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UPDATE ON RADIATION-HARDENED MICROCOMPUTERS FOR ROBOTICS AND TELEOPERATED SYSTEMS

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ABSTRACT

Since many programs sponsored by the Department of Defense are being canceled, it is important to select carefully radiation-hardened microprocessors for projects that will mature (or will required continued support) several years in the future. At the present time there are seven candidate 32-bit processors that should be considered for long-range planning for high-performance radiation-hardened computer systems. For Department of Energy applications it is also important to consider efforts at standardization that require the use of the VxWorks operating system and hardware based on the VMEbus.

Of the seven processors, one has been delivered and is operating and other systems are scheduled to be delivered late in 1993 or early in 1994. At the present time the Honeywell-developed RH32, the Harris RH-3000 and the Harris RHC-3000 are leading contenders for meeting DOE requirements for a radiation-hardened advanced 32-bit microprocessor. These are all either compatible with or are derivatives of the MIPS R3000 Reduced Instruction Set Computer. It is anticipated that as few as two of the seven radiation-hardened processors will be supported by the space program in the long run.

INTRODUCTION

Future applications of robots for Environmental Restoration and Waste Management (EM) will require radiation-hardened high-performance 32-bit microcomputers for advanced control and sensory integration. With the winding down of many programs sponsored by the Department of Defense, it is important to select carefully microprocessors for projects that will mature (or will required continued support) several years in the future. Other studies[1] have examined a broad range of radiation-hardened microprocessors available. However, at the present time there are only seven candidate rad-hard 32-bit processors that should be considered for long-range planning for high-performance systems. For Department of Energy applications it is also important to consider efforts at standardization that require the use of the VxWorks operating system and hardware based on the VMEbus.

ANALYSIS

The second day of a meeting titled "The 32-bit Space Processor Showcase" (Las Vegas, May 6-7, 1993) was opened by Lt. Col. William Swiderek, from Phillips Laboratory, who said that now is a "time of consolidation" -- industry must "invest or get out." He also emphasized that "cost/schedule risk is in *computer* development, not just the processor. "Processors are important, but more important is the computer built around the processor when it comes to cost and schedule risk."

The 32-bit radiation-hardened microprocessors now in some stage of development are shown in the following table:

Harris	RH-3000
Harris	RHC-3000
Honeywell	RH32
IBM	RAD6000
NASA(LSI/Harris)	Mongoose
Texas Instruments (DSP)	SMJ320C30
TRW (UTMC)	RH32

Of the seven processors, one has been delivered. On October 28, 1992, the first Mongoose prototypes were delivered to NASA and software was running two days later. The IBM RAD6000 was demonstrated at the 32-bit Microprocessor Showcase executing demonstration programs side-by-side with a commercial system. Other systems are scheduled to be delivered late in 1993 or early in 1994.

All 32-bit space processors except the RAD6000 and the Texas Instruments SMJ320C30 are derivatives of the MIPS R3000. The RAD6000 is a radiation-hardened duplicate of the commercial RISC6000, and the SMJ320C30 is a digital signal processor (DSP). The Mongoose, RH-3000 and RHC-3000 all will execute code produced by standard MIPS compilers while both RH32's require software translation from "pure" R3000 object code.

Development of the special-purpose Texas Instruments SMJ320C30 is still progressing slowly. TI projects a 1994 second quarter delivery, however, fabrication is planned in Japan which requires State Department approval.

The route to an environmentally-hardened embedded "microcomputer" is not trivial. Previous experience[2] has demonstrated that development of a microcomputer based on a standard commercial backplane bus requires considerable effort to select appropriate radiation-hardened peripherals and bus-interface logic.

If one neglects the special-purpose Texas Instruments DSP, the first choice is between the single-vendor IBM RAD6000 and some descendent of the MIPS R3000. In favor of the IBM choice are the following features: The chip set is available now and it is fully software compatible with a large family of installed commercial RISC6000 systems. A microchannel CPU board using rad-hardened modules is available now with complete software support.

The RAD6000 is a processor developed by transferring a commercial processor design to a rad-hard fabrication line. By this process total-dose hardness in excess of 10,000 Gy (1 megarad) is guaranteed but single-event reliability is not achieved without further design effort. A 6U VMEbus-size card is being developed for a Jet Propulsion Laboratory Mars project using a single-chip version of the RAD6000. There is no commercial VMEbus processor board based on the commercial RISC6000 and IBM has not announced a full VMEbus processor board based on the RAD6000 or VxWorks support for the RAD6000.

The Mongoose, is a MIPS R3000 clone with extra features for embedded design developed by LSI and Harris for NASA-Goddard project. Developers LSI Logic and Harris have not announced a marketing support strategy for the Mongoose; however, NASA reportedly[3] has made special arrangements to make Mongoose chips available at approximately $36,000 each.

Since delivering the Mongoose, Harris has produced two additional R3000-based processors. The RH-3000 is a Complementary Metal-Oxide Semiconductor Silicon-on-sapphire (CMOS-SOS) chip set developed for the Naval Research Laboratories and the RHC-3000 is an internally funded bulk CMOS offshoot of the Mongoose. An RH-3000/SOI, silicon-on-insulator chip set is currently in design.

The RH-3000 chip set includes a floating point processor module and is fully software compatible with the commercial MIPS R-3000 development tools. Harris offers an RH-3000 Module that includes the CPU, FPU, 256K cache, and 1 MB main memory. The RH-3000 offers full concurrent error detection and hardware assisted real-time rollback. The logic design is based on an existing CPU/FPU static CMOS core logic design netlist from LSI Logic Corporation, ported to the Harris CMOS-SOS fabrication process.

The RHC-3000 is a bulk CMOS, highly integrated single-chip Rad-Hard Controller based on the Mongoose design. It does not include floating-point hardware, however, the RH-3000 FPU may be used with it. Due to the Harris-LSI agreement, the chipsets produced at Harris cannot be sold directly but only in system modules manufactured by Harris. A RHC-3000 demonstration module is available now. A 6U VMEbus form-factor board with a pseudo-VMEbus interface is scheduled for delivery to the University of Arizona in December 1993. The board may be plugged in to a VMEbus backplane and will communicate with VMEbus memory modules; however, DMA, bus-contention control, and the interrupt interface signals do not meet VME bus standards. The initial prototype will be supported with non-hardened chips but it will be upgradable to a fully hardened board. Detailed schematics have also been created for an RHC-3000 board with a full VMEbus interface.

Other recent changes in the availability of rad-hard chips makes the possibility of a radiation-hardened VMEbus R3000-based computer much better now than it was even six months ago. Of particular importance is the availability of a commercial VMEbus interface logic chip that has been tested[3] and found to survive a total dose of 3,000 Gy (300,000 rads). Testing was stopped at that point so the functional hardness limit is not known, although it could be above 10,000 Gy (1 megarad).

Large DRAM memories have been a feature of modern VMEbus processor boards. DRAMS are generally fairly susceptible to radiation – usually limited to a few thousand rads total dose at best. However, now IBM has produced the 16 Mbyte DRAM for the LUNA "C" program which tests showed were capable of surviving a total dose of up to 900 Gy (90,000 rads).

Honeywell and TRW are both in the final phases of contracts to produce megarad hard 32-bit advanced space processors known as the RH32. Air Force contracts with Honeywell and TRW each call for the delivery of a VMEbus board using each company's respective RH32 processor that are derivatives of the R3000 but will not directly execute R3000 binary code. The Honeywell RH32 is to be supported by VxWorks so a relatively seamless translation of R3000 software is anticipated. ADA will be the basic support system for the TRW version of the RH32. An RH32 is planned to be flown aboard the ARGOS satellite in September 1995 so both RH32 products should mature in the near future. Both manufacturers plan development configurations based on the VMEbus although "flight" configurations will probably be based on some other back-plane bus.

Honeywell and TRW will soon complete their RH32 contracts that include delivery of non-hardened VMEbus development systems that include the hardened RH32 chip set. The RH32s are mega-rad hardened processor chip sets that incorporate on-chip self-checking logic designed to tolerate the single-event upset environment in space in addition to the total-dose specifications. RH32 designs are not MIPS R3000 instruction-set compatible although the architectures are similar and translation of R3000 code is said to be relatively trivial. In fact, Honeywell uses an off-the-shelf R3000 VMEbus processor board for software development for the RH32.

CONCLUSION

A radiation-hardened embedded VMEbus micro-computer could be constructed using either the IBM RAD6000 or one of the R3000 descendants. With sufficient funding either route could be viable. However, development of the RAD6000 VMEbus single-board computer with VxWorks target-processor support would require future funding while two or three presently-funded R3000

derivatives will be available on a 6U VMEbus board with VxWorks support. Therefore, it seems that choosing an R3000-based processor is the best alternative. Selection of the R3000/RH32 as the future target embedded microprocessor also allows one to make an immediate commitment in software development. For example, the commercial Heurikon VMEbus R3000 single-board computer is supported by VxWorks. Lockheed-Sanders offers a ruggedized VMEbus R3000-based CPU board supported by VxWorks. The inherent radiation tolerance of these non-hardened boards can be determined now for use in low-level radiation environments.

At the present time the Honeywell-developed RH32, the TRW-developed RH32 or either of the Harris R3000 clones is a technically acceptable processor choice for a rad-hard advanced microcomputer. The RH-3000 and RHC-3000 do not include the extensive on-chip self-checking built into the RH32 and should result in a less expensive system. Since single-event upset is not a problem with most (if not all) DOE requirements for rad-hard processors, the RH-3000 and RHC-3000 systems should be more economical. Harris has, in fact, developed a rad-hard RH-3000 computer module in small quantities for the University of Arizona for about $100,000. It has been suggested that a VMEbus based RHC-3000 board should cost in the same order.

Honeywell is a strong contender with a long history in the development of avionics and space processors. Harris on the other hand, claims to be the largest supplier of radiation-hardened semiconductors in the United States and world wide. Recent acquisitions of the General Electric and RCA rad-hard divisions has created the largest radiation-hardened product line available. The Harris semi-conductor business is 60 per cent commercial and 40 per cent Department of Defense related thus their survival in the post-cold-war era is probably insured.

A completely radiation hardened VMEbus RISC processor board is not currently available; however, commercial R3000 systems, the Honeywell Avionics RISC Processor (HARP) system based on a commercial R3000 CPU, or the RH32 development boards may be used during the intermediate time frame. VxWorks is applicable across the whole family of systems and will be supported by Honeywell (at least) on the RH32 system. Software migration could be as simple as recompiling the application code..

Harris RH-3000 and RHC-3000 are leading contenders for meeting DOE rad-hard requirements. Systems with mega-rad static RAMS (SRAMS) could be developed now and less radiation-tolerant systems with larger DRAM memory could be produced. Since reasonably radiation-tolerant commercial VMEbus interface logic is now available for projects that have only total-dose requirements, a radiation-tolerant VMEbus R3000-compatible processor board is only a purchase order and some development effort away.

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