Application Note

78K0

8-Bit Single-Chip Microcontroller

EEPROM Emulation

Kx2/Fx2/Lx2/Dx2/Lx3/LIN4/uCFL/Ix2/Kx2-L

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Chapter 1 Overview

Conventional EEPROM memory (electrically erasable programmable read only memory) is used in embedded applications for storing data that has been modify at operation time but must maintain after power supply is switched off. It’s normally used as an external component controlled by the micro-controller via appropriate communication interface (CSI, I²C or others). Some microcontrollers are already equipped with EEPROM on-chip, but in any case an real EEPROM in a system is always a matter of costs.

Modern microcontroller are using flash technologies with sufficient endurance and data retention characteristics suitable for storing of dynamical data in flash memory under software control only.

Generally EEPROM emulation is a piece of software emulating the functionality of a conventional EEPROM based on usage of internal flash memory. It’s managing the used resources like flash memory space, endurance, data retention and the access to the virtual EEPROM memory during its operation..

As well real EEPROM as its emulation can only write into location eased beforehand, but there is one fundamental difference between both:

- in case of conventional EEPROM the memory content can be re-programmed (erased and written) as one access in units of one ore more bytes.

- EEPROM emulation driver has to consider the device and flash technology requirements and restrictions during its operation. One of these is the difference between the smallest erasable unit (one flash block) and the smallest writeable unit (here 1 flash-word = 4 bytes). This specific characteristic requires some tricky countermeasure to keep the data always consistent. Another constraining parameter is the limited number of block erase-cycles (endurance) requires an efficient, secure and sophisticated implementation.

This User’s Manual describes the usage of NEC’s EEPROM emulation library featuring EEPROM emulation on NEC’s 78k0 microcontroller with embedded single voltage flash. It sketches the internal driver architecture necessary for general understanding but its emphasis is the integration and operation of the EEPROM emulation driver in embedded applications.

1.1 Naming convention

Active block

the only one block inside the EEL pool that contains all actual instances of EEL variables. The read and write access is processed via this block.

Firmware
Internal software, that is managing the access to the flash system.

FSL
Short form of **F**lash **S**elf-programming **L**ibrary

EEL
Short form of **E**prom **E**mulation **L**ibrary

EEL pool
Set of subsequent flash blocks used for saving the EEPROM data.

EEL anchor
ROM constant structure containing EEL variable description managed by EEL.

Chopper
- periodical interrupt source “chopping” the execution time of the self-programming commands used by the EEL driver into predefined time slices.

Background operation mode
EEL driver commands are executed state-wise (state by state) controlled by the EEL-Handler. In this operation mode the application undertakes the CPU control in between internal EEL states. This mode is preferably in applications using preemptive or non-preemptive operating systems.

Enforced operation mode
EEL driver commands are executed completely at the caller side. In this operation mode the EEL driver retains the CPU control as long executing the command.

EEL variable
Variable registered in eel_anchor[] with its attributes “identifier” and “size”.

EEL instance
Data-set of a given EEL variable written to the flash. Each write access to the EEL generates a new reference inside the ILT and a new instance in the data flash area (DFA).

ILT (Instance LookupTable)
Area on the top of active block containing all active instance references.

DFA (Data Flash Area)
Area on the bottom of the active block where pure data of the instances are stored.

Separator
The first flash word inside the erased area between the ILT and the DFA. The separator must not disappear.

1.2 General approach

For the 78k0 devices the same physical flash memory is used for storing application code as well for the EEL data. The flash memory does not support so called “dual operation”, consequently each flash access being performed by the self-programming firmware inhibits the execution of application code at the same time. From CPU point of view the application code disappears practically during the flash access. This fact influences seriously the real-time behavior of the whole system when the EEL driver is active. NEC’s implementation of the EEPROM emulation tries to defuse the real-time situation and to retrieve the maximum of flexibility and transparency for applications operation. Following claims and requirements formed the guideline for the chosen implementation way:

- simple straight forward architecture based on request-response model
- write and read access of any data portions between 1 and 255 bytes
- EEL variable identification based on unique 1 byte identifier
- inconsistencies caused by asynchronous power-off RESET are always detectable and repairable
- reparation initiated by the application to avoid a non-deterministic write/read access time
- read- and write-access time is independent of the internal driver status
- no blocking time longer than a period pre-determined by the user
- user configurable interrupt scenario for EEL operation
- no additional interrupt latency caused by the EEL driver

Basically the data stored in an EEPROM could be categorized as following:

1. static data like product number, serial number, static parameter….
2. rare updatable data like immobilizer key, engine characteristic…
3. agile, dynamic data like ODO-meter, window lifter position….

For handling of data type (1.) we recommend to use pure self-programming functions however it is also possible to integrate it into the EEPROM emulation. Data of type (2.) and (3.) are predestined to be managed by the EEPROM emulation driver. The partitioning of the data should be done with respect to constrains resulting from the limited flash block-size. This causes limited number of independent EEL variables and is limiting total size (sum of particular sizes) of all EEL variables.

Chapter 2 Architecture

The EEPROM emulation driver architecture and strategy described in this document is chosen by NEC to offer the user a maximum of flexibility and safety under acceptable losses in real-time behavior. But this is one possible implementation. Principally based on the flash self-programming library **FSL** the user can implement a different EEPROM emulation strategy. However some rules and recommendation has to be considered to achieve the specified flash endurance and data retention of the EEPROM data:

1. only commands offered by NEC's self-programming library can be used for implementation
2. write access into previously erased full flash words (4 bytes) is allowed only
3. after power-on RESET read- and write-access to/from the related flash block is possible after successful internal verification by the "FSL_IVerify" command.
4. do not use a flash blocks for data and code anymore when "FSL_Write" or "FSL_EEPROMWrite" was terminated with error code “0x1C(FSL_ERR_WRITE)" or “0x1D (FSL_ERR_EEPWRITE_VERIFY)“
5. do not use a flash block for data and code anymore when "FSL_Erase" command was terminated with error code “"0x1A (FSL_ERR_ERASE)"
6. It is recommended to keep one data block available for redundancy reasons

Note:
Data retention time starts when writing a word into an erased block. When adding more data records into the same block, full data retention of the whole block is achieved only, if internal verify command is executed after writing the last data record.

2.1 System architecture

The EEL driver is embedded in a strictly layered system and building up on NEC's self-programming library as a bridge between the flash control subsystem (firmware and hardware) and the EEL. For details please refer to the flash self-programming library user's manual.

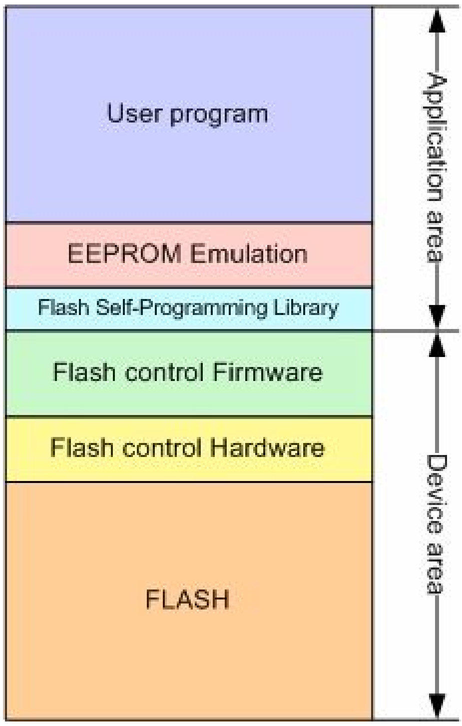


Figure 2-1 EEPROM emulation layer model

2.1.1 Import-, export-lists

The EEL driver is using the software interface (FSL API) offered by NEC's flash self-programming library (FSL). On its part the EEL driver offers a dedicated user interface (EEL API) can be used by the application for operative and administrative measures like command execution and operation supervision. The precompiled EEL like the FSL, contains an user configurable parts bordered in red.

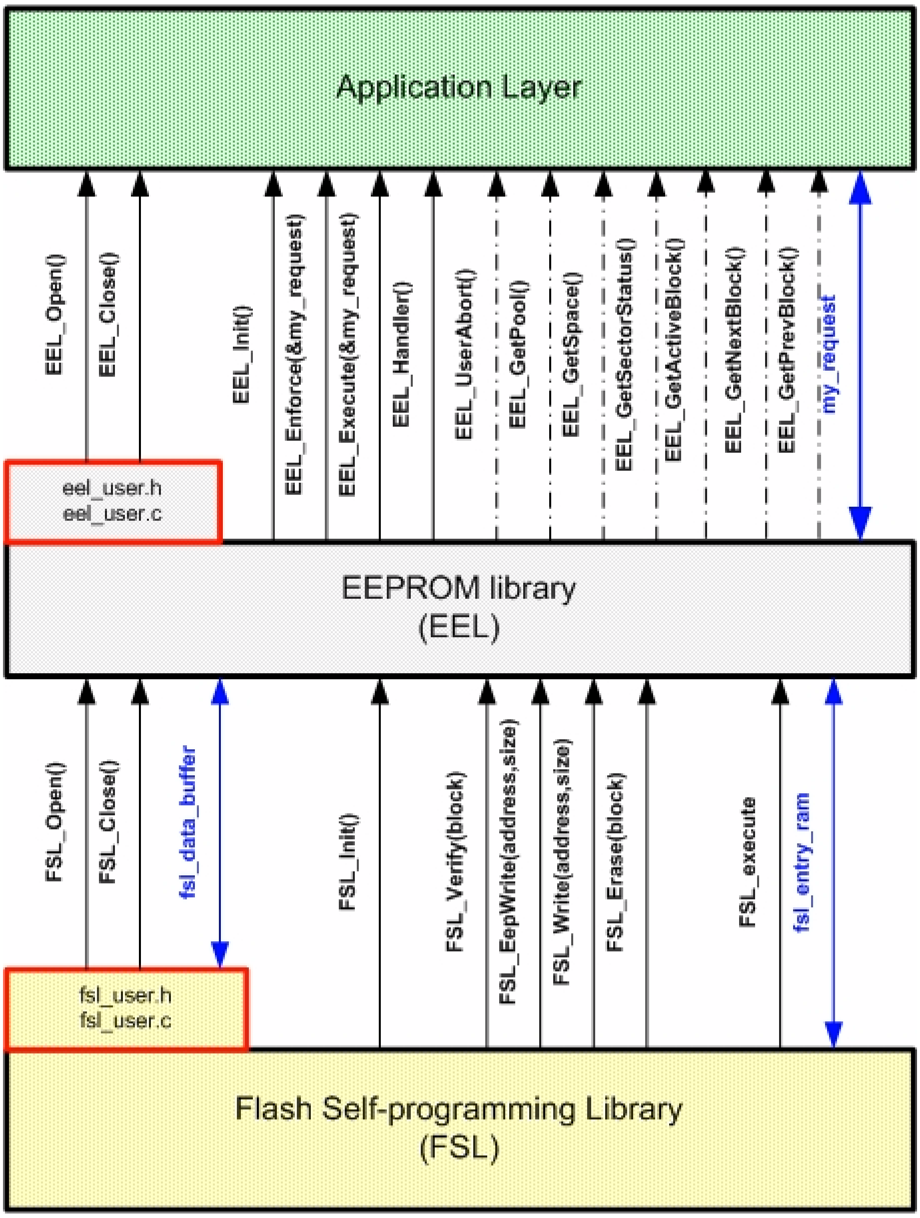


Figure 2-2 import export diagram (RAM variables marked in blue)

2.1.2 Module relationship

The file relationship of the EEL library obeys strict hierarchical top down order.

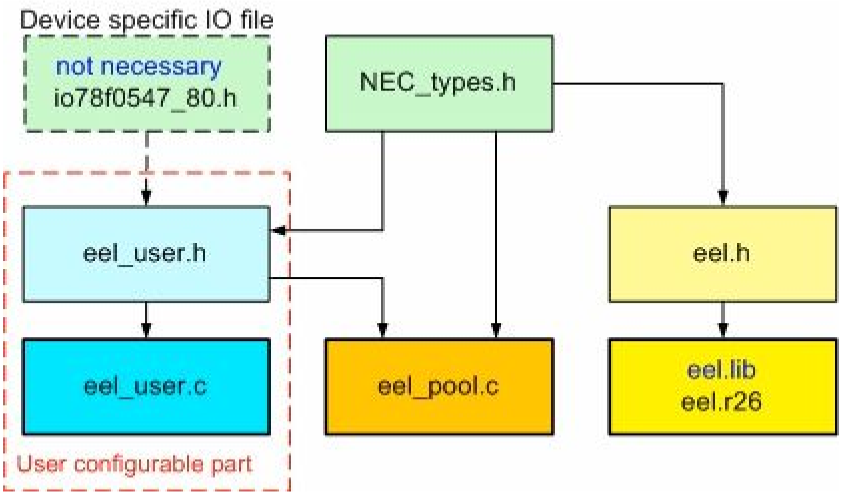


Figure 2-3 include hierarchy diagram

Note

1. NEC compatible modules are marked in blue.
2. NEC compatible version of the EEL driver specifies the device file in the project manager PM3+
3. IAR version of the EEL driver has to include the device I/O-file explicit in eel_user.h

2.2 Driver architecture

The strongest requirement for the design of the driver was avoiding of blocking time during driver operation time. For that reason this EEL implementation dispenses of any automatic mode, like automatic copy process (refresh), automatic erase process (prepare) and others. The application can check the internal status of the driver and can initiate appropriate command at most convenient time. This can be used to prepare erased blocks in advance in uncritical timing situation. Leaned on a typical client-server architecture the application (client) can formulate some requests (commands) and can “send” it to the server via proprietary software interface. However in case of the 78k0 EEL driver command queuing is not implemented, its architecture and the chosen application interface are already prepared for that.

2.2.1 Request response model

The user application can use the pre-defined data type t_eel_request to define a private EEL request variable. Using the request variable the application and the EEL driver can exchange information. The owner task can formulate and “send” private requests to the EEL driver. On the other hand the EEL driver can use it for sending feedback to the “requester”. The request variable is synchronizing the application and the driver. Please have a look to chapter 3.2 for details.

2.2.2 Resource consumption and its distribution

The EEL is consuming some resources distributed across the device memory address space.
From compiler/linker point of view, the EEL driver consists of three logical parts:

- user configurable source file where all driver parameter are defined
- precompiled EEL library containing the whole driver functionality
- self-programming library interfacing the firmware

Each of the above parts claims resources as shown in the figure below:

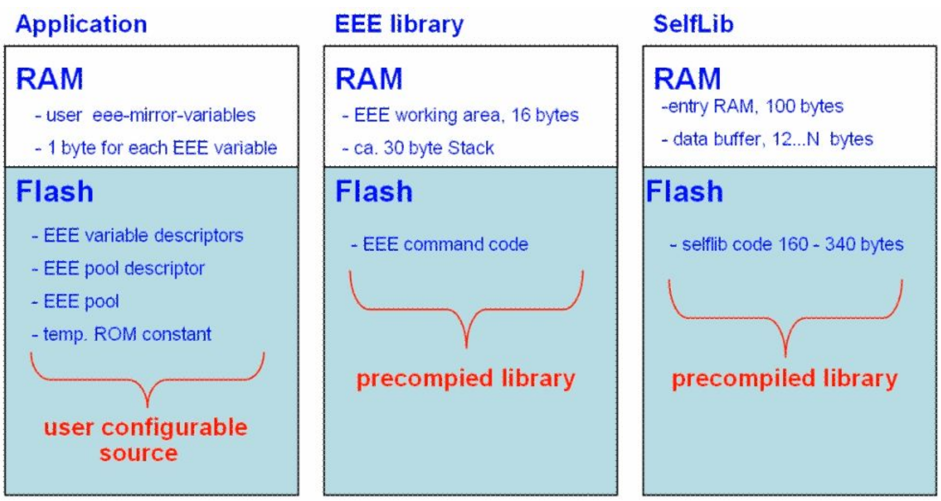


Figure 2-4 resource distribution

2.2.3 Physical placement of driver components

In the EEL driver the part where the data are stored is completely independent from the part where the driver code is stored. The EEL driver code is fully re-locatable and can be linked into the application code as a pre-compiled library. The EEL pool area defined by the user is complete out of linker control. Please take care, that EEL_POOL and application code does not overlap by creation of a suitable linker description file (*.DR for NEC linker or *.XCL for the IAR compiler).

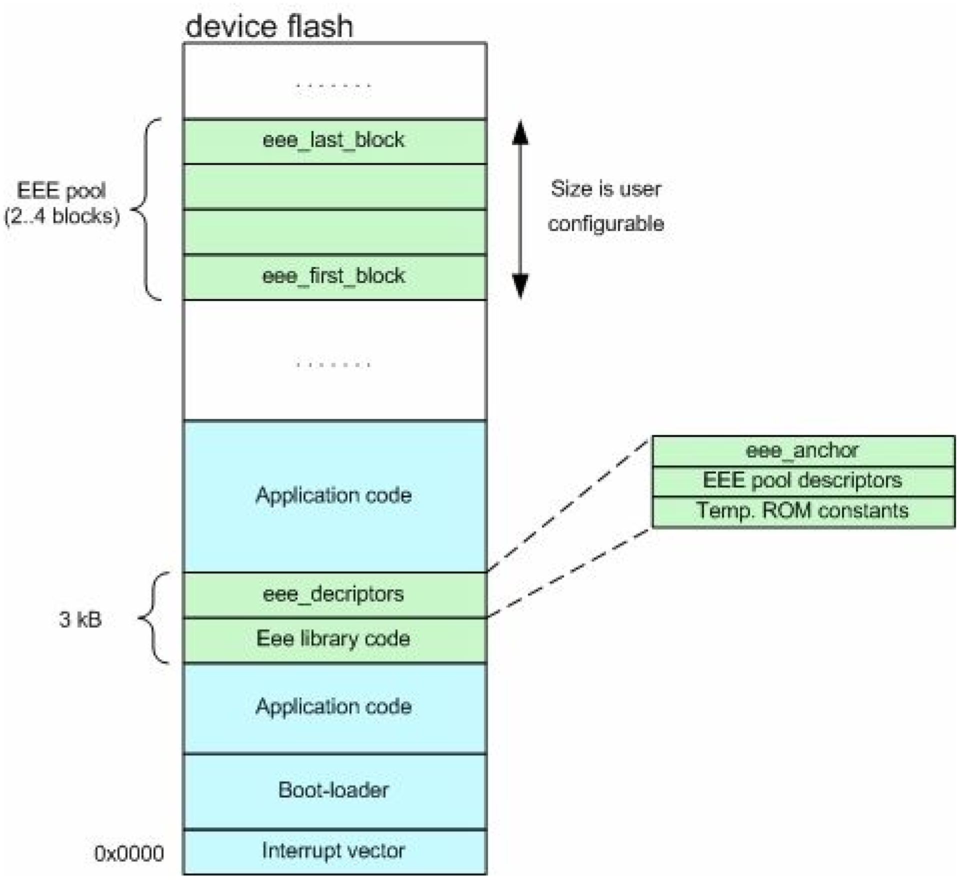


Figure 2-5 physical placement inside device flash memory

2.2.4 EEL anchor

The ROM constant **eel_anchor[...]** contains the description of all variables the EEL driver can handle. It reserves unique identifier code for each EEL variable and defines its size expressed in bytes and flash-words. Other identifier than defined in **eel_anchor[]** cannot be used. Zero flash-word has to terminate the array **eel_anchor[...]**

The **eel_anchor[var_no+1][4]** is a two dimensional array of bytes. Both dimensions are defined automatically without user intervention. The only configurable parameter influencing the dimension is the constant **EEL_VAR_NO**. Each element of **eel_anchor[N]** is a complete EEL variable descriptor consisting of 4 bytes:

eel_anchor[N][0] EEL variable identifier (unique inside the eel_anchor). Valid range 0x01…0xFE (253 identifiers possible).

eel_anchor[N][1] EEL variable size expressed in flash word units. Valid range 0x01…0x40 (1..64 words possible).

eel_anchor[N][2] EEL variable size expressed in flash byte units (1…254) Valid range 0x01…0xFF (1..255 bytes possible).

eel_anchor[N][3] 0x00, limiter

eel_anchor[5][4]

id_1	wsize_1	bsize_1	0x00
id_2	wsize_2	bsize_2	0x00
id_3	wsize_3	bsize_3	0x00
id_4	wsize_4	bsize_4	0x00
0x00	0x00	0x00	0x00

Figure 2-6 EEL anchor structure (example).

2.2.5 EEL pool

the EEL_pool is a flash area consists of 2-4 subsequent flash blocks where the EEL instances are stored. The flash blocks of the EEL-pool are organized like a ring where the “activated” status is passed to the next higher block by the refresh command (for details refer to the command description). When the last block is reached, the 1’st one becomes the “activated” one after “refresh”. To have at least one redundant block in spare that can be excluded in case of flash problems the recommended min. pool-size is 3 blocks. When no active block can be found by StartUp command the complete EEL_POOL has to be formatted by using the "format" command. All data are lost in that case.

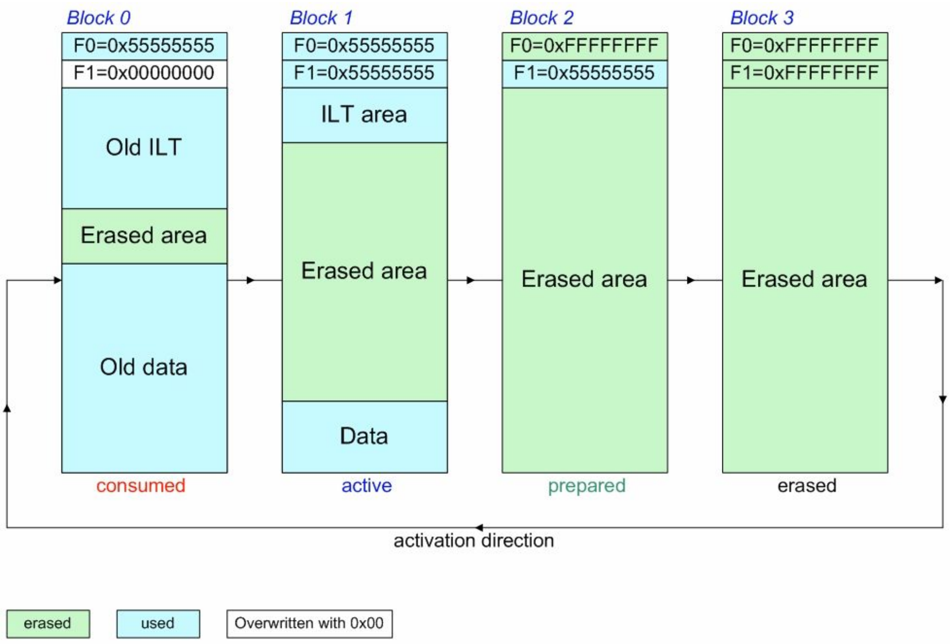


Figure 2-7 EEL pool

2.2.6 EEL block

Each of the flash blocks belonging to the EEL_POOL is structured in the same wise. On the top two flash words are used as block status flags followed by the erase counter. Underlying the instance lookup table is used for stacking the instance references from the top to the bottom. At the bottom of the active block the referenced instances are stacked in the opposed direction. Both zones are running contrary to meet somewhere in the middle of the block. At least one "erased" flash word called separator has to isolate both zones. In case the separator is not available in the active block, the complete EEL_POOL hast to be formatted by using the "format" command. All data are lost in that case.

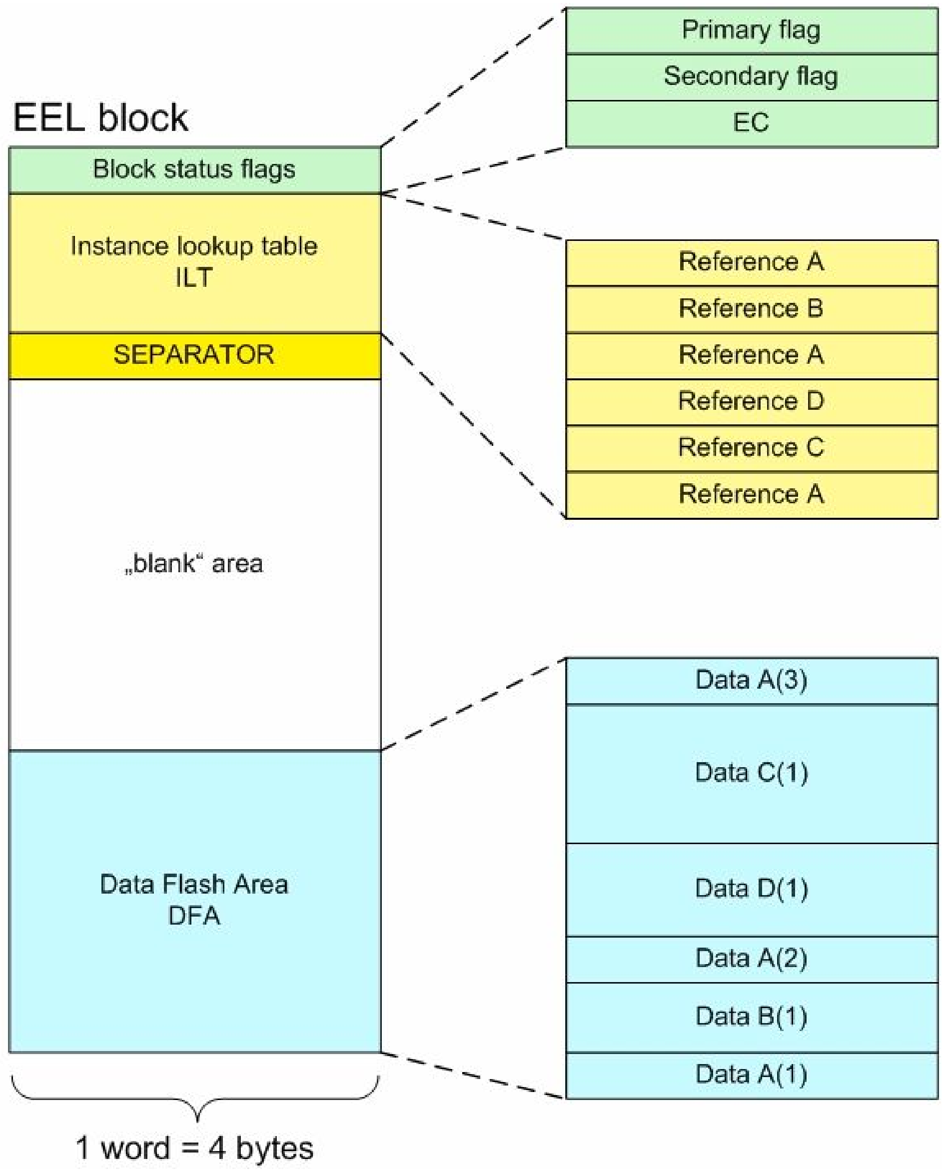


Figure 2-8 Typical structure of an EEL block

2.2.7 EEL reference table

The EEL reference table is a simple RAM vector defined in **eel.c**.
The number of EEL variables managed by the driver hast to be configured in the header-file **eel.h**

```
eel_u08 eel_reference[EEL_VAR_NO];
```

The read-pointer of each EEL variables is saved there to accelerate read access and makes the read access time independent of fill status of the active block. Linear search of the youngest instances is not necessary anymore. The reference table is initialized during startup command and updated in each write access. A refresh command is modifying the reference table to. Analogical, the separator word-index is used as a write pointer inside the active block to provide constant write access time. The separator widx is not visible to the user.

The reference table is automatically defined in **eel_user.c**. The user does not need to take care of the right dimension.

2.2.8 EEL instance lookup table

The **I**nstance **L**ookup **T**able (ILT) is located at the begin of the active block and realizes two main purposes:

- connection between the EEL variable identifier (identifier field) and its written instance (widx field)
- detection of problems caused by unexpected disturbance like asynchronous power on RESET, power supply voltage drop or others.

ILT

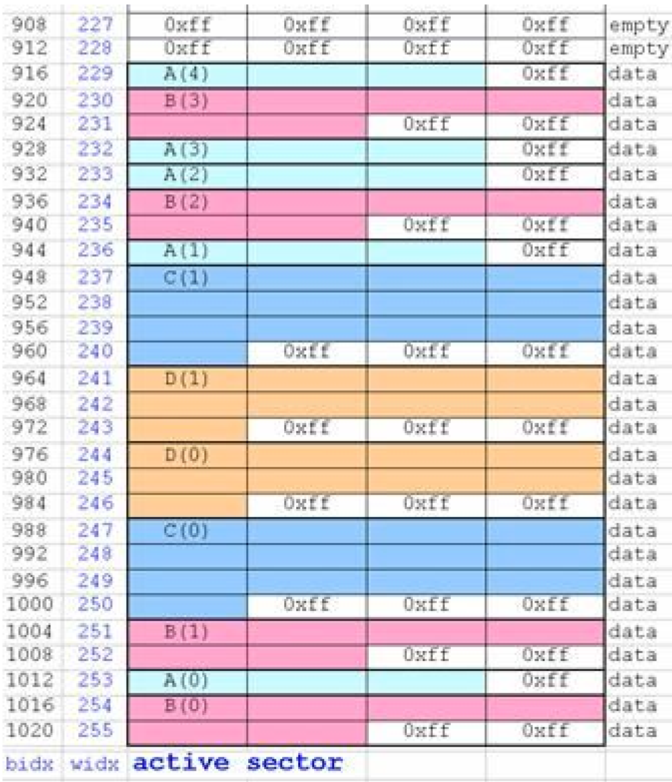
bidx	widx	byte 0	byte 1	byte 2	byte 3	
0	0		primary	flag		flag 0
4	1		secondary	flag		flag 1
8	2	EC(low)	EC(mid)	csum	EC(high)	erase cnt
12	3	widx	wsize	CSUM	B(0)	ref
16	4	widx	wsize	CSUM	A(0)	ref
20	5	widx	wsize	CSUM	B(1)	ref
24	6	widx	wsize	CSUM	C(0)	ref
28	7	widx	wsize	CSUM	D(0)	ref
32	8	widx	wsize	CSUM	D(1)	ref
36	9	widx	wsize	CSUM	C(1)	ref
40	10	widx	wsize	CSUM	A(1)	ref
44	11	widx	wsize	CSUM	B(2)	ref
48	12	widx	wsize	CSUM	A(2)	ref
52	13	widx	wsize	CSUM	A(3)	ref
56	14	widx	wsize	CSUM	B(3)	ref
60	15	widx	wsize	CSUM	A(4)	ref
64	16	0xff	0xff	0xff	0xff	SEP
68	17	0xff	0xff	0xff	0xff	empty
72	18	0xff	0xff	0xff	0xff	empty
76	19	0xff	0xff	0xff	0xff	empty

Figure 2-9 Instance lookup table (ILT) structure

Note Each write access is divided into two separated phases. In the first one the reference is written into the ILT to allocate the needed space inside the data flash area (DFA). In the second one the actual data of the written instance are written into the DFA.

2.2.9 EEL data flash area

The Data Flash Area (DFA) is located at the end of the active block and contains the pure data of the written instances only. The DFA is growing downstairs from higher addresses to lower addresses inside the active block.



908	227	0xff	0xff	0xff	0xff	empty
912	228	0xff	0xff	0xff	0xff	empty
916	229	A(4)			0xff	data
920	230	B(3)				data
924	231			0xff	0xff	data
928	232	A(3)			0xff	data
932	233	A(2)			0xff	data
936	234	B(2)				data
940	235			0xff	0xff	data
944	236	A(1)			0xff	data
948	237	C(1)				data
952	238					data
956	239					data
960	240		0xff	0xff	0xff	data
964	241	D(1)				data
968	242					data
972	243		0xff	0xff	0xff	data
976	244	D(0)				data
980	245					data
984	246		0xff	0xff	0xff	data
988	247	C(0)				data
992	248					data
996	249					data
1000	250		0xff	0xff	0xff	data
1004	251	B(1)				data
1008	252			0xff	0xff	data
1012	253	A(0)			0xff	data
1016	254	B(0)				data
1020	255			0xff	0xff	data
bidx	widx	active sector				

Figure 2-10 Data flash area (DFA) structure

Note The content of unused bytes inside the instance data is undefined.

Chapter 3 Application Programming Interface

The application programmer interface is completely defined in the header file **eel.h** It contains all necessary constant, type definitions as well all function prototypes interfacing the functionality of the EEL driver. The interface definition is fully C-compatible even though the implementation is done in assembler.

3.1 Constant definitions

All constants used for the EEL driver operation are available in form of enumeration types defined in eel.h. The meaning of all particular enumeration codes is described in the following chapter "Data type definitions".

3.2 Data type definitions

All data types used by the EEL driver are defined in the eel.h header file.

Table 3-1 overview of predefined data types

data type	description
eel_block_status_t	enumeration type for coding the status of each EEL pool block
eel_command_t	enumeration type for coding the available commands
eel_status_t	enumeration type for coding the driver and request status
eel_error_t	enumeration type coding all possible errors
eel_request_t	structure type for definition of EEL request variables

3.2.1 Block status type

Each block of the EEL_POOL contains two 32-bit status flags F0 and F1 on its top. Both flags are coding all the block conditions can appear during EEPROM emulation. The data type **eel_block_status_t** reflects all relevant combination of both status flags.

Table 3-2 EEL block status code

block flag pattern	block status code	comment
F0=0xFFFFFFFF F1=0xFFFFFFFF	EEL_BLK_ERASED	status of a virgin erased block, means “block can be prepared”
F0=0xFFFFFFFF F1=0x555555555	EEL_BLK_PREPARED	block status after "prepare" or "format", means “block can be activated”
F0=0x55555555 F1=0x55555555	EEL_BLK_ACTIVATED	status of EEL block being “in use”, contains actual data
F0=0x55555555 F1=0x00000000	EEL_BLK_CONSUMED	block filled up with old instances, means “block can be prepared”
F0=0x00000000 F1=0x00000000	EEL_BLK_EXCLUDED	after problems the block was excluded by the application
other pattern than above	EEL_BLK_INVALID	unknown status, means "block has to be repaired"
blocks outside EEL pool	EEL_BLK_UNDEFINED	the specified block does not belong to the EEL pool area

Caution:

The block status reflects only the interpretation of both status flags F0 and F1. Power-on RESET during execution time of the erase command can produce scenarios where even though both flags are indicating the “erased” status, some words inside are not erased correctly. The only one way to ensure, that the status flags express the real physical status of the blocks is the positive termination of the StartUp command.

3.2.2 Command code type

All commands provided by the EEL driver are represented by the enumeration type **eel_command_t**.

Table 3-3 EEL command code

Command code	Comment
EEL_CMD_STARTUP	Electrical and logical plausibility checks of all blocks belonging to the EEL pool
EEL_CMD_WRITE	Writes the actual data of an EEL-variable from its mirror variable (RAM) into the active block of the EEL pool. Creates a new instance of the EEL-variable.
EEL_CMD_READ	the data of the youngest instance of the specified EEL-variable are copied into its mirror-variable (RAM)
EEL_CMD_REFRESH	Copies the lates instances of all registered EEL variables into the next "fresh" block.
EEL_CMD_FORMAT	Create a virgin EEL-pool, all instances of EEL-variables are lost
EEL_CMD_PREPARE	the next “non-prepared” and “non-active” block is erased and marked as “prepared”
EEL_CMD_REPAIR	Erase and mark as “prepared” the specified block
EEL_CMD_EXCLUDE	Excludes the specified block from pool EEL management.
EEL_CMD_SHUTDOWN	Verifies the active block to ensure the data retention of the data inside. Disables read- and write-access.

3.2.3 Status type

The predefined type **eel_status_t** ca be used for two different purposes. The first one is to indicate the status of the EEL request serviced by the driver. The other one meaning is to represent the internal status of the EEL driver themselves.

Table 3-4 request and driver status codes

status code	related to	Comment
EEL_STS_READY	request	the related request was finished successfully
	driver	the driver is ready to accept any EEL request
EEL_STS_ACTIVE	request	driver is processing a request in background mode
	driver	the driver is processing any request
EEL_STS_ABORTED	request	the request is not finished due to any problems
	driver	not relevant

Use cases:

1. The request-status can be used by the application (the requesting task) for checking the status of its own request (polling mode).
2. The EEL driver-status can be used by the application to check the availability of the EEL driver in advance.
3. Before entering the standby mode the application can check whether any EEL request is pending and can wait active until it’s finished.

Note: The function EEL_CheckDriverStatus() can be used for 2) and 3).

3.2.4 Error type

All error codes supported by the driver during execution of EEL requests are collected in the predefined enumeration type **eel_error_t**. In case of problems the application can analyze the error-code to identify the reason.

Table 3-5 EEL error code

Error code	meaning
EEL_OK	no error occurred during command execution
EEL_ERR_PARAMETER 1)	parameter error **(FSL)**2)
EEL_ERR_PROTECTION	protection error **(FSL)**2)
EEL_ERR_ERASE	flash block could not been erased **(FSL)**2)
EEL_ERR_VERIFY	data couldn't be verified **(FSL)**2)
EEL_ERR_WRITE	data could not been written into flash **(FSL)**2)
EEL_ERR_EEPWRITE_VERIFY	verify error during writing into flash **(FSL)**2)
EEL_ERR_EEPWRITE_BLANK	area not blank, data remain untouched **(FSL)**2)
EEL_ERR_INTERRUPTED	self-programming interrupted **(FSL)**2)
EEL_ERR_DRIVER_BUSY	the driver is currently busy with an other request
EEL_ERR_STARTUP_MISSING	read/write access is disabled as long **"startup"** isn't executed successfully
EEL_ERR_POOL_CONSUMED	no "prepared" block available for "refresh" execution
EEL_ERR_BLOCK_CONSUMED	no space for the instance in the active block
EEL_ERR_FLMD0_LOW	FLMD0 signal error
EEL_ERR_TWO_ACTIVE_BLOCKS	startup found two EEL blocks marked as **"active"**
EEL_ERR_BLOCK_NOT_EMPTY	any "prepared" block contains undefined data.
EEL_ERR_BLOCK_INVALIDE	EEL block status flags couldn't been interpreted
EEL_ERR_INSTANCE_UNKNOWN	specified EEL variable was never written
EEL_ERR_VARIABLE_CHECKSUM	checksum of the read instance does not match
EEL_ERR_NO_ACTIVE_BLOCK	startup could not recognize any **"active"** block
EEL_ERR_SEPARATOR_LOST	ILT and DFA not separated anymore
EEL_ERR_POOL_EXHAUSTED	less than two "healthy" blocks inside the EEL-pool
EEL_ERR_COMMAND_UNKNOWN	invalid command code detected
EEL_ERR_POOL_SIZE	invalid EEL pool configuration
EEL_ERR_VARIABLE_UNKNOWN	variable identifier not registered in eel_anchor[]
EEL_ERR_PROTECTED_BLOCK	block protected against **"repair"** or **"exclude"**

Note 1)
this error can happen when any of the EEL RAM mirror variables is located in the short-address area 0xFE20…0xFE83. The reason is, that this RAM area cannot be used by the firmware as a data-buffer. To reduce the RAM consumption and CPU time the EEL driver is using the EEL RAM mirror variables directly as data-buffer. Other user variables can be located in area 0xFE20…0xFE83 without restrictions.

Note 2)
Error generated by the Flash Selfprogramming Library converted (FSL error code + 0x80) and passed directly to EEL.

3.2.5 Request type

Using the predefined request type the application can create request variables and use it for communication and synchronization purpose with the EEL driver. Status of the request can be polled and error code can be analyzed in case of any problems. It's practically the central point of interaction between the application and the EEL driver. The request data type is predefined in eel.h

```
 // EEL request type (base type for any EEL access)
typedef struct
        {
          eel_u08*        address;    // 2, source/destination address
          eel_u08         identifier; // 1, identifier (variable/block)
          eel_command_t   command;    // 1, command has to be processed
          eel_status_t    status;     // 1, status during/after execution
          eel_error_t     error;      // 1, error after command execution
        } eel_request_t;              // -------------------------------
                                      // 6 bytes in total
```

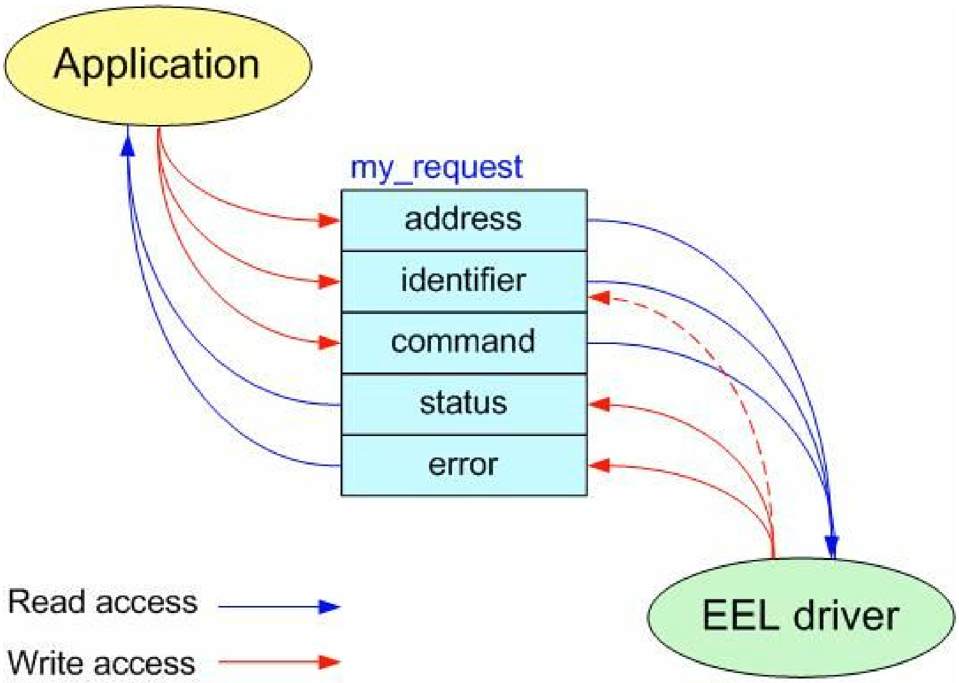


Figure 3-1 request variable synchronizing EEL and the application

Variables of that type can be used as a kind of common area where the application and the EEL driver can exchange information. The application formulates the request (command) and initiates the execution. The driver is returning the request-status and error-code. The parameter-less commands like **"startup"** or **"prepare"** can return the related block number in identifier-field when problems occur.

3.3 Function prototypes

The functions offered by the EEL API are divided in operative and administrative. Operative functions are responsible for the pure request registration and request execution. Administrative functions can be used by the application to examine the status of some internal EEL parameters. Based on that information the application can always act and react in suitable and reasonable wise depending on its own context.

Table 3-6 EEL function overview

functions		
operative	**administrative**	**description**
EEL_Init()		driver initialization
EEL_Enforce(…)		request and execution in standalone applications
EEL_Execute(…)		request in real-time applications
EEL_Handler()		execution in real-time applications
	EEL_CheckDriverStatus()	returns the current EEL driver status
	EEL_GetPool()	returns the number of “prepared” blocks
	EEL_GetSpace()	returns the number of free words inside the active block
	EEL_GetBlockStatus(...)	returns the status of the specified block
	EEL_GetActiveBlock()	returns the number of the "active" block
	EEL_GetNextBlock()	returns the number of the subsequent, "non-excluded" block to the "active" one
	EEL_GetPrevBlock()	returns the number of the previous, "non-excluded" block to the "active" one

3.3.1 EEL_Init()

This parameter less function should be used during power-on initialization of the device. All internal EEL variables are initialized but the driver remains inactive.

3.3.2 EEL_Enforce(my_request)

This function can be used to execute any EEL command in so called “enforced" mode. This way of command execution is designed to support standalone applications. Such an application can call EEL_Enforce() to execute specified command and waits at the calling position until the command execution is completed. From the application point of view it works like a simple call, but it takes much “longer” time. During the command execution in “enforced" mode all enabled interrupts will be serviced with a delay specific for the self-programming commands used inside the EEL command.

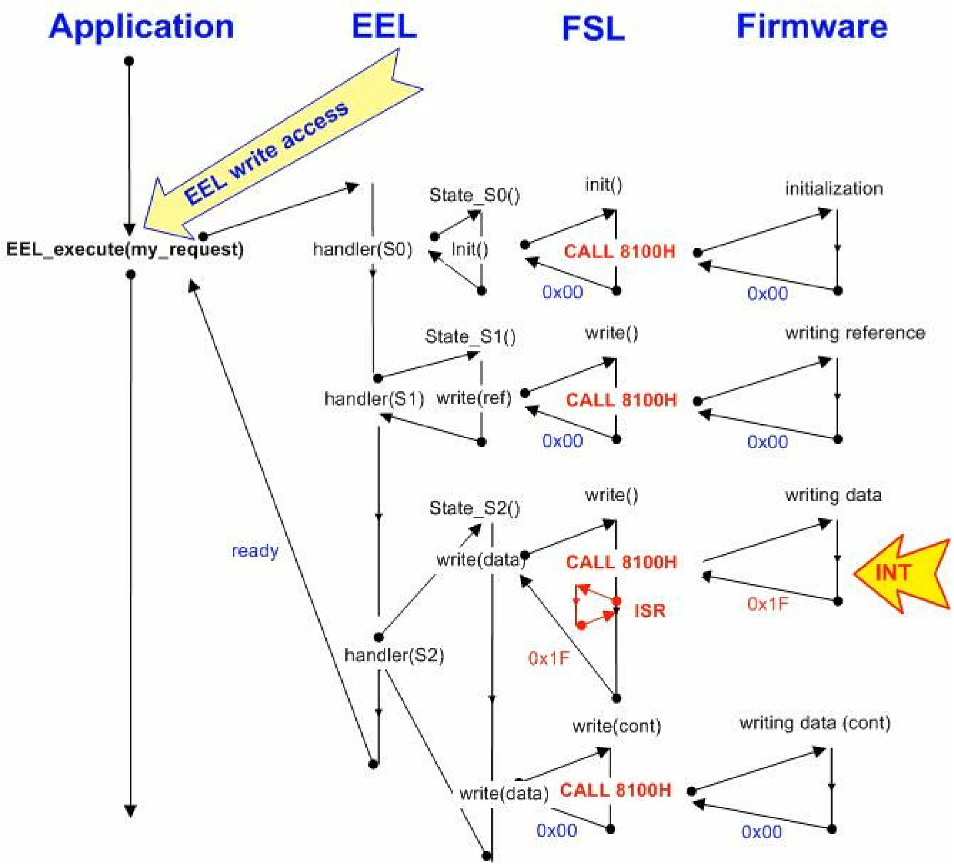


Figure 3-2 Typical flow of an interrupted EEL command in “enforced" mode

Code example:

```
// "StartUp" commad request
 my_eel_request.command = EEL_CMD_STARTUP;
 EEL_Enforce(&my_eel_request);
 if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
```

3.3.3 EEL_Execute(my_request)

This function can be used to execute any EEL command in so called “background" mode. This way of command execution is designed to support real-time multitasking applications. Such applications reserve a time slice for the EEL task (process) and calls periodically EEL_Execute() to execute specified command in predetermined time pieces until the command execution is completed. The application can check the status of its own EEL request by polling the variable my_request.status. In between the time slices the application reclaims the fully control about the CPU and can manage time critical tasks, like watchdog reset or readout and release of communication-buffer. During the command execution in “background mode” all enabled interrupts will be serviced with a delay specific for the self-programming commands used inside the EEL command.

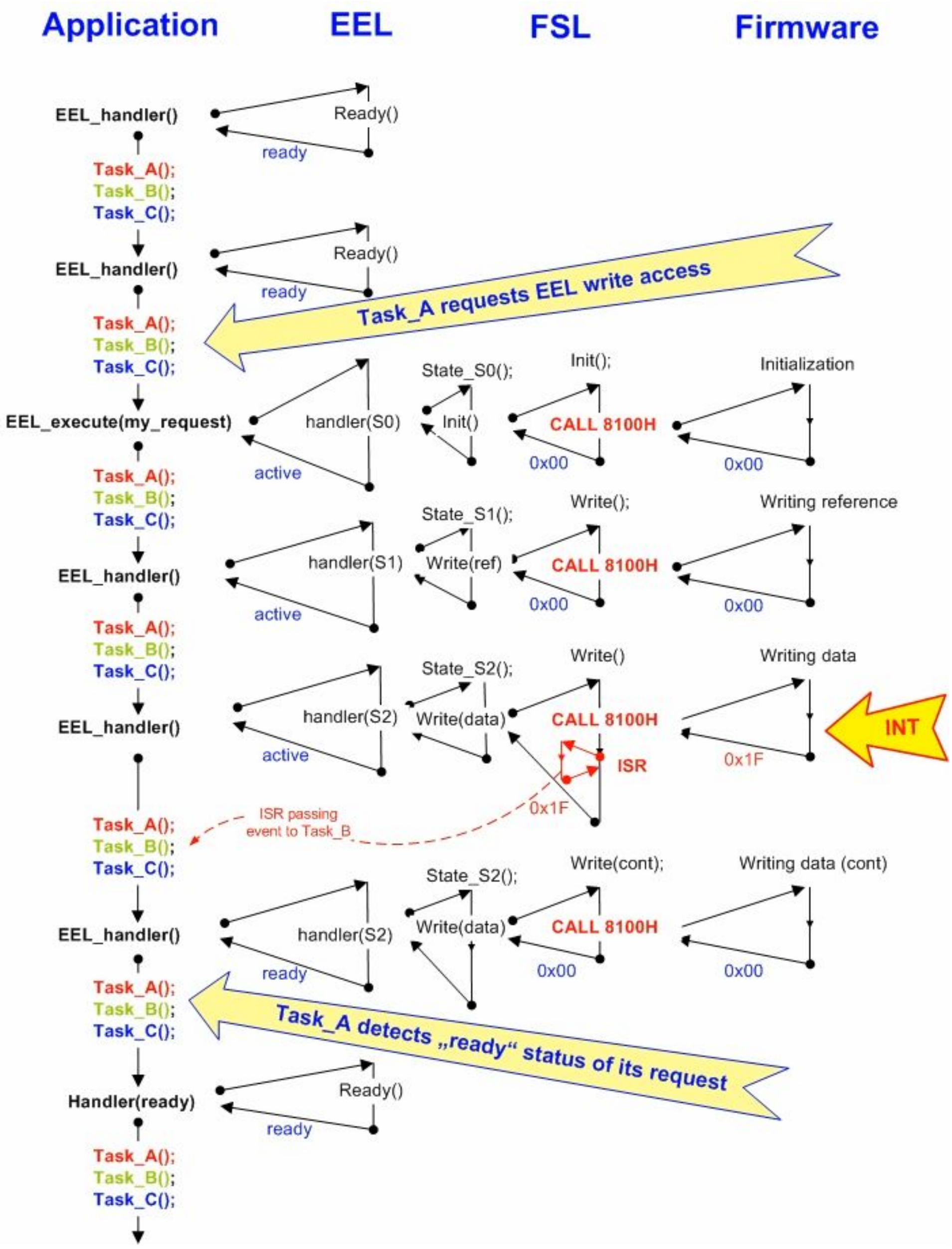


Figure 3-3 Typical flow of EEL command execution in “background mode”

Code example:

```
"StartUp" commad request
 my_eel_request.command = EEL_CMD_STARTUP;
 EEL_Execute(&my_eel_request);
 my_state = default_state;
 if (my_eel_request.status == EEL_STS_ABORTED)  my_state = error_state;
 if (my_eel_request.status == EEL_STS_ACTIVE)   my_state = polling_state;
```

3.3.4 EEL_Handler()

This function can be used to execute EEL command time-slice by time-slice in so called “background " mode. Typically, it should be called in the scheduler loop to share the CPU time with other processes. Theoretically the EEL_Handler() can also be called in a waiting-loop, but better to use EEL_Enforce() directly for such purpose. Have a look to the listing below that illustrates the typical use-case for the EEL handler.

Code examples:

```
1)
// ----------------------------------------------
// OS scheduler's idle loop (cooperative system)
// ----------------------------------------------
do {
    EEL_Handler();
    if (task_A.tcb.status==active) (*task_A.tcb.state)();
    if (task_B.tcb.status==active) (*task_B.tcb.state)();
    if (task_C.tcb.status==active) (*task_C.tcb.state)();
    if (task_D.tcb.status==active) (*task_D.tcb.state)();
} while (true);
```

```
2)
// --------------------------
// possible, but not preferable
// --------------------------
my_eel_request.command = EEL_CMD_STARTUP;
EEL_Execute(&my_eel_request);
while (my_eel_request.status) == EEL_STS_ACTIVE
{
  EEL_Handler();
}
if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
```

3.3.5 EEL_CheckDriverStatus()

This function can be used to check the internal status of the EEL driver in advance before placing the EEL request. Also other administrative functions requiring "ready" status can use **EEL_CheckDriverStatus()** to check it.

The result returned by EEL_CheckDriverStatus() is:

- EEL_STS_READY – when he EEL driver is ready to accept a new request.
- EEL_STS_ACTIVE – when the EEL driver is processing an other request in “background mode”

Note The status returned by this function cannot be “EEL_STS_ABORTED”. This value is reserved for request status only.

Code examples:

```
1) check in advance if request acceptable
// -------------------------------------
if (EEL_CheckDriverStatus()==EEL_STS_READY)
{
  my_eel_request.command = EEL_CMD_PREPARE;
  EEL_Execute(&my_eel_request);
  if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
};
```

```
2) check if driver "passive" before reading its parameter
// ----------------------------------------------------
if (EEL_CheckDriverStatus()==EEL_STS_READY)
    my_eel_space = EEL_GetSpace();
```

3.3.6 EEL_GetPool()

This function provides the number of “prepared” coherent blocks inside the EEL pool. The application can use it to check the stock of prepared blocks in advance at most convenient time.

Code example:

```
if (EEL_CheckDriverStatus()==EEL_STS_READY) my_eel_pool = EEL_GetPool();
```

3.3.7 EEL_GetSpace()

This function provides the “free” space inside the active block. The application can use it to check if the available space is sufficient for the incoming write access, but it has to take care, that the driver is not “busy” at that time. The returned value represents the erased space inside the active block expressed in flash words (4 bytes)

Code example:

```
if (EEL_CheckDriverStatus()==EEL_STS_READY)
my_eel_space = EEL_GetSpace();
```

3.3.8 EEL_GetBlockStatus(my_block_u08)

This function provides the status of the specified EEL block. It can be useful for reparation purpose when the application has to distinguish between active and other block.

Code example:

```
if (EEL_CheckDriverStatus()==EEL_STS_READY)
{
    if (EEL_GetBlockStatus()==EEL_BLK_ACTIVATED)
        my_request.command = EEL_CMD_REFRESH;
    else
        my_request.command = EEL_CMD_PREPARE;
}

EEL_Enforce(&my_eel_request);
if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
```

3.3.9 EEL_GetActiveBlock()

This function provides the number of currently "active" block. It can be useful for reparation purpose.

Code example:

```
if (EEL_CheckDriverStatus()==EEL_STS_READY)
      my_active_block = EEL_GetActiveBlock();
```

3.3.10 EEL_GetNextBlock()

This function provides the number of next block to the currently "active" one. Blocks marked as "excluded" are ignored. It can be useful for reparation purpose.

Code example:

```
if (EEL_CheckDriverStatus()==EEL_STS_READY)
    my_active_block = EEL_GetNextBlock();
```

3.3.11 EEL_GetPrevBlock()

This function provides the number of previous block to the currently "active" one. Blocks marked as "excluded" are ignored. It can be useful for reparation purpose.

Code example:

```
if (EEL_CheckDriverStatus()==EEL_STS_READY)
    my_active_block = EEL_GetPrevBlock();
```

Chapter 4 Commands

The available command codes are defined in the enumeration type **eel_command_t**. The EEL commands can be divided into two groups: operative (necessary for access to the virtual EEPROM) and administrative (used for administrative measures necessary for smooth and secure driver operation).

Table 4-1 EEL command overview

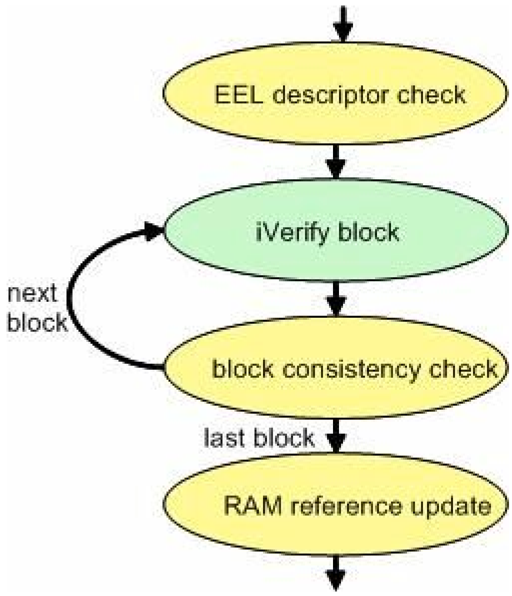
commands		
operative	**administrative**	**short description**
	EEL_CMD_STARTUP	plausibility check of the EEL, unlocks access to EEL
EEL_CMD_WRITE		write access to virtual EEPROM memory
EEL_CMD_READ		read access to virtual EEPROM memory
	EEL_CMD_PREPARE	formats of one additional (subsequent) block
	EEL_CMD_REFRESH	copy all recent instances into a fresh block
	EEL_CMD_REPAIR	formats of one dedicated block
	EEL_CMD_FORMAT	formats the complete EEL pool (all blocks), data are lost
	EEL_CMD_EXCLUDE	excludes one block from EEL pool management
	EEL_CMD_SHUTDOWN	electrical check of the active EEL block, locks the access to EEL

4.1 startup

The StartUp command is checking the plausibility and consistency of the EEL pool. This is the first command has to be executed before read- and write-access to the EEL is possible at all. Before the structure of each block can be analyzed logically, the electrical status of the information stored in the flash is checked by the self-programming command “verify”. After that the status of each block and its logical block structure can be analyzed. Finally the reference table (all EEL variable read pointer) and the separator-index (EEL write pointer) are initialized to achieve fast and constant read/write access time.

State sequence of the startup command:

1. plausibility check of EEL configuration data (descriptors in eel_user.c)
2. electrical verification of each block of the EEL pool
3. structure and status of the EEL pool
4. status and structure of each block

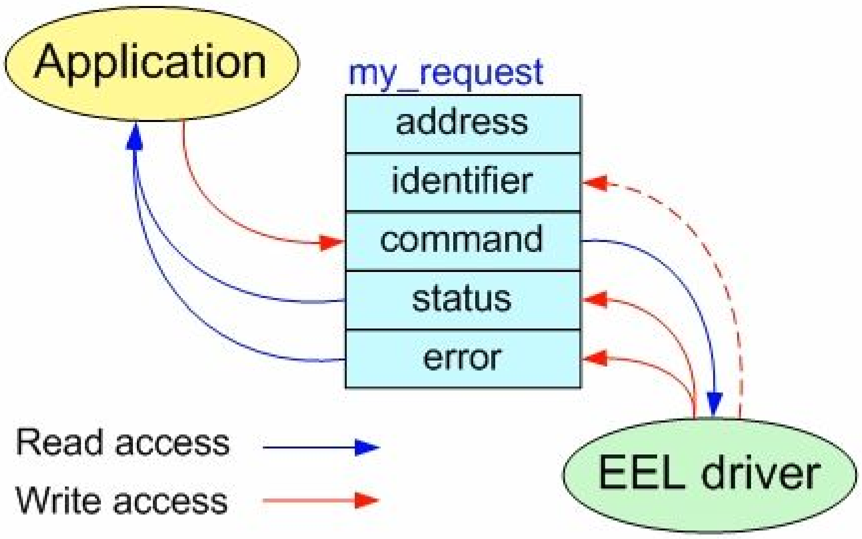


Self-programming commands used by startup

- FSL_IVerify(my_block_u08)

Startup request and feedback

To initiate the startup command the application has to specify the command code only. Any problems during startup execution time will be signaled in the request variable via its status and error members. In case of block related problems, the number of the affected block can be found in the identifier field. The application (its central error handler) has to take care for reparation. After that the startup command has to be executed again.



Code example:

```
 // "StartUp" commad request
my_eel_request.command = EEL_CMD_STARTUP;
EEL_Enforce(&my_eel_request);
if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
```

Startup error handling

Whenever problems are detected during "startup"-command execution, the request status is modified by the EEL driver to "EEL_STS_ABORTED". In such a case the application has to analyze the error code and initiate appropriate reparation. The possible error codes with corresponding reparation rules can be found below:

Table 4-2 Startup error code

startup error codes	class	error background and handling	
EEL_ERR_DRIVER_BUSY	normal	meaning	driver is already “busy” with another request
		reason	another task already initiated its own request
		remedy	**wait** until driver-status is “ready” and retry
EEL_ERR_COMMAND_UNKNOWN	initial	meaning	undefined command code detected
		reason	propably wrong command code used by the user
		remedy	check source code, correct the command code and re-compile the project.
EEL_ERR_BLOCK_INVALIDE	middle	meaning	block status flags F0/F1 could not be interpreted
		reason	probably RESET during writing F0/F1
		remedy	execute **“repair”** command and **“startup”** again.
EEL_ERR_BLOCK_NOT_EMPTY	middle	meaning	A “prepared” block is not “erased” anymore.
		reason	probably RESET during “refresh” command
		remedy	execute **“repair”** command and **“startup”** again.
EEL_ERR_VERIFY	middle	meaning	the level of some data dropped below the verify level
		reason	RESET during writing into flash, data retention
		remedy	1) affected block is the “active”–> execute **“refresh”**
			2) affected block is not “active” -> execute **“repair”**
EEL_ERR_TWO_ACTIVE_BLOCKS	middle	meaning	there are two “active” blocks detected in the EEL pool
		reason	RESET during execution of “refresh” command
		remedy	execute **“repair”** command and **“startup”** again.
EEL_ERR_SEPARATOR_LOST	heavy	meaning	ILT and DFA not separated anymore
		reason	EMI, malfunction, flash problems
		remedy	execute **“format”** , all data are lost
EEL_ERR_NO_ACTIVE_BLOCK	heavy	meaning	no “active” block detected during startup
		reason	possibly EMI, malfunction, flash problems
		remedy	execute **“format”**, all data are lost
EEL_ERR_POOL_EXHAUSTED	fatal	meaning	EEL pool consists of less than two “healthy” blocks
		reason	flash endurance exceeded
		remedy	none

4.2 write

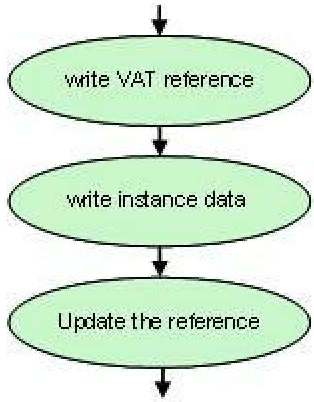
The write command is writing a data-set of a registered EEL variable from its RAM-mirror into the virtual EEPROM memory. The application has to specify the identifier and the starting address of the RAM-mirror variable before initiating the command execution.

Caution:

The EEL RAM mirror variables shouldn't be located in the short-address area 0xFE20…0xFE83 because this area cannot be used by the firmware as a data-buffer. To reduce the RAM consumption of the driver the EEL RAM variables are used directly as a kind of "temporary data-buffer" during the write command. Other user variables can be located in area 0xFE20…0xFE83.

State sequence of the write command:

1. allocating the space for the data by writing the new reference into the ILT
2. writing the new data set into the allocated space inside the DFA
3. actualize the corresponding EEL variable reference inside the **eel_reference[…]**

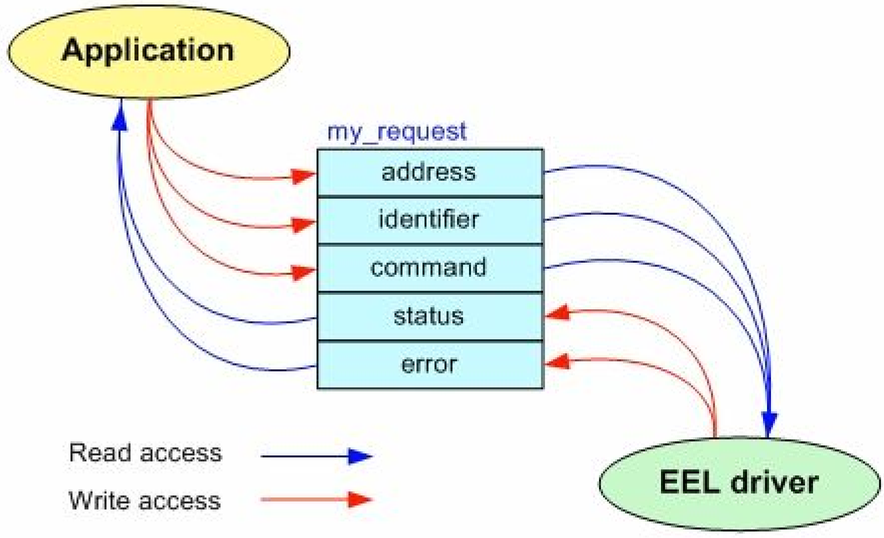


Self-programming commands used by write command

- FSL_EEPROMWrite(my_addr_u32, my_wordcount_u08)

Write request and feedback

The application has to specify the EEL variable identifier of and the starting address of the RAM-mirror variable.



Code example:

```
// "Write" commad request
my_eel_request.command    = EEL_CMD_WRITE;
my_eel_request.identifer = 'A';
my_eel_request.address    = (eel_u08*)&A[0];
EEL_Enforce(&my_eel_request);
if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
```

Write error handling

Whenever problems are detected during "write"-command execution, the request status is modified by the EEL driver to EEL_STS_ABORTED. In such a case the application can analyze the error code and react to properly to that exception. The possible error codes with recommended reparation rules can be found below:

Table 4-3 Write command error handling

write error codes	class	error background and handling	
EEL_ERR_DRIVER_BUSY	normal	meaning	driver is already “busy” with a request
		reason	another task initiated its own request
		remedy	**wait** until driver-status is “ready” and retry
EEL_ERR_STARTUP_MISSING	normal	meaning	write access is not yet enabled
		reason	“startup” command wasn’t successful till now
		remedy	execute **“startup”** and **“write”** again
EEL_ERR_BLOCK_CONSUMED	normal	meaning	the active block is full
		reason	size of the EEL variable exceeds the available space
		remedy	execute the **“refresh”** command and **“write”** again
EEL_ERR_VARIABLE_UNKNOWN	initial	meaning	specified EEL variable unknown by the EEL driver
		reason	used identifier is not registered in eel_anchor[]
		remedy	**register** variable in eel_anchor[], re-compile the project
EEL_ERR_FLMD0_LOW	unlikely	meaning	FLMD0 signal error
		reason	FLMD0 signal remains LOW during self-programming
		remedy	**check** FLMD0 hardware and software
EEL_ERR_EEPWRITE_BLANK	heavy	meaning	the destination flash area in not erased enymore
		reason	possibly EMI, malfunction, flash problems
		remedy	execute the **“refresh”** command and **“write”** again
EEL_ERR_EEPWRITE_VERIFY	heavy	meaning	the written data could not be verified electrically
		reason	power, EMI or flash problem
		remedy	retry write up to 3 times, if not successful: execute **“refresh”** and **“exclude”** the previous block and **"write"** again
EEL_ERR_WRITE	heavy	meaning	the data could not be written correctly into flash
		reason	power, EMI or flash problem
		remedy	retry write up to 3 times, if not successful: execute **“refresh”** and **“exclude”** the previous block and **"write"** again
EEL_ERR_NO_ACTIVE_BLOCK	heavy	meaning	no “active” block found
		reason	possibly EMI, malfunction
		remedy	execute **“format”** command, all data are lost

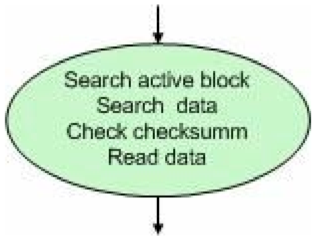
4.3 read

The read command can be used to read the youngest written data-set from the virtual EEPROM memory into the specified RAM-mirror variable. Beside the command-code, the application has to specify the identifier of the EEL-variable and the starting address of the RAM-mirror variable.

State sequence of the read command:

The read command returns immediately the result of the read-access, independent whether "background" or "enforced" mode was used for the execution. The actual data-set is copied immediately from flash into the RAM mirror variable.

1. search active block
2. search the actual instance
3. check the checksum
4. copy data of the instance into RAM mirror variable

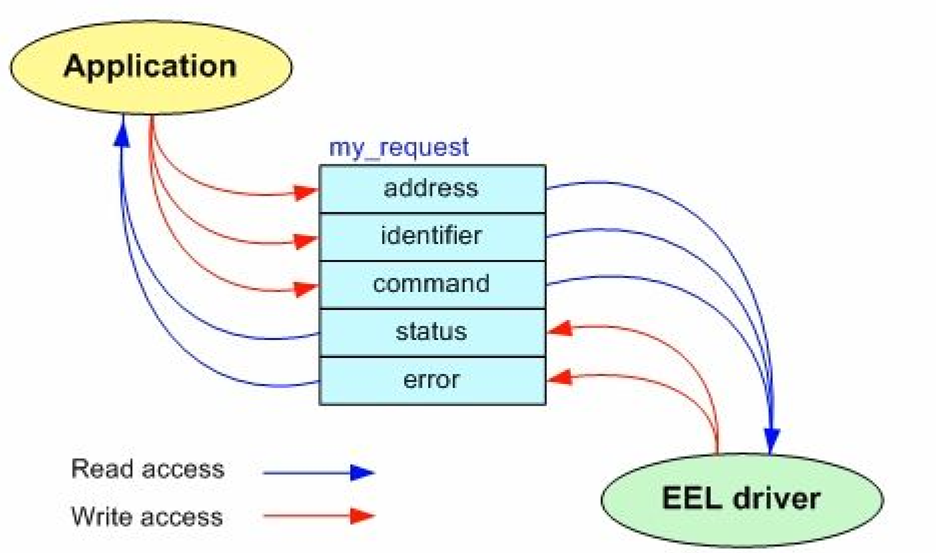


Self-programming commands used by read command

- none FSL function is used

Read request and feedback

The application has to specify the EEL variable identifier and the starting address of the RAM-mirror variable.



Code example:

```
// "Read" commad request
 my_eel_request.command   = EEL_CMD_READ;
 my_eel_request.identifer = 'A';
 my_eel_request.address   = (eel_u08*)&A[0];
 EEL_Enforce(&my_eel_request);
 if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
```

Read error handling

Whenever problems are detected during "read"-command execution, the request status is modified by the EEL driver to EEL_STS_ABORTED. In such a case the application can analyze the error code and react properly to that exception. The possible error codes with corresponding reparation rules can be found below:

Table 4-4 Read error handling

read error code	class	error background and handling	
EEL_ERR_DRIVER_BUSY	normal	meaning	driver is already "busy" with another request
		reason	another task initiated its own request
		remedy	**wait** until driver-status is "ready" and retry
EEL_ERR_STARTUP_MISSING	normal	meaning	read access is not yet enabled
		reason	"startup" command wasn't successful till now
		remedy	execute **"startup"** and **"read"** again
EEL_ERR_VARIABLE_UNKNOWN	initial	meaning	specified EEL variable unknown by the EEL driver
		reason	used identifier is not registered in eel_anchor[]
		remedy	**register** variables in eel_anchor[], re-compile the project
EEL_ERR_INSTANCE_UNKNOWN	normal	meaning	no data set found for the used EEL variable
		reason	the used EEL variable was never written into EEL
		remedy	**initialize** the EEL variable by writing initial value
EEL_ERR_VARIABLE_CHECKSUM	normal	meaning	checksum error detected
		reason	RESET during last EEL write access
		remedy	over-**"write"** the EEL variable with corrected value
EEL_ERR_NO_ACTIVE_BLOCK	heavy	meaning	no "active" block detected during startup
		reason	possibly EMI, malfunction
		remedy	execute **"format"** command, all data are lost

4.4 refresh

Each write access to the virtual EEPROM consumes some “erased” space within the active block as long as enough space is available. When the active block becomes full, the write access is not possible anymore. To enable the write access new space has to be created. The refresh command is doing that by copying the relevant information only from the currently "active" (full) block into a "prepared" (empty) one.

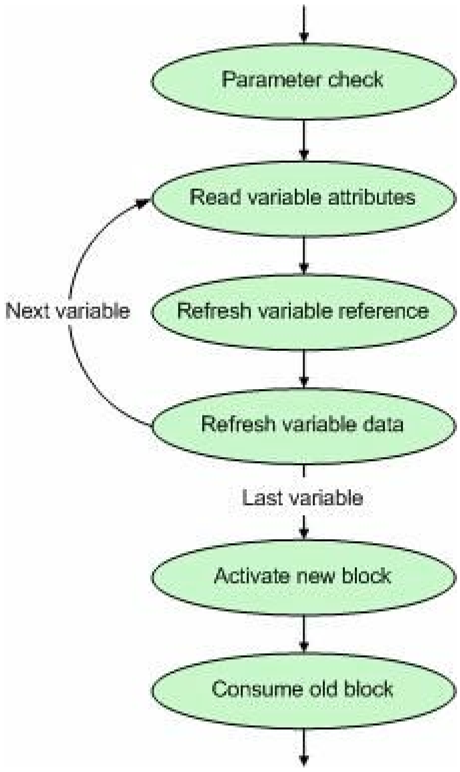
Especially when fast, immediately write access is required by the application, it has to take care for enough space inside the active block in advance. This can be performed by the application using the EEL_GetSpace() function and refresh command. Depending on the situation the application can realized it immediately or at more comfortable time in advance.

State sequence of the refresh command:

The refresh command is performed in three steps:

1. copy all latest instances of all registered EEL variables into the subsequent block.
2. mark the new, “fresh” block is marked as “active”
3. mark the old one block as “consumed”.

However asynchronous RESET during execution of the refresh command can produced some inconsistencies that has to be detected by the startup command and has to be repaired by the application.

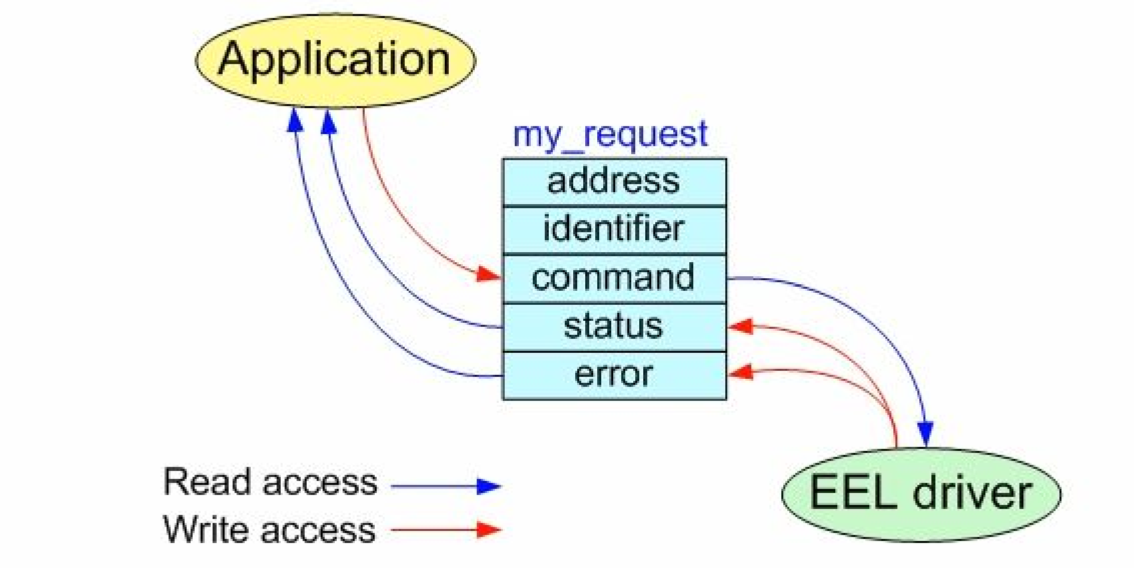


Self-programming commands used by refresh command

- FSL_EEPROMWrite(my_addr_u32, my_wordcount_u08)
- FSL_Write(my_addr_u32, my_wordcount_u08)

Refresh request and feedback

The application has to specify the command code only.



Code example:

```
// "Refresh" commad request
 my_eel_request.command    = EEL_CMD_REFRESH;
 EEL_Enforce(&my_eel_request);
 if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
```

Refresh error handling

Whenever problems are detected during "refresh"-command execution, the request status is modified by the EEL driver to EEL_STS_ABORTED. In such a case the application can analyze the error code and react properly to that exception. The possible error codes with corresponding reparation rules can be found below:

Table 4-5 Refresh error handling

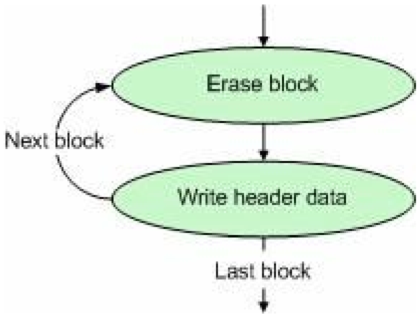
refresh error codes	class	error background and handling	
EEL_ERR_DRIVER_BUSY	normal	meaning	driver is already “busy” with another request
		reason	another task initiated its own request
		remedy	**wait** until driver “ready” and retry
EEL_ERR_POOL_CONSUMED	normal	meaning	no “prepared” block for "refresh"
		reason	all clocks were consumed or are invalide
		remedy	execute **“prepare”** and **“refresh”** again
EEL_ERR_FLMD0_LOW	unlikely	meaning	FLMD0 signal out of control
		reason	FLMD0 signal remains LOW during self-programming
		remedy	**check** FLMD0 hardware/software
EEL_ERR_VARIABLE_UNKNOWN	initial	meaning	EEL variables unknown by the EEL
		reason	used identifier is not registered in eel_anchor[]
		remedy	**register** variable in eel_anchor[], re-compile the project
EEL_ERR_BLOCK_CONSUMED	unlikely	meaning	no space for initial data inside the “new” block
		reason	the sum of EEL variable sizes
		remedy	**reduce** the amount of data (count or size of variables) and re-compile the project.
EEL_ERR_EEPWRITE_BLANK	heavy	meaning	the destination flash area is not erased anymore
		reason	possibly EMI, malfunction, flash problems
		remedy	**"repair"** next block and **"refresh"** again
EEL_ERR_EEPWRITE_VERIFY	heavy	meaning	the written data could not be verified electrically
		reason	possibly EMI, malfunction, flash problems
		remedy	**“exclude”** next block, execute **"prepare"** and **"refresh"** again
EEL_ERR_WRITE	heavy	meaning	the data could not be written correctly into flash
		reason	possibly EMI, malfunction, flash problems
		remedy	**“exclude”** next block, execute **"prepare"** and **"refresh"** again
EEL_ERR_NO_ACTIVE_BLOCK	heavy	meaning	no “active” block found
		reason	possibly EMI, malfunction, flash problems
		remedy	execute **“format”** command, all data are lost

4.5 format

The format command is a command that should be used in exceptional cases only. It erases the whole EEL pool, marks one block as “activated” and all other blocks as “prepared”. All data in the previously “active” block are lost. The application has to take care for re-incarnation (initial write) of all EEL variable after “format”.

State sequence of the format command:

The format command erases the complete EEL pool block by block and writes the header data into each of it. The block next to the previously active one becomes "activated" after format. All other blocks becomes "prepared". The erase counter is managed by the format command.

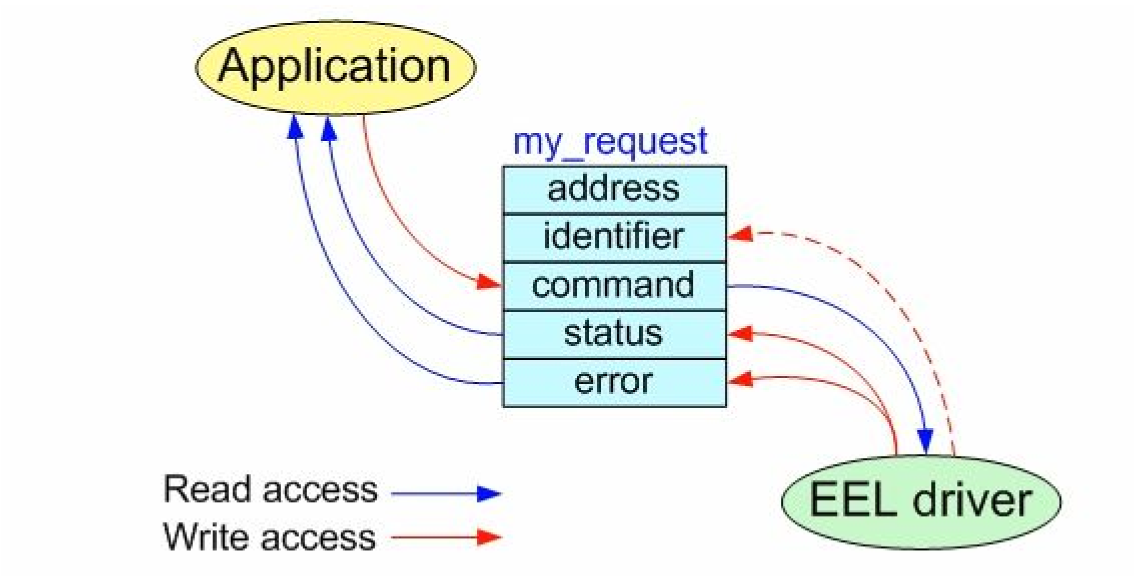


Self-programming commands used by format command

- FSL_Erase(my_block_u08)
- FSL_EEPROMWrite(my_addr_u32, my_wordcount_u08)
- FSL_IVerify(my_block_u08)

Format request and feedback

The application has to specify the command code only. When problems occur during execution the affected block number is provided by the driver in the identifier field of the request variable.



Code example:

```
// "Format" commad request
my_eel_request.command   = EEL_CMD_FORMAT;
EEL_Enforce(&my_eel_request);
if (my_eel_request.status == EEL_STS_ABORTED) my_EEL_ErrorHandler();
```

Format error handling

Whenever problems are detected during “format”-command execution, the request status is modified by the EEL driver to EEL_STS_ABORTED. In such a case the application can analyze the error code and react properly to that exception. The possible error codes with corresponding reparation rules can be found below:

Table 4-6 Format error handling

format error code	class	error background and handling	
EEL_ERR_DRIVER_BUSY	light	meaning	driver is already “busy” with another request
		reason	another task initiated its own request
		remedy	**wait** until driver-status is “ready” and retry
EEL_ERR_FLMD0_LOW	heavy	meaning	FLMD0 signal out of control
		reason	FLMD0 signal remains LOW during self-programming
		remedy	**check** FLMD0 hardware and software
EEL_ERR_PROTECTION	initial	meaning	EEL driver tries to overwrite protected area
		reason	possibly EMI, malfunction, boot-cluster
		remedy	**check** EEL pool range
EEL_ERR_EEPWRITE_BLANK	unlikely	meaning	destination flash area is not blank enymore
		reason	possibly EMI, malfunction, flash problems
		remedy	depends on the origin of the problem
EEL_ERR_EEPWRITE_VERIFY	heavy	meaning	the written data could not be verified electrically
		reason	possibly flash problem
		remedy	**"exclude"** the block and **"format"** again
EEL_ERR_WRITE	heavy	meaning	the data could not be written correctly into flash
		reason	possibly flash problem
		remedy	**"exclude"** the block and **"format"** again
EEL_ERR_ERASE	heavy	meaning	the specified flash block could not be erased
		reason	possibly flash problems
		remedy	**"exclude"** the block and **"format"** again

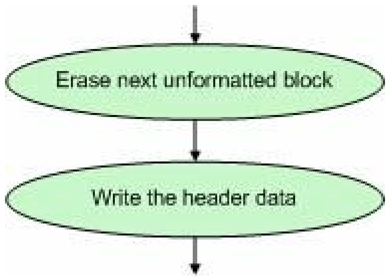
4.6 prepare

The prepare command looks for the next “consumed” or "erased" block inside the EEL pool, erases and marks it as “prepared”. The application can execute this command whenever it can take the liberty to spend time for that. In case that all blocks of the EEL pool are already “prepared” the command will terminate immediately with minimum of CPU load. It can be used by the application in advance, just to avoid driver blocking at uncomfortable time period. Blocks marked as “excluded” or “invalid” are over-jumped by the “prepare” command.

Especially when immediately write access is required by the application, it has to take care for availability of at least one “prepared” block for execution of unexpected “refresh” command. The administrative function EEL_GetPool() can be used for that purpose

State sequence of the prepare command:

The prepare command is performed in two steps: 1) searching and erasing of the next “consumed” or "erased" block. 2) marking of the erased block as “prepared”. However asynchronous RESET during execution of the refresh command can produced some inconsistencies that has to be detected by the startup command and has to be repaired by the application.

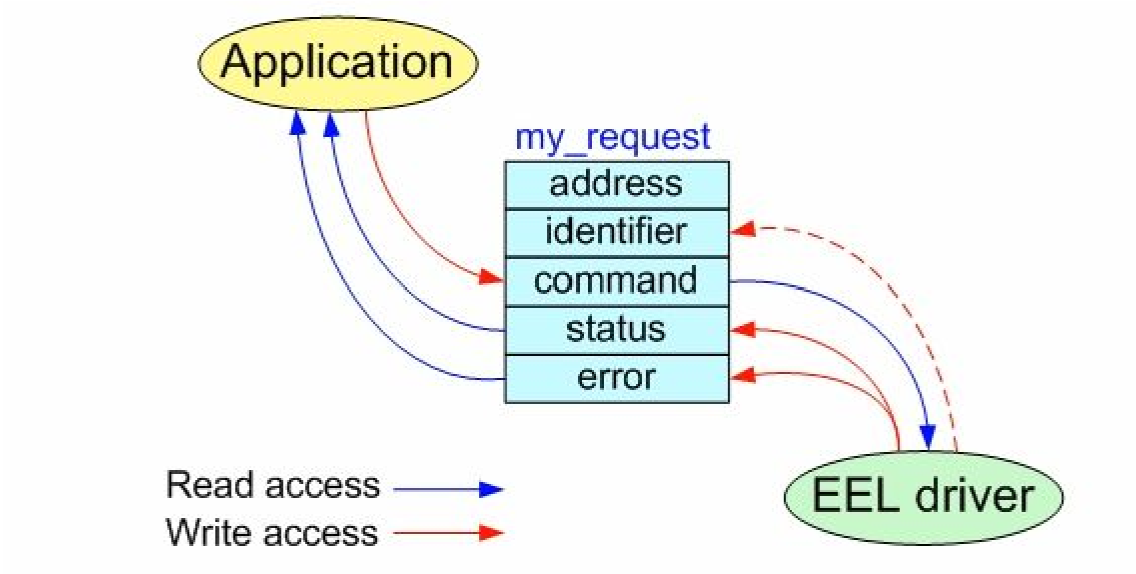


Self-programming commands used by prepare command

- FSL_Erase(my_block_u08)
- FSL_EEPROMWrite(my_addr_u32, my_wordcount_u08)

Prepare request and feedback

The application has to specify the command code only. When problems occur during execution the affected block number is provided by the driver in the identifier field of the request variable.



Code example:

```
// "Prepare" commad request
 my_eel_request.command    = EEL_CMD_PREPARE;
 EEL_Enforce(&my_eel_request);
 if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
```

Prepare error handling

Whenever problems are detected during execution of the "prepare"-command, the request status is modified by the EEL driver to EEL_STS_ABORTED. In such a case the application can analyze the error code and react properly to that exception. The possible error codes with corresponding reparation rules can be found below:

Table 4-7 Prepare error handling

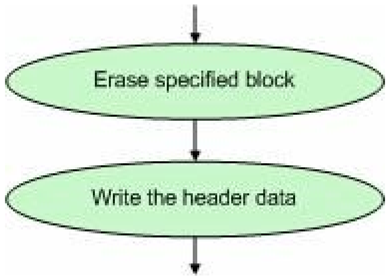
prepare error code	class	error background and handling	
EEL_ERR_DRIVER_BUSY	normal	meaning	driver is already “busy” with another request
		reason	another task initiated its own request
		remedy	**wait** until driver-status is “ready” and retry
EEL_ERR_FLMD0_LOW	heavy	meaning	FLMD0 signal error
		reason	FLMD0 signal remains LOW during self-programming
		remedy	**check** FLMD0 hardware and software
EEL_ERR_PROTECTED_BLOCK	heavy	meaning	EEL driver tries to overwrite protected area
		reason	the block is “active” or it doesn't belong to EEL pool
		remedy	**check** EEL pool range
EEL_ERR_EEPWRITE_BLANK	unlikely	meaning	the destination flash area ins not erased enymore
		reason	possibly EMI, malfunction, flash problem
		remedy	depends on the origin of the problem
EEL_ERR_EEPWRITE_VERIFY	heavy	meaning	the written data could not be verified electrically
		reason	EMI, malfunction, flash problem
		remedy	**“exclude”** the block, "prepare" again
EEL_ERR_WRITE	heavy	meaning	the data could not be written correctly into flash
		reason	possibly flash problem
		remedy	**“exclude”** the block, "prepare" again
EEL_ERR_ERASE	heavy	meaning	the specified flash block could not be erased
		reason	possibly flash problems
		remedy	**“exclude”** the block, "prepare" again
EEL_ERR_NO_ACTIVE_BLOCK	heavy	meaning	no “active” block detected during startup
		reason	possibly EMI, malfunction, flash problems
		remedy	execute **“format”** command, all data are lost

4.7 repair

The repair command erases and marks as “prepared” a specific block. This command can be used for reparation purpose of undefined or inconsistent blocks.

State sequence of the repaire command:

The repair command is performed in two steps: 1) erasing of the specified block. 2) marking of the erased block as “prepared”. However asynchronous RESET during execution of the refresh command can produced some inconsistencies that has to be detected by the startup command and has to be repaired by the application.

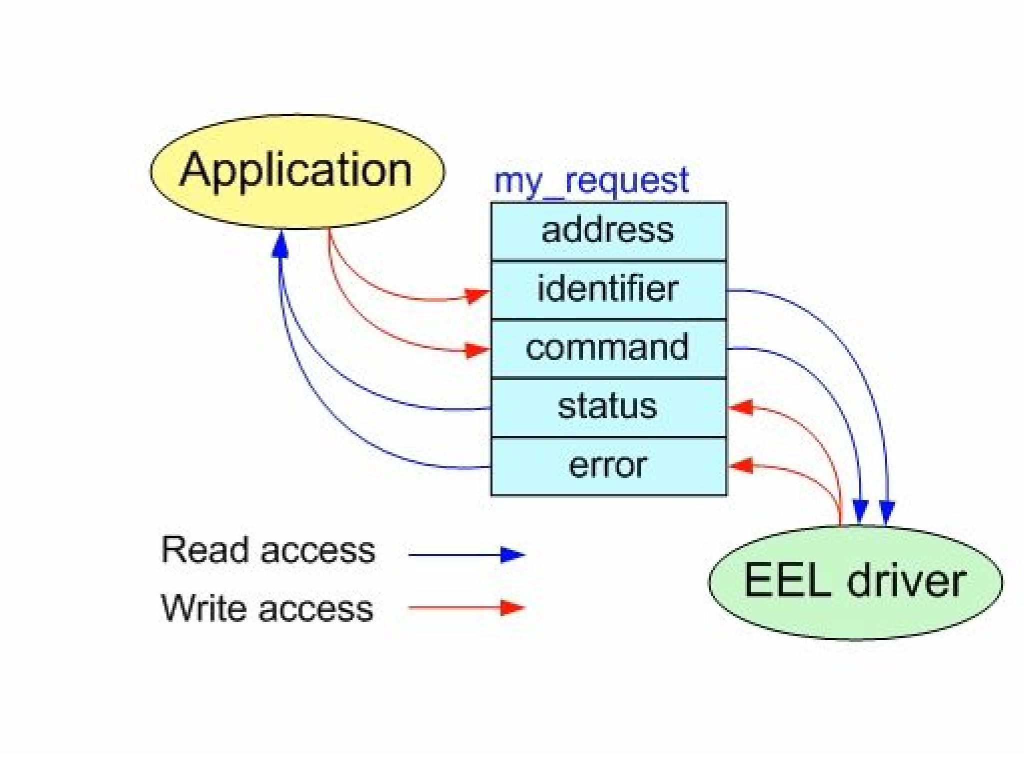


Self-programming commands used by repair command

- FSL_Erase(my_block_u08)
- FSL_EEPROMWrite(my_addr_u32, my_wordcount_u08)

Repair request and feedback

The application has to specify the command code and the block number has to be repaired.



Code example:

```
// "Repair" commad request
 my_eel_request.command    = EEL_CMD_REPAIR;
 my_eel_request.identifier= my_eel_block_u08;
 EEL_Enforce(&my_eel_request);
 if (my_eel_request.status == EEL_STS_ABORTED)  my_EEL_ErrorHandler();
```

Repair error handling

Whenever problems are detected during execution of the "repair"-command, the request status is modified by the EEL driver to EEL_STS_ABORTED. In such a case the application can analyze the error code and react properly to that exception. The possible error codes with corresponding reparation rules can be found below:

Table 4-8 Repair error handling

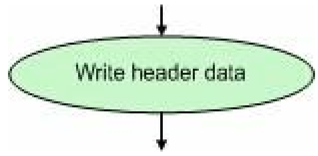
repair error code	class	error background and handling	
EEL_ERR_DRIVER_BUSY	normal	meaning	driver is already "busy" with another request
		reason	another task initiated its own request
		remedy	**wait** until driver-status is "ready" and retry
EEL_ERR_FLMD0_LOW	heavy	meaning	FLMD0 signal out of control
		reason	FLMD0 signal remains LOW during self-programming
		remedy	**check** FLMD0 hardware and software
EEL_ERR_PROTECTED_BLOCK	initial	meaning	EEL driver tries to erase protected area
		reason	the block is "active" or it doesn't belong to EEL pool
		remedy	**correct** the flow and re-compile the project
EEL_ERR_EEPWRITE_BLANK	unlikely	meaning	the destination flash area is not erased enymore
		reason	possibly EMI, malfunction, flash problems
		remedy	depends on the origin of the problem
EEL_ERR_EEPWRITE_VERIFY	heavy	meaning	the written data could not be verified electrically
		reason	possibly flash problem
		remedy	**"exclude"** the block
EEL_ERR_WRITE	heavy	meaning	the data could not be written correctly into flash
		reason	possible flash problem
		remedy	**"exclude"** the block
EEL_ERR_ERASE	heavy	meaning	the specified flash block could not be erased
		reason	possible flash problem
		remedy	**"exclude"** the block
EEL_ERR_NO_ACTIVE_BLOCK	heavy	meaning	no "active" block detected during startup
		reason	possibly EMI, malfunction, flash problems
		remedy	execute **"format"** command, all data are lost

4.8 exclude

The exclude command marks the specified block as “excluded”. It can be used for exclude any EEL block, except the active one, from the EEL block management. Data are not stored in that block anymore.

State sequence of the exclude command:

The exclude command overwrites both status flags of the specified EEL block with the pattern 0x00000000. However asynchronous RESET during execution of the refresh command can produced some inconsistencies that has to be detected by the startup command and has to be repaired by the application.

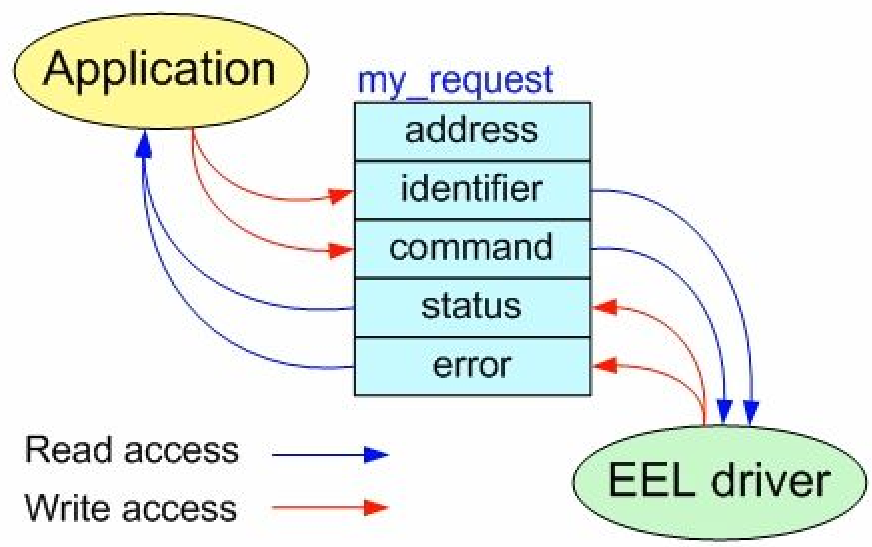


Self-programming commands used by exclude command

- FSL_Write(my_addr_u32, my_wordcount_u08)

Repair request and feedback

The application has to specify the command code and the block number has to be excluded.



Code example:

```
// "Exclude" commad request
  my_eel_request.command    = EEL_CMD_EXCLUDE;
```

```
my_eel_request.identifier= my_eel_block_u08;
EEL_Enforce(&my_eel_request);
if (my_eel_request.status == EEL_STS_ABORTED) my_EEL_ErrorHandler();
```

Exclude error handling

Whenever problems are detected during execution of the “shutdown”-command, the request status is modified by the EEL driver to EEL_STS_ABORTED. In such a case the application can analyze the error code and react properly to that exception. The possible error codes with corresponding reparation rules can be found below:

Table 4-9 Exclude error handling

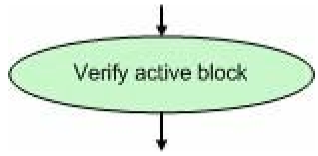
exclude error code	class	error background and handling	
EEL_ERR_DRIVER_BUSY	normal	meaning	driver is already “busy” with another request
		reason	another task initiated its own request
		remedy	**wait** until driver-status is “ready” and retry
EEL_ERR_FLMD0_LOW	heavy	meaning	FLMD0 signal error
		reason	FLMD0 signal remains LOW during self-programming
		remedy	**check** FLMD0 hardware and software
EEL_ERR_PROTECTED_BLOCK	light	meaning	the specified block cannot be excluded
		reason	the block is “active” or it doesn't belong to EEL pool
		remedy	**check/correct** the software flow, re-compiler the project
EEL_ERR_WRITE	unlikely	meaning	block flags couldn’t be overwritten with 0x00000000
		reason	possibly flash problem
		remedy	**None.** Block status "excluded" could not be written correctly. F0/F1 are probably damaged and indicates a block status “invalid”. Blocks marked as “invalid” are treated as “excluded”

4.9 shutdown

The shutdown command verifies electrically the “active” block to ensure the maximum specified data retention for the EEL data.

State sequence of the shutdown command:

The shutdown performs the internal verify and marks the status of the driver as “non started up”. In that status read and write access to the EEL in disabled.

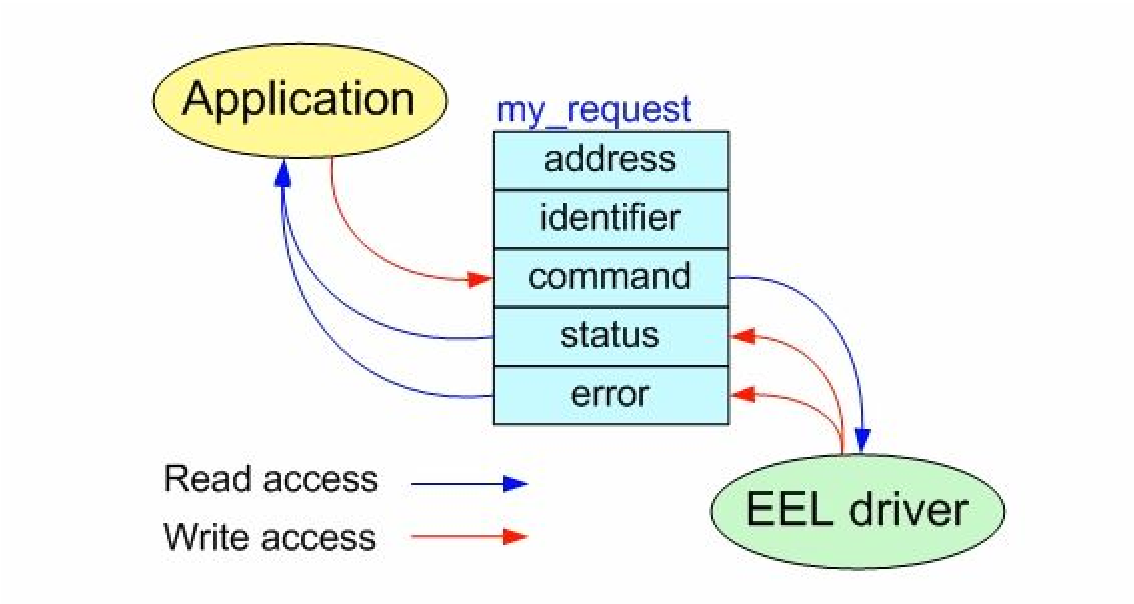


Self-programming commands used by shutdown command

- FSL_IVerify(my_block_u08)

Shutdown request and feedback

The application has to specify the command code only.



Code example:

```
// "Shutdown" commad request
  my_eel_request.command    = EEL_CMD_SHUTDOWN;
 EEL_Enforce(&my_eel_request);
 if (my_eel_request.status == EEL_STS_ABORTED)  EEL_ErrorHandler();
```

Shutdown error handling

Whenever problems are detected during execution of the “shutdown”-command, the request status is modified by the EEL driver to EEL_STS_ABORTED. In such a case the application can analyze the error code and react properly to that exception. The possible error codes with corresponding reparation rules can be found below:

Table 4-10 Shutdown error handling

shutdown error code	class	error background and handling	
EEL_ERR_DRIVER_BUSY	normal	meaning	driver is already “busy” with another request
		reason	another task initiated its own request
		remedy	**wait** until driver-status is “ready” and retry
EEL_ERR_VERIFY	light	meaning	the active block could not be verified sucessfully
		reason	any data bit in “active” block dropped below the verify level
		remedy	execute **“refresh”** and **“shutdown”** again.
EEL_ERR_NO_ACTIVE_BLOCK	heavy	meaning	no “active” block detected during startup
		reason	possibly EMI, malfunction
		remedy	execute **“format”** command, all data are lost

Chapter 5 EEL driver integration

Before the EEL driver can be integrated several parameter has to be configured. Following files are touched by this configuration: **fsl_user.h**, **eel_user.h**, **eel_user.c** and linker description file (my_project.dr or my_project.xcl)

5.1 Flash self-programming library configuration

The self-programming library is used by the EEPROM emulation to access the flash memory. Be aware, that the chosen configuration is valid and constant for the operation time of each self-programming command. The functions **FSL_Open ()** and **FSL_Close()** are called directly by the EEL driver and its handler.

fsl_user.h

constants:

FSL_DATA_BUFFER_SIZE, the min. size for correct EEL operation is 12 bytes

FSL_MKmn_MASK, interrupt configuration during firmware operation,

effective when FSL_INT_BACKUP defined

macros:

FSL_FLMD0_HIGH,

FSL_FLMD0_LOW, assignment of the FLMD0 control port

controls:

FSL_INT_BACKUP, determines whether a specific interrupt scenario defined as

FSL_MKmn_MASK is effective during firmware operation

fsl_user.c

code:

FSL_Open(), adapt the functions due to the requirements

FSL_Close()

5.2 EEPROM library configuration

Before being integrated into users application, the EEPROM emulation must be adapted its requirements to. The main parameters are memory mode and the number and size of EEL variables.

eel_user.h

constants:

EEL_BANKED_MODEL, = 0x00 when EEL pool is located in common area of the flash

= 0x01 when EEL pool is located in any of flash bank 1…5

EEL_FIRST_BLOCK, assignment of the EEL pool, check if it does match

EEL_LAST_BLOCK, with segment EEL pool limits

Blocks are numbered lineary (regardless of tflash banking) starting with block 0x00 and ending with the last block of the flash macro.

EEL_VAR_NO, number of EEL variables handled by the EEL driver

macros:

EEL_START_CHOPPER, starts the periodical interrupt used as a chopper

EEL_STOP_CHOPPER, stops the chopper interrupt

eel_user.h

ROM constants:

eel_anchor[…][4], fill in description data of all your EEL variables (identifier and size)

code:

EEL_Open(), adapt the functions due to the requirements

EEL_Close()

Note In module eel_user.c some configuration checks are realize to omit contradictory configuration parameters. Following errors can be generated during compilation:

EEL ERROR=001, data flash overlaps the NON-BANKED area in BANKED-mode !

EEL ERROR=002, flash overlaps the BANKED area in NON-BANKED-mode !

EEL ERROR=003, EEL data flash size invalid !

EEL ERROR=004, at least 1 EEL-variable has to be registrated in eel_anchor[..] !

5.3 Linker configuration

Using the linker description file the application can bind necessary logical segments the EEL requires to absolute addresses the application can offer. Examples of platform specific linker description files are part of the installation package:

EEL_78F054780.DR for NEC's CC78k0 tool chain

EEL_78F054780.XCL for the IAR platform.

Required logical segments are:

FSL_DATA data segment where entry_ram[100] is located
FSL_CODE code segment where the FSL code is located
EEL_POOL specify the address space of the EEL pool

Note The NEC version of the EEL driver reserves the last byte of the short adress area at address **0xFEDF** for internal purpose. The application cannot allocate this byte when integrating the EEL driver.

Chapter 6 EEL driver operation

6.1 EEL activation and deactivation sequence

One important issue in systems using EEPROM (internal, external as well EEL) is the integrity and consistency of the stored data. In all the systems listed above the write access takes certain time an unexpected RESET or power break can produce data inconsistencies. To ensure proper EEL driver operation and to discover potential inconsistencies in an early stage the following activation sequence:

Startup phase:

1. execute **EEL_Init()**, power-on initialization, driver remains passiv
2. execute **EEL_Open()**, activation of chopper interrupt and other user defined functionalities
3. execute the startup-command to check the driver consistency. In case of problems process suitable reparation and repeat step 3.

Normal operation:

4. execute of any defined EEL driver commands

Shutdown phase:

5. execute of shutdown-command to ensure the max. data retention.
6. execute **EEL_Close()**, deactivate the chopper and other user defined functionalities
7. EEL driver is inactive, standby mode can be entered

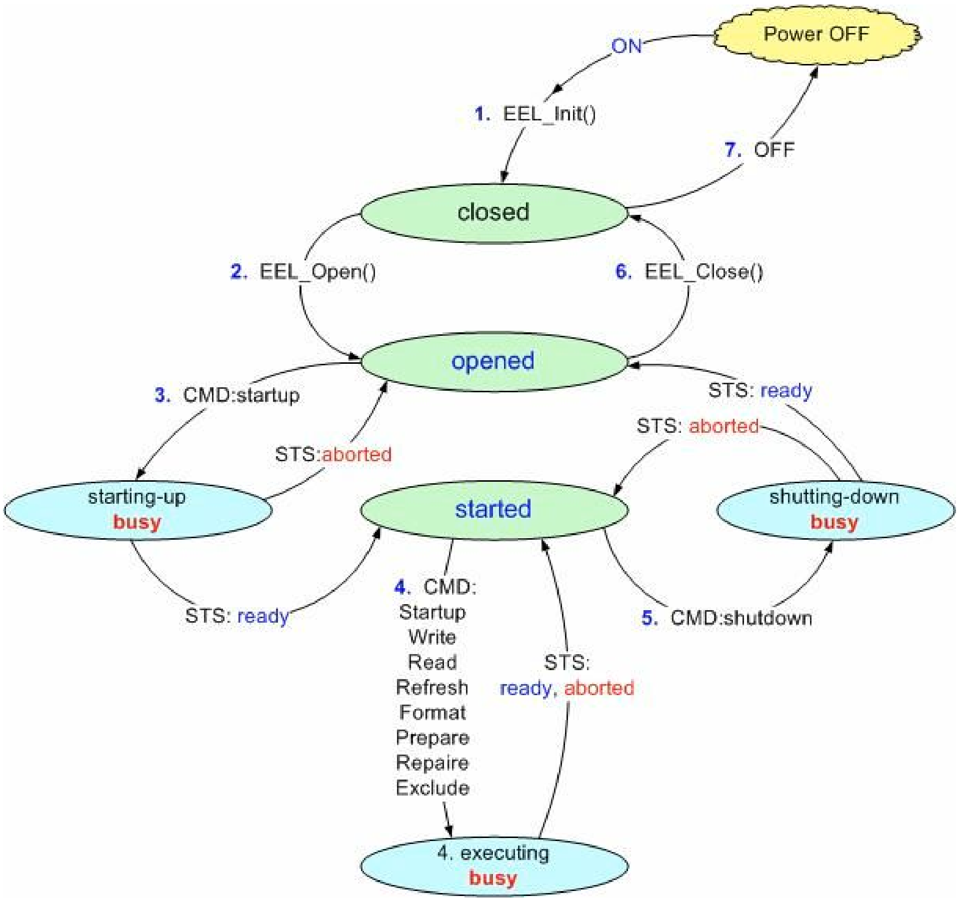


Figure 6-1 EEL driver activation and deactivation sequence

6.2 Real-time capabilities

The EEL driver is using commands of the self-programming library their execution time is not always constant. It depends on the device oscillator configuration (internal/external) as well on the system configuration (entry RAM location). The execution time of some self-programming commands is not always deterministic. Especially the real execution time of the Erase- and Write-command can enlarge during the device live time. Some systems cannot accept this fact due to its critical timing requirements (i.e. communication protocols). Also watchdog based systems has to re-trigger it at certain, precise pre-defined time point. To fulfill such strict timing requirements during EEPROM emulation running in the background the complete system has to be configured very carefully. Execution time of self-programming commands is specified in the device user's manual.

The execution time of the self-programming commands isn't the only parameter influencing the real-time behavior of the EEPROM emulation. Each time a running FSL command is interrupted by a non-masked interrupt source the corresponding interrupt service routine is invoked after certain non-deterministic delay. This interrupt latency depends several factors like: the interrupted command, the used oscillator type (internal/external), the internal status of the interrupted firmware. For device specific interrupt latency please have a look to the user's manual of the used device.

The interrupt latency in firmware operation cannot be influenced by the application, but the problem of non-deterministic command execution time can be solved by using any periodical non-masked interrupt source for interruption of the command execution. We call such an interrupt “chopper” because it’s interrupting running self-programming commands each predetermined period. Of course, jitter caused by the interrupt latency mentioned before has to be taken into account.

6.2.1 Interrupts in enforced operation mode

When EEL commands are executed in “enforced” mode, the application gives up the control of the CPU until the entire command is finished. However during the whole command execution time all non-masked interrupts are serviced, but the application “blocked” for this period. The worst-case interrupt latency specified for the used device has to be taken into account. From application point of view the EEL command execution is like a simple function call.

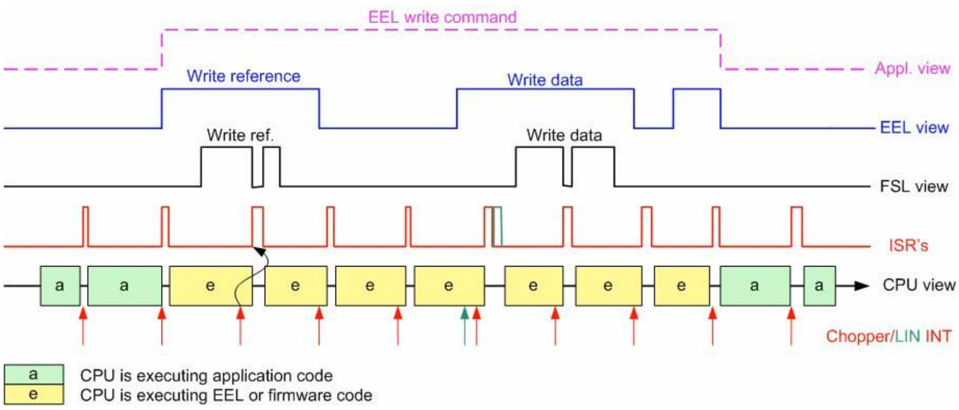


Figure 6-2 Timing example of interrupted "enforced" operation mode

6.2.2 Interrupts in background operation mode

When EEL commands are executed in “background” mode, the application regains the CPU control for any desired time after a non-masked interrupt was serviced. The application gets the chance to react to the interrupt event, but also watchdog or other timed actions can be processed. The resumption of the not finished command is done by the EEL_Handler() who is re-calling the EEL driver recurrently. The worst-case interrupt latency specified for the used device has to be taken into account.

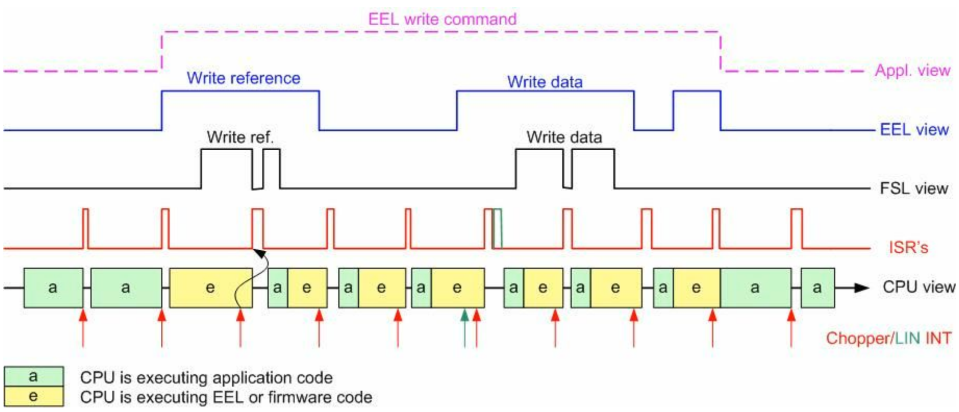


Figure 6-3 Timing example of interrupted "background" operation mode

6.2.3 Chopper configuration

Chopper is a periodical interrupt source that should prevent the system against undetermined holding time inside the firmware in the meantime the application is blocked. Any periodical interrupt source generating periodical interrupts requests can be used as a chopper. Examples: internal interval timer, external square-wave interrupt signal and others. The EEL library offers two predefined macros located in eel_user.h. The user can adapt these macros and use it to control the chopper operation. In the delivered EEL library the chopper is automatically activated in EEL_Open() and deactivated in EEL_Close().

```
#define EEL_START_CHOPPER { TMC51  = 0x03; /* stop TM51             */\
                            TCL51  = 0x06; /* set TM51 clock        */\
                            CR51   = 0x50; /* set TM51 interval     */\
                            TMIF51 = 0;    /* init TM51 interrupt   */\
                            TMMK51 = 0;    /* enable TM51 interrupt */\
                            TMC51  = 0x87; /* start TM51            */\
                          }

 #define EEL_STOP_CHOPPER { TMC51  = 0x03; /* stop TM51 generator  */\
                            TMIF51 = 0;    /* init TM51 interrupt  */\
                            TMMK51 = 1;    /* disable TM51 int.    */\
                          }
```

Chapter 7 Error handling

During operation time several problems can be signalized by the EEL driver. Some of them are indicating normal internal status that can be used by the application to maintain the operation of the EEL driver. Other signalizes more or less serious problems and requires reparation sequences to be removed. All the possible error codes are described in the command related chapters. The developer can use this description to implement a standard, central error handler for his application. The EEL driver does not correct/repair such problems automatically to avoid any unnecessary negative impact of the real-time characteristics. The application retains the flexibility to decide about CPU allocation used for the reparation process in dependency on the current situation.

Chapter 8 Supported platforms

There are two platform specific versions of the 78k0 EEL driver.

Both libraries are precompiled offers the same application programming interface.

The file structure and hierarchy is also widely the same.

8.1 NEC compiler compatible version

This EEL driver version is supporting the compiler version 3v70 and later.

Package content:

eel.h - API definition header file

eel.lib - precompiled EEL library

eel_user.h - user configurable definitions of the EEL driver

eel_user.c - user configurable part of the EEL driver

eel_pool.c - EEL pool area allocation

eel_78F054780_NEC.dr - linker description file

8.2 IAR compiler compatible version

This EEL driver version is supporting the compiler version 4v20 and later.

Package content:

eel.h - API definition header file

eel.r26 - precompiled EEL library

eel_user.h - user configurable definitions of the EEL driver

eel_user.c - user configurable part of the EEL driver

eel_pool.c - EEL pool area allocation

eel_78f0547_80_saddr.xcl - linker description file (debug version)

eel_78f0547_80_saddr_hex.xcl - linker description file (release version)

Chapter 9 Supplemental information

9.1 Driver configuration

Driver configuration:

EEL pool:

- the EEL pool can be located in common area as well in any of the flash banks

- maximum 4 blocks can be assigned to the EEL pool (4k in total)

- minimum 2 blocks have to be assigned to the EEL pool (block redundancy required)

EEL variables (recommendation):

- total number of EEL variables should not exceed 30

- total size (sum of all particular sizes) of all EEL variables should not exceed 100 bytes.

Flash characteristics:

- for flash specification (flash endurance and data retention data) please refer to the device users manual.

Interrupt latency:

- the interrupt latency during EEPROM emulation is identical with the interrupt latency during self-programming functions. For interrupt latency of self-programming please refer to the device users manual.

9.2 Resource consumption

The resource consumption is directly influenced by the number of required EEL variables and by the number of required flash blocks of the EEL pool.

Table 9-1 Resources consumed by the EEPROM emulation

Object	type	size	unit	comment
fsl_entry_ram	RAM	100	byte	allocated by the FSL (automatically)
fsl_data_buffer	RAM	min. 12	byte	allocated by the FSL (user configurable)
EEL driver data	RAM	16	byte	internal EEL driver variables
eel_references	RAM	N	byte	1 byte for each EEL variable
EEL pool	ROM	max. 4k	byte	EEL data flash area
EEL descriptors	ROM	10	byte	EEL driver descriptors
eel_anchor	ROM	4*(N+1)	byte	EEL variable descriptors
EEL code	ROM	3100	byte	EEL driver functionality

9.3 Typical timing

The execution time is influenced by following factors:

- execution time of used self-programming commands
- eventually necessity of firmware internal retries of erase- or write-pulses
- time consumed by the application in between the chopper time-slices
- time consumed in the interrupt services.
- overhead time caused by the interruption of self-programming commands

All these factors make it difficult to specify the real execution time of the EEL commands absolutely. For better estimation of the timing behavior the typical execution time of all commands was measured.

Conditions:

Device: uPD78F0547A
Frequency: 20 MHz

Table 9-2 Typical EEL command execution time

Command	Conditions	non-interrupted	interrupted each 1 ms
		[ms]	[ms]
startup	4 blocks	78	108
	3 blocks	68	98
	2 blocks	58	88
write	1 byte	2.3	2.7
	13 bytes	2.8	5.7
	27 bytes	3.3	6.5
	255 bytes	14	26
read	1 byte	0.7	0.7
	13 bytes	0.9	0.9
	27 bytes	1.1	1.1
	255 bytes	4.5	4.8
prepare	1 block	20	38
refresh	4 EEL variables	45	46
repair	1 block	20	38
format	4 blocks	120	220
	3 blocks	90	170
	2 blocks	60	110
exclude	1 block	1.2	1.2
shutdown	1 block	13	20

Note **This timing information is not a specification.** They are typical values measured on one specific device in the laboratory. In reality the EEL command execution time can be influenced by the retry-counters inside the used FSL commands like FSL_Write(...), FSL_EEPROMWrite(...) and FSL_Erase(...). For details please refer to the users manual of the target device.

Revision History

All changes of this document revision are related to the new supported devices (78K0/Ix2/Kx2-L/Dx2/uCFL/LIN4). The previous version of this document is U18991EE1V0AN00.

Chapter	Page	Description
1	9	Chapter Overview and Architecture exchanged.
4	34	Error code description changed