275°C Downhole Switched-Mode Power Supply

DE-FC26-06NT42948

Goal

The goal of this project is to develop a downhole switched-mode power supply (SMPS) capable of operating at 275°C for 1000 hours. The base SMPS will include among its necessary components, a V^2 controller, Buck Converter, and SiC power switches, which together will constitute a DC-DC SMPS.

Performer

Oklahoma State University, Stillwater, Oklahoma 74078

Results

Project work began late in 2006. Preliminary overall circuit and high temperature packaging designs have been reviewed by industry advisors. An initial submission of circuits for fabrication has been made. This was an engineering run to fabricate some chips that will be used in the V^2 circuitry. The design work for the Buck Converter has been completed. Characterization of the discrete devices (i.e. capacitors, inductors and resistors) that will be utilized in the SMPS is underway. Design work on high temperature packaging is also underway.

Benefits

This 275°C SMPS will become a critical component for all high temperature downhole equipment that requires a steady supply of current at the correct voltage. It will find ready application in several current Deep Trek projects as well as in tools and equipment yet to be developed. High temperature sensing IC's under development by Deep Trek projects require 3.5V or 5.0V, while downhole power equipment utilizes higher voltages, and this SMPS will enable such applications.

Background

Among the more critical, yet basic, electronic systems needed for extreme temperature subsurface operations is the high efficiency switched mode power supply (SMPS). Such power supplies typically use high frequency switching at frequencies of 50 kHz to 1 MHz to periodically sample and store energy in an inductor, and then convert this stored inductor energy to a charge on a filter capacitor at the desired voltage. Regulation of a SMPS is performed using a control loop to vary the duty cycle of the switch, which regulates the supply output voltage. The use of high frequency switching greatly reduces the size of inductors and filter capacitors in the circuit, and allows for the attainment of power conversion efficiencies up to 95% for high performance multiple output designs. Typical power efficiencies for most SMPS applications are 75% to 90%.

The proposed controller will perform its function in switching power supplies that support downhole measurement systems that heavily rely on digital logic and embedded microcontrollers, e.g., gamma ray counters, frequency based precision pressure and temperature measurement systems, and motor control applications. The proposed controller will be implemented as a monolithic Silicon on Sapphire (SOS) integrated circuit (IC). The SMPS IC will be based on the V2 controller algorithm and use the Peregrine Semiconductor (of San Diego, CA) SOS semiconductor process for fabrication of the IC's. The Peregrine SOS process is a mature, inexpensive, and stable technology that is well-characterized and similar to the SOI process used by Honeywell in another high temperature electronics project being supported by NETL (NT41834).

For the proposed controller, the following analog building blocks will be developed and packaged: 1) a 7-bit voltage reference, 2) comparators, with and without hysteresis, and 3) a general purpose operational transconductance amplifier (OTA). The development and use of analog building blocks for the V2 mode of control allows their reuse as standard cells or building blocks, further leveraging controller design effort. The architecture of the 275°C SMPS IC will be tailored to support output voltage ranges of 1.5 to 25V and input voltages up to 30V.

This project proposes to formulate a viable low volume solution for packaging IC's for extreme temperature operation. All parts being considered have either gold metallization or aluminum pads and the Peregrine SOS complementary metal-oxide semiconductor (CMOS) and packages will be aluminum nitride. An aluminum nitride based enclosure will be developed for a SOS V2 controller and the spinoff ICs; comparators, OTAs and voltage reference. The proposed assembly would be in the form of substrates of aluminum nitride with one level sub-mount packaging and a motherboard.

When compared to commercially available SMPS systems, the proposed 275°C SMPS will be unique in three respects: 1) the system will have a very high input to output voltage ratio, 2) at >3 watts, the system will be lower power than typical SMPS systems, and 3) the temperature range of operation will be well beyond existing systems.

Summary

A kick-off meeting involving all of the recently initiated high temperature electronic research projects was held Wednesday, November 29, 2006, in Morgantown, West Virginia. The Research Management Plan and Technology Status Assessment documents have been approved.

Project work began October 1, 2006, although an Industry Advisory Committee meeting had been held in conjunction with OSU's 275°C Downhole Microcomputer System project in September. At that time, preliminary overall circuit and high temperature packaging designs were reviewed by the industry advisors, as well as the general utility of the 275°C SMPS. An initial submission of circuits for fabrication was done in December 2006. This was an engineering run to fabricate some chips that will be used in the V^2 circuitry. The design work for the Buck Converter has been completed. Characterization of the discrete devices (i.e. capacitors, inductors and resistors) that will be utilized in the SPMS is underway. Design work on high temperature packaging is also underway.

Current Status

Initial design of the circuits is underway.

Project Start Date: October 1, 2006
Project End Date: April 30, 2008

DOE Contribution: $465,888
Performer Contribution: $120,140

Contact Information

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Pertinent Publications:

Hutchens, C., Liu, C., Miin Soo, H., and T.C. Grant, 2007, High Temperature Downhole Microcomputer System and Switched-Mode Power Supply Component Development, GasTIPS, vol. 13, no. 1, in press.