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Magnetic Immunity of the MRAM Devices

Table 1: Cross Reference of Applicable Products

Product Name	Manufacturer Part Number	SMD #	Device Type	Internal PIC#
16Mb MRAM Device	UT8MR2M8	5962-12227	01	WP01
64Mb MRAM Device	UT8MR8M8	5962-13207	01	MQ09

*PIC = Product Identification Code

1.0 Overview

CAES Colorado Springs offers a 16Mb and 64Mb Non-Volatile Magnetoresistive Random Access Memory (MRAM) device. The MRAM devices are designed specifically for operation in both HiRel and Space environments. This application note addresses concerns with the magnetic immunity of these devices. CAES has determined that the MRAM devices have no magnetic risk in the space environment and recommends proper handling to address terrestrial environments.

2.0 Magnetic Fields

All magnetic fields are caused by electrical charge in motion. Even the fields from a stationary permanent magnet are the result of the rotation (quantum spin) of electrons within the material. There are two "components" of a magnetic field which are both commonly called "magnetic field." They are the B field (historically called Magnetic Induction) and the H field (historically called Magnetic Field). They are related by the equation $B = H + 4\pi M$ where M is a term called "Magnetization" or "Magnetic Polarization" and is a property of the materials through which the fields pass. Technically, M is the magnetic moment of the material per unit volume. To obtain the total B field, if considering the field in a volume of space, the free (unbound field) H plus the bound fields (magnetic dipoles) M must be known. If there are no permanent magnets in the particular volume of space being analyzed, then M is proportional to H and $B = \mu H$ where μ = magnetic permeability. Because the B field is dependent on material properties that can be introduced into any given environment, CAES specifies the H field when it determines its environmental conditions.

3.0 Units of Measure

Both B and H fields have their own unique units of measure. As explained previously, CAES specifies the magnetic field in terms of H and in CGS (centimetre-gram-second) units.

	CGS Units	S. I. Units
Magnetic Induction (B)	**Gauss (G)**	**Tesla (T)**
Magnetic Field (H)	**Oersted (Oe)**	**Amps/meter (A/m)**

1 Oe = 1G (in free space)
$1\ G = 10^{-4}\ T$
$1\ Oe = 79.6\ A/m = 10^3/4\pi\ A/m$
1 nT = 1 Gamma

Figure 1: CGS vs S.I. Units

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The constant 4π is present in the term μ described in the Magnetic Fields section above. The 4π is absorbed into the definition of the oersted; therefore, in regions of space where no external dipoles are present, 1 oersted = 1 Gauss. This 4π is not incorporated into the definition when converting Gauss to A/m. A conversion table is useful; however, note that B is not truly equivalent to H and can sometimes be off by a factor of 4π. The following conversion table and a link to a calculator that facilitates converting between these units can be found at http://www.smpspowersupply.com/magnetic-unit-conversion.html.

Table 2: Magnetic Field Conversion Table

Quantity	Symbol	SI Unit	SI Equation	CGS Unit	CGS Equation	Conversion Factor
Magnetic induction	B	tesla (T)	$B=\mu_0(H+M)$	Gauss (G)	$B = H+4\pi M$	$1\ T = 10^4\ G$
Magnetic field strength	H	ampere/meter (A/m)	$H = N\times I/lc$ (lc - magnetic path, m)	oersted (Oe)	$H = 0.4\pi N\times I/lc$ (lc - magnetic path, cm)	$1\ A/m = 4\ \pi\times10^{-3}\ Oe$
Magnetic flux	Φ	weber (Wb)	$\Phi = B\times Ac$ (Ac - area, m^2)	Maxwell (M)	$\Phi = B\times Ac$ (Ac - area, cm^2)	$1\ Wb = 10^8\ M$
Magnetization	M	ampere/meter (A/m)	M=m/V (m- total magnetic moment, V- volume, m^3)	emu/cm^3	M=m/V (m- total magnetic moment, V- volume, cm^3)	$1\ A/m = 10^{-3}$ emu / cm^3
Magnetic permeability of vacuum	μ_0	newton/ampere	$\mu_0 = 4\pi\times10^{-7}$	1	-	$4\pi\times10^{-7}$
Inductance	L	henry	$L=\mu_0\mu N^2Ac/lc$ (Ac- area, m^2, lc - magnetic path, m)	henry	$L=0.4\ \pi\mu N^2Ac/lc\times 10^{-8}$ (Ac-area, cm^2, lc - magnetic path, cm)	1
Emf (voltage)	V	volt	$V=-N\times d\Phi/dt$	volt	$V=-10^{-8}N\times d\Phi/dt$	1

4.0 CAES MRAM Magnetic Immunity

The storage element in an MRAM stores data on magnetic layers that are switched by very localized magnetic fields developed on chip. To change the state of a memory element, the circuit applies three sequential magnetic fields to a bit cell, each with a different orientation. Without this specific pattern, the bit will not flip. This technique called "Toggle MRAM," along with the shielding solution from CAES, prevents even strong external magnetic fields from inadvertently corrupting the memory. The MRAM products are guaranteed to be immune to magnetic fields up to 8000 A/M (100 G) during reading, writing, static, or unpowered operation. The magnetic immunity specifications are valid during both powered and unpowered conditions.

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5.0 Magnetic Shielding

Magnetic shielding can be incorporated into a package by surrounding the die with high permeability metal. Shields don't block magnetic fields, rather these shields channel magnetic flux into them much like a low resistance conductor does for electrical current. This property of high permeability materials can lead to both increased and decreased fields near the shield; therefore, a complete understanding of the physics is vital to constructing a well shielded device. CAES utilized electromagnetic field solver simulation tools to create a robust shielding solution that was integrated into the MRAM package. CAES also performed magnetic field immunity tests with external magnetic fields that exceeded the guaranteed magnetic field specifications.

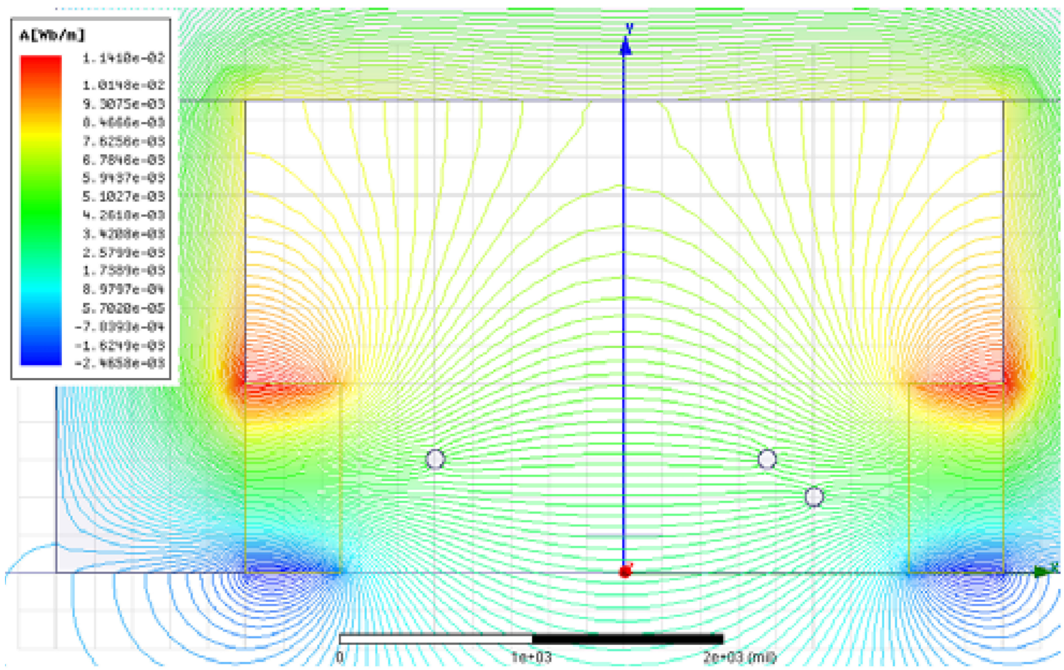

Figure 2: Electromagnetic Field Simulation Tool

6.0 Magnetic Field Environments

The earth's magnetic field is approximately 0.5G but varies depending on your location. Stray magnetic fields (SMFs), caused by electrical currents running through high current wires or from permanent magnetic fields such as those in speakers, leads to much higher values which is why shielding is imperative for the MRAM product. Although these fields can be quite strong they fall off rapidly with distance from the source. For instance a field of a phone speaker magnet may be 60G at the surface of the speaker but will fall off to < 2G at 2cm from the speaker. Below is a list of the strongest ambient magnetic fields found in the solar system along with some examples of man-made magnetic fields.

Table 3: Ambient and Man-Made Magnetic Field Strengths

Source	Magnetic Field	Units
Typical Magnetic Storm	0.001	Gauss
Strongest Magnetic Storm in Space (measured by THEMIS)	0.14	Gauss
Earth's Magnet Field	0.5	Gauss
5cm from MT400 Magnetic Torque Arm Max Field	< 1	Gauss
Adjacent to MT400 Magnetic Torque Arm Max Field	7.6	Gauss
Field at the poles of the Sun	10	Gauss
Field at Jupiter's North Pole (Highest natural field in solar system)	15	Gauss
Field at surface of a typical phone speaker magnet	60	Gauss
Field at 2cm from typical phone speaker magnet	< 2	Gauss

7.0 Magnetic Fields in PCB Manufacturing

The MRAM devices can be introduced to magnetic fields during PCB manufacturing and handling. CAES Colorado Springs has performed a complete facility audit for magnetic fields. Certain equipment and tools may contain rare earth magnets or can be exposed to magnetic fields that, in time, can become magnetized. Table 4 lists CAES Colorado Springs PCB manufacturing equipment and its associated measured magnetic field measurement. Table 5 lists loose and miscellaneous items commonly found in a PCB manufacturing environment along with its associated measured magnetic field measurement. The column labelled Drop Off lists the distance in inches in which the magnetic field from the listed tool drops off to less than 5 gauss. It is recommended that MRAM devices be kept a minimum of this distance from the tool during PCB assembly operations. It can be observed that as a general rule stray magnetic fields drop off to levels that are safe for the CAES MRAM at a minimum distance of 3 inches from most equipment.

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Table 4: Magnetic Field Measurements of PCB Manufacturing Equipment/Machines at CAES

Equipment/Process Description	Make	Model	Direct Measurement (G)	> 0.25 (Inches)	Drop Off (Inches)	Use Measurement (Inches)
Forming	Fancort	Universal Press	N/A	2.1	>1	5.2
Forming	Fancort	Flex Former	N/A	3.2	>1	12.4
Tinning	HMP	Solder Tinning System	<1	<1	N/A	<1
Pick and Place Y Wagon	MyData	MY19	>800	135	>1	7.3
Pick and Place Tray Wagon	MyData	MY19	195	20.6	>1	4.42
Pick and Place Head	MyData	MY19	N/A	<1	N/A	3.2
Pick and Place Motor (not running)	MyData	MY19	62.3	24	>1	N/A
Pick and Place Y Wagon	MyData	MY100	736	156	>1	5.6
Pick and Place Tray Wagon	MyData	MY100	130	32	>1	24
Pick and Place Machine Running	MyData	MY100	N/A	N/A	<1	5.3
Stream Printing Motor	MPM	Momentum	26.7	14.8	>1	0.9
Stream Printing Board Support Bar	MPM	Momentum	16.4	5.2	>1	N/A
Reflow Oven	Vitronics	Soltec	<2	<2	N/A	<2
Reflow Oven	Vitronics	Soltec	N/A	N/A	N/A	8.2
X-Ray	Station	1525	<1	<1	N/A	<1
Air-Vac	Air-Vac	DRS22	<1	<1	N/A	<1
Flying Probe Support Magnet	Genrad	Pilot	>800	152	>1	6.8
Flying Probe Probes	Genrad	Pilot	41	22	>1	4.1
AOI	Mirtec	MV-7XI	<1	<1	N/A	<1
Bake Oven	Blue-X	256	<1	<1	N/A	<1
Adhesive Dispenser Support Magnets	Camelot	FX-D	>800	254	>1.5	130
De-Paneling Router	Cencorp	TR1000	<1	<1	N/A	<1

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Table 5: Magnetic Field Measurements of Miscellaneous Items Commonly Found in PCB Manufacturing

Description of Item	Direct Measurement (G)	> 0.25 (Inches)	Drop Off (Inches)
Magnetic Pencil/Wand	>800	185	>1
Tweezers	14.6	8.2	<1
6 Inch Steel Ruler	12.05	1.4	<1
Magnet for board clamping	637	140	>1
Pick Up Tool	<1	N/A	<1
Metcal Solder Iron	1.9	N/A	<1
Screwdriver – Non Magnetic Tip	36.7	12.2	<1
Plating Brush	6.5	3.1	<1
Hot Plate	<5	N/A	<1
Hot Plate Stands	<1	N/A	<1
Impulse 4G Cell Phone Speaker	107.8	30.4	>1
Iphone ear buds	79.1	10.9	>1
Dremel Model 4000 with Flex Shaft	40.1	N/A	N/A
Ipod Nano	1.79	N/A	<1
Lenovo Laptop Speakers (T420)	186.6	71.7	>1
Jewelry	>800	174	>1
Micrometer – Exposed to SMF's over time	>100	N/A	<1

8.0 CAES Colorado Springs Magnetic Process and Flow

CAES Colorado Springs strives to deliver product with the highest quality and reliability. Therefore, we have taken the necessary steps to ensure the MRAM products meet all performance and quality expectations of our customers. To assure we attain this high goal, CAES Colorado Springs has implemented a magnetic process/flow to eliminate any potential stray magnetic fields which may interact with the MRAM devices. The following lists manufacturing specific procedures which are currently being implemented in the development of the MRAM devices:

- Added Magnetic Environment and Handling criteria to applicable internal documentation (similar to ESD control)
- Created detailed manufacturing flows for MRAM/magnetic devices
- Removal or limited use of magnetic wands/pencils/pick-up tools
- Labeling of equipment that contains magnets with Universal Magnetic Symbol

- CAES Colorado Springs Training and Awareness

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The following lists product specific features which are currently being implemented on the MRAM devices:

- Marked lids with a Magnetic Warning Symbol
- Magnetic Warning Labels added to shipping bags, boxes, and other packaging materials
- Shipping boxes have at least 2 inches of clearance around the MRAM device
- Application Note for Customer Awareness and Handling Recommendations added to shipping boxes

9.0 CAES Handling Recommendations for MRAM products

CAES Colorado Springs recommends that customer's keep the MRAM device at least three inches away from any SMF to avoid potential damage to the MRAM device. CAES also recommends that customer's perform a facility audit for SMF's to include any equipment/tools that contain magnets or have been exposed to magnets. CAES Colorado Springs used a Vector/Magnitude Gaussmeter Model VGM to perform a facility audit.

CAES Colorado Springs also recommends degaussing any non-magnetic equipment/tool that measures over 100G. Degaussing is the process of decreasing or eliminating a remnant magnetic field. CAES utilizes demagnetizers with a portable pistol grip rated from +60G to –60G. CAES recommends that the user move the "wand" in a circular motion while moving over the entire area of the object. When the demagnetizer moves in a circular motion across the area, the demagnetizer will produce +60G and –60G and the magnetic field will decrease to zero over a certain amount of time. CAES uses the following demagnetizers:

- Industrial Magnets – P/N DSC423-120
- Walker Hagou Magnetics – P/N HD2

For more information on the specific demagnetizers that CAES uses, click on the following links:
http://www.magnetics.com/product.asp?ProductID=49
http://www.walkermagnet.com/other-products-demagnetizers-aperture.htm

Plate Type Demagnetizers are ideal for tool room use to demagnetize drills, cutters, ball and roller bearings, etc. The part demagnetizes by sliding it smoothly and slowly over the top of the plate, passing it clear of the demagnetizing field. The flat surface allows easy demagnetization of numerous objects.

Aperture Type Demagnetizers are widely used to demagnetize tools, cutters, small parts, bearing components, and assemblies. The item passes through the aperture and taken away from the demagnetizing field. The user must make sure that the object is well away from the demagnetizing field before the user switches off the demagnetizer.

The product specific demagnetizer manual will have detailed instructions on how to de-gauss an object. Each demagnetizer is different, so the user should understand the operation of the specific demagnetizer purchased.

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10.0 Summary

In summary, CAES MRAMs are immune to magnetic fields below 100G during reading, writing, standby, and unpowered operating conditions. Magnetic exposure is a non-issue in Space as the strongest natural field in the solar system is at Jupiter's North Pole measuring 15G. Proper handling is required terrestrially, as indicated in this application note. By following CAES' recommendation to keep the MRAM devices at least 3 inches away from SMFs greater than 100G, is an easy way to avoid magnetic exposure to the MRAM devices. Knowing and understanding the magnetic environment surrounding the MRAM device will help enable the customer to easily and properly handle the MRAM devices.

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