Phase I Project Summary

Firm: CFD Research Corporation
Contract Number: NNX10CF01P
Project Title: Improved Design of Radiation Hardened, Wide-Temperature Analog and Mixed-Signal Electronics

Identification and Significance of Innovation: (Limit 200 words or 2,000 characters whichever is less)

Future NASA exploration missions into deep space, the lunar surface, and the Martian surface require the electronics for avionic systems, components, and controllers that are capable of operating in extreme temperature and radiation environments. To design wide-temperature radiation-hardened electronics and predict reliability in space, advanced models and simulation tools are required at multiple levels. Such tools should support new circuit designs and development of layout methodologies/techniques that facilitate improved radiation hardness and wide-temperature circuit performance. Contrary to digital circuits, single-event effects in analog/mixed-signal circuits required for space missions have not been adequately addressed yet.

Innovations from this Project:
(a) Novel Radiation Hardened By Design (RHBD) solutions specific for analog/mixed-signal/radio-frequency (RF) integrated circuits aimed for extreme environments of space.
(b) First-ever application of mixed-mode simulations (3D physical models coupled with circuit/system) to silicon-germanium (SiGe) heterojunction bipolar transistor (HBT) analog/RF circuits, utilizing CFDRC's unique new software. Such modeling is crucial to develop new RHBD solutions;
(c) New, physics-based SiGe HBT device models valid at temperatures ranging from -230°C to +130°C;
(d) New circuit design and layout methodologies/techniques that facilitate improved radiation hardness and low-temperature performance;
(e) Innovative product: at the end of Phase 2, demonstration of the world's first radiation-hardened-by-design (RHBD) analog/mixed-signal/RF circuits resistant to single-event effects.

Technical Objectives and Work Plan: (Limit 200 words or 2,000 characters whichever is less)

Overall technical objectives of this effort: (a) design and demonstrate innovative RHBD devices and analog/mixed-signal ICs for space environments, and (b) deliver mixed-mode CAD tools, for the wide temperature range from -230°C to +130°C, for design of radiation-hardened custom analog/mixed-signal circuits. Specific Phase 1 objectives included:
(a) Enhance the applicability of CFDRC's mixed-mode simulation package for wide temperature range and high radiation (SEE) simulations;
(b) Provide detailed understanding of experimentally observed SEE results/trends, using mixed-mode, SEE simulations of SiGe HBT analog/mixed-signal circuits; and
(c) Develop new RHBD guidelines for selected analog/mixed-signal SiGe HBT circuits, for future evaluation and implementation in Phase 2.

Work Plan:
(a) Identifying an appropriate technology and analog/mixed-signal circuit, for SEE analyses;
(b) Validating device physics models in NanoTCAD for SiGe HBTs, across a wide temperature range, and identifying models for implementation in Phase 2;
(c) Utilizing CFDRC's MixCad software (NanoTCAD + Cadence Spectre) to perform detailed, mixed-mode (3D TCAD + full external circuit), SEE simulations on the BGR circuits to explain experimental SEE results/trends;
(d) Evaluating various simulation approaches (Spice-only using various single-event current inputs vs. full mixed-mode) to generate guidelines for future SEE analyses of SiGe circuits;

(e) Identifying new RHBD concepts for analog/mixed-signal, digital, and RF circuits based on SiGe BiCMOS technologies, to be implemented and demonstrated in Phase 2.

Technical Accomplishments: (Limit 200 words or 2,000 characters whichever is less)

All the technical objectives of the project have been accomplished by the SBIR team. The major achievements include:

1. Developed and calibrated full-3D TCAD models corresponding to the SiGe HBT devices of interest (IBM 5AM SiGe BiCMOS technology).
2. Validated the existing device-physics models in NanoTCAD by computing steady-state characteristics of the SiGe HBT at multiple temperatures, and obtaining good match against Georgia Tech measured data; identified enhancements in models and numerical techniques required in Phase 2.
3. Enhanced CFDRC's MixCad software by enabling multiple TCAD models in the same simulation. This feature is especially important for new device designs such as the inverse-mode cascode SiGe HBT developed at Georgia Tech, for which no compact models exist.
4. Performed a detailed evaluation of the various modeling approaches (Spice-only using different current injection profiles - vs. – full mixed-mode), and identified preliminary guidelines for suitability of each approach. This work will be enhanced in Phase 2 to include dependencies on temperature, circuit type (analog vs. digital vs. RF), etc.
5. Performed the first ever mixed-mode SEE simulations on SiGe HBT based analog circuits (BGR), and obtained close agreement with prior experimental results. (a) Important understanding was gained into prior SEE experimental data for RHBD SiGe circuits; (b) Scaling trends were derived between the IBM 5AM and 8HP technologies.

NASA Application(s): (Limit 100 words or 1,000 characters whichever is less)

Prediction of electrical performance and radiation hardness of electronic components in extreme environments (wide temperatures, high radiation) is crucial to design reliable electronics for NASA Exploration Missions. Since electronic parts are getting smaller, the radiation/temperature effects are more severe, and the physics-based capability to predict them increases confidence. Radiation-hardened and wide-temperature analog/mixed-signal circuits are essential for all avionic systems used in NASA exploration projects. The optimized, wide-temperature RHBD designs from this SBIR will add to the pre-existing NASA "component library" developed in the ETDP SiGe electronics effort. The physics-based mixed-mode tools will help NASA design rad-hard analog/mixed-signal electronics with better control of design margins and reduce the testing cost and time.

Non-NASA Commercial Application(s): (Limit 200 words or 2,000 characters whichever is less)

Various critical analog and mixed-signal circuits are used in all space-based platforms, including DoD space systems (communication, surveillance, ballistic missiles, missile defense), and commercial satellites. Since modern electronic technologies and components are becoming increasingly sensitive to extreme environments, the mission lifetime and reliability are becoming increasingly susceptible to adverse effects, and the capability to predict the behavior of electronics dramatically increases confidence and reduces risk. The new RHBD designs and circuit/cell libraries, as well as the physics-based computer aided design (CAD) tools, can also be applied to cryogenic electronics for high-sensitivity, low-noise analog and mixed-signal applications, such as metrology, infrared (IR) imagers, sensors (radiation, optical, X-ray), radiometrology, precision instruments, radio and optical astronomy, infrared and photon detectors, and other high-end equipment. For all such devices and systems, predictive and accurate modeling and design tools reduce the amount of required radiation/temperature testing, thus decreasing their cost, and time to market or field application.

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