Excelon F-RAM system life expectancy calculation

About this document

Scope and purpose

Excelon™ F-RAM™, like any other nonvolatile memory technology, is subject to physical degradation that can eventually lead to device failure if not addressed appropriately. F-RAM write/read endurance and data retention are the two end-of-life (EoL) parameters to specify its reliability and performance in a system.

F-RAM offers up to 10^{14} (100 trillion) write/read endurance cycle, which allows systems to continuously access the F-RAM at 40-MHz SPI clock for more than 43 years before it wears out its endurance limit. This exceptionally high endurance offered by F-RAM eliminates any problem associated with the system's life expectancy and performance.

The F-RAM data retention, which is the other EoL parameter, reduces the system's life expectancy when the system's operating temperature increases. Therefore, appropriate measures must be taken to guarantee the system's operational life through its usages.

This application note discusses the F-RAM data retention performance at various operating temperatures and provides a method and guidance to accurately calculate the system's EoL based on its operating temperature profile.

Intended audience

This application note is intended for system design/qualification engineers and system/product architects.

Table of contents

1 Introduction

Excelon Auto F-RAM data retention is specified as 11,000 hours (approximately 1.25 years) @ 125 °C. This data retention seems very small when compared to an actual automotive system's operational life.

However, in reality, most automotive systems do not operate under a steady temperature through their usage life. Instead, these systems typically experience varying temperature profiles during their operational life. Therefore, the life expectancy of such systems should not be estimated only on the basis of their rated extreme (peak) operating temperature, which is achieved once in a while, but according to their actual operating temperature profiles during their usage life.

The data retention specification for the F-RAM technology is cumulative, which means that if a portion of F-RAM data retention has been utilized at a specific temperature, and if the F-RAM content is refreshed with new data, the retention of the newly written data can be guaranteed only for the remaining duration at that temperature. Once the operating temperature changes, based on whether the temperature value decreases or increases, the remaining data retention period will increase or decrease, respectively.

This application note provides a method to calculate the Excelon F-RAM cumulative retention for multiple temperature environments throughout the end-applications' usage lifetime. The formula used to determine the acceleration factor (Arrhenius) is an industry standard; therefore, the same formula will apply to all F-RAM products including Excelon as well as legacy F-RAM family. The data retention performance and system life expectancy impact have been demonstrated further with the help of two use cases.

2 F-RAM data retention lifetime

A primary measure of reliability of F-RAMs is the retention lifetime of the ferro-capacitor-based memory cell that has been previously stored in a polarization state for an extended time and then written to the opposite polarization state. This type of retention is known as Opposite State (OS) retention. The effect of imprint makes the previously stored state, or Same State (SS), more stable than the OS retention. Therefore, this document focuses on the OS retention performance.

The OS retention is often specified as the device exposure to an amount of time at a given constant temperature. Thus, the OS retention (time) specification of F-RAM products for constant-temperature profiles are given in respective product datasheets. This application note discusses a cumulative scenario of multiple temperature profiles over the life of the product and how to apply the acceleration factor to estimate a system's EoL.

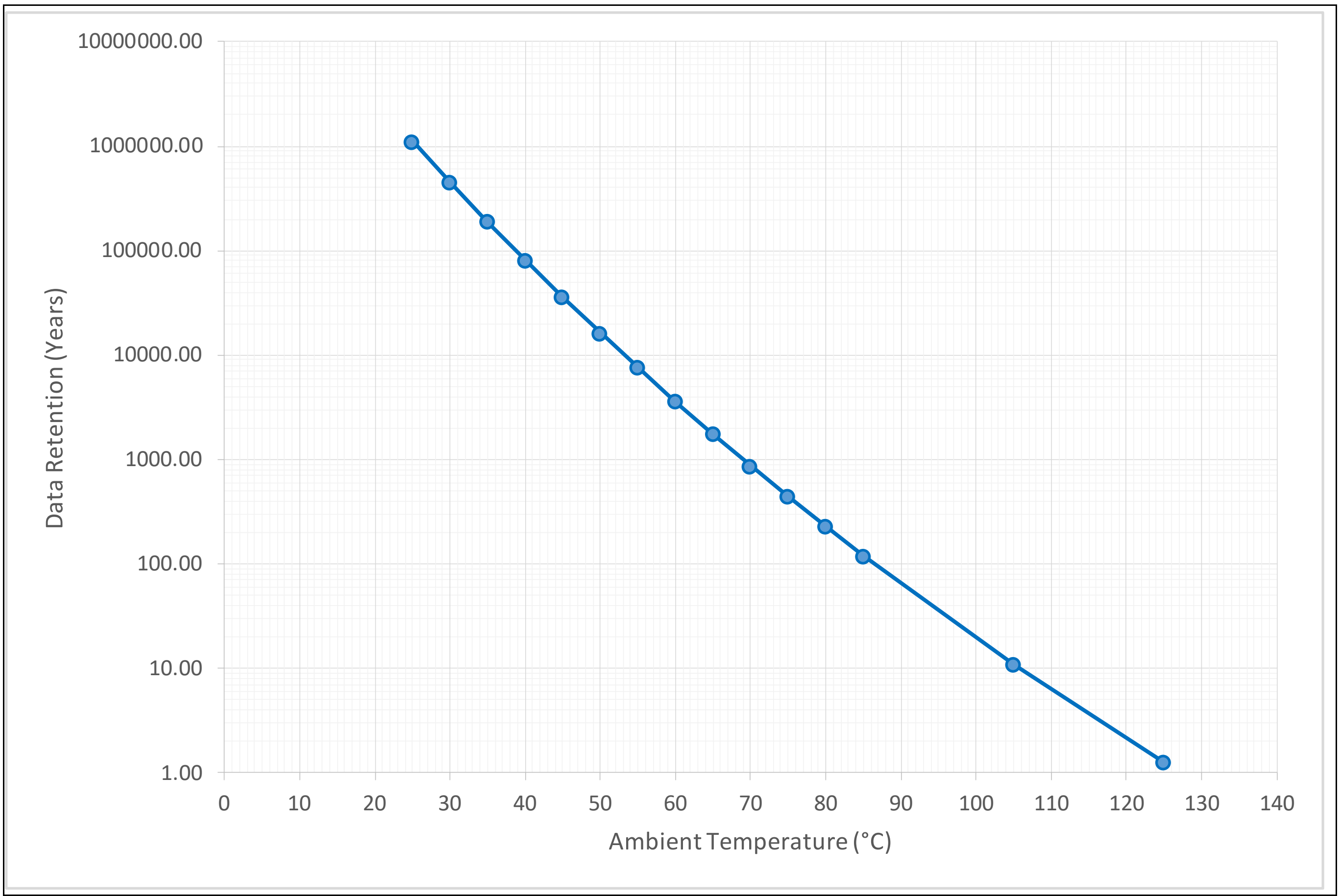

Figure 1 **Excelon F-RAM data retention vs. temperature**

3 System life calculations for customized temperature profiles

It is rare for an application to actually operate under a steady temperature for its entire usage life time. Instead, an application is often expected to operate in multiple temperature environments throughout the application's usage. Accordingly, the retention specification for F-RAM in applications often needs to be calculated cumulatively. Like other nonvolatile memories, F-RAM can use the Arrhenius equation (for reliability) to calculate the thermal acceleration factors for time-to-failure distributions.

By applying the Arrhenius equation, the acceleration factor A between T and Tmax is:

$$A = \frac{L(T)}{L(Tmax)} = e^{\frac{Ea}{k}\left(\frac{1}{T} - \frac{1}{Tmax}\right)}$$

Where:

A is the acceleration factor due to changes in temperature
E_a is the data retention activation energy (eV); E_a= 1.4eV for F-RAM
k is Boltzmann's constant (8.62 × 10^{-5}eV/K)
T is the system temperature (K)
Tmax is the highest temperature specified for F-RAM (K)

The Profile factor P is determined by:

$$P = \frac{1}{\frac{t1}{A1} + \frac{t2}{A2} + \frac{t3}{A3} + \frac{t4}{A4}}$$

Where:

P is the cumulative profile factor across the system's usage lifetime due to exposure to various operating temperatures t1, t2, and so on
A1 is the acceleration factor due to changes in temperature from Tmax to t1
A2 is the acceleration factor due to changes in temperature from Tmax to t2, and so on.

The system life expectancy of a temperature profile, L(P), is calculated by:

$$L(P) = P \times L(Tmax)$$

Where:

L(Tmax) is the retention time, specified in the datasheet, at maximum temperature; for example, Excelon Auto F-RAM data retention (T_{DR}) specification is 11,000 hours (approximately 1.25 years) at 125°C.

Table 1 and Table 2 demonstrate two use cases, which calculate the respective system's EoL based on the system's operating temperature profiles. You can also observe that the lifetime of a profile is dominated by the highest usage temperature and its time factor. Note that all calculations use 'T' as equal to or lower than the rated maximum operating temperature (Tmax) and equal to or higher than the rated minimum operating temperature (Tmin). It is mathematically correct to use the equations when T > Tmax, and T < Tmin; however, Infineon does not guarantee proper working of parts when the system's operating temperature (T) exceeds the F-RAM temperature specifications mentioned in the datasheet.

3.1 Use case 1 - automotive example (Excelon Auto F-RAM)

Tmax = 125 °C; T_{DR} (Data Retention) @125 °C = 11,000 hours.

Table 1 Automotive use case

Temperature	Time factor	Acceleration factor with respect to Tmax	Profile factor	System life time for the profile
(T)	(t)	(A)	(P)	L(P)
T1 = 125 °C	t1 = 0.10	A1 = 1	$P=\frac{1}{\frac{t1}{A1}+\frac{t2}{A2}+\frac{t3}{A3}+\frac{t4}{A4}}$ = 8.33	$L(P) = P \times L(Tmax)$ = 10.46 years
T2 = 105 °C	t2 = 0.15	A2 = 8.67		
T3 = 85 °C	t3 = 0.25	A3 = 95.68		
T4 = 55 °C	t4 = 0.5	A4 = 6074.80		

System lifetime of 10.46 years with time factor t1 = 0.1 indicates that the system is exposed to 125 °C for 10 percent of its total life, which is equivalent to 1.046 years or approximately 9163 hours.

Another use case: if an automotive system requirement is to operate for 1 year at 125 °C and for 19 years at 55 °C, then:

t1 =1-year/ (1-year + 19-year), or 0.05 (5%) of the system's life @125 °C;
t2=19-year/ (1-year + 19-year) or 0.95 (95%) of the system's life @55 °C;

The Profile Factor (P)=19.94 and the lifetime for such temperature profile L(P) is approximately 25 years.

3.2 Use case 2: industrial application (Excelon LP F-RAM)

Tmax= 85 °C; T_{DR} (Data Retention) @85 °C = 10 years

Table 2 Industrial use case

Temperature	Time factor	Acceleration factor with respect to Tmax	Profile factor	System life time for the profile
(T)	(t)	(A)	(P)	L(P)
T1 = 85 °C	t1 = 0.20	A1 = 1	$P=\frac{1}{\frac{t1}{A1}+\frac{t2}{A2}+\frac{t3}{A3}+\frac{t4}{A4}}$ = 3.67	$L(P) = P \times L(Tmax)$ = 36.68 years
T2 = 75 °C	t2 = 0.25	A2 = 3.7		
T3 = 55 °C	t3 = 0.30	A3 = 63.5		
T4 = 25 °C	t4 = 0.25	A4 = 9296.8		

3.3 Key notes

- The time factor should always add up to 1, which is 100 percent of the system's life.
- The total cumulative exposure of the system at its rated temperature should not exceed its rated retention specification at a specific temperature. For example, an automotive system with F-RAM should never be exposed to 125 °C for more than 11,000 hours (cumulatively), during its operational life.

It is possible to apply the reliability formula for operating temperature (T) above the rated (Tmax) to calculate the acceleration factor and estimate the system's life. However, if the device is exposed to higher temperature than rated, Infineon cannot guarantee the performance.

For example, you can use industrial data retention specification of 10 years at 85 °C to calculate the data retention value at 95 °C using the acceleration formula. However, because the operating temperature, 95 °C, is higher than the temperature rated for the industrial device, device performance at 95 °C cannot be guaranteed. In that case, it is highly recommended to select appropriate temperature grade parts, such as 105 °C or 125 °C rated device.

Revision history

Document version	Date of release	Description of changes
**	2021-04-01	Initial release

Trademarks
All referenced product or service names and trademarks are the property of their respective owners.

Edition 2021-04-01

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about this document?

Go to: www.cypress.com/support

Document reference

002-32889 Rev.**