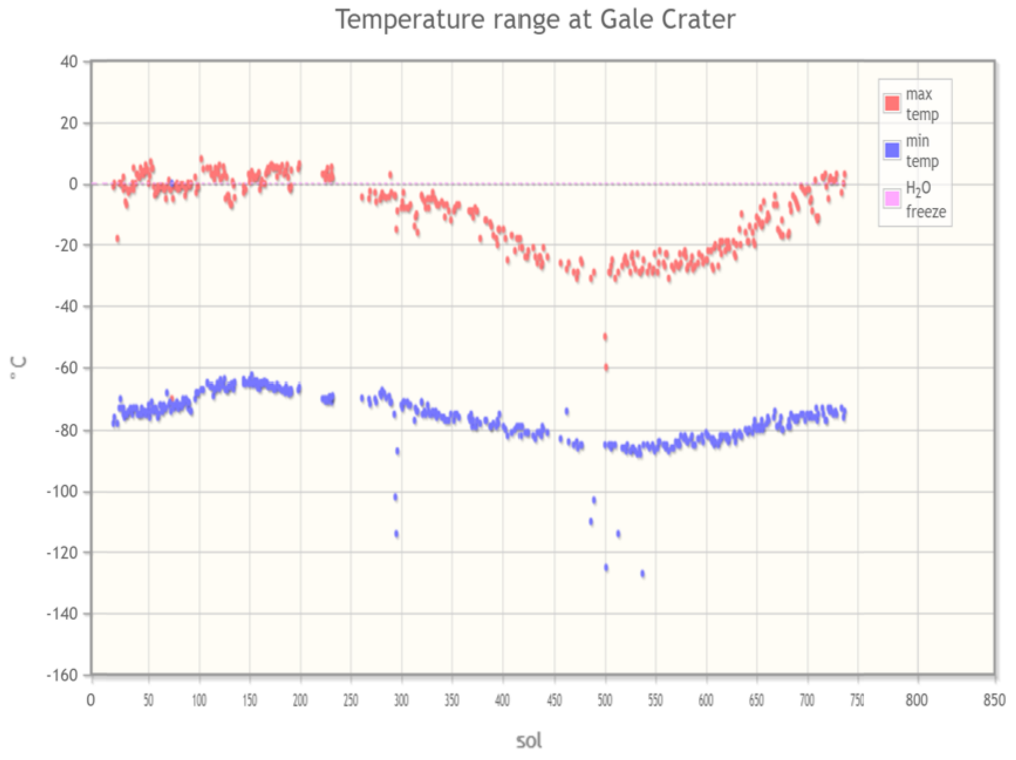


Image credit: S. Garman

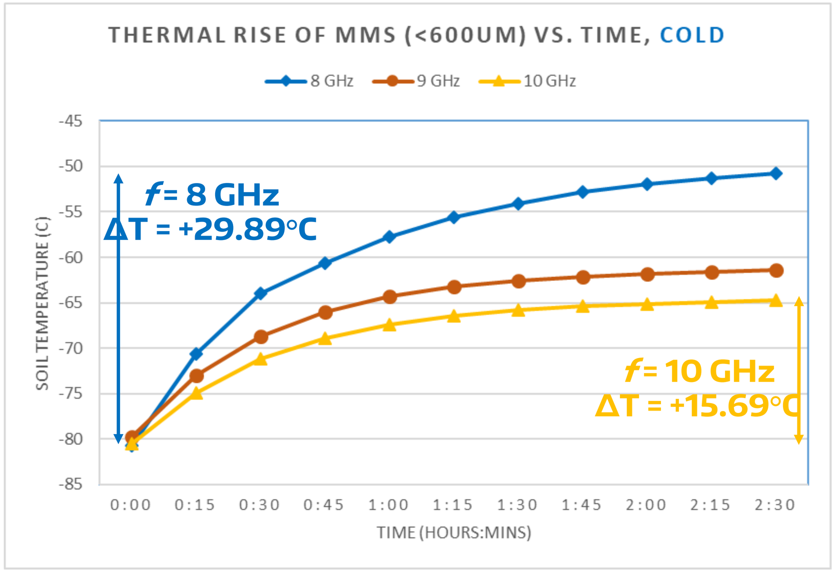
Simulating the Mars Environment

- Mars daily temperatures range from approx. -80°C to 0°C



Data from Mars Curiosity Rover Environmental Monitoring Station (REMS), courtesy of the Centro de Astrobiologia (Spain)

Thermal Response Due to Frequency (Initial System)



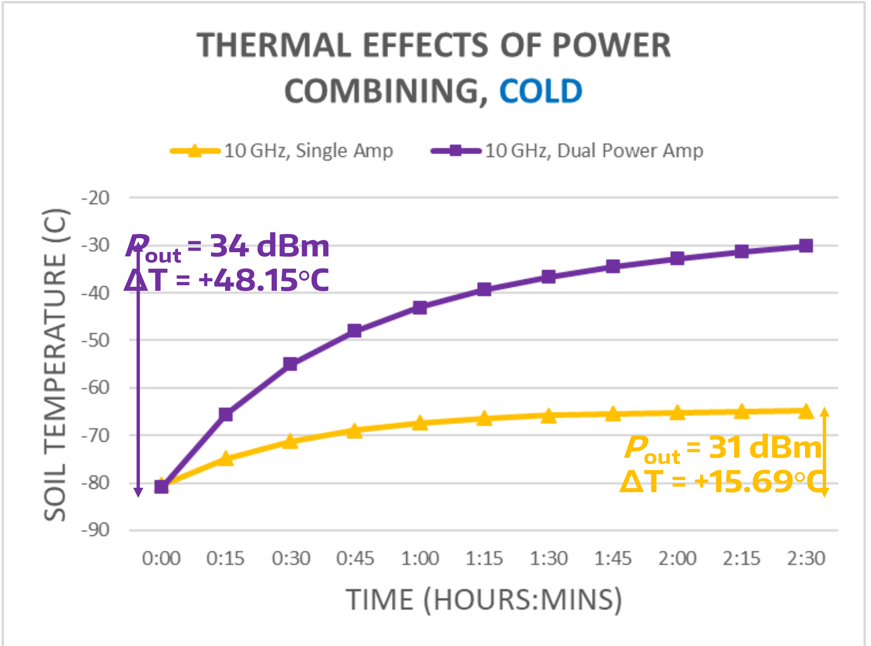
- Experimental results left and below use initial microwave transmission system (transmitted power P_{out}=+31 dBm)

	Total Thermal Rise	
Frequency (GHz)	ΔT, Amb (T= +20°C)	ΔT, Cold (T= -80°C)
8	41.6	29.9
9	35.0	18.4
10	31.5	15.7

Thermal Response Due to Transmitted Power

- Experimental results at right and below use both initial transmission system (gold curve) and dual-power system (purple curve)
- Thermal rise approaching level required for sublimation (melt)

	Total Thermal Rise ΔT, Cold (T= -80°C)	
Frequency (GHz)	Initial (P_{out} = 31 dBm)	Dual-Power (P_{out} = 34 dBm)
10	15.7	48.2



Future Work, References, and Acknowledgments

- Experiments ongoing with dual-power amp across 8-11 GHz
- EM coupling relationship to water content ("icy soil" experiments)
- Measure and compare response of JSC-Rocknest simulant
- Investigate EM coupling relationship to soil grain size

Faculty: Yasuo Kuga
Graduate Student: Shanti Garman
Undergraduate Students: Oliver Ruo, Salma Hassanain

[1] O. Igbinosun. 2019. *Characterization of Mars Analog Soils with Microwave Radiation to Investigate Subsurface Water Extraction Utilizing Dielectric Heating.* Doctoral Dissertation, University of Washington.

[2] E. Ethridge, W. Kaukler. 2012. *Finite Element Analysis of Three Methods for Microwave Heating of Planetary Surfaces.* In *Proceedings of the 50th AIAA Aerospace Sciences Meeting.*

[3] P. Hoekstra, W. T. Doyle. 1970. *Dielectric Relaxation of Surface Adsorbed Water. In Journal of Colloid and Interface Science, Vol. 36, No. 4.,* 513-521.

[4] J.V. Hogancamp, P.D. Archer, J. Gruener, D.W. Ming, V. Tu. 2019. *JSC-Rocknest: A large-scale Mojave Mars Simulant (MMS) based soil simulant for in-situ resource utilization water-extraction studies. In Proceedings of 50th Lunar and Planetary Science Conference.*

ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY *of* WASHINGTON

ADVISOR: YASUO KUGA