

LONG-LIVED IN-SITU SOLAR SYSTEM EXPLORER (LLISSE)

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Abstract

Venus, while having similar size, mass, and location in the solar system to Earth, varies from Earth in many ways. The differences include its climate, atmosphere, and surface conditions. Surface conditions present formidable engineering challenges due to the high temperature and pressure. To date, landed missions have not been able to last more than about 2 hours on the surface [1]. This has resulted in significant knowledge gaps about the surface conditions of this important body in the solar system. The science community has effectively no in-situ temporal data on Venus surface conditions (temperature, pressure, winds and chemistry). These data are critical for the development of a thorough understanding of Venus' weather and the processes by which chemical species interact with each other, and are transported throughout the atmospheric column. This will help understand aspects of the atmosphere/planet interactions such as momentum exchange. To date, no capability has been available to enable a long lived surface probe to make these kinds of measurements. However, recently developed Silicon Carbide based electronics, sensors, and other technologies have matured to a state where a simple, but powerful long-life scientific probe would be feasible for Venus. It is now possible to directly qualify the durability and functionality of these components in a simulated Venus surface environment and demonstrate the ability to return valuable scientific data.

Introduction

Development has begun on an integrated probe system to enable a long lived surface mission. This probe, the Long-Life In-situ Solar System Explorer (LLISSE), would provide key measurements to help make progress in our understanding of three key questions for Venus exploration. These are identified in the planetary science decadal survey and the Venus exploration Goals, Objectives, and Investigations document (GOI) as produced by the Venus Exploration Analysis Group (VEXAG). The key questions addressed by this probe include better knowledge of super-rotation of the atmosphere (Goal 1, Objective B), the climate and its evolution (Goal 1, Objective B), and surface – atmosphere interaction/weathering (Goal 3, Objective B).

Discussion

LLISSE Concept Overview

LLISSE is a small (~ 10kg) and completely independent probe for Venus surface applications. The LLISSE project includes the design and development of the probe(s) and the demonstration of the probe(s) to function at the surface conditions of Venus and communicate periodic measurements of temperature, pressure, wind velocity and direction, and chemical composition [2] (Fig. 1). These periodic measurements (every 8 hours or better) would occur over the duration of a Venus day-light period including the terminator at one or both ends of that period. The goal of LLISSE is to operate in Venus conditions for approximately 60 Earth days. If deployed on Venus, LLISSE would provide unique and significant science impact.

The main product for the first three years of the project's development will be a primary battery powered version capable of surviving the approximately 60 Earth and transmit data at approximately 10 MHz. The fifth-year product is the demonstration of the wind-powered version and increasing transmit capability of the probe to between 50 and 150 MHz.

The capabilities that enable LLISSE include:

- High temperature Sensors, Electronics, Communications, and Power Generation
- High fidelity test/validation capability, in particular the Glenn Extreme Environment Rig



Fig. 1 Notional wind powered version of the Long-Life In-situ Solar System Explorer Venus Probe Concept

(GEER) Fig. 2. [3]

- Creative operations approach including the simple operation premise of periodic data transmission.

High Temperature Electronics

Advancements in high temperature electronics are particularly enabling to multiple aspects of LLISSE. Standard electronics for planetary instrumentation/operations are often silicon (Si) based. However, Si-based electronics do not operate at Venus temperatures [4]. This implies a need to use wide bandgap electronics, such as silicon carbide (SiC), or other high temperature electronic systems. The design choices available in a small package, the capability to withstand harsh environments including high pressure/temperature for potentially prolonged time periods, and the ability to form complex integrated circuits (IC's) suggest SiC as the most viable technology for multiple high temperature applications.



Fig. 2 Testing in GEER at Venus surface conditions

Recent work has notably expanded capabilities and produced the world's first microcircuits of moderate complexity (Medium Scale Integration) that have the potential for sustained operation at 500°C [5-8]. These circuits contain 10's of JFETs and two metal interconnect layers, an order of magnitude more complicated than previous long-term 500°C demonstrations. This enables a wide range of on-board data processing, including signal amplification, local processing, and wireless transmission of data. Operational life at 500°C for thousands of hours has been shown for several circuits. Table 1 shows a sample compilation of circuits fabricated that can enable other Venus and harsh environment applications. A direct extension of the processing provides other circuit types with prolonged 500°C operational lifetimes.

Table 1 A sampling of high temperature circuits fabricated and in development

CIRCUIT	STANDARD INPUTS	OUTPUTS	COMMENTS
Ring Oscillators	Capacitive sensors, Resonator Circuits	Frequency modulated signals	Can add on-chip large transistors for power amplification.
Binary RF Transmitter	Low power binary signal	High-Power RF signal to antenna	Conditions the signal for wireless transmission and feeds antenna
Op Amp, 2- Stage	Differential inputs	Voltage gains to 50	Crucial circuit building block for signal processing
4-Bit D/A	4 digital Inputs	1 analog	A/D circuit also achievable given these components
Logic gates	Up to 8 inputs/outputs	Typically 1 digital	Types include: NOT, NOR, NAND, XNOR
4X4 Bit Static RAM	Read, Write, Data Lines, Address Lines	4 bit parallel digital latch	Memory element

Key elements leveraged

A significant Venus relevant activity associated with moderately complex electronics occurred when [9] high temperature electronics, including a high temperature ring oscillator, were demonstrated in GEER at Venus conditions. To very briefly summarize [10], a packaged SiC JFET ring oscillator chip was immersed in the simulated Venus atmosphere for over 21 days. Simulated conditions included temperature, pressure, and atmospheric species. The test was successful only before ending for scheduling reasons. The SiC ring oscillator integrated circuit fully functioned at 1.26 ± 0.06 MHz over the entire 521 hours it was exposed to Venus surface atmospheric conditions. This was the world's first demonstration of moderately complex electronics operating for an extended period in-situ in Venus surface atmospheric conditions and this represents a major advancement in technology, and notably expands potential for new Venus missions. It is upon this potential that not only missions such as LLISSE can be envisioned, but a new range of future planetary exploration.

Scientific Measurements With Low Data Volume

Presently the LLISSE probe will measure surface wind speed, wind direction (relative to surface), surface temperature and pressure, near-surface atmospheric chemical composition, and incident solar radiance. Surface wind speed sensor, surface temperature and pressure sensors, radiance and near-surface atmospheric chemical composition sensors have recently been tested at Venus conditions in the GEER for 60 days. These sensors have several things in common which contribute to the LLISSE science theme and help enable the extended life. First, the sensors target science that is enabled or significantly enhanced by temporal measurements. Second, the science return does not require large volumes of data, which contributes to power conservation and hence, longer life.

Battery Development

NASA has a dual-approach for battery development. Fig. 3 highlights the first version of the LLISSE probe. The first approach is to develop a high-temperature tolerant battery (HTTB) technology to achieve safe, long-life, high specific energy operation, and powered only by the charged battery. The battery is operated only in the discharge mode. The non-rechargeable battery would have a life of 3000 hours of operation if data is sent for two minutes every eight hours. The main product for the first three years of

LLISSE development will be a battery powered probe with capability to transmit data using a ~10 MHz carrier RF transmitter. The LLISSE probe would stay dormant during cruise and launch. It automatically powers on and begins operation at the surface of Venus. A high temperature battery development is in progress with backup approaches available if required.

The second approach is a re-chargeable battery with a wind turbine. Surface winds on Venus would recharge the battery via a small wind turbine mounted on the top of the LLISSE prototype probe, perhaps appearing as depicted in Fig. 4. The wind version could theoretically have indefinite life (but the goal would be life expectancy of a Venus year or 224 Earth days or more). This approach however may result in variable data transmission frequency due to the uncertain wind conditions as no one has measured these over time. The fifth-year product of the LLISSE project is the demonstration of the rechargeable battery, wind powered version of the probe. GEER testing of wind turbine motor component materials is planned by end of 2021.

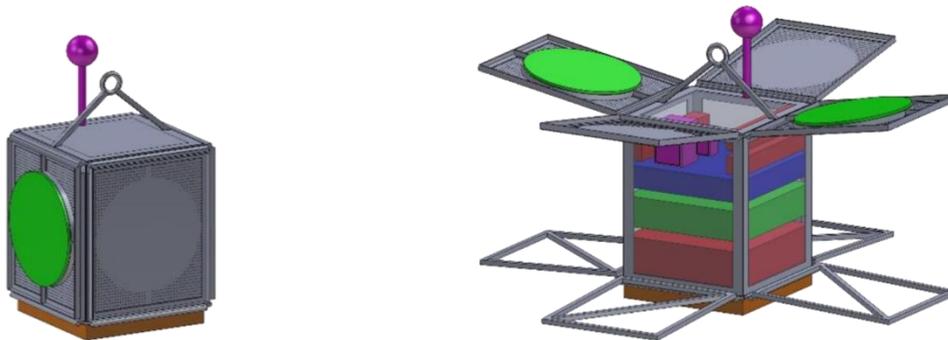


Fig. 3 Schematic of LLISSE-B Battery Prototype

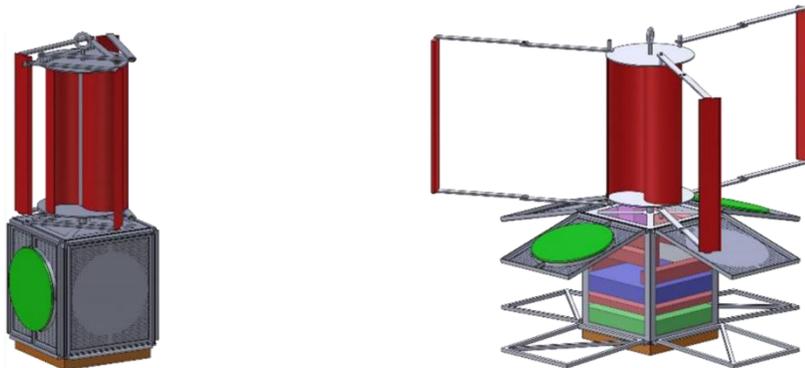


Fig. 4 Schematic of LLISSE-W Wind Turbine/Rechargeable

LLISSE and Venera-D

An exciting potential application of LLISSE could be to serve as the “long-lived station” on the potential Venera-D mission. The Venera-D JSDT is currently recommending the inclusion of a long lived station to the mission to begin to take the temporal measurements that LLISSE is targeting. If employed on Venera-D, LLISSE could be deployed in several ways. One is to be attached and serve as an instrument on the main lander. LLISSE could also be deployed independently in its own entry shell separate from the lander, or it could be part of an aerial platform payload and dropped from the platform when desired. Finally, multiple copies of LLISSE could be deployed to several locations if packaged and released accordingly from an entry capsule. The Venera-D mission concept is in early formulation phase so how that potential application or contribution is yet to be defined and determined.

Conclusion

The component level hardware exists and performance has been demonstrated at Venus temperatures to enable a probe to survive for extended periods on the surface of Venus. Recent successes in high temperature electronics, multispecies chemical sensor array, and high temperature pressure and temperature sensors are paving the way to successful LLISSE probe development effort where operation on Venus will be demonstrated. The non-rechargeable battery is targeting demonstration in late 2019 and the wind powered version in late 2021. Venera-D may be an opportunity to contribute LLISSE to a Venus mission. That contribution could enable temporal science that has not been possible to date.

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