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Erasable Disk Mass Memory, STEP Mission 3 Integration and Flight Support; Post Flight Performance Report

By Scott Bussinger

Spectrum Astro Inc.
1440 N Fiesta Boulevard
Gilbert AZ 85233

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Final Report

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AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
3550 Aberdeen Ave SE
AIR FORCE MATERIEL COMMAND
KIRTLAND AIR FORCE BASE, NM 87117-5776

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This report has been approved for publication.

Joseph Chavez

JOSEPH CHAVEZ
Project Manager

FOR THE COMMANDER

Kenneth G. Merkel

KENNETH G. MERKEL II, Maj, USAF
Deputy Chief, Space Electronics and Protection Branch

CHRISTINE M. ANDERSON, SES
Director, Space Vehicles

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Scott D. Bussinger

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13. ABSTRACT *(Maximum 200 words)*

This final report deals primarily with the performance of the Erasable Disk Mass Memory (EDMM) component that was developed for the Defense Advanced Research Projects Agency (DARPA). The program objective was to determine feasibility and, if possible, develop a space-qualified mass data storage system using commercial magnetic disk drive technology. After determining the concept feasibility, two units were built. One flight unit was scheduled to fly on Step Mission 3 in order to gather space flight data on the unit/design. The failure of the STEP-3 mission prevented detailed study of the unit's performance on orbit. A similar unit was flown on the MSTI-3 spacecraft allowing a more limited evaluation of the on-orbit performance. There is a brief description of the entire program and its progression as well as descriptions of the design goals and achievements. The report also describes the on-orbit performance of the design as flown on the MISTI-3 spacecraft .

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TABLE OF CONTENTS

PAGE

LIST OF FIGURES

LIST OF TABLES

1. EXECTUTIVE SUMMARY (INTRODUCTION)

This final report documents work and activities performed under Contract F29601-90-C-0009 during the period 30 April 1993 through 30 January 1997 and deals primarily with the performance of the Erasable Disk Mass Memory (EDMM) component that was developed for the Defense Advanced Research Projects Agency (DARPA).

The EDMM project evolved into a three phase effort with phase one involving a study on the feasibility of using magnetic disk drive technology in a spaceborne environment by assessing the ability to package commercial disk drives in a space-qualified enclosure and take advantage of technology developed for the commercial computer industry by using it in spacecraft memory applications. Phase 2 consisted of the actual hardware development activity. This activity included review and selection of an appropriate commercially available disk drive unit, bounding expected environmental conditions and development of techniques or methods to mitigate their effect on the disk drives, and analyses of the selected techniques to ensure their successful application. With these tasks completed the actual prototyping, development, and qualification testing of two complete flight units was performed. The third phase of this project consisted of the actual integration of one of the flight units with the Space Test Experiment Platform (STEP) Mission 3 spacecraft, support for pre-launch and launch-operations, and actual on-orbit performance evaluation of the flight unit for one year. Phase 3 also included the performance of a leak test and EMI/EMC test in accordance with MIL-STD-461 and MIL-STD-462 as currently revised.

As an experiment on the STEP-3 spacecraft, the EDMM characteristics and performance could be closely watched and evaluated under actual low earth orbit flight conditions with specific tests and testing scenarios designed for this purpose. Successful completion of the STEP-3 mission would demonstrate the feasibility of using commercial magnetic-disk technology in a space environment.

The activities of phase three through integration and launch was supported as planned. Unfortunately, when the STEP-3 vehicle was launched in June of 1995, a boost vehicle anomaly forced an abort and destruction of the STEP-3 spacecraft pre-maturely ending the mission. This prevented the final portion of the third phase, on-orbit performance evaluation, from being completed. As a compromise, it was known that Spectrum Astro, Inc. would be flying another EDMM unit on the Miniature Sensor Technology Insertion (MSTI) Mission-3 spacecraft as the primary mass data storage system. The MSTI-3 was scheduled to launch in November of 1995, however, due to the STEP boost vehicle mishap, a complete review of the booster design was ordered by the governing agencies. This led to the delay of the MSTI-3 launch until May of 1996. This launch was successful and the EDMM has been operating for approximately eight months (237 days) as of this writing. The MSTI-3 EDMM is not an experiment, but a fully operational subsystem of the MSTI-3 spacecraft. As such, no specialized tests or evaluation periods were ever intended to be run on MSTI-3. Therefore the post flight evaluation data is limited in scope due to the difference in missions between MSTI-3 and STEP-3.

2. HARDWARE DESCRIPTION

2.1 Design Specifications

The EDMM design specifications were originally determined during the Phase One study portion of the program and are reflected in Table 2-1 below.

Table 2-1. Design Specifications of the EDMM

	Goal	Achievement	Compliance	Notes
Data Modes				
TT&C Mode	2Kbps - 1024Kbps	2Kbps -1024Kbps	Complies	Requires Appropriate Host Adapter
Mission Mode	3Mbps - 274Mbps	3Mbps - 12.8Mbps	Non-Compl.	State of the Art Technology Limitation
Physical				
Storage Capacity	1.0 Gbyte	1.08 Gbyte	Complies	
Volume	1728 cu in.	400 cu in.	Complies	
Weight	15lb/ Gbyte	10lb/Gbyte	Complies	
Momentum	Zero Net Momentum	<.002m-N	Complies	Essentially zero
Power(28VDC)	< 25 Watts	18.3 Watts	Complies	No spin-up requirement. No heaters
EMI	MIL-STD-461	Passes 5 of 9	Non-Compl.	Refer to EMC Final Report
Environments				
Linear Acceleration				
Operating	0.5 G	Analysis	Complies	
Non-Oper.	10.0 G	Analysis	Complies	
Random Vibration	12 Grms	15 Grms	Complies	
Pyroshock	1000 G 500 -1000Hz	>100 G 100Hz - 500Hz	Non-Compl.	Test SRS did not reach 1000Hz
Temperature	-30°C to +70°C	-25°C to +55°C	Non-Compl.	Packaging Design Limitation
Vacuum	10e-5 Torr	Space Vacuum	Complies	
Radiation				
TID	100,000 Rads (Si)	25,000 Rads (Si)	Non-Compl.	No selective parts hardening done
Latchup	Immune	Mitigation Required	Non-Compl.	No selective parts hardening done
SEU	1.0 x 10e10 Err/Bit/Day	1.35 x 10e15 Err/Bit/Day	Complies	Empirical Data

2.2 Design Physical Description

The EDMM is comprised of two Conner Peripherals CP-3540 545 Mbyte fifth generation magnetic disk drives mounted in counter-rotating orientations so as to be momentum neutral. The drives are enclosed with their power supplies and a latchup mitigation circuit in and aluminum clamshell container with a hermetic O-ring seal. See Figure 2-1. The EDMM uses 28±6 VDC nominal power for its two internal thermostatically controlled 15W heaters and to power the drives. The data and control interface is based on the open standard SCSI computer bus (ANSI - X3.131-1986) with each drive ganged on a single SCSI bus with different Logical Unit Numbers. The EDMM provides telemetry for temperatures and power relay status and has an internal pressure transducer. All components except the disk drives are of high reliability MIL-STD-883C Class B parts.

2.3 MSTI EDMM Design Differences

The MSTI EDMM's were practically identical to the original EDMM design described above. The only change to the MSTI EDMM design was in the SCSI Interface to the disk drives. In this design each drive was interfaced to a separate SCSI port. This allowed the data rate for this EDMM to be doubled to 25.6Mbps in order to meet the MSTI mission mode requirements.

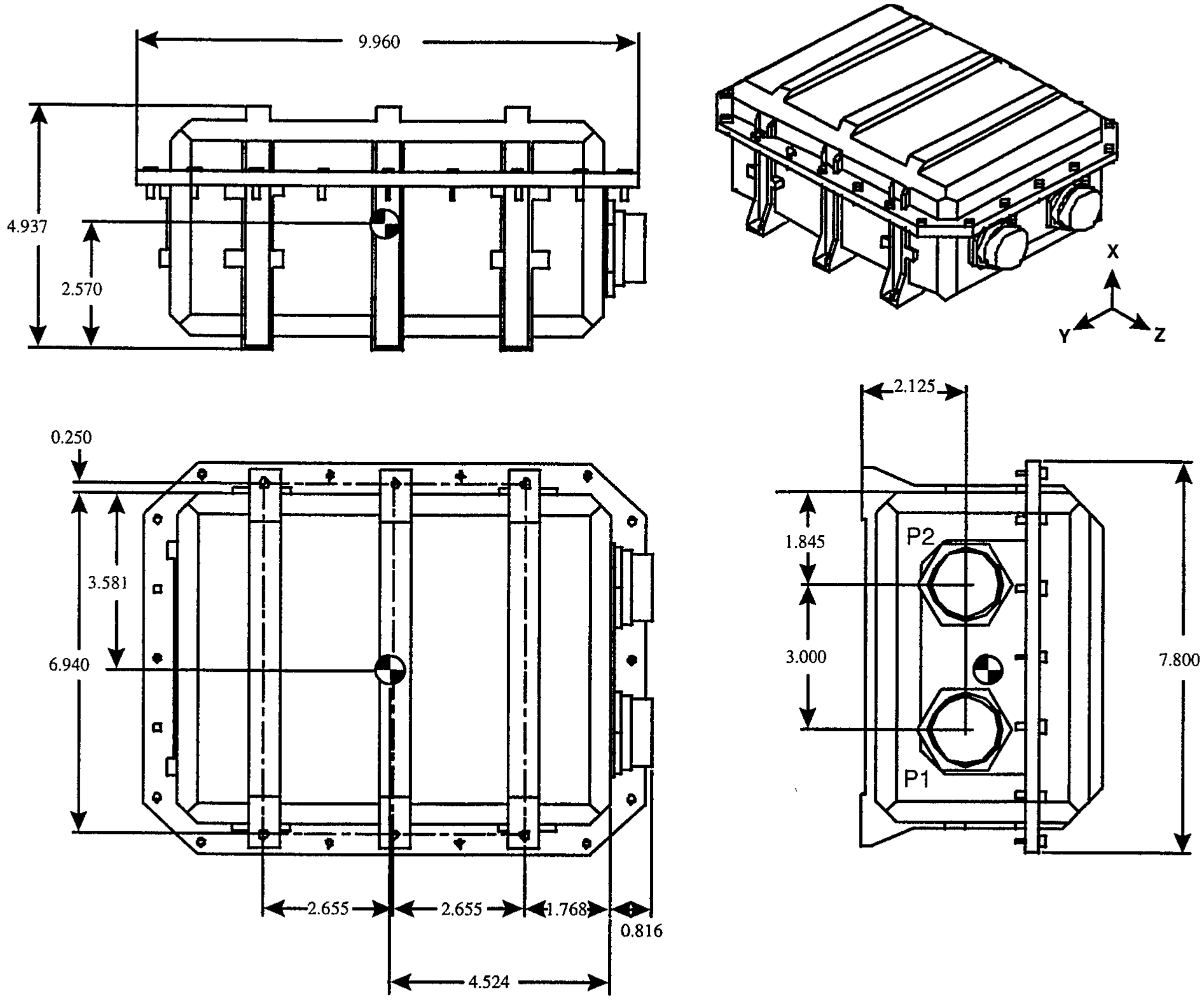

Figure 2-1. Mechanical Dimensioning of the EDMM Unit

3. PERFORMANCE CHARACTERISTICS

There are several performance characteristics associated with the operation of magnetic disks as a spacecraft mass storage system. The primary characteristics are data throughput and data integrity. However, for long term missions, issues of life and power cycling and radiation effects can become more and more important. Also, as an indication of the robustness of the enclosure design and thermal management system, the temperature, pressure, and EMI/EMC characteristics can be useful and may indicate the need for improvements or changes required to meet future missions. This section will detail the intended performance evaluation planned for the STEP-3 mission and the actual measured data obtained by the MSTI-3 mission where available.

3.1 STEP-3 Mission Performance Evaluation Intent

The following paragraphs describe the various parametric characteristics and planned measurements for the STEP-3 mission.

3.1.1 Read/Write Performance

The Conner drives use thin film heads to change magnetic domains and store binary data on the disk platter media. The STEP-3 mission intended to write a predetermined bit-sequences to the disks in sequential locations and then read these bit-sequences back ten times to get some idea of the disk head read/write performance over time and at different locations on the media platters. The STEP-3 SCSI software interface would detect discrepancies and log these items on a daily basis for easy evaluation and trending of performance.

3.1.2 Data Fidelity/Throughput

The reliability of a mass storage system is dependent upon its data error rates. These Conner drives use an 88-bit Reed-Solomon Error Correction Coding (ECC) that can correct errors up to 11-bits long on-the-fly and detect errors up to 51-bits. Newer technology drives use 243-bit ECC that correct and detect errors over 75-bits long. In the STEP-3 mission, the diagnostic software was able to detect errors in the predetermined sequence and log those errors if they should get past the drives very capable ECC circuitry. With such a system, it is relatively easy to calculate the error rates over a period of time using several sets of data.

3.1.3 Power Cycles

These particular Conner drives are specified to 10,000 total power (ON/OFF) cycles. Many of the newer disk drives specify unlimited cycles or have such a high number it outlasts the specified drive lifetime. The intent on the STEP-3 mission was to run the EDMM continuously after LEO and only power cycle as necessary to reset hardware if the SCSI bus would hang. This would maximize and data for power-on hours and life as opposed to power cycles.

3.1.4 Operating Life

The total number of powered-on hours is a primary factor in determining the useful operating life of the EDMM. The STEP-3 operational scenario was designed to maximize the number of power-on hours experienced by the EDMM by running it continuously or as long as the spacecraft energy balance would allow.

3.1.5 Ionizing Radiation Effects

As for all equipment designed for use in the space environment, consideration of the effects of ionizing radiation on the EDMM is of particular importance for the perpetuation of the use of this technology in future spacecraft. The EDMM is designed to withstand at least 25 Krads TID without significant performance degradation. The Single-Event-Upset (SEU) errors are handled by the powerful Error-Correction-Codes used within the drives data path. The EDMM is also equipped with a latch-up detection and mitigation circuit that will automatically power cycle the drives when an over-current latch-up event is detected.

3.1.6 Thermal Management

The EDMM is equipped with passive and active thermal management devices to help maintain the disk drives within their specified operating temperatures of 0 C to +55 C. The EDMM is equipped with two strip heaters to maintain the EDMM temperature above the 0 C ice-point and uses thermal strapping to transfer heat from the disk drive housing to the EDMM enclosure to keep the EDMM below +55 C. Both items can be sized within certain limitations to meet the expected temperature extremes of any unique mission. The STEP-3 EDMM was placed inside the spacecraft enclosure which limited its heat radiation capability.

3.1.7 Enclosure Pressure Seal

The EDMM is designed to maintain atmospheric pressure within its enclosure to provide for proper functioning of the drives. The design life of the seal is approximately five years. The pressure seal is one of the items that has been scrutinized the most over the life of this program and that of MSTI-3. The original flight units were sealed in just a standard open air environment with no means of determining leaks except for gross changes to the pressure transducer readings. As a result, Spectrum was directed to perform a long term leak test of the flight back-up unit in order to determine if the seal design was robust. A thirty-day test under 300,000 ft vacuum showed no gross variation in pressure except for temperature effects. Due to an engineering change during the STEP-3 integration phase the flight EDMM was opened and re-sealed with a small quantity of helium and then leak tested using a mass spectrometer to determine the seal leak rate. Testing indicated the seal life at 20+ years. Additionally, the EDMMs from both MSTI-2 and MSTI-3 were tested in a similar manner.

3.1.8 EMI/EMC Performance

The STEP-3 Spacecraft Mission required all experiment payloads to comply with the appropriate requirements of MIL-STD-461. To meet this requirement, the EDMM was tested per MIL-STD-462 to the levels of MIL-STD-461 as a part of the Phase Three activities. The results of this test were that the EDMM passed: CE01, CS01, CS02, RE01, and RS03. The EDMM was not compliant with the remaining requirements: CE03, CE07, CS06, RE02, and RS02. None of these noncompliance's were determined to prevent the EDMM from operating properly on the STEP-3 spacecraft. They were also determined to not be capable of degrading other spacecraft equipment operation. As a result the program sponsor requested a waiver for the STEP-3 mission and this was granted. The EDMM was integrated with the STEP-3 spacecraft and the other payload experiments and went through rigorous levels of testing through all environments without having any detectable affect on the operations of the other spacecraft equipment.

3.2 MSTI-3 Mission Performance Intent

The following paragraphs describe the measurements and data actually taken during the MSTI-3 mission.

3.2.1 Read/Write Performance

The precise testing regime and bit-sequence detail intended for the STEP-3 mission was not achievable with the MSTI-3 EDMM due to the differences in mission requirements and the fact that the MSTI-3 EDMM was an operational and integral component of the spacecraft. There was no diagnostic software written to log disk location defects or to detect bit sequence errors since this was not operationally required. The random nature of the data prevents any structured measurements of the number of reads and writes at particular locations. Therefore , totals for any particular physical location cannot be estimated.

Overall, the MSTI-3 has performed almost 3000 read operations including 1740 payload data dumps and 1186 Stored State of Health (SSOH) dumps as well as over 620 payload write operations of various lengths (usually involving hundreds of Mbytes of data) and has stored and downloaded more than 575,000 images for payload calibration and science data. The amount of data archived and downloaded including calibration, science, and SSOH telemetry is over half a Terabyte. Out of all of this data, over 112 Gigabytes of post processed science data has been gathered for current and future science evaluation.

3.2.2 Data Fidelity/Throughput

Once again, due to the operational nature of the MSTI-3 mission, it was not equipped with any diagnostic software to detect bit errors beyond the capability of the drive ECC circuitry. Also, the data path and its randomness makes it almost impossible to determine the source of a data error at the ground site so no reliable method exists to determine if the EDMM is a major source of errors.

3.2.3 Power Cycles

Again, the situation is different for MSTI-3 as its operational realities required more power cycling than the STEP-3 operations. Even so, the MSTI-3 EDMM will not even approach the specified number of cycles during its mission lifetime. As of this writing the MSTI-3 EDMM has seen over 1300 power cycles on orbit. Trending of the telemetry data indicates that the EDMM power supplies and drives have not been affected by the power cycling. Power consumption of the EDMM could not be directly measured during the mission since the EDMM shared a power bus with many other dynamically operating components.

3.2.4 Operating Life

The MSTI-3 operations were intended to operate the EDMM continuously like the STEP-3 mission. However, due to a power availability problem during eclipse season the MSTI-3 EDMM, has been turned off to save power and cycled for each payload operation instead of running continuously. This mode is similar to that of the MSTI-2 EDMM that was launched in May of 1994. So far the MSTI-3 EDMM has had approximately 4,000 total power-on hours.

3.2.5 Ionizing Radiation Effects

The STEP-3 orbit, at 450Km circular altitude with 70° inclination, was different from the MSTI-3 orbit, at 425Km circular altitude with 97° inclination. Additionally, the MSTI-3 EDMM is more exposed than in STEP-3 configuration , which significantly increases the MSTI-3 total dose exposure as shown in Table 3-1. The Table assumes a May 1996 Launch(Solar Min) into the respective orbits : Orbit 1) 450Km; 70° and Orbit 2) 425Km; 97° and takes into account the shielding provided by the spacecraft as well as the EDMM enclosure shell giving the dose seen by the EDMM drives and electronics piece parts. Calculations are provided by the SE Analyst™ software package.

Table 3-1. Radiation Dose Comparison

	Proton Dose (rads/day)	Electron Dose (rads/day)	Total Dose (rads/day)	Total Dose (rads/year)
Orbit 1	0.2165	0.3715	0.588	214.767
Orbit 2	0.1662	1.023	1.1892	434.3553

The MSTI-3 EDMM has experienced approximately 30 bus lockup events so far. Seven of those events have been unexplainable. The operational characteristics of the MSTI-3 EDMM require power cycling of the unit which resets the latch-up detect telemetry point so it is very difficult to determine if latch-up events have occurred while out of contact with the ground. Many of these events were shown to be caused by a hardware/software interface problem with the SCSI interface and software drivers. The others must be assumed to be caused by external phenomenon. To this point, no observable effects of radiation exposure can be seen to have affected the overall performance or functions of the MSTI-3 EDMM. The estimated ionizing total dose for the MSTI-3 EDMM so far is 282 rads.

3.2.6 Thermal Management

The STEP-3 EDMM was configured to be inside the spacecraft enclosure while the MSTI-3 EDMM is bolted to the external skin and allowed to radiate to space. The orbital average temperatures for the MSTI-3 EDMM have been well below the specified operating limits of the disk drives. The EDMM enclosure temperature extremes so far have been measured at +28 C and -0.9°C. The average case temperature of the EDMM has been 11 ±1.5°C. The disk drives inside the unit have seen a maximum temperature of +41°C and a minimum of 3.5°C. There have been no adverse effects attributable to the thermal environment.

3.2.7 Enclosure Pressure Seal

For the MSTI-3 unit, the exact temperature, atmospheric pressure, and transducer voltage data was taken at the time of closure. After all environment testing was completed, the unit was stabilized at the temperature at the time of seal and the transducer voltages were compared to determine if any detectable difference in pressure had occurred. No detectable change in pressure was observed insuring that the trace helium content had not leaked out and thus verifying the validity of the mass spectrometer readings and seal life projections.

The on-orbit performance of the pressure seal shows no detectable gross leaks with the internal pressure of the MSTI-3 EDMM maintaining at 14.3 psi. This reading is in accordance with the temperature effects of a sealed enclosure and has not changed since launch of the MSTI-3 spacecraft. The variation in internal pressure so far has been measured at 12.432 psi to 15.165 psi. These readings have occurred at the temperature extremes described in the above section.

3.2.8 EMI/EMC Performance

The MSTI-3 Spacecraft Mission also required compliance with the MIL-STD-461 requirements. No formal EMI/EMC testing was ever performed at the Integrated Spacecraft level. All components and assemblies were expected to comply. The MSTI-3 EDMM was integrated with the other spacecraft components and underwent rigorous functional testing for several months with no detectable effects on the operations of the spacecraft equipment.

4. OBSERVATIONS AND RECOMMENDATIONS

The STEP-3 launch abort and destruction prevented the long term evaluation and analysis of the EDMM performance and characteristics. However Spectrum Astro, and the MSTI-3 program office were so confident in the theory and design as well as the qualification testing of the EDMM units that additional units were fabricated and eventually flown as the primary data storage subsystem for two MSTI missions. Operational performance was laudatory in both cases and hundreds of Gigabytes of stored payload data was archived for analysis. Even with these facts at hand, there is still much industry skepticism or resistance to using commercial quality hardware in spaceflight missions.

Spectrum Astro has been contacted by several potential users about the use of this technology. In addition, Spectrum Astro has also proposed the use of this technology on various spacecraft RFP responses but it seems, in each case, the potential user is not willing to "compromise" one or more of their requirements in order to enjoy the measurable cost savings this approach usually allows. Many potential users take issue with using non-hardened and commercial components. Others question the long-term reliability of the EDMM. The data throughput rates are not fast enough to meet some user requirements. Still others are concerned about the problem of configuration management with the disk technology changing so fast. Perhaps as the industry changes and more and more missions and programs take on the same costs, requirements and objectives as the MSTI program this resistance will fade. However, the concept and design of the EDMM is also flexible and can be adjusted within certain constraints to more closely approach mission requirements. Even with this flexibility, there are certain factors that will remain problematical. These issues include the rapidly changing technology and design curve that the magnetic disk industry is pursuing due to its competitive environment. The other is the issue of parts quality and suitability to the space radiation environment.

4.1 Disk Drive Industry Technology Curve

At the time of the design phase of the program, beginning in mid 1992, the Conner Peripherals CP-3540 was a state of the art, fifth generation, high-performance, 3.5 inch form factor, magnetic disk drive. Its maximum "Sustained Data Transfer Rate" was 12.5 Mbps and it had a total data capacity of 545 million bytes, weighed approximately 1.0 kilogram, and dissipated 10W nominally. By the time an actual EDMM had flown in orbit, the drives were at their ninth and tenth generations with performance characteristics at 50-80 Mbps sustained throughput, 2.0 Gigabytes storage, weighing 0.5 kilogram and using the same power. At the time of this writing, the industry has settled to about the same power and weight numbers but has increased throughput to 100-140 Mbps and capacities up to 10 Gigabytes in the 3.5-inch form factor.

The driving force behind this incredible evolution and performance increase is the cut-throat competition created by the personal computer and business based network server markets. The average lifetime of a particular design has shrunk from 12-18 months in 1992 to 6-9 months currently. This has come about through the use and exploitation of primarily two recently developed technologies. One, Partial-Response Maximum-Likelihood (PRML) is a digital signal processing based method that has replaced the older analog read channel technology. The other, Magneto-Resistive (MR) head technology, is a materials based improvement first discovered and later developed by IBM as a replacement for older thick-film and Metal-in-Gap (MIG) heads. These two technologies plus continual research and development in magnetic media ferrite materials and the ever increasing integration of electronic circuitry on the PWB have been the primary reasons behind such rapid design obsolescence.

This fact of design obsolescence has been an issue with potential users and is quite hard to overcome since a particular drive design can become obsolete and drop from production before an EDMM gets integrated with the spacecraft not to mention being launched. Therefore users must be prepared to cope with changing parts and parameters or be prepared to lifetime buy quantities of drives to assure a stable drive supply for the anticipated product lifetime. This circumstance of design obsolescence will play a major part in the production of any new EDMM design as there will be a need to evaluate the introduction of these new technologies for their appropriateness for the space environment.

The use of newer disk drives in the EDMM design will entail a new evaluation of both digital read channel (PRML) components and Magneto-Resistive materials as well as a general review of all electronic components in the disk design. The review of all disk components should be mitigated somewhat by the fact that integration of circuitry has substantially reduced the number of disk components and substantially improved disk reliability as a result. Current industry trends are toward having two to three major Application Specific Integrated Circuit (ASIC) chips supported by a few passive components and power FETS that control the spindle motor. As this trend unfolds it may make disk technology more attractive to the space user by making it easier to evaluate or to modify if necessary.

4.2 Radiation Hardening

Other than the disk drive all components in the EDMM design can be obtained in radiation tolerant forms. As for the drive itself, the only radiation susceptible components are the electronic components primarily found on the drive's PWB. In addition the drive housing and media platters provide a good deal of shielding for the susceptible components. As an added protection Spectrum adds a latch-up detection circuit to power cycle the unit and prevent destructive latch-up from damaging susceptible components. However, there are certain users that may require a more straightforward solution that does not require exotic or extraneous circuitry and that does not cycle power and interrupt data storage. A solution does exist but at a cost.

As explained previously, most of the PWB components are trending toward total integration due to cost, size and weight pressures generated by industry competition to sell more drives. For those potential users who desire a level of radiation hardness greater than the inherent tolerance of the disk drive itself, this development portends the possibility of hardening the disk drive further by fabricating custom ASICs in a hardened process and replacing the softer components. Such a change would most definitely add to the cost of development but may trade well given the right circumstances and mission requirements.

A second alternative could be to fly redundant units. The tremendous storage density of EDMM approaches, and in some cases exceeds, that of solid state memory and allows some amount of flexibility in providing redundant capability. By flying more than one unit, a backup could take over in the event of a failure to the primary unit. The EDMM data/control bus architecture allows for multiple units on the bus and for multiple busses thus allowing flexibility in the redundancy architecture.

4.3 Competitiveness

As shown by their performance on the MSTI spacecraft, the EDMM has demonstrated the capability of magnetic disk storage devices to provide reliable and cost effective mass storage capability to spacecraft. The primary competition to magnetic disk storage is solid state memory. Though the EDMM will never replace the need for Solid State Recorders (SSR), it can match and/or exceed most of the desirable characteristics of SSRs including mass, power, storage density, and with comparable reliability with lower costs due to the use of commercial drive technology.

Currently the densest solid state memory is flash EEPROM which provides non-volatile memory but has a finite and limited number of write cycles as opposed to the magnetic disks which have unlimited read/write capability. As a consequence, most SSR need to use DRAM memories to allow unlimited read/write cycles. DRAM's are generally four to eight times less dense than flash EEPROM and are volatile so they must be powered at all times to hold their contents. The one area where solid state memories still out-perform disks is raw data throughput. They still have data rates an order of magnitude greater than disk drives and, though disks are improving continuously, there will always be the physical limitations due to the rotating media platters. However, when using most standardized interfaces, the solid state memories are usually limited to the bus bandwidth available which in most cases is well within the capabilities of most newer disk drive designs.

As a comparison, a mass storage device industry leader is marketing a VME 6U form factor board with 480 Mbytes total storage using stacked DRAM die technology. A similar VME 6U design by Spectrum Astro, would use small form factor magnetic disks to provide 4-8 Gigabytes of total storage or less storage (1 Gigabyte) but with 4:1 redundancy.

5. FUTURE PLANS

As a result of the EDMM performance on the MSTI program, Spectrum has continued to propose its use or the use of magnetic disk technology on various programs and projects. The EDMM was proposed on Spectrum Astro's version of the SSTI-Lewis spacecraft. In addition, the use of magnetic disks in an EDMM like form were proposed for use on the Space Station, the Shuttle Furnace Facility, and as mass storage for several Shuttle payloads. Up-coming missions of Phillips Laboratory programs such as MSTI, Clementine, and MightySat may see the use of EDMMs or magnetic disk technology as mass storage subsystems.

5.1 Trends in Architecture

5.1.1 VME Form Factor

Spectrum Astro's seven years of previous experience with the commercial drive industry, magnetic disk technology, and modular electronics systems has led to the concept of a modular magnetic disk based mass memory to compliment our flight proven modular avionics bays used on the MSTI program. This concept continues the movement toward absorbing most if not all "black box" functions and interfaces into a central modular electronics bay.

The concept involves the use of four to six 1.8 inch or 2.5 inch high capacity (420 MBytes to 2.0 GBytes) disk drives along with radiation hardened host interface controller components packaged onto a VME 6U form factor board. This provides a standard and easily maintainable mechanical and electrical interface (reference Figure 5-1). The design achieves a minimum storage capacity of 1.68 to 8.0 GBytes and throughput ranging from 5 to 20 MBytes/sec depending upon the interface and redundancy requirements.

Figure 5-1. Spectrum Astro's Concept for a Modular Magnetic Disk Mass Memory (VME 6U Form Factor)

The disk array interface controller can be designed for maximum throughput and storage with no memory redundancy by implementing a round robin interface controller. In addition, an architecture using a Redundant Array of Independent Disks (RAID) could be implemented for improved data redundancy at the cost of some throughput and storage capacity.

The primary challenge to fabricating this modular mass memory is packaging the disk drives for a space environment. The technology exists for completing this task. The same packaging technology that is used to produce Hybrid's and certain hermetic Multi-chip Modules (MCMs) can be applied to this problem. An example of this can be seen in Figure 5-2. Spectrum's relationship with White Technology, a local MCM and Hybrid packaging company, can be used in procuring such a package.

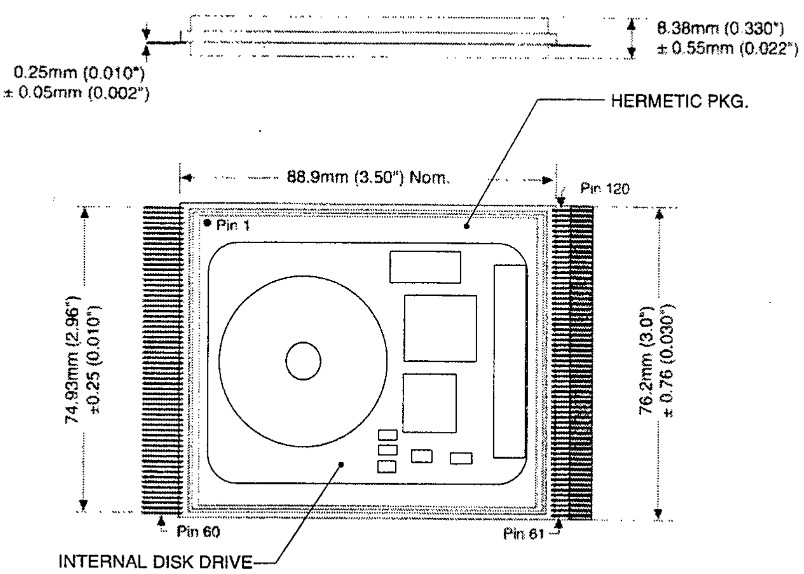

Figure 5-2. MCM-Type Packaging Concept for a Hermetic Magnetic Disk (White Technology Standard Package 14B92)

5.1.2 Box Level

For those missions that require unusually large amounts of storage, such as LightSAR, the use of dozens of disks in a RAID architecture is comparable storage-wise to the current use of tape recorders but provides much greater reliability. The concept is the same as that of the EDMM but on a larger scale.

6. CONCLUSIONS

Although the STEP-3 mission, including the EDMM experiment, was unable to complete its detailed study of the EDMM performance, the EDMM program was a success for several reasons. First, the use of high reliability commercial technology and open industry standards was shown to be easily integrated into the design of two separate spacecraft programs. Secondly, the excellent performance of the EDMM on both MSTI missions demonstrates that the feasibility of using this technology in a space environment is valid and can lower overall system costs and provide remarkable performance if traditional ways of building spacecraft can accommodate this technology. In the new post cold war environment and under the Defense Department directives for use of COTS components and standards as a means to reduce cost and increase efficiency, this program's legacy should only increase in value to the government, the space industry, and science community.

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