

SPACECRAFT ERASABLE DISK MASS MEMORY (EDMM)

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ABSTRACT

A low cost alternative to tape recorders has been developed by Spectrum Astro, Inc. in an experimental program under the sponsorship of the USAF Phillips Laboratory and the ARPA Advanced Space Technology Program. The erasable disk magnetic memory (EDMM) data storage system has been developed and has completed environmental qualification for space flight. A hermetically sealed and vibration isolated enclosure was designed to accommodate a commercial state-of-the-art hard disk drive. This effort has resulted a space qualified data storage system that weighs less than 4.5 Kg, consumes 17 watts of power for record and playback, will record data at 24 Mbps and will store 8 G-bits of data. This paper describes the development program, the test program, the test results and plans for future development including space flight.

INTRODUCTION

A low cost alternative to tape recorders has been developed by Spectrum Astro, Inc. in an experimental program under the sponsorship of the USAF Phillips Laboratory and the ARPA Advanced Space Technology Program. The primary objective of the program was to determine the feasibility of utilizing commercially available state-of-the-art hard disk drives for space applications. The disk drives would be subjected to environmental conditions including atmospheric pressures, temperature extremes and temperature cycling, magnetic fields, radial accelerations, shock, vibration and radiation levels possibly beyond their design limits. As part of the developmental program: (1) commercially available disk drives were evaluated and a specific drive type was selected;

(2) environmental conditions were bounded and techniques for minimizing their impact on the disk drives were investigated; and (3) analyses were performed to ensure that selected techniques would allow satisfactory operation of the disk drives in space environments. Following these analyses, an Erasable Disk Mass Memory (EDMM) breadboard incorporating two of the selected disk drives was developed and functionally tested. Two flyable prototypes of the EDMM were fabricated and have undergone environmental testing. One of these prototypes will be flown on the STEP-M3 satellite to determine the long term effects of the LEO environment on the disk drives. A production unit is currently being fabricated and will be flown in the Miniature Sensor Technology Integration (MSTI) program this year.

Based on the evaluation of several disk drives, a Conner Peripherals, Inc. fifth generation disk drive, type CP-3540, was selected. In the EDMM two of these 3.5 inch diameter disk drives are shock mounted back-to-back in a hermetically sealed enclosure. A Small Computer System Interface (SCSI)¹ operating in single-ended mode is used for interfacing with the two drives. The two drives together are capable of storing up to one gigabyte of data. Control, power, test, and monitoring circuitry were developed and integrated with the two drives.

EDMM DESIGN

The EDMM design was based on using the Small Computer System Interface (SCSI). This interface is the de-facto industry standard for mass storage and special I/O devices. In addition to the host/initiator, up to seven SCSI compatible devices can be connected to a

common SCSI bus. By being an industry standard, it is well defined and is continuously maintained and improved with time. Accordingly new peripherals will be designed to be compatible with a SCSI bus and no comprehensive Electrical Interface Control Document (EICD) will be required to ensure compatibility of these peripherals. Host controller cards are in existence for most small computers to allow them to be the host controller for a SCSI bus. In effect a SCSI bus can act as a low cost and versatile "preconfigured electrical interface" for satellite subsystems.

Guidelines from Phillips Laboratory for this development program placed emphasis upon utilizing to the maximum extent practicable existing commercial hardware and software including disk drives, a SCSI bus, host controllers, and associated test software. This allowed the government to take advantage of the millions of dollars already spent by industry in developing compact, low cost, and highly reliable disk drives, a standardized interface bus, and associated test hardware and software.

Requirements Analysis

Analyses were conducted to determine the impact of the following environmental conditions on the disk drives and associated circuitry:

1. Atmospheric Pressure
2. Temperature
3. Shock and Vibration
4. Magnetic Fields
5. Radial Acceleration
6. Radiation

With the possible exception of radiation levels, the analyses showed that the EDMM could be packaged and installed aboard a spacecraft in such a manner that it would be expected to survive the boost phase of typical launch vehicles and operate on the spacecraft within the manufacturer's design limits. Vehicles considered were as follows:

- 1) Titan IV, 6.5 G at Stage 1 Burnout (Titan IV Final User's Handbook, MCR-86-2541, June 1989)

- 2) Atlas, 5.3 G at Booster Engine Cutoff (Atlas Mission Planner's Guide, Rev. 2, 10 July 1990)
- 3) Delta, 7.5 G at Stage 3 burnout (2000 lb vehicle, 3 sigma high accel.) (Delta II Payload Planner's Guide, Dec. 1989)
- 4) Taurus, 6 G (Taurus T1 Data Package, 13 Nov. 1990)
- 5) Pegasus, 7.5 G at Stage 3 Burnout (200 Kg Payload) (Pegasus Payload User's Guide, 1 May 1991)
- 6) Scout, 10 G at Fourth Stage Burnout (150 Kg Payload) (Scout Payload Planning Guide, Oct. 1988)

Mechanical Design

The mechanical design accommodates two of the Conner CP-3540 disk drives mounted back-to-back, to minimize net angular momentum, and suspended in a cradle subassembly. This entire subassembly is shock and vibration isolated from the internal walls of a hermetically sealed enclosure. The enclosure and its cover are machined from solid stock 7075 T73 aluminum. Both enclosure and cover (except where required for bonding) are hard black anodized per MIL-A- 8625, Type II, Class 2. Two 55-pin hermetically sealed connectors are used for electrical interfacing of the unit. A Viton O-Ring per MIL-R-83248A, Type 1, Class 1 is used to provide hermetic sealing of the cover and enclosure. External bosses are provided on the sides and one end of the enclosure to allow internal mounting of circuit subassemblies for power supplies, control and monitoring circuitry.

Electrical Design

Although no changes were made to the Conner disk drives, all the peripheral control and power circuitry was designed using high-reliability parts. Latching relays are used to connect prime 28 volt power to the internal power converters. Actual turn on and turn off of the disk drives are via solid state relays which in turn are controlled by 5 volt logic levels. These logic levels are isolated from local chassis ground by an opto-isolator. Since a radiation hardness assessment could not conclusively preclude the possibility of latchup in the commercial disk drive circuitry, a Latchup Mitigation Circuit

(LMC) was designed into the control electronics. After normal turn-on and after the disks have reached operating speed, this gate array circuit automatically shuts down both disk drives if instrumented pulse trains indicate a failure in either drive. After disk coast-down, the drives are automatically rebooted, and allowed to reach normal operating speed again before the shutdown circuitry becomes operational and checks for their status. An over-ride turn-on logic level completely bypasses this protective circuitry.

A Small Computer System Interface (SCSI) operating in a single ended mode is used for interfacing with the two drives.² The two drives together are capable of storing up to one gigabyte of data. Thermostatically controlled heaters are included inside the EDMM enclosure. Thermistors are provided for temperature measurements. A pressure transducer is also included to allow monitoring of internal enclosure atmospheric pressure.

ENVIRONMENTAL TESTING/ANALYSIS

Radiation Analysis

The components within the disk drive circuitry were analyzed for sensitivity to radiation.³ This analysis indicated the EDMM could survive a total lifetime dose of 25Krad. Additionally a worst case analysis of 116 typical orbits was completed to determine expected total dose radiation for each orbit type. The results of this analysis, which took into account the shielding provided by the EDMM enclosure, indicated the EDMM would have an expected useful life of 4 - 5 years for the worst case orbit. Since the radiation analysis could not conclusively evaluate the potential for latchup, a latchup mitigation circuit was designed to shut down the drives and then reboot in the event of a latchup condition.

EMI/EMC Analysis

As part of the requirements of the STEP program an analysis of the EDMM's susceptibility to and effects upon electromagnetic fields is currently underway.

The unit is being evaluated with respect to MIL-STD-461C.

Shock Testing

At the time of the prototype development no shock tests were performed since Conner Peripherals has previously shock tested three of the CP-3540 drives both in an operating mode and in a non-operating mode. All three of the units passed a 125 G test level for 11 milliseconds in a non-operating mode and a 15 G test level for the same period in an operating mode. The production unit slated for use on the MSTI program will be tested at 40 G's for 6 milliseconds in a non-operating mode in its thrust axis.

Radial Acceleration

In a satellite such as STEP-M3 that is three-axis stabilized, the radial acceleration requirements for the EDMM are modest. However in a yaw spinner satellite, radial acceleration places a force which could cause failure of the voice coil servo in the disk drive. A location on the periphery of a large spinning satellite would result in centrifugal forces that could degrade performance or cause complete failure. The analysis relative to radial acceleration showed that with a 2 G safety factor the EDMM could be mounted up to 15.75 inches off the spin axis for spin rates of up to 95 revolutions per minute.

Random Vibration

As part of the prototype development program the one of the units was tested for random vibration from 30Hz to 2000Hz at 15.0 grms \pm 1.5 dB for three minutes in each axis and passed without failures. Additionally, the production unit for MSTI will be tested at 9.8 grms \pm 1.5 dB for two minutes in each axis as part of its acceptance testing.

Thermal Cycling

The EDMM prototype unit was thermally cycled eight times between -16 °C and +41 °C, its designed operational limits. It also was subjected to + 50 °C for a period of four hours

during the testing period. All cycles were passed with no failures. The production unit is planned to be tested from -25 °C to + 55 °C to meet its MSTI acceptance requirements.

Thermal Vacuum Cycling

The prototype units were thermal vacuum cycled three times from -16 °C to + 41 °C with no functional failures and no detectable loss of internal ambient pressure. The production unit is also scheduled for thermal vacuum testing prior to its launch.

Pressure Seal Life Test

As an added measure of confidence in the EDMM design, a prototype unit is currently undergoing a long term life test of the vacuum seal. To date the unit has not had a detectable loss in internal pressure.

DESIGN IMPROVEMENTS

Thermal Control

Since the guidelines and budget for development of the EDMM did not allow for any modification of the commercial disk drives, the thermal management task of the EDMM was more challenging than normally required. The CP-3540 is not specified to operate below zero degrees C or at zero percent relative humidity. This condition would most likely cause a failure in the disk head mechanism. To alleviate this hazard at the lower end of the EDMM's operating temperature, heaters are employed to maintain the disk drives temperature above the ice point. In the prototype designs, the thermostats controlling the heaters were positioned too close to the heaters causing an extremely short duty cycle. This in turn extended the disk drive warm-up time beyond what was considered optimum.

Following further analysis and empirical evaluation of the prototype units, the production design has had its thermostats and heaters placed such that the heater duty cycle should allow for a more acceptable warm-up time.

Multiple SCSI Bus Architecture

In the original prototype design of the EDMM the two disk drives were daisy-chained on the same SCSI bus. Although the SCSI-2 data transfer rate over the bus is specified to be five Mbytes/sec, the architecture of the disk drive electronics can have a significant effect on the actual media transfer rate or how fast the data is physically inscribed on the disk. One way of improving this situation is to allow each disk drive to be the sole target on its SCSI bus. This has the disadvantage of adding hardware and design complexity.

This multiple-bus design is being implemented in the production EDMM used in the MSTI program. The use of dual SCSI interfaces will allow for the faster data transfer required for this application.

FUTURE PRODUCT DEVELOPMENT

"BAJA" Series

The continuous product improvement philosophy found in the commercial disk drive industry can only lead to even more impressive capabilities being implemented in disk based mass memory storage systems for space applications. An example of this is Spectrum Astro's intention to use Conner Peripherals "Baja" series disk drives in an EDMM to be used in a future MSTI mission in 1994. The Baja drive weighs slightly more, has a media transfer rate almost fifty percent greater, and stores 1.28 Gbytes of data. Thus an EDMM equipped with these new drives can store a total of 2.56 Gbytes of data. These advantages come at the cost of increasing the power consumption. However the Watts/Gbyte ratio is still much lower than that using the CP-3540 drives.

New Architectures

The wide array of commercial disk drive products allows for flexibility in design architectures. The use of several disks in a Redundant Array of Independent Disks(RAID)

type of system could improve reliability and alleviate the effects of potential latchup events in a single drive. If a disk experiences a failure, its redundant counterpart can come on line and would be transparent to the end user.

The various form factors and storage capacities available also allow custom designs tailored to the specific memory storage requirements of the application in question.

EDMM UNIT PERFORMANCE				
SAI MODEL	EDMM-1	EDMM-1A	EDMM-2	EDMM-X
Development Status	Prototype	Production	Planned	Conceptual
Basic Disk				
Manufacturer	Conner Peripherals	Conner Peripherals	Conner Peripherals	Hewlett-Packard
Model	CP-3540	CP-3540	CP-31370	C3014A
Diameter(in)	3.5	3.5	3.5	1.3
Unit Capacity (Gbits)	8.106	8.106	20.48	0.638
Data Transfer Rate(Mbits/sec)				
Sustained	12.8(measured)	25.6(measured)	34.21(est.)	17.6(est.)
Peak	40.0	80.0	160.0	24.0(est.)
Dimensions(in)	5 X 8 X 10.2	5 X 8 X 10.2	5 X 8 X 10.2	2 X 3 X 4(est.)
Weight(lb)	9.2	9.2	10.0(est.)	2.75(est.)
Power(Watts)				
Spin Up	66.6	66.6	106.9	9.0(est.)
Read/Write	17.4	17.4	23.6	5.8(est.)
Idle	16.6	16.6	21.35	1.0(est.)
Heater Peak	30.0	30.0	30.0	3.0(est.)
Heater Avg.(-16 C)	15.0	15.0	15.0	1.0(est.)
Angular Momentum(ft/lb)	0.0013	0.0013	0.0013	0.0005(est.)
Operating Temperature	-16°C to +41°C	-20°C to +50°C	-25°C to +55°C(est.)	-30°C to +60°C(est.)

REFERENCES

(1) ANSI X3.131-1986
American National Standard
for Information Systems
Small Computer System Interface (SCSI)

(2) Product Manual, SUMMIT SCSI
Intelligent Disk Drives
Revision H.2, August 1991
Conner Peripherals, Inc.
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(3) "EDMM Subsystem Hardness Assessment"
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