

# LPC8xx Safety Example



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# Chapter 1

## IEC60730B Safety library example user's guide

For easier development of the IEC60730B application, the library also provides the example code. This example is distributed through the [MCUXpresso SDK website](#). This example user's guide describes how to set the hardware correctly and how to use the example code with the IEC60730B Safety library.

The library user's guide is the main documentation for IEC60730B. It is also part this package and accessible at [www.nxp.com/IEC60730](http://www.nxp.com/IEC60730).

# Chapter 2

## Hardware settings

This chapter describes how to set up the hardware of the evaluation board. The MCU peripherals' setup is described later on.

The IEC60730B library example for the LPC8xx family supports the following development boards:

- LPCxpresso845Max
- LPCxpresso824Max
- LPCxpresso804

To run the IEC60730B example application, it is necessary to make some hardware settings. For the default configuration of your development board, see the corresponding board's user manual at [www.nxp.com](http://www.nxp.com).

### 2.1 LPCXpresso824MAX

To use the on-board debugger, make sure that jumper JP1 (next to the USB connector) is open. Short this jumper to use an external debug connector.

The ADC module on LPCXpresso824MAX does not allow to connect the VrefH, VrefL, and Bandgap internally to the ADC input. Connect these signals (for the Analog I/O test) as follows:

- VrefH - 3.3 V on PIO0\_21(conn. J5-5).
- VrefL - GND on PIO0\_20 (conn. J5-6).
- Bandgap - connect a custom reference (for example 1.65 V) to PIO0\_22 (conn. J5-4). The expected value of the custom bandgap can be set in the *safety\_config.h* file (`#define ADC_BANDGAP_LEVEL 1.65`).

An example of the corresponding connection is shown in [Figure 1](#).

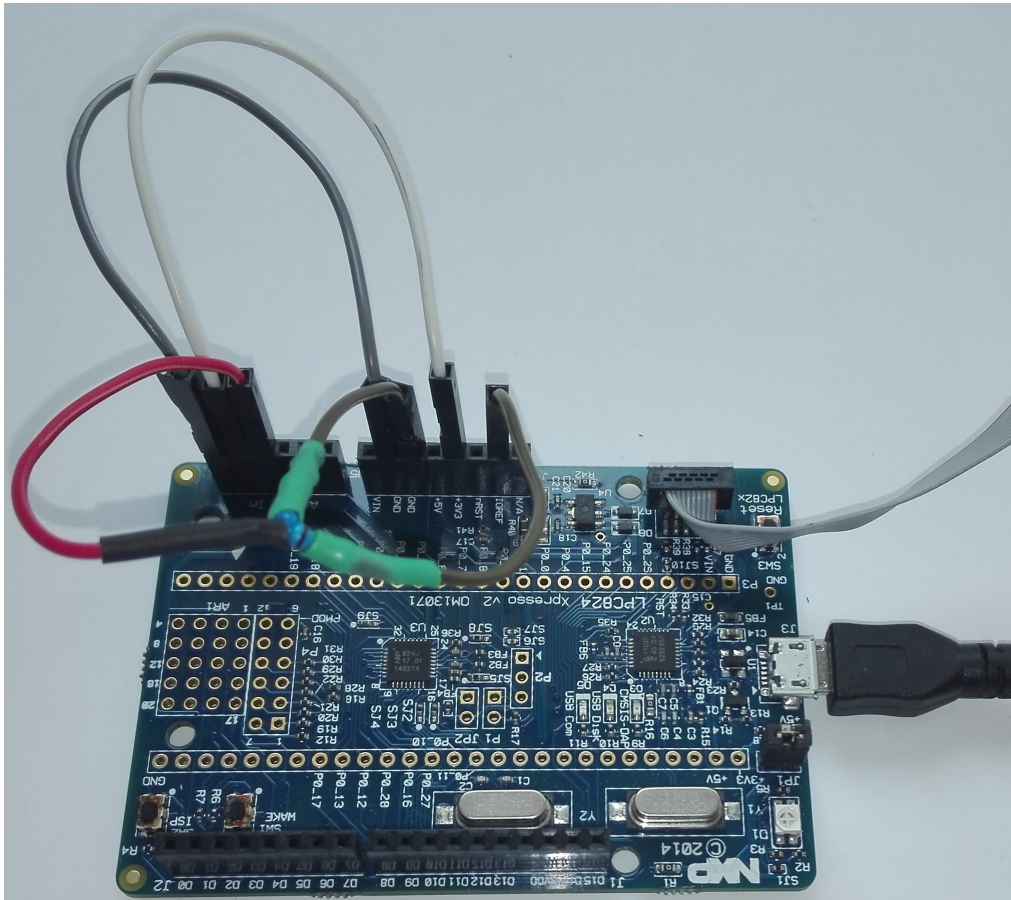


Figure 1. Hardware connection of LPCXpresso824MAX

In Figure 1, an external debugger is used. Due to this, jumper JP1 is shorted. The test voltage of 1.65 V is provided by a resistor voltage divider from the VCC (3.3 V).

#### NOTE

To use FreeMASTER, ensure that solderjumper SJ9 is set to position 2-3 (default is 1-2). For more information, see the LPCXpresso824MAX schematic on [www.nxp.com](http://www.nxp.com).

## 2.2 LPCXpresso845MAX

To use the on-board debugger, make sure that jumper JP1 (next to the USB connector) is open. Short this jumper to use an external debug connector.

The ADC module on LPCXpresso845MAX does not allow to connect the VrefH, VrefL, and Bandgap internally to the ADC input. Connect these signals (for the Analog I/O test) as follows:

- VrefH - 3.3 V on PIO0\_23 (conn. J6-2).
- VrefL - GND on PIO0\_14 (conn. J6-1).
- Bandgap - connect a custom reference (for example 1.65 V) to PIO0\_19 (conn. J6-3). The expected value of the custom bandgap can be set in the *safety\_config.h* file (`#define ADC_BANDGAP_LEVEL 1.65`).

An example of the corresponding connection is shown in Figure 2.

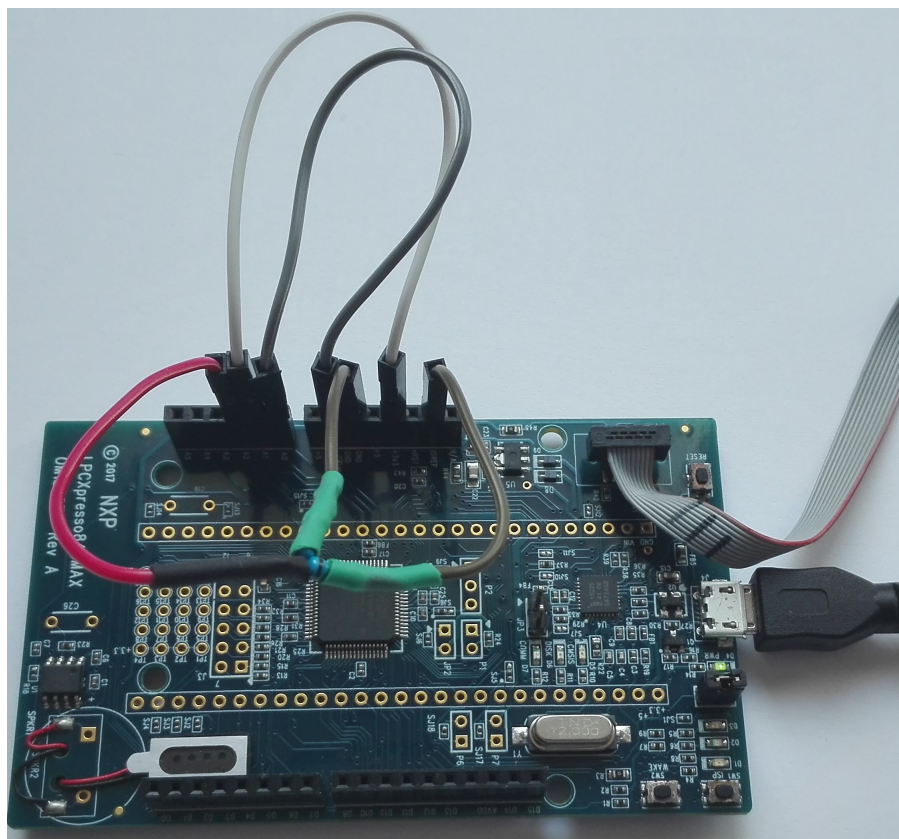


Figure 2. Hardware connection of LPCXpresso845MAX

In [Figure 2](#), the external debugger is used. Due to this, jumper JP1 is shorted. The test voltage of 1.65 V is provided by a resistor voltage divider from the VCC (3.3 V).

# Chapter 3

## File structure

Safety is only a small part of the whole SDK package for your device. The IEC60730 library and examples are located in the middleware and in the board folders. The IEC60730 library is independent of the SDK and can be used stand-alone.

### 3.1 Library source files location

The library source files are in the *middleware/safety\_iec60730b/safety/v4\_1* folder in the SDK package.

The folder has the following structure:

Name	Ext	S
[..]		<
[common_test]		<
[compiler]		<
[core_test]		<
IEC60730B_M4_M7_KEIL_v4_1	lib	
IEC60730B_M4_M7_COM_KEIL_v4_1	lib	
IEC60730B_M33_KEIL_v4_1	lib	
IEC60730B_M33_COM_KEIL_v4_1	lib	
IEC60730B_M0_KEIL_v4_1	lib	
IEC60730B_M0_COM_KEIL_v4_1	lib	
iec60730b_types	h	
iec60730b	h	
libIEC60730B_M4_M7_MCUX_v4_1	a	
libIEC60730B_M4_M7_COM_MCUX_v4_1	a	
libIEC60730B_M33_MCUX_v4_1	a	
libIEC60730B_M33_COM_MCUX_v4_1	a	
libIEC60730B_M0_MCUX_v4_1	a	
libIEC60730B_M0_COM_MCUX_v4_1	a	
IEC60730B_M4_M7_IAR_v4_1	a	
IEC60730B_M4_M7_COM_IAR_v4_1	a	
IEC60730B_M33_IAR_v4_1	a	
IEC60730B_M33_COM_IAR_v4_1	a	
IEC60730B_M0_IAR_v4_1	a	
IEC60730B_M0_COM_IAR_v4_1	a	

Where:

- common\_test contains the source files for the “peripheral” test – this is a common cross core. These tests are compiled to library *libIEC60730B\_<core>\_COM\_<compiler>\_<version>.a*.
- compiler - compiler support files.
- core\_test contains the source files for the core-dependent test. These tests are compiled to library *libIEC60730B\_<core>\_<compiler>\_<version>.a*.
- *iec60730b.h* is the main library header file.
- *iec60730b\_types.h* is the header file with the necessary defines for the library.

The folder also contains binary *\*.lib* files which are compiled for the IAR, Keil, and MCUXpresso IDEs (see the release notes for details).

## 3.2 Example of library handling code

The library-handling code and the example application are separate from the library file. The example source files and other SDK examples are at this path:

***boards/<your board>/demo\_apps/safety\_iec60730b/***

The safety example code is shown in Figure 3.

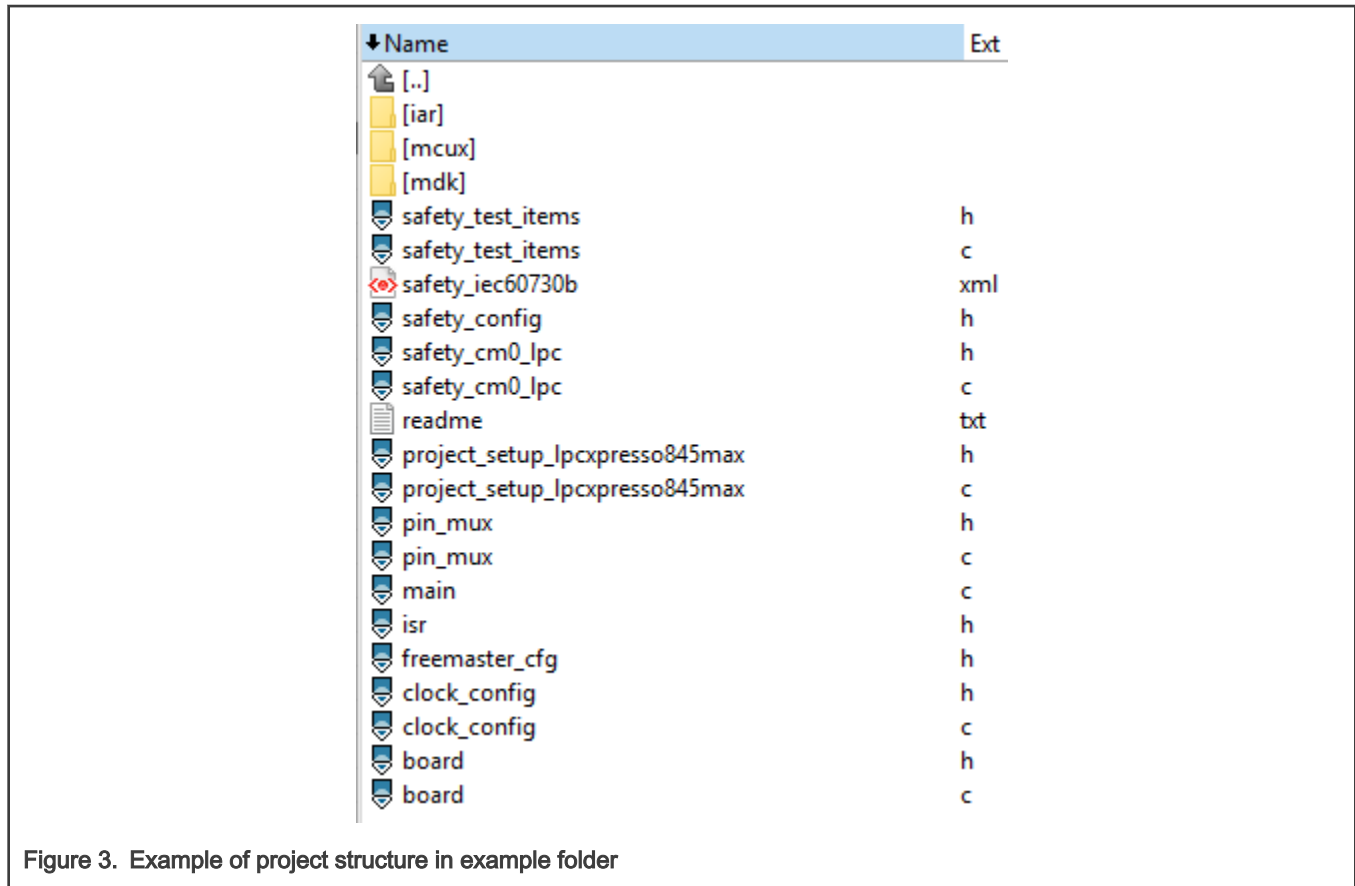


Figure 3. Example of project structure in example folder

This folder contains the example source file and three folders for the IDE project file:

- *iar*
- *mcux*
- *mdk*

The following files are generated by the MCUXpresso configuration tool:

- *clock\_config.h*
- *clock\_config.c*
- *pin\_mux.c*
- *pin\_mux.h*

Other files are used only for safety examples and their contents are described in the next chapter.



## Chapter 4

# Example application

The structure of the example is common in all supported IDEs (IAR, Keil, MCUXpresso).

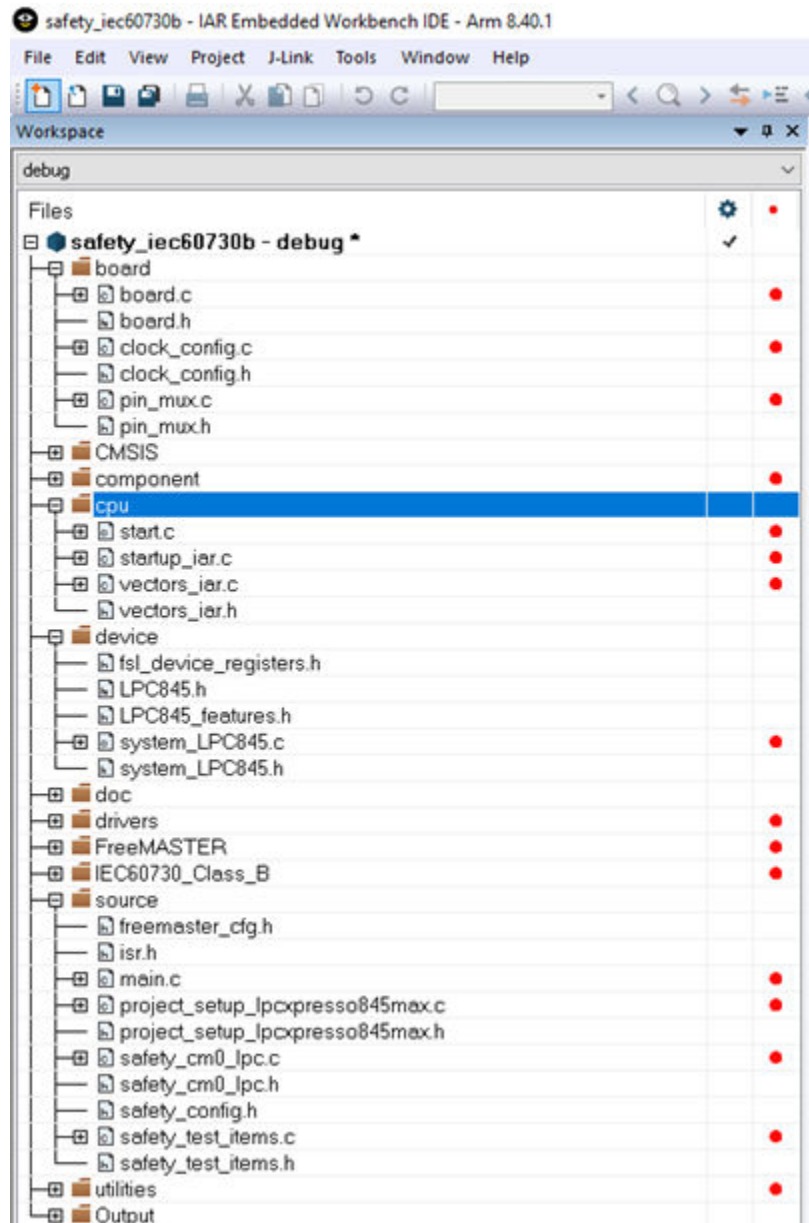


Figure 4. IAR example application structure

The project contains the CMSIS, SDK, library, and safety example-related folders.

The safety-related folders are the following:

- *Board* – this folder contains the files related to the board used (*clock\_config.h*, *pin\_config.h*, *board.h*, and so on).
- *CPU* – this folder contains the startup code and vectors table.
- *IEC60730\_Class\_B* – files for the IEC60730B Safety library.

- *Source* – source file for the safety example (see the next explanation).

The example of project hierarchy is shown in [Figure 5](#).

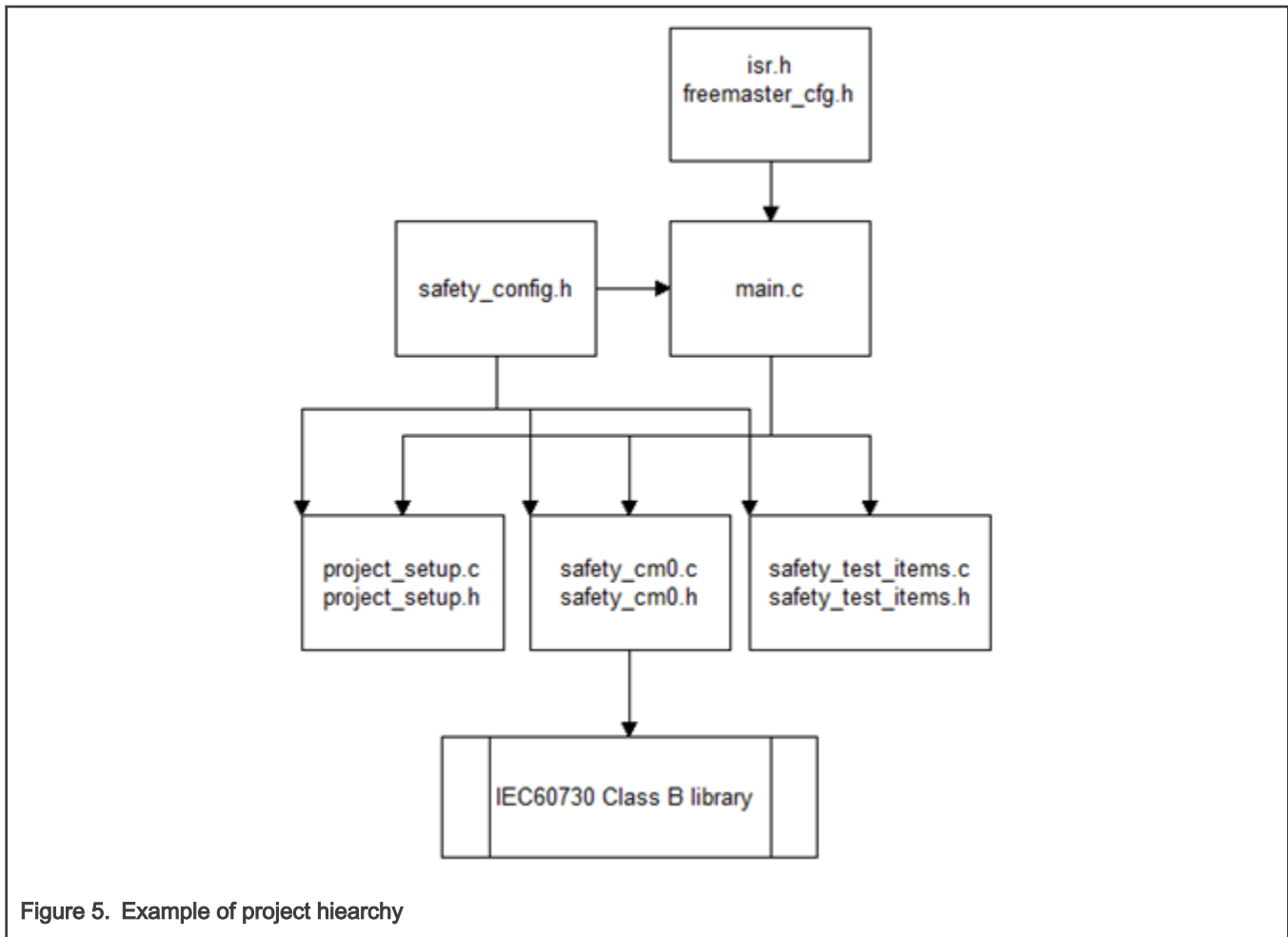


Figure 5. Example of project hierarchy

[Figure 5](#) shows that the functions in the *project\_setup.c* file are called from the *main.c* file. The library-handling functions are located in the *safety\_cm0\_lpc.c* file and also called from the *main.c* file.

The main example application header file *safety\_config.h* contains all definitions for running the safety test in examples. The *safety\_test\_items.c* file declares the structures for the DIO (or TSI) safety test. The *project\_setup\_<your\_board>.c* file contains the setup functions (clock, port, UART, and so on). The *safety\_cm0\_lpc.c* file contains the handling function for safety routines from the IEC60730B library and also the test-initialization function for safety.

## 4.1 How to open the project

### IAR IDE

Open the project file located at *boards/<your\_board>/demo\_apps/safety\_iec60730b/iar/safety\_iec60730b.eww*.

### Arm Keil IDE

Open the project file located at *boards/<your\_board>/demo\_apps/safety\_iec60730b/mdk/safety\_iec60730b.uvprojx*.

### MCUXpresso IDE

Firstly, drag and drop the *<name\_of\_the\_package>.zip* package into the MCUXpresso IDE (into the "Installed SDKs" tab). Secondly, import the SDK example (*safety\_iec60730b*).

If you are not familiar with the MCUXpresso IDE yet, see *docs/Getting Started with MCUXpresso SDK for <your\_board>.pdf* ("Build an example application" section).

## 4.2 Example settings - safety\_config.h

The main example settings header file is *safety\_config.h*. The necessary macros for the safety example are defined in this file.

The "switch macros", which enable the user to turn off calling of the safety test, are defined in the beginning. When starting, turn off the FLASH test and the WDOG test. On LPC devices, turn off also the Clock test.

```
/* This macro enables infinity while loop in SafetyErrorHandling() function */
#define SAFETY_ERROR_ACTION 1

/* TEST SWITCHES - for debugging it is better to turn the flash test and watchdog OFF */
#define ADC_TEST_ENABLED 1
#define CLOCK_TEST_ENABLED 1
#define DIO_TEST_ENABLED 1
#define FLASH_TEST_ENABLED 1
#define PC_TEST_ENABLED 1
#define WATCHDOG_ENABLED 1
#define FMSTR_SERIAL_ENABLE 1
```

Other defines are used to configure the safety test as a parameter to a function or to fill structures.

## 4.3 safety\_test\_items.c file

The *safety\_test\_items.c* and *.h* files are the configuration files for the DIO test.

The file contains the *fs\_dio\_test\_<platform>\_t* list of structures. The pointers to these structures are collected in the *dio\_safety\_test\_items[]* array, which is used in the example application.

```
fs_dio_test_lpc_t dio_safety_test_item_0 = /* P0_13 */
{
    .iocon_mode_shift = IOCON_PIO_MODE_SHIFT, /*Device depend */
    .pPort_byte = (uint8_t *)&(GPIO->B[0][13]), /* Address of byte register in GPIO */
    .pPort_dir = (uint32_t *)&(GPIO->DIR[0]), /* Address of dir1 register */
    .pPort_iocon = (uint32_t *)&(IOCON->PIO[IOCON_INDEX_PIO0_13]), /* Address of concrete IOCON register */
    .pinNum = 13, /* Position in DIR register */
    .gpio_clkc_shift = SYSCON_SYSAHBCLKCTRL_GPIO_SHIFT
};

/* NULL terminated array of pointers to dio_test_lpc_t items for safety DIO test */
fs_dio_test_lpc_t *dio_safety_test_items[] = {&dio_safety_test_item_0, &dio_safety_test_item_1, NULL};
```

## 4.4 Source file - `safety_cm0_lpc.c/.h`

The *safety\_cm0\_lpc.c* source file and the corresponding *\*.h* file contain a library handling function. Each function contains a detection. If a safety error occurs, the *SafetyErrorHandling()* function is called.

## Chapter 5

# Running example

For the first run of the example on your hardware, it is recommended to turn off Flash, WDOG, Clock, AIO, and DIO test. In the next step, turn on step by step.

When the WDOG is turned off and a safety error happens, the example stays in an endless loop.

### 5.1 FreeMASTER monitoring

FreeMASTER is used as the external PC tool for real-time monitoring. FreeMASTER is also implemented in the IEC60730B safety examples. For simplicity reasons, the MAP file is the source of the variable address. Before connecting FreeMASTER to your application, make sure that the application is running.

#### Running FreeMASTER:

Download and install FreeMASTER from [www.nxp.com/freemaster](http://www.nxp.com/freemaster).

The example project is in the *safety.pmp* file. Open it.

Check the project settings for your application:

- Open "Project->Options ->MAP Files". It must point to your output files.

#### IAR IDE and ARM Keil IDE

Navigate to the *boards/<your\_board>/demo\_apps/safety\_iec60730b/<compiler>/<debug or release>/\*.out* file.

#### MCUXpresso IDE

Navigate to the *<workspace>/<project\_name>/<Debug or Release>/<project\_name>.axf* file.

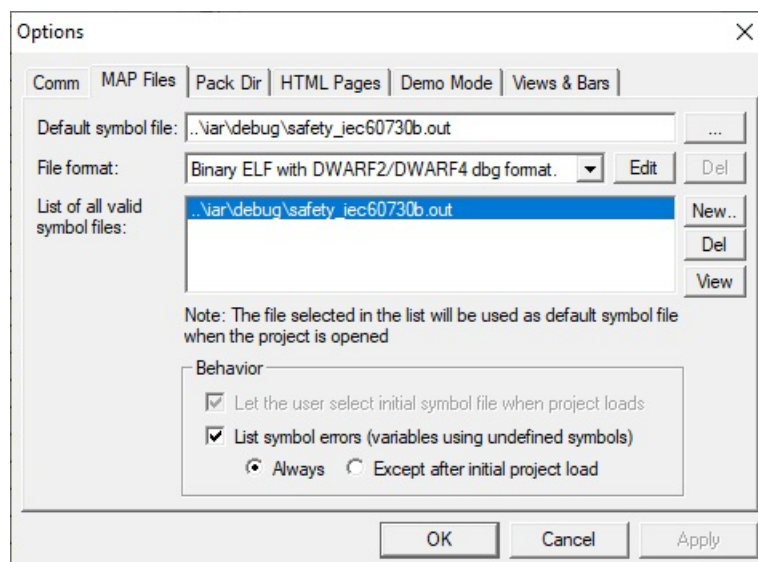


Figure 6. Example of setting MAP files for FRDM-KV11 board

- Open "Project ->Options ->Comm" and select a correct RS-232 connection and speed. The connection speed is in the *safety\_config.h* file's "SERIAL\_BAUD\_RATE" macros. By default, this speed is set to 9600 bd.

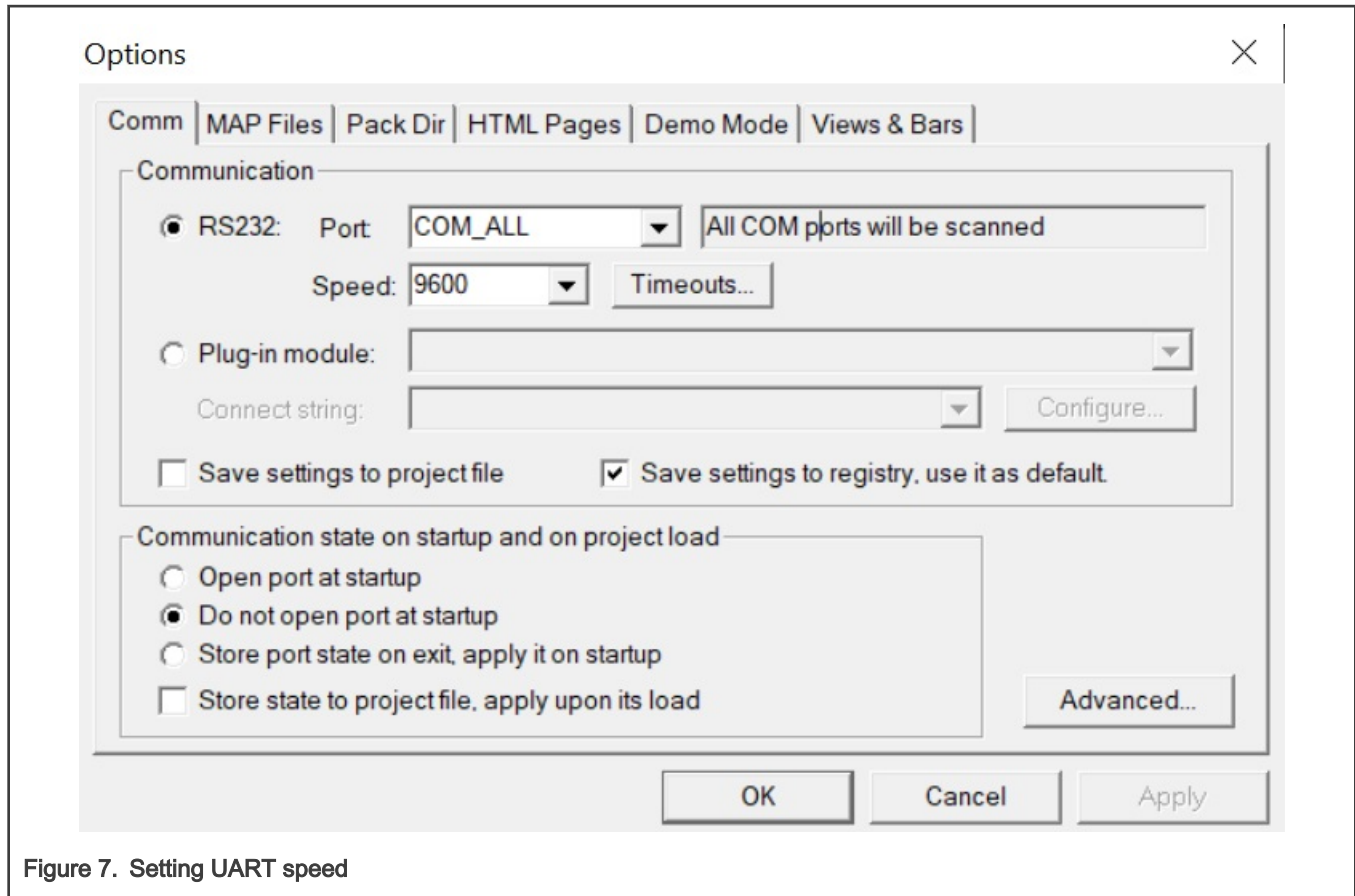


Figure 7. Setting UART speed

Now you can connect to the development board by pressing "CTRL+G" or clicking the "GO" button:

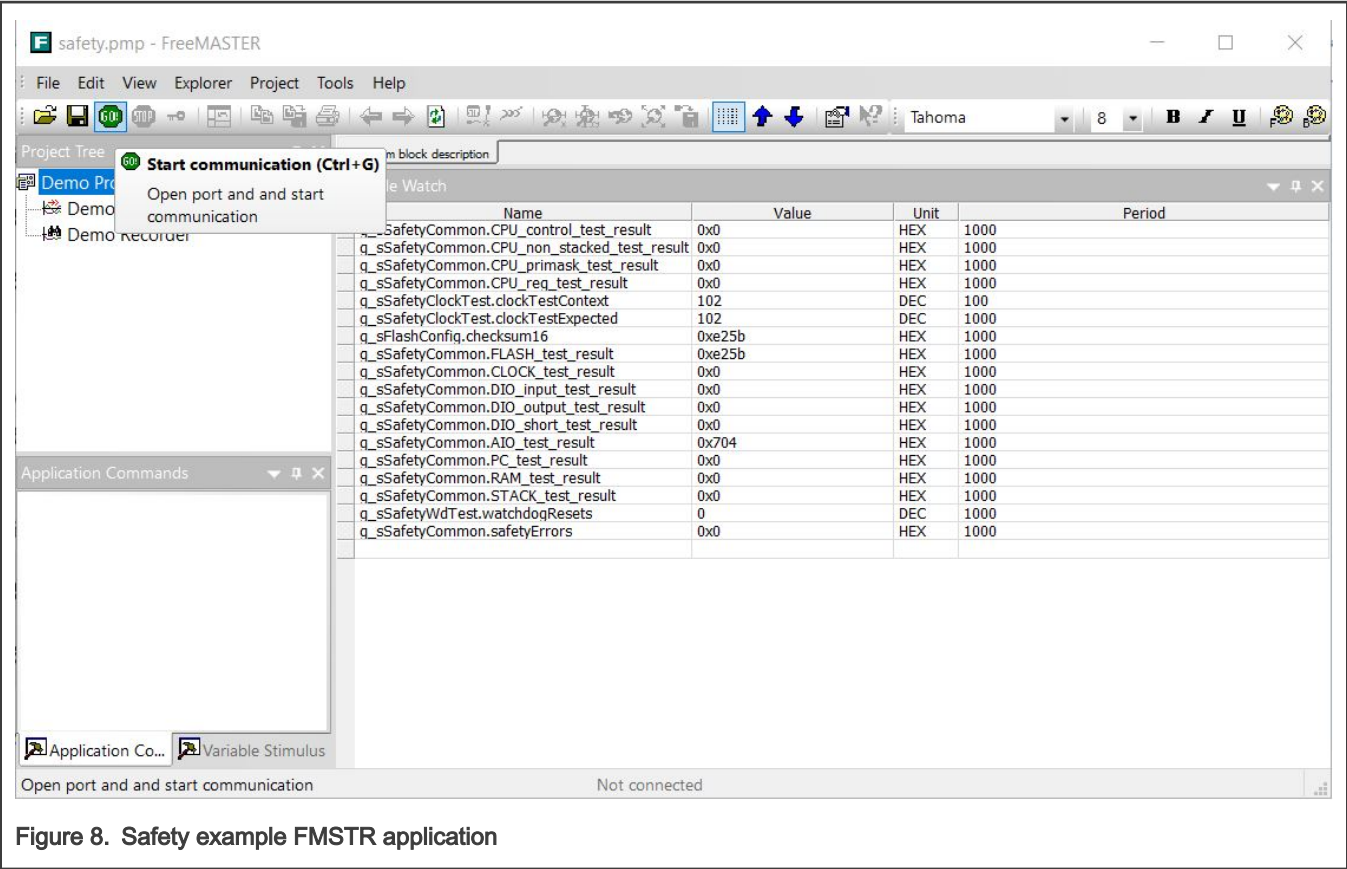


Figure 8. Safety example FMSTR application

Usually, the AIO test is a number of results oscillating between 0x0 and 0x704 (test passed and test in progress).

# Chapter 6

## IEC60730B tests

The library contains the following tests:

- Analog I/O test
- Clock test
- CPU register test
- Digital I/O test
- Invariable memory (flash) test
- Variable memory (RAM) test
- Program counter test
- Stack test
- Watchdog test
- Touch-sensing peripheral TSIv5 test

The following chapters describe each test with focus on the example application (debugging).

### 6.1 AIO test

The analog IO test procedure performs the plausibility check of the digital IO interface of the processor. The analog IO test can be performed once after the MCU reset and also during runtime.

There are three values tested in the application:

- VrefH
- VrefL
- Bandgap

Ensure that the ADC peripheral is set up correctly before calling the AIO test. In some cases, it is necessary to connect this signal externally (by a wire) to the corresponding pin. The test is performed in a sequence, as defined in the *safety\_config.h* file:

```
/* ADC test */
...
...
{
    {(uint32_t)ADC_MIN_LIMIT(0), (uint32_t)ADC_MAX_LIMIT(60)}, |
    {(uint32_t)ADC_MIN_LIMIT(ADC_MAX), (uint32_t)ADC_MAX_LIMIT(ADC_MAX)}, |
    {(uint32_t)ADC_MIN_LIMIT(ADC_BANDGAP_LEVEL_RAW),
    (uint32_t)ADC_MAX_LIMIT(ADC_BANDGAP_LEVEL_RAW)} | }

#define FS_CFG_AIO_CHANNELS_INIT {6, 5, 4} /* ADC Channels for V_refl, V_refh, bandgap */
```

An example of the setting is shown above. The "FS\_CFG\_AIO\_CHANNELS\_INIT" macro defines that the ADC channel 6 is tested first, with the limits corresponding to VrefL (GND). Channel 5 is tested next, with the limits of VrefH (VCC). Channel 4 is tested next, with the limits for the bandgap.



## 6.2 Clock test

The clock test procedure tests the oscillator frequency for the CPU core in the wrong frequency condition.

### NOTE

The default clock setting from the SDK library is used in the example. For a real application, ensure that the reference clock source is not dependent on the primary (tested) clock.

## 6.3 CPU register

The CPU register test procedure tests all CPU registers for the stuck-at condition (except for the program counter register). The program counter test is implemented as a stand-alone safety routine.

Some tests stay in an endless loop in case of an error, others return a corresponding error message.

## 6.4 DIO test

The Digital Input/Output (DIO) test procedure performs the plausibility check of the processor's digital IO interface.

### NOTE

Make sure that the time between the "set" and "get" functions is sufficient for the GPIO peripheral speed.

## 6.5 Invariable memory test

The invariable (Flash) memory test provides a CRC check of a dedicated part of memory. This test is turned off by default in the *safety\_config.h* file.

The test consists of the following two parts:

- Post-build CRC calculation of the dedicated memory.
- Runtime CRC calculation and comparison with the post-build result.

The post-build calculation is different for each IDE:

In the IAR IDE, the CRC is calculated by the IDE directly using the linker (see Options->Build Action). The Flash test is fully integrated to the example project in the IAR IDE. It is necessary only to turn this test on in the *safety\_config.h* file.

In the Arm Keil IDE, it is necessary to use a third-party tool (Srecord):

- Srecord and all necessary settings are added to the presented example by default.
- Turn on the Flash test in the *safety\_config.h* file.
- The final post-processed image is downloaded to the ROM memory using the "Download" button.
- For more information on using Srecord in Arm Keil IDE, see *Calculating Post-Build CRC in Arm® Keil®* (document [AN12520](#)).

In case of an issue, check the following settings:

- Check if the "Option -> User -> AfterBuild" tab contains the `"../..../middleware/safety_iec60730b/tools/crc/crc_hex.bat  
-..../boards/<YOUR_BOARD>demo_apps/safety_iec60730b/mdk/debug/safety_iec60730b.hex  
-..../boards/<YOUR_BOARD>demo_apps/safety_iec60730b/mdk/debug/safety_iec60730b_crc.hex  
-..../tools/srecord/srec_cat"` path and if the checkbox is selected (it should be filled and checked by default).
- Check if the "Option->Debug ->Initialization File" tab contains the `"../..../middleware/safety_iec60730b/boards/  
common/debug.inl"` path.

In the MCUXpresso IDE:

- Srecord and all necessary settings are added to the presented example by default.
- Turn on the Flash test in the *safety\_config.h* file.

- Create the "debug configuration" for your debugger.
- Open the "Debug Configurations" menu ("Run->Debug configuration") and select the "Startup" tab. In this tab, select "Load Image -> Use File -> <YOUR\_BOARD>\_safety\_iec60730b\_crc.hex".
- This edited HEX file is located in the <workspace>/<your\_project>/Debug/<your\_project>\_crc.hex folder.

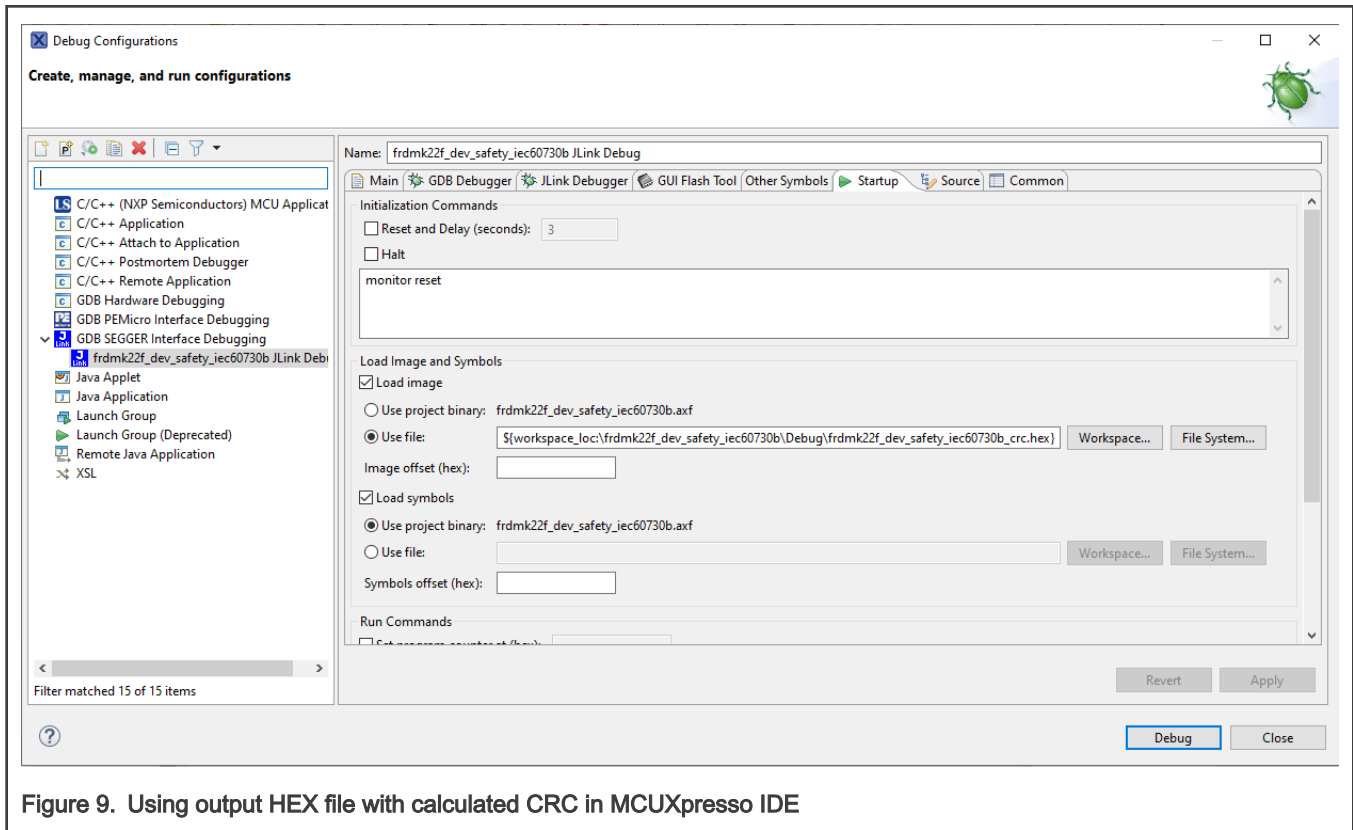


Figure 9. Using output HEX file with calculated CRC in MCUXpresso IDE

In case of an issue, check also the following settings:

- Check if the post-build actions are set: `"arm-none-eabi-objcopy -v -O ihex "${BuildArtifactFileName}" "${BuildArtifactFileName}.hex" "${ProjDirPath}/linker/crc_hex.bat -..|||${ConfigName}|frdmk22f_dev_safety_iec60730b.hex -..|||${ConfigName}|frdmk22f_dev_safety_iec60730b_crc.hex -..||safety_iec60730b|tools|srec|srec_cat"`. It should be filled by default.

#### NOTE

When you debug your application with the Flash test turned on, be careful when using the breakpoint. The software breakpoint usually changes the CRC result and causes a safety error.

## 6.6 Variable memory test

The variable memory on the supported MCU is an on-chip RAM.

The RAM memory test is provided by the MarchC or MarchX tests.

The test copies a block of memory to the backup area defined by the linker. Be sure that the BLOCK\_SIZE parameter is smaller than the backup area defined by the linker.

#### NOTE

This test cannot be interrupted.

## 6.7 Program counter test

The CPU program counter register test procedure tests the CPU program counter register for the stuck-at condition. The program counter register test can be performed once after the MCU reset and also during runtime.

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**NOTE**

The program counter test cannot be interrupted.

---

## 6.8 Stack test

This test routine is used to test the overflow and underflow conditions of the application stack. The testing of the stuck-at faults in the memory area occupied by the stack is covered by the variable memory test. The overflow or underflow of the stack can occur if the stack is incorrectly controlled or by defining the "too-low" stack area for the given application.

---

**NOTE**

Choose a correct pattern to fill the tested area. This pattern must be unique to the application.

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## 6.9 Watchdog test

The watchdog test provides the testing of the watchdog timer functionality. The test is run only once after the reset. The test causes the WDOG reset and compares the preset time for the WDOG reset to the real time.

For this test to run correctly, it is necessary to keep the WDOG\_backup variable in a part of memory which is not corrupted by the WDOG reset.

---

**NOTE**

Some debuggers do not allow the WDOG reset. Due to this, it is necessary to turn off the WDOG when debugging the application.

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