Application Note

32

EEPROM Emulation Library

EEL - T06

EEPROM Emulation Library for
RC03F Flash based V850 devices

Renesas Electronics
www.renesas.com

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- • Availability of related technical literature
- • Development environment specifications (for example, specifications for third-party tools and components, host computers, power plugs, AC supply voltages, and so forth)
- • Network requirements

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Preface

Readers	This manual is intended for users who want to understand the functions of the concerned libraries.	
Purpose	This manual presents the software manual for the concerned libraries.	
Organisation	This document describes the following sections:	
	• Architecture	
	• Implementation and Usage	
	• API	
Note	Additional remark or tip	
Caution	Item deserving extra attention	
Numeric notation	Binary:	xxxx or xxxB
	Decimal:	xxxx
	Hexadecimal	xxxxH or 0x xxxx
Numeric prefixes	representing powers of 2 (address space, memory capacity):	
	K (kilo):	2^{10} = 1024
	M (mega):	2^{20} = 1024^2 = 1,048,576
	G (giga):	2^{30} = 1024^3 = 1,073,741,824
Register contents	X, x = don’t care	
Diagrams	Block diagrams do not necessarily show the exact software flow but the functional structure. Timing diagrams are for functional explanation purposes only, without any relevance to the real hardware implementation.	

How to Use This Manual

Purpose and Target Readers

This manual is designed to provide the user with an understanding of the library itself and the functionality provided by the library. It is intended for users designing applications using libraries provided by Renesas. A basic knowledge of software systems as well as Renesas microcontrollers is necessary in order to use this manual. The manual comprises an overview of the library, its functionality and its structure, how to use it and restrictions in using the library.

Particular attention should be paid to the precautionary notes when using the manual. These notes occur within the body of the text, at the end of each section, and in the Special Considerations section.

The revision history summarizes the locations of revisions and additions. It does not list all revisions. Refer to the text of the manual for details.

List of Abbreviations and Acronyms

Abbreviation	Full Form
API	Application Programming Interface
Flash Area	Area of Flash consists of several coherent Flash Blocks
Code Flash	Embedded Flash where the application code or constant data is stored.
CR	Complementary Read
Data Flash	Embedded Flash where mainly the data of the EEPROM emulation are stored.
Data Set	Instance of data written to the Flash by the EEPROM Emulation Library (EEL), identified by the Data Set ID
DS	Short for Data Set
Dual Operation	Dual operation is the capability to access flash memory during reprogramming another flash memory range. Dual operation is available between Code Flash and Data Flash. Between different Code Flash macros dual operation depends on the device implementation.
ECC	Error Correction Code
EEL	EEPROM Emulation Library
EEPROM	Electrically erasable programmable read-only memory
EEPROM emulation	In distinction to a real EEPROM the EEPROM emulation uses some portion of the flash memory to emulate the EEPROM behaviour. To gain a similar behaviour some side parameters have to be taken in account.

FAL	Flash Access Library (Flash access layer)
FDL	Data Flash Library (Data Flash access layer)
Flash	Electrically erasable and programmable nonvolatile memory. The difference to ROM is, that this type of memory can be re-programmed several times.
Flash Block	A flash block is the smallest erasable unit of the flash memory.
Flash Macro	A certain number of Flash blocks is grouped together in a Flash macro.
HWd	Half Word (16bit) data
HWIdx	Half Word Index (index to HWd data)
ID	Identifier of a Data Set instance in the Renesas EEPROM Emulation
NVM	Non volatile memory. All memories that hold the value, even when the power is cut off. E.g. Flash memory, EEPROM, MRAM...
RAM	“Random access memory” - volatile memory with random access
REE	Renesas Electronics Europe GmbH
REL	Renesas Electronics Japan
ROM	“Read only memory” - nonvolatile memory. The content of that memory can not be changed.
Segment / Section	Segment of Flash is a part of the flash that might consist of several blocks. Important is, that this segment can be protected against manipulation.
Serial programming	The onboard programming mode is used to program the device with an external programmer tool.
Virtual Flash blocks	The EEL merges together small physical Flash blocks to bigger virtual Flash blocks which are then managed in the ring buffer

Table of Contents

Chapter 1 Introduction

This user's manual describes the internal structure, the functionality and software interfaces (API) of the RENESAS V850 EEPROM Emulation Library (EEL) type T06, designed for V850 based Flash devices with Data Flash based on the RC03F Flash technology, such as V850E2S/Fx4-L.

The device features differ depending on the used Flash implementation and basic technology node. Therefore, pre-compile and run-time configuration options allow adaptation of the library to the device features and to the application needs.

The libraries are delivered in source code. However it has to be considered carefully to do any changes, as not intended behaviour and programming faults might be the result.

The development environments of the companies Green Hills (GHS), IAR and RENESAS are supported. Due to the different compiler and assembler features, especially the assembler implementations differ between the environments. So, the library and application programs are distributed using an installer tool that allows selecting the appropriate environment.

For support of other development environments, additional development effort may be necessary. Especially, but maybe not only, the calling conventions to the assembler code and compiler dependent section defines differ significantly.

The libraries are delivered together with device dependent application programs, showing the implementation of the libraries and the usage of the library functions.

The different options of setup and usage of the libraries are explained in detail in this document.

Caution Please read all chapters of the application note carefully.

Much attention has been put to proper conditions and limitations description. Anyhow, it can never be ensured completely that all not allowed concepts of library implementation into the user application are explicitly forbidden. So, please follow exactly the given sequences and recommendations in this document in order to make full use of the libraries functionality and features and in order to avoid any possible problems caused by libraries misuse.

The EEPROM emulation libraries together with the application samples, this application note and other device dependent information can be downloaded from the following URL:

www.renesas.eu/update

Chapter 2 Architecture

2.1 Flash Infrastructure

2.1.1 Complementary Read Flash

Based on the different application needs, the Flash implementation used for Data Flash differs from the Code Flash implementation. In order to achieve the required high endurance (erase cycles), Renesas decided for a Complementary Read (CR) Flash implementation on Data Flash. Each data bit is realized by two Flash cells, which are programmed to the opposite direction data bit. The cell value difference is read to judge the data value:

Data bit	Flash cell 1level	Flash cell 2 level
0	high	low
1	low	high

Resulting from the implementation, erased Flash (both Flash cells with same/similar level) has a very small differential level. The resulting data bit judgement has an undefined result, but with a tendency to formerly written data. This need to be considered on interpretation of the read values:

- The lower level library FDL provides a blank check to distinguish between erased and written Flash on read level (not exact electrical margins, please refer to the FDL UM).
- The EEL handles this CR behaviour of erased cells in the library concept.
- When inspecting the Data Flash contents (e.g. using a debugger), the debugger need to provide the information on the Flash status (erased/written)

2.1.2 Dual operation

Common for all Flash implementations is, that during Flash modification operations (Erase/Write) a certain amount of Flash memory is not accessible for any read operation (e.g. program execution or data read).

This does not only concern the modified Flash range, but a certain part of the complete Flash system. The amount of not accessible Flash depends on the device architecture.

A standard architectural approach is the separation of the Flash into Code Flash and Data Flash. By that, it is possible to read from the Code Flash (to execute program code or read data) while Data Flash is modified, and vice versa. This allows implementation of EEPROM emulation concepts with Data storage on Data Flash while all program code is executed from Code Flash.

If not mentioned otherwise in the device users manuals, the devices with Data Flash are designed according to this standard approach.

Note It is not possible to modify Code Flash and Data Flash in parallel!

2.1.3 Flash granularity

The Data Flash can be erased in 32 Byte units.

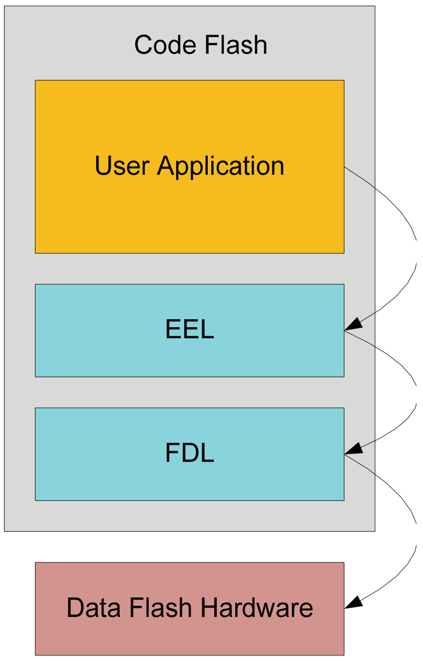
The Data Flash can be written and read in 2 Byte units. As the CPU is able to handle 4 Byte units as one “Word”, this document often refers to the “Half Word” (HWd) as 2 Byte units.

2.2 Layered software architecture

This chapter describes the function of all blocks belonging to the EEPROM Emulation System.

Even though this specification describes the functional block EEL, a short description of all concerned functional blocks and their relationship can be beneficial for the general understanding.

Figure 2-1



Rough symbolic relationship between the functional blocks

Application

The functional block “Application” should not use the functions offered by the FDL directly. FDL functions are reserved for EEL only. Exception is when the user implements a proprietary EEPROM emulation, it has to use functions provided by the FDL only.

EEPROM Emulation Library (EEL)

The functional block “EEPROM Emulation library” is the subject of this document. It offers all functions and commands the “Application” can use in order to handle its EEPROM data.

Data Flash Access Library (FDL)

The “Data Flash Access Library” offers an interface to access any user-defined flash area, so called “FDL-pool” (described in next chapter). Beside the initialization function the FDL allows the execution of access-commands like write as well as a suspend-able erase command.

Note General requirement is to be able to deliver pre-compiled EEL libraries, which can be linked to either Data Flash Access Libraries (FDL) or Code Flash Access Libraries (FCL). To support this, a unique API towards the EEL must be provided by these libraries. Following that, the standard API prefix FDL_... which would usually be provided by the FDL library, will be replaced by a standard Flash Access Layer prefix FAL_...

All functions, type definitions, enumerations etc. will be prefixed by FAL_ or fal_.

Independent from the API, the module names will be prefixed with FLD_ in order to distinguish the source/object modules for Code and Data Flash.

2.3 Data Flash Pools

The FDL pool defines the Flash blocks, which may be accessed by any FDL operation (e.g. write, erase). The limits of the FDL pool are taken into consideration by any of the FDL flash access commands. The user can define the size of the FDL-pool freely at project compilation time, while usually the complete Data Flash is selected.

The FDL pool provides the space for the EEL pool which is allocated by the EEL inside the FDL-pool. The EEL pool provides the Flash space for the EEL to store the emulation data and management information.

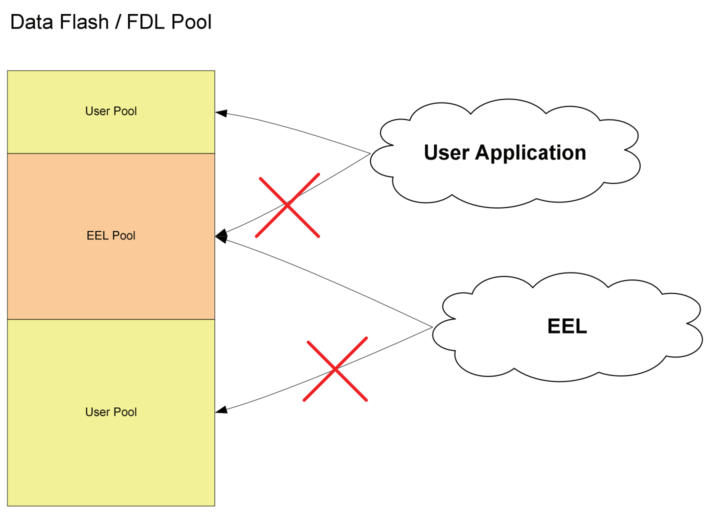
All FDL pool space not allocated by the EEL pool is freely usable by the user application, so is called the “User pool”.

Pools details:

- FDL-pool is just a place holder for the EEL-pool. It does not allocate any flash memory. The FDL-pool descriptor defines the valid address space for FDL access to protect all flash outside the FDL-pool against destructive access (write/erase) by a simple address check in the library.

  To simplify function parameter passing between FDL and the higher layer the physical Flash addresses (e.g. 0xfe000000….0xfe00FFFF) are transformed into a linear address room 0x0000….0xFFFF used by the FDL.
- EEL-pool allocates and formats (virgin initialization) all flash blocks belonging to the EEL-pool. The header data are generated in proper way to be directly usable by the application.
- User Pool is completely in the hands of the user application. It can be used to build up an own user EEPROM emulation or to simply store constants.

Figure 2-2



Data Flash / FDL Pool

2.4 Safety Considerations

EEPROM emulation in the automotive market is not only operated under normal conditions, where stable function execution can be guaranteed. In fact, several failure scenarios should be considered.

Most important issue to be considered is the interruption of a function e.g. by power fail or Reset.

Differing from a normal digital system, where the operation is re-started from a defined entry point (e.g. Reset vector), the EEPROM emulation modifies Flash cells, which is an analogue process with permanent impact on the cells. Such an interruption may lead to instable electrical cell conditions of affected cells. This might be visible by undefined read values (read value != write value), but also to defined read values (blank or read value = write value). In each case the read margin of these cells is not given. The value may change by time into any direction.

This is considered in the emulation design. Safety relevant considerations and concepts are mentioned in dedicated sup-chapters in this document.

2.5 Feature Overview

The new EEL concept improves quite some features known from today’s V850 MF2/UX4 EEELib. Beside the same kind of user data management, based on data sets (DS) identified with certain IDs, many new or extended features are implemented:

The old V850 MF2/UX4 EEELib searches DSs in the Flash memory on every Read access as well as during the Refresh process. Even though being executed in background, the read latency is very big.

In order to overcome this situation, the new EEL concept uses a RAM table to store the latest DS instance. So, the read access performance will be significantly increased.

The startup worst case performance is significantly improved regarding the V850 MF2/UX4 implementation as the DS management does no longer need to overwrite data and refresh complete sections in order to ensure the data consistency.

Ring buffer style Flash block management reaches better Flash endurance usage. While the old concept required a constant “copy zone” in order to execute

Refresh section operations, the new concept requires copy space only if the data at the ring buffer tail (eldest part of the ring buffer) is not already written new in the ring buffer.

2.6 EEL Flash management

2.6.1 Physical vs. virtual address range

To simplify function parameter passing between the FAL and the EEL the physical space used to directly access the device is transformed into a linear address room starting from 0x00000000 (FDL address range). This should save space in the reference-area of the EEPROM driver when writing new instance references. Also the protection mechanisms can be implemented in a more effective way.

2.6.2 Physical vs. virtual Flash blocks

The EEL concept relies on Flash blocks of a reasonable size to store block management data and Data Sets (DSs). As the concept is derived from the EEL T05 used for UX6LF Flash based devices with 2kB Flash block size, also the T06 library merges the physical RC03F Flash blocks together to virtual Flash blocks of 2kB which are managed by the EEL.

The transition from physical to virtual blocks is done within the EEL near to the FDL interface. As the FDL API handles physical blocks, an EEL internal low level routine converts the virtual blocks to physical blocks before calling the FDL to execute Flash erase. The complete EEL works on virtual blocks.

2.6.3 Virtual block structure

The virtual Flash blocks are used as a kind of ring buffer. The below picture considers a write pointer staying fix, while the ring buffer rotates clockwise.

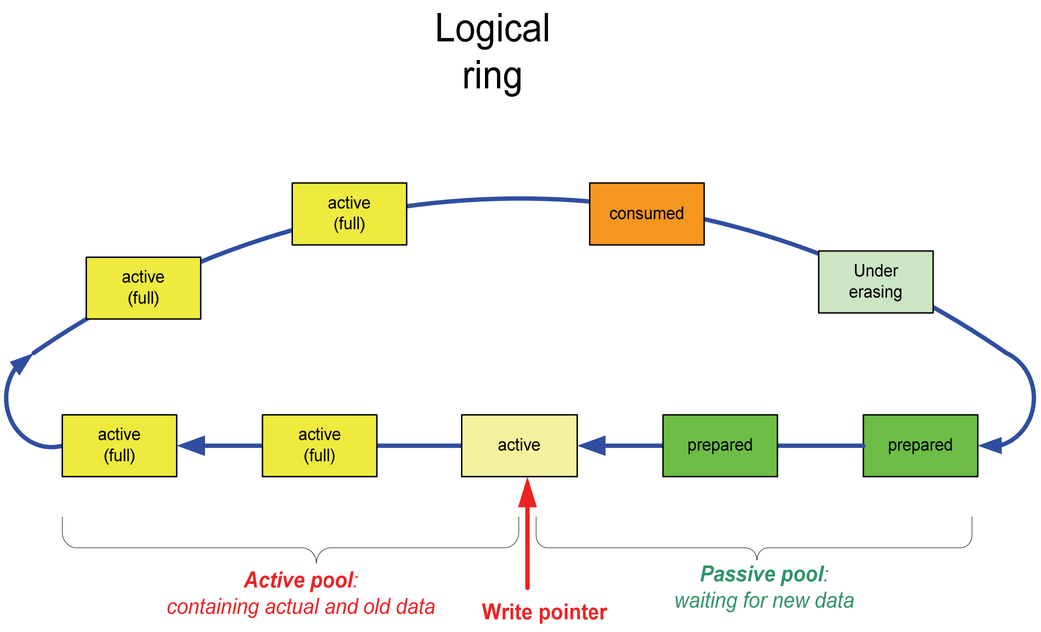
Every block reaching the write pointer gets activated. This block is called the active zone head.

When a block reaches the end of the active zone it is called the active zone tail.

Before getting activated again the block is prepared.

Each virtual block will pass a complete life cycle on every ring buffer loop.

Figure 2-3



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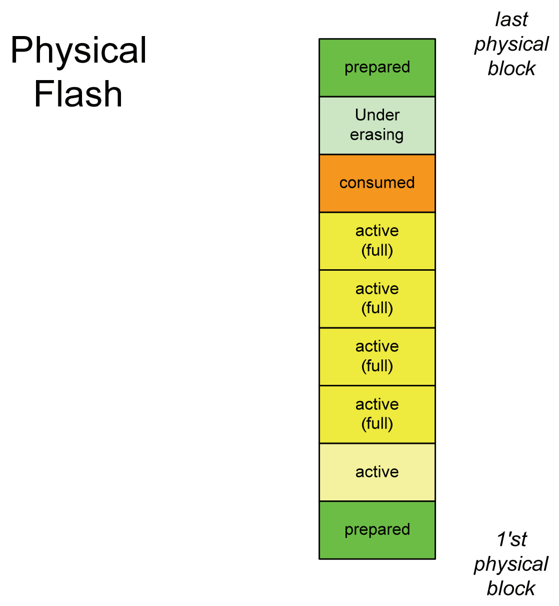


Basic ring buffer structure

2.6.4 Block lifecycle

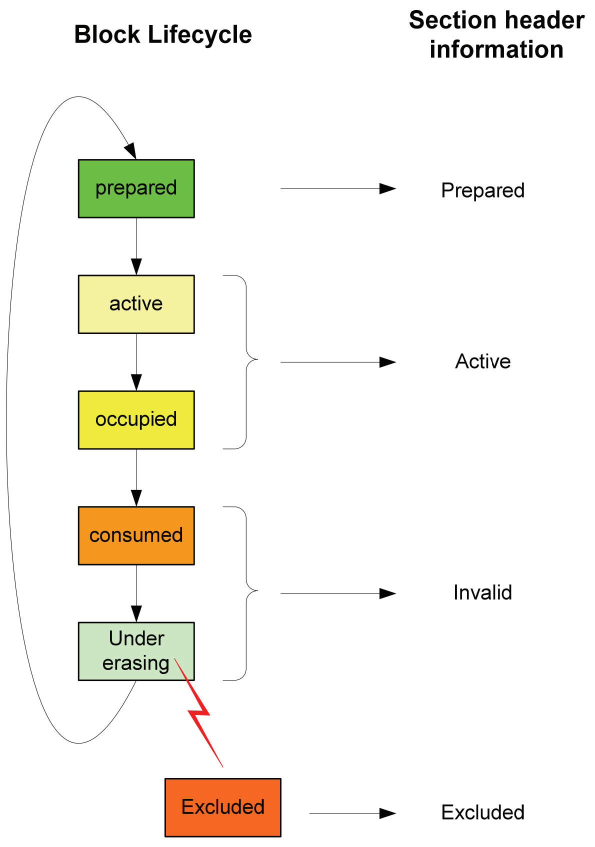
The life cycle of a block passes different steps which are largely marked inside the block header in specific half words.

The active state and the occupied state are not explicitly distinguished by block header information. They all have the active marker set. Anyhow, inside the library only the latest block containing required data (not full, the write pointer points into this block) contains the active status. All other blocks containing required data are full and so, are treated internally occupied.

The consumed blocks, blocks under erasing or other blocks with undefined state due to power fail are considered as invalid and are all treated in the same way by the library. They enter the preparation phase in the next life cycle and are then prepared.

In case of an erase fail the affected Flash block is considered to be defect and is so marked excluded. This block will not enter the lifecycle again.

Figure 2-4



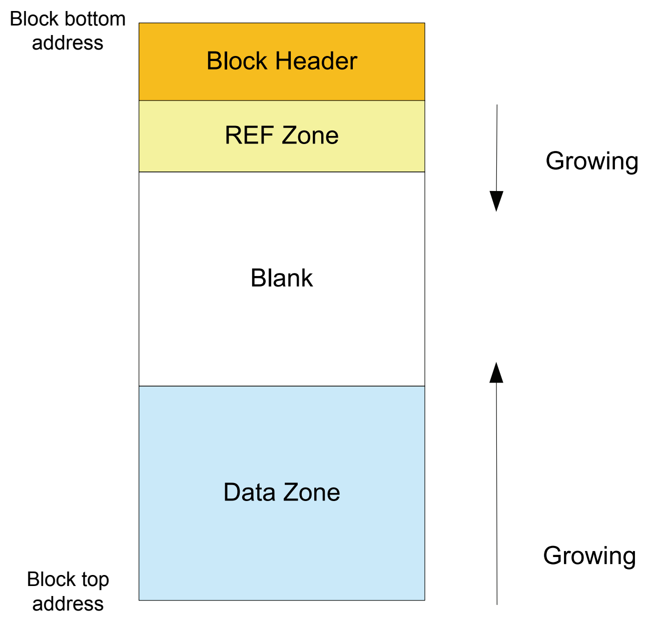
Block Lifecycle

2.6.5 Internal block structure

Every Flash block of the logical ring buffer contains 3 areas. While the block header size is fix, the data zone and the Reference (REF) zone grow towards each other. A block is full and the next block must be activated, when only 1~3 blank half words (depending on different conditions) as delimiter remain between the two zones.

- Block header:
  The header contains the block status information.
- Data Zone:
  Contains the pure user data to be stored without any management information.
- Reference (REF) zone:
  This is a table with entries containing the references (pointers) to the data.

Figure 2-5



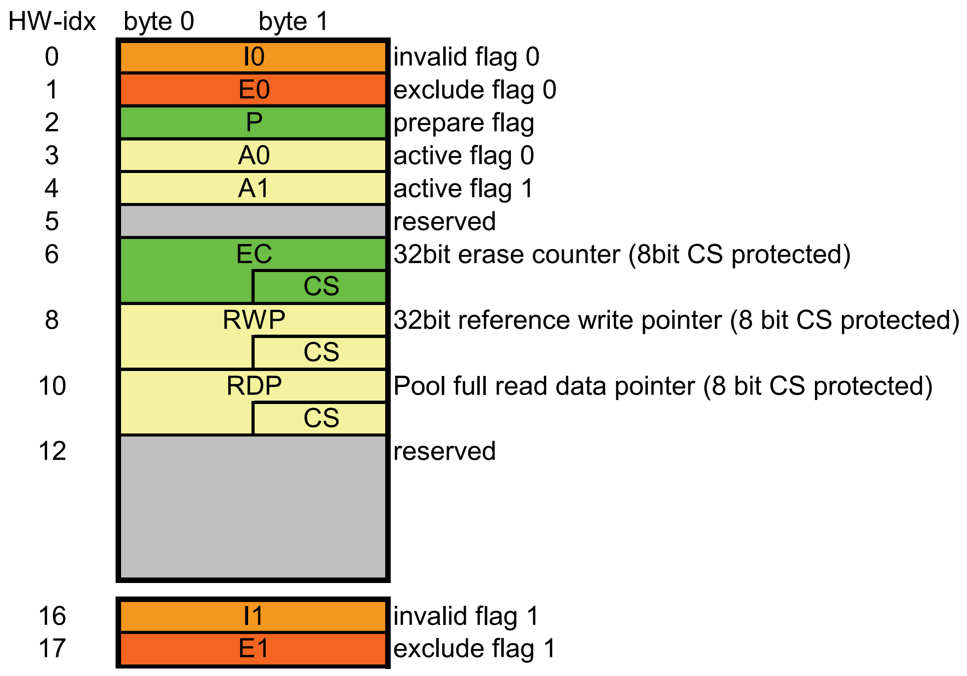
Basic Block structure

While the block management (including the block header) is described in the next sub-chapters, the data management within the blocks (including REF Zone and Data Zone) is described in the main chapter EEL Data Sets Management.

2.6.5.1 Block Header

The block header contains the block status half words.

Figure 2-6



Block header half words

I – 0, I – 1:

The flags are written by the Refresh process when a block does not contain any more valid DSs with relevant data and shall be marked for the later Prepare process.
Furthermore, the invalidation flags are written during execution of the startup process, when a block status is detected as invalid but the flags are not valid. This ought to result from an interrupted invalidation of the virtual block.

- By writing 0x5555, the block is marked invalid
- If on startup the half words are not blank and not matching one of the above patterns, the block is judged invalid. This is the block default state which may result from a power fail during block status change operations
- If on startup the entries are blank, the other header entries determine the block status

E – 0, E – 1:

The flags are written to 0x5555 to mark a virtual block excluded. This is done, when the Flash erase returns an erase error. The blocks are then judged defect.

P:

The prepare marker is set by the preparation process. With the pattern 0x5555, the block is marked prepared.

A – 0:

The activation flag 0 is written 1st in the block activation process with the pattern 0x5555. It locks the block for activation, to indicate the started activation process. In case of a power fail during activation the next block is used.

A – 1:

The activation flag 1 is written last in the activation process with the pattern 0x5555.

EC:

The erase counter is written as the 1st entry in the preparation process.

Rule for counter calculation is:

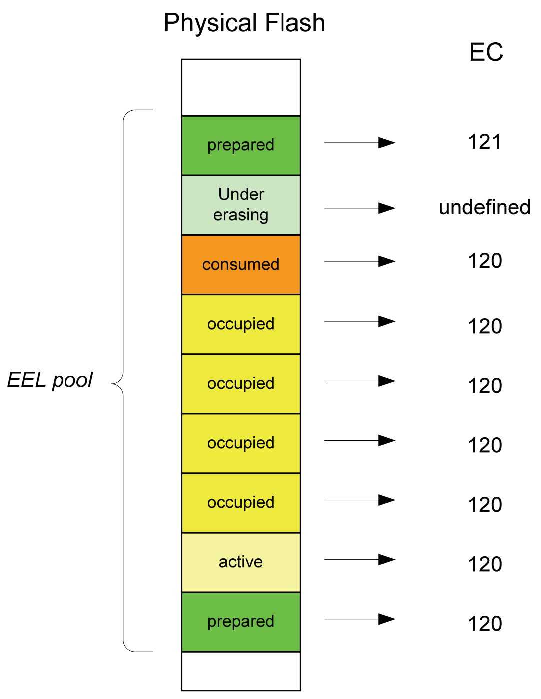
```
if the block is the 1st physical block
    EC = ( previous block EC ) + 1
otherwise
    EC = ( previous block EC )
```

By that rule, on each ring buffer turn around the erase counter in each block is increased by 1.

The erase counter stability is ensured by the P entry, written afterwards in the preparation process. If the P entry is valid, the EC is electrically stable.

Additionally, the EC is checksum protected in order to be robust against accidental overwriting due to application failures.

Figure 2-7



Erase Counter example

Note The erase counter does not necessarily match the real Flash block erase cycles, but only the erase cycles since the EEPROM emulation has been set up last time.

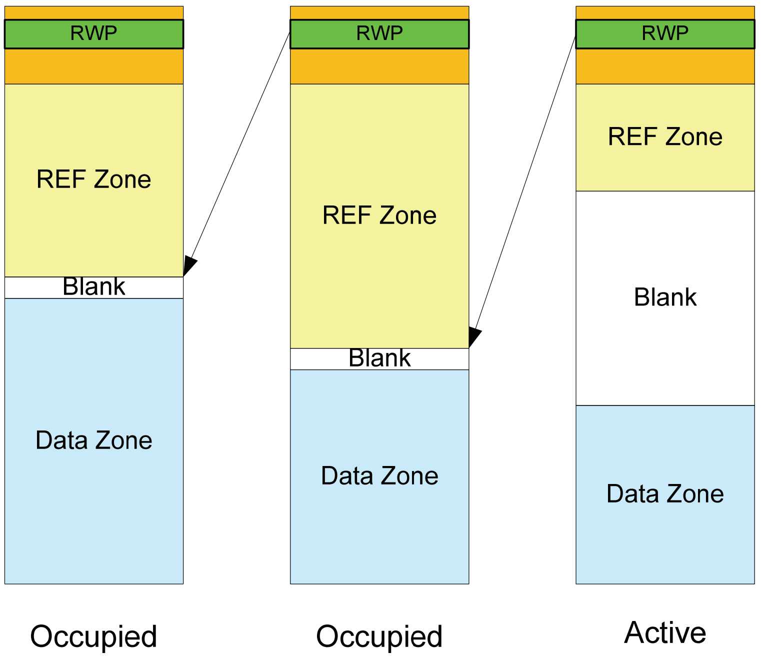
The erase counter is affected by Data Flash complete erase or manual Flash modification (programmer or debugger).

RWP:

The reference write pointer is written in the activation process after A – 0 and before A – 1. It points to the previous block separator between REF zone and Data zone. By that, the EEL knows for each occupied block the last REF zone entry. The RWP stability is ensured by the A - 1 entry, written afterwards in the activation process. If the A - 1 entry is valid, the RWP is electrically stable.

Additionally, the RWP is checksum protected in order to be robust against accidental overwriting due to application failures

Figure 2-8



Reference Write Pointer

RDP:

The Read Data Pointer is used for special treatment of the situation, that only one block is left for refresh.

The RDP is not related to the block status and so, need not be considered in the power fail FMEA considerations regarding block status management.

Reserved areas:

Reserved header areas are unused. These areas result from the fact that I1 and E1 have to be placed into another physical Flash block.

2.6.5.2 Block header data transitions

During EEPROM emulation block header information changes according to the block status. The following table shows the data change process and the resulting block header data.

As the RDP word (see last sub-chapter) is not block status related, it is not mentioned here.

Figure 2-9

Block Operation	Status	Block Header words								
		I-0	I-1	E-0	E-1	P	A-0	A-1	EC	RWP
-	erased	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF
"Set Prepared"	ongoing	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	????	FFFF
	ongoing	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	XXXX	FFFF
	ongoing	FFFF	FFFF	FFFF	FFFF	????	FFFF	FFFF	XXXX	FFFF
	finished	FFFF	FFFF	FFFF	FFFF	5555	FFFF	FFFF	XXXX	FFFF
"Set Active"	ongoing	FFFF	FFFF	FFFF	FFFF	5555	????	FFFF	XXXX	FFFF
	ongoing	FFFF	FFFF	FFFF	FFFF	5555	5555	FFFF	XXXX	FFFF
	ongoing	FFFF	FFFF	FFFF	FFFF	5555	5555	FFFF	XXXX	????
	ongoing	FFFF	FFFF	FFFF	FFFF	5555	5555	FFFF	XXXX	XXXX
	ongoing	FFFF	FFFF	FFFF	FFFF	5555	5555	????	XXXX	XXXX
	finished	FFFF	FFFF	FFFF	FFFF	5555	5555	5555	XXXX	XXXX
"Set Excluded"	ongoing	- - - -	- - - -	????	FFFF	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	- - - -	- - - -	5555	FFFF	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	- - - -	- - - -	5555	????	- - - -	- - - -	- - - -	- - - -	- - - -
	finished	- - - -	- - - -	5555	5555	- - - -	- - - -	- - - -	- - - -	- - - -
"Set Invalid" (normal case)	ongoing	????	FFFF	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	5555	FFFF	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	5555	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	finished	5555	5555	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
"Set Invalid" (special case 1)	ongoing	????	FFFF	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	????	FFFF	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	????	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	finished	????	5555	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
"Set Invalid" (special case 2)	ongoing	????	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	5555	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	5555	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	finished	5555	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
"Set Invalid" (special case 3)	ongoing	????	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	????	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	ongoing	????	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -
	finished	????	????	- - - - *	- - - - *	- - - -	- - - -	- - - -	- - - -	- - - -

FFFF	Blank Flash word
5555	Pattern 0x5555
0	Pattern 0x00000000
XXXX	Erase counter / reference write pointer data
????	Data write in progress --> Data is undefined
- - - -	Data is irrelevant and/or undefined
- - - - *	Data on E-0/E-1 is any data != 0x5555/0x5555

Block header data transitions

The block header information is read on library startup and maintained library internal during run-time.

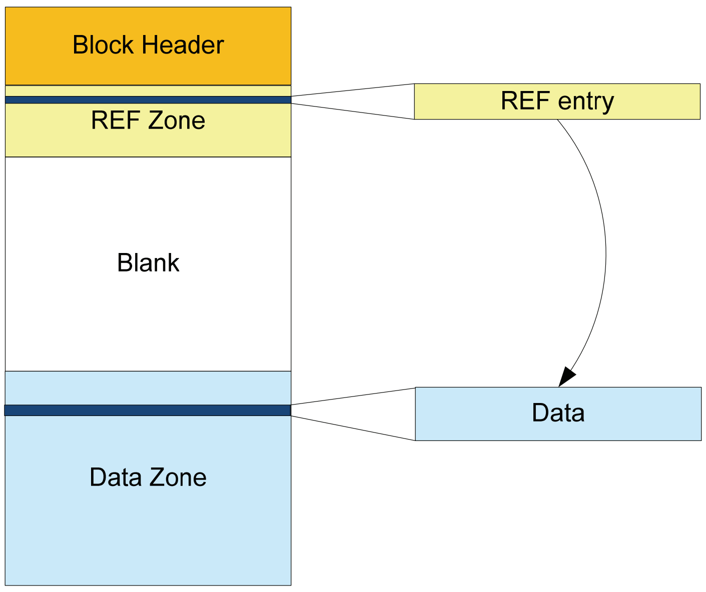
The block header data is modified during run-time by the block management processes (see next chapter) and during startup in case of detected inconsistencies.

2.7 EEL Data Sets Management

2.7.1 Basic Concept

Differing from real EEPROM, where user data is referenced by the address information, the user data in the RENESAS EEPROM emulation is referenced by an identifier (ID). An ID is unique for a certain set of data with a dedicated length. Differing from EEPROM, the data is stored “somewhere” in the Flash memory but not on a fix address.

Figure 2-10



Overview - Entry in the REF zone pointing to the user data in the Data zone

The user data is stored in the Data Zone sequentially according to the write sequence. Based on the Flash write size of 1 HWd, the data is stored HWd aligned.

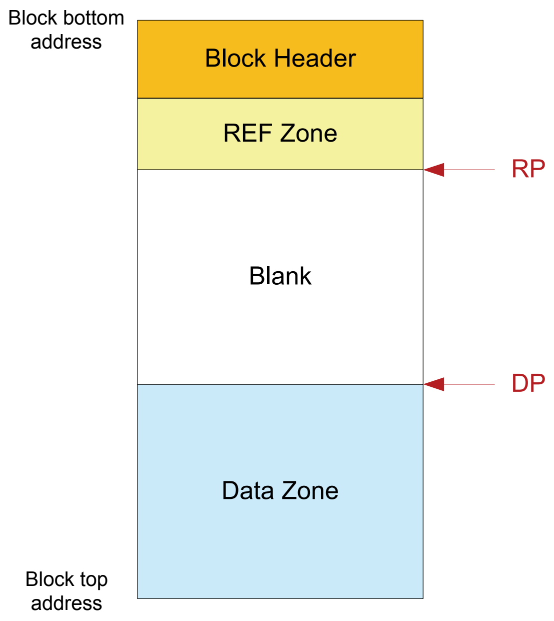
In order to find the data later on in the Flash, the REF zone contains the DS management information, which is basically the ID and the pointer to the data. Further information is required in the REF-zone to ensure data consistency in case of write interruption and in order to improve the robustness against user application fails resulting in Flash overwrite.

2.7.2 DP and RP

The emulation library requires two pointers in the active section in order to write new DS instances to the Flash

- Data Pointer (DP)
  The DP is the pointer to the next write location for the user data.
- Reference Pointer (RP)
  The RP is the pointer to the next location for a REF zone entry.

Figure 2-11



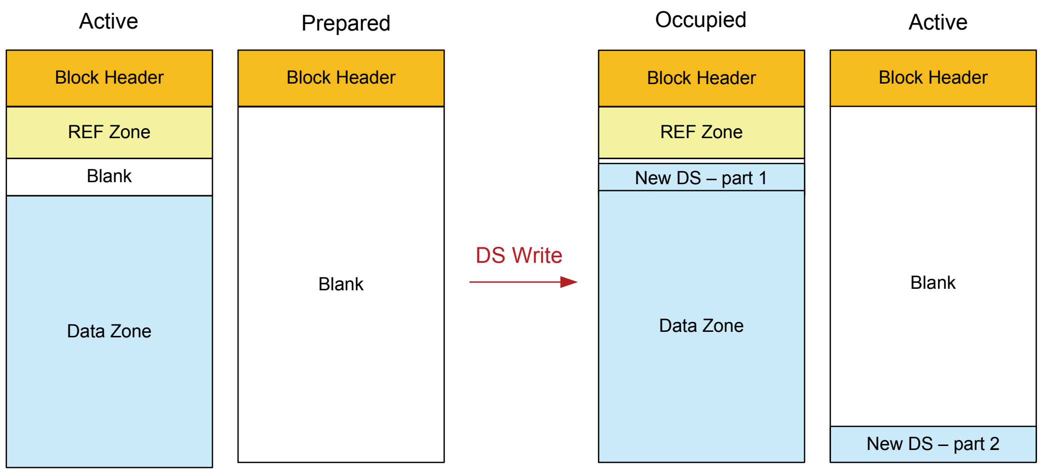
DP and RP

RP and DP grow together. When the pointers match, only one blank HWd is between the zones. The Flash block is considered as full and the next block must be activated.

2.7.3 Block overlapping DS's

In order not to waste Flash space when a DS does not completely fit into a Flash block, the DS is partly written into the block and finished in the next block (or blocks in case of DS bigger than one block).

Figure 2-12



Block Overlapping DS (normal size DS)

Note Based on the EEL implementation it is not allowed that the DS size exceeds more than one Data Flash block. So, overlapping multiple blocks is not possible.

2.7.4 Storage structure details

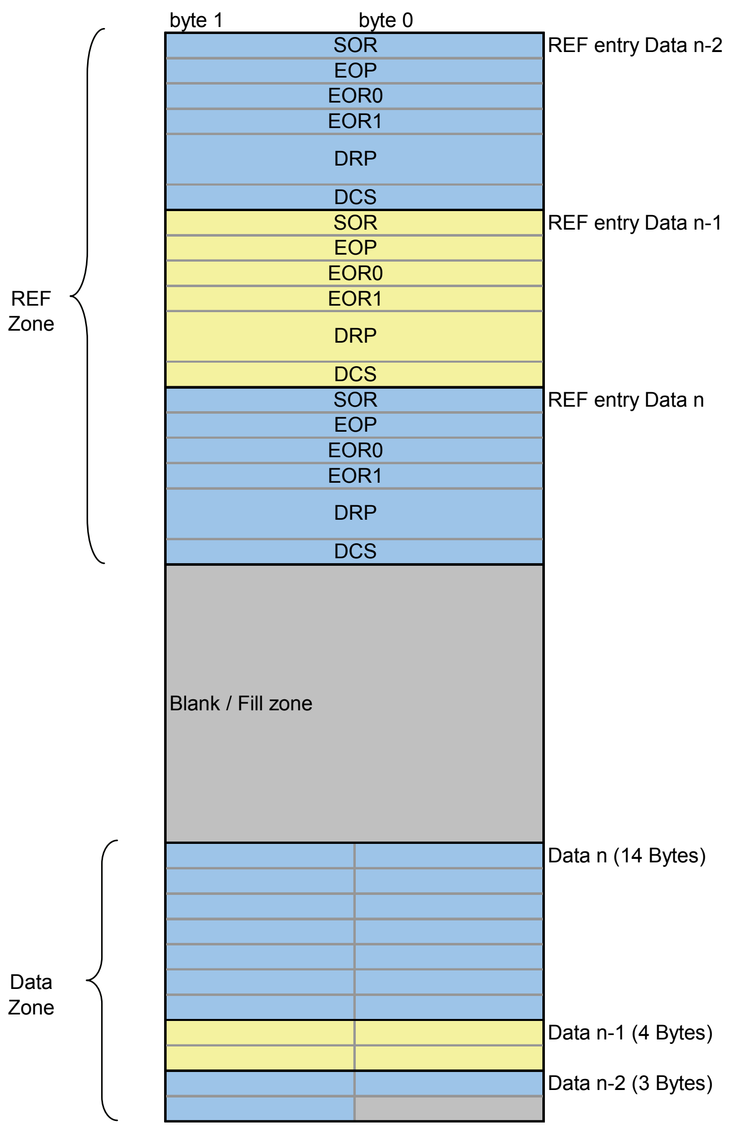
The following 2 sub-chapters describe the Data Sets (DS) storage structure details. The structures differ depending on:

- The DS contains valid user data
- The DS contains the information that the user data of a certain ID is invalid and so, may not be read until valid data is written again.
  A Read command on a ID which last DS instance is invalidated will return the error "invalidated" instead of returning data.

2.7.4.1 DS containing normal data

The DSs are stored according to the following picture:

Figure 2-13



DS Data and management information in Flash

- SOR - Start of reference entry

  It is written 1st in order to block one REF zone list entry.

- DRP - Data Reference Pointer

  Is written after SOR and contains:
  - 16-bit lower half word: ID
  - 16-bit upper half word: word index, a pointer to the data

Note DRP can address 64k indexes. This is sufficient to cover 128kB Flash with HWd addressing (indexing).

- EOP - End of DRP

  Is written immediately after the DRP. When written, the read margin of the DRP word is ensured by the write sequence.

- DCS - Data Check Sum

  This is a simple 16bit checksum, calculated over the user data and DRP. It ensures higher robustness (detection) on accidental overwriting of data or DRP.

Note The DRP widx is excluded from the checksum as it is updated in case of a Refresh, where the DCS is not re-calculated (may not be recalculated as in case of an application update combined with IDL table update, the DCS indicates a possible DS length change to the user application).

- EOR0 - End of Reference 0

  EOR0/1 are the last written HWds of a DS. When EOR0 pattern is correct, it is ensured that the previously written REF entry part and data are written correct

- EOR1 - End of Reference 1

  Additional safety for the case of data set write interruptions.
  At the end of the startup phase EOR1 is checked for each DS and on not available or invalid EOR1 the DS is refreshed to ensure the electrical margin of the complete DS

2.7.4.2 Invalidated DS

One requirement is to provide a possibility to invalidate the last DS instance of a certain ID.
Sample use case: When activating a window lifter, the last stored window position is invalidated, then the lifter is turned on. At the end when the lifter stops the new position is written.

Invalidation is realized by a special kind of REF entry. The widx entry is set to zero and no data is written in the data zone.

A later on Read on this ID will return an error EEL_ERR_NO_INSTANCE to indicate this non existing data.

Chapter 3 EEL Design

3.1 Asynchronous architecture

Each state has a strictly limited execution time. Based on that, the library function controlling the state machine (EEL_Handler, see API description) will immediately return to the user application. Due to dual operation between Code Flash and Data Flash the upper application can continue operation while frequently invoking the state machine handler function.

3.2 Flash interrupt support

The EEL is prepared to support the Flash interrupt. This means, that the EEL triggers the Flash interrupt when the handler function shall be called in order to process a next EEL process state. By that, the handler function can be executed in the Flash interrupt context or in an interrupt triggered task which means as few as possible handler function calls (no polling) by achieving the best EEL performance.

Basically, each Flash operation end triggers the Flash interrupt. However, quite some EEL state machine internal states (User operations as well as background processes) don't issue a Flash operation. In order to support the Flash interrupt in a sufficient way, these states must issue the Flash interrupt by SW. This can be achieved by the EEL configuration (See 5.1, "Pre-compile configuration").

Note Even when the EEL is idle, the handler function shall be called regularly in order to execute idle time supervision tasks like bit error check (See 3.4, "Background operations"). As for that the handler shall not be called with high frequency (e.g. 10ms~100ms task), the user application need to trigger the interrupt by SW.

3.3 EEL user operations priority

The EEL provides the following user operations which are invoked by appropriate commands: Immediate DS Write, Immediate DS Invalidate, DS Write, DS Invalidate, DS Read, Format, Cleanup. These commands have partially been mentioned before and are described in the API description.

The Read and Write operations are considered to be prioritized according to the following scheme:

- Priority 1
  Read, can interrupt Write, Incremental Write, Invalidation, Immediate Write, Immediate Incremental Write and Immediate Invalidation
- Priority 2
  Immediate Write Immediate Incremental Write and Immediate Invalidation can interrupt Write, Incremental Write and Invalidation
- Priority 3
  Write, Incremental Write and Invalidation cannot interrupt any other user operation

The following rules apply to these operations:

All of the above operations can interrupt ongoing background operations.

A command invoking an operation when an operation of the same priority is ongoing will be rejected.

When an operation of a higher priority is invoked, a possibly ongoing operation of a lower priority will be suspended.

When invoking an operation of a lower priority, a possibly ongoing operation of a higher priority is will be finished first then the lower priority operation is executed.

Furthermore, special conditions apply for the other operations:

- Format operation
  Requires that the system executes no user or background operations. If this is not the case, the command will be rejected. When started, all other operations are blocked.
- Cleanup operation
  Requires that the system executes no user or background operations. If this is not the case, the command will be rejected.
  After being started other operations can be executed, the cleanup operation will be suspended and later on resumed automatically.

3.4 Background operations

The EEL operations are based on independent processes for the different user operations, such as Read, Write, Immediate Write. Furthermore, background processes are to be executed in order to manage the EEL pool and to manage the startup flow.

The following background operations and their processes are available:

- Refresh
  This process manages copying any potential DS instances from the EEL pool active tail to the head before invalidating a virtual block. The copy process itself is done by the Write (Refresh) process. After invalidation, the block can be prepared again.
- Write (Refresh)
  This process is triggered by Refresh to copy one DS
- Prepare
  Erase invalid Flash blocks and mark them prepared. This process provides new space for the active pool.
- Supervision
  This process manages the complete startup processing (See 3.7, “Start-up processing”). When the library is up and in normal operation, it controls the background processes:
  - When the refresh threshold is underrun, the process triggers first the Refresh process, then the Prepare process to provide enough prepared pool space to store new DS instances.
  - When no further pool handling is required, the process checks the EEL pool for bit errors. To do so, the complete pool address range (only active and prepared virtual blocks) is checked HWd by HWd using the FDL bit error check function. On detection of a bit error, further Refresh and Prepare operations are triggered and by that, sequentially all blocks are refreshed. This is continued until the bit error is gone.

On invocation of a user operation, the background processes are interrupted at the next possible state in order to execute the user processes. After user process termination, the background processes are continued.

Note When the Supervision process need not execute any pool operations beside bit error check, the EEL driver status is set to idle. Nevertheless, the handler function shall be called regularly (even with lower frequency, e.g. 10ms task) in order to execute the bit error checks. This need to be considered too, when the library is executed in the Flash interrupt context.

3.5 Error and warning levels

Due to the case, that errors may happen in cause of user activated processes (e.g. write, read, format) or automatic handled background processes (prepare, refresh, supervision), the error return to the user and the complete system reaction on the errors must be clearly defined.

The error reaction is classified in the (5.3.1, “Error Codes”):

- Warnings, e.g. EEL_ERR_BLOCK_EXCLUDED
  These warnings are signalled to the user application but don’t result in a emulation system reaction.
- Errors resulting in complete system lock, e.g.
  EEL_ERR_POOL_INCONSISTENT
  The error is signalled to the user application and the complete system is locked:
  - No user commands accepted.
  - All ongoing user operations are stopped and return with error EEL_ERR_ACCESS_LOCKED.
  - All background processes are stopped.
- Errors resulting in read only mode, e.g. EEL_ERR_FLASH_ERROR during data set write:
  The error is signalled to the user application and the complete system is in read only mode:
  - Only further user read command accepted, write and format are locked.
  - All ongoing user operations are stopped and return with error EEL_ERR_ACCESS_LOCKED (a read operation cannot be ongoing as this has the highest priority).
  - All background processes are stopped.

The errors/warnings are returned to the user application on two different ways:

- Errors on background operations are returned by a special function returning the driver status. Independently, in case of errors, ongoing and future user commands will be answered with EEL_ERR_ACCESS_LOCKED.
- Errors on user commands (Write, Read, Format) will be returned as command answer.

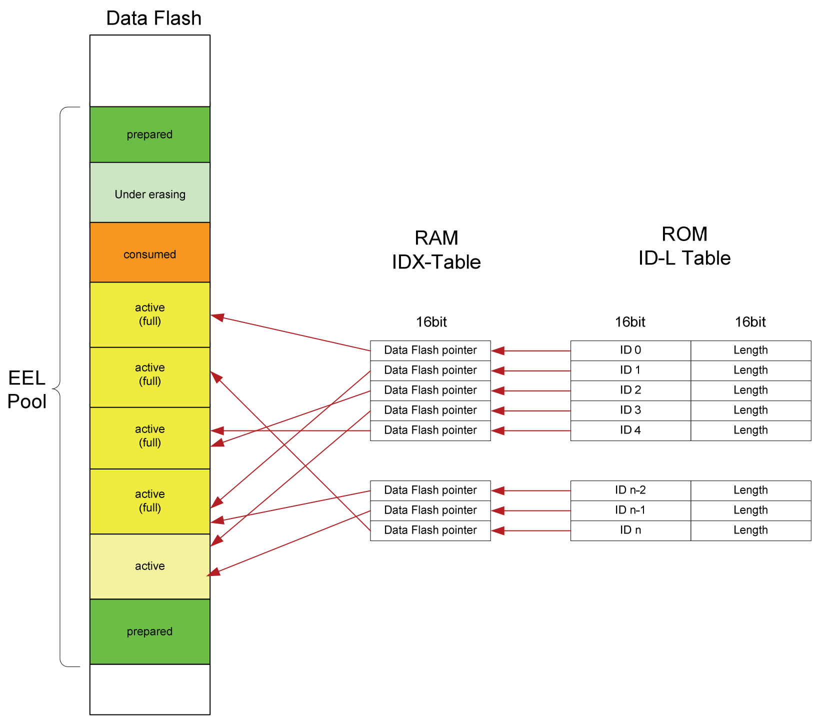
3.6 Data Set search and read

3.6.1 ID-L and IDX tables

The library uses internal tables to store the DS size information and latest DS location.

While the DS size is stored together with the ID statically in ROM, the pointers to the latest DS instances are evaluated on library startup and stored in RAM.

Figure 3-1



Library ID Tables

The ID-L table (ROM table) contains one entry for each ID available in the system, together with its DS length information. This table is configured at compile time.

IDX table (RAM table) contains for each ID available in the system the pointer to the latest data instance. On EEL startup the IDX table is filled and continuously updated on each DS Write access.

3.6.1.1 Data Read Mechanisms

ROM table search

Whenever a DS with a dedicated ID shall be read, the requested ID is searched in the ROM table. The index of the ROM table entry with the fitting ID is then used to get the data pointer (to the Data Flash) from the RAM table.

This ROM table search is fast, but the RAM table must be initialized on startup which requires some time.

The Rom table is used for Read as well as for the Refresh process.

REF zone search

In order to be able to read data without initialized RAM table, the library provides another read (data search) mechanism. The library can parse the REF zone of the blocks and read the entries sequentially until an entry with the requested ID is found. It needs to be considered, that the REF zone parsing requires some time and 100% CPU load.

This search mechanism is called REF-zone search.

The REF zone search is used in the library startup phase, when the RAM table is not yet initialized and also in special library operation modes (see next sub-chapter).

3.7 Start-up processing

The start-up processing is controlled by the EEL state machine. After library initialization and start-up invocation (see EEL_Startup function API), several start-up process steps are executed until the system is in normal operation. Along with the start-up progress the access rights to the data and the library features are unlocked and the full performance of the EEL is reached.

The start-up progress can be checked by the user application with the function EEL_GetDriverStatus which returns the access status and the operational status. Please check the next figure for the status values depending on the progress:

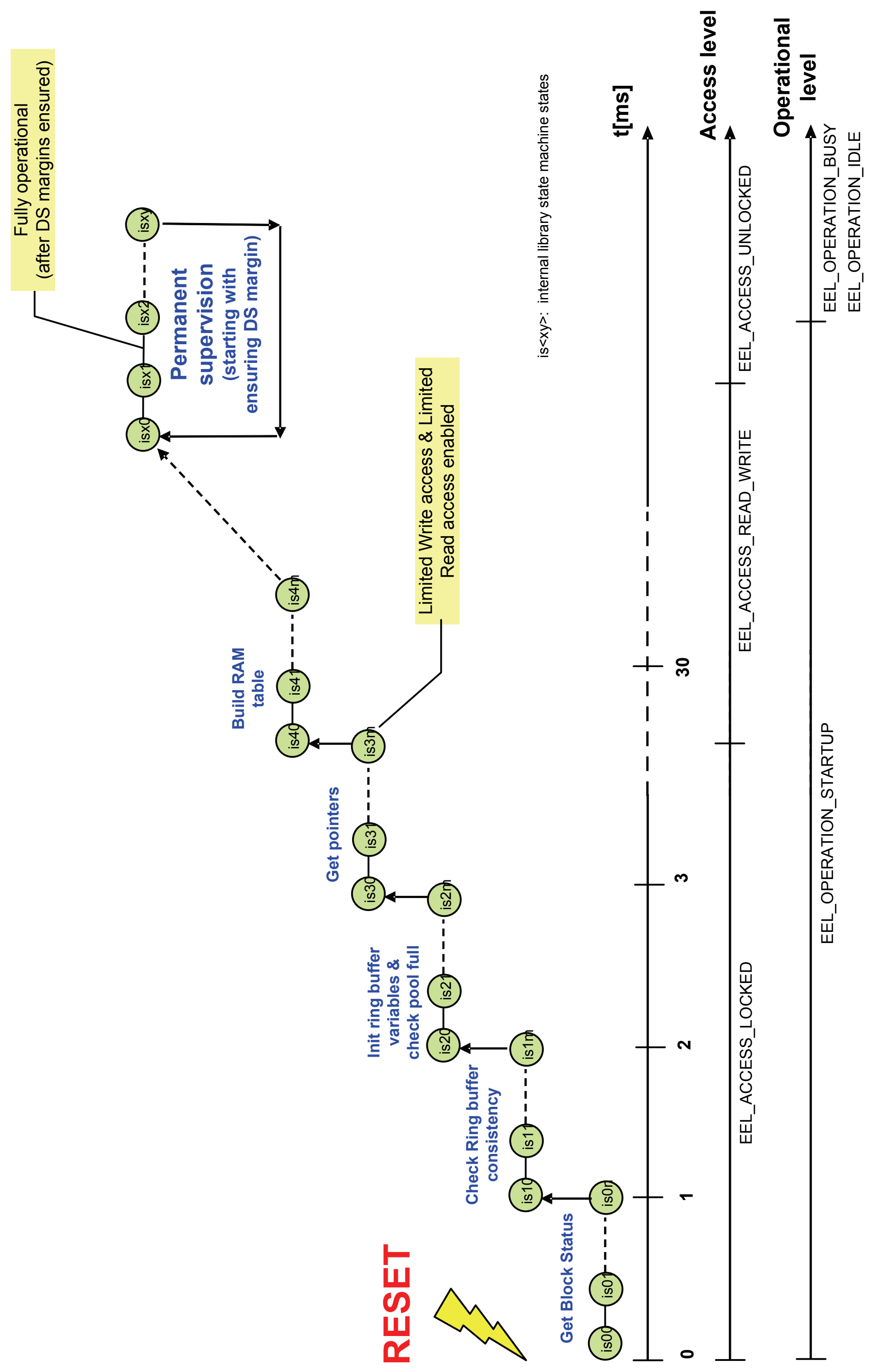
Start-up progress	access status	operational status	comment
EEL Initialized	EEL_ACCESS _LOCKED	EEL_OPERATION _PASSIVE	All library operations are prevented.
EEL startup started	EEL_ACCESS _LOCKED	EEL_OPERATION _STARTUP	All library operations are prevented.
EEL startup ongoing - basic startup finished	EEL_ACCESS _READ_WRIT E	EEL_OPERATION _STARTUP	DS Read is possible with limited performance (REF zone search). DS Write is possible until the prepared blocks are full.
EEL startup ongoing - RAM table filled	EEL_ACCESS _UNLOCKED	EEL_OPERATION _STARTUP	DS Read is possible with full performance (ROM table search). DS Write is possible and supervision processing is active to manage the ring buffer.
EEL startup end	EEL_ACCESS _UNLOCKED	EEL_OPERATION _BUSY or _IDLE (depending if Refresh/Prepare operations are to be done)	- DS Read and DS Write as before - Electrical margin of the latest DS instances is ensured.

Startup process progress steps

In case of a fatal error during any start-up step, the library switches to EEL_ACCESS_LOCKED and EEL_OPERATION_PASSIVE and the function EEL_GetDriverStatus will additionally return an appropriate error.

Note The last startup processing step (Ensure the electrical margin of the latest DS instances) checks if the valid DS instances have been completely written. Therefore it checks if the last step of a DS write was executed (EOR1 is written). If not, redundant information (valid EOR0) ensures that the DS data is valid. On detection of such cases, the DS is refreshed (copied to active zone head).

Figure 3-2



Start-up processing steps

3.8 Function & command execution times & latencies

Basically three important times need to be considered when implementing the EEL into a user application:

- **Operation invocation latency**

  This is the time from calling EEL_Execute to issue the command and start an operation (e.g. Read, Write, ...) up to the point where the process of the operation is really started.
  This latency is determined by execution of higher priority operations but also by the delay to suspend a lower priority operation. Some process steps of lower priority operations cannot be suspended because they started Flash Write operations (erase can immediately be suspended).
  E.g. the DS Write process cannot be suspended until the user data write has started (After SOR, DRP, EOP write and potential new block activation) because otherwise the data consistency would be endangered.
  So, these process steps must be finished and by this determine the invocation latency of a higher priority operation.

- **EEL_Handler/EEL_Execute execution time**

  The execution time should be typically below 100us on a 100MHz device in order to realize a system with reliable timing. During normal operation this can be reached, but in the startup phase the execution times will be longer as complex calculations and searches are executed. In the startup phase this time is affected by many conditions and so can only be measured for a reference system, whereas the real timing needs to be evaluated by the customer in the user application.
  Issues affecting this time are e.g. DS Size, higher priority operations ongoing, pool size,...

- **Overall operation execution time**

  This is the time to execute a complete operation, like user DS write, user DS Read from operation invocation to operation finish.
  This time is affected by many conditions and so can only be measured for a reference system, whereas the real timing needs to be evaluated by the customer in the user application.
  Issues affecting this time are e.g. Flash Write time (in the evaluations also the worst case time need to be considered), DS Size, operation invocation latency, higher priority operations ongoing, ...
  So, in the next sub-chapters this time is not mentioned again.

3.8.1 Library startup phase

The library needs to execute various process steps according to the implementation concept (see startup phase description). The EEL_Handler execution time during steps will be partially >>100us, which need to be considered in the library implementation concept.

Note From EEL implementation point of view the startup phase will end when the operational status changes from EEL_OPERATION_STARTUP to EEL_OPERATION_BUSY/IDLE. Then all startup operations are finished.
From timing point of view, the startup phase will end when the access status changes from EEL_ACCESS_READ_WRITE to EEL_ACCESS_UNLOCKED.
The remaining startup operations are executed in background and transparent for the user. Also the early Read (see below) ends on EEL_ACCESS_UNLOCKED.

3.8.1.1 Early Read command

Operation invocation latency

The maximum latency of the Read operation invocation by the EEL_Execute function is defined by the EEL_Handler execution time (see comments above).

Furthermore, after invocation of the read, start of the Read process need to wait for the end of a possibly started 4-HWd Data Flash write (up to 4 half words can be written by the Flash hardware in sequence without software interaction) caused by a Write command or by the startup process.

EEL_Handler execution time

A Read command executed in the library startup phase while the RAM table is not (completely) filled is called early read. The data of a DS with a certain ID to be read is found as follows:

- If the ID-X RAM table entry belonging to the ID is already filled, the entry addresses the data and the data can be read quickly.
- If the ID-X RAM table entry belonging to the ID is not yet filled, the DS is searched by parsing the REF entries from the youngest one backwards until a valid DS with the ID is found.

According to the possibly necessary REF entry parsing, the early Read may last longer time (>>100us) and requires 100% CPU load.

Furthermore, the data read from Flash itself together with the checksum calculation need some time. So, the time can increase 100us already by DS sizes > 32 Bytes

3.8.1.2 Early Immediate Write / Immediate Incremental Write / Immediate Invalidation command

The early Immediate Write sequence does not differ to the normal Immediate Write.

Generally, a Write operation needs to wait for the end of a preceding Write or Invalidation operation. Trying to invoke a Write before will be rejected.

Operation invocation latency

The maximum latency of the Write operation invocation by the EEL_Execute function is defined by the EEL_Handler execution time (see comments above).

Furthermore, after invocation of the write, starting of the Write/Invalidation process need to wait for:

- The end of a higher priority Read command.
- The end of blocking by a lower priority DS Write process invoked by user DS Write/Invalidation command or background Refresh process. In order to ensure data and ring buffer consistency, any DS Write process need to block higher priority Write commands until the process step to write the user data is reached. Blocking time is defined by 8 times a 1-word Data Flash Write (4-times to write SOR, DRP, EOP & 4 times to possibly activate a new block).

EEL_Handler execution time

The execution time should be <100us on a 100MHz device.

3.8.1.3 Early Write / Incremental Write / Invalidation command

The early Write sequence does not differ to the normal Write.

Generally, a Write operation needs to wait for the end of a preceding Write or Invalidation operation. Trying to invoke a Write before will be rejected.

Operation invocation latency

The maximum latency of the Write operation invocation by the EEL_Execute function is defined by the EEL_Handler execution time (see comments above).

Furthermore, after invocation of the write, starting of the Write process need to wait for:

- The end of a higher priority Read, Immediate Write or Immediate Invalidation command.
- The end of blocking by a lower priority DS Write process invoked by user DS Write/Invalidation command or background Refresh process. In order to ensure data and ring buffer consistency, any DS Write process need to block higher priority Write commands until the process step to write the user data is reached. Blocking time is defined by 6 times a 1-HWd Data Flash Write (4-times to write SOR, DRP, EOP & 4 times to possibly activate a new block).

EEL_Handler execution time

The execution time should be <100us on a 100MHz device.

3.8.2 Normal operation phase

If not mentioned otherwise, in the normal operation phase the EEL_Handler function execution time should always below 100us on a 100MHz device.

An ongoing Flash erase will not block any user command. The erase will be suspended and later on resumed. Anyhow, after a configurable number of times suspending, the warning EEL_ERR_ERASESUSPEND_OVERFLOW is returned in order to inform the user to give sufficient time to complete the erase operation rather than extremely frequently invoking Read/Write/Invalidation operations.

3.8.2.1 Read command

Operation invocation latency

The maximum latency of the Read operation invocation by the EEL_Execute function is defined by the EEL_Handler execution time (see comments above).

Furthermore, after invocation of the read, start of the Read process need to wait for the end of a possibly started 4-HWd Data Flash write (up to 4 half words can be written by the Flash hardware in sequence without software interaction) caused by a Write command or by the background process.

EEL_Handler execution time

Typically the handler execution time will be below 100us.

However, the data read from Flash itself together with the checksum calculation need some time. So, the time can increase 100us by DS sizes > 32 Bytes.

3.8.2.2 Immediate Write / Immediate Incremental Write / Immediate Invalidation command

The normal operation Immediate Write and Immediate Invalidation sequence does not differ to the early Immediate Write/Invalidation. So please refer to this description.

3.8.2.3 Write / Incremental Write / Invalidation command

The normal operation Write/Invalidation sequence does not differ to the early Write/Invalidation. So please refer to this description.

3.8.2.4 Format command

The Format command is considered as an exclusive command and can only be executed if the background state machine is EEL_OPERATION_IDLE or EEL_OPERATION_PASSIVE. So, invocation by EEL_Execute is rejected until this state is reached.

Operation invocation latency

The operation is invoked without latency as no other operations are ongoing.

EEL_Handler execution time

The handler execution time will be below 100us.

3.8.2.5 Cleanup command

The Cleanup command is considered as an exclusive command and can only be executed if the background state machine is EEL_OPERATION_IDLE. So, invocation by EEL_Execute is rejected until this state is reached.

Operation invocation latency

The operation is invoked without latency as no other operations are ongoing.

EEL_Handler execution time

The Cleanup command only sets a variable to more often call the Refresh process and Prepare process in background. The handler execution time will be below 100us.

Chapter 4 Implementation

4.1 File structure

The library is delivered as a complete compile-able sample project which contains the EEL and FDL libraries and in addition to an application sample to show the library implementation and usage in the target application.

The application sample initializes the EEL and does some dummy data set Write and Read operations.

Differing from former EEPROM emulation libraries, this one is realized not as a graphical IDE related specific sample project, but as a standard sample project which is controlled by make files.

Following that, the sample project can be built in a command line interface and the resulting elf-file can be run in the debugger.

The FDL and EEL files are strictly separated, so that the FDL can be used without the EEL. However, using EEL without FDL is not possible.

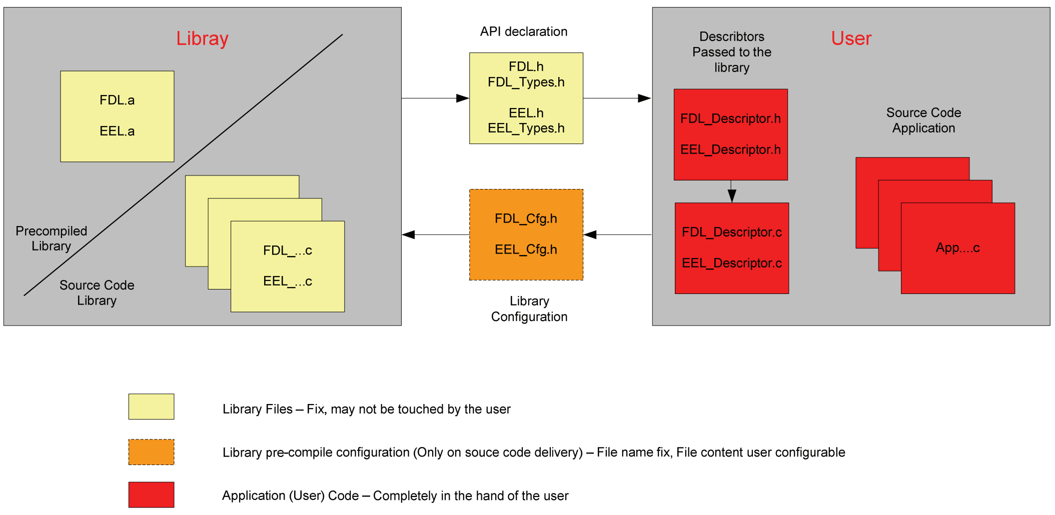
The delivery package contains dedicated directories for both libraries containing the source and the header files.

Note The application sample does not contain sample code for the FDL interface usage, but only for the EEL interface. Anyhow, as the EEL contains FDL functions calls, the usage of the FDL functions can be derived from that.

4.1.1 Overview

The following picture contains the library and application related files.

Figure 4-1


Libray
FDL.a
EEL.a
Precompiled Library
Source Code Library
FDL_...c
EEL_...c
API declaration
FDL.h
FDL_Types.h
EEL.h
EEL_Types.h
FDL_Cfg.h
EEL_Cfg.h
Library Configuration
Describtors Passed to the library
User
FDL_Descriptor.h
EEL_Descriptor.h
FDL_Descriptor.c
EEL_Descriptor.c
Source Code Application
App....c
Library Files – Fix, may not be touched by the user
Library pre-compile configuration (Only on souce code delivery) – File name fix, File content user configurable
Application (User) Code – Completely in the hand of the user

Library and application file structure

The library code consists of different source files, starting with FDL/EEL_... The files may not be touched by the user, independently, if the library is distributed as source code or pre-compiled.

The file FDL/EEL.h is the library interface functions header file.

The file FDL/EEL_Types.h is the library interface parameters and types header file.

In case of source code delivery, the library must be configured for compilation. The file FDL/EEL_Cfg.h contains defines for that. As it is included by the library source files, the file contents may be modified by the user, but the file name may not.

FDL/EEL_Descriptor.c and FDL/EEL_Descriptor.h do not belong to the libraries themselves, but to the user application. These files reflect an example, how the library descriptor ROM variables can be built up which need to be passed with the functions FDL/EEL_Init to the FDL/EEL for run-time configuration (see FDL user manual and 5.4.1.1, "EEL_Init").

- The structure of the descriptor is passed to the user application by FDL/EEL_Types.h.
- The value definition should be done in the file FDL/EEL_Descriptor.h.
- The constant variable definition and value assignment should be done in the file FDL/EEL_Descriptor.c.

If overtaking the files FDL/EEL_Descriptor.c/h into the user application, only the file FDL/EEL_Descriptor.h need to be adapted by the user, while FDL/EEL_Descriptor.c may remain unchanged.

4.1.2 Delivery package directory structure and files

The following table contains all files installed by the library installer.

- Files in red belong to the build environment, controlling the compile, link and target build process
- Files in blue belong to the sample application
- Files in green are description files only
- Files in black belong to the FDL and EEL (in the separate directories for EEL and FDL)

[root]	
Release.txt	Installer package release notes
[root]\[make]	
GNUPublicLicense.txt	Make utility license file
libiconv2.dll	DLL-File required by make.exe
libintl3.dll	DLL-File required by make.exe
make.exe	Make utility
[root]\[<device name>]\[compiler]	
Build.bat	Batch file to build the application sample

Clean.bat	Batch file to clean the application sample	
Makefile	Makefile that controls the build and clean process	
[root]\ [<device name>]\[<compiler>]\[sample]		
EELApp_Main.c	Main source code	
EELApp_Control.c	EEPROM emulation sample code	
target.h	target device and application related definitions	
device header files	GHS	df<device number>.h
		df<device number>_irq.h
		io_macros_v2.h
	IAR	io_70f< device number>.h
		io_macros.h
		lxx.h
		cfi.h
start-up file	GHS	DF<dev. num.>_startup.850
	IAR	l07.s85
		cstartup.s85
	REC	cstart.asm
linker directive file	GHS	df<dev. num.>.ld
	IAR	lnk70f<dev. num.>.xcl
	REC	df<dev. num.>.dir
[root]\ [<device name>]\[<compiler>]\[sample]\[FDL]		
FDL.h	Header file containing function prototypes of the library user interface.	
FDL_Types.h	Header file containing calling structures and error enumerations of the library user interface.	
FDL_Descriptor.h	Descriptor file header with the run-time FDL configuration. To be edited by the user.	
FDL_Descriptor.c	Descriptor file with the run-time FDL configuration. Using the defines of FDL_Descriptor.h. Should not be edited by the user.	
FDL_User.c	Library related functions, which may be edited by the user	
FDL_Cfg.h	Header file with definitions for library setup at compile time.	
[root]\ [<device name>]\[<compiler>]\[sample]\[FDL]\[lib]		
FDL_Env.h	Library internal defines for accessing the Flash programming hardware and Data Flash related definitions.	
FDL_Global.h	Library internal defines, function prototypes and variables.	

FDL_HWAccess.c	Source code for the library Hardware interface.
FDL_UserIF.c	Source code for the library user interface and service functions.
[root]\ [<device name>]\[<compiler>]\[sample]\[EEL]	
EEL.h	Header file containing all function prototypes of the library user interface.
EEL_Types.h	Header file containing calling structures and error enumerations of the library user interface.
EEL_Cfg.h	Header file with definitions for library setup at compile time.
EEL_Descriptor.c	Descriptor file with the run-time EEL configuration. Using the defines of EEL_Descriptor.h and should not be edited by the user.
EEL_Descriptor.h	Descriptor file header with the run-time EEL configuration. To be edited by the user.
[root]\ [<device name>]\[<compiler>]\[sample]\[EEL]\[lib]	
EEL_Global.h	Library internal defines, function prototypes and variables
EEL_BasicFct.c	EEL internal functions & state machine
EEL_UserIF.c	EEL user interface functions

4.2 EEL Linker sections

The following sections are EEPROM emulation library related:

- **FAL_Text**

  FDL code section, containing the hardware interface and user interface.
- **FAL_Const**

  FDL data section, containing library internal constant data
- **FAL_Data**

  FDL Data section containing all FDL internal variables
- **EEL_Text**

  EEL code section containing the state machine, user interface and FAL interface
- **EEL_Const**

  EEL data section, containing library internal constant data
- **EEL_Data**

  EEL Data section containing all EEL internal variables

4.3 MISRA Compliance

The EEL and FDL have been tested regarding MISRA compliance.

The used tool is the QAC Source Code Analyzer which tests against the MISRA 2004 standard rules.

All MISRA related rules have been enabled. Findings are commented in the code while the QAC checker machine is set to silent mode in the concerning code lines.

Chapter 5 User Interface (API)

5.1 Pre-compile configuration

The pre-compile configuration of the EEL may be located in the EEL_cfg.h. The user has to configure all parameters and attributes by adapting the related constant definition in that header-file.

The configuration for Fx4-L contains the following element:

EEL_FLINT_SET_SW:

Basically, each Flash operation end triggers the Flash interrupt. However, quite some EEL state machine internal states don't issue a Flash operation. If the handler function shall be executed in the Flash interrupt context, these states must issue the Flash interrupt by SW.

The define basically is a macro to request the Flash interrupt by SW. If set, it is called within the handler function at the end of each process state, when no Flash operation was started.

Implementation in EEL_Cfg.h:

```
#define EEL_FLINT_SET_SW ( ( *(eel_u16*)0xffff60feuL ) =
( *(eel_u16*)0xffff60feuL ) | 0x1000 )
```

5.2 Run-time configuration

The overall EEL run-time configuration is defined by an EEL specific part (EEL run-time configuration) and by the FDL run-time configuration. Background of the splitting is that the FDL requires either common, by EEL and FDL used information (e.g. block size) or EEL related information (e.g. about the EEL pool size). So, this information is part of the FDL run-time configuration.

Both configurations of FDL and EEL are stored in descriptor structures which are declared in FDL_Types.h / EEL_Types.h and defined in FDL_Descriptor.c / EEL_Descriptor.c with header files FDL_Descriptor.h / EEL_Descriptor.h. The descriptor files (.c and .h) are considered as part of the user application.

The defined descriptor structures are passed to the libraries as reference by the functions FDL_Init and EEL_Init.

5.2.1 FDL run-time configuration elements

The descriptor contains the following elements.

falFrequencyCpuMHz_u16:

Defines the device CPU frequency. The Flash hardware frequency is device internally derived from the CPU frequency.

Note The define requires the CPU frequency, not the crystal frequency!
The CPU frequency must be set correctly. If not, malfunction may occur such as unstable Flash data without data retention, programming failure, operation blocking.

falPoolSize:

Defines the number of physical Flash blocks used for the FAL pool, which means the User Pool + EEL Pool. Usually, the FAL pool size equals the total number of Flash blocks.

Value range:	Min:	EEL pool size
	Max:	Physical number of Data Flash blocks

eelPoolStart:

Defines the first physical Data Flash block number used as EEL pool.

The block number must be aligned to the virtual block size (2kB) used by the EEL! Following that, the block number must be a multiple of 64
(2kB = 64 * 32Byte)

Value range:	Min:	FAL Pool start block
Max:	eelPoolStart + eelPoolSize <= falPoolSize	

eelPoolSize:

Defines the number of blocks used for the EEL pool.

The block number must be aligned to the virtual block size (2kB) used by the EEL! Following that, the block number must be a multiple of 64
(2kB = 64 * 32Byte)

Value range:	Min:	64 * 4 Blocks (required for proper EEL operation)
	Max:	FAL pool size, condition:
		eelPoolStart + eelPoolSize <= falPoolSize

Implementation:

The descriptor structure is defined in the module FDL_Types.h

```
typedef struct FAL_DESCRIPTOR_T {
    fal_u16 falFrequencyCpuMHz_u16;
    fal_u16 falPoolSize_u16;
    fal_u16 eelPoolStart_u16;
    fal_u16 eelPoolSize_u16;
} fal_descriptor_t;
```

The descriptor variable definition and filling is part of the user application. The files FDL_Descriptor.h/.c give an example which shall be used by the user application. Only FDL_Descriptor.h need to be modified for proper configuration while FDL_Descriptor.c can be kept unchanged.

Example variable definition and filling in FDL_Descriptor.c:

```
const fal_descriptor_t eelApp_falConfig_enu =
{
    FAL_CPU_FREQUENCY_MHZ,
    FAL_FAL_POOL_SIZE,
    FAL_EEL_POOL_START,
    FAL_EEL_POOL_SIZE
};
```

Example configuration in FDL_Descriptor.h:

Example 1)

Data Flash size is 32kB.

The EEL shall use the complete Data Flash for the EEL pool:

```
#define FAL_EEL_VIRTUALBLOCKSIZE 64u

#define FAL_FAL_POOL_SIZE     16u * FAL_EEL_VIRTUALBLOCKSIZE
#define FAL_EEL_POOL_START    0u * FAL_EEL_VIRTUALBLOCKSIZE
#define FAL_EEL_POOL_SIZE     16u * FAL_EEL_VIRTUALBLOCKSIZE
```

Example 2)

Data Flash size is 32kB.

The EEL shall use blocks 2 to 9 for the EEL pool, while blocks 0 to 1 and 10 to 15 can be used as user pool:

```
#define FAL_EEL_VIRTUALBLOCKSIZE 64u

#define FAL_FAL_POOL_SIZE     16u * FAL_EEL_VIRTUALBLOCKSIZE
#define FAL_EEL_POOL_START    2u * FAL_EEL_VIRTUALBLOCKSIZE
#define FAL_EEL_POOL_SIZE     8u * FAL_EEL_VIRTUALBLOCKSIZE
```

Example 3)

Data Flash size is 32kB; the EEL shall not be used at all. The complete Data Flash shall be used as user pool:

```
#define FAL_EEL_VIRTUALBLOCKSIZE 64u

#define FAL_FAL_POOL_SIZE     16u * FAL_EEL_VIRTUALBLOCKSIZE
#define FAL_EEL_POOL_START    0u * FAL_EEL_VIRTUALBLOCKSIZE
#define FAL_EEL_POOL_SIZE     0u * FAL_EEL_VIRTUALBLOCKSIZE
```

5.2.2 EEL run time configuration elements

The descriptor contains the following elements:

addDF

Defines the Data Flash start address in the physical address room. The definition is required for EEL internal calculations.

This is just a configuration option reserved for future use. In all current Devices the Data Flash address is fixed.

Value range: Fixed to 0xFE00000

blkRefreshThreshold

Defines the number of virtual blocks that shall be prepared in the ring buffer by default. In case of threshold underflow, the EEL supervision will initiate Refresh / Prepare operations to cleanup the active EEL pool range and provide more prepared blocks by time until the threshold is exceeded again.

Increasing the threshold allows fast sequences of data write without having to give the EEL time to do the Refresh/Prepare operations. Reducing the threshold improves the Flash usage as written data sets stay longer in the ring buffer and need less Refresh copy operations. When the threshold is set too low and the ring buffer gets full due to continuous data set write, the library will return error Pool Full and block further write operations until the supervision had enough time to prepare at least one additional Flash block.

Value range:	Min:	2 Blocks (required for proper EEL operation)
	Max:	EEL pool size – 2

Example:

On a threshold of 6 the EEL will always try to have 6 prepared blocks as passive pool in the ring buffer. This means that the user application could write 10kB data in sequence without giving the EEL time to do background operations to prepare new space again (one block must remain prepared for pool full situation handling).

~1/3 of the total available Flash blocks might be a reasonable starting point to evaluate the balance between the possibility to write fast data sequences (big threshold) and reducing the data copy effort on refresh (low threshold). The service function EEL_GetSpace provides a tool to trace the available free space in the ring buffer during run-time which allows threshold optimization during run-time.

**IDLTab_pau16*

Pointer to ROM ID-L table (See chapter 3.6.1, "ID-L and IDX tables")

The ID-L table need to be defined as a 2-dimensional array of 16bit values as follows:

{ { ID1, size 1 }, { ID2, size 2 }, { ID3, size 3 }, ... }

Value range:	ID Min:	1
	ID Max:	0xFFFE
	Size min:	1Byte
	Size max:	Block size – Block header size – REF zone size - 2 = 2048 – 36 – 14 - 2 = 1996 Bytes (this is caused by the EEL implementation. Bigger data size would require significant overhead in the power fail and supervision concepts).

**IDXTab_pau16*

Pointer to ROM ID-X table (See chapter 3.6.1, "ID-L and IDX tables")

The ID-X table is a 1-dimensional array of 16bit values. The ID-X table RAM is provided by the user application and filled and handled by the EEL.

IDLTabIdxCnt_u16

Defines the size of the ID-L/X table in “number of entries”.

eraseSuspendThreshold_u16

When the EEL background operation executes the Prepare process, the Data Flash block is erased. Any user Read or Write operation will suspend the Flash Erase and after the operation resume the Erase again. Based on the Flash implementation, this Erase Suspend/Resume flow is restricted. The Erase operation might not finish, if it is interrupted continuously. The user application must be realized in a way that the erase operation once gets the time to complete, which means that the user application must provide a time frame as long as the worst case Flash block erase time in which the erase operation is not suspended. As long as the erase is not finished, the EEL cannot continue to provide new free passive pool space for further write operations. In order to signal too often Erase suspends to the user application, the eraseSuspendThreshold_u16 can be configured. A user operation resulting in exceeding the threshold will return a warning “erase suspend overflow”. This is no hard error resulting in EEL reaction but just a signal to the user application to provide enough time to the EEL to finish the background operation.

Value range:	Min:	0 (On every erase suspend the warning is returned)
	Max:	0xFFFF

Implementation:

The descriptor structure is defined in the module EEL_Types.h

```
typedef struct EEL_DESCRIPTOR_T {
    eel_u32         addDF_u32;
    eel_u16         blkRefreshThreshold_u16;
    const eel_u16   (*IDLTab_pau16)[2];
    eel_u16         *IDXTab_pau16;
    eel_u16         IDLTabIdxCnt_u16;
    eel_u16         eraseSuspendThreshold_u16;
}    eel_descriptor_t;
```

The descriptor variable definition and filling is part of the user application. The files EEL_Descriptor.h/.c give an example which shall be used by the user application. Only EEL_Descriptor.h need to be modified for proper configuration while EEL_Descriptor.c can be kept unchanged.

Example variable definition and filling in EEL_Descriptor.c:

```
const eel_u16   IDLTab_au16[][2] = EEL_CONFIG_IDL_TABLE;
eel_u16         IDXTab_au16[sizeof( IDLTab_au16 )>>2];
const eel_descriptor_t  eelApp_eelConfig =
{
    EEL_CONFIG_DF_BASE_ADDRESS,
    EEL_CONFIG_BLOCK_CNT_REFRESH_THRESHOLD,
    IDLTab_au16,
    &(IDXTab_au16[0]),
    ( sizeof( IDLTab_au16 ) >> 2 ),
    EEL_CONFIG_ERASE_SUSPEND_THRESHOLD
};
```

Example configuration in EEL_Descriptor.h:

Data Flash size is 32kB.

The EEL shall use the complete Data Flash for the EEL pool, blkRefreshThreshold is set to ~1/3 of 16 Flash blocks = 5, the erase shall be suspend able up to 10 times until the erase suspend warning is issued:

```
#define EEL_CONFIG_DF_BASE_ADDRESS              0xfe000000
#define EEL_CONFIG_BLOCK_CNT_REFRESH_THRESHOLD  0x05
#define EEL_CONFIG_ERASE_SUSPEND_THRESHOLD      10

/*-------------------------------------------------------------*/
    EEL_CONFIG_IDL_TABLE
    Descriptor table containing data set identifier and data set
    length as:
    { { <16-bit ID>, <16-bit length in bytes> }, {...},
      {...}, .... }
/*-------------------------------------------------------------*/
#define EEL_CONFIG_IDL_TABLE {
                               { 0x1111, 0x0005 },   \
                               { 0x2222, 0x0006 },   \
                               { 0x3333, 0x0007 },   \
                               { 0x4444, 0x0008 },   \
                               { 0x5555, 0x0009 },   \
                               { 0x6666, 0x000a },   \
                               { 0x7777, 0x000b },   \
                               { 0x8888, 0x000c },   \
                               { 0x9999, 0x000d },   \
                               { 0xaaaa, 0x0015 },   \
                               { 0xbbbb, 0x0018 },   \
                               { 0xcccc, 0x0033 }    \
                             }
```

5.3 Data Types

5.3.1 Error Codes

Figure 5-1

	Explanation	Root Cause Judgment	EEL Operation Impact	Recommended Application Reaction
EEL_OK	The operation finished successfully		None	Continue operation
EEL_BUSY	The operation has been started successfully		None	Continue operation
EEL_ERR_CONFIGURATION	The EEL_Init function was called with wrong configuration data	Application bug	The library is not initialized	Stop EEPROM emulation and investigate in the root cause
EEE_ERR_PARAMETER	Wrong parameters have been passed to the EEL, e.g.: Wrong parameter in the request structure	Application bug	Current command rejected	Stop EEPROM emulation and investigate in the root cause
EEE_ERR_REJECTED	A new operation should be initiated although the state machine is still busy with a concurrent operation (e.g. EEL_CMD_READ --> EEL_CMD_READ, but not EEL_CMD_WRITE --> EEL_CMD_READ)	Application bug or intended behavior	Current command rejected	Repeat the command when the concurrent operation has finished
EEE_ERR_ERASESUSPEND_OVERFLOW	A Read/Write operation is started and lead to a background erase operation suspend. The Erase suspend took place so often, that the erase could not be completed for a long time. This error return shall be treated as warning. The counter until the warning is configurable by the user	EEL System overload	None / Warning only	Reduce the EEL load with Read/Write operations so that the Flash Erase has time to finish
EEL_ERR_ACCESS_LOCKED	A command which is locked was called. Reason for locking may be: 1) The library is not started-up far enough for a operation 2) Due to an error the library switched to passive and locks all new operations and ongoing lower priority operations	1) Application bug 2) Application bug or hardware problem	Current command / function execution is rejected	Stop EEPROM emulation and investigate in the root cause
EEL_ERR_NO_INSTANCE	Either no DS corresponding to the ID could be found or the data has been invalidated explicitly (See Invalidation command API)	Application bug or intended behavior	None / Warning only	Continue operation -or- if the result is not expected, stop EEPROM emulation and investigate in the root cause
EEL_ERR_WRONG_CHECKSUM	The checksum of the Data Set does not match. Beside accidental data overwrite, also a change of the IDL ROM table (data length information) during application update by a boot loader might be the root cause	Application bug or hardware problem or intended behavior	Read operation returned data, but the contents might be wrong	Continue operation -or- if the result is not expected, stop EEPROM emulation and investigate in the root cause
EEL_ERR_POOL_FULL	Due to high DS Write load, no more blocks could be prepared to gain space for new data	EEL system overload	Current command rejected	Stop issuing further Write/Invalidate commands but call the EEL_Handler frequently until the EEL had time to prepare enough passive pool space
EEL_ERR_FLASH_ERROR	A Flash operation of the *FDL* (called by *EEL*) failed due to a Flash problem.	Hardware problem or application bug	The Flash should be considered as defect, the library accesses are locked: - Write locked (Error occurred during normal operation) - Read & Write locked (Error occurred during startup)	Stop EEPROM emulation and investigate in the root cause
EEL_ERR_INTERNAL	A library internal error occurred, which could not happen in case of normal program execution (E.g. Program run-away, bug, ...)	Application bug	The further library reaction is undefined: - All access is locked	Stop EEPROM emulation and investigate in the root cause
EEL_ERR_POOL_EXHAUSTED	Due to multiple Flash block exclusion no more blocks are available for Prepare operations. The error is very unlikely due to the Flash failure rate!	Hardware problem	The Flash should be considered as defect: - Write locked	Stop EEPROM emulation and investigate in the root cause
EEE_ERR_BLOCK_EXCLUDED	A Prepare operation excluded a block as this could not be erased	Hardware problem	None / Warning only	Continue operation
EEL_ERR_FIX_DONE	Startup has done a consistency fix-operation. This is a normal return value on Startup after power fail. The sections are assumed to be consistent and emulation can continue normally	Ring buffer consistency problems (Incomplete erased/written Flash cells, caused e.g. by reset on power fails) are fixed	None / Warning only	Continue operation
EEL_ERR_POOL_INCONSISTENT	The block consistency check of the startup routine found an inconsistency in the startup routine. This error is also returned in case of blank (unformatted) Flash	Application bug or hardware problem or intended behavior	The Flash must be formatted: - Read & Write locked	Continue EEL operation with EEL_CMD_FORMAT -or- if the result is not expected, stop EEPROM emulation and investigate in the root cause
EEE_ERR_COMMAND	The command to be executed is unknown	Application bug	Current command rejected	Stop EEPROM emulation and investigate in the root cause

EEL status & error codes

The error code table shows quite some severe error messages, which lead to the situation, that the EEL cannot continue operation. It needs to be considered carefully, how to deal with the error fro application side.

The following options are worth to discussing:

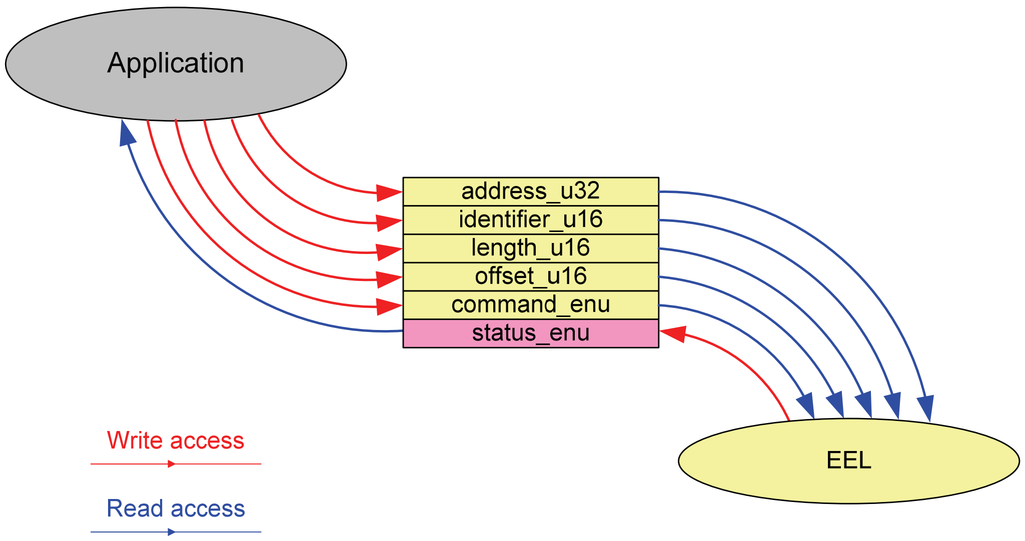
- Stop and permanently disable emulation (emulation is dead):
  This mostly lead to complete application failure and the system need to be changed. This allows a certain kind of "post mortem" analysis, but lower availability rates
- Format the Data Flash and re-start the emulation:
  This will destroy all data and prevent any kind of "post mortem" analysis, but increase the availability rates of the system if data loss can be accepted.
- Re-initialize and re-start the EEL a certain number of times before permanently disable emulation (emulation is dead):
  This allows potentially to recover from some failures, e.g. EEL_ERR_INTERNAL. While increasing the availability rates of the system, a "post mortem" analysis will get much more difficult or impossible, as the Flash contents may change since appearance of the problem root cause.

While in the debugging phase the emulation should be stopped immediately for problem analysis, the system reaction in field should be carefully judged depending on the application requirements to the system availability and failure analysis options.

5.3.2 User operation request structure

All different user operations are initiated by a central initiation function (EEL_Execute). All information required for the execution is passes to the EEL by a central request structure. Also the error is returned by the same structure:

Figure 5-2



Request structure handling

The following request elements are defined:

- command_enu: User operation to execute:

EEL_CMD_READ	Read a DS
EEL_CMD_WRITE	Write a DS
EEL_CMD_WRITE_INC	Incremental Write a DS
EEL_CMD_INVALIDATE	Write a DS data invalid
EEL_CMD_WRITE_IMM	Write a DS with high priority
EEL_CMD_WRITE_IMM_INC	Incremental Write a DS with high priority
EEL_EMD_INVALIDATE_IMM	Write a DS data invalid with high priority
EEL_CMD_FORMAT	Format the Data Flash for EEPROM
EEL_CMD_CLEANUP	Clean up ring buffer to provide as much as possible prepared ring buffer space

- address_u32 Buffer address for the Read and Write operation.
- identifier_u16: 16bit ID, identifying the DS to read or write.
- length_u16: Only required for Read operation:
  Number of bytes to read from the DS.
- offset_u16: Only required for Read operation:
  Read offset from the DS bottom. Together with length the parameter is used to read only a fraction of the DS.
- status_enu: Status/Error codes returned by the library (see next page).

Type definition in EEL_Types.h:

```
typedef enum EEL_COMMAND_T {
    EEL_CMD_READ,
    EEL_CMD_WRITE,
    EEL_CMD_WRITE_INC,
    EEL_CMD_INVALIDATE,
    EEL_CMD_WRITE_IMM,
    EEL_CMD_WRITE_INC_IMM,
    EEL_CMD_INVALIDATE_IMM,
    EEL_CMD_FORMAT,
    EEL_CMD_CLEANUP
} eel_command_t;
```

```
typedef enum EEL_STATUS_T {

    /* Normal operation */
    EEL_OK,
    EEL_BUSY,

    /* Warnings */
    EEL_ERR_ERASESUSPEND_OVERFLOW,
    EEL_ERR_WRONG_CHECKSUM,
    EEL_ERR_BLOCK_EXCLUDED,
    EEL_ERR_FIX_DONE,

    /* Errors */
    EEL_ERR_CONFIGURATION,
    EEL_ERR_PARAMETER,
    EEL_ERR_REJECTED,
    EEL_ERR_ACCESS_LOCKED,
    EEL_ERR_NO_INSTANCE,
    EEL_ERR_POOL_FULL,
    EEL_ERR_FLASH_ERROR,
    EEL_ERR_INTERNAL,
    EEL_ERR_POOL_EXHAUSTED,
    EEL_ERR_POOL_INCONSISTENT,
    EEL_ERR_COMMAND
} eel_status_t;
```

```
typedef volatile struct EEL_REQUEST_T {
    eel_u08         *address_pu08;
    eel_u16         identifier_u16;
    eel_u16         length_u16;
    eel_u16         offset_u16;
    eel_command_t   command_enu;
    eel_status_t    status_enu;
} eel_request_t;
```

5.3.3 Driver status

The EEL supervision process collects and signals all background operations/processes errors. Furthermore, the process controls two driver status values which describe the status of the EEL background operations. These are the operation status and access status:

- **Operational status**

  Defining the status of the state machine according to the following:

  - **EEL_OPERATION_PASSIVE**
    The state machine can handle neither internal nor user initiated processes.
    This state is set:
    - before EEL startup
    - after EEL shutdown is finished
    - after fatal EEL operations errors
  - **EEL_ OPERATION _IDLE**
    No process active except supervision doing margin checks. No Refresh or Prepare necessary and no user process Read, Write, Format active.
  - **EEL_ OPERATION _BUSY**
    This status is set, if either a background process, e.g. Refresh or Prepare is active or a user process Read or Write is being processed. As Flash operations may be processed, the device should not be switched off in this status in order to avoid repair operations to be executed on EEL startup.
  - **EEL_OPERATION_STARTUP**
    This status is set as long as the startup background process is executed. This indicates that the EEL is not completely up and running. As long as this operational status is returned, EEL functionality is possibly limited. Please see emulation access status below.
  - **EEL_OPERATION_SUSPENDED**
    When the suspend request is issued to the EEL by the EEL_Suspend function, the state machine enters the suspend mode. As this cannot be

done immediately, the application need to wait until the suspend status is set.

- **Access status**

  During Startup the full functionality of the EEPROM emulation is not given. It is increased step by step depending on the proceeding of the Startup flow.

  It is important, that not only Startup affects the access level, but also EEL failures resulting in loss of functionality. Depending on the failure, either Write is prohibited or no access is possible. See also error codes of the request structure.

  - **EEL_ACCESS_LOCKED**
    During Startup:
    The state machine is in an early startup phase and so, does not accept any user operation.

    During normal operation:
    Due to a failure no more data access is possible.
  - **EEL_ACCESS_ READ_WRITE**
    During Startup only:
    The state machine proceeded further in the startup phase and so, accepts DS read and write operations.
    - The read operations require REF table search as the RAM table is not yet available. So, the Read requires longer execution time at 100% CPU load.
    - The DS write capability is limited to the available passive blocks (prepared and invalid) as due to the missing RAM table no Refresh operation is possible.
  - **EEL_ACCESS_ READ_ONLY**
    During normal operation only:
    A user DS Write operation resulted in a Flash Write error, either caused by a hardware or a software problem. In order to preserve the remaining Flash contents the library forbids any further Flash modification operations. Read operations are still possible, however a certain risk is given, that the read data may be wrong if the write operation caused damage to the read data. This should be detected by the DCS check.
  - **EEL_ACCESS_UNLOCK**
    The state machine is up and running. All user and background operations should be possible, if no error occurred. The RAM table is built up, so Read operations are executed fast from now on.

- **State machine errors**

  Error values of the state machine are returned. Only background process errors are considered.

  Please refer to the error description (5.3.1, “Error Codes”) and the handler function description (5.4.3, “Operational functions”) for details.

Note The user application needs to check the driver status and react on it when necessary. When a user operation ends with EEL_ERR_ACCESS_LOCKED, the driver status will indicate why and allow the user application to decide how to react. Furthermore, when the handler is called to execute background operations, the driver status will indicate the operations result. The driver status can be checked by the function EEL_GetDriverStatus.

Type definition:

```
typedef enum EEL_ACCESS_STATUS_T {
       /* read- & write access disabled*/
       EEL_ACCESS_LOCKED,

       /* read only access, set in case of write
          error */
       EEL_ACCESS_READ_ONLY,

       /* read- & write-access enabled limited
          performance */
       EEL_ACCESS_READ_WRITE,

       /* full read- and write-access enabled */
       EEL_ACCESS_UNLOCKED

} eel_access_status_t;
```

```
typedef enum EEL_OPERATION_STATUS_T {
       /* all operations locked */
       EEL_OPERATION_PASSIVE,

       /* after Startup, maintainance passive,
          full operation possible */
       EEL_OPERATION_IDLE,

       /* any user request under processing */
       EEL_OPERATION_BUSY,

       /* While startup processes are running */
       EEL_OPERATION_STARTUP,

       /* User suspend */
       EEL_OPERATION_SUSPENDED

} eel_operation_status_t;
```

```
typedef struct EEL_DRIVER_STATUS_T {
       eel_operation_status_t    operationStatus_enu;
       eel_access_status_t       accessStatus_enu;
       eel_request_status_t             error_enu;
} eel_driver_status_t;
```

5.4 EEL Functions

Functions represent the functional interface to the EEL which other SW can use.

5.4.1 Initialization / Shut down

5.4.1.1 EEL_Init

Description

The EEL_Init() function is executed before any execution of other EEL functions. It initializes the basic EEL variables, but the state machine is not started.

This function also defines the operation mode of the library. While in the normal application the full operation must be enabled, in case of a boot loader not all information required for full operation might be available. Especially the ROM ID–table might be not present or not completely present if the application is being updated.

Interface

```
eel_status_t EEL_Init( const eel_descriptor_t* descriptor_pstr,
                       eel_operation_mode_t    opMode_enu );
```

Arguments

Type	Argument	Description
eel_opMode	opMode_enu	• EEL_OPERATION_MODE_NORMAL Full operation of the library • EEL_OPERATION_MODE_LIMITED Operation with limited ID-L-table in ROM (containing not all IDs → no Refresh possible)
eel_descriptor_t	descriptor_pstr	Pointer to the EEL run-time configuration descriptor structure in ROM

Return types/values

Type	Argument	Description
eel_status_t	None	Result of the function. Possible values are: EEL_OK EEL_ERR_ACCESS_LOCKED EEL_ERR_CONFIGURATION

The function checks the configuration in the descriptor variable for consistency. If a problem is found in the configuration, the error EEL_ERR_CONFIGURATION is returned:

- RAM or ROM table pointer pointing to 0
- Any ID entry = 0 or = 0xFFFF
- Max. DS length exceeded
- Threshold must be >=2 blocks and at least 2 blocks must remain between threshold and EEL pool size.
- Max DS size must be < EEL_PFct_Calc_BlkSpace - REF entry size.

On check fail, the startup processing is locked and user operations will never be unlocked.

Pre-conditions

EEL initialization is not possible when Flash operations are active. So, FAL_Init need to be called before EEL_Init may be called. In between, no Flash operations may be started. On violation the function ends with EEL_ERR_ACCESS_LOCKED.

Post-conditions

None

Example

eel_rtConfiguration is configured globally in EEL_Descriptor.c

```
ret = EEL_Init( eel_rtConfiguration, EEL_OPMODE_FULL );

if( EEL_OK != ret )
{
 /* Error treatment */
}
```

5.4.1.2 EEL_Startup

Description

This function starts the EEL state machine and initiates execution of the startup process.

By this function and continuous EEL_Handler calls, the library passes the startup status and enters the operational status.

Interface

```
eel_status_t EEL_Startup( void );
```

Arguments

None

Return types/values

Type	Argument	Description
eel_status_t	None	Result of the function. Possible values are: EEL_OK EEL_ERR_ACCESS_LOCKED

Pre-conditions

- The library must be initialized. Call EEL_Init before.
- The library may not already be active (function EEL_Startup already called). On violation the function ends with EEL_ERR_ACCESS_LOCKED.

In case of re-initialization, the function EEL_ShutDown must be called before EEL_Init and EEL_Startup.

Post-conditions

- Continuously call the EEL_Handler() function to forward the state machine to come to normal operation.

Example

Option: Wait after EEL_Startup until the library is completely up and running

```
eel_driver_status_t dStat;

ret = EEL_Init();

if( EEL_OK == ret )
{
    ret = EEL_Startup();
}

if( EEL_OK != ret )
{
     /*error treatment */
}
else
{
    do
    {
        EEL_Handler();
        EEL_GetDriverStatus( &dStat );
    }
    /* Wait until the system is up and running (or error) */
    while(EEL_OPERATION_STARTUP ==
          dStat.operationStatus_enu );

    /* Error check */
    if( EEL_OK != dStat.errorStatus_enu )
    {
        /* Error handler */
        . . .
    }
}
```

Option: Wait after EEL_Startup until the library at least partially unlocked

```
eel_driver_status_t dStat;

ret = EEL_Init();

ret = EEL_Init();

if( EEL_OK == ret )
{
    ret = EEL_Startup();
}

if( EEL_OK != ret )
{
 /*error treatment */
}
else
{
    do
    {
        EEL_Handler();
        EEL_GetDriverStatus( &dStat );
    }
    /* Wait until early read/write is possible (or error) */
    while(    ( EEL_OPERATION_STARTUP == dStat.operationStatus_enu )
           &&( EEL_ACCESS_LOCKED == dStat.accessStatus_enu ) );
    /* Error check */
    if( EEL_OK != dStat.errorStatus_enu )
    {
        /* Error handler */
        . . .
    }
}
```

5.4.1.3 EEL_ShutDown

Description

This function initiates deactivation of the EEL state machine.

After this function the EEL_Handler need to be continuously executed in order to finish eventually executed processes and to set the state machine status passive.

Effect on the processes:

- Startup

  The process is stopped after a sub-process execution.
- Refresh

  A ongoing DS Write is finished, then the Refresh is stopped.
- Prepare

  The Prepare is finished in order not to waste a Flash erase cycle.

- User DS Write

  A ongoing DS Write is finished.
- User DS Read

  A ongoing DS Read is finished.

Interface

```
eel_status_t EEL_ShutDown( void );
```

Arguments

None

Return types/values

Type	Argument	Description
eel_status_t	None	Result of the function. Possible values are: EEL_OK EEL_ERR_ACCESS_LOCKED

Pre-conditions

- The library must be active. Call EEL_Startup before.

On violation the function ends with EEL_ERR_ACCESS_LOCKED.

Post-conditions

- Continuously call the EEL_Handler() function to forward the state machine to the shut-down status.
- Continuously call EEL_GetDriverStatus to detect when the state machine is shut-down

Example

```
eel_driver_status_t dStat;

/* ... */

Ret = EEL_ShutDown();
if( EEL_OK != ret )
{
        /* Error treatment */
}

/* Wait until operation end */
do
{
    EEL_Handler();
    EEL_GetDriverStatus( &dStat );
}
while(EEL_OPERATION_PASSIVE != dStat.operationStatus_enu );

/* Error check */
if( EEL_OK != dStat.errorStatus_enu )
{
 /* Error handler */
   . . .
}
```

5.4.2 Suspend / Resume

The library provides the functionality to suspend and resume the library operation in order to provide the possibility to synchronize the EEL Flash operations with possible user application Flash operations, e.g. write/erase by using the FDL library directly or read by direct Data Flash read access.

5.4.2.1 EEL_Suspend

Description

This function initiates the suspend mechanism for EEL operations to put the EEL in a passive state.

Interface

```
eel_status_t  EEL_Suspend( void );
```

Arguments

None

Return types/values

Type	Argument	Description
eel_status_t	None	Result of the function. Possible values are: EEL_OK EEL_ERR_ACCESS_LOCKED

Pre-conditions

- The library must be initialized. Call EEL_Init before.
- The Library may not already be suspended

On violation the function ends with EEL_ERR_ACCESS_LOCKED.

Post-conditions

- Call EEL_Handler until the library is suspended (status EEL_OPERATION_SUSPENDED).

If the function returned successfully, no further error check of the suspend procedure is necessary, as a potential error is saved. This is restored on EEL_Resume.

Example

```
eel_driver_status_t dStat;

/* ... */

ret = EEL_Suspend();
if( EEL_OK != ret )
{
 /* Error treatment */
}

/* Wait until operation end */
do
{
    EEL_Handler();
    EEL_GetDriverStatus( &dStat );
}
while(EEL_OPERATION_SUSPENDED != dStat.operationStatus_enu );

/* Do other Flash operations or bring the device in power safe
   mode */
   ...


ret = EEL_Resume();
if( EEL_OK != ret )
{
 /* Error treatment */
}


/ Continue with EEL operations */
```

5.4.2.2 EEL_Resume

Description

This function resumes the EEL operations after suspend.

Interface

```
ret =  EEL_Resume( void );
```

Arguments

None

Return types/values

Type	Argument	Description
eel_status_t	None	Result of the function. Possible values are: EEL_OK EEL_ERR_ACCESS_LOCKED

Pre-conditions

- The library must be suspended. Call EEL_Suspend before and wait until the suspend process finished.

On violation the function ends with EEL_ERR_ACCESS_LOCKED.

Post-conditions

None

Example

See EEL_Suspend

5.4.3 Operational functions

5.4.3.1 EEL_Execute

Description

This function initiates an EEL user operation. The operation type and operation parameters are passed to the EEL by a request structure, the status and the result of the operation are returned to the user application also by the same structure. The required parameters as well as the possible return values depend on the operation to be started.

This function only starts a process according to the operation to be executed. The processes must be controlled and stepped forward by the state machine handler function EEL_Handler (explained later on).

Possible user operations are:

- Read

  Read a DS or a fraction of the DS from the Data Flash to a user defined buffer address. The DS is identified by the ID. The offset from the DS start and the number of bytes to read can be specified.

  Required parameters from the request structure:

- identifier_u16 → ID to read
- address_u32 → Destination buffer address
- length_u16 → Number of bytes to read
- offset_u16 → Offset from DS begin to start reading
- command_enu → EEL_CMD_READ for the Read operation

Parameter checks, resulting in return value EEL_ERR_PARAMETER:

- Offset + length > DS size
- Unknown ID

- Write

  Writing data from a user defined address (buffer) into a new DS instance, identified by a given ID. This is done with normal priority.

  Required parameters from the request structure:

  - identifier_u16 → ID to write
  - address_u32 → source buffer address
  - command_enu → EEL_CMD_WRITE for the Write operation

  Parameter checks, resulting in return value EEL_ERR_PARAMETER:

  - Unknown ID

- Write Incremental

  Writing data from a user defined address (buffer) into a new DS instance, identified by a given ID. The data write is only executed when the given data in the write buffer differs from the data of the last DS instance in the EEL pool. If the data equals, the operation is successfully finished without data write operation.
  This is done with normal priority.

  Required parameters from the request structure:

  - identifier_u16 → ID to write
  - address_u32 → source buffer address
  - command_enu → EEL_CMD_WRITE_INC for the Write operation

  Parameter checks, resulting in return value EEL_ERR_PARAMETER:

  - Unknown ID

- Invalidate

  Writing a DS instance, identified by an ID invalid. This is done with normal priority.

  Required parameters from the request structure:

  - identifier_u16 → ID to invalidate

- command_enu → EEL_CMD_INVALIDATE for the Invalidation operation

Parameter checks, resulting in return value EEL_ERR_PARAMETER:

- Unknown ID

- Write Immediate

  Writing data from a user defined address into a new DS instance identified by an ID. This is done with high priority, resulting in suspending an eventually ongoing DS write/invalidate with normal priority. Later on the normal priority operation is resumed.

  Required parameters from the request structure:

identifier_u16	→ ID to write
address_u32	→ source buffer address
command_enu	→ EEL_CMD_WRITE_IMM for the Write operation

  Parameter checks, resulting in return value EEL_ERR_PARAMETER:

  - Unknown ID

- Write Incremental Immediate

  Writing data from a user defined address (buffer) into a new DS instance, identified by a given ID. The data write is only executed when the given data in the write buffer differs from the data of the last DS instance in the EEL pool. If the data equals, the operation is successfully finished without data write operation.
  This is done with high priority, resulting in suspending an eventually ongoing DS write/invalidate with normal priority. Later on the normal priority operation is resumed.

  Required parameters from the request structure:

identifier_u16	→ ID to write
address_u32	→ source buffer address
command_enu	→ EEL_CMD_WRITE_INC_IMM for the Write operation

  Parameter checks, resulting in return value EEL_ERR_PARAMETER:

  - Unknown ID

- Invalidate Immediate

  Writing a DS instance invalid, identified by an ID. This is done with high priority, resulting in suspending an eventually ongoing DS write/invalidate with normal priority. Later on the normal priority operation is resumed.

  Required parameters from the request structure:

identifier_u16	→ ID to invalidate

- command_enu → EEL_CMD_INVALIDATE for the Invalidation operation

Parameter checks, resulting in return value EEL_ERR_PARAMETER:

- Unknown ID

- Format

  Format the Data Flash block structure, so that DS can be written. Format erases all Flash blocks and so deletes all eventually existing DS instances:

  Required parameters from the request structure:

  - command_enu → Set to EEL_CMD_FORMAT for the Format operation

Note After successful Format, the EEL must be restarted with EEL_Init → EEL_Startup → ...

- Clean-up

  This operation initiates, that the active blocks are defragmented/cleaned-up in order to achieve as much as possible prepared blocks for new data. This command is recommended, before the EEL is started without a complete reference list (ID-L table). As in this case the Refresh cannot be executed, as much free space as possible for DS Write should be available.

  Cleanup concept:
  This command sets an indication flag for cleaning to the supervision. The cleaning itself is handled by the supervision process by executing Refresh & Prepare operations over all active/occupied blocks. Cleaning is finished when the driver status changes from busy to idle again. The cleanup request structure immediately returns with EEL_OK.

  Required parameters from the request structure:

  - command_enu → Set to EEL_CMD_CLEANUP for the Clean-up operation

Note Clean-up requires at least one DS entry in the EEL pool. If not, the operation is not accepted, resulting in access locked error.

Note Format is executed as exclusive operation, Cleanup is started as exclusive operation (finished in background). Exclusive operations require that no other operation (except supervision) is ongoing. All other functions can be prioritized.

This priorization allows executing up to three operations in parallel:

- Read
- Normal priority write/invalidate
- High priority write/invalidate

In order to do so, the application needs to provide separate request structures for these operations.

Interface

```
void EEL_Execute( eel_request_t request_str );
```

Arguments

Type	Argument	Description
eel_request_t	request_str	See chapter 5.3.2, “User operation request structure”

Return types/values

Type	Argument	Description
eel_request_t	request_str. status_enu	The value is returned in the request structure error variable. EEL_BUSY EEL_ERR_ REJECTED EEL_ERR_ACCESS_LOCKED EEL_ERR_PARAMETER EEL_ERR_COMMAND EEL_ERR_POOL_FULL

Note The user application can either react directly on the errors returned by the EEL_Execute function or call the handler function EEL_Handler and react on errors then. The errors set on EEL_Execute are not reset and the handler execution does not do additional operations in case of an error already set.

Pre-conditions

- Call EEL_Init to initialize the library
- Call EEL_Startup and call EEL_Handler cyclically to bring the library into operational status

Post-conditions

Call EEL_Handler to complete the initiated operation

Example

See EEL_Handler function

5.4.3.2 EEL_Handler

Description

This function handles the complete state machine. It shall be called frequently, but the calling style depends on the user application. Possible solutions are:

- Asynchronous to EEL operation invocation by EEL_Execute in an operating system idle task

  In a normal system the CPU load is balanced in a way, that a sufficient idle time is available.
  By calling from the idle task loop, the handler can be called frequently and the EEPROM Emulation performance is quite high. However, as the idle time is not always deterministic, also the emulation performance might not be deterministic enough.

- Advantages:
  + Usually high emulation performance
  + No blocking of other user application operations

  Disadvantages:
  - Not always deterministic
- Asynchronous to EEL operation invocation by EEL_Execute in a timed task

  By calling in a timed task a deterministic performance can be reached. However, as the Flash operations execution (Flash Write) usually require less than 500us, for best possible performance the handler should be called in very short time slices. As these are usually not available, the performance of the emulation decreases.

  Advantages:
  + Deterministic
  Disadvantages:
  - Lower emulation performance
- Synchronous with EEL operation invocation by EEL_Execute

  The handler is called in the same function context as EEL_Execute. The handler call is repeated in this function in a loop until the EEL operation has finished.

  Advantages:
  + Highest performance
  Disadvantages:
  - function execution time is high and not deterministic
- In the Flash interrupt context

  The handler is called in the Flash intrrupt context. In that case the function is not polled, but exactly called when required to finish a user or background operation. Therefore, the library must be configured to support the Flash interrupt (See 5.1, “Pre-compile configuration”)

  Advantages:
  + Highest performance
  Disadvantages:
  - function execution time in interrupt context
  - Synchronization between handler call in interrupt context and other EEL function in tasks
  - handler must be called in other timed tasks to do bit error checks (See 3.2, “Flash interrupt support”)

Interface

```
void EEL_Handler( void );
```

Arguments

None

Return types/values

Type	Argument	Description
eel_request_t	request_str.status_enu	The value is returned in the request structure error variable, passed to the EEL_Execute function. The possible return values depend on the operation that was started as well as on the errors of background operations. This table describes not the errors set by operation invocation with the EEL_Execute function, but the errors, additionally set during operation execution.
		All operations • EEL_OK • EEL_BUSY • EEL_ERR_REJECTED • EEL_ERR_COMMAND • EEL_ERR_ERASESUSPEND_OVERFLOW • EEL_ERR_INTERNAL
		Additionally on Write and Invalidate: • EEL_ERR_FLASH_ERROR • EEL_ERR_POOL_FULL • EEL_ERR_ACCESS_LOCKED
		Additionally on immediate Write and immediate Invalidate: • EEL_ERR_FLASH_ERROR • EEL_ERR_POOL_FULL • EEL_ERR_ACCESS_LOCKED
		Additionally on Read: • EEL_ERR_WRONG_CHECKSUM • EEL_ERR_NO_INSTANCE **Note**: Even when the error EEL_ERR_WRONG_CHECKSUM is returned, the data is copied to the destination buffer in order to have the possibility to check the content.
		Additionally on Format: • EEL_ERR_BLOCK_EXCLUDED • EEL_ERR_FLASH_ERROR • EEL_ERR_POOL_EXHAUSTED

Pre-conditions

- Call EEL_Init to initialize the library
- Call EEL_Startup and call EEL_Handler cyclically to bring the library into operational status
- Call EEL_Execute to initiate an EEL operation

Post-conditions

None

Example

```
eel_request_t req_str;
eel_u08       buffer[0x100];

/* Start the read operation */
req_str.address_u32    = (u32)(&buffer); /* Set receive buffer */
req_str.identifier_u16 = 10u;
req_str.length_u16     = 0x10u;
req_str.offset_u16     = 0x13u;
req_str.command_enu    = EEL_CMD_READ;

EEL_Execute( &req_str );

/* Wait until operation end */
while( EEL_BUSY == req_str.status_enu )
{
 EEL_Handler();
}

/* Error check */
If( EEL_OK != req_str. status )
{
 /* Error handler */
   . . .
}
```

5.4.4 Administrative functions

5.4.4.1 EEL_GetEraseCounter

Description

This function reads the current erase counter at the active Flash block of the ring buffer. Except potentially excluded blocks, the erase counter of all other blocks only differs from the active block in the range of +-1.

Note The erase counter is counting the ring buffer loops. As long as the ring buffer is normally handled by the library, the erase counter is counted up. Of cause, the erase counter is as reliable as all EEPROM emulation data. It is handled by the library and any mistreatment outside the library (e.g. manual erase of the Flash) will destroy the erase counter.

Interface

```
eel_status_t EEL_GetEraseCounter( eel_u32 *counter_pu32 );
```

Arguments

None

Return types/values

Type	Argument	Description
eel_status_t		Result of the function. Possible values are: EEL_OK EEL_ERR_ACCESS_LOCKED
u32	counter_pu32	Pointer to the erase counter storage location

Pre-conditions

- The library must be unlocked:
    - Call EEL_Init to initialize the library
    - Call EEL_Startup and call EEL_Handler cyclically to unlock the access status (access status != EEL_ACCESS_LOCKED)
    - Do not call EEL_ShutDown or EEL_Suspend before

Post-conditions

None

Example

```
eel_u32        eraseCounter;
eel_status_t   ret;

ret = EEL_GetEraseCounter( &EraseCounter );

if( EEL_OK != ret )
{
 /* Error treatment */
}
```

5.4.4.2 EEL_GetDriverStatus

Description

This function returns the state machine status into the driver status structure.

Interface

```
eel_status_t EEL_GetDriverStatus( eel_driver_status_t
                                  *driverStatus_str );
```

Arguments

None

Return types/values

Type	Argument	Description
eel_status_t		Result of the function. Possible values are: EEL_OK EEL_ERR_ACCESS_LOCKED
eel_driver_status_t	driverStatus_str	Pointer to the driver status structure to update.

See chapter Chapter 15.3.3, “Driver status”

Pre-conditions

- Call EEL_Init to initialize the library

Post-conditions

None

Example

```
eel_driver_status_t  dStat;
eel_status_t         ret;

ret = EEL_GetDriverStatus( &dStat );

if( EEL_OK != ret )
{
 /* Error treatment */
}
```

5.4.4.3 EEL_GetSpace

Description

This function returns the current free space in the EEL ring buffer (prepared space for new data).

As the library always need to reserve one block for refreshing data sets (copy from the ring buffer tail to the front), the function reduces the prepared space by one block.

Calculation base:

Free space = ((no. of prepared blocks – 1) *
(block size – block header – 1 HWd)) +
remaining space in the active block

Interface

```
eel_status_t EEL_GetSpace( eel_u32 *space_pu32 );
```

Arguments

None

Return types/values

Type	Argument	Description
eel_status_t		Result of the function. Possible values are: EEL_OK EEL_ERR_ACCESS_LOCKED
u32	space_pu32	Pointer to the space calculation result storage location

Pre-conditions

- The library must be unlocked:
  - Call EEL_Init to initialize the library
  - Call EEL_Startup and call EEL_Handler cyclically to unlock the access status (access status != EEL_ACCESS_LOCKED)
  - Do not call EEL_ShutDown or EEL_Suspend before

Post-conditions

None

Example

```
eel_u32       space;
eel_status_t  ret;

ret = EEL_GetSpace( &space );

if( EEL_OK != ret )
{
 /* Error treatment */
}
```

5.4.4.4 EEL_GetVersionString

Description

This function returns the pointer to the library version string. The version string is the zero terminated string identifying the library.

Interface

```
(const eel_u08*) EEL_GetVersionString( void );
```

Arguments

None

Return types/values

The library version is returned as string value in the following style:

“EV850T06xxxxyZabcd”

with

x = supported compiler
y = compiler option
Z = “E” for engineering versions,
 “V” for final versions
abcd = Library version numbers according to version Va.bc or E1.00a
 d: optional on E-versions

Pre-conditions

None

Post-conditions

None

Example

```
eel_u08 *vstr_pu08;

vstr_pu08 = EEL_GetVersionString();
```

Chapter 6 EEL Implementation into the user application

6.1 First steps

There are several ways to approach the EEPROM emulation concept and the implementation into the user application.

It is for sure worth knowing the basics of the RENESAS EEPROM emulation concept and the library architecture, design and implementation. By that, you most probably get a feeling of the EEPROM emulation complexity at all and might consider that the implementation into the user's application is not done in a few days but requires careful consideration of the libraries features and requirements and the users application requirements.

A few things worth mentioning here are:

- Start-up time until 1st data read and write
- CPU load by the EEL, during library start-up and during normal operation
- Where to call the EEL_Handler function
- Where to call the EEL_Execute function
- How to map application variables to the EEL IDs
- ...

All these questions require some hands on experience with the EEL.

The best way after initial reading the user manual will be testing the EEL application sample.

6.1.1 Application sample

After a first compile run, it will be worth playing around with the library in the debugger. By that you will get a feeling for the source code files, the request structure mechanism and the library startup behavior.

Note **Before the first compile run, the compiler path must be configured in the application sample file "makefile":**
Set the variable COMPILER_INSTALL_DIR to the correct compiler directory

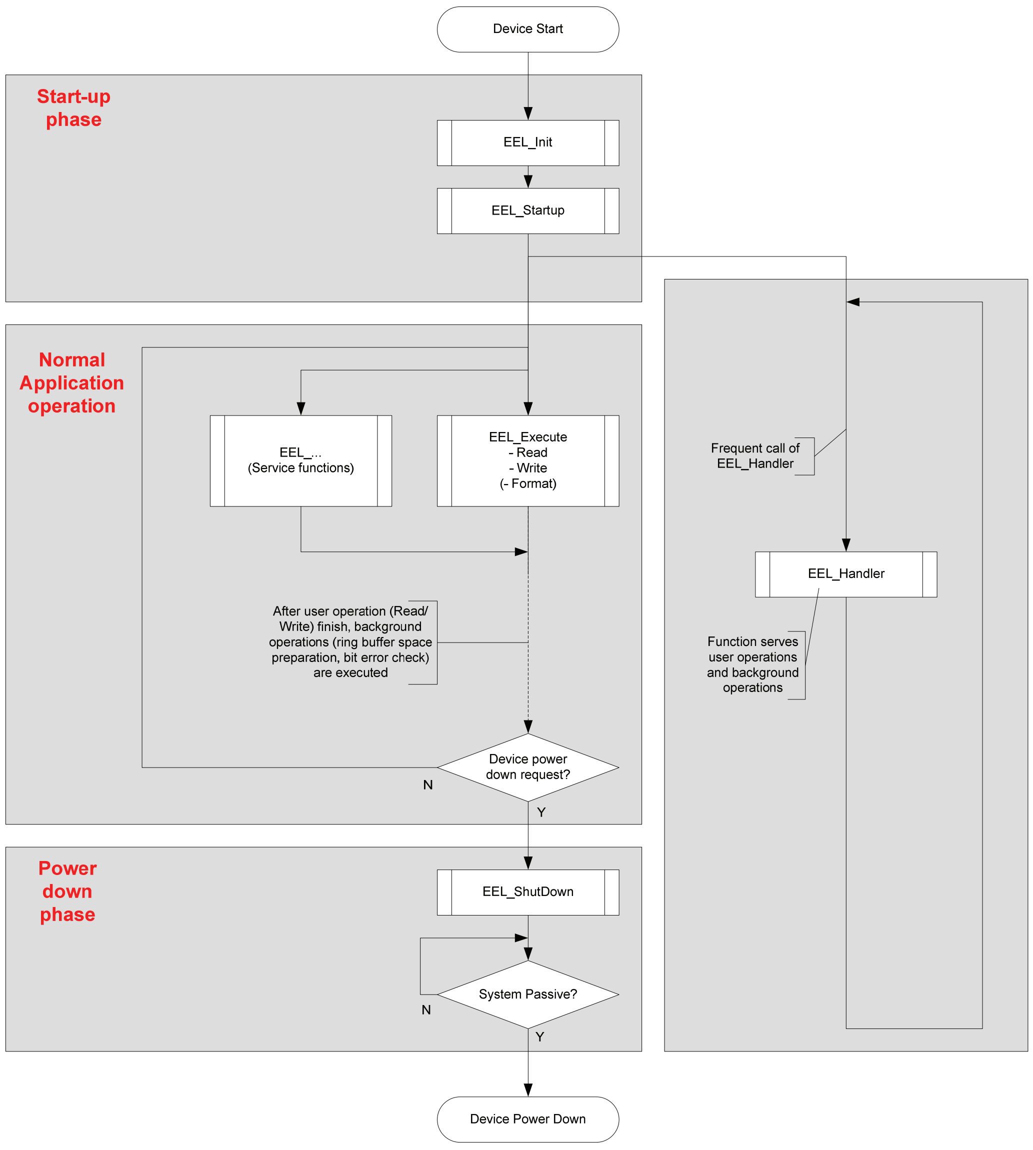
Later on the sample might be extended by further IDs and different data read and write sequences in order to come nearer to the later application requirements (data set amount and size) and to get a feeling of the CPU load and execution time during start-up and normal operation.

After this exercise, it might be easier to understand and follow the recommendations and considerations of this document.

6.2 Standard EEL life cycle

The following flow chart represents the recommended EEL life cycle during device operation including the API functions to be used.

Figure 6-1


Device Start
Start-up phase
EEL_Init
EEL_Startup
Normal Application operation
EEL_...
(Service functions)
EEL_Execute
- Read
- Write
(- Format)
After user operation (Read/ Write) finish, background operations (ring buffer space preparation, bit error check) are executed
Device power down request?
N
Y
Power down phase
EEL_ShutDown
System Passive?
N
Y
Device Power Down
Frequent call of EEL_Handler
EEL_Handler
Function serves user operations and background operations

EEL life cycle

In the startup phase, the EEL is initialized by EEL_Init and the background operation is started by EEL_StartUp

During normal operation, the foreground operations (user operations) are initiated synchronous to the application, while the background handler task ought to be executed in a task, asynchronous to the application (idle task, interrupt task, timed task)

In the power down phase the EEL is shut down. EEL_Handler need to be executed until the library status is passive. This is required in order to finalize ongoing EEL processes.

6.2.1 Device start-up

The device boots and the application start up. Usually very soon some data sets need to be read. Then the EEPROM emulation has some time to come up completely before the rest of the data need to be read (e.g. build up a RAM mirror) and written.

The example code below reads and writes data as soon as possible and then waits until the EEL is fully operational and unlocked

```
u08                  buffer_au08[0x100];
eel_request_t        req_str;
eel_driver_status_t dStat;
eel_status_t         res;

/* ----------------------------------------------------------
   Initialize the EEL
   - eel_RTConfiguration_str should have been set in
     EEL_Descriptor.c
   ---------------------------------------------------------- */
res = EEL_Init( eel_RTConfiguration_str,
                EEL_OPERATION_MODE_NORMAL );
if( EEL_OK != res )
{
 /* Error handler */
  . . .
}

res = EEL_Startup();
if( EEL_OK != res )
{
 /* Error handler */
  . . .
}

/* ----------------------------------------------------------
   Wait until we can read/write 1st data sets
   ---------------------------------------------------------- */
do
{
    EEL_Handler();
    EEL_GetDriverStatus( &dStat );
}
/* Wait until early read/write is possible (or error) */
while(   ( EEL_OPERATION_STARTUP == dStat.operationStatus_enu )
       &&( EEL_ACCESS_LOCKED     == dStat. accessStatus_enu) );

/* Error check */
if( EEL_OK != dStat.errorStatus_enu)
{
 /* Error handler */
  . . .
}


/* ----------------------------------------------------------
   Early read/write operation
   ---------------------------------------------------------- */
req_str.address_u32    = (u32)(&buffer_au08);
req_str.identifier_u16 = 10u;
req_str.length_u16     = 0x10u;
req_str.offset_u16     = 0x13u;
req_str.command_enu    = EEL_CMD_READ;

EEL_Execute( &req_str );

/* Wait until operation end */
while( EEL_BUSY == req_str.status_enu )
{
     EEL_Handler();
}

/* Error check */
```

```
if( EEL_OK != req_str.status_enu )
{
 /* Error handler */
  . . .
}

req_str.address_u32    = (u32)(&buffer_au08);
req_str.identifier_u16 = 10u;
req_str.command_enu    = EEL_CMD_WRITE;

EEL_Execute( &req_str );

/* Wait until operation end */
while( EEL_BUSY == req_str.status_enu )
{
     EEL_Handler();
}

/* Error check */
if( EEL_OK != req_str.status_enu )
{
 /* Error handler */
  . . .
}

/* ----------------------------------------------------------
   Wait for fully operational and access unlock
   ---------------------------------------------------------- */
do
{
    EEL_Handler();
    EEL_GetDriverStatus( &dStat );
}
/* Wait until the system is completely up and running
   (or error) */
while(EEL_OPERATION_STARTUP == dStat.operationStatus_enu );

/* Error check */
if( EEL_OK != dStat.errorStatus_enu)
{
 /* Error handler */
  . . .
}

/* ----------------------------------------------------------
   Now the EEL is fully operational
   ---------------------------------------------------------- */
```

6.2.2 Device normal operation

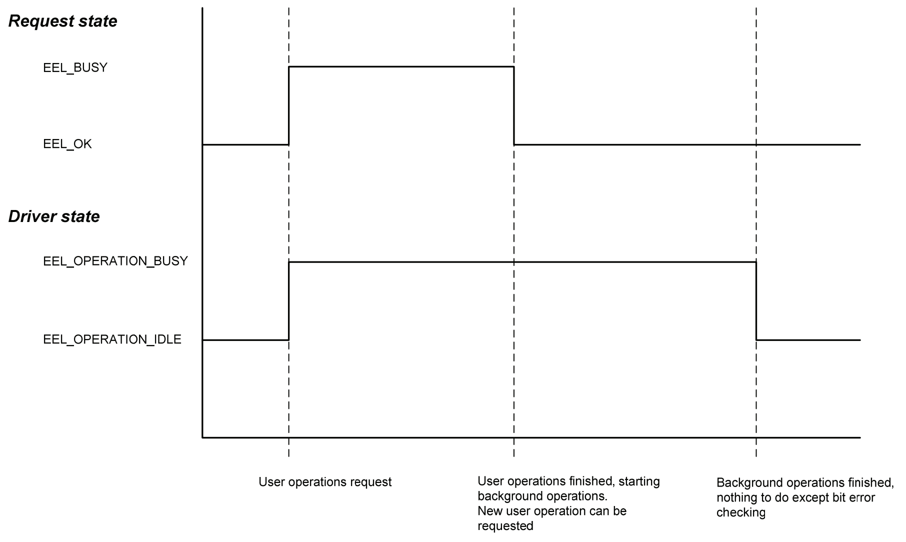
When the device has passed the startup phase and is in normal operation, the complete functionality is available.

The example code below reads and writes data sets.

```
/* ----------------------------------------------------------
        Normal operations
   ---------------------------------------------------------- */
req_str.address_u32    = (u32)(&buffer_au08);
req_str.identifier_u16 = 10u;
req_str.length_u16     = 0x10u;
req_str.offset_u16     = 0x13u;
req_str.command_enu    = EEL_CMD_READ;

EEL_Execute( &req_str );

/* Wait until operation end */
while( EEL_BUSY == req_str.status_enu )
{
     EEL_Handler();
}

/* Error check */
if( EEL_OK != req_str.status_enu )
{
 /* Error handler */
  . . .
}

req_str.address_u32    = (u32)(&buffer_au08);
req_str.identifier_u16 = 10u;
req_str.command_enu    = EEL_CMD_WRITE;

EEL_Execute( &req_str );

/* Wait until operation end */
while( EEL_BUSY == req_str.status_enu )
{
     EEL_Handler();
}

/* Error check */
if( EEL_OK != req_str.status_enu )
{
 /* Error handler */
  . . .
}
```

Most important operation control signals are the status of a requested user operation and the driver status. The following diagram shows the relationship between a request and execution of background operations.

Figure 6-2


Request state
EEL_BUSY
EEL_OK
Driver state
EEL_OPERATION_BUSY
EEL_OPERATION_IDLE
User operations request
User operations finished, starting background operations. New user operation can be requested
Background operations finished, nothing to do except bit error checking

Operations state diagram

The handler call frequency significantly determines the EEL performance. As long as the driver or request state is busy, the handler should be called with higher frequency. When the driver state is idle, the call frequency can be reduced as then only cyclical bit error checks are done by the EEL. Then, on each handler call one Flash HWd is checked.

6.2.3 Device power down

On power down, the user application should give the library time to finish background operations which are under progress. This can be reached by using the service functions in the following way:

```
/* ----------------------------------------------------------
   Request Library shutdown
   ---------------------------------------------------------- */
EEL_Shutdown();

/* ----------------------------------------------------------
   Wait until all background processes are finished and the
   supervision gets passive
   ---------------------------------------------------------- */
do
{
    EEL_Handler();
    EEL_GetDriverStatus( &dStat );
}
while(EEL_OPERATION_PASSIVE != dStat.operationStatus_enu );

/* Error check */
if( EEL_OK != dStat.errorStatus_enu)
{
 /* Error handler */
  . . .
}
```

6.3 Special considerations

6.3.1 Endurance calculations

Every write operation of a new data set instance occupies space in the Data Flash. When a certain amount of Data Flash is filled, new space is created by Refresh and Prepare processes where the Refresh process copies data which is still valid from the ring buffers active zone tail block to the active zone head block. When finished the Prepare operation can erase the tail block.

This is repeated many times over device lifetime. However, the endurance of the Data Flash blocks regarding number of erase cycles is limited. So, it is necessary to calculate the number of erase cycles required over device life time and to judge if this does not exceed the specified Data Flash endurance.

RENESAS provides an endurance calculation sheet which can be filled with the different data sets sizes and the required write cycles. That sheet can estimate the expected number of Flash erase cycles and judge if this exceeds the specification.

Note **The endurance calculation sheet is a very helpful tool, but still the result is just an estimation and cannot be absolute accurate because the result depends on different conditions like e.g. the sequence of the written Data sets. So, the result must be confirmed in the real user application.**

The calculation sheet can be requested at the RENESAS Flash support under:

mailto:application_support.flash-eu@lm.renesas.com

6.3.2 Data Flash initialization

Before being able to normally use the Data Flash for EEPROM emulation, the Flash must be formatted and (depending on the application) be filled with initial data set instances.

This can be done using different approaches. Often used ones are:

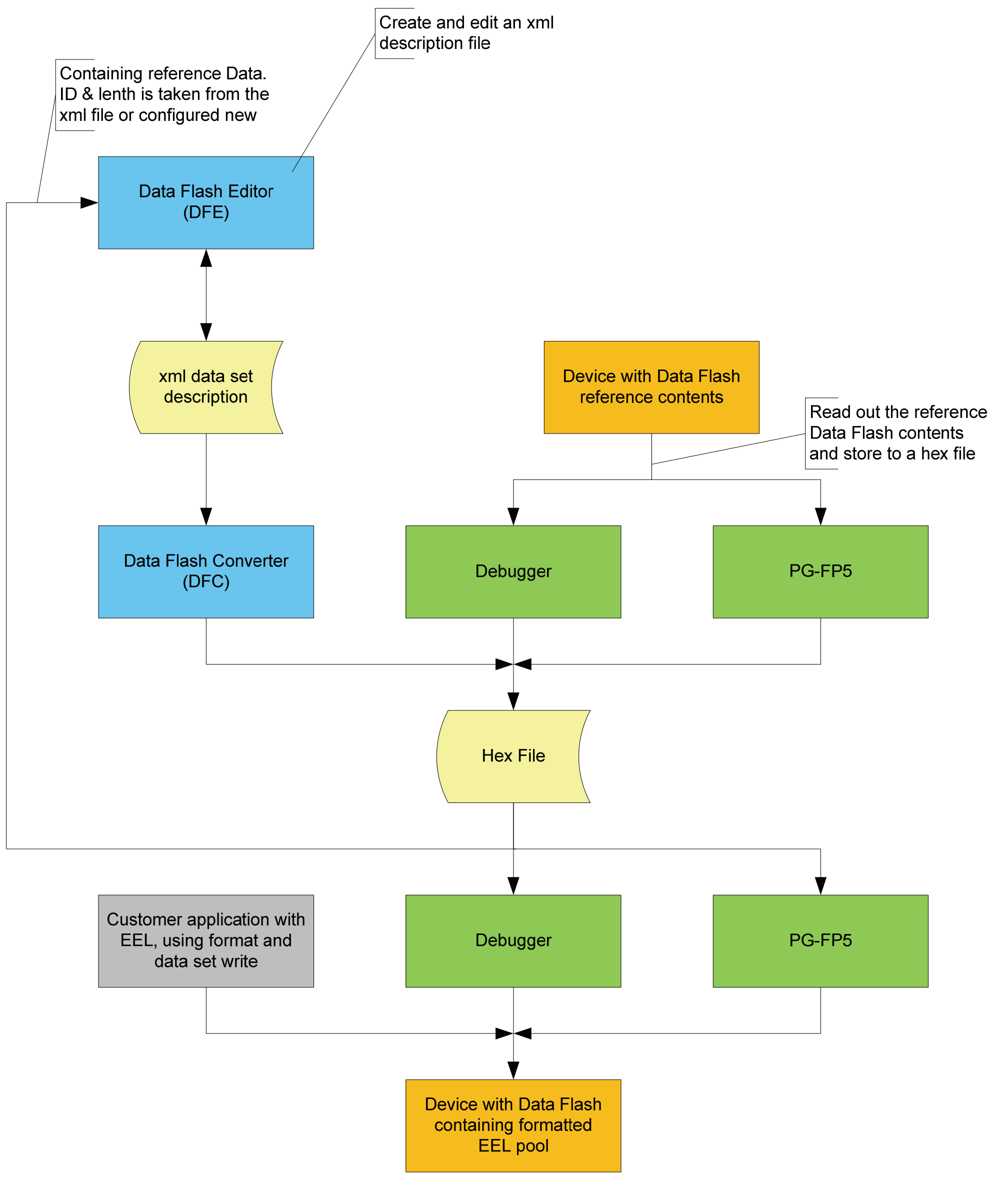
- The application itself executes the Format operation and then writes initial instances of the data sets.
  As the format operation deletes all data, it shall be carefully considered how to prevent accidental formatting by the application!
- A serial programming tool (e.g. PG-FP5) or debugger is used to program the Data Flash in the same flow that also programmes the Code Flash.
- In a self-programming flow a boot loader normally updates the application code in the Code Flash. During this flow, also the Data Flash can be filled using the FDL directly.

For the later solution with the programming tool or debugger a hex file is required which contains the Data Flash contents (complete EEL pool content).

This content can be gained by:

- Dumping the Flash content of an already formatted Data Flash to a hex file using a serial programming tool or the debugger.
- Using a tool chain called Data Flash Converter and Data Flash Editor to convert a raw data description in an xml file into a hex file. This tool chain will be provided by RENESAS on request when available.

Figure 6-3


Create and edit an xml description file
Containing reference Data. ID & lenth is taken from the xml file or configured new
Data Flash Editor (DFE)
xml data set description
Device with Data Flash reference contents
Read out the reference Data Flash contents and store to a hex file
Data Flash Converter (DFC)
Debugger
PG-FP5
Hex File
Customer application with EEL, using format and data set write
Debugger
PG-FP5
Device with Data Flash containing formatted EEL pool

Data Flash initialization tool chain

6.3.3 Library handling by the user application

6.3.3.1 Function reentrancy

All functions are not re-entrant. So, re-entrant calls of any EEL or FDL functions must be avoided.

6.3.3.2 Task switches, context changes and synchronization between EEL functions

All EEL functions depend on EEL global available information and are able to modify this. In order to avoid synchronization problems, it is necessary that at any time only one EEL function is executed. So, it is not allowed to start an EEL function, then switch to another task context and execute another EEL function while the last one has not finished.

Example of not allowed sequence:

- Task1: Start an EEL operation with EEL_Execute
- Interrupt the function execution and switch to task 2, executing EEL_Handler function
- Return to task 1 and finish EEL_Execute function

As the EEL may not define critical sections which disable interrupts in order to avoid context changes and task switches, this synchronization need to be done by the user application.

6.3.3.3 EEL operation performance

The performance of the EEL operations strongly depends on the frequency of the handler calls. This especially affects operations which require many Flash write operations until the operation is finished, such as DS Write and background operations such as Startup processing or Refresh.

As the typical Flash write operation needs between 200 and 700us, a slower handler call frequency significantly reduces the operation performance.

The following user application implementations are judged regarding advantages and disadvantages (also mixtures are possible if the synchronization of the function calls is ensured):

- Call in a timed task

  In order to archive a reasonable emulation operation performance, the time slice should not be selected too big. A 500us interval would not significantly reduce the EEL performance and so seems to be a reasonable compromise between library performance and CPU load.

- Call in the idle task

  If it is ensured that the idle task is called often enough, that method might result in the good performance as the handler can be called continuously. However, as this method is not deterministic in case of higher CPU load by the application, it might be combined with calls in a timed task.

6.3.3.4 EEL Start-up time optimization

The duration from EEL initialization up to EEL full operation is usually a critical value for the application.

This time is largely defined by the process step to fill the RAM ID-L table for fast DS search and read. The complete active part of the EEL pool is parsed DS to DS and on each found DS, the library checks if the appropriate RAM table entry is already filled. Therefore, the ROM table is searched for the correct ID from the last entry (table end) to the first entry.

If all IDs of often written Data Sets are placed to the ID-L table end and all rarely written DS IDs are placed to the ID-L Table begin, the EEL Start-up performance is significantly increased.

6.3.4 Concurrent Data Flash accesses

Depending on the user application scenario, the Data Flash might be used for different purposes, e.g. one part is reserved for direct access by the user application and one part is reserved for EEPROM emulation by the Renesas EEL. The FDL is prepared to split the Data Flash into an EEL Pool and a User Pool.

On splitted Data Flash, the EEL is the only master on the EEL pool, accesses to this pool shall be done via the EEL API only.

Access to the user pool is done by using the FDL API functions for all accesses except read (e.g. FDL_Erase, FDL_Write, ...), while Data Flash read is directly done by the CPU.

The configuration of FDL pool and EEL pool (and resulting user pool) is done in the FDL descriptor.

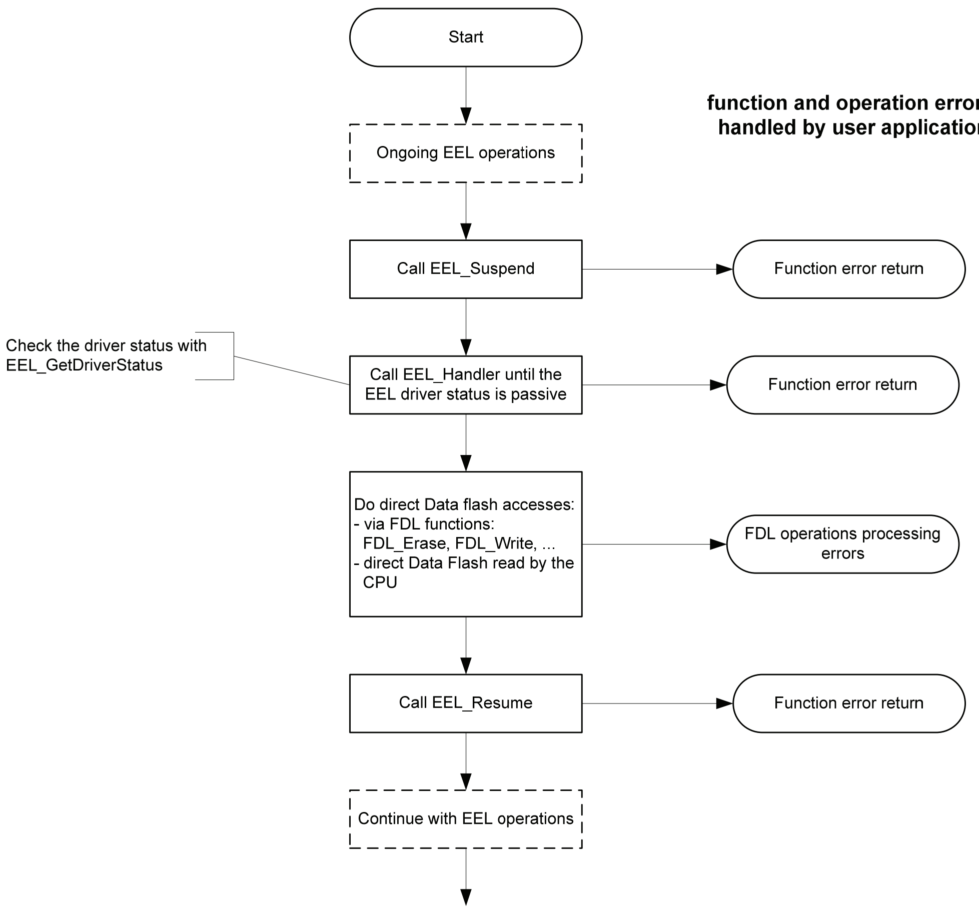
6.3.4.1 User Data Flash access during active EEPROM emulation

While the EEL is active, any direct Data Flash access like Data Flash Read by the CPU or execution of FLD functions are not allowed at all!

The EEL can at each time erase or write Data Flash. During these operations Data Flash is not accessible for Read operations, even not on other address ranges. Furthermore, execution of FDL operations like Flash Erase or Write would be blocked.

Following that, EEL operations and user accesses to Data Flash must be synchronized. This has to be done by the application, considering the EEL as the default master. If the user application wants to get access rights, the EEL need to be suspended beforehand. The API contains the functions EEL_Suspend and EEL_Resume for this. The following flow chart shows the correct handling.

Figure 6-4


Start
function and operation errors, handled by user application
Ongoing EEL operations
Call EEL_Suspend
Function error return
Check the driver status with EEL_GetDriverStatus
Call EEL_Handler until the EEL driver status is passive
Function error return
Do direct Data flash accesses:
- via FDL functions: FDL_Erase, FDL_Write, ...
- direct Data Flash read by the CPU
FDL operations processing errors
Call EEL_Resume
Function error return
Continue with EEL operations

EEL Suspend / Resume

6.3.4.2 Direct access to the Data Flash by the user application by DMA

Basically, DMA transfers from Data Flash are permitted, but need to be synchronized with the EEL. Same considerations apply as mentioned in the last sub-chapter for accesses by the user application.

6.3.5 Entering power safe mode

Entering power safe modes is delayed by the device hardware until eventually ongoing Data Flash operations are finished.

In order to gain a proper synchronisation between EEL and Power safe mode entering, the library operations must be suspended before entering the mode (Please check EEL_Suspend API description).

6.3.6 Library behaviour after operation interruption

Library operation might be suddenly interrupted e.g. by a power fail. Depending on the interrupted operation (E.g. Flash erase, write ....) the behaviour of the library on the next start-up might differ:

- Library was idle or at the end of a operation:

  Normal library start-up

- Flash block erase or Flash block header operation was interrupted:

  Eventually it is necessary to fix a block status (e.g. block activation or block erase was interrupted). In this case additionally Flash write operations might take some more time and so, slightly enlarge the time until the driver leaves the state EEL_OPERATION_STARTUP.
  Furthermore, the driver will return the warning EEL_ERR_FIX_DONE as an indication that a fix was done. The library operation continues normal, the application need not react on the warning
- DS Write was interrupted

  If the DS write proceeded up to writing the DCS, the DS is valid. If the EOR has not been written, the DS will automatically be refreshed.
  In this case additionally Flash write operations might take some more time and so, enlarge the time until the driver leaves the state EEL_OPERATION_STARTUP
- DS Write was interrupted

  If the DS write did not proceed up to writing the DCS, the DS is invalid. The start-up process does no special action, but this DS instance is not considered on DS read

6.3.7 Application update issues

6.3.7.1 Change DS length

When a user application shall be updated but the EEPROM emulation data shall be used also further on, different constraints need to be considered with respect to the ROM ID-L table.

On application update it might be required to change the DS length of some IDs. Differing from the MF2/UX4 EEELib, this is automatically done, when the ID-L table in ROM is updated. After that update all DS's are read/written with the new length and also the Refresh process copies the data with the new length:

- Old length < new length

  Data is extended by any data stored after the DS (data of the next DS = undefined)
- Old length > new length

  Data is cut to new length

Note After DS length change, a Read operation will always return a checksum error (EEL_ERR_WRONG_CHECKSUM) as the checksum does not match to the DS data (see above) anymore. To fix this, the DS must be written once more by the application.

Anyhow, differing from the EEELib, the DS length is no longer stored within the DS, but in the ID-L table. When the table is updated, the information of the former DS size get lost. So, the library provides no measure to get the length of the last stored DS instance. This information must be provided otherwise.

Possible options to store the DS lengths are:

- Store the length of the DS in the DS itself

If the length is stored in the 1st Bytes, a read operation on the 1st Bytes only can be done.

- Reserve a special DS only containing all available DS IDs and the length information

  A comparison with the ROM ID-L table will identify the IDs with changed length.
- Protect the DSs with a checksum

  Calculating the checksum from data with a different length result in a checksum differing from the stored one (not 100% safe!).

6.3.7.2 ID-L ROM table temporarily not available

The boot loader as well as the application needs to access EEPROM emulation data with Read as well as Write. While the application requires frequent data write, the boot loader will only store a very limited amount of data, e.g. to store the application update process state.

The ROM ID-L table containing all IDs available in the emulation belongs to the application. On application update it needs to be removed together with the application. After removal of the ID-L table, normal operation of the EEPROM emulation cannot continue. In order to continue at least with limited functionality, the library provides operation modes to survive at least with limited functionality.

The mode configuration is done by the initialization function EEL_Init. In order to change the mode, EEL_Init need to be called again.

- EEL_OPERATION_MODE_NORMAL

  Full (normal) operation of the library, requires the complete ID-L table in ROM
- EEL_OPERATION_MODE_LIMITED

  Operation with limited ID-L-table in ROM, containing only the IDs, required by the boot loader. The DS Read and Write work on the ID-L table. The Refresh process is not possible as this would require a list of all available IDs. Following this, Data Sets can only be written until the passive Flash space of the Data Flash (prepared and invalid blocks) is consumed. Then the library must switch to read only.

  As the size of data to be written by the boot loader is very limited, it is considered, that the passive space should be sufficient, even in case of frequent interruptions of the application update process.
  Additionally the library provides a function to defragment the active space (activated blocks) in the Flash by Refreshing all activated blocks. By that all DS instances which are not the latest ones are removed and as much as possible passive space is provided.

  The limited mode is realized by simply stopping the EEL start-up process before it could complete. The resulting access state is EEL_ACCESS_READ_WRITE (see chapter 5.3.3, “Driver status”)

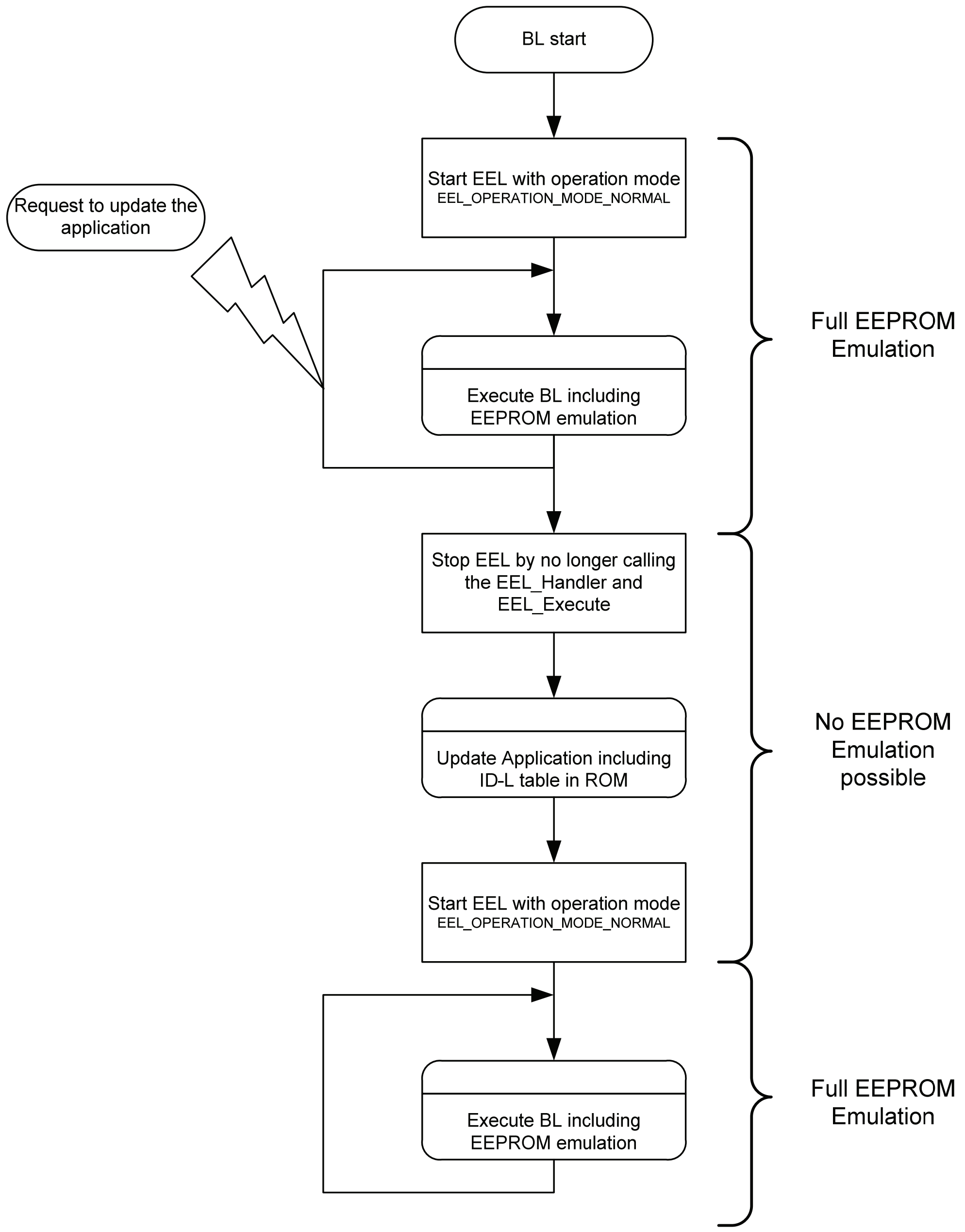
The following explanations describe the different application update strategies which we consider to be reasonable. The different strategies use the different operation modes.

Application update flow proposal -
Stop EEPROM emulation until ROM ID-L table is available

The following flow chart explains the application update idea. Timely no EEPROM emulation is possible.

The emulation is started in normal operation mode, using the parameter EEL_OPERATION_MODE_NORMAL when calling the function EEL_Init.

Figure 6-5


BL start
Start EEL with operation mode EEL_OPERATION_MODE_NORMAL
Request to update the application
Execute BL including EEPROM emulation
Full EEPROM Emulation
Stop EEL by no longer calling the EEL_Handler and EEL_Execute
Update Application including ID-L table in ROM
Start EEL with operation mode EEL_OPERATION_MODE_NORMAL
No EEPROM Emulation possible
Execute BL including EEPROM emulation
Full EEPROM Emulation

Application update concept with timely stopping EEPROM emulation

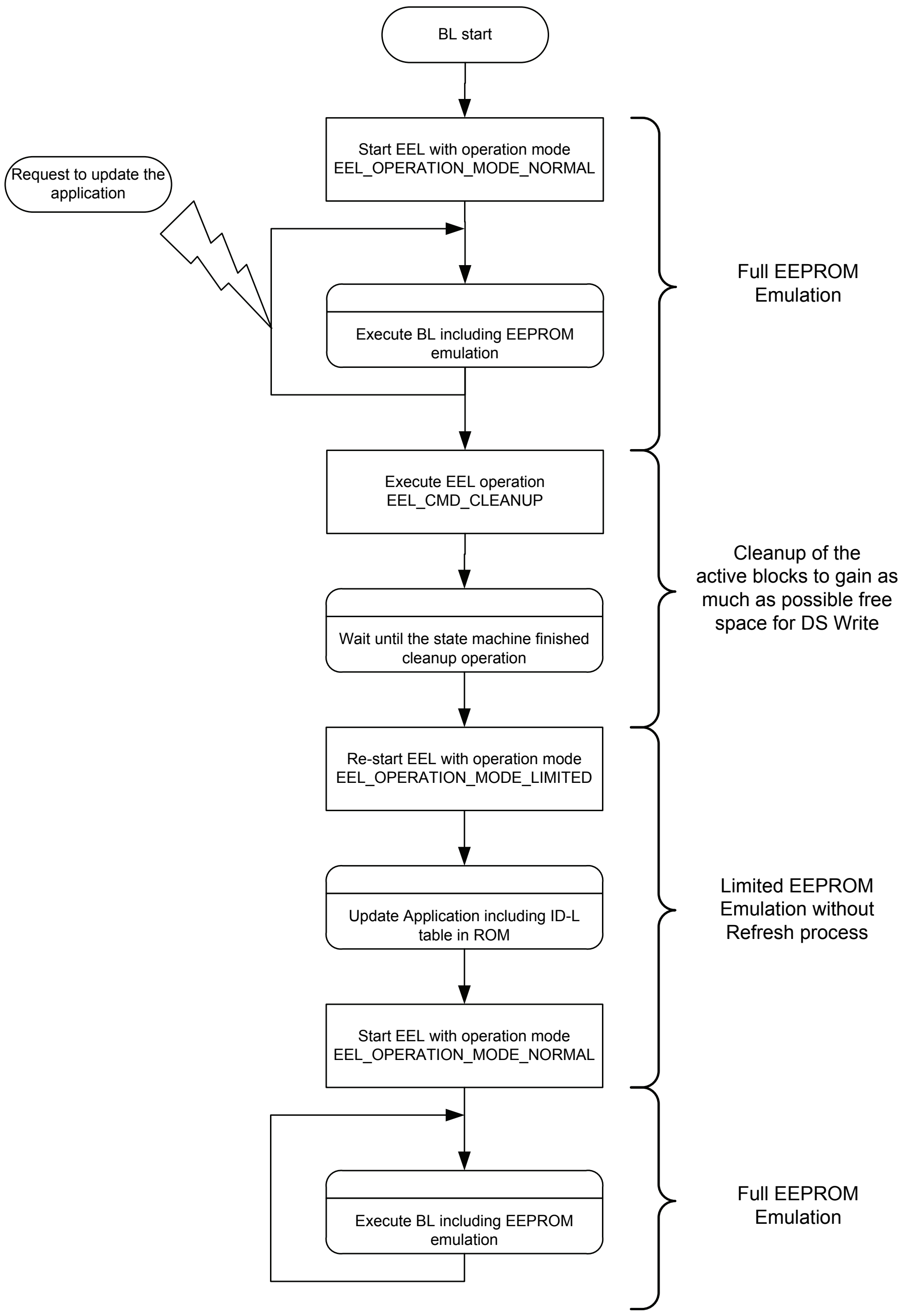
Application update flow proposal -
Boot loader with independent ID-L table and limited Write

The following flow chart explains the application update idea. Timely only limited EEPROM emulation is possible.

In order to overcome the situation of no Refresh during the limited emulation period, the active blocks ought to be defragmented/cleaned. See Cleanup command.

The emulation is started in limited operation mode, using the parameter EEL_OPERATION_MODE_LIMITED when calling the function EEL_Init.

Figure 6-6


BL start
Start EEL with operation mode EEL_OPERATION_MODE_NORMAL
Request to update the application
Execute BL including EEPROM emulation
Full EEPROM Emulation
Execute EEL operation EEL_CMD_CLEANUP
Wait until the state machine finished cleanup operation
Cleanup of the active blocks to gain as much as possible free space for DS Write
Re-start EEL with operation mode EEL_OPERATION_MODE_LIMITED
Update Application including ID-L table in ROM
Start EEL with operation mode EEL_OPERATION_MODE_NORMAL
Limited EEPROM Emulation without Refresh process
Execute BL including EEPROM emulation
Full EEPROM Emulation

Application update concept with timely limited EEPROM emulation

6.3.8 Device performance during active Flash operations

Based on the devices system architecture, the APB bus access by the application is affected by active Flash operations:

During the Flash operations, the APB bus access is delayed by up to 32 wait states.

Revision History

Chapter	Page	Description
		new version

EEPROM Emulation Library

Renesas Electronics Corporation