APPLICATION NOTE

Design Guidelines on Magnetic Immunity

Ultra-Low Power Apollo SoC Family

A-SOCAP4-ANGA01EN v2.1

Legal Information and Disclaimers

Revision History

Revision	Date	Description
1.0	June 10, 2022	Initial Release.
1.1	August 2, 2022	Updated Table 5-1 Safe Distance (in mm) vs Magnet Size in Free Space.
1.2	September 2, 2022	▪ Corrected 6mm magnet diameter, 3mm magnet thickness value from 2.0mm to 2.9mm in Table 5-1 Safe Distance (in mm) vs Magnet Size in Free Space (page 13). ▪ Corrected 4mm magnet diameter, 3mm (10x10) magnet thickness value from 2/4mm to 2.4mm in Table 6.7 SUS430 Free Space vs. Shielding Model B (page 18).
1.3	June 22, 2023	▪ Corrected unit from Hmax to Bmax for Tables 4-1 and 4-2. ▪ Updated section 2 for Apollo4 Lite Family
1.3	July 6, 2023	▪ Updated section 2 MRAM Location Overview ▪ Updated Table 4-1 Active Write Safe Field Limit ▪ Updated Table 4-2 Static Mode Safe Field Limits
2.0	January 30, 2025	▪ Added MRAM cell locations for Apollo510 family. ▪ Corrected Table 4-1 Bmax specification for 70C. Added limits for 85C.
2.1	August 8, 2025	▪ Corrected Apollo510 BGA second MRAM cell z-axis center point location in Table 2-1. ▪ Updated Apollo510 CSP MRAM cell locations for z-axis in Table 2-1.

Reference Documents

Document ID	Description

Table of Contents

List of Tables

List of Figures

SECTION 1

Introduction

The Apollo4 and Apollo510 Families contain non-volatile Magneto-resistive Random Access Memory (MRAM). MRAM is susceptible to strong external magnetic fields and requires proper handling in the commercial and industrial environments.

This document has been written to provide basic guidelines that are easy to follow and help guide users while designing their applications. If an application is safely within the guidelines provided in this document, magnetostatic simulations can be avoided. However, in the case where an application is outside of the limits herein, it is straightforward to run simulations to assess a system's performance.

NOTES:

The Apollo510 SoC architecture was updated to harden the device against MRAM corruption. This includes holding trims, security configurations, and key assets in dedicated anti-fuse-based OTP memory, moving the Secure BootROM to ROM, and adding an MRAM Recovery feature as part of the Secure Boot flow. For more details, see the Apollo510 MRAM Recovery Guide and the examples provided in the AmbiqSuite SDK for reference.

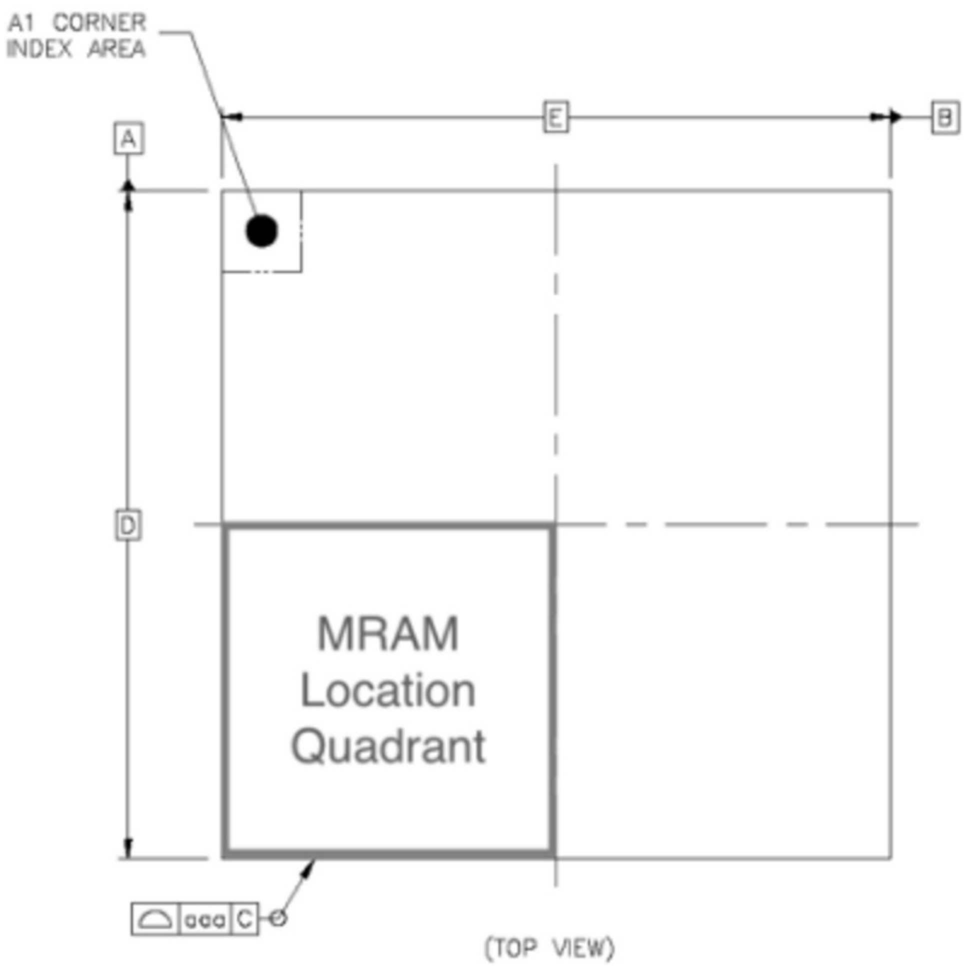
SECTION

2

MRAM Location Overview

The MRAM is located at the following position for the Apollo4, as seen from the top side of the IC:

Figure 2-1: MRAM Location Quadrant



The size of an MRAM cell is roughly 1.72 mm x 1.37 mm, and is 0.1 mm thick. Members of the Apollo510 family have two side-by-side MRAM cells, so there are listed two MRAM center points per SoC. The MRAM center points are shown in Table 2-1, measured from pin 1 corner, top side of package:

Table 2-1: MRAM Center Points

Ambiq Product	**MRAM Center Points**
Apollo4, Apollo4 Plus	(1.5 mm, -3.5 mm, -0.4 mm)
Apollo4 Blue, Apollo4 Blue Plus	(1.35 mm, -3.35 mm, -0.5 mm)
Apollo4 Lite	(1.72 mm, -3.1 mm, -0.4 mm)
Apollo4 Blue Lite	(1.75 mm, -2.96 mm, -0.5 mm)
Apollo510 BGA	(1.81 mm, -4.69 mm, -0.28 mm), (3.68 mm, -4.81 mm, -0.28 mm)
Apollo510 CSP	(0.96 mm, -3.73 mm, -0.25 mm), (2.84 mm, -3.84 mm, -0.25 mm)
Apollo510B	(1.31 mm, -4.19 mm, -0.36 mm), (3.18 mm, -4.31 mm, -0.36 mm)

SECTION 3

Magnetic Fields

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.

Magnetic field measurement units are shown in Table 3-1.

Table 3-1: Magnetic Field Measurement Units

Magnetic Fields	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:

$$1 \text{ Oe} = 1 \text{ G} = 10^{-4} \text{ T} = 103/(4*\pi) \text{ A/m}$$

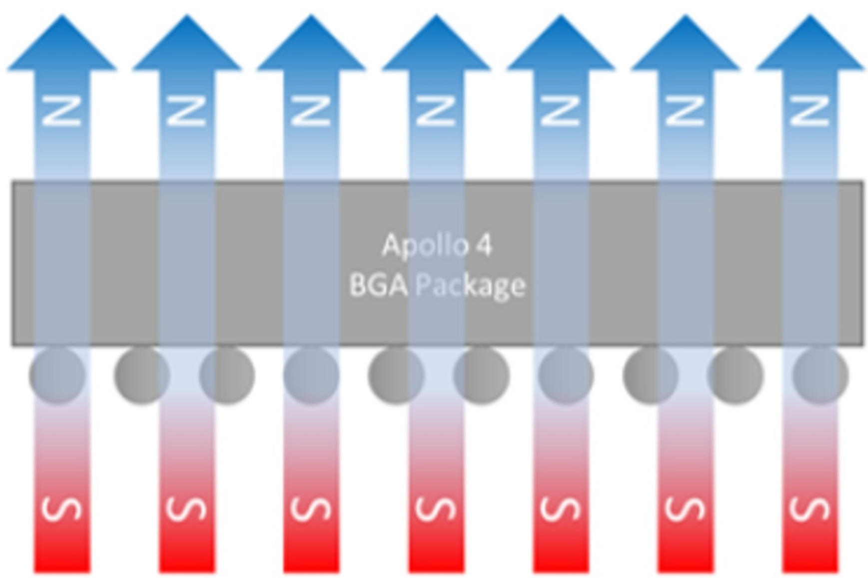
In addition, this document discusses magnetic shielding materials. These materials have two properties: permeability and saturation. Magnetic permeability (B/H) is defined as the magnetic induction, B, divided by the magnetic field, H. The saturation point of a material is defined simply by the magnetic induction, B. Magnetic permeability describes the change in magnetic field inside a material in response to an applied magnetic field, while saturation is the point where the magnetic flux inside the material begins to level off and no longer increases with applied magnetic field.

SECTION 4

Magnetic Field Limits

Table 4-1 and Table 4-2 on page 12 specify the safe operation magnetic field limits for two operating cases: static read only MRAM operations, and active write MRAM operations. The 'static' cases also apply when MRAM is not being read or written, and include the Apollo SoC not being powered. The limits assume a vertical orientation between magnet and MRAM, as shown below. The limits are the same whether the flux is traveling through the bottom of package or top of package. These limits apply to Apollo4, Apollo4 Plus, Apollo4 Lite, and Apollo510, including the Blue variants.

Figure 4-1: Magnetic Field Direction



The chip failure rate is defined as the percentage of failed Apollo devices after a given number of operations in specified conditions. For example, 100 ppm after 100k cycles means that 100 out of 1,000,000 parts would have at least one bit failure after 100,000 cycles of operations throughout the entire MRAM array.

Note that MRAM has internal error correction code (ECC). A 1-bit error will not result in an actual external error. The below tables represent 100 ppm chip failures with ECC functionality enabled. The below failures are for data retention. If a data retention failure occurs in a user's application region of MRAM, a reprogram operation will recover the content.

The 'static' cases show both a 1-day and 0.1-day (or 144 minute) exposure to the external magnetic field.

Table 4-1: Active Write Safe Field Limit

	Temperature						
Safe Magnetic Field Induction Limit for Active Write	**-40°C**	**0°C**	**25°C**	**45°C**	**60°C**	**70°C**	**85°C**
Cycle	20k	100k	100k	100k	100k	100k	100k
Bmax	208G	272G	310G	345G	369G	387G	410G

Table 4-2: Static Mode Safe Field Limits

	Temperature						
Safe Magnetic Field Induction Limit for Static Mode	**-40°C**	**0°C**	**25°C**	**45°C**	**60°C**	**70°C**	**85°C**
Bmax (1 day)	2238G	1876G	1660G	1468G	1333G	1242G	1080G
Bmax (0.1 day)	2335G	1961G	1740G	1539G	1398G	1305G	1130G

SECTION

5

General Guidance

In general, the magnetic field strength a given distance from a magnet is the result of several factors:

- The shape of the magnet
- The size of the magnet
- Magnetic material
- Pull strength
- Distance and direction of the magnet with respect to the point of measurement

For the general case, an N52 magnet with various diameters and thicknesses are used to recommend safe distances from the magnet to an Apollo4 device. Note that the below guidelines are targeting total magnetic induction of less than 1400 G. While the safe limit for active write operations is much lower than static operations, applications can implement MRAM write retries, which is the act of verifying MRAM contents after a write and subsequently re-writing if necessary. This allows the static safe operation limit to become the worst-case design target. For typical operation, it is recommended that users observe the active write limit.

Figure 5-1: Free Space Model

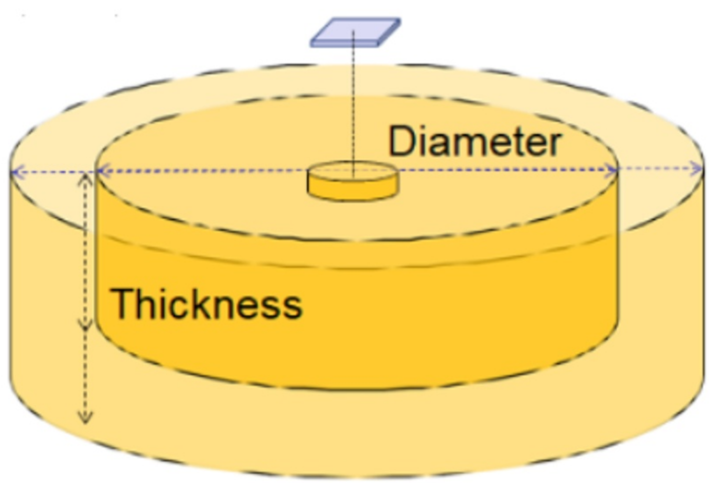


Table 5-1 below represents the safe distance, in mm, from an N52 magnet of various dimensions from the SoC package in free space, with the magnet and the SoC package centered over each other as shown in Figure 5-1:

Table 5-1: Safe Distance (in mm) vs Magnet Size in Free Space

	Magnet Thickness (mm)				
Magnet Diameter (mm)	**1**	**2**	**3**	**4**	**5**
20	-	-	3.7	5.5	6.7
15	-	2.4	4.2	5.3	6
10	1.1	2.8	3.8	4.4	4.8
8	1.3	2.7	3.4	3.8	4.1
6	1.4	2.4	2.9	3.2	3.3
4	1.4	1.9	2.2	2.3	2.4
2	1	1.2	1.3	1.3	1.3

NOTES:

- The results marked with '-' indicate a required distance of 0 mm. This is due to the aspect ratio of the magnet causing the field strength in the center to be extremely low. Care should be taken in designs with magnets of such size to simulate the field strength if the SoC package is off-center with the magnet.
- The results in Table 5-1 as listed are for an Apollo4 SoC. Users should consider the difference in distance from the MRAM to the top of the package for the various products listed in *Section 2 MRAM Location Overview on page 8* when determining the safe distance for their system. In *Section 6 Shielding on page 15*, the safe distances reported are measured by distance from the MRAM cell, and as such, the results are package and SoC agnostic.

SECTION

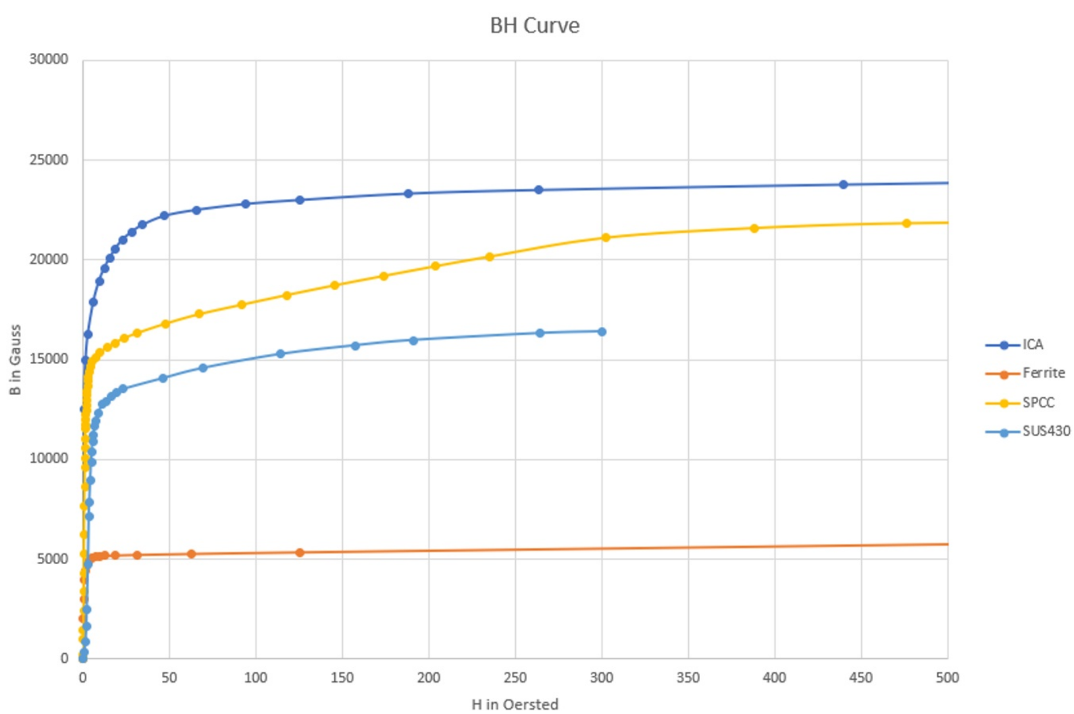
6

Shielding

The best way to mitigate magnetic induction on the Apollo SoC MRAM is by keeping it sufficiently far from the magnetic source, as defined by Table 5-1 on page 14. However, this is not always possible in small form factor IoT or wearable devices. Introducing magnetic shielding into a design can allow for more compact placement of magnet and MRAM devices, if sufficient care is taken for the selection of materials and the geometry of the shielding.

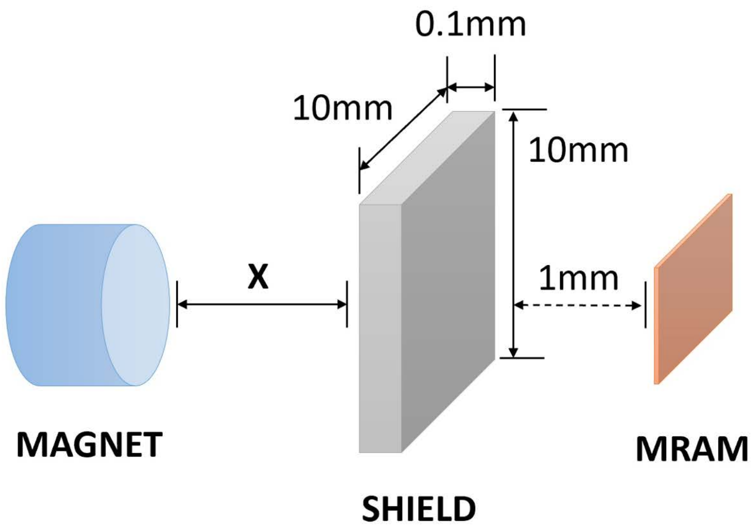
As described in 'Magnetic Fields', the effectiveness of the shielding material is described by its permeability and saturation point. The Tables below show the effectiveness of four shielding materials: cold rolled carbon steel (SPCC), stainless steel 430 (SUS430), standard ferrite material, and an iron cobalt alloy (ICA). Their respective BH curves are shown in Figure 6-1.

Figure 6-1: Material BH Curves



A model for the environment with these shielding materials is shown in Figure 6-2. A magnet of variable size is separated by some distance ‘x’ from the shielding material, which is 1 mm away from the MRAM cell. The MRAM, magnet face, and shield are centered horizontally. The shielding material has a length and width of 10 mm and is 0.1 mm thick.

Figure 6-2: Shielding Model A



The tables below specify the distance ‘x’, in mm, between the face of the magnet and the edge of the various 0.1mm thick shielding material, which results in less than 1400 G on the MRAM cell. At a distance of 0mm, the magnet can be in contact with the shield. Note that the same considerations apply for the 20, 15 and 10 mm diameter, 1 mm thick magnets as described in *Section 5 General Guidance on page 13*.

Table 6-1: Magnet-to-shield distance for < 1400 G using SUS430 Shielding Material

	Magnet Thickness (mm)				
Magnet Diameter (mm)	**1**	**2**	**3**	**4**	**5**
20	0	0	1.1	2.8	4.1
15	0	0.2	1.9	2.7	3.5
10	0	0.7	1.6	2.2	2.6
8	0	0.8	1.4	1.8	2.1
6	0	0.7	1.1	1.3	1.5
4	0	0.4	0.6	0.7	0.8
2	0	0	0	0	0

Table 6-2: Magnet-to-shield distance for < 1400 G using Ferrite Shielding Material

	Magnet Thickness (mm)				
Magnet Diameter (mm)	**1**	**2**	**3**	**4**	**5**
20	0	0	1.4	3.5	4.8
15	0	0.2	2.3	3.5	4.3
10	0	1.2	2.2	2.8	3.2
8	0	1.3	2	2.4	2.7
6	0.1	1.1	1.5	1.8	2
4	0.2	0.7	0.9	1	1.1
2	0	0	0.1	0.1	0.2

Table 6-3: Magnet-to-shield distance for < 1400 G using ICA Shielding Material

	Magnet Thickness (mm)				
Magnet Diameter (mm)	**1**	**2**	**3**	**4**	**5**
20	0	0	1	2.6	3.7
15	0	0.1	1.5	2.5	3.1
10	0	0.5	1.3	1.9	2.3
8	0	0.5	1.2	1.5	1.8
6	0	0.5	0.8	1.1	1.2
4	0	0.2	0.4	0.5	0.6
2	0	0	0	0	0

Table 6-4: Magnet-to-shield distance for < 1400 G using SPCC Shielding Material

	Magnet Thickness (mm)				
Magnet Diameter (mm)	**1**	**2**	**3**	**4**	**5**
20	0	0	1	2.7	3.8
15	0	0.1	1.5	2.6	3.3
10	0	0.6	1.4	2	2.4
8	0	0.6	1.2	1.6	1.9
6	0	0.5	0.9	1.2	1.3
4	0	0.3	0.5	0.6	0.6
2	0	0	0	0	0

As an example of how material thickness can influence the material's ability to provide magnetic shielding for MRAM devices, the below table demonstrates how increasing the thickness of a 10 mm x 10 mm SUS430 from 0.1 mm thick to 0.2 mm can benefit an end application:

Table 6-5: Effect of incremental increase in magnet thickness on shielding using SUS430 material

Magnet Diameter (mm)	Magnet Thickness (mm)									
	1		2		3		4		5	
	+0.1	+0.2	+0.1	+0.2	+0.1	+0.2	+0.1	+0.2	+0.1	+0.2
20	0	0	0	0	1.1	1	2.8	2.6	4.1	3.7
15	0	0	0.2	0.1	1.9	1.2	2.7	2.2	3.5	3
10	0	0	0.7	0.3	1.6	1.1	2.2	1.6	2.6	2
8	0	0	0.8	0.3	1.4	0.9	1.8	1.3	2.1	1.5
6	0	0	0.7	0.3	1.1	0.6	1.3	0.8	1.5	1
4	0	0	0.4	0.1	0.6	0.2	0.7	0.3	0.8	0.4
2	0	0	0	0	0	0	0	0	0	0

Another factor that must be considered is the relationship between the size of the magnet and the size of the shield. Table 6-6 demonstrates how a 6 mm x 6 mm, 0.1 mm thickness SUS430 shield influences the safe distance against the 10 mm x 10 mm shield demonstrated previously:

Table 6-6: Effect of shield diameter on shielding using SUS430 material

Magnet Diameter (mm)	Magnet Thickness (mm)									
	1		2		3		4		5	
	10x10	6x6	10x10	6x6	10x10	6x6	10x10	6x6	10x10	6x6
20	0	0	0	0	1.1	1.6	2.8	3.7	4.1	4.8
15	0	0	0.2	0.2	1.9	2.3	2.7	3.3	3.5	4
10	0	0	0.7	0.9	1.6	1.8	2.2	2.4	2.6	2.8
8	0	0	0.8	0.9	1.4	1.6	1.8	1.9	2.1	2.2
6	0	0	0.7	0.7	1.1	1.1	1.3	1.4	1.5	1.6
4	0	0	0.4	0.4	0.6	0.6	0.7	0.7	0.8	0.8
2	0	0	0	0	0	0	0	0	0	0

As the magnet diameter gets larger compared to the size of the shielding, the shield acts more to attract the field lines from the edges of the magnet towards the Ambiq device than provide shielding. As such, care should be taken when choosing the appropriate geometry for the MRAM shielding.

Thus far, all cases have been based on model A shown in Figure 6-2 on page 16. The designer should take care to consider the scenario where the Ambiq device is in between the shielding and a magnet. In such a case, the shielding on the other side of the MRAM can act to focus more flux on the MRAM than would otherwise be the case. Figure 6-3 below is a diagram of Model B and Table 6-7 shows the safe distance comparison between a magnet and MRAM in free air.

Figure 6-3: Shielding Model B

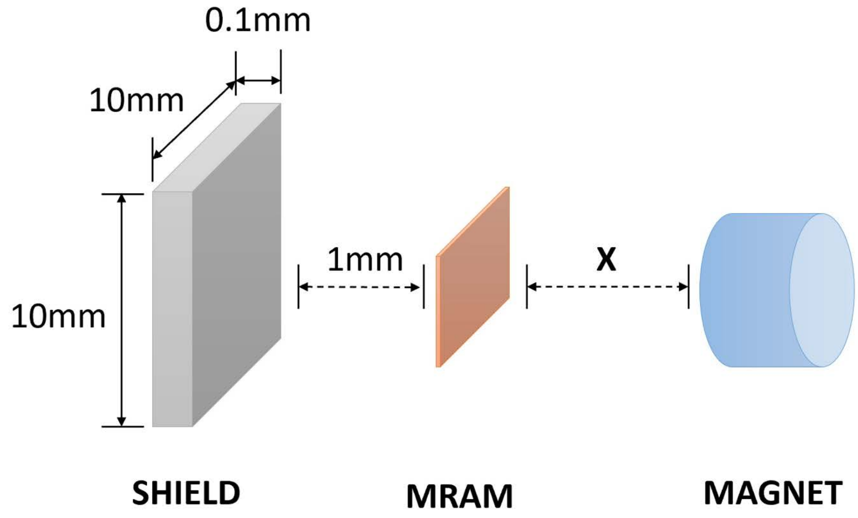


Table 6-7: Magnet-to-shield distance for < 1400 G in Model B vs Free Air (FA) configuration using SUS430 Material

Magnet Diameter (mm)	Magnet Thickness (mm)									
	1		2		3		4		5	
	FA	10x10	FA	10x10	FA	10x10	FA	10x10	FA	10x10
20	0	0	0	0.1	3.5	4.7	5.5	6.6	6.7	8.1
15	0	0	1.7	3.6	4.2	5.1	5.3	6.2	6	6.9
10	0	1.2	2.8	3.7	3.8	4.5	4.4	5.1	4.8	5.6
8	0.5	1.8	2.7	3.3	3.4	4	3.8	4.4	4.1	4.8
6	1.4	1.8	2.4	2.8	2.9	3.4	3.2	3.7	3.3	3.9
4	1.4	1.5	1.9	2.1	2.2	2.4	2.3	2.6	2.4	2.7
2	1	1	1.2	1.2	1.3	1.3	1.3	1.4	1.3	1.4

SECTION

7

Other Considerations

While the above considerations are helpful in the industrial design of a product, care must be taken to ensure that MRAM contents are protected even before final product assembly. Many product assembly lines have exposure to strong magnetic fields. Product designers should take care to evaluate the environment of their production assembly line to ensure that Apollo4 and Apollo510 devices are not subject to strong fields that may corrupt MRAM contents prior to final assembly.

In cases where the above guidelines cannot be met, or where the design is only marginally able to achieve the distances outlined above, the user should perform magnetostatic simulation of their industrial design to ensure the Apollo4 or Apollo510 MRAM field limits are not violated.

6500 River Place Boulevard, Building 7, Suite 200, Austin, TX 78730
www.ambiq.com
sales@ambiq.com
+1 (512) 879-2850

A-SOCAP4-ANGA01EN v2.1
August 2025