Digital Technical Journal
Volume 6, Number 2
Militarized paper

The E^{2}COTS System and Alpha AXP Technology: The New Computer Standard for Military Use

by

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ABSTRACT

The translation of Digital products applicable to military application has been affected by the DoD's need for lower cost products. Products developed for military application must retain robust mechanical characteristics; however, each product may be tailored to meet government specifications such as mean time between failure and temperature range. Design changes for military use have had a beneficial second effect. Militarized products may be readily modified to meet a severe industrial environment that previously could only be accomplished with commercial products in special enclosures. As a result of the close cooperation between Digital and Raytheon, cost-effective, severe environment products can be provided to the DoD and the industry.

INTRODUCTION

In 1986, the Raytheon Company and Digital Equipment Corporation entered into a licensing agreement to equip Raytheon's militarized computer system with the best commercial computer technology of the time, Digital's VAX processor. The agreement had two major objectives. The first was to incorporate VAX computer technology into a configuration that complied with the government's existing military specifications. The second was to make the militarized VAX technology available as a strictly commercial effort. The concept was not unique. The Rolm Corporation had militarized a number of the commercial computers designed originally by Data General Corporation, and Norden Systems, Inc. had militarized and marketed Digital's PDP-11 system and earlier VAX processors. Under the Raytheon/Digital agreement, the first computer converted to a configuration usable by the military was the VAX 6200 system. The VAX 6200 incorporated very large-scale integration (VLSI) device technology.

Prior to the introduction of VLSI technology, the militarization of computers was difficult but manageable. The military was a major customer of semiconductor vendors, who would commonly manufacture parts to meet both commercial and military standards. The semiconductors, resistors, capacitors, switches, and other parts were tested and certified to be used in military computers, and the mechanical and electrical structure was also tested to meet extremes of temperature, shock, and vibration. It was, and still is, not unusual to encounter a requirement for computer operation over the temperature range of -54 degrees Celsius to 70 degrees Celsius with a 30-minute period of 85 degrees Celsius.[1] In contrast, the commercial units operate in a benign office environment of 0 degrees Celsius to 50 degrees Celsius.[2-4]

With the evolution of the proprietary VLSI computer in 1986, the cost of developing a new military computer would have strained the government's ability to fund the development of modern architectures to support the advances made in the field of software. The funding of new custom VLSI devices to become the core of military computers required that a large market was available, and the military sector offered only a small percentage of the total market.

Military specifications require the costly and time-consuming testing and documentation that have been in place since World War II. With the end of the Cold War and the serious decline of the Department of Defense (DoD) budget, the military began looking for new ways to procure the weapons systems using VLSI computers. For many new procurements, the DoD approach has been to buy commercial computers for applications in which the environment is expected to be office-like. The forward edge of the battle area (FEBA), however, is anything but office-like and usually presents environmental challenges that are not normally those anticipated by designers of commercial systems. For example, when one thinks of the climate conditions encountered in the Gulf War, a vision of blowing sand and dry, hot weather comes to mind. In reality, the desert sand is a fine caustic dust, and the air over the Persian Gulf contains significant moisture. The combination is lethal to conventionally designed electronic equipment, etching away unprotected circuit board runs and contacts.

To address the combined budgetary and performance dilemma, Raytheon developed the extended environment, commercial off-the-shelf (E^{2}COTS) computer. To provide the best microprocessor performance available in 1990 and for the forseeable future, the E^{2}COTS computer is powered by Digital's commercial Alpha AXP technology and is constructed to meet the extended environmental needs of defense projects. In addition, that technology is made available to the government via weapon system integrators as a non-developmental item (NDI) and on a strictly commercial basis. As a result, the first of the E^{2}COTS line, Digital's DEC 4000 AXP Model 500 workstation is already flying as the Raytheon Model 920 on the JSTARS aircraft.

This paper explores some of the changes made in the militarization process. It describes the characteristics of the E^{2}COTS computer combined with Alpha AXP technology and the versatile microprocessor (VME) 64 bus. It then discusses the relevance of conduction cooling for the militarized module and design trade-offs based on space and thermal differences.

CHARACTERISTICS OF AN E^{2}COTS COMPUTER

There are three major characteristics of an E^{2}COTS computer with Alpha AXP technology:

1. It is software identical to the commercial equivalent.

2. The basic commercial design is modified only to the extent necessary to meet the extended environmental and reliability requirements of the system in which it is employed.

3. It is tested at the unit level to meet the military operational and logistical specifications required of the hardware.

The commercial software (operating system, high-level languages, and development environments) executed on the commercial product can be captured for the E^{2}COTS counterpart. Software executed on the commercial computer can be executed on the E^{2}COTS computer without change at the binary level. Further, the system developer can use benign environment commercial equipment to start developing and testing the military design. Finally, standardized code for high-level languages such as Ada can be readily transported to subsequent E^{2}COTS computers as technology advances.

VLSI computers must be carefully designed to take into consideration even the length of the interconnect etch on the circuit board. A seemingly minor change in the characteristics of the etch may affect the signal timing, cross talk, or similar parameters, resulting in either unreliability or total failure to operate. Thus, any change in the component layout to meet the E^{2}COTS configuration must be undertaken with extreme care and then only when required to meet environmental, reliability, or physical space requirements.

Finally, the historical test methodology of design validation tests every component used in the design. The completed computer is then tested for throughput, power consumption, electromagnetic compatibility, and durability. For the E^{2}COTS system, this expensive and time-consuming test cycle is replaced with the review of the commercial components used in the original design. Based on this review, some components may be replaced with higher quality or specially screened components, and environmental and performance verification testing of the completed computer follows. It should be noted here that testing may be accomplished at the circuit card assembly (CCA) level where such CCAs may be separately developed. CCAs that are used in conjunction with a standardized backplane bus such as the VME bus are typically developed at this level.

DEVELOPMENT OF AN E^{2}COTS SINGLE MODULE COMPUTER FOR THE VME BUS

The close cooperation between Raytheon and Digital led to an early identification of the DECchip 21066 and DECchip 21068 processors and VME 64 bus based on Alpha AXP technology as an excellent choice for translation into an E^{2}COTS design. Table 1 compares the technical specifications of Digital's and Raytheon's modules.[2,4,5] There are, at present, a number of manufacturers of NDI single module computers that build to a configuration much like the E^{2}COTS specifications. Most, although not all, are based on the Motorola MC68000 series processors. Vendors include Motorola Inc., Radstone Technology, and DY-4 Corporation.

The major reasons for choosing Digital's AXPvme 64 system were the performance and extensive software support desired by embedded processor users. Further, the computer was being designed for the VME 64 backplane bus. The VME bus has been selected by numerous military design organizations to be the backplane bus of choice, providing for an open systems architecture. In addition, the AXPvme 64 system incorporated the peripheral component interconnect (PCI) bus, thereby offering flexibility of I/O design with a minimum of component overhead.[6]

Table 1 Technical Specifications Comparing the Digital Commercial and the Raytheon E^{2}COTS Single Module Computers

Physical Characteristics	Digital Commercial Module	Raytheon E^{2}COTS Module
Single board computer	Standard Eurocard format (6U) 233 mm X 160 mm (9 inch X 6.25 inch) (20.3 mm) wide	Standard Eurocard format (6U) 233 mm X 160 mm (9 inch X 6.25 inch) (20.33 mm) wide
PCI mezzanine card	5.9 inch X 2.95 inch	2.5 inch X 5.5 inch
Software Support		
Operating systems	DEC OSF/1 AXP, VxWorks for Alpha AXP	DEC OSF/1 AXP, VxWorks for Alpha AXP
Compilers	Ada, Fortran, C/C++	Ada, Fortran, C/C++

Power Requirements		
Power supply voltage	With 32 MB and no PCI options: 7.64 amperes @ 5 VDC and 0.6 ampere @ 12 VDC	With 32 MB and no PCI options: 4.6 amperes @ 5 VDC and 0.6 ampere @ 12 VDC
Environmental Specifications		
Operating temperature	0°C to +50°C with forced air cooling of 200 linear feet per minute at ambient	-54°C to +55°C system ambient (70°C sidewall), +85°C side rail for 30 minutes
Storage temperature	-40°C to +66°C	-62°C to +95°C
Temperature change	20°C per hour	1°C per minute
Relative humidity	10% to 95% (noncondensing)	0% to 100% (condensing)
Mechanical shock	7.5 G peak (+/-1 G) half sine pulse of 10 ms (+/-3 ms)	Per MIL-STD-810D Method 516.3
Acceleration	Not specified	9 G continuous operation
Vibration	5-10 Hz 0.02 in double amplitude, 10-500 Hz 0.1 G peak	Sinusoidal 5 Gs 50-2,000 Hz random 0.10 g^2/Hz

Figure 1 shows the functional block diagram of Digital's AXPvme 64 single module computer. In most applications, computers of this class are used to handle the real-time control of a complex system. The computer uses the DECchip 21068, capable of 40 SPECfp92, as the base processor. It provides standard I/O: small computer systems interface (SCSI-2), Ethernet, two serial ports, and a VME 64 backplane bus interface as well as three configurable timers. Further configuration of the module has been made possible through provisions for two mezzanine modules. The first contains dynamic random-access memory (DRAM) for program and data storage. The second interfaces to the PCI bus and provides the user the option of adding a custom interface to the module.

Figure 1 Block Diagram of Digital's AXPvme 64 Single Board Computer

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+----------------+
| DECCHIP 21068  |-----------------------------------
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```
| MICROPROCESSOR |         |            |
+----------------+         |            |
    |                +----------+ +=============+
    |                | OPTIONAL | | DRAM MEMORY |
    |                | 256-KB   | | MEZZANINE   |
    |                | CACHE    | | MODULE      |
    |                +----------+ | 8-256 MB    |
    |                             +=============+
    |
    |
    |     +---------------+
    |-----| ISA INTERFACE |----------------------------------------------
    |     +---------------+ |          |           |             |
    |                       |          |           |             |
    |                  +--------+ +--------+ +----------+ +-------------+
    |                  | FLASH  | | TWO    | | INTERVAL | | REAL-TIME   |
    |                  | MEMORY | | SERIAL | | AND      | | CLOCK AND   |
    |                  +--------+ | PORTS  | | WATCHDOG | | NONVOLATILE |
    |                             +--------+ | TIMERS   | | RAM         |
    |                                        +----------+ +-------------+
    |
    |
+--------------+
| VME 64       |
| INTERFACE TO |------------------------------------------------
| BACKPLANE    |      |               |                |
+--------------+      |               |                |
    |            +----------+ +---------------+ +===============+
    v            | OPTIONAL | | DECCHIP 21040 | | PCI MEZZANINE |
 VME 64 BUS      | SCSI-2   | | ETHERNET      | | MODULE        |
                 +----------+ | CONTROLLER    | +===============+
                              +---------------+
```

NOTE: FUNCTIONS DISPLAYED IN DOUBLE RULES ARE ON MEZZANINE MODULES.

CONDUCTION COOLING OF THE MODULE

The design of a commercial VME module must be modified to meet the needs of the military. Commercial VME modules (as shown in Figure 2) use both the front panel and the connector edges of the module for interconnect. Military systems preclude front (top) of module interfacing because one or more cables may be required to be moved for servicing. This increases maintenance time and the risk of interconnect damage by battlefield personnel.

[Figure 2 (Digital's AXPvme 64 Single Module Computer) is not available in ASCII format.]

Standard commercial modules are normally cooled by blowing air over the module. In a commercial installation, the air is drawn from an air-conditioned office enviroment and is therefore devoid of excess humidity or damaging chemicals. In the military environment, cooling air is expected to contain impurities that will have an adverse effect on the long-term, worldwide reliability of the module. The AXPvme 64 module is convection cooled.[7] One technique used to extend the environmental range of the E²COTS unit is conduction cooling. Conduction cooling eliminates the need to bring air, and with it potentially damaging contaminants, into the computer enclosure. Conformal coating, covering the board and components with a moisture-resistant material similar to plastic, further ensures no contact between the circuit card assembly and contaminants. It also provides protection from condensing humidity. For these reasons, the E²COTS module (shown in Figure 3) is configured to be conduction cooled.

[Figure 3 (Raytheon Model 910 VME Single Module Computer with Alpha AXP Microprocessor) is not available in ASCII format.]

The decomposition of the module assembly in Figure 4 shows a number of techniques used to reduce the thermal resistance between the individual components and the module/side rail interface. The first is the design of the circuit card on which all components are mounted. Figure 5 shows the layer stackup on the circuit board. Power, both 5.0 volt (V) and 3.3 V, and the associated ground planes provide a low-impedance power distribution path for the various components and allow the transmission of heat from the component to the frame and sidewalls. Figure 6 shows the thermal path from a typical surface to the sidewall/heat exchanger. The heat from the component is passed into the copper power planes for transmission to the sidewall/heat exchanger. Due to the low thermal resistance of copper plus the increased thickness of these planes, the thermal resistance is significantly reduced. In addition, the combined copper and polyimide layers provide a circuit board with the necessary strength to support the components without an additional backbone, although one is used for other purposes as noted in the next paragraph.

A second technique is the use of a combination thermal and support frame for the memory module and PCI adapter. The use of copper-loaded circuit cards extends to the PCI and memory modules. The thermal path for components mounted on these mezzanine modules is from the component through the circuit board embedded copper to the heat frame. From the heat frame, the thermal path is directly to the sidewall/heat exchangers. The mezzanine modules are designed to be screwed into the heat frame for both minimal thermal resistance and structural support against the shock, vibration, and "g" loading indicated in the technical specifications.

[Figure 4 (Exploded View of the AXPvme 64 Single Module Computer) is not available in ASCII format.]

[Figure 5 (Printed Circuit Board Layer Stackup) is not available in ASCII format.]

Finally, the two most active thermal radiators are the Alpha AXP processor and the 5.0-VDC to 3.3-VDC regulator. These components have been placed on opposite sides of the circuit board and directly adjacent to the wedgelocks to achieve a minimal thermal path. Because the DECchip 21068 processor is mounted cavity down in the ceramic pin grid array (PGA), its primary thermal path has been provided in the form of a cover plate.

Instead of cooling air passing over the surface of the module, the air is passed through a heat exchanger. Normally this is a brazed sidewall that provides both the outer structural shell of the computer and a duct, which has embedded heat fins for improved heat transfer. Individual modules are structurally connected to the sidewall/heat exchanger by wedgelocks that force a strong mechanical and a relatively low thermal interface.

[Figure 6 (Thermal Flow to the Heat Exchanger) is not available in ASCII format.]

The nominal temperature rise in the heat exchanger for an air transport rack (ATR) chassis and a total thermal load of approximately 300 watts (W) is 14 degrees Celsius.[5,8] Thus, with a nominal inlet air temperature of 25 degrees Celsius, the wedgelock interface of an E^2COTS module is at 39 degrees Celsius. For modules with total thermal dissipation of 20 to 25 W, a nominal 7 degrees Celsius rise is anticipated between the sidewall and the module, yielding a module temperature of 46 degrees Celsius. The heavy aluminum cover essentially maintains the base module temperature to the microprocessor's case. Measurements of the DECchip 21068 processor on the computer have shown an average power of 5.3 W. With a [Greek uppercase theta, subscript J-C] of 1.1 degrees Celsius per watt, the junction temperature is ~52 degrees Celsius. At the normal high end of the temperature range, 70 degrees Celsius inlet air, the chip temperature will increase to 97 degrees Celsius. It should be noted that the examples of temperature rise are nominal and must be computed accurately for each module type, total chassis dissipation, and the position of the module in the chassis.

As part of the thermal analysis of the design, a thermal map of the base module was developed as shown in Figure 7. The figure is an overlay of the thermal profile on the mechanical outline of the E^2COTS single module computer. Although planning for the dissipation of power from the microprocessor and the voltage regulator proved successful, the computer-simulated thermal plot indicated a high-temperature region at the top center of the module. This area corresponds to the location of the 256-kilobyte (kB) cache. The junction temperature of the cache static RAMs (SRAMs) could approach 76 degrees Celsius given an inlet air temperature of 25 degrees Celsius.

Although it might be anticipated that the microprocessor would be the board hot spot, the higher thermal resistance of the printed circuit board results in a potentially higher junction temperature of the lower dissipating SRAM devices. Operating at 70 degrees Celsius inlet air temperature, the resultant SRAM junction temperature would be 104 degrees Celsius. Although this high junction temperature is still acceptable, it is not desirable because it decreases product reliability. Thus, an appropriate modification in the thermal design will be made to the circuit board stackup before release to production.

DESIGN TRADE-OFFS

This section discusses design trade-offs for the single module computer based on space and thermal differences.

Space Trade-offs

The conduction-cooled module has significantly less surface area for mounting components than its convection-cooled counterpart. This is due to the use of a thermal frame that serves the dual purposes of conducting heat to the heat exchanger and structurally supporting the mezzanine modules to meet shock and vibration specifications. In addition to the component mounting constraints already identified, Digital's mezzanine module provides approximately 17 square inches per side for mounting components whereas the Raytheon conduction-cooled PCI mezzanine module provides approximately 13.8 square inches per side. An additional constraint was that the module layout, including pad dimensions, had to support a range of components from commercial to Class B-1 components. As a result, it was necessary to reduce the area required for components to fit on the board.

[Figure 7 (Thermal Map for the Circuit Card) is not available in ASCII format.]

The necessary reduction in component area was accomplished by the incorporation of a number of functions into a programmable gate array. The functions include

1. Fault logic

2. Interrupt multiplexer

3. All control/status registers (CSRs)

4. All address decoding

5. Interval timer glue logic

A second and more difficult selection was module I/O functionality. In Raytheon's planning stages, it was determined that each single module computer needed a SCSI bus port for interfacing with a disk. Ethernet support was important, but this interface seemed to be needed on every computer module only in the development phase of a new project. Since the development of a PCI adapter to verify the performance of the adapter interface was an obvious requirement, an adapter was developed for the single module computer that contained two interfaces: SCSI and Ethernet. An alternate objective of this adapter development was to test the capability of the PCI drive circuitry to support two interfaces on a single PCI adapter. Although exhaustive signal integrity testing has not been accomplished over the temperature range, the Ethernet portion of the adapter was used in initial debug of the module, including download of the system console. It has consistently performed without problem.

A final decision was the establishment of package lead geometries that could be supported by both commercial and military components. In many cases, both commercial and military components are available that meet the design criteria. In some cases, commercial components are supplied from one vendor and military components are procured from a second vendor. Unique cases required special solutions. The cache SRAMs are available in commercial-quality, J-leaded packages, but no military counterpart could be found. To resolve this problem, leadless chip carriers were procured from the military vendor and J-leads were welded on the basic components by a specialty supplier.

Thermal Trade-offs

The extremes of temperature over which an E^2COTS module must operate require careful consideration of the effects of thermal cycling on the component solder joint with the circuit board. Leadless devices such as chip carriers, capacitors, and resistors have advantages in the manufacture of circuit boards. However, leadless devices also require special care in the process whereby these components are attached to the circuit card to ensure high solder joint reliability during thermal cycling. For example, Figure 8 shows a crack in the solder joint of a chip capacitor that had undergone thermal cycling to determine equipment lifetime under the anticipated operating environment. Although these failures can be eliminated by special manufacturing processes for soldering leadless components, the use of leaded, active components has been made a requirement. This is consistent with the use of leadless SRAM with welded-on J-leads described in the previous section to help ensure reliability and long module life.

[Figure 8 (Failure Crack in the Solder Joint of a Chip Capacitor) is not available in ASCII format.]

A second aspect of the thermal environment range is the use of large PGA devices soldered into a circuit board of copper-polyimide. The Alpha AXP device has a diagonal dimension of ~2.96 inches. The expansion of the ceramic PGA between corner pins over a temperature range of -54 degrees Celsius to +70 degrees Celsius was studied using polyimide boards and ceramic PGAs fully inserted into the circuit board to the package standoffs. The PGAs did not contain semiconductor devices for reasons of cost.

Pin failures occurred at the corner positions of the PGA between 10 and 25 cycles. Additional tests were conducted with the PGA inserted so that the pin tips protruded slightly below the surface of the circuit board before soldering. Thus, the PGA was actually standing off the active component surface of the circuit board. In this configuration, the PGA withstood repeated thermal cycles because the pins had an opportunity to absorb the strain caused by the expansion mismatch. A negative element of this strategy is the inability to adequately inspect for solder bridging, which may occur in the area under the PGA and on the active component surface of the circuit board. It was concluded that repeated cycling of the module over even a moderate part of the temperature range would result in the deformation and eventual failure of the pins in the corners of the properly mounted PGA.

As an alternative to soldering the chip's PGA to the circuit board, a socket comprised of individual sleeves inserted into each hole was used successfully. This type of socketing provides sufficient contact flexibility to eliminate pin cracking of the PGA, yet provides a reliable contact during shock and vibration. With the use of a socket, the question of potential "walking out" of the socket by the PGA was raised. The primary thermal path for the Alpha AXP processor, as shown in Figure 9, provides the additional function of securing the device in the socket, thus eliminating the "walk out" problem.

PCI I/O

As previously noted, the standard PCI mezzanine module design for the single module computer has 19 percent less surface area than that of Digital's mezzanine module. In addition, all I/O from the PCI adapter must be routed through 50 pins on the P2 connector to the backplane to meet the criteria for the standard VME 64 bus. Figure 9 is a component side mechanical drawing of the single module computer.

[Figure 9 (Mechanical Drawing of the Top Surface of the Raytheon Single Module Computer) is not available in ASCII format.]

In many single module computer applications, the interface to analog, video, and fiber optics is required to control or sense synchronous signals and status data such as temperature and air velocity, and to handle video signals (RS-170, RS-343). For this reason the PCI mezzanine module has been designed to include an impedance-controlled I/O interface by way of a third connector mounted between P1 and P2. Such an interface was found to be superior to routing analog and video signals out the P2 connector and made practical the inclusion of fiber-optic interfaces directly to the PCI adapter.

PARTS SELECTION FOR THE E^{2}COTS COMPUTER

The characteristics of Raytheon's E^{2}COTS computer are detailed in the equipment performance specification. The mechanical features that make it compatible with military shock and vibration specifications are incorporated at the inception of the design. Once the mechanical features have been designed into the product, the additional cost at production is marginal. The primary factor affecting the cost is the quality of the semiconductor devices used for a given application. In previous DoD procurements, all parts were required to procure to MIL-STD-883 or MIL-STD-38510, the quality standards for all electronic components. Included in the requirements were hermetically sealed packages, semiconductor fabrication process validation, and in many cases extensive parts testing. All of these factors escalated cost substantially.

The E^{2}COTS system allows the temperature and reliability requirements of a given application to determine the quality of semiconductor components utilized. In fact, reliability, much more than temperature range, forces the incorporation of military specification Class B-1 components. Clearly, there are some component types used by the commercial vendors that are inherently not suitable for military application. A prime example is that of oscillators in which the frequency drift over temperature range in commercial components is excessive. In the larger view, specified reliability is the determining factor because the DoD relies on MIL-HDBK-217F for the calculation of component, subsystem, and system reliability. MIL-STD-217F is the hardware benchmark against which all designs are evaluated.[9] Table 2 compares two part types that are typical of the single module computer design. In both cases the reliability improvement achieved in theory by using military-quality parts is a factor of five.

Table 2 A Comparison of Reliability for Commercial-quality and Military-quality Parts

Device Type	Reliability Calculated for Class B-1 Parts at 25°C for a Transport Aircraft Environment	Reliability Calculated for Commercial Parts at 25°C for a Transport Aircraft Environment	Ratio of Calculated Military-Quality-Part Failure Rate to Commercial-Quality-Part Failure Rate
32K X 8	0.137 failures	0.686 failures	5.007

SRAMs for the cache	per million hours	per million hours	
VIC-64 VME interface	0.613 failures per million hours	3.066 failures per million hours	5.001

Since many of the passive components (e.g., resistors and capacitors) are normally procured to military specification, the ratio of calculated reliability for a full military-specification-compliant single module computer to a commercial single module computer is approximately 4.99. For a calculated increase in reliability of approximately 5.0, however, the full military-compliant module, subsystem, or system may cost 10 times that of the commercial system. This is an unacceptable cost-performance trade-off in today's defense environment.

Using an E^{2}COTS computer, parts selection is conducted to meet the required mean time between failures (MTBFs) and temperature range. The "mil-spec" semiconductor parts cost is reduced to only those parts necessary for the application. The robust structure of the module is standard, thus providing protection against shock, vibration, and acceleration.

BUILT-IN TEST

Digital's built-in test (BIT), boot, and console code are used on an almost "as is" basis. The diagnostics provided on previous processors, such as Digital's VAX 6200 and VAX 6600 systems and the DEC 3000 Model 500 AXP workstation, have proven to be very robust. The exception is the incorporation of a system-level BIT strategy that is built upon the existing BIT design.

The BIT from each system component must be capable of being integrated into the overall system environment so that system-level test results may be easily obtained and the failed component rapidly replaced. To meet this requirement, Raytheon has extended the access to the BIT information at the system level by making test results available on the VME 64 bus. This is accomplished by using the VME interprocessor communication registers (ICRs) as mailboxes that may be accessed by any bus user. Upon initialization, the ICRs are set to zero. At the end of the BIT, the results are written to the ICRs. Basically, there are three possible results available in the ICRs after BIT:

1. The ICRs contain zero, in which case the module has failed to execute the complete BIT and is therefore FAILED.

2. The ICRs contain the PASSED message.

3. The ICRs contain the FAILED message and identify the test(s) that were failed.

Supervisory processors may poll the single module computers and determine their status.

PLANNED UPGRADES TO THE MODEL 910

The first deliveries of the Raytheon Model 910 utilize the 66-megahertz (66-MHz) DECchip 21068 processor. Since capabilities drive requirements, the availability of the DECchip 21066 necessitates the addition of a 160-MHz version of the Model 910. Key issues in the incorporation of the DECchip 21066 processor into the single module computer structure are the thermal dissipation of the design and the limited number of power and ground pins as provided under the VME bus specification.

Power dissipation of 23 W occurs on a system powered by the DECchip 21068 and having 32 megabytes (MB) of memory, a SCSI bus, and Ethernet running the DEC OSF/1 AXP operating system and a graphics demonstration on an X window terminal. When the same unit was exercised with the DECchip 21066, the power dissipation increased to 40 W, underscoring the need for more power/ground pins and additional thermal paths to the sidewall/heat exchanger. The memory capacity will also be expanded in 1994 to a maximum of 256 MB in increments of 128 MB.

Completion of these design upgrades is being conducted during 1994.

ACKNOWLEDGMENT

I would like to acknowledge the efforts of the Raytheon design team of Ted Rogers, project leader; Stewart Berke and Mark Lewin, electrical design; Jim Lanzafane, mechanical and thermal design; Ted King, firmware; and Dave Golden, operating system integration. The Raytheon team would also like to express their appreciation to the many fine Digital people who have supported the project and especially to Don DeRome, our Digital point of contact.

REFERENCES

1. MIL-E-5400T, General Specification for Electronic Equipment, Aerospace (May 1990).

2. Digital Standard 102-1 Environmental Standard for Computers and Peripherals--Temperature, Humidity, and Altitude Test Requirements (Maynard, MA: Digital Equipment Corporation, Order No. EL-00102-01, Revision F, September 1992).

3. Digital Standard 102-2 Environmental Standard for Computers and Peripherals--Mechanical Shock and Vibration Test Requirements (Maynard, MA: Digital Equipment Corporation, Order No. EL-00102-02, Revision K, November 1992).

4. Alpha AXPvme 64 Engineering Hardware Specification, Version 0.9 (Maynard, MA: Digital Equipment Corporation, December 1992).

5. AVSMC Development Specification, Spec. No. CRG605203, Revision 1.2 (Lexington, MA: Raytheon Company, Computer Products Directorate, August 1993).

6. PCI Local Bus Specification, Revision 2.0 (Hillsboro, OR: PCI Special Interest Group, April 1993).

7. MEDULLA Engineering Hardware Specification (Maynard, MA: Digital Equipment Corporation, March 1993).

8. MIL-C-172C, Cases; Bases, Mounting; and Mounts, Vibration (for use with Electronic Equipment on Aircraft), Amendment 5 (February 1977).

9. MIL-HDBK-217F, Reliability Prediction of Electronic Equipment (July 1992).

TRADEMARKS

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