

Harsh Environment And Remote Technology Overview for the 2023 SMD Technology Showcase

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**2023 Technology Showcase for Future NASA Planetary Science Missions
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LLISSE Electronics Summary

World Record Achievements

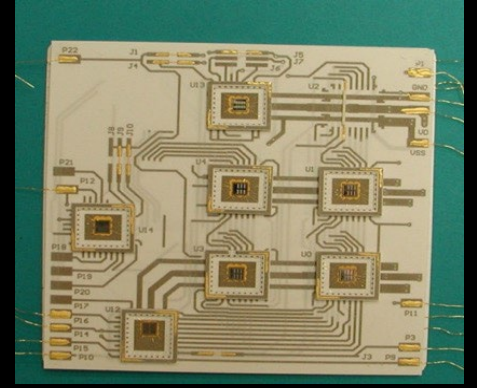
- Notable Advancements Have Been High Temperature SiC Electronics To Enable Long Term Surface Operations. This Includes:
 - World's First Demonstration Of Stable Electrical Operation Of Semiconductor Integrated Circuits For Over One Year At 500 °C In Air
 - Increasing Levels of Complexity Being Demonstrated: Nearing ~ 1000 Transistors
 - Circuit Demonstration 60 Days In Simulated Venus Surface Conditions Unshielded And Open To The Environment

Development Approach

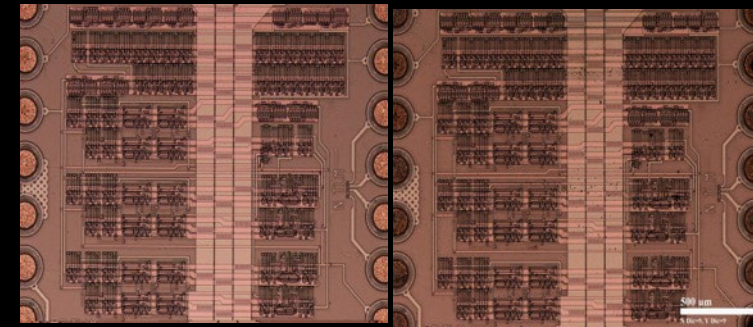
- Integrated Testing Based on Each New Generation of Electronics
- “Learn By Doing” Cycles: Design, Build, GEER Test, Improve, Repeat
- Show Enhancing Capabilities To Reach Success Criteria For Measurement Objectives; On-going Demonstration Testing Throughout Project As Available

Status

- Circuits with the Capability to Provide the Majority of Basic Functionality For LLISSE Have Been Designed and Fabricated
- The Next Generation Of Circuits Viable For Implementation Into a Lander Have Been Designed and are In Fabrication (Including a Microprocessor)
- The Status Of Venus Electronics Development is at the Level of 1970's to 1980's Technology; at These Levels Significant Science Can Be Accomplished



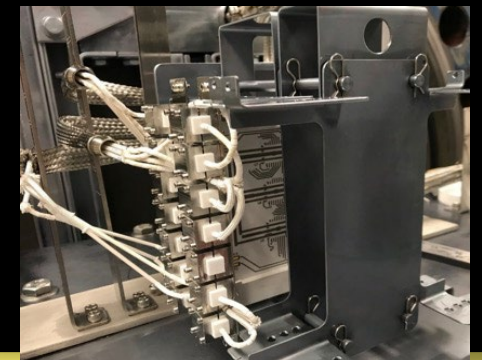
Prototype LLISSE Control Board



Before Packaging

After 60-Day GEER Test

Electronics Chips operated for 60 days in Venus Simulated Environment



LLISSE Cube Test Structure:²

LLISSE Communications Summary

History of Cutting Edge Development in High Temperature Wireless Communications

- Wireless Signal Spectra For High Temperature Seismometer Sensor Displacements Demonstrated (2012)
- Demonstrated Wireless Pressure Sensor At 475°C Including Pressure Sensor, SiC Circuitry, and Wireless Circuit (2013)

Development Approach

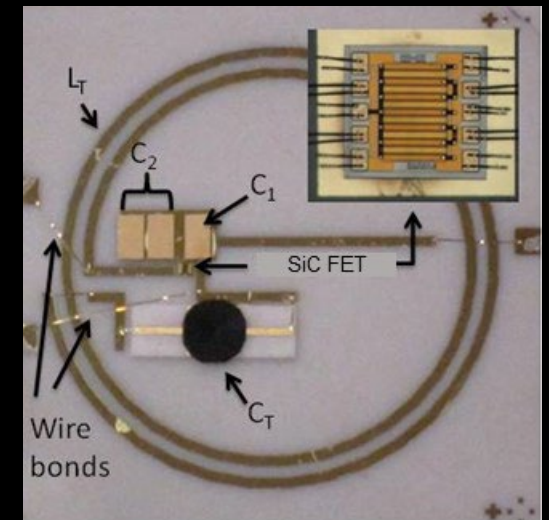
- Activities Include Venus Relevant Development Of Antennas, Transmitters, and Other Components
- Increasing Capabilities and Complexity of High Temperature Electronics Circuits Increases Communication System Capabilities
- Targeted Operation of Communication System from 100 to 150 MHz.

Status

- Development of Circuit Hardware Architecture for Higher Frequency Communications Systems On-going
- Baseline LLISSE Antenna Materials and Design Approach Identified And Initial Material Testing In Venus Simulated Conditions Begun
- Proof-of-concept Demonstration of Ability to Determine Orientation of the Lander from the Communication System Achieved



**Baseline LLISSE
Antenna Design: Spiral
Antenna Structure**



**Wireless Pressure Sensing Circuit
(Previous Work)**

LLISSE Baseline Sensors Summary

Broad Array Of Sensor Technology For Venus Applications Leveraged From Aeronautics Development

- Long History Of Active Development of Harsh Environment Smart Sensors Systems For Engine Test Stand, Health Management, and Intelligent Engines
- Multiple Demonstrations/Applications e.g., Including On-wing Engine Testing

Development Approach

- Miniaturized Sensor Systems Produced By Microfabrication Techniques and High Temperature Compatible Materials
- Parallel Development Of Multiple Sensor Types
 - Multiple Chemical Species
 - Temperature
 - Wind (3 Directions)
 - Pressure
 - Radiance
- Each Sensor Has Targeted Specifications and Associated Electronics Requirements

Status

- Several Sensors Have Reached High Levels of Maturity For This Application
- Integration of Multiple Sensor Types with SiC Electronics Demonstrated



Courtesy of D. Makel, Makel Engineering, Inc.

SiC Electronics Combined With Chemical Sensor for GEER Testing



High Temperature Pressure Sensor

LLISSE Sensors Background

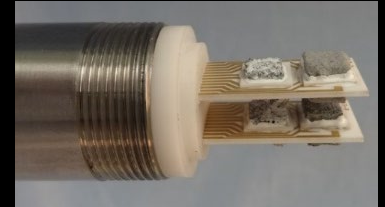
- Significant History Of MicroSensor Development For Aeronautic Applications Including Demonstration of a Multiparameter Sensor Array On An On-wing Engine of a C-17 Aircraft
- Building from this base, LLISSE Sensor Development Targeted Toward Venus Specific Applications and Measurement Targets

LLISSE Measurement Targets

Sensor	Description	Number	Sensor Input	Sensor Output	Draft Requirements				
					Target Min	Target Max	Target Accuracy (+/-)	Success Criteria Min/Max	Success Criteria Resolution
Wind Sensor	Cantilever with strain gage	3 perpendicular	voltage	voltage	0.25 m/s	2.5 m/s	0.1 m/s	0.5-2.5 m/s	0.25 m/s
Temperature Sensor	RTD in electronics	1	current	voltage	450°C	490°C	0.2°C	450-470°C	0.2°C
Pressure	Resistive or Capacitive	1	voltage	voltage	80 bar	95 bar	1 % full scale	80-90 bar	5% full scale
			capacitance	voltage					
Radiometer	Thermopile	1	voltage	voltage	4 W/m ²	25 W/m ²	2 W/m ²	4-25 W/m ²	2 W/m ²
Chemical Species	SOx	1	voltage	voltage	0	400 ppm	0.3 ppm	3-400 ppm	1.6 ppm
	H2O	1	voltage	voltage	0	100 ppm	1 ppm	5-100 ppm	0.4 ppm
	OCS	1	voltage	resistance	0	50 ppm	1 ppm	5-50 ppm	0.2 ppm
	CO	1	voltage	resistance	0	50 ppm	1 ppm	5-50 ppm	0.2 ppm
	HF	1	voltage	voltage	0	5 ppm	0.5 ppm	1-5 ppm	20 ppb
	NO	1	voltage	voltage	0	10 ppm	2 ppm	4-10 ppm	39 ppb
	N2	1	voltage	voltage	0	5%	0.10%	0-5%	0.02%



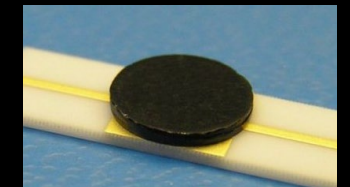
Sensor Array Testing on an On-Wing C-17 Engine



Chemical Sensor Probe



Wind Sensor Cantilever

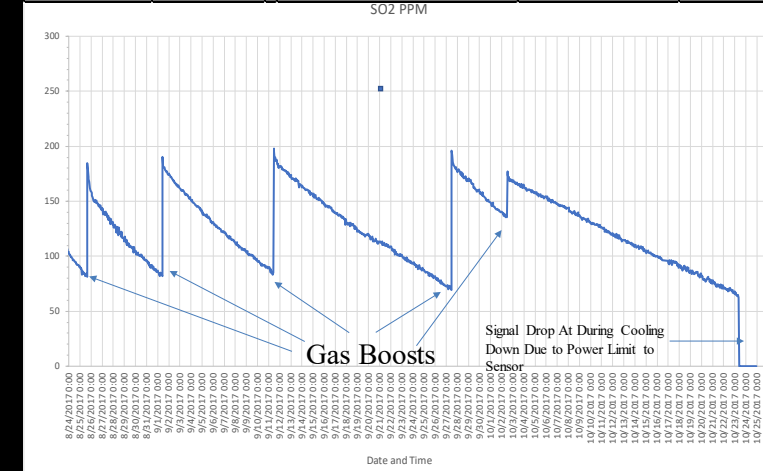


Capacitive pressure sensor

LLISSE Chemical Sensors Summary

SO₂ Sensor Operation in GEER for 60 Days in Venus Simulated Conditions

Type	Date	GEER GAS ANALYSIS	SENSOR	Δ ppm
Pre-boost	8/25/2017	89.4	84.7	4.7
Post-boost	8/28/2017	132.2	126.9	5.3
Pre-boost	9/1/2017	82.6	83.3	-0.7
Post-boost	9/1/2017	178.0	180.9	-2.9
Pre-boost	9/11/2017	76.7	83.5	-6.8
Post-boost	9/11/2017	186.0	186.8	-0.8
Pre-boost	9/27/2017	64.8	71.4	-6.6
Post-boost	9/27/2017	177.2	183.2	-6.0
Pre-boost	10/2/2017	139.8	135.6	4.2
Post-boost	10/4/2017	161.6	159.5	2.1
Post-boost	10/18/2017	80.0	88.8	-8.8
Post-boost	10/20/2017	70.0	80.9	-10.9



Background: Sensor Array Developed Under Completed NASA Phase I and Phase II SBIR

- Demonstrated Measurement of Key Species Including SO₂, H₂O, OCS, CO, HCl, and HF Under Relevant Conditions
- Sensors are selective to targeted species with minimal cross sensitivity to other species in Venus atmosphere

Status: Development of Chemical Sensors (including GRC sensors)

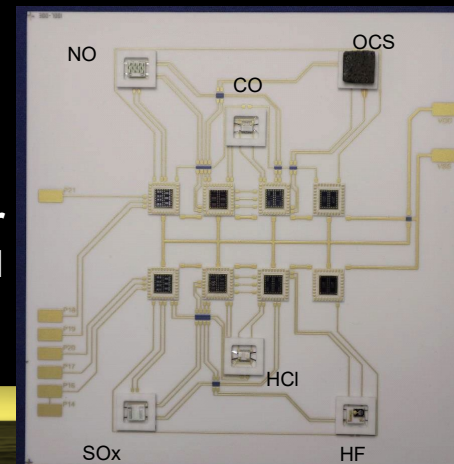
Integrated with NASA GRC SiC Electronics On-Going in HOTTech project

Four Chemical Microsensors (SO₂, CO, OCS, HF) Tested for 60 days in Venus Simulated Conditions in GEER

- All 4 Sensors Operated Nominally During 60 Day Test
- First Demonstration of In-Situ SO₂ Tracking in GEER for Extended Periods
- HF Sensor Integrated With Signal Transduction/Amplification SiC Electronics Monitored HF Boosts in GEER 10 Day Test

TRL Summary: Four chemical sensors successfully tested in Venus conditions for 60 days with SO₂ sensor tracking concentration changes and consistent with gas chromatograph readings. HF sensor with SiC electronics responded to concentration changes in 12 day testing. Near term permanent installation in GEER planned

Multiparameter Sensors Board



LLISSE Wind Sensor Summary

Background: *Drag-Force Anemometer (Cantilever) Baseline Approach with Significant History of Demonstrations in Engine Environments*

- Full Bridge Strain Gage Approach Allows Flow Measurements with Minimal Power Consumption
- Force of Wind Bends Cantilever; Deformation Measured Using Strain Gages.
- Wind Speed/Direction Determined Using 3 Perpendicular Cantilevers

Status: *Wind Sensor Tested in Wind Tunnel and Multiple Times In GEER Environment Showing Viability of Approach*

- Core Material Compatibility Demonstrated
- Wind Sensor Integrated with Electronic Amplification Has Shown Ability to Track Gas Flow in GEER Simulated Venus Conditions
- CFD Models Suggest LLISSE Structure Would Not Inhibit Wind Measurement

TRL Summary: Prototype versions with high temperature electronics designed and tested in Venus conditions. Tracking measurement of environmental changes in Venus conditions demonstrated. Improvements to sensor and driving electronics towards meeting LLISSE specs designed and in fabrication. Integration and testing in a multiaxis system needed.

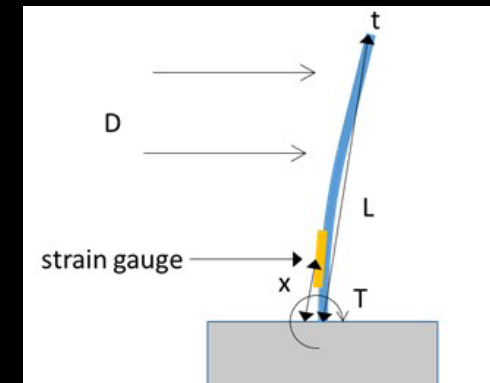
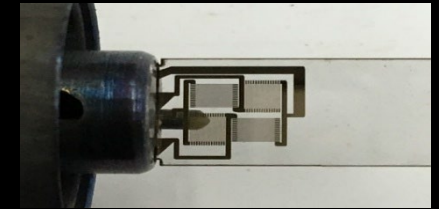


Diagram of drag-force anemometer cantilever



Wind Sensor Strain Gage Full Bridge assembly



LLISSE Temperature Sensor Summary

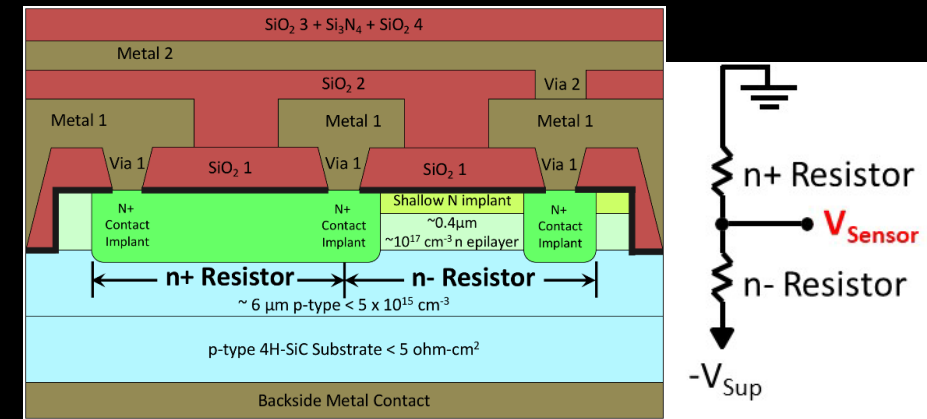
Background: Multiple Methods for Temperature Detection Viable; Integration into SiC electronics Has Inherent Stability

- Half-bridge” integrated SiC T-Sensor is a simple voltage divider: Very dissimilar responses of n+ resistor and n- resistor to temperature produces T-sensitive divider output V_{Sensor}

Status: Development of temperature sensor part of electronics development

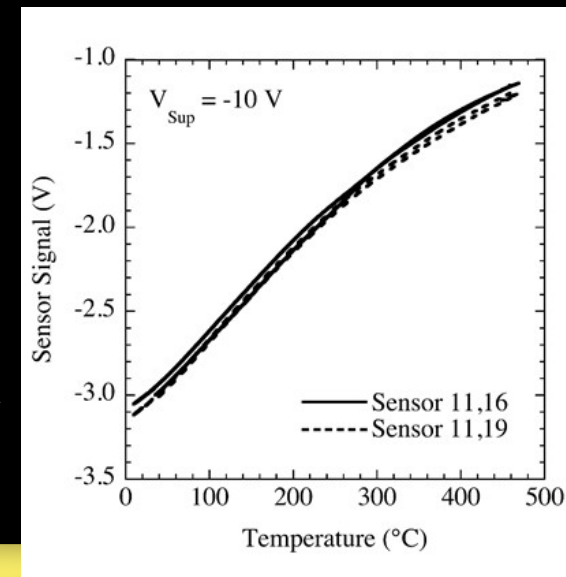
- Version 10 IC Chips With Prototype Venus-durable Temperature Sensor Tested in GEER and Tracked Environmental Changes
- Response of Temperature Sensors in GEER Nominal
- Broad Range Temperature Measurement Approach Relatively Mature, but Meeting Venus Surface T-Range specifications Not Yet Accomplished

TRL Summary: Multiple initial tests of wide T-range sensors have been completed in Venus conditions including successful 60 day test. Stable measurements achieved consistent with other temperature measurements were achieved. Design challenge to meet LLISSE Venus-T-Range measurement specifications ongoing.



Temperature Sensor/Electronics Approach: Integrated in SiC Electronics

GEER Broad Range Temperature Sensor Test Data



Pressure Sensor Summary

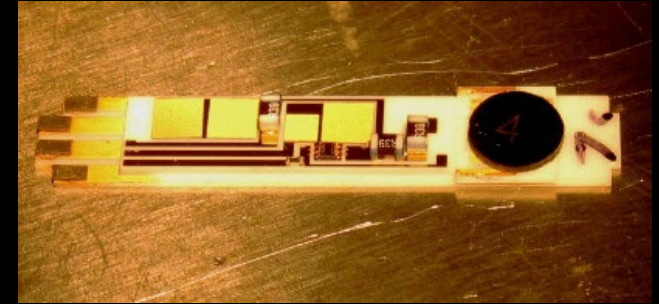
Background: *Significant History In Development Of Pressure Sensor Systems, Including On-engine Testing And Commercialization. Two Major Sensor Types:*

- Resistive Pressure Sensors: Mature, Commercialized, and Demonstrated in Engine Environments
- Capacitive Pressure Sensors: Simpler Measurement System/Electronics and in Development
- Aeronautics and SBIR Funds Support Development

Status: *Parallel Path Development Approach Until Operational Sensor Demonstrated*

- Both Sensor Types Viable For Venus Surface Applications
- Multiple GEER Tests Conducted, including Pressure Sensors With Electronics.
- Pressure Sensors Yet To Provide Relevant Durability/Dynamic Range In GEER Conditions

TRL Summary: Two wide pressure range sensor designs demonstrated in harsh conditions. Demonstrated integration with electronics, and 12 days of operation/ 60-day survival of sensor element in Venus conditions. Meeting LLISSE measurements specifications is next focus.



Capacitive Pressure Composed Of Silicon Carbon Nitride (SiCN) With Electronics



Resistive SiC pressure sensor in preparation for evaluation in GEER.



Optical Images Of Resistive Pressure Sensor Face After GEER Testing: Structure Maintains Integrity

Radiometer Sensor Summary

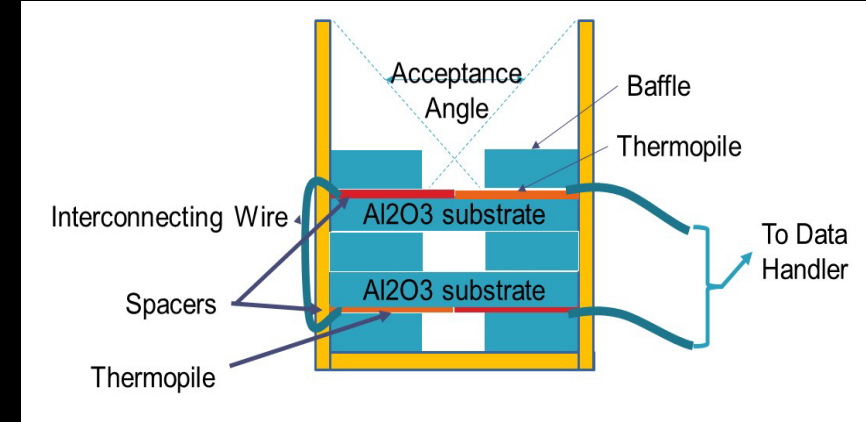
Background: *History of Radiometer Measurements Including on Pioneer Venus. Objective is to measure both Upward and Downward Looking Net Flux Rates From the Venus Surface*

- Overall Net Flux Rates Are Bounded By These and Other Measurements with Modeling
- Bolometer is the Sensor in a Radiometer Instrument That Measures the Temperature Change From Absorbing Radiant Power and Can Be Based on Thermopiles
- Notable History of High Temperature Thermopile Development

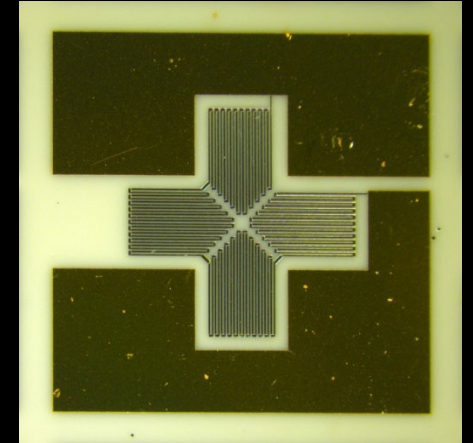
Status: *Approach Toward Radiometer Design Established Based on Past Development and Initial Bolometers Fabricated*

- Activity Initiated Later in the Project; Earlier State of Development
- Baseline Radiometer Design Identified Based on High Temperature Thermopile Approach
- Initial Thermopile Materials Identified and Prototype Fabricated

TRL Summary: Baseline design approach established and prototype bolometer sensors fabricated. Relevant materials tested in Venus conditions



Schematic of Baseline Radiometer Approach



Microbolometer based on High Temperature Materials Thermopile

SHALLOWS

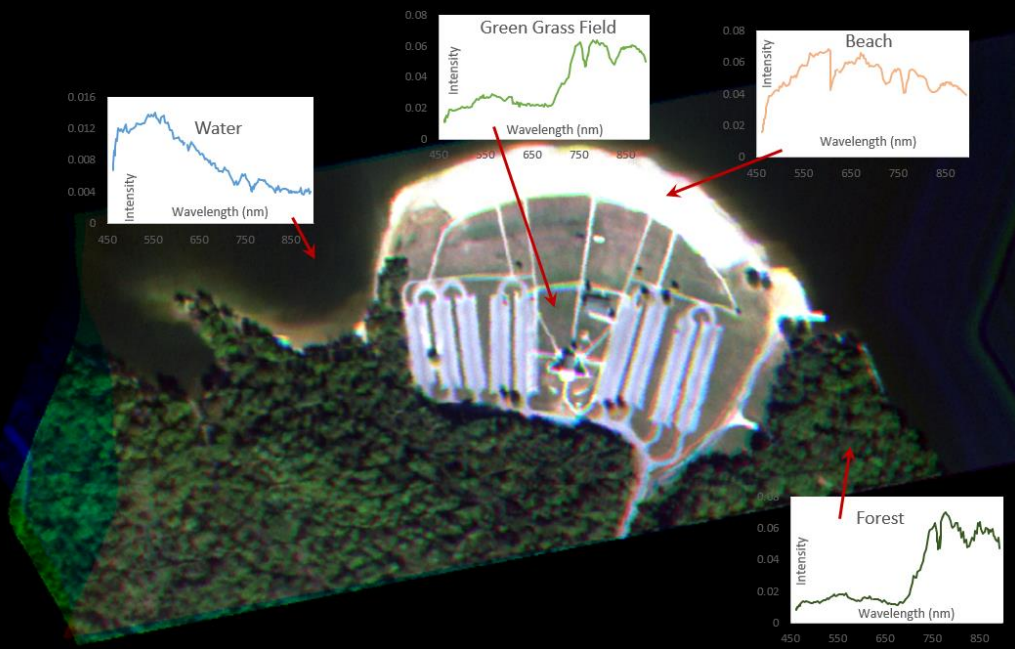
Formally known as
HABSat-2



6U prototype



Installed with HSI3 on
Twin Otter aircraft



Harsha Lake georeferenced dataset
collected at 10k feet altitude in 2019

SHALLOWS is a multi-resolution visible near infrared (VNIR) software defined hyperspectral imaging CubeSat.

Funded by the National Oceanographic Partnership Program (NOPP) Small satellites for Ocean & Atmosphere Research (SOAR) through Office of Naval Research (ONR).

- Developed with University of Cincinnati and Pumpkin Space Systems.
- Science: Ocean Turbidity, Algal Ecology, bathymetry and sea ice characterization.
- 30 m ground resolution from low earth orbit.
- 2048 x 1088 pixel sensor collects 470 nm to 900nm wavelengths in 3 nm steps.
- Designed to acquire two 200 km by 50 km acquisitions per orbit.

Satellite
concept

