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# GMCLIB User's Guide

ARM® Cortex® M7F

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# Contents

Section number	Title	Page
<b>Chapter 1</b>		
<b>Library</b>		
1.1	Introduction.....	5
1.2	Library integration into project (Kinetis Design Studio) .....	7
1.3	Library integration into project (Keil $\mu$ Vision) .....	16
1.4	Library integration into project (IAR Embedded Workbench) .....	23
<b>Chapter 2</b>		
<b>Algorithms in detail</b>		
2.1	GMCLIB_Clark.....	31
2.2	GMCLIB_ClarkInv.....	32
2.3	GMCLIB_Park.....	34
2.4	GMCLIB_ParkInv.....	36
2.5	GMCLIB_DecouplingPMSM.....	38
2.6	GMCLIB_ElimDcBusRipFOC.....	43
2.7	GMCLIB_ElimDcBusRip.....	47
2.8	GMCLIB_SvmStd.....	52
2.9	GMCLIB_SvmIct.....	67
2.10	GMCLIB_SvmU0n.....	71
2.11	GMCLIB_SvmU7n.....	75



# Chapter 1

## Library

### 1.1 Introduction

#### 1.1.1 Overview

This user's guide describes the General Motor Control Library (GMCLIB) for the family of ARM Cortex M7F core-based microcontrollers. This library contains optimized functions.

#### 1.1.2 Data types

GMCLIB supports several data types: (un)signed integer, fractional, and accumulator, and floating point. The integer data types are useful for general-purpose computation; they are familiar to the MPU and MCU programmers. The fractional data types enable powerful numeric and digital-signal-processing algorithms to be implemented. The accumulator data type is a combination of both; that means it has the integer and fractional portions. The floating-point data types are capable of storing real numbers in wide dynamic ranges. The type is represented by binary digits and an exponent. The exponent allows scaling the numbers from extremely small to extremely big numbers. Because the exponent takes part of the type, the overall resolution of the number is reduced when compared to the fixed-point type of the same size.

The following list shows the integer types defined in the libraries:

- [Unsigned 16-bit integer](#) —<0 ; 65535> with the minimum resolution of 1
- [Signed 16-bit integer](#) —<-32768 ; 32767> with the minimum resolution of 1
- [Unsigned 32-bit integer](#) —<0 ; 4294967295> with the minimum resolution of 1
- [Signed 32-bit integer](#) —<-2147483648 ; 2147483647> with the minimum resolution of 1

The following list shows the fractional types defined in the libraries:

- **Fixed-point 16-bit fractional** — $\langle -1 ; 1 - 2^{-15} \rangle$  with the minimum resolution of  $2^{-15}$
- **Fixed-point 32-bit fractional** — $\langle -1 ; 1 - 2^{-31} \rangle$  with the minimum resolution of  $2^{-31}$

The following list shows the accumulator types defined in the libraries:

- **Fixed-point 16-bit accumulator** — $\langle -256.0 ; 256.0 - 2^{-7} \rangle$  with the minimum resolution of  $2^{-7}$
- **Fixed-point 32-bit accumulator** — $\langle -65536.0 ; 65536.0 - 2^{-15} \rangle$  with the minimum resolution of  $2^{-15}$

The following list shows the floating-point types defined in the libraries:

- **Floating point 32-bit single precision** — $\langle -3.40282 \cdot 10^{38} ; 3.40282 \cdot 10^{38} \rangle$  with the minimum resolution of  $2^{-23}$

### 1.1.3 API definition

GMCLIB uses the types mentioned in the previous section. To enable simple usage of the algorithms, their names use set prefixes and postfixes to distinguish the functions' versions. See the following example:

```
f32Result = MLIB_Mac_F32lss(f32Accum, f16Mult1, f16Mult2);
```

where the function is compiled from four parts:

- **MLIB**—this is the library prefix
- **Mac**—the function name—Multiply-Accumulate
- **F32**—the function output type
- **lss**—the types of the function inputs; if all the inputs have the same type as the output, the inputs are not marked

The input and output types are described in the following table:

**Table 1-1. Input/output types**

Type	Output	Input
<a href="#">frac16_t</a>	F16	s
<a href="#">frac32_t</a>	F32	l
<a href="#">acc32_t</a>	A32	a
<a href="#">float_t</a>	FLT	f

### 1.1.4 Supported compilers

GMCLIB for the ARM Cortex M7F core is written in . The library is built and tested using the following compilers:

- Kinetis Design Studio
- IAR Embedded Workbench
- Keil  $\mu$ Vision

For the Kinetis Design Studio, the library is delivered in the *gmclib.a* file.

For the IAR Embedded Workbench, the library is delivered in the *gmclib.a* file.

For the Keil  $\mu$ Vision, the library is delivered in the *gmclib.lib* file.

The interfaces to the algorithms included in this library are combined into a single public interface include file, *gmclib.h*. This is done to lower the number of files required to be included in your application.

### 1.1.5 Special issues

1. The equations describing the algorithms are symbolic. If there is positive 1, the number is the closest number to 1 that the resolution of the used fractional type allows. If there are maximum or minimum values mentioned, check the range allowed by the type of the particular function version.
2. The library functions that round the result (the API contains Rnd) round to nearest (half up).

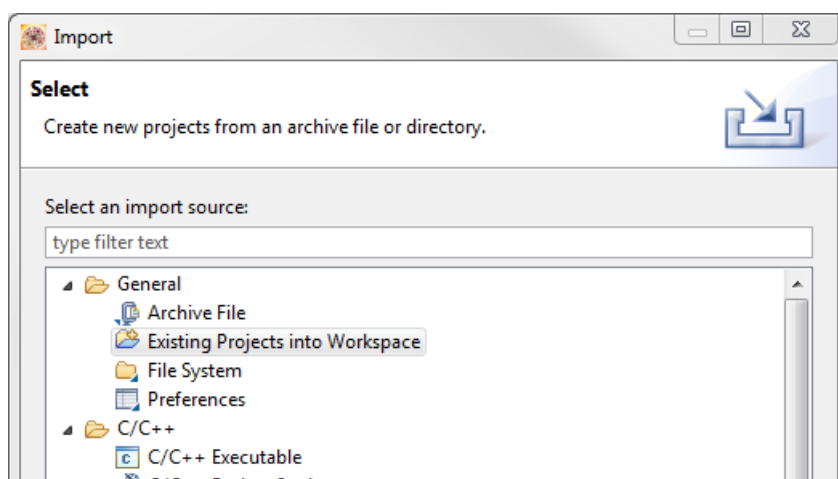
## 1.2 Library integration into project (Kinetis Design Studio)

This section provides a step-by-step guide on how to quickly and easily include GMCLIB into an empty project or any SDK example or demo application projects using Kinetis Design Studio. This example uses the default installation path (C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KDS). If you have a different installation path, use that path instead. If you want to use an existing SDK project (for example the hello\_world project) see [Library path variable](#). If not, continue with the next section.

## 1.2.1 New project (without SDK)

To start working on an application, create a new project. If the project already exists and is opened, skip to the next section. Follow these steps to create a new project:

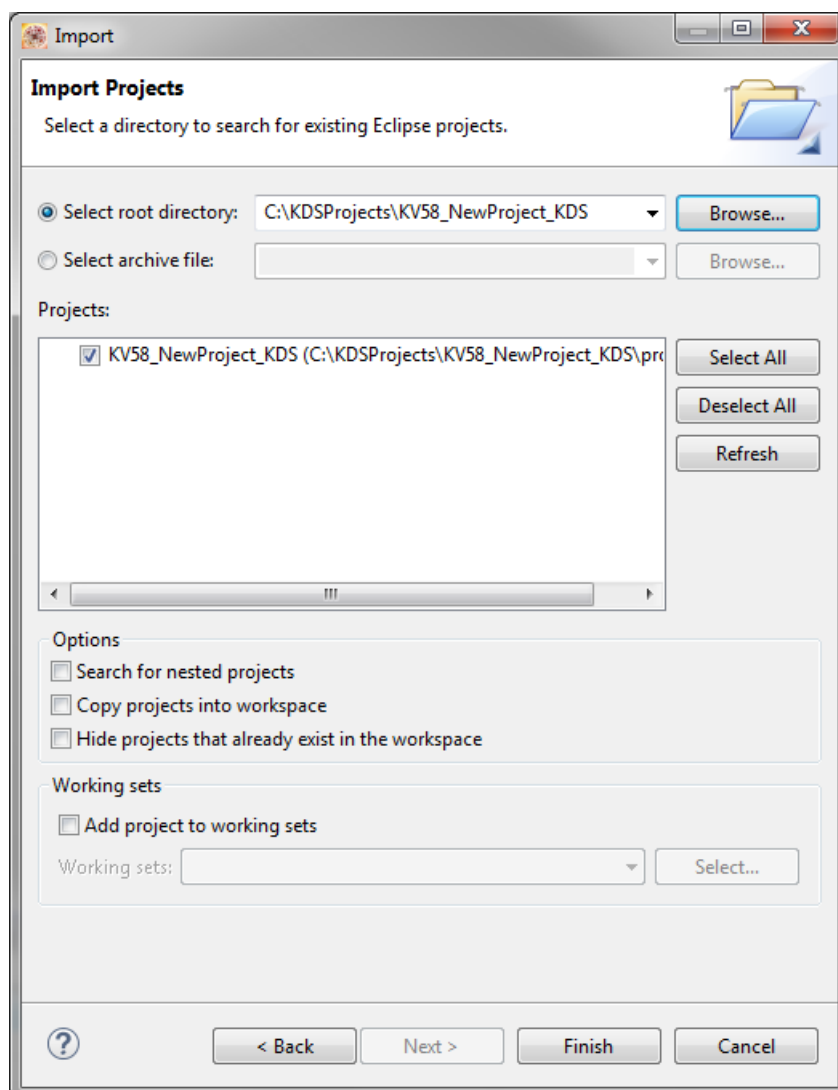
1. Because Kinetis Design Studio does not have any stationary for Kinetis CM7-based platforms, the library installation comes with an empty project for the KV5x family (the empty project is not attached if NXP Kinetis Expert was used for RTCESL download). Copy the existing empty project folder KV58\_NewProject\_KDS (located in the library installation sub-folder Projects) to your projects folder (for example, C:\KDSProjects).
2. Launch Kinetis Design Studio.
3. Select File > Import... so that the Import dialog appears. See [Figure 1-1](#).



**Figure 1-1. Project import**

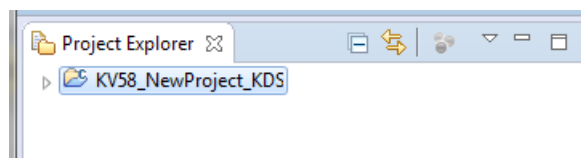
4. Select the General > Existing Projects into Workspace node and click Next.
5. In the Select root directory box, type the path to which you copied the project (C:\KDSProjects\KV58\_NewProject\_KDS), or look for it by clicking Browse. See [Figure 1-2](#).





**Figure 1-2. Project import folder**

6. In the Projects dialog, tick the right project and then click Finish.
7. In the Project Explorer dialog, right-click the newly-imported project KV58\_NewProject\_KDS and select Rename. See [Figure 1-3](#).



**Figure 1-3. Project Explorer**

8. In the next dialog, type the name of your project (for example MyProject01) and click OK.
9. Right-click the MyProject01 node, click Properties in the Project Explorer, or select Project > Properties from the menu. A project properties dialog appears.
10. Expand the C/C++ Build node and select Settings.

11. In the right-hand part, set the Float ABI as FP instructions (hard) and the FPU type as fpv5\_sp\_d16. See [Figure 1-4](#).

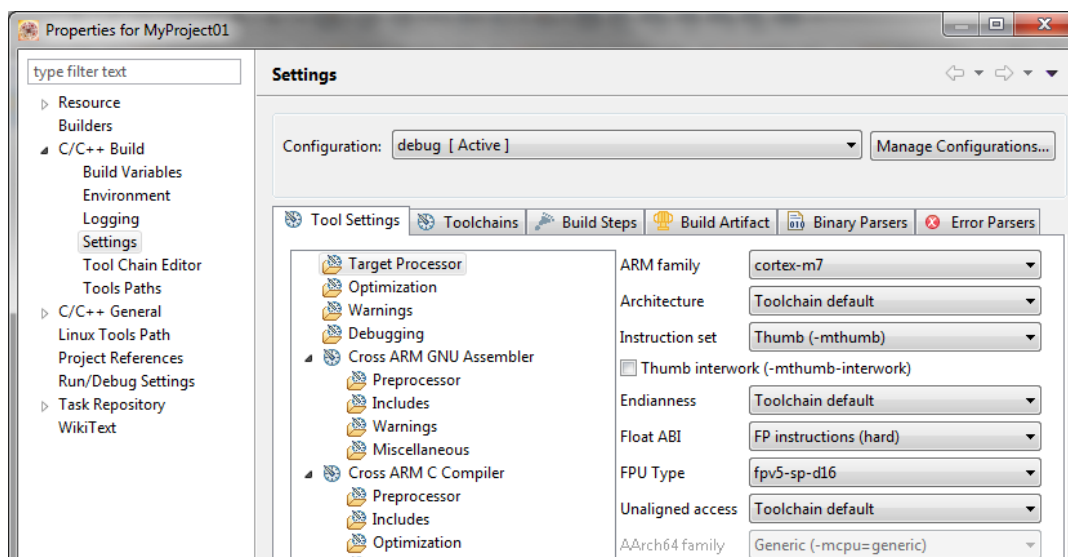


Figure 1-4. FPU setting

## 1.2.2 Library path variable

To make the library integration easier, create a variable that will hold the information about the library path.

1. Right-click the MyProject01 or SDK project name node in the left-hand part and click Properties, or select Project > Properties from the menu. A project properties dialog appears.
2. Expand the Resource node and click Linked Resources. See [Figure 1-5](#).

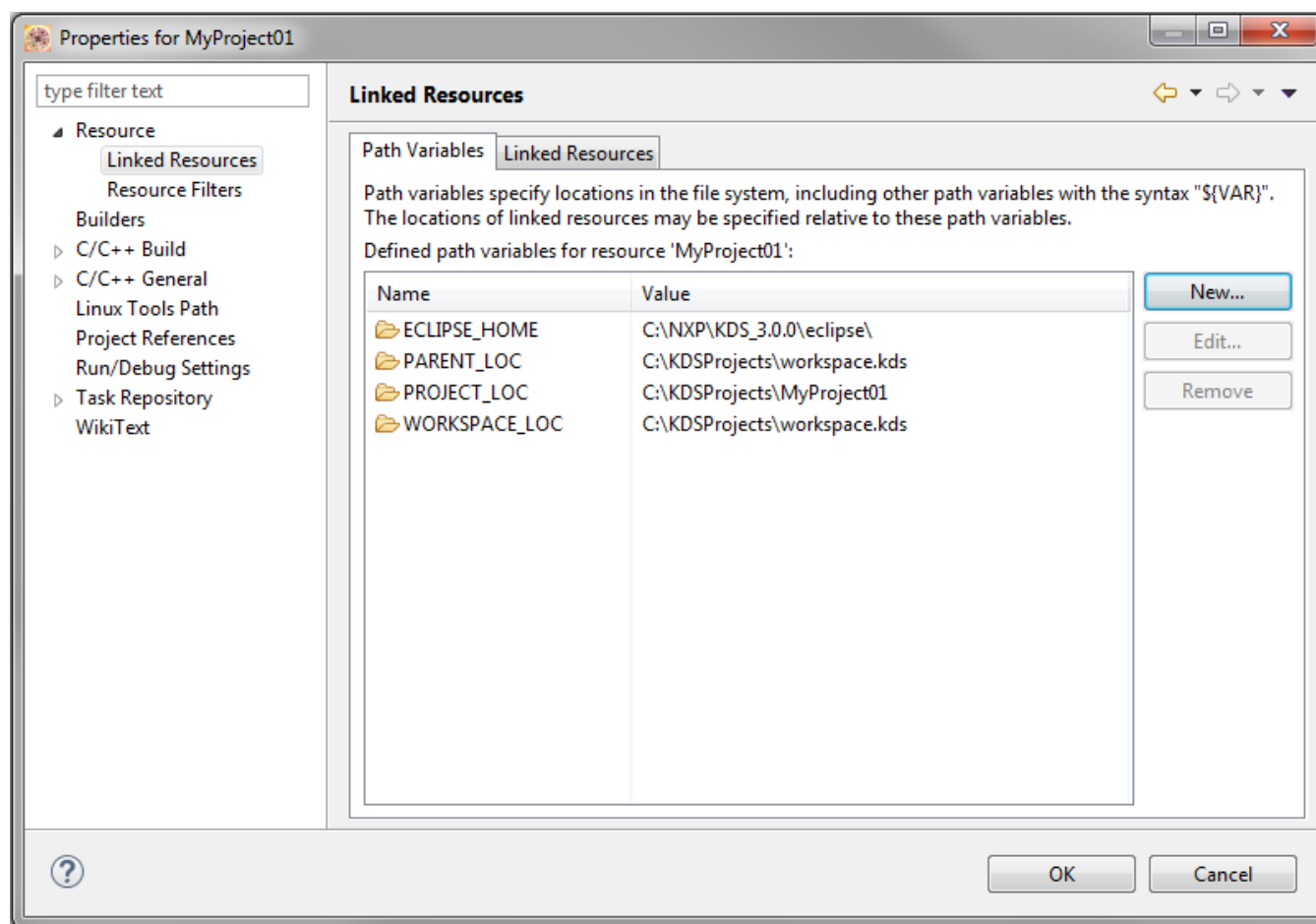


Figure 1-5. Project properties

3. Click the New... button in the right-hand side.
4. In the dialog that appears (see [Figure 1-6](#)), type this variable name into the Name box: RTCESL\_LOC.
5. Select the library parent folder by clicking Folder..., or just type the following path into the Location box: C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KDS. Click OK.

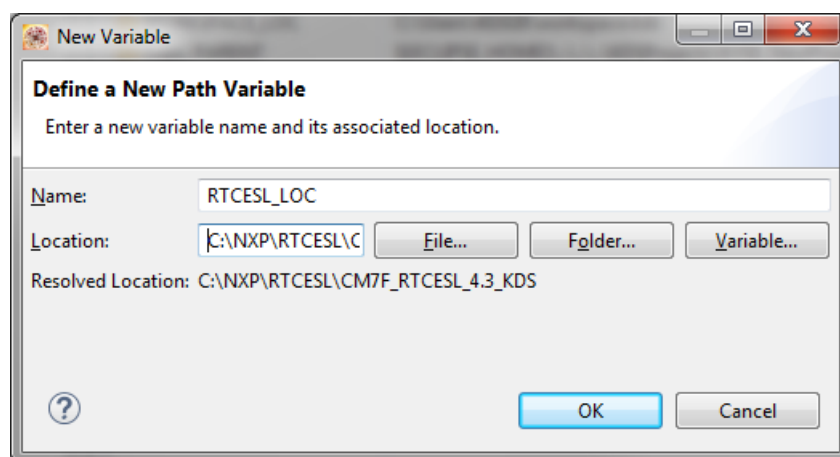


Figure 1-6. New variable

6. Create such variable for the environment. Expand the C/C++ Build node and click Environment.
7. Click the Add... button in the right-hand side.
8. In the dialog that appears (see [Figure 1-7](#)), type this variable name into the Name box: RTCESL\_LOC.
9. Type the library parent folder path into the Value box: C:\NXP\RTCESL\CM7F\_RTCESEL\_4.3\_KDS.
10. Tick the Add to all configurations box to use this variable in all configurations. See [Figure 1-7](#).
11. Click OK.
12. In the previous dialog, click OK.

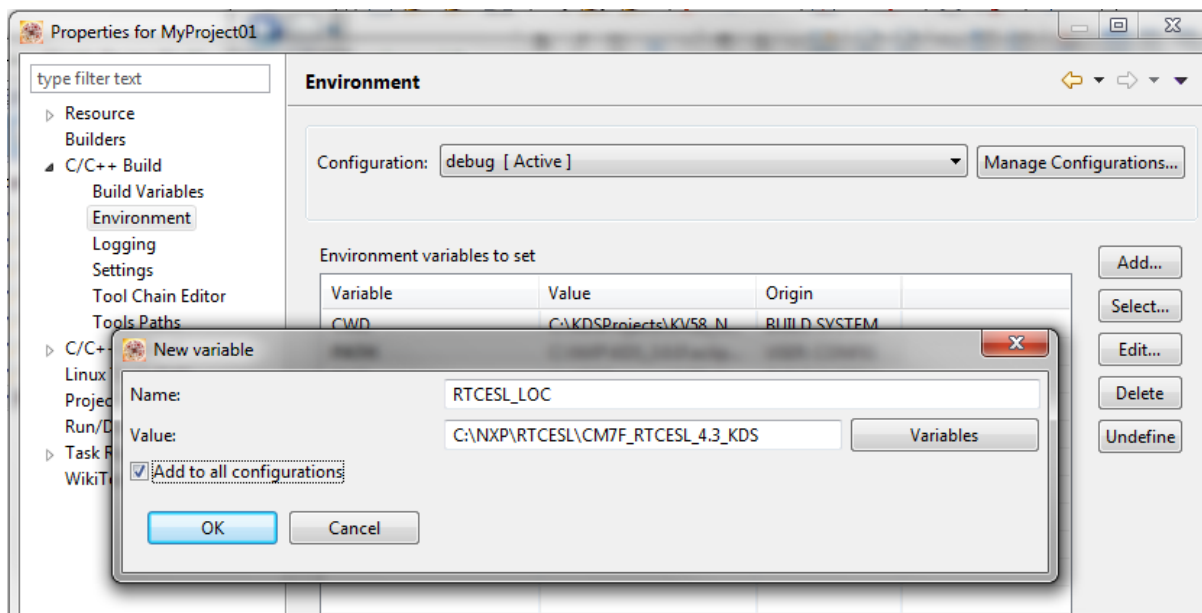


Figure 1-7. Environment variable

### 1.2.3 Library folder addition

To use the library, add it into the Project tree dialog.

1. Right-click the MyProject01 or SDK project name node in the left-hand part and click New > Folder, or select File > New > Folder from the menu. A dialog appears.
2. Click Advanced to show the advanced options.
3. To link the library source, select the option Link to alternate location (Linked Folder).
4. Click Variables..., select the RTCESL\_LOC variable in the dialog, click OK, and/or type the variable name into the box. See [Figure 1-8](#).
5. Click Finish, and you will see the library folder linked in the project. See [Figure 1-9](#).

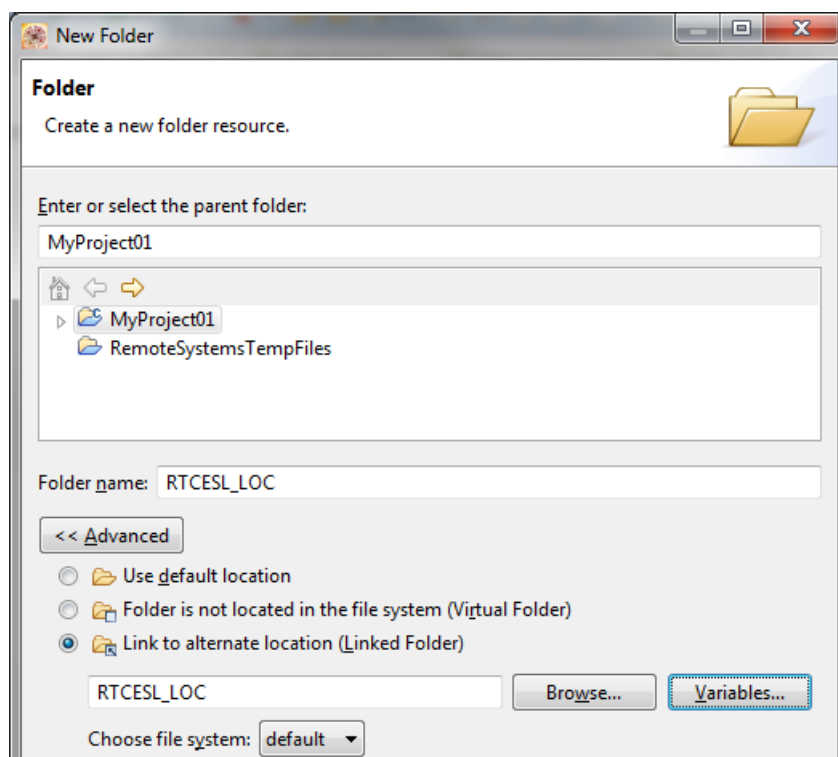


Figure 1-8. Folder link

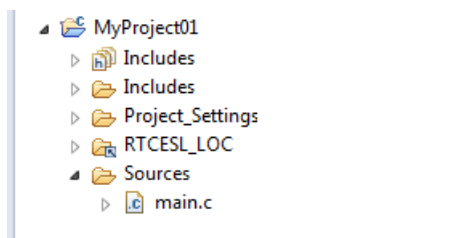


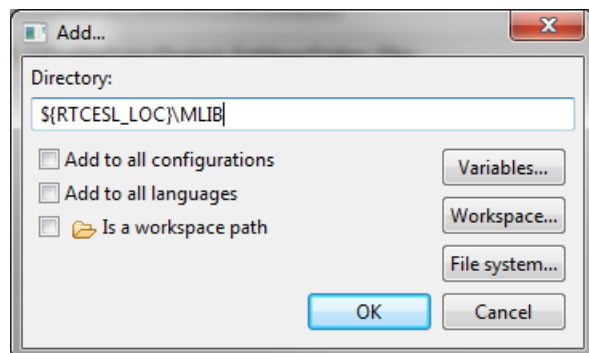
Figure 1-9. Projects libraries paths

## 1.2.4 Library path setup

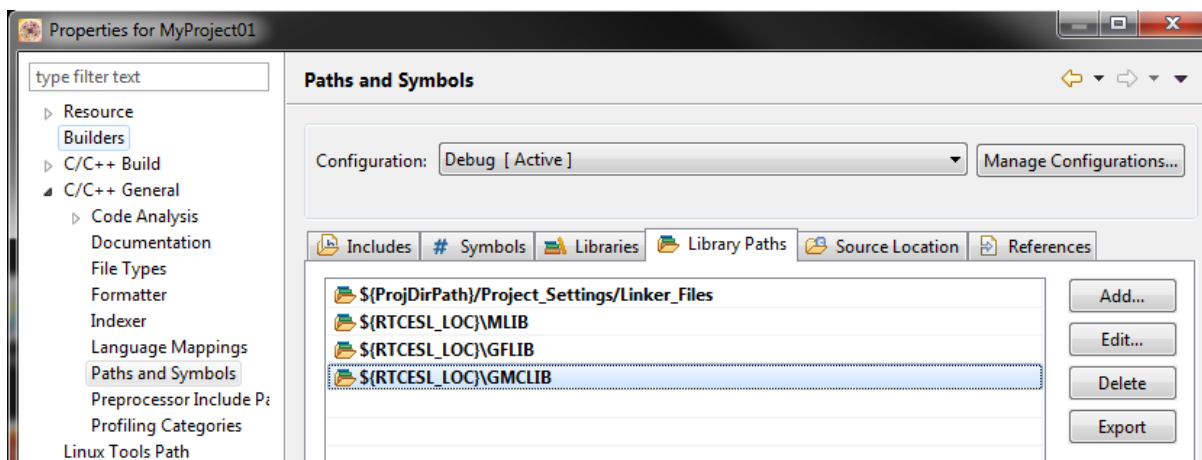
GMCLIB requires MLIB and GFLIB to be included too. These steps show how to include all dependent modules:

1. Right-click the MyProject01 or SDK project name node in the left-hand part and click Properties, or select Project > Properties from the menu. A project properties dialog appears.
2. Expand the C/C++ General node, and click Paths and Symbols.
3. In the right-hand dialog, select the Library Paths tab. See [Figure 1-11](#).
4. Click the Add... button on the right, and a dialog appears.
5. Look for the RTCESL\_LOC variable by clicking Variables..., and then finish the path in the box by adding the following (see [Figure 1-10](#)): `${RTCESL_LOC}\MLIB`.

6. Click OK, and then click the Add... button.
7. Look for the RTCESL\_LOC variable by clicking Variables..., and then finish the path in the box by adding the following: \${RTCESL\_LOC}\GFLIB.
8. Click OK, and then click the Add... button.
9. Look for the RTCESL\_LOC variable by clicking Variables..., and then finish the path in the box by adding the following: \${RTCESL\_LOC}\GMCLIB.
10. Click OK, and the paths will be visible in the list. See [Figure 1-11](#).



**Figure 1-10. Library path inclusion**



**Figure 1-11. Library paths**

11. After adding the library paths, add the library files. Click the Libraries tab. See [Figure 1-13](#).
12. Click the Add... button on the right, and a dialog appears.
13. Type the following into the File text box (see [Figure 1-12](#)): :mlib.a
14. Click OK, and then click the Add... button.
15. Type the following into the File text box: :gflib.a
16. Click OK, and then click the Add... button.
17. Type the following into the File text box: :gmclib.a
18. Click OK, and you will see the libraries added in the list. See [Figure 1-13](#).

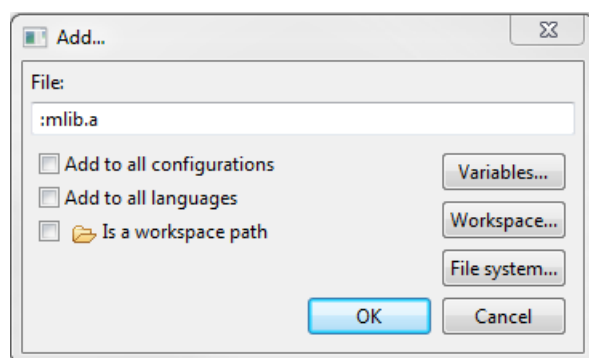


Figure 1-12. Library file inclusion

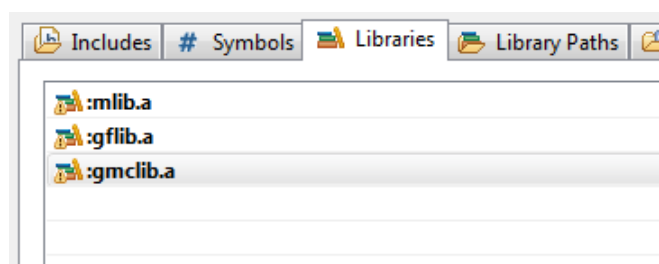


Figure 1-13. Libraries

19. In the right-hand dialog, select the Includes tab, and click GNU C in the Languages list. See [Figure 1-15](#).
20. Click the Add... button on the right, and a dialog appears. See [Figure 1-14](#).
21. Look for the RTCESL\_LOC variable by clicking Variables..., and then finish the path in the box to be: `${RTCESL_LOC}\MLIB\Include`
22. Click OK, and then click the Add... button.
23. Look for the RTCESL\_LOC variable by clicking Variables..., and then finish the path in the box to be: `${RTCESL_LOC}\GFLIB\Include`
24. Click OK, and then click the Add... button.
25. Look for the RTCESL\_LOC variable by clicking Variables..., and then finish the path in the box to be: `${RTCESL_LOC}\GMCLIB\Include`
26. Click OK, and you will see the paths added in the list. See [Figure 1-15](#). Click OK.

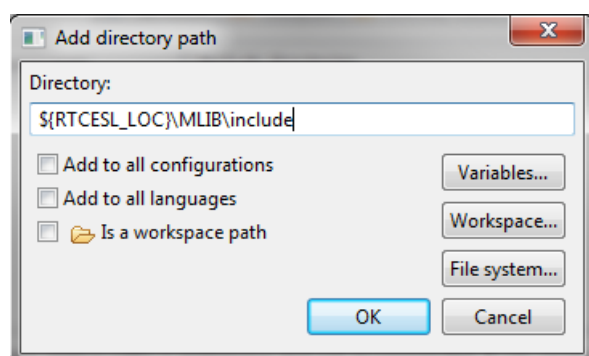


Figure 1-14. Library include path addition

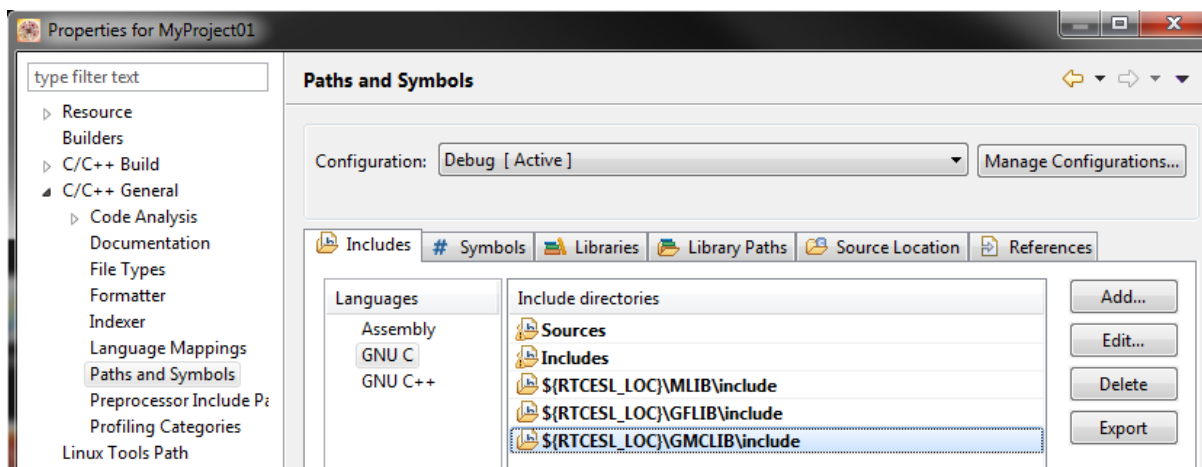


Figure 1-15. Compiler setting

Type the `#include` syntax into the code. Include the library into the *main.c* file. In the left-hand dialog, open the Sources folder of the project, and double-click the *main.c* file. After the *main.c* file opens up, include the following lines in the `#include` section:

```
#include "mlib_fp.h"
#include "gflib_fp.h"
#include "gmclib_fp.h"
```

When you click the Build icon (hammer), the project will be compiled without errors.

## 1.3 Library integration into project (Keil µVision)

This section provides a step-by-step guide on how to quickly and easily include GMCLIB into an empty project or any SDK example or demo application projects using Keil µVision. This example uses the default installation path (C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL). If you have a different installation path, use that path instead. If any SDK project is intended to use (for example hello\_world project) go to [Linking the files into the project](#) chapter otherwise read next chapter.

### 1.3.1 NXP pack installation for new project (without SDK)

This example uses the NXP MKV58F1M0xxx22 part, and the default installation path (C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL) is supposed. If the compiler has never been used to create any NXP MCU-based projects before, check whether the NXP MCU pack for the particular device is installed. Follow these steps:

1. Launch Keil µVision.
2. In the main menu, go to Project > Manage > Pack Installer....



3. In the left-hand dialog (under the Devices tab), expand the All Devices > Freescale (NXP) node.
4. Look for a line called "KVxx Series" and click it.
5. In the right-hand dialog (under the Packs tab), expand the Device Specific node.
6. Look for a node called "Keil::Kinetis\_KVxx\_DFP." If there are the Install or Update options, click the button to install/update the package. See [Figure 1-16](#).
7. When installed, the button has the "Up to date" title. Now close the Pack Installer.

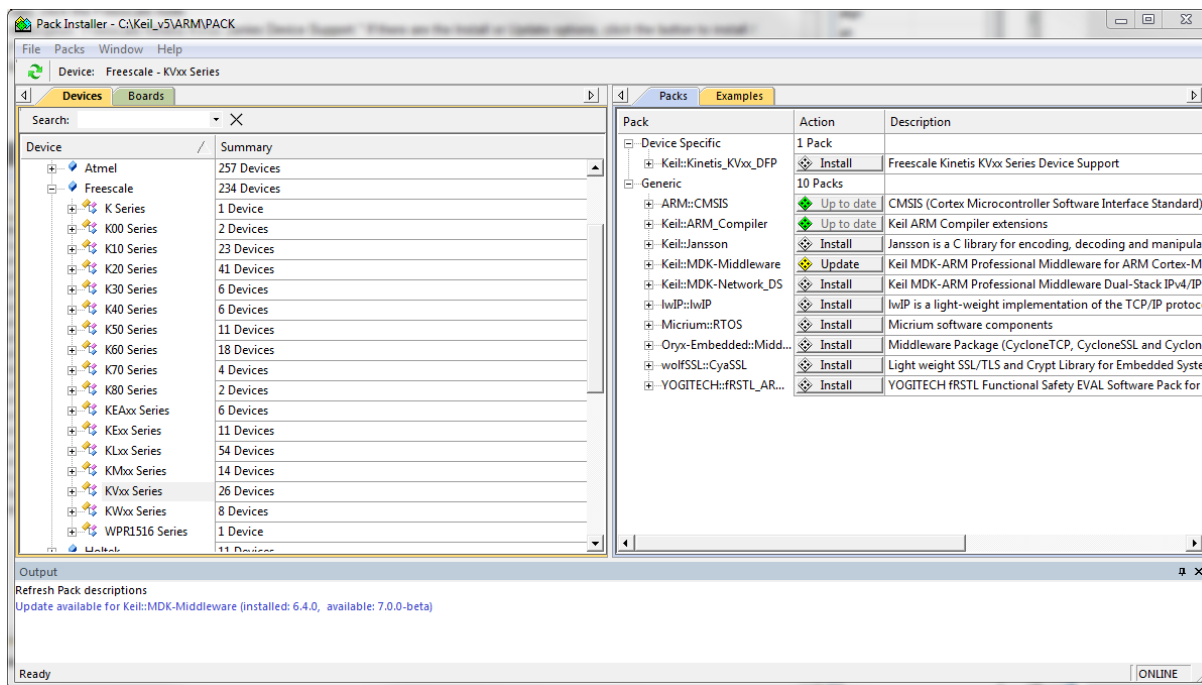
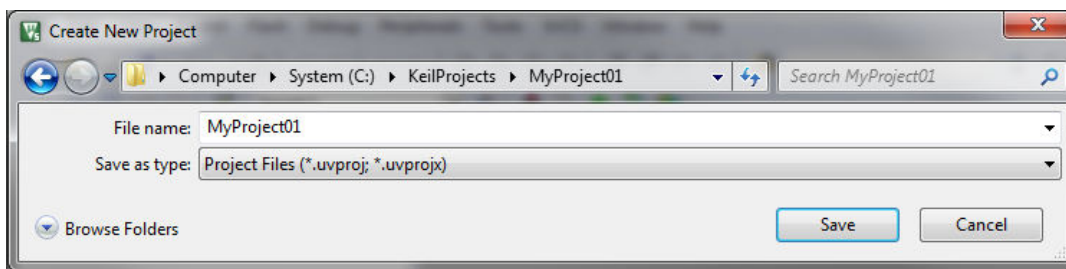


Figure 1-16. Pack Installer

### 1.3.2 New project (without SDK)

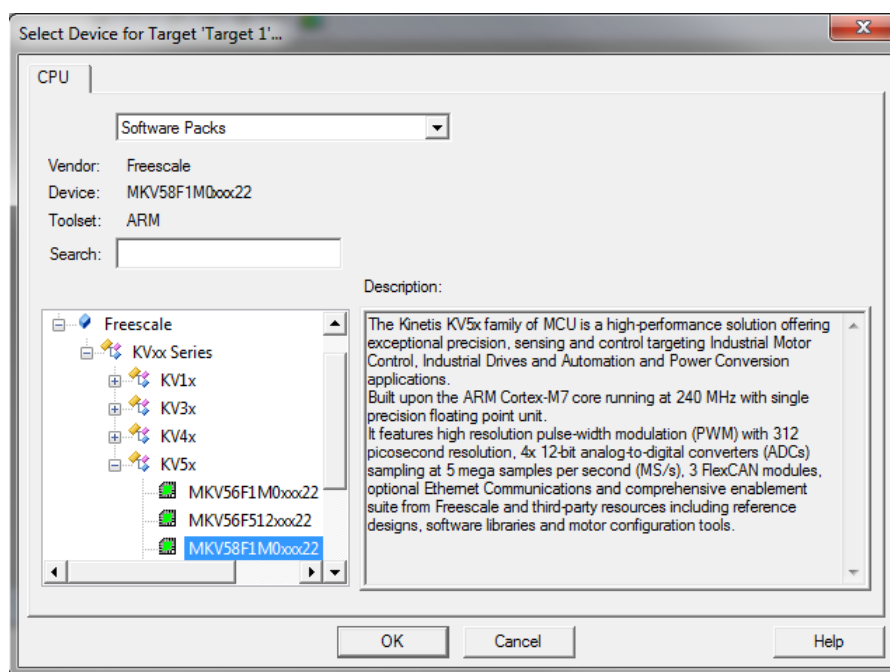
To start working on an application, create a new project. If the project already exists and is opened, skip to the next section. Follow these steps to create a new project:

1. Launch Keil  $\mu$ Vision.
2. In the main menu, select Project > New  $\mu$ Vision Project..., and the Create New Project dialog appears.
3. Navigate to the folder where you want to create the project, for example C:\KeilProjects\MyProject01. Type the name of the project, for example MyProject01. Click Save. See [Figure 1-17](#).



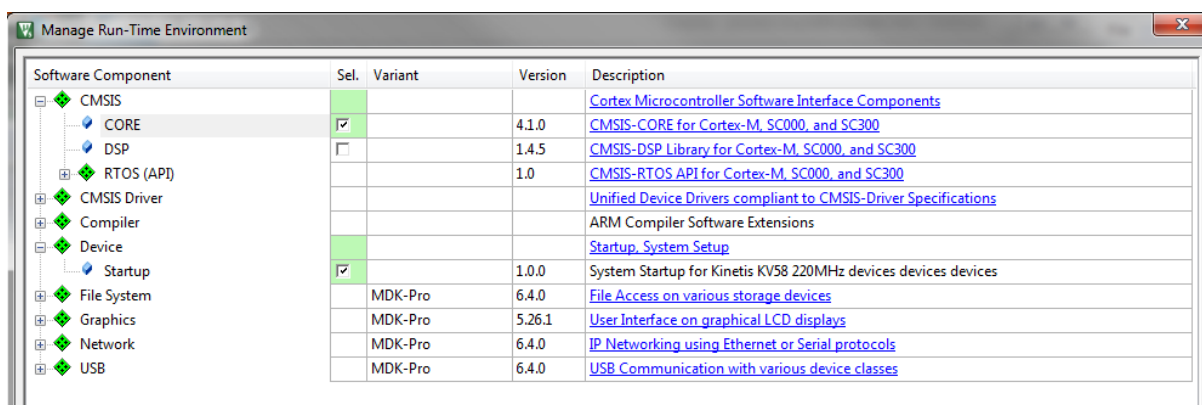
**Figure 1-17. Create New Project dialog**

4. In the next dialog, select the Software Packs in the very first box.
5. Type " into the Search box, so that the device list is reduced to the devices.
6. Expand the node.
7. Click the MKV58F1M0xxx22 node, and then click OK. See [Figure 1-18](#).



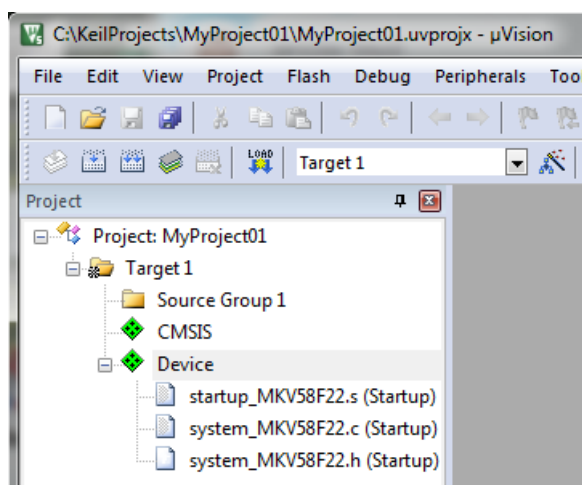
**Figure 1-18. Select Device dialog**

8. In the next dialog, expand the Device node, and tick the box next to the Startup node. See [Figure 1-19](#).
9. Expand the CMSIS node, and tick the box next to the CORE node.



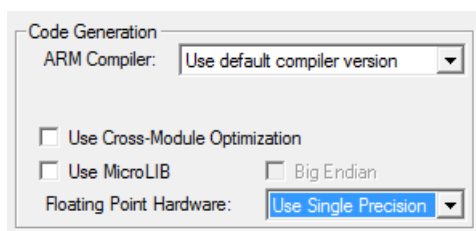
**Figure 1-19. Manage Run-Time Environment dialog**

10. Click OK, and a new project is created. The new project is now visible in the left-hand part of Keil  $\mu$ Vision. See [Figure 1-20](#).



**Figure 1-20. Project**

11. In the main menu, go to Project > Options for Target 'Target1'..., and a dialog appears.
12. Select the Target tab.
13. Select Use Single Precision in the Floating Point Hardware option. See [Figure 1-20](#).



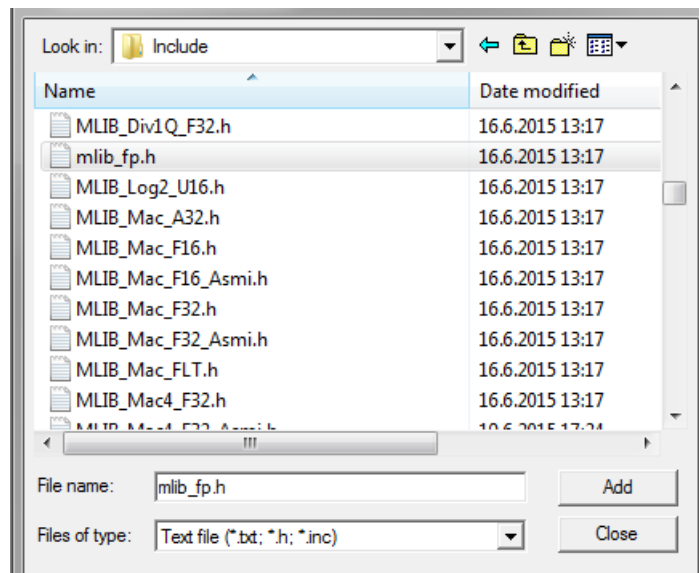
**Figure 1-21. FPU**

### 1.3.3 Linking the files into the project

GMCLIB requires MLIB and GFLIB to be included too. The following steps show how to include all dependent modules.

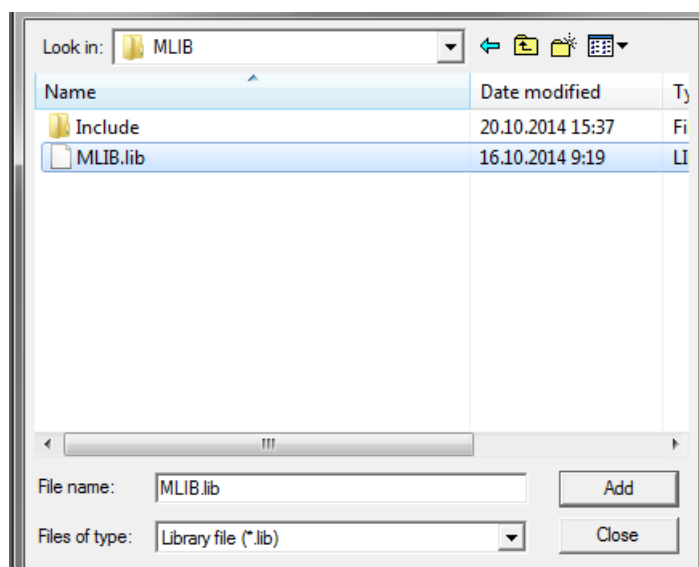
To include the library files in the project, create groups and add them.

1. Right-click the Target 1 node in the left-hand part of the Project tree, and select Add Group... from the menu. A new group with the name New Group is added.
2. Click the newly created group, and press F2 to rename it to RTCESL.
3. Right-click the RTCESL node, and select Add Existing Files to Group 'RTCESL'... from the menu.
4. Navigate into the library installation folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL\MLIB\Include, and select the *mllib\_fp.h* file. If the file does not appear, set the Files of type filter to Text file. Click Add. See [Figure 1-22](#).



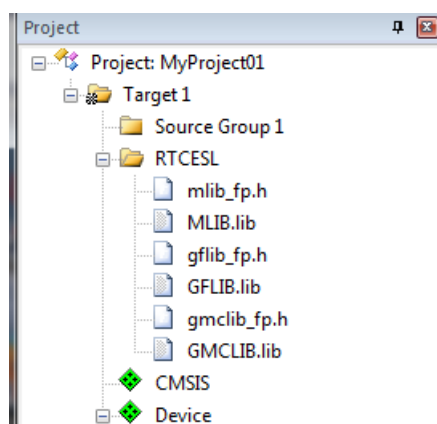
**Figure 1-22. Adding .h files dialog**

5. Navigate to the parent folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL\MLIB, and select the *mllib.lib* file. If the file does not appear, set the Files of type filter to Library file. Click Add. See [Figure 1-23](#).



**Figure 1-23. Adding .lib files dialog**

6. Navigate into the library installation folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL\GFLIB\Include, and select the *gflib\_fp.h* file. If the file does not appear, set the Files of type filter to Text file. Click Add.
7. Navigate to the parent folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL\GFLIB, and select the *gflib.lib* file. If the file does not appear, set the Files of type filter to Library file. Click Add.
8. Navigate into the library installation folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL\GMCLIB\Include, and select the *gmclib\_fp.h* file. If the file does not appear, set the Files of type filter to Text file. Click Add.
9. Navigate to the parent folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL\GMCLIB, and select the *gmclib.lib* file. If the file does not appear, set the Files of type filter to Library file. Click Add.
10. Now, all necessary files are in the project tree; see [Figure 1-24](#). Click Close.

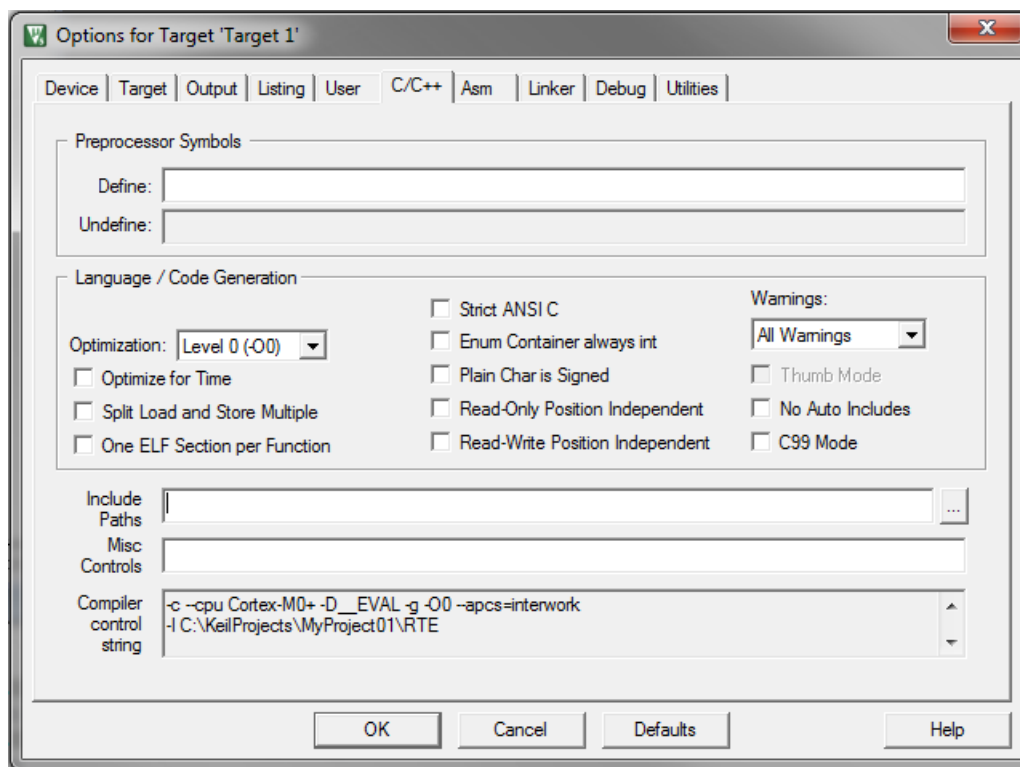


**Figure 1-24. Project workspace**

### 1.3.4 Library path setup

The following steps show the inclusion of all dependent modules.

1. In the main menu, go to Project > Options for Target 'Target1'..., and a dialog appears.
2. Select the C/C++ tab. See [Figure 1-25](#).
3. In the Include Paths text box, type the following paths (if there are more paths, they must be separated by ';') or add them by clicking the ... button next to the text box:
  - "C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL\MLIB\Include"
  - "C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL\GFLIB\Include"
  - "C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_KEIL\GMCLIB\Include"
4. Click OK.
5. Click OK in the main dialog.

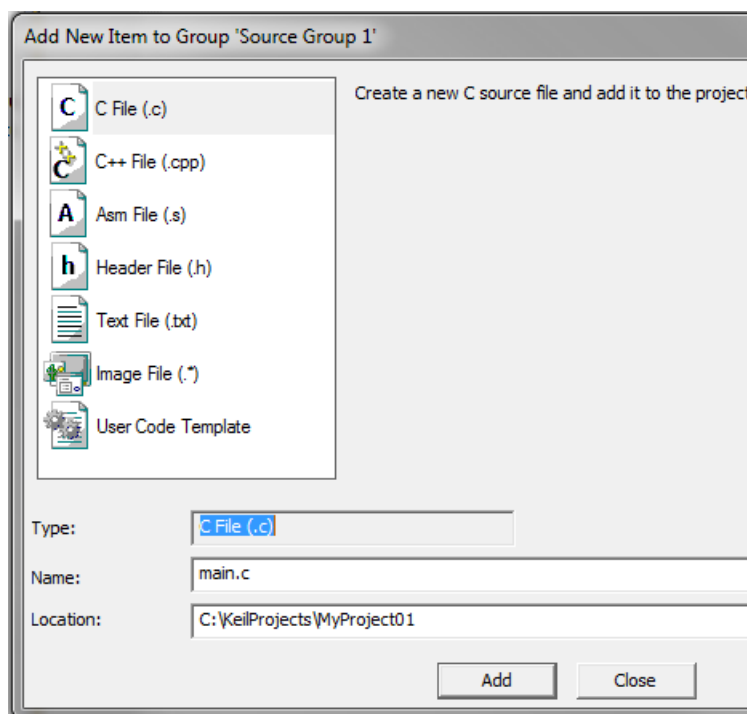


**Figure 1-25. Library path addition**

Type the #include syntax into the code. Include the library into a source file. In the new project, it is necessary to create a source file:

1. Right-click the Source Group 1 node, and Add New Item to Group 'Source Group 1'... from the menu.

2. Select the C File (.c) option, and type a name of the file into the Name box, for example '*main.c*'. See [Figure 1-26](#).



**Figure 1-26. Adding new source file dialog**

3. Click Add, and a new source file is created and opened up.
4. In the opened source file, include the following lines into the #include section, and create a main function:

```
#include "mlib_fp.h"
#include "gflib_fp.h"
#include "gmclib_fp.h"

int main(void)
{
    while(1);
}
```

When you click the Build (F7) icon, the project will be compiled without errors.

## 1.4 Library integration into project (IAR Embedded Workbench)

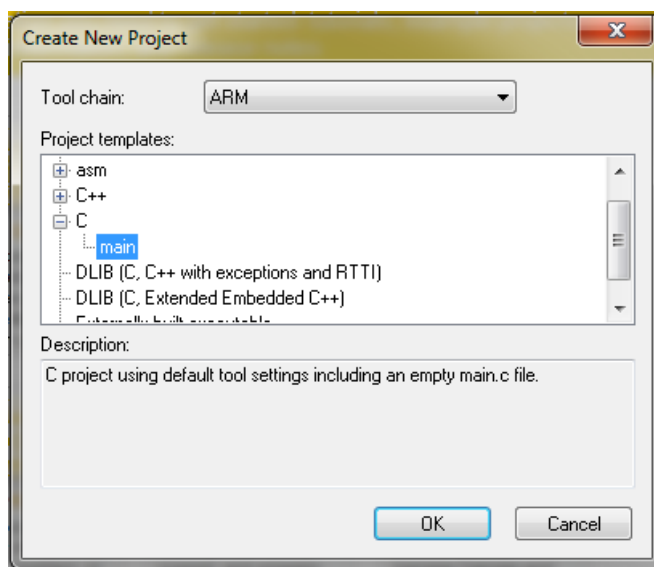
This section provides a step-by-step guide on how to quickly and easily include the GMCLIB into an empty project or any SDK example or demo application projects using IAR Embedded Workbench. This example uses the default installation path (C:\NXP

\RTCESL\CM7F\_RTCESL\_4.3\_IAR). If you have a different installation path, use that path instead. If any SDK project is intended to use (for example hello\_world project) go to [Linking the files into the project](#) chapter otherwise read next chapter.

### 1.4.1 New project (without SDK)

This example uses the NXP MKV58F1M0xxx22 part, and the default installation path (C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_IAR) is supposed. To start working on an application, create a new project. If the project already exists and is opened, skip to the next section. Perform these steps to create a new project:

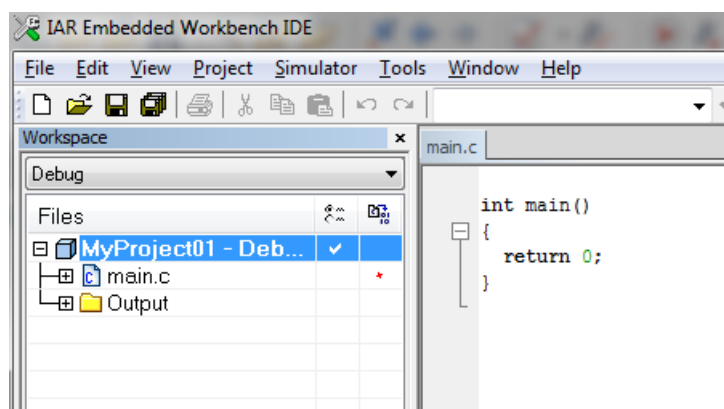
1. Launch IAR Embedded Workbench.
2. In the main menu, select Project > Create New Project... so that the "Create New Project" dialog appears. See [Figure 1-27](#).



**Figure 1-27. Create New Project dialog**

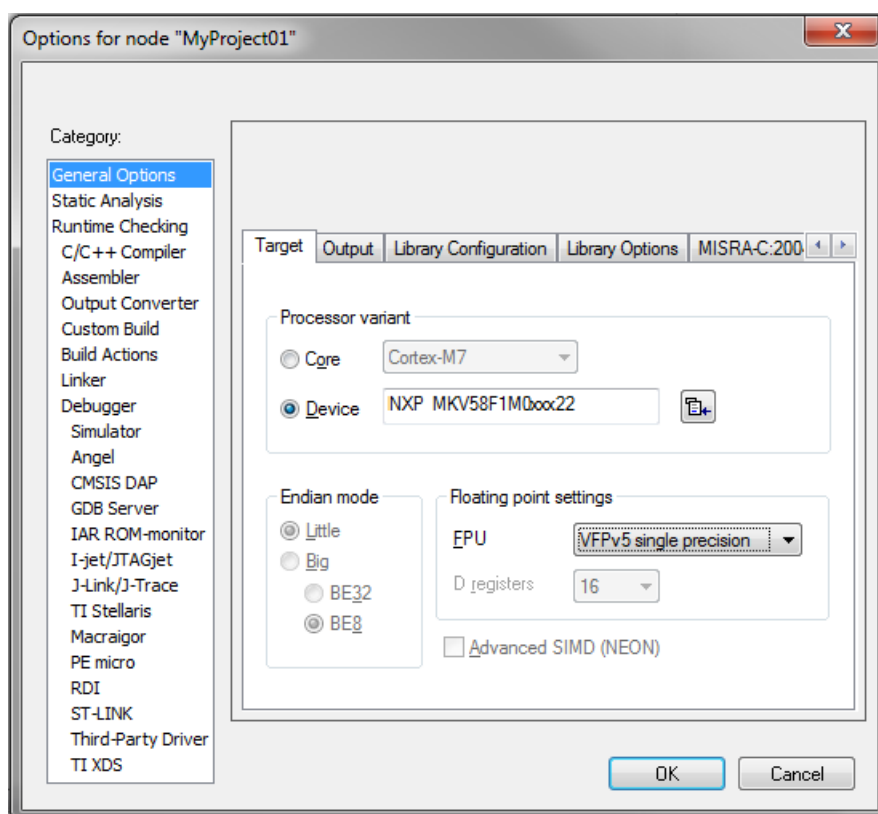
3. Expand the C node in the tree, and select the "main" node. Click OK.
4. Navigate to the folder where you want to create the project, for example, C:\IARProjects\MyProject01. Type the name of the project, for example, MyProject01. Click Save, and a new project is created. The new project is now visible in the left-hand part of IAR Embedded Workbench. See [Figure 1-28](#).





**Figure 1-28. New project**

5. In the main menu, go to Project > Options..., and a dialog appears.
6. In the Target tab, select the Device option, and click the button next to the dialog to select the MCU. In this example, select NXP > KV5x > NXP MKV58F1M0xxx22. Select VFPv5 single precision in the FPU option. Click OK. See [Figure 1-29](#).

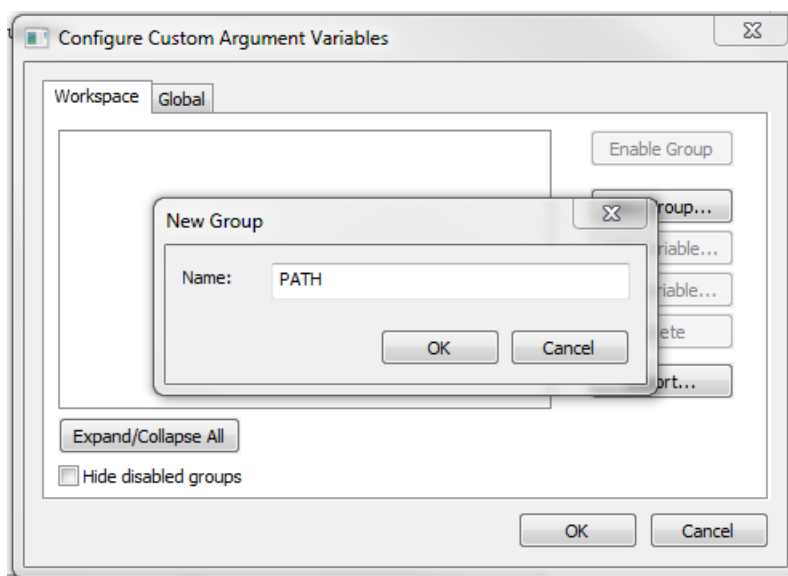


**Figure 1-29. Options dialog**

## 1.4.2 Library path variable

To make the library integration easier, create a variable that will hold the information about the library path.

1. In the main menu, go to Tools > Configure Custom Argument Variables..., and a dialog appears.
2. Click the New Group button, and another dialog appears. In this dialog, type the name of the group PATH, and click OK. See [Figure 1-30](#).



**Figure 1-30. New Group**

3. Click on the newly created group, and click the Add Variable button. A dialog appears.
4. Type this name: RTCESL\_LOC
5. To set up the value, look for the library by clicking the '...' button, or just type the installation path into the box: C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_IAR. Click OK.
6. In the main dialog, click OK. See [Figure 1-31](#).

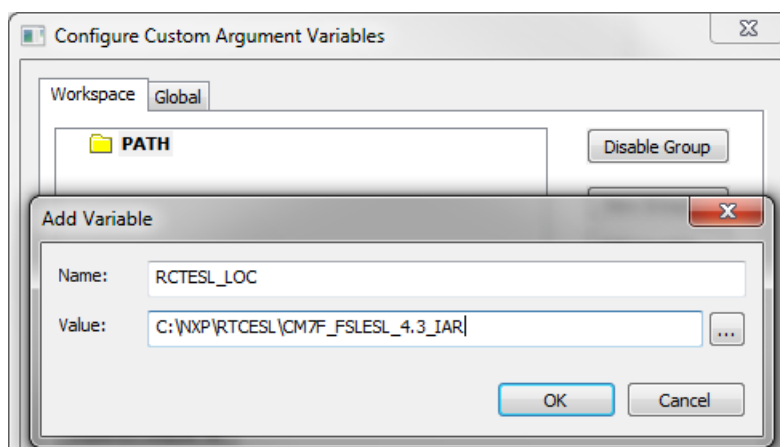


Figure 1-31. New variable

### 1.4.3 Linking the files into the project

GMCLIB requires MLIB and GFLIB to be included too. The following steps show the inclusion of all dependent modules.

To include the library files into the project, create groups and add them.

1. Go to the main menu Project > Add Group...
2. Type RTCESL, and click OK.
3. Click on the newly created node RTCESL, go to Project > Add Group..., and create a MLIB subgroup.
4. Click on the newly created node MLIB, and go to the main menu Project > Add Files... See [Figure 1-33](#).
5. Navigate into the library installation folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_IAR\MLIB\Include, and select the *mlib\_fp.h* file. (If the file does not appear, set the file-type filter to Source Files.) Click Open. See [Figure 1-32](#).
6. Navigate into the library installation folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_IAR\MLIB, and select the *mlib.a* file. If the file does not appear, set the file-type filter to Library / Object files. Click Open.

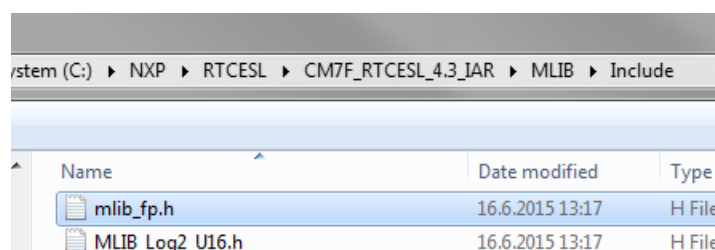
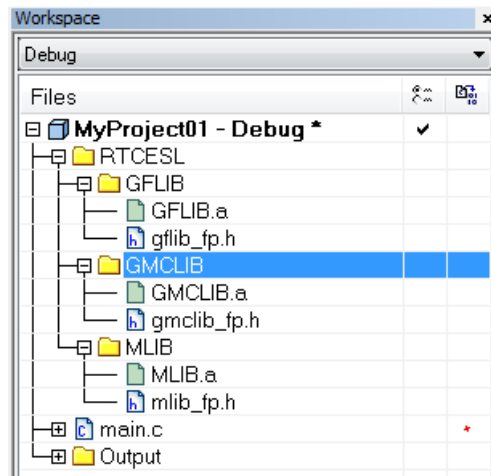


Figure 1-32. Add Files dialog

7. Click on the RTCESL node, go to Project > Add Group..., and create a GFLIB subgroup.

8. Click on the newly created node GFLIB, and go to the main menu Project > Add Files....
9. Navigate into the library installation folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_IAR\GFLIB\Include, and select the *gflib\_fp.h* file. (If the file does not appear, set the file-type filter to Source Files.) Click Open.
10. Navigate into the library installation folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_IAR\GFLIB, and select the *gflib.a* file. If the file does not appear, set the file-type filter to Library / Object files. Click Open.
11. Click on the RTCESL node, go to Project > Add Group..., and create a GMCLIB subgroup.
12. Click on the newly created node GMCLIB, and go to the main menu Project > Add Files....
13. Navigate into the library installation folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_IAR\GMCLIB\Include, and select the *gmclib\_fp.h* file. If the file does not appear, set the file-type filter to Source Files. Click Open.
14. Navigate into the library installation folder C:\NXP\RTCESL\CM7F\_RTCESL\_4.3\_IAR\GMCLIB, and select the *gmclib.a* file. If the file does not appear, set the file-type filter to Library / Object files. Click Open.
15. Now you will see the files added in the workspace. See [Figure 1-33](#).



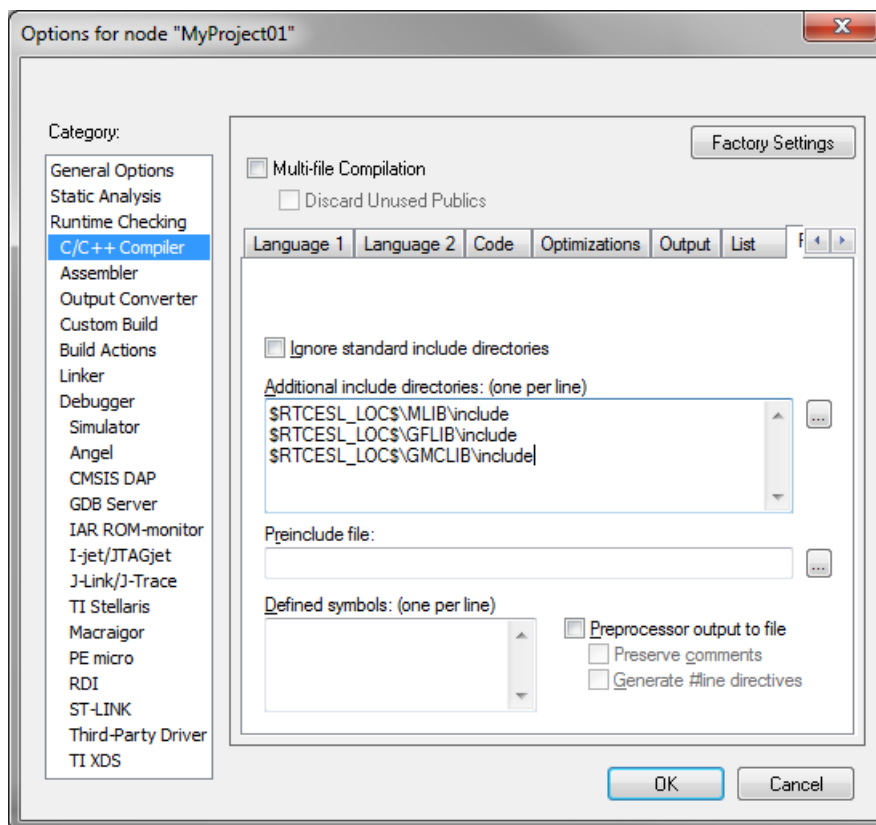
**Figure 1-33. Project workspace**

## 1.4.4 Library path setup

The following steps show the inclusion of all dependent modules:

1. In the main menu, go to Project > Options..., and a dialog appears.
2. In the left-hand column, select C/C++ Compiler.
3. In the right-hand part of the dialog, click on the Preprocessor tab (it can be hidden in the right; use the arrow icons for navigation).

4. In the text box (at the Additional include directories title), type the following folder (using the created variable):
  - \$RTCESL\_LOC\$\MLIB\Include
  - \$RTCESL\_LOC\$\GFLIB\Include
  - \$RTCESL\_LOC\$\GMCLIB\Include
5. Click OK in the main dialog. See [Figure 1-34](#).



**Figure 1-34. Library path addition**

Type the `#include` syntax into the code. Include the library included into the *main.c* file. In the workspace tree, double-click the *main.c* file. After the *main.c* file opens up, include the following lines into the `#include` section:

```
#include "mlib_fp.h"
#include "gflib_fp.h"
#include "gmclib_fp.h"
```

When you click the Make icon, the project will be compiled without errors.



## Chapter 2

# Algorithms in detail

## 2.1 GMCLIB\_Clark

The [GMCLIB\\_Clark](#) function calculates the Clarke transformation, which is used to transform values (flux, voltage, current) from the three-phase coordinate system to the two-phase ( $\alpha$ - $\beta$ ) orthogonal coordinate system, according to the following equations:

$$\alpha = a$$

**Equation 1**

$$\beta = \frac{1}{\sqrt{3}}b - \frac{1}{\sqrt{3}}c$$

**Equation 2**

### 2.1.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range  $<-1 ; 1$ ). The result may saturate.
- Floating-point output - the output is the floating-point result within the type's full range.

The available versions of the [GMCLIB\\_Clark](#) function are shown in the following table:

**Table 2-1. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_Clark_F16	<a href="#">GMCLIB_3COOR_T_F16</a> *	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *	void
	Clarke transformation of a 16-bit fractional three-phase system input to a 16-bit fractional two-phase system. The input and output are within the fractional range $<-1 ; 1$ ).		
GMCLIB_Clark_FLT	<a href="#">GMCLIB_3COOR_T_FLT</a> *	<a href="#">GMCLIB_2COOR_ALBE_T_FLT</a> *	void

*Table continues on the next page...*

**Table 2-1. Function versions (continued)**

Function name	Input type	Output type	Result type
	Clarke transformation of a 32-bit single precision floating-point three-phase system input to a 32-bit single-point floating-point two-phase system. The input and output are within the full 32-bit single-point floating-point range.		

## 2.1.2 Declaration

The available [GMCLIB\\_Clark](#) functions have the following declarations:

```
void GMCLIB_Clark_F16(const GMCLIB_3COOR_T_F16 *psIn, GMCLIB_2COOR_ALBE_T_F16 *psOut)
void GMCLIB_Clark_FLT(const GMCLIB_3COOR_T_FLT *psIn, GMCLIB_2COOR_ALBE_T_FLT *psOut)
```

## 2.1.3 Function use

The use of the [GMCLIB\\_Clark](#) function is shown in the following example:

```
#include "gmclib.h"

static GMCLIB_2COOR_ALBE_T_F16 sAlphaBeta;
static GMCLIB_3COOR_T_F16 sAbc;

void Isr(void);

void main(void)
{
    /* ABC structure initialization */
    sAbc.f16A = FRAC16(0.0);
    sAbc.f16B = FRAC16(0.0);
    sAbc.f16C = FRAC16(0.0);
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Clarke Transformation calculation */
    GMCLIB_Clark_F16(&sAbc, &sAlphaBeta);
}
```

## 2.2 GMCLIB\_ClarkInv

The [GMCLIB\\_ClarkInv](#) function calculates the Clarke transformation, which is used to transform values (flux, voltage, current) from the two-phase ( $\alpha$ - $\beta$ ) orthogonal coordinate system to the three-phase coordinate system, according to the following equations:



$$a = \alpha$$

### Equation 3

$$b = -\frac{1}{2}\alpha + \frac{\sqrt{3}}{2}\beta$$

### Equation 4

$$c = -(a + b)$$

### Equation 5

## 2.2.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range <-1 ; 1). The result may saturate.
- Floating-point output - the output is the floating-point result within the type's full range.

The available versions of the [GMCLIB\\_ClarkInv](#) function are shown in the following table:

**Table 2-2. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_ClarkInv_F16	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *	<a href="#">GMCLIB_3COOR_T_F16</a> *	void
	Inverse Clarke transformation with a 16-bit fractional two-phase system input and a 16-bit fractional three-phase output. The input and output are within the fractional range <-1 ; 1).		
GMCLIB_ClarkInv_FLT	<a href="#">GMCLIB_2COOR_ALBE_T_FLT</a> *	<a href="#">GMCLIB_3COOR_T_FLT</a> *	void
	Inverse Clarke transformation with a 32-bit single precision floating-point two-phase system input and a 32-bit single precision floating-point three-phase output. The input and output are within the full 32-bit single-point floating-point range.		

## 2.2.2 Declaration

The available [GMCLIB\\_ClarkInv](#) functions have the following declarations:

```
void GMCLIB_ClarkInv_F16(const GMCLIB\_2COOR\_ALBE\_T\_F16 *psIn, GMCLIB\_3COOR\_T\_F16 *psOut)
void GMCLIB_ClarkInv_FLT(const GMCLIB\_2COOR\_ALBE\_T\_FLT *psIn, GMCLIB\_3COOR\_T\_FLT *psOut)
```

## 2.2.3 Function use

The use of the [GMCLIB\\_ClarkInv](#) function is shown in the following example:

```
#include "gmclib.h"

static GMCLIB_2COOR_ALBE_T_F16 sAlphaBeta;
static GMCLIB_3COOR_T_F16 sAbc;

void Isr(void);

void main(void)
{
    /* Alpha, Beta structure initialization */
    sAlphaBeta.f16Alpha = FRAC16(0.0);
    sAlphaBeta.f16Beta = FRAC16(0.0);
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Inverse Clarke Transformation calculation */
    GMCLIB_ClarkInv_F16(&sAlphaBeta, &sAbc);
}
```

## 2.3 GMCLIB\_Park

The [GMCLIB\\_Park](#) function calculates the Park transformation, which transforms values (flux, voltage, current) from the stationary two-phase ( $\alpha$ - $\beta$ ) orthogonal coordinate system to the rotating two-phase (d-q) orthogonal coordinate system, according to the following equations:

$$d = \alpha \cdot \cos(\theta) + \beta \cdot \sin(\theta)$$

**Equation 6**

$$q = \beta \cdot \cos(\theta) - \alpha \cdot \sin(\theta)$$

**Equation 7**

where:

- $\theta$  is the position (angle)

### 2.3.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range  $<-1 ; 1)$ . The result may saturate.
- Floating-point output - the output is the floating-point result within the type's full range.

The available versions of the [GMCLIB\\_Park](#) function are shown in the following table:

**Table 2-3. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_Park_F16	GMCLIB_2COOR_ALBE_T_F16 *	GMCLIB_2COOR_DQ_T_F16 *	void
	GMCLIB_2COOR_SINCOS_T_F16 *		
	The Park transformation of a 16-bit fractional two-phase stationary system input to a 16-bit fractional two-phase rotating system, using a 16-bit fractional angle two-component (sin / cos) position information. The inputs and the output are within the fractional range <-1 ; 1).		
GMCLIB_Park_FLT	GMCLIB_2COOR_ALBE_T_FLT *	GMCLIB_2COOR_DQ_T_FLT *	void
	GMCLIB_2COOR_SINCOS_T_FLT *		
	The Park transformation of a 32-bit single precision floating-point two-phase stationary system input to a 32-bit single precision floating-point two-phase rotating system, using a 32-bit single precision floating-point angle two-component (sin / cos) position information. The two-phase stationary system input and the output are within the full 32-bit single-point floating-point range; the angle input is within the range <-1.0 ; 1.0>.		

## 2.3.2 Declaration

The available [GMCLIB\\_Park](#) functions have the following declarations:

```
void GMCLIB_Park_F16(const GMCLIB\_2COOR\_ALBE\_T\_F16 *psIn, const GMCLIB\_2COOR\_SINCOS\_T\_F16
*psAnglePos, GMCLIB\_2COOR\_DQ\_T\_F16 *psOut)
void GMCLIB_Park_FLT(const GMCLIB\_2COOR\_ALBE\_T\_FLT *psIn, const GMCLIB\_2COOR\_SINCOS\_T\_FLT
*psAnglePos, GMCLIB\_2COOR\_DQ\_T\_FLT *psOut)
```

## 2.3.3 Function use

The use of the [GMCLIB\\_Park](#) function is shown in the following example:

```
#include "gmclib.h"

static GMCLIB\_2COOR\_ALBE\_T\_F16 sAlphaBeta;
static GMCLIB\_2COOR\_DQ\_T\_F16 sDQ;
static GMCLIB\_2COOR\_SINCOS\_T\_F16 sAngle;

void Isr(void);

void main(void)
{
    /* Alpha, Beta structure initialization */
    sAlphaBeta.f16Alpha = FRAC16(0.0);
```

```

sAlphaBeta.fl6Beta = FRAC16(0.0);

/* Angle structure initialization */
sAngle.fl6Sin = FRAC16(0.0);
sAngle.fl6Cos = FRAC16(1.0);
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Park Transformation calculation */
    GMCLIB_Park_F16(&sAlphaBeta, &sAngle, &sDQ);
}

```

## 2.4 GMCLIB\_ParkInv

The [GMCLIB\\_ParkInv](#) function calculates the Park transformation, which transforms values (flux, voltage, current) from the rotating two-phase (d-q) orthogonal coordinate system to the stationary two-phase ( $\alpha$ - $\beta$ ) coordinate system, according to the following equations:

$$\alpha = d \cdot \cos(\theta) - q \cdot \sin(\theta)$$

**Equation 8**

$$\beta = d \cdot \sin(\theta) + q \cdot \cos(\theta)$$

**Equation 9**

where:

- $\theta$  is the position (angle)

### 2.4.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range  $<-1 ; 1$ ). The result may saturate.
- Floating-point output - the output is the floating-point result within the type's full range.

The available versions of the [GMCLIB\\_ParkInv](#) function are shown in the following table:

**Table 2-4. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_ParkInv_F16	GMCLIB_2COOR_DQ_T_F16 *	GMCLIB_2COOR_ALBE_T_F16 *	void
	GMCLIB_2COOR_SINCOS_T_F16 *		
	Inverse Park transformation of a 16-bit fractional two-phase rotating system input to a 16-bit fractional two-phase stationary system, using a 16-bit fractional angle two-component (sin / cos) position information. The inputs and the output are within the fractional range <-1 ; 1).		
GMCLIB_ParkInv_FLT	GMCLIB_2COOR_DQ_T_FLT *	GMCLIB_2COOR_ALBE_T_FLT *	void
	GMCLIB_2COOR_SINCOS_T_FLT *		
	Inverse Park transformation of a 32-bit single precision floating-point two-phase rotating system input to a 32-bit single precision floating-point two-phase stationary system, using a 32-bit single precision floating-point angle two-component (sin / cos) position information. The two-phase rotating system input and the output are within the full 32-bit single-point floating-point range; the angle input is within the range <-1.0 ; 1.0> .		

## 2.4.2 Declaration

The available [GMCLIB\\_ParkInv](#) functions have the following declarations:

```
void GMCLIB_ParkInv_F16(const GMCLIB\_2COOR\_DQ\_T\_F16 *psIn, const GMCLIB\_2COOR\_SINCOS\_T\_F16
*psAnglePos, GMCLIB\_2COOR\_ALBE\_T\_F16 *psOut)
void GMCLIB_ParkInv_FLT(const GMCLIB\_2COOR\_DQ\_T\_FLT *psIn, const GMCLIB\_2COOR\_SINCOS\_T\_FLT
*psAnglePos, GMCLIB\_2COOR\_ALBE\_T\_FLT *psOut)
```

## 2.4.3 Function use

The use of the [GMCLIB\\_ParkInv](#) function is shown in the following example:

```
#include "gmclib.h"

static GMCLIB\_2COOR\_ALBE\_T\_F16 sAlphaBeta;
static GMCLIB\_2COOR\_DQ\_T\_F16 sDQ;
static GMCLIB\_2COOR\_SINCOS\_T\_F16 sAngle;

void Isr(void);

void main(void)
{
    /* D, Q structure initialization */
    sDQ.f16D = FRAC16(0.0);
    sDQ.f16Q = FRAC16(0.0);

    /* Angle structure initialization */
    sAngle.f16Sin = FRAC16(0.0);
    sAngle.f16Cos = FRAC16(1.0);
}
```

```

/* Periodical function or interrupt */
void Isr(void)
{
    /* Inverse Park Transformation calculation */
    GMCLIB_ParkInv_F16(&sDQ, &sAngle, &sAlphaBeta);
}

```

## 2.5 GMCLIB\_DecouplingPMSM

The [GMCLIB\\_DecouplingPMSM](#) function calculates the cross-coupling voltages to eliminate the d-q axis coupling that causes nonlinearity of the control.

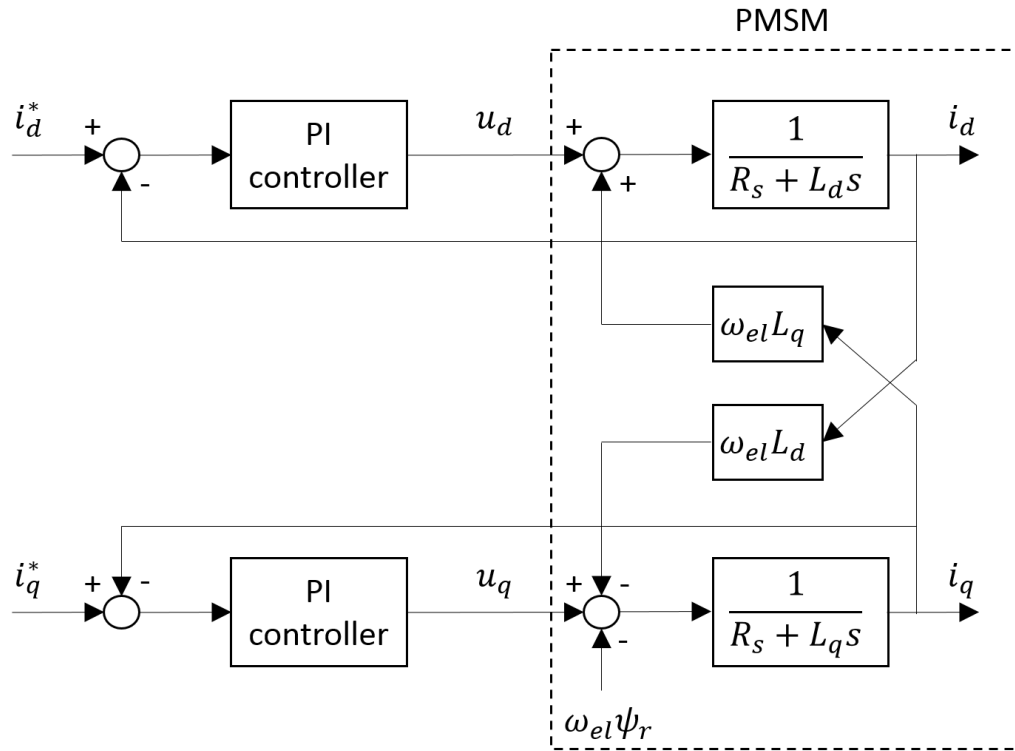
The d-q model of the motor contains cross-coupling voltage that causes nonlinearity of the control. [Figure 2-1](#) represents the d-q model of the motor that can be described using the following equations, where the underlined portion is the cross-coupling voltage:

$$\begin{aligned}
 u_d &= R_s \cdot i_d + L_d \frac{d}{dt} i_d + \underline{L_q \cdot \omega_{el} \cdot i_q} \\
 u_q &= R_s \cdot i_q + L_q \frac{d}{dt} i_q - \underline{L_d \cdot \omega_{el} \cdot i_d} + \omega_{el} \cdot \psi_r
 \end{aligned}$$

**Equation 10**

where:

- $u_d, u_q$  are the d and q voltages
- $i_d, i_q$  are the d and q currents
- $R_s$  is the stator winding resistance
- $L_d, L_q$  are the stator winding d and q inductances
- $\omega_{el}$  is the electrical angular speed
- $\psi_r$  is the rotor flux constant



**Figure 2-1. The d-q PMSM model**

To eliminate the nonlinearity, the cross-coupling voltage is calculated using the [GMCLIB\\_DecouplingPMSM](#) algorithm, and feedforwarded to the d and q voltages. The decoupling algorithm is calculated using the following equations:

$$\begin{aligned} u_{ddec} &= u_d - L_q \cdot \omega_{el} \cdot i_q \\ u_{qdec} &= u_q + L_d \cdot \omega_{el} \cdot i_d \end{aligned}$$

**Equation 11**

where:

- $u_d, u_q$  are the d and q voltages; inputs to the algorithm
- $u_{ddec}, u_{qdec}$  are the d and q decoupled voltages; outputs from the algorithm

The fractional representation of the d-component equation is as follows:

$$\begin{aligned} u_{ddec} &= u_d - \omega_{el} \cdot i_q \left( L_q \cdot \omega_{el\_max} \cdot \frac{i_{max}}{u_{max}} \right) \\ k_q &= L_q \cdot \omega_{el\_max} \cdot \frac{i_{max}}{u_{max}} \\ u_{ddec} &= u_d - \omega_{el} \cdot i_q \cdot k_q \end{aligned}$$

**Equation 12**

The fractional representation of the q-component equation is as follows:

$$u_{qdec} = u_q + \omega_{el} \cdot i_d \left( L_d \cdot \omega_{el\_max} \cdot \frac{i_{max}}{u_{max}} \right)$$

$$k_d = L_d \cdot \omega_{el\_max} \cdot \frac{i_{max}}{u_{max}}$$

$$u_{qdec} = u_q + \omega_{el} \cdot i_d \cdot k_d$$

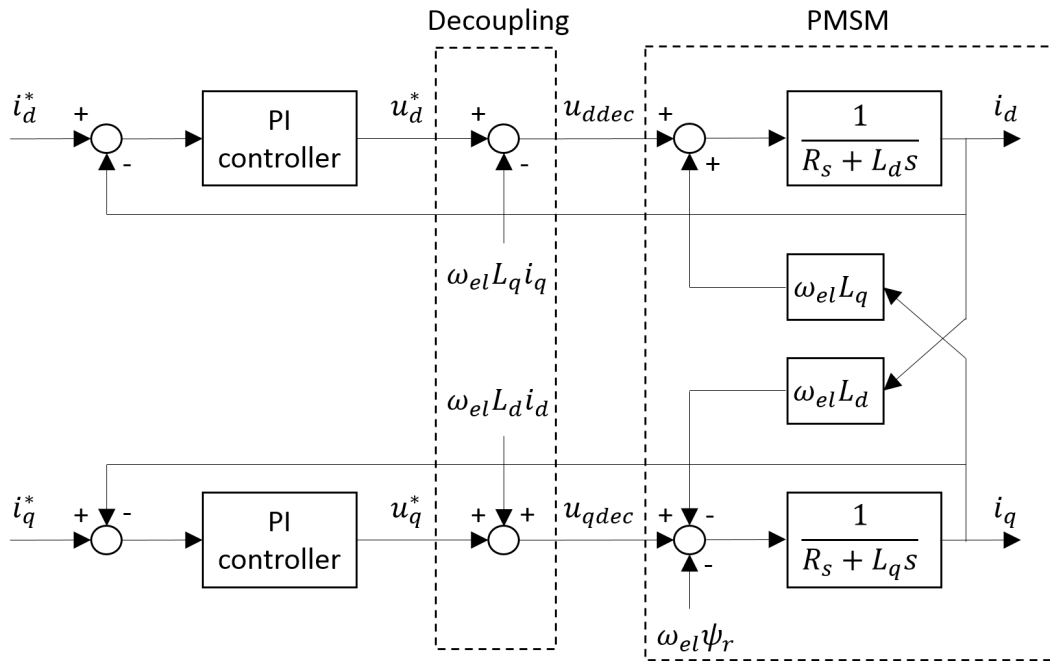
**Equation 13**

where:

- $k_d, k_q$  are the scaling coefficients
- $i_{max}$  is the maximum current
- $u_{max}$  is the maximum voltage
- $\omega_{el\_max}$  is the maximum electrical speed

The  $k_d$  and  $k_q$  parameters must be set up properly.

The principle of the algorithm is depicted in [Figure 2-2](#) :

**Figure 2-2. Algorithm diagram**

## 2.5.1 Available versions

This function is available in the following versions:



- Fractional output - the output is the fractional portion of the result; the result is within the range  $-1 ; 1$ ). The result may saturate. The parameters use the accumulator types.
- Floating-point output - the output is the floating-point result within the type's full range.

The available versions of the [GMCLIB\\_DecouplingPMSM](#) function are shown in the following table:

**Table 2-5. Function versions**

Function name	Input/output type		Result type
GMCLIB_DecouplingPMSM_F16	Input	GMCLIB_2COOR_DQ_T_F16 *	void
		GMCLIB_2COOR_DQ_T_F16 *	
		frac16_t	
	Parameters	GMCLIB_DECOUPLINGPMSM_T_A32 *	
	Output	GMCLIB_2COOR_DQ_T_F16 *	
	The PMSM decoupling with a 16-bit fractional d-q voltage, current inputs, and a 16-bit fractional electrical speed input. The parameters are 32-bit accumulator types. The output is a 16-bit fractional decoupled d-q voltage. The inputs and the output are within the range <-1 ; 1).		
GMCLIB_DecouplingPMSM_FLT	Input	GMCLIB_2COOR_DQ_T_FLT *	void
		GMCLIB_2COOR_DQ_T_FLT *	
		float_t	
	Parameters	GMCLIB_DECOUPLINGPMSM_T_FLT *	
	Output	GMCLIB_2COOR_DQ_T_FLT *	
	The PMSM decoupling with a 32-bit single precision floating-point d-q voltage, current, and electrical speed input. The parameters are 32-bit single precision floating-point types. The output is a 32-bit single precision floating-point decoupled d-q voltage. The inputs and the output are within the full 32-bit single-point floating-point range.		

## 2.5.2 GMCLIB\_DECOUPLINGPMSM\_T\_A32 type description

Variable name	Input type	Description
a32KdGain	<a href="#">acc32_t</a>	Direct axis decoupling parameter. The parameter is within the range $<0 ; 65536.0$ )
a32KqGain	<a href="#">acc32_t</a>	Quadrature axis decoupling parameter. The parameter is within the range $<0 ; 65536.0$ )

## 2.5.3 GMCLIB\_DECOUPLINGPMSM\_T\_FLT type description

Variable name	Input type	Description
fltLd	float_t	Direct axis inductance parameter. The parameter is a nonnegative value.
fltLq	float_t	Quadrature axis inductance parameter. The parameter is a nonnegative value.

## 2.5.4 Declaration

The available [GMCLIB\\_DecouplingPMSM](#) functions have the following declarations:

```
void GMCLIB_DecouplingPMSM_F16(const GMCLIB_2COOR_DQ_T_F16 *psUDQ, const
GMCLIB_2COOR_DQ_T_F16 *psIDQ, frac16_t f16SpeedEl, const GMCLIB_DECOUPLINGPMSM_T_A32
*psParam, GMCLIB_2COOR_DQ_T_F16 *psUDQDec)
void GMCLIB_DecouplingPMSM_FLT(const GMCLIB_2COOR_DQ_T_FLT *psUDQ, const
GMCLIB_2COOR_DQ_T_FLT *psIDQ, float_t fltSpeedEl, const GMCLIB_DECOUPLINGPMSM_T_FLT
*psParam, GMCLIB_2COOR_DQ_T_FLT *psUDQDec)
```

## 2.5.5 Function use

The use of the [GMCLIB\\_DecouplingPMSM](#) function is shown in the following example:

```
#include "gmclib.h"

static GMCLIB_2COOR_DQ_T_F16 sVoltageDQ;
static GMCLIB_2COOR_DQ_T_F16 sCurrentDQ;
static frac16_t f16AngularSpeed;
static GMCLIB_DECOUPLINGPMSM_T_A32 sDecouplingParam;
static GMCLIB_2COOR_DQ_T_F16 sVoltageDQDecoupled;

void Isr(void);

void main(void)
{
    /* Voltage D, Q structure initialization */
    sVoltageDQ.f16D = FRAC16(0.0);
    sVoltageDQ.f16Q = FRAC16(0.0);

    /* Current D, Q structure initialization */
    sCurrentDQ.f16D = FRAC16(0.0);
    sCurrentDQ.f16Q = FRAC16(0.0);

    /* Speed initialization */
    f16AngularSpeed = FRAC16(0.0);

    /* Motor parameters for decoupling Kd = 40, Kq = 20 */
    sDecouplingParam.a32KdGain = ACC32(40.0);
    sDecouplingParam.a32KqGain = ACC32(20.0);
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Decoupling calculation */
```

```
GMCLIB_DecouplingPMSM_F16(&sVoltageDQ, &sCurrentDQ, f16AngularSpeed, &sDecouplingParam,
&sVoltageDQDecoupled);
}
```

## 2.6 GMCLIB\_ElimDcBusRipFOC

The [GMCLIB\\_ElimDcBusRipFOC](#) function is used for the correct PWM duty cycle output calculation, based on the measured DC-bus voltage. The side effect is the elimination of the the DC-bus voltage ripple in the output PWM duty cycle. This function is meant to be used with a space vector modulation, whose modulation index (with respect to the DC-bus voltage) is an inverse square root of 3.

The general equation to calculate the duty cycle for the above-mentioned space vector modulation is as follows:

$$U_{PWM} = \frac{u_{FOC}}{u_{dcbus}} \cdot \sqrt{3}$$

**Equation 14**

where:

- $U_{PWM}$  is the duty cycle output
- $u_{FOC}$  is the real FOC voltage
- $u_{dcbus}$  is the real measured DC-bus voltage

Using the previous equations, the [GMCLIB\\_ElimDcBusRipFOC](#) function compensates an amplitude of the direct- $\alpha$  and the quadrature- $\beta$  component of the stator-reference voltage vector, using the formula shown in the following equations:

$$U_{\alpha}^* = \begin{cases} 0, & U_{\alpha} = 0 \wedge U_{dcbus} = 0 \\ 1, & U_{\alpha} \geq 0 \wedge |U_{\alpha}| \geq \frac{U_{dcbus}}{\sqrt{3}} \\ -1, & U_{\alpha} < 0 \wedge |U_{\alpha}| \geq \frac{U_{dcbus}}{\sqrt{3}} \\ \frac{U_{\alpha}}{U_{dcbus}} \cdot \sqrt{3}, & \text{else} \end{cases}$$

**Equation 15**

$$U_{\beta}^* = \begin{cases} 0, & U_{\beta} = 0 \wedge U_{dcbus} = 0 \\ 1, & U_{\beta} \geq 0 \wedge |U_{\beta}| \geq \frac{U_{dcbus}}{\sqrt{3}} \\ -1, & U_{\beta} < 0 \wedge |U_{\beta}| \geq \frac{U_{dcbus}}{\sqrt{3}} \\ \frac{U_{\beta}}{U_{dcbus}} \cdot \sqrt{3}, & \text{else} \end{cases}$$

**Equation 16**

where:

- $U_{\alpha}^*$  is the direct- $\alpha$  duty cycle ratio
- $U_{\beta}^*$  is the direct- $\beta$  duty cycle ratio
- $U_{\alpha}$  is the direct- $\alpha$  voltage
- $U_{\beta}$  is the quadrature- $\beta$  voltage

If the fractional arithmetic is used, the FOC and DC-bus voltages have their scales, which take place in [Equation 14 on page 43](#); the equation is as follows:

$$U_{PWM} = \frac{U_{FOC} U_{FOC\_max}}{U_{dcbus} U_{dcbus\_max}} \cdot \sqrt{3}$$

**Equation 17**

where:

- $U_{FOC}$  is the scaled FOC voltage
- $U_{dcbus}$  is the scaled measured DC-bus voltage
- $U_{FOC\_max}$  is the FOC voltage scale
- $U_{dcbus\_max}$  is the DC-bus voltage scale

If this algorithm is used with the space vector modulation with the ratio of square root equal to 3, then the FOC voltage scale is expressed as follows :

$$U_{FOC\_max} = \frac{U_{dcbus\_max}}{\sqrt{3}}$$

**Equation 18**

The equation can be simplified as follows:

$$U_{PWM} = \frac{U_{FOC} \frac{U_{dcbus\_max}}{\sqrt{3}}}{U_{dcbus} U_{dcbus\_max}} \cdot \sqrt{3} = \frac{U_{FOC}}{U_{dcbus}}$$

**Equation 19**

The [GMCLIB\\_ElimDcBusRipFOC](#) function compensates an amplitude of the direct- $\alpha$  and the quadrature- $\beta$  component of the stator-reference voltage vector in the fractional arithmetic, using the formula shown in the following equations:

$$U_{\alpha}^* = \begin{cases} 0, & U_{\alpha} = 0 \wedge U_{dcbus} = 0 \\ 1, & U_{\alpha} > 0 \wedge |U_{\alpha}| \geq U_{dcbus} \\ -1, & U_{\alpha} < 0 \wedge |U_{\alpha}| \geq U_{dcbus} \\ \frac{U_{\alpha}}{U_{dcbus}}, & \text{else} \end{cases}$$

**Equation 20**

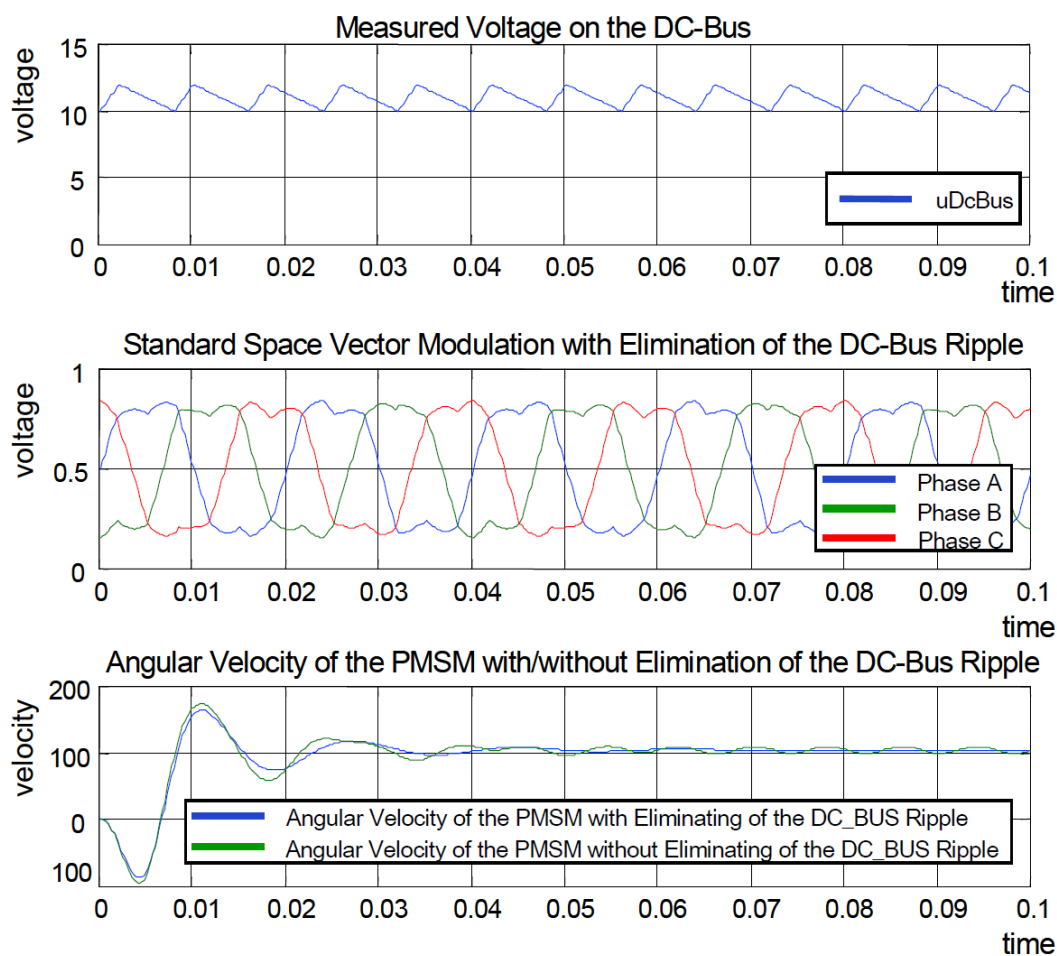
$$U_{\beta}^* = \begin{cases} 0, & U_{\beta} = 0 \wedge U_{dcbus} = 0 \\ 1, & U_{\beta} > 0 \wedge |U_{\beta}| \geq U_{dcbus} \\ -1, & U_{\beta} < 0 \wedge |U_{\beta}| \geq U_{dcbus} \\ \frac{U_{\beta}}{U_{dcbus}}, & \text{else} \end{cases}$$

Equation 21

where:

- $U_{\alpha}^*$  is the direct- $\alpha$  duty cycle ratio
- $U_{\beta}^*$  is the direct- $\beta$  duty cycle ratio
- $U_{\alpha}$  is the direct- $\alpha$  voltage
- $U_{\beta}$  is the quadrature- $\beta$  voltage

The [GMCLIB\\_ElimDcBusRipFOC](#) function can be used in general motor-control applications, and it provides elimination of the voltage ripple on the DC-bus of the power stage. [Figure 2-3](#) shows the results of the DC-bus ripple elimination, while compensating the ripples of the rectified voltage using a three-phase uncontrolled rectifier.



**Figure 2-3. Results of the DC-bus voltage ripple elimination**

## 2.6.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range  $<-1 ; 1$ ). The result may saturate.
- Fractional output with floating-point input - the output is the fractional portion of the result; the result is within the range  $<-1 ; 1$ ). The result may saturate. The inputs are floating-point values.

The available versions of the [GMCLIB\\_ElimDcBusRipFOC](#) function are shown in the following table:

**Table 2-6. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_ElimDcBusRipFOC_F16	<a href="#">frac16_t</a>	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *	void
	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *		
	Compensation of a 16-bit fractional two-phase system input to a 16-bit fractional two-phase system, using a 16-bit fractional DC-bus voltage information. The DC-bus voltage input is within the fractional range $<0 ; 1$ ); the stationary ( $\alpha$ - $\beta$ ) voltage input and the output are within the fractional range $<-1 ; 1$ ).		
GMCLIB_ElimDcBusRipFOC_F16ff	<a href="#">float_t</a>	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *	void
	<a href="#">GMCLIB_2COOR_ALBE_T_FLT</a> *		
	Compensation of a 32-bit single precision floating-point two-phase system input to a 16-bit fractional two-phase system, using a 32-bit single precision floating-point DC-bus voltage information. The DC-bus voltage input is a nonnegative value; the two-phase voltage input is within the full 32-bit single-point floating-point range, and the output is within the fractional range $<-1 ; 1$ ).		

## 2.6.2 Declaration

The available [GMCLIB\\_ElimDcBusRipFOC](#) functions have the following declarations:

```
void GMCLIB_ElimDcBusRipFOC_F16(frac16\_t f16UDCbus, const GMCLIB\_2COOR\_ALBE\_T\_F16 *psUAlBe,
GMCLIB\_2COOR\_ALBE\_T\_F16 *psUAlBeComp)
void GMCLIB_ElimDcBusRipFOC_F16ff(float\_t fltUDCbus, const GMCLIB\_2COOR\_ALBE\_T\_FLT *psUAlBe,
GMCLIB\_2COOR\_ALBE\_T\_F16 *psUAlBeComp)
```

## 2.6.3 Function use

The use of the [GMCLIB\\_ElimDcBusRipFOC](#) function is shown in the following example:

```

#include "gmclib.h"

static frac16_t f16UDcBus;
static GMCLIB_2COOR_ALBE_T_F16 sUAlBe;
static GMCLIB_2COOR_ALBE_T_F16 sUAlBeComp;

void Isr(void);

void main(void)
{
    /* Voltage Alpha, Beta structure initialization */
    sUAlBe.f16Alpha = FRAC16(0.0);
    sUAlBe.f16Beta = FRAC16(0.0);

    /* DC bus voltage initialization */
    f16DcBus = FRAC16(0.8);
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* FOC Ripple elimination calculation */
    GMCLIB_ElimDcBusRipFOC_F16(f16UDcBus, &sUAlBe, &sUAlBeComp);
}

```

## 2.7 GMCLIB\_ElimDcBusRip

The [GMCLIB\\_ElimDcBusRip](#) function is used for a correct PWM duty cycle output calculation, based on the measured DC-bus voltage. The side effect is the elimination of the the DC-bus voltage ripple in the output PWM duty cycle. This function can be used with any kind of space vector modulation; it has an additional input - the modulation index (with respect to the DC-bus voltage).

The general equation to calculate the duty cycle is as follows:

$$U_{PWM} = \frac{u_{FOC}}{u_{dcbus}} \cdot i_{mod}$$

**Equation 22**

where:

- $U_{PWM}$  is the duty cycle output
- $u_{FOC}$  is the real FOC voltage
- $u_{dcbus}$  is the real measured DC-bus voltage
- $i_{mod}$  is the space vector modulation index

Using the previous equations, the [GMCLIB\\_ElimDcBusRip](#) function compensates an amplitude of the direct- $\alpha$  and the quadrature- $\beta$  component of the stator-reference voltage vector, using the formula shown in the following equations:

$$U_{\alpha}^* = \begin{cases} 0, & U_{\alpha} = 0 \wedge U_{dcbus} = 0 \vee i_{mod} = 0 \\ 1, & U_{\alpha} > 0 \wedge |U_{\alpha}| \geq \frac{U_{dcbus}}{i_{mod}} \wedge i_{mod} > 0 \\ -1, & U_{\alpha} < 0 \wedge |U_{\alpha}| \geq \frac{U_{dcbus}}{i_{mod}} \wedge i_{mod} > 0 \\ \frac{U_{\alpha}}{U_{dcbus}} \cdot i_{mod}, & i_{mod} > 0 \end{cases}$$

**Equation 23**

$$U_{\beta}^* = \begin{cases} 0, & U_{\beta} = 0 \wedge U_{dcbus} = 0 \vee i_{mod} = 0 \\ 1, & U_{\beta} > 0 \wedge |U_{\beta}| \geq \frac{U_{dcbus}}{i_{mod}} \wedge i_{mod} > 0 \\ -1, & U_{\beta} < 0 \wedge |U_{\beta}| \geq \frac{U_{dcbus}}{i_{mod}} \wedge i_{mod} > 0 \\ \frac{U_{\beta}}{U_{dcbus}} \cdot i_{mod}, & i_{mod} > 0 \end{cases}$$

**Equation 24**

where:

- $U_{\alpha}^*$  is the direct- $\alpha$  duty cycle ratio
- $U_{\beta}^*$  is the direct- $\beta$  duty cycle ratio
- $U_{\alpha}$  is the direct- $\alpha$  voltage
- $U_{\beta}$  is the quadrature- $\beta$  voltage

If the fractional arithmetic is used, the FOC and DC-bus voltages have their scales, which take place in [Equation 22 on page 47](#); the equation is as follows:

$$U_{PWM} = \frac{U_{FOC} U_{FOC\_max}}{U_{dcbus} U_{dcbus\_max}} \cdot i_{mod} = \frac{U_{FOC}}{U_{dcbus}} \cdot \frac{U_{FOC\_max}}{U_{dcbus\_max}} \cdot i_{mod}$$

**Equation 25**

where:

- $U_{FOC}$  is the scaled FOC voltage
- $U_{dcbus}$  is the scaled measured DC-bus voltage
- $U_{FOC\_max}$  is the FOC voltage scale
- $U_{dcbus\_max}$  is the DC-bus voltage scale

Thus, the modulation index in the fractional representation is expressed as follows :

$$i_{modfr} = \frac{U_{FOC\_max}}{U_{dcbus\_max}} \cdot i_{mod}$$

**Equation 26**

where:

- $i_{modfr}$  is the space vector modulation index in the fractional arithmetic



The [GMCLIB\\_ElimDcBusRip](#) function compensates an amplitude of the direct- $\alpha$  and the quadrature- $\beta$  component of the stator-reference voltage vector in the fractional arithmetic, using the formula shown in the following equations:

$$U_{\alpha}^* = \begin{cases} 0, & U_{\alpha} = 0 \wedge U_{dcbus} = 0 \vee i_{modfr} = 0 \\ 1, & U_{\alpha} > 0 \wedge |U_{\alpha}| \geq \frac{U_{dcbus}}{i_{modfr}} \wedge i_{modfr} > 0 \\ -1, & U_{\alpha} < 0 \wedge |U_{\alpha}| \geq \frac{U_{dcbus}}{i_{modfr}} \wedge i_{modfr} > 0 \\ \frac{U_{\alpha}}{U_{dcbus}} \cdot i_{modfr}, & i_{modfr} > 0 \end{cases}$$

Equation 27

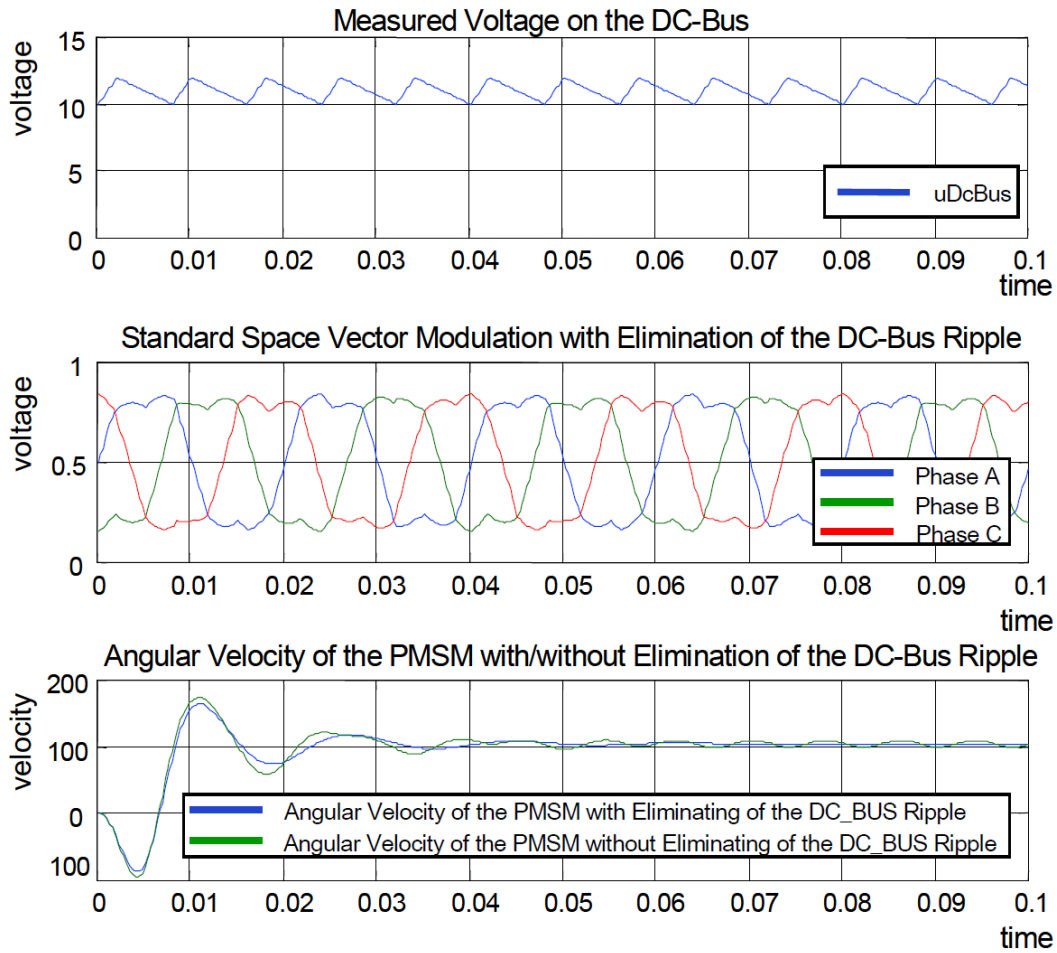
$$U_{\beta}^* = \begin{cases} 0, & U_{\beta} = 0 \wedge U_{dcbus} = 0 \vee i_{modfr} = 0 \\ 1, & U_{\beta} > 0 \wedge |U_{\beta}| \geq \frac{U_{dcbus}}{i_{modfr}} \wedge i_{modfr} > 0 \\ -1, & U_{\beta} < 0 \wedge |U_{\beta}| \geq \frac{U_{dcbus}}{i_{modfr}} \wedge i_{modfr} > 0 \\ \frac{U_{\beta}}{U_{dcbus}} \cdot i_{modfr}, & i_{modfr} > 0 \end{cases}$$

Equation 28

where:

- $U_{\alpha}^*$  is the direct- $\alpha$  duty cycle ratio
- $U_{\beta}^*$  is the direct- $\beta$  duty cycle ratio
- $U_{\alpha}$  is the direct- $\alpha$  voltage
- $U_{\beta}$  is the quadrature- $\beta$  voltage

The [GMCLIB\\_ElimDcBusRip](#) function can be used in general motor-control applications, and it provides elimination of the voltage ripple on the DC-bus of the power stage. [Figure 2-4](#) shows the results of the DC-bus ripple elimination, while compensating the ripples of the rectified voltage, using a three-phase uncontrolled rectifier.



**Figure 2-4. Results of the DC-bus voltage ripple elimination**

## 2.7.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range  $[-1; 1)$ . The result may saturate. The modulation index is a non-negative accumulator type value.
- Fractional output with floating-point input - the output is the fractional portion of the result; the result is within the range  $[-1; 1)$ . The result may saturate. The inputs are floating-point values.

The available versions of the [GMCLIB\\_ElimDcBusRip](#) function are shown in the following table:

**Table 2-7. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_ElimDcBusRip_F16sas	<a href="#">frac16_t</a>	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *	void
	<a href="#">acc32_t</a>		
	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *		
	Compensation of a 16-bit fractional two-phase system input to a 16-bit fractional two-phase system using a 16-bit fractional DC-bus voltage information and a 32-bit accumulator modulation index. The DC-bus voltage input is within the fractional range <0 ; 1); the modulation index is a non-negative value; the stationary ( $\alpha$ - $\beta$ ) voltage input and output are within the fractional range <-1 ; 1).		
GMCLIB_ElimDcBusRip_F16fff	<a href="#">float_t</a>	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *	void
	<a href="#">float_t</a>		
	<a href="#">GMCLIB_2COOR_ALBE_T_FLT</a> *		
	Compensation of a 32-bit single precision floating-point two-phase system input to a 16-bit fractional two-phase system using a 32-bit single precision floating-point DC-bus voltage information and modulation index. The DC-bus voltage and modulation index inputs are non-negative values; the two-phase voltage input is within the full 32-bit single-point floating-point range, and the output is within the fractional range <-1 ; 1).		

## 2.7.2 Declaration

The available [GMCLIB\\_ElimDcBusRip](#) functions have the following declarations:

```
void GMCLIB_ElimDcBusRip_F16sas(frac16\_t f16UDcBus, acc32\_t a32IdxMod, const
GMCLIB\_2COOR\_ALBE\_T\_F16 *psUAlBeComp, GMCLIB\_2COOR\_ALBE\_T\_F16 *psUAlBe)
void GMCLIB_ElimDcBusRip_F16fff(float\_t fltUDcBus, float\_t fltIdxMod, const
GMCLIB\_2COOR\_ALBE\_T\_FLT *psUAlBeComp, GMCLIB\_2COOR\_ALBE\_T\_F16 *psUAlBe)
```

## 2.7.3 Function use

The use of the [GMCLIB\\_ElimDcBusRip](#) function is shown in the following example:

```
#include "gmclib.h"

static frac16\_t f16UDcBus;
static acc32\_t a32IdxMod;
static GMCLIB\_2COOR\_ALBE\_T\_F16 sUAlBe;
static GMCLIB\_2COOR\_ALBE\_T\_F16 sUAlBeComp;

void Isr(void);

void main(void)
```

```
{
    /* Voltage Alpha, Beta structure initialization */
    sUAlBe.f16Alpha = FRAC16(0.0);
    sUAlBe.f16Beta = FRAC16(0.0);

    /* SVM modulation index */
    a32IdxMod = ACC32(1.3);

    /* DC bus voltage initialization */
    f16UDcBus = FRAC16(0.8);
}

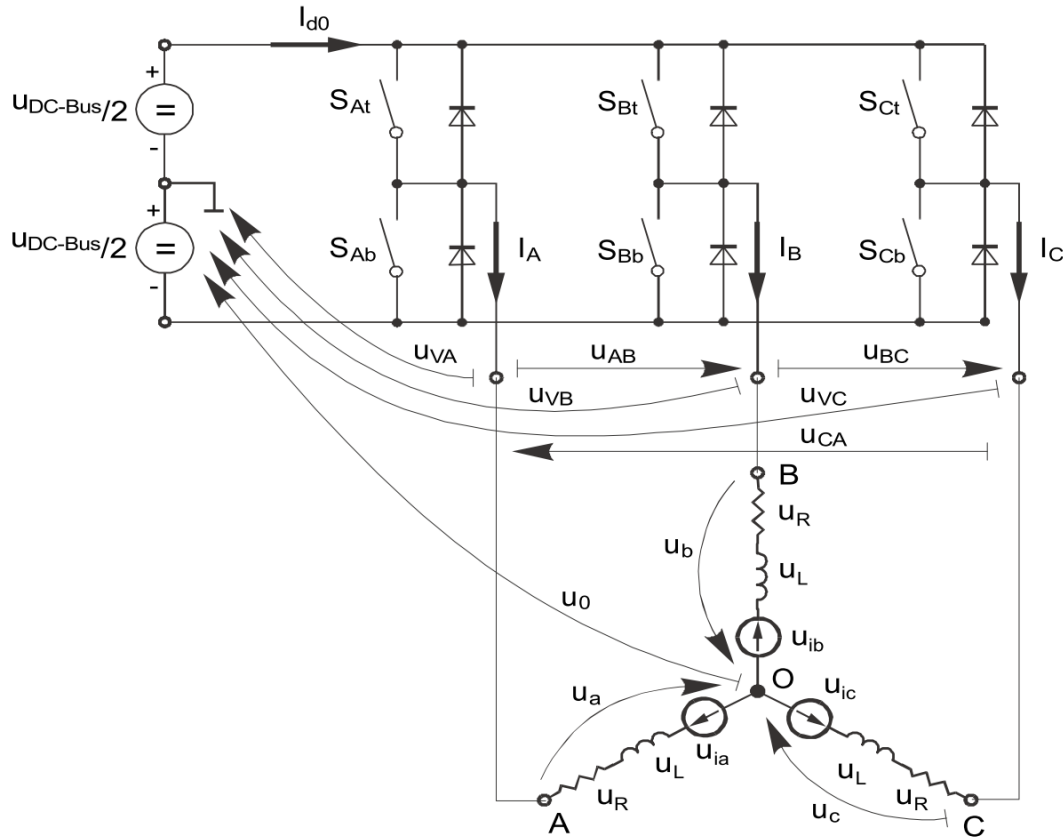
/* Periodical function or interrupt */
void Isr(void)
{
    /* Ripple elimination calculation */
    GMCLIB_ElimDcBusRip_F16sas(f16UDcBus, a32IdxMod, &sUAlBe, &sUAlBeComp);
}
```

## 2.8 GMCLIB\_SvmStd

The [GMCLIB\\_SvmStd](#) function calculates the appropriate duty-cycle ratios, which are needed for generation of the given stator-reference voltage vector, using a special standard space vector modulation technique.

The [GMCLIB\\_SvmStd](#) function for calculating the duty-cycle ratios is widely used in modern electric drives. This function calculates the appropriate duty-cycle ratios, which are needed for generating the given stator reference voltage vector, using a special space vector modulation technique, called standard space vector modulation.

The basic principle of the standard space vector modulation technique can be explained using the power stage diagram shown in [Figure 2-5](#).



**Figure 2-5. Power stage schematic diagram**

The top and bottom switches are working in a complementary mode; for example, if the top switch  $S_{At}$  is on, then the corresponding bottom switch  $S_{Ab}$  is off, and vice versa. Considering that the value 1 is assigned to the ON state of the top switch, and value 0 is assigned to the ON state of the bottom switch, the switching vector  $[a, b, c]^T$  can be defined. Creating of such vector allows for numerical definition of all possible switching states. Phase-to-phase voltages can then be expressed in terms of the following states:

$$\begin{bmatrix} U_{AB} \\ U_{BC} \\ U_{CA} \end{bmatrix} = U_{DCBus} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

**Equation 29**

where  $U_{DCBus}$  is the instantaneous voltage measured on the DC-bus.

Assuming that the motor is completely symmetrical, it is possible to write a matrix equation, which expresses the motor phase voltages shown in [Equation 29 on page 53](#).

$$\begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix} = \frac{U_{DCBus}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

**Equation 30**

In a three-phase power stage configuration (as shown in [Figure 2-5](#)), eight possible switching states (shown in [Figure 2-6](#)) are feasible. These states, together with the resulting instantaneous output line-to-line and phase voltages, are listed in [Table 2-8](#).

**Table 2-8. Switching patterns**

A	B	C	$U_a$	$U_b$	$U_c$	$U_{AB}$	$U_{BC}$	$U_{CA}$	Vector
0	0	0	0	0	0	0	0	0	$O_{000}$
1	0	0	$2U_{DCBus}/3$	$-U_{DCBus}/3$	$-U_{DCBus}/3$	$U_{DCBus}$	0	$-U_{DCBus}$	$U_0$
1	1	0	$U_{DCBus}/3$	$U_{DCBus}/3$	$-2U_{DCBus}/3$	0	$U_{DCBus}$	$-U_{DCBus}$	$U_{60}$
0	1	0	$-U_{DCBus}/3$	$2U_{DCBus}/3$	$-U_{DCBus}/3$	$-U_{DCBus}$	$U_{DCBus}$	0	$U_{120}$
0	1	1	$-2U_{DCBus}/3$	$U_{DCBus}/3$	$U_{DCBus}/3$	$-U_{DCBus}$	0	$U_{DCBus}$	$U_{240}$
0	0	1	$-U_{DCBus}/3$	$-U_{DCBus}/3$	$2U_{DCBus}/3$	0	$-U_{DCBus}$	$U_{DCBus}$	$U_{300}$
1	0	1	$U_{DCBus}/3$	$-2U_{DCBus}/3$	$U_{DCBus}/3$	$U_{DCBus}$	$-U_{DCBus}$	0	$U_{360}$
1	1	1	0	0	0	0	0	0	$O_{111}$

The quantities of the direct- $\alpha$  and the quadrature- $\beta$  components of the two-phase orthogonal coordinate system, describing the three-phase stator voltages, are expressed using the Clark transformation, arranged in a matrix form:

$$\begin{bmatrix} U_\alpha \\ U_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix}$$

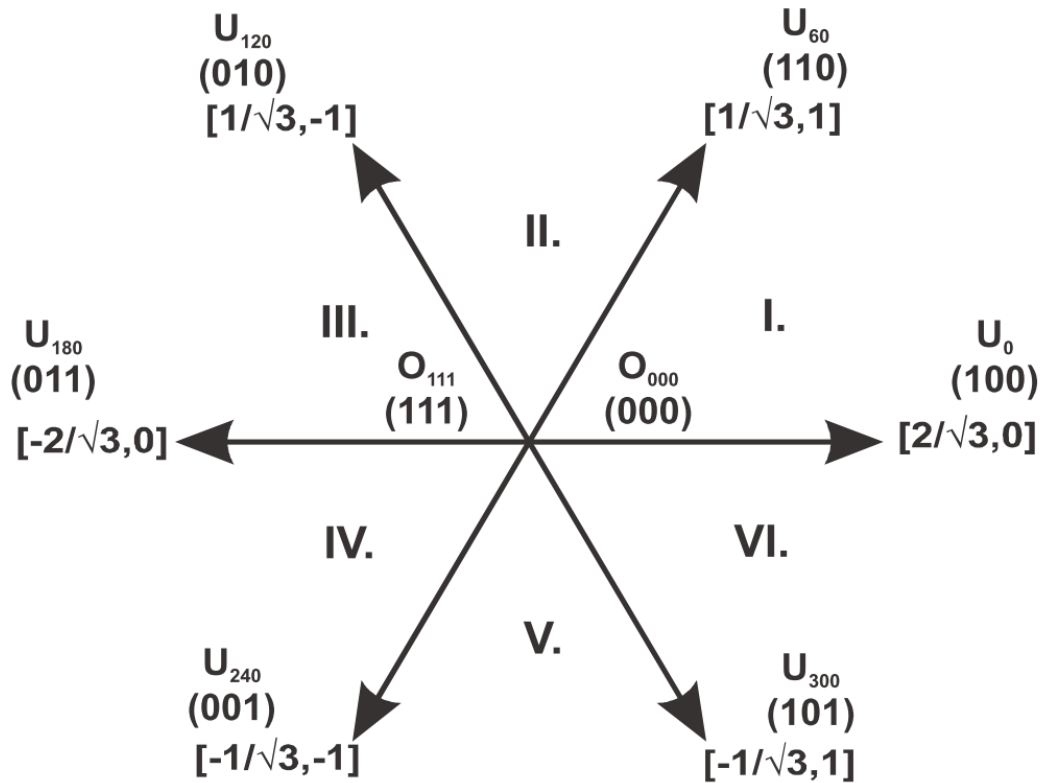
**Equation 31**

The three-phase stator voltages -  $U_a$ ,  $U_b$ , and  $U_c$ , are transformed using the Clark transformation into the direct- $\alpha$  and the quadrature- $\beta$  components of the two-phase orthogonal coordinate system. The transformation results are listed in [Table 2-9](#).

**Table 2-9. Switching patterns and space vectors**

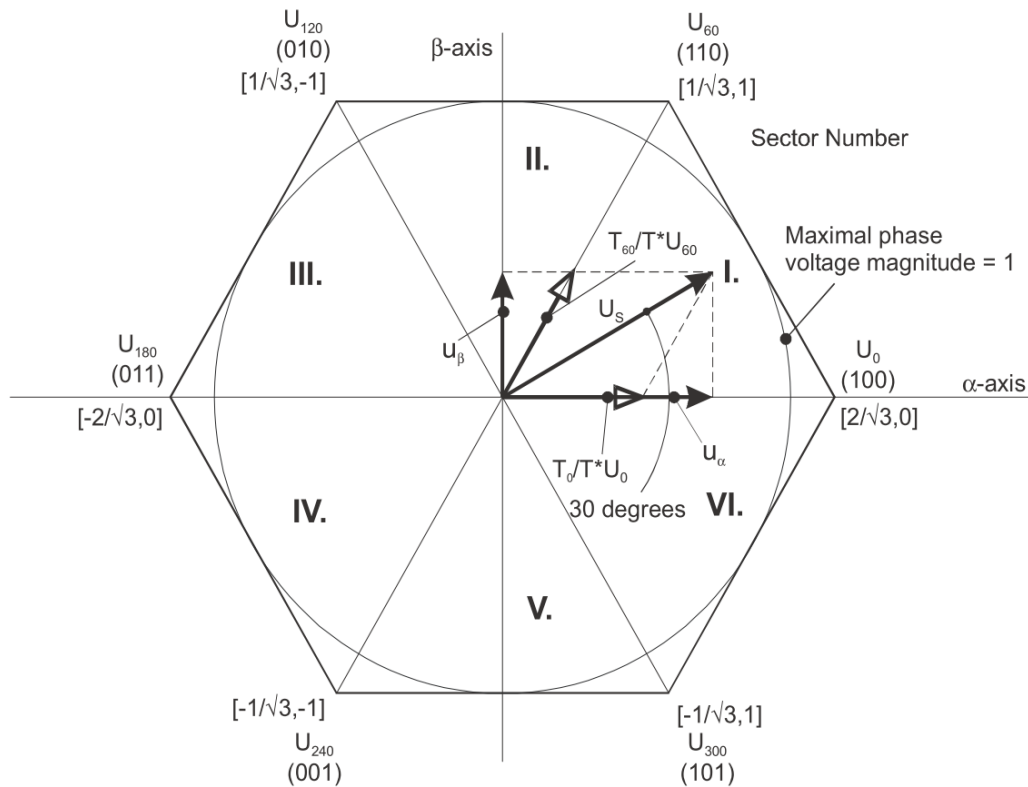
A	B	C	$U_\alpha$	$U_\beta$	Vector
0	0	0	0	0	$O_{000}$
1	0	0	$2U_{DCBus}/3$	0	$U_0$
1	1	0	$U_{DCBus}/3$	$U_{DCBus}/\sqrt{3}$	$U_{60}$
0	1	0	$-U_{DCBus}/3$	$U_{DCBus}/\sqrt{3}$	$U_{120}$
0	1	1	$-2U_{DCBus}/3$	0	$U_{240}$
0	0	1	$-U_{DCBus}/3$	$-U_{DCBus}/\sqrt{3}$	$U_{300}$
1	0	1	$U_{DCBus}/3$	$-U_{DCBus}/\sqrt{3}$	$U_{360}$
1	1	1	0	0	$O_{111}$

Figure 2-6 depicts the basic feasible switching states (vectors). There are six nonzero vectors -  $U_0$ ,  $U_{60}$ ,  $U_{120}$ ,  $U_{180}$ ,  $U_{240}$ , and  $U_{300}$ , and two zero vectors -  $O_{111}$  and  $O_{000}$ , usable for switching. Therefore, the principle of the standard space vector modulation lies in applying the appropriate switching states for a certain time, and thus generating a voltage vector identical to the reference one.



**Figure 2-6. Basic space vectors**

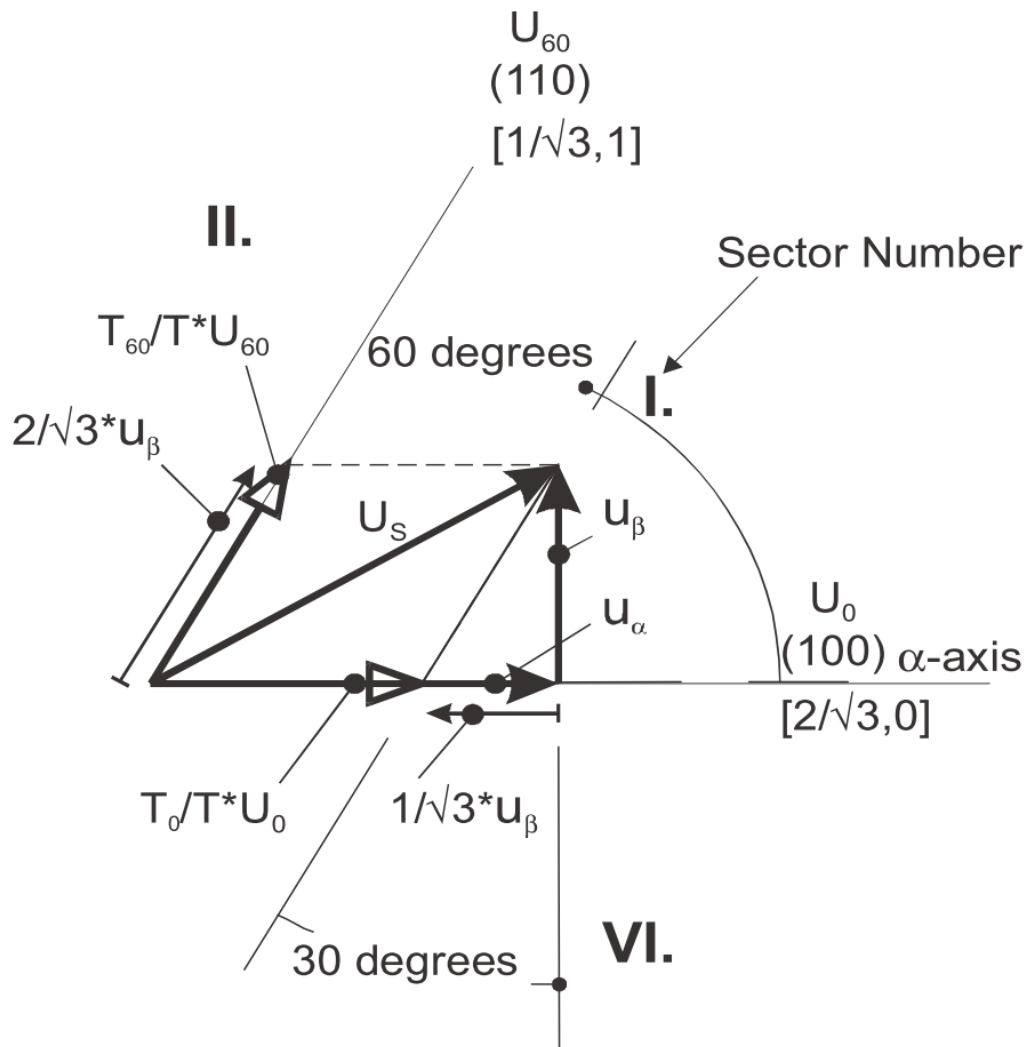
Referring to this principle, the objective of the standard space vector modulation is an approximation of the reference stator voltage vector  $U_s$ , with an appropriate combination of the switching patterns, composed of basic space vectors. The graphical explanation of this objective is shown in Figure 2-7 and Figure 2-8.



**Figure 2-7. Projection of reference voltage vector in the respective sector**

The stator reference voltage vector  $U_s$  is phase-advanced by  $30^\circ$  from the direct- $\alpha$ , and thus can be generated with an appropriate combination of the adjacent basic switching states  $U_0$  and  $U_{60}$ . These figures also indicate the resultant direct- $\alpha$  and quadrature- $\beta$  components for space vectors  $U_0$  and  $U_{60}$ .





**Figure 2-8. Detail of the voltage vector projection in the respective sector**

In this case, the reference stator voltage vector  $U_s$  is located in sector I, and can be generated using the appropriate duty-cycle ratios of the basic switching states  $U_0$  and  $U_{60}$ . The principal equations concerning this vector location are as follows:

$$T = T_{60} + T_0 + T_{null}$$

$$U_s = \frac{T_{60}}{T} \cdot U_{60} + \frac{T_0}{T} \cdot U_0$$

**Equation 32**

where  $T_{60}$  and  $T_0$  are the respective duty-cycle ratios, for which the basic space vectors  $T_{60}$  and  $T_0$  should be applied within the time period  $T$ .  $T_{null}$  is the time, for which the null vectors  $O_{000}$  and  $O_{111}$  are applied. Those duty-cycle ratios can be calculated using the following equations:

$$u_{\beta} = \frac{T_{60}}{T} \cdot |U_d| \cdot \sin 60^{\circ}$$

$$u_{\alpha} = \frac{T_0}{T} \cdot |U_d| + \frac{u_{\beta}}{\tan 60^{\circ}}$$

**Equation 33**

Considering that normalized magnitudes of basic space vectors are  $|U_{60}| = |U_0| = 2 / \sqrt{3}$ , and by the substitution of the trigonometric expressions  $\sin 60^{\circ}$  and  $\tan 60^{\circ}$  by their quantities  $2 / \sqrt{3}$ , and  $\sqrt{3}$ , respectively, the [Equation 33 on page 58](#) can be rearranged for the unknown duty-cycle ratios  $T_{60} / T$  and  $T_0 / T$  as follows:

$$\frac{T_{60}}{T} = u_{\beta}$$

$$U_S = \frac{T_{120}}{T} \cdot U_{120} + \frac{T_{60}}{T} \cdot U_{60}$$

**Equation 34**

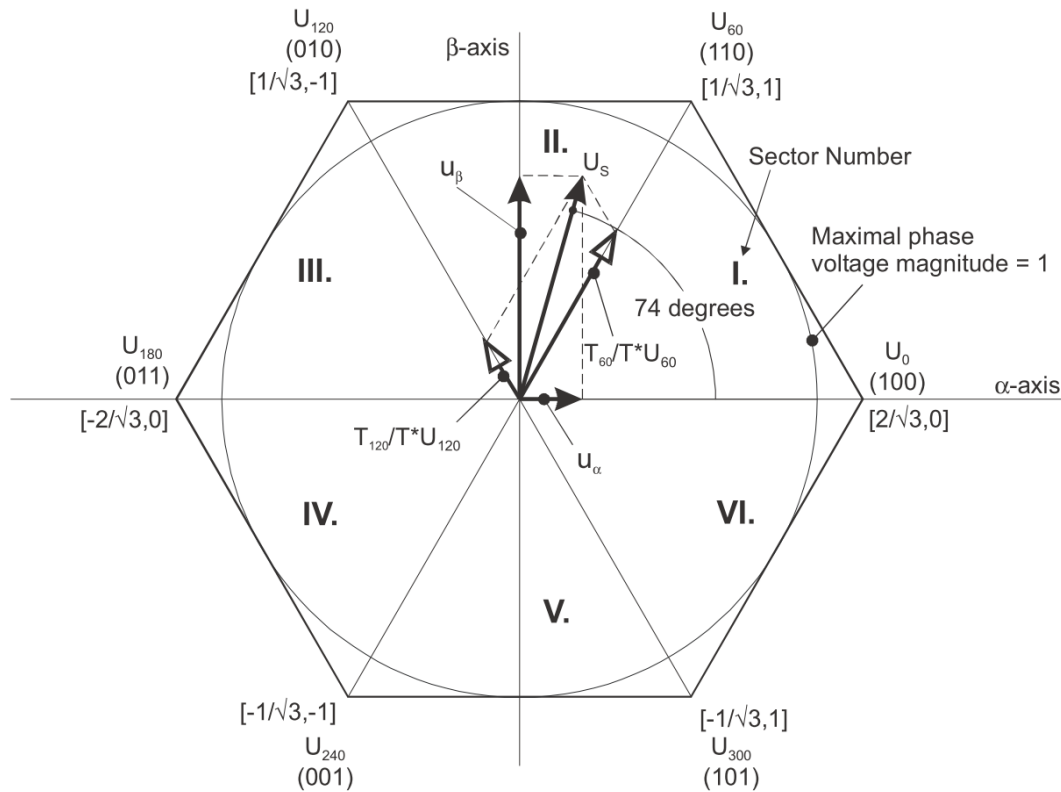
Sector II is depicted in [Figure 2-9](#). In this particular case, the reference stator voltage vector  $U_S$  is generated using the appropriate duty-cycle ratios of the basic switching states  $T_{60}$  and  $T_{120}$ . The basic equations describing this sector are as follows:

$$T = T_{120} + T_{60} + T_{null}$$

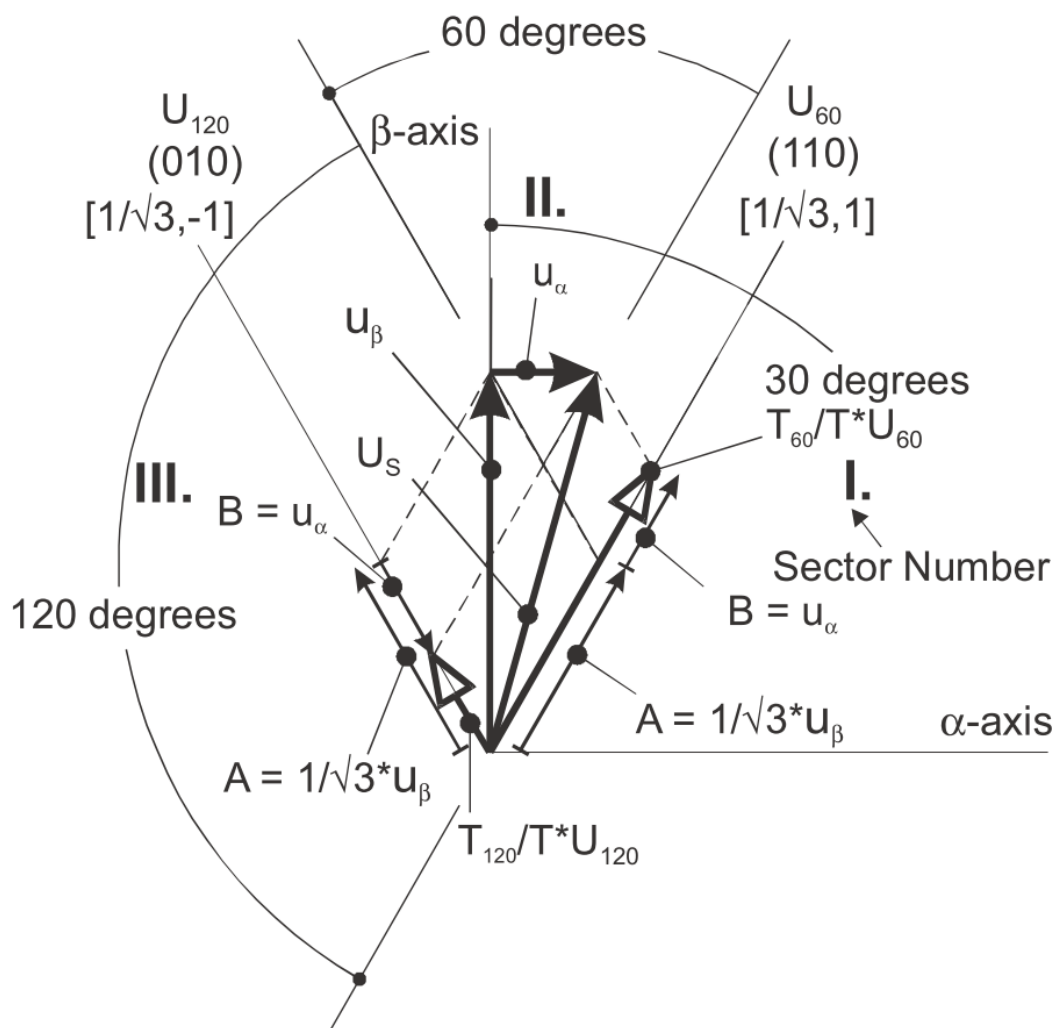
$$U_S = \frac{T_{120}}{T} \cdot U_{120} + \frac{T_{60}}{T} \cdot U_{60}$$

**Equation 35**

where  $T_{120}$  and  $T_{60}$  are the respective duty-cycle ratios, for which the basic space vectors  $U_{120}$  and  $U_{60}$  should be applied within the time period  $T$ .  $T_{null}$  is the time, for which the null vectors  $O_{000}$  and  $O_{111}$  are applied. These resultant duty-cycle ratios are formed from the auxiliary components, termed A and B. The graphical representation of the auxiliary components is shown in [Figure 2-10](#).



**Figure 2-9. Projection of the reference voltage vector in the respective sector**



**Figure 2-10. Detail of the voltage vector projection in the respective sector**

The equations describing those auxiliary time-duration components are as follows:

$$\frac{\sin 30^\circ}{\sin 120^\circ} = \frac{A}{u_\beta}$$

$$\frac{\sin 60^\circ}{\sin 60^\circ} = \frac{B}{u_\alpha}$$

**Equation 36**

Equations in [Equation 36 on page 60](#) have been created using the sine rule.

The resultant duty-cycle ratios  $T_{120} / T$  and  $T_{60} / T$  are then expressed in terms of the auxiliary time-duration components, defined by [Equation 37 on page 60](#) as follows:

$$A = \frac{1}{\sqrt{3}} \cdot u_\beta$$

$$B = u_\alpha$$

**Equation 37**

Using these equations, and also considering that the normalized magnitudes of the basic space vectors are  $|U_{120}| = |U_{60}| = 2 / \sqrt{3}$ , the equations expressed for the unknown duty-cycle ratios of basic space vectors  $T_{120} / T$  and  $T_{60} / T$  can be expressed as follows:

$$\begin{aligned}\frac{T_{120}}{T} \cdot |U_{120}| &= (A - B) \\ \frac{T_{60}}{T} \cdot |U_{60}| &= (A + B)\end{aligned}$$

### Equation 38

The duty-cycle ratios in the remaining sectors can be derived using the same approach. The resulting equations will be similar to those derived for sector I and sector II.

$$\begin{aligned}\frac{T_{120}}{T} &= \frac{1}{2}(u_\beta - \sqrt{3} \cdot u_\alpha) \\ \frac{T_{60}}{T} &= \frac{1}{2}(u_\beta + \sqrt{3} \cdot u_\alpha)\end{aligned}$$

### Equation 39

To depict the duty-cycle ratios of the basic space vectors for all sectors, we define:

- Three auxiliary variables:

$$\begin{aligned}X &= u_\beta \\ Y &= \frac{1}{2}(u_\beta + \sqrt{3} \cdot u_\alpha) \\ Z &= \frac{1}{2}(u_\beta - \sqrt{3} \cdot u_\alpha)\end{aligned}$$

### Equation 40

- Two expressions -  $t_1$  and  $t_2$ , which generally represent the duty-cycle ratios of the basic space vectors in the respective sector (for example, for the first sector,  $t_1$  and  $t_2$ ), represent duty-cycle ratios of the basic space vectors  $U_{60}$  and  $U_0$ ; for the second sector,  $t_1$  and  $t_2$  represent duty-cycle ratios of the basic space vectors  $U_{120}$  and  $U_{60}$ , and so on.

The expressions  $t_1$  and  $t_2$ , in terms of auxiliary variables  $X$ ,  $Y$ , and  $Z$  for each sector, are listed in [Table 2-10](#).

**Table 2-10. Determination of  $t_1$  and  $t_2$  expressions**

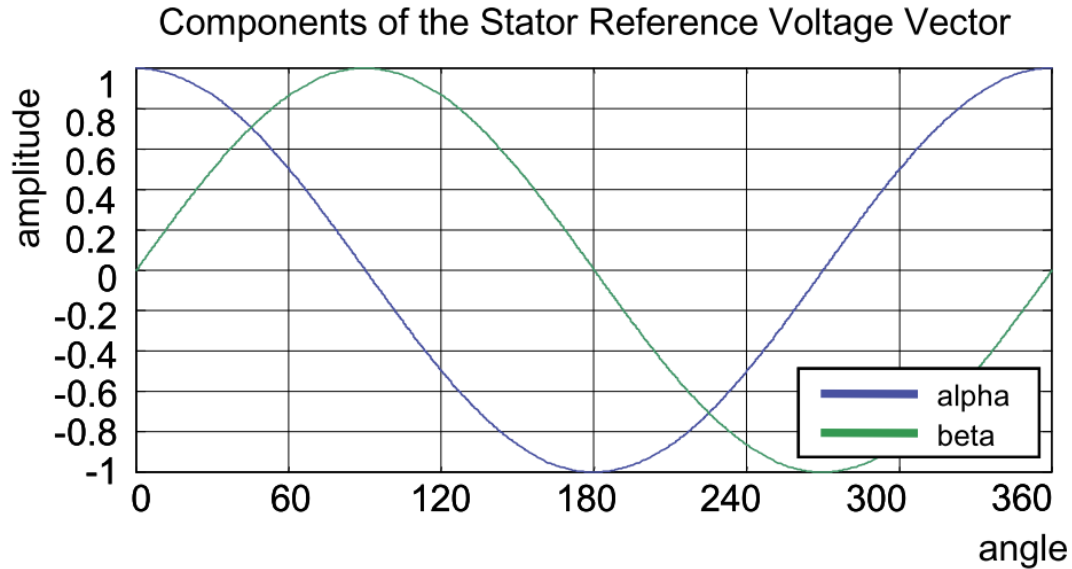
Sectors	$U_0, U_{60}$	$U_{60}, U_{120}$	$U_{120}, U_{180}$	$U_{180}, U_{240}$	$U_{240}, U_{300}$	$U_{300}, U_0$
$t_1$	X	Y	-Y	Z	-Z	-X
$t_2$	-Z	Z	X	-X	-Y	Y

For the determination of auxiliary variables  $X$ ,  $Y$ , and  $Z$ , the sector number is required. This information can be obtained using several approaches. The approach discussed here requires the use of modified Inverse Clark transformation to transform the direct- $\alpha$  and quadrature- $\beta$  components into balanced three-phase quantities  $u_{\text{ref1}}$ ,  $u_{\text{ref2}}$ , and  $u_{\text{ref3}}$ , used for straightforward calculation of the sector number, to be shown later.

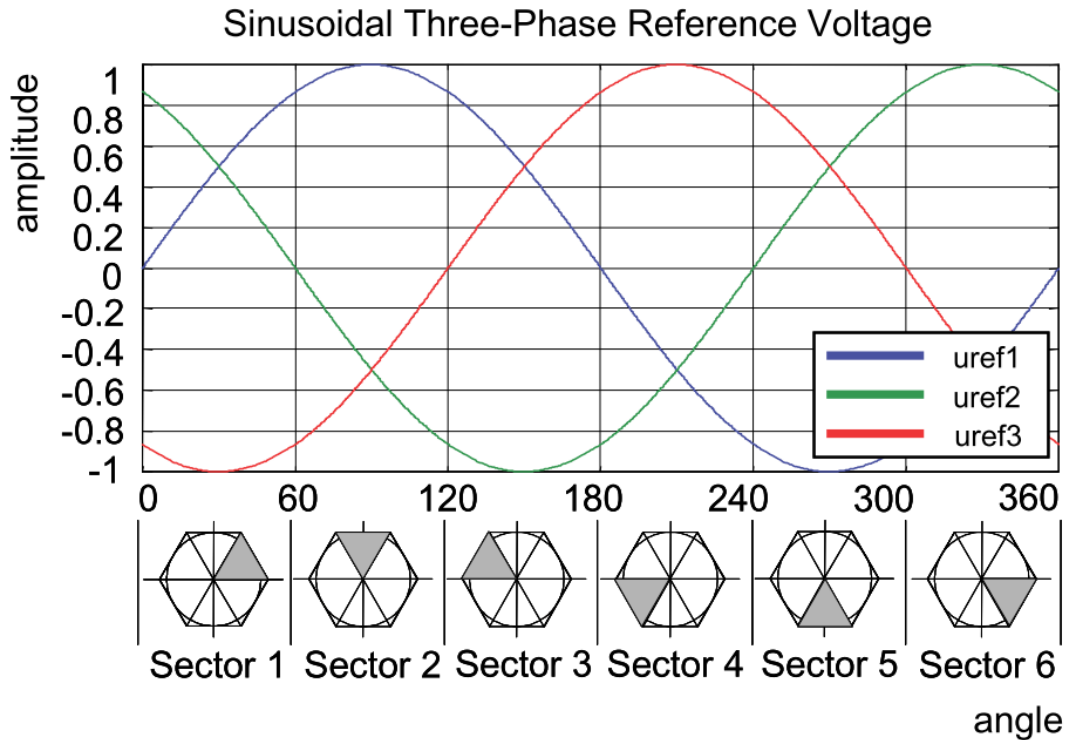
$$\begin{aligned}
 u_{ref1} &= u_{\beta} \\
 u_{ref2} &= \frac{-u_{\beta} + \sqrt{3}u_{\alpha}}{2} \\
 u_{ref3} &= \frac{-u_{\beta} - \sqrt{3}u_{\alpha}}{2}
 \end{aligned}$$

**Equation 41**

The modified Inverse Clark transformation projects the quadrature- $u_{\beta}$  component into  $u_{ref1}$ , as shown in [Figure 2-11](#) and [Figure 2-12](#), whereas voltages generated by the conventional Inverse Clark transformation project the direct- $u_{\alpha}$  component into  $u_{ref1}$ .

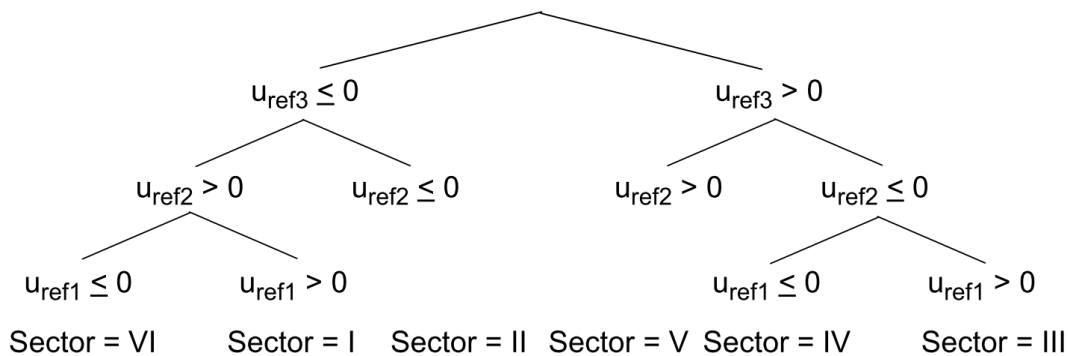
**Figure 2-11. Direct- $u_{\alpha}$  and quadrature- $u_{\beta}$  components of the stator reference voltage**

[Figure 2-11](#) depicts the direct- $u_{\alpha}$  and quadrature- $u_{\beta}$  components of the stator reference voltage vector  $U_S$ , which were calculated using equations  $u_{\alpha} = \cos \vartheta$  and  $u_{\beta} = \sin \vartheta$ , respectively.



**Figure 2-12. Reference voltages  $U_{ref1}$ ,  $U_{ref2}$ , and  $U_{ref3}$**

The sector identification tree shown in [Figure 2-13](#) can be a numerical solution of the approach shown in [GMCLIB\\_SvmStd\\_Img8](#).



**Figure 2-13. Identification of the sector number**

In the worst case, at least three simple comparisons are required to precisely identify the sector of the stator reference voltage vector. For example, if the stator reference voltage vector is located as shown in [Figure 2-7](#), the stator-reference voltage vector is phase-advanced by  $30^\circ$  from the direct  $\alpha$ -axis, which results in the positive quantities of  $u_{ref1}$  and  $u_{ref2}$ , and the negative quantity of  $u_{ref3}$ ; see [Figure 2-12](#). If these quantities are used as the inputs for the sector identification tree, the product of those comparisons will be sector I. The same approach identifies sector II, if the stator-reference voltage vector is

located as shown in [Figure 2-9](#). The variables  $t_1$ ,  $t_2$ , and  $t_3$ , which represent the switching duty-cycle ratios of the respective three-phase system, are calculated according to the following equations:

$$\begin{aligned} t_1 &= \frac{T-t_{-1}-t_{-2}}{2} \\ t_2 &= t_1 + t_{-1} \\ t_3 &= t_2 + t_{-2} \end{aligned}$$

**Equation 42**

where  $T$  is the switching period, and  $t_{-1}$  and  $t_{-2}$  are the duty-cycle ratios of the basic space vectors given for the respective sector; [Table 2-10](#), [Equation 31 on page 54](#), and [Equation 42 on page 64](#) are specific solely to the standard space vector modulation technique; other space vector modulation techniques discussed later will require deriving different equations.

The next step is to assign the correct duty-cycle ratios -  $t_1$ ,  $t_2$ , and  $t_3$ , to the respective motor phases. This is a simple task, accomplished in a view of the position of the stator reference voltage vector; see [Table 4](#).

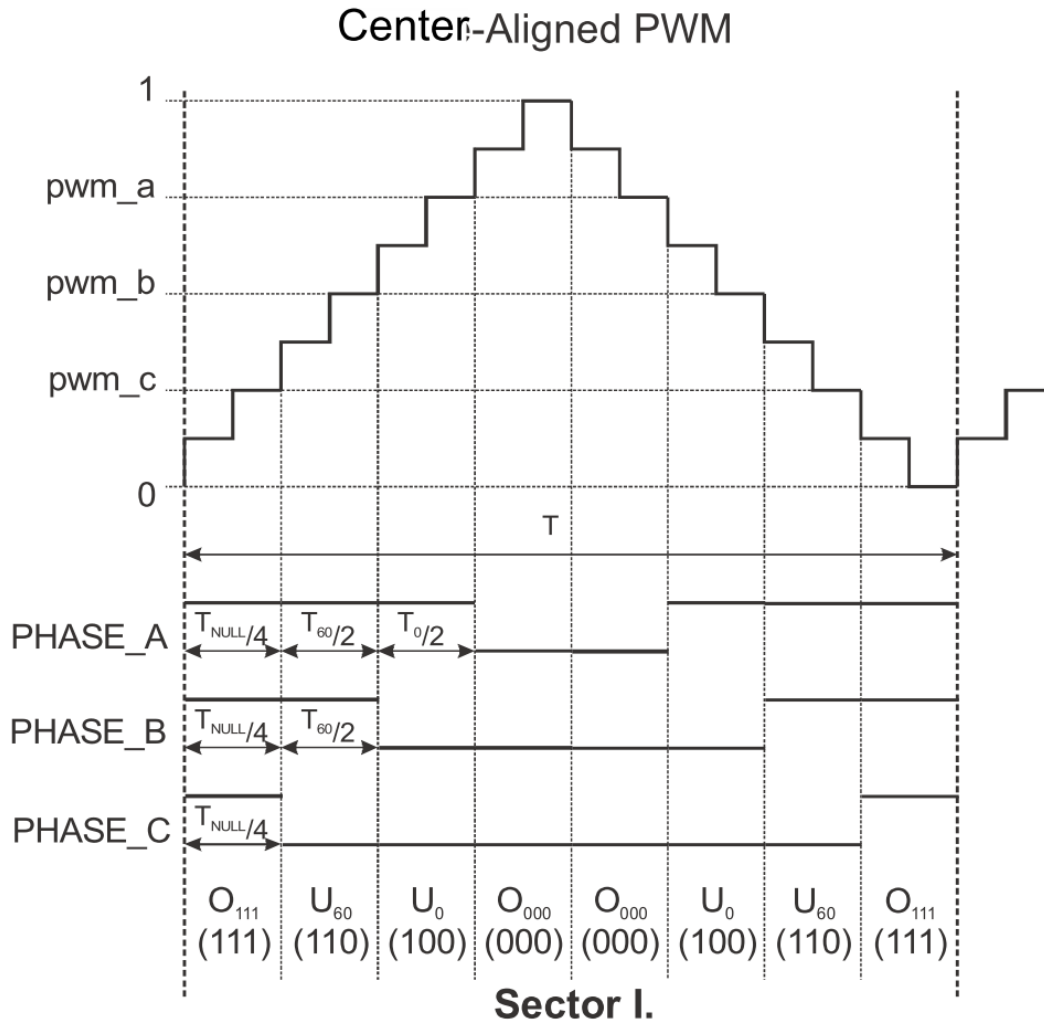
**Table 2-11. Assignment of the duty-cycle ratios to motor phases**

Sectors	$U_0, U_{60}$	$U_{60}, U_{120}$	$U_{120}, U_{180}$	$U_{180}, U_{240}$	$U_{240}, U_{300}$	$U_{300}, U_0$
pwm_a	$t_3$	$t_2$	$t_1$	$t_1$	$t_2$	$t_3$
pwm_b	$t_2$	$t_3$	$t_3$	$t_2$	$t_1$	$t_1$
pwm_c	$t_1$	$t_1$	$t_2$	$t_3$	$t_3$	$t_2$

The principle of the space vector modulation technique consists of applying the basic voltage vectors  $U_{xxx}$  and  $O_{xxx}$  for certain time, in such a way that the main vector generated by the pulse width modulation approach for the period  $T$  is equal to the original stator reference voltage vector  $U_S$ . This provides a great variability of arrangement of the basic vectors during the PWM period  $T$ . These vectors might be arranged either to lower the switching losses, or to achieve diverse results, such as center-aligned PWM, edge-aligned PWM, or a minimal number of switching states. A brief discussion of the widely used center-aligned PWM follows.

Generating the center-aligned PWM pattern is accomplished by comparing the threshold levels pwm\_a, pwm\_b, and pwm\_c with a free-running up-down counter. The timer counts to one, and then down to zero. It is supposed that when a threshold level is larger than the timer value, the respective PWM output is active. Otherwise, it is inactive; see [Figure 2-14](#).

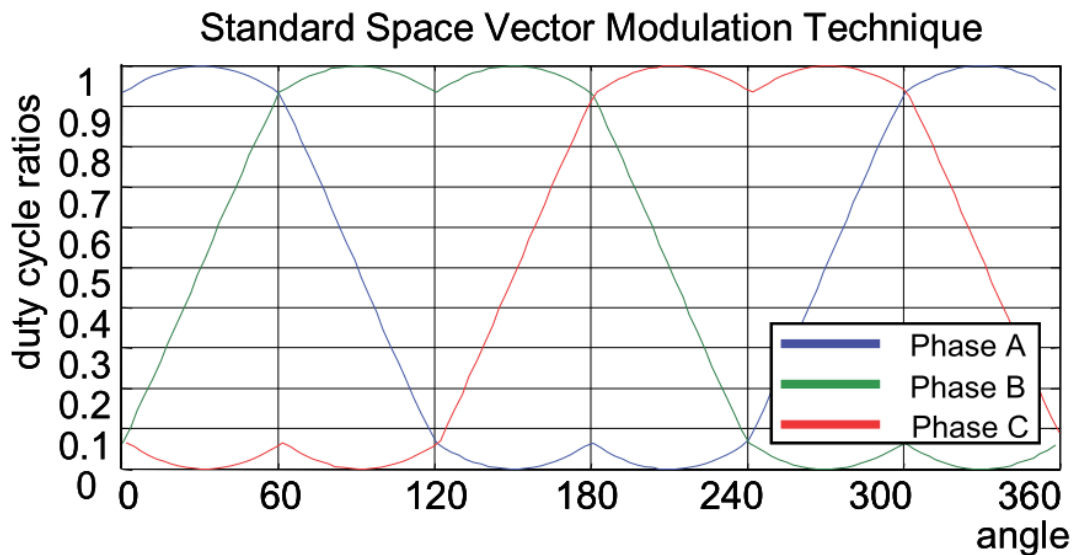
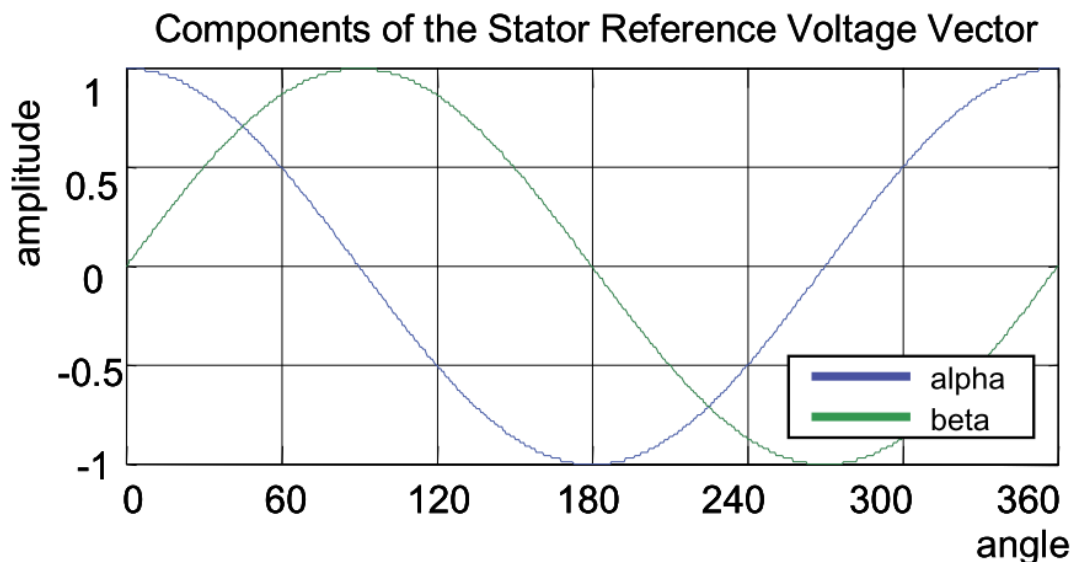




**Figure 2-14. Standard space vector modulation technique — center-aligned PWM**

Figure 2-15 shows the waveforms of the duty-cycle ratios, calculated using standard space vector modulation.

For the accurate calculation of the duty-cycle ratios, direct- $\alpha$ , and quadrature- $\beta$  components of the stator reference voltage vector, it must be considered that the duty cycle cannot be higher than one (100 %); in other words, the assumption  $\sqrt{\alpha^2 + \beta^2} \leq 1$  must be met.



**Figure 2-15. Standard space vector modulation technique**

## 2.8.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range  $<0 ; 1)$ . The result may saturate.

The available versions of the [GMCLIB\\_SvmStd](#) function are shown in the following table.

**Table 2-12. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_SvmStd_F16	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *	<a href="#">GMCLIB_3COOR_T_F16</a> *	<a href="#">uint16_t</a>
	Standard space vector modulation with a 16-bit fractional stationary ( $\alpha$ - $\beta$ ) input and a 16-bit fractional three-phase output. The result type is a 16-bit unsigned integer, which indicates the actual SVM sector. The input is within the range $<-1 ; 1>$ ; the output duty cycle is within the range $<0 ; 1>$ . The output sector is an integer value within the range $<1 ; 6>$ .		

## 2.8.2 Declaration

The available [GMCLIB\\_SvmStd](#) functions have the following declarations:

```
uint16_t GMCLIB_SvmStd_F16(const GMCLIB\_2COOR\_ALBE\_T\_F16 *psIn, GMCLIB\_3COOR\_T\_F16 *psOut)
```

## 2.8.3 Function use

The use of the [GMCLIB\\_SvmStd](#) function is shown in the following example:

```
#include "gmclib.h"

static uint16\_t ul6Sector;
static GMCLIB\_2COOR\_ALBE\_T\_F16 sAlphaBeta;
static GMCLIB\_3COOR\_T\_F16 sAbc;

void Isr(void);

void main(void)
{
    /* Alpha, Beta structure initialization */
    sAlphaBeta.f16Alpha = FRAC16(0.0);
    sAlphaBeta.f16Beta = FRAC16(0.0);
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* SVM calculation */
    ul6Sector = GMCLIB_SvmStd_F16(&sAlphaBeta, &sAbc);
}
```

## 2.9 GMCLIB\_SvmIct

The [GMCLIB\\_SvmIct](#) function calculates the appropriate duty-cycle ratios, which are needed for generation of the given stator-reference voltage vector using the general sinusoidal modulation technique.

The [GMCLIB\\_SvmIct](#) function calculates the appropriate duty-cycle ratios, needed for generation of the given stator reference voltage vector using the conventional Inverse Clark transformation. Finding the sector in which the reference stator voltage vector  $U_S$  resides is similar to [GMCLIB\\_SvmStd](#). This is achieved by first converting the direct- $\alpha$  and the quadrature- $\beta$  components of the reference stator voltage vector  $U_S$  into the balanced three-phase quantities  $u_{ref1}$ ,  $u_{ref2}$ , and  $u_{ref3}$  using the modified Inverse Clark transformation:

$$\begin{aligned} u_{ref1} &= u_\beta \\ u_{ref2} &= \frac{-u_\beta + \sqrt{3}u_\alpha}{2} \\ u_{ref3} &= \frac{-u_\beta - \sqrt{3}u_\alpha}{2} \end{aligned}$$

**Equation 43**

The calculation of the sector number is based on comparing the three-phase reference voltages  $u_{ref1}$ ,  $u_{ref2}$ , and  $u_{ref3}$  with zero. This computation is described by the following set of rules:

$$\begin{aligned} a &= \begin{cases} 1, & u_{ref1} > 0 \\ 0, & \text{else} \end{cases} \\ b &= \begin{cases} 2, & u_{ref2} > 0 \\ 0, & \text{else} \end{cases} \\ c &= \begin{cases} 4, & u_{ref3} > 0 \\ 0, & \text{else} \end{cases} \end{aligned}$$

**Equation 44**

After passing these rules, the modified sector numbers are then derived using the following formula:

$$sector^* = a + b + c$$

**Equation 45**

The sector numbers determined by this formula must be further transformed to correspond to those determined by the sector identification tree. The transformation which meets this requirement is shown in the following table:

**Table 2-13. Transformation of the sectors**

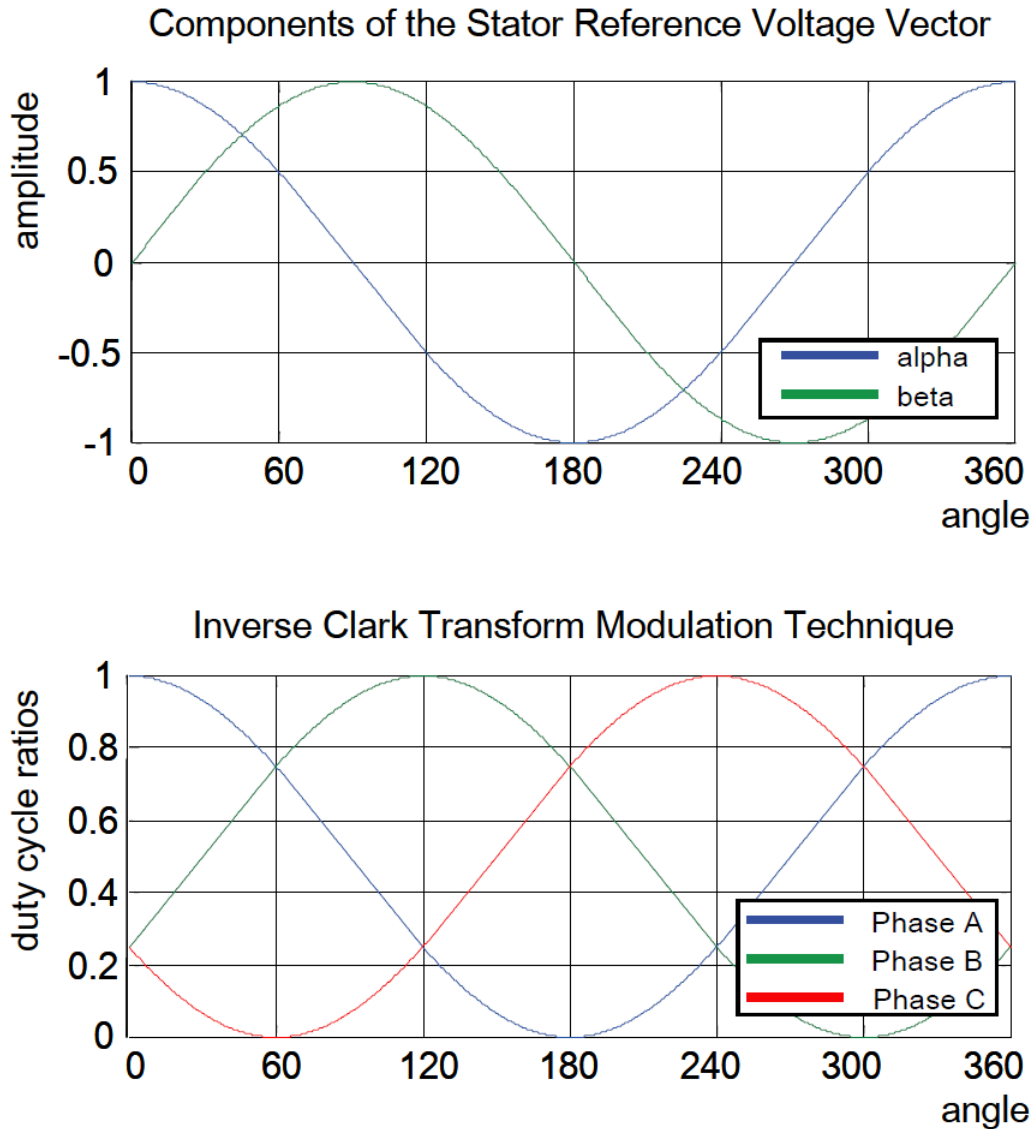
Sector*	1	2	3	4	5	6
Sector	2	6	1	4	3	5

Use the Inverse Clark transformation for transforming values such as flux, voltage, and current from an orthogonal rotating coordination system ( $u_\alpha$ ,  $u_\beta$ ) to a three-phase rotating coordination system ( $u_a$ ,  $u_b$ , and  $u_c$ ). The original equations of the Inverse Clark transformation are scaled here to provide the duty-cycle ratios in the range  $[0; 1)$ . These scaled duty cycle ratios  $pwm\_a$ ,  $pwm\_b$ , and  $pwm\_c$  can be used directly by the registers of the PWM block.

$$\begin{aligned} pwm\_a &= 0.5 + \frac{u_\alpha}{2} \\ pwm\_b &= 0.5 + \frac{-u_\alpha + \sqrt{3}u_\beta}{4} \\ pwm\_c &= 0.5 + \frac{-u_\alpha - \sqrt{3}u_\beta}{4} \end{aligned}$$

#### Equation 46

The following figure shows the waveforms of the duty-cycle ratios calculated using the Inverse Clark transformation.



**Figure 2-16. Inverse Clark transform modulation technique**

For an accurate calculation of the duty-cycle ratios and the direct- $\alpha$  and quadrature- $\beta$  components of the stator reference voltage vector, the duty cycle cannot be higher than one (100 %); in other words, the assumption  $\sqrt{\alpha^2 + \beta^2} \leq 1$  must be met.

## 2.9.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range  $<0 ; 1$ ). The result may saturate.

The available versions of the [GMCLIB\\_SvmIct](#) function are shown in the following table:

**Table 2-14. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_SvmIct_F16	GMCLIB_2COOR_ALBE_T_F16 *	GMCLIB_3COOR_T_F16 *	uint16_t
	General sinusoidal space vector modulation with a 16-bit fractional stationary ( $\alpha$ - $\beta$ ) input and a 16-bit fractional three-phase output. The result type is a 16-bit unsigned integer, which indicates the actual SVM sector. The input is within the range <-1 ; 1); the output duty cycle is within the range <0 ; 1). The output sector is an integer value within the range <1 ; 6>.		

## 2.9.2 Declaration

The available [GMCLIB\\_SvmIct](#) functions have the following declarations:

```
uint16_t GMCLIB_SvmIct_F16(const GMCLIB\_2COOR\_ALBE\_T\_F16 *psIn, GMCLIB\_3COOR\_T\_F16 *psOut)
```

## 2.9.3 Function use

The use of the [GMCLIB\\_SvmIct](#) function is shown in the following example:

```
#include "gmclib.h"

static uint16\_t ul6Sector;
static GMCLIB\_2COOR\_ALBE\_T\_F16 sAlphaBeta;
static GMCLIB\_3COOR\_T\_F16 sAbc;

void Isr(void);

void main(void)
{
    /* Alpha, Beta structure initialization */
    sAlphaBeta.f16Alpha = FRAC16(0.0);
    sAlphaBeta.f16Beta = FRAC16(0.0);
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* SVM calculation */
    ul6Sector = GMCLIB_SvmIct_F16(&sAlphaBeta, &sAbc);
}
```

## 2.10 GMCLIB\_SvmU0n

The [GMCLIB\\_SvmU0n](#) function calculates the appropriate duty-cycle ratios, which are needed for generation of the given stator-reference voltage vector using the general sinusoidal modulation technique.

The [GMCLIB\\_SvmU0n](#) function for calculating of duty-cycle ratios is widely used in modern electric drives. This function calculates the appropriate duty-cycle ratios, which are needed for generating the given stator reference voltage vector using a special space vector modulation technique called space vector modulation with  $O_{000}$  nulls, where only one type of null vector  $O_{000}$  is used (all bottom switches are turned on in the inverter).

The derivation approach of the space vector modulation technique with  $O_{000}$  nulls is in many aspects identical to the approach presented in [GMCLIB\\_SvmStd](#). However, a distinct difference lies in the definition of the variables  $t_1$ ,  $t_2$ , and  $t_3$  that represent switching duty-cycle ratios of the respective phases:

$$\begin{aligned}t_1 &= 0 \\t_2 &= t_1 + t_{\_1} \\t_3 &= t_2 + t_{\_2}\end{aligned}$$

**Equation 47**

where  $T$  is the switching period, and  $t_{\_1}$  and  $t_{\_2}$  are the duty-cycle ratios of the basic space vectors that are defined for the respective sector in [Table 2-10](#).

The generally used center-aligned PWM is discussed briefly in the following sections. Generating the center-aligned PWM pattern is accomplished practically by comparing the threshold levels `pwm_a`, `pwm_b`, and `pwm_c` with the free-running up/down counter. The timer counts up to 1 (0x7FFF) and then down to 0 (0x0000). It is supposed that when a threshold level is larger than the timer value, the respective PWM output is active. Otherwise it is inactive (see [Figure 2-17](#)).





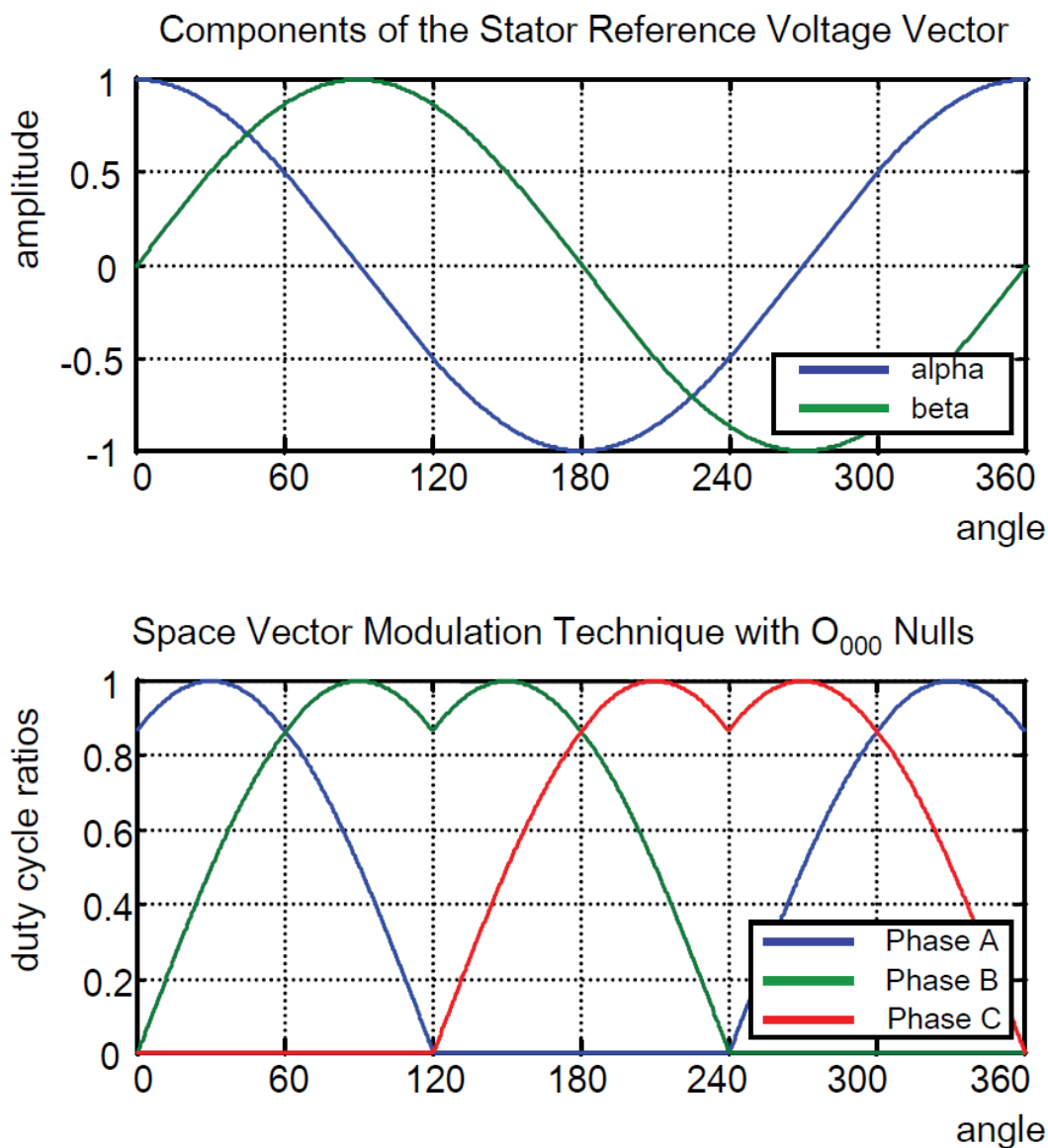


Figure 2-18. Space vector modulation technique with  $O_{000}$  nulls

### 2.10.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range  $<0 ; 1)$ . The result may saturate.

The available versions of the [GMCLIB\\_SvmU0n](#) function are shown in the following table:

**Table 2-15. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_SvmU0n_F16	GMCLIB_2COOR_ALBE_T_F16 *	GMCLIB_3COOR_T_F16 *	uint16_t
	General sinusoidal space vector modulation with a 16-bit fractional stationary ( $\alpha$ - $\beta$ ) input, and a 16-bit fractional three-phase output. The result type is a 16-bit unsigned integer, which indicates the actual SVM sector. The input is within the range <-1 ; 1); the output duty cycle is within the range <0 ; 1). The output sector is an integer value within the range <1 ; 6>.		

## 2.10.2 Declaration

The available [GMCLIB\\_SvmU0n](#) functions have the following declarations:

```
uint16_t GMCLIB_SvmU0n_F16(const GMCLIB\_2COOR\_ALBE\_T\_F16 *psIn, GMCLIB\_3COOR\_T\_F16 *psOut)
```

## 2.10.3 Function use

The use of the [GMCLIB\\_SvmU0n](#) function is shown in the following example:

```
#include "gmclib.h"

static uint16\_t ul6Sector;
static GMCLIB\_2COOR\_ALBE\_T\_F16 sAlphaBeta;
static GMCLIB\_3COOR\_T\_F16 sAbc;

void Isr(void);

void main(void)
{
    /* Alpha, Beta structure initialization */
    sAlphaBeta.f16Alpha = FRAC16(0.0);
    sAlphaBeta.f16Beta = FRAC16(0.0);
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* SVM calculation */
    ul6Sector = GMCLIB_SvmU0n_F16(&sAlphaBeta, &sAbc);
}
```

## 2.11 GMCLIB\_SvmU7n

The [GMCLIB\\_SvmU7n](#) function calculates the appropriate duty-cycle ratios, which are needed for generation of the given stator-reference voltage vector, using the general sinusoidal modulation technique.

The [GMCLIB\\_SvmU7n](#) function for calculating the duty-cycle ratios is widely used in modern electric drives. This function calculates the appropriate duty-cycle ratios, which are needed for generating the given stator reference voltage vector using a special space vector modulation technique called space vector modulation with  $O_{111}$  nulls, where only one type of null vector  $O_{111}$  is used (all top switches are turned on in the inverter).

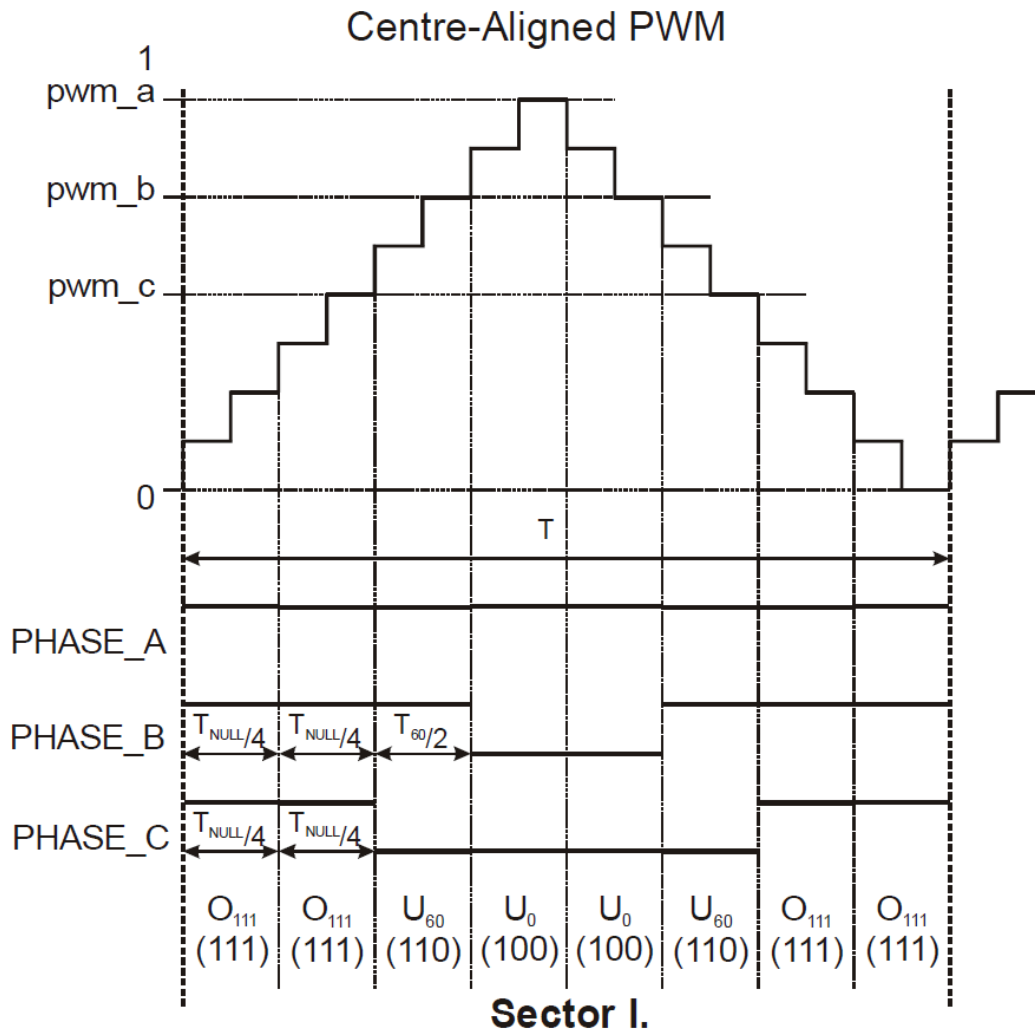
The derivation approach of the space vector modulation technique with  $O_{111}$  nulls is identical (in many aspects) to the approach presented in [GMCLIB\\_SvmStd](#). However, a distinct difference lies in the definition of variables  $t_1$ ,  $t_2$ , and  $t_3$  that represent switching duty-cycle ratios of the respective phases:

$$\begin{aligned}t_1 &= T - t_{-1} - t_{-2} \\t_2 &= t_1 + t_{-1} \\t_3 &= t_2 + t_{-2}\end{aligned}$$

**Equation 48**

where  $T$  is the switching period, and  $t_{-1}$  and  $t_{-2}$  are the duty-cycle ratios of the basic space vectors defined for the respective sector in [Table 2-10](#).

The generally-used center-aligned PWM is discussed briefly in the following sections. Generating the center-aligned PWM pattern is accomplished by comparing threshold levels `pwm_a`, `pwm_b`, and `pwm_c` with the free-running up/down counter. The timer counts up to 1 (0x7FFF) and then down to 0 (0x0000). It is supposed that when a threshold level is larger than the timer value, the respective PWM output is active. Otherwise, it is inactive (see [Figure 2-19](#)).



**Figure 2-19. Space vector modulation technique with O<sub>111</sub> nulls — center-aligned PWM**

Figure [Figure 2-19](#) shows calculated waveforms of the duty-cycle ratios using Space Vector Modulation with O<sub>111</sub> nulls.

For an accurate calculation of the duty-cycle ratios, direct- $\alpha$ , and quadrature- $\beta$  components of the stator reference voltage vector, it must be considered that the duty cycle cannot be higher than one (100 %); in other words, the assumption  $\sqrt{\alpha^2 + \beta^2} \leq 1$  must be met.

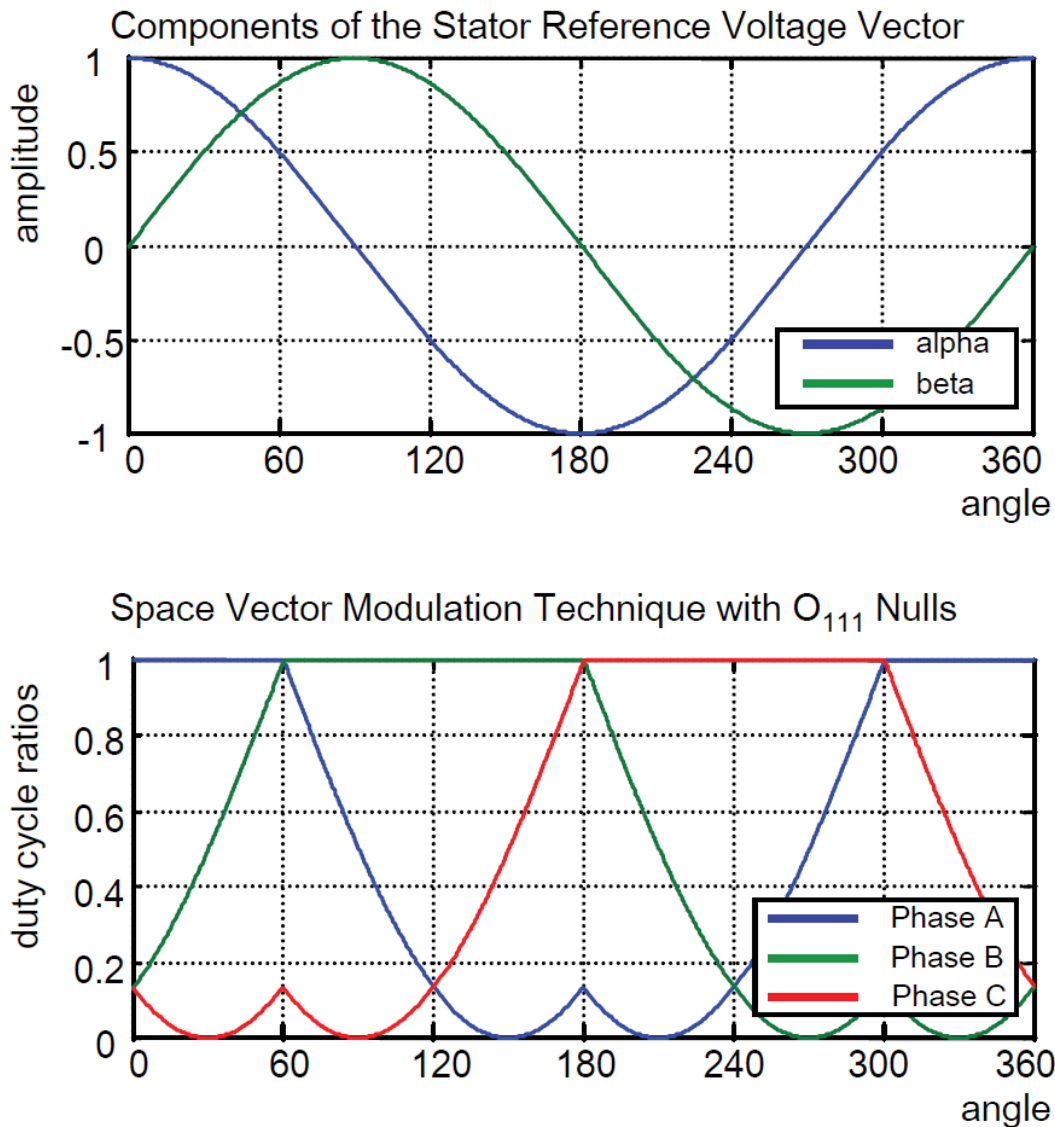


Figure 2-20. Space vector modulation technique with  $O_{111}$  nulls

### 2.11.1 Available versions

This function is available in the following versions:

- Fractional output - the output is the fractional portion of the result; the result is within the range  $<0 ; 1)$ . The result may saturate.

The available versions of the [GMCLIB\\_SvmU7n](#) function are shown in the following table:

**Table 2-16. Function versions**

Function name	Input type	Output type	Result type
GMCLIB_SvmU7n_F16	<a href="#">GMCLIB_2COOR_ALBE_T_F16</a> *	<a href="#">GMCLIB_3COOR_T_F16</a> *	<a href="#">uint16_t</a>
	General sinusoidal space vector modulation with a 16-bit fractional stationary ( $\alpha$ - $\beta$ ) input and a 16-bit fractional three-phase output. The result type is a 16-bit unsigned integer, which indicates the actual SVM sector. The input is within the range $<-1 ; 1$ ); the output duty cycle is within the range $<0 ; 1$ ). The output sector is an integer value within the range $<1 ; 6$ >.		

## 2.11.2 Declaration

The available [GMCLIB\\_SvmU7n](#) functions have the following declarations:

```
uint16_t GMCLIB_SvmU7n_F16(const GMCLIB\_2COOR\_ALBE\_T\_F16 *psIn, GMCLIB\_3COOR\_T\_F16 *psOut)
```

## 2.11.3 Function use

The use of the [GMCLIB\\_SvmU7n](#) function is shown in the following example:

```
#include "gmclib.h"

static uint16\_t ul6Sector;
static GMCLIB\_2COOR\_ALBE\_T\_F16 sAlphaBeta;
static GMCLIB\_3COOR\_T\_F16 sAbc;

void Isr(void);

void main(void)
{
    /* Alpha, Beta structure initialization */
    sAlphaBeta.f16Alpha = FRAC16(0.0);
    sAlphaBeta.f16Beta = FRAC16(0.0);
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* SVM calculation */
    ul6Sector = GMCLIB_SvmU7n_F16(&sAlphaBeta, &sAbc);
}
```





# Appendix A

## Library types

### A.1 bool\_t

The `bool_t` type is a logical 16-bit type. It is able to store the boolean variables with two states: TRUE (1) or FALSE (0). Its definition is as follows:

```
typedef unsigned short bool_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-1. Data storage**

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Value	Unused															Logical
TRUE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	0				0				0				1			
FALSE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0				0				0				0			

To store a logical value as `bool_t`, use the `FALSE` or `TRUE` macros.

### A.2 uint8\_t

The `uint8_t` type is an unsigned 8-bit integer type. It is able to store the variables within the range <0 ; 255>. Its definition is as follows:

```
typedef unsigned char uint8_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-2. Data storage**

	7	6	5	4	3	2	1	0
Value	Integer							
255	1	1	1	1	1	1	1	1
	F				F			
11	0	0	0	0	1	0	1	1
	0				B			
124	0	1	1	1	1	1	0	0
	7				C			
159	1	0	0	1	1	1	1	1
	9				F			

## A.3 uint16\_t

The `uint16_t` type is an unsigned 16-bit integer type. It is able to store the variables within the range  $<0 ; 65535>$ . Its definition is as follows:

```
typedef unsigned short uint16_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-3. Data storage**

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Value	Integer															
65535	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	F				F				F				F			
5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	0				0				0				5			
15518	0	0	1	1	1	1	0	0	1	0	0	1	1	1	1	0
	3				C				9				E			
40768	1	0	0	1	1	1	1	1	0	1	0	0	0	0	0	0
	9				F				4				0			

## A.4 uint32\_t

The `uint32_t` type is an unsigned 32-bit integer type. It is able to store the variables within the range  $\langle 0 ; 4294967295 \rangle$ . Its definition is as follows:

```
typedef unsigned long uint32_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-4. Data storage**

	31	24	23	16	15	8	7	0
Value	Integer							
4294967295	F	F	F	F	F	F	F	F
2147483648	8	0	0	0	0	0	0	0
55977296	0	3	5	6	2	5	5	0
3451051828	C	D	B	2	D	F	3	4

## A.5 int8\_t

The `int8_t` type is a signed 8-bit integer type. It is able to store the variables within the range  $\langle -128 ; 127 \rangle$ . Its definition is as follows:

```
typedef char int8_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-5. Data storage**

	7	6	5	4	3	2	1	0
Value	Sign	Integer						
127	0	1	1	1	1	1	1	1
	7				F			
-128	1	0	0	0	0	0	0	0
	8				0			
60	0	0	1	1	1	1	0	0
	3				C			
-97	1	0	0	1	1	1	1	1
	9				F			

## A.6 int16\_t

The `int16_t` type is a signed 16-bit integer type. It is able to store the variables within the range  $<-32768 ; 32767>$ . Its definition is as follows:

```
typedef short int16_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-6. Data storage**

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Value	Sign	Integer														
32767	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	7				F				F				F			
-32768	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8				0				0				0			
15518	0	0	1	1	1	1	0	0	1	0	0	1	1	1	1	0
	3				C				9				E			
-24768	1	0	0	1	1	1	1	1	0	1	0	0	0	0	0	0
	9				F				4				0			

## A.7 int32\_t

The `int32_t` type is a signed 32-bit integer type. It is able to store the variables within the range  $<-2147483648 ; 2147483647>$ . Its definition is as follows:

```
typedef long int32_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-7. Data storage**

	31	24	23	16	15	8	7	0
Value	S	Integer						
2147483647	7	F	F	F	F	F	F	F
-2147483648	8	0	0	0	0	0	0	0
55977296	0	3	5	6	2	5	5	0
-843915468	C	D	B	2	D	F	3	4

## A.8 frac8\_t

The `frac8_t` type is a signed 8-bit fractional type. It is able to store the variables within the range  $<-1 ; 1$ ). Its definition is as follows:

```
typedef char frac8_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-8. Data storage**

	7	6	5	4	3	2	1	0
Value	Sign	Fractional						
0.99219	0	1	1	1	1	1	1	1
	7				F			
-1.0	1	0	0	0	0	0	0	0
	8				0			
0.46875	0	0	1	1	1	1	0	0
	3				C			
-0.75781	1	0	0	1	1	1	1	1
	9				F			

To store a real number as `frac8_t`, use the `FRAC8` macro.

## A.9 frac16\_t

The `frac16_t` type is a signed 16-bit fractional type. It is able to store the variables within the range  $<-1 ; 1$ ). Its definition is as follows:

```
typedef short frac16_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-9. Data storage**

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Value	Sign	Fractional														
0.99997	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	7				F				F				F			
-1.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*Table continues on the next page...*

**Table A-9. Data storage (continued)**

0.47357	8				0				0				0			
	0	0	1	1	1	1	0	0	1	0	0	1	1	1	1	0
	3				C				9				E			
	1	0	0	1	1	1	1	1	0	1	0	0	0	0	0	0
-0.75586	9				F				4				0			

To store a real number as `frac16_t`, use the `FRAC16` macro.

## A.10 frac32\_t

The `frac32_t` type is a signed 32-bit fractional type. It is able to store the variables within the range  $<-1 ; 1$ ). Its definition is as follows:

```
typedef long frac32_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-10. Data storage**

	31	24 23		16 15		8 7		0
Value	S	Fractional						
0.9999999995	7	F	F	F	F	F	F	F
-1.0	8	0	0	0	0	0	0	0
0.02606645970	0	3	5	6	2	5	5	0
-0.3929787632	C	D	B	2	D	F	3	4

To store a real number as `frac32_t`, use the `FRAC32` macro.

## A.11 acc16\_t

The `acc16_t` type is a signed 16-bit fractional type. It is able to store the variables within the range  $<-256 ; 256$ ). Its definition is as follows:

```
typedef short acc16_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-11. Data storage**

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
Value	Sign	Integer								Fractional							
255.9921875	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	7				F				F				F				
-256.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	8				0				0				0				
1.0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
	0				0				8				0				
-1.0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	
	F				F				8				0				
13.7890625	0	0	0	0	0	1	1	0	1	1	1	0	0	1	0	1	
	0				6				E				5				
-89.71875	1	1	0	1	0	0	1	1	0	0	1	0	0	1	0	0	
	D				3				2				4				

To store a real number as `acc16_t`, use the `ACC16` macro.

## A.12 `acc32_t`

The `acc32_t` type is a signed 32-bit accumulator type. It is able to store the variables within the range  $<-65536 ; 65536$ ). Its definition is as follows:

```
typedef long acc32_t;
```

The following figure shows the way in which the data is stored by this type:

**Table A-12. Data storage**

	31	24 23		16 15		8 7		0	
Value	S	Integer				Fractional			
65535.999969	7	F	F	F	F	F	F	F	
-65536.0	8	0	0	0	0	0	0	0	
1.0	0	0	0	0	8	0	0	0	
-1.0	F	F	F	F	8	0	0	0	
23.789734	0	0	0	B	E	5	1	6	
-1171.306793	F	D	B	6	5	8	B	C	

To store a real number as `acc32_t`, use the `ACC32` macro.

- The `float_t` type is a signed 32-bit single precision floating-point type, defined by IEEE 754. It is able to store the full precision (normalized) finite variables within the range  $[-3.40282 \cdot 10^{38}; 3.40282 \cdot 10^{38}]$  with the minimum resolution of  $2^{-23}$ . The smallest normalized number is  $\pm 1.17549 \cdot 10^{-38}$ . Nevertheless, the denormalized numbers (with reduced precision) reach yet lower values, from  $\pm 1.40130 \cdot 10^{-45}$  to  $\pm 1.17549 \cdot 10^{-38}$ . The standard also defines the additional values:

- The 32-bit type is composed of:

The conversion of the number is straightforward. The sign of the number is stored in bit 31. The binary exponent is decoded as an integer from bits 23 to 30 by subtracting 127. The mantissa (fraction) is stored in bits 0 to 22. An invisible leading bit (it is not actually stored) with value 1.0 is placed in front; therefore, bit 23 has a value of 0.5, bit 22 has a value 0.25, and so on. As a result, the mantissa has a value between 1.0 and 2. If the exponent reaches -127 (binary 00000000), the leading 1.0 is no longer used to enable the gradual underflow.

The `float_t` type definition is as follows:

```
typedef float float t;
```

The following figure shows the way in which the data is stored by this type:

	31	24 23							16 15							8 7							0								
Value	S	Exponent							Mantissa																						
$(2.0 - 2^{-23}) \cdot 2^{127}$	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
$\approx 3.40282 \cdot 10^{38}$	7 F							7 F							F F							F F									
$-(2.0 - 2^{-23}) \cdot 2^{127}$	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
$\approx -3.40282 \cdot 10^{38}$	F F							7 F							F F							F F									

*Table continues on the next page...*



**Table A-13. Data storage - normalized values (continued)**

$2^{-126}$ $\approx 1.17549 \cdot 10^{-38}$	0	0 0 0 0 0 0 0 0 1	0 0
	0	0	8 0 0 0 0 0
$-2^{-126}$ $\approx -1.17549 \cdot 10^{-38}$	1	0 0 0 0 0 0 0 0 1	0 0
	8	0	8 0 0 0 0 0
1.0	0	0 1 1 1 1 1 1 1 1	0 0
	3	F	8 0 0 0 0 0
-1.0	1	0 1 1 1 1 1 1 1 1	0 0
	B	F	8 0 0 0 0 0
$\pi$ $\approx 3.1415927$	0	1 0 0 0 0 0 0 0 0	1 0 0 1 0 0 1 0 0 0 0 1 1 1 1 1 1 1 0 1 1 0 1 1 1 1 1 1
	4	0	4 9 0 F D B
-20810.086	1	1 0 0 0 1 1 0 1	0 1 0 0 0 1 0 1 0 0 1 0 1 0 0 0 0 1 0 1 1 0 0 0 0 0 0 0
	C	6	A 2 9 4 2 C

**Table A-14. Data storage - denormalized values**

	31	24 23	16 15	8 7	0													
Value	S	Exponent	Mantissa															
0.0	0	0 0 0 0 0 0 0 0 0	0 0															
		0 0	0 0	0 0	0 0													
-0.0	1	0 0 0 0 0 0 0 0 0	0 0															
		8 0	0 0	0 0	0 0													
$(1.0 - 2^{-23}) \cdot 2^{-126}$ $\approx 1.17549 \cdot 10^{-38}$	0	0 0 0 0 0 0 0 0 0	1 1															
		0 0	7 F	F F	F F													
$-(1.0 - 2^{-23}) \cdot 2^{-126}$ $\approx -1.17549 \cdot 10^{-38}$	1	0 0 0 0 0 0 0 0 0	1 1															
		8 0	7 F	F F	F F													
$2^{-1} \cdot 2^{-126}$ $\approx 5.87747 \cdot 10^{-39}$	0	0 0 0 0 0 0 0 0 0	1 0															
		0 0	4 0	0 0	0 0													
$-2^{-1} \cdot 2^{-126}$ $\approx -5.87747 \cdot 10^{-39}$	1	0 0 0 0 0 0 0 0 0	1 0															
		8 0	4 0	0 0	0 0													
$2^{-23} \cdot 2^{-126}$ $\approx 1.40130 \cdot 10^{-45}$	0	0 0 0 0 0 0 0 0 0	0 1															
		0 0	0 0	0 0	0 1													
$-2^{-23} \cdot 2^{-126}$ $\approx -1.40130 \cdot 10^{-45}$	1	0 0 0 0 0 0 0 0 0	0 1															
		8 0	0 0	0 0	0 1													

Table A-15. Data storage - special values

	31	24 23							16 15								8 7				0						
Value	S	Exponent							Mantissa																		
$\infty$	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7 F							8 0				0 0				0 0											
$-\infty$	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F F							8 0				0 0				0 0											
Not a number	*	1	1	1	1	1	1	1	non zero																		
	7/F F							800001 to FFFFFFFF																			

## A.14 GMCLIB\_3COOR\_T\_F16

The [GMCLIB\\_3COOR\\_T\\_F16](#) structure type corresponds to the three-phase stationary coordinate system, based on the A, B, and C components. Each member is of the [frac16\\_t](#) data type. The structure definition is as follows:

```
typedef struct
{
    frac16_t f16A;
    frac16_t f16B;
    frac16_t f16C;
} GMCLIB_3COOR_T_F16;
```

The structure description is as follows:

Table A-16. GMCLIB\_3COOR\_T\_F16 members description

Type	Name	Description
<a href="#">frac16_t</a>	f16A	A component; 16-bit fractional type
<a href="#">frac16_t</a>	f16B	B component; 16-bit fractional type
<a href="#">frac16_t</a>	f16C	C component; 16-bit fractional type

## A.15 GMCLIB\_3COOR\_T\_FLT

The [GMCLIB\\_3COOR\\_T\\_FLT](#) structure type corresponds to the three-phase stationary coordinate system, based on the A, B, and C components. Each member is of the [float\\_t](#) data type. The structure definition is as follows:

```
typedef struct
{
```

```

float_t fltA;
float_t fltB;
float_t fltC;
} GMCLIB_3COOR_T_FLT;

```

The structure description is as follows:

**Table A-17. GMCLIB\_3COOR\_T\_FLT members description**

Type	Name	Description
float_t	fltA	A component; 32-bit single precision floating-point type
float_t	fltB	B component; 32-bit single precision floating-point type
float_t	fltC	C component; 32-bit single precision floating-point type

## A.16 GMCLIB\_2COOR\_ALBE\_T\_F16

The [GMCLIB\\_2COOR\\_ALBE\\_T\\_F16](#) structure type corresponds to the two-phase stationary coordinate system, based on the Alpha and Beta orthogonal components. Each member is of the [frac16\\_t](#) data type. The structure definition is as follows:

```

typedef struct
{
    frac16_t f16Alpha;
    frac16_t f16Beta;
} GMCLIB_2COOR_ALBE_T_F16;

```

The structure description is as follows:

**Table A-18. GMCLIB\_2COOR\_ALBE\_T\_F16 members description**

Type	Name	Description
frac16_t	f16Apha	$\alpha$ -component; 16-bit fractional type
frac16_t	f16Beta	$\beta$ -component; 16-bit fractional type

## A.17 GMCLIB\_2COOR\_ALBE\_T\_FLT

The [GMCLIB\\_2COOR\\_ALBE\\_T\\_FLT](#) structure type corresponds to the two-phase stationary coordinate system based on the Alpha and Beta orthogonal components. Each member is of the [float\\_t](#) data type. The structure definition is as follows:

```

typedef struct
{
    float_t fltAlpha;
    float_t fltBeta;
} GMCLIB_2COOR_ALBE_T_FLT;

```

The structure description is as follows:

**Table A-19. GMCLIB\_2COOR\_ALBE\_T\_FLT members description**

Type	Name	Description
<a href="#">float_t</a>	fltAlpha	$\alpha$ -component; 32-bit single precision floating-point type
<a href="#">float_t</a>	fltBeta	$\beta$ -component; 32-bit single precision floating-point type

## A.18 GMCLIB\_2COOR\_DQ\_T\_F16

The [GMCLIB\\_2COOR\\_DQ\\_T\\_F16](#) structure type corresponds to the two-phase rotating coordinate system, based on the D and Q orthogonal components. Each member is of the [frac16\\_t](#) data type. The structure definition is as follows:

```
typedef struct
{
    frac16\_t f16D;
    frac16\_t f16Q;
} GMCLIB_2COOR_DQ_T_F16;
```

The structure description is as follows:

**Table A-20. GMCLIB\_2COOR\_DQ\_T\_F16 members description**

Type	Name	Description
<a href="#">frac16_t</a>	f16D	D-component; 16-bit fractional type
<a href="#">frac16_t</a>	f16Q	Q-component; 16-bit fractional type

## A.19 GMCLIB\_2COOR\_DQ\_T\_F32

The [GMCLIB\\_2COOR\\_DQ\\_T\\_F32](#) structure type corresponds to the two-phase rotating coordinate system, based on the D and Q orthogonal components. Each member is of the [frac32\\_t](#) data type. The structure definition is as follows:

```
typedef struct
{
    frac32\_t f32D;
    frac32\_t f32Q;
} GMCLIB_2COOR_DQ_T_F32;
```

The structure description is as follows:

**Table A-21. GMCLIB\_2COOR\_DQ\_T\_F32 members description**

Type	Name	Description
<a href="#">frac32_t</a>	f32D	D-component; 32-bit fractional type
<a href="#">frac32_t</a>	f32Q	Q-component; 32-bit fractional type

## A.20 GMCLIB\_2COOR\_DQ\_T\_FLT

The [GMCLIB\\_2COOR\\_DQ\\_T\\_FLT](#) structure type corresponds to the two-phase rotating coordinate system, based on the D and Q orthogonal components. Each member is of the [float\\_t](#) data type. The structure definition is as follows:

```
typedef struct
{
    float_t fltD;
    float_t fltQ;
} GMCLIB_2COOR_DQ_T_FLT;
```

The structure description is as follows:

**Table A-22. GMCLIB\_2COOR\_DQ\_T\_FLT members description**

Type	Name	Description
<a href="#">float_t</a>	fltD	D-component; 32-bit single precision floating-point type
<a href="#">float_t</a>	fltQ	Q-component; 32-bit single precision floating-point type

## A.21 GMCLIB\_2COOR\_SINCOS\_T\_F16

The [GMCLIB\\_2COOR\\_SINCOS\\_T\\_F16](#) structure type corresponds to the two-phase coordinate system, based on the Sin and Cos components of a certain angle. Each member is of the [frac16\\_t](#) data type. The structure definition is as follows:

```
typedef struct
{
    frac16_t f16Sin;
    frac16_t f16Cos;
} GMCLIB_2COOR_SINCOS_T_F16;
```

The structure description is as follows:

**Table A-23. GMCLIB\_2COOR\_SINCOS\_T\_F16 members description**

Type	Name	Description
frac16_t	f16Sin	Sin component; 16-bit fractional type
frac16_t	f16Cos	Cos component; 16-bit fractional type

## A.22 GMCLIB\_2COOR\_SINCOS\_T\_FLT

The [GMCLIB\\_2COOR\\_SINCOS\\_T\\_FLT](#) structure type corresponds to the two-phase coordinate system, based on the Sin and Cos components of a certain angle. Each member is of the [float\\_t](#) data type. The structure definition is as follows:

```
typedef struct
{
    float_t fltSin;
    float_t fltCos;
} GMCLIB_2COOR_SINCOS_T_FLT;
```

The structure description is as follows:

**Table A-24. GMCLIB\_2COOR\_SINCOS\_T\_FLT members description**

Type	Name	Description
float_t	fltSin	Sin component; 32-bit single precision floating-point type
float_t	fltCos	Cos component; 32-bit single precision floating-point type

## A.23 FALSE

The [FALSE](#) macro serves to write a correct value standing for the logical FALSE value of the [bool\\_t](#) type. Its definition is as follows:

```
#define FALSE    ((bool_t)0)

#include "mlib.h"

static bool_t bVal;

void main(void)
{
    bVal = FALSE;                /* bVal = FALSE */
}
```

## A.24 TRUE

The **TRUE** macro serves to write a correct value standing for the logical TRUE value of the **bool\_t** type. Its definition is as follows:

```
#define TRUE      ((bool_t)1)

#include "mlib.h"

static bool_t bVal;

void main(void)
{
    bVal = TRUE;                /* bVal = TRUE */
}
```

## A.25 FRAC8

The **FRAC8** macro serves to convert a real number to the **frac8\_t** type. Its definition is as follows:

```
#define FRAC8(x) ((frac8_t)((x) < 0.9921875 ? ((x) >= -1 ? (x)*0x80 : 0x80) : 0x7F))
```

The input is multiplied by 128 ( $=2^7$ ). The output is limited to the range  $\langle 0x80 ; 0x7F \rangle$ , which corresponds to  $\langle -1.0 ; 1.0 \cdot 2^{-7} \rangle$ .

```
#include "mlib.h"

static frac8_t f8Val;

void main(void)
{
    f8Val = FRAC8(0.187);      /* f8Val = 0.187 */
}
```

## A.26 FRAC16

The **FRAC16** macro serves to convert a real number to the **frac16\_t** type. Its definition is as follows:

```
#define FRAC16(x) ((frac16_t)((x) < 0.999969482421875 ? ((x) >= -1 ? (x)*0x8000 : 0x8000) : 0x7FFF))
```

The input is multiplied by 32768 ( $=2^{15}$ ). The output is limited to the range  $\langle 0x8000 ; 0x7FFF \rangle$ , which corresponds to  $\langle -1.0 ; 1.0 \cdot 2^{-15} \rangle$ .

```
#include "mlib.h"

static frac16_t f16Val;

void main(void)
{
    f16Val = FRAC16(0.736);          /* f16Val = 0.736 */
}
```

## A.27 FRAC32

The **FRAC32** macro serves to convert a real number to the **frac32\_t** type. Its definition is as follows:

```
#define FRAC32(x) ((frac32_t)((x) < 1 ? ((x) >= -1 ? (x)*0x80000000 : 0x80000000) : 0x7FFFFFFF))
```

The input is multiplied by 2147483648 ( $=2^{31}$ ). The output is limited to the range  $\langle 0x80000000 ; 0x7FFFFFFF \rangle$ , which corresponds to  $\langle -1.0 ; 1.0 \cdot 2^{-31} \rangle$ .

```
#include "mlib.h"

static frac32_t f32Val;

void main(void)
{
    f32Val = FRAC32(-0.1735667);    /* f32Val = -0.1735667 */
}
```

## A.28 ACC16

The **ACC16** macro serves to convert a real number to the **acc16\_t** type. Its definition is as follows:

```
#define ACC16(x) ((acc16_t)((x) < 255.9921875 ? ((x) >= -256 ? (x)*0x80 : 0x8000) : 0x7FFF))
```

The input is multiplied by 128 ( $=2^7$ ). The output is limited to the range  $\langle 0x8000 ; 0x7FFF \rangle$  that corresponds to  $\langle -256.0 ; 255.9921875 \rangle$ .

```
#include "mlib.h"

static acc16_t a16Val;
```



```

void main(void)
{
    a16Val = ACC16(19.45627);           /* a16Val = 19.45627 */
}

```

## A.29 ACC32

The **ACC32** macro serves to convert a real number to the **acc32\_t** type. Its definition is as follows:

```

#define ACC32(x) ((acc32_t)((x) < 65535.999969482421875 ? ((x) >= -65536 ? (x)*0x8000 : 0x80000000) : 0x7FFFFFFF))

```

The input is multiplied by 32768 ( $=2^{15}$ ). The output is limited to the range  $\langle 0x80000000 ; 0x7FFFFFFF \rangle$ , which corresponds to  $\langle -65536.0 ; 65536.0 \cdot 2^{-15} \rangle$ .

```

#include "mlib.h"

static acc32_t a32Val;

void main(void)
{
    a32Val = ACC32(-13.654437);         /* a32Val = -13.654437 */
}

```



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