Paulus

CANopen Mini Bootloader
User Manual

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1. General Remarks

Modern device designs need enormous flexibility in hard- and software. This flexibility is reached by integration of download-mechanisms and programming functions within the software and the dimensioning of hardware for the future.
Bootloaders with a communication interface make allow firmware updates by use of an appropriate network Standardized communication objects and algorithms provide a high transparency and operator convenience.

The CANopen Bootloader makes this flexibility available for devices in CANopen networks. With the SDO transfer CANopen provides a standardized mechanism for the transfer of large blocks of data. The Bootloader is independent of the application and works as a minimal CANopen slave node according to the standard CiA 301.

It allows to use regular CANopen master software or configuration tools to download new firmware into the user FLASH code memory.

Paulus is a bootloader optimized to code size and highly compatible to CANopen. To achieve the aim of minimal code size there are only those functionalities of a CANopen protocol stack included that are indespenseable. Nevertheless the project is flexible enough to provide a hardware independent code part for carrying out the protocol.

Implementations for the following controller families are available:

- dsPIC33F by Microchip
- DSP Controller TMS320F2812/2808/28335 by Texas Instruments (in development)
- 32-bit ARM Controller STM32 by ST Microelectronics

The recent list of supported processors is available at our sales department. Please ask our sales team for the latest versions. We would of course also make the adaptions to not yet supported processors by your order.

The bootloader code is written rather universal and modular. It can therefore easily applicable to other architectures. For the full application code two further steps are required:

- The respective main initializing of the processor
- The FLASH handling for the programming
- The regulation for the linking of loadable applications.

2. CANopen features

Some of the described features are always available, others can be activated by setting `#define` in the file *<target>/bl_config.h*

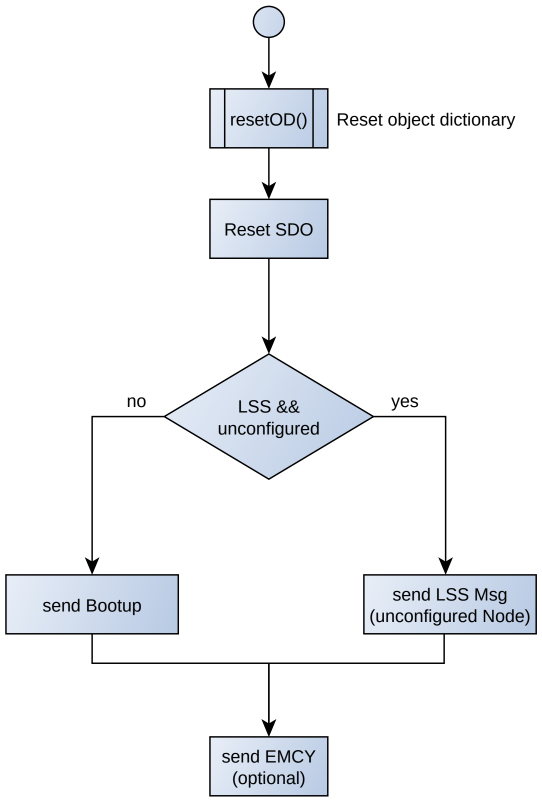
2.1. NMT

A NMT state machine does not make sense for the CANopen bootloader. The CANopen bootloder stays in pre-operational mode that is set immediately after the boot-up. For data communication only the SDO transfer is used.

NMT command	activity
reset application	reset
reset communication	send boot up
start	ignored
preoperational	permanent
stopped	ignored

The NMT command *Reset Application* analyzes the bootloader for a software reset, e.g. when it was received after a successful firmware download. The NMT command *Reset Communication* leads to the activation of a new Node Id when LSS is active. Additional the SDO communication will be reset.

2.1.1. Implementation Reset Communication



2.2. NMT Error

Heartbeat creation by the bootloader is possible. Dependent on the target, different variants are implemented.

- counting loop in main loop; rather imprecise
- Hardware timer, with higher need of resources

It is also possible to set the heartbeat production aside.

When sufficient code is available the bootloader can send a boot-up message.

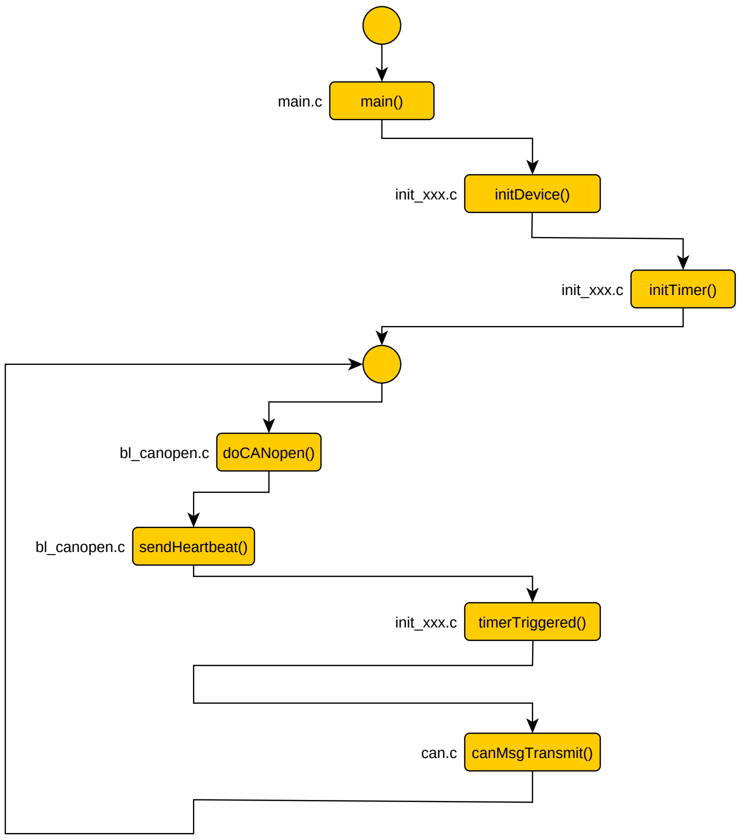
service	activity
boot-up message	supported
heartbeat	fixed heartbeat time 0
heartbeat	optional - fixed heartbeat time greater than 0

The Heartbeat Producer entry is available at 0x1017. The optional functionality to send the heartbeat cyclic requires the function *timerTriggered()*.

2.2.1. Implementation

In case the bootloader should send a cyclic heartbeat, the functionality must be configured by using `#define` and of course **the target specific code must be available**.

```
#define BL_USE_HB 1
```



2.3. Emergency

If necessary, emergency functionalities can be used with limitations. The emergency functionality is reduced to the bare sending of a CAN message.

- The COB-ID of emergency is fixed (predefined connection set).
- Inhibit time is not supported.
- 0x1001 is not adjusted.
- 0x1003 is not supported.

Activate EMCY functionality in bootloader configuration.

```
#define BL_USE_EMCY 1
```

After sending the bootup message, the bootloader can send an additional emergency. This is usefull to signal the bootloader start in difference to an application start.

```
#define BL_TXEMCY_AFTER_BOOTUP 1
```

After the bootup message the first defined emergency is sending (`emcyErrMsg[EMCY_0]` in *bl_canopen.c*).

You can send own emergencys in the same manner.

```
canMsgTransmit(EMCY_COBID, &emcyErrMsg[EMCY_0]);
```

2.4. CANopen Layer Setting Services, LSS

CANopen LSS is supported as slave. Paulus can get a CANopen node ID by a LSS Master. This information can be forwarded to an application that was started by the Bootloader when there is a Shared Memory.

Solutions that use a hardware daisy-chain with simplified LSS services were also been implemented before.

```
#define BL_USE_LSS 1
```

2.5. SDO

Paulus Bootloader is SDO server.

Expedited and segmented SDO transfer are supported for access to the object dictionary and for firmware download.
The reason for the predefinitions that are used mostly, is the fixed coding of the SDO command bytes. There is no detailed decoding.

Possible error code is limited to a few error codes. Mainly error code *Generic Error*, is used.

2.6. PDO

No support of PDO service.

2.7. Object dictionary

The following table gives an overview of implemented objects in Paulus. Optional entries are marked. A reference is also the EDS file and its documentation in HTML format[1]. The electronic data sheet is available in the traditional format as *paulus.eds* but as well in the XML based format according CiA 311 as *paulus.xdd*. Both were generated by the CANopen Design Tool[2].

[1] Are available as enclosures

[2] http://www.port.de/0640

Index	Subindex	Mode	comment
0x1000	0	co	Device Type
0x1001	0	co	(*) no error signaling supported
0x1014	0	co	(*) fixed Emcy COB-ID
0x1017	0	co	(*) 0 or fixed time
0x1018	0-2	co	(*) Identify object
0x1018	3-4	co	(*) with LSS
0x1F50	0	co	(*) Number of Elements
0x1F50	1	wo	Domain Entry - new firmware
0x1F51	0-1	rw	(*) Program Control
0x1F56	0-1	ro	(*) Application software identification
0x1F57	0-1	ro	(*) Flash status identification

(*) to achieve a small code size these objects can be set aside

Program Control — 0x1F51

Writing the value 0x01 to this entry will cause the Bootloader to start the loaded application. Writing the value 0x03 to this entry will "ERASE" the application FLASH area.

Attention: The start of the application with this entry is harmful, because the periphery is only partly initialized. The application run should be done by a power on reset.

Application software identification — 0x1F56

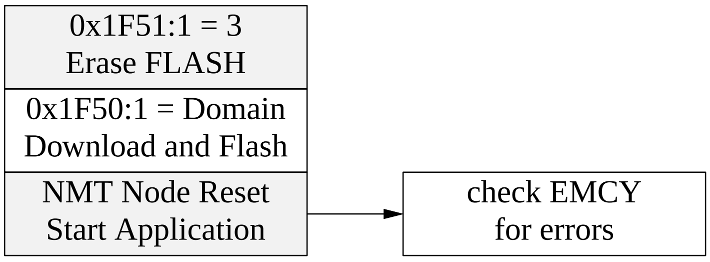
Depending on the implementation there is only strongly limited support for this object available. It is possible to read out and in consequence identify the CRC sum of the flashed application.

Flash status identification — 0x1F57

Depending on the implementation there is only strongly limited support for this object available.

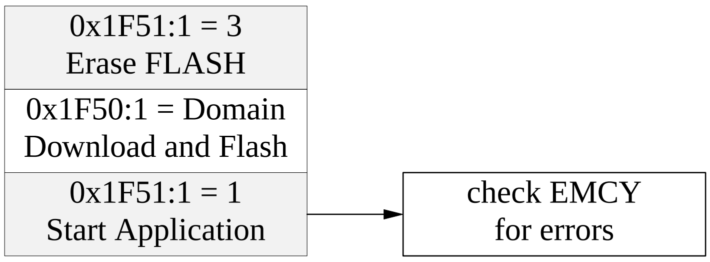
2.7.1. Programming

Install a new user software with the following steps:



The application can be startet during the development also via SD . That simplifies debugging.

```
#define BL_CALL_BY_SDO 1
```



2.8. CANopen node number and bit rate

If LSS service is not implemented easier methods can be chosen, such as reading out of switches or EEPROM. In this case the functions *getNodeId*() and *getBitRate*() provided in *<target>/<target>_init.c* have to provide thees information to the CANopen layer.

LSS service can be added in the bootloader configuration[3]

```
#define BL_USE_LSS 1
```

2.9. Data exchange between Paulus and the User Application

The interface between Paulus protocol layer and hardware application is in *bl_interface.[ch]*.

Applications should use macros defined in *bl_interface.h* to jump back to the bootloader. According to the Paulus principles the application has to request an update by jumping back to the boot loader using the macro

```
    BOOTLOADER_JUMP(APPL);
```

Using

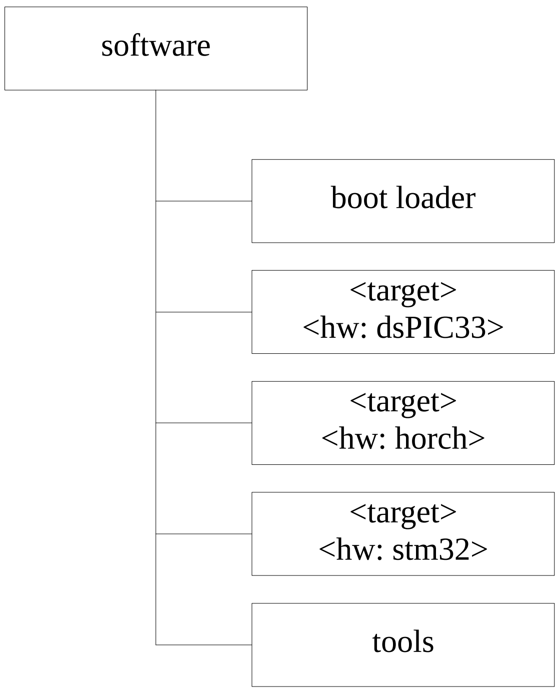
```
    BOOTLOADER_JUMP(BL);
```

the boot loader will be called, checks again the application image and starts it again. In case of an CRC error Paulus will stay in boot loader mode and expects an new image via object 1f50.

[3] Target platform and specific information or hints can always be found in the file *<target>/bl_config.h* that is part of the source code delivery.

3. Structure of the directory

Hardware dependent and hardware independent source code are in different directories. That makes handling of the sources in CVS easier.



The directory *bootloader* contains the hardware independent part of the software. The hardware dependent part of the software is named after its hardware, e.g. *horch*. Configuration is stored in the *horch*-directory. Projects and *main.c* are stored in *software*

The tools directory contains software that is necessary to create images for the bootloader.

4. Hardware Requirements

By dividing protocol layer and HAL[4] the bootloader can be used on all supported target platforms. Solely the FLASH routines have to be adopted.

Depending on CPU, compiler and compiler settings the consumption of resources varies. Typical values are 4-8KiB flash and 2KiB RAM.
Every PC interface hardware can be used as a client counterpart
- e.g. a USB-CAN interface (CPC-USB or USB-XS) or a gateway according to the CiA DS309-3 (EtherCAN).

[4] HAL — Hardware Abstraction Layer

5. Software Requirements

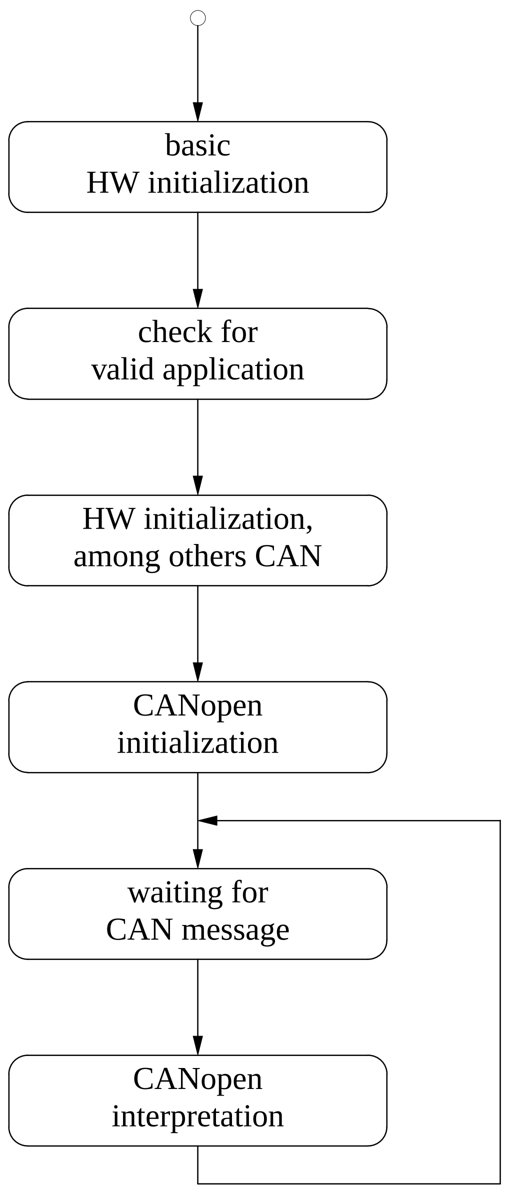
The downloading software has to support the CANopen SDO domain transfer. For a free download of the **downloader** goto: http://www.port.de
Best results can be obtained by using standard CANopen configuration tools like the **CANopen Device Monitor**[5].

[5] http://www.port.de/0642

6. Implementation

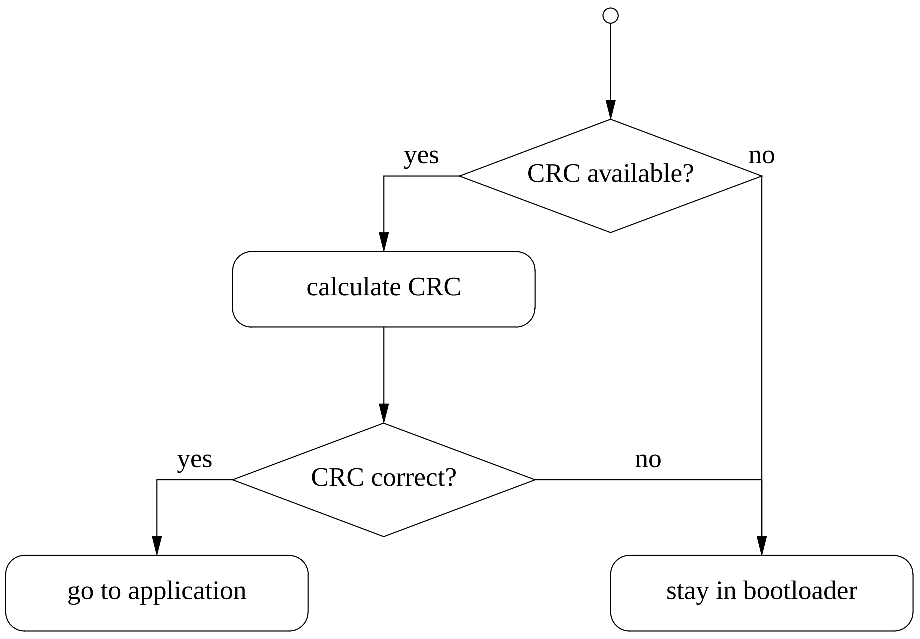
6.1. Processes

6.1.1. Main Loop



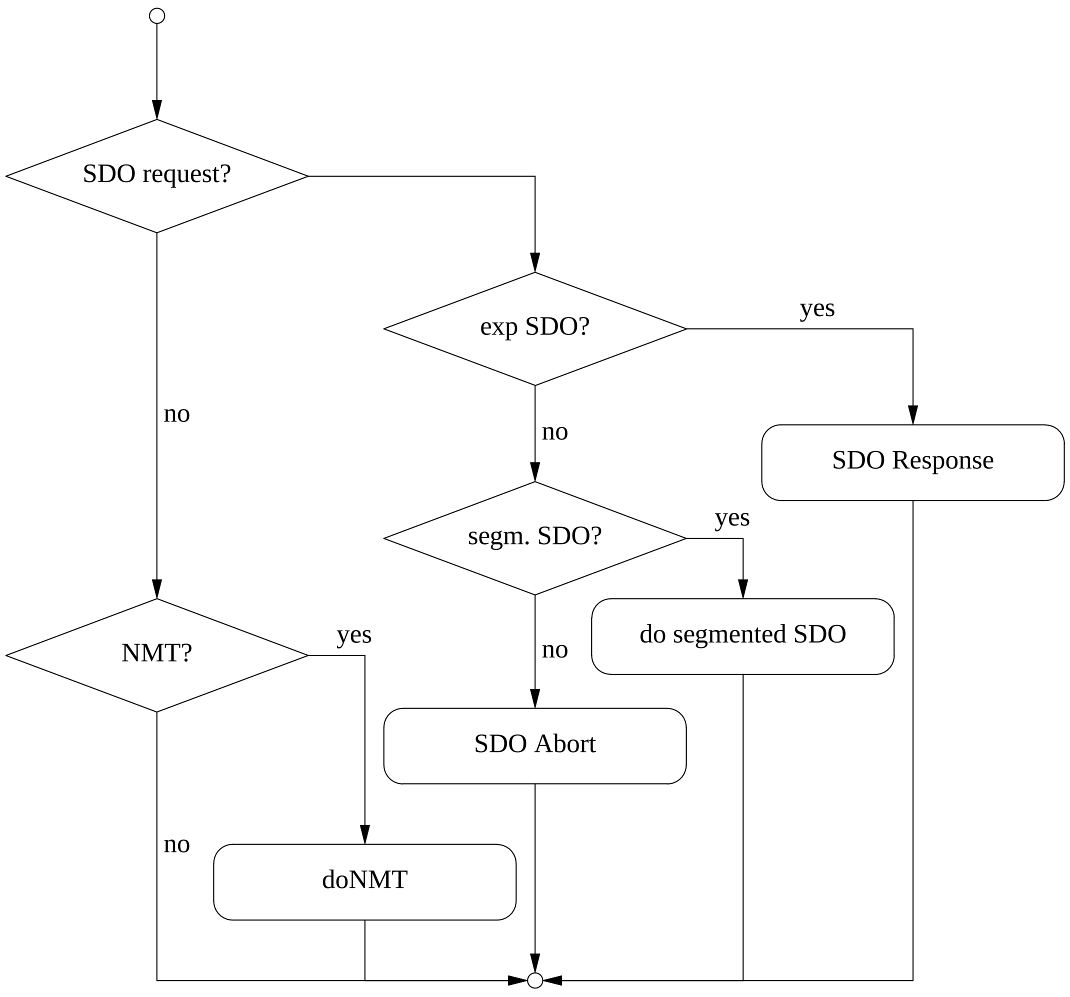
Program flow in *main.c*

6.1.2. Tesing for valid applications



callApplication(), <hw>_appl.c

6.1.3. Interpretation of CANopen requests



doCANopen(), bl_canopen.c

Other services accordingly.

6.2. Used structures

6.2.1. CanMsgRx_T

```
typedef struct
{
  UNSIGNED16 StdId;                /**< identifier */
  UNSIGNED8 DLC;                   /**< message length */
  union {
      UNSIGNED32 u32Data[2];       /**< data as 2x32bit values */
      UNSIGNED16 u16Data[4];       /**< data as 4x16bit values */
      UNSIGNED8 u8Data[8];         /**< data as 8x8bit values */
  } Msg;
} CanMsgRx_T;
```

low-level Receive message

CanMsgRx_T is from the CAN driver. There is no content or invalid content when StdId == 0xFFFF.

6.2.2. CanMsgTx_T

```
typedef struct
{
  UNSIGNED8 DLC;                   /**< message length */
  union {
      UNSIGNED32 u32Data[2];       /**< data as 2x32bit values */
      UNSIGNED16 u16Data[4];       /**< data as 4x16bit values */
      UNSIGNED8 u8Data[8];         /**< data as 8x8bit values */
  } Msg;
} CanMsgTx_T;
```

low-level Transmit message

UNSIGNED8 entries have to be used with care on DSP systems, because they are internal 16bit in size!

CanMsgTx_T is used to define send and response messages. These definitions can be stored in flash. They do not contain CAN-IDs which is often dependent on the node ID.

Example

```
static const CanMsgTx_T bootupMsg = {
    1, {.u32Data[0] = 0ul, 0ul}
};
```

6.2.3. SdoRequest_T

```
typedef struct
{
    UNSIGNED32 request;   /**< first 4 Bytes of the SDO Request */
                          /**< contains command, Index and Subindex */
                          /**< of the Request */
    CanMsgTx_T response;  /**< complete SDO Response */

} SdoRequest_T;
```

This structure consists mainly of the object dictionary. There are mainly constant entries defined that are transmitted by exp. SDO transfer.

At that point the values are in the RAM and can be changed during the initialization. That allows for example to put the version of the bootloader into the object dictionary. It is also possible to put down software states in the object dictionary, at a later point of time.

example:

```
#define SDO_REQ_COBID (0x600 + nodeId)
#define SDO_RESP_COBID (0x580 + nodeId)

static SdoRequest_T sdoRequest[] = {
#define SDO_1000_0_IDX 0
    {0x00100040ul /* 0 - sdo 1000:0 */,
                    {8,{.u32Data[0]=0x00100043ul,0x0000FFFEul}} },
 ...
}
```

6.3. segmented SDO transfer

SDO upload is not supported!

Initiate SDO Download

	CMD	Index,SubIndex	Length
Request	0x21	0x1F50 0x01	0x00004610
Response	0x60	0x1F50 0x01	0x00000000

SDO Download

	CMD	data
Request	0x00	7 Byte
Response	0x20	reserved
Request	0x00+0x10<togglebit>	7 Byte
Response	0x20+0x10<togglebit>	reserved
...		
Request	0x00+<togglebit>+<7-Länge>	0..7 Byte
Response	0x20+<togglebit>+<7-Länge>	reserved

7. Implementation Details and Application Requirements

The Paulus Bootloader can only handle application programs in binary format. The processing of programs in the Intel-Hex-Format will be supported in the future if required by customers.

The Bootloader checks the received data by a CRC checksum. Therefore an application header of 128 byte is necessary. This header can be generated with the tool **paulus_cksum** and contains the following information:

```
struct {
  UNSIGNED32  length;            /* application length       */
  UNSIGNED16  crc;               /* application crc          */
  UNSIGNED16  applicationType;   /* reserved                 */
  void (* entry_point)(void);    /* Application Entry point  */
} APPLICATION_HEADER_T;
```

Unused bytes in the application header are by default 0x00. There may be differences depending on the target.

8. Porting to STM32

Porting was carried out with the gcc based development environment CrossWorks for ARM version 2. The root of the project directory is in project file *paulus_cw_stm32.hzp*. The following figure shows the directory structure:

```
|-- Readme
|-- THUMB Debug
|-- THUMB Release
|-- bootloader
|    |-- bl_can.h
|    |-- bl_canopen.c
|    |-- bl_canopen.h
|    |-- bl_crc.c
|    |-- bl_hw.h
|    |-- bl_type.h
|    \-- bl_user.c
|-- eds
|    |-- paulus.can
|    |-- paulus.eds
|    |-- paulus.html
|    |-- paulus.xdd
|    \-- style.css
|-- flash_placement.xml
|-- hello
|    |-- flash_placement.xml
|    |-- init.c
|    |-- main.c
|    |-- main.c.bak
|    \-- stm32f10x_conf.h
|-- main.c
|-- paulus_cw_stm32.hzp
|-- paulus_cw_stm32.hzs
|-- stm32     $(TargetDir)
|    |-- STM32F10x_Startup.s
|    |-- STM32_Startup.s
|    |-- STM32_Target.js
|    |-- bl_config.h
|    |-- cw_settings
|    |-- environ.h
|    |-- fwlib3.3.0
|    |    |-- inc
|    |    \-- src
|    |-- linkeropts
|    |-- stm32_appl.c
|    |-- stm32_can.c
|    |-- stm32_flash.c
|    |-- stm32_flash.h
|    |-- stm32_init.c
|    |-- stm32f10x_conf.h
|    |-- stm32f10x_it.c
|    |-- stm32f10x_it.h
|    \-- thumb_crt0.s
\-- tools
     |-- paulus_cksum
     |-- paulus_cksum.c
     \-- create
```

When using different development environments it is important to stick to the given directory structure and the correct setup of the include paths. CAN driver and flash routines must be provided for the targets.

$(TargetDir)/$(Target)_flash.[ch]	FLASH Routinen
$(TargetDir)/$(Target)_can.[ch]	CAN Routinen
$(TargetDir)/$(Target)_init.c	CPU Initialisierung
$(TargetDir)/environ.h	allgemeiner Header

All of these modules fall back to functions of the ST firmware library. By use of the general header file *environ.h* the header files of firmware Lib are inserted. To do so the configuration file *stm32f10x_conf.h* of firmware Lib must be adjusted.

Initialization of the CAN controller is done in module *<target>/<target>_can.c*. In module *<target>/targetw>_init.c* the IO pins in function and assignment for CAN-RX and CAN-TX have to be initialized. Due to type and diverse possibilities there may be adjustments necessary.
Check the code of the functions *RCC_Configuration*(), *GPIO_Configuration*() and *initDevice*() in the file *stm32_init.c* and the used `#define`STM32F10* in *bl_config.h*.

Auto-Bus-on function of the CAN controller is used in Paulus. It constantly check for recessive bus and wakes the CAN controller automatically up from bus-off. In case of hardware errors it could disturb the complete construction.

In module *stm32_init.c* there must be the functions *getBitRate*() and *getNodeId()* available. Usually this is done by reading out jumpers or the values are stored in an area of the FLASH. For internal coding of the CAN bit rate, the CANopen index is used, a number between 0 and 8. For easier reading the following defines are available *bl_config.h*

```
#define BL_USED_BITRATE_INDEX    BITRATE_INDEX_1000K
```

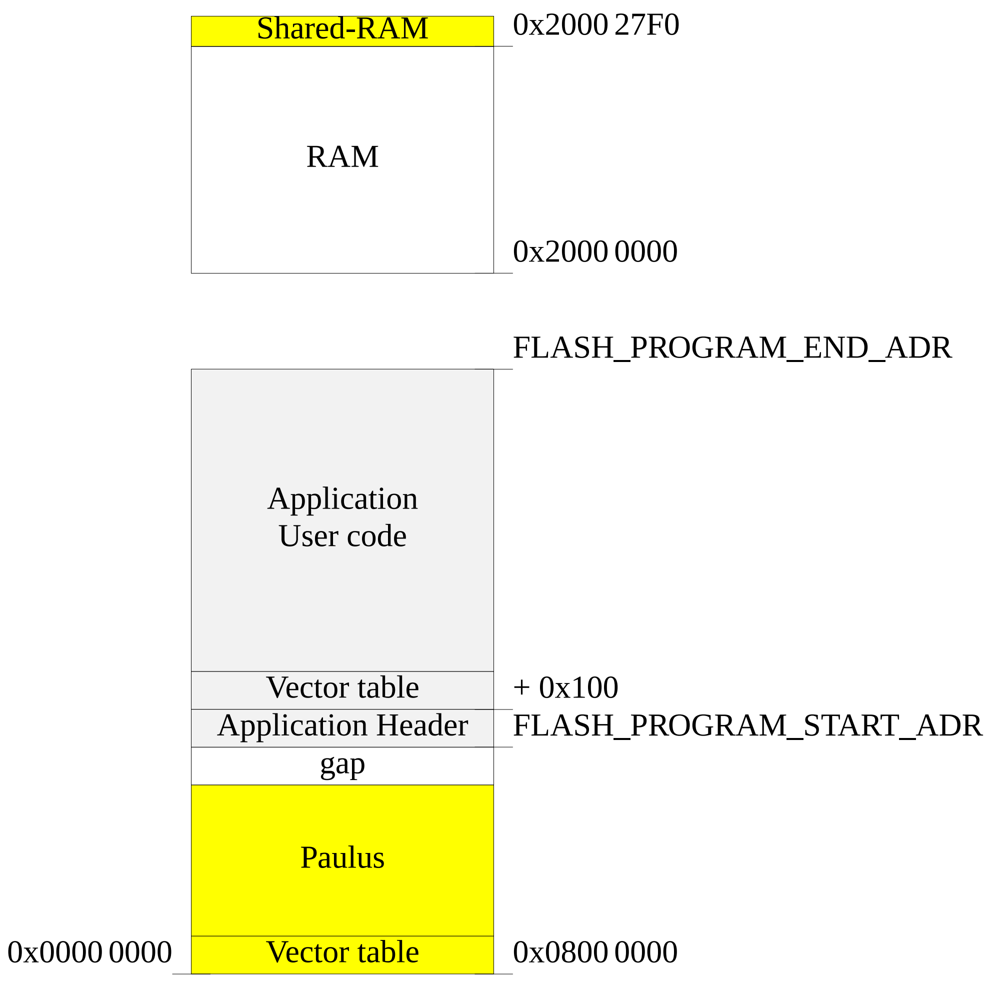
During development a debug output can be activated by a serial interface In header *bl_config.h* line

```
#define DEBUG 1
```

must be active.

In general the initialization function will initialize only the absolutely necessary peripherals like clock system, CAN, memory management as needed by Paulus. Nevertheless, there might be situations where it makes sense that Paulus initializes other functionalities which are later used by the application as well. As an example consider the UART for Debug messages and LEDs as simple status displays.

8.1. Memory usage



Memory usage (example with 10 KiB RAM)

The original flash programming of the firmware Lib is written in 2 byte style. Therefore Paulus uses the firmware Lib function *FLASH_ProgramHalfWord*(); This function takes over to unlock the programming function, writing and waiting for completion. The memory area for the application i.e. the area that can be deleted and rewritten is defined in *stm32/stm32_flash.h* with constants

```
#define FLASH_PROGRAM_START_ADR
#define FLASH_PROGRAM_END_ADR
```

It must be adjusted when the the processor is changed. That defines the area which is deleted when writing to 0x1f51:1=3 The area that is written is defined by the length of the download image.

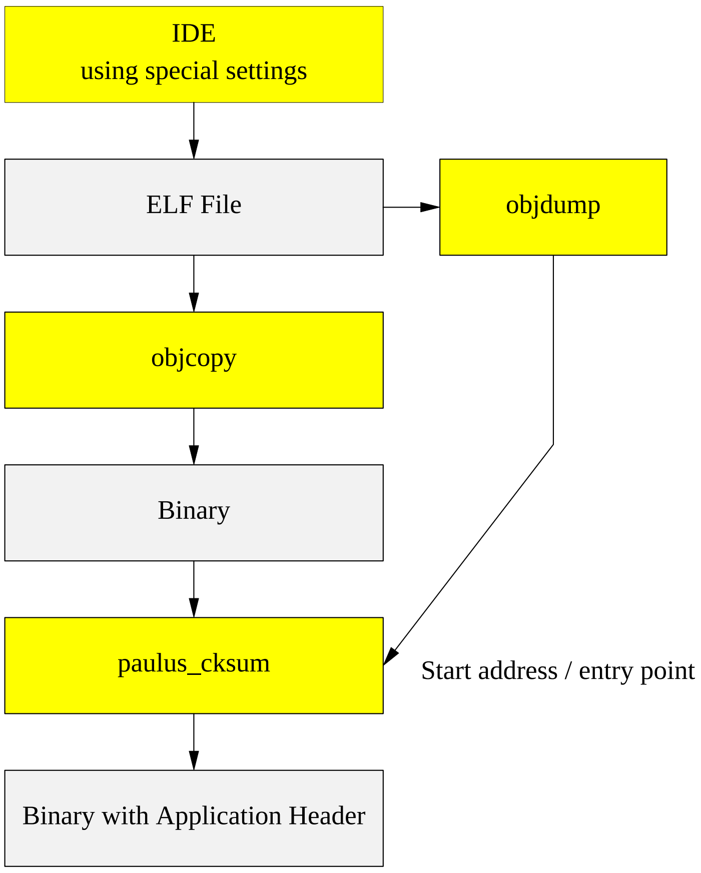
8.1.1. Code size

The following table shows typical FLASH sizes of an typical minimum implementation[6].

section	size
.vectors	236
.init	384
.text	4.1 KiB
.rodata	564
.data	256
overall	0x1660 (5.6 KiB)

8.2. Generating the user image

The user image is created as follows.



The shell script *tools/createstm32image* organizes these steps.

The following command sequence shows the result of objdump:

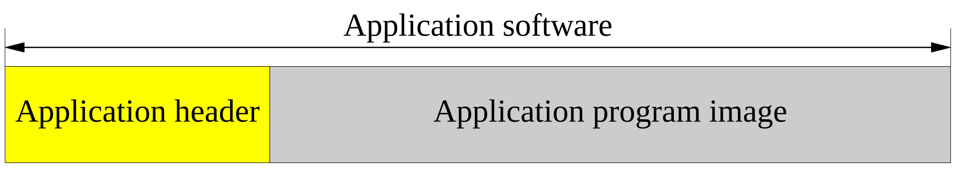
[6] without LSS

```
$ /usr/share/crossworks_for_arm_2.0/gcc/bin/objdump -f THUMB Release/hello.elf

THUMB Release/hello.elf:     file format elf32-littlearm
architecture: arm, flags 0x00000012:
EXEC_P, HAS_SYMS
start address 0x080022ed
```

Using CrossWorks, the *start address* is the address of the *reset_handler* in *STM32_Startup.s*.

8.2.1. paulus_cksum

paulus_cksum calculates the CRC checksum of the binary application program, generates the application header and stores the application header and the application program in a new file. This file can be loaded in a device with the Bootloader.



The Bootloader checks the received data by a CRC checksum. Therefore an application header is necessary. This header can be generated with the tool **paulus_cksum** and contains the following information as described in chapter 7 `APPLICATION_HEADER_T`.

Unused bytes in the application header are set to 0xFF with the STM32. Length of the application header is 256 bytes.
Example:

```
$ tools/paulus_cksum -v -l 256 -C -O download.bin -v -x $EXEC appl.bin
size: 0x00003524,  crc: 0x1cb5,  file: >appl.bin<
$ l appl.bin  download.bin
-rwxrwxrwx 1 oe users 13604  9. Sep 16:59 appl.bin*
-rw-rw-rw- 1 oe users 13732  9. Sep 17:00 download.bin
```

Besides checking the CRC the bootloader is checking also the size information of the header. A size of 0 is invalid. An application may destroy the 'valid' information by overwriting the size information with 0. That is always possible on the STM32 FLASH, because erased content is 0xFF.

8.3. Creation of the application

Following explanations are written as general as possible, but refer to the use of CrossWorks for ARM version 2.

8.3.1. Start address

It is important that the start address of the user application in FLASH and the information in the Paulus configuration in Flash in *stm32/stm32_flash.h* are the same. The user image is stored into FLASH behind Paulus code. Therefore the image is flashed to

```
#define FLASH_DATA_START_ADR
```

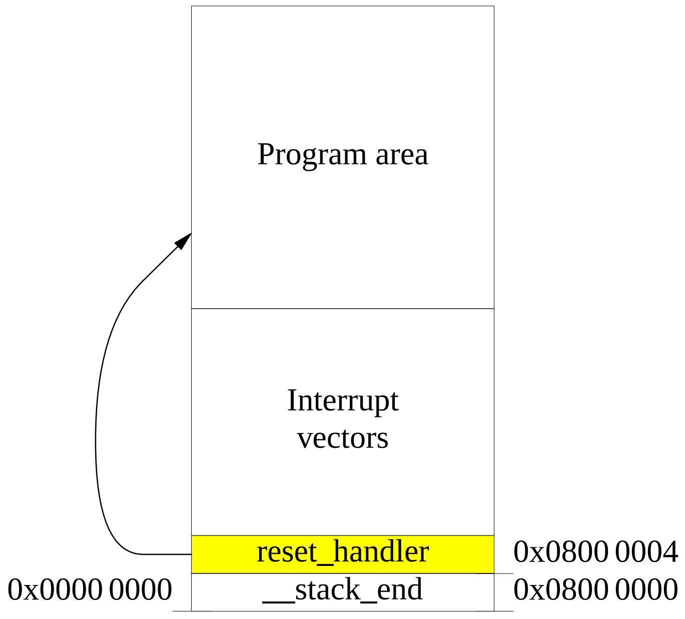
The actual application starts 256 byte later. The given start address for the linker is e.g. for CrossWorks with

```
linker_section_placement_macros="FLASH_START=0x8002100" 7
```

From the STM32 manual:

> *After this startup delay has elapsed, the CPU fetches the top-of-stack value from address 0x0000 0000, then starts code execution from the boot memory starting from 0x0000 0004.*

A STM32 program starts as follows (names as used in CrossWorks): (Address labels as used in CrossWorks):



In order to start the application correctly it is necessary to set the *define* `STARTUP_FROM_RESET` when compiling *STM32_Startup.s*. Otherwise, at least CrossWorks compiles a loop as the *reset_handler* called *reset_wait* to give a Debugger the chance to stop execution at e defined location.

8.4. Use case

Paulus Bootloader and an example use case are included in the delivery as two projects for one *Solution*. The application is the project **hello** which gives out instruction messages at the UART and receives instructions by the user at the UART. It is possible to

[7] allocated under the premise that Paulus takes 0x2000 byte.

command different possibilities to return to PAULUS. Both, application and PAULUS, are communicating via the shared memory in RAM by using different signatures built of 4 bytes in RAM.

9. Porting to dsPIC33

Porting was carried out with the Microchip MPLAB development environment. The root of the project directory is in project file *paulus_dspic.mcp*. The following figure shows the directory structure:

```
|-- bootloader
|    |-- bl_can.h
|    |-- bl_canopen.c
|    |-- bl_canopen.h
|    |-- bl_config.h_template
|    |-- bl_crc.c
|    |-- bl_hw.h
|    |-- bl_type.h
|    \-- bl_user.c
|-- dsPIC
|    |-- Readme
|    |-- bl_config.h
|    |-- bl_flash.h
|    |-- bl_interface.c
|    |-- bl_interface.h
|    |-- dspic_appl.c
|    |-- dspic_can.c
|    |-- dspic_flash.c
|    |-- dspic_flash.h
|    |-- dspic_init.c
|    |-- environ.h
|    |-- p33FJ256GP710.gld  >gcc 3.20
|    \-- p33FJ256GP710_old.gld <gcc 3.20
|-- eds
|    |-- paulus.can
|    |-- paulus.eds
|    \-- paulus.html
|-- examples    Example projects
|-- main.c
|-- paulus_dspic.bin
|-- paulus_dspic.cof
|-- paulus_dspic.hex
|-- paulus_dspic.map
|-- paulus_dspic.mcp  Paulus project
|-- paulus_dspic.mcs
|-- paulus_dspic.mcw
|-- tools
|    |-- paulus_cksum
|    |-- paulus_cksum.c
|    \-- dsPIC_binutils
|        |-- objcopy
|        \-- objdump
\-- version.h
```

These components were used for the porting:

Derivate	dsPic33FJ256GP710
Quarz	8MHz
IDE	MPlab 8.60
Compiler	pic30-gcc v3.24

Settings for CAN and flash are dependent on the used derivates. There are also dependencies on the used clock.

dsPIC/dspic_can.[ch]	CAN Routinen
dsPIC/dspic_init.c	CPU Initialisierung
dsPIC/dspic_flash.[ch]	FLASH Routinen
dsPIC/environ.h	allgemeiner Header
dsPIC/bl_interface.[ch]	Interface zu Applikation

To achieve a minimal code size interrupts are not applied. As consequence the IVT is free for usage by the application. The reset vector must point to the vector address of the bootloader to make sure it starts there and carries out check sum.

Reset vector is deleted during Erase and overwritten with the applications images.

For the adaption of the flah routines some steps are necessary. They are in *dspic_flash.h* and are dependent on the derivates.

```
/* (reserved) Paulus code size */
#define FLASH_SIZE_PAULUS     16   /* in KiB */

/* first flash address (incl. Bootloader) */
#define FLASH_START_ADR            0x00000000ul

/* Define the FLASH Page Size depending on the used device */
#define FLASH_ERASE_PAGE_SIZE (512*2)
/* Number of words to gbe flashed at a time */
#define FLASH_PAGE_SIZE  (64*4)         /* in words */
```

Flashing starts with address 0. The application starts after the bootloader. To skip the bootloader the addresses are needed.

```
/** Applikationsstartaddr im Flash (incl header ) */

/* Reset vector - start of flashing */
#define FLASH_PROGRAM_START_ADR 0x0000ul

/* word address */
#define FLASH_PROGRAM_REAL_START_ADR 0x4000ul

/** max. Application size im Flash (incl header) */
#define FLASH_PROGRAM_MAX_SIZE     \
     (FLASH_PROGRAM_END_ADR - FLASH_PROGRAM_START_ADR + 1)

/* max siez without vectors - word size */
#define FLASH_PROGRAM_REAL_MAX_SIZE     \
     (FLASH_PROGRAM_END_ADR - FLASH_PROGRAM_REAL_START_ADR + 1)
```

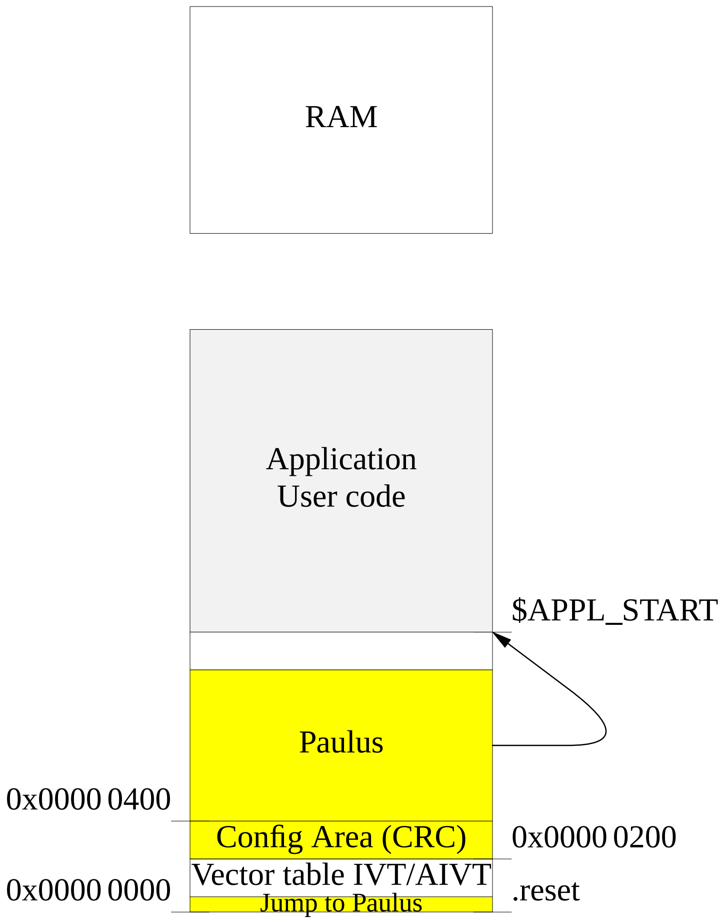
Maximum size of the application and end of flash depend on the chosen derivate.

```
/* FLASH config data - word address */
#if defined(DSPIC33FJ64)
#define FLASH_PROGRAM_END_ADR 0xABFF

#elif defined(DSPIC33FJ128)
#define FLASH_PROGRAM_END_ADR 0x157FF

#elif defined(DSPIC33FJ256)
#define FLASH_PROGRAM_END_ADR 0x2ABFF /* word address */

#else
# error "One DSP version has to be specified"
#endif
```

When Paulus size was not changed, only adaption of the value for `FLASH_PROGRAM_END_ADR` is necessary. It is recommended to check the other values.

Value for `FLASH_PROGRAM_REAL_START_ADR` must be the same as the linker settings of Paulus (after the memory area **program**) and the application linker settings (start of **program**)

9.1. Memory



The APPL_START value is set with 0x4000 which allows an easy implementation with debugging and a great number of printf output. After doing own adjustments it is possible to optimize this value to get more space for the application.

9.2. Application

In linker file (e.g. *paulusExample_p33FJ256GP710.gld*) the reset vector must be on address 0, but it has to point to the beginning of Paulus.

```
__CODE_BASE = 0x4000;
__BL_BASE = 0x400;
```

```
SECTIONS
{
  .reset :
  {
        /* Jump to the boot-loader entry */
        SHORT(ABSOLUTE(__BL_BASE));
        SHORT(0x04);
        SHORT((ABSOLUTE(__BL_BASE) >> 16) & 0x7F);
        SHORT(0);
  } >reset

}
```

The application starts after Paulus.

```
MEMORY
{
    program (xr) : ORIGIN = 0x4000,         LENGTH = 0x26C00
}
```

The vector address must now be on the first possible address in the linkerfile.

```
0x004000                  __resetPRI
```

The application should not contain fuse settings. They blow up the image and Paulus uses its own fuse settings.

9.2.1. Debugging

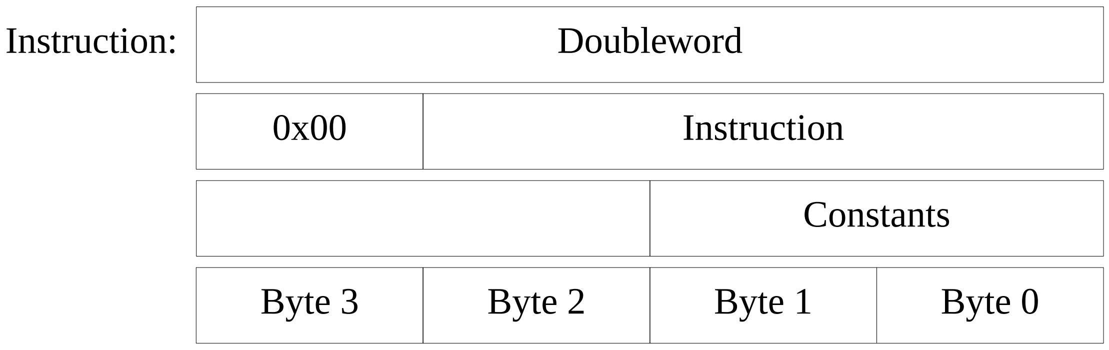
It is recommenden to develop the application without the bootloader. For debugging with the bootloader following steps are recommended.

- Paulus is already installed on dsPic33. It was flashed in debug mode.
- The application project is opened in MPLAB.
- Application and download image are created. Paulus has to be activated with "RUN" in the debugger. Ignore the note that memory has changed. The image is flashed by Paulus (not by debugger).
- After a reset of the processor, Paulus analyzes the checksum and starts the application.
- Now it is possible to debug as usual.

9.3. Binary image

The binary image is created of the kind to make working within Paulus as easy as possible. MPLAB routines are used:

- _write_flash24() - flashing the image, needs 4 byte per instruction
- _memcpy_p2d24() - for CRC calculating of the application supplies 3 byte per instruction
- _memcpy_p2d16() - for data reading from flash, 2 byte per instruction

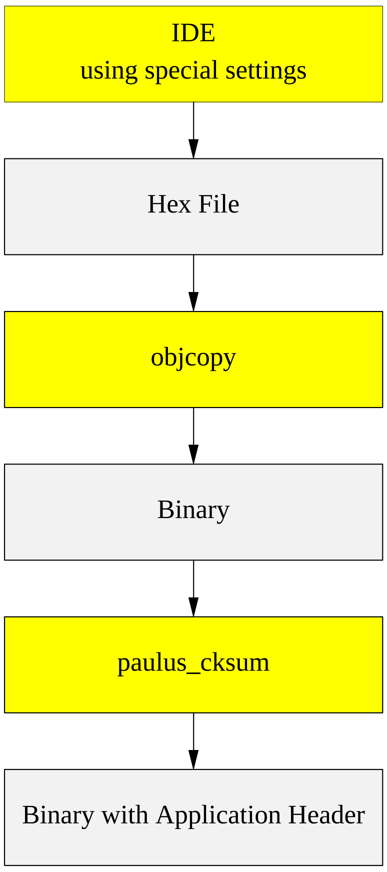


For calculating CRC byte 3 is ignored.

The address area of the botloader is transmitted with the image, but not flashed.

9.4. Generation of the user image

The user image is created with following steps.



The shell script *create* organizes these steps.

9.4.1. objcopy

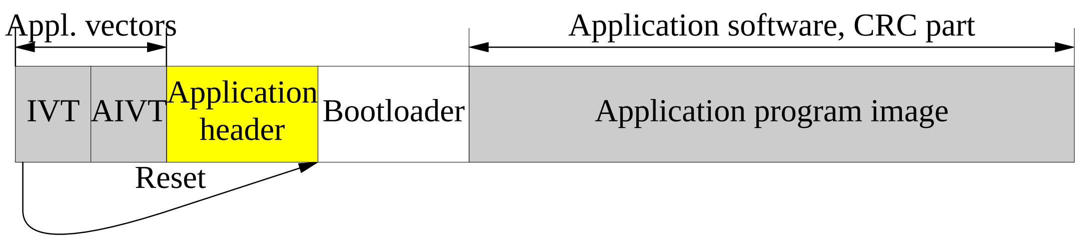
The creation of the binary image is done out of the iHex-file. It is recommended not to compile a fuse bit configuration into the application. The fuse bit configuration of Paulus is used. The fuse bit configuration within the application is therefore dispensable and would enlarge the binary image significantly .

```
objcopy -I ihex -O binary --gap-fill 0xFF appl.hex appl.bin
```

-I ihex	Inputformat ihex
-O binary	Outputformat binary
−−gap-fill 0xFF	fill gaps with 0xFF

9.4.2. paulus_cksum

paulus_cksum calculates the CRC checksum of the binary application program, generates the application header and stores the application header and the application program in a new file. This file can be loaded in a device with the bootloader.



The bootloader checks the received data by a CRC checksum. Therefore an application header of 128 byte is necessary. This header can be generated with the tool **paulus_cksum** and contains the following information as described in chapter 7 `APPLICATION_HEADER_T`.

Bsp: dsPic33FJ256GP710

```
paulus_cksum -P -C -a 0x400 -b 0x8000 -c 0x55800 -x 0x4000 \
-O appl.crc appl.bin
```

-P	dsPic33
-C	CANopen CRC
-a	CRC Block address (byte address)
-b	Application start address (byte address)
-F	Flash end address (byte address)
-O	output file (incl appl.bin) == complete domain
-x	Entry point (without conversion)

The Flash end address is required to ignore the Configuration bits, if this bits are included in the binary. The used addresses are byte addresses, the common Word-addresses of dsPIC33 have to be duplicated, therefore.