Between Fuses and Flash

An Overview of CMOS NVM in Consumer Applications

Virage Logic Blue
Pantone: 534
RGB: 40/70/115
CMYK: 100/80/30/5

Red
Pantone: 484
RGB: 180/35/25
CMYK: 0/95/100/29

Purple
Pantone: 2415
RGB: 165/25/130
CMYK: 35/100/0/10

Green
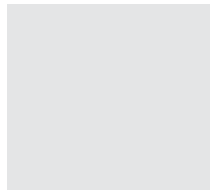Pantone: 368
RGB: 123/190/67
CMYK: 7/5/5/5

Orange
Pantone: 158
RGB: 245/128/37
CMYK: 0/61/97/0

Yellow
Pantone: 123
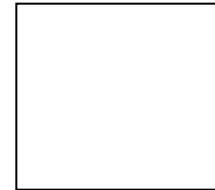RGB: 255/196/37
CMYK: 0/25/95/0

Teal
Pantone: 327
RGB: 0/145/145
CMYK: 100/0/45/15

Light Grey
Pantone: 427
RGB: 228/229/230
CMYK: 7/5/5/5

Medium Blue
Pantone: 286
RGB: 0/95/170
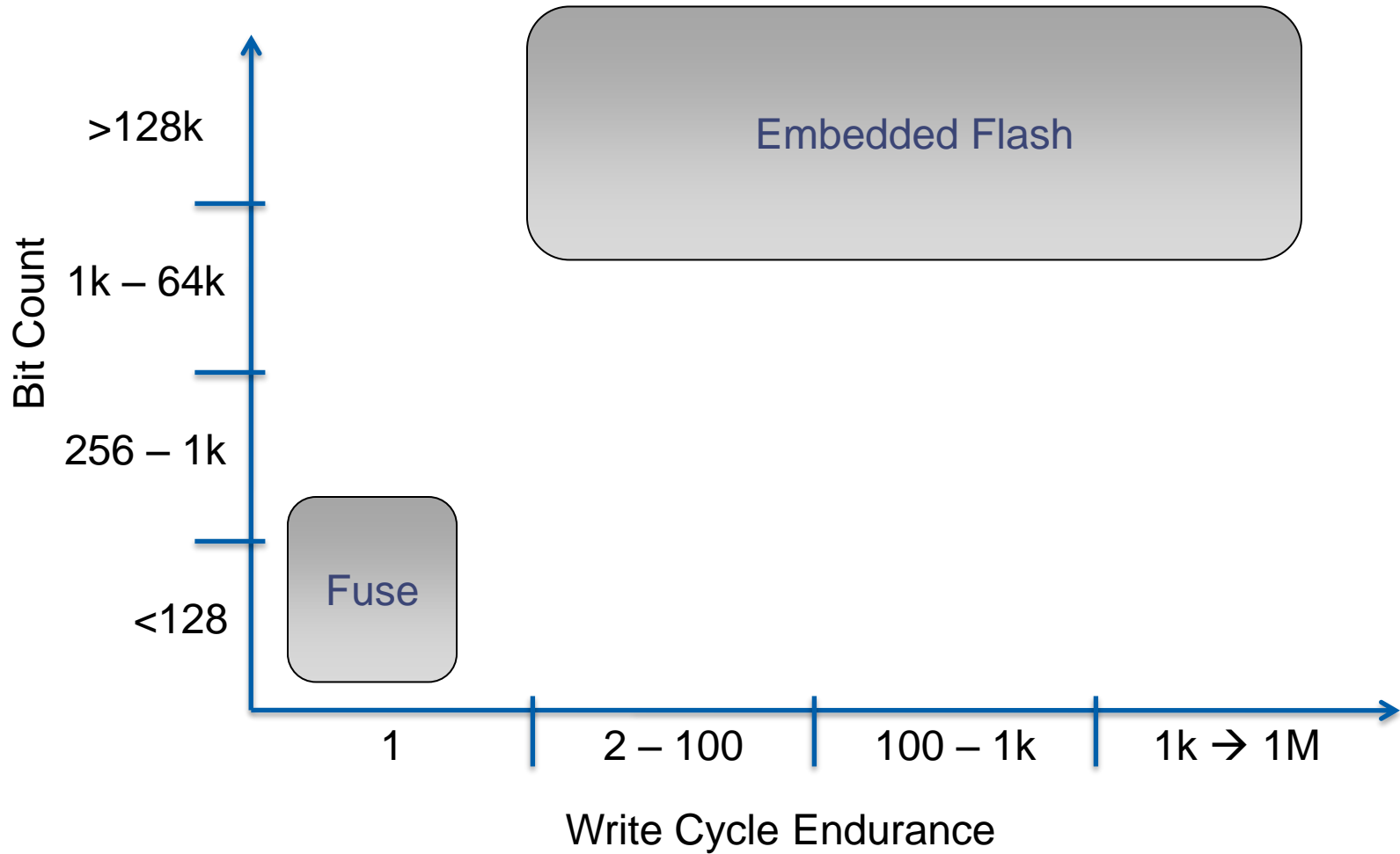CMYK: 100/65/0/5

White
RGB: 255/255/255
CMYK: 0/0/0/0

Agenda

- Definition of CMOS NVM

- Market Landscape

- Technologies

- Applications

- Summary / Conclusions

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What Is CMOS NVM?

- **CMOS NVM** = nonvolatile memory manufactured in a standard CMOS process

  - No additional masks or processing steps

- Includes several different technologies

  - **MTP** = **M**ultiple **T**ime **P**rogrammable

    - Up to 1M cycle endurance

  - **FTP** = **F**ew **T**ime **P**rogrammable

    - ~100 cycle endurance

  - **OTP** = **O**ne **T**ime **P**rogrammable

    - Either floating gate or antifuse based technologies

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Embedded NVM Landscape

Traditional Fuses and Flash Leave Significant Applications Unserviced

Bit Count (y-axis)
- >128k
- 1k – 64k
- 256 – 1k
- <128

Embedded Flash

Fuse

Write Cycle Endurance (x-axis)
- 1
- 2 – 100
- 100 – 1k
- 1k → 1M

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Embedded NVM Landscape

CMOS NVM Fills the Gap
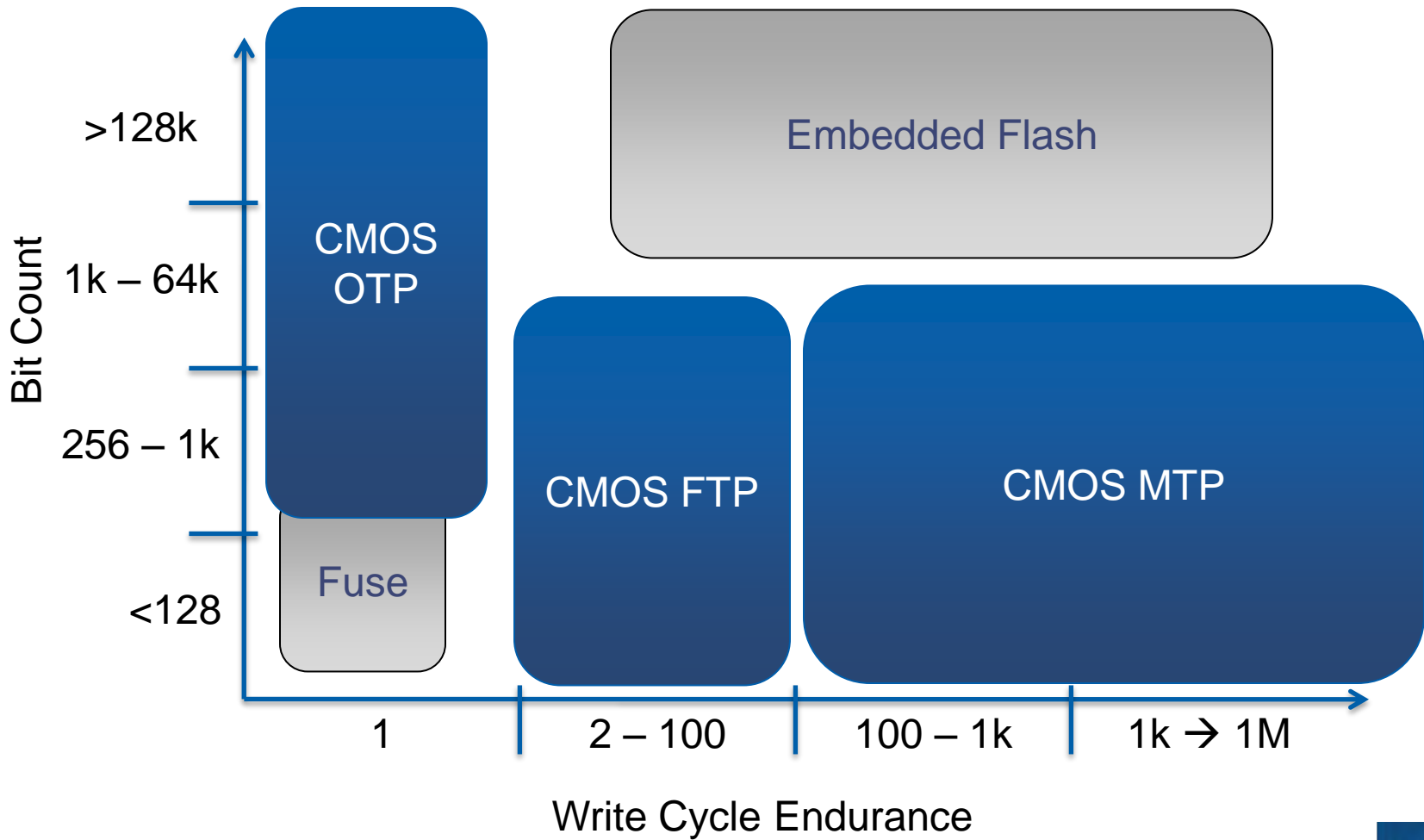
Embedded Flash Overview

Includes Other Mask Adder Solutions (SONOS, FRAM, MRAM, etc.)

Basic Technology

- Floating gate / charge storage
- Process / mask adders to standard CMOS process
- Available from foundries – technology from 3rd parties
- Available down to 90nm?

Advantages

- High endurance (20k $\rightarrow$ 100k write-erase cycles)
- High density (>1Mb)
- Production proven for high reliability applications (i.e. automotive)

Target Applications

- Microcontrollers
- Embedded code storage

Limitations

- Process cost / complexity
- 25% $\rightarrow$ 100% wafer adder
- Advanced process node support
- Long test times for large arrays (several seconds)

Fuse Overview

Includes Other Mask Adder Solutions (SONOS, FRAM, MRAM, etc.)

Basic Technology
- Overstress of poly, metal, oxide to create an open/short
- Developed and available from foundries
- Available down to 40nm

Advantages
- ~Free from the foundry
- Available early in process life – foundries develop fuse technology along with advanced nodes

Target Applications
- Trim
- Device ID

Limitations
- One time programmable only
- Limited bit count
- Long-term reliability concerns

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OTP Overview

CMOS Based OTP Technology

Basic Technology
- Floating Gate – typically hot carrier injection
- Antifuse – overstress of gate oxide causing a short
- Available down to 55nm

Advantages
- High density (1Mb or more)
- Low cost CMOS process

Target Applications
- Code storage
- Encryption keys
- Trim / configuration data

Limitations
- One time programmable only
- Long test time for large arrays
- No electrical testing capability

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MTP / FTP Overview

Reprogrammable NVM in Standard CMOS

Basic Technology
- Floating Gate – combination of FN-FN and hot carrier-FN
- Single poly standard CMOS process
- Supports up to ~16k bits
- Available down to 65nm

Advantages
- High endurance (MTP) up to 1M cycles
- Minimal area (FTP)
- High temperature (150C operation)
- Qualified to meet automotive standards

Target Applications
- Encryption keys
- Datalogging
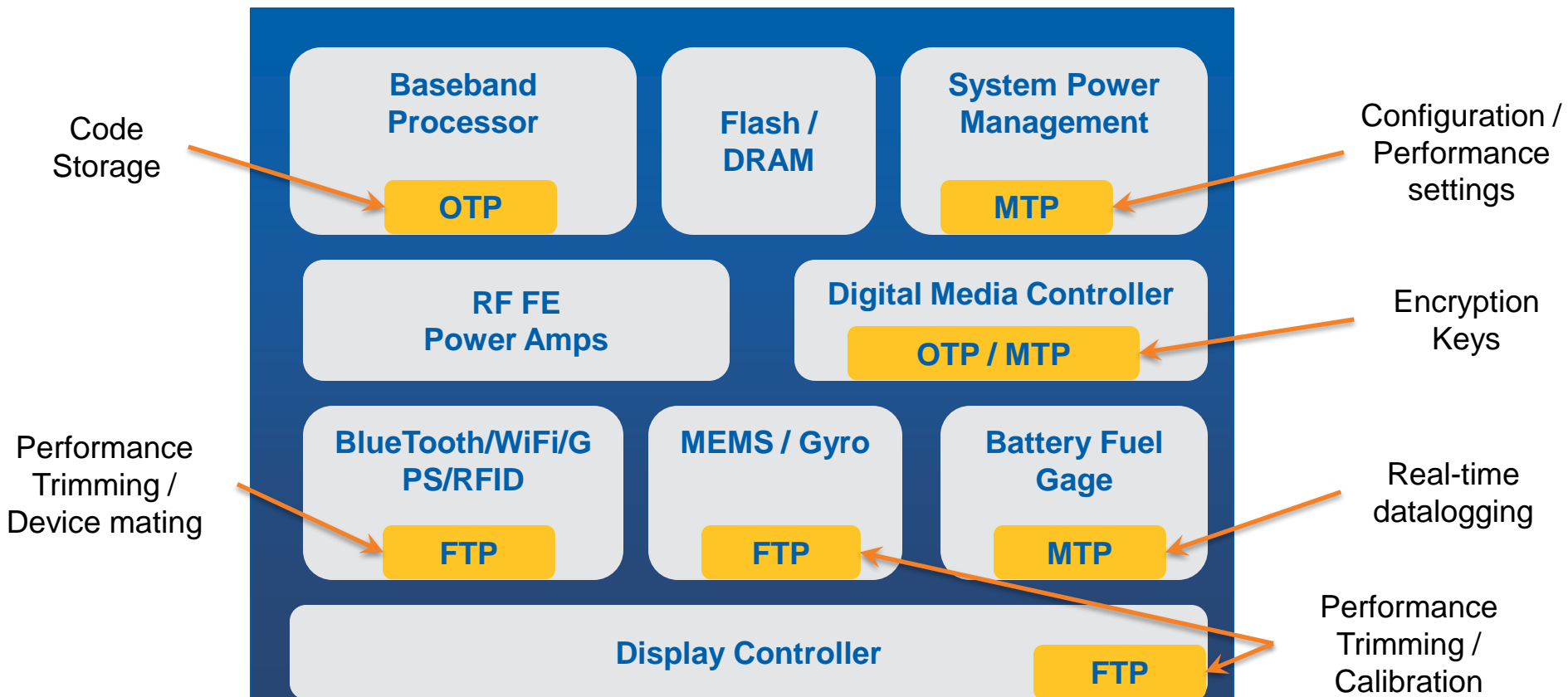- Trim / configuration settings
- Wireless / RFID

Limitations
- Currently limited to ~16kbit
- Currently requires 50A gate oxide (solutions already in development)

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Key Applications

CMOS NVM in Smartphones

Code Storage → **Baseband Processor** — **OTP**

Flash / DRAM

System Power Management — **MTP** ← Configuration / Performance settings

RF FE Power Amps

Digital Media Controller — **OTP / MTP** ← Encryption Keys

Performance Trimming / Device mating → **BlueTooth/WiFi/GPS/RFID** — **FTP**

MEMS / Gyro — **FTP**

Battery Fuel Gage — **MTP** ← Real-time datalogging

Display Controller — **FTP** ← Performance Trimming / Calibration

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Code Storage Applications

Using OTP to Store Boot / Firmware Code

Attribute	Importance
Density	★★★★
Area	★★★
Flexibility (i.e. reprogrammability)	★★
Power	★

- CMOS NVM Advantages
  - Post-fab programming (ROM)
  - Advanced process node support (eFlash)
  - Available at power-up (external)

- Competing Solutions
  - Mask ROM
  - Embedded Flash
  - External NVM

Microcontroller

Core

IO

OTP

Misc

- End Products
  - Consumer electronics
  - Automotive
  - Energy monitoring
  - Medical

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Storing Encryption Keys

OTP or MTP to Store AES, HDMI, etc. Keys

Attribute	Importance
Density	★
Area	★ ★ ★
Flexibility (i.e. reprogrammability)	★ ★ ★
Power	★ ★

- CMOS NVM Advantages
  - Secure – both floating gate and antifuse
  - Advanced process support
  - Ability to tightly integrate with crypto engine
  - MTP allows proactive / reactive key updates

- Competing Solutions
  - Software implementation (no NVM needed)
  - External Storage

Media Controller

uP Core	Crypto
	NVM
SRAM	ROM
IO	

- End Products
  - HDMI Tx/Rx
  - Digital media controllers
  - Secure Flash Drives
  - Encrypted HDD
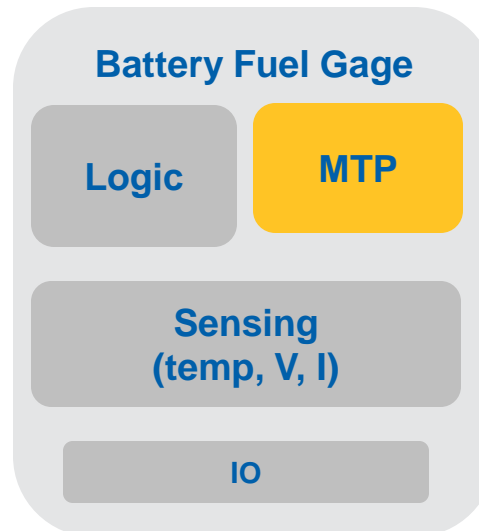
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Real-time Datalogging

OTP or MTP to Store AES, HDMI, etc. Keys

| Attribute	Importance
Density	★ ★
Area	★ ★
Flexibility (i.e. reprogrammability)	★ ★ ★ ★
Power	★ ★ ★

- **CMOS NVM Advantages**
  - Up to 1M cycle endurance
  - Support for BCD processes
  - High temperature operation (150C)

- **Competing Solutions**
  - Embedded Flash

Battery Fuel Gage

Logic

MTP

Sensing (temp, V, I)

IO

- **End Products**
  - Portable Devices
  - Notebook
  - Server / Telecom Power Management

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Performance Trim

Overcoming the Limitations of Fuses

Attribute	Importance
Density	★
Area	★ ★ ★ ★
Flexibility (i.e. reprogrammability)	★ ★ ★
Power	★ ★ ★
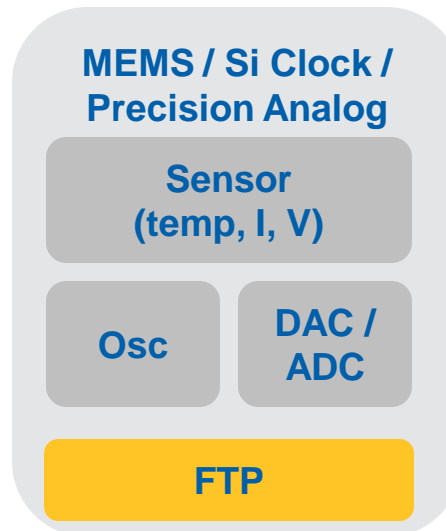
- **CMOS NVM Advantages**
  - Reprogrammable up to 100 times
  - Allows post-package / in-field calibration
  - Fully integrated high voltage circuitry

- **Competing Solutions**
  - Fuses

MEMS / Si Clock / Precision Analog

> **Sensor (temp, I, V)**
>
> **Osc** | **DAC / ADC**
>
> **FTP**

- **End Products**
  - MEMS devices
  - Silicon clocks
  - Precision analog

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Example FTP Specification

Targeted at MEMS, Si Clocks, Precision Analog

Parameter	Min	Typ	Max	Units
General				
Retention	10			Years
Endurance	100			Cycles
Temperature Range	-40	+25	+85	°C
Bit Counts	64		1k	bits
Program				
Input		16		Bits
Power Supply	1.55	1.8	2.0	V
Current		200	400	µA
Time		4	8	ms
Erase				
Input		16		Bits
Power Supply	1.55	1.8	2.0	V
Current		200	400	µA
Time		4	8	ms
Read				
Output		16		Bits
Power Supply	1.55	1.8	2.0	V
Current		100	200	µA/MHz
Time		50	120	ns

- Targets bit counts from 64 bits → 1k bits

- 100 write-erase cycle endurance

- Ideal for trim / OTP replacement applications

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Embedded NVM Performance Summary

Technology	Process Node	Process Adders	Bit Counts	Endurance	Key Usage
Embedded Flash	180nm 90nm?	Yes	>1Mb	20k → 100k	Code storage
Fuses	→ 40nm	No	<1kb	1	Factory Trim
FG OTP	→ 110nm	No	<256kb	1	Trim / config Code storage
Antifuse OTP	→ 55nm	No	>1Mb	1	Code storage Keys
MTP	→ 65nm	No	<16kb	1M	Datalogging Keys
FTP	→ 65nm	No	<16kb	100	Precision trim Config

Conclusions

- Traditional embedded NVM technologies are not sufficient to cover the breadth of new applications and technologies today

- Emerging applications are driving high volumes and new requirements for embedded NVM
    - Firmware / Boot code for SoC
    - Encryption keys for securing data / media
    - Real-time datalogging
    - Precision trim for MEMS, analog
    - Wireless / RFID

- CMOS based NVM fills the gaps with a variety of enabling technologies
    - OTP → code storage
    - MTP → encryption keys, datalogging, RFID
    - FTP → precision trim, wireless

- Visit us at www.viragelogic.com for additional information on CMOS based NVM

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