WHITE PAPER

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Energy Comparison of Cypress F-RAM and EEPROM

Abstract

F-RAM (Ferroelectric Random Access Memory) is a nonvolatile memory that uses a ferroelectric capacitor to store data. It offers higher write speeds and lower energy consumption than flash/EEPROM.

This white paper compares the energy consumption of the Cypress F-RAM and EEPROM under typical application scenarios.

Introduction

Ferroelectric Random Access Memory (F-RAM) is a truly nonvolatile RAM that combines the advantages of RAM and nonvolatile memory. F-RAM is far superior to flash/EEPROM in write speed, endurance, and energy efficiency.

Traditional nonvolatile memories derived from floating-gate technology use charge pumps to develop a high voltage on-chip (10 V or more) to force carriers through the gate oxide. As a result, there are long write delays, high write power, and the write operation is destructive to the memory cell. Floating-gate devices cannot support writes that exceed 10^6 accesses. To put this in perspective, a data recorder using EEPROM that was recording data at 1 sample/s would wear out in fewer than 12 days. In comparison, the F-RAM products offer virtually unlimited endurance (10^{14} accesses).

The F-RAM is far superior to floating-gate devices in both write speed and power. For a typical serial EEPROM with a clock rate of 20 MHz, it would take 5 ms to write 256 bits (32-byte page buffer) and 1283.6 ms to write to the entire 64 Kb. For an equivalent F-RAM, it takes only 14 µs for 256 bits and just 3.25 ms to write to the entire 64 Kb. In addition, it requires 3900 µJ to write 64 Kb for the EEPROM, compared with 17 µJ to write 64 Kb to an F-RAM—a difference of more than 229 magnitudes.

The fast write speed and low energy consumption of F-RAM makes it ideal for low-power applications, such as e-meters, wearable electronics, and battery-operated systems. To quantify the overall impact that F-RAM has on energy consumption of practical systems, this paper considers different write/read scenarios and energy consumed is compared with that of an EEPROM.

Devices

The following devices are used in the experiment.

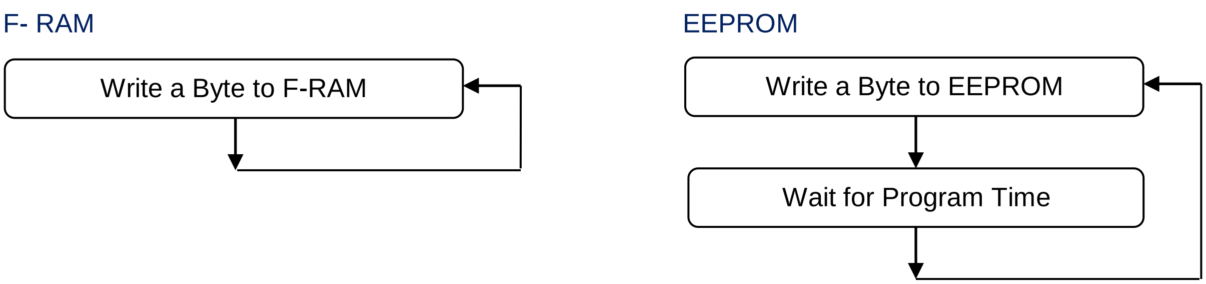
- 64 Kb SPI F-RAM from Cypress
- 64 Kb SPI EEPROM from Atmel
- 2 Mb SPI F-RAM from Cypress
- 2 Mb SPI EEPROM from ST

Test Methodology

Test Flow

The energy consumed to write a byte is calculated by measuring the write currents. The write currents of F-RAM and EEPROM are measured by continuously writing one byte of data to each F-RAM and EEPROM, respectively. While F-RAM is a no-delay (or zero-delay) write, EEPROM requires a delay equivalent to its program time to successfully complete the write. The average current measured is the write current. Similarly, the read current is obtained by looping in read continuously.

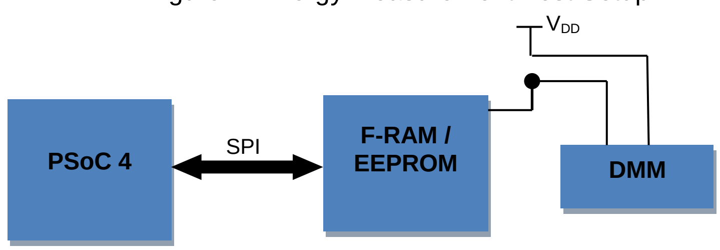
Figure 1. F-RAM and EEPROM Energy Measurement Test Flow



Test Setup

The test setup requires a simple read/write capability from the device. To achieve this, use a PSoC[1]® 4 development kit (CY8CKIT-042 PSoC® 4 Pioneer Kit). PSoC 4 is interfaced to the F-RAM or EEPROM through a serial peripheral interface (SPI). A digital multimeter (DMM) is inserted in series with the device supply to measure the device current.

Figure 2. Energy Measurement Test Setup



Measurements

The following measurements are made from the test setup. The EEPROM consumes more current during both write (including program cycle) and read operation when compared to F-RAM.

Table 1. Current Measurement Data

	64 Kb		2 Mb		
Function \ Current	Cypress F-RAM (FM25CL64B)	EEPROM (AT25640B)	Cypress F-RAM (FM25V20A)	EEPROM (M95M02-DR)	Unit
Write Current	77.1	33	130	333	µA
Program Current	-	2600 (for 1.5 ms)	-	275 (for 6.25 ms)	µA
Read Current	82	640	122	240	µA
Standby Current	1.35	0.62	87	0.34	µA
Sleep Current	-	-	2	-	µA
Wakeup Current	-	-	920 (for 385 µs)	-	µA

Note:
1. PSoC (Programmable System-on-Chip) is a highly programmable embedded design platform, based on flexible and open hardware, combined with easy-to-use, free software

Analysis

To obtain the energy consumption, plug the measurement into different use cases.

Consider a 64 Kb use case in which a single byte of data is written continuously. A single byte of data written would have an overhead of four bytes (1-byte write enable command, 1-byte write command and 2-byte address). Therefore, at a 1-MHz clock frequency, the total write time is 40 µs. The EEPROM has an added program time (approx. 1500 µs). In summary, a complete 1-byte write takes 1540 µs in EEPROM but only 40 µs in F-RAM.

During write, an EEPROM consumes an average current of 2600 µA, while F-RAM consumes an average current of 77.1 µA. The current is high in EEPROM because a write involves erase and program cycles. Because of these factors, the total energy required to write a byte is very low in F-RAM compared to that of EEPROM. F-RAM requires only 0.01 µJ, while EEPROM requires 13.21 µJ, resulting in an advantage of the order of 1321 for F-RAM. For detailed energy calculations, see Table 2.

Table 2. Energy Calculations for a 1-Byte Write in 64Kb F-RAM and EEPROM

Parameter	F-RAM (64 Kb)	EEPROM (64 Kb)	Units; Calculation
Supply Voltage (V_{DD})	3.3	3.3	V
Active Write Current (µA)	77.1	2600	I_{WR}
Clock Frequency (MHz)	1	1	Freq
Clock Cycle Time (µs)	1	1	t_{CLK} = 1/Freq
No. of Overhead Bytes	4	4	Obytes
No. of Data Bytes	1	1	Dbytes
Write / Program Time (µs)	0	1500	t_{WC}
Total Write Time	40	1540	$t_{WRITE} = t_{CLK}$* (Obytes + Dbytes) *8 + t_{WC}
Memory Write Charge (µC)	0.003	4.004	$Q_{WR} = I_{WR} * t_{WRITE}$
Total Energy for 1-Byte Write (µJ)	**0.01**	**13.21**	**$E = Q_{WR} * V$**
F-RAM Energy Advantage	**1321**		**E_{EEPROM} / E_{FRAM}**

In Table 2, the application logs 1 byte of data continuously. In a practical application, data is measured periodically and logged. The energy comparison of 1-byte data logging at every 100 ms in F-RAM and EEPROM is shown in Table 3.

Table 3. Energy Calculations for a 1-Byte Write Every 100 ms in 64 Kb F-RAM and EEPROM

Parameter	F-RAM (64 Kb)	EEPROM (64 Kb)	Units; Calculation
Supply Voltage (V_{DD})	3.3	3.3	V
Active Write Current (µA)	77.1	2600	I_{WR}
Standby Current (µA)	1.35	0.62	I_{SB}
Loop Time (µs)	100000	100000	t_{LOOP}
Clock Frequency (MHz)	1	1	Freq
Clock Cycle Time (µs)	1	1	t_{CLK} = 1/Freq
No. of Overhead Bytes	4	4	Obytes
No. of Data Bytes	1	1	Dbytes
Write / Program Time (µs)	0	1500	t_{WC}

Parameter	F-RAM (64 Kb)	EEPROM (64 Kb)	Units; Calculation
Total Write Time (µs)	40	1540	$t_{WRITE} = t_{CLK}$* (Obytes + Dbytes) *8 + t_{WC}
Standby Time (µs)	99,960	98,460	$t_{SB} = t_{LOOP} - t_{WRITE}$
Memory Write Charge (µC)	0.003	4.004	$Q_{WR} = I_{WR} * t_{WRITE}$
Memory Standby Charge (µC)	0.135	0.061	$Q_{SB} = I_{SB} * t_{SB}$
Total Charge (µC)	0.138	4.065	$Q = Q_{WR} + Q_{SB}$
Total Energy (µJ)	**0.456**	**13.41**	**E = Q * V**
Power (µW)	**4.56**	**134.1**	**$P = E / t_{LOOP}$**
F-RAM Energy Advantage	**29**		**E_{EEPROM} / E_{FRAM}**

For a 1-byte write at a 100-ms measurment rate, F-RAM consumes only 4.56 µW, while an EEPROM consumes 134.1 µW, resulting in an advantage in the order of 29 for F-RAM. Therefore, for a given periodicity (measurement frequency), F-RAM offers a significant power advantage over EEPROM, as Figure 3 shows. For battery-powered sensor nodes, the energy reduction results in less frequent battery changes. In some cases, it can eliminate the need for battery changes.

On the other hand, for a given power budget, F-RAM allows measurements to be taken significantly more often. In such systems, use of nonvolatile memory is required because the power supply may be intermittent, and F-RAM offers a performance advantage. In Figure 3, the graph shows that a system power budget of 10 µW limits the measurement rate of writes to EEPROM to slower than once every 1.66 second, while writes to F-RAM allow the same measurements to happen faster than once every 1.80 millisecond. This is a performance advantage by a factor of 920. F-RAM enables a wide variety of practical systems to log data more frequently and reduce the system energy consumption at the same time.

Figure 3. Power Comparisons of F-RAM and EEPROM During a 1-Byte Data Write

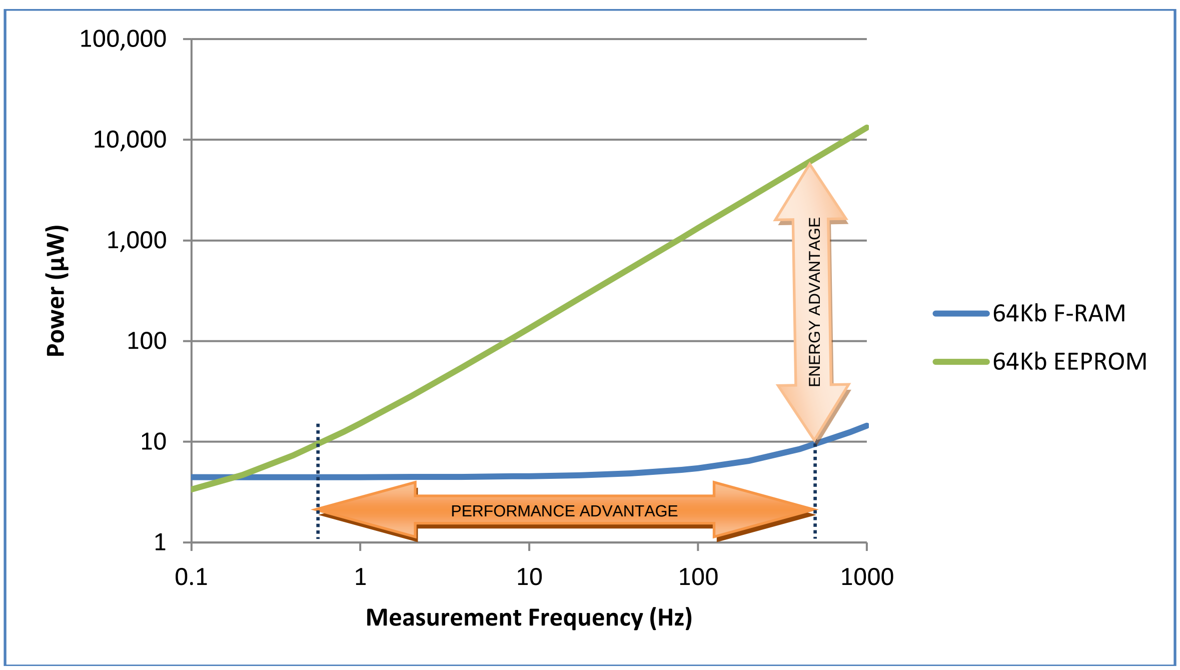
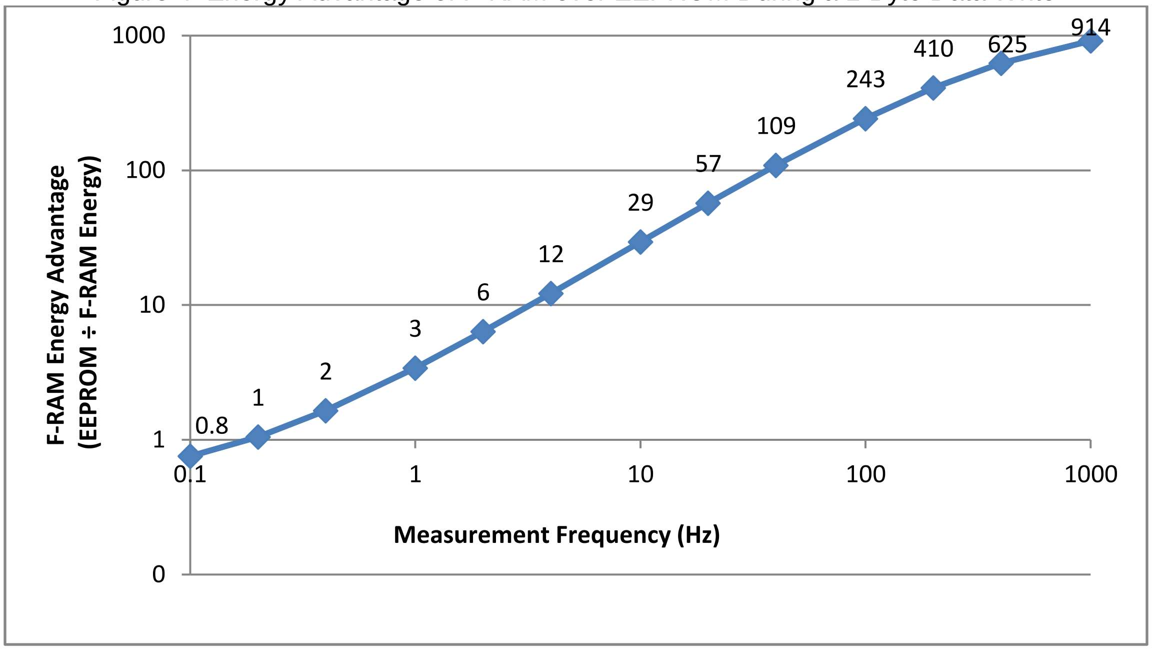


Figure 4 shows the energy advantage of F-RAM over EEPROM at different measurement frequencies.

Figure 4. Energy Advantage of F-RAM over EEPROM During a 1-Byte Data Write



Extending the exercise in Table 3, Table 4 summarizes the energy consumption for other practical scenarios.

Table 4. Energy Consumption in Different Practical Scenarios

	64 Kb Device			2 Mb Device		
Energy / Function	F-RAM FM25CL64B (µJ)	EEPROM AT25640B (µJ)	F-RAM vs. EEPROM (Ratio)	F-RAM FM25V20A (µJ)	EEPROM M95M02-DR (µJ)	F-RAM vs. EEPROM (Ratio)
Write Full Memory[2]	17.0	3.9×10^3	**229.4**	900.0	7.7×10^3	**8.6**
Write 1 byte every 100 ms with standby during idle[3]	0.5	13.1	**29**	28.7	5.8	**0.2**
Write 1 byte every 100 ms with F-RAM put to sleep during idle[4]	-	-	**-**	1.8	5.8	**3.2**
Read Full Memory[5]	17.7	138.5	**7.8**	844.0	1.7×10^3	**2.0**
Write-Read 1 byte (full memory)[6]	154.3	108.8×10^3	**705.1**	9.6×10^3	1.5×10^6	**156.3**

Notes:

2. Energy = Energy for 1-byte write enable command + Energy for writing 1-byte command + Energy for writing 2-byte / 3-byte address + (Energy for writing 1 byte of data * Total number of bytes)
3. Energy = Energy for 1-byte write enable command + Energy for writing 1-byte command + Energy for writing 2-byte / 3-byte address + Energy for writing 1 byte of data + Energy consumed during 100 ms of standby mode
4. Energy = Energy for 1-byte write enable command + Energy for writing 1-byte command + Energy for writing 2-byte / 3-byte address + Energy for writing 1 byte of data + Energy consumed during 100 ms of Sleep Mode (For EEPROM standby mode)
5. Energy = Energy for writing 1-byte command + Energy for writing 2-byte / 3-byte address + (Energy for reading 1 byte of data * Total number of bytes)
6. Energy = Energy for 1-byte write enable command + Energy for writing 1-byte command + Energy for writing 2-byte / 3-byte address + Energy for writing 1 byte of data + Energy for writing 1-byte command + Energy for writing 2-byte / 3-byte address + Energy for reading 1 byte of data

Conclusion

Quantifying the energy consumption in different practical scenarios proves that the Cypress F-RAM is a superior low-energy solution in nonvolatile memory. The values measured are typical values at room temperature. In addition, at the datasheet spec limits, F-RAM remains the lowest-energy solution, demonstrating its considerable advantage over EEPROM.

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