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Evaluation of Magnetoresistive RAM for Space Applications

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1.0 INTRODUCTION

Magnetoresistive random-access memory (MRAM) is a non-volatile memory that exploits electronic spin, rather than charge, to store data. Instead of moving charge on and off a floating gate to alter the threshold voltage of a complementary metallic oxide semiconductor (CMOS) transistor (creating different bit states), MRAM uses magnetic fields to flip the polarization of a ferromagnetic material, thus switching its resistance and bit state. These polarized states are immune to radiation-induced upset, thus making MRAM very attractive for space application. These magnetic memory elements also have infinite data retention and erase/program endurance. Further information regarding MRAM technology and the MRAM market can be found in Ref. 1.

Presented here are results of reliability testing of two space-qualified MRAM products from Aeroflex and Honeywell. The March 17N functional test [2] was applied to the test samples at a variety of temperature and voltage combinations ("schmoo testing"), and the failure regions were identified.

2.0 DEVICES UNDER TEST (DUTS)

The two parts tested, listed in Table 2.0-1, were a 16Mb from Aeroflex and 1Mb device from Honeywell. Both parts are marketed for “hi-rel” space application and utilize radiation hardened by design (RHBD) design methodology to harden the CMOS control circuitry against radiation effects. Everspin in Chandler, Arizona, does the back-end magnetic memory element processing for both Aeroflex and Honeywell.

The Aeroflex UT8MR2M8-40XPC is a 3.3-V device that is organized as 2,097,152 8-bit words and has single-bit internal error-correcting code (ECC). This particular part number is “prototype” quality, meaning it was only tested at room temperature by Aeroflex prior to shipment.

The Honeywell HXNV0100AEN is a dual-power supply 3.3-V and 1.8-V device organized as 65,536 16-bit words of and has single-bit ECC. This particular part number is “engineering model” quality, meaning it was tested at –40°C and 105°C with a 24-hour burn-in by Honeywell.

Table 2.0-1. Devices under test.

	Aeroflex	Honeywell
Part Number	UT8MR2M8-40XPC	HXNV0100AEN
Number of Die/Packages	1	1
Date Code	1225	1218
Quality Level	“Prototype”	“Engineering Model”
Number of Samples	3	3
Recommended Operating Voltage	3.0 to 3.6 V	Dual Supply Required: 3.0 to 3.6 V and 1.65 to 1.95 V
Manuf. Screening Temperature	25°C	–40°C to 105°C

3.0 TEST SETUP

Functional testing of the MRAM samples was carried out with a JD Instruments, LLC (JDI) automated test vector (ATV) digital tester (Figure 3.0-1). The test program was simply a March 17N algorithm. The inventors of this algorithm design it to uncover faults specific to MRAM-technology such as soft writes and erases [2].

Temperature control was provided by a Sun Electronic Systems EC1 environmental chamber with a temperature range of –184°C (LN_2) to 300°C.

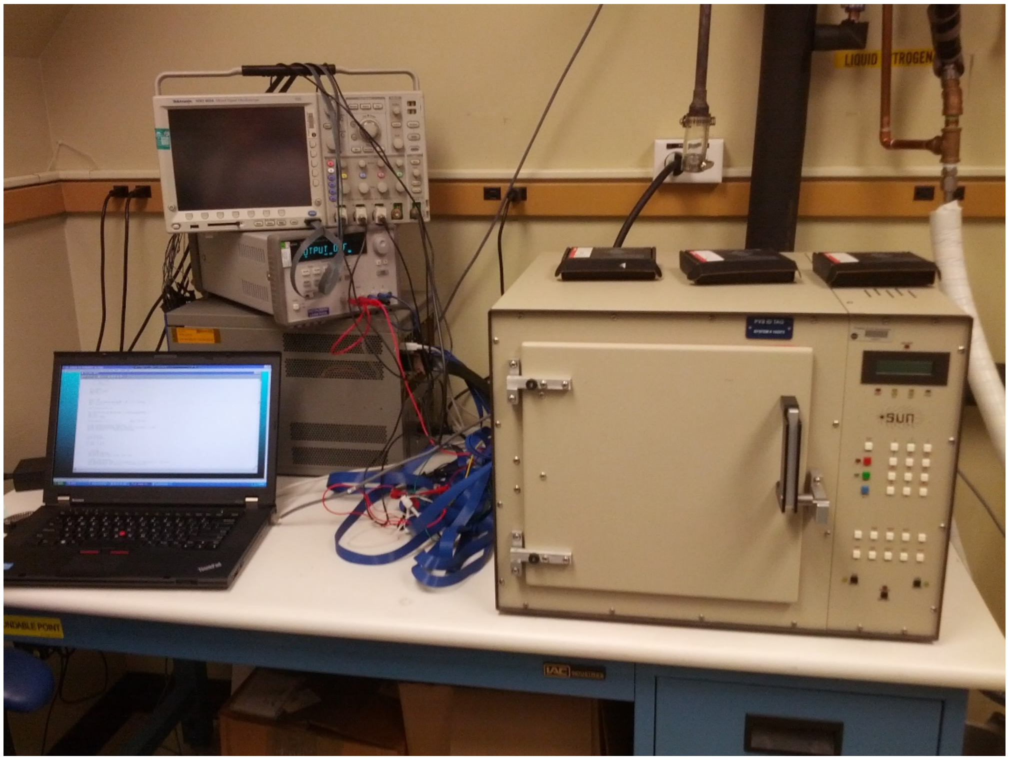

Figure 3.0-1. JDI ATV tester and Sun Electronic Systems environmental chamber.

Each DUT was tested at a variety of temperature and voltage combinations. At each temperature-voltage (T-V) combination, the March 17N test was run three times, and the average number of bit errors was reported.

The voltage and temperature combinations tested are given in Table 3.0-1. The Aeroflex part was tested at 13 voltages and 5 temperatures, for a total of 65 tests per DUT. There is just one table of results for each Aeroflex sample tested. However, because the Honeywell parts require two power supplies, there is an added dimension to the test matrix. So each DUT has 5 tables of results (one for each V_{CC2} value tested).

Table 3.0-1. Test Voltages and Temperatures.

	Aeroflex	Honeywell
Voltages	V_{CC}: 2.7 to 3.9 V (0.1 V step)	V_{CC1}: 2.9 V, 3.0 V, 3.3 V, 3.6 V, 3.7 V V_{CC2}: 1.5 to 2.1 V (0.15 V step)
Case Temperature	–55°C, –40°C, 25°C, 55°C, 65°C	–100°C, –80°C, –40°C, 25°C, 105°C, 115°C
Number of Samples	3	2

4.0 TEST RESULTS

Bit error rates for the March 17N test at the various temperature and voltage combinations is given in the tables in sections 4.1 and 4.2. Because the temperature and voltage ranges that were tested extend beyond the manufacturer's recommended operating ranges, thick black boxes were drawn in the results tables to illustrate how much margin is provided over the manufacturers' guaranteed ranges.

The Aeroflex parts are "prototype" quality guaranteed to operate between 3.0 V to 3.6 V at 25°C. During our testing the DUTs were subjected to voltages from 2.7 V to 3.9 V and temperatures from –55°C to 65°C.

The Honeywell parts are specified to operate between 1.65 V and 1.95 V (V_{CC1}), 3.0 V and 3.6 V (V_{CC2}) and –40°C to 105°C. As was the case with the Aeroflex part, our testing included these ranges and beyond.

The March 17N algorithm was run three times at each voltage/temperature combination and the average number of bit errors (order of magnitude) reported. It should be noted that both DUTs have internal error correction code (ECC) so the number of bit errors reported here are those that could not be corrected by the internal "single error correct, double error detect (SECDED)" ECC.

4.1 Aeroflex

Table 4.1-1. March 17N bit errors at various V_{CC} and temperature combinations, Aeroflex Sample #1.

	2.7 V	2.8 V	2.9 V	3.0 V	3.1 V	3.2 V	3.3 V	3.4 V	3.5 V	3.6 V	3.7 V	3.8 V	3.9 V
65°C	10^9	10^1	10^1	10^1	10^1	10^1	10^1	10^1	10^1	10^1	10^1	10^1	10^1
55°C	10^9	0	0	0	0	0	0	0	0	0	0	0	10^2
25°C	10^9	0	0	0	0	0	0	0	0	0	0	0	0
-40°C	0	0	0	0	0	0	0	0	0	0	0	0	10^1
-55°C	0	0	0	0	0	0	0	0	0	0	0	0	10^4

Table 4.1-2. March 17N bit errors at various V_{CC} and temperature combinations, Aeroflex Sample #2.

	2.7 V	2.8 V	2.9 V	3.0 V	3.1 V	3.2 V	3.3 V	3.4 V	3.5 V	3.6 V	3.7 V	3.8 V	3.9 V
65°C	10^9	10^1	10^1	10^1	10^1	10^1	10^1	10^1	10^1	10^1	10^1	10^3	10^4
55°C	10^9	0	0	0	0	0	0	0	0	0	10^1	10^4	10^4
25°C	10^9	0	0	0	0	0	0	0	0	0	0	0	10^1
-40°C	0	0	0	0	0	0	0	0	0	0	0	0	10^7
-55°C	0	0	0	0	0	0	0	0	0	0	10^4	10^3	10^8

Table 4.1-3. March 17N bit errors at various V_{CC} and temperature combinations, Aeroflex Sample #3

	2.7 V	2.8 V	2.9 V	3.0 V	3.1 V	3.2 V	3.3 V	3.4 V	3.5 V	3.6 V	3.7 V	3.8 V	3.9 V
65°C	10^9	0	0	0	0	0	0	0	0	0	0	10^5	10^6
55°C	10^9	0	0	0	0	0	0	0	0	0	0	10^5	10^5
25°C	10^9	0	0	0	0	0	0	0	0	0	0	0	10^6
-40°C	0	0	0	0	0	0	0	0	0	0	0	0	10^9
-55°C	0	0	0	0	0	0	0	0	0	0	0	0	10^7

4.2 Honeywell

4.2.1 Sample #1

Table 4.2.1-1. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #1, V_{CC2} = 1.5 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	10^5	10^5	10^8	10^8	10^8
105°C	10^1	0	0	10^2	10^5
25°C	10^2	10^1	10^2	10^2	10^4
-40°C	10^6	10^6	10^6	10^7	10^7
-80°C	10^6	10^6	10^6	10^7	10^7
-100°C	10^6	10^6	10^6	10^7	10^7

Table 4.2.1-2. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #1, V_{CC2} = 1.65 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	10^5	10^5	10^8	10^8	10^8
105°C	0	0	0	0	0
25°C	10^2	0	0	0	0
-40°C	10^2	0	0	0	0
-80°C	10^6	10^6	10^6	10^6	10^6
-100°C	10^8	10^8	10^8	10^8	10^8

Table 4.2.1-3. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #1, V_{CC2} = 1.8 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	10^5	10^5	10^8	10^8	10^8
105°C	10^1	0	0	0	0
25°C	10^2	0	0	0	0
-40°C	10^2	0	0	0	0
-80°C	10^6	10^6	10^6	10^6	10^6
-100°C	10^8	10^8	10^8	10^8	10^8

Table 4.2.1-4. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #1, V_{CC2} = 1.95 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	10^5	10^5	10^8	10^8	10^8
105°C	10^2	0	0	0	0
25°C	10^2	0	0	0	0
-40°C	10^2	0	0	0	0
-80°C	10^6	10^6	10^6	10^6	10^6
-100°C	10^8	10^8	10^8	10^8	10^8

Table 4.2.1-5. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #1, V_{CC2} = 2.1 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	10^5	10^5	10^8	10^8	10^8
105°C	10^2	0	0	0	0
25°C	10^2	0	0	0	0
-40°C	10^6	0	0	0	0
-80°C	10^6	10^6	10^6	10^6	10^6
-100°C	10^8	10^8	10^8	10^8	10^8

4.2.2 Sample #2

Table 4.2.2-1. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #2, V_{CC2} = 1.5 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	0	10^1	0	10^1	10^1
105°C	10^1	10^1	10^1	0	0
25°C	10^1	10^1	0	10^1	0
-40°C	10^2	10^1	0	0	0
-80°C	10^2	0	0	0	0
-100°C	10^2	0	10^4	10^7	10^7

Table 4.2.2-2. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #2, V_{CC2} = 1.65 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	0	0	0	0	0
105°C	0	0	0	0	0
25°C	10^2	0	0	0	0
-40°C	10^1	0	0	0	0
-80°C	10^2	0	0	0	0
-100°C	10^1	0	0	0	0

Table 4.2.2-3. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #2, V_{CC2} = 1.8 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	0	0	0	0	0
105°C	0	0	0	0	0
25°C	10^2	0	0	0	0
-40°C	10^2	0	0	0	0
-80°C	10^2	0	0	0	0
-100°C	10^2	0	10^4	10^7	10^7

Table 4.2.2-4. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #2, V_{CC2} = 1.95 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	0	0	0	0	0
105°C	10^1	0	0	0	0
25°C	10^2	0	0	0	0
-40°C	10^2	0	0	0	0
-80°C	10^2	0	0	0	0
-100°C	10^2	0	0	0	0

Table 4.2.2-5. March 17N bit errors at various V_{CC1} and temperature combinations, Honeywell Sample #2, V_{CC2} = 2.1 V.

	2.9 V	3.0 V	3.3 V	3.6 V	3.7 V
115°C	10^2	0	0	0	0
105°C	10^2	0	0	0	0
25°C	10^2	0	0	0	0
-40°C	10^2	0	0	0	0
-80°C	10^2	0	10^2	10^2	10^2
-100°C	10^2	0	10^4	10^7	10^7

5.0 CONCLUSION

The parts tested never failed in the regions tested/guaranteed by the manufacturer. And in most cases worked well beyond the specified voltage and temperature limits.

Voltage appears to be more critical than temperature. Bit errors were seen in many cases at voltages right outside the manufacturers' recommended operating ranges.

As for the Honeywell parts, they operated well above and below the min/max operating temperature limits. We did not test beyond +115°C or –100°C, so they could have operated beyond those values.

As for the Aeroflex part, it did not perform as well. This is because the parts tested were materially different than the fully-tested space quality devices. There are "trim settings" that Aeroflex adjusts on each chip during fabrication that adjusts the read and write control circuitry in order to achieve datasheet operation over a wide range of temperatures. The prototype quality parts tested here did not have those trim settings adjusted. So although they worked at cold temperatures, they began to fail at only 65°C, even though the space part is specified to work up to 125°C.

Future reliability study of these devices should include fully-tested, space quality devices. At a price of about $5000/part, the study would need to budget at least $30,000 just for parts.

ACRONYMS AND ABBREVIATIONS

ATV	automated test vector
CMOS	complementary metallic oxide semiconductor
DUT	device under test
ECC	error correcting code
JDI	JD Instruments, LLC
MRAM	magnetoresistive random-access memory
RHBD	radiation hardened by design
SECDED	single error correct, double error detect
T-V	temperature-voltage

6.0 REFERENCES

[1] Heidecker, J., *MRAM Technology Status*, JPL Publication 13-3, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, Feb. 2013.

[2] Li, J.-F., K.-L. Cheng, C.-T. Huang, and C.-W. Wu, "March-based RAM diagnosis algorithms for stuck-at and coupling faults," Paper 28.1, *Proceedings of the IEEE International Test Conference*, pp. 758–767, 2001.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
Magnetoresistive random-access memory (MRAM) is a non-volatile memory that exploits electronic spin, rather than charge, to store data. Instead of moving charge on and off a floating gate to alter the threshold voltage of a CMOS transistor (creating different bit states), MRAM uses magnetic fields to flip the polarization of a ferromagnetic material thus switching its resistance and bit state. These polarized states are immune to radiation-induced upset, thus making MRAM very attractive for space application. These magnetic memory elements also have infinite data retention and erase/program endurance. Presented here are results of reliability testing of two space-qualified MRAM products from Aeroflex and Honeywell.

15. SUBJECT TERMS
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