Introduction to software tools for Automotive Electronics lab

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5^{e} année ESPE
November 2019

This document aims at providing basic support for the different software tools used to achieve the motor application project in Automotive Electronics lab:

- S32 Design Studio (S32DS) IDE: the integrated development environment provided by NXP for Power Architecture MCU
- Matlab / Simulink: As NXP provides Simulink toolbox for modeling and simulation of the motor and its command
- FREEMASTER: NXP proposes this tool to communicate with embedded applications and monitor/visualize in real-time internal variables of embedded applications

In order to facilitate the development, simulation and debugging of motor control applications, NXP also provides Automotive Math and Motor Control Library (AMMCLIB) for NXP MPC574xP. This library is compatible with both S32DS and Matlab/Simulink as a toolbox. It contains basic and complex mathematical functions dedicated to motor control applications (basic mathematical operation, digital filtering, Park transform, SVM, etc…)

The purpose of this document is to help you to start development with these tools rapidly and underlines the functionality offered by these tools in order to help you to choose the more appropriate design flow.
This document is intended for motor control application development on MPC5744P microcontroller, mounted on the DEVKIT-MPC5744P development kit.
This document is not exhaustive. More information about the different tools, toolbox and library can be found in the references provided in the part Links.

I - Getting started S32 Design Studio for Power Architecture IDE

1. Overview of S32DS for Power architecture

S32DS for Power architecture is the integrated development environment provided by NXP for Power Architecture microcontroller (MCU) and automotive applications. The S32 Design Studio is based on the Eclipse open development platform and integrates the Eclipse IDE, GNU Compiler Collection (GCC), GNU Debugger (GDB). It also provides in-situ debugger through several interfaces: P&E Multilink/Cyclone/OpenSDA and supports two software design kits (SDK) that will be used in this lab: FREEMASTER serial communication drivers and Automotive Math and Motor Control Libraries (AMMCLIB).
In this part, the main steps to launch S32DS, create a new project, compile, build, debug and flash your application in the MCU will be described. Here, the MCU MPC5744P is considered.

2. Create a project from scratch

Launch the S32 Design Studio for Power Architecture. A dialog window opens in order to select your workspace. All the S32 project saved in this workspace will be imported.

The window shown in Figure 1 opens. If some existing projects are in the workspace, they will appear in the Project Explorer. The organization of the window is configurable with the menu Window.

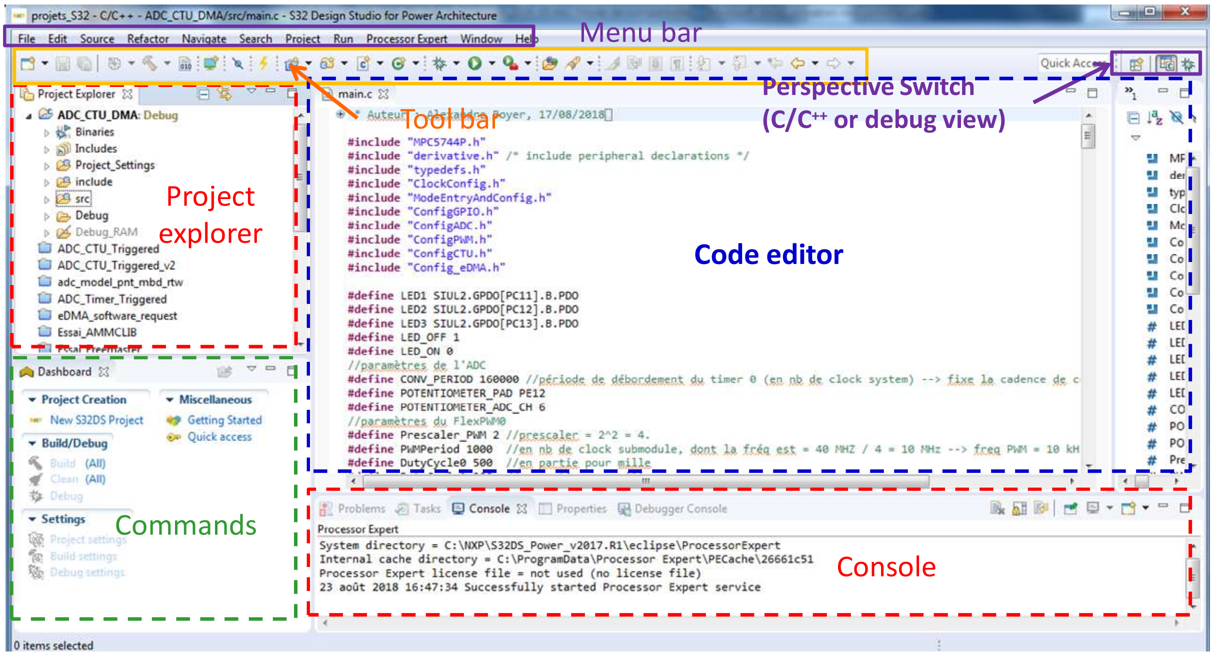


Figure 1 - Main window of S32DS IDE

To open an existing project, write click on its name in the project explorer and select Open Project. You can open source files (.c or .h) and modify them in the Code editor part. Several commands available either in the menu bar, tool bar or Commands window launch the compilation, building, debugging and flashing process. They will be presented later.

In order to create a project from scratch for MPC5744P, follow the procedure described below:

- In the menu bar, click on **File > New > New S32DS project**. The window below opens to setting the target MCU and the project options
- Enter the name of the project in Project Name and its location (by default, in your workspace). In the Elf S32DS project window, select the target microcontroller: **Family MPC574xP** > **MPC5744P**. Click on Next button.

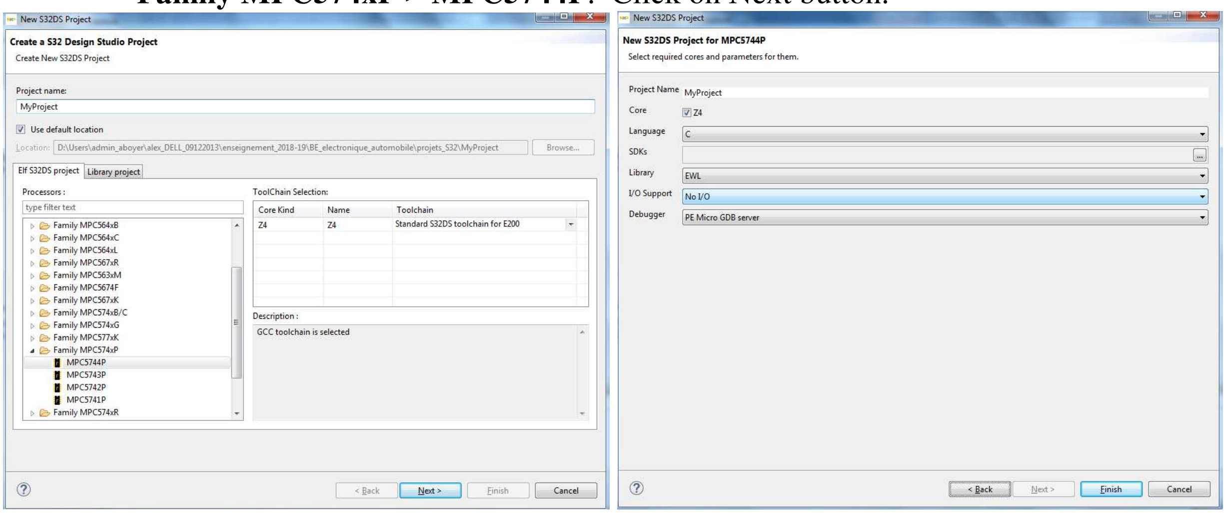


Figure 2 - Creating a new S32DS project from scratch

- Select the project options (language, import Software Design Kits (SDK), type of debugger, …). The default configurations are sufficient for this project, except if you need to import SDK (AMMCLIB or FREEMASTER). This point will be addressed in 5).
- Click on Finish to generate the project

S32DS generates the project with all the necessary libraries, start-up, debugger and linker codes. The project folder is visible in the Project Explorer. By default, the Perspective Switch is in C/C++ mode for code development. The target memory is written just after the name of the project:

- debug: the executable code will be downloaded in the Flash memory of the MCU
- debug RAM: the executable code will be downloaded in the SRAM of the MCU

Tips: select Flash to store your program in non volatile memory. Programming Flash is a little longer than programming RAM. During debug stage, it can be more convenient to download your code in RAM.

The project structure is organized as follows:

- Project_Settings: this folder contains all the required files to compile the project, link the files and the start-up code.
- Include: it contains all the header files .h of the project.
- src: it contains all the C/C++ source file of the project. By default, the following files are added after the creation of a new project:
  - main.c: your main code
  - intc_SW_mode_isr_vectors_MPC5744P.c: this file defines the interrupt vector table
  - MPC57xx__Interrupt_Init.c, vector.c and intc_sw_handlers.s: these files define all the function requires for interrupt management
- Debug: this folder contains all the executable source files that will be downloaded into Flash memory. The .elf file is the executable file and the .map file provides the memory location of the code.
- Debug_RAM : this folder contains all the executable source files that will be downloaded into SRAM. The .elf file is the executable file and the .map file provides the memory location of the code.

A default main.c file is opened in the code editor. You can write your own code in this file. Existing files can be copied and pasted from one project to another directly by right clicking on them and selecting Copy or Paste. You can create new source C file by clicking on src folder in your own project and clicking on **New** > **Source File** or on the icon . Type the name of the new source file (give .c as extension). Do not forget to create also the associated header file (.h) that must be included in the folder include. To do so, click on include folder in your own project and clicking on **New** > **Header File** or on the icon .

3. Compile and build your project

Once your source code files (.h and .c files) are written, they must be compiled and the project has to be built before downloading it to the MCU for debugging purpose.

Click on the button **Build** in the Command part, or click in the menu **Project > Build**. Prior to this step, it is necessary to define the target memory (Flash or RAM), as shown in the figure below. It can also be defined by clicking on the small arrow in the right of the button Build .

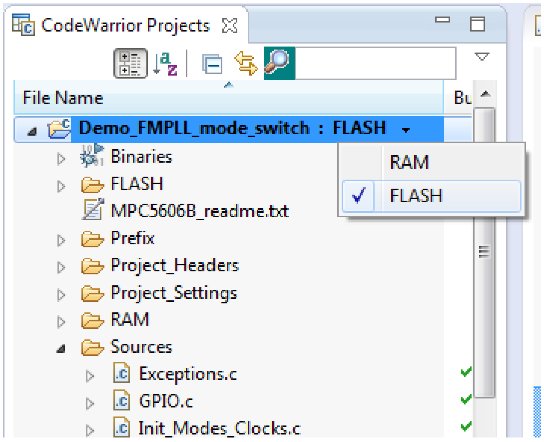


Figure 3 - Select the target memory (Flash or RAM)

Tips: in case of problems during build and link steps, it is recommended to click on the button **Clean**  .

4. Programming the MCU

The first step consists in configuring the debug settings. Here, only the selection of the executable files (either those for Flash or those for SRAM) and the programming of the MCU is configured. For the other parameters, the default values can be kept.
Click on the menu **Run > Debug configurations** or on the small arrow in the right of the button Debug  to open the debug configuration panel. The window shown in Figure 4 opens. On the left part of the window, the different opened and built source code projects are shown. Select the project the project that you want to download to the MCU. If the executable files have to be downloaded into Flash, select the project with '_Debug' suffix. Otherwise, select the project with '_Debug_RAM' suffix. In right part of the window, in the page **Main**, verify that the correct executable file .elf is selected.

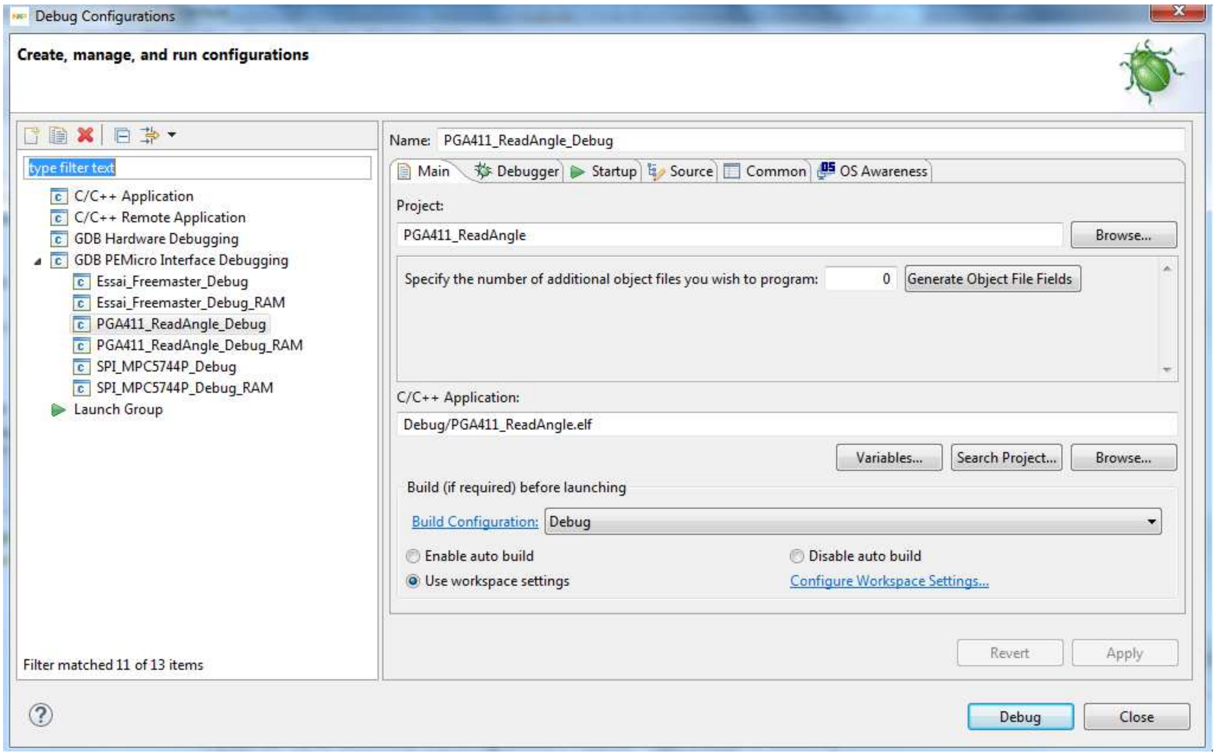


Figure 4 - Debug configuration panel (Run > Debug configurations)

Then, go to the page **Debugger**. The list **Interface** contains all the supported programming interfaces, as shown below. In this lab, you will use development board DEVKIT_MPC5744P. An on-board programming interface, called Open-Standard Serial and Debug Adapter (OpenSDA) is mounted on the board, offering an economical programming interface for the user. You will use this interface primarily. Thus select **OpenSDA Embedded Debug- USB Port** in the list. If the board is connected on a USB port of your computer, information about the port number and the device mounted on the development kit should appear in the fields **Port**, **Device Name** and **Core**.

A programming interface alternative is the **USB Multilink**. This external programming interface is available in this lab.

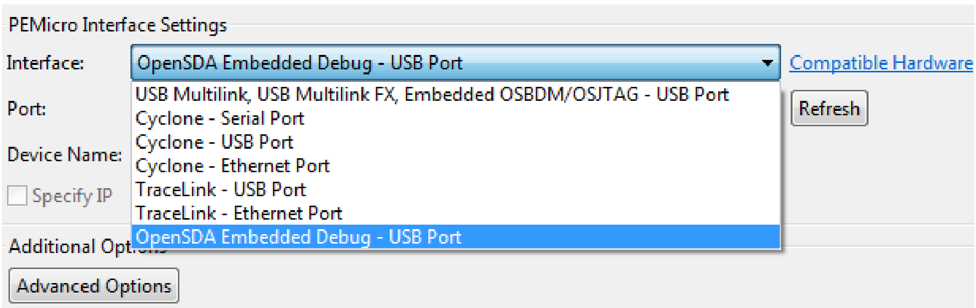


Figure 5 - Selection of the programming interface (Run > Debug configurations)

Finally, you can click on the button Debug to start the downloading of the code into MCU memory.

You are not forced to return to the Debug configurations to start the programming of the MCU. Once it has been configuring, you can click on the menu **Run > Run** (Ctrl + F11) or on the button .

5. Debugging your application

Once you click on the button Debug, the downloading of the executable files into the MCU starts. Ensure that the MCU board is connected to your computer through a programming interface and correctly powered. The process can last several tens of seconds. As explained before, programming the Flash memory is longer than the programming of the RAM.
During the downloading process, the Perspective Switch changes from C/C++ to Debug mode  and window shown in Figure 6 appears.

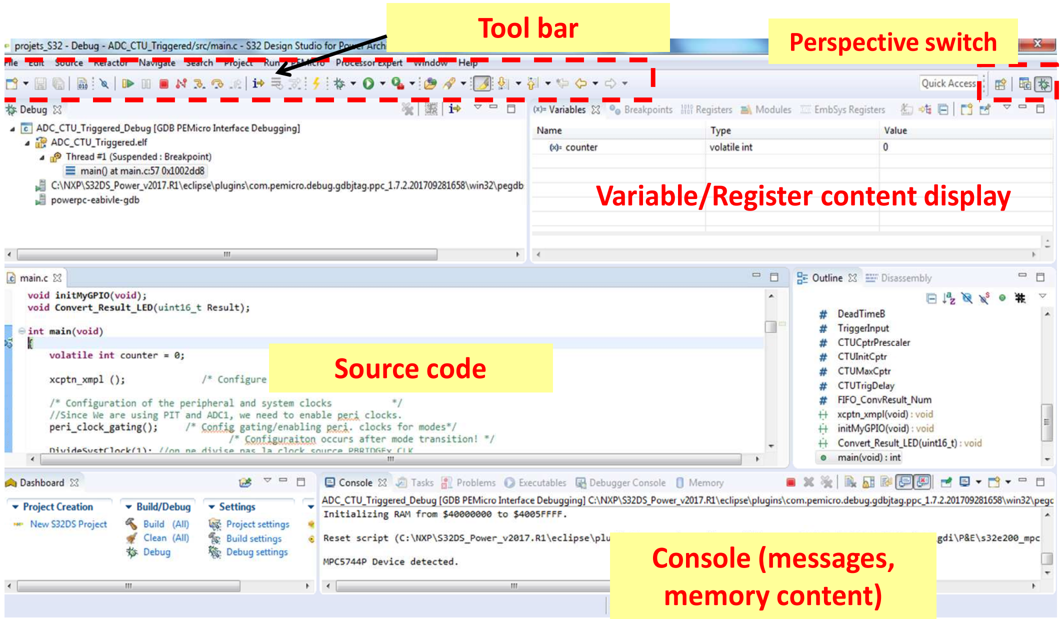


Figure 6 - In-situ debugging interface

The debugging process is controlled by the commands provided in the Tool bar (Figure 7). The Run button starts the execution of the embedded program. The execution can be paused by clicking on the button Pause. The execution can be performed step-by-step by clicking on the step buttons.

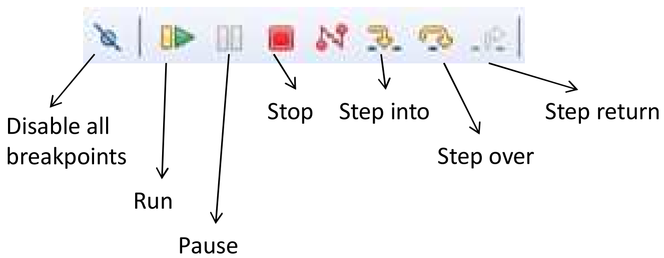


Figure 7 - Debug toolbar

Breakpoints can be inserted in the source code by double clicking on the source code line where you want to insert the breakpoint. You can also right click and select **Add Breakpoint**. The breakpoint is removed by double clicking on it or right clicking and select sur **Toggle Breakpoint**. It can be deactivated by clicking on **Disable breakpoint** and reactivated with **Enable Breakpoint**. Each time the execution pauses (due to a breakpoint or a click on button Pause), the memory content is refreshed.
At the end of in-situ debug operation, you have to stop the debugger by clicking on the button Stop. Then, click on the perspective switch to return in C/C++ mode.

Tips : do not forget to stop the debugger before returning in C/C++ Perspective. Otherwise, the debugger will continue to run. The next time you will try to reprogram the MCU, an error message will be displayed to warn you that a in-situ debug is still on-going.

6. Closing and importing project

In order to close a project, select the project in the Project Explorer. Click on the menu **Project > Close Project** or right click on it and select **Close Project**.
If you click on **Edit > Delete**, the project is removed from the Workspace and thus from the Project Explorer.
If you want to import an existing project into your workspace, click in the menu **File > Import** or on the button **Import project**.

7. Installing and using SDK

In this lab, you will certainly use two software design kits (SDK) provided by NXP:

- FREEMASTER communication drivers
- Automotive Math and Motor Control Libraries (AMMCLIB)

Both SDK are free but they are not installed in S32DS by default. Here, we explain how to install SDK and use the provided source codes and drivers. The downloading links and the contents of these SDK will be detailed in part III and V of this document.
SDK have to be selected during the project creation, in order to import all the library files. When you create a new project with S32DS, as explained in part I.2, click on the button ... in the field SDK of the window New S32DS Project. The window shown in Figure 8 opens. All the SDK installed in your PC are listed (in this example, Freemaster and AMMCLIB are installed). Select the SDK that you want to use and click OK. In the window New S32DS Project, click on Finish. A new project is automatically generated. In the Project Explorer, you can verity that source files associated to the SDK have been added.

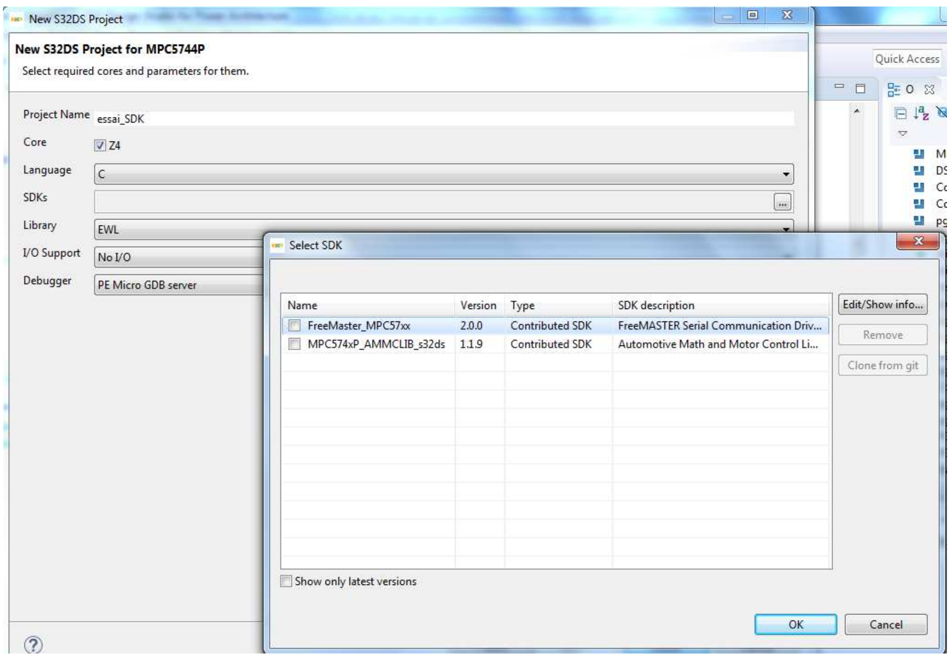


Figure 8 - Selecting SDK in a S32DS project

II - Presentation of Matlab/Simulink for motor control simulation

Simulink is dedicated to the modeling and simulation of dynamic multidomain systems, operating in continuous or discrete time, or mixed. For this reason, it is widely used in motor control design in order to fit the parameters of the controllers and anticipate the performance of the command. That's why we use it also in this Automotive Lab. In this chapter, a rapid description of the steps to create and simulate Simulink models is provided. The most important Simulink libraries for the project are presented briefly.

1. Creating model in Simulink

In Matlab, the first step before the creation of any model files is the definition of a workspare, where all your models and associated data will be saved.

From Matlab, you can launch Simulink by clicking on Simulink icon (in Home) or in the menu **Home > New > Simulink model**. You can also click on the icon New and select Simulink model. If existing Simulink models exist in your workspace, you can directly click on them to launch Simulink.
Simulink opens after several seconds. In order to create a new model, click on the menu **File > New > Blank model** or on the icon . A Simulink model consists in a set of interconnected blocks which models a continuous, discrete or mixed systems. Existing blocks can be found in libraries and toolboxes installed on your working environment. Click on the menu **View > Library browser** or on the icon to open the library browser, which lists all the installed libraries, as shown in Figure 9. The main common libraries for the Automotive electronics lab will be briefly presented in part II.2.
To place a block in the model diagram, click on the library to open it. Then, select the correct category and the desired block. Finally, drag and drop it on the model schematic. Place as many blocks on the diagram.
Each block has a name, which appears on the bottom side of the block. You can change it by clicking on the name. The properties of the model associated to the block can be modified by double clicking on the block. A window opens to modify the model properties (model parameters, data type, min/max value…). Graphical properties can be modified by right clicking on the block and select **Properties** in the pop-up window. The different blocks can be interconnected by clicking on one terminal of a block. A wire starts to be plotted. It finishes at the position where you release the mouse cursor. If you double click on a wire, you can give a label to the wire.

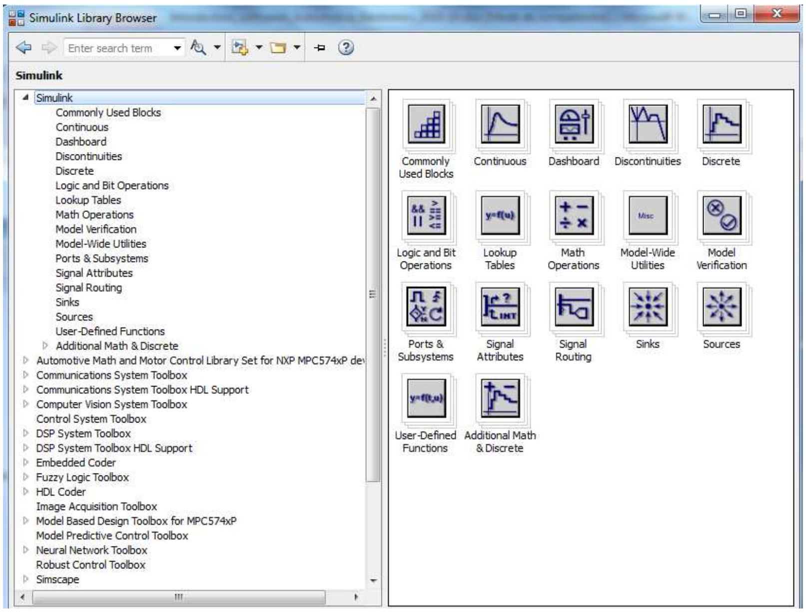


Figure 9 - Simulink Library browser

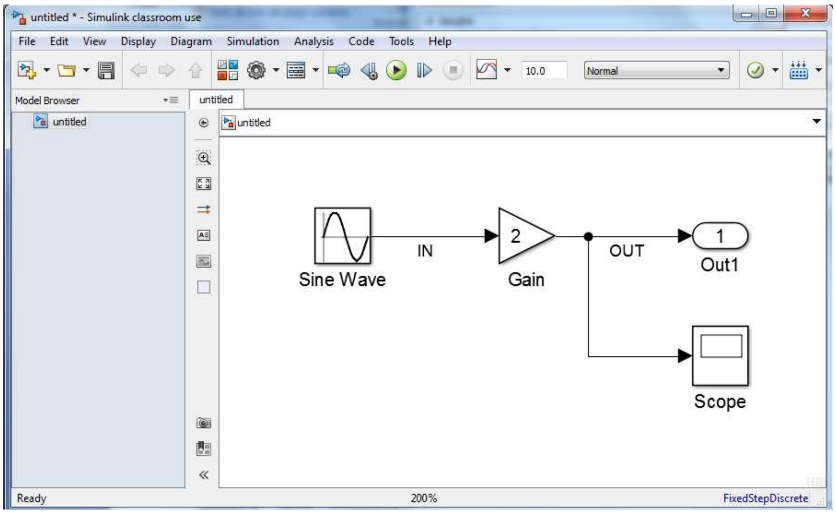
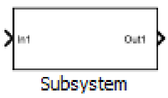


Figure 10 - Creation of a simple Simulink diagram

<u>Tips : data type.</u> Most of the blocks has an output data type properties (in Signal Attributes). By default, it is set to Inherit, meaning that Simulink will set the type after a global analysis of the schematic. It is recommended to set the data type to prevent errors due to data type mismatch.

When a large number of blocks are added on the diagram, its reading becomes quite difficult. Moreover, the complete model of a system is usually divided in several subparts. That's why it is recommended to organize blocks. Simulink proposes to build hierarchical view of models through the use of subsystems. Several types of subsystem blocks are proposed in the native Simulink library / Ports & Subsystems. More details about the different subsystems will be given in part II.3. The most basic subsystem block is:



Place it on the diagram. Select the blocks that you want to insert in the subsystem, cut them, double click on the subsystem to open it and paste the blocks. If input and output ports are required, add  and  on the terminals.

The main icons to interact with diagram are summarized in the following table:

	View fil all (space bar)		Add image
	View in (CTRL + '+'). View out = CTRL + '-'.		To return to the higher level in the diagram hierarchy
	Add text annotation		Back/forward = return to the previous/next view

2. Creation of variables

Variables can be added in Simulink's diagrams. These variables are stored in the workspace shared with Matlab. To create or modify variable properties, you have to open the **Model Explorer**, by clicking on icon, or on menu **View > Model Explorer > Model Explorer** or CTRL+ H. The window shown below appears. On the panel on the left, all the variables, subsystems, blocks, charts added in the opened model diagrams are visible. For each Simulink model, a Model Workspace is defined by default. It stores all the variables of this model. The values of the variables, types and properties are visible in the central panel. Double click on them to change their properties. After each change, click to button **Apply** to validate the changes.

To create new variables, click on the icon Add MATLAB variable. To remove one variable, click on it and press the key 'Delete'.

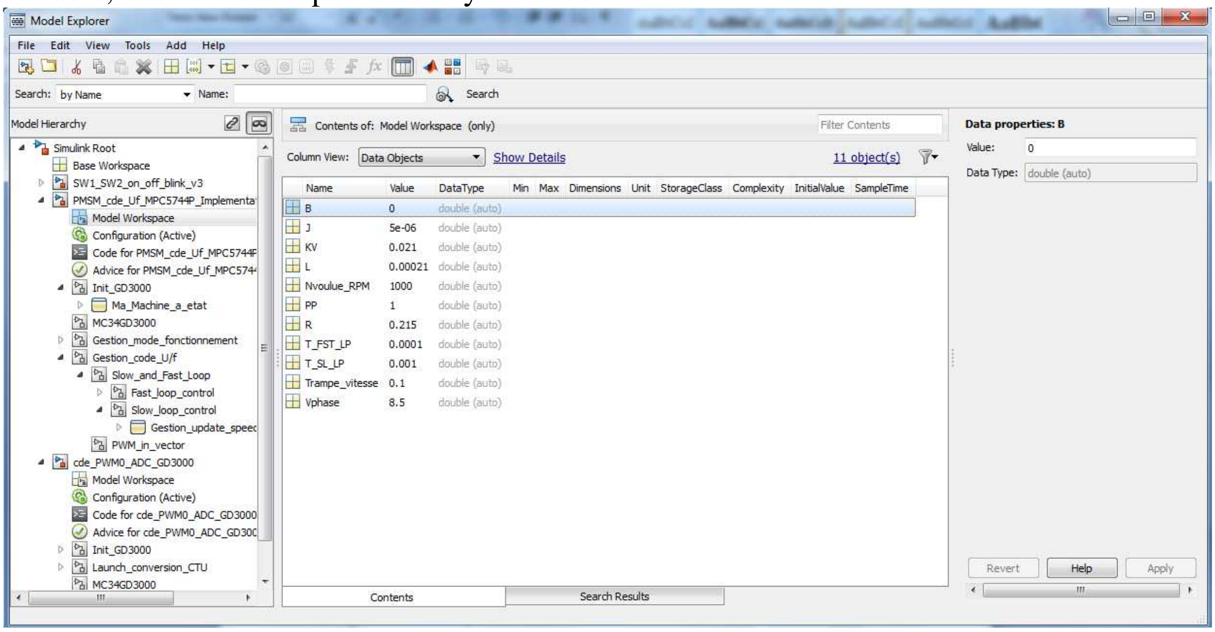
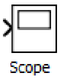


Figure 11 - Model Explorer

3. Placing scopes

Several methods can be used to display the values of one net of the diagram during simulation of a Simulink model.

The first method consists in placing a scope connected to the net. Only the net connected to the block can be observed with this method. Scope block is available in the native Simulink library / Sinks 

. Click on this block to configure the scope settings.

In complex diagrams, it is usually necessary to observe numerous signals simultaneously and plot them either on the same graphs or one different subwindows. It is possible with Floating scope, which is also available in Sinks library 

. You can place it anywhere on the diagram. Double click on this block to edit its properties. Click on **View > Layout** to select the number of subwindows. Click on **Simulation > Signal selector** to select the signals to be plotted and the destination subwindows (or axes).

4. Configuration of simulation

The simulation must be configured before the first launching. Click on **Simulation > Model Configuration Parameters** or on the icon  to open the simulation configuration window, as shown in Figure 12. Select the pane Solver. By default, the solver is automatically chosen by Simulink and only the start and stop times can be configured. The solver can be chosen and also the step type (fixed or variable). In the pane Diagnostics, various sources of errors can be configured to trigger simulation errors or be ignored.

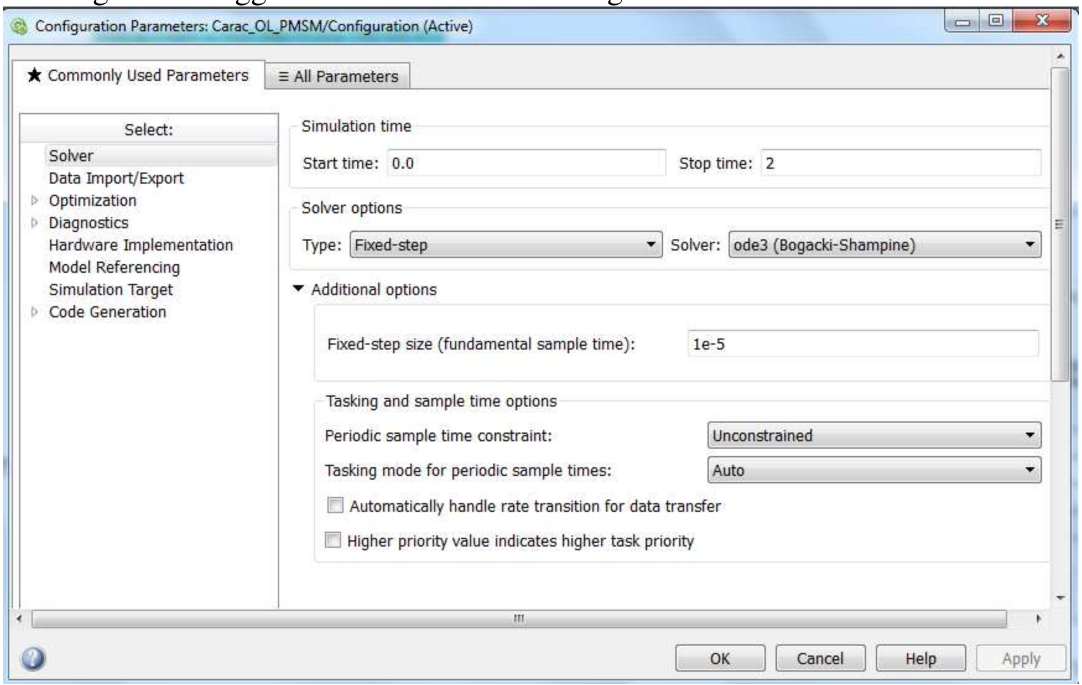
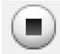


Figure 12 - Configuration Parameters window

5. Launching simulation

The simulation can be launched by clicking on **Simulation > Run** or on the icon . Simulink starts the simulation process by a compilation of the model and, if no errors are detected, launches the simulation. It ends when the stop time is reached. The simulation can be also done step-by-step by clicking on the icon . It can be stopped by clicking on the icon .

Results are displayed in real-time on all the opened oscilloscopes. For example, Figure 13 shows simulation results plotted on a floating oscilloscope, configured with three subwindows. The menu and toolbar aim at controlling simulation, selecting the curves to be plotted, modifying graphical parameters and placing cursors.

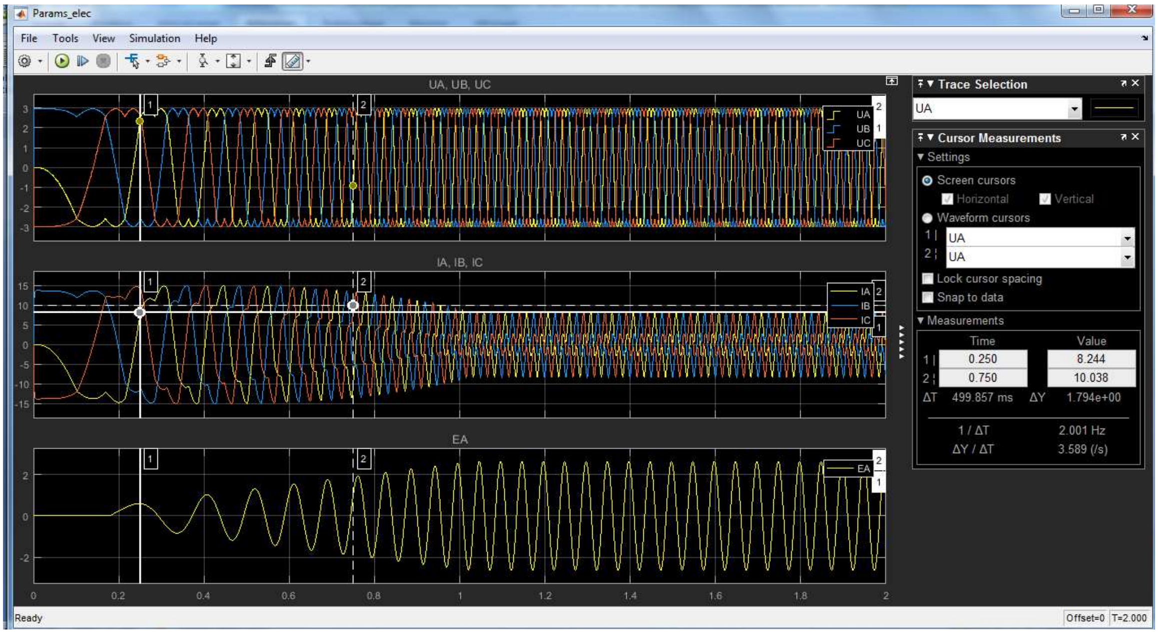


Figure 13 - Example of simulation results plotted on a floating oscilloscope

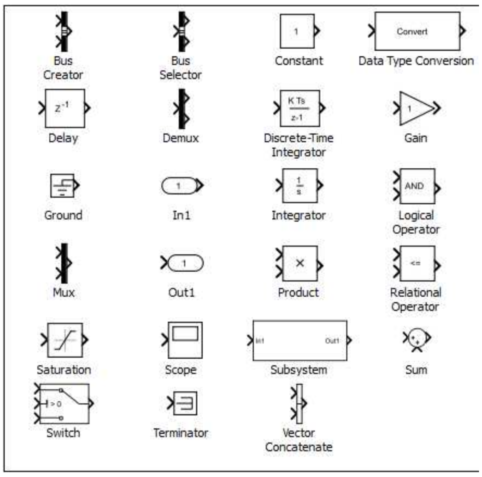
In View > Configuration Properties …, the main properties of the graph window can be modified. For example, click on the panel Display and check the box Show Legend to display the legend of the plotted curves. Click on Tools > Measurements > Curve measurements to display cursors on the graph. The cursor panel is displayed on the right of the graph, as shown in Figure 13.

6. The main common libraries

In this part, the most important library for the Automotive Lab are presented briefly. More details can be found in the on-line help of Simulink. These libraries are present by default in Simulink. These are those shown in Figure 9.

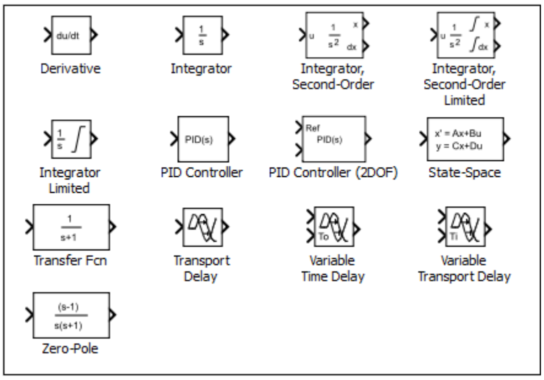
a. Commonly used blocks

The sublibrary lists the mostly used blocks. These blocks are available in other sublibraries.



b. Continuous

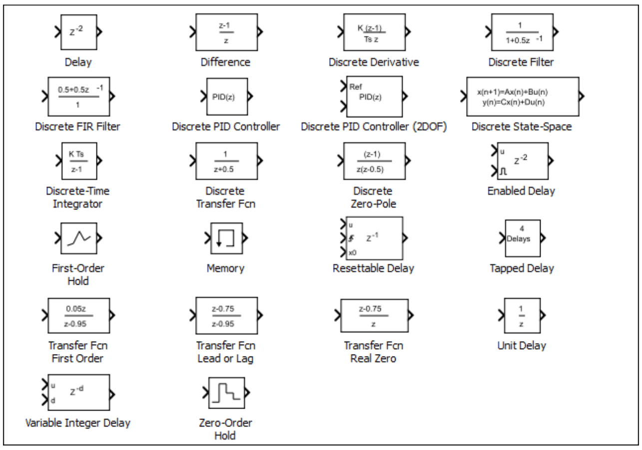
This sublibrary proposes all the basic blocks to define linear system behavior in continuous time: derivator, integrator, transfer function in Laplace domain, PID controller, state-space model…

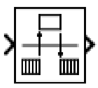


c. Discrete

This sublibrary proposes all the basic blocks to define linear system behavior in discrete time: discrete-time derivator, discrete-time integrator, delay, transfer function in Z-domain, discrete PID controller, …

Discrete-time blocks can coexist with continuous-time blocks. Use of discrete-time function requires sampling time, which must be in accordance with simulation step time.



Two discrete-time blocks which operate at two different sampling times can be connected, if Rate transition block  Rate Transition (available in Signal Attributes sublibrary) is inserted within the interconnection.

d. Math operation

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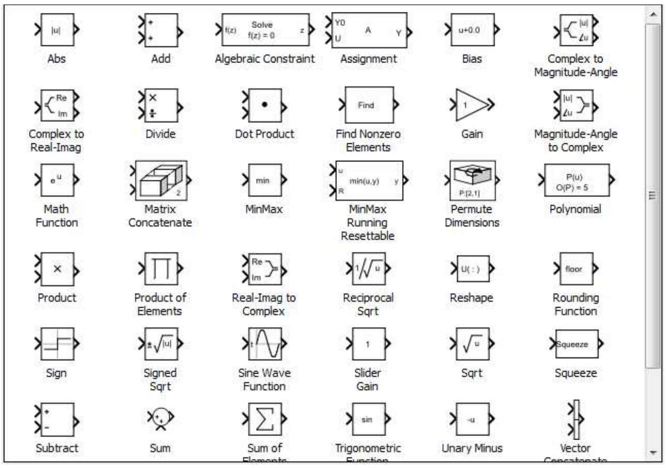
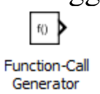
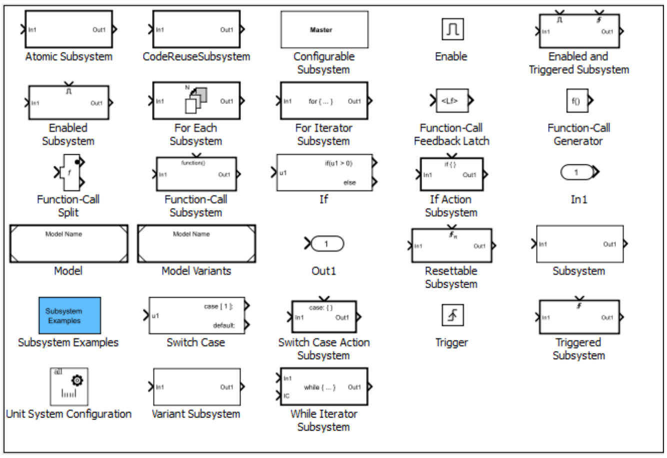
This sublibrary proposes all the basic mathematical operations: add, substract, multiply, gain, sign, sqrt…
.



e. Ports and subsystem

This sublibrary proposes all the elements to build subsystems (refer to part 1), to define their ports and call them.
Submodels inserted in a block Subsystem are executed all the time. Submodels inserted in Function-Call Subsystem are executed only when a function-call trigger them. Function-call generator 

can be inserted in a subsystem to trigger a function-call when the subsystem is executed.

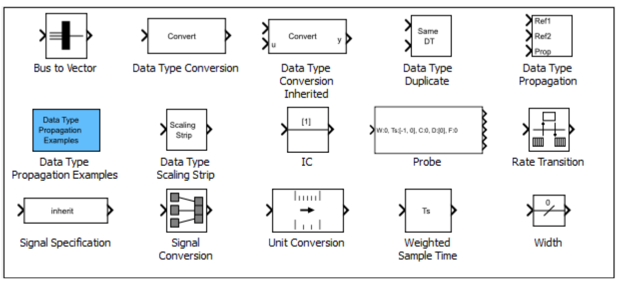


Function-call signals is a specific signal in Simulink which cannot be processed as the other signals (whatever their types). Blocks as Function-call Split 

are useful to deliver the same function-call signal to several subsystems.

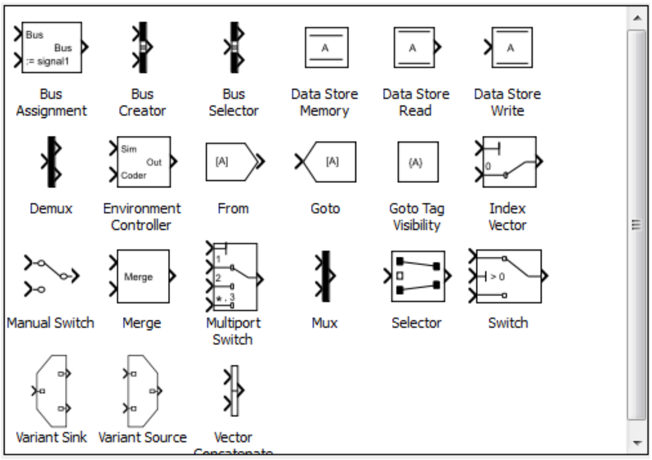
f. Signal attributes

This sublibrary provides blocks to manipulate signal properties: data type conversion, rate transition (when two interconnected blocks operate at two different sampling times)…



g. Signal routing

This sublibrary provides blocks to route signals and manipulate variables stored in memory.
Blocks Mux and Demux are useful in a complex diagram where a large number of signals are exchanged. Signals with similar functions can be gathered by multiplexing.
Variables can be created with the block Data Store Memory. the variable name is defined in this block When C code is generated with Simulink, a variable is creates when this block is inserted.



Writing this variable is done with the block Data Store Write 

. This variable is read with the block Data Store Read 

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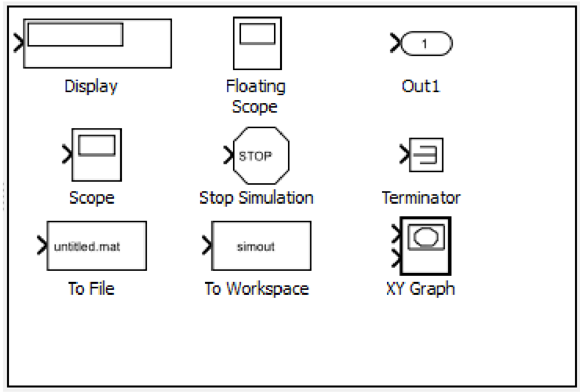
h. Sinks

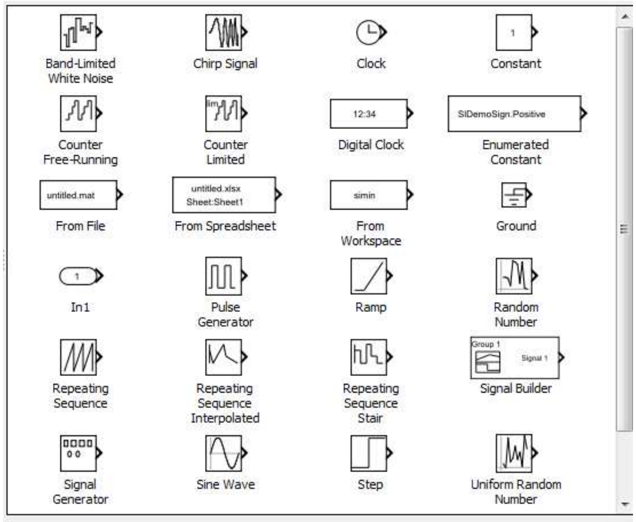
This sublibrary contains elements that terminate a chain of elements. An output cannot be let floating.
Signals can be terminated by graphical visualization tools, such as oscilloscopes (Floating scope, scope, XY Graph). signals waveforms can also be exported to result file or workspace.
Placing an output port is also acceptable for a subsystem. If the previous solutions are not possible, place Terminator block.



i. Sources

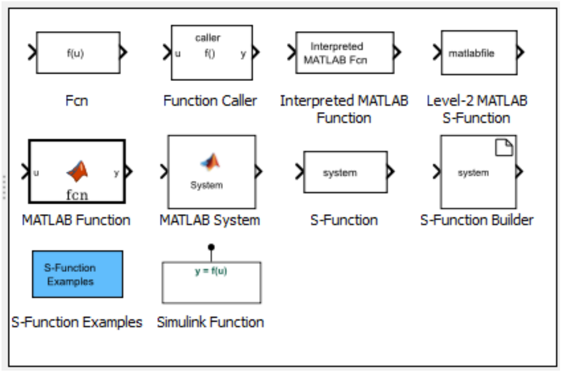
This sublibrary provides various excitation sources: constant signal, sine waveform, step, pulse, ramp, random signal, noise, arbitrary signal …

If the simulation time has to be stored, the Clock symbol can be placed on the model diagram and connected to Workspace.
Signal Generator block provides a graphical interface to set the time-domain evolution of a signal.



j. User-defined function

This sublibrary provides blocks to include functions developed by the user: Matlab function, Simulink model, S-function.



III - Presentation of FREEMASTER

1. Overview

FREEMASTER is a PC-based development tool serving as a real-time monitor, visualization tool, and graphical control panel of embedded applications implemented on NXP microcontroller, as described in Figure 14. The FREEMASTER application repetitively sends a request to obtain the current values of chosen variables used in the embedded application and display them on a graphical interface. Communication between FREEMASTER application is supported by serial communication interface (SCI) such as UART, CAN bus or JTAG. In this document, we will only consider communication through UART (based on LIN interface). In the MPC5744P_DEVKIT, communication will pass transit through the USB port of the OpenSDA interface.

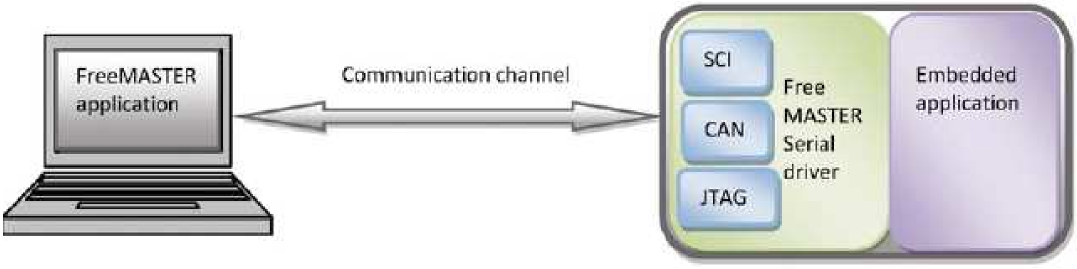


Figure 14 - Freemaster principle

However, the communication requires FREEMASTER serial driver, that must be used by the embedded application to ensure protocol functions and handle peripherals. This part aims at:

- describing the main functions of FREEMASTER serial driver to enable FREEMASTER communication either in S32DS or Simulink project
- presenting the interface of FREEMASTER application

FREEMASTER application and serial driver can be downloaded from NXP website (www.nxp.com) without any charge. Refer to part VI for installation of FREEMASTER application and serial drivers.

2. Adding FREEMASTER communication driver to S32DS project

a. The main macros and functions of FREEMASTER API

All the details about the functions and macros of FREEMASTER driver API can be found in [FRUG].
The configuration of FREEMASTER is done by freemaster_cfg.h file, through several macros. Here, only the most important are described here:

- Interrupt mode selection: assert to '1' only one the three macros below. If long interrupt mode is used, the function FMSTR_Isr() handles FreeMASTER protocol decoding and execution. As it can be a long process, give it a low interrupt priority level. In short interrupt mode (the most versatile mode), the raw serial communication is handled by the FMSTR_Isr() interrupt service routine, while the protocol decoding and execution is handled in the FMSTR_Poll() routine. In polling mode, Both the serial (SCI/CAN) communication and the FreeMASTER protocol execution are done in the FMSTR_Poll() routine.

```
#define FMSTR_LONG_INTR 0 /* complete message processing in interrupt */
#define FMSTR_SHORT_INTR 1 /* only SCI FIFO - queuing done in interrupt */
#define FMSTR_POLL_DRIVEN 0 /* no interrupt needed, polling only */
```

- Selection of communication interface: FMSTR_DISABLE must be set to '0' (default value) to enable FREEMASTER functionalities. FREEMASTER communication is based either on SCI (LINFlexD_0 or 1), CAN or BDM communication interface. To select one of these interfaces, set the corresponding macros to '1'.

```
#define FMSTR_DISABLE         0    /* To disable all FreeMASTER functionalities */
#define FMSTR_USE_SCI         1    /* To select SCI communication interface */
#define FMSTR_USE_FLEXCAN     0    /* To select FlexCAN communication interface */
#define FMSTR_USE_PDBDM         0     /* To select Packet Driven BDM communication
interface (optional) */
```

- Definition of communication interface memory address for SCI and CAN interface: refer to memory address map of the microcontroller and write the starting memory address corresponding to communication interface. Any errors in memory address will result in unpredictable application error.

```
#define FMSTR_SCI_BASE          0xFFE90000UL /* LINFlex1 base on MPC574xP */
#define FMSTR_CAN_BASE          0xFFEC0000UL /* FlexCAN0 base on MPC574xP */
```

For the other macros, the default values are sufficient for the application developed in the Automotive Electronics lab.

FREEMASTER API contains numerous functions. However, in order to initialize and launch communication with FREEMASTER application, only three functions are required, which have to be called by the embedded C code:

- FMSTR_init(): it initializes internal variables of the FreeMASTER driver and enables the communication interface (SCI, JTAG or CAN). It does not change the configuration of the selected communication module. The user must initialize the communication module (LINFlex as UART, JTAG or CAN) before the FMSTR_Init() function is called.
- FMSTR_Poll(): in poll-driven or short interrupt modes, this function handles the protocol decoding and execution. In the poll-driven mode, this function also handles the interface communication with the PC. Typically, FMSTR_Poll() is called during the 'idle' time in the main application loop.
- FMSTR_Isr(): it is the interface to the interrupt service routine of the FreeMASTER serial driver. In long or short interrupt modes, this function must be set as the interrupt vector calling address when a transmission or reception is performed by the communication module (LIN, CAN or JTAG). On platforms where interface processing is split into multiple interrupts, this function should be set as a vector for each such interrupt.

Besides, two additional functions can be used if the recorder functionality is used:

- FMSTR_Recorder(): it takes one sample of the variables being recorded using the FreeMASTER recorder. If the recorder is not active at the moment when FMSTR_Recorder is called, the function returns immediately. When the recorder is initialized and active, the values of the variables being recorded are copied to the recorder buffer and the trigger condition is evaluated.
- FMSTR_TriggerRec(): it forces the recorder trigger condition to happen, which causes the recorder to be automatically de-activated after post-trigger samples are sampled. This function can be used in the application when it needs to have the trigger occurrence under its control. This function is optional. The recorder can also be triggered by the PC tool or when the selected variable exceeds a threshold value.

It is not necessary to indicate which variables will be transferred from the MCU to the FREEMASTER PC-application. All the global variables can be transferred to FREEMASTER application, if these variables have been selected to be watched.

b. Configuration of FREEMASTER driver in C code application

FREEMASTER serial drivers are provided as a SDK. In order to use FREEMASTER communication in a new S32DS project, FREEMASTER SDK has to be imported first. Refer to part I.7 for this action.

The header file freemaster_cfg.h is automatically added in the folder include of S32DS project. The macros should be updated following the explanation given in part III.2.a. Include the header file freemaster.h in all the source code file where a FREEMASTER API function is used.

The four main steps are:

1. Configure all the necessary peripherals required for the FREEMASTER communication (clock gating, interrupt controller, initialization of the UART (SCI or CAN) and the used external pins). Ensure that the UART, its pins and its timing parameters are correctly set.
2. Initialize FREEMASTER by calling FMSTR_Init() just once at the code start, typically after the start-up code, at the beginning of the main function.
3. Call FMSTR_Poll(void) periodically in your code. A typical place is in the main loop.
4. FMSTR_Isr() must be assigned to the used UART interrupt vectors (e.g. interrupt vectors associated to transmission and reception of the used UART). Configure also the interrupt priority level associated to these interrupt requests. Use a low priority level to ensure that FREEMASTER will not affect your application. In S32DS project, the interrupt vectors are defined in the file intc_SW_mode_isr_vectors_MPC5744P.c.

3. Configuring FREEMASTER application

Connect the microcontroller to a USB port of your PC through. Ensure that the microcontroller has been flashed and is powered correctly.

Click on FREEMASTER 2.0 icon to launch the FREEMASTER application. The following window opens. By default, no project is loaded. Here, the different steps to start communication with an embedded program in a microcontroller and to visualize internal variables will be explained.

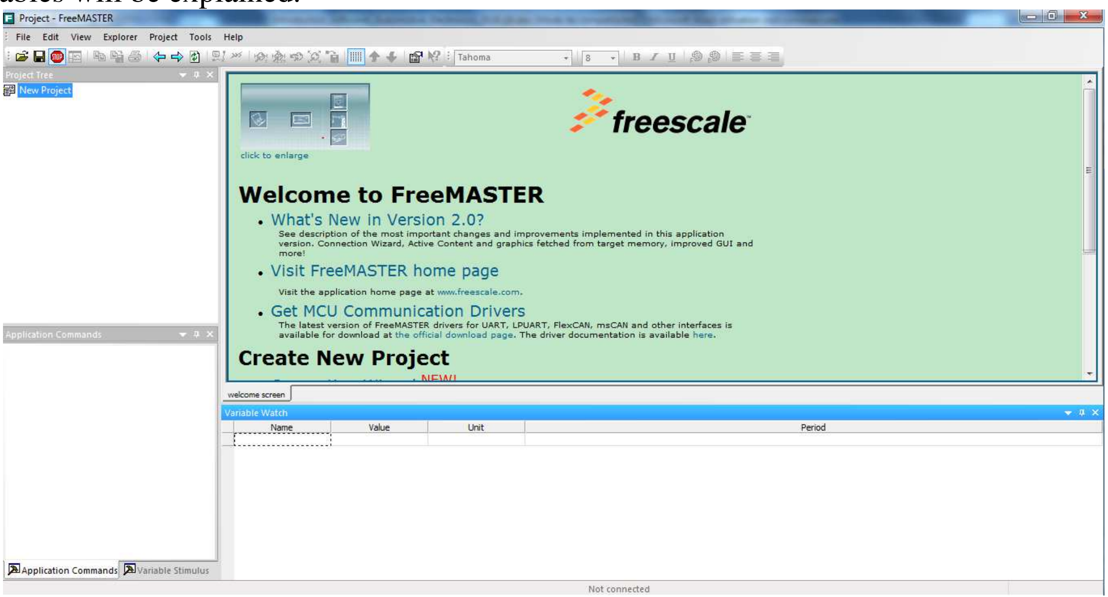


Figure 15 - FREEMASTER application - main window

In the menu bar, click on **Project > Options**. The window shown below appears. Only two operations are required to configure the communication. First, you have to set the parameters of the communication port. In the tab **Comm.**, select the communication port on which the microcontroller board is connected. If you do not know it, in Window start menu, go to **Control Panel > Device manager > Ports (COM & LPT)** and find the number of the Com port. Then, set the correct baud rate. Secondly, the executable file (.elf) embedded in the microcontroller must be provided to FREEMASTER to make the link with variables read continuously. In the tab MAP Files, select the .elf file in the field **Default symbol file**.

<u>Tips:</u> ensure that the .elf file corresponds to the actual code embedded in the microcontroller. Otherwise, communication may fail.

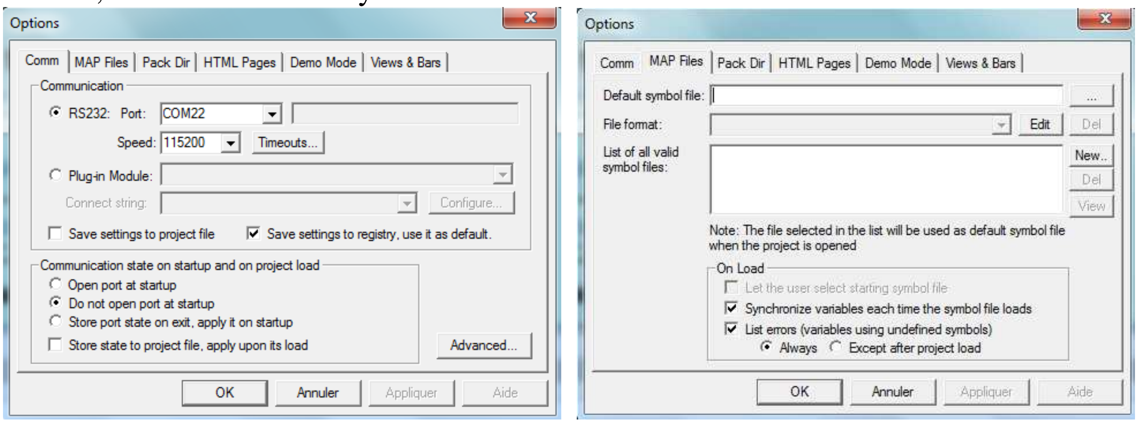
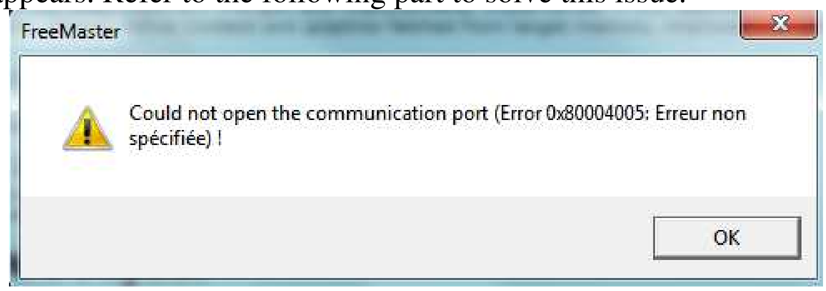


Figure 16 - FREEMASTER application - configuration of the communication port (on the left) and selection of the executable file (on the right)

Click on the button OK. A new project was created, visible in the Project tree. Click in the menu **File > Save Project** or on icon to save it. The extension of the file is .pmp. The communication port configuration and visualized variables are saved. The next time you will connect to the microcontroller, you will import the .pmp file directly.

In order to launch the communication with the microcontroller, click on the button **Start/stop communication** . The status of the communication is displayed in the message bar, in the bottom part of the main window. If the communication is active, the COM port, and the baud rate must be written. Otherwise, the message "Not connected" is written and an error message shown below appears. Refer to the following part to solve this issue.



Once the .elf file has been loaded, the variables to be visualized can be selected. In the table **Variable Watch**, right click and select **Create New Watched Var…** in the pop-up menu. The following window appears. In the list **Type**, select the type of the variable. In the list **Address**, select the variable to be visualized. Give it an arbitrary name in **Variable name**. Set the **Sampling period**. If the visualization must refreshed as fast as possible, select Fastest. Select also the format of the visualized variable (decimal, hexadecimal, binary…) in the list **Show as**.

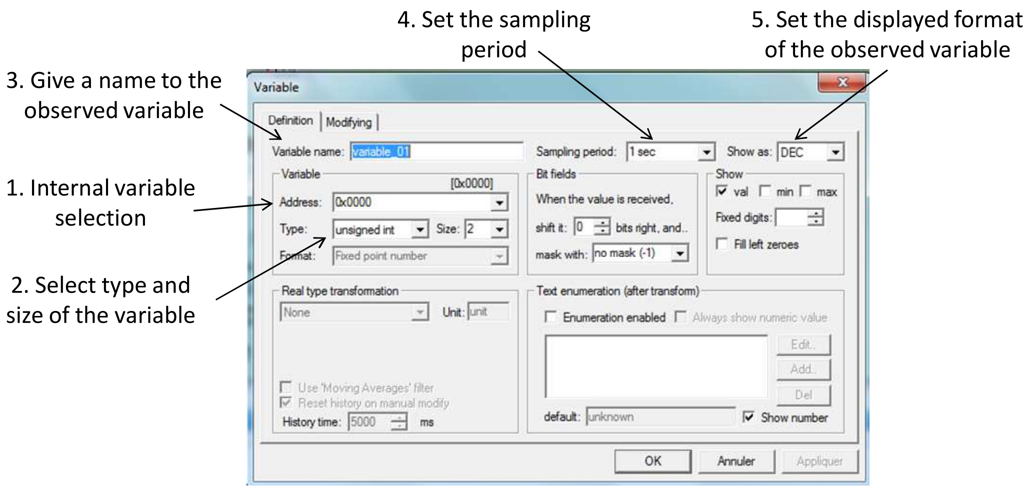


Figure 17 - Selection of a new variable to be visualized with FREEMASTER

Click on OK. The new variable is added in the table **Variable Watch**, as shown in Figure 18 where three variables have been added in the Variable Watch panels. When the communication is active, they are updated in real-time.
Repeat the operation for all the variables that you want to visualize. To delete one variable, right click on the variables and select **Remove from watch** in the pop-up menu. To modify it, select **Edit variable**.

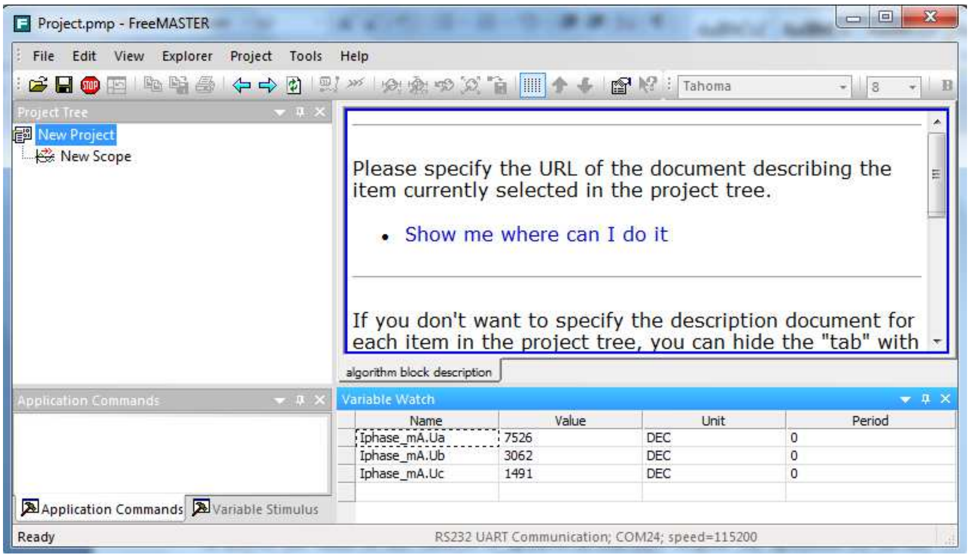


Figure 18 - Example of real-time observation of three variables with Freemaster

FREEMASTER application proposes also to visualize time domain evolution of variables in a 2D graph (called Scope). In Project tree, right click on the project name and select **Create scope** in the pop-up menu. In the tab **Main**, define the name of the Scope in the field **Name**. Specify the sampling period in the field **Period**. Define the number of points visualized in a scope in **Buffer**. You can also modify general graphical properties of the Scope.

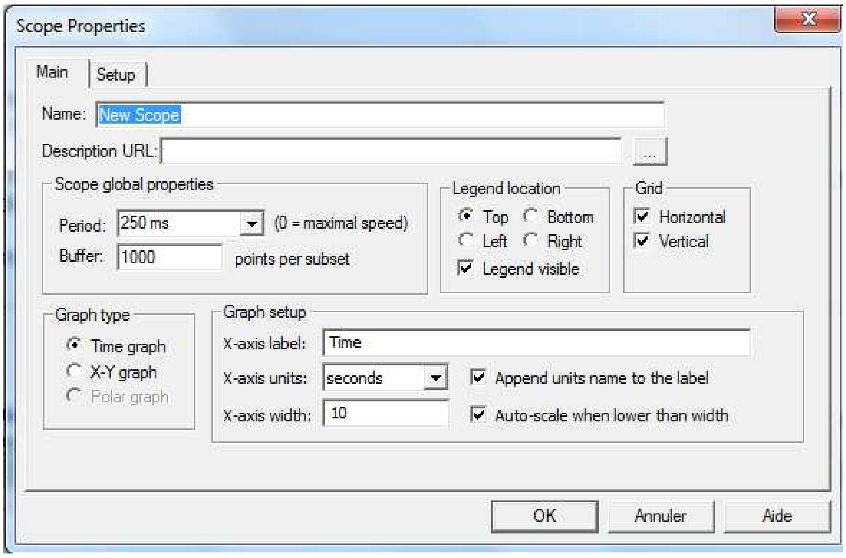


Figure 19 - Properties of a scope

Then, select the variables that you want to visualize. Only watched variables can be displayed in a scope. Click on the tab Setup. The window shown below is displayed. **Graph vars** lists all the variables to be plotted In the list below, select the watched variables to be plotted. The variable appears in **Graph Vars** list. On the right, the list **Assignment to Y blocks** is visible. A block is a subgraph. You can plot as many variables in a block. If you want to plot two variables in two different blocks, select the variables, the block and click on the button **Assign vars to block**. You can modify general properties of curves and blocks in this screen.

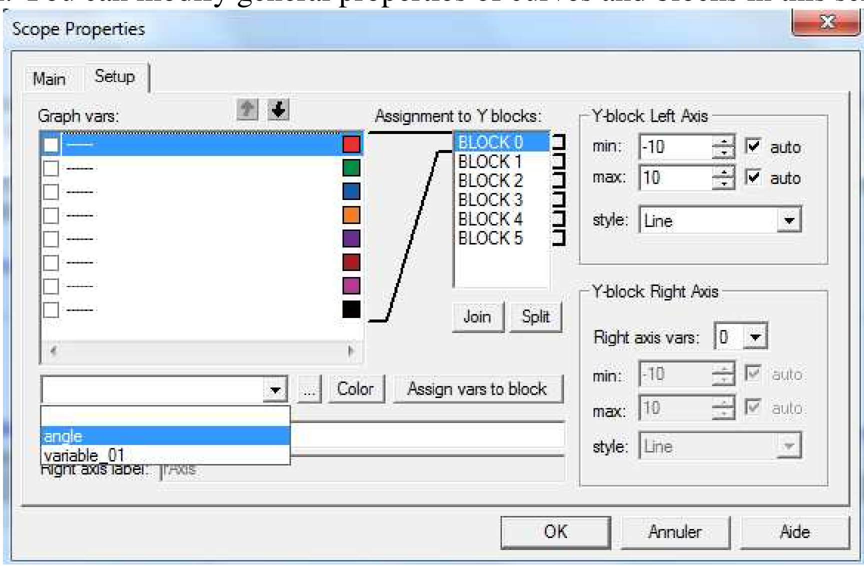


Figure 20 - Selection of plotted variables in a Scope

Click on OK. The graph appears. If the communication is active, the selected watched variables are plotted directly. Their evolution is plotted in real-time, as shown in the figure below.

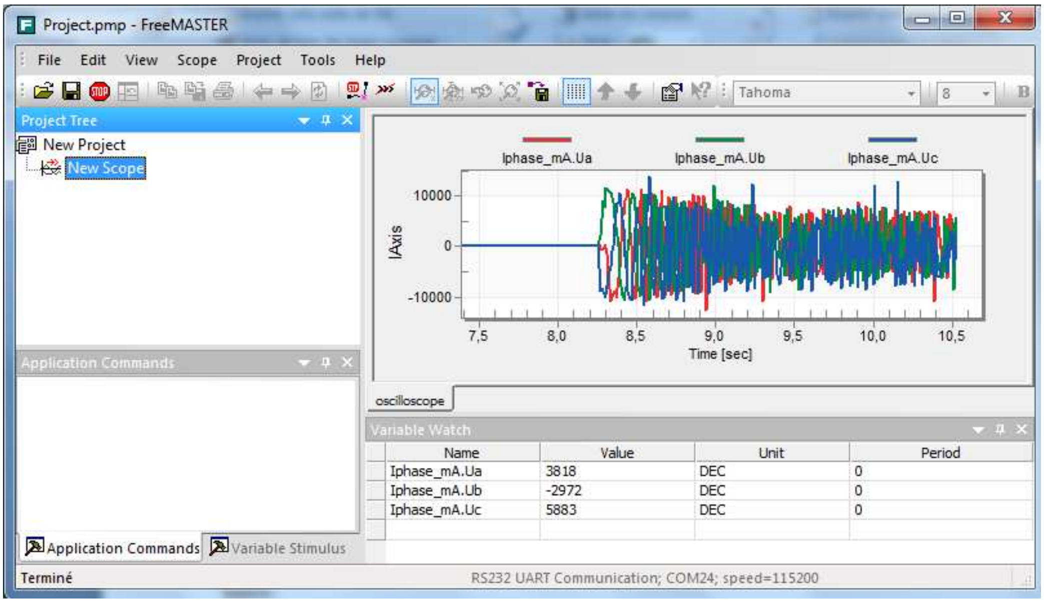
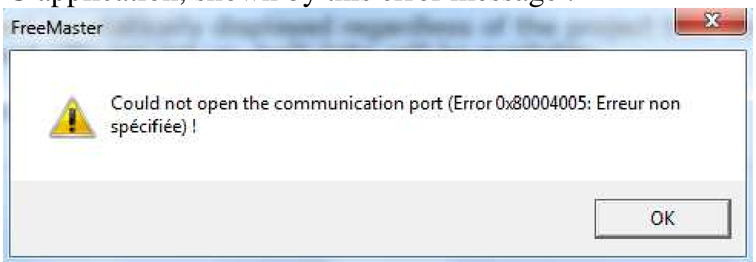


Figure 21 - Observation of the time-domain evolution of three variables in a Scope

Do not forget to save the project before closing FREEMASTER application.

4. Debug FREEMASTER

Wrong configurations will result in loss of communications between the MCU board and FREEMASTER PC application, shown by this error message :



Freemaster is usually not able to communicate with the board in the five following situations:

- FREEMASTER drivers have not been called in the embedded application (or incorrectly called)
- the associated UART has not been correctly configured (baud rate, I/O pads not configured, …)
- FMSTR_Isr() function has not been linked to interrupts vectors associated to the UART (for TX and RX)
- port and baud rate specified in FREEMASTER application are wrong
- the communication port between your PC and the microcontroller board is already used by another application (e.g. S32DS in-situ debugger).
- the embedded application was compiled and built, but it results in wrong operation (e.g. crash due to a critical interrupt request).

If the first four reasons have been verified, then you can conclude that FREEMASTER is correctly configured, but your embedded application is not operational.

IV - Presentation of Automotive Math and Motor Control Library for MPC574xP

This Matlab/Simulink toolbox is compatible only from R2014.a release. In this document, the version 2.2 for MPC574xP MCU is considered. More information about the mathematical functions provided by this toolbox can be found in [AMMC]. Model-Based Design Toolbox can be downloaded here: http://www.nxp.com/support/developer-resources/run-time-software/automotive-software-and-tools/model-based-design-toolbox:MC_TOOLBOX

1. Overview

The NXP's Automotive Math and Motor Control Library (AMMCLIB) provides a list of mathematical functions dedicated to motor control, which supports different number representations (fixed or floating point). This library is supported by S32DS compiler so it appears as a SDK for S32DS. Moreover, models compatible with Simulink are also available. Thus it can be used as a Matlab/Simulink's toolbox.
The AMMCLIB for NXP MPC574xP devices is organized in several sub-libraries, as depicted in Figure 22:

- Mathematical Function Library (MLIB) - it comprises basic mathematical operations such as addition, multiplication, etc.
- General Function Library (GFLIB) - it comprises basic trigonometric and general math functions such as sine, cosine, tan, hysteresis, limit, etc.
- General Digital Filters Library (GDFLIB) - it includes digital IIR and FIR filters designed to be used in a motor control application
- General Motor Control Library (GMCLIB) - it includes standard algorithms used for motor control such as Clarke/Park transformations, Space Vector Modulation, etc.
- Advanced Motor Control Function Library (AMCLIB) - it comprises advanced algorithms used for motor control purposes

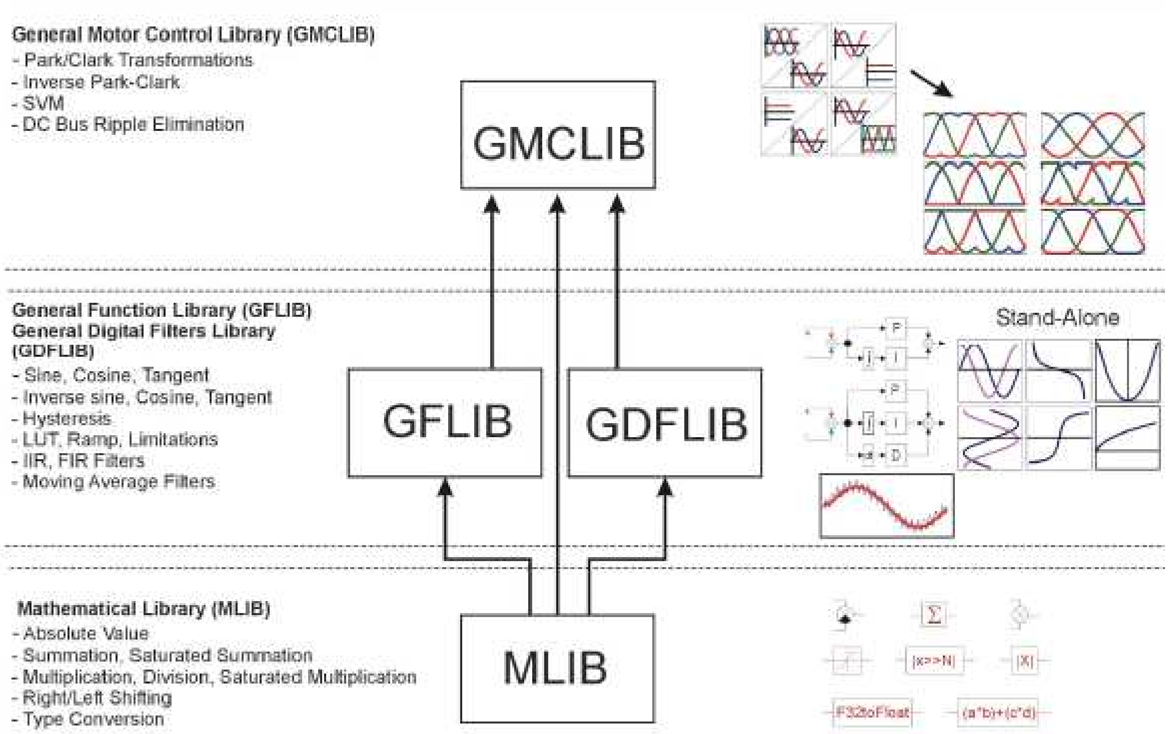


Figure 22 - Organization of sublibraries of AMMCLIB [AMMC]

The AMMCLIB for NXP MPC574xP devices was developed to support three major implementations:

- Fixed-point 32-bit fractional (suffix F32) or Q1.31 format: in this format, the number are comprised between -1 and $1\text{-}2^{-31}$. The minimum positive value is normalized to 2^{-31}. Using the format requires a scaling of number to the interval [-1;+1] beforehand.
- Fixed-point 16-bit fractional (suffix F16) or Q1.15 format : in this format, the number are comprised between -1 and $1\text{-}2^{-15.}$ The minimum positive value is normalized to 2^{-15}. Using the format requires a scaling of number to the interval [-1;+1] beforehand.
- Single precision (32 bits) floating point (suffix FLT): in this format, the number are comprised between -2^{128} and 2^{128}, with a minimum positive value normalized to 2^{-128}. The MSB is the sign, the next 24 bits are the mantissa and the 7 last bits form the exponent.

The fixed-point 32-bit fractional and fixed-point 16-bit rational functions are implemented based on the unity model. It means that, before using blocks based on these formats, numbers must be normalized so that their values remain in the range [-1 ; +1]. Most of the functions do not integrate saturation function: any output that exceed this range induce an overflow condition.

Tips: converting binary code to decimal number in Q1.31 format: evaluation by the hand the number coded by a binary or hexadecimal in Q1.31 representation can be quite tedious. In Matlab, the function dec2hex() can be used to convert decimal number to hexadecimal representation, while the function hex2dec() aims at converting hexadecimal to decimal representation. Based on this two functions and on scaling transform, the conversion between decimal and Q1.31 is possible:

- Conversion from decimal to Q1.31 format:

- if the number is positive, use the following command: dec2hex(floor(number*2^{31})).
- if the number is negative, the sign is indicated by the MSB while the other bits code the shift from -1. Use the following command: dec2hex(floor((1-number)*2^{31})).

- Conversion from Q1.31 format to decimal:
  - if the number is positive (MSB = '0'), use the following command: hex2dec('hexa_code')/2^{31}.
  - if the number is negative (MSB = '1'), remove the MSB and use the following command: hex2dec('hexa_code')/2^{31}-1

2. Types provided by AMMCLIB

Numerous types are defined in AMMCLIB files. The basic types are summarized in the following table. Boolean, unsigned/signed integer or floating number formats are provided. Fixed-point 32-bit fractional type is called tFrac32, while tFrac16 is the type for fixed-pont 16 bit fractional number.

Type	Name	Description
typedef unsigned char	tBool	basic boolean type
typedef double	tDouble	double precision float type
typedef float	tFloat	single precision float type
typedef tS16	tFrac16	16-bit signed fractional Q1.15 type
typedef tS32	tFrac32	32-bit Q1.31 type
typedef signed short	tS16	signed 16-bit integer type
typedef signed long	tS32	signed 32-bit integer type
typedef signed long long	tS64	signed 64-bit integer type
typedef signed char	tS8	signed 8-bit integer type
typedef unsigned short	tU16	unsigned 16-bit integer type
typedef unsigned long	tU32	unsigned 32-bit integer type
typedef unsigned long long	tU64	unsigned 64-bit integer type
typedef unsigned char	tU8	unsigned 8-bit integer type

Numerous compound types also exist. They are detailed in part 7 of the AMMCLIB reference document [AMMC].

3. Brief presentation of the functions

Functions of Advanced Motor Control sublibrary are not presented in this document as they will not be used in the Automotive Electronics lab. The full list of functions is given in chapter 4 (p 151) of [AMMC].
Read carefully the MMCLIB User's guide [AMMC] to verify the performed mathematical operations, the input and output types and the required conditions. Any violation of these conditions may result in bug of Simulink simulation or code compilation (best case), or in unpredictable behavior of the embedded application (worst case).

In the following paragraphs, the list of functions in each sublibrary is given. Each function is terminated by a suffix F16, F32 or FLT to indicate the supported format. As all the functions support these three formats, the suffix is omitted in the next parts.

a. Math Function library (MLIB)

All these functions start with the prefix MLIB_. Details can be found between pages 531 and 650 of [AMMC].

Name	Description
Abs	Absolute value of input parameter
AbsSat	Absolute value of input parameter with saturation on output
Add	Addition of the two input parameters
AddSat	Addition of the two input parameters with saturation on output
Convert_FaFb	Conversion between type Fa and type Fb. The conversion functions exist for the three supported types of the library
Div	Division of the two input parameters
DivSat	Division of the two input parameters with saturation on output
Mac	Multiply - accumulate function
MacSat	Multiply - accumulate function with saturation on output
Mnac	Multiply - substract function
Msu	Multiply - substract function
Mul	Multiplication of the two input parameters
MulSat	Multiplication of the two input parameters with saturation on output
Neg	Negative value of the input parameter
NegSat	Negative value of the input parameter with saturation on output
RndSat	Round the input parameter
Round	Round the input parameter with saturation on output
ShBi	Shift to the left or right
ShBiSat	Shift to the left or right with saturation on output
ShL	Shift to the left
ShLSat	Shift to the left with saturation on output
ShR	Shift to the right
Sub	Substrate the two input parameters
SubSat	Substrate the two input parameters with saturation on output
VMac	Vector multiply accumulate function

b. General Functions library (GFLIB)

All these functions start with the prefix GFLIB_. Details can be found between pages 255 and 469 of [AMMC].

Name	Description
Acos	Arccosine function
Asin	Arcsine function
Atan	Arctangent function
AtanYX	Arctangent function applied on two input arguments
AtanYXShifted	Calculate the angle of two sinusoidal signals, one shifted in phase to the other.
ControllerPip	Parallel form of the Proportional-Integral controller, without integral anti-windup
ControllerPipAW	Parallel form of the Proportional-Integral controller, with integral anti-windup

ControllerPir	Standard recurrent form of the Proportional-Integral controller, without integral anti-windup
ControllerPirAW	Standard recurrent form of the Proportional-Integral controller, with integral anti-windup
Cos	Cosine function
Hyst	Calculation of a hysteresis function
IntegratorTR	Discrete implementation of the integrator (sum)
Limit	Test whether the input value is within the upper and lower limits
LowerLimit	Test whether the input value is above the lower limit
Lut1D	Implementation of a one-dimensional look-up table
Lut2D	Implementation of a two-dimensional look-up table
Ramp	Up/down ramp with a step increment/decrement
Sign	Sign of the input argument
Sin	Sine function
SinCos	Return Sine and Cosine functions
Sqrt	Square-root function
Tan	Tangent function
UpperLimit	Test whether the input value is below the upper limit
VectorLimit	Limit the magnitude of the input vector

c. General Digital Filters library (GDFLIB)

All these functions start with the prefix GDFLIB_. Details can be found between pages 208 and 254 of [AMMC].

Name	Description
FilterFIRInit	Initialization of FIR filter buffer
FilterFIR	Performs a single iteration of an FIR filter
FilterIIR1Init	Initialization of first order IIR filter buffer
FilterIIR1	Implements the first order IIR filter
FilterIIR2Init	Initialization of second order IIR filter buffer
FilterIIR2	Implements the second order IIR filter
FilterMAInit	Clears the internal filter accumulator
FilterMA	Implements an exponential moving average filter

d. General Motor Control library (GMCLIB)

All these functions start with the prefix GMCLIB_. Not all the functions are listed below. More details can be found between pages 474 and 526 of [AMMC].

Name	Description
ClarkInv	Compute inverse Clark transform
Clark	Compute Clark transform
ParkInv	Compute inverse Park transform
Park	Compute Park transform
SvmStd	Duty-cycle ratios using the Standard Space Vector Modulation technique

4. Using in S32DS environment

The first step is the import of AMMCLIB SDK during the creation of S32DS project. Refer to part I.7 of this document for SDK import.

a. Setting the implementation

By default the support of all implementations is turned off, thus the error message *"Define at least one supported implementation in SWLIBS_Config.h file."* is displayed during the compilation if no implementation is selected, preventing the user application building. Following are the macro definitions enabling or disabling the implementation support:

- SWLIBS_SUPPORT_F32 for 32-bit fixed-point implementation support selection
- SWLIBS_SUPPORT_F16 for 16-bit fixed-point implementation support selection
- SWLIBS_SUPPORT_FLT for single precision floating-point implementation support selection

These macros are defined in the SWLIBS_Config.h file located in Common directory of the AMMCLIB for NXP MPC574xP devices installation destination. To enable the support of each individual implementation the relevant macro definition has to be set to *SWLIBS_STD_ON*.

Moreover, the SWLIBS_DEFAULT_IMPLEMENTATION macro definition has to be setup properly. This macro definition is not defined by default thus the error message "Define default implementation in SWLIBS_Config.h file." is displayed during the compilation, preventing the user application building. The SWLIBS_DEFAULT_IMPLEMENTATION macro is defined in the SWLIBS_Config.h file located in Common directory of the AMMCLIB for NXP MPC574xP devices installation destination. The SWLIBS_DEFAULT_IMPLEMENTATION can be defined as the one of the following supported implementations:

- SWLIBS_DEFAULT_IMPLEMENTATION_F32 for 32-bit fixed-point implementation
- SWLIBS_DEFAULT_IMPLEMENTATION_F16 for 16-bit fixed-point implementation
- SWLIBS_DEFAULT_IMPLEMENTATION_FLT for single precision floating point implementation

b. Calling mathematical function

After proper definition of *SWLIBS_DEFAULT_IMPLEMENTATION* macro, the AMMCLIB for NXP MPC574xP devices functions can be called using standard legacy API convention: 'Sublibrary_name'_'Function_name'_'Format_suffix'. For example if the *SWLIBS_DEFAULT_IMPLEMENTATION* macro definition is set to *SWLIBS_DEFAULT_IMPLEMENTATION_F32*, the 32-bit fixed-point implementation of sine function is invoked after the *GFLIB_Sin(x)* API call. The command GFLIB_Sin_F32(x) has to be added in the C code. Moreover, the header file where the used mathematical function is declared must be included in the C code file which uses the function. For example, if the GFLIB_Sin_F32(x) is used, the directive '#include gflib.h' must be added in the C code.

5. Using in Matlab/Simulink environment

The functions provided by the library can be used in Simulink directly (once the library has been installed).

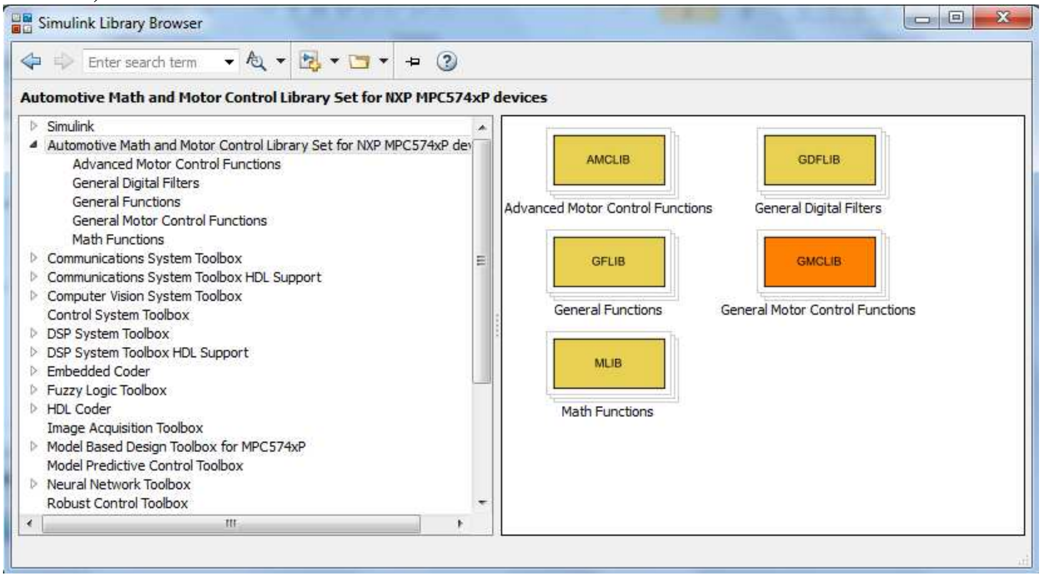


Figure 23 - AMMCLIB library in Simulink

V - References

[FRUG]	FreeMASTER Serial Communication Driver, User's Guide, Rev. 3.0, August 2016, NXP Semiconductors, www.nxp.com/docs/en/user-guide/FMSTRSCIDRVUG.pdf
[AMMC]	Automotive Math and Motor Control Library Set for NXP MPC574xP devices, User's Guide, Rev. 12, MPC574XPMCLUG, www.nxp.com