Freescale Semiconductor
Application Note

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Impact of External Magnetic Fields on MRAM Products

by: Jason Janesky
Freescale Semiconductor
Austin, TX

1 Introduction

This application note discusses magnetic fields, the sources and magnitudes of magnetic fields, and their impact on the performance of Freescale's MRAM products.

2 Overview of MRAM Operation

MRAM uses data bits made from magnetic tunnel junctions (MTJ) composed of two magnetic layers separated by an oxide tunneling barrier. One of the magnetic layers has a free magnetization that can be switched between two stable directions, while the other layer has a fixed magnetization direction that acts as a reference. See Figure 1.

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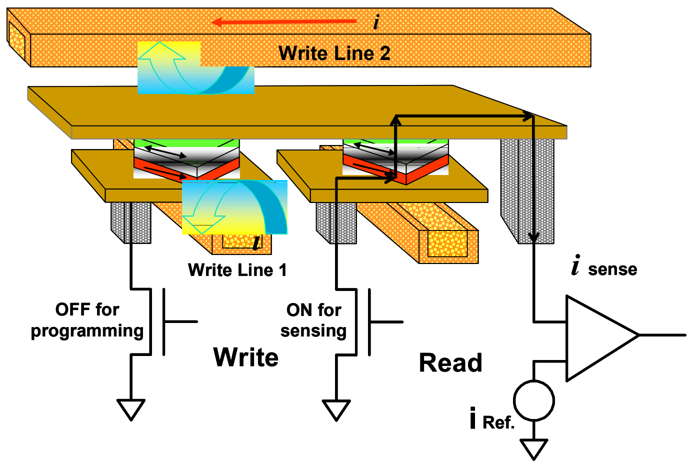

Figure 1. Bit Cell

The electrical resistance of the MTJ is low when the magnetizations of the layers are aligned in the same direction and high when they are oppositely aligned. Data is therefore stored by switching the direction of the free layer magnetization into the high resistance state for a one or a low-resistance state for a zero. This is accomplished by passing currents along mutually orthogonal lines that intersect over the target cell, generating a sufficient magnetic field to cause the cell to switch. The nominal magnetic field required to switch a bit is approximately 90 gauss. Because the device operation depends on magnetic fields to program the memory, stray magnetic fields can impact the performance if the part is unshielded.

Freescale MRAM devices have been shielded to be immune to magnetic fields in all reasonable applications and environments. The current spec for field immunity is 25 gauss in any direction, which is an adequate margin to meet requirements in all but the most extreme applications where simple layout considerations can provide a solution.

3 Magnetic Fields, Magnitudes and Sources, and Government Standards

Magnetic fields are used and produced in many everyday technologies, including cell phone and radio speakers, electrical transmission lines, disk drives, motors, TVs, many household appliances, and medical devices such as MRIs. Despite this preponderance of magnetic fields in the environment, finding magnetic fields of a magnitude greater than a few gauss is rare. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has set a limit for magnetic field exposure at 4.2 gauss for occupational workers and 0.8 gauss for the general public. In addition, there have been numerous studies of household and work environments from a variety of appliances and tools that show all items measured to have less than 1 gauss at distances greater than six inches. As a comparison, these values are comparable to the Earth's magnetic field, at approximately 0.5 gauss. These values represent the general environment applicable to normal human experiences and are well below the current specification of 25 gauss on MR2A16A. There is also an internationally adopted standard covered by the European Union, IEC-61000-4-8, on the magnitude of magnetic fields that a device can experience under normal operation. The maximum value of 12.6 gauss is well below the current MRAM specification of 25 gauss.

Despite the pervasive use and production of magnetic fields within everyday equipment, magnetic fields of significant magnitude are difficult to find. This is because of the rapid decay of a magnetic field's strength as distance increases from its source. There are two main sources of magnetic fields: current carrying wires and permanent magnetic materials. Both of these sources produce a magnetic field of magnitude and extent determined by the source's geometry. In practice, it is difficult to generate large magnetic fields at considerable distances from the field's source.

4 How Fields are Measured and Calculated

This section discusses the scientific terminology of magnetic fields. See Table 1 for the various units that describe the magnitude of a magnetic field. Magnetic induction, B, is used to describe the magnetic environment inside of a magnetic material. When describing the magnetic environment in free space, such as around an MRAM device, magnetic induction, B, is proportional to magnetic field, H.

Table 1. Units for Magnetism in Different Systems

	CGS Unit System	S.I. Unit System
Magnetic induction, B	Gauss (G)	Tesla (T)
Magnetic field, H	Oersted (Oe)	Amps/meter

In free space, all four units can be used with the conversion being:

Eqn. 1

$$1 Oersted = 1 Gauss = \frac{10^3}{4\pi}\frac{A}{m} = 10^{-4} Tesla$$

Magnetic fields are a vector entity, meaning that field magnitude and direction are required to completely describe them.

Magnetic fields can also be calculated using several commercially available simulation software packages. These packages solve Maxwell's equations for the boundary value problem specified in a user-defined situation. They provide the magnitude and direction of the magnetic field produced by user defined sources. The sources can be a permanent magnet, as used in say a cell phone speaker, or current carrying lines.

5 Examples of Calculated and Measured Magnetic Fields

The first example is a long straight wire carrying 200 Amps, such as a starter cable for an engine with a cross-section of 1.5 centimeters. This is at the extreme end of magnetic field production for a current carrying wire. The equation used to calculate the magnetic field for this situation is called Ampere's Law:

Eqn. 2

$$B = \frac{\mu_0 I}{2\pi r} \times 10^4 \quad \text{(gauss)}$$

where μ_0 is the permeability of free space and equals $4\pi \times (10^{-7} Tesla \times meter)/Amp$, I is the current in Amps, and r is the radial distance from the center of the wire in meters. The direction of the magnetic field circulates around the wire.

Table 2. Magnetic Field Versus Distance from a Wire Carrying 200 Amps

Distance from Wire Center (cm)	Magnetic Field (gauss)
2	20
3	13.3
4	10
5	8
6	6.6
7	5.8
8	5
9	4.2
10	4

As shown in Table 2, the magnitude of the field decays rapidly with distance and only exceeds the spec for MR2A16A within approximately 1 cm from the wire surface.

This is a good example of a large source of magnetic fields where the extent of magnetic field is very small. For applications such as this, a simple design/layout modification of keeping the chip more than 2 cm from the wire would be adequate.

The general trend of the distance from the center of a wire to the 25 gauss boundary versus current in the wire is shown in Figure 2. For typical currents observed on a circuit board, 25 gauss is only achieved within the physical dimensions of the wire. As is evident, the production of magnetic fields greater than the specification for MR2A16A is difficult to achieve and can be designed around easily.

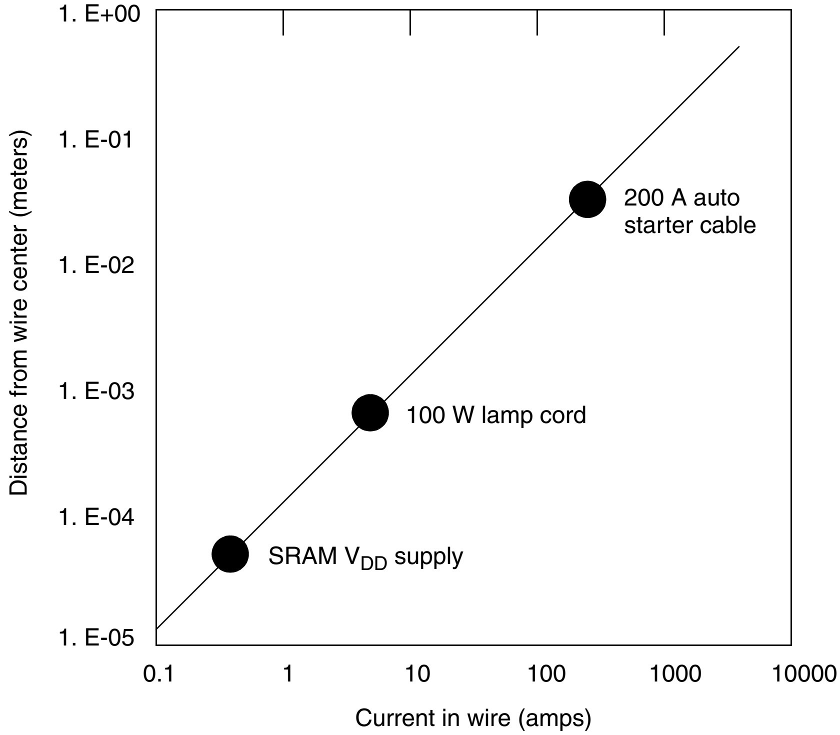

Figure 2. Distance from the Wire Versus Wire Current Below the 25 Gauss Spec for MR2A16A.

The second example is a hard permanent magnet, such as a refrigerator magnet or one found in the speaker of a cellular phone. A magnitude of 90 Gauss was measured at the surface of a cellular phone speaker. However, within 5 mm of the surface the field was below 10 gauss and negligible beyond 1 cm. Again, a small design/layout consideration would meet the spec required for MRAM operation.

As can be seen, the exact details and extent of the magnetic field depend critically on the geometry of the source of the magnetic field. However, there are a variety of analytical, simulation and measurement techniques that can easily provide the assurances required to meet the 25 gauss spec.

6 How Freescale's MRAM is Shielded from Magnetic Fields

Magnetic fields can be effectively attenuated by surrounding the region of interest by a high permeability material. High permeability materials are ferromagnetic materials that respond to and, in part, cancel external magnetic fields by adjusting their internal magnetization. MRAM devices have a layer of magnetic shielding, called mu-metal, that effectively attenuate external fields by a factor of 10. In extreme magnetic environments, additional layers of shielding can be used to provide substantially more isolation.

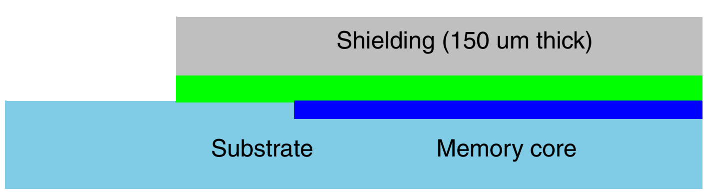

Figure 3. Layout of the Shielding Used in MRAM.

7 Example of Testing MRAM Field Sensitivity

Testing of MRAM has been conducted in a variety of environments. Figure 4 is a quadruple magnet capable of producing magnetic fields of several hundred gauss in any direction within the plane of the part. A Helmholtz pair (not shown) has been used to generate field perpendicular to the part.

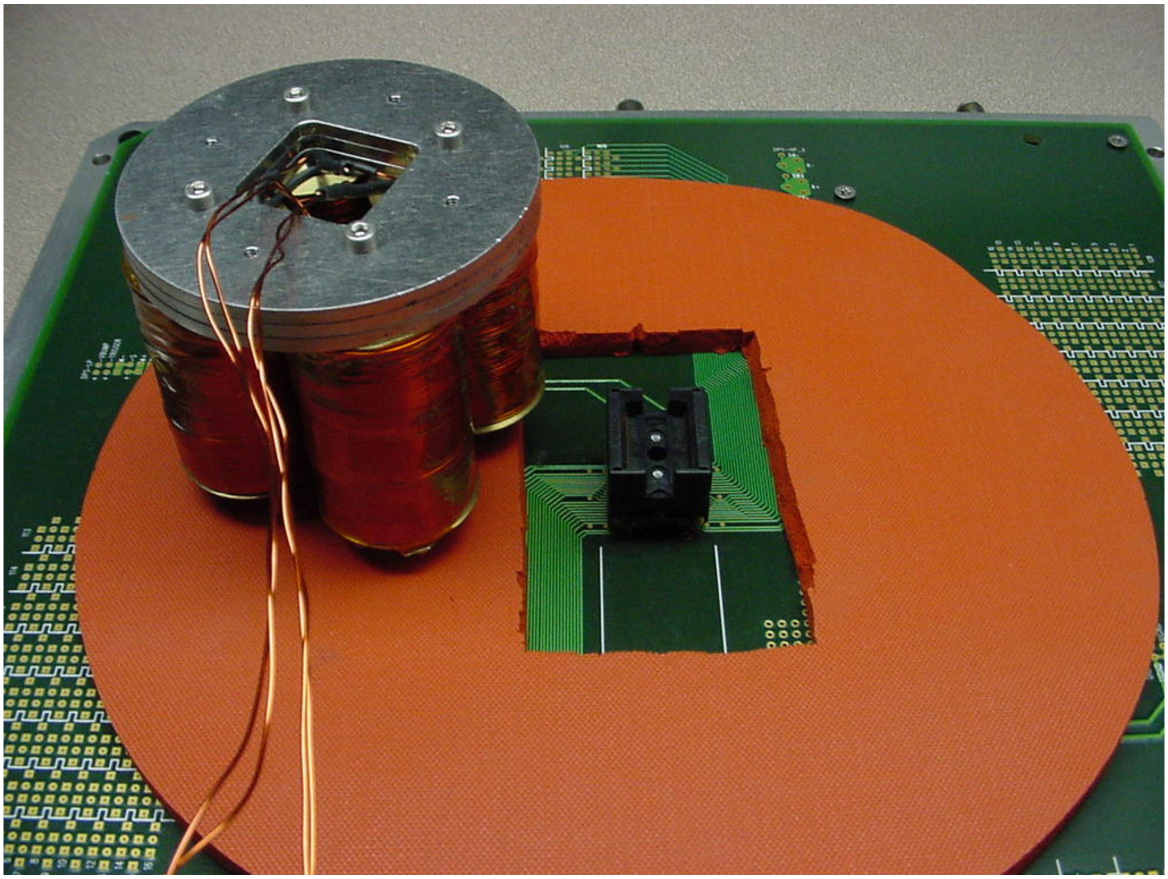

Figure 4. Field-Generating Coils Near Socket

These coils generate several hundred gauss in any direction relative to the part.

Extensive tests were carried out measuring performance versus applied field during part operation and after application of external fields.

Typical tests were as follows:

1. Set the field to X gauss at angle Y degrees relative to the long axis of the device
2. Measure part performance (to determine error rate while operating)
3. Return field to 0 gauss
4. Measure part performance (to determine destructive error rate)
5. Repeat 1-4 by changing angle through 360 degrees in 45 degree steps
6. Repeat 1-5 by changing the field in five gauss steps until failures are observed.

Data collected from a test flow and setup similar to the one shown were used to set the MRAM specification with sufficient margin to ensure good process control.

8 Conclusion

Freescale's MRAM memory devices have a specification on maximum external magnetic fields. The current specification is an order of magnitude above typical values found in everyday environment and more than three times government standards. This magnitude should require no design consideration in most applications and a minimal amount of physical layout optimization in special cases. Given the rapid decay of magnetic fields from their sources, separating MRAM devices from a high magnetic field source by approximately one centimeter meets the specification. Contact Freescale for any special cases, environments, or general consultation on magnetic fields and their impact on part performance.

How to Reach Us:

Home Page:
www.freescale.com

Web Support:
http://www.freescale.com/support

USA/Europe or Locations Not Listed:
Freescale Semiconductor, Inc.
Technical Information Center, EL516
2100 East Elliot Road
Tempe, Arizona 85284
+1-800-521-6274 or +1-480-768-2130
www.freescale.com/support

Europe, Middle East, and Africa:
Freescale Halbleiter Deutschland GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
www.freescale.com/support

Japan:
Freescale Semiconductor Japan Ltd.
Headquarters
ARCO Tower 15F
1-8-1, Shimo-Meguro, Meguro-ku,
Tokyo 153-0064
Japan
0120 191014 or +81 3 5437 9125
support.japan@freescale.com

Asia/Pacific:
Freescale Semiconductor Hong Kong Ltd.
Technical Information Center
2 Dai King Street
Tai Po Industrial Estate
Tai Po, N.T., Hong Kong
+800 2666 8080
support.asia@freescale.com

For Literature Requests Only:
Freescale Semiconductor Literature Distribution Center
P.O. Box 5405
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Fax: 303-675-2150
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