General Functions Library

User Reference Manual

56800E
Digital Signal Controller

56800E_GFLIB
Rev. 3
06/2011

freescale.com
The following revision history table summarizes changes contained in this document.

Table 0-1. Revision History

<table>
<thead>
<tr>
<th>Date</th>
<th>Revision Label</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>Initial release</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Reformatted and updated revision</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>FSLES 2.0</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Fixed inconsistence in the API Summary table</td>
</tr>
</tbody>
</table>
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Chapter 2  INTRODUCTION

2.1  Overview

This reference manual describes General Functions Library for Freescale 56800E family of Digital Signal Controllers. This library contains optimized functions for 56800E family of controllers. The library is supplied in a binary form, which is unique by its simplicity to integrate with user application.

2.2  Supported Compilers

The General Functions Library (GFLIB) is written in assembly language with a C-callable interface. The library was built and tested using the following compiler:

- CodeWarrior™ Development Studio for Freescale™ DSC56800/E Digital Signal Controllers, version 8.3

The library is delivered in the 56800E_GFLIB.lib library module. The interfaces to the algorithms included in this library have been combined into a single public interface include file, the gflib.h. This was done to reduce the number of files required for inclusion by the application programs. Refer to the specific algorithm sections of this document for details on the software application programming interface (API), defined and functionality provided for the individual algorithms.

2.3  Installation

If the user wants to fully use this library, the CodeWarrior tools should be installed prior to the General Functions Library. In case that the General Functions Library tool is installed while CodeWarrior is not present, users can only browse the installed software package, but will not be able to build, download, and run the code. The installation itself consists of copying the required files to the destination hard drive, checking the presence of CodeWarrior, and creating the shortcut under the Start->Programs menu.

Each General Functions Library release is installed in its own new folder, named 56800E_GFLIB_rX.X, where X.X denotes the actual release number. This way of library installation allows the users to maintain older releases and projects and gives them a free choice to select the active library release.

To start the installation process, follow the following steps:

1. Execute the 56800E_FSLESL_rXX.exe file.
2. Follow the FSLESL software installation instructions on your screen.
2.4 Library Integration

General Functions Library is added into a new CodeWarrior project by taking the following steps:

1. Create a new empty project.
2. Create GFLIB group in your new open project. Note that this step is not mandatory, it is mentioned here just for the purpose of maintaining file consistency in the CodeWarrior project window. In the CodeWarrior menu, choose Project > Create Group..., type GFLIB into the dialog window that pops up, and click <OK>.
3. Refer the 56800E_GFLIB.lib file in the project window. This can be achieved by dragging the library file from the proper library subfolder and dropping it into the GFLIB group in the CodeWarrior project window. This step will automatically add the GFLIB path into the project access paths, such as the user can take advantage of the library functions to achieve flawless project compilation and linking.
4. It is similar with the reference file gflib.h. This file can be dragged from the proper library subfolder and dropped into the GFLIB group in the CodeWarrior project window.
5. The following program line must be added into the user-application source code in order to use the library functions.

```
#include "gflib.h"
```

2.5 API Definition

The description of each function described in this General Functions Library user reference manual consists of a number of subsections:

**Synopsis**

This subsection gives the header files that should be included within a source file that references the function or macro. It also shows an appropriate declaration for the function or for a function that can be substituted by a macro. This declaration is not included in your program; only the header file(s) should be included.

**Prototype**

This subsection shows the original function prototype declaration with all its arguments.

**Arguments**

This optional subsection describes input arguments to a function or macro.

**Description**

This subsection is a description of the function or macro. It explains algorithms being used by functions or macros.
Return
This optional subsection describes the return value (if any) of the function or macro.

Range Issues
This optional subsection specifies the ranges of input variables.

Special Issues
This optional subsection specifies special assumptions that are mandatory for correct function calculation; for example saturation, rounding, and so on.

Implementation
This optional subsection specifies, whether a call of the function generates a library function call or a macro expansion. This subsection also consists of one or more examples of the use of the function. The examples are often fragments of code (not completed programs) for illustration purposes.

See Also
This optional subsection provides a list of related functions or macros.

Performance
This section specifies the actual requirements of the function or macro in terms of required code memory, data memory, and number of clock cycles to execute. If the clock cycles have two numbers for instance 21/22, then the number 21 is measured on the MCF56F80xx core and the number 22 is measured on the MCF56F83xx core.

2.6 Data Types
The 16-bit DSC core supports four types of two’s-complement data formats:

- Signed integer
- Unsigned integer
- Signed fractional
- Unsigned fractional

Signed and unsigned integer data types are useful for general-purpose computation; they are familiar with the microprocessor and microcontroller programmers. Fractional data types allow powerful numeric and digital-signal-processing algorithms to be implemented.
2.6.1  Signed Integer (SI)

This format is used for processing data as integers. In this format, the N-bit operand is represented using the N.0 format (N integer bits). The signed integer numbers lie in the following range:

\[
-2^{N-1} \leq SI \leq 2^{N-1} - 1
\]

Eqn. 2-1

This data format is available for bytes, words, and longs. The most negative, signed word that can be represented is \(-32,768\) (\$8000), and the most negative, signed long word is \(-2,147,483,648\) (\$80000000).

The most positive, signed word is 32,767 (\$7FFF), and the most positive signed long word is 2,147,483,647 (\$7FFFFFFF).

2.6.2  Unsigned Integer (UI)

The unsigned integer numbers are positive only, and they have nearly twice the magnitude of a signed number of the same size. The unsigned integer numbers lie in the following range:

\[
0 \leq UI \leq 2^{N-1} - 1
\]

Eqn. 2-2

The binary word is interpreted as having a binary point immediately to the right of the integer’s least significant bit. This data format is available for bytes, words, and long words. The most positive, 16-bit, unsigned integer is 65,535 (\$FFFF), and the most positive, 32-bit, unsigned integer is 4,294,967,295 (\$FFFFFFFF). The smallest unsigned integer number is zero (\$0000), regardless of size.

2.6.3  Signed Fractional (SF)

In this format, the N-bit operand is represented using the 1.[N–1] format (one sign bit, N–1 fractional bits). The signed fractional numbers lie in the following range:

\[
-1.0 \leq SF \leq 1.0 - 2^{-(N-1)}
\]

Eqn. 2-3

This data format is available for words and long words. For both word and long-word signed fractions, the most negative number that can be represented is \(-1.0\); its internal representation is \$8000\) (word) or \$80000000\) (long word). The most positive word is \$7FFF\) (1.0 \(- 2^{-15}\); its most positive long word is \$7FFFFFFFF\) (1.0 \(- 2^{-31}\)).

2.6.4  Unsigned Fractional (UF)

The unsigned fractional numbers can be positive only, and they have nearly twice the magnitude of a signed number with the same number of bits. The unsigned fractional numbers lie in the following range:
The binary word is interpreted as having a binary point after the MSB. This data format is available for words and longs. The most positive, 16-bit, unsigned number is $FFFF$, or $1.0 + (1.0 - 2^{-[N-1]}) = 1.99997$. The smallest unsigned fractional number is zero ($0000$).

### 2.7 User Common Types

#### Table 2-1. User-Defined Typedefs in 56800E_types.h

<table>
<thead>
<tr>
<th>Mnemonics</th>
<th>Size — bits</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word8</td>
<td>8</td>
<td>To represent 8-bit signed variable/value.</td>
</tr>
<tr>
<td>UWord8</td>
<td>8</td>
<td>To represent 16-bit unsigned variable/value.</td>
</tr>
<tr>
<td>Word16</td>
<td>16</td>
<td>To represent 16-bit signed variable/value.</td>
</tr>
<tr>
<td>UWord16</td>
<td>16</td>
<td>To represent 16-bit unsigned variable/value.</td>
</tr>
<tr>
<td>Word32</td>
<td>32</td>
<td>To represent 32-bit signed variable/value.</td>
</tr>
<tr>
<td>UWord32</td>
<td>32</td>
<td>To represent 16-bit unsigned variable/value.</td>
</tr>
<tr>
<td>Int8</td>
<td>8</td>
<td>To represent 8-bit signed variable/value.</td>
</tr>
<tr>
<td>UInt8</td>
<td>8</td>
<td>To represent 16-bit unsigned variable/value.</td>
</tr>
<tr>
<td>Int16</td>
<td>16</td>
<td>To represent 16-bit signed variable/value.</td>
</tr>
<tr>
<td>UInt16</td>
<td>16</td>
<td>To represent 16-bit unsigned variable/value.</td>
</tr>
<tr>
<td>Int32</td>
<td>32</td>
<td>To represent 32-bit signed variable/value.</td>
</tr>
<tr>
<td>UInt32</td>
<td>32</td>
<td>To represent 16-bit unsigned variable/value.</td>
</tr>
<tr>
<td>Frac16</td>
<td>16</td>
<td>To represent 16-bit signed variable/value.</td>
</tr>
<tr>
<td>Frac32</td>
<td>32</td>
<td>To represent 32-bit signed variable/value.</td>
</tr>
<tr>
<td>NULL</td>
<td>constant</td>
<td>Represents NULL pointer.</td>
</tr>
<tr>
<td>bool</td>
<td>16</td>
<td>Boolean variable.</td>
</tr>
<tr>
<td>false</td>
<td>constant</td>
<td>Represents false value.</td>
</tr>
<tr>
<td>true</td>
<td>constant</td>
<td>Represents true value.</td>
</tr>
<tr>
<td>FRAC16()</td>
<td>macro</td>
<td>Transforms float value from $&lt;-1, 1)$ range into fractional representation $&lt;-32768, 32767&gt;$.</td>
</tr>
<tr>
<td>FRAC32()</td>
<td>macro</td>
<td>Transforms float value from $&lt;-1, 1)$ range into fractional representation $&lt;-2147483648, 2147483648&gt;$.</td>
</tr>
</tbody>
</table>
2.8 Special Issues

All functions in the General Functions Library are implemented without storing any of the volatile registers (refer to the compiler manual) used by the respective routine. Only non-volatile registers (C10, D10, R5) are saved by pushing the registers on the stack. Therefore, if the particular registers initialized before the library function call are to be used after the function call, it is necessary to save them manually.
### 3.1 API Summary

#### Table 3-1. API Functions Summary

<table>
<thead>
<tr>
<th>Name</th>
<th>Arguments</th>
<th>Output</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_SinTlr</td>
<td>Frac16 f16In</td>
<td>Frac16</td>
<td>The function calculates the sine value of the argument using 9th order Taylor polynomial approximation.</td>
</tr>
<tr>
<td>GFLIB_Sin12Tlr</td>
<td>Frac16 f16In</td>
<td>Frac16</td>
<td>The function calculates the sine value of the argument using 9th order Taylor polynomial approximation. This function is quicker with lower precision in comparison to GFLIB_SinTlr.</td>
</tr>
<tr>
<td>GFLIB_SinLut</td>
<td>Frac16 f16Arg</td>
<td>Frac16</td>
<td>The function calculates the sine value of the argument using lookup table.</td>
</tr>
<tr>
<td>GFLIB_CosTlr</td>
<td>Frac16 f16In</td>
<td>Frac16</td>
<td>The function calculates the cosine value of the argument using 9th order Taylor polynomial approximation.</td>
</tr>
<tr>
<td>GFLIB_Cos12Tlr</td>
<td>Frac16 f16In</td>
<td>Frac16</td>
<td>The function calculates the cosine value of the argument using 9th order Taylor polynomial approximation. This function is quicker with lower precision in comparison to GFLIB_Cos12Tlr.</td>
</tr>
<tr>
<td>GFLIB_CosLut</td>
<td>Frac16 f16Arg</td>
<td>Frac16</td>
<td>The function calculates the cosine value of the argument using lookup table.</td>
</tr>
<tr>
<td>GFLIB_Tan</td>
<td>Frac16 f16Arg</td>
<td>Frac16</td>
<td>The function calculates the tangent value of the argument using piece-wise polynomial approximation.</td>
</tr>
<tr>
<td>GFLIB_Asin</td>
<td>Frac16 f16Arg</td>
<td>Frac16</td>
<td>The function calculates the arcus sine value of the argument using piece-wise polynomial approximation.</td>
</tr>
<tr>
<td>GFLIB_Acos</td>
<td>Frac16 f16Arg</td>
<td>Frac16</td>
<td>The function calculates the arcus cosine value of the argument using piece-wise polynomial approximation.</td>
</tr>
<tr>
<td>GFLIB_Atan</td>
<td>Frac16 f16Arg</td>
<td>Frac16</td>
<td>The function calculates the arcus tangent value of the argument using piece-wise polynomial approximation.</td>
</tr>
<tr>
<td>GFLIB_AtanYX</td>
<td>Frac16 f16ValY Frac16 f16ValX Int16 *pi16ErrFlag</td>
<td>Frac16</td>
<td>The function calculates the arcus tangent value based on the provided x, y co-ordinates as arguments using division and piece-wise polynomial approximation.</td>
</tr>
</tbody>
</table>
### Table 3-1. API Functions Summary

<table>
<thead>
<tr>
<th>Function</th>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_AtanYXShifted</td>
<td>Frac16 f16ValY Frac16 f16ValX GFLIB_ATANYXSHIFTED_T *pudtAtanYXCoeff</td>
<td>The function computes angle of two sine waves shifted in phase one to each other.</td>
</tr>
<tr>
<td>GFLIB_SqrtPoly</td>
<td>Frac32 f32Arg</td>
<td>The function calculates the square root value of the argument using piece-wise polynomial approximation with post-adjustment method.</td>
</tr>
<tr>
<td>GFLIB_SqrtIter</td>
<td>Frac32 f32Arg</td>
<td>The function calculates the square root value using four iterations. This function is quicker with lower precision in comparison to GFLIB_SqrtPoly.</td>
</tr>
<tr>
<td>GFLIB_Lut</td>
<td>Frac16 f16Arg Frac16 *p16Table UWord16 uw16TableSize</td>
<td>The function approximates a one-dimensional arbitrary user function using the interpolation lookup method. The user function is stored in the table of size specified in uw16TableSize and pointed to by *pTable pointer.</td>
</tr>
<tr>
<td>GFLIB_Ramp16</td>
<td>Frac16 f16Desired Frac16 f16Actual GFLIB_RAMP16_T *pudtParam</td>
<td>The function calculates 16-bit version of up/down ramp with step increment/decrement defined in pudtParam structure.</td>
</tr>
<tr>
<td>GFLIB_Ramp32</td>
<td>Frac32 f32Desired Frac32 f32Actual GFLIB_RAMP32_T *pudtParam</td>
<td>The function calculates 32-bit version of up/down ramp with step increment/decrement defined in pudtParam structure.</td>
</tr>
<tr>
<td>GFLIB_DynRamp16</td>
<td>Frac16 f16Desired Frac16 f16Instant UWord16 uw16SatFlag GFLIB_DYNRAMP16_T *pudtParam</td>
<td>The function calculates a 16-bit version of the ramp with a different set of up/down parameters depending on the state of uw16SatFlag. If uw16SatFlag is set, the ramp counts up/down towards the f16Instant value.</td>
</tr>
<tr>
<td>GFLIB_DynRamp32</td>
<td>Frac32 f32Desired Frac32 f32Instant UWord16 uw16SatFlag GFLIB_DYNRAMP32_T *pudtParam</td>
<td>The function calculates a 32-bit version of the ramp with a different set of the up/down parameters depending on the state of uw16SatFlag. If uw16SatFlag is set, the ramp counts up/down towards the f32Instant value.</td>
</tr>
<tr>
<td>GFLIB_Limit16</td>
<td>Frac16 f16Arg GFLIB_LIMIT16_T *pudtLimit</td>
<td>The function calculates 16-bit scalar upper/lower limitation of the input signal.</td>
</tr>
<tr>
<td>GFLIB_Limit32</td>
<td>Frac32 f32Arg GFLIB_LIMIT32_T *pudtLimit</td>
<td>The function calculates 32-bit scalar upper/lower limitation of the input signal.</td>
</tr>
<tr>
<td>GFLIB_LowerLimit16</td>
<td>Frac16 f16Arg Frac16 f16LowerLimit</td>
<td>The function calculates 16-bit scalar lower limitation of the input signal.</td>
</tr>
</tbody>
</table>
### Table 3-1. API Functions Summary

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Input/Parameters</th>
<th>Output/Return</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_LowerLimit32</td>
<td>Frac32 f32Arg Frac32 f32LowerLimit</td>
<td>Frac32</td>
<td>The function calculates 32-bit scalar lower limitation of the input signal.</td>
</tr>
<tr>
<td>GFLIB_UpperLimit16</td>
<td>Frac16 f16Arg Frac16 f16UpperLimit</td>
<td>Frac16</td>
<td>The function calculates 16-bit scalar upper limitation of the input signal.</td>
</tr>
<tr>
<td>GFLIB_UpperLimit32</td>
<td>Frac32 f32Arg Frac32 f32UpperLimit</td>
<td>Frac32</td>
<td>The function calculates 32-bit scalar upper limitation of the input signal.</td>
</tr>
<tr>
<td>GFLIB_Sgn</td>
<td>Frac16 f16Arg</td>
<td>Frac16</td>
<td>The function calculates signum of the input argument. The function returns: $7FFF if X &gt; 0 $0 if X = 0 $8000 if X &lt; 0.</td>
</tr>
<tr>
<td>GFLIB_Sgn2</td>
<td>Frac16 f16Arg</td>
<td>Frac16</td>
<td>The function calculates signum of the input argument with zero being considered as positive value. The function returns: $7FFF if X &gt;= 0 $8000 if X &lt; 0.</td>
</tr>
<tr>
<td>GFLIB_Hyst</td>
<td>GFLIB_HYST_T *pudtHystVar</td>
<td>Frac16</td>
<td>The function switches output between two predefined values when the input crosses the threshold values.</td>
</tr>
<tr>
<td>GFLIB_ControllerPkp</td>
<td>Frac16 f16InputErrorK GFLIB_CONTROLLER_PI_P_PARAMS_T *pudtPParams Int16 *pi16SatFlag</td>
<td>Frac16</td>
<td>The function calculates the parallel form of Proportional-Integral (PI) regulator.</td>
</tr>
<tr>
<td>GFLIB_ControllerPkr</td>
<td>Frac16 f16Error GFLIB_CONTROLLER_PI_RECURRENT_ASM_T *pudtCtrl</td>
<td>Frac16</td>
<td>The function calculates the recurrent form of Proportional-Integral (PI) regulator.</td>
</tr>
<tr>
<td>GFLIB_ControllerPkrLim</td>
<td>Frac16 f16Error GFLIB_CONTROLLER_PI_RECURRENT_LIM_T *pudtCtrl</td>
<td>Frac16</td>
<td>The function calculates the recurrent form of Proportional-Integral (PI) regulator with limitation.</td>
</tr>
<tr>
<td>GFLIB_ControllerPdp</td>
<td>Frac16 f16InputErrorK Frac16 f16InputDErrorK GFLIB_CONTROLLER_PID_P_PARAMS_T *pudtPidParams Int16 *pi16SatFlag Frac16 *pf16InputDErrorK_1</td>
<td>Frac16</td>
<td>The function calculates the parallel form of Proportional-Integral-Derivative (PID) regulator.</td>
</tr>
<tr>
<td>GFLIB_ControllerPdr</td>
<td>Frac16 f16Error GFLIB_CONTROLLER_PID_RECURRENT_ASM_T *pudtCtrl</td>
<td>Frac16</td>
<td>The function calculates the recurrent form of Proportional-Integral-Derivative (PID) regulator.</td>
</tr>
</tbody>
</table>
3.2 GFLIB_SinTlr

The function calculates the sine value of the argument using the ninth order Taylor polynomial approximation.

3.2.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_SinTlr(Frac16 f16In)
```

3.2.2 Prototype

```c
asm Frac16 GFLIB_SinTlrFAsm(Frac16 f16In, const GFLIB_SIN_TAYLOR_COEF_T *pudtSinData)
```

3.2.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16In</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtSinData</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Optional argument; pointer to Taylor polynomial coefficients table.</td>
</tr>
</tbody>
</table>

3.2.4 Availability

This library module is available in the C-callable interface assembly formats.

This library module is targeted for the DSC 56F80xx platforms.

3.2.5 Dependencies

List of all dependent files:
- GFLIB_SinCosTlrAsm.h
- GFLIB_SinCosTlrDefAsm.h
- GFLIB_types.h
3.2.6 Description

The **GFLIB_SinTlr** function computes the \( \sin(\pi \times x) \) using the ninth order Taylor polynomial approximation. The ninth order polynomial approximation is sufficient for the 16-bit result.

The function \( \sin(x) \) using the ninth order Taylor polynomial is expressed as follows:

\[
\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \frac{x^9}{9!}
\]  
\( Eqn.\ 3-1 \)

\[
\sin(x) = x(d_1 + x^2(d_3 + x^2(d_5 + x^2(d_7 + x^2d_9))))
\]  
\( Eqn.\ 3-2 \)

where the constants:

\[
d_1 = 1 \\
d_3 = -1 / 3! \\
d_5 = 1 / 5! \\
d_7 = -1 / 7! \\
d_9 = 1 / 9!
\]

The function \( \sin(\pi \times x) \) using the ninth order Taylor polynomial:

\[
\sin(\pi \cdot x) = x(c_1 + x^2(c_3 + x^2(c_5 + x^2(c_7 + x^2c_9))))
\]  
\( Eqn.\ 3-3 \)

where:

\[
c_1 = d_1 \cdot \pi^1 = \pi \\
c_3 = d_3 \cdot \pi^3 = -\pi^3 / 3! \\
c_5 = d_5 \cdot \pi^5 = \pi^5 / 5! \\
c_7 = d_7 \cdot \pi^7 = -\pi^7 / 7! \\
c_9 = d_9 \cdot \pi^9 = \pi^9 / 9!
\]

The ninth order polynomial approximation of the sine function has a very good accuracy in the range \(-\pi/2; \pi/2\) of the argument, but in wider ranges the calculation error is quickly growing up. To avoid this inaccuracy there is used the symmetry of the sine function \([\sin(alpha) = \sin(\pi - alpha)]\), by this technique the input argument is transferred to be always in the range \(-\pi/2; \pi/2\), therefore the Taylor polynomial is calculated only in the range of the argument \(-\pi/2; \pi/2\).

To make calculations more precise (because in calculations there is used value of \( x^2 \) rounded to a 16-bit fractional number), the given argument value \( x \) (transferred to be in the range \(-0.5; 0.5\) due to the sine function symmetry) is shifted by 1 bit to the left (multiplied by 2), then the value of \( x^2 \) used in the calculations is in the range \(-1; 1\) instead of \(-0.25; 0.25\). Shifting of the \( x \) value by 1 bit to the left increases the accuracy of the calculated \( \sin(\pi \times x) \) function.
Because the \( x \) value is shifted one bit to the left the polynomial coefficients 'c' need to be scaled (shifted to the right):

\[
\begin{align*}
    b_1 &= c_1 / 2^1 = \pi / 2 \\
    b_3 &= c_3 / 2^3 = -\pi^3 / 3! / 23 \\
    b_5 &= c_5 / 2^5 = \pi^5 / 5! / 25 \\
    b_7 &= c_7 / 2^7 = -\pi^7 / 7! / 27 \\
    b_9 &= c_9 / 2^9 = \pi^9 / 9! / 29
\end{align*}
\]

To avoid the saturation error during the polynomial calculation the coefficients 'b' are divided by 2. After the polynomial calculation the result is multiplied by 2 (shifted 1 bit to the left) to take the right result of the function \( \sin(\pi \cdot x) \) in the range \((-1; 1)\) of the given \( x \).

\[
\begin{align*}
    a_1 &= b_1 / 2 = \pi / 2^2 = 0.785398163 \\
    a_3 &= b_3 / 2 = -\pi^3 / 3! / 24 = -0.322982049 \\
    a_5 &= b_5 / 2 = \pi^5 / 5! / 26 = 0.039846313 \\
    a_7 &= b_7 / 2 = -\pi^7 / 7! / 28 = -0.002340877 \\
    a_9 &= b_9 / 2 = \pi^9 / 9! / 210 = 0.000080220
\end{align*}
\]

\[
\sin(\pi \cdot x) = (x \ll 1)((a_1 + (x \ll 1)^2(a_3 + (x \ll 1)^2(a_5 + (x \ll 1)^2(a_7 + (x \ll 1)a_9)))) \ll 1)
\]

Eqn. 3-4

For a better accuracy the 'a' coefficients are used as 32-bit signed fractional constants in the multiplication operations, \((x<<1)^2\) is a 16-bit fractional variable, the result of the \((x<<1)^2(a#...)\) multiplication is a 32-bit fractional number.

The polynomial coefficients in the 32-bit signed fractional representation:

\[
\begin{align*}
    a_1 &= 0x6487ED51 \\
    a_3 &= 0xD6A88634 \\
    a_5 &= 0x0519AF1A \\
    a_7 &= 0xFFB34B4D \\
    a_9 &= 0x0002A0F0
\end{align*}
\]

\[
\sin(\pi \cdot x) = (x \ll 1)(0x6487ED51 + (x \ll 1)^2(0xD6A88634 + (x \ll 1)^2(0x0519AF1A + (x \ll 1)^2(0xFFB34B4D + (x \ll 1)^2(0x0002A0F0)))))) \ll 1
\]

Eqn. 3-5
3.2.7 Returns

The function returns the result of \( \sin(\pi \cdot x) \).

3.2.8 Range Issues

The input data value is in the range of \(<-1,1)\), which corresponds to the angle in the range of \(<-\pi,\pi)\). The output data value is in the range of \(<-1,1)\). This means that the function value of the input argument 0.5, which corresponds to \(\pi/2\), is 0x7FFF and -0.5, which corresponds to \(-\pi/2\), is 0x8000.

3.2.9 Special Issues

The function \texttt{GFLIB_SinTlr} is the saturation mode independent.

3.2.10 Implementation

The \texttt{GFLIB_SinTlr} function is implemented as a function call.

\begin{verbatim}
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

/* input data value in range <-1,1) corresponds to <-pi,pi) */
#define PIBY4 0.25 /* 0.25 equals to pi / 4 */

void main(void)
{
    /* input value pi / 4 */
    mf16Input = FRAC16(PIBY4);

    /* Compute the sine value */
    mf16Output = GFLIB_SinTlr(mf16Input);
}
\end{verbatim}

3.2.11 See Also

See \texttt{GFLIB_Sin12Tlr}, \texttt{GFLIB_SinLut}, \texttt{GFLIB_CosTlr}, \texttt{GFLIB_Cos12Tlr}, \texttt{GFLIB_CosLut} and \texttt{GFLIB_Tan} for more information.
### 3.2.12 Performance

<table>
<thead>
<tr>
<th>Table 3-4. Performance of GFLIB_SinTlr Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Code Size (words)</strong></td>
</tr>
<tr>
<td><strong>Data Size (words)</strong></td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
</tr>
<tr>
<td>Min</td>
</tr>
<tr>
<td>Max</td>
</tr>
</tbody>
</table>
3.3 GFLIB_Sin12Tlr

The function calculates the sine value of the argument using the ninth order Taylor polynomial approximation. This function has quicker calculation paid by reduced precision to 12 bits.

3.3.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_Sin12Tlr(Frac16 f16In)
```

3.3.2 Prototype

```assembly
asm Frac16 GFLIB_Sin12TlrFAsm(Frac16 f16In, const GFLIB_SIN12_TAYLOR_COEF_T *pudtSinData)
```

3.3.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16In</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0xFFFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtSinData</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Optional argument; pointer to Taylor polynomial coefficients table.</td>
</tr>
</tbody>
</table>

3.3.4 Availability

This library module is available in the C-callable interface assembly formats.

This library module is targeted for the DSC 56F80xx platforms.

3.3.5 Dependencies

List of all dependent files:
- GFLIB_SinCosTlrAsm.h
- GFLIB_SinCosTlrDefAsm.h
- GFLIB_types.h
3.3.6 Description

The **GFLIB_Sin12Tlr** function computes the sin(pi * x) using the ninth order Taylor polynomial approximation. The ninth order polynomial approximation is sufficient for the 16-bit result.

The function sin(x) using the ninth order Taylor polynomial is expressed as follows:

\[
\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7!} + \frac{x^9}{9!} \quad \text{Eqn. 3-6}
\]

\[
\sin(x) = x(d_1 + x^2(d_3 + x^2(d_5 + x^2(d_7 + x^2d_9)))) \quad \text{Eqn. 3-7}
\]

where the constants:

- \(d_1 = 1\)
- \(d_3 = -1 / 3!\)
- \(d_5 = 1 / 5!\)
- \(d_7 = -1 / 7!\)
- \(d_9 = 1 / 9!\)

The function sin(pi * x) using the ninth order Taylor polynomial:

\[
\sin(\pi \cdot x) = x(c_1 + x^2(c_3 + x^2(c_5 + x^2(c_7 + x^2c_9)))) \quad \text{Eqn. 3-8}
\]

where:

- \(c_1 = d_1 \cdot \pi^1 = \pi\)
- \(c_3 = d_3 \cdot \pi^3 = -\pi^3 / 3!\)
- \(c_5 = d_5 \cdot \pi^5 = \pi^5 / 5!\)
- \(c_7 = d_7 \cdot \pi^7 = -\pi^7 / 7!\)
- \(c_9 = d_9 \cdot \pi^9 = \pi^9 / 9!\)

The ninth order polynomial approximation of the sine function has a very high accuracy in the range <-pi/2; pi/2> of the argument, but in wider ranges the calculation error is quickly growing up. To avoid this inaccuracy there is used the symmetry of the sine function [\(\sin(\alpha) = \sin(\pi - \alpha)\)], by this technique the input argument is transferred to be always in the range <-pi/2; pi/2>, therefore the Taylor polynomial is calculated only in the range of the argument <-pi/2; pi/2>.

To make calculations more precise (because in calculations there is used value of \(x^2\) rounded to a 16-bit fractional number), the given argument value x (transferred to be in the range <-0.5; 0.5) due to the sine function symmetry) is shifted by 1 bit to the left (multiplied by 2), then the value of \(x^2\) used in the calculations is in the range <-1; 1) instead of <-0.25; 0.25). Shifting of the x value by 1 bit to the left increases the accuracy of the calculated sin(pi * x) function.
Because the x value is shifted one bit to the left the polynomial coefficients 'c' need to be scaled (shifted to the right):
\[
b_1 = c_1 / 21 = \pi / 2 \\
b_3 = c_3 / 23 = -\pi^3 / 3! / 23 \\
b_5 = c_5 / 25 = \pi^5 / 5! / 25 \\
b_7 = c_7 / 27 = -\pi^7 / 7! / 27 \\
b_9 = c_9 / 29 = \pi^9 / 9! / 29
\]
To avoid the saturation error during the polynomial calculation the coefficients 'b' are divided by 2. After the polynomial calculation the result is multiplied by 2 (shifted 1 bit to the left) to take the right result of the function \( \sin(\pi \times x) \) in the range <-1; 1) of the given x.
\[
a_1 = b_1 / 2 = \pi / 22 = 0.785398163 \\
a_3 = b_3 / 2 = -\pi^3 / 3! / 24 = -0.322982049 \\
a_5 = b_5 / 2 = \pi^5 / 5! / 26 = 0.039846313 \\
a_7 = b_7 / 2 = -\pi^7 / 7! / 28 = -0.002340877 \\
a_9 = b_9 / 2 = \pi^9 / 9! / 210 = 0.000080220
\]
\[
\sin(\pi \cdot x) = (x \ll 1)((a_1 + (x \ll 1)^2(a_3 + (x \ll 1)^2(a_5 + (x \ll 1)^2(a_7 + (x \ll 1)a_9)))) \ll 1)
\]

Eqn. 3-9

For a better accuracy the 'a' coefficients are used as 16-bit signed fractional constants in the multiplication operations, \((x\ll 1)^2\) is a 16-bit fractional variable, the result of the \( (x\ll 1)^2(a\ldots) \) multiplication is a 32-bit fractional number.

The polynomial coefficients in the 16-bit signed fractional representation:
\[
a_1 = 0x6488 \\
a_3 = 0xD6A9 \\
a_5 = 0x051A \\
a_7 = 0xFFB3 \\
a_9 = 0x0003
\]
\[
\sin(\pi \cdot x) = (x \ll 1)(0x6488 + \\
(x \ll 1)^2(0xD6A9 + \\
(x \ll 1)^2(0x051A + \\
(x \ll 1)^2(0xFFB3 + \\
(x \ll 1)^2(0x0003)))))) \ll 1
\]

Eqn. 3-10
3.3.7 Returns

The function returns the result of $\sin(\pi \cdot x)$.

3.3.8 Range Issues

The input data value is in the range of <-1,1), which corresponds to the angle in the range of <-pi,pi). The output data value is in the range of <-1,1). This means that the function value of the input argument 0.5, which corresponds to pi/2, is 0x7FFF and -0.5, which corresponds to -pi/2, is 0x8000.

3.3.9 Special Issues

The function GFLIB_Sin12Tlr is the saturation mode independent.

3.3.10 Implementation

The GFLIB_Sin12Tlr function is implemented as a function call.

```
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

/* input data value in range <-1,1) corresponds to <-pi,pi) */
#define PIBY4 0.25 /* 0.25 equals to pi / 4 */

void main(void)
{
    /* input value pi / 4 */
    mf16Input = FRAC16(PIBY4);

    /* Compute the sine value */
    mf16Output = GFLIB_Sin12Tlr(mf16Input);
}
```

3.3.11 See Also

See GFLIB_SinTlr, GFLIB_SinLut, GFLIB_CosTlr, GFLIB_Cos12Tlr, GFLIB_CosLut and GFLIB_Tan for more information.
### 3.3.12 Performance

Table 3-7. Performance of **GFLIB_Sin12Tlr** Function

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Code Size (words)</td>
<td>25</td>
</tr>
<tr>
<td>Data Size (words)</td>
<td>5</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>38 cycles</td>
</tr>
<tr>
<td></td>
<td>38 cycles</td>
</tr>
</tbody>
</table>
3.4 GFLIB_SinLut

The function calculates the sine value of the argument using lookup table.

3.4.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_SinLut(Frac16 f16Arg)
```

3.4.2 Prototype

```asm
asm Frac16 GFLIB_SinLutFAsm(Frac16 f16Arg, Frac16 *pudtSinTable, UWord16 uw16TableSize)
```

3.4.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtSinTable</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to the 1q sine values table</td>
</tr>
<tr>
<td>uw16TableSize</td>
<td>In</td>
<td>UI16</td>
<td>0x0...0xFFFF</td>
<td>The sine table size in bit shifts of number 1.</td>
</tr>
</tbody>
</table>

3.4.4 Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platforms.

3.4.5 Dependencies

List of all dependent files:
- GFLIB_SinLutAsm.h
- GFLIB_SinCosDefAsm.h
- GFLIB_types.h

3.4.6 Description

The GFLIB_SinLut uses a table of precalculated function points. These points are selected with a fixed step and must be in a number of $2^n$, where $n$ can be 1 through to 15. The table contains $2^n + 1$ points.
The function finds two nearest precalculated points of the input argument and using the linear interpolation between these two points calculates the output value.

The \( \sin \) function is a symmetrical along the defined interval, therefore the table contains precalculated values for the range \(-\pi/2\) to 0. For the values outside this interval, the function transforms the input value to the \(-\pi/2\) to 0 interval and calculates as if it was in this interval. In the end if the input was in the interval of 0 to \( \pi \) the output is negated.

Figure 0-1 shows the function that has 9 table points, i.e. \( 2^3 + 1 \), therefore the table size is 3.

![Figure 3-1. Algorithm Diagram](image)

The \texttt{GFLIB_SinLut} function by default uses a \( \sin \) table of 257 points.

3.4.7 Returns

The function returns the result of \( \sin(\pi \cdot x) \).

3.4.8 Range Issues

The input data value is in the range of \((-1,1)\), which corresponds to the angle in the range of \((-\pi,\pi)\). The output data value is in the range of \((-1,1)\). This means that with the input value 0, it has the output result of 0. Similarly if the input value is 0.5, the output is 1.

3.4.9 Special Issues

The function \texttt{GFLIB_SinLut} requires the saturation mode to be set.
3.4.10 Implementation

The **GFLIB_SinLut** function is implemented as a function call.

**Example 3-3. Implementation Code**

```c
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

/* input data value in range <-1,1) corresponds to <-pi,pi) */
#define PIBY4 0.25 /* 0.25 equals to pi / 4 */

void main(void)
{
    /* input value pi / 4 */
    mf16Input = FRAC16(PIBY4);

    /* turns on the saturation */
    __turn_on_sat();

    /* Compute the sine value */
    mf16Output = GFLIB_SinLut(mf16Input);

    /* turns off the saturation */
    __turn_off_sat();
}
```

3.4.11 See Also

See **GFLIB_SinTlr**, **GFLIB_Sin12Tlr**, **GFLIB_CosLut**, **GFLIB_CosTlr**, **GFLIB_Cos12Tlr** and **GFLIB_Tan** for more information.

3.4.12 Performance

**Table 3-9. Performance of GFLIB_SinLut function**

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>43</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>258</td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
<td><strong>Min</strong></td>
</tr>
<tr>
<td></td>
<td>61/62 cycles</td>
</tr>
</tbody>
</table>
3.5 **GFLIB_CosTlr**

The function calculates the cosine value of the argument using the 9th order Taylor polynomial approximation. The function is implemented as inline reusing the **GFLIB_SinTlr** function.

### 3.5.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_CosTlr(Frac16 f16In)
```

### 3.5.2 Prototype

```c
inline Frac16 GFLIB_CosTlrFAsmi(Frac16 f16In, const GFLIB_SIN_TAYLOR_COEF_T *pudtSinData)
```

### 3.5.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16In</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtSinData</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to Taylor polynomial coefficients</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_SIN_TAYLOR_COEF_T</td>
<td>f32A[5]</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFF</td>
<td>Array of 32bit taylor polynom coefficients.</td>
</tr>
</tbody>
</table>

### 3.5.4 Availability

This library module is available in the C-callable interface assembly formats.

This library module is targeted for the DSC 56F80xx platform.

### 3.5.5 Dependencies

List of all dependent files:

- GFLIB_SinCosTlrAsm.h
- GFLIB_SinCosTlrDefAsm.h
- GFLIB_types.h
3.5.6 Description

The \texttt{GFLIB\_CosTlr} function computes \(\cos(\pi \times x)\) using 9th order Taylor polynomial approximation of the sine function where its equation is:

\[
\cos(\text{angle}) = \sin \left( \frac{\pi}{2} - \text{ABS(\text{angle})} \right)
\]

\textit{Eqn. 3-11}

Then the cosine function is calculated using the sine function. The 9th order polynomial approximation is sufficient for the 16-bit result.

The function \(\sin(x)\) using the 9th order Taylor polynomial:

\[
\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \frac{x^9}{9!}
\]

\textit{Eqn. 3-12}

\[
\sin(x) = x(d_1 + x^2(d_3 + x^2(d_5 + x^2(d_7 + x^2d_9))))
\]

\textit{Eqn. 3-13}

where constants:

\[
\begin{align*}
    d_1 &= 1 \\
    d_3 &= -1 / 3! \\
    d_5 &= 1 / 5! \\
    d_7 &= -1 / 7! \\
    d_9 &= 1 / 9!
\end{align*}
\]

The function \(\sin(\pi \times x)\) using the 9th order Taylor polynomial:

\[
\sin(\pi \times x) = x(c_1 + x^2(c_3 + x^2(c_5 + x^2(c_7 + x^2c_9))))
\]

\textit{Eqn. 3-14}

where the constants:

\[
\begin{align*}
    c_1 &= d_1 \times \pi^1 = \pi \\
    c_3 &= d_3 \times \pi^3 = -\pi^3 / 3! \\
    c_5 &= d_5 \times \pi^5 = \pi^5 / 5! \\
    c_7 &= d_7 \times \pi^7 = -\pi^7 / 7! \\
    c_9 &= d_9 \times \pi^9 = \pi^9 / 9!
\end{align*}
\]

The 9th order polynomial approximation of the sine function has a very good accuracy in the range \(<-\pi/2; \pi/2>\) of the argument, but in wider ranges the calculation error is quickly growing up. To avoid this inaccuracy there is used the symmetry of the sine function \([\sin(\text{alpha}) = \sin(\pi - \text{alpha})]\), by this technique the input argument is transferred to be always in the range \(<-\pi/2; \pi/2>\), therefore the Taylor polynomial is calculated only in the range of argument \(<-\pi/2; \pi/2>\).

To make the calculations more precise (because in calculations there is used the value of \(x^2\) rounded to a 16-bit fractional number), the given argument value \(x\) (transferred to be in the range \(<-0.5; 0.5>\) due to sine function symmetry) is
shifted by 1 bit to the left (multiplied by 2), then the value of \( x^2 \) used in the calculations is in the range \(-1; 1\) instead of \(-0.25; 0.25\). Shifting of the \( x \) value by 1 bit to the left increases the accuracy of the calculated \( \sin(\pi \times x) \) function.

Because the \( x \) value is shifted one bit to the left the polynomial coefficients 'c' needs to be scaled (shifted to the right):

\[
\begin{align*}
b_1 &= c_1 / 2^1 = \pi / 2 \\
b_3 &= c_3 / 2^3 = -\pi^3 / 3! / 23 \\
b_5 &= c_5 / 2^5 = \pi^5 / 5! / 25 \\
b_7 &= c_7 / 2^7 = -\pi^7 / 7! / 27 \\
b_9 &= c_9 / 2^9 = \pi^9 / 9! / 29
\end{align*}
\]

To avoid the saturation error during the polynomial calculation the coefficients 'b' are divided by 2. After the polynomial calculation the result is multiplied by 2 (shifted 1 bit to the left) to get the correct result of the function \( \sin(\pi \times x) \) in the range \(-1; 1\) of the given \( x \).

\[
\begin{align*}
a_1 &= b_1 / 2 = \pi / 2^2 = 0.785398163 \\
a_3 &= b_3 / 2 = -\pi^3 / 3! / 2^4 = -0.322982049 \\
a_5 &= b_5 / 2 = \pi^5 / 5! / 2^6 = 0.039846313 \\
a_7 &= b_7 / 2 = -\pi^7 / 7! / 2^8 = -0.002340877 \\
a_9 &= b_9 / 2 = \pi^9 / 9! / 2^{10} = 0.000080220
\end{align*}
\]

\[
\sin(\pi \times x) = (x \ll 1)((a_1 + (x \ll 1)^2(a_3 + (x \ll 1)^2(a_5 + (x \ll 1)^2(a_7 + (x \ll 1)a_9)))) \tag{Eqn. 3-15}
\]

For a better accuracy the 'a' coefficients are used as 32-bit signed fractional constants in the multiplication operations, \((x\ll1)^2\) is a 16-bit fractional variable, the result of the \'(x\ll1)^2(a\#...)' multiplication operation is a 32-bit fractional number.

The polynomial coefficients in the 32-bit signed fractional representation:

\[
\begin{align*}
a_1 &= 0x6487ED51 \\
a_3 &= 0xD6A88634 \\
a_5 &= 0x0519AF1A \\
a_7 &= 0xFFB34B4D \\
a_9 &= 0x0002A0F0
\end{align*}
\]
\[
\sin(\pi \cdot x) = (x \ll 1)(0x6487ED51 + \\
(x \ll 1)^2(0xD6A88634 + \\
(x \ll 1)^2(0x0519AF1A + \\
(x \ll 1)^2(0xFFB34B4D + \\
(x \ll 1)^2(0x0002A0F0))) < 1
\]

3.5.7 Returns

The function returns the result of \( \cos(\pi \cdot x) \).

3.5.8 Range Issues

The input data value is in the range of <-1,1), which corresponds to the angle in the range of <-pi,pi). The output data value is in the range of <-1,1). It means that the function value of the input argument 0.5, which corresponds to \( \pi/2 \), is 0x7FFF and -0.5, which corresponds to \(-\pi/2\), is 0x8000.

3.5.9 Special Issues

The function \texttt{GFLIB_CosTlr} is the saturation mode independent.

3.5.10 Implementation

The \texttt{GFLIB_CosTlr} function is implemented as a function call.

\begin{verbatim}
#include "gflib.h"

static Fract16 ml16Input;
static Fract16 ml16Output;

/* input data value in range <1,1) corresponds to <pi,pi) */
#define PIBY4 0.25 /* 0.25 equals to pi / 4 */

void main(void)
{ 
  /* input value pi / 4 */
  ml16Input = FRAC16(PIBY4);

  /* Compute the cosine value */
  ml16Output = GFLIB_CosTlr(ml16Input);
}
\end{verbatim}

3.5.11 See Also

See \texttt{GFLIB_Cos12Tlr}, \texttt{GFLIB_CosLut}, \texttt{GFLIB_SinTlr}, \texttt{GFLIB_Sin12Tlr}, \texttt{GFLIB_SinLut} and \texttt{GFLIB_Tan} for more information.
3.5.12 Performance

Table 3-12. Performance of GFLIB_CosTlr function

<table>
<thead>
<tr>
<th></th>
<th>Code Size (words)</th>
<th>Data Size (words)</th>
<th>Execution Clock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22 + 38 (GFLIB_SinTlr)</td>
<td>0 + 10 (GFLIB_SinTlr)</td>
<td>Min 56 cycles</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max 56 cycles</td>
</tr>
</tbody>
</table>
3.6  **GFLIB_Cos12Tlr**

The function calculates the cosine value of the argument using the 9th order Taylor polynomial approximation. The function is implemented as inline reusing the **GFLIB_Sin12Tlr** function. This function has quicker calculation paid by reduced precision to 12 bits.

3.6.1  **Synopsis**

```c
#include "glib.h"
Frac16 GFLIB_Cos12Tlr(Frac16 f16In)
```

3.6.2  **Prototype**

```c
eextern inline Frac16 GFLIB_Cos12TlrFAsmi(Frac16 f16In, const GFLIB_SIN_TAYLOR_COEF_T *pudtSinData)
```

3.6.3  **Arguments**

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16In</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtSinData</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to Taylor polynomial coefficients</td>
</tr>
</tbody>
</table>

3.6.4  **Availability**

This library module is available in the C-callable interface assembly formats.

This library module is targeted for the DSC 56F80xx platform.

3.6.5  **Dependencies**

List of all dependent files:

- GFLIB_SinCosTlrAsm.h
- GFLIB_SinCosTlrDefAsm.h
- GFLIB_types.h
3.6.6 Description

The **GFLIB_Cos12Tlr** function computes $\cos(\pi \times x)$ using 9th order Taylor polynomial approximation of the sine function where its equation is:

$$
\cos(\alpha) = \sin\left[\frac{\pi}{2} + |\alpha|\right] 
$$

*Eqn. 3-17*

Then the cosine function is calculated using the sine function. The 9th order polynomial approximation is sufficient for the 16-bit result.

The function $\sin(x)$ using the 9th order Taylor polynomial:

$$
\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7!} + \frac{x^9}{9!}
$$

*Eqn. 3-18*

$$
\sin(x) = x(d_1 + x^2(d_3 + x^2(d_5 + x^2(d_7 + x^2d_9))))
$$

*Eqn. 3-19*

where constants:

- $d_1 = 1$
- $d_3 = -1 / 3!$
- $d_5 = 1 / 5!$
- $d_7 = -1 / 7!$
- $d_9 = 1 / 9!$

The function $\sin(\pi \times x)$ using the 9th order Taylor polynomial:

$$
\sin(\pi \cdot x) = x(c_1 + x^2(c_3 + x^2(c_5 + x^2(c_7 + x^2c_9))))
$$

*Eqn. 3-20*

where the constants:

- $c_1 = d_1 \times \pi^1 = \pi$
- $c_3 = d_3 \times \pi^3 = -\pi^3 / 3!$
- $c_5 = d_5 \times \pi^5 = \pi^5 / 5!$
- $c_7 = d_7 \times \pi^7 = -\pi^7 / 7!$
- $c_9 = d_9 \times \pi^9 = \pi^9 / 9!$

The 9th order polynomial approximation of the sine function has a very good accuracy in the range $<-\pi/2; \pi/2>$ of the argument, but in wider ranges the calculation error is quickly growing up. To avoid this inaccuracy there is used the symmetry of the sine function $\sin(alpha) = \sin(pi - alpha)$, by this technique the input argument is transferred to be always in the range $<-\pi/2; \pi/2>$, therefore the Taylor polynomial is calculated only in the range of argument $<-\pi/2; \pi/2>$.

To make the calculations more precise (because in calculations there is used the value of $x^2$ rounded to a 16-bit fractional number), the given argument value $x$ (transferred to be in the range $<-0.5; 0.5>$ due to sine function symmetry) is
shifted by 1 bit to the left (multiplied by 2), then the value of \(x^2\) used in the calculations is in the range \(-1; 1\) instead of \(-0.25; 0.25\). Shifting of the \(x\) value by 1 bit to the left increases the accuracy of the calculated \(\sin(\pi \times x)\) function.

Because the \(x\) value is shifted one bit to the left the polynomial coefficients 'c' needs to be scaled (shifted to the right):

\[
b_1 = c_1 / 2^1 = \pi / 2
\]
\[
b_3 = c_3 / 2^3 = -\pi^3 / 3! / 23
\]
\[
b_5 = c_5 / 2^5 = \pi^5 / 5! / 25
\]
\[
b_7 = c_7 / 2^7 = -\pi^7 / 7! / 27
\]
\[
b_9 = c_9 / 2^9 = \pi^9 / 9! / 29
\]

To avoid the saturation error during the polynomial calculation the coefficients 'b' are divided by 2. After the polynomial calculation the result is multiplied by 2 (shifted 1 bit to the left) to get the correct result of the function \(\sin(\pi \times x)\) in the range \(-1; 1\) of the given \(x\).

\[
a_1 = b_1 / 2 = \pi / 2^2 = 0.785398163
\]
\[
a_3 = b_3 / 2 = -\pi^3 / 3! / 24 = -0.322982049
\]
\[
a_5 = b_5 / 2 = \pi^5 / 5! / 26 = 0.039846313
\]
\[
a_7 = b_7 / 2 = -\pi^7 / 7! / 28 = -0.002340877
\]
\[
a_9 = b_9 / 2 = \pi^9 / 9! / 210 = 0.000080220
\]

\[
\sin(\pi \times x) = (x << 1)((a_1 + (x << 1)^2)(a_3 + (x << 1)^2)(a_5 + (x << 1)^2)(a_7 + (x << 1)a_9))) \quad \text{Eqn. 3-21}
\]

For a better accuracy the 'a' coefficients are used as 32-bit signed fractional constants in the multiplication operations, \((x<<1)^2\) is a 16-bit fractional variable, the result of the \((x<<1)^2(a\#...)\) multiplication operation is a 32-bit fractional number.

The polynomial coefficients in the 32-bit signed fractional representation:

\[
a_1 = 0x6488
\]
\[
a_3 = 0xD6A9
\]
\[
a_5 = 0x051A
\]
\[
a_7 = 0xFFB3
\]
\[
a_9 = 0x0003
\]
\[
\sin(\pi \cdot x) = (x \cdot 1) \times (0x6488 + (x \cdot 1)^2 \times (0xD6A9 + (x \cdot 1)^2 \times (0x051A + (x \cdot 1)^2 \times (0xFFB3 + (x \cdot 1)^2 \times (0x0033)))))) \times 1
\]

Eqn. 3-22

3.6.7 Returns

The function returns the result of \( \cos(\pi \cdot x) \).

3.6.8 Range Issues

The input data value is in the range of \((-1,1)\), which corresponds to the angle in the range of \((-\pi,\pi)\). The output data value is in the range of \((-1,1)\). It means that the function value of the input argument 0.5, which corresponds to \(\pi/2\), is 0x7FFF and -0.5, which corresponds to \(-\pi/2\), is 0x8000.

3.6.9 Special Issues

The function \texttt{GFLIB\_Cos12Tlr} is the saturation mode independent.

3.6.10 Implementation

The \texttt{GFLIB\_Cos12Tlr} function is implemented as a function call.

Example 3-5. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

/* input data value in range <-1,1) corresponds to <-pi,pi) */
#define PIBY4 0.25 /* 0.25 equals to pi / 4 */

void main(void)
{
    /* input value pi / 4 */
    mf16Input = FRAC16(PIBY4);
    /* Compute the cosine value */
    mf16Output = GFLIB\_Cos12Tlr(mf16Input);
}
```

3.6.11 See Also

See \texttt{GFLIB\_CosTlr}, \texttt{GFLIB\_CosLut}, \texttt{GFLIB\_SinTlr}, \texttt{GFLIB\_Sin12Tlr}, \texttt{GFLIB\_SinLut} and \texttt{GFLIB\_Tan} for more information.
3.6.12 Performance

Table 3-15. Performance of GFLIB_Cos12Tlr function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>11 + 25 (GFLIB_Sin12Tlr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0 + 5 (GFLIB_Sin12Tlr)</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>42/43 cycles</td>
</tr>
<tr>
<td>Max</td>
<td>42/43 cycles</td>
</tr>
</tbody>
</table>
3.7 GFLIB_CosLut

The function calculates the cosine value of the argument using lookup table.

3.7.1 Synopsis

```
#include "gflib.h"
Frac16 GFLIB_CosLut(Frac16 f16Arg)
```

3.7.2 Prototype

```
asm Frac16 GFLIB_CosLutFAsm(Frac16 f16Arg, Frac16 *pudtSinTable, UWord16 uw16TableSize)
```

3.7.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtSinTable</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to the 1q sin values table</td>
</tr>
<tr>
<td>uw16TableSize</td>
<td>In</td>
<td>UI16</td>
<td>0x0...0xFFFF</td>
<td>The sine table size in bit shifts of number 1.</td>
</tr>
</tbody>
</table>

3.7.4 Availability

This library module is available in the C-callable interface assembly formats.
This library module is targeted for the DSC 56F80xx platform.

3.7.5 Dependencies

List of all dependent files:
- GFLIB_CosLutAsm.h
- GFLIB_SinCosDefAsm.h
- GFLIB_types.h

3.7.6 Description

The GFLIB_CosLut function uses a table of precalculated function points. These points are selected with a fixed step and must be in a number of $2^n$, where $n$ can be 1 through to 15. The table contains $2^n + 1$ points.
The function finds two nearest precalculated points of the input argument and using the linear interpolation between these two points calculates the output value.

The cos function is a symmetrical along the defined interval, therefore the table contains precalculated values for the range -\pi to -\pi/2. This interval is used to share the sine function table to save memory space. For the values outside this interval, the function transforms the input value to the -\pi to -\pi/2 interval and calculates as if it was in this interval. In the end if the input was in the interval of -\pi/2 to \pi/2 the output is negated.

Figure 3-2 shows the function that has 9 table points, i.e. \(2^3 + 1\), therefore the table size is 3.

![Figure 3-2. Algorithm diagram](image)

The function GFLIB_CosLut by default uses a sin table of 257 points.

### 3.7.7 Returns

The function returns the result of \(\cos(\pi \cdot f16Arg)\).

### 3.7.8 Range Issues

The input data value is in the range of \(-1, 1\), which corresponds to the angle in the range of \(-\pi, \pi\) and the output data value is in the range \(-1, 1\). It means that with the input value 0, it has the output result of 1. Similarly if the input value is \(+1\), the output is \(-1\).

### 3.7.9 Special Issues

The function GFLIB_CosLut requires the saturation mode to be set.
3.7.10 Implementation

The **GFLIB_CosLut** function is implemented as a function call.

**Example 3-6. Implementation Code**

```c
#include "gflib.h"
static Frac16 mf16Input;
static Frac16 mf16Output;

/* input data value in range <-1,1) corresponds to <-pi,pi) */
#define PIBY4 0.25 /* 0.25 equals to pi / 4 */

void main(void)
{
    /* input value pi / 4 */
    mf16Input = FRAC16(PIBY4);

    /* turns on the saturation */
    __turn_on_sat();

    /* Compute the cosine value */
    mf16Output = GFLIB_CosLut(mf16Input);

    /* turns off the saturation */
    __turn_off_sat();
}
```

3.7.11 See Also

See **GFLIB_CosTlr**, **GFLIB_Cos12Tlr**, **GFLIB_SinLut**, **GFLIB_SinTlr**, **GFLIB_Sin12Tlr** and **GFLIB_Tan** for more information.

3.7.12 Performance

**Table 3-17. Performance of GFLIB_CosLut function**

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>41</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>258</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>59 cycles</td>
</tr>
<tr>
<td>Max</td>
<td>59 cycles</td>
</tr>
</tbody>
</table>
3.8 **GFLIB_Tan**

The function calculates the tangent value of the argument using the piece-wise polynomial approximation.

### 3.8.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_Tan(Frac16 f16Arg)
```

### 3.8.2 Prototype

```c
asm Frac16 GFLIB_TanFAsm(Frac16 f16Arg, const GFLIB_TAN_COEFFICIENTS_ADDR_T *pudtTanPoly)
```

### 3.8.3 Arguments

#### Table 3-18. Function Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtTanPoly</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Optional argument; pointer to a structure containing polynomial coefficients for the intervals where the function is calculated.</td>
</tr>
</tbody>
</table>

### 3.8.4 Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

### 3.8.5 Dependencies

List of all dependent files:
- GFLIB_TanAsm.h
- GFLIB_TanAsmDef.h
- GFLIB_types.h

### 3.8.6 Description

The **GFLIB_Tan** function computes \( \tan(\pi x) \) using the piece-wise polynomial approximation.

Due to the limits of the fractional arithmetic all tangent values falling beyond \((-1, 1)\), are truncated to -1 and 1. This function evaluates polynomial according
to the Horner scheme. The input and output values are additionally scaled and centered for the best accuracy.

\[ u = (x - x_{\text{offset}}) \cdot 2^{k_x} \]
\[ v = ((a_n \cdot u + a_{n-1}) \cdot u + a_{n-2}) \cdot u + \ldots + a_0 \]
\[ y = v \cdot 2^{k_y} + y_{\text{offset}} \]

where

- \( x \) is the input argument (\text{f16Arg})
- \( y \) is the evaluated value
- \( u, v \) are the intermediate variables
- \( a_n, a_{n-1}, \ldots, a_0 \) are the coefficients of the polynomial
- \( k_x \) is the scaling factor for the input value
- \( x_{\text{offset}} \) is the offset for the input value
- \( k_y \) is the scaling factor for the output value
- \( y_{\text{offset}} \) is the offset for the output value

The function input range is divided into three intervals within which all the coefficients are calculated as follows:

The coefficients for the input argument falling into the interval \((-0,125\pi ; 0)\)

\[ k_x = 4 \]
\[ x_{\text{offset}} = -2048 \]
\[ a_6, a_5, a_4, a_3, a_2, a_1, a_0 = -1, 7, -28, 385, -1045, 26754, -4548 \]
\[ y_{\text{offset}} = -176322970L \]
\[ k_y = 3 \]

The coefficients for the interval \((-0,25\pi ; -0,125\pi)\)

\[ k_x = 4 \]
\[ x_{\text{offset}} = -6144 \]
\[ a_6, a_5, a_4, a_3, a_2, a_1, a_0 = -5, 23, -104, 559, -2442, 18613, -11022 \]
\[ y_{\text{offset}} = -536870912L \]
\[ k_y = 2 \]

The coefficients for the interval \(<0>\)

\[ k_x = 0 \]
\[ x_{\text{offset}} = 0 \]
\[ a_6, a_5, a_4, a_3, a_2, a_1, a_0 = 0, 0, 0 \]
\[ y_{\text{offset}} = 0L \]
\[ k_y = 0 \]

The scaling factors and offsets should be set to use the whole available fractional range of \([-1, 1)\).

The exact values are provided in the table Figure 3-19 (see Figure 3-3).

### Figure 3-3. GFLIB_Tan Function

#### Table 3-19. GFLIB_Tan Function Values

<table>
<thead>
<tr>
<th>Input Argument Value</th>
<th>Computed Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>((-\pi, -\frac{3}{4} \cdot \pi))</td>
<td>((-\pi, -\frac{3}{4} \cdot \pi))</td>
</tr>
<tr>
<td>((-\frac{3}{4} \cdot \pi, \pi))</td>
<td>((-\frac{3}{4} \cdot \pi, \pi))</td>
</tr>
<tr>
<td>((-\frac{1}{2} \cdot \pi, -\frac{1}{2} \cdot \pi))</td>
<td>((-\frac{1}{2} \cdot \pi, -\frac{1}{2} \cdot \pi))</td>
</tr>
<tr>
<td>(-\frac{1}{2} \cdot \pi)</td>
<td>(-\frac{1}{2} \cdot \pi)</td>
</tr>
</tbody>
</table>
Table 3-19. GFLIB_Tan Function Values

<table>
<thead>
<tr>
<th>Input Argument Value</th>
<th>Computed Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real</td>
<td>Fractional (Hex)</td>
</tr>
<tr>
<td>((-\frac{1}{2} \cdot \pi, -\frac{1}{4} \cdot \pi))</td>
<td>(C000, E000)</td>
</tr>
<tr>
<td>(\frac{-1}{4} \cdot \pi)</td>
<td>E000</td>
</tr>
<tr>
<td>((-\frac{1}{4} \cdot \pi, \frac{1}{4} \cdot \pi))</td>
<td>(E000, 2000)</td>
</tr>
<tr>
<td>(\frac{1}{4} \cdot \pi)</td>
<td>2000</td>
</tr>
<tr>
<td>(\left(\frac{1}{4} \cdot \pi, \frac{1}{2} \cdot \pi\right))</td>
<td>(2000,4000)</td>
</tr>
<tr>
<td>(\frac{1}{2} \cdot \pi)</td>
<td>4000</td>
</tr>
<tr>
<td>(\left(\frac{1}{2} \cdot \pi, \frac{3}{2} \cdot \pi\right))</td>
<td>(4000, 6000)</td>
</tr>
<tr>
<td>(\left(\frac{3}{4} \cdot \pi, \pi\right))</td>
<td>(6000,7FFF)</td>
</tr>
</tbody>
</table>

3.8.7 Returns

The function returns \(\tan(\pi x)\) with limits imposed by the fractional arithmetic.

3.8.8 Range Issues

The input data value is in the range of \(<-1,1)\), which corresponds to the angle in the range of \(<-\pi, \pi)\). The output data value is in the range of \(<-1,1)\), i.e. the function value of 0.25 is 1. If the input is -0.25, the result is -1.

If a tangent value is beyond the permissible range of \(<-1, 1)\), then it is truncated to -1 and 1 respectively.

3.8.9 Special Issues

The GFLIB_Tan function is the saturation mode independent.

3.8.10 Implementation

The GFLIB_Tan function is implemented as a function call.
Example 3-7. Implementation Code

```
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

/* input data value in range <-1,1) corresponds to <-pi,pi) */
#define PIBY4 0.25 /* 0.25 equals to pi / 4 */

void main(void)
{
    /* input value pi / 4 */
    mf16Input = FRAC16(PIBY4);

    /* Compute the tan value */
    mf16Output = GFLIB_Tan(mf16Input);
}
```

3.8.11 See Also

See `GFLIB_SinTlr`, `GFLIB_Sin12Tlr`, `GFLIB_SinLut`, `GFLIB_CosTlr`, `GFLIB_Cos12Tlr` and `GFLIB_CosLut` for more information.

3.8.12 Performance

Table 3-20. Performance of GFLIB_Tan function

<table>
<thead>
<tr>
<th></th>
<th>Code Size (words)</th>
<th>Data Size (words)</th>
<th>Execution Clock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>Code Size (words)</td>
<td>59</td>
<td></td>
<td>76cycles</td>
</tr>
<tr>
<td>Data Size (words)</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
<td></td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>76 cycles</td>
</tr>
</tbody>
</table>
3.9  GFLIB_Asin

The function calculates the arcus sine value of the argument using the piece-wise polynomial approximation.

3.9.1  Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_Asin(Frac16 f16Arg)
```

3.9.2  Prototype

```c
asm Frac16 GFLIB_AsinFAsm(Frac16 f16Arg,
GFLIB_ASINACOS_COEFFICIENTS_ADDR_T *pudtAsinPoly)
```

3.9.3  Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtAsinPoly</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Optional argument; pointer to data needed for the calculation.</td>
</tr>
</tbody>
</table>

3.9.4  Availability

This library module is available in the C-callable interface assembly formats.

This library module is targeted for the DSC 56F80xx platform.

3.9.5  Dependencies

List of all dependent files:
- GFLIB_AsinAcosAsm.h
- GFLIB_AsinAcosAsmDef.h
- GFLIB_types.h

3.9.6  Description

The GFLIB_Asin function computes the \(\frac{\text{asin}(x)}{(\pi/2)}\) using the piece-wise polynomial approximation (see Figure 3-4). This function evaluates the polynomial according to the Horner scheme. The input and output values are additionally scaled and centered for the best accuracy.
where

- \( x \) is the input argument (f16Arg)
- \( y \) is the evaluated value
- \( u, v \) are the intermediate variables
- \( a_n, a_{n-1}, \ldots, a_0 \) are the coefficients of the polynomial
- \( k_X \) is the scaling factor for the input value
- \( x_{\text{offset}} \) is the offset for the input value
- \( k_Y \) is the scaling factor for the output value
- \( y_{\text{offset}} \) is the offset for the output value

The function input range is divided into three intervals within which all the coefficients are calculated as follows:

**The coefficients for the input argument falling into the interval \(<-0.5 ; 0> \)**

\[
u = (x-x_{\text{offset}}) \cdot 2^{k_X}
\]

\[
v = (((a_n \cdot u + a_{n-1}) \cdot u + a_{n-2}) \cdot u + \ldots + a_0)
\]

\[
v = v \cdot 2^{k_Y} + y_{\text{offset}}
\]

\( k_X = 3 \)
\( x_{\text{offset}} = -0.4096 \)
\( a_5, a_2, a_1, a_0 = 59, -169, 21026, -11514 \)
\( y_{\text{offset}} = -19252860L \)
\( k_Y = 5 \)

**The coefficients for the interval \(<-1; -0.5) \)**

\[
u = (- \sqrt[1]{x} - x_{\text{offset}}) \cdot 2^{k_X}
\]

\[
v = (((a_n \cdot u + a_{n-1}) \cdot u + a_{n-2}) \cdot u + \ldots + a_0)
\]

\[
v = v \cdot 2^{k_Y} + y_{\text{offset}}
\]

\( k_X = 3 \)
\( x_{\text{offset}} = -12288 \)
\( a_5, a_2, a_1, a_0 = 104, -623, 22502, -9536 \)
\( y_{\text{offset}} = -11148107L \)
\( k_Y = 5 \)

**The coefficients for the interval \(<0> \)**

\( k_X = 0 \)
\( x_{\text{offset}} = 0 \)
\( a_5, a_2, a_1, a_0 = 0, 0, 0, 0 \)
\( y_{\text{offset}} = 0L \)
\[ k_f = 0 \]

The scaling factors and offsets should be set to use the whole available fractional range of \([-1, 1]\).

![Graph](image_url)

**Figure 3-4. GFLIB_Asin Function**

### 3.9.7 Returns

The function returns \( \text{asin}(x)/(\pi/2) \).

### 3.9.8 Range Issues

The input data value is in the range of \([-1, 1]\). The output data value is in the range \([-0.5, 0.5]\), which corresponds to the angle in the range of \([-\pi/2, \pi/2]\).

### 3.9.9 Special Issues

The **GFLIB_Asin** function is the saturation mode independent.

### 3.9.10 Implementation

The **GFLIB_Asin** function is implemented as a function call.

#### Example 3-8. Implementation Code

```
#include "gflib.h"
```

General Functions Library, Rev. 3
static Frac16 mf16Input;
static Frac16 mf16Output;

void main(void)
{
    /* input value 0.5 */
    mf16Input = FRAC16(0.5);

    /* Compute the arcsin value */
    mf16Output = GFLIB_Asin(mf16Input);
}

3.9.11 See Also

See GFLIB_Acos, GFLIB_Atan, GFLIB_AtanYX and GFLIB_AtanYXShifted for more information.

3.9.12 Performance

Table 3-22. Performance of GFLIB_Asin function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>73 + 65 (GFLIB_SqrtPoly)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>27+34 (GFLIB_SqrtPoly)</td>
</tr>
<tr>
<td>Execution Clock</td>
<td>Min 86/85 cycles</td>
</tr>
<tr>
<td></td>
<td>Max 185/178 cycles</td>
</tr>
</tbody>
</table>
3.10  GFLIB_Acos

The function calculates the arcus cosine value of the argument using the piece-wise polynomial approximation.

3.10.1  Synopsis

```c
#include "glib.h"
Frac16 GFLIB_Acos(Frac16 f16Arg)
```

3.10.2  Prototype

```c
asm Frac16 GFLIB_AcosFAsm(Frac16 f16Arg,
GFLIB_ASINACOS_COEFFICIENTS_ADDR_T *pudtAcosPoly)
```

3.10.3  Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtAcosPoly</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Optional argument; pointer to data needed for the calculation.</td>
</tr>
</tbody>
</table>

3.10.4  Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

3.10.5  Dependencies

List of all dependent files:
- GFLIB_AsinAcosAsm.h
- GFLIB_AsinAcosAsmDef.h
- GFLIB_types.h

3.10.6  Description

The `GFLIB_Acos` function computes the `acos(f16Arg)/(pi/2)` using the arcus sine calculation as follows:

\[
\text{Acos}(x) = ((-0.5) + \text{A}\sin(x)) \cdot (-1)
\]

Eqn. 3-29
The sine calculation uses the piece-wise polynomial approximation (see Figure 3-5).

### 3.10.7 Returns

The function returns \( \frac{\text{acos}(x)}{(\pi/2)} \).

### 3.10.8 Range Issues

The input data value is in the range of \(-1,1\). The output data value is in the range \(<0,1\), which corresponds to the angle in the range of \(<0,\pi\).

### 3.10.9 Special Issues

The function `GFLIB_Acos` is the saturation mode independent.

The function is very short and to reduce the time consumption of this function call, it may be reasonable to implement it as an inline function.

### 3.10.10 Implementation

The `GFLIB_Acos` function is implemented as a function call.
Example 3-9. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

void main(void)
{
    /* input value 0.5 */
    mf16Input = FRAC16(0.5);

    /* Compute the arccos value */
    mf16Output = GFLIB_Acos(mf16Input);
}
```

3.10.11 See Also

See GFLIB_Asin, GFLIB_Atan, GFLIB_AtanYX and GFLIB_AtanYXShifted for more information.

3.10.12 Performance

<table>
<thead>
<tr>
<th>Table 3-24. Performance of GFLIB_Acos function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Code Size (words)</strong></td>
</tr>
<tr>
<td><strong>Data Size (words)</strong></td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
</tr>
</tbody>
</table>

¹ Code size of GFLIB_Acos() function is 8 words. GFLIB_Acos() function however uses additional two functions for calculation: GFLIB_Asin() and GFLIB_Sqrt(), which if not already used within the application source code is included into the code together with GFLIB_Acos().
3.11 GFLIB_Atan

The function calculates the arcus tangent value of the argument using the piece-wise polynomial approximation.

3.11.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_Atan(Frac16 f16Arg)
```

3.11.2 Prototype

```c
asm Frac16 GFLIB_AtanFAsm(Frac16 f16Arg, GFLIB_ATAN_COEFFICIENTS_ADDR_T *pudtAtanPoly)
```

3.11.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtAtanPoly</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Optional argument; pointer to data needed for the calculation.</td>
</tr>
</tbody>
</table>

3.11.4 Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

3.11.5 Dependencies

List of all dependent files:
- GFLIB_AtanAsm.h
- GFLIB_AtanAsmDef.h
- GFLIB_types.h

3.11.6 Description

The **GFLIB_Atan** function computes atan(x)/(pi/4) using the piece-wise polynomial approximation (see Figure 3-6). This function evaluates the polynomial according to the Horner scheme. The input and output values are additionally scaled and centered for the best accuracy.
\[ u = (x - x_{\text{offset}}) \cdot 2^{k_X} \quad \text{Eqn. 3-30} \]
\[ v = ((a_n \cdot u + a_{n-1}) \cdot u + a_{n-2}) \cdot u + \ldots + a_0 \quad \text{Eqn. 3-31} \]
\[ y = v \cdot 2^{k_Y} + y_{\text{offset}} \quad \text{Eqn. 3-32} \]

where

- \( x \) is the input argument (f16Arg)
- \( y \) is the evaluated value
- \( u, v \) are the intermediate variables
- \( a_n, a_{n-1}, \ldots, a_0 \) are the coefficients of the polynomial
- \( k_X \) is the scaling factor for the input value
- \( x_{\text{offset}} \) is the offset for the input value
- \( k_Y \) is the scaling factor for the output value
- \( y_{\text{offset}} \) is the offset for the output value

The function input range is divided into three intervals within which all the coefficients are calculated as follows (in the integer format):

The coefficients for the input argument falling into the interval \(<-0.5 ; 0)\)

\[
\begin{align*}
    k_X &= 2 \\
    x_{\text{offset}} &= -8192 \\
    a_4, a_3, a_2, a_1, a_0 &= -56, -289, 1154, 19633, -14522 \\
    y_{\text{offset}} &= -24248975L \\
    k_Y &= 4 
\end{align*}
\]

The coefficients for the interval \(<-1 ; -0.5)\)

\[
\begin{align*}
    k_X &= 2 \\
    x_{\text{offset}} &= -24576 \\
    a_4, a_3, a_2, a_1, a_0 &= -37, 145, 3204, 26704, -9087 \\
    y_{\text{offset}} &= -201326592L \\
    k_Y &= 5 
\end{align*}
\]

The coefficients for the interval \(<0>\)

\[
\begin{align*}
    k_X &= 0 \\
    x_{\text{offset}} &= 0 \\
    a_4, a_3, a_2, a_1, a_0 &= 0, 0, 0, 0 \\
    y_{\text{offset}} &= 0L \\
    k_Y &= 0 
\end{align*}
\]

The scaling factors and offsets should be set to use the whole available fractional range of \(<-1, 1)\).
3.11.7 Returns

The function returns \( \text{atan}(x)/(\pi/4) \).

3.11.8 Range Issues

The input data value is in the range of \(-1,1\). The output data value is in the range \(-0.25, 0.25\), which corresponds to the angle in the range of \(-\pi/4,\pi/4\).

3.11.9 Special Issues

The GFLIB_Atan function is the saturation mode independent.

3.11.10 Implementation

The GFLIB_Atan function is implemented as a function call.

```
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

void main(void)
```

---

General Functions Library, Rev. 3

Freescale Semiconductor
{ /* input value 0.5 */
    mf16Input = FRAC16(0.5);

    /* Compute the arctan value */
    mf16Output = GFLIB_Atan(mf16Input);
}

3.11.11 See Also

See GFLIB_Asin, GFLIB_Acos, GFLIB_AtanYX and GFLIB_AtanYXShifted for more information.

3.11.12 Performance

Table 3-26. Performance of GFLIB_Atan function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>44</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>33</td>
</tr>
<tr>
<td>Execution Clock</td>
<td>Min 61/60 cycles</td>
</tr>
<tr>
<td></td>
<td>Max 61/60 cycles</td>
</tr>
</tbody>
</table>
3.12 GFLIB_AtanYX

The function calculates the arcus tangent value based on the provided x, y co-ordinates as arguments using the division and the piece-wise polynomial approximation

3.12.1 Synopsis

#include "gflib.h"
Frac16 GFLIB_AtanYX(Frac16 f16ValY, Frac16 f16ValX, const Int16 *pi16ErrFlag)

3.12.2 Prototype

asm Frac16 GFLIB_AtanYXFAsm(Frac16 f16ValY, Frac16 f16ValX, const Int16 *pi16ErrFlag, GFLIB_ATANYX_COEFFICIENTS_ADDR_T *pudtAtanYXPoly)

3.12.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16ValY</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Y-coordinate input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>f16ValX</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>X-coordinate input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pi16ErrFlag</td>
<td>Out</td>
<td>SI16</td>
<td>0...1</td>
<td>Pointer to the error flag. 0 - no error, 1 - both coordinates are zero.</td>
</tr>
<tr>
<td>*pudtAtanYXPoly</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Optional argument; pointer to data needed for the calculation.</td>
</tr>
</tbody>
</table>

3.12.4 Availability

This library module is available in the C-callable interface assembly format. This library module is targeted for the DSC 56F80xx platform.

3.12.5 Dependencies

List of all dependent files:
- GFLIB_AtanYXAsm.h
- GFLIB_AtanYXAsmDef.h
- GFLIB_types.h
3.12.6 Description

The GFLIB_AtanYX function computes the angle where its tangent is y/x. This calculation is based on the input arguments division (y divided by x) and the piece-wise polynomial approximation. This function is the fractional counterpart of the well-known atan2() function defined in the ANSI-C math library.

In comparison to GFLIB_Atan, the GFLIB_AtanYX function correctly places the calculated angle in the whole <-pi, pi) range, according to the signs of the x and y coordinates provided as the arguments.

If the x and y coordinates are 0 (zero), the function returns 0 and the address pointed by the pi16ErrFlag pointer is set to 1 (otherwise it is set to 0).

3.12.7 Returns

The function returns the angle that has its tangent equal to y/x (arcus tangent from the x, y coordinates).

3.12.8 Range Issues

The input data value is in the range of <-1,1). The output data value is in the range <-1, 1), which corresponds to the angle in the range of <-pi,pi).

3.12.9 Special Issues

The GFLIB_AtanYX function is the saturation mode independent.

3.12.10 Implementation

The GFLIB_AtanYX function is implemented as a function call.

Example 3-11. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16InputY;
static Frac16 mf16InputX;
static Frac16 mf16Output;
static Int16 mi16Flag;

void main(void)
{
    /* x input value 0.5 */
    mf16InputX = FRAC16(0.5);

    /* y input value 1.0 */
    mf16InputY = FRAC16(1.0);

    /* Compute the arctan value */
    mf16Output = GFLIB_AtanYX(mf16InputY, mf16InputX, &mi16Flag);
}
```

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Freescale Semiconductor
3.12.11 See Also

See GFLIB_Asin, GFLIB_Acos, GFLIB_Atan and GFLIB_AtanYXShifted for more information.

3.12.12 Performance

Table 3-28. Performance of GFLIB_AtanYX function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>33</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>46/46 cycles</td>
</tr>
<tr>
<td>Max</td>
<td>122/119 cycles</td>
</tr>
</tbody>
</table>
3.13 GFLIB_AtanYXShifted

The function calculates angle of two sine waves shifted in phase one to each other.

3.13.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_AtanYXShifted(Frac16 f16ValY, Frac16 f16ValX,
GFLIB_ATANYXSHIFTED_T *pudtAtanYXCoeff)
```

3.13.2 Prototype

```c
asm Frac16 GFLIB_AtanYXShiftedFAsm(Frac16 f16ValY, Frac16 f16ValX,
GFLIB_ATANYXSHIFTED_T *pudtAtanYXCoeff)
```

3.13.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16ValY</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Y input data value, equal to sin θ</td>
</tr>
<tr>
<td>f16ValX</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>X input data value, equal to sin(θ + Δθ)</td>
</tr>
<tr>
<td>*pudtAtanYXCoeff</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Input pointer of the struct initialization parameters</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_ATANYXSHIFTED_T</td>
<td>f16Ky</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Multiplication coefficient of the y signal</td>
</tr>
<tr>
<td></td>
<td>f16Kx</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Multiplication coefficient of the x signal</td>
</tr>
<tr>
<td></td>
<td>i16Ny</td>
<td>In</td>
<td>SI16</td>
<td>0x8000...0x7FFF</td>
<td>Scaling coefficient of the y signal</td>
</tr>
<tr>
<td></td>
<td>i16Nx</td>
<td>In</td>
<td>SI16</td>
<td>0x8000...0x7FFF</td>
<td>Scaling coefficient of the x signal</td>
</tr>
<tr>
<td></td>
<td>f16ThetaAdj</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Adjusting angle</td>
</tr>
</tbody>
</table>
3.13.4 Availability

This library module is available in the C-callable interface assembly format.
This library module is targeted for the DSC 56F80xx platform.

3.13.5 Dependencies

List of all dependent files:
1. GFLIB_AtanYXShiftedAsm.h
2. GFLIB_AtanYXShiftedAsmDef.h
3. GFLIB_types.h

3.13.6 Description

The parameters should be initialization before the first call of the 
GFLIB_AtanYXShifted function.

The initialization parameters can be calculated according to the algorithm 
provided as a Matlab code, see Example 3-12.

The GFLIB_AtanYXShifted function computes an angle assuming that the 
arguments denote the following values:

\[
\begin{align*}
    y &= \sin \theta \\
    x &= \sin (\theta + \Delta \theta)
\end{align*}
\]

Eqn. 3-33

where:
\- \( x, y \) signal values provided as the arguments
\- \( \theta \) angle to be computed by the function
\- \( \Delta \theta \) phase difference between the \( x, y \) signals

If \( \Delta \theta = \pi/2 \) or \( \Delta \theta = -\pi/2 \) then the function is similar to the GFLIB_AtanYX
function, however the GFLIB_AtanYX function in this case is more effective.

The function uses the following algorithm for computing the angle:

\[
\begin{align*}
    b &= \frac{S}{2 \cdot \cos \frac{\Delta \theta}{2}} \cdot (y + x) \\
    a &= \frac{S}{2 \cdot \sin \frac{\Delta \theta}{2}} \cdot (x - y) \\
    \theta &= \text{atan2}(b,a) - \Delta \theta / 2 + \theta_{\text{offset}}
\end{align*}
\]

Eqn. 3-34

where:
\- \( x, y \) signal values provided as arguments in Equation 3-33
\[ \frac{S}{2 \cdot \cos \frac{\Delta \theta}{2}} = K_y \cdot 2^{N_y} \]
\[ \frac{S}{2 \cdot \sin \frac{\Delta \theta}{2}} = K_x \cdot 2^{N_x} \]
\[ \theta_{adj} = \frac{\Delta \theta}{2} - \theta_{offset} \]

where:
- \( K_y \) multiplication coefficient of the \( y \) signal
- \( N_y \) scaling coefficient of the \( y \) signal
- \( K_x \) multiplication coefficient of the \( x \) signal
- \( N_x \) scaling coefficient of the \( x \) signal
- \( \theta_{adj} \) adjusting angle

The signal values need to be provided as the function arguments. The phase difference \( \Delta \theta \) needs to be set through the initialization parameters.

The function initialization parameters can be calculated as shown in the following Matlab code:

```matlab
function [KY, KX, NY, NX, THETAADJ] = atan2shiftedpar(dthdeg, thoffsetdeg)

% ATAN2SHIFTEDPAR  calculation of parameters for atan2shifted() function
%
% [NY, NX, KY, KX, THETAADJ] = atan2shiftedpar(dthdeg, thoffsetdeg)
%
% dthdeg = phase shift between sine waves in degrees
% thoffsetdeg = angle offset in degrees
% NY       - scaling coefficient of y signal
% NX       - scaling coefficient of x signal
% KY       - multiplication coefficient of y signal
% KX       - multiplication coefficient of x signal
% THETAADJ - adjusting angle in radians, scaled from [-pi, pi) to [-1, 1)

dth2 = ((dthdeg/2)/180*pi);
thoffset = (thoffsetdeg/180*pi);
CY = (1 - 2^-15)/(2*cos(dth2));
CX = (1 - 2^-15)/(2*sin(dth2));

KY = (1 - 2^-15)/(2*cos(dth2));
NX = (1 - 2^-15)/(2*sin(dth2));

```

For the fractional conventions purposes the algorithm is implemented such that addition values are used as shown in the equation Equation 3-35 below:
if(abs(CY) >= 1) NY = ceil(log2(abs(CY))); else NY = 0; end

if(abs(CX) >= 1) NX = ceil(log2(abs(CX))); else NX = 0; end

KY = CY/2^NY;
KX = CX/2^NX;

THETAADJ = (dthdeg/2 - thoffsetdeg)/180;

For example if $\Delta \theta = 69.33^\circ$, $\theta = 0^\circ$, then:

$d\theta = 69.33$deg, $\theta_{offset} = 0$deg
$CY = (1 - 2^{-15})/(2*cos((69.33/2)/180*pi)) = 0.60789036201452440$
$CX = (1 - 2^{-15})/(2*sin((69.33/2)/180*pi)) = 0.87905201358520957$
$NY = 0$ $($abs(CY) < 1$)
$NX = 0$ $($abs(CX) < 1$)
$KY = 0.60789/2^0 = 0.60789036201452440 = (Frac16) 19919$
$KX = 0.87905/2^0 = 0.87905201358520957 = (Frac16) 28805$
$THETAADJ = 0.19259643554687500 = (Frac16) 6311$

The function requires both signals to have the same amplitude equal to 1.0. If not, an additional error is contributed, see Equation 3-36 and Equation 3-37.

The algorithm may become numerically unstable under some conditions. For example, if $\Delta \theta$ approaches 0, then the intermediate variable $a$ cannot be computed due to discontinuity at 0.

Using the theory of the partial derivatives a more precise formula can be derived to express the error of the presented algorithm:

**Equation 3-36**

$$
\varepsilon_{\theta_c} = \left[ \frac{0.318}{\sin(\Delta \theta_{mod}/2)} \cdot \varepsilon_{yx} + 0.159 \cdot \coth(\Delta \theta_{mod}) \cdot \varepsilon_A + \left( 1 + \frac{0.318}{\sin(\Delta \theta_{mod})} \right) \cdot \varepsilon_{\Delta \theta_{c}/2} + 1.23 \cdot LSB \right]
$$

if $0 < \Delta \theta_m < \pi/2$

**Equation 3-37**

$$
\varepsilon_{\theta_c} = \left[ \frac{0.318}{\cos(\Delta \theta_{mod}/2)} \cdot \varepsilon_{yx} + 0.159 \cdot \coth(\Delta \theta_{mod}) \cdot \varepsilon_A + \left( 1 + \frac{0.318}{\sin(\Delta \theta_{mod})} \right) \cdot \varepsilon_{\Delta \theta_{c}/2} + 1.23 \cdot LSB \right]
$$

if $\pi/2 \leq \Delta \theta_m$

where:

- $LSB$ Least Significant Bit, for 16-bits fractional numbers equal to $2^{-15}$
- $\lceil \ldots \rceil$ ceiling function (the least integer larger or equal to)
- $\varepsilon_{\theta_c}$ error of the computed angle expressed in LSB
- $\varepsilon_A$ difference in signal amplitudes, absolute value, in LSB

General Functions Library, Rev. 3
\( \varepsilon_{yx} \) error contributed by the \( x, y \) signals, \( \varepsilon_x = \varepsilon_y = \varepsilon_{yx} \) in LSB

\( \varepsilon_{\Delta \theta/2} \) measurement error of the phase difference between the signals divided by 2 plus the error due to the finite binary resolution

\( \Delta \theta_{\text{mod}} \) phase difference \( \Delta \theta \) modulo \( \pi \)

The signal error \( \varepsilon_{yx} \) includes an error due to the limited resolution (for example of an ADC converter) and signal distortion by higher order harmonics.

The reference for the derivation of the error can be found at the end of this section.

It should be noticed that the error reaches its minimum at \( \Delta \theta = \pi/2 \) or \(-\pi/2\) and in this case the function becomes similar to the trivial arcus tangent function. On the other hand the error is approaching the infinity with \( \Delta \theta \) approaching 0 or \( \Delta \theta \pi \). Therefore the function is able to provide the most accurate results if \( \Delta \theta \) does not differ much from \( \pi/2 \) or \(-\pi/2\).

Due to the cyclic nature of the angle (\( \pi = -\pi \)) even a small error may cause the angle shift by \( 2 \cdot \pi \). For example if the correct angle is \( \pi \) (or 7FFF hex), due to contribution of various errors listed above, the computation may result in the value of \( -\pi \) (or 8000 hex). It should be noticed that due to the random nature of errors it is not possible to detect this type of errors by the functions itself. It is recommended to consider if such a behavior may cause any computational problems in the final application.

### 3.13.6.1 Derivation of Numerical Error

The error of the computed angle consists of:

- error of the supplied signals values due to the finite resolution of the ADC converter: \( \varepsilon_y \) and \( \varepsilon_x \)
- error contributed by higher order harmonics appearing in the signal values: \( \varepsilon_y \) and \( \varepsilon_x \) (included in the variable)
- computational error of the multiplication due to the finite length of the micro-controller registers: \( \varepsilon_b \) and \( \varepsilon_a \)
- error of the angle difference representation \( \Delta \theta \) in the finite precision arithmetic: \( \varepsilon_{(\Delta \theta)/2} \)
- error due to the angle difference measurement: (included in the variable)
- error due to differences in signal amplitudes

Using elementary mathematical functions and operators, the computed angle can be expressed as:

\[
\theta_C = \frac{1}{\pi} \cdot \tan \left( \frac{\Delta \theta_C}{2} \right) \cdot \frac{S \cdot A_y \cdot \sin(\Delta \theta_d) + S \cdot A_x \cdot \sin(\theta_d + \Delta \theta_d) + \varepsilon_y + \varepsilon_x + \varepsilon_b \cdot 2 \cdot \cos \left( \frac{\Delta \theta_d}{2} \right) - \varepsilon_{(\Delta \theta)/2}}{S \cdot A_x \cdot \sin(\theta_d) - S \cdot A_x \cdot \sin(\theta_d + \Delta \theta_d) + \varepsilon_y - \varepsilon_x + \varepsilon_a \cdot 2 \cdot \sin \left( \frac{\Delta \theta_C}{2} \right)}
\]

Eqn. 3-38

where:

**General Functions Library, Rev. 3**
$A_y$, amplitude of the signal $y$, nearly 1.0
$A_x$, amplitude of the signal $x$, nearly 1.0
$\theta_c$, computed angle
$\theta_A$, the actual angle
$\Delta\theta_A$, the actual phase difference between the signals
$\epsilon_y$, error contributed by the signal includes the error contributed by the ADC converter and the higher order harmonics
$\epsilon_x$, error contributed by the signal includes the error contributed by the ADC converter and the higher order harmonics
$\epsilon_{\Delta\theta_A/2}$, error contributed by the representation of the fractional format (numerical resolution) plus the measurement error of the divided by 2
$\epsilon_b$, error contributed by the multiplication to compute the intermediate variable $b$, see Equation 3-34
$\epsilon_a$, error contributed by the multiplication to compute the intermediate variable $a$, see Equation 3-34

The error of the computed angle is equal to:

$$\delta\theta_c = \max_{\theta_A} \left[ \sum_u \frac{\partial \theta_A}{\partial u} \cdot \delta u \right]$$

(Eqn. 3-39)

where:

$u$ independent variable
$max_{\theta_A}$ maximum over the whole range of
$\delta$ partial difference operator
$\frac{\partial}{\partial}$ partial derivative operator
Furthermore we can assume:

\[
\begin{align*}
\varepsilon_y &= \delta e_y \geq 0 \\
\varepsilon_x &= \delta e_x \geq 0 \\
\varepsilon_b &= \delta e_b \geq 0 \\
\varepsilon_a &= \delta e_a \geq 0 \\
\varepsilon_{\Delta \theta_{c/2}} &= \delta (\Delta \theta_{c/2}) \geq 0 \\
\varepsilon_d &= |A_y - A_x| \geq 0 \\
\Delta \theta_c &= \Delta \theta_d = \Delta \theta \\
S &= 1 \\
\varepsilon_{\theta_c} &= \delta \theta_c \\
A_y &= A_x = A_{yx} \equiv 1; A_{yx} < 1
\end{align*}
\]

\textit{Eqn. 3-40}

where:

- \(\varepsilon_d\) error contributed by the difference in signal amplitudes
- \(\varepsilon_{\theta_c}\) the resulting error of the computed angle

It should be noticed that the error contributed by the signals (\(\varepsilon_y\) and \(\varepsilon_x\)), the errors due to the finite precision arithmetic (\(\varepsilon_b\), \(\varepsilon_a\) and \(\varepsilon_{\Delta \theta_{c/2}}\)) have a random nature. On contrary, the error due to the unequal signal amplitudes \(\varepsilon_d\) is a systematic error\(^1\).

Then the maximum error computed from the partial differences is equal to:

\[
\theta_c = \frac{1}{\pi} \cdot \max_{\Delta \theta} \left[ \frac{\sin(\theta_d + \Delta \theta)}{A_{yx} \cdot \sin \Delta \theta} \cdot \varepsilon_x + \frac{\sin \theta_d}{A_{yx} \cdot \sin \Delta \theta} \cdot \varepsilon_y + \frac{\cos(\theta_d + \Delta \theta)}{2 \cdot A_{yx}} \cdot \varepsilon_b + \frac{\sin(\theta_d + \Delta \theta)}{2 \cdot A_{yx}} \cdot \varepsilon_a \right]
\]

\textit{Eqn. 3-41}

\[
\begin{align*}
&+ \left[ \frac{\coth \Delta \theta}{2 \cdot A_{yx}} \cdot \varepsilon_d + \frac{\sin(2 \cdot \theta_d + \Delta \theta)}{\sin \Delta \theta} \cdot \varepsilon_{\Delta \theta_{c/2}} + \varepsilon_{\Delta \theta_{c/2}} \right]
\end{align*}
\]

Apart from the error sources mentioned above, an additional error is contributed by the \texttt{GFLIB\_AtanYX} function. In case of the \texttt{GFLIB\_AtanYX} function from the GFLIB the computation error is equal to one LSB.

The errors of the \(y\) and \(x\) signals, \(\varepsilon_y\) and \(\varepsilon_x\), appear due to the finite resolution of the A/D converter and higher order harmonics and is equal to a certain amount of LSB.

The computation error due to the multiplication in the numerator and the denominator in \textit{Equation 3-34}, \(\varepsilon_b\) and \(\varepsilon_a\), is equal to the half of LSB (each one).

\(^1\) The division into random and systematic errors is conventional, indeed the \(\varepsilon_{\Delta \theta_{c/2}}\) error can be also treated as a systematic error as well as \(\varepsilon_d\).
The error due to finite, binary representation of $\Delta \theta_c/2$ is equal to the half of LSB. Finally the measurement error of the phase angle which is equal to a certain amount of LSB needs to be considered.

The error due to the signal amplitude difference, $\epsilon$, is equal to a certain amount of LSB. It should be noticed that the error appears only if the amplitudes of both signals differ.

After the appropriate calculation and substitutions the upper boundary for the error becomes Equation 3-36.

### 3.13.7 Returns

The function returns an angle of two sine waves shifted in phase.

### 3.13.8 Range Issues

The input data value is in the range of <-1,1). The output data value is in the range <-1, 1), which corresponds to the angle in the range of <-pi,pi).

The computation error strongly depends on the phase difference between the sine waves which may cause numerical issues.

### 3.13.9 Special Issues

The function internally calls the GFLIB_AtanYX function.

The function is not sensitive to the saturation mode setting. However it should be noticed that the function actually uses the saturation mode bit. The saturation mode bit is stored and restored during a function call.

The function uses REP instruction to perform shifting with the scaling coefficients $N_y$, $N_x$ used as repetition amounts. Therefore large values of the scaling coefficient may increase the interrupt latency time.

### 3.13.10 Implementation

The GFLIB_AtanYXShifted function is implemented as a function call with an initialization.

#### Example 3-13. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16InputY;
static Frac16 mf16InputX;
static Frac16 mf16OutputZ;

/* Define appropriate data */
/* dtheta = 5deg, thetaoffset = 0deg */
#define NY 0
```

General Functions Library, Rev. 3
#define NX 4
#define KY FRAC16(0.50046106925577549)
#define KX FRAC16(0.71640268727196699)
#define THETAADJ FRAC16(0.01388549804687500)

/* Initialize */
static GFLIB_ATANYXSHIFTED_T mudtMyAtanYX = {NY, NX, KY, KX, THETAADJ};

void main(void)
{
  /* ~= sin(-166.811) */
  mf16InputY = -7477;

  /* ~= sin(-166.811 + 5) */
  mf16InputX = -10229;

  /* Compute angle */
  mf16OutputZ = GFLIB_AtanYXShifted(mf16InputY, mf16InputX, &mudtMyAtanYX);
}

### 3.13.11 See Also

See GFLIB_Asin, GFLIB_Acos, GFLIB_Atan and GFLIB_AtanYX for more information.

### 3.13.12 Performance

#### Table 3-31. Performance of GFLIB_AtanYXShifted function

<table>
<thead>
<tr>
<th></th>
<th>Code Size (words)</th>
<th>Data Size (words)</th>
<th>Execution Clock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>52 + 100 (GFLIB_AtanYX)</td>
<td>0 + 33 (GFLIB_AtanYX)</td>
<td>Min 105/102 cycles</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max 185/179 cycles</td>
</tr>
</tbody>
</table>
3.14 GFLIB_SqrtPoly

The function calculates the square root value of the argument using the piece-wise polynomial approximation with the post-adjustment method.

3.14.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_SqrtPoly(Frac32 f32Arg)
```

3.14.2 Prototype

```c
asm Frac16 GFLIB_SqrtPolyFAsm(Frac32 f32Arg, const GFLIB_SQRT_POLY_TABLE_T *pudtPolyTable)
```

3.14.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f32Arg</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Input argument; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtPolyTable</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Optional argument; pointer to data needed for the calculation.</td>
</tr>
</tbody>
</table>

3.14.4 Availability

This library module is available in the C-callable interface assembly format. This library module is targeted for the DSC 56F80xx platform.

3.14.5 Dependencies

List of all dependent files:
- GFLIB_SqrtAsm.h
- GFLIB_SqrtDefAsm.h
- GFLIB_types.h

3.14.6 Description

The function **GFLIB_SqrtPoly** calculates computes the square root of the input argument using the piece-wise polynomial approximation and the post-adjustment of the least significant bits. The function calculates the square root correctly for the values equal to or larger than zero. For the negative arguments the function may behave unpredictably.
The algorithm calculates the raw result using a polynomial of the 4th order with 3 intervals. Then the raw result is iterated in 3 steps to get a more precise result.

### 3.14.7 Returns

For the argument equal to or larger than zero the function `GFLIB_SqrtPoly` returns the square root of the argument, which is a number which if squared is the best approximation of the argument. The function correctly rounds the least significant bit. For the negative arguments the function returns undefined values.

### 3.14.8 Range Issues

The input data value is in the range of <0,1), expressed with the 32-bit precision. The output data value is in the range of <0, 1) expressed with the 16-bit precision.

### 3.14.9 Special Issues

The `GFLIB_SqrtPoly` function is the saturation mode independent.

### 3.14.10 Implementation

The `GFLIB_SqrtPoly` function is implemented as a function call.

**Example 3-14. Implementation Code**

```c
#include "gflib.h"

static Frac32 mf32Input;
static Frac16 mf16Output;

void main(void)
{
    /* input value 0.5 */
    mf32Input = FRAC32(0.5);

    /* Compute the sine value */
    mf16Output = GFLIB_SqrtPoly(mf32Input);
}
```

### 3.14.11 See Also

See `GFLIB_SqrtIter` for more information.
3.14.12 Performance

Table 3-33. Performance of GFLIB_SqrtPoly function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>65</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>34</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>22/22 cycles</td>
</tr>
<tr>
<td>Max</td>
<td>90/85 cycles</td>
</tr>
</tbody>
</table>
3.15  **GFLIB_SqrtIter**

The function calculates the square root value of the argument using four iterations.

### 3.15.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_SqrtIter(Frac32 f32Arg)
```

### 3.15.2 Prototype

```c
asm Frac16 GFLIB_SqrtIterFAsm(Frac32 f32Arg)
```

### 3.15.3 Arguments

#### Table 3-34. Function Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f32Arg</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Input argument; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
</tbody>
</table>

### 3.15.4 Availability

This library module is available in the C-callable interface assembly format. This library module is targeted for the DSC 56F80xx platform.

### 3.15.5 Dependencies

List of all dependent files:
- GFLIB_SqrtAsm.h
- GFLIB_SqrtDefAsm.h
- GFLIB_types.h

### 3.15.6 Description

The function **GFLIB_SqrtIter** calculates computes the square root of the input argument using the following steps:

1. The argument is normalized to a range of a 32-bit signed number where the number of shift is saved.
2. The four iterations use this equation:
3. The final square root is

\[ Y = 2 \cdot X \cdot Y_4 \]  \hspace{1cm} \text{Eqn. 3-43}

4. As the number was shifted to the left at the beginning, at the end it must be shifted to the right by the half of the shifts. Here arise two cases:

a) The number of shifts is odd, the 0.5 shift can be represented by the following formula. So the result is multiplied by 0.70711 and then it is shifted to the right by the entire number of half of the shifts.

\[ 2^{-\frac{1}{2}} = \frac{1}{\sqrt{2}} = 0.70711 \]  \hspace{1cm} \text{Eqn. 3-44}

b) The number of shifts is even, so the result is shifted to the right by the half of the shifts.

The algorithm uses the hardware do-loop instructions for the iteration process.

### 3.15.7 Returns

For the argument equal to or larger than zero the function GFLIB_SqrtIter returns the square root of the argument. For the negative arguments the function returns undefined values.

### 3.15.8 Range Issues

The input data value is in the range of <0,1), expressed with the 32-bit precision. The output data value is in the range of <0, 1) expressed with the 16-bit precision.

### 3.15.9 Special Issues

The GFLIB_SqrtIter function is the saturation mode independent.

### 3.15.10 Implementation

The GFLIB_SqrtIter function is implemented as a function call.

#### Example 3-15. Implementation Code

```c
#include "gflib.h"

static Frac32 mf32Input;
static Frac16 mf16Output;
```
void main(void)
{
    /* input value 0.5 */
mf32Input = FRAC32(0.5);

    /* Compute the sine value */
mf16Output = GFLIB_SqrtIter(mf32Input);
}

3.15.11 See Also

See GFLIB_SqrtPoly for more information.

3.15.12 Performance

Table 3-35. Performance of GFLIB_SqrtIter function

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Code Size (words)</td>
<td>28</td>
</tr>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min 65 cycles</td>
</tr>
<tr>
<td></td>
<td>Max 65 cycles</td>
</tr>
</tbody>
</table>
3.16 GFLIB_Lut

The function approximates a one-dimensional arbitrary user function using the interpolation lookup method. The user function is stored in the table of size specified in uw16TableSize and pointed to by *pf16Table pointer.

3.16.1 Synopsis

```
#include "gflib.h"
Frac16 GFLIB_Lut(Frac16 f16Arg, Frac16 *pf16Table, UWord16 uw16TableSize)
```

3.16.2 Prototype

```
asm Frac16 GFLIB_LutFAsm(Frac16 f16Arg, const Frac16 *pf16Table, UWord16 uw16TableSize)
```

3.16.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pf16Table</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to the values table</td>
</tr>
<tr>
<td>uw16TableSize</td>
<td>In</td>
<td>UI16</td>
<td>0x0...0xFFFF</td>
<td>The table size in bit shifts of number 1.</td>
</tr>
</tbody>
</table>

3.16.4 Availability

This library module is available in the C-callable interface assembly format. This library module is targeted for the DSC 56F80xx platform.

3.16.5 Dependencies

List of all dependent files:
- GFLIB_LutAsm.h
- GFLIB_types.h

3.16.6 Description

The **GFLIB_Lut** fuses a table of the precalculated function points. These points are selected with a fixed step and must be in a number of $2^n$, where $n$ can be 1 through to 15.
The function finds two nearest precalculated points of the input argument and using the linear interpolation between these two points calculates the output value.

This algorithm serves for periodical functions i.e. if the input argument lies behind the last precalculated point of the function, the interpolation is calculated between the last and the first point of the table as if it was a periodical function.

![Algorithm Diagram](image)

**Figure 3-7. Algorithm Diagram**

### 3.16.7 Returns

The function `GFLIB_Lut` returns a value calculated from a linear interpolation between two points according to the input argument.

### 3.16.8 Range Issues

The input value is in the range of `<0,1)`, expressed with the 16-bit precision. The output data value is in the range of `<0, 1)` expressed with 16-bits precision. The table size depends on the available memory.

### 3.16.9 Special Issues

The function `GFLIB_Lut` requires the saturation mode to be set OFF.

### 3.16.10 Implementation

The `GFLIB_Lut` function is implemented as a function call.

#### Example 3-16. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16Input;
```

---

General Functions Library, Rev. 3
static Frac16 mf16Output;

/* 8-values table, 2 ^ 3 = 8 */
static UWord16 muw16TableSize = 3;
static Frac16 mudtTableValues[] =
{
    0, -16384, -32768, -16384, 0, 16384, 32767, 16384
};

void main(void)
{
    /* input value 0.6 */
    mf16Input = FRAC16(-0.125);

    /* turns off the saturation */
    __turn_off_sat();

    /* Compute the look-up table algorithm */
    mf16Output = GFLIB_Lut(mf16Input, mudtTableValues,
                           muw16TableSize);
}

3.16.11 Performance

<table>
<thead>
<tr>
<th>Table 3-37. Performance of GFLIB_Lut function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Code Size (words)</strong></td>
</tr>
<tr>
<td><strong>Data Size (words)</strong></td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
</tr>
<tr>
<td>Min</td>
</tr>
<tr>
<td>Max</td>
</tr>
</tbody>
</table>
3.17  GFLIB_Ramp16

The function calculates a 16-bit version of the up/down ramp with the step increment/decrement defined in the pParam structure.

3.17.1  Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_Ramp16(Frac16 f16Desired, Frac16 f16Actual, const
GFLIB_RAMP16_T *pudtParam)
```

3.17.2  Prototype

```c
asm Frac16 GFLIB_Ramp16FAsm(Frac16 f16Desired, Frac16 f16Actual, const
GFLIB_RAMP16_T *pudtParam)
```

3.17.3  Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Desired</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Desired value; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>f16Actual</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Actual value; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtParam</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to structure containing the ramp-up and -down increments</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_RAMP16_T</td>
<td>f16RampUp</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Ramp up increment</td>
</tr>
<tr>
<td>GFLIB_RAMP16_T</td>
<td>f16RampDown</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Ramp down increment</td>
</tr>
</tbody>
</table>

3.17.4  Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

3.17.5  Dependencies

List of all dependent files:
- GFLIB_RampAsm.h
3.17.6 Description

The **GFLIB_Ramp16** calculates the 16-bit ramp of the actual value by the up or down increments contained in the pudtParam structure.

If the desired value is greater than the actual value, the function adds the ramp-up value to the actual value. The output cannot be greater than the desired value.

If the desired value is lower than the actual value, the function subtracts the ramp-down value from the actual value. The output cannot be lower than the desired value.

![Algorithm Diagram](image)

3.17.7 Returns

If f16Desired is greater than f16Actual, the function returns f16Actual + the ramp-up value until f16Desired is reached.

If f16Desired is less than f16Actual, the function returns f16Actual - the ramp-down value until the f16Desired is reached.

3.17.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are in the range <-1,1).
3.17.9 Special Issues

The function **GFLIB_Ramp16** is the saturation mode independent.

3.17.10 Implementation

The **GFLIB_Ramp16** function is implemented as a function call.

```
#include "gflib.h"

static Frac16 mf16DesiredValue;
static Frac16 mf16ActualValue;

/* Ramp parameters */
static GFLIB_RAMP16_T mudtRamp16;

void Isr(void);

void main(void)
{
    /* Ramp parameters initialization */
    mudtRamp16.f16RampUp = FRAC16(0.25);
    mudtRamp16.f16RampDown = FRAC16(0.25);

    /* Desired value initialization */
    mf16DesiredValue = FRAC16(1.0);

    /* Actual value initialization */
    mf16ActualValue = 0;
}

void Isr(void)
{
    /* Ramp generation */
    mf16ActualValue = GFLIB_Ramp16(mf16DesiredValue, 
    mf16ActualValue, &mudtRamp16);
}
```

3.17.11 See Also

See **GFLIB_Ramp32**, **GFLIB_DynRamp16** and **GFLIB_DynRamp32** for more information.
### 3.17.12 Performance

#### Table 3-40. Performance of `GFLIB_Ramp16` function

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Code Size (words)</strong></td>
<td>18</td>
</tr>
<tr>
<td><strong>Data Size (words)</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>Max</td>
</tr>
</tbody>
</table>
3.18  GFLIB_Ramp32

The function calculates a 32-bit version of the up/down ramp with the step increment/decrement defined in the pParam structure.

3.18.1  Synopsis

```
#include "gflib.h"
Frac32 GFLIB_Ramp32(Frac32 f32Desired, Frac32 f32Actual, const GFLIB_RAMP32_T *pudtParam)
```

3.18.2  Prototype

```
asm Frac32 GFLIB_Ramp32FAsm(Frac32 f32Desired, Frac32 f32Actual, const GFLIB_RAMP32_T *pudtParam)
```

3.18.3  Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f32Desired</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Desired value; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>f32Actual</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Actual value; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtParam</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to structure containing the ramp-up and down increments</td>
</tr>
</tbody>
</table>

3.18.4  Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

3.18.5  Dependencies

List of all dependent files:
- GFLIB_RampAsm.h

```
```
3.18.6 Description

The **GFLIB_Ramp32** calculates the 32-bit ramp of the actual value by the up or down increments contained in the pudtParam structure.

If the desired value is greater than the actual value, the function adds the ramp-up value to the actual value. The output cannot be greater than the desired value.

If the desired value is lower than the actual value, the function subtracts the ramp-down value from the actual value. The output cannot be lower than the desired value.

3.18.7 Returns

If f32Desired is greater than f32Actual, the function returns f32Actual + the ramp-up value until the f32Desired is reached.

If f32Desired is less than f32Actual, the function returns f32Actual - the ramp-down value until f32Desired is reached.

3.18.8 Range Issues

The input data value is in the range of <-1,1) in the 32-bit dynamics and the output data values are in the range <-1,1) in the 32-bit dynamics.
3.18.9 Special Issues

The function GFLIB_Ramp32 is the saturation mode independent.

3.18.10 Implementation

The GFLIB_Ramp32 function is implemented as a function.

```
Example 3-18. Implementation Code

#include "gflib.h"

static Frac32 mf32DesiredValue;
static Frac32 mf32ActualValue;

/* Ramp parameters */
static GFLIB_RAMP32_T mudtRamp32;

void Isr(void);

void main(void)
{
  /* Ramp parameters initialization */
  mudtRamp32.f32RampUp = FRAC32(0.25);
  mudtRamp32.f32RampDown = FRAC32(0.25);

  /* Desired value initialization */
  mf32DesiredValue = FRAC32(1.0);

  /* Actual value initialization */
  mf32ActualValue = 0;
}

/* Periodical function or interrupt */
void Isr(void)
{
  /* Ramp generation */
  mf32ActualValue = GFLIB_Ramp32(mf32DesiredValue,
                              mf32ActualValue, &mudtRamp32);
}
```

3.18.11 See Also

See GFLIB_Ramp16, GFLIB_DynRamp16 and GFLIB_DynRamp32 for more information.
3.18.12  Performance

Table 3-43. Performance of GFLIB_Ramp32 function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>49/42 cycles</td>
</tr>
<tr>
<td>Max</td>
<td>49/42 cycles</td>
</tr>
</tbody>
</table>
3.19 GFLIB_DynRamp16

This calculates a 16-bit version of the ramp with a different set of up/down parameters depending on the state of uw16SatFlag. If uw16SatFlag is set, the ramp counts up/down towards the f16Instant value.

3.19.1 Synopsis

```c
#include "gflib.h"

Frac16 GFLIB_DynRamp16(Frac16 f16Desired, Frac16 f16Instant, UWord16 uw16SatFlag, GFLIB_DYNRAMP16_T *pudtParam)
```

3.19.2 Prototype

```asm
asm Frac16 GFLIB_DynRamp16FAsm(Frac16 f16Desired, Frac16 f16Instant, UWord16 uw16SatFlag, GFLIB_DYNRAMP16_T *pudtParam)
```

3.19.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Desired</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Desired value; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>f16Instant</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Instant value; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>uw16SatFlag</td>
<td>In</td>
<td>UI16</td>
<td>0x00...0xFFFF</td>
<td>Saturation flag</td>
</tr>
<tr>
<td>*pudtParam</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to structure containing the ramp-up and -down increments, saturation ramp-up and -down increments and the last actual values</td>
</tr>
</tbody>
</table>

### Table 3-45. User Type Definitions

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_DYNRAMP16_T</td>
<td>f16RampUp</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Ramp up increment</td>
</tr>
<tr>
<td></td>
<td>f16RampDown</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Ramp down increment</td>
</tr>
<tr>
<td></td>
<td>f16RampUpSat</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Ramp up increment when saturation</td>
</tr>
<tr>
<td></td>
<td>f16RampDownSat</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Ramp down increment when saturation</td>
</tr>
<tr>
<td></td>
<td>f16Actual</td>
<td>In/Out</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Actual value</td>
</tr>
</tbody>
</table>
3.19.4 Availability

This library module is available in the C-callable interface assembly format.
This library module is targeted for the DSC 56F80xx platform.

3.19.5 Dependencies

List of all dependent files:
- GFLIB_DynRampAsm.h
- GFLIB_types.h

3.19.6 Description

If the saturation flag is zero, the `GFLIB_DynRamp16` function calculates the 16-bit ramp of the actual value (which is contained in the pParam structure) toward the desired value by the up or down increments contained in the pudtParam structure. If the saturation flag is non-zero, the function calculates the ramp toward the instant value using the saturation up or down increments contained in the pudtParam structure.

If the desired value is greater than the actual value, the function adds the ramp-up value to the actual value. The output cannot be greater than the desired value (saturation flag is zero) nor the instant value (saturation flag is non-zero).

If the desired value is lower than the actual value, the function subtracts the ramp-down value from the actual value. The output cannot be lower than the desired value (saturation flag is zero) nor the instant value (saturation flag is non-zero).
3.19.7 Returns

The GFLIB_DynRamp16 function returns the 16-bit ramp value as described in Section 3.19.6, “Description”.

3.19.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are in the range <-1,1).

3.19.9 Special Issues

The GFLIB_DynRamp16 function calculation is correct regardless of saturation mode.
### 3.19.10 Implementation

The **GFLIB_DynRamp16** function is implemented as a function call.

#### Example 3-19. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16DesiredValue;
static Frac16 mf16InstantValue;
static UWord16 muw16SatFlag;
static Frac16 mf16RampOutput;

/* Ramp parameters */
static GFLIB_DYNRAMP16_T mudtDynRamp16;

void Isr(void);

void main(void)
{
    /* Ramp parameters initialization */
    mudtDynRamp16.f16RampUp = FRAC16(0.25);
    mudtDynRamp16.f16RampDown = FRAC16(0.25);
    mudtDynRamp16.f16RampUpSat = FRAC16(0.125);
    mudtDynRamp16.f16RampDownSat = FRAC16(0.125);

    /* Desired value initialization */
    mf16DesiredValue = FRAC16(1.0);

    /* Instant value initialization */
    mf16InstantValue = 0;

    /* Actual value initialization */
    mudtDynRamp16.f16Actual = mf16InstantValue;

    /* Saturation flag initialization */
    muw16SatFlag = 0;
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Ramp generation */
    mf16RampOutput = GFLIB_DynRamp16(mf16DesiredValue, 
                                    mf16InstantValue, 
                                    muw16SatFlag, 
                                    &mudtDynRamp16);
}
```

### 3.19.11 See Also

See **GFLIB_Ramp16**, **GFLIB_Ramp32** and **GFLIB_DynRamp32** for more information.
3.19.12 Performance

Table 3-46. Performance of GFLIB_DynRamp16 function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>49/50 cycles</td>
</tr>
<tr>
<td>Max</td>
<td>49/50 cycles</td>
</tr>
</tbody>
</table>
3.20 GFLIB_DynRamp32

The function calculates a 32-bit version of the ramp with a different set of the up/down parameters depending on the state of uw16SatFlag. If uw16SatFlag is set, the ramp counts up/down towards the f32Instant value.

3.20.1 Synopsis

#define "gflib.h"
Frac32 GFLIB_DynRamp32(Frac32 f32Desired, Frac32 f32Instant, UWord16 uw16SatFlag, GFLIB_DYNRAMP32_T *pudtParam)

3.20.2 Prototype

asm Frac32 GFLIB_DynRamp32FAsm(Frac32 f32Desired, Frac32 f32Instant, UWord16 uw16SatFlag, GFLIB_DYNRAMP32_T *pudtParam)

3.20.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f32Desired</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Desired value; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>f32Instant</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Instant value (measured or reported value); the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>uw16SatFlag</td>
<td>In</td>
<td>UI16</td>
<td>0x0...0xFFFF</td>
<td>Saturation flag</td>
</tr>
<tr>
<td>*pudtParam</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to structure containing the ramp-up and -down increments, saturation ramp-up and -down increments and the last actual values</td>
</tr>
</tbody>
</table>

Table 3-48. User Type Definitions

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_DYNRAMP32_T</td>
<td>f32RampUp</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Ramp up increment</td>
</tr>
<tr>
<td></td>
<td>f32RampDown</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Ramp down increment</td>
</tr>
<tr>
<td></td>
<td>f32RampUpSat</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Ramp up increment when saturation</td>
</tr>
<tr>
<td></td>
<td>f32RampDownSat</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Ramp down increment when saturation</td>
</tr>
<tr>
<td></td>
<td>f32Actual</td>
<td>In/Out</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Actual value</td>
</tr>
</tbody>
</table>
3.20.4 Availability

This library module is available in the C-callable interface assembly format.
This library module is targeted for the DSC 56F80xx platform.

3.20.5 Dependencies

List of all dependent files:
- GFLIB_DynRampAsm.h
- GFLIB_types.h

3.20.6 Description

If the saturation flag is zero, the GFLIB_DynRamp32 function calculates the 32-bit ramp of the actual value (which is contained in the pParam structure) toward the desired value by the up or down increments contained in the pudtParam structure. If the saturation flag is non-zero, the function calculates the ramp toward the instant value using the saturation up or down increments contained in the pudtParam structure.

If the desired value is greater than the actual value, the function adds the ramp-up value to the actual value. The output cannot be greater than the desired value (saturation flag is zero) nor the instant value (saturation flag is non-zero).

If the desired value is lower than the actual value, the function subtracts the ramp-down value from the actual value. The output cannot be lower than the desired value (saturation flag is zero) nor the instant value (saturation flag is non-zero).
3.20.7 Returns

The `GFLIB_DynRamp32` function returns a 32-bit value.

3.20.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are in the range <-1,1).

3.20.9 Special Issues

The `GFLIB_DynRamp32` function calculation is correct regardless of saturation mode.

3.20.10 Implementation

The `GFLIB_DynRamp32` function is implemented as a function call.
Example 3-20. Implementation Code

```c
#include "gflib.h"

static Frac32 mf32DesiredValue;
static Frac32 mf32InstantValue;
static UWord16 muw16SatFlag;
static Frac32 mf32RampOutput;

/* Ramp parameters */
static GFLIB_DYNRAMP32_T mudtDynRamp32;

void Isr(void);

void main(void)
{
    /* Ramp parameters initialization */
    mudtDynRamp32.f32RampUp = FRAC32(0.25);
    mudtDynRamp32.f32RampDown = FRAC32(0.25);
    mudtDynRamp32.f32RampUpSat = FRAC32(0.125);
    mudtDynRamp32.f32RampDownSat = FRAC32(0.125);

    /* Desired value initialization */
    mf32DesiredValue = FRAC32(1.0);

    /* Instant value initialization */
    mf32InstantValue = 0;

    /* Actual value initialization */
    mudtDynRamp32.f32Actual = mf32InstantValue;

    /* Saturation flag initialization */
    muw16SatFlag = 0;

    /* Periodical function or interrupt */
    void Isr(void)
    {
        /* Ramp generation */
        mf32RampOutput = GFLIB_DynRamp32(mf32DesiredValue,
                                         mf32InstantValue, muw16SatFlag, &mudtDynRamp32);
    }
}
```

### 3.20.11 See Also

See **GFLIB_Ramp16**, **GFLIB_Ramp32** and **GFLIB_DynRamp16** for more information.
3.20.12 Performance

Table 3-49. Performance of GFLIB_DynRamp32 function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>60/51 cycles</td>
</tr>
<tr>
<td>Max</td>
<td>60/51 cycles</td>
</tr>
</tbody>
</table>
3.21 GFLIB_Limit16

The function calculates the 16-bit scalar upper/lower limitation of the input signal.

3.21.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_Limit16(Frac16 f16Arg, const GFLIB_LIMIT16_T *pudtLimit)
```

3.21.2 Prototype

```c
asm Frac16 GFLIB_Limit16FAsm(Frac16 f16Arg, const GFLIB_LIMIT16_T *pudtLimit)
```

3.21.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtLimit</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to structure containing the upper and lower limits</td>
</tr>
</tbody>
</table>

3.21.4 Availability

This library module is available in the C-callable interface assembly format. This library module is targeted for the DSC 56F80xx platform.

3.21.5 Dependencies

List of all dependent files:
- GFLIB_LimitAsm.h
- GFLIB_types.h
3.21.6 Description

The **GFLIB_Limit16** function returns the trimmed number according to the 16-bit upper and lower limits.

![Figure 3-12. Algorithm Transition](image)

3.21.7 Returns

The **GFLIB_Limit16** function returns the trimmed number according to the 16-bit upper and lower limits.

3.21.8 Range Issues

The input data value is in the range of \(-1, 1\) and the output data values are in the range \(<f16UpperLimit, f16LowerLimit>\).

3.21.9 Special Issues

The **GFLIB_Limit16** function calculation is correct regardless of saturation mode.

3.21.10 Implementation

The **GFLIB_Limit16** function is implemented as a function call.

```c
#include "gflib.h"

static Frac16 mf16InputValue;
static Frac16 mf16OutputValue;

/* Trim parameters */
static GFLIB_LIMIT16_T mudtLimit16;

void main(void)
{
    /* Limit parameters initialization */
    mudtLimit16.f16UpperLimit = FRAC16(0.5);
    mudtLimit16.f16LowerLimit = FRAC16(-0.5);
}
```

General Functions Library, Rev. 3
/* Desired value initialization */
mf16InputValue = FRAC16(0.6);

/* Limitation */
mf16OutputValue = GFLIB_Limit16(mf16InputValue, &mudtLimit16);
}

### 3.21.11 See Also

See [GFLIB_Limit32](#), [GFLIB_LowerLimit16](#), [GFLIB_LowerLimit32](#), [GFLIB_UpperLimit16](#) and [GFLIB_UpperLimit32](#) for more information.

### 3.21.12 Performance

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td>Min 25/25 cycles</td>
</tr>
</tbody>
</table>
3.22 GFLIB_Limit32

The function calculates the 32-bit scalar upper/lower limitation of the input signal.

3.22.1 Synopsis

```c
#include "gflib.h"
Frac32 GFLIB_Limit32(Frac32 f32Arg, const GFLIB_LIMIT32_T *pudtLimit)
```

3.22.2 Prototype

```c
asm Frac32 GFLIB_Limit32FAsm(Frac32 f32Arg, const GFLIB_LIMIT32_T *pudtLimit)
```

3.22.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f32Arg</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Input argument; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtLimit</td>
<td>In</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to structure containing the upper and lower limits</td>
</tr>
</tbody>
</table>

3.22.4 Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

3.22.5 Dependencies

List of all dependent files:
- GFLIB_LimitAsm.h
- GFLIB_types.h
3.22.6 Description

The **GFLIB_Limit32** function returns the trimmed number according to the 32-bit upper and lower limits.

![Figure 3-13. Algorithm Transition](image)

3.22.7 Returns

The **GFLIB_Limit32** function returns the trimmed number according to the 32-bit upper and lower limits.

3.22.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are in the range <f32UpperLimit, f32LowerLimit>

3.22.9 Special Issues

The **GFLIB_Limit32** function calculation is correct regardless of saturation mode.

3.22.10 Implementation

The **GFLIB_Limit32** function is implemented as a function call.

```c
#include "gflib.h"

static Frac32 mf32InputValue;
static Frac32 mf32OutputValue;

/* Trim parameters */
static GFLIB_LIMIT32_T mudtLimit32;

void main(void)
{
    /* Limit parameters initialization */
    mudtLimit32.f32UpperLimit = FRAC32(0.5);
    mudtLimit32.f32LowerLimit = FRAC32(-0.5);
```

---

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/* Desired value initialization */
mf32InputValue = FRAC32(0.6);

/* Limitation */
mf32OutputValue = GFLIB_Limit32(mf32InputValue, &mudtLimit32);
}

3.22.11 See Also

See GFLIB_Limit16, GFLIB_LowerLimit16, GFLIB_LowerLimit32, GFLIB_UpperLimit16 and GFLIB_UpperLimit32 for more information.

3.22.12 Performance

Table 3-55. Performance of GFLIB_Limit32 function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td>Min 26/24 cycles</td>
</tr>
</tbody>
</table>


3.23 GFLIB_LowerLimit16

The function calculates the 16-bit scalar lower limitation of the input signal.

3.23.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_LowerLimit16(Frac16 f16Arg, Frac16 f16LowerLimit)
```

3.23.2 Prototype

```asm
asm Frac16 GFLIB_LowerLimit16FAsm(Frac16 f16Arg, Frac16 f16LowerLimit)
```

3.23.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>f16LowerLimit</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Lower limit trim; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
</tbody>
</table>

3.23.4 Availability

This library module is available in the C-callable interface assembly format.
This library module is targeted for the DSC 56F80xx platform.

3.23.5 Dependencies

List of all dependent files:
- GFLIB_LimitAsm.h
- GFLIB_types.h

3.23.6 Description

The **GFLIB_LowerLimit16** function returns the trimmed number according to the 16-bit lower limit. The functionality can be explained with use of Figure 3-14.
3.23.7 Returns

The `GFLIB_LowerLimit16` function returns the trimmed number according to the 16-bit lower limit.

3.23.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are in the range <f16LowerLimit, 1).

3.23.9 Special Issues

The `GFLIB_LowerLimit16` function calculation is correct regardless of saturation mode.

3.23.10 Implementation

The `GFLIB_LowerLimit16` function is implemented as a function.

Example 3-23. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16InputValue;
static Frac16 mf16OutputValue;

/* Trim parameter */
static Frac16 mf16TrimValue;

void main(void)
{
    /* Limit parameter initialization */
    mf16TrimValue = FRAC16(-0.5);
```

---

GFLIB_LowerLimit16

General Functions Library, Rev. 3

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/* Desired value initialization */
mf16InputValue = FRAC16(-0.6);

/* Limitation */
mf16OutputValue = GFLIB_LowerLimit16(mf16InputValue, mf16TrimValue);
}

### 3.23.11 See Also

See `GFLIB_Limit16`, `GFLIB_Limit32`, `GFLIB_LowerLimit32`, `GFLIB_UpperLimit16` and `GFLIB_UpperLimit32` for more information.

### 3.23.12 Performance

Table 3-57. Performance of `GFLIB_LowerLimit16` function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td>Min 18/19 cycles</td>
</tr>
</tbody>
</table>
3.24 GFLIB_LowerLimit32

The function calculates the 32-bit scalar lower limitation of the input signal.

3.24.1 Synopsis

```c
#include "gflib.h"
Frac32 GFLIB_LowerLimit32(Frac32 f32Arg, Frac32 f32LowerLimit)
```

3.24.2 Prototype

```asm
asm Frac32 GFLIB_LowerLimit32FAsm(Frac32 f32Arg, Frac32 f32LowerLimit)
```

3.24.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f32Arg</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Input argument; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>f32LowerLimit</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Lower limit trim; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
</tbody>
</table>

3.24.4 Availability

This library module is available in the C-callable interface assembly format. This library module is targeted for the DSC 56F80xx platform.

3.24.5 Dependencies

List of all dependent files:

- GFLIB_LimitAsm.h
- GFLIB_types.h

3.24.6 Description

The GFLIB_LowerLimit32 function returns the trimmed number according to the 32-bit lower limit. The functionality can be explained with use of Figure 3-15.
3.24.7 Returns

The GFLIB_LowerLimit32 function returns the trimmed number according to the 32-bit lower limit.

3.24.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are in the range <f32LowerLimit, 1).

3.24.9 Special Issues

The GFLIB_LowerLimit32 function calculation is correct regardless of saturation mode.

3.24.10 Implementation

The GFLIB_LowerLimit32 function is implemented as a function call.

Example 3-24. Implementation Code

```c
#include "gflib.h"

static Frac32 mf32InputValue;
static Frac32 mf32OutputValue;

/* Trim parameter */
static Frac32 mf32TrimValue;

void main(void)
{   /* Limit parameter initialization */
    mf32TrimValue = FRAC32(-0.5);
```
/* Desired value initialization */
mf32InputValue = FRAC32(-0.6);

/* Limitation */
mf32OutputValue = GFLIB_LowerLimit32(mf32InputValue, 
    mf32TrimValue);
}

3.24.11 See Also

See GFLIB_Limit16, GFLIB_Limit32, GFLIB_LowerLimit16, 
GFLIB_UpperLimit16 and GFLIB_UpperLimit32 for more information.

3.24.12 Performance

Table 3-59. Performance of GFLIB_LowerLimit32 function

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Code Size (words)</td>
<td>3</td>
</tr>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>17/17 cycles</td>
</tr>
<tr>
<td>Max</td>
<td>17/17 cycles</td>
</tr>
</tbody>
</table>
3.25 GFLIB_UpperLimit16

The function calculates the 16-bit scalar upper limitation of the input signal.

3.25.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_UpperLimit16(Frac16 f16Arg, Frac16 f16UpperLimit)
```

3.25.2 Prototype

```asm
asm Frac16 GFLIB_UpperLimit16FAsm(Frac16 f16Arg, Frac16 f16UpperLimit)
```

3.25.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>f16UpperLimit</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Upper limit trim; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
</tbody>
</table>

3.25.4 Availability

This library module is available in the C-callable interface assembly format. This library module is targeted for the DSC 56F80xx platform.

3.25.5 Dependencies

List of all dependent files:
- GFLIB_LimitAsm.h
- GFLIB_types.h

3.25.6 Description

The GFLIB_UpperLimit16 function returns the trimmed number according to the 16-bit upper limit. The functionality can be explained with use of Figure 3-16.
3.25.7 Returns

The GFLIB_UpperLimit16 function returns the trimmed number according to the 16-bit upper limit.

3.25.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are in the range <-1, f16UpperLimit>.

3.25.9 Special Issues

The GFLIB_UpperLimit16 function calculation is correct regardless of saturation mode.

3.25.10 Implementation

The GFLIB_UpperLimit16 function is implemented as a function call.

Example 3-25. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16InputValue;
static Frac16 mf16OutputValue;

/* Trim parameter */
static Frac16 mf16TrimValue;

void main(void)
{
    /* Limit parameter initialization */
    mf16TrimValue = FRAC16(0.5);

    /* Desired value initialization */
    mf16InputValue = FRAC16(0.6);
}
```

General Functions Library, Rev. 3
/* Limitation */
mf16OutputValue = GFLIB_UpperLimit16(mf16InputValue, mf16TrimValue);
}

### 3.25.11 See Also

See [GFLIB Limit16](#), [GFLIB Limit32](#), [GFLIB LowerLimit16](#), [GFLIB LowerLimit32](#) and [GFLIB UpperLimit32](#) for more information.

### 3.25.12 Performance

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Code Size (words)</td>
<td>5</td>
</tr>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>18/18 cycles</td>
</tr>
<tr>
<td></td>
<td>18/18 cycles</td>
</tr>
</tbody>
</table>
3.26 **GFLIB_UpperLimit32**

The function calculates the 32-bit scalar upper limitation of the input signal.

### 3.26.1 Synopsis

```c
#include "gflib.h"
Frac32 GFLIB_UpperLimit32(Frac32 f32Arg, Frac32 f32UpperLimit)
```

### 3.26.2 Prototype

```assembly
asm Frac32 GFLIB_UpperLimit32FAsm(Frac32 f32Arg, Frac32 f32UpperLimit)
```

### 3.26.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f32Arg</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Input argument; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>f32UpperLimit</td>
<td>In</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFFF</td>
<td>Lower limit trim; the Frac32 data type is defined in header file GFLIB_types.h</td>
</tr>
</tbody>
</table>

### 3.26.4 Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

### 3.26.5 Dependencies

List of all dependent files:
- GFLIB_LimitAsm.h
- GFLIB_types.h

### 3.26.6 Description

The **GFLIB_UpperLimit32** function returns the trimmed number according to the 32-bit upper limit. The functionality can be explained with use of Figure 3-17.
3.26.7 Returns

The **GFLIB_UpperLimit32** function returns the trimmed number according to the 32-bit upper limit.

3.26.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are in the range <-1, f32UpperLimit>.

3.26.9 Special Issues

The **GFLIB_UpperLimit32** function calculation is correct regardless of saturation mode.

3.26.10 Implementation

The **GFLIB_UpperLimit32** function is implemented as a function call.

**Example 3-26. Implementation Code**

```c
#include "gflib.h"

static Frac32 mf32InputValue;
static Frac32 mf32OutputValue;

/* Trim parameter */
static Frac32 mf32TrimValue;

void main(void)
{
    /* Limit parameter initialization */
    mf32TrimValue = FRAC32(0.5);

    /* Desired value initialization */
    mf32InputValue = FRAC32(0.6);
```
/* Limitation */
mf32OutputValue = GFLIB_UpperLimit32(mf32InputValue, 
mf32TrimValue);
}

### 3.26.11 See Also

See [GFLIB Limit16](#), [GFLIB Limit32](#), [GFLIB LowerLimit16](#), [GFLIB LowerLimit32](#) and [GFLIB UpperLimit16](#) for more information.

### 3.26.12 Performance

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
<td><strong>Min</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Max</strong></td>
</tr>
</tbody>
</table>
3.27 GFLIB_Sgn

The function calculates signum of the input argument. The function returns:

- $0x7FFF$ if $X > 0$
- $0$ if $X = 0$
- $0x8000$ if $X < 0$

3.27.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_Sgn(Frac16 f16Arg)
```

3.27.2 Prototype

```c
asm Frac16 GFLIB_SgnFAsm(Frac16 f16Arg)
```

3.27.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...</td>
<td>Input argument; the Frac16 data type is</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0x7FFF</td>
<td>defined in header file GFLIB_types.h</td>
</tr>
</tbody>
</table>

3.27.4 Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

3.27.5 Dependencies

List of all dependent files:

- GFLIB_SgnAsm.h
- GFLIB_types.h

3.27.6 Description

The function GFLIB_Sgn calculates the signum of the input argument as depicted in Figure 3-18. For the input values smaller than zero the output is set to 0x8000 and for the values greater than zero the output is set to 0x7FFF. The output is set to zero, if the input argument is equal to zero.
3.27.7 Returns

The GFLIB_Sgn function returns the sign of the argument.

Table 3-65. Input and Output Returns for the GFLIB_Sgn Function

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>= 0</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 0</td>
<td>1 (32767)</td>
</tr>
<tr>
<td>&lt; 0</td>
<td>-1 (-32768)</td>
</tr>
</tbody>
</table>

3.27.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are 0, 1 or -1.

3.27.9 Special Issues

The GFLIB_Sgn function calculation is correct regardless of saturation mode.

3.27.10 Implementation

The GFLIB_Sgn function is implemented as a function call.

Example 3-27. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

void main(void)
{
    /* input value 0.6 */
    mf16Input = FRAC16(0.6);

    /* Compute the sgn value */
    /* General Functions Library, Rev. 3 */
```
mf16Output = GFLIB_Sgn(mf16Input);
}

3.27.11 See Also

See GFLIB_Sgn2 for more information.

3.27.12 Performance

<table>
<thead>
<tr>
<th>Table 3-66. Performance of GFLIB_Sgn function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code Size (words)</td>
</tr>
<tr>
<td>Data Size (words)</td>
</tr>
<tr>
<td>Execution Clock</td>
</tr>
<tr>
<td>Min</td>
</tr>
<tr>
<td>Max</td>
</tr>
</tbody>
</table>
3.28 GFLIB_Sgn2

The function calculates signum of the input argument with zero being considered as a positive value. The function returns:

0x7FFF if X >= 0
0x8000 if X < 0

3.28.1 Synopsis

```
#include "gflib.h"
Frac16 GFLIB_Sgn2(Frac16 f16Arg)
```

3.28.2 Prototype

```
asm Frac16 GFLIB_Sgn2FAsm(Frac16 f16Arg)
```

3.28.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Arg</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...</td>
<td>Input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0x7FFF</td>
<td></td>
</tr>
</tbody>
</table>

3.28.4 Availability

This library module is available in the C-callable interface assembly format. This library module is targeted for the DSC 56F80xx platform.

3.28.5 Dependencies

List of all dependent files:

- GFLIB_Sgn2Asm.h
- GFLIB_types.h

3.28.6 Description

The GFLIB_Sgn2 calculates the signum of the input argument as is depicted in Figure 3-19. For the input values smaller than zero the output is set to 0x8000 and for the values equal or greater than zero the output is set to 0x7FFF.
3.28.7 Returns

The GFLIB_Sgn2 function returns the sign of the argument:

Table 3-68.

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 0</td>
<td>1 (32767)</td>
</tr>
<tr>
<td>&lt; 0</td>
<td>-1 (-32768)</td>
</tr>
</tbody>
</table>

3.28.8 Range Issues

The input data value is in the range of <-1,1) and the output data values are 1 (0x7FFF) or -1 (0x8000).

3.28.9 Special Issues

The GFLIB_Sgn2 function calculation is correct regardless of saturation mode.

3.28.10 Implementation

The GFLIB_Sgn2 function is implemented as a function call.

Example 3-28. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

void main(void)
{
    /* input value 0.6 */
    mf16Input = FRAC16(0.6);

    /* Compute the sgn value */
    mf16Output = GFLIB_Sgn2(mf16Input);
```

Figure 3-19. Algorithm Transition
3.28.11 See Also

See `GFLIB_Sgn` for more information.

3.28.12 Performance

<table>
<thead>
<tr>
<th>Table 3-69. Performance of <code>GFLIB_Sgn2</code> function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code Size (words)</td>
</tr>
<tr>
<td>Data Size (words)</td>
</tr>
<tr>
<td>Execution Clock</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
3.29 GFLIB_Hyst

The hysteresis function switches output between two predefined values when the input crosses the threshold values.

3.29.1 Synopsis

#include "gflib.h"

void GFLIB_Hyst(GFLIB_HYST_T *pudtHystVar)

3.29.2 Prototype

asm void GFLIB_HystFAsm(GFLIB_HYST_T *pudtHystVar)

3.29.3 Arguments

Table 3-70. Function Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Valid Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>*pudtHystVar</td>
<td>in/out</td>
<td>N/A</td>
<td>N/A</td>
<td>pointer to structure containing the input, output values, input thresholds and output constants.</td>
</tr>
</tbody>
</table>

Table 3-71. User type definitions

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Valid Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_HYST_T</td>
<td>f16In</td>
<td>in</td>
<td>SF16</td>
<td>$8000...$7FFF</td>
<td>input</td>
</tr>
<tr>
<td></td>
<td>f16Out</td>
<td>out</td>
<td>SF16</td>
<td>$8000...$7FFF</td>
<td>hysteresis output</td>
</tr>
<tr>
<td></td>
<td>f16HystOff</td>
<td>in</td>
<td>SF16</td>
<td>$8000...$7FFF</td>
<td>value determining the lower threshold</td>
</tr>
<tr>
<td></td>
<td>f16OutOff</td>
<td>in</td>
<td>SF16</td>
<td>$8000...$7FFF</td>
<td>value of output when the input is lower than f16HystOff</td>
</tr>
<tr>
<td></td>
<td>f16HystOn</td>
<td>in</td>
<td>SF16</td>
<td>$8000...$7FFF</td>
<td>value determining the upper threshold</td>
</tr>
<tr>
<td></td>
<td>f16OutOn</td>
<td>in</td>
<td>SF16</td>
<td>$8000...$7FFF</td>
<td>value of output when the input is higher than f16HystOn</td>
</tr>
</tbody>
</table>
3.29.4 Availability

This library module is available in the C-callable interface assembly format.
This library module is targeted for the DSC 56F80xx platform.

3.29.5 Dependencies

List of all dependent files:
- GFLIB_HystAsm.h
- gflib.h

3.29.6 Description

The **GFLIB_Hyst** represents a hysteresis (or relay) function. The function switches output between the two predefined values. When the input is higher than upper threshold \( f_{16\text{HystOn}} \), the output is high; when the input is below another (lower) threshold \( f_{16\text{HystOff}} \), the output is low; when the input is between the two, the output retains its value.

![Figure 3-20. Hysteresis function](image)

For correct functionality, \( f_{16\text{HystOn}} \) must be greater than \( f_{16\text{HystOff}} \).

3.29.7 Returns

The calculated output of the function is contained in the function structure pointed to by the pointer \(*\text{pudtHystVar}\) in the variable \( f_{16\text{Out}} \).
3.29.8 Range Issues

The input and output data values are in the fractional range of <-1,1)

3.29.9 Special Issues

The function GFLIB_Hyst is the saturation mode independent.

3.29.10 Implementation

Example 3-29. Implementation Code

```c
#include "gflib.h"

static GFLIB_HYST_T gudtHyst = GFLIB_HYST_DEFAULT;
static Frac16 f16Out;

void main (void)
{
  gudtHyst.f16HystOn = FRAC16(0.5);
  gudtHyst.f16HystOff = FRAC16(-0.5);
  gudtHyst.f16OutOn = FRAC16(0.25);
  gudtHyst.f16OutOff = FRAC16(-0.25);

  /* Vary the input value to cross the threshold f16HystOn and f16HystOff */
  gudtHyst.f16In = FRAC16(-0.75);

  GFLIB_Hyst(&gudtHyst);

  f16Out = gudtHyst.f16Out;

  /* f16Out = 0xE000 (e.g. -0.25) if f16In <= 0xC000 (e.g. -0.5) */
  /* f16Out = 0x2000 (e.g. 0.25) if f16In >= 0x4000 (e.g. 0.5) */
}
```

3.29.11 Performance

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td>Execution Clock</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>Max</td>
</tr>
</tbody>
</table>
3.30 GFLIB_ControllerPIp

This calculates the parallel form of the Proportional-Integral (PI) regulator.

3.30.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_ControllerPIp(Frac16 f16InputErrorK,
GFLIB_CONTROLLER_PI_P_PARAMS_T *pudtPiParams, const Int16 *pi16SatFlag)
```

3.30.2 Prototype

```c
asm Frac16 GFLIB_ControllerPIpFAsm(Frac16 f16InputErrorK,
GFLIB_CONTROLLER_PI_P_PARAMS_T *pudtPiParams, const Int16 *pi16SatFlag)
```

3.30.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16InputErrorK</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Input error at step K processed by P and I terms of the PI algorithm</td>
</tr>
</tbody>
</table>
| *pudtPiParams    | In/Out | N/A   | N/A         | Pointer to a structure of PI controller parameters; the
GFLIB_CONTROLLER_PI_P_PARAMS_T data type is defined in the header file
GFLIB_ControllerPlpAsm.h |
| *pi16SatFlag     | In   | SI16   | 0...1       | Pointer to a 16-bit integer variable; if the integer variable passed into the function as a
pointer is set to 0, then the integral part is limited only by the PI controller limits.
If the integer variable is not zero, then the integral part is frozen immediately |
### 3.30.4 Availability

This library module is available in the C-callable interface assembly format. This library module is targeted for the DSC 56F80xx platform.

### 3.30.5 Dependencies

List of all dependent files:
- GFLIB_ControllerPIpAsm.h
- GFLIB_types.h

### 3.30.6 Description

The **GFLIB_ControllerPIp** function calculates the Proportional-Integral (PI) algorithm according to the equations below. The PI algorithm is implemented in the parallel (non-interacting) form allowing user to define the P and I parameters independently without interaction. The controller output is limited and the limit values (f16UpperLimit and f16LowerLimit) are defined by the user. The PI algorithm is implemented in the parallel (non-interacting) form allowing user to define the P and I parameters independently without interaction. The controller output is limited and the limit values (f16UpperLimit and f16LowerLimit) are defined by the user.

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_CONTROLLER_PI_P_PARAMS_T</td>
<td>f16PropGain</td>
<td>In</td>
<td>SF16</td>
<td>0x0...0x7FFF</td>
<td>Proportional gain</td>
</tr>
<tr>
<td></td>
<td>f16IntegGain</td>
<td>In</td>
<td>SF16</td>
<td>0x0...0x7FFF</td>
<td>Integral gain</td>
</tr>
<tr>
<td></td>
<td>i16PropGainShift</td>
<td>In</td>
<td>SI16</td>
<td>0...13</td>
<td>Proportional gain shift</td>
</tr>
<tr>
<td></td>
<td>i16IntegGainShift</td>
<td>In</td>
<td>SI16</td>
<td>0...13</td>
<td>Integral gain shift</td>
</tr>
<tr>
<td></td>
<td>f32IntegPartK_1</td>
<td>In/Out</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFF</td>
<td>State variable; integral part at step k-1; can be modified outside of the function.</td>
</tr>
<tr>
<td></td>
<td>f16UpperLimit</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ...0x7FFF</td>
<td>Upper limit of the controller; f16UpperLimit &gt; f16LowerLimit</td>
</tr>
<tr>
<td></td>
<td>f16LowerLimit</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ...0x7FFF</td>
<td>Lower limit of the controller; f16UpperLimit &gt; f16LowerLimit</td>
</tr>
<tr>
<td></td>
<td>i16LimitFlag</td>
<td>Out</td>
<td>SI16</td>
<td>0 or 1</td>
<td>Limitation flag; if set to 1, the controller output reached f16UpperLimit or f16LowerLimit</td>
</tr>
</tbody>
</table>

**Table 3-74. User Type Definitions**

General Functions Library, Rev. 3
controller algorithm also returns a limitation flag. This flag named "i16LimitFlag" is the member of the structure of the PI controller parameters (GFLIB_CONTROLLER_PI_P_PARAMS_T). If the PI controller output reaches the upper or lower limit then i16LimitFlag = 1 otherwise i16LimitFlag = 0.

An anti-windup strategy is implemented by limiting the integral portion. There are two ways of limiting the integral portion:

- The integral state is limited by the controller limits, in the same way as the controller output.
- When the variable i16SatFlag set by the user software outside the PI controller function and passed into the function and the pointer pi16SatFlag is not zero, then the integral portion is frozen.

The PI algorithm in the continuous time domain:

\[
 u(t) = K \left[ e(t) + \frac{1}{T_I} \int_0^t e(\tau) d\tau \right] \quad \text{Eqn. 3-45}
\]

where
- \( e(t) \) - input error in the continuous time domain; processed by the P and I terms of the PI algorithm
- \( u(t) \) - controller output in the continuous time domain
- \( T_I \) - integral time constant - [s]

Equation 3-45 can be rewritten into the discrete time domain by approximating the integral and derivative terms.

The integral term is approximated by the Backward Euler method, also known as backward rectangular or right-hand approximation as follows.

\[
 u_I(k) = u_I(k-1) + T \cdot e(k) \quad \text{Eqn. 3-46}
\]

The discrete time domain representation of the PI algorithms

\[
 u(k) = K \cdot e(k) + u_I(k-1) + K_I \cdot e(k) \quad \text{Eqn. 3-47}
\]

where
- \( e(k) \) - input error at step k; processed by the P and I terms
- \( u(k) \) - controller output at step k
- \( K \) - proportional gain
- \( K_I \) - integral gain
- \( T \) - sampling time/period - [s]
The discrete time domain representation of the PI algorithm scaled into the fractional range.

\[ u_f(k) = K_{sc} \cdot e_f(k) + u_f(k-1) + K_{isc} \cdot e_f(k) \]  \hspace{1cm} \text{Eqn. 3-49} \\

where

\[ u_f(k) = u(k)/u_{\text{max}} \]  \hspace{1cm} \text{Eqn. 3-50} \\
\[ e_f(k) = e(k)/e_{\text{max}} \]  \hspace{1cm} \text{Eqn. 3-51} \\
\[ K_{sc} = K \cdot \frac{e_{\text{max}}}{u_{\text{max}}} \]  \hspace{1cm} \text{Eqn. 3-52} \\
\[ K_{isc} = K \cdot \frac{T}{T_i} = K_I \cdot \frac{e_{\text{max}}}{u_{\text{max}}} \]  \hspace{1cm} \text{Eqn. 3-53} \\

where

\[ e_{\text{max}} \] - input max range
\[ u_{\text{max}} \] - output max range

Each parameter (e.g. \( K_{isc} \)) of the PI algorithm is represented by two parameters in the processor implementation (e.g. \( f_{16}\text{IntegGain} \) and \( i_{16}\text{IntegGainShift} \)).

\[ f_{16}\text{PropGain} = K_{sc} \cdot 2^{-i_{16}\text{PropGainShift}} \]  \hspace{1cm} \text{Eqn. 3-54} \\
\[ f_{16}\text{IntegGain} = K_{isc} \cdot 2^{-i_{16}\text{IntegGainShift}} \]  \hspace{1cm} \text{Eqn. 3-55} \\

where

\[ 0 \leq f_{16}\text{PropGain} < 1 \]  \hspace{1cm} \text{Eqn. 3-56} \\
\[ 0 \leq f_{16}\text{IntegGain} < 1 \]  \hspace{1cm} \text{Eqn. 3-57} \\
\[ 0 \leq i_{16}\text{PropGainShift} < 14 \]  \hspace{1cm} \text{Eqn. 3-58} \\
\[ 0 \leq i_{16}\text{IntegGainShift} < 14 \]  \hspace{1cm} \text{Eqn. 3-59} \\

Example

Assumption: \( K_{isc} = 2.4 \)

In this case, \( K_{isc} \) cannot be directly interpreted as a fractional value because the range of fractional values is \((-1, 1)\) and the range of the parameter \( f_{16}\text{IntegGain} \) is \((-0, 1)\). It is necessary to scale the \( K_{isc} \).
parameter using i16IntegGainShift to fit the parameter f16IntegGain into the range <0,1)

Solution:
The most precise scaling approach is to scale down the parameter \( K_{isc} \) to have f16IntegGain in the following range
\[ 0.5 \leq f16\text{IntegGain} < 1 \]
and to calculate the corresponding i16IntegGainShift parameter.

\[
\frac{\log(K_{isc}) - \log(0.5)}{\log 2} \geq i16\text{IntegGainShift} \quad \text{Eqn. 3-60}
\]
\[
\frac{\log(2.4) - \log(0.5)}{\log 2} \geq i16\text{IntegGainShift} \quad \text{Eqn. 3-61}
\]
\[ 2.26 \geq i16\text{IntegGainShift} \quad \text{Eqn. 3-62} \]
\[
\frac{\log(K_{isc}) - \log(1)}{\log 2} < i16\text{IntegGainShift} \quad \text{Eqn. 3-63}
\]
\[
\frac{\log(K_{isc})}{\log 2} < i16\text{IntegGainShift} \quad \text{Eqn. 3-64}
\]
\[
\frac{\log(2.4)}{\log 2} < i16\text{IntegGainShift} \quad \text{Eqn. 3-65}
\]
\[ 1.26 < i16\text{IntegGainShift} \quad \text{Eqn. 3-66} \]

The parameter i16IntegGainShift is in the following range:
\[ 1.26 < i16\text{IntegGainShift} \leq 2.26 \quad \text{Eqn. 3-67} \]

Because this parameter is an integer value, the result is
\[ i16\text{IntegGainShift} = 2 \quad \text{Eqn. 3-68} \]

Then
\[ f16\text{IntegGain} = K_{isc} \cdot 2^{-i16\text{IntegGainShift}} \quad \text{Eqn. 3-69} \]
\[ f16\text{IntegGain} = 2.4 \cdot 2^{-2} = 0.6 \quad \text{Eqn. 3-70} \]

Result:
f16IntegGain = 0.6
i16IntegGainShift = 2
3.30.7 Returns

The function **GFLIB_ControllerPIp** returns a fractional value as a result of the PI algorithm. The value returned by the algorithm is in the following range:

\[ f_{\text{LowerLimit}} \leq \text{PIresult} \leq f_{\text{UpperLimit}} \]  \hspace{1cm} \text{Eqn. 3-71}

3.30.8 Range Issues

The PI controller parameters are in the following range

\[ 0 \leq f_{16}\text{PropGain} < 1 \]  \hspace{1cm} \text{Eqn. 3-72}

\[ 0 \leq f_{16}\text{IntegGain} < 1 \]  \hspace{1cm} \text{Eqn. 3-73}

\[ 0 \leq i_{16}\text{PropGainShift} < 14 \]  \hspace{1cm} \text{Eqn. 3-74}

\[ 0 \leq i_{16}\text{IntegGainShift} < 14 \]  \hspace{1cm} \text{Eqn. 3-75}

3.30.9 Special Issues

The function **GFLIB_ControllerPIp** is the saturation mode independent.

3.30.10 Implementation

**Example 3-30. Implementation Code**

```c
#include "glib.h"

static Frac16 mf16DesiredValue;
static Frac16 mf16MeasuredValue;
static Frac16 mf16ErrorK;
static Int16 mi16SatFlag;
static Frac16 mf16ControllerOutput;

/* Controller parameters */
static GFLIB_CONTROLLER_PI_P_PARAMS_T mudtControllerParam;

void Isr(void);

void main(void)
{
    /* Controller parameters initialization */
    mudtControllerParam.f16PropGain = FRAC16(0.5);
    mudtControllerParam.f16IntegGain = FRAC16(0.032);
    mudtControllerParam.i16PropGainShift = 1;
    mudtControllerParam.i16IntegGainShift = 0;
    mudtControllerParam.f32IntegPartK_1 = 0;
    mudtControllerParam.f16UpperLimit = FRAC16(0.8);
    mudtControllerParam.f16LowerLimit = FRAC16(-0.7);
```

**General Functions Library, Rev. 3**
/* Desired value initialization */
mf16DesiredValue = FRAC16(0.5);

/* Measured value initialization */
mf16MeasuredValue = 0;

/* Saturation flag initialization */
mi16SatFlag = 0;
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Error calculation */
    mf16ErrorK = mf16DesiredValue - mf16MeasuredValue;

    /* Controller calculation */
    mf16ControllerOutput = GFLIB_ControllerPIp(mf16ErrorK,
        &mudtControllerParam, &mi16SatFlag);
}

3.30.11 See Also

See GFLIB_ControllerPIr, GFLIB_ControllerPIrLim, GFLIB_ControllerPIDp and GFLIB_ControllerPIDr for more information.

3.30.12 Performance

<table>
<thead>
<tr>
<th>Table 3-75. Performance of GFLIB_ControllerPIp function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code Size (words)</td>
</tr>
<tr>
<td>Data Size (words)</td>
</tr>
<tr>
<td>Execution Clock</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
3.31 GFLIB_ControllerPIr

The function calculates the recurrent form of the Proportional-Integral (PI) regulator.

3.31.1 Synopsis

```c
#include "gflib.h"
Frac16 GFLIB_ControllerPIr(Frac16 f16Error,
GFLIB_CONTROLLER_PI_RECURRENT_T * const pudtCtrl)
```

3.31.2 Prototype

```c
asm Frac16 GFLIB_ControllerPIRecurrentFAsm(Frac16 f16Err,
GFLIB_CONTROLLER_PI_RECURRENT_T * const pudtCtrl)
```

3.31.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Error</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>Error as input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtCtrl</td>
<td>In/out</td>
<td>struct</td>
<td>N/A</td>
<td>Pointer to a controller structure, which contains controller coefficients and integrator delay line; the GFLIB_CONTROLLER_PI_RECURRENT_T data type is defined in header file GFLIB_ControllerPIRecurrentAsm.h</td>
</tr>
</tbody>
</table>

Table 3-77. User Type Definitions

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_CONTROLLER_PI_RECURRENT_T</td>
<td>f32Acc</td>
<td>In/Out</td>
<td>SF32</td>
<td>0x80000000...0xFFFFFFFF</td>
<td>Internal controller accumulator</td>
</tr>
<tr>
<td></td>
<td>f16ErrorK_1</td>
<td>In/Out</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>Input error at step k-1; delayed value of error at step k</td>
</tr>
<tr>
<td></td>
<td>f16CC1Sc</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>First controller coefficient scaled to fractional format</td>
</tr>
<tr>
<td></td>
<td>f16CC2Sc</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>Second controller coefficient scaled to fractional format</td>
</tr>
<tr>
<td></td>
<td>ui16NShift</td>
<td>In</td>
<td>UI16</td>
<td>0...15</td>
<td>Scaling shift</td>
</tr>
</tbody>
</table>
3.31.4 Availability
This library module is available in the C-callable interface assembly format.
This library module is targeted for the DSC 56F80xx platform.

3.31.5 Dependencies
List of all dependent files:
- GFLIB_ControllerPIRecurrentAsm.h
- GFLIB_types.h

3.31.6 Description
The time continuos function of the PI controller is defined as

\[ u(t) = K_P \cdot e(t) + K_I \cdot \int_0^t e(t)dt \]  
\text{Eqn. 3-76}

Different techniques are used to convert the continuous PI controller function into the discrete representation. However, the continuous function can only be approximated and the discrete representation can never be exactly equivalent. Different methods can result different controller performances.

The resulting difference equation derived by the discretization method is in the form as reported below

\[ u(k) = u(k-1) + CC1 \cdot e(k) + CC2 \cdot e(k-1) \]  
\text{Eqn. 3-77}

The transition from the continuous to the discrete time domain reveals the following controller coefficients

<table>
<thead>
<tr>
<th>Controller Coefficients</th>
<th>Bilinear Transformation</th>
<th>Backward Rectangular</th>
<th>Forward Rectangular</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1</td>
<td>( K_P + K_I \cdot T_S/2 )</td>
<td>( K_P + K_I \cdot T_S )</td>
<td>( K_P )</td>
</tr>
<tr>
<td>CC2</td>
<td>( -K_P + K_I \cdot T_S/2 )</td>
<td>( -K_P )</td>
<td>( -K_P + K_I \cdot T_S )</td>
</tr>
</tbody>
</table>

where
- \( K_P \) - proportional gain
- \( K_I \) - integral gain
- \( T_S \) - sampling period

The discrete time domain representation of the recurrent PI algorithm scaled into the fractional range is as
where $f_{32Acc}$ is the accumulated controller portion over time and is used as the internal variable of this algorithm. The $f_{16CC1}$ and $f_{16CC2}$ are recurrent controller coefficients which are adapted as

$$f_{16CC1} = CC1 \cdot \frac{E_{max}}{U_{max}} \quad \text{Eqn. 3-79}$$

$$f_{16CC2} = CC2 \cdot \frac{E_{max}}{U_{max}} \quad \text{Eqn. 3-80}$$

The input for the recurrent PI controller is $f_{16Error}$ which is adapted as

$$f_{16Error} = f_{16Desired} - f_{16Actual} \quad \text{Eqn. 3-81}$$

where $f_{16Error}$ is a fractional number which must be within the fractional range $<-1, 0.9999>$. The $f_{16Error}$ value is processed within the PI controller algorithm and the delayed value is stored in $f_{16Error\_1}$ for the next calculation. The delayed operation is performed internally by the algorithm itself where any user interaction is not required.

For proper operation of the recurrent PI controller implemented on the 16/32-bit DSC a care must be taken due to the fixed point representation of individual values. All coefficients need to be represented as 16-bit fixed point numbers. The input value $f_{16Error}$ is assumed to be already in the correct 16-bit fixed point number format. Other controller variables as $f_{32Acc}$, $f_{16Error\_16K\_1}$ are internally handled by the algorithm of the recurrent PI controller. The controller coefficients $f_{16CC1}$, $f_{16CC2}$ must be prepared in the correct 16-bit fixed point number format by user. A scaling shift $ui_{16NShift}$ is introduced to be scaled to the 16-bit fixed point format. Then fractional representation on the DSC of the recurrent PI controller is calculated by the following formula as

$$f_{16Uk} = f_{16Acc} + f_{16CC1Sc} \cdot f_{16Error} + f_{16CC2Sc} \cdot f_{16Error\_1} \quad \text{Eqn. 3-83}$$

where

$$f_{16CC1Sc} = f_{16CC1} \cdot 2^{\text{ui}_{NShift_{16}}} \quad \text{Eqn. 3-84}$$

$$f_{16CC2Sc} = f_{16CC2} \cdot 2^{\text{ui}_{NShift_{16}}} \quad \text{Eqn. 3-85}$$

ui_{16NShift} is chosen that the coefficients reside within the common range $<-1, 0.9999>$. In addition, ui_{16NShift} is chosen as a power of 2, the final de-scaling is a simple shift operation.
Example:

After the controller coefficients $K_p$ and $K_i$ are determined in the continuous time domain and the suitable sampling time $T_s$ is chosen, then controller coefficients in the discrete domain are calculated as stated in Table 3-79.

<table>
<thead>
<tr>
<th>Controller Coefficients</th>
<th>Bilinear Transformation</th>
<th>Backward Rectangular</th>
<th>Forward Rectangular</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1</td>
<td>126.5</td>
<td>128</td>
<td>125</td>
</tr>
<tr>
<td>CC2</td>
<td>-123.5</td>
<td>-125</td>
<td>-122</td>
</tr>
<tr>
<td>f16CC1</td>
<td>4.216666667</td>
<td>4.266666667</td>
<td>4.166666667</td>
</tr>
<tr>
<td>f16CC2</td>
<td>-4.116666667</td>
<td>-4.166666667</td>
<td>-4.066666667</td>
</tr>
<tr>
<td>ui16NShift</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>f16CC1Sc</td>
<td>0.527083333</td>
<td>0.533333333</td>
<td>0.520833333</td>
</tr>
<tr>
<td>f16CC2Sc</td>
<td>-0.514583333</td>
<td>-0.520833333</td>
<td>-0.508333333</td>
</tr>
</tbody>
</table>

### 3.3.7 Returns

The function returns a 16-bit fractional value as result of the calculation of PI algorithm.

### 3.3.8 Range Issues

The PI controller parameters are in the following range

\[-1 \leq f16ErrorK_1 \leq 0.9999\]  \hspace{1cm}  \textit{Eqn. 3-87}

\[-1 \leq f16CC1Sc \leq 0.9999\]  \hspace{1cm}  \textit{Eqn. 3-88}

\[-1 \leq f16CC2Sc \leq 0.9999\]  \hspace{1cm}  \textit{Eqn. 3-89}

\[0 \leq ui16NShift < 16\]  \hspace{1cm}  \textit{Eqn. 3-90}

### 3.3.9 Special Issues

The function $\text{GFLIB\_ControllerPIr}$ is the saturation mode independent.
3.31.10 Implementation

Example 3-31. Implementation Code

```c
#include "gflib.h"

static Frac16 mf16DesiredValue;
static Frac16 mf16MeasuredValue;
static Frac16 mf16ErrorK;
static Frac16 mf16ControllerOutput;

/* Controller parameters */
static GFLIB_CONTROLLER_PI_RECURRENT_T mudtControllerParam;

void Isr(void);

void main(void)
{
    /* Controller parameters initialization */
    mudtControllerParam.f16CC1Sc = FRAC16(0.527083333);
    mudtControllerParam.f16CC2Sc = FRAC16(-0.514583333);
    mudtControllerParam.ui16NShift = 3;
    mudtControllerParam.f16ErrorK_1 = 0;
    mudtControllerParam.f32Acc = 0;

    /* Desired value initialization */
    mf16DesiredValue = FRAC16(0.5);

    /* Measured value initialization */
    mf16MeasuredValue = 0;
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Error calculation */
    mf16ErrorK = mf16DesiredValue - mf16MeasuredValue;

    /* Ramp generation */
    mf16ControllerOutput = GFLIB_ControllerPIr(mf16ErrorK,
        &mudtControllerParam);
}
```

3.31.11 See Also

See GFLIB_ControllerPIp, GFLIB_ControllerPIrLim, GFLIB_ControllerPIDp and GFLIB_ControllerPIDr for more information.
### 3.31.12 Performance

**Table 3-80. Performance of GFLIB_ControllerPlr function**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Code Size (words)</strong></td>
<td>19</td>
</tr>
<tr>
<td><strong>Data Size (words)</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>Max</td>
</tr>
</tbody>
</table>
3.32 GFLIB_ControllerPIrLim

The function calculates the recurrent form of the Proportional-Integral (PI) regulator with limitation.

3.32.1 Synopsis

```
#include "gflib.h"
Frac16 GFLIB_ControllerPIrLim(Frac16 f16Error,
GFLIB_CONTROLLER_PI_RECURRENT_LIM_T * const pudtCtrl)
```

3.32.2 Prototype

```
asm Frac16 GFLIB_ControllerPIRecurrentLimFAsm(Frac16 f16Err,
GFLIB_CONTROLLER_PI_RECURRENT_LIM_T * const pudtCtrl)
```

3.32.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Error</td>
<td>In</td>
<td>SF16</td>
<td>0x8000...0x7FFF</td>
<td>error as input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtCtrl</td>
<td>In/Out</td>
<td>struct</td>
<td>N/A</td>
<td>pointer to a controller structure, which contains controller coefficients and integrator delay line; the GFLIB_CONTROLLER_PI_RECURRENT_ASM_T data type is defined in header file GFLIB_ControllerPIRecurrentLimAsm.h</td>
</tr>
</tbody>
</table>
3.32.4 Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

3.32.5 Dependencies

List of all dependent files:

1. GFLIB_ControllerPIRecurrentLimAsm.h
2. GFLIB_types.h

3.32.6 Description

The time continuos function of the PI controller is defined as
Different techniques are used to convert the continuous PI controller function into the discrete representation. However, the continuous function can only be approximated and the discrete representation can never be exactly equivalent. Different methods can result different controller performances.

The resulting difference equation derived by the discretization method is in the form as reported below

\[ u(k) = u(k-1) + CC1 \cdot e(k) + CC2 \cdot e(k-1) \]  \hspace{1cm} \text{Eqn. 3-92}

The transition from the continuous to the discrete time domain reveals the following controller coefficients

<table>
<thead>
<tr>
<th>Controller Coefficients</th>
<th>Bilinear Transformation</th>
<th>Backward Rectangular</th>
<th>Forward Rectangular</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1</td>
<td>( K_p + K_I \cdot T_S/2 )</td>
<td>( K_p + K_I \cdot T_S )</td>
<td>( K_p )</td>
</tr>
<tr>
<td>CC2</td>
<td>(-K_p + K_I \cdot T_S/2 )</td>
<td>(-K_p )</td>
<td>(-K_p + K_I \cdot T_S )</td>
</tr>
</tbody>
</table>

where

- \( K_p \) - proportional gain
- \( K_I \) - integral gain
- \( T_S \) - sampling period

In this controller implementation the actual output variable \( u(k) \) is bounded not to exceed the given limit values UpperLimit, LowerLimit. This is the case due to the bounded power of the actuator or to the physical constraints of the plant. The bounds are described by a saturation element equation Equation 3-93 where the calculated variable \( u(k) \) obtained from the controller is further limited and the resulting variable acting on the plant is determined as

\[
\begin{align*}
    u(k) &= \begin{cases}
        \text{UpperLimit} & \rightarrow u(k) > \text{UpperLimit} \\
        u(k) & \rightarrow \text{LowerLimit} \leq u(k) \leq \text{UpperLimit} \\
        \text{LowerLimit} & \rightarrow u(k) < \text{LowerLimit}
    \end{cases}
\end{align*}
\]  \hspace{1cm} \text{Eqn. 3-93}

When the bounds are exceeded, the non-linear saturation characteristic takes effect and influences the dynamic behavior. The described limitation is implemented within the PI recurrent controller where the limitation is evaluated during the calculation. If the limitation occurs the controller output is clipped to its bounds and the wind-up occurrence of the accumulator portion is avoided by saturating the actual sum.
The discrete time domain representation of the recurrent PI algorithm scaled into the fractional range is as

\[ f_{16}U_k = f_{32}\text{Acc} + f_{16}CC1 \cdot f_{16}\text{Error} + f_{16}CC2 \cdot f_{16}\text{Error}_1 \quad \text{Eqn. 3-94} \]

where \( f_{32}\text{Acc} \) is the accumulated controller portion over time and is used as an internal variable of this algorithm. \( f_{16}CC1 \) and \( f_{16}CC2 \) are the recurrent controller coefficients which are adapted as

\[ f_{16}CC1 = CC1 \cdot \frac{E_{\text{max}}}{U_{\text{max}}} \quad \text{Eqn. 3-95} \]

\[ f_{16}CC2 = CC2 \cdot \frac{E_{\text{max}}}{U_{\text{max}}} \quad \text{Eqn. 3-96} \]

The input for the recurrent PI controller is considered \( f_{16}\text{Error} \) which is adapted as

\[ f_{16}\text{Error} = f_{16}\text{Desired} - f_{16}\text{Actual} \quad \text{Eqn. 3-97} \]

\[ f_{16}\text{Error} = \frac{\text{Error}}{E_{\text{max}}} \quad \text{Eqn. 3-98} \]

where \( f_{16}\text{Error} \) is a fractional number which must be within the fractional range \((-1, 0.9999]\). The \( f_{16}\text{Error} \) value is processed within the PI controller algorithm and the delayed value is stored in \( f_{16}\text{Error}_1 \) for the next calculation. The delayed operation is performed internally by the algorithm itself where any user interaction is not required.

For proper operation of the recurrent PI controller implemented on the 16/32-bit DSC a care must be taken due to fixed point representation of the individual values. All coefficients need to be represented as 16-bit fixed point numbers. The input value \( f_{16}\text{Error} \) is assumed to be already in the correct 16-bit fixed point number format. Other controller variables as \( f_{32}\text{Acc}, f_{16}\text{Error}_{16}\text{K}_1 \) are internally handled by the algorithm of the recurrent PI controller. The controller coefficients \( f_{16}CC1, f_{16}CC2 \) must be prepared in the correct 16-bit fixed point number format by user. A scaling shift \( \text{ui16NShift} \) is introduced to be scaled to the 16-bit fixed point format. Then the fractional representation on the DSC of the recurrent PI controller is calculated by the following formula as

\[ f_{16}U_k = f_{16}\text{Acc} + f_{16}CC1Sc \cdot f_{16}\text{Error} + f_{16}CC2Sc \cdot f_{16}\text{Error}_1 \quad \text{Eqn. 3-99} \]

where

\[ f_{16}CC1Sc = f_{16}CC1 \cdot 2^{-\text{ui16NShift}16} \quad \text{Eqn. 3-100} \]

\[ f_{16}CC2Sc = f_{16}CC2 \cdot 2^{-\text{ui16NShift}16} \quad \text{Eqn. 3-101} \]
ui16NShift is chosen that the coefficients reside within the common range <-1, 0.9999>. In addition, ui16NShift is chosen as a power of 2, the final de-scaling is a simple shift operation.

\[
\text{ui16NShift} = \max \left\{ \left\lceil \frac{\log(f16CC1)}{\log(2)} \right\rceil, \left\lceil \frac{\log(f16CC2)}{\log(2)} \right\rceil \right\}
\]

 Eqn. 3-102

Example:

After the controller coefficients Kp, Ki are determined in the continuous time domain and the suitable sampling time Ts is chosen, then controller coefficients in the discrete domain are calculated as stated in Table 3-84.

<table>
<thead>
<tr>
<th>Controller Coefficients</th>
<th>Bilinear Transformation</th>
<th>Backward Rectangular</th>
<th>Forward Rectangular</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1</td>
<td>126.5</td>
<td>128</td>
<td>125</td>
</tr>
<tr>
<td>CC2</td>
<td>-123.5</td>
<td>-125</td>
<td>-122</td>
</tr>
<tr>
<td>f16CC1</td>
<td>4.216666667</td>
<td>4.266666667</td>
<td>4.166666667</td>
</tr>
<tr>
<td>f16CC2</td>
<td>-4.116666667</td>
<td>-4.166666667</td>
<td>-4.066666667</td>
</tr>
<tr>
<td>ui16NShift</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>f16CC1Sc</td>
<td>0.527083333</td>
<td>0.533333333</td>
<td>0.520833333</td>
</tr>
<tr>
<td>f16CC2Sc</td>
<td>-0.514583333</td>
<td>-0.520833333</td>
<td>-0.508333333</td>
</tr>
</tbody>
</table>

3.32.7 Returns

The function returns a 16-bit fractional value as result of calculation of the PI algorithm.

3.32.8 Range Issues

The PI controller parameters are in the following range

\[-1 \leq f16ErrorK_1 \leq 0,9999\]  
 Eqn. 3-103

\[-1 \leq f16CC1Sc \leq 0,9999\]  
 Eqn. 3-104

\[-1 \leq f16CC2Sc \leq 0,9999\]  
 Eqn. 3-105

\[0 \leq \text{ui}16NShift < 16\]  
 Eqn. 3-106
3.32.9 Special Issues

The function `GFLIB_ControllerPIrLim` is the saturation mode independent.

3.32.10 Implementation

Example 3-32. Implementation Code

```c
#include "glib.h"

static Frac16 mf16DesiredValue;
static Frac16 mf16MeasuredValue;
static Frac16 mf16ErrorK;
static Frac16 mf16ControllerOutput;

/* Controller parameters */
static GFLIB_CONTROLLER_PI_RECURRENT_LIM_T mudtControllerParam;

void Isr(void);

void main(void)
{
    /* Controller parameters initialization */
    mudtControllerParam.f16CC1Sc = FRAC16(0.527083333);
    mudtControllerParam.f16CC2Sc = FRAC16(-0.514583333);
    mudtControllerParam.ui16NShift = 3;
    mudtControllerParam.f16UpperLim = FRAC16(0.5);
    mudtControllerParam.f16LowerLim = FRAC16(-0.5);
    mudtControllerParam.f16ErrorK_1 = 0;
    mudtControllerParam.f32Acc = 0;

    /* Desired value initialization */
    mf16DesiredValue = FRAC16(0.5);

    /* Measured value initialization */
    mf16MeasuredValue = 0;
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Error calculation */
    mf16ErrorK = mf16DesiredValue - mf16MeasuredValue;

    /* Controller calculation */
    mf16ControllerOutput = GFLIB_ControllerPIrLim(mf16ErrorK,
        &mudtControllerParam);
}
```

3.32.11 See Also

See `GFLIB_ControllerPIp`, `GFLIB_ControllerPIr`, `GFLIB_ControllerPIDp` and `GFLIB_ControllerPIDr` for more information.
3.32.12 Performance

Table 3-85. Performance of **GFLIB_ControllerPIrLim** Function

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
<td><strong>Min</strong></td>
</tr>
<tr>
<td></td>
<td>43/41 cycles</td>
</tr>
</tbody>
</table>
3.33 GFLIB_ControllerPIDp

The function calculates the parallel form of the Proportional-Integral-Derivative (PID) regulator.

3.33.1 Synopsis

```
#include "gflib.h"
Frac16 GFLIB_ControllerPIDp(Frac16 f16InputErrorK, Frac16 f16InputDErrorK, GFLIB_CONTROLLER_PID_P_PARAMS_T *pudtPidParams, const Int16 *pi16SatFlag, Frac16 *pf16InputDErrorK_1)
```

3.33.2 Prototype

```
asm Frac16 GFLIB_ControllerPIDpFAsm(Frac16 f16InputErrorK, Frac16 f16InputDErrorK, GFLIB_CONTROLLER_PID_P_PARAMS_T *pudtPidParams, const Int16 *pi16SatFlag, Frac16 *pf16InputDErrorK_1)
```

3.33.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16InputErrorK</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>Input error at step K processed by P and I terms of the PID algorithm</td>
</tr>
<tr>
<td>f16InputDErrorK</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>Input error at step K processed by the D term of the PID algorithm</td>
</tr>
<tr>
<td>*pudtPidParams</td>
<td>In/Out</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to a structure of PID controller parameters; the GFLIB_CONTROLLER_PID_P_PARAMS_T data type is defined in header file GFLIB_ControllerPIDpAsm.h</td>
</tr>
<tr>
<td>*pi16SatFlag</td>
<td>In/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to a 16-bit integer variable; if the integer variable passed into the function as a pointer is set to 0, then the integral part is limited by the PID controller limits. If the integer variable is not zero, then the integral part is frozen</td>
</tr>
<tr>
<td>*pf16InputDErrorK_1</td>
<td>In/Out</td>
<td>N/A</td>
<td>N/A</td>
<td>Pointer to a 16-bit fractional variable; input error at step K-1 processed only by the derivative term of the PID algorithm. It is the state variable modified by the function. The variable can also be modified outside of the function. The purpose can be the initialization of the variable</td>
</tr>
</tbody>
</table>
## 3.3.3.4 Availability

This library module is available in the C-callable interface assembly format.

This library module is targeted for the DSC 56F80xx platform.

## 3.3.5 Dependencies

List of all dependent files:

1. GFLIB_ControllerPIDpAsm.h
2. GFLIB_types.h

## 3.3.6 Description

The **GFLIB_ControllerPIDp** function calculates the Proportional-Integral-Derivative (PID) algorithm according to the equations below. The PID algorithm is implemented in the parallel (non-interacting) form allowing the user to define the P, I and D parameters independently without

### Table 3-87. User Type Definitions

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16PropGain</td>
<td>In</td>
<td>SF16</td>
<td>0x0...</td>
<td>0x7FFF</td>
<td>Proportional gain</td>
</tr>
<tr>
<td>f16IntegGain</td>
<td>In</td>
<td>SF16</td>
<td>0x0...</td>
<td>0x7FFF</td>
<td>Integral gain</td>
</tr>
<tr>
<td>f16DerGain</td>
<td>In</td>
<td>SF16</td>
<td>0x0...</td>
<td>0x7FFF</td>
<td>Derivative gain</td>
</tr>
<tr>
<td>i16PropGainShift</td>
<td>In</td>
<td>SI16</td>
<td>0...13</td>
<td></td>
<td>Proportional gain shift</td>
</tr>
<tr>
<td>i16IntegGainShift</td>
<td>In</td>
<td>SI16</td>
<td>0...13</td>
<td></td>
<td>Integral gain shift</td>
</tr>
<tr>
<td>i16DerGainShift</td>
<td>In</td>
<td>SI16</td>
<td>0...13</td>
<td></td>
<td>Derivative gain shift</td>
</tr>
<tr>
<td>f32IntegPartK_1</td>
<td>In/Out</td>
<td>SF32</td>
<td>0x80000000...</td>
<td>0x7FFFFFF</td>
<td>State variable; integral part at step k-1; can be modified outside of the function.</td>
</tr>
<tr>
<td>f16UpperLimit</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ...</td>
<td>0x7FFF</td>
<td>Upper limit of the controller; f16UpperLimit &gt; f16LowerLimit</td>
</tr>
<tr>
<td>f16LowerLimit</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ...</td>
<td>0x7FFF</td>
<td>Lower limit of the controller; f16UpperLimit &gt; f16LowerLimit</td>
</tr>
<tr>
<td>i16LimitFlag</td>
<td>Out</td>
<td>SI16</td>
<td>0 or 1</td>
<td></td>
<td>Limitation flag; if set to 1, the controller output reached f16UpperLimit or f16LowerLimit</td>
</tr>
</tbody>
</table>
interaction. The controller output is limited and the limit values (f16UpperLimit and f16LowerLimit) are defined by user. The PID controller algorithm also returns the limitation flag. This flag named "i16LimitFlag" is the member of the structure of the PID controller parameters (GFLIB_CONTROLLER_PID_P_PARAMS_T). If the PID controller output reaches the upper or lower limit then i16LimitFlag = 1 otherwise i16LimitFlag = 0.

An anti-windup strategy is implemented by limiting the integral portion. There are two ways of limiting the integral part:

- The integral state is limited by the controller limits, in the same way as the controller output.
- When the variable satFlag set by the user software outside the PID controller function and passed into the function and the pointer pi16SatFlag is not zero, then the integral portion is frozen.

The PID algorithm in the continuous time domain:

$$ u(t) = K \left[ e(t) + \frac{1}{T_p} \int_0^t e(\tau) d(\tau) + T_D \cdot \frac{d}{dt} e_D(t) \right] $$  \hspace{1cm} \text{Eqn. 3-107}

where

- $e(t)$ - input error in the continuous time domain; processed by the P and I terms of the PID algorithm
- $e_D(t)$ - input error in the continuous time domain; processed by the D term of the PID algorithm
- $u(t)$ - controller output in the continuous time domain
- $T_I$ - integral time constant - [s]
- $T_D$ - derivative time constant - [s]

Equation 3-107 can be rewritten into the discrete time domain by approximating the integral and derivative terms.

The integral term is approximated by the Backward Euler method, also known as backward rectangular or right-hand or backward difference approximation as follows.

$$ u_I(k) = u_I(k-1) + T \cdot e(k) $$  \hspace{1cm} \text{Eqn. 3-108}

The derivative term is approximated in the same way as the integral term (backward difference).

$$ \frac{d}{dt} e_D(t) = \frac{e_D(k) - e_D(k-1)}{T} $$  \hspace{1cm} \text{Eqn. 3-109}

The discrete time domain representation of the PID algorithm
\[ u(k) = K \cdot e(k) + u_D(k-1) + K_I \cdot e(k) + K_D \cdot (e_D(k) - e_D(k-1)) \]  \hspace{1cm} \text{Eqn. 3-110}

where

- \( e(k) \) - input error at step \( k \); processed by the P and I terms
- \( e_D(k) \) - input error at step \( k \); processed by the D term
- \( e_D(k-1) \) - input error at step \( k-1 \); processed by the D term
- \( u(k) \) - controller output at the step \( k \)
- \( K \) - proportional gain
- \( K_I \) - integral gain
- \( K_D \) - derivative gain
- \( T \) - sampling time/period - [s]

\[ K_I = K \cdot \frac{T}{T_I} \]  \hspace{1cm} \text{Eqn. 3-111}

\[ K_D = K \cdot \frac{T_D}{T} \]  \hspace{1cm} \text{Eqn. 3-112}

The discrete time domain representation of the PID algorithm scaled into the fractional range.

\[ u_f(k) = K_{sc} \cdot e_f(k) + u_f(k-1) + K_{isc} \cdot e_f(k) + K_{Dsc} \cdot (e_D(k) - e_D(k-1)) \]  \hspace{1cm} \text{Eqn. 3-113}

where

\[ u_f(k) = \frac{u(k)}{u_{max}} \]  \hspace{1cm} \text{Eqn. 3-114}

\[ e_f(k) = \frac{e(k)}{e_{max}} \]  \hspace{1cm} \text{Eqn. 3-115}

\[ e_{Df}(k) = \frac{e_D(k)}{e_{max}} \]  \hspace{1cm} \text{Eqn. 3-116}

\[ K_{sc} = K \cdot \frac{e_{max}}{u_{max}} \]  \hspace{1cm} \text{Eqn. 3-117}

\[ K_{isc} = K \cdot \frac{e_{max}}{u_{max}} \cdot \frac{T}{T_I} = K_I \cdot \frac{e_{max}}{u_{max}} \]  \hspace{1cm} \text{Eqn. 3-118}

\[ K_{Dsc} = K \cdot \frac{e_{max}}{u_{max}} \cdot \frac{T_D}{T} = K_D \cdot \frac{e_{max}}{u_{max}} \]  \hspace{1cm} \text{Eqn. 3-119}

where

- \( e_{max} \) - input max range
- \( u_{max} \) - output max range

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Each parameter (e.g. \(K_{sc}\)) of the PID algorithm is represented by two parameters in the processor implementation (e.g. \(f_{16}{\text{PropGain}}\) and \(i_{16}{\text{PropGainShift}}\)).

\[
f_{16}{\text{PropGain}} = K_{sc} \cdot 2^{-i_{16}{\text{PropGainShift}}} \quad \text{Eqn. 3-120}
\]

\[
f_{16}{\text{IntegGain}} = K_{Isc} \cdot 2^{-i_{16}{\text{IntegGainShift}}} \quad \text{Eqn. 3-121}
\]

\[
f_{16}{\text{DerGain}} = K_{Dsc} \cdot 2^{-i_{16}{\text{DerGainShift}}} \quad \text{Eqn. 3-122}
\]

where

\[
0 \leq f_{16}{\text{PropGain}} < 1 \quad \text{Eqn. 3-123}
\]

\[
0 \leq f_{16}{\text{IntegGain}} < 1 \quad \text{Eqn. 3-124}
\]

\[
0 \leq f_{16}{\text{DerGain}} < 1 \quad \text{Eqn. 3-125}
\]

\[
0 \leq i_{16}{\text{PropGainShift}} < 14 \quad \text{Eqn. 3-126}
\]

\[
0 \leq i_{16}{\text{IntegGainShift}} < 14 \quad \text{Eqn. 3-127}
\]

\[
0 \leq i_{16}{\text{DerGainShift}} < 14 \quad \text{Eqn. 3-128}
\]

Example

Assumption: \(K_{sc}=1.8\)

In this case \(K_{sc}\) cannot be directly interpreted as a fractional value because the range of the fractional values is \(-1,1)\) and the range of the parameter \(f_{16}{\text{PropGain}}\) is \(<0,1)\). It is necessary to scale the \(K_{sc}\) parameter using \(i_{16}{\text{PropGainShift}}\) to fit the parameter \(f_{16}{\text{PropGain}}\) into the range \(<0,1)\)

Solution:
The most precise scaling approach is to scale down the parameter \(K_{sc}\) to have the \(f_{16}{\text{PropGain}}\) in the following range

\[
0.5 \leq f_{16}{\text{PropGain}} < 1
\]

and to calculate the corresponding \(i_{16}{\text{PropGainShift}}\) parameter.

\[
\frac{\log(K_{sc}) - \log(0.5)}{\log 2} \geq i_{16}{\text{PropGainShift}} \quad \text{Eqn. 3-129}
\]

\[
\frac{\log(1.8) - \log(0.5)}{\log 2} \geq i_{16}{\text{PropGainShift}} \quad \text{Eqn. 3-130}
\]

\[
1.8 \geq i_{16}{\text{PropGainShift}} \quad \text{Eqn. 3-131}
\]
The parameter $i_{16\text{PropGainShift}}$ is in the following range:

$$0,8 < i_{16\text{PropGainShift}} \leq 1,8$$

Because this parameter is an integer value, the result is

$$i_{16\text{PropGainShift}} = 1$$

Then

$$f_{16\text{PropGain}} = K_{sc} \cdot 2^{-i_{16\text{PropGainShift}}}$$

$$f_{16\text{PropGain}} = 1,8 \cdot 2^{-1} = 0,9$$

Result:

$$f_{16\text{PropGain}} = 0,9$$
$$i_{16\text{PropGainShift}} = 1$$

Note:

$$Ti > 4^*Td$$

### 3.33.7 Returns

The function `GFLIB_ControllerPIDp` returns a fractional value as result of the PID algorithm. The value returned by the algorithm is in the following range:

$$f_{16\text{LowerLimit}} \leq \text{PIDresult} \leq f_{16\text{UpperLimit}}$$

### 3.33.8 Range Issues

The PID controller parameters are in the following range

$$0 \leq f_{16\text{PropGain}} < 1$$
$$0 \leq f_{16\text{IntegGain}} < 1$$
$$0 \leq f_{16\text{DerGain}} < 1$$

$$0 \leq i_{16\text{PropGainShift}} < 14$$
$$0 \leq i_{16\text{IntegGainShift}} < 14$$
$$0 \leq i_{16\text{DerGainShift}} < 14$$
3.33.9 Special Issues

The function **GFLIB_ControllerPIDp** is the saturation mode independent.

3.33.10 Implementation

**Example 3-33. Implementation Code**

```c
#include "gflib.h"

static Frac16 mf16DesiredValue;
static Frac16 mf16MeasuredValue;
static Frac16 mf16ErrorK;
static Frac16 mf16DErrorK;
static Frac16 mf16DErrorK_1;
static Int16 mi16SatFlag;
static Frac16 mf16ControllerOutput;

/* Controller parameters */
static GFLIB_CONTROLLER_PID_P_PARAMS_T mudtControllerParam;

void Isr(void);

void main(void)
{
    /* Controller parameters initialization */
    mudtControllerParam.f16PropGain = FRAC16(0.5);
    mudtControllerParam.f16IntegGain = FRAC16(0.032);
    mudtControllerParam.f16DerGain = FRAC16(0.01);
    mudtControllerParam.i16PropGainShift = 1;
    mudtControllerParam.i16IntegGainShift = 0;
    mudtControllerParam.i16DerGainShift = 0;
    mudtControllerParam.f32IntegPartK_1 = 0;
    mudtControllerParam.f16UpperLimit = FRAC16(0.8);
    mudtControllerParam.f16LowerLimit = FRAC16(-0.7);
    mf16DErrorK_1 = 0;

    /* Desired value initialization */
    mf16DesiredValue = FRAC16(0.5);

    /* Measured value initialization */
    mf16MeasuredValue = 0;

    /* Saturation flag initialization */
    mi16SatFlag = 0;
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Error calculation */
    mf16ErrorK = mf16DesiredValue - mf16MeasuredValue;
    mf16ErrorK = mf16DErrorK;

    /* Controller calculation */
    mf16ControllerOutput = GFLIB_ControllerPIDp(mf16ErrorK, mf16ErrorK, &mudtControllerParam, &mi16SatFlag, &mf16DErrorK_1);
```

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3.33.11 See Also

See `GFLIB_ControllerPIp`, `GFLIB_ControllerPIr`, `GFLIB_ControllerPIrLim` and `GFLIB_ControllerPIDr` for more information.

3.33.12 Performance

<table>
<thead>
<tr>
<th>Table 3-88. Performance of <code>GFLIB_ControllerPIDp</code> Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Code Size (words)</strong></td>
</tr>
<tr>
<td><strong>Data Size (words)</strong></td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
</tr>
<tr>
<td>Min</td>
</tr>
<tr>
<td>Max</td>
</tr>
</tbody>
</table>
3.34 GFLIB_ControllerPIDr

The function calculates the recurrent form of the Proportional-Integral-Derivative (PID) regulator.

3.34.1 Synopsis

#include "gflib.h"
Frac16 GFLIB_ControllerPIDr(Frac16 f16Error,
GFLIB_CONTROLLER_PID_RECURRENT_T * const pudtCtrl)

3.34.2 Prototype

asm Frac16 GFLIB_ControllerPIDRecurrentFAsm(Frac16 f16Err,
GFLIB_CONTROLLER_PID_RECURRENT_T * const pudtCtrl)

3.34.3 Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f16Error</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>Error as input argument; the Frac16 data type is defined in header file GFLIB_types.h</td>
</tr>
<tr>
<td>*pudtCtrl</td>
<td>In/Out</td>
<td>struct</td>
<td>N/A</td>
<td>Pointer to a controller structure, which contains controller coefficients and integrator delay line; the GFLIB_CONTROLLER_PID_RECURRENT_T data type is defined in header file GFLIB_ControllerPIDRecurrentAsm.h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Name</th>
<th>In/Out</th>
<th>Format</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFLIB_CONTROLLER_PID_RECURRENT_T</td>
<td>f32Acc</td>
<td>In/Out</td>
<td>SF32</td>
<td>0x80000000...0x7FFFFFF</td>
<td>Internal controller accumulator</td>
</tr>
<tr>
<td></td>
<td>f16ErrorK_1</td>
<td>In/Out</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>Input error at step k-1; delayed value of error at step k</td>
</tr>
<tr>
<td></td>
<td>f16CC1Sc</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>First controller coefficient scaled to fractional format</td>
</tr>
<tr>
<td></td>
<td>f16CC2Sc</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>Second controller coefficient scaled to fractional format</td>
</tr>
<tr>
<td></td>
<td>f16CC3Sc</td>
<td>In</td>
<td>SF16</td>
<td>0x8000 ... 0x7FFF</td>
<td>Third controller coefficient scaled to fractional format</td>
</tr>
<tr>
<td></td>
<td>ui16NShift</td>
<td>In</td>
<td>UI16</td>
<td>0...15</td>
<td>Scaling shift</td>
</tr>
</tbody>
</table>

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3.34.4 Availability

This library module is available in the C-callable interface assembly format.
This library module is targeted for the DSC 56F80xx platform.

3.34.5 Dependencies

List of all dependent files:
- GFLIB_ControllerPIDRecurrentAsm.h
- GFLIB_types.h

3.34.6 Description

The time continuous function of the PID controller is defined as

\[ u(t) = K_P \cdot e(t) + K_I \cdot \int_0^t e(t) dt + K_D \cdot \frac{de(t)}{dt} \tag{Eqn. 3-139} \]

Different techniques can be used to convert the continuous PID controller function into the discrete representation. However, the continuous function can only be approximated and the discrete representation can never be exactly equivalent. Different methods can result different controller performances.

The resulting difference equation derived by the discretization method is in the form as reported below

\[ u(k) = u(k-1) + CC1 \cdot e(k) + CC2 \cdot e(k-1) + CC3 \cdot e(k-2) \tag{Eqn. 3-140} \]

The transition from the continuous to the discrete time domain reveals the following controller coefficients

<table>
<thead>
<tr>
<th>Controller Coefficients</th>
<th>Integration with Bilinear Transformation Derivation with Backward Rectangular</th>
<th>Integration with Backward Rectangular Derivation with Backward Rectangular</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1</td>
<td>( K_P + K_I \cdot \frac{T_S}{2} + K_D/T_S )</td>
<td>( K_P + K_I \cdot \frac{T_S}{2} + K_D/T_S )</td>
</tr>
<tr>
<td>CC2</td>
<td>( -K_P + K_I \cdot \frac{T_S}{2} - 2K_D/T_S )</td>
<td>( -K_P - 2K_D/T_S )</td>
</tr>
<tr>
<td>CC3</td>
<td>( K_D/T_S )</td>
<td>( K_D/T_S )</td>
</tr>
</tbody>
</table>

where
- \( K_P \) - proportional gain
- \( K_I \) - integral gain
- \( K_D \) - derivation gain
• $T_s$ - sampling period

The discrete time domain representation of the recurrent PI algorithm scaled into the fractional range as

$$f_{16}U_k = f_{32}Acc + f_{16}CC1 \cdot f_{16}Error + f_{16}CC2 \cdot f_{16}ErrorK_1 + f_{16}CC3 \cdot f_{16}ErrorK_2$$

Eqn. 3-141

where $f_{32}Acc$ is the accumulated controller portion over time and is used as an internal variable of this algorithm. $f_{16}CC1$, $f_{16}CC2$ and $f_{16}CC3$ are the recurrent controller coefficients which are adapted as

$$f_{16}CC1 = CC1 \cdot \frac{E_{max}}{U_{max}}$$

Eqn. 3-142

$$f_{16}CC2 = CC2 \cdot \frac{E_{max}}{U_{max}}$$

Eqn. 3-143

$$f_{16}CC3 = CC3 \cdot \frac{E_{max}}{U_{max}}$$

Eqn. 3-144

The input for the recurrent PI controller is considered $f_{16}Error$ which is adapted as

$$f_{16}Error = f_{16}Desired - f_{16}Actual$$

Eqn. 3-145

$$f_{16}Error = \frac{Error}{E_{max}}$$

Eqn. 3-146

where $f_{16}Error$ is a fractional number which must be within the fractional range $<-1, 0.9999>$. The $f_{16}Error$ value is processed within the PID controller algorithm and the delayed values are stored in $f_{16}ErrorK_1$, $f_{16}ErrorK_2$ for the next calculation. The operation of the delaying error values is performed internally by the algorithm itself and any user action is not required.

For proper operation of the recurrent PID controller implemented on the 16/32-bit DSC a care must be taken due to fixed point representation of individual values. All coefficients need to be represented as 16-bit fixed point numbers. The input value $f_{16}Error$ is assumed to be already in the correct 16-bit fixed point number format. Other controller variables as $f_{32}Acc$, $f_{16}Error16K_1$, $f_{16}Error16K_2$ are internally handled by the algorithm of the recurrent PID controller. The controller coefficients $f_{16}CC1$, $f_{16}CC2$, and $f_{16}CC3$ must be prepared in the correct 16-bit fixed point number format by the user. A scaling shift $ui16NShift$ is introduced to be scaled to the 16-bit fixed point format. Then the fractional representation on the DSC of the recurrent PID controller is calculated by the following formula as

$$f_{16}U_k = f_{16}Acc + f_{16}CC1Sc \cdot f_{16}Error + f_{16}CC2Sc \cdot f_{16}ErrorK1 + f_{16}CC3Sc \cdot f_{16}ErrorK2$$

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where

\[ f_{16CC1Sc} = f_{16CC1} \cdot 2^{-ui16NShift} \quad \text{Eqn. 3-148} \]

\[ f_{16CC2Sc} = f_{16CC2} \cdot 2^{-ui16NShift} \quad \text{Eqn. 3-149} \]

\[ f_{16CC3Sc} = f_{16CC3} \cdot 2^{-ui16NShift} \quad \text{Eqn. 3-150} \]

\( ui16NShift \) is chosen that the coefficients reside within the common range \((-1, 0.9999]\).

\[ ui16NShift = \max\left(\ceil{\log(f_{16CC1})/\log(2)}, \ceil{\log(f_{16CC2})/\log(2)}, \ceil{\log(f_{16CC3})/\log(2)}\right) \quad \text{Eqn. 3-151} \]

In addition, \( ui16NShift \) is chosen as a power of 2, then the final de-scaling is a simple shift operation.

### 3.34.7 Returns

The function returns a 16-bit fractional value as result of calculation of the PID algorithm.

### 3.34.8 Range Issues

The PID controller parameters are in the following range

\[ -1 \leq f_{16ErrorK_1} \leq 0.9999 \quad \text{Eqn. 3-152} \]

\[ -1 \leq f_{16ErrorK_2} \leq 0.9999 \quad \text{Eqn. 3-153} \]

\[ -1 \leq f_{16CC1Sc} \leq 0.9999 \quad \text{Eqn. 3-154} \]

\[ -1 \leq f_{16CC2Sc} \leq 0.9999 \quad \text{Eqn. 3-155} \]

\[ -1 \leq f_{16CC3Sc} \leq 0.9999 \quad \text{Eqn. 3-156} \]

\[ 0 \leq ui16NShift < 16 \quad \text{Eqn. 3-157} \]

### 3.34.9 Special Issues

The function `GFLIB_ControllerPIDr` is saturation mode independent.

### 3.34.10 Implementation

**Example 3-34. Implementation Code**

```c
#include "gflib.h"
```

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---

Freescale Semiconductor
static Frac16 mf16DesiredValue;
static Frac16 mf16MeasuredValue;
static Frac16 mf16ErrorK;
static Frac16 mf16ControllerOutput;

/* Controller parameters */
static GFLIB_CONTROLLER_PID_RECURRENT_T mudtControllerParam;

void Isr(void);

void main(void)
{
    /* Controller parameters initialization */
    mudtControllerParam.f16CC1Sc = FRAC16(0.527083333);
    mudtControllerParam.f16CC2Sc = FRAC16(-0.514583333);
    mudtControllerParam.f16CC3Sc = FRAC16(-0.514583333);
    mudtControllerParam.ui16NShift = 3;
    mudtControllerParam.f16ErrorK_1 = 0;
    mudtControllerParam.f16ErrorK_2 = 0;
    mudtControllerParam.f32Acc = 0;

    /* Desired value initialization */
    mf16DesiredValue = FRAC16(0.5);

    /* Measured value initialization */
    mf16MeasuredValue = 0;
}

/* Periodical function or interrupt */
void Isr(void)
{
    /* Error calculation */
    mf16ErrorK = mf16DesiredValue - mf16MeasuredValue;

    /* Controller calculation */
    mf16ControllerOutput = GFLIB_ControllerPIDr(mf16ErrorK, &mudtControllerParam);
}

3.34.11 See Also

See GFLIB_ControllerPIp, GFLIB_ControllerPIr, GFLIB_ControllerPIrLim and GFLIB_ControllerPIDp for more information.
### 3.34.12 Performance

<table>
<thead>
<tr>
<th>Code Size (words)</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Size (words)</td>
<td>0</td>
</tr>
<tr>
<td><strong>Execution Clock</strong></td>
<td><strong>Min</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Max</strong></td>
</tr>
</tbody>
</table>
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