Title of Investigation:

Ultra-High Density Printed Circuit Boards with Embedded Passive Devices

Principal Investigator:

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Other In-house Members of the Team:

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External Collaborators: At the Jet Propulsion Laboratory:

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Initiation Year:

FY 2003

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

$35,000

FY 2004 Authorized Funding:

$35,000

Actual or Expected Expenditure of FY 2004 Funding:

In-house: $35,000

Status of Investigation at End of FY 2004:

Completed in FY 2004 and transitioned to in-house project support

Purpose of Investigation:

The goal of this investigation is to develop a smaller and lighter circuit board without sacrificing reliability, a key requirement for future NASA space missions that emphasize smaller, lighter satellites and components. We plan to accomplish this through the development of ultra-high density Printed Circuit Boards (PCBs). This would move resistors and capacitors, which take up space, off the board's surface and into the layering of the board itself. This would improve the size, performance, cost, and reliability of PCBs. Space needed to power a satellite's many components can add up. Miniaturization would lend itself to a more compact spacecraft.

To design and build a successful circuit with embedded components, we must use advanced design tools and perform careful analysis. In addition, the circuit used must be portable so that we can demonstrate the validity of the research and impose real flight hardware concerns into the planning process. DC/DC converters were chosen as the design vehicle for this investigation because of their inherent difficulty to miniaturize. The miniaturization challenges make them an excellent candidate for a high-risk, Director's Discretionary Fund (DDF) application.

Accomplishments to Date:

A volumetric efficiency of 37 W/inch^3 has been achieved in various practical applications. Higher W/inch^3 values are achieved by using new component technologies that can deliver higher currents with the same or lower bias voltages, using new components that are more electrically efficient in at higher-frequency ranges (this allows the use of physically smaller magnetic components) and by using advanced packaging configurations that shorten connections and remove heat more effectively. Examples are developments in SiC semiconductor substrates, multiple separately engineered substrates in one package, embedded components, such as resistors, capacitors and coils, clamshell ferrites, low-ESR capacitors and stacked ceramic capacitors.

Goddard Space Flight Center's Codes 562 and 563 have collaborated on the investigation of circuits and electronic packaging technologies that may be used to realize DC-to-DC converter volumetric efficiency for future NASA missions. This report will summarize the preliminary results of the design, processing, board assembly, and the initial testing of circuits that address the following technical issues: (1) Implementation of high-thermal conductive materials as thermal path and heat sink to improve the heat dissipation efficiency; (2) Miniaturization through passive component embedding and by multi-layer circuit stacking.

Three configurations were built to investigate opportunities for miniaturization. The first two used a simple switched mode DC-to-DC converter circuit provided by Code 563. This circuit was built two times exploring the use of AlN substrates alone and integrated with FR4 boards. A second circuit provided by the Jet Propulsion Laboratory was used to demonstrate an FR4 PCB system, which included embedded passives. The project plan also included demonstrating innovative ways of embedding the magnetic components. This part of the project was completed through design, but the project ended short of the board being fabricated. Electrical and thermal testing was performed to measure thermal behavior and to calculate volumetric efficiency. Figure 1 depicts the basic circuit fabricated on AlN. Figure 2 depicts the same circuit AlN substrate on a Diamond/Al heat sink. Table 1 depicts the performance of the basic circuit on AlN using Al versus Diamond/Al. The Diamond/Al mole fraction can be continuously varied to optimize thermal, mechanical, or electrical characteristics

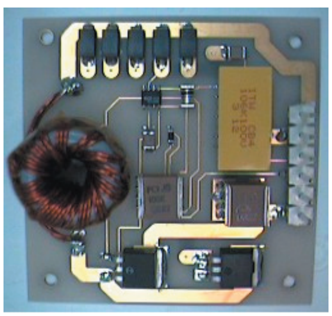

Figure 1. Power Circuit on AlN substrate

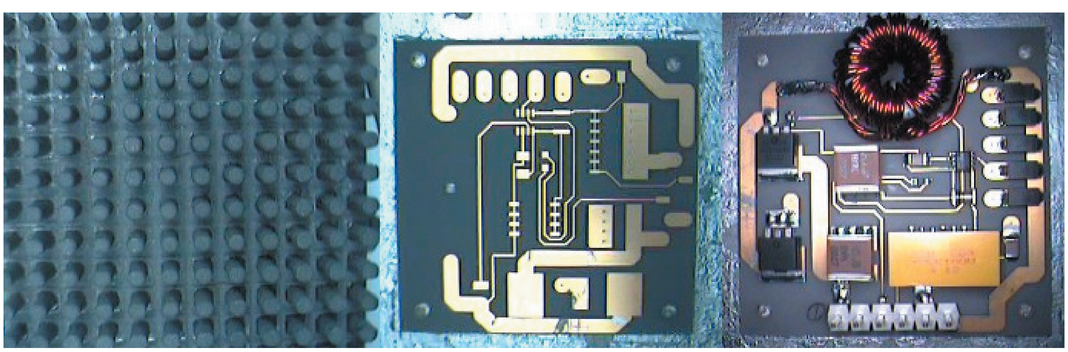

Figure 2. Same as Figure 1 with Diamond/Al Heat sink

Figure 3. Basic circuit performance with Al versus Diamond/Al composite heat sink

	Input Volt. (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Input Power (W)	Output Power (W)	Volumetric Efficiency (W/Inch3)	Efficiency (%)	Measured Temperature Rise (°C)			
									Board Center	Q1 Case	D1 Case	L1 Core
AlN + 4"x4"x_" Al Plate	28.04	2.43	3.40	15.04	68.04	51.32	27.15	75.56	60.8	50.2	51.5	63.5
AlN + 4x4x_" Diamond/Al HS	28.02	2.35	3.40	15.04	65.85	51.14	27.05	77.66	60.5	50.8	51.3	61.3
AlN + 4"x4"x_" Al Plate	35.01	2.89	3.41	20.55	101.18	70.08	37.07	69.26	80.8	72.5	71.2	90.4
AlN + 4x4x_" Diamond/Al HS	35.02	2.68	3.41	20.54	93.85	70.04	37.06	74.63	69.6	63.4	60.3	75.6

A paper entitled, "Advanced DC/DC Converters Towards Higher Volumetric Efficiencies for Space Applications," 7th European Space Power Conference (Planned), was authored by Harry Shaw and Jack Shue, NASA Goddard Space Flight Center; David Liu, Orbital Science Corporation; Bright Wang, QSS Corporation; Brandon Lee, Patrick Dudgeon, and Jeannette Plante, Dynamic Range Corporation; Brad Kercheval, Northrup Grumman; and Sion Pickard, MER Corporation.

Planned Future Work:

We plan to embed complete magnetics with a larger number of embedded passive devices, fabricate direct circuit on diamond/Al composite, and produce higher volumetric efficiency designs.

Summary:

This project will be the first to bring advanced imbedded magnetics, capacitor, and resistor technology to a NASA design and the first to show the use of fully embedded magnetics in a space application. These technologies hold great potential for reducing power systems circuits with no loss of reliability. This study has provided important data, within the context of a subsystem of great use and interest to NASA, particularly on the effectiveness and usefulness of embedded passives in this type of critical application. Circuits that are 100% portable to NASA missions are being used to demonstrate this technology. Good results during this research and development effort will quickly translate into flight-grade hardware.

To succeed, the circuits that use embedded passives must operate at least as well as the original designs over a moderate temperature range and in a hard vacuum. Technical risks lie in the varying performance of the embedded passives as compared with their surface-mount equivalents. Significantly different performance on the plus-or-minus side can prevent the circuit from behaving properly to the point of harming itself and collateral circuitry. Storage components, such as capacitors and magnetic devices (inductors and transformers), play important roles in converters both as sources of voltage and current during the internal duty cycle of the switch-mode converter and as sources of impedance into and out of the converter. Embedded magnetic cores undergo magneto-strictive effects that alter the effective component values and must be accounted for. Unexpected behavior or out of specification parameters cause resonance and oscillations.