Design of a Radiation-Tolerant Low-Power Transceiver

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Abstract for 2001 MAPLD International Conference

***Overview*—This paper describes the development of a radiation-tolerant version of ITT Industries' Low-Power Transceiver (LPT). The LPT is a compact, flexible device that can be configured to perform custom communications and navigation functions in terrestrial, airborne, and space applications. The radiation-tolerant version of the LPT will maintain all of the LPT's existing functionality and reprogrammability. This paper emphasizes the development of the radiation-tolerant DSP module, which contains reprogrammable FPGA and DSP devices, and its application to future space applications.**

I. Background

The paradigm for spacecraft design is changing—using multiple, small, less-expensive spacecraft is often more cost-effective and reliable than using a few, large, expensive spacecraft. As an example, the vision of NASA's Office of Earth Science (OES) involves the interconnection of future space instruments into a vast network, with each space instrument working individually yet collaboratively to achieve new levels of performance. This future network, which is referred to as the Sensorweb, allows multiple vantage points (e.g., LEO, MEO, and GEO) to provide data diversity. Within the Sensorweb, formations of micro- and nano-satellites perform autonomously while achieving reliability through redundancy. In addition, reconfigurable payloads reduce risk by allowing for context switching and instrument/algorithm upgrades and adaptations after deployment [1]. Throughout the space industry, designs are requiring smaller, cheaper, and more capable systems. A key technology component that will enable these types of designs is a small, highly integrated, reprogrammable, multi-purpose communications and navigation payload that can withstand the radiation environments encountered over a variety of orbits.

II. The Low Power Transceiver (LPT)

Over the last three years, ITT Industries and the National Aeronautics and Space Administration (NASA) have been developing the Low Power Transceiver (LPT). The LPT (Fig. 1) is a compact, flexible device that can be configured to perform custom communications and navigation functions in terrestrial, airborne, and space applications. Composed of multiple PC/104 modules, the LPT assembly is modular in nature and therefore suitable for implementing a wide variety of integrated functions (e.g., numerous simultaneous software receiver and transmitter channels over multiple frequency bands). The LPT performs signal-processing functions with reprogrammable FPGA and DSP devices. Additionally, the industry standard modules used in the LPT allow it to host application-specific and COTS modules that contain processors and interfaces.

As a highly integrated, multi-purpose communications and navigation payload, the LPT achieves a level of cost-reduction, miniaturization, reprogrammability, and performance that will be attractive to future space missions. A current LPT configuration integrates the functions of communications, using both NASA's Space (TDRSS) and Ground Networks (STDN) for TT&C and science data relay, and navigation, using GPS. This specific capability will be demonstrated in orbit on an upcoming Shuttle flight (STS-107). The experiment will demonstrate simultaneous communications and autonomous navigation capabilities on orbit—critical requirements for both Space-Based Range Safety and Formation Flying applications.

Fig. 1. The Low-Power Transceiver (LPT)

III. The Radiation-Tolerant LPT (rLPT)

The intended operational environment of the LPT has always included the space environment. Although the first two generations of the LPT were focused more on proving functionality and performance and less on environmental aspects, the third generation of the LPT will address the issues of high reliability and radiation tolerance. ITT and NASA are in the process of working towards developing a radiation-tolerant LPT (rLPT) that has all the functionality and reprogrammability of the current LPT with the ability to operate reliably in the space radiation environment. Since the LPT is composed of multiple modules (e.g., Power Supply and I/O module, Digital Signal Processing (DSP) module, RF Transmitter module, RF Receiver module, and Power Amplifier module), each module's radiation-tolerance is being addressed independently. This paper focuses on the development of the radiation-tolerant DSP module.

IV. The rLPT DSP Module Design Approach

NASA's Earth Science Technology Office (ESTO) is funding research through the Advanced Information Systems Technology (AIST) program to design and develop the radiation-tolerant third generation LPT DSP module. This effort poses several design challenges, because it requires hardening the module's FPGA and DSP devices, which perform the LPT's advanced signal processing functions. Developing a fault-tolerant architecture for the SRAM-based reprogrammable FPGAs to mitigate single-event upsets (SEUs) and replacing the current DSP with a radiation-tolerant alternative are key elements of this effort. The resulting DSP module will be stacked with other radiation-tolerant modules to form the rLPT.

A. Fault-Tolerant, Reconfigurable FPGA Design

The second generation LPT DSP module (Fig. 2) uses two Xilinx Virtex-E FPGAs to provide the bulk of the LPT's signal processing capability. In the third generation LPT, these FPGAs will be replaced with radiation-tolerant Xilinx FPGAs that are immune to a total ionizing dose (TID) of 300 krads(Si) and to single-event latch-up (SEL) below a LET of 120 MeV-cm^2/mg. However, these radiation-tolerant FPGAs are susceptible to SEUs that manifest themselves as configuration upsets, user logic upsets, and architectural upsets, which are also known as single event functional interrupts (SEFIs) [2].

The impact of the various manifestations of SEUs is dependent upon both the space radiation environment and the SEU mitigation techniques that are used, because ultimately, the SEUs' impact on performance is quantified by the FPGA's functional upset rate with mitigation. A number of techniques to mitigate SEUs in the Xilinx parts are available and have been thoroughly characterized by Xilinx in radiation test facilities. Using these techniques and other lessons learned, ITT Industries has developed a set of guidelines that include general and LPT-specific design approaches for adding redundancy to the VHDL code and for implementing the partial reconfiguration scrubbing. The design guidelines will continue to evolve as they are applied to the LPT architecture.

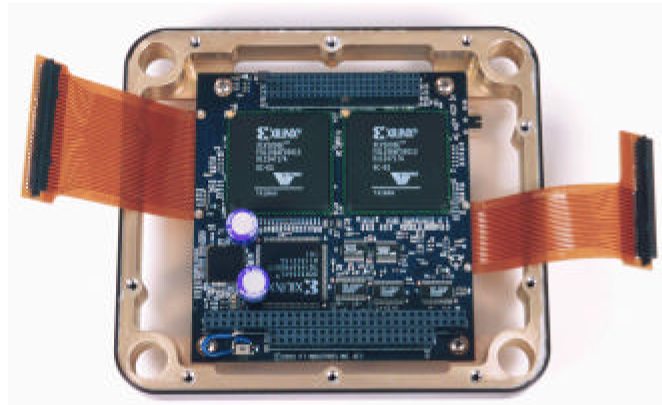

Fig. 2. The Second Generation LPT DSP Module

B. Radiation-Tolerant DSP

The second generation LPT DSP module currently uses a 200 MIPS Texas Instruments TMS320C5421 DSP. Unfortunately, there is not a radiation-tolerant version of this COTS DSP currently available, so an appropriate replacement processor must be used. In an effort to simplify the hardware design, many of the DSP's current functions will be moved into the FPGA. Fortunately, this migration will result in a reduction of the total processing power required for the replacement DSP.

The third generation DSP module will use a radiation-tolerant Actel FPGA for all functions that must be available upon application of power to the LPT and that are required to support the higher density Xilinx FPGAs. A modest soft processor core will be embedded in this Actel FPGA. Additional processing will be embedded in the Xilinx FPGAs—by converting the DSP functions to VHDL and/or by embedding a soft processor core (with TMR added) in the Xilinx FPGA. The use of soft processor cores is attractive, since it moves the design one step closer to being a system-on-a-chip, and prepares the LPT for its future evolution.

V. The Future of LPT

The generational evolution of LPT is far from over. ITT has already described the vision for a so-called fourth generation LPT, which will be termed the Miniature Transceiver (MinT). This new generation will evolve the LPT packaging system into a miniature form factor while preserving or improving upon the core LPT capabilities. In its own right, the third generation LPT platform is a compact device measuring approximately 100 cubic inches in volume. However, the MinT will strive to be only 8 cubic inches in volume—a cube measuring approximately two inches on a side. This will be accomplished by following the same formula used in the earlier generations of LPT—exploit latest-generation, commercially available technology while being mindful of the environmental requirements of space applications. This new, light-weight form factor will help revolutionize spacecraft design by allowing the transceiver to be placed near or inside antenna structures, virtually eliminating cable losses that plague existing spacecraft and limit the bandwidth available for science. Additionally, it will act as an enabler for a new generation of nano-satellites whose entire mass is less than a conventional transceiver/transponder.

New packaging schemes will be developed that expand upon the modular foundation of the first three generations of LPT, improving bottlenecks and trouble spots inherent to the existing design. Printed circuit boards will most likely be assembled using chip-on-board techniques in order to eliminate the size restriction imposed by chip packages. Likewise, innovative and ultra-high-density signal routing will be utilized in order to provide a dramatically improved bandwidth potential, allowing the new form factor to take advantage of future advancements in signal processing speed and density.

VI. Summary

The successful conversion of the LPT to a functionally equivalent rLPT is critical for many space applications. Although this task is challenging, the recent development of radiation-tolerant COTS devices will facilitate this effort. ITT Industries plans to apply these new devices and technologies to the development of the rLPT. Furthermore, the MinT promises to be a breakthrough technology for the emerging fleet of nano-satellites currently being planned.

References

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