Using F-RAM for
Automotive Event Data Recording

Douglas Mitchell

Presentation Outline

- F-RAM Technology

- F-RAM vs Competition

- F-RAM Automotive Applications

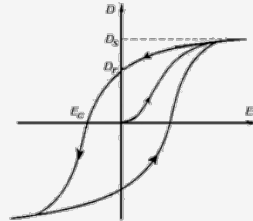- F-RAM Portfolio

- Ultra-Low-Energy (ULE) F-RAM

F-RAM Technology

Technology

The storage element in an F-RAM is a thin-film ferroelectric capacitor made of lead zirconate titanate or PZT

PZT is not ferromagnetic (MRAM)

F-RAM is called "ferro" because molecule follows a hysteresis loop.
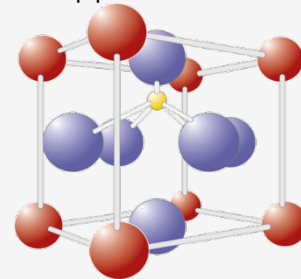
Benefits

Switch in states is instantaneous and offers fast writes and low energy consumption

Two symmetrical states and has no reason to degrade so it offers high data retention (635 years @ 55°C)
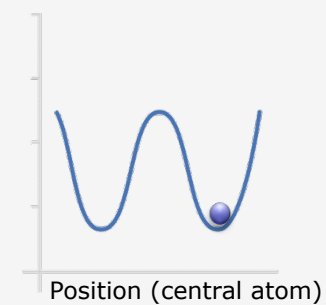
Based on "atomic position" vs. "trapped charge" and offers SER immunity and Radiation tolerant
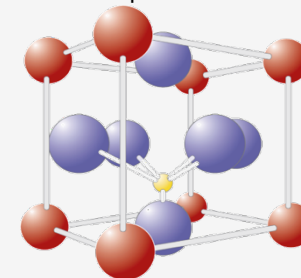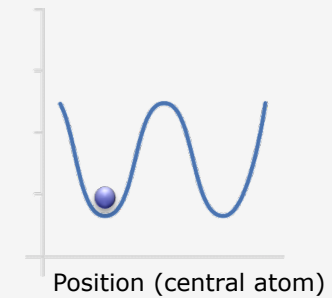
Cell Operation

Up polarization

Energy (E)

Position (central atom)

Down polarization

Energy (E)

Position (central atom)

Electric field

Cypress F-RAM Data Retention

Primary F-RAM reliability measure is the retention lifetime of a capacitor cell that has been previously stored in a polarization state for an extended time and then written to the opposite polarization state (OS)[1]
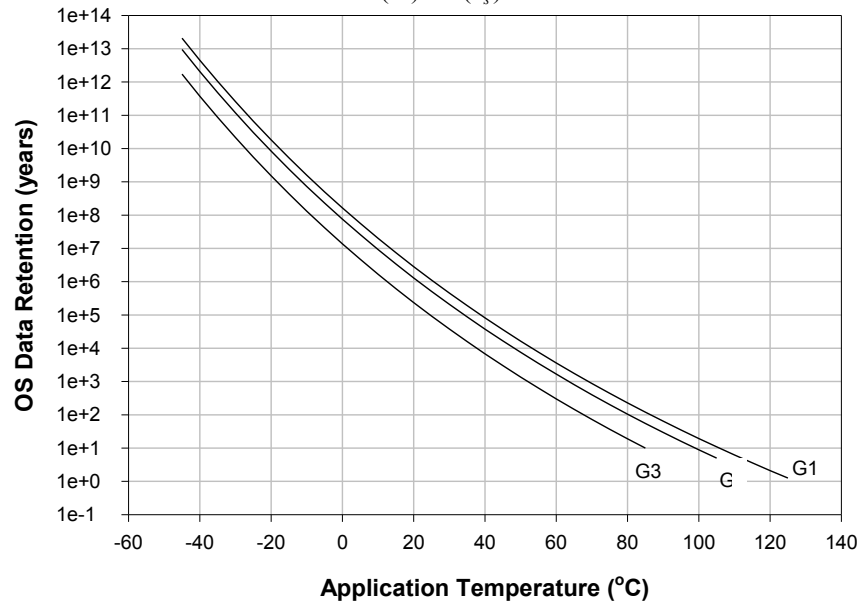
Retention Specs for Cypress F-RAMs[2]:

Cypress F-RAM	Data Retention
AEC-Q100 Grade 3 (G3)	>10 yrs @ 85ºC
AEC-Q100 Grade 2 (G2)	>5 yrs @ 105ºC
AEC-Q100 Grade 1 (G1)	>11k hrs @ 125ºC

The specifications can be converted to multi-temperature profiles

Example for G1 F-RAM[3]:

Temperature	Time Factor	Profile Life time
(T)	(t)	L(P)
T1=125ºC	10%	
T2=105ºC	15%	> 10.46 years
T3=85ºC	25%	
T3=55ºC	50%	

$$L(T) = L(T_s)e^{\frac{Ea}{k}(\frac{1}{T}-\frac{1}{T_s})}$$

[1] This type of retention is called as Opposite State (OS) retention. F-RAM has unlimited Same State (SS) retention life within the specified temperature range
[2] Conditions: 130nm 2T2C F-RAMs (all AEC-Q-100 Qualified F-RAMs are currently 2T2C)
[3] G3 Stress temperature T_s= 125ºC, G2 and G1 Stress temperature T_s= 150ºC

Cypress F-RAM Endurance

Memory endurance is specified as number of times that a memory cell can be written-to or erased

- F-RAM endurance tests are difficult to practically perform due to very high endurance performance of F-RAM.

- Innovative test methodologies are needed to determine the endurance limit of 0.13µm F-RAM product

- Endurance behavior of scribe line test structures i.e., intrinsic material can be measured with acceleration

- F-RAM device endurance can be measured up to 10^{13} cycles through lab tests[1] and extrapolated to 10^{15} based on slope of the curve for intrinsic material

- Signal margin vs. cycles for both F-RAM device and intrinsic material shows higher signal margin of the F-RAM device at 10^{15} cycles compared with the initial value[2]

Intrinsic material and device endurance characteristics:
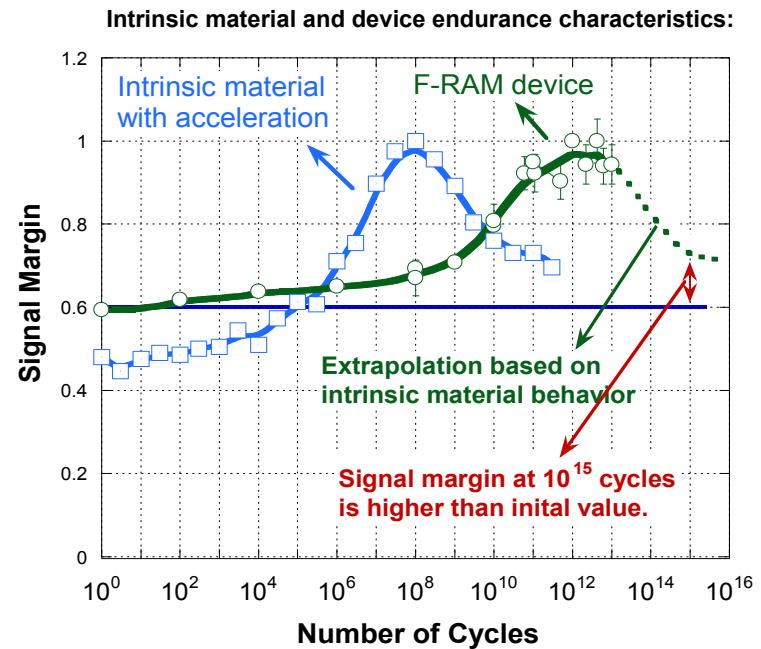
[1] Continuous 1 byte writes on FM22L16 at speed of 110ns cycle time (i.e., 220ns for writing both state): 0.025 days for 10^{10} cycles, 2.55 days for 10^{12} cycles, 255 days for 10^{14} cycles
Ref: http://www.cypress.com/?docID=44702
[2] Cypress takes a guard band and specs up to 10^{14} (instead of 10^{15}) on datasheets for endurance

ULE F-RAM vs. Competition

Feature	ULE F-RAM	MRAM	EEPROM
Density Range	2Mb-16Mb[1]	256Kb-4Mb	1Kb-2Mb
Interface Frequency (Maximum)	54-MHz DDR	108-MHz SDR	5-MHz SDR
Write Bandwidth (Mbps)[2]	432	432	0.197
Hibernate Current[3]	0.1 µA	15 µA	N/A
Deep Power-Down Current[3]	0.65 µA	N/A	N/A
Standby Current[3]	1.0 µA	90 µA	0.16 µA
Active Write Current[4]	0.6 mA	26.9 mA	3 mA
Write Energy for 4Mb (µJ)[4, 5]	1,510	67,700	192,000
Product Battery Life (Days)[6]	9,549	213	6.1
Write/Program Latency	0 ms	0 ms	10 ms
Endurance (Cycles)	10^{14}	Unlimited	10^6

[1] Current Cypress F-RAM portfolio offers a density range of 4Kb to 4Mb
[2] Conditions: 10-ms Page write for 2Mb 5-MHz SDR EEPROM
[3] Conditions: 4Mb, typical current, 2.7 to 3.6 V
[4] Conditions: 4Mb density, maximum current, 5-MHz SPI, 2.7 to 3.6 V
[5] Condition: 4Mb burst write at 5-MHz SPI. Example: with a CR2032 battery, ULE F-RAM provides 1,573,551 writes vs. Fujitsu F-RAM's 429,150, MRAM's 35,098 and EEPROM's 12,376
[6] 16-byte samples at a sampling interval of 20-ms with a CR2032 battery

Competitive Comparison

ADAS[1]

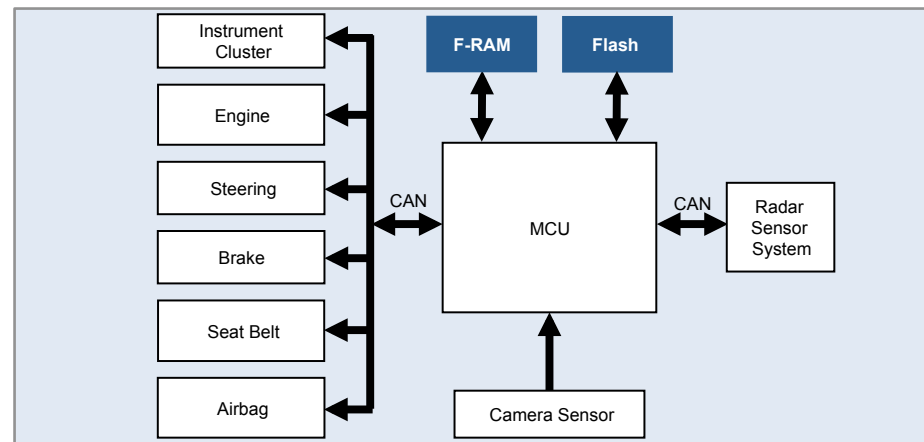## F-RAM and Flash Value

- **Design Challenges**
  - Capture real-time data instantly and store data on power loss
  - Store boot code and video overlays reliably on power loss
  - Ensure sufficient write-cycle endurance to log data for 20 years
  - Design with AEC-Q100-qualified memory components

- **Cypress F-RAM and Flash Solutions**
  - Captures data instantly with no soak time[2] requirement and Flash stores boot code data/STORE video overlays reliability
  - Provides endurance for 100 trillion write cycles to log data every 10 µs for 20 years and Flash provides endurance for 100 K write cycles to store data for 20 years
  - Provides AEC-Q100-qualified memory components

[1] Advanced Driver Assistance System
[2] The approximate 5 ms required to complete an EEPROM Page Write after the data is presented at the input buffers

ADAS
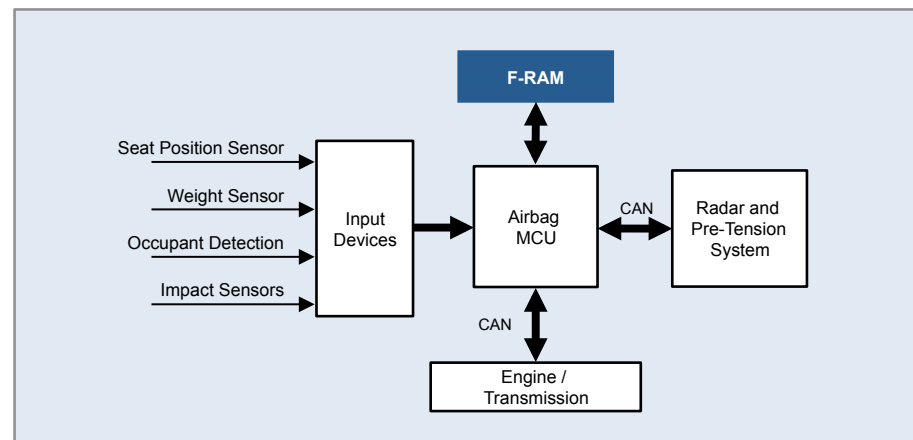by Continental

Smart Airbag System

F-RAM and Flash Value

Design Challenges

- Capture real-time sensor data and store data on power loss
- Ensure sufficient write-cycle endurance to log data for 20 years
- Design with AEC-Q100-qualified memory components

Cypress F-RAM Solution

- Captures data instantly with no soak time[1] requirement
- Provides endurance for 100 trillion write cycles to log data every 10 µs for 20 years
- Provides AEC-Q100-qualified memory components

[1] The approximate 5 ms required to complete an EEPROM Page Write after the data is presented at the input buffers

Smart Airbag
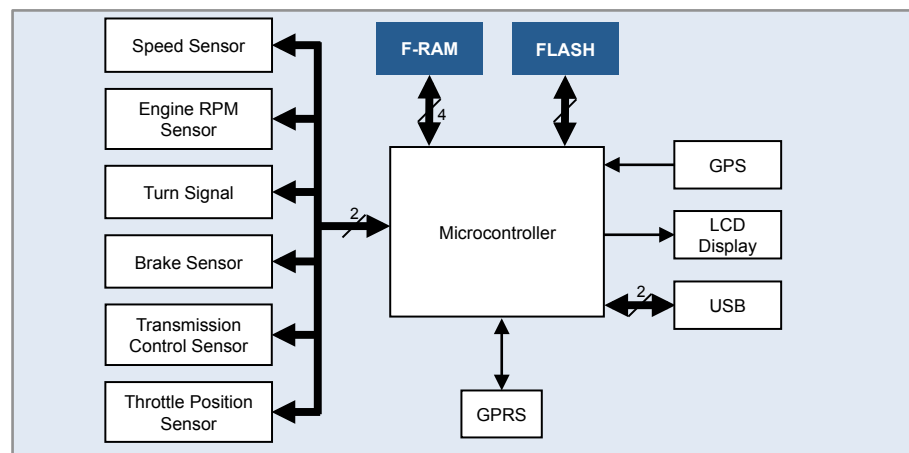by Bosch

VDTR[1]

Flash Memory Summit

F-RAM Value

- **Design Challenges**
  - Capture real-time data instantly on power loss
  - Ensure sufficient write-cycle endurance to log data over a 20-year product lifespan
  - Design with AEC-Q100-qualified memory components

- **Cypress F-RAM Solution**
  - Captures data instantly with no soak time requirement
  - Provides endurance for 100 trillion write cycles to log data every 10 μs for 20 years
  - Provides AEC-Q100-qualified memory components

[1] Vehicle Traveling Data Recorder

Vehicle Traveling Data Recorder by HUABAO

Speed Sensor	F-RAM	FLASH
Engine RPM Sensor		
Turn Signal	Microcontroller	GPS
Brake Sensor		LCD Display
Transmission Control Sensor		USB
Throttle Position Sensor	GPRS	

F-RAM Portfolio

	LPC[1] F-RAM			Processor Companion	Parallel F-RAM	
512Kb – 4Mb	**CY15B104Q** 4Mb; 2.0-3.6 V 40-MHz SPI; Ind	**CY15V/B104/8Q/S 4/8Mb** 1.71–1.89V / 1.8–3.6 V 108-MHz QSPI[7], Ind[3]	**CY15B102/4Q/S 2/4Mb** 1.71–1.89V / 1.8–3.6 V 108-MHz QSPI[7], Auto A[3], Auto E[4]		**FM22L16/LD16** 4Mb; 2.7-3.6 V 55 ns; x8; Ind	
	CY15B102Q 2Mb; 2.0-3.6 V 25-MHz SPI; Auto E[3]	**FM25V20A** 2Mb; 2.0-3.6 V 40-MHz SPI; Ind[2]	**FM24V10/VN10** 1Mb; 2.0-3.6 V 3.4-MHz I²C; Ind, Auto A		**FM28V102A** 1Mb; 2.0-3.6 V 60 ns; x16; Ind	**FM28V202A** 2Mb; 2.0-3.6 V 60 ns; x16; Ind
	FM25V05 512Kb; 2.0-3.6 V 40-MHz SPI; Ind, Auto A	**FM25V10/VN10** 1Mb; 2.0-3.6 V 40-MHz SPI; Ind, Auto A	**FM24V05** 512Kb; 2.0-3.6 V 3.4-MHz I²C; Ind, Auto A		**CY15B101N** 1Mb; 2.0-3.6 V 60 ns; x16; Auto A	**CY15B102N** 2Mb; 2.0-3.6 V 60 ns; x16; Auto A
4Kb – 256Kb	**FM25V02A/W256** 256Kb; V02A: 2.0-3.6 V W256: 2.7-5.5 V 40-MHz SPI; Ind, Auto A		**FM24V02A/W256** 256Kb; V02A: 2.0-3.6 V W256: 2.7-5.5 V 3.4-MHz I²C; Ind, Auto A	**FM33256** 256Kb; 3.3V; 16-MHz SPI Ind; RTC[5]; Power Fail Watchdog; Counter	**FM28V020** 256Kb; 2.0-3.6 V 70 ns; x8; Ind	**FM18W08** 256Kb; 2.7-5.5 V 70 ns; x8; Ind
	FM25V01A 128Kb; 2.0-3.6 V 40-MHz SPI; Ind, Auto A		**FM24V01A** 128Kb; 2.0-3.6 V 3.4-MHz I²C; Ind, Auto A	**FM31256/31(L)278** 256Kb; 3.3, 5.0V; 1-MHz I²C; Ind; RTC; Power Fail; Watchdog; Counter	**FM1808B** 256Kb; 5.0 V 70 ns; x8; Ind	**FM16W08** 64Kb; 2.7-5.5 V 70 ns; x8; Ind
	FM25640/CL64 64Kb; 3.3, 5.0 V 20-MHz SPI; Ind, Auto E[4]		**FM24C64/CL64** 64Kb; 3.3, 5.0 V 1-MHz I²C; Ind, Auto E	**FM3164/31(L)276** 64Kb; 3.3, 5.0 V; 1-MHz I²C; Ind; RTC; Power Fail; Watchdog; Counter		
	FM25C160/L16 16Kb; 3.3, 5.0 V 20-MHz SPI; Ind, Auto E		**FM24C16/CL16** 16Kb; 3.3, 5.0 V 1-MHz I²C; Ind, Auto A			
	FM25040/L04 4Kb; 3.3, 5.0 V 20-MHz SPI; Ind, Auto E		**FM24C04/CL04** 4Kb; 3.3, 5.0 V 1-MHz I²C; Ind, Auto A			

[1] Low-pin-count [2] Industrial grade -40°C to +85°C [3] AEC-Q100 -40°C to +85°C [4] AEC-Q100 -40°C to +125°C
[5] Real-time clock [6] Ultra-Low-Energy [7] Quad serial peripheral interface

Concept   Development   Sampling   Production
Industrial
Automotive

2Mb-to-16Mb ULE F-RAM Family

Features

- **High Speed**
  - 50-MHz Serial Peripheral Interface (SPI)
  - 54-MHz Double Data Rate (DDR) / 108-MHz Single Data Rate (SDR) Quad SPI
- **Low Power**
  - Operating voltage range: 1.71-1.89 V, 1.80-3.60 V
  - Ultra-low (0.10-µA) hibernate current
  - Ultra-low (0.65-µA) deep power-down current
  - Ultra-low (1.00-µA) standby current
- **Non-volatile**
  - 100-trillion read/write cycle endurance
  - 100-year data retention
- **Multiple operating temperatures**
  - Commercial temperature range: 0ºC to +70ºC
  - Industrial temperature range: -40ºC to +85ºC
  - Automotive (AEC-Q100) temperature range grade A: -40ºC to +85ºC
  - Automotive (AEC-Q100) temperature range grade E: -40ºC to +125ºC
  -

ULE F-RAM
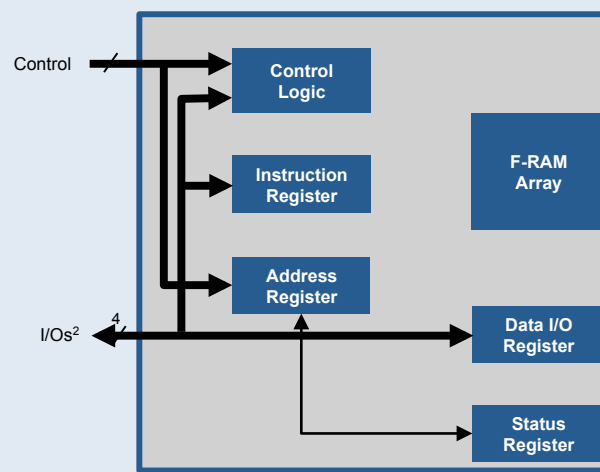
Family Table

Density	Standby Current (Typ.)	Active Current (Typ.)	Packages
2Mb	1 µA	3 mA	SOIC (8), GQFN (8)
4Mb	1 µA	3 mA	SOIC (8), GQFN (8)
8Mb	1 µA	3 mA	SOIC (8), GQFN (8)
16Mb	1 µA	3 mA	SOIC (8)

Product Overview