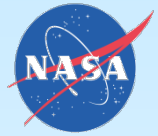

Development of a High Temperature Venus Seismometer and Extreme Environment Testing Chamber

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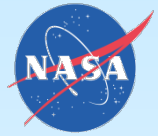
Houston, TX



OUTLINE

- INTRODUCTION
- SEISMOMETER MEASURMENT BACKGROUND
- HIGH TEMPERATURE TECHNOLOGIES
- SEISMOMETER DEVELOPMENT
- EXTREME ENVIRONMENT CHAMBER
- SUMMARY AND FURTHER WORK

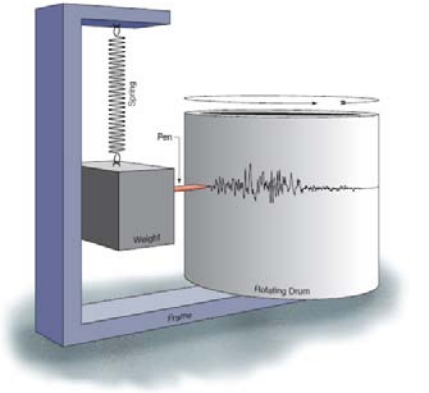
BACKGROUND

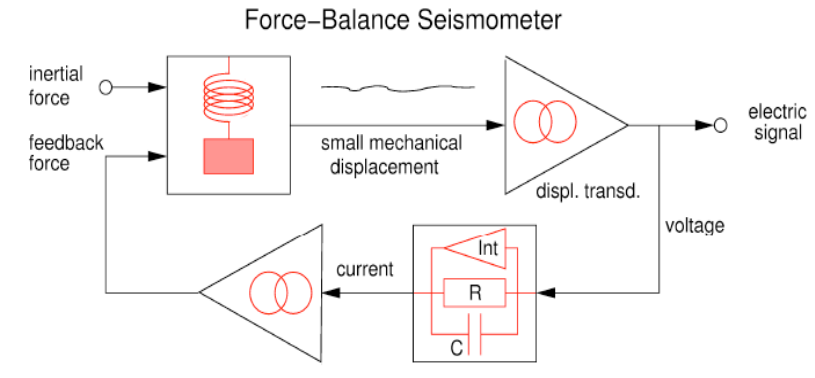
- **SEISMIC MEASUREMENTS CAN HAVE REVOLUTIONARY IMPLICATIONS IN THE UNDERSTANDING OF VENUS PLANETARY SCIENCE**
  - **VEXAG HIGH-PRIORITY TECHNOLOGY DEVELOPMENT NEED : *"SEISMOMETERS CAPABLE OF OPERATION UNDER VENUS-SURFACE CONDITIONS"***
- **ONE OF THE FUNDAMENTAL QUESTIONS IN VENUS STDT DISCUSSIONS INVOLVED WHETHER VENUS SEISMOMETRY WAS VIABLE**
- **MAJOR TECHNICAL HURDLE IS THAT IN ORDER FOR A SEISMOMETER TO BE EFFECTIVE IT MUST BE COUPLED IN SITU TO THE PLANET**
  - **THIS IMPLIES HIGH TEMPERATURE OPERATION OF AT LEAST SOME SYSTEM COMPONENTS**
  - **EXTENDED OPERATION OF AT LEAST 117 DAYS DESIRED (1 VENUS SOLAR DAY)**
- **SEVERAL POSSIBLE DIFFERENT ARCHITECTURES WERE DISCUSSED**
  - **STAND-ALONE SYSTEM**
  - **SEISMOMETER SYSTEM COUPLED WITH LANDER POWER**
  - **SEISMOMETER SYSTEM COUPLED WITH LANDER POWER AND COOLED SUPPORT SYSTEM**
- **IN RESPONSE TO THESE QUESTIONS AND TO MEET A SCIENTIFIC NEED, DEVELOPMENT OF A SEISMOMETER IS ON-GOING**

WHAT IS A SEISMOMETER

Instruments that measure and record motions of the ground

- **Vibrations affect an inertial mass or sensor attached to an instrument by a mechanical system (involving e.g. springs). The mechanical system as well as the sensor needs to be specially designed for frequency range**
- **Modern instruments using electronics so that the mass is held nearly motionless relative to the frame by an electronic negative feedback loop**
- **The feedback loop applies a magnetic or electrostatic force to keep the mass nearly motionless. The voltage needed to produce this force is the output of the seismometer**
- **Sensors and electronics not viable for Venus missions as-is.**





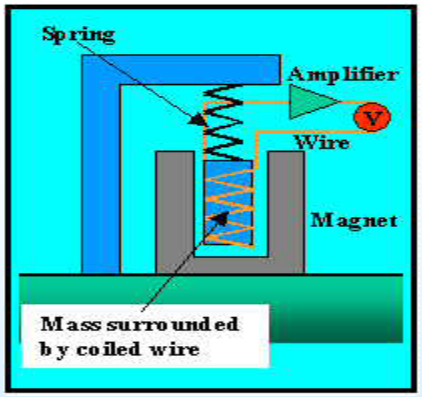
http://www.iris.edu/stations/seisWorkshop04/PDF/Wielandt-Design3.pdf

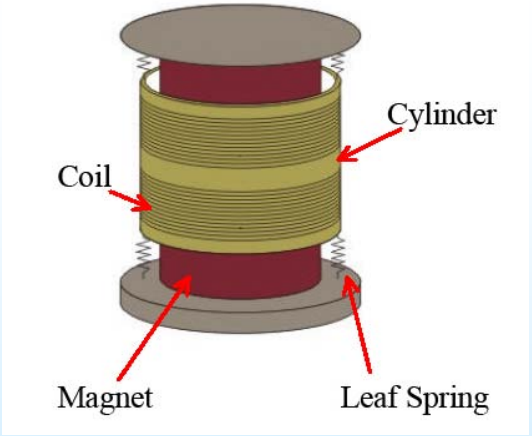
http://www.nanometrics.ca/index.php?option=com_content&task=blogcategory&id=18&Itemid=82&gclid=CPzD8o_PuZUCFRQEIwodg3YrRQ;http://en.wikipedia.org/wiki/Seismometer#Basic_principles;http://www.iris.washington.edu/edu/onepagers/Hi-Res/OnePager7.pdf

WHAT IS A GEOPHONE

Generally, a simpler instrument that measures and record motions of the ground usually for higher frequencies

- **A long history of operation of measuring seismic events before the more recent introduction of electronic circuits into seismic instruments**
- **Standard instruments include a coil generating a field which is affected by motion of a magnet**
- **Viable for high frequency ranges e.g. 1-30 Hz but with demonstrated range of sensitivity relevant to seismic events**





http://micromachine.stanford.edu/smssl/projects/Geophones/DefenseBarzilaiFinalCopyWeb/DefenseBarzilaiFinalCopy.pdf
http://www.earthsci.unimelb.edu.au/ES304/MODULES/SEIS/NOTES/geophone.html

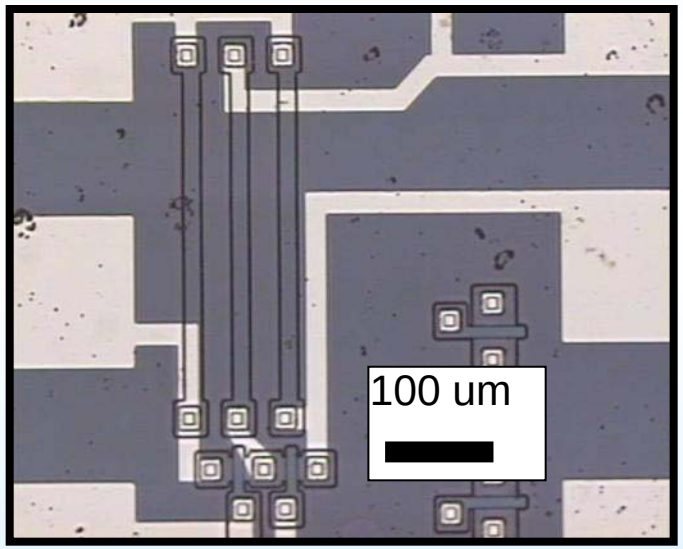
NASA Glenn Silicon Carbide Differential Amplifier

World's First Semiconductor IC to Surpass 4000 Hours of Operation at 500 °C

A NASA Top Discovery Story in 2007

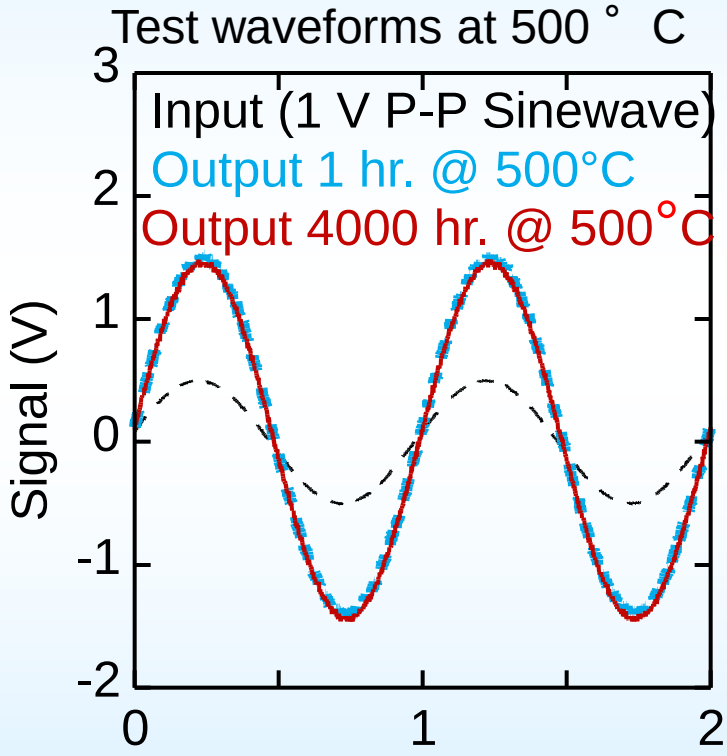
Demonstrates CRITICAL ability to interconnect transistors and other components (resistors) in a small area on a single SiC chip to form useful integrated circuits that are durable at 500°C.

Optical micrograph of demonstration amplifier circuit before packaging



2 transistors and 3 resistors integrated into less than half a square millimeter.

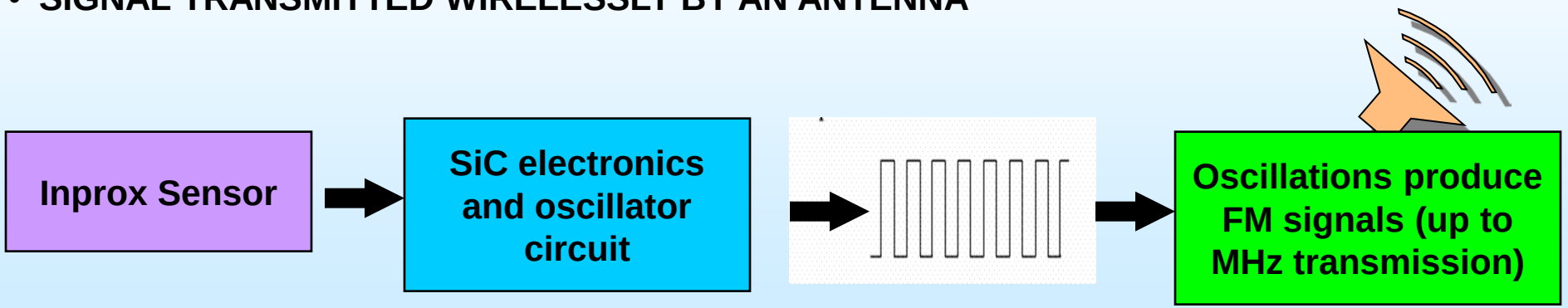
Single-metal level interconnect.



Less than 5% change in operating characteristics during 4000 hours of 500°C operation.

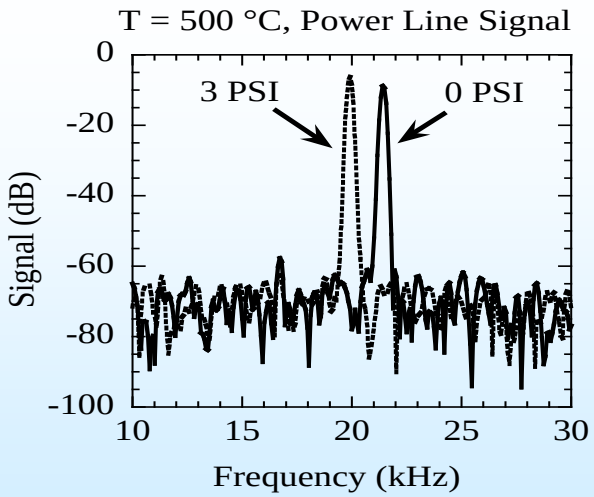
SEISMOMETER DESIGN APPROACH

- PROCESS AND DIGITIZE AT THE SOURCE:
  - NEED COMPONENTS SUCH AS CAPACITORS, RESISTORS, AMPLIFIERS, LOGIC GATES
  - NEED APPROPRIATE SIGNAL COMING FROM SEISMIC INSTRUMENT
- SIC ELECTRONICS IS USED IN CONJUNCTION WITH THIN FILM CAPACITORS AND INDUCTORS CAPABLE OF 500ºC OPERATION
- A HIGH TEMPERATURE SEISMOMETER UTILIZING A VERTICAL PENDULUM DESIGN HAS BEEN FABRICATED
  - A LEAF-SPRING SEISMOMETER DESIGN IS USED
  - A SEISMIC MASS ON A BOOM SUPPORTED BY CROSSED HINGES IS COUNTER BALANCED WITH A LEAF SPRING
- A SIMPLE SIGNAL CONDITIONING CIRCUIT IS EMPLOYED IN WHICH THE VARIABLE INDUCTANCE TRANSDUCER IS USED IN AN OSCILLATOR CIRCUIT TO CONVERT THE SENSED BOOM POSITION TO AN ELECTRICAL FREQUENCY
- SIGNAL TRANSMITTED WIRELESSLY BY AN ANTENNA

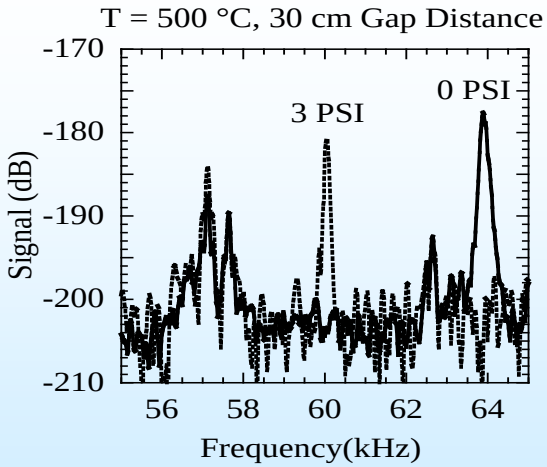


High Temperature Wireless RF sensor data signal transmission at 500˚C

- **Based On NASA SiC Components Previously Demonstrated For Long-life Operation**
- **Modulation Of Oscillator Output Frequency As A Function Of Applied Pressure At 500ºC**
- **Sensor Data Transmission Across A Power Wire Of A Complete System At 500ºC Has Been Demonstrated For 1 Hour**
- **Demonstration Of Wireless Sensor Transmission At 500˚C At A Distance Of 30 cm Has Been Achieved With An External Antenna**
- **Both Are Considered World Firsts And Building Blocks For Future Technology Demonstrations**



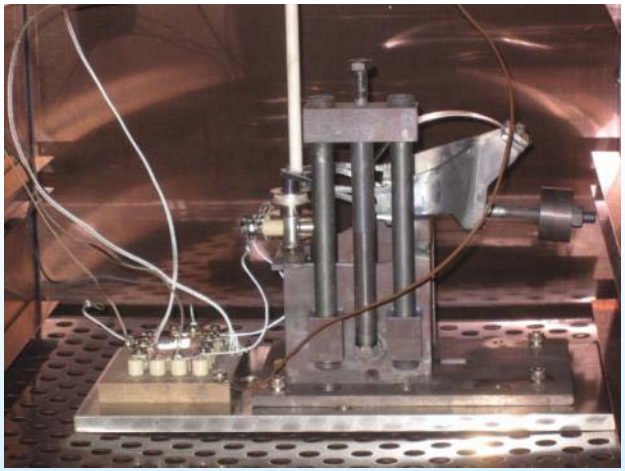
Transmission through power wire at 500°C over more than 1m



Wireless Transmission at 500°C with external antenna at 30 cm

500ºC Venus Seismometer Progress

- **Seismometer and SiC Electronics Have Been Demonstrated Separately at 500°C in Year 1**
- **Year 2:**
  - **Conversion Of Seismometer Mechanism Output At 500°C Correlated To Input Frequency**
  - **Seismometer Mechanism Modifications Identified**
  - **Seismometer Integrated With High Temperature SiC Circuit Established Including Wireless Circuit**

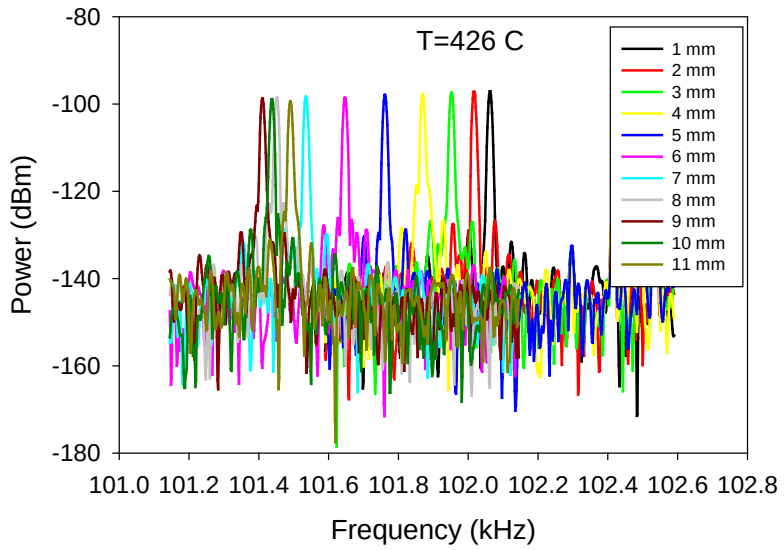


Photographs Of The Wireless Seismometer Mechanism and Circuit in an Oven

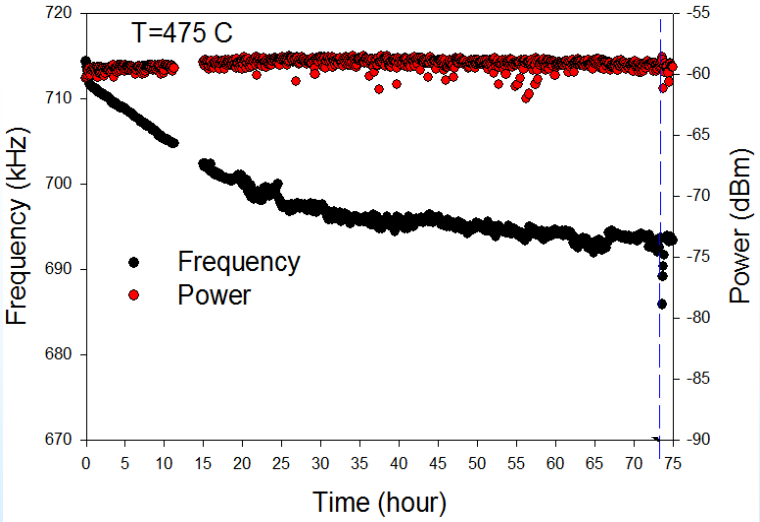
Photographs Of The Wireless Seismometer Sensor Test Setup.

First Generation 500ºC Venus Seismometer System

- **Venus Seismometer and Oscillator Tested In Oven With Demonstrated Operation Temperature From 425°C To 475°C**
- **Continuous Wireless Operation Achieved With Changes To Output Signal Correlated With Seismometer Sensor Displacement**
- **Seismometer/Oscillator Stable Operation For 73 Hours/Degraded Operation Until 119 Hours; Seismometer Mechanism Still Operational**
- **This Is With a Commercial SiC MESFET Combined with NASA High Temperature Packaging and Components**



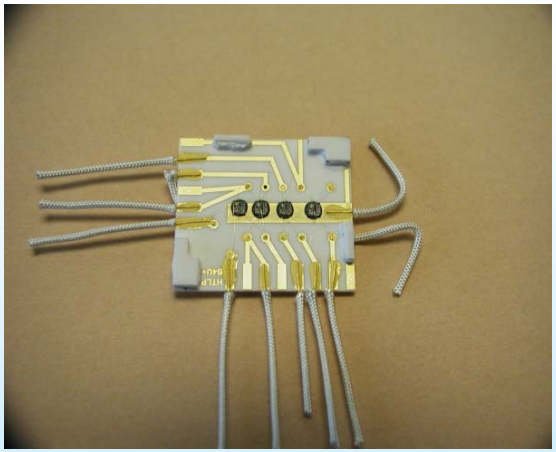
Measured spectra of the received wireless signal from the wireless Seismometer system for various seismometer probe positions at 426°C



Measurement of received oscillator frequency and power of Seismometer system at 475°C over time

PRESENT STATUS

- **INTEGRATION OF NASA GRC SiC ELECTRONICS, CAPACITIORS, AND CIRCUIT DESIGN WITH SEISMOMETER MECHANISM**
  - **SIGNIFICANT ADVANCES IN COMPONENT PARTS FOR CIRCUIT DESIGN**
  - **MODIFICATION OF SENSING MECHANISM TO ALLOW IMPROVED CIRCUIT RESPONSE**
- **OPERATION OF COMBINED SYSTEM AT 500ºC FOR 2O DAYS THUS MEETING A PROJECT OBJECTIVE; AT LEAST 40 DAYS OF OPERATION PLANNED**
- **WIRELESS TRANSMISSION OVER 2 METERS OF RESULTING SIGNAL**
- **SECOND GENERATION SEISMOMETER MECHANISM FABRICATED; PLANS TO BE INTEGRATED WITH ELECTRONICS IN THE NEAR FUTURE**

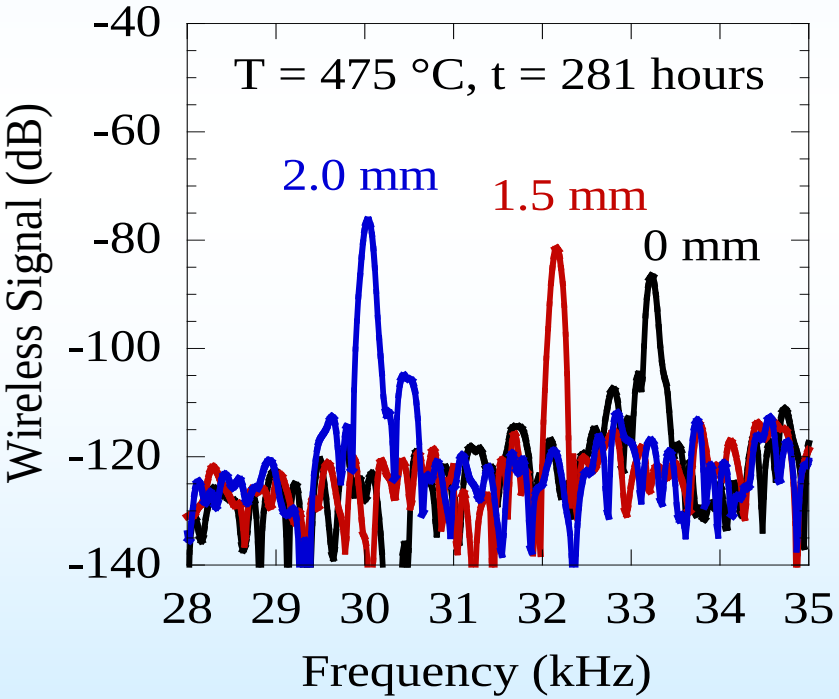


High Temperature Wireless Resonator Unit

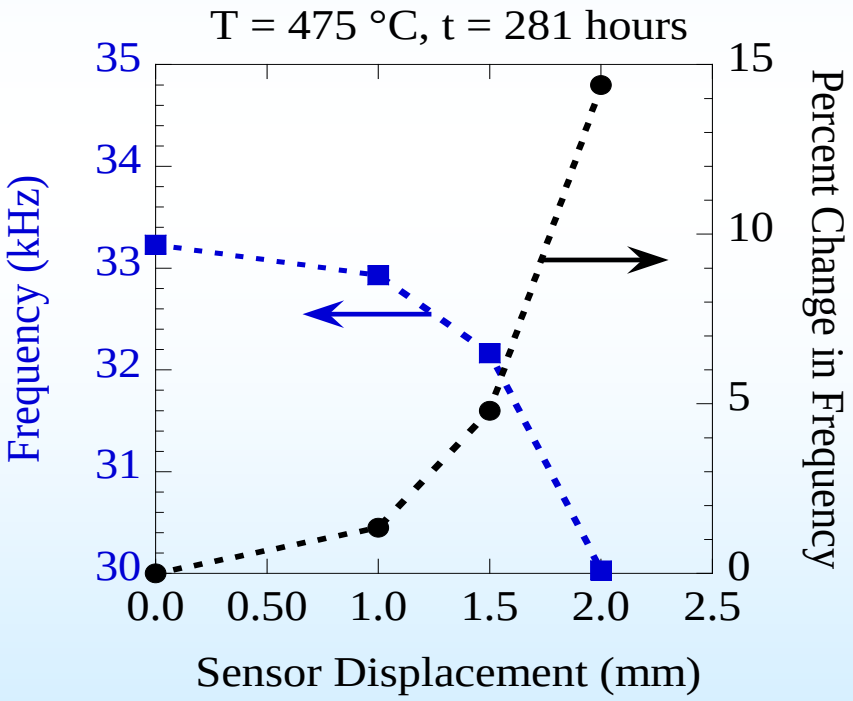
High Temperature Seismometer Mechanism

PRELIMINARY DATA: WIRELESS SIGNAL SPECTRA FOR SENSOR DISPLACMENTS AT 475 ° C

- ANTENNA DISTANCE ~ 2 METERS
- FURTHER ASPECTS OF DEVICE PERFORMANCE TO BE EXAMINED
- LONG TERM DIRECTION: TESTING IN VENUS RELEVANT ENVIRONMENTS

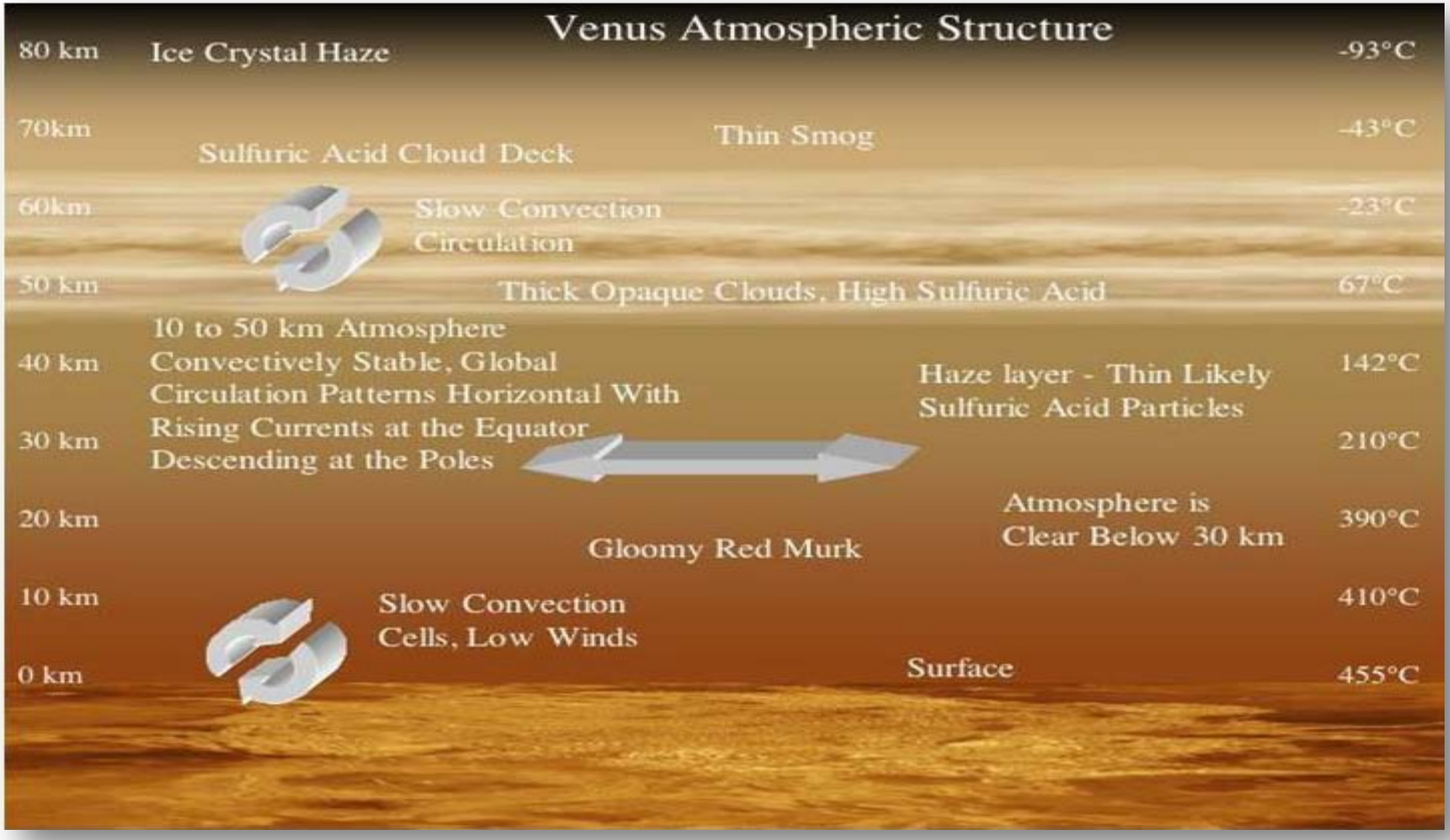


Capacitive sensor element and oscillator circuit with output buffer in oven at 475 °C.



Wireless signal frequency as a function of capacitive sensor element displacement

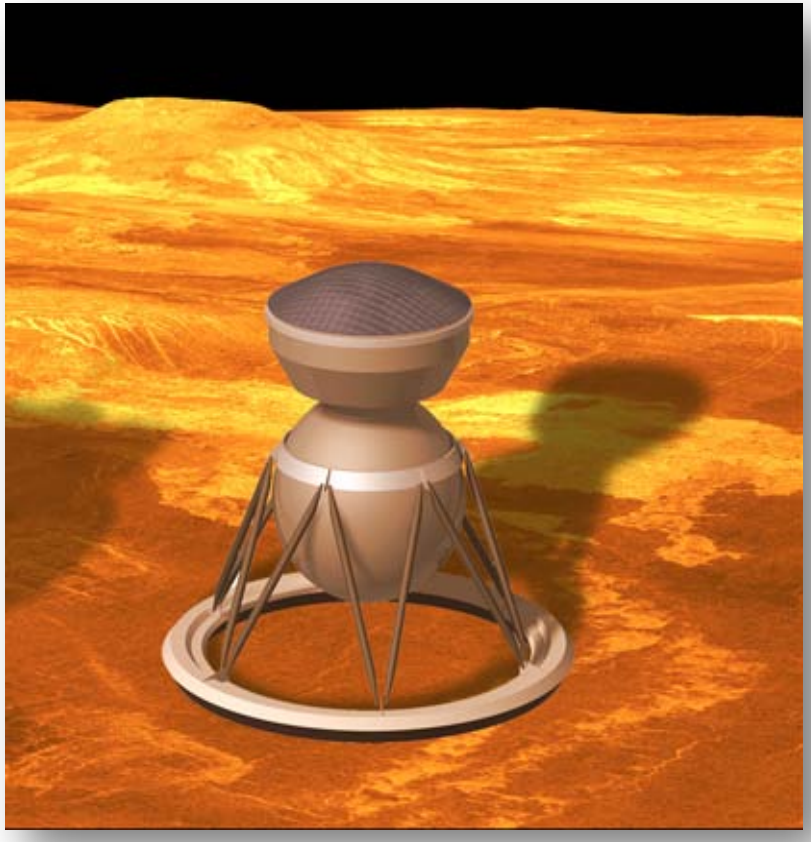
Extreme Environment Profile of Venus



Venus Pressure and Temperature Profile

Glenn Extreme Environments Rig (GEER)

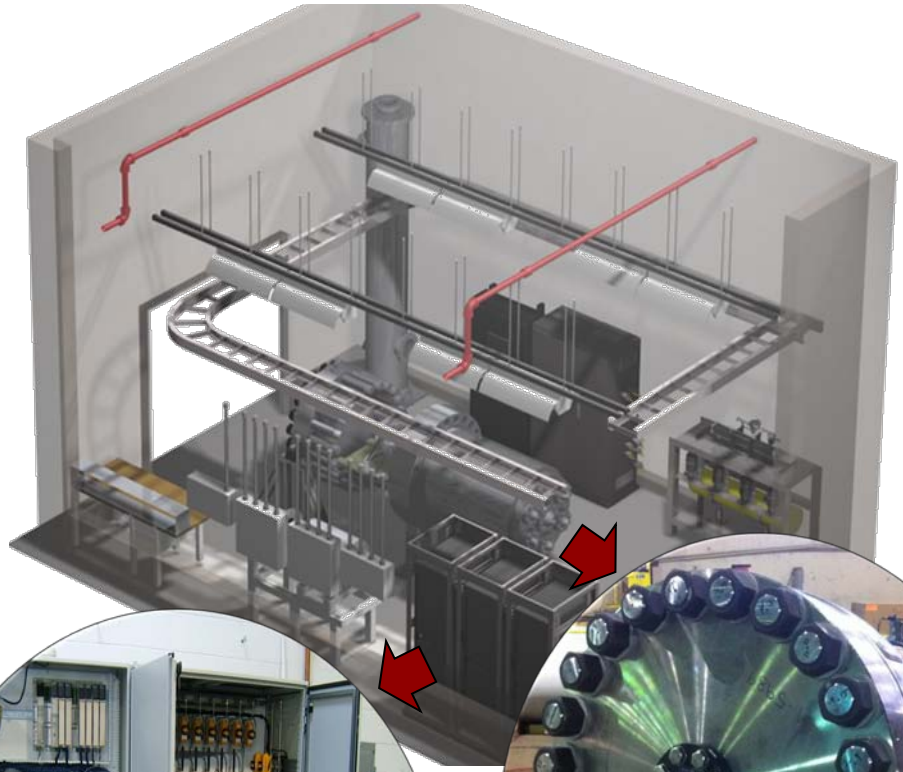
Supporting science and technology testing in high temperature, high pressure, cryogenic, and vacuum environments with time accurate, parts per billion atmospheric mixing



Long-lived Venus Lander

Extreme Environment Simulation at GRC

- Unique chamber developed for up to 1500 PSI and 500°C full atmospheric testing



- Any atmosphere
- Vacuum & Cryo
- Dynamic PPB accuracy
- Science
- Technology Development

Gas Mixer

3’ by 4’ Chamber

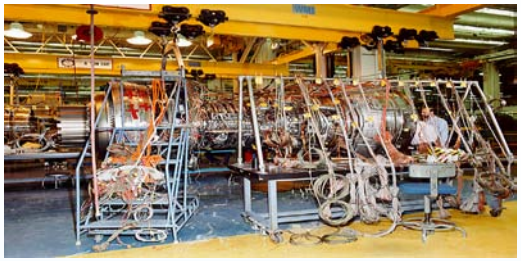
HIGH TEMPERATURE ELECTRONICS OBJECTIVE : MOVE TOWARD HIGHER DEGREES OF COMPLEXITY ALLOWING HARSH ENVIRONMENT SMART SENSOR SYSTEMS

NASA AVIATION SAFETY PROGRAM: FULL SYSTEM APPROACH TOWARD HARSHENVIRONMENT SMART SENSOR SYSTEMS

- **Milestone: Demonstrate High Temperature Sensing, Wireless Communication, and Power Scavenging for Propulsion Health Management FY2013**

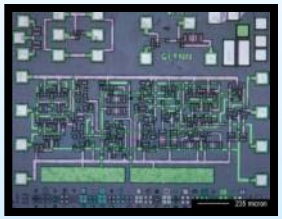
- **Metric: Demonstrate integrated self powered wireless sensor system at 500 ˚C with data transmission with operational life of at least 1 hr**

Significant wiring exists with present sensor systems

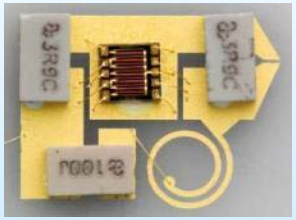


Allow Sensor Implementation by Eliminating Wires

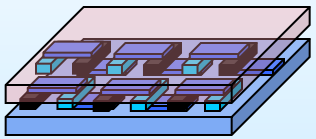
High Temperature Sensor Systems



World Record High Temperature Electronics Device Operation



High Temperature RF Components



Energy Harvesting Thin Film Thermoelectrics

SiC ICs to be Fabricated in Next Wafer Production Cycle

Circuit	Inputs	Outputs	Transistors, I/O Pads	Comments
4-Bit A/D	Analog voltage signal, optional external clock, output type select	4 bit parallel digital latch, pulse width modulated (PWM)	203 JFETs, 23 I/Os	Internal ring-oscillator clock circuit
2X2 Bit Static RAM	Read, Write, Data Lines, Address Lines	4 bit parallel digital latch, pulse width modulated (PWM)	220 JFETs, 30 I/Os	Address decoder, sense amplifiers
Source Separation Sensor Signal Transmitter	Capacitive sensor	Frequency modulated with address code	301 JFETs, 20 I/Os	Each sensor signal is tagged with unique address code
Ring Oscillators	Capacitive sensors	Frequency modulated signals (up to 500 MHz)	10-12 JFETs, 6 I/Os	On-chip large transistors for power amplification
Binary Amplitude Modulation RF Transmitter	Low power binary signal	High-Power RF signal to antenna		Could connect with PWM from A/D
Op Amp, 2-Stage	Differential	Voltage gains to 50 w/ on-chip resistors	10 JFETs	For piezoelectric SiC pressure sensors
4-Bit D/A	4 digital	1 analog	20 JFETs	

VENUS METEOROLOGY

EXAMPLE POSSIBLE MISSION: Venus Integrated Weather Sensor (VIWS) System

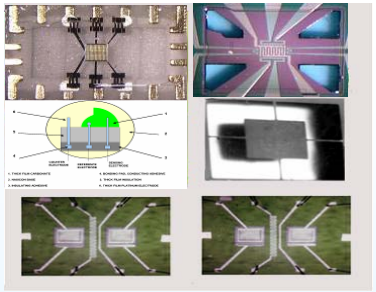
Sensor Suite to Monitor Venus Weather Conditions including:

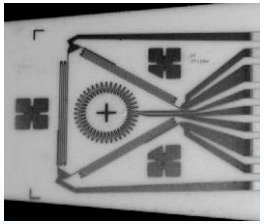
Wind Flow, Pressure/Temperature/Heat Flux,

Chemical Environment, Data Processing

- **AERONAUTICS DEVELOPMENT CAN ENABLE OTHER IN-SITU VENUS SYSTEMS**
  - **SIGNAL PROCESSING AND DATA COMMUNICATION**
  - **HIGH TEMPERATURE PACKAGING AND SENSOR SYSTEMS**
- **ALL OF THE TECHNOLOGIES BELOW HAVE BEEN DEMONSTRATED AT 500˚C AND OFTEN SIGNIFICANTLY ABOVE**
- **SUGGEST IN-SITU VENUS WEATHER SYSTEM ACHIEVABLE**

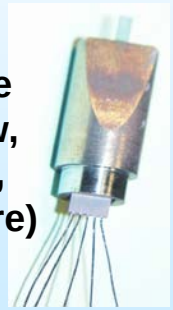
HIGH TEMPERATURE ELECTRONIC NOSE (Chemical Species)



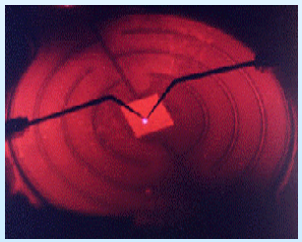


MULTIFUNCTIONAL PHYSICAL SENSOR ARRAY (Temperature, Heat Flux, Flow)

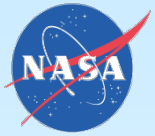
HOTProbe (Wind flow, Pressure, Temperature)



PRESSURE SENSOR (Pressure)



SiC ELECTRONICS (Data Processing)



SUMMARY

- Venus seismology is of significant scientific interest
- The core technologies to enable Venus seismology exist
- Progress is being made towards demonstration of a proof-of-concept Venus Seismometer
- The design of the system is targeted towards enabling new scientific investigations
- Planned technology advancements will notably increase system capabilities

FUTURE PLANS

- Demonstrate extended operation seismometer over 1-30 Hz range for extended periods
- Improve dynamic range of seismometer mechanism
- High Temperature Wireless System (500°C) planned in 2012
- Next Generation Electronic Circuits in development