MAHRS: A Simple Instrument Suite to Characterize the Weathering and Habitability of the Shallow Martian Subsurface

University of Michigan and Glenn Research Center

Discovery Workshop
April 9, 2014

Decadal Survey Recommendations

Michigan Engineering
University of Michigan ▪ College of Engineering

Understand the processes that determine the history and future of habitability in the solar system.

Identify and investigate past or present habitable environments on Mars and other worlds.

Search for modern habitats with the necessary conditions, organic matter, water, energy, and nutrients to sustain life.

Make comprehensive measurements of the atmosphere and surface of Mars.

Inventory and characterize planetary resources that can sustain human explorers.

MAHRS Science Goals

Search for wet brines in the shallow subsurface.

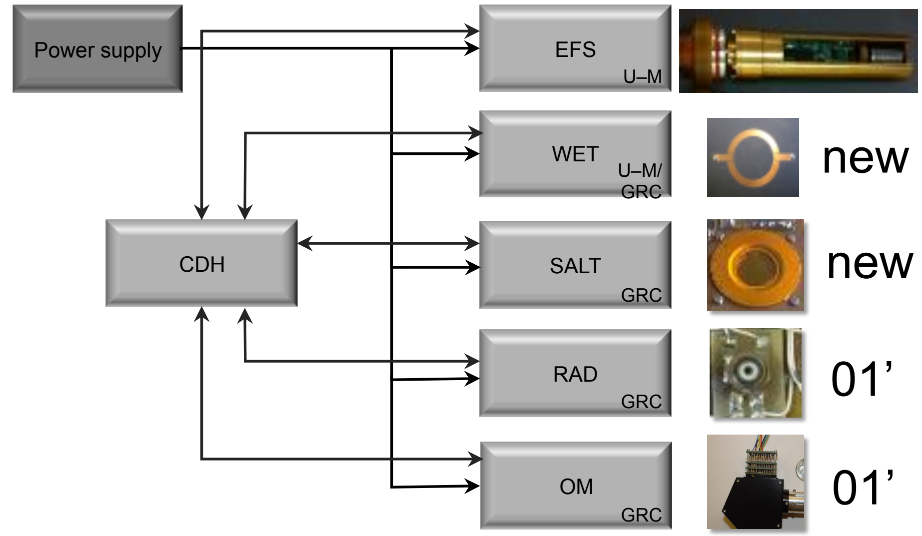
Determine the effects of regolith wetness on saltation and on the exchange of dust between the surface and the atmosphere.

Characterize aeolian processes and the exchange of material between the surface and the atmosphere.

Determine the effects of dust aerosols on the local climate.

MAHRS Instrument Suite Overview

DESCRIPTION:
- The MAHRS Project has been maturing a set of instruments for detecting potentially habitable zones in shallow planetary subsurfaces, and for studying the exchange of matter between planetary atmospheres and shallow subsurfaces.



VALUE TO NASA:
- MAHRS responds to the top priorities of the 2013–2022 Decadal Survey and the 2007–2016 Science Plan for NASA's Science Mission Directorate.
- Instruments are being optimized by minimizing mass, volume, and power consumption while meeting the science requirements described in the MAHRS traceability matrix.
- Leverages instrument development funded by NSF Geo, NSF SBIR, NASA PIDDP, NASA ASTID, NASA Mars Exploration Program, The University of Michigan, and the State of Michigan.

OBJECTIVES:
- To refine the Electric Field Sensor (EFS) design by minimizing mass, volume, and power consumption.
- To integrate the EFS, Optical Microscope (OM), Radiometer (RAD), Saltation Sensor (SALT), and soil Wetness sensor (WET) instruments into a single instrument package optimized for accommodation onto future planetary missions.

SCHEDULE:

Revised schedule due to late start..

Nilton O. Renno (University of Michigan), PI; **Michael J. Krasowski** (GRC), Co-I; **George E. Ponchak** (GRC), Co-I; **Norman F. Prokop** (GRC), Co-I; **Joseph M. Flatico** (Ohio Aerospace Institute), Co-I

Entry TRL: 3-5 **Exit TRL**: 6

MAHRS Quad Chart

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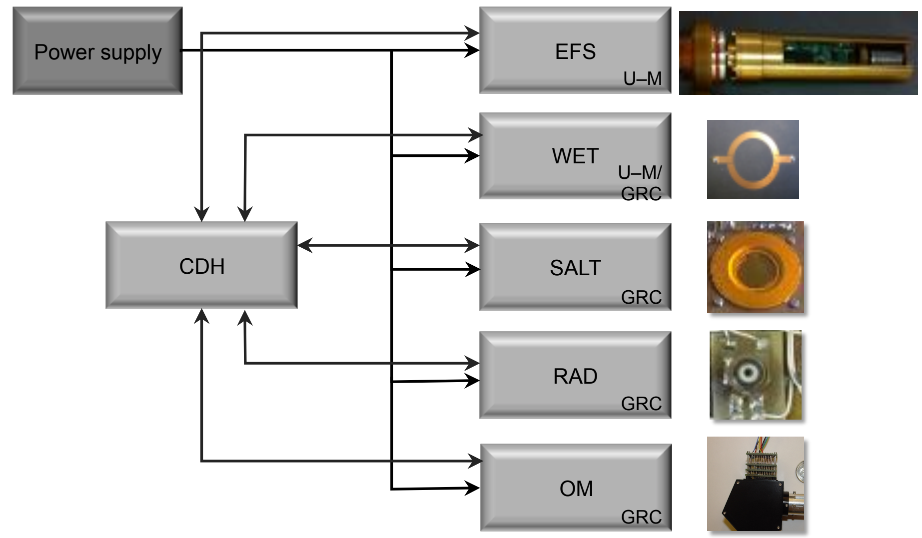

Q1-2 ACCOMPLISHMENTS:
Made progress on preparations for the subsystem PDR.
- **EFS**: Designed and fabricated a prototype sensor capable of operating for years on Mars-like dusty conditions.
  - Tested the EFS prototype in the laboratory and deployed to the field.
- **SALT**: Characterized waveform and have been developing measurement strategy.
- **WET**: Performed numerical simulations to optimize the ring resonator. Fabricated and tested various candidates resonators.
  - Developed method for measuring soil wetness. Currently characterizing the selected resonators.
  - Detection depth is being studied, meeting the initial requirements of 10 cm is more challenging than anticipated.
- **RAD**: Will share the electronics with OM.
  - Development focused on optical assembly and FPGA design, initial tests indicated that requirements are met.
- **OM**: Designed the microscope based on a STAR1000 radiation hard CMOS image sensor and a Microsemi ProASIC3 FPGA development board (FPGA-DB).

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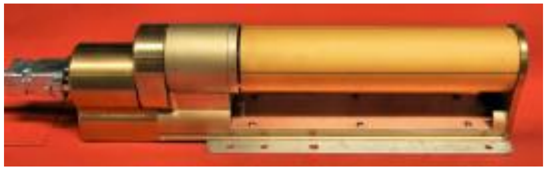
Electric Field Sensor (EFS)

DESCRIPTION: The MAHRS Electric Field Sensor is unique because it is capable of making accurate measurements of electric fields even when subject to the impact of charged particles. This set the patent protected EFS apart from other technologies such as electrometers.


Original EFS Prototype


New EFS Prototype

OBJECTIVES:
- To mature the flight qualifyable EFS prototype into a sensor capable of operating for years in Mars-like dusty environments.
- To test the prototype at the field.

Q1-2 ACCOMPLISHMENTS:
Developed a cantilever version of EFS capable of operating for years in dusty environments.
- The prototype sensor was tested successfully in the laboratory.
- The sensor was deployed to the field on 14 January 2014.
- The sensor has been operating continuously (even during winds of 70 mph on March 2014).

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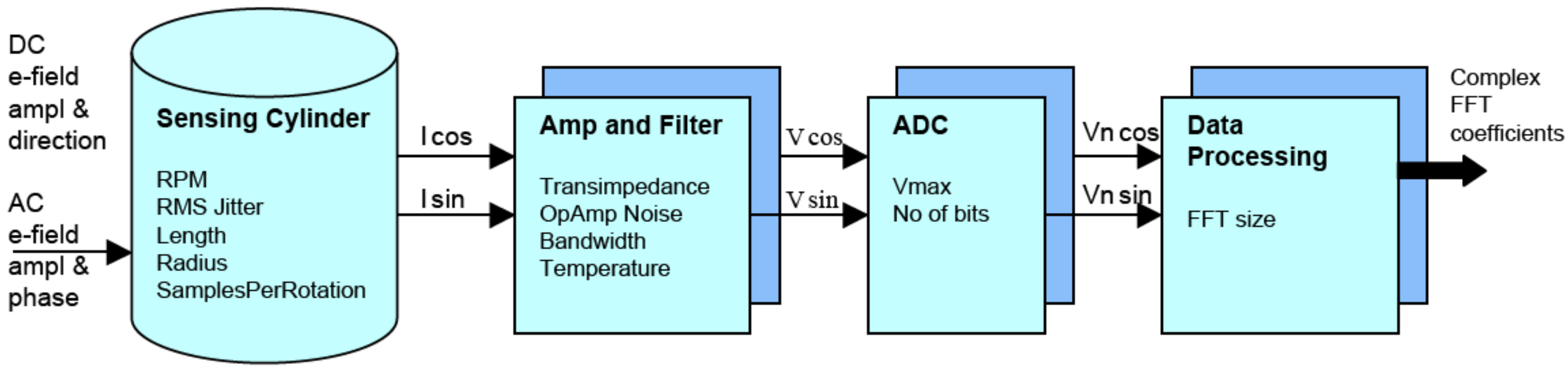
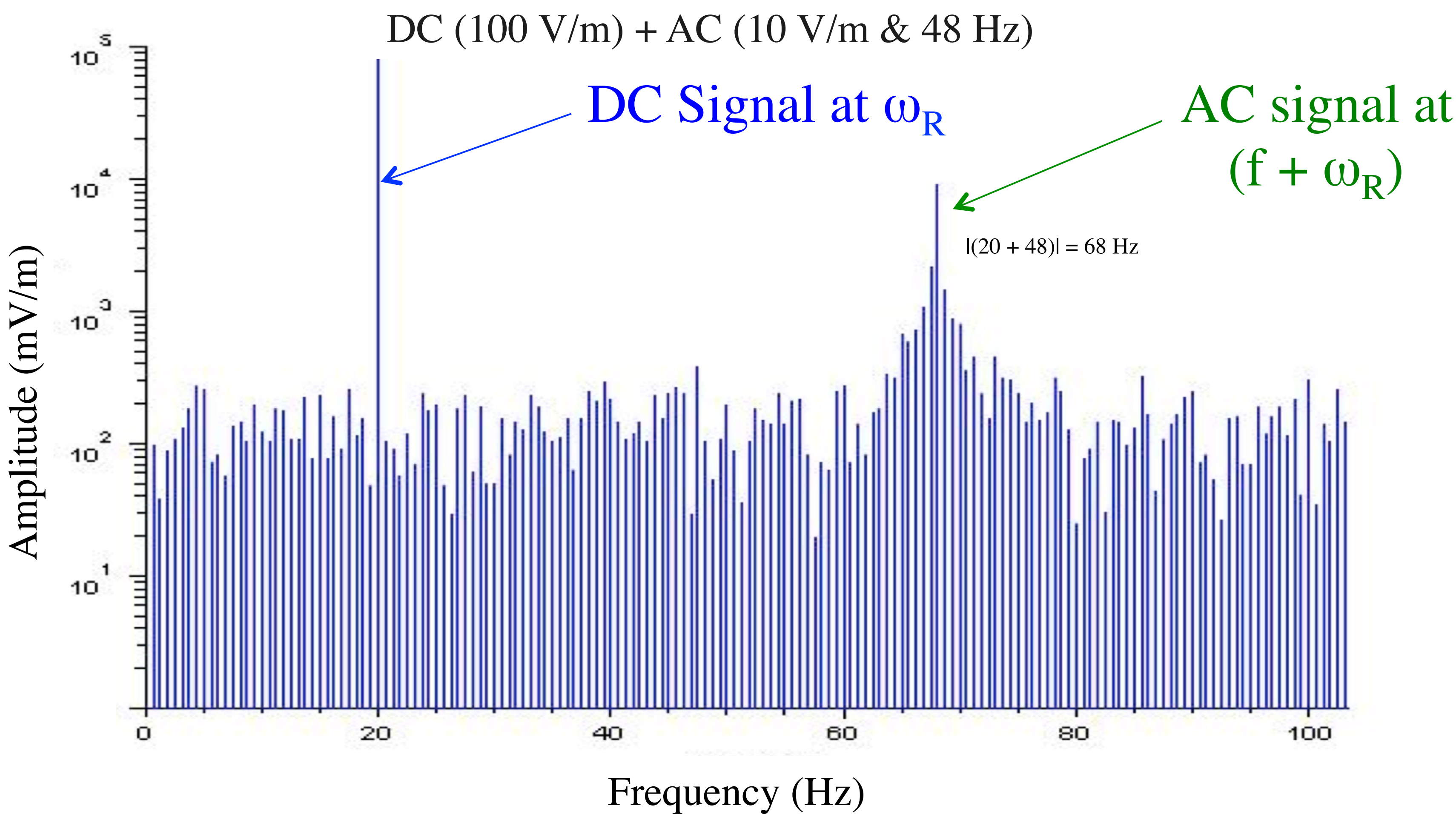
EFS Entry TRL: 5 **EFS Exit TRL**: 6

EFS Block Diagram



FFT Coefficients (Quadrature)



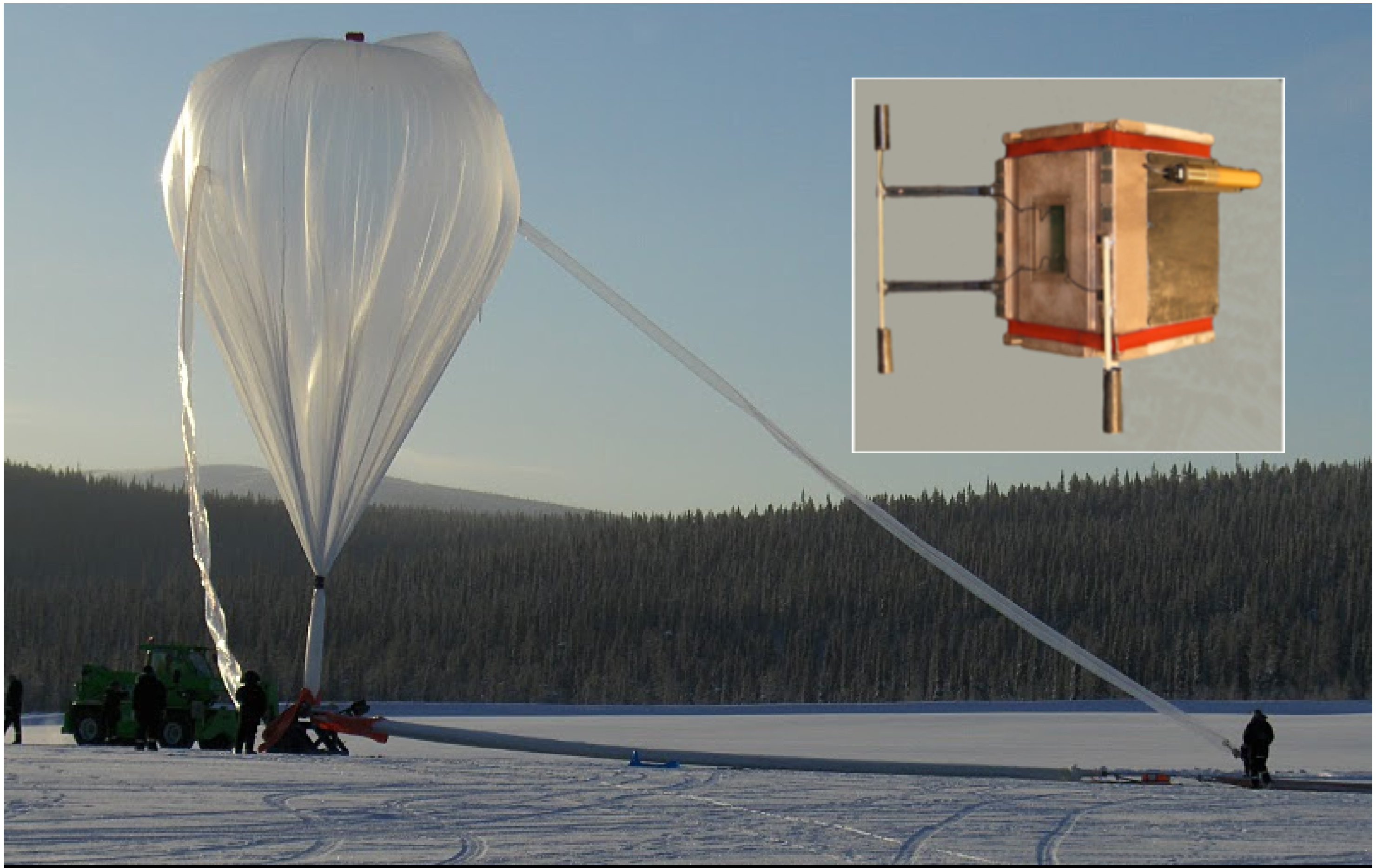
ω_R = Rotating Frequency = 20 Hz (1200 rpm)
f = E-Field Frequency = DC & 8 Hz

Characteristics of v2

Parameter	Value	Remarks
RPM	2400	Avoid 1500/1800 RPM (50/60 Hz)
Rotations per FFT	307	
Samples per FFT	16384	A power of 2 number
Number of bits of digitizer	15.5	
Rotation rate (Hz)	40	
Sample rate (Hz)	2134.7	
Spectral resolution (Hz)	0.13	Freq. width of FFT coefficients
RMS noise (dB)	95.1	
FFT noise (dB)	134.2	Measured values are 10 dB larger
LP filter noise (-60dB/dec)	162.5	Fc should be smaller than this value for attenuation at Fs to be 10 dB above FFT noise floor
Sensor length (m)	0.16	
Sensor diameter (m)	0.037	
Transductance gain (Ohms)	7.5E+06	
Vmax for ADC (V/m)	3	
Max e-field (V/m)	7591	Without gains
FFT noise floor (V/m)	0.0030	
OpAmp filter RMS noise (V)	1.15E-04	
OpAmp noise floor (V/m)	0.5820	Of each reading
Combined noise floor (V/m)	0.0054	Reduced by increasing the # samples per FFT

Two Flights in a Stratospheric Balloon

Kiruna



Original v2 EFS

This version of the sensor is capable of measuring electric fields from 0.1 to 75,000 V/m, with frequencies ranging from true DC to a few 100 Hz.

EFS Test Prior to Field Deployment

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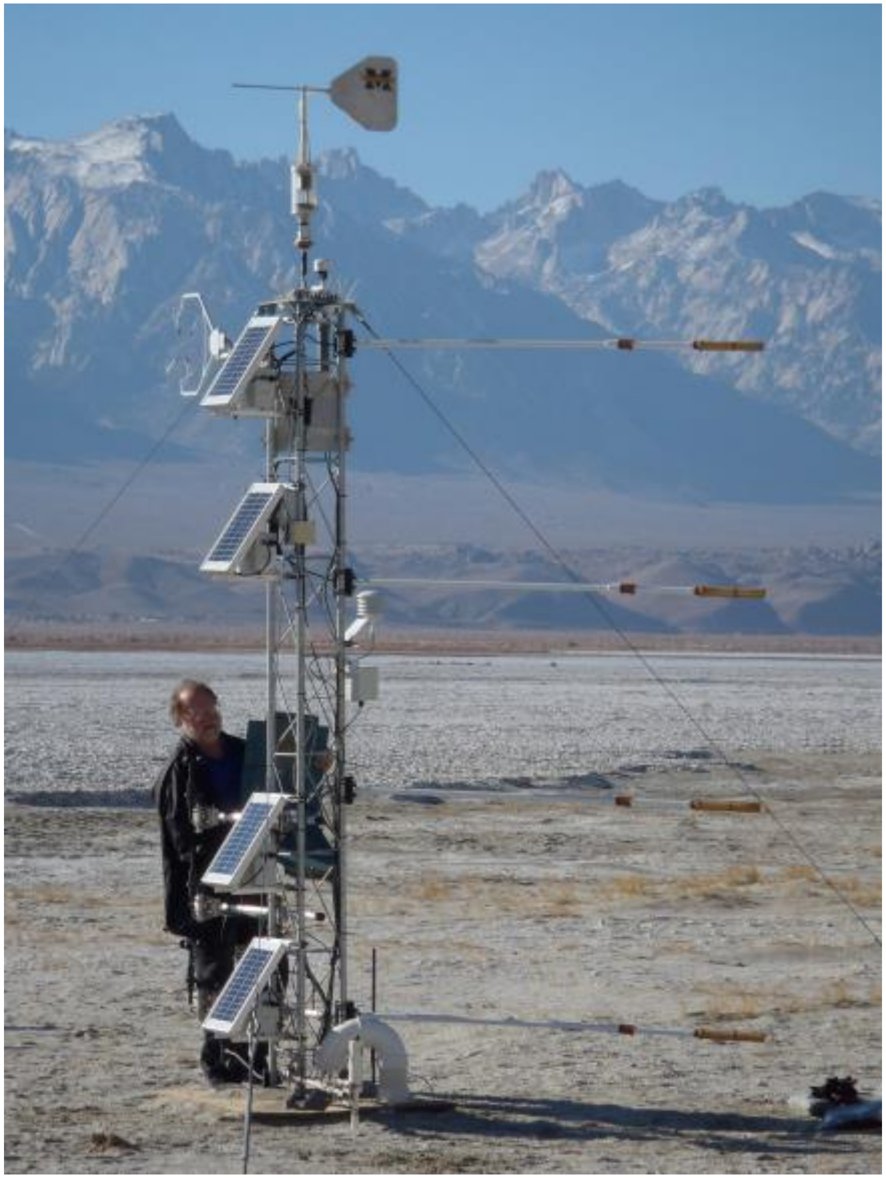
EFS Test in Dusty Conditions



Telemetry Snap Shot

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ACI Real Time Telemetry Viewer (Version 1.4)

1/30/2014 12:11:32.030: Starting up
1/30/2014 12:11:32.045: Connected to remote system

Freeze Msgs | Unfreeze Msgs | **Connected**

Electric Field	Sensor 1	Sensor 2	Sensor 3	Sensor 4
Magnitude, V/m	95	116	81	103
Direction, deg	164	101	161	144
Motor Speed, RPM	1000	1000	1000	998
Error Code	0	0	0	0
Motor Position	17	22	6	14
Fixed Batt V	3.27	3.22	3.21	3.24
Rotating Batt V	3.30	3.34	3.26	3.25
Seconds	1391102732	1391102732	1391102732	1391102732
Milliseconds	985	575	626	445

CR3000 1 Hz	Value	Units
Date	2014-01-30	UTC
Time	17:25:28	UTC
Rel. Humidity	49.25	%
Temp, Air	13.55	C
Particle Count	0	
Kinetic Energy	0	
Solar Irradiance	NAN	W/m^2
Aerosol Conc.	0.029	kg/m^3
Solar Irr., Direct	286.8	W/m^2
Long Wave Rad., Above	-60.38	W/m^2
Solar Irr., Reflected	117.2	W/m^2
Long Wave Rad, Below	-4.027	W/m^2
Temp, Net Radiometer	13.96	C
Air Pressure	882.5447	hPa
Temp, Rad. Tripod	13.51	C
Abbrev. Time Stamp	28.30	secs.msecs
Wind Speed, X	-3.73475	m/s
Wind Speed, Y	7.55725	m/s
Wind Speed, Z	-0.243	m/s
Temp, Fine Wire	339.222	C
Diagnostic Code	36	

Prandtl Probe	Value	Units
Wind Direction	331	deg from N
Static (ADC 0)	882.619	hPa
Stagnation (ADC 1)	882.801	hPa

CR3000 0.1 Hz	Value	Units
Date	2014-01-30	UTC
Time	17:25:30	UTC
Vol. Water Content	0.85	Kg/m^3
Rel. Humidity, Encl.	54.61	%
Temp, Enclosure	19.34	C
Temp, Soil	-5.324	C

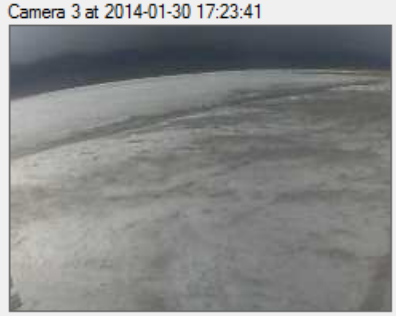
CR1000 1 Hz	Value	Units
Date	2014-01-30	UTC
Time	17:25:33	UTC
Wind Speed 1	5	m/s
Wind Speed 2	5.45	m/s
Wind Speed 3	5.45	m/s
Wind Speed 4	6.2	m/s

Housekeeping	Value	Units
Latched Overcurrent	off	
Shutdown Request	off	
V input	11.800	V
I input	0.000	A
Time sync age	4011	s
Time error	-2	msec
Recording data	yes	

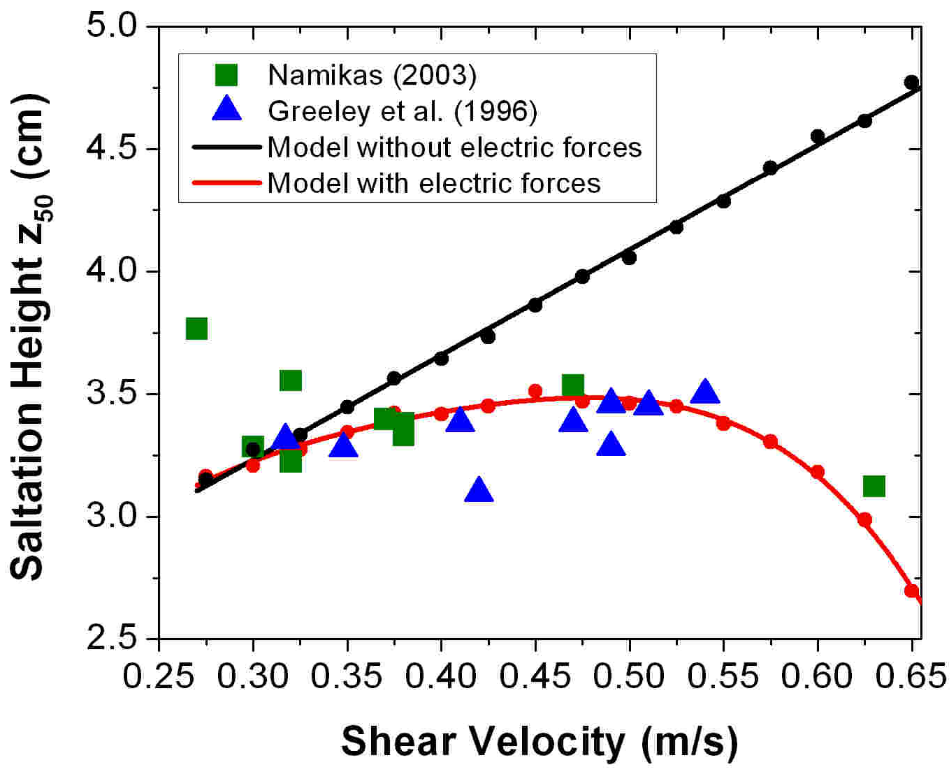
Camera 1 at 2014-01-30 17:23:38

Camera 2 at 2014-01-30 17:23:40

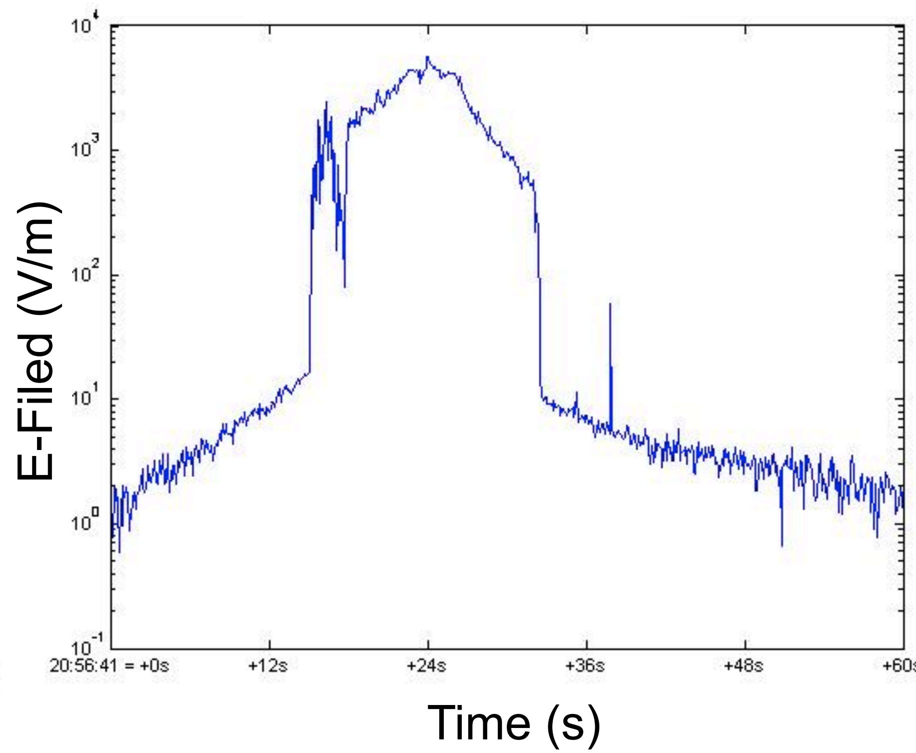
Camera 3 at 2014-01-30 17:23:41



E-Fields & Dusty Events



(Kok and Renno 2007)



(Renno *et al.* 2010)

Soil Wetness Sensor (WET)

DESCRIPTION: The MAHRS soil wetness sensor is capable of measuring soil wetness without the need of inserting the sensor into the soil.

OBJECTIVES:

- To develop the WET sensor technique and test it in the laboratory. To integrate the various subsystems into a brassboard model, instead of using rack-mounted laboratory equipment.
- To test the brassboard prototype sensor.

Candidate Ring Resonator

Q1-2 ACCOMPLISHMENTS:

Conducted numerical simulations and tested various candidate microstrip ring resonators in the laboratory.

- Conceptualized a technique for detecting liquid brines unambiguously using the differences in permittivity between liquid water and water ice or regolith at two frequencies.
- Testing the technique for detecting liquid brines unambiguously.
- Testing the capability of detecting liquid brines more 1 cm below the surface.

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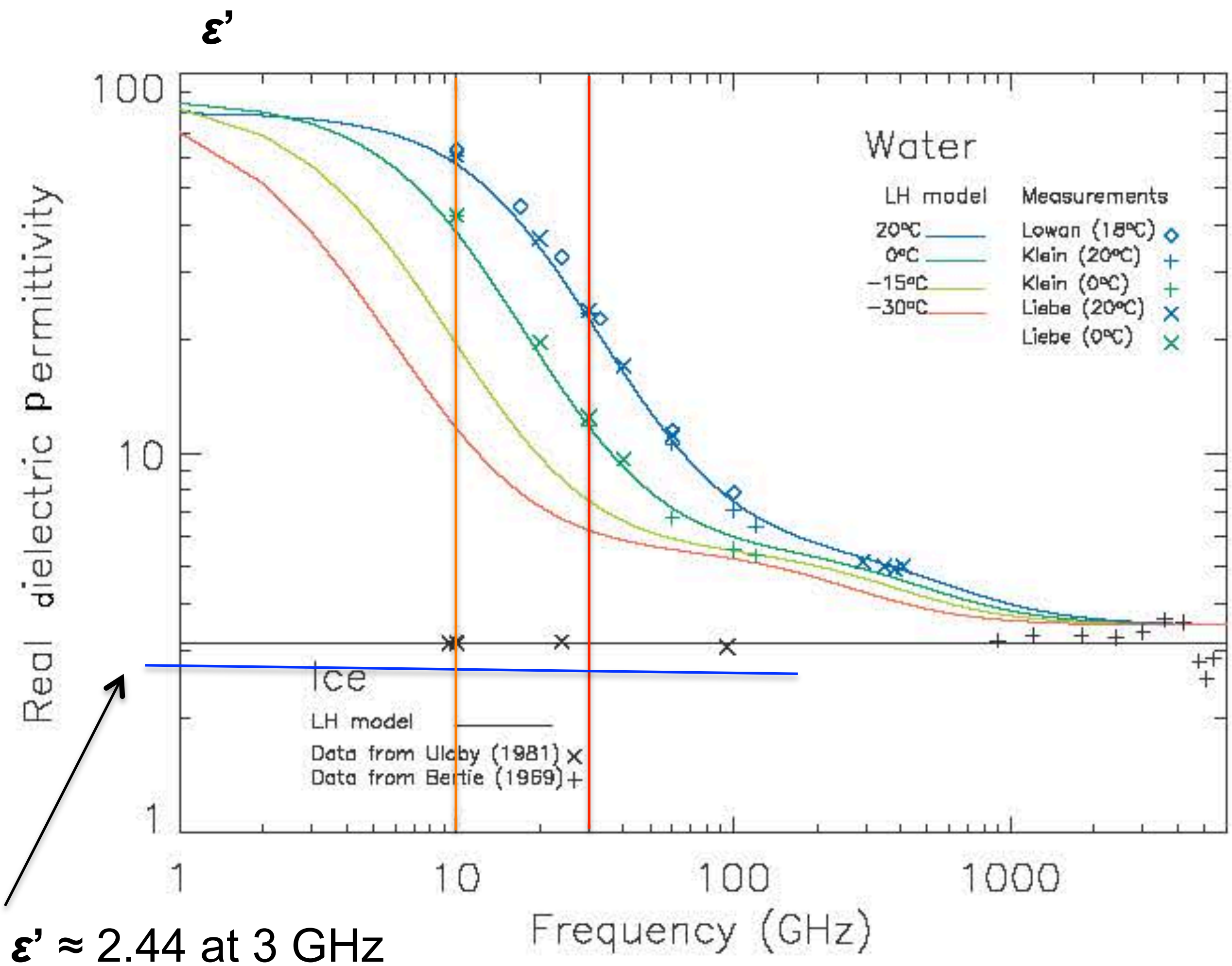
WET Entry TRL: 4 **WET Exit TRL**: 6

Permittivity of Ice and Water: Re(ε)

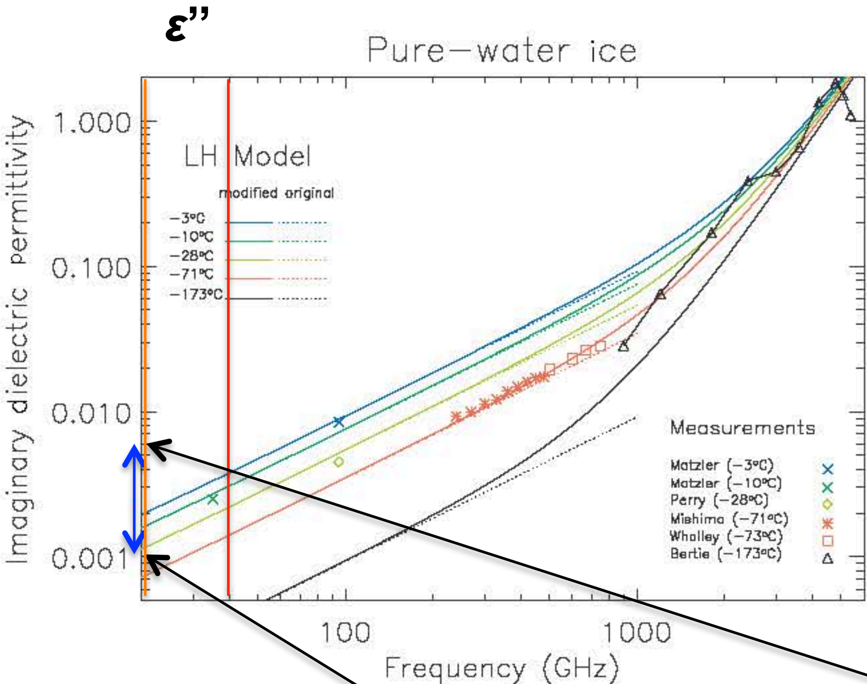


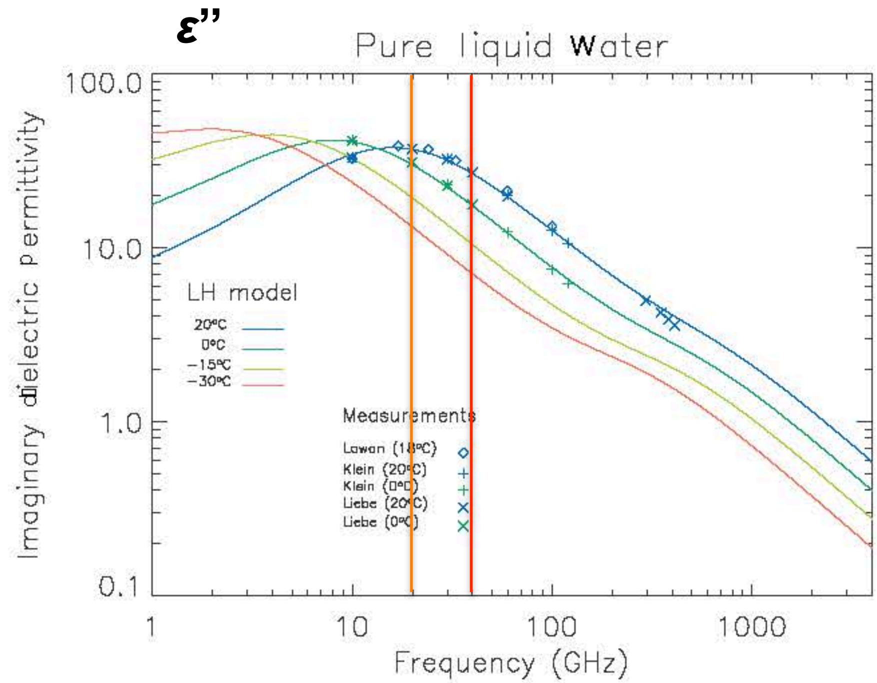
Dry loamy soil: $\boldsymbol{\varepsilon}'$ ≈ 2.44 at 3 GHz

Dry sandy soil: $\boldsymbol{\varepsilon}'$ ≈ 2.55 at 3 GHz

(Jiang and Wu, 2004)

Permittivity of Ice and Water: Im(*ε*)





Dry sandy soil: ***ε''*** ≈ 006 at 3 GHz

Dry loamy soil: ***ε''*** ≈ 001 at 3 GHz

Reflection & Transmission Coefficients

$S_{11} \approx f(\varepsilon', d)$ Reflected signal

$S_{21} = f(\varepsilon', \varepsilon'', d)$ Transmitted signal

where d is the depth (thickness) of the layer of permittivity $\varepsilon = \varepsilon' + i\,\varepsilon''$

WET Development

- Determining best resonators for measuring soil bulk ice and liquid water content of soils (frequency range 0.5-20 GHz).
- Currently studying the performance of various types of resonators.
- A dual frequency probe operating is necessary to meet the requirements.

Radiometer (RAD) and Optical Microscope (OM)

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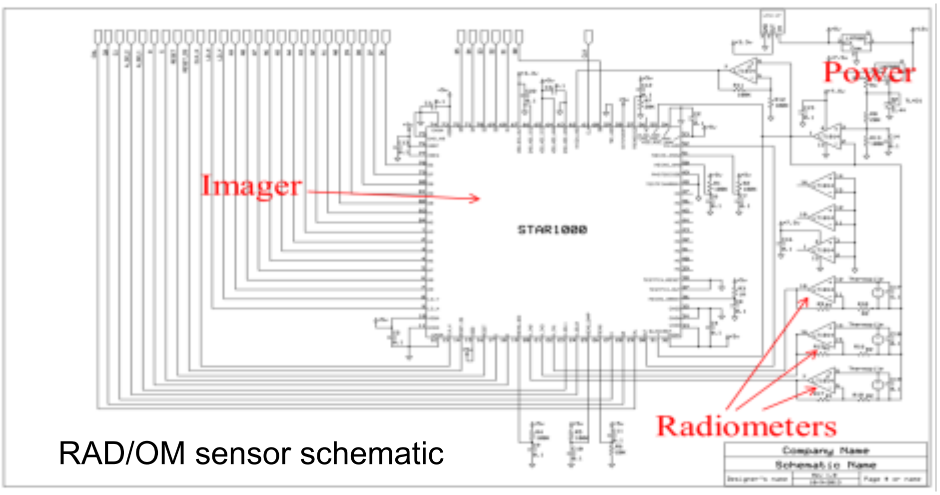
DESCRIPTION: The MAHRS Radiometer (RAD) and Optical Microscopes (OM) are leverage on the Mars Array Technology Experiment (MATE) developed for the Mars 2001 Lander.

OBJECTIVES:
- To fabricate the RAD/OM assembly and connect it into a host processor via serial link.
- To study the idea of using three set of sensor assemblies on the MAHRS instrument suite, one to look upward to measure solar radiation and measure dust particles deposited into the optical window, one downward to image particles on the surface and measure solar radiation reflected by it, and another to look at the horizon.



RAD/OM sensor schematic

Q1-2 ACCOMPLISHMENTS:
Designed and tested the instrument optical assembly and electronics.
- Designed the microscope based on a STAR1000 radiation hard CMOS image sensor and a Microsemi ProASIC3 FPGA development board (FPGA-DB).
- Currently testing the FPGA memory interface.

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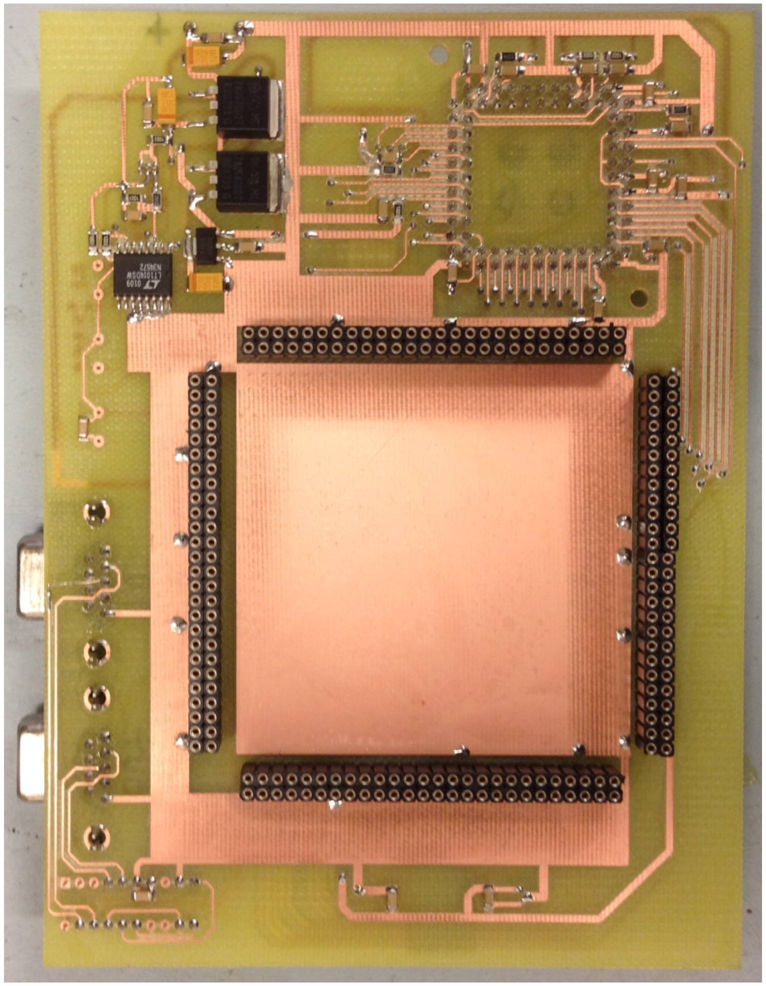
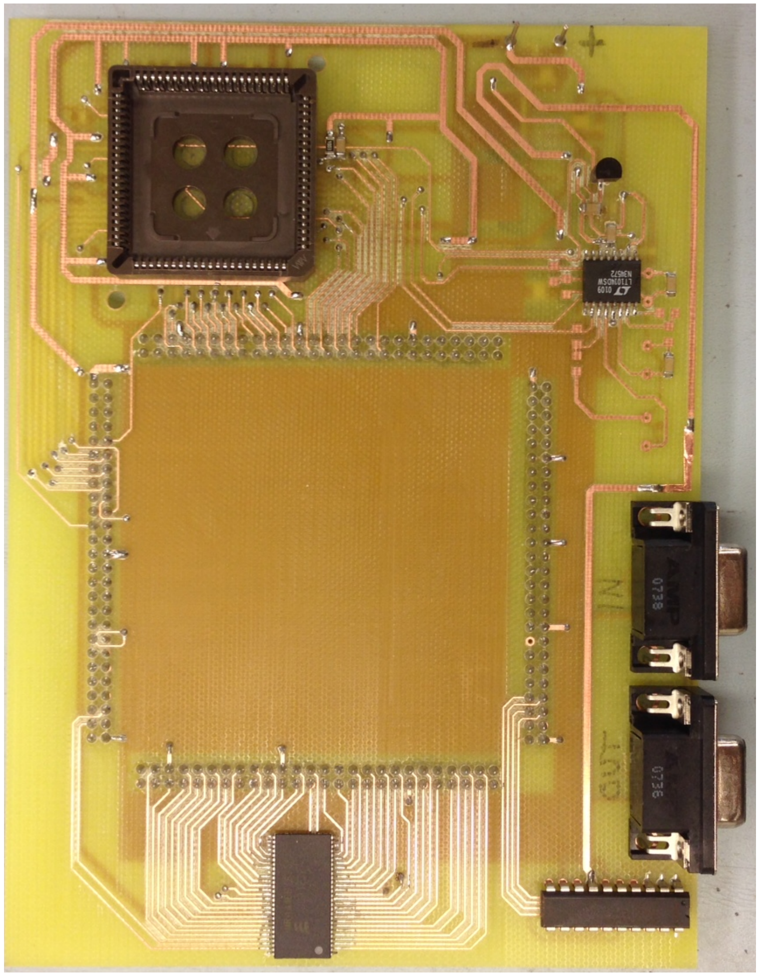
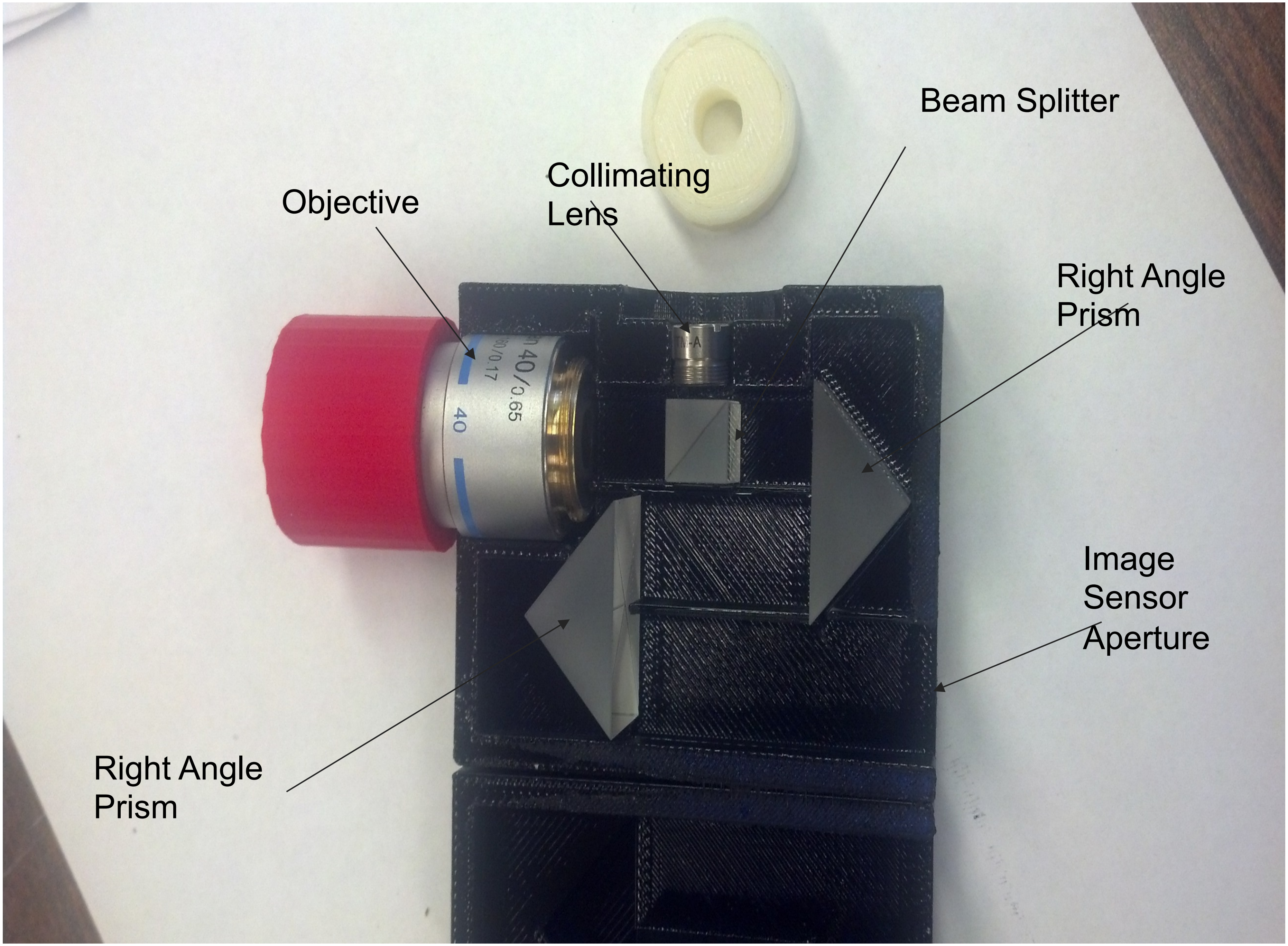
RAD/OM Entry TRL: 4 **RAD/OM Exit TRL**: 6

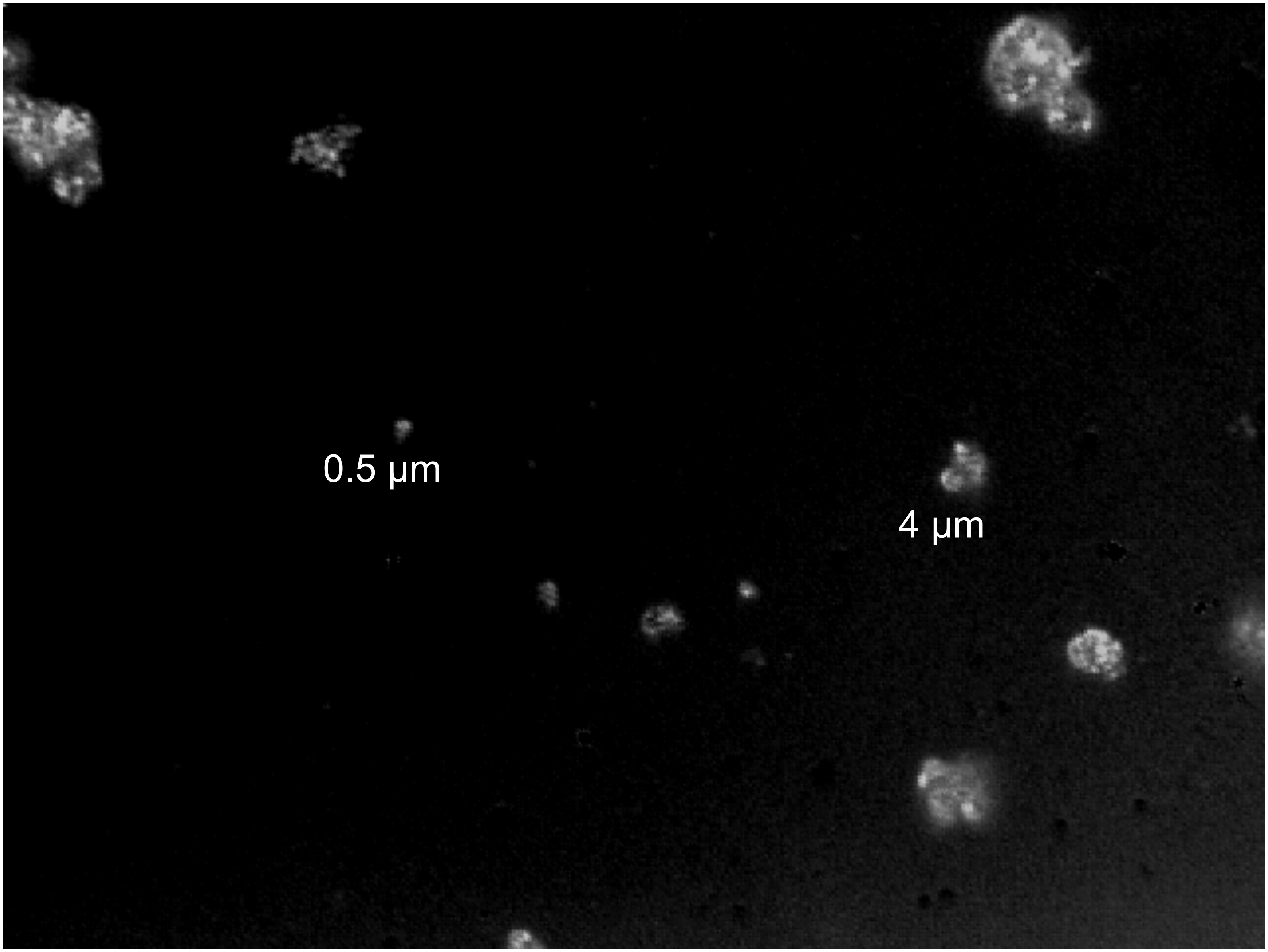
Star1000 Development Board






Beam Splitter
Collimating Lens
Objective
Right Angle Prism
Image Sensor Aperture
Right Angle Prism

OM: STAR1000 Image



Project Summary

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- **The U–M group has been refining the EFS and building prototypes in collaboration with GRC**. EFS prototypes are being characterized in the field and in the Michigan Mars Environmental Chamber (MMEC) at temperatures as low as 140 K and under a CO_2 atmosphere at about 700 Pa.

- **WET is being developed jointly by GRC and U–M.** Two prototype WET sensors will be fabricated and characterized at the MMEC, also to temperatures of about 140 K and a pressure of about 700 Pa.

- **OM, RAD, and SALT prototypes will be fabricated at GRC** and delivered to U–M for characterization in the MMEC, also to temperatures of about 140 K and 700 Pa.

- **EFS, OM, RAD, SALT, and WET instruments will be integrated** into two single MAHRS prototype systems at U–M. These single systems will be connected with a **Unix-based CDH simulator**. An integrated system will be tested at Mars conditions in the MMEC.

- **A MAHRS instrument suite prototype will be deployed to our field site at the Owens Dry Lake for tests under dusty atmospheric conditions.** A second prototype will be tested in the Atacama Desert and the McMurdo Dry Valleys.

THANKS!