General Functions Library

User Reference Manual

56800E, 56800Ex
Digital Signal Controller

56800Ex_GFLIB
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Chapter 2 INTRODUCTION

2.1 Overview

This reference manual describes the General Functions Library (GFLIB) for the Freescale 56F800E(X) family of Digital Signal Controllers. This library contains optimized functions.

2.2 Supported Compilers

General Functions Library (GFLIB) is written in assembly language with C-callable interface. The library was built and tested using the CodeWarrior™ Development Studio version 10.3.

The library is delivered in library module 56800Ex_GFLIB.lib and is intended for use in small data memory model projects. The interfaces to the algorithms included in this library have been combined into a single public interface include file, gdflib.h. This was done to simplify the number of files required for inclusion by 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 user wants to fully use this library, the CodeWarrior™ Development Studio should be installed prior to the General Functions Library. In case that General Functions Library is installed while CodeWarrior™ Development Studio is not present, users can only browse the installed software package, but will not be able to build, download and run 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.

The General Functions Library release is installed in its own folder named 56800Ex_GFLIB.

To start the installation process, perform the following steps:

1. Execute 56800Ex_FSLESL_rXX.exe.
2. Follow the FSLESL software installation instructions on your screen.

2.4 Library Integration

The library integration is described in AN4586 which can be downloaded from www.freescale.com.

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.

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:

$$-2^{[N-1]} \leq SI \leq [2^{[N-1]} - 1] \qquad \textit{Eqn. 2-1}$$

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:

$$0 \leq UI \leq [2^{[N-1]} - 1] \qquad \textit{Eqn. 2-2}$$

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:

$$-1.0 \le SF \le 1.0 - 2^{-[N-1]} \qquad \textit{Eqn. 2-3}$$

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 $7FFFFFFF ($1.0 - 2^{-31}$).

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:

$$0.0 \le UF \le 2.0 - 2^{-[N-1]} \qquad \textit{Eqn. 2-4}$$

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*

Mnemonics	Size — bits	Description
Word8	8	To represent 8-bit signed variable/value.
UWord8	8	To represent 16-bit unsigned variable/value.
Word16	16	To represent 16-bit signed variable/value.
UWord16	16	To represent 16-bit unsigned variable/value.
Word32	32	To represent 32-bit signed variable/value.
UWord32	32	To represent 16-bit unsigned variable/value.
Int8	8	To represent 8-bit signed variable/value.
UInt8	8	To represent 16-bit unsigned variable/value.
Int16	16	To represent 16-bit signed variable/value.
UInt16	16	To represent 16-bit unsigned variable/value.
Int32	32	To represent 32-bit signed variable/value.

Table 2-1. User-Defined Typedefs in *56800E_types.h* (continued)

UInt32	32	To represent 16-bit unsigned variable/value.
Frac16	16	To represent 16-bit signed variable/value.
Frac32	32	To represent 32-bit signed variable/value.
NULL	constant	Represents NULL pointer.
bool	16	Boolean variable.
false	constant	Represents false value.
true	constant	Represents true value.
FRAC16()	macro	Transforms float value from <–1, 1) range into fractional representation <–32768, 32767>.
FRAC32()	macro	Transforms float value from <–1, 1) range into fractional representation <–2147483648, 2147483648>.

2.8 V2 and V3 Core Support

The library has been written to support both 56800E (V2) and 56800Ex (V3) cores. The V3 core offers new set of math instructions which can simplify and accelarete the algorithm runtime. Therefore certain algorithms can have two prototypes.

If the library is used on the 56800Ex core, the V3 algorithms use is recommended because:

- the code is shorter
- the execution is faster
- the precision of 32-bit calculation is higher

The final algorithm is selected by a define. To select the correct algorithm implementation the user has to set up a define: OPTION_CORE_V3. If this define is not defined, it is automatically set up as 0. If its value is 0, the V2 algorithms are used. If its value is 1, the V3 algorithms are used.

The best way is to define this define is in the project properties (see Figure 2-1):

1. In the left hand tree, expand the C/C++ Build node
2. Click on the Settings node
3. Under the Tool Settings tab, click on the DSC Compiler/Input node
4. In the Defined Macros dialog box click on the first icon (+) and type the following: OPTION_CORE_V3=1
5. Click OK
6. Click OK on the Properties dialog box

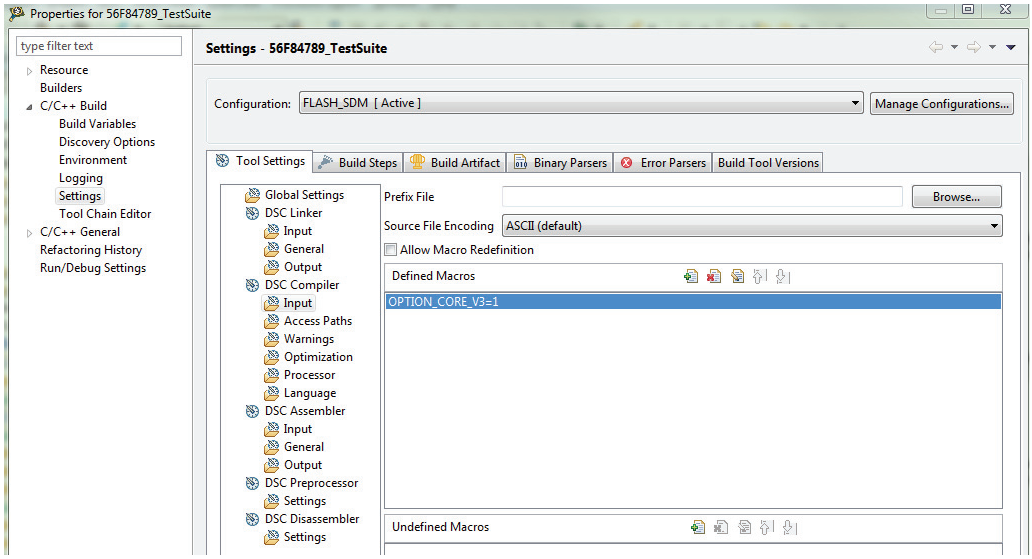

Figure 2-1. V2/V3 core option

2.9 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.

Chapter 3 FUNCTION API

3.1 API Summary

Table 3-1. API Functions Summary

Name	Arguments	Output	Description
GFLIB_SinTlr	Frac16 f16In	Frac16	The function calculates the sine value of the argument using 9th order Taylor polynomial approximation.
GFLIB_Sin12Tlr	Frac16 f16In	Frac16	The function calculates the sine value of the argument using 9th order Taylor polynomial approximation. This funcion is quicker with lower precision in camparison to GFLIB_SinTlr.
GFLIB_SinLut	Frac16 f16Arg	Frac16	The function calculates the sine value of the argument using lookup table.
GFLIB_CosTlr	Frac16 f16In	Frac16	The function calculates the cosine value of the argument using 9th order Taylor polynomial approximation.
GFLIB_Cos12Tlr	Frac16 f16In	Frac16	The function calculates the cosine value of the argument using 9th order Taylor polynomial approximation. This funcion is quicker with lower precision in camparison to GFLIB_Cos12Tlr.
GFLIB_CosLut	Frac16 f16Arg	Frac16	The function calculates the cosine value of the argument using lookup table.
GFLIB_Tan	Frac16 f16Arg	Frac16	The function calculates the tangent value of the argument using piece-wise polynomial approximation.
GFLIB_Asin	Frac16 f16Arg	Frac16	The function calculates the arcus sine value of the argument using piece-wise polynomial approximation.
GFLIB_Acos	Frac16 f16Arg	Frac16	The function calculates the arcus cosine value of the argument using piece-wise polynomial approximation.
GFLIB_Atan	Frac16 f16Arg	Frac16	The function calculates the arcus tangent value of the argument using piece-wise polynomial approximation.
GFLIB_AtanYX	Frac16 f16ValY Frac16 f16ValX Int16 *pi16ErrFlag	Frac16	The function calculates the arcus tangent value based on the provided x, y co-ordinates as arguments using division and piece-wise polynomial approximation.

Table 3-1. API Functions Summary

GFLIB_AtanYXShifted	Frac16 f16ValY Frac16 f16ValX GFLIB_ATANYXSHIFTED_T *pudtAtanYXCoeff	Frac16	The function computes angle of two sine waves shifted in phase one to each other.
GFLIB_SqrtPoly	Frac32 f32Arg	Frac16	The function calculates the square root value of the argument using piece-wise polynomial approximation with post-adjustment method.
GFLIB_SqrtIter	Frac32 f32Arg	Frac16	The function calculates the square root value using four iterations. This funcion is quicker with lower precision in camparison to **GFLIB_SqrtPoly**.
GFLIB_Lut	Frac16 f16Arg Frac16 *pf16Table UWord16 uw16TableSize	Frac16	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.
GFLIB_Ramp16	Frac16 f16Desired Frac16 f16Actual GFLIB_RAMP16_T *pudtParam	Frac16	The function calculates 16-bit version of up/down ramp with step increment/decrement defined in pudtParam structure.
GFLIB_Ramp32	Frac32 f32Desired Frac32 f32Actual GFLIB_RAMP32_T *pudtParam	Frac32	The function calculates 32-bit version of up/down ramp with step increment/decrement defined in pudtParam structure.
GFLIB_DynRamp16InitVal	Frac16 f16InitVal GFLIB_DYNRAMP16_T *pudtParam	void	This function initializes the internal variables of the **GFLIB_DynRamp16** algorithm with a value.
GFLIB_DynRamp16	Frac16 f16Desired Frac16 f16Instant UWord16 uw16SatFlag GFLIB_DYNRAMP16_T *pudtParam	Frac16	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.
GFLIB_DynRamp32InitVal	Frac32 f32InitVal GFLIB_DYNRAMP32_T *pudtParam	void	This function initializes the internal variables of the **GFLIB_DynRamp32** algorithm with a value.
GFLIB_DynRamp32	Frac32 f32Desired Frac32 f32Instant UWord16 uw16SatFlag GFLIB_DYNRAMP32_T *pudtParam	Frac32	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.
GFLIB_Limit16	Frac16 f16Arg GFLIB_LIMIT16_T *pudtLimit	Frac16	The function calculates 16-bit scalar upper/lower limitation of the input signal.

Table 3-1. API Functions Summary

GFLIB_Limit32	Frac32 f32Arg GFLIB_LIMIT32_T *pudtLimit	Frac32	The function calculates 32-bit scalar upper/lower limitation of the input signal.
GFLIB_LowerLimit16	Frac16 f16Arg Frac16 f16LowerLimit	Frac16	The function calculates 16-bit scalar lower limitation of the input signal.
GFLIB_LowerLimit32	Frac32 f32Arg Frac32 f32LowerLimit	Frac32	The function calculates 32-bit scalar lower limitation of the input signal.
GFLIB_UpperLimit16	Frac16 f16Arg Frac16 f16UpperLimit	Frac16	The function calculates 16-bit scalar upper limitation of the input signal.
GFLIB_UpperLimit32	Frac32 f32Arg Frac32 f32UpperLimit	Frac32	The function calculates 32-bit scalar upper limitation of the input signal.
GFLIB_Sgn	Frac16 f16Arg	Frac16	The function calculates signum of the input argument. The function returns: $7FFF if X > 0 0 if X = 0 $8000 if X < 0
GFLIB_Sgn2	Frac16 f16Arg	Frac16	The function calculates signum of the input argument with zero being considered as positive value. The function returns: $7FFFif X >= 0 $8000 if X < 0
GFLIB_Hyst	GFLIB_HYST_T *pudtHystVar	Frac16	The function switches output between two predefined values when the input crosses the threshold values.
GFLIB_ControllerPIpInitVal	Frac16 f16InitVal GFLIB_CONTROLLER_PI_P_PARAMS_T *pudtPiParams	Frac16	This function initializes the integral portion of the **GFLIB_ControllerPIp** algorithm.
GFLIB_ControllerPIp	Frac16 f16InputErrorK GFLIB_CONTROLLER_PI_P_PARAMS_T *pudtPiParams Int16 *pi16SatFlag	Frac16	The function calculates the parallel form of Proportional-Integral (PI) regulator.
GFLIB_ControllerPIr	Frac16 f16Error GFLIB_CONTROLLER_PI_RECURRENT_T *pudtCtrl	Frac16	The function calculates the recurrent form of Proportional-Integral (PI) regulator.
GFLIB_ControllerPIrLim	Frac16 f16Error GFLIB_CONTROLLER_PI_RECURRENT_LIM_T *pudtCtrl	Frac16	The function calculates the recurrent form of Proportional-Integral (PI) regulator with limitation.
GFLIB_ControllerPIDpInitVal	Frac16 f16InitVal GFLIB_CONTROLLER_PID_P_PARAMS_T *pudtPidParams	Frac16	The function initializes the integral portion of the parallel form of the **GFLIB_ControllerPIDp** algorithm.

Table 3-1. API Functions Summary

GFLIB_ControllerPIDp	Frac16 f16InputErrorK Frac16 f16InputDErrorK GFLIB_CONTROLLER_PID_P_PARAMS_T *pudtPidParams Int16 *pi16SatFlag Frac16 *pf16InputDErrorK_1	Frac16	The function calculates the parallel form of Proportional-Integral-Derivative (PID) regulator.
GFLIB_ControllerPIDr	Frac16 f16Error GFLIB_CONTROLLER_PID_RECURRENT_ASM_T *pudtCtrl	Frac16	The function calculates the recurrent form of Proportional-Integral-Derivative (PID) regulator.

3.2 GFLIB_SinTlr

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

3.2.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_SinTlr(Frac16 f16In)
```

3.2.2 Prototype

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

V3 core version:

```
asm Frac16 GFLIB_V3SinTlrFAsm(Frac16 f16In, const
GFLIB_SIN_TAYLOR_COEF_T *pudtSinData)
```

3.2.3 Arguments

Table 3-2. Function Arguments

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

Table 3-3. `

Typedef	Name	In/Out	Format	Range	Description
GFLIB_SIN_TAYLOR_COEF_T	f32A[5]	In	SF32	0x80000000... 0x7FFFFFFF	Array of 32-bit taylor polynom coefficients.

3.2.4 Availability

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

This library module is targeted for the 56800E and 56800Ex 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 * 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:

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

$$\sin(x) = x(d_1 + x^2(d_3 + x^2(d_5 + x^2(d_7 + x^2 d_9)))) \qquad \textit{Eqn. 3-2}$$

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 * x) using the ninth order Taylor polynomial:

$$\sin(\pi \cdot x) = x(c_1 + x^2(c_3 + x^2(c_5 + x^2(c_7 + x^2 c_9)))) \qquad \textit{Eqn. 3-3}$$

where:

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

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 * 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 * 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. 3-4

For a better accuracy the 'a' coefficients are used as 32-bit signed fractional constants in the multiplication operations, $(x<<l)^2$ 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:

$a_1 = 0x6487ED51$

$a_3 = 0xD6A88634$

$a_5 = 0x0519AF1A$

$a_7 = 0xFFB34B4D$

$a_9 = 0x0002A0F0$

$$\begin{aligned}\sin(\pi \cdot x) = {} & (x \ll 1)(0x6487ED51 + \\ & (x \ll 1)^2(0xD6A88634 + \\ & (x \ll 1)^2(0x0519AF1A + \\ & (x \ll 1)^2(0xFFB34B4D + \\ & (x \ll 1)^2(0x0002A0F0))))) \ll 1\end{aligned}$$

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 **GFLIB_SinTlr** is the saturation mode independent.

3.2.10 Implementation

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

Example 3-1. 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 sine value */
         mf16Output = GFLIB_SinTlr(mf16Input);
}
```

3.2.11 See Also

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

3.2.12 Performance

Table 3-4. Performance of GFLIB_SinTlr Function

Code Size (words)	V2: 38, V3: 28	
Data Size (words)	10	
Execution Clock	Min	V2: 60, V3: 48 cycles
	Max	V2: 60, V3: 48 cycles

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

```
#include ”gflib.h”
Frac16 GFLIB_Sin12Tlr(Frac16 f16In)
```

3.3.2 Prototype

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

3.3.3 Arguments

Table 3-5. Function Arguments

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

Table 3-6. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_SIN12_TAYLOR_COEF_T	f32A[5]	In	SF32	0x80000000... 0x7FFFFFFF	Array of 32-0bit taylor polynom coefficients.

3.3.4 Availability

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

This library module is targeted for the 56800E and 56800Ex 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:

$$\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7!} + \frac{x^9}{9!} \qquad \textit{Eqn. 3-6}$$

$$\sin(x) = x(d_1 + x^2(d_3 + x^2(d_5 + x^2(d_7 + x^2 d_9)))) \qquad \textit{Eqn. 3-7}$$

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:

$$\sin(\pi \cdot x) = x(c_1 + x^2(c_3 + x^2(c_5 + x^2(c_7 + x^2 c_9)))) \qquad \textit{Eqn. 3-8}$$

where:

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

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 * 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 * 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, $(x<<l)^2$ 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 16-bit signed fractional representation:

$a_1 = 0x6488$

$a_3 = 0xD6A9$

$a_5 = 0x051A$

$a_7 = 0xFFB3$

$a_9 = 0x0003$

$$\begin{aligned}\sin(\pi \cdot x) = {} & (x \ll 1)(0x6488 + \\ & (x \ll 1)^2(0xD6A9 + \\ & (x \ll 1)^2(0x051A + \\ & (x \ll 1)^2(0xFFB3 + \\ & (x \ll 1)^2(0x0003))))) \ll 1\end{aligned}$$

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.

Example 3-2. 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 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

Code Size (words)	25	
Data Size (words)	5	
Execution Clock	Min	41 cycles
	Max	41 cycles

3.4 GFLIB_SinLut

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

3.4.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_SinLut(Frac16 f16Arg)
```

3.4.2 Prototype

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

3.4.3 Arguments

Table 3-8. Function Arguments

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

3.4.4 Availability

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

This library module is targeted for the 56800E and 56800Ex 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.

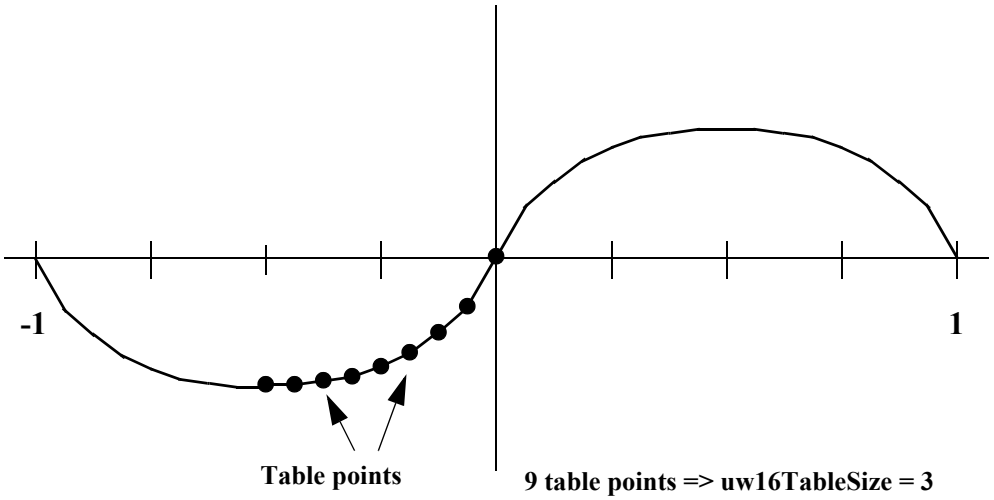

Figure 3-1. Algorithm Diagram

The **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 **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

```
#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

Code Size (words)	27	
Data Size (words)	258	
Execution Clock	Min	62 cycles
	Max	62 cycles

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

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

3.5.2 Prototype

```
inline Frac16 GFLIB_V3CosTlrFAsmi(Frac16 f16In, const
GFLIB_SIN_TAYLOR_COEF_T *pudtSinData)
```

V3 core version:

```
inline Frac16 GFLIB_V3CosTlrFAsmi(Frac16 f16In, const
GFLIB_SIN_TAYLOR_COEF_T *pudtSinData)
```

3.5.3 Arguments

Table 3-10. Function Arguments

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

Table 3-11. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_SIN_TAYLOR_COEF_T	f32A[5]	In	SF32	0x80000000... 0x7FFFFFFF	Array of 32bit taylor polynom coefficients.

3.5.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.5.5 Dependencies

List of all dependent files:

- GFLIB_SinCosTlrAsm.h
- GFLIB_SinCosTlrDefAsm.h
- GFLIB_types.h

3.5.6 Description

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

$$\cos(\alpha) = \sin\left[\frac{\pi}{2} + |\alpha|\right] \qquad \textit{Eqn. 3-11}$$

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:

$$\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7!} + \frac{x^9}{9!} \qquad \textit{Eqn. 3-12}$$

$$\sin(x) = x(d_1 + x^2(d_3 + x^2(d_5 + x^2(d_7 + x^2 d_9)))) \qquad \textit{Eqn. 3-13}$$

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 * x) using the 9th order Taylor polynomial:

$$\sin(\pi \cdot x) = x(c_1 + x^2(c_3 + x^2(c_5 + x^2(c_7 + x^2 c_9)))) \qquad \textit{Eqn. 3-14}$$

where the constants:

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

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 * 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):

$b_1 = c_1 / 21 = pi / 2$

$b_3 = c_3 / 23 = -pi^3 / 3! / 23$

$b_5 = c_5 / 25 = pi^5 / 5! / 25$

$b_7 = c_7 / 27 = -pi^7 / 7! / 27$

$b_9 = c_9 / 29 = pi^9 / 9! / 29$

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 get the correct result of the function sin(pi * x) in the range <-1; 1) of the given x.

$a_1 = b_1 / 2 = pi / 22 = 0.785398163$

$a_3 = b_3 / 2 = -pi^3 / 3! / 24 = -0.322982049$

$a_5 = b_5 / 2 = pi^5 / 5! / 26 = 0.039846313$

$a_7 = b_7 / 2 = -pi^7 / 7! / 28 = -0.002340877$

$a_9 = b_9 / 2 = pi^9 / 9! / 210 = 0.000080220$

$$\sin(\pi \cdot x) = (x \ll 1)((a_1 + (x \ll 1)^2(a_3 + (x \ll 1)^2(a_5 + (x \ll 1)^2(a_7 + (x \ll 1)a_9)))) \ll 1) \quad \textit{Eqn. 3-15}$$

For a better accuracy the 'a' coefficients are used as 32-bit signed fractional constants in the multiplication operations, $(x<<1)^2$ is a16-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 = 0x6487ED51

a_3 = 0xD6A88634

a_5 = 0x0519AF1A

a_7 = 0xFFB34B4D

a_9 = 0x0002A0F0

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

Eqn. 3-16

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 **GFLIB_CosTlr** is the saturation mode independent.

3.5.10 Implementation

The **GFLIB_CosTlr** function is implemented as an inline function than uses that calls the **GFLIB_SinTlr** function.

Example 3-4. 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 cosine value */
        mf16Output = GFLIB_CosTlr(mf16Input);

}
```

3.5.11 See Also

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

3.5.12 Performance

Table 3-12. Performance of GFLIB_CosTlr function

Code Size (words)	V2: 7 + 38, V3: 7 + 28 (GFLIB_SinTlr)	
Data Size (words)	0 + 10 (GFLIB_SinTlr)	
Execution Clock	Min	V2: 65, V3: 54 cycles
	Max	V2: 65, V3: 54 cycles

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

```
#include ”gflib.h”
Frac16 GFLIB_Cos12Tlr(Frac16 f16In)
```

3.6.2 Prototype

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

3.6.3 Arguments

Table 3-13. Function Arguments

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

Table 3-14. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_SIN_TAYLOR_COEF_T	f32A[5]	In	SF32	0x80000000... 0x7FFFFFFF	Array of 32bit taylor polynom coefficients.

3.6.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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 * x) using 9th order Taylor polynomial approximation of the sine function where its equation is:

$$\cos(\alpha) = \sin\left[\frac{\pi}{2} + |\alpha|\right] \qquad \textit{Eqn. 3-17}$$

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:

$$\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7!} + \frac{x^9}{9!} \qquad \textit{Eqn. 3-18}$$

$$\sin(x) = x(d_1 + x^2(d_3 + x^2(d_5 + x^2(d_7 + x^2 d_9)))) \qquad \textit{Eqn. 3-19}$$

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 * x) using the 9th order Taylor polynomial:

$$\sin(\pi \cdot x) = x(c_1 + x^2(c_3 + x^2(c_5 + x^2(c_7 + x^2 c_9)))) \qquad \textit{Eqn. 3-20}$$

where the constants:

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

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 * 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):

$b_1 = c_1 / 21 = pi / 2$

$b_3 = c_3 / 23 = -pi^3 / 3! / 23$

$b_5 = c_5 / 25 = pi^5 / 5! / 25$

$b_7 = c_7 / 27 = -pi^7 / 7! / 27$

$b_9 = c_9 / 29 = pi^9 / 9! / 29$

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 get the correct result of the function sin(pi * x) in the range <-1; 1) of the given x.

$a_1 = b_1 / 2 = pi / 22 = 0.785398163$

$a_3 = b_3 / 2 = -pi^3 / 3! / 24 = -0.322982049$

$a_5 = b_5 / 2 = pi^5 / 5! / 26 = 0.039846313$

$a_7 = b_7 / 2 = -pi^7 / 7! / 28 = -0.002340877$

$a_9 = b_9 / 2 = pi^9 / 9! / 210 = 0.000080220$

$$\sin(\pi \cdot x) = (x \ll 1)((a_1 + (x \ll 1)^2(a_3 + (x \ll 1)^2(a_5 + (x \ll 1)^2(a_7 + (x \ll 1)a_9)))) \ll 1) \quad \textit{Eqn. 3-21}$$

For a better accuracy the 'a' coefficients are used as 32-bit signed fractional constants in the multiplication operations, $(x<<1)^2$ is a16-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:

$a_1 = 0x6488$

$a_3 = 0xD6A9$

$a_5 = 0x051A$

$a_7 = 0xFFB3$

$a_9 = 0x0003$

$$\sin(\pi \cdot x) = (x \ll 1)(0x6488 + (x \ll 1)^2(0xD6A9 + (x \ll 1)^2(0x051A + (x \ll 1)^2(0xFFB3 + (x \ll 1)^2(0x0003))))) \ll 1 \quad \textit{Eqn. 3-22}$$

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 **GFLIB_Cos12Tlr** is the saturation mode independent.

3.6.10 Implementation

The **GFLIB_Cos12Tlr** function is implemented as an inline function than uses that calls the **GFLIB_Sin12Tlr** function.

Example 3-5. 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 cosine value */
        mf16Output = GFLIB_Cos12Tlr(mf16Input);

}
```

3.6.11 See Also

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

3.6.12 Performance

Table 3-15. Performance of GFLIB_Cos12Tlr function

Code Size (words)	7 + 25 (GFLIB_Sin12Tlr)	
Data Size (words)	0 + 5 (GFLIB_Sin12Tlr)	
Execution Clock	Min	49 cycles
	Max	49 cycles

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 3-16. Function Arguments

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

3.7.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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.

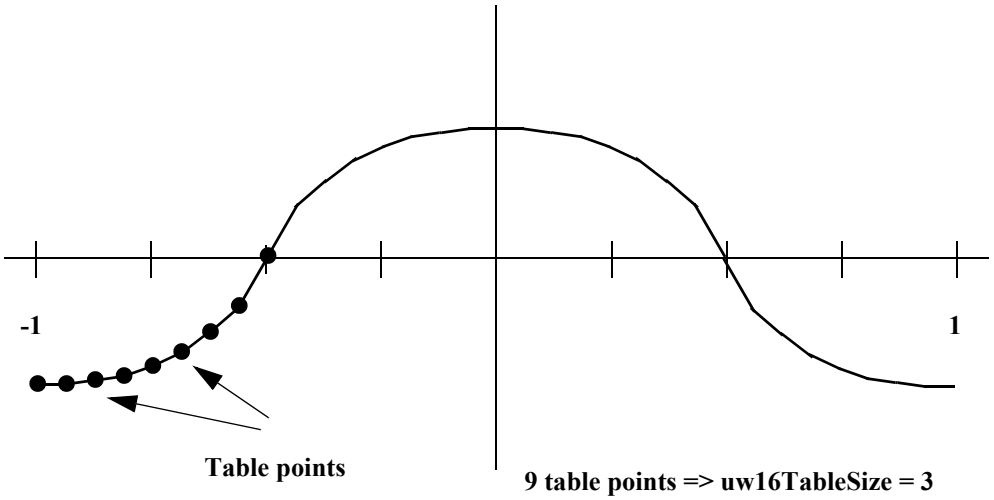

Figure 3-2. Algorithm diagram

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

```
#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

Code Size (words)	41	
Data Size (words)	258	
Execution Clock	Min	63 cycles
	Max	63 cycles

3.8 GFLIB_Tan

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

3.8.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_Tan(Frac16 f16Arg)
```

3.8.2 Prototype

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

3.8.3 Arguments

Table 3-18. Function Arguments

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

3.8.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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.

$$u = (x - x_{\text{offset}}) \cdot 2^{k_X} \quad \textit{Eqn. 3-23}$$

$$v = ((a_n \cdot u + a_{n-1}) \cdot u + a_{n-2}) \cdot u \ldots + a_0 \quad \textit{Eqn. 3-24}$$

$$y = v \cdot 2^{k_Y} + y_{\text{offset}} \quad \textit{Eqn. 3-25}$$

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_{offset} is the offset for the input value
k_Y is the scaling factor for the output value
y_{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>

$k_X = 0$
$x_{\text{offset}} = 0$
$a_6, a_5, a_4, a_3, a_2, a_1, a_0 = 0, 0, 0, 0$
$y_{\text{offset}} = 0L$

$$k_Y = 0$$

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).

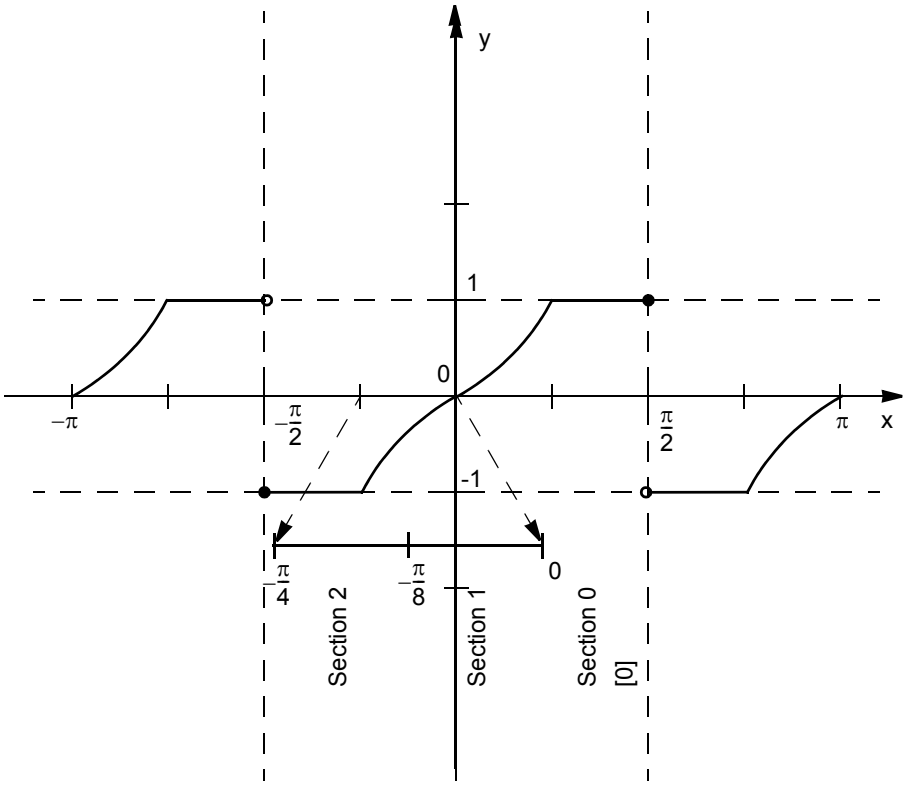

Figure 3-3. GFLIB_Tan Function

Table 3-19. GFLIB_Tan Function Values

Input Argument Value		Computed Result	
Real	**Fractional (Hex)**	**Real**	**Fractional (Hex)**
$\left(-\pi, -\frac{3}{4}\cdot\pi\right)$	(8000, A000)	Tan	Tan
$-\frac{3}{4}\cdot\pi$ s	A000	1.0	7FFF
$\left(-\frac{3}{4}\cdot\pi, -\frac{1}{2}\cdot\pi\right)$	(A000, C000)	1.0	7FFF
$-\frac{1}{2}\cdot\pi$	C000	-1.0	8000

Table 3-19. GFLIB_Tan Function Values

Input Argument Value		Computed Result	
Real	**Fractional (Hex)**	**Real**	**Fractional (Hex)**
$\left(-\frac{1}{2}\cdot\pi, -\frac{1}{4}\cdot\pi\right)$	(C000, E000)	-1.0	8000
$-\frac{1}{4}\cdot\pi$	E000	-1.0	8000
$\left(-\frac{1}{4}\cdot\pi, \frac{1}{4}\cdot\pi\right)$	(E000, 2000)	Tan	Tan
$\frac{1}{4}\cdot\pi$	2000	1.0	7FFF
$\left(\frac{1}{4}\cdot\pi, \frac{1}{2}\cdot\pi\right)$	(2000,4000)	1.0	7FFF
$\frac{1}{2}\cdot\pi$	4000	1.0	7FFF
$\left(\frac{1}{2}\cdot\pi, \frac{3}{2}\cdot\pi\right)$	(4000, 6000)	-1.0	8000
$\left(\frac{3}{4}\cdot\pi, \pi\right)$	(6000,7FFF)	Tan	Tan

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

Code Size (words)	59	
Data Size (words)	39	
Execution Clock	Min	76 cycles
	Max	76 cycles

3.9 GFLIB_Asin

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

3.9.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_Asin(Frac16 f16Arg)
```

3.9.2 Prototype

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

3.9.3 Arguments

Table 3-21. Function Arguments

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

3.9.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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 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.

$$u = (x - x_{\text{offset}}) \cdot 2^{k_X} \qquad \textit{Eqn. 3-26}$$

$$v = ((a_n \cdot u + a_{n-1}) \cdot u + a_{n-2}) \cdot u \ldots + a_0 \qquad \textit{Eqn. 3-27}$$

$$y = v \cdot 2^{k_Y} + y_{\text{offset}} \qquad \textit{Eqn. 3-28}$$

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_{offset} is the offset for the input value
k_Y is the scaling factor for the output value
y_{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)

$k_X = 3$
$x_{\text{offset}} = -4096$
$a_3, a_2, a_1, a_0 = 59, -169, 21026, -11514$
$y_{\text{offset}} = -19252860L$
$k_Y = 5$

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

$u = (-\sqrt{|x|} - x_{\text{offset}}) \cdot 2^{k_X}$
$v = (((a_n \cdot u + a_{n-1}) \cdot u + a_{n-2}) \cdot u \ldots + a_0)$
$y = v \cdot 2^{k_Y} + y_{\text{offset}}$
$k_X = 3$
$x_{\text{offset}} = -12288$
$a_3, a_2, a_1, a_0 = 104, -623, 22502, -9536$
$y_{\text{offset}} = -111848107L$
$k_Y = 5$

The coefficients for the interval <0>

$k_X = 0$
$x_{\text{offset}} = 0$
$a_3, a_2, a_1, a_0 = 0, 0, 0, 0$
$y_{\text{offset}} = 0L$

$$k_Y = 0$$

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

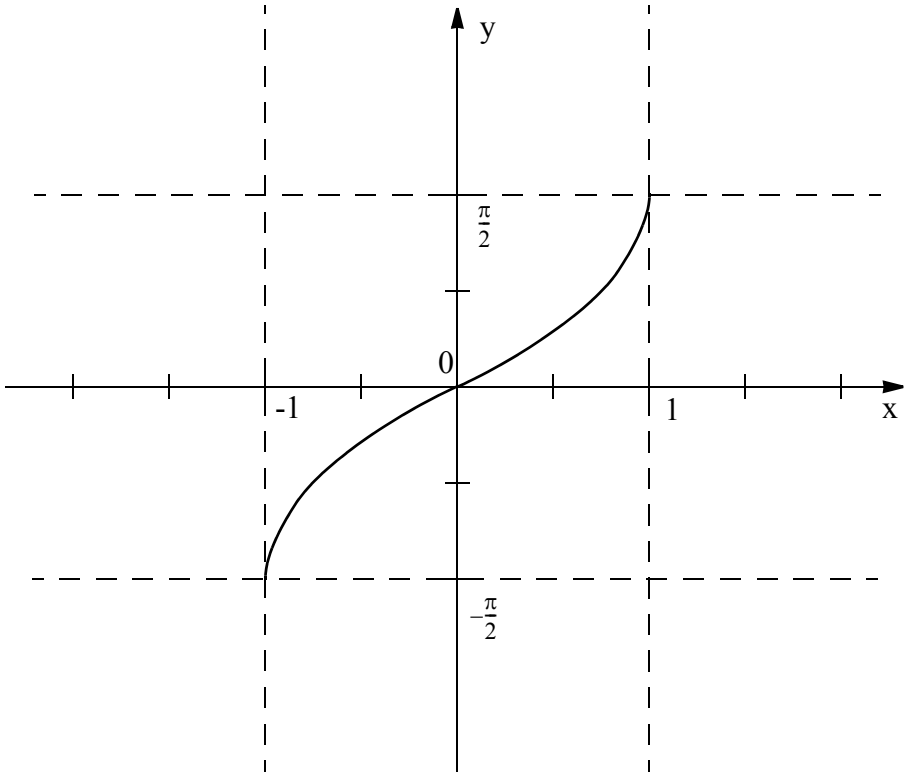

Figure 3-4. GFLIB_Asin Function

3.9.7 Returns

The function returns 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"
```

```
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

Code Size (words)	74 + 65 (GFLIB_SqrtPoly)	
Data Size (words)	27+34 (GFLIB_SqrtPoly)	
Execution Clock	Min	96 cycles
	Max	216 cycles

3.10 GFLIB_Acos

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

3.10.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_Acos(Frac16 f16Arg)
```

3.10.2 Prototype

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

3.10.3 Arguments

Table 3-23. Function Arguments

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

3.10.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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:

$$A\cos(x) = ((-0.5) + A\sin(x)) \cdot (-1) \qquad \textit{Eqn. 3-29}$$

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

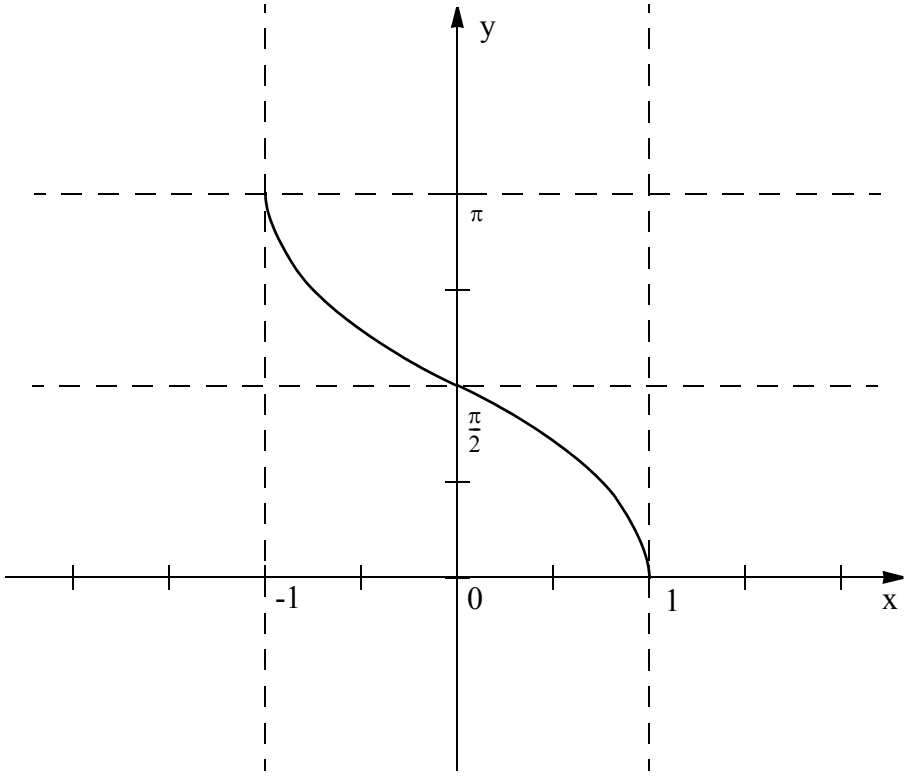

Figure 3-5. GFLIB_Acos Function

3.10.7 Returns

The function returns 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

```
#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 3-24. Performance of GFLIB_Acos function

Code Size (words)	8 + 74 (GFLIB_Asin) + 65 (GFLIB_SqrtPoly)	
Data Size (words)	27 + 34 (GFLIB_SqrtPoly)	
Execution Clock	Min	120 cycles
	Max	240 cycles

3.11 GFLIB_Atan

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

3.11.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_Atan(Frac16 f16Arg)
```

3.11.2 Prototype

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

3.11.3 Arguments

Table 3-25. Function Arguments

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

3.11.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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.

$$u = (x - x_{\text{offset}}) \cdot 2^{k_X} \qquad \textit{Eqn. 3-30}$$

$$v = ((a_n \cdot u + a_{n-1}) \cdot u + a_{n-2}) \cdot u \ldots + a_0 \qquad \textit{Eqn. 3-31}$$

$$y = v \cdot 2^{k_Y} + y_{\text{offset}} \qquad \textit{Eqn. 3-32}$$

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_{offset} is the offset for the input value
k_Y is the scaling factor for the output value
y_{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)

k_X = 2
x_{offset} = -8192
a_4, a_3, a_2, a_1, a_0 = -56, -289, 1154, 19633, -14522
y_{offset} = -24248975L
k_Y = 4

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

k_X = 2
x_{offset} = -24576
a_4, a_3, a_2, a_1, a_0 = -37, 145, 3204, 26704, -9087
y_{offset} = -201326592L
k_Y = 5

The coefficients for the interval <0>

k_X = 0
x_{offset} = 0
a_4, a_3, a_2, a_1, a_0 = 0, 0, 0, 0
y_{offset} = 0L
k_Y = 0

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

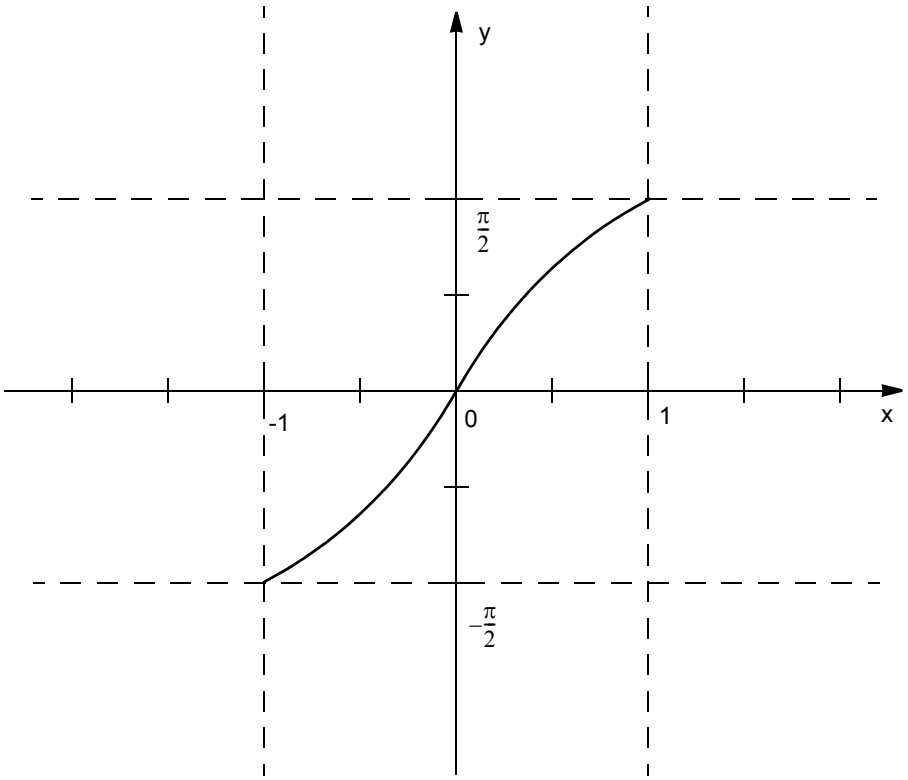

Figure 3-6. GFLIB_Atan Function

3.11.7 Returns

The function returns 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.

Example 3-10. Implementation Code

```
#include "gflib.h"

static Frac16 mf16Input;
static Frac16 mf16Output;

void main(void)
```

```
{
        /* 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

Code Size (words)	44	
Data Size (words)	33	
Execution Clock	Min	68 cycles
	Max	68 cycles

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 3-27. Function Arguments

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

3.12.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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

```
#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);
}
```

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

Code Size (words)	102	
Data Size (words)	33	
Execution Clock	Min	74 cycles
	Max	146 cycles

3.13 GFLIB_AtanYXShifted

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

3.13.1 Synopsis

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

3.13.2 Prototype

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

3.13.3 Arguments

Table 3-29. Function Arguments

Name	In/Out	Format	Range	Description
f16ValY	In	SF16	0x8000... 0x7FFF	Y input data value, equal to $\sin\theta$
f16ValX	In	SF16	0x8000... 0x7FFF	X input data value, equal to $\sin(\theta + \Delta\theta)$
*pudtAtanYXCoeff	In	N/A	N/A	Input pointer of the struct initialization parameters

Table 3-30. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_ATANYXSHIFTED_T	f16Ky	In	SF16	0x8000... 0x7FFF	Multiplication coefficient of the y signal
	f16Kx	In	SF16	0x8000... 0x7FFF	Multiplication coefficient of the x signal
	i16Ny	In	SI16	0x8000... 0x7FFF	Scaling coefficient of the y signal
	i16Nx	In	SI16	0x8000... 0x7FFF	Scaling coefficient of the x signal
	f16ThetaAdj	In	SF16	0x8000... 0x7FFF	Adjusting angle

3.13.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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:

$$\begin{aligned} y &= \sin\theta \\ x &= \sin(\theta + \Delta\theta) \end{aligned} \qquad \textit{Eqn. 3-33}$$

where:

x, y signal values provided as the arguments

θ 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:

$$\begin{aligned} b &= \frac{S}{2 \cdot \cos\frac{\Delta\theta}{2}} \cdot (y + x) \\ a &= \frac{S}{2 \cdot \sin\frac{\Delta\theta}{2}} \cdot (x - y) \\ \theta &= \text{atan2}(b,a) - \Delta\theta/2 + \theta_{offset} \end{aligned} \qquad \textit{Eqn. 3-34}$$

where:

x, y signal values provided as arguments in Equation 3-33

θ angle to be computed by the function in Equation 3-33

$\Delta\theta$ angle offset

θ_{offset} scaling coefficient to prevent an overflow over 1, S is nearly 1 and $S < 1$

a,b intermediate variables

For the fractional conventions purposes the algorithm is implemented such that addition values are used as shown in the equation Equation 3-35 below:

$$\frac{S}{2 \cdot \cos\frac{\Delta\theta}{2}} = K_y \cdot 2^{N_y}$$

$$\frac{S}{2 \cdot \sin\frac{\Delta\theta}{2}} = K_x \cdot 2^{N_x} \qquad \textit{Eqn. 3-35}$$

$$\theta_{adj} = \Delta\theta/2 - \theta_{offset}$$

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

θ_{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:

Example 3-12. Initialization Parameters Calculation in 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));
```

```
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 $\Delta\theta = 69.33°$, $\theta = 0°$, then:

```
dtheta = 69.33deg, thetaoffset = 0deg
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 instable 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:

$$\varepsilon_{\theta_C} = \left\lceil \frac{0.318}{\sin(\Delta\theta_{mod}/2)} \cdot \varepsilon_{yx} + 0.159 \cdot \coth\Delta\theta_{mod} \cdot \varepsilon_A + \left(1 + \frac{0.318}{\sin\Delta\theta_{mod}}\right) \cdot \varepsilon_{\Delta\theta_C/2} + 1.23 \cdot LSB \right\rceil \quad \text{if } 0 < \Delta\theta_m < \pi/2 \qquad \textbf{Eqn. 3-36}$$

$$\varepsilon_{\theta_C} = \left\lceil \frac{0.318}{\cos(\Delta\theta_{mod}/2)} \cdot \varepsilon_{yx} + 0.159 \cdot \coth\Delta\theta_{mod} \cdot \varepsilon_A + \left(1 + \frac{0.318}{\sin\Delta\theta_{mod}}\right) \cdot \varepsilon_{\Delta\theta_C/2} + 1.23 \cdot LSB \right\rceil \quad \text{if } \pi/2 \le \Delta\theta_m \qquad \textbf{Eqn. 3-37}$$

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)

ε_{θ_C} error of the computed angle expressed in LSB

ε_A difference in signal amplitudes, absolute value, in LSB

ε_{yx} error contributed by the x, y signals, $\varepsilon_y = \varepsilon_x = \varepsilon_{yx}$ in LSB

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

$\Delta\theta_{mod}$ phase difference $\Delta\theta$ modulo π

The signal error ε_{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 $\Delta\theta$ equal to $\pi/2$ 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 π (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: ε_y and ε_x
- error contributed by higher order harmonics appearing in the signal values: ε_y and ε_x (included in the variable)
- computational error of the multiplication due to the finite length of the micro-controller registers: ε_b and ε_a
- error of the angle difference representation $\Delta\theta$ in the finite precision arithmetic: $\varepsilon_{(\Delta\theta_c)/2}$
- 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:

$$\theta_C = \frac{1}{\pi} \cdot \operatorname{atan}\left(\tan\left(\frac{\Delta\theta_C}{2}\right) \cdot \frac{S \cdot A_y \cdot \sin(\Delta\theta_A) + S \cdot A_x \cdot \sin(\theta_A + \Delta\theta_A) + \varepsilon_y + \varepsilon_x + \varepsilon_b \cdot 2 \cdot \cos\frac{\Delta\theta_C}{2}}{S \cdot A_x \cdot \sin(\theta_A) - S \cdot A_x \cdot \sin(\theta_A + \Delta\theta_A) + \varepsilon_y - \varepsilon_x + \varepsilon_a \cdot 2 \cdot \sin\frac{\Delta\theta_C}{2}} \right) - \varepsilon_{\Delta\theta_C/2} \qquad \textit{Eqn. 3-38}$$

where:

A_y amplitude of the signal y, nearly 1.0

A_x amplitude of the signal x, nearly 1.0

θ_C computed angle

θ_A the actual angle

$\Delta\theta_A$ the actual phase difference between the signals

ε_y error contributed by the signal includes the error contributed by the ADC converter and the higher order harmonics

ε_x error contributed by the signal includes the error contributed by the ADC converter and the higher order harmonics

$\varepsilon_{\Delta\theta_C/2}$ error contributed by the representation of the fractional format (numerical resolution) plus the measurement error of the divided by 2

ε_b error contributed by the multiplication to compute the intermediate variable b, see Equation 3-34

ε_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:

$$\delta\theta_C = \max_{\theta_A}\left(\left|\sum_u \frac{\partial\theta_A}{\partial u}\cdot\delta u\right|\right)\Bigg|_{\substack{\Delta\theta_C/2\\ \varepsilon_y=0\\ \varepsilon_x=0\\ \varepsilon_b=0\\ \varepsilon_a=0\\ A_y=1\\ A_x=1}} \qquad \textit{Eqn. 3-39}$$

$$u = \Delta\theta_C/2,\ \varepsilon_y,\ \varepsilon_x,\ \varepsilon_b,\ \varepsilon_a,\ A_y,\ A_x$$

where:

u independent variable

$\max_{\theta_A}$ maximum over the whole range of

δ partial difference operator

$\frac{\partial}{\partial}$ partial derivative operator

Furthermore we can assume:

$$\begin{gathered}\varepsilon_y = \delta\varepsilon_y \geq 0 \\ \varepsilon_x = \delta\varepsilon_x \geq 0 \\ \varepsilon_b = \delta\varepsilon_b \geq 0 \\ \varepsilon_a = \delta\varepsilon_a \geq 0 \\ \varepsilon_{\Delta\theta_C/2} = \delta(\Delta\theta_C/2) \geq 0 \\ \varepsilon_A = |A_y - A_x| \geq 0 \\ \Delta\theta_C \cong \Delta\theta_A = \Delta\theta \\ S \cong 1 \\ \varepsilon_{\theta_C} = \delta\theta_C \\ A_y \cong A_x = A_{yx} \cong 1,\ A_{yx} < 1\end{gathered} \qquad \textit{Eqn. 3-40}$$

where:

ε_A error contributed by the difference in signal amplitudes

ε_{θ_C} the resulting error of the computed angle

It should be noticed that the error contributed by the signals (ε_y and ε_x), the errors due to the finite precision arithmetic (ε_b, ε_a and $\varepsilon_{\Delta\theta_C/2}$) have a random nature. On contrary, the error due to the unequal signal amplitudes ε_A is a systematic error[1].

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

$$\varepsilon_{\theta_C} = \frac{1}{\pi} \cdot \max_{\theta_A}\left(\left|\frac{\sin(\theta_A + \Delta\theta)}{A_{yx} \cdot \sin\Delta\theta}\right| \cdot \varepsilon_x + \left|\frac{\sin\theta_A}{A_{yx} \cdot \sin\Delta\theta}\right| \cdot \varepsilon_y + \left|\frac{\cos\left(\theta_A + \frac{\Delta\theta}{2}\right)}{A_{yx}}\right| \cdot \varepsilon_b + \left|\frac{\sin\left(\theta_A + \frac{\Delta\theta}{2}\right)}{A_{yx}}\right| \cdot \varepsilon_a \right. \qquad \textit{Eqn. 3-41}$$

$$\left. + \left|\frac{\coth\Delta\theta}{2 \cdot A_{yx}}\right| \cdot \varepsilon_A + \left|\frac{\sin(2 \cdot \theta_A + \Delta\theta)}{\sin\Delta\theta}\right| \cdot \varepsilon_{\Delta\theta_C/2}\right) + \varepsilon_{\Delta\theta_C/2}$$

Apart of the error sources mentioned above, an additional error is contributed by the **GFLIB_AtanYX** function. In case of the **GFLIB_AtanYX** function from the GFLIB the computation error is equal to one LSB.

The errors of the y and x signals, ε_y and ε_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 Equation 3-34, ε_b and ε_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 ε_A

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, e ε_A, 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

```
#include "gflib.h"

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

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

```
#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

Code Size (words)	51 + 102 (GFLIB_AtanYX)	
Data Size (words)	0 + 33 (GFLIB_AtanYX)	
Execution Clock	Min	140 cycles
	Max	216 cycles

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

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

3.14.2 Prototype

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

3.14.3 Arguments

Table 3-32. Function Arguments

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

3.14.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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 polynom 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

```
#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

Code Size (words)	65	
Data Size (words)	34	
Execution Clock	Min	38 cycles
	Max	103 cycles

3.15 GFLIB_SqrtIter

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

3.15.1 Synopsis

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

3.15.2 Prototype

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

3.15.3 Arguments

Table 3-34. Function Arguments

Name	In/Out	Format	Range	Description
f32Arg	In	SF32	0x80000000... 0x7FFFFFFF	Input argument; the Frac32 data type is defined in header file GFLIB_types.h

3.15.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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:

$$Y_{k+1} = 2 \cdot Y_k \cdot \left(\frac{3}{4} - Y_k^2 \cdot \frac{X}{4}\right) \quad \textit{Eqn. 3-42}$$

3. The final square root is

$$Y = 2 \cdot X \cdot Y_4 \quad \textit{Eqn. 3-43}$$

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.

$$2^{-\frac{1}{2}} = \frac{1}{\sqrt{2}} = 0{,}70711 \quad \textit{Eqn. 3-44}$$

   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

```
#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

Code Size (words)	28	
Data Size (words)	0	
Execution Clock	Min	73 cycles
	Max	73 cycles

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)
```

V3 core version:

```
asm Frac16 GFLIB_V3LutFAsm(Frac16 f16Arg, const Frac16 *pf16Table,
UWord16 uw16TableSize)
```

3.16.3 Arguments

Table 3-36. Function Arguments

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

3.16.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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.

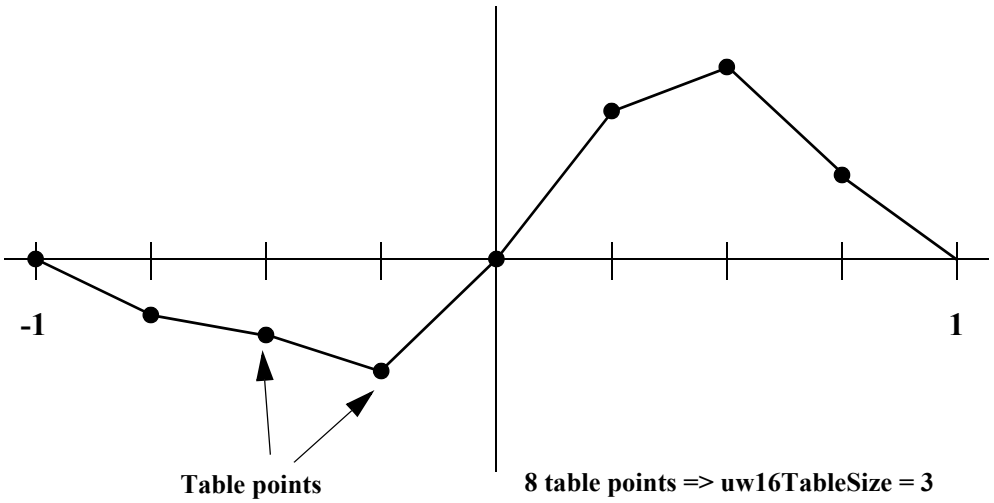

Figure 3-7. Algorithm Diagram

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

```
#include "gflib.h"

static Frac16 mf16Input;
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 3-37. Performance of GFLIB_Lut function

Code Size (words)	V2: 34, V3: 31	
Data Size (words)	0	
Execution Clock	Min	V2: 63, V3: 55 cycles
	Max	V2: 63, V3: 55 cycles

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

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

3.17.2 Prototype

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

3.17.3 Arguments

Table 3-38. Function Arguments

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

Table 3-39. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_RAMP16_T	f16RampUp	In	SF16	0x8000... 0x7FFF	Ramp up increment
	f16RampDown	In	SF16	0x8000... 0x7FFF	Ramp down increment

3.17.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.17.5 Dependencies

List of all dependent files:

- GFLIB_RampAsm.h

- GFLIB_types.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.

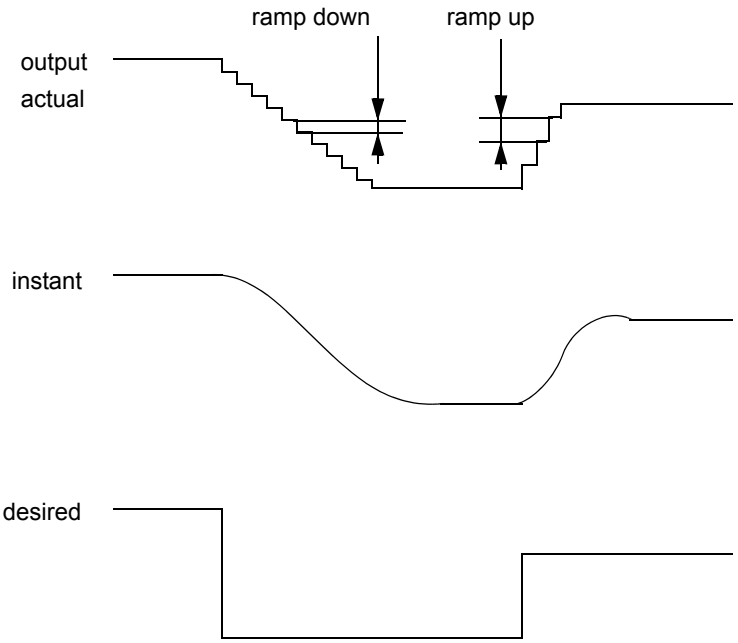

Figure 3-8. Algorithm Diagram

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.

Example 3-17. Implementation Code

```
#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;
}

/* Periodical function or interrupt */
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

Code Size (words)	20	
Data Size (words)	0	
Execution Clock	Min	44 cycles
	Max	44 cycles

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 3-41. Function Arguments

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

Table 3-42. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_RAMP32_T	f32RampUp	In	SF32	0x80000000... 0x7FFFFFFF	Ramp up increment
	f32RampDown	In	SF32	0x80000000... 0x7FFFFFFF	Ramp down increment

3.18.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.18.5 Dependencies

List of all dependent files:

- GFLIB_RampAsm.h

- GFLIB_types.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.

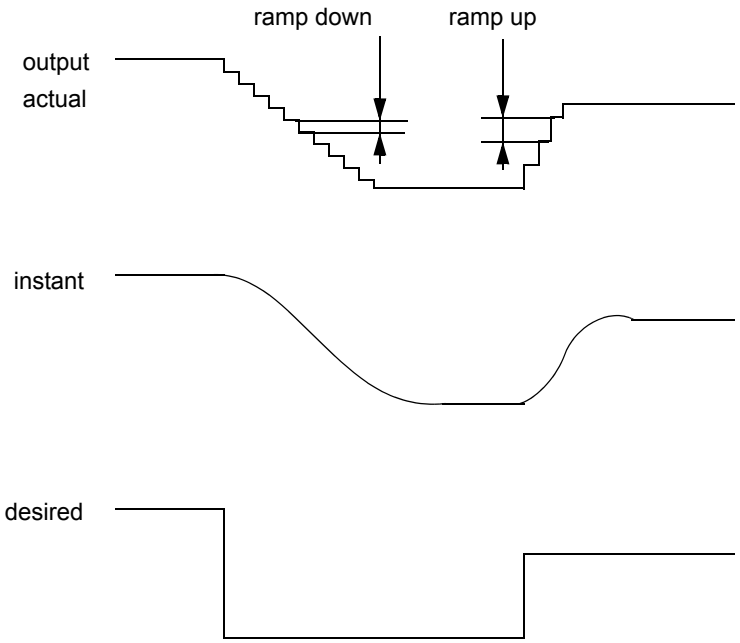

Figure 3-9. Algorithm Diagram

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

Code Size (words)	24	
Data Size (words)	0	
Execution Clock	Min	48 cycles
	Max	48 cycles

3.19 GFLIB_DynRamp16InitVal

This function initializes the internal variables of the **GFLIB_DynRamp16** algorithm with a value.

3.19.1 Synopsis

```
#include ”gflib.h”
void GFLIB_DynRamp16InitVal(Frac16 f16InitVal, GFLIB_DYNRAMP16_T
*pudtParam)
```

3.19.2 Prototype

```
asm void GFLIB_DynRamp16InitValFAsm(Frac16 f16InitVal, GFLIB_DYNRAMP16_T
*pudtParam)
```

3.19.3 Arguments

Table 3-44. Function Arguments

Name	In/Out	Format	Range	Description
f16InitVal	In	SF16	0x8000... 0x7FFF	Initial value of the ramp algorithm
*pudtParam	In	N/A	N/A	Pointer to structure containing the ramp-up and -down increments, saturation ramp-up and -down increments and the last actual values

Table 3-45. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_DYNRAMP16_T	f16RampUp	In	SF16	0x8000... 0x7FFF	Ramp up increment
	f16RampDown	In	SF16	0x8000... 0x7FFF	Ramp down increment
	f16RampUpSat	In	SF16	0x8000... 0x7FFF	Ramp up increment when saturation
	f16RampDownSat	In	SF16	0x8000... 0x7FFF	Ramp down increment when saturation
	f16Actual	In/Out	SF16	0x8000... 0x7FFF	Actual value

3.19.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.19.5 Dependencies

List of all dependent files:

- GFLIB_DynRampAsm.h
- GFLIB_types.h

3.19.6 Description

The **GFLIB_DynRamp16InitVal** function initializes the accumulator of the ramp algorithm with a predefined value. This function is called once where the user wants the ramp to be initialized. The buffer is set up in the manner the output is the input initial value in the first step.

3.19.7 Returns

None.

3.19.8 Range Issues

The input data value is in the range of <-1,1).

3.19.9 Special Issues

The **GFLIB_DynRamp16InitVal** function is saturation mode independent.

3.19.10 Implementation

The **GFLIB_DynRamp16InitVal** function is implemented as a function call.

Example 3-19. Implementation Code

```
#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 */
         GFLIB_DynRamp16InitVal(mf16InstantValue, &mudtDynRamp16);

         /* 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_DynRamp16InitVal function

Code Size (words)	4	
Data Size (words)	0	
Execution Clock	Min	24 cycles
	Max	24 cycles

3.20 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.

3.20.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_DynRamp16(Frac16 f16Desired, Frac16 f16Instant, UWord16
uw16SatFlag, GFLIB_DYNRAMP16_T *pudtParam)
```

3.20.2 Prototype

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

3.20.3 Arguments

Table 3-47. Function Arguments

Name	In/Out	Format	Range	Description
f16Desired	In	SF16	0x8000... 0x7FFF	Desired value; the Frac16 data type is defined in header file GFLIB_types.h
f16Instant	In	SF16	0x8000... 0x7FFF	Instant value; the Frac16 data type is defined in header file GFLIB_types.h
uw16SatFlag	In	UI16	0x0... 0xFFFF	Saturation flag
*pudtParam	In	N/A	N/A	Pointer to structure containing the ramp-up and -down increments, saturation ramp-up and -down increments and the last actual values

Table 3-48. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_DYNRAMP16_T	f16RampUp	In	SF16	0x8000... 0x7FFF	Ramp up increment
	f16RampDown	In	SF16	0x8000... 0x7FFF	Ramp down increment
	f16RampUpSat	In	SF16	0x8000... 0x7FFF	Ramp up increment when saturation
	f16RampDownSat	In	SF16	0x8000... 0x7FFF	Ramp down increment when saturation
	f16Actual	In/Out	SF16	0x8000... 0x7FFF	Actual value

3.20.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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_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).

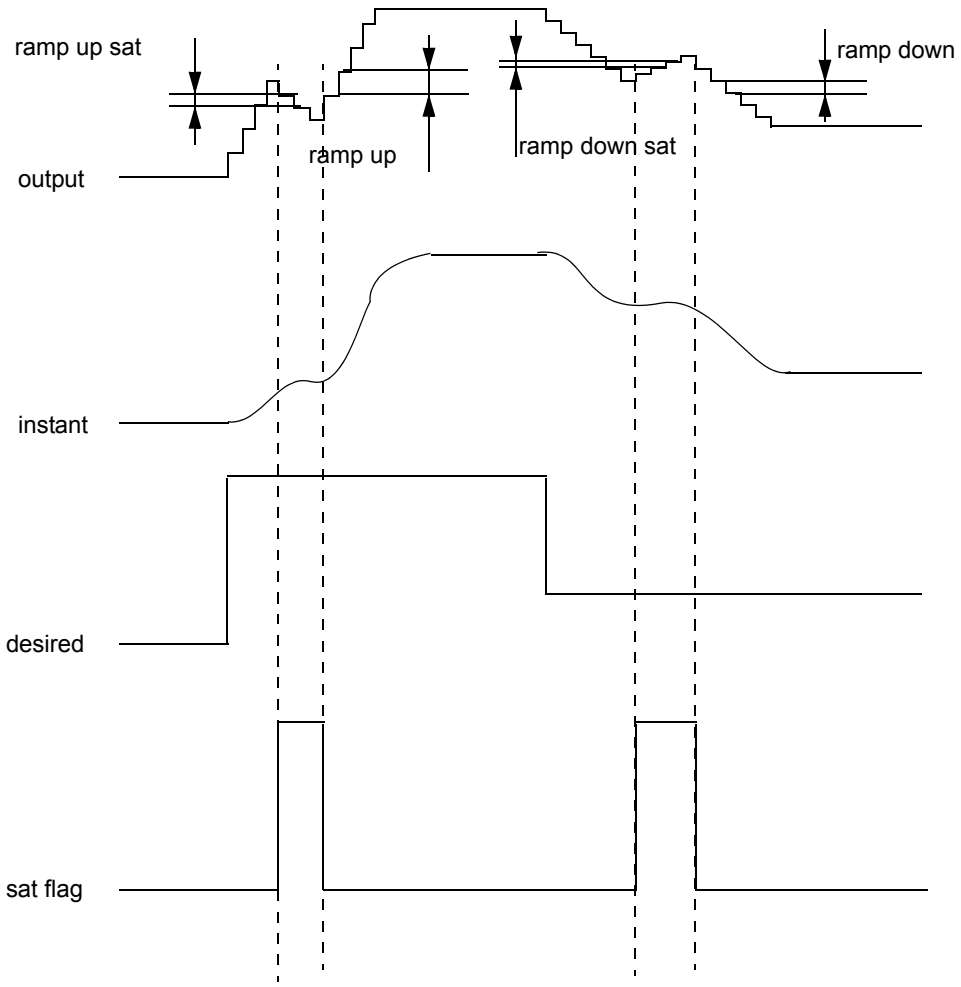

Figure 3-10. Algorithm Diagram

3.20.7 Returns

The **GFLIB_DynRamp16** function returns the 16-bit ramp value as described in Section 3.20.6, “Description”.

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 algorithm’s structure should be initialized by the **GFLIB_DynRamp16InitVal** function prior the ramp algorithm use.

The **GFLIB_DynRamp16** function calculation is correct regardless of saturation mode.

3.20.10 Implementation

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

Example 3-20. Implementation Code

```
#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 */
         GFLIB_DynRamp16(mf16InstantValue, &mudtDynRamp16);

         /* Saturation flag initialization */
         muw16SatFlag = 0;

}

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

3.20.11 See Also

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

3.20.12 Performance

Table 3-49. Performance of GFLIB_DynRamp16 function

Code Size (words)	31	
Data Size (words)	0	
Execution Clock	Min	61 cycles
	Max	61 cycles

3.21 GFLIB_DynRamp32InitVal

This function initializes the internal variables of the **GFLIB_DynRamp32** algorithm with a value.

3.21.1 Synopsis

```
#include ”gflib.h”
void GFLIB_DynRamp32InitVal(Frac32 f32InitVal, GFLIB_DYNRAMP32_T
*pudtParam)
```

3.21.2 Prototype

```
asm void GFLIB_DynRamp32InitValFAsm(Frac32 f32InitVal, GFLIB_DYNRAMP32_T
*pudtParam)
```

3.21.3 Arguments

Table 3-50. Function Arguments

Name	In/Out	Format	Range	Description
f32InitVal	In	SF32	0x80000000... 0x7FFFFFFF	Initial value of the ramp algorithm
*pudtParam	In	N/A	N/A	Pointer to structure containing the ramp-up and -down increments, saturation ramp-up and -down increments and the last actual values

Table 3-51. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_DYNRAMP32_T	f32RampUp	In	SF32	0x80000000... 0x7FFFFFFF	Ramp up increment
	f32RampDown	In	SF32	0x80000000... 0x7FFFFFFF	Ramp down increment
	f32RampUpSat	In	SF32	0x80000000... 0x7FFFFFFF	Ramp up increment when saturation
	f32RampDownSat	In	SF32	0x80000000... 0x7FFFFFFF	Ramp down increment when saturation
	f32Actual	In/Out	SF32	0x80000000... 0x7FFFFFFF	Actual value

3.21.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.21.5 Dependencies

List of all dependent files:

- GFLIB_DynRampAsm.h
- GFLIB_types.h

3.21.6 Description

The **GFLIB_DynRamp32InitVal** function initializes the accumulator of the ramp algorithm with a predefined value. This function is called once where the user wants the ramp to be initialized. The buffer is set up in the manner the output is the input initial value in the first step.

3.21.7 Returns

None.

3.21.8 Range Issues

The input data value is in the range of <-1,1).

3.21.9 Special Issues

The **GFLIB_DynRamp32InitVal** function is saturation mode independent.

3.21.10 Implementation

The **GFLIB_DynRamp32InitVal** function is implemented as a function call.

Example 3-21. Implementation Code

```
#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 */
        GFLIB_DynRamp32InitVal(mf32InstantValue, &mudtDynRamp32);

        /* Saturation flag initialization */
        muw16SatFlag = 0;

}

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

3.21.11 See Also

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

3.21.12 Performance

Table 3-52. Performance of GFLIB_DynRamp32InitVal function

Code Size (words)	4	
Data Size (words)	0	
Execution Clock	Min	24 cycles
	Max	24 cycles

3.22 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.

3.22.1 Synopsis

```
#include ”gflib.h”
Frac32 GFLIB_DynRamp32(Frac32 f32Desired, Frac32 f32Instant, UWord16
uw16SatFlag, GFLIB_DYNRAMP32_T *pudtParam)
```

3.22.2 Prototype

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

3.22.3 Arguments

Table 3-53. Function Arguments

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

Table 3-54. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_DYNRAMP32_T	f32RampUp	In	SF32	0x80000000... 0x7FFFFFFF	Ramp up increment
	f32RampDown	In	SF32	0x80000000... 0x7FFFFFFF	Ramp down increment
	f32RampUpSat	In	SF32	0x80000000... 0x7FFFFFFF	Ramp up increment when saturation
	f32RampDownSat	In	SF32	0x80000000... 0x7FFFFFFF	Ramp down increment when saturation
	f32Actual	In/Out	SF32	0x80000000... 0x7FFFFFFF	Actual value

3.22.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.22.5 Dependencies

List of all dependent files:

- GFLIB_DynRampAsm.h
- GFLIB_types.h

3.22.6 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).

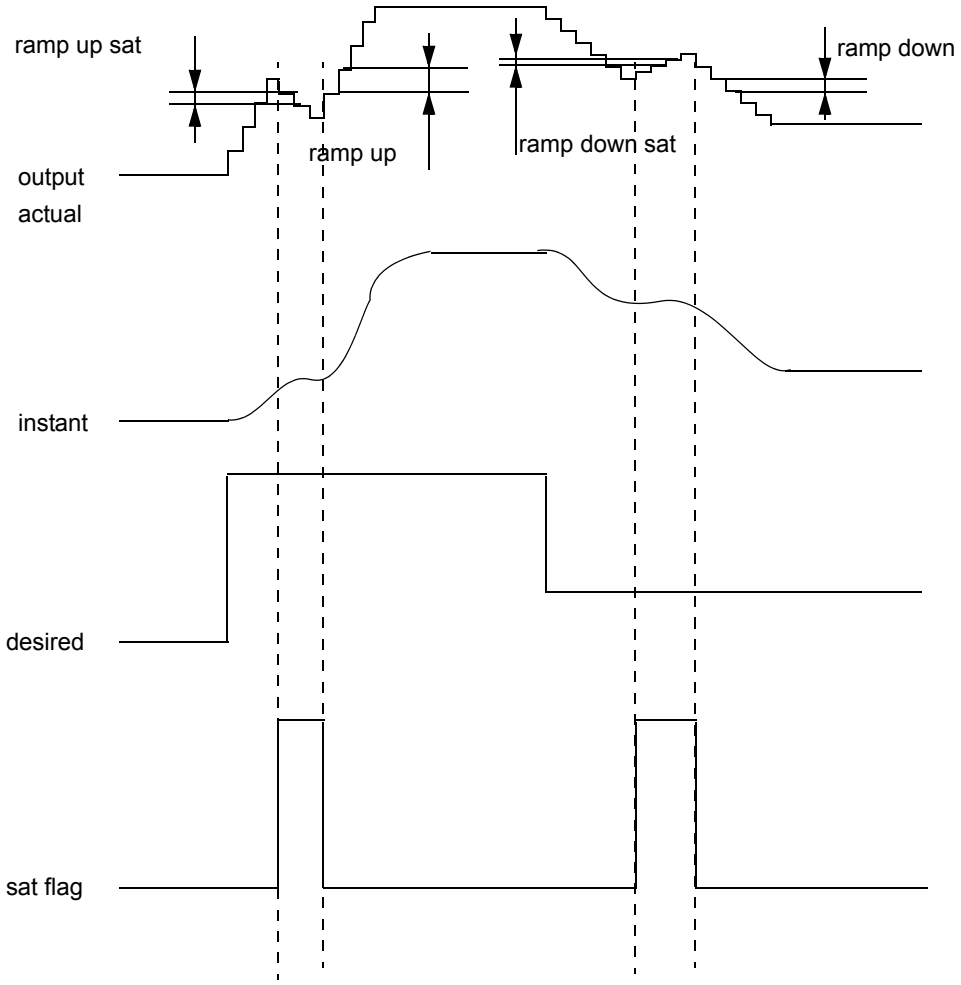

Figure 3-11. Algorithm Diagram

3.22.7 Returns

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

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 <-1,1).

3.22.9 Special Issues

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

3.22.10 Implementation

The **GFLIB_DynRamp32** function is implemented as a function call.

Example 3-22. Implementation Code

```
#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);
}
```

3.22.11 See Also

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

3.22.12 Performance

Table 3-55. Performance of GFLIB_DynRamp32 function

Code Size (words)	35	
Data Size (words)	0	
Execution Clock	Min	65 cycles
	Max	65 cycles

3.23 GFLIB_Limit16

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

3.23.1 Synopsis

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

3.23.2 Prototype

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

3.23.3 Arguments

Table 3-56. Function Arguments

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

Table 3-57. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_LIMIT16_T	f16UpperLimit	In	SF16	0x8000... 0x7FFF	Upper limit
	f16LowerLimit	In	SF16	0x8000... 0x7FFF	Lower limit

3.23.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.23.5 Dependencies

List of all dependent files:

- GFLIB_LimitAsm.h
- GFLIB_types.h

3.23.6 Description

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

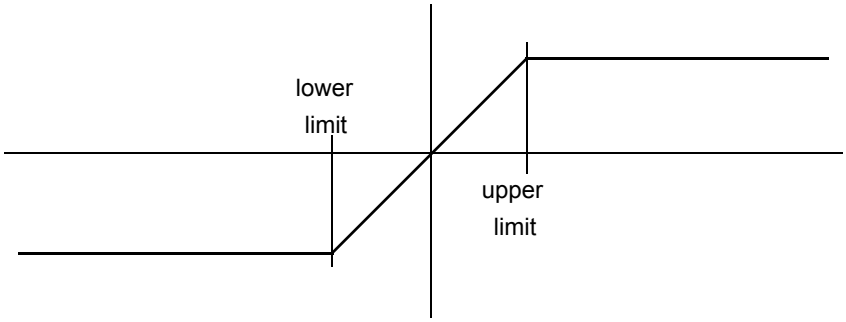

Figure 3-12. Algorithm Transition

3.23.7 Returns

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

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 <f16UpperLimit, f16LowerLimit>.

3.23.9 Special Issues

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

3.23.10 Implementation

The **GFLIB_Limit16** function is implemented as an inline function.

Example 3-23. Implementation Code

```
#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);
```

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

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

3.23.11 See Also

See **GFLIB_Limit32**, **GFLIB_LowerLimit16**, **GFLIB_LowerLimit32**, **GFLIB_UpperLimit16** and **GFLIB_UpperLimit32** for more information.

3.23.12 Performance

Table 3-58. Performance of GFLIB_Limit16 function

Code Size (words)	8	
Data Size (words)	0	
Execution Clock	Min	16 cycles
	Max	16 cycles

3.24 GFLIB_LowerLimit16

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

3.24.1 Synopsis

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

3.24.2 Prototype

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

3.24.3 Arguments

Table 3-59. Function Arguments

Name	In/Out	Format	Range	Description
f16Arg	In	SF16	0x8000... 0x7FFF	Input argument; the Frac16 data type is defined in header file GFLIB_types.h
f16LowerLimit	In	SF16	0x8000... 0x7FFF	Lower limit trim; the Frac16 data type is defined in header file GFLIB_types.h

3.24.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.24.5 Dependencies

List of all dependent files:

- GFLIB_LimitAsm.h
- GFLIB_types.h

3.24.6 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 3-13.

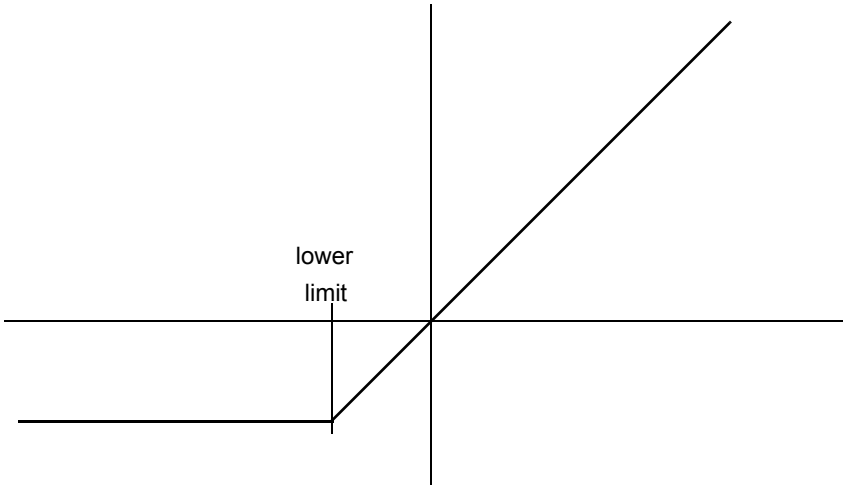

Figure 3-13. Algorithm Transition

3.24.7 Returns

The **GFLIB_LowerLimit16** function returns the trimmed number according to the 16-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 <f16LowerLimit, 1).

3.24.9 Special Issues

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

3.24.10 Implementation

The **GFLIB_LowerLimit16** function is implemented as an inline function.

Example 3-24. Implementation Code

```
#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);

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

3.24.11 See Also

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

3.24.12 Performance

Table 3-60. Performance of GFLIB_LowerLimit16 function

Code Size (words)	4	
Data Size (words)	0	
Execution Clock	Min	12 cycles
	Max	12 cycles

3.25 GFLIB_UpperLimit16

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

3.25.1 Synopsis

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

3.25.2 Prototype

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

3.25.3 Arguments

Table 3-61. Function Arguments

Name	In/Out	Format	Range	Description
f16Arg	In	SF16	0x8000... 0x7FFF	Input argument; the Frac16 data type is defined in header file GFLIB_types.h
f16UpperLimit	In	SF16	0x8000... 0x7FFF	Upper limit trim; the Frac16 data type is defined in header file GFLIB_types.h

3.25.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

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 3-14.

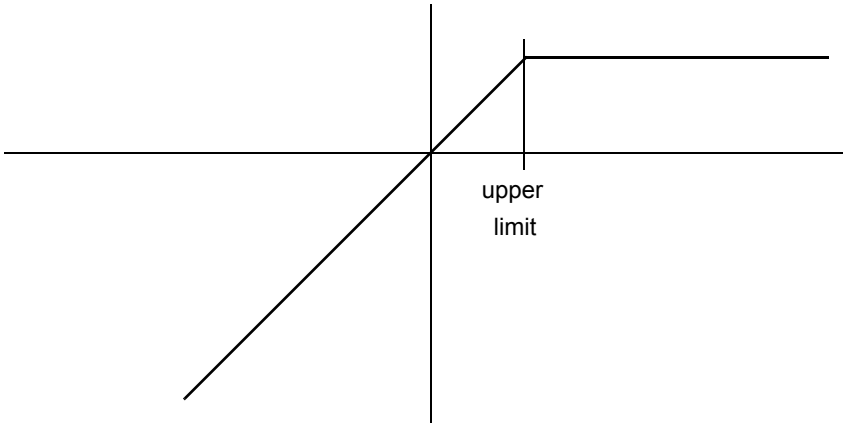

Figure 3-14. Algorithm Transition

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 an inline function.

Example 3-25. Implementation Code

```
#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);
```

```
        /* 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

Table 3-62. Performance of GFLIB_UpperLimit16 function

Code Size (words)	4	
Data Size (words)	0	
Execution Clock	Min	12 cycles
	Max	12 cycles

3.26 GFLIB_Limit32

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

3.26.1 Synopsis

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

3.26.2 Prototype

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

3.26.3 Arguments

Table 3-63. Function Arguments

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

Table 3-64. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_LIMIT32_T	f32UpperLimit	In	SF32	0x80000000... 0x7FFFFFFF	Ramp up increment
	f32LowerLimit	In	SF32	0x80000000... 0x7FFFFFFF	Ramp down increment

3.26.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.26.5 Dependencies

List of all dependent files:

- GFLIB_LimitAsm.h
- GFLIB_types.h

3.26.6 Description

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

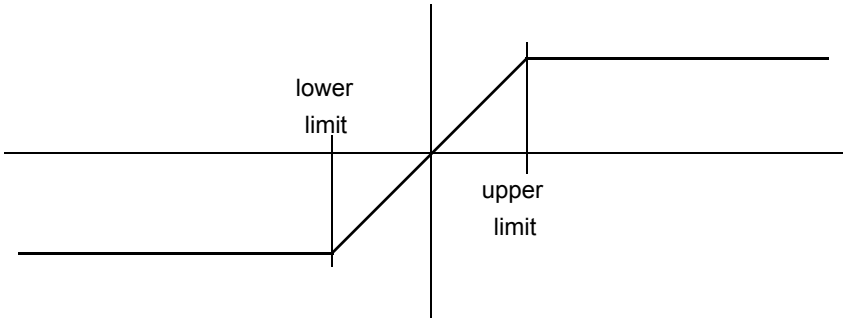

Figure 3-15. Algorithm Transition

3.26.7 Returns

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

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 <f32UpperLimit, f32LowerLimit>

3.26.9 Special Issues

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

3.26.10 Implementation

The **GFLIB_Limit32** function is implemented as an inline function.

Example 3-26. Implementation Code

```
#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);
```

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

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

3.26.11 See Also

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

3.26.12 Performance

Table 3-65. Performance of GFLIB_Limit32 function

Code Size (words)	6	
Data Size (words)	0	
Execution Clock	Min	14 cycles
	Max	14 cycles

3.27 GFLIB_LowerLimit32

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

3.27.1 Synopsis

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

3.27.2 Prototype

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

3.27.3 Arguments

Table 3-66. Function Arguments

Name	In/Out	Format	Range	Description
f32Arg	In	SF32	0x80000000... 0x7FFFFFFF	Input argument; the Frac32 data type is defined in header file GFLIB_types.h
f32LowerLimit	In	SF32	0x80000000... 0x7FFFFFFF	Lower limit trim; the Frac32 data type is defined in header file GFLIB_types.h

3.27.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.27.5 Dependencies

List of all dependent files:

- GFLIB_LimitAsm.h
- GFLIB_types.h

3.27.6 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 3-16.

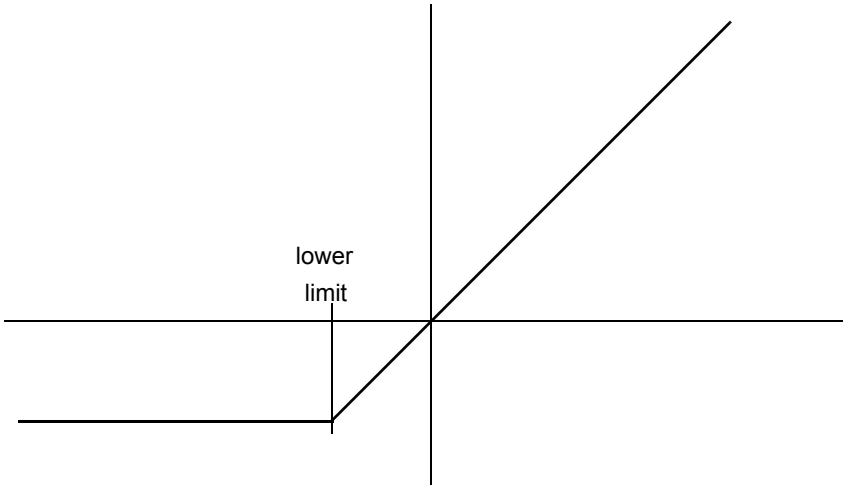

Figure 3-16. Algorithm Transition

3.27.7 Returns

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

3.27.8 Range Issues

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

3.27.9 Special Issues

The **GFLIB_LowerLimit32** function calculation is correct regardless of saturation mode.

3.27.10 Implementation

The **GFLIB_LowerLimit32** function is implemented as an inline function.

Example 3-27. Implementation Code

```
#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);
}
```

3.27.11 See Also

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

3.27.12 Performance

Table 3-67. Performance of GFLIB_LowerLimit32 function

Code Size (words)	2	
Data Size (words)	0	
Execution Clock	Min	10 cycles
	Max	10 cycles

3.28 GFLIB_UpperLimit32

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

3.28.1 Synopsis

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

3.28.2 Prototype

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

3.28.3 Arguments

Table 3-68. Function Arguments

Name	In/Out	Format	Range	Description
f32Arg	In	SF32	0x80000000... 0x7FFFFFFF	Input argument; the Frac32 data type is defined in header file GFLIB_types.h
f32UpperLimit	In	SF32	0x80000000... 0x7FFFFFFF	Lower limit trim; the Frac32 data type is defined in header file GFLIB_types.h

3.28.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.28.5 Dependencies

List of all dependent files:

- GFLIB_LimitAsm.h
- GFLIB_types.h

3.28.6 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

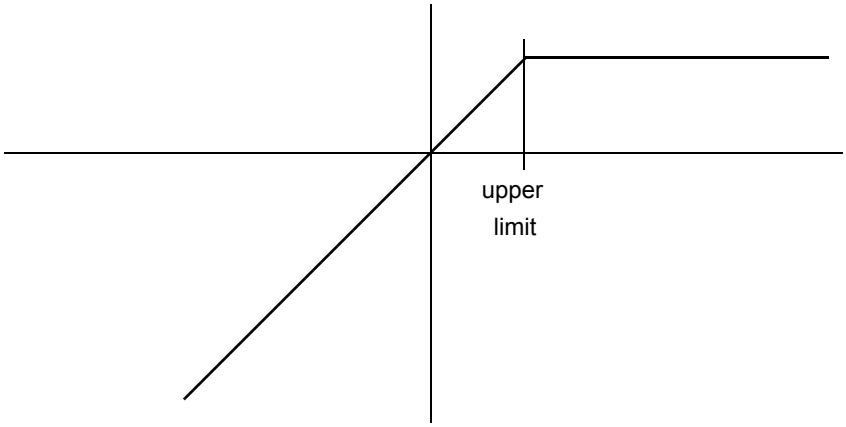

Figure 3-17. Algorithm Transition

3.28.7 Returns

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

3.28.8 Range Issues

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

3.28.9 Special Issues

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

3.28.10 Implementation

The **GFLIB_UpperLimit32** function is implemented as an inline function.

Example 3-28. Implementation Code

```
#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);
}
```

3.28.11 See Also

See **GFLIB_Limit16**, **GFLIB_Limit32**, **GFLIB_LowerLimit16**, **GFLIB_LowerLimit32** and **GFLIB_UpperLimit16** for more information.

3.28.12 Performance

Table 3-69. Performance of GFLIB_UpperLimit32 function

Code Size (words)	2	
Data Size (words)	0	
Execution Clock	Min	10 cycles
	Max	10 cycles

3.29 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

3.29.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_Sgn(Frac16 f16Arg)
```

3.29.2 Prototype

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

3.29.3 Arguments

Table 3-70. Function Arguments

Name	In/Out	Format	Range	Description
f16Arg	In	SF16	0x8000... 0x7FFF	Input argument; the Frac16 data type is defined in header file GFLIB_types.h

3.29.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.29.5 Dependencies

List of all dependent files:

- GFLIB_SgnAsm.h
- GFLIB_types.h

3.29.6 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.

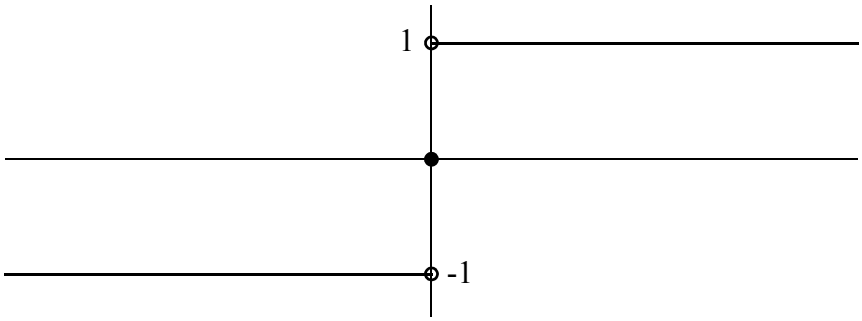

Figure 3-18. Algorithm Transition

3.29.7 Returns

The **GFLIB_Sgn** function returns the sign of the argument.

Table 3-71. Input and Output Returns for the GFLIB_Sgn Function

Input	Output
= 0	0
> 0	1 (32767)
< 0	-1 (-32768)

3.29.8 Range Issues

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

3.29.9 Special Issues

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

3.29.10 Implementation

The **GFLIB_Sgn** function is implemented as an inline function.

Example 3-29. Implementation Code

```
#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_Sgn(mf16Input);
}
```

3.29.11 See Also

See **GFLIB_Sgn2** for more information.

3.29.12 Performance

Table 3-72. Performance of GFLIB_Sgn function

Code Size (words)	9	
Data Size (words)	0	
Execution Clock	Min	13 cycles
	Max	13 cycles

3.30 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

3.30.1 Synopsis

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

3.30.2 Prototype

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

3.30.3 Arguments

Table 3-73. Function Arguments

Name	In/Out	Format	Range	Description
f16Arg	In	SF16	0x8000... 0x7FFF	Input argument; the Frac16 data type is defined in header file GFLIB_types.h

3.30.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.30.5 Dependencies

List of all dependent files:

- GFLIB_Sgn2Asm.h
- GFLIB_types.h

3.30.6 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.

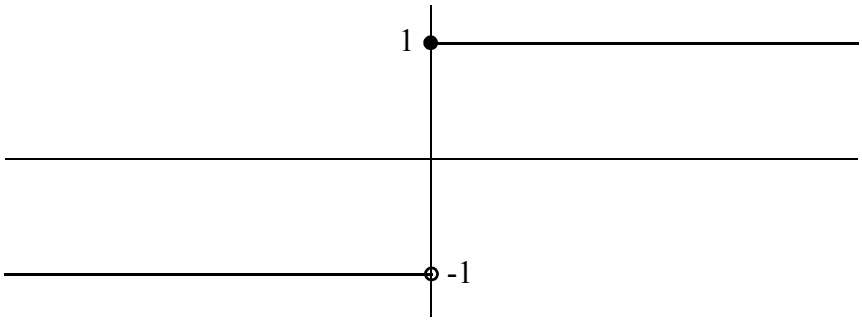

Figure 3-19. Algorithm Transition

3.30.7 Returns

The **GFLIB_Sgn2** function returns the sign of the argument:

Table 3-74.

Input	Output
>= 0	1 (32767)
< 0	-1 (-32768)

3.30.8 Range Issues

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

3.30.9 Special Issues

The **GFLIB_Sgn2** function calculation is correct regardless of saturation mode.

3.30.10 Implementation

The **GFLIB_Sgn2** function is implemented as an inline function.

Example 3-30. Implementation Code

```
#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);
```

```
}
```

3.30.11 See Also

See **GFLIB_Sgn** for more information.

3.30.12 Performance

Table 3-75. Performance of GFLIB_Sgn2 function

Code Size (words)	4	
Data Size (words)	0	
Execution Clock	Min	8 cycles
	Max	8 cycles

3.31 GFLIB_Hyst

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

3.31.1 Synopsis

```
#include "gflib.h"
void GFLIB_Hyst(GFLIB_HYST_T *pudtHystVar)
```

3.31.2 Prototype

```
asm void GFLIB_HystFAsm(GFLIB_HYST_T *pudtHystVar)
```

3.31.3 Arguments

Table 3-76. Function Arguments

Name	In/ Out	Format	Valid Range	Description
*pudtHystVar	in/out	N/A	N/A	pointer to structure containing the input, output values, input thresholds and output constants.

Table 3-77. User type definitions

Typedef	Name	In/ Out	Format	Valid Range	Description
GFLIB_HYST_T	f16In	in	SF16	$8000... $7FFF	input
	f16Out	out	SF16	$8000... $7FFF	hysteresis output
	f16HystOff	in	SF16	$8000... $7FFF	value determining the lower threshold
	f16OutOff	in	SF16	$8000... $7FFF	value of output when the input is lower than f16HystOff
	f16HystOn	in	SF16	$8000... $7FFF	value determining the upper threshold
	f16OutOn	in	SF16	$8000... $7FFF	value of output when the input is higher than f16HystOn

3.31.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.31.5 Dependencies

List of all dependent files:

- GFLIB_HystAsm.h
- gflib.h

3.31.6 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 f16HystOn, the output is high; when the input is below another (lower) threshold f16HystOff, the output is low; when the input is between the two, the output retains its value.

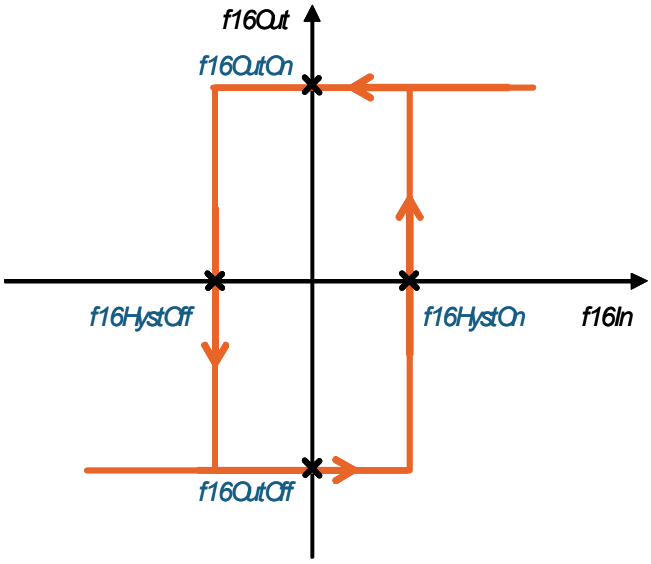

Figure 3-20. Hysteresis function

For correct functionality, f16HystOn must be greater than f16HystOff.

3.31.7 Returns

The calculated output of the function is contained in the function structure pointed to by the pointer *pudtHystVar in the variable f16Out.

3.31.8 Range Issues

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

3.31.9 Special Issues

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

3.31.10 Implementation

Example 3-31. Implementation Code

```
#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)  */

}
```

3.31.11 Performance

Table 3-78. Performance of GFLIB_Hyst function

Code Size (words)	14	
Data Size (words)	0	
Execution Clock	Min	35 cycles
	Max	35 cycles

3.32 GFLIB_ControllerPIpInitVal

This function initializes the integral portion of the **GFLIB_ControllerPIp** algorithm.

3.32.1 Synopsis

```
#include ”gflib.h”
void GFLIB_ControllerPIpInitVal(Frac16 f16InitVal,
GFLIB_CONTROLLER_PI_P_PARAMS_T *pudtPiParams)
```

3.32.2 Prototype

```
asm void GFLIB_ControllerPIpInitValFAsm(Frac16 f16InitVal,
GFLIB_CONTROLLER_PI_P_PARAMS_T *pudtPiParams)
```

3.32.3 Arguments

Table 3-79. Function Arguments

Name	Type	Format	Range	Description
f16InputVal	In	SF16	0x8000... 0x7FFF	Initial integral portion of the PI controller
*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_ControllerPIpAsm.h

Table 3-80. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_CONTROLLER_PI_P_PARAMS_T	f16PropGain	In	SF16	0x0... 0x7FFF	Proportional gain
	f16IntegGain	In	SF16	0x0... 0x7FFF	Integral gain
	i16PropGainShift	In	SI16	0...13	Proportional gain shift
	i16IntegGainShift	In	SI16	0...13	Integral gain shift
	f32IntegPartK_1	In/Out	SF32	0x80000000... 0x7FFFFFFF	State variable; integral part at step k-1; can be modified outside of the function.
	f16UpperLimit	In	SF16	0x8000 ... 0x7FFF	Upper limit of the controller; f16UpperLimit > f16LowerLimit
	f16LowerLimit	In	SF16	0x8000 ... 0x7FFF	Lower limit of the controller; f16UpperLimit > f16LowerLimit
	i16LimitFlag	Out	SI16	0 or 1	Limitation flag; if set to 1, the controller output reached f16UpperLimit or f16LowerLimit

3.32.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.32.5 Dependencies

List of all dependent files:

- GFLIB_ControllerPIpAsm.h
- GFLIB_types.h

3.32.6 Description

The **GFLIB_ControllerPIpInitVal** function initializes the integral potion of the PI controller so as the output is the value in the first step.

3.32.7 Returns

None.

3.32.8 Range Issues

The input data value is in the range of <-1,1).

3.32.9 Special Issues

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

3.32.10 Implementation

Example 3-32. Implementation Code

```
#include "gflib.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);

         /* Integral portion initialization to zero*/
         GFLIB_ControllerPIpInitVal(0, &mudtControllerParam);

         /* 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);
}
```

3.32.11 See Also

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

3.32.12 Performance

Table 3-81. Performance of GFLIB_ControllerPIpInitVal function

Code Size (words)	4	
Data Size (words)	0	
Execution Clock	Min	24 cycles
	Max	24 cycles

3.33 GFLIB_ControllerPIp

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

3.33.1 Synopsis

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

3.33.2 Prototype

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

3.33.3 Arguments

Table 3-82. Function Arguments

Name	Type	Format	Range	Description
f16InputErrorK	In	SF16	0x8000... 0x7FFF	Input error at step K processed by P and I terms of the PI algorithm
*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_ControllerPIpAsm.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

Table 3-83. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_CONTROLLER_PI_P_PARAMS_T	f16PropGain	In	SF16	0x0... 0x7FFF	Proportional gain
	f16IntegGain	In	SF16	0x0... 0x7FFF	Integral gain
	i16PropGainShift	In	SI16	0...13	Proportional gain shift
	i16IntegGainShift	In	SI16	0...13	Integral gain shift
	f32IntegPartK_1	In/Out	SF32	0x80000000... 0x7FFFFFFF	State variable; integral part at step k-1; can be modified outside of the function.
	f16UpperLimit	In	SF16	0x8000 ... 0x7FFF	Upper limit of the controller; f16UpperLimit > f16LowerLimit
	f16LowerLimit	In	SF16	0x8000 ... 0x7FFF	Lower limit of the controller; f16UpperLimit > f16LowerLimit
	i16LimitFlag	Out	SI16	0 or 1	Limitation flag; if set to 1, the controller output reached f16UpperLimit or f16LowerLimit

3.33.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.33.5 Dependencies

List of all dependent files:

- GFLIB_ControllerPIpAsm.h
- GFLIB_types.h

3.33.6 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

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:

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

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.

$$u_I(k) = u_I(k-1) + T \cdot e(k) \qquad \textbf{Eqn. 3-46}$$

The discrete time domain representation of the PI algorithms

$$u(k) = K \cdot e(k) + u_I(k-1) + K_I \cdot e(k) \qquad \textbf{Eqn. 3-47}$$

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]

$$K_I = K \cdot \frac{T}{T_I} \quad \textbf{Eqn. 3-48}$$

The discrete time domain representation of the PI algorithm scaled into the fractional range.

$$u_f(k) = K_{sc} \cdot e_f(k) + u_{If}(k-1) + K_{Isc} \cdot e_f(k) \quad \textbf{Eqn. 3-49}$$

where

$$u_f(k) = u(k) / u_{max} \quad \textbf{Eqn. 3-50}$$

$$e_f(k) = e(k) / e_{max} \quad \textbf{Eqn. 3-51}$$

$$K_{sc} = K \cdot \frac{e_{max}}{u_{max}} \quad \textbf{Eqn. 3-52}$$

$$K_{Isc} = K \cdot \frac{T}{T_I} \cdot \frac{e_{max}}{u_{max}} = K_I \cdot \frac{e_{max}}{u_{max}} \quad \textbf{Eqn. 3-53}$$

where

e_{max} - input max range

u_{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. f16IntegGain and i16IntegGainShift).

$$f16PropGain = K_{sc} \cdot 2^{-i16PropGainShift} \quad \textbf{Eqn. 3-54}$$

$$f16IntegGain = K_{Isc} \cdot 2^{-i16IntegGainShift} \quad \textbf{Eqn. 3-55}$$

where

$$0 \le f16PropGain < 1 \quad \textbf{Eqn. 3-56}$$

$$0 \le f16IntegGain < 1 \quad \textbf{Eqn. 3-57}$$

$$0 \le i16PropGainShift < 14 \quad \textbf{Eqn. 3-58}$$

$$0 \le i16IntegGainShift < 14 \quad \textbf{Eqn. 3-59}$$

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 f16IntegGain 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 <= f16IntegGain < 1

and to calculate the corresponding i16IntegGainShift parameter.

$$\frac{\log(K_{Isc}) - \log(0.5)}{\log 2} \geq i16IntegGainShift \qquad \textbf{Eqn. 3-60}$$

$$\frac{\log(2.4) - \log(0.5)}{\log 2} \geq i16IntegGainShift \qquad \textbf{Eqn. 3-61}$$

$$2.26 \geq i16IntegGainShift \qquad \textbf{Eqn. 3-62}$$

$$\frac{\log(K_{Isc}) - \log(1)}{\log 2} < i16IntegGainShift \qquad \textbf{Eqn. 3-63}$$

$$\frac{\log(K_{Isc})}{\log 2} < i16IntegGainShift \qquad \textbf{Eqn. 3-64}$$

$$\frac{\log(2.4)}{\log 2} < i16IntegGainShift \qquad \textbf{Eqn. 3-65}$$

$$1.26 < i16IntegGainShift \qquad \textbf{Eqn. 3-66}$$

The parameter i16IntegGainShift is in the following range:

$$1.26 < i16IntegGainShift \leq 2.26 \qquad \textbf{Eqn. 3-67}$$

Because this parameter is an integer value, the result is

$$i16IntegGainShift = 2 \qquad \textbf{Eqn. 3-68}$$

Then

$$f16IntegGain = K_{Isc} \cdot 2^{-i16IntegGainShift} \qquad \textbf{Eqn. 3-69}$$

$$f16IntegGain = 2.4 \cdot 2^{(-2)} = 0.6 \qquad \textbf{Eqn. 3-70}$$

Result:

f16IntegGain = 0.6

i16IntegGainShift = 2

3.33.7 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:

$$f16LowerLimit \le PIresult \le f16UpperLimit \qquad \textbf{Eqn. 3-71}$$

3.33.8 Range Issues

The PI controller parameters are in the following range

$$0 \le f16PropGain < 1 \qquad \textbf{Eqn. 3-72}$$

$$0 \le f16IntegGain < 1 \qquad \textbf{Eqn. 3-73}$$

$$0 \le i16PropGainShift < 14 \qquad \textbf{Eqn. 3-74}$$

$$0 \le i16IntegGainShift < 14 \qquad \textbf{Eqn. 3-75}$$

3.33.9 Special Issues

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

3.33.10 Implementation

Example 3-33. Implementation Code

```
#include "gflib.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);
```

```
        /* Integral portion initialization to zero*/
        GFLIB_ControllerPIpInitVal(0, &mudtControllerParam);

        /* 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);
}
```

3.33.11 See Also

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

3.33.12 Performance

Table 3-84. Performance of GFLIB_ControllerPIp function

Code Size (words)	50	
Data Size (words)	0	
Execution Clock	Min	76 cycles
	Max	76 cycles

3.34 GFLIB_ControllerPIr

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

3.34.1 Synopsis

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

3.34.2 Prototype

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

3.34.3 Arguments

Table 3-85. Function Arguments

Name	In/Out	Format	Range	Description
f16Error	In	SF16	0x8000... 0x7FFF	Error as input argument; the **Frac16** data type is defined in header file GFLIB_types.h
*pudtCtrl	In/out	struct	N/A	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

Table 3-86. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_CONTROLLER_PI_RECURRENT_T	f32Acc	In/Out	SF32	0x80000000... 0x7FFFFFFF	Internal controller accumulator
	f16ErrorK_1	In/Out	SF16	0x8000 ... 0x7FFF	Input error at step k-1; delayed value of error at step k
	f16CC1Sc	In	SF16	0x8000 ... 0x7FFF	First controller coefficient scaled to fractional format
	f16CC2Sc	In	SF16	0x8000 ... 0x7FFF	Second controller coefficient scaled to fractional format
	ui16NShift	In	UI16	0...15	Scaling shift

3.34.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.34.5 Dependencies

List of all dependent files:

- GFLIB_ControllerPIRecurrentAsm.h
- GFLIB_types.h

3.34.6 Description

The time continuos function of the PI controller is defined as

$$u(t) = K_P \cdot e(t) + K_I \cdot \int_0^t e(t)dt \qquad \textit{Eqn. 3-76}$$

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

$$u(k) = u(k-1) + CC1 \cdot e(k) + CC2 \cdot e(k-1) \qquad \textit{Eqn. 3-77}$$

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

Table 3-87. Controller Coefficients

Controller Coefficients	Bilinear Transformation	Backward Rectangular	Forward Rectangular
CC1	$K_P + K_I \cdot T_S/2$	$K_P + K_I \cdot T_S$	K_P
CC2	$-K_P + K_I \cdot T_S/2$	$-K_P$	$-K_P + K_I \cdot T_S$

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

$$f16Uk = f32Acc + f16CC1 \cdot f16Error + f16CC2 \cdot \text{f16ErrorK\_1} \qquad \textbf{Eqn. 3-78}$$

where f32Acc is the accumulated controller portion over time and is used as the internal variable of this algorithm. The f16CC1 and f16CC2 are recurrent controller coefficients which are adapted as

$$f16CC1 = CC1 \cdot \frac{Emax}{Umax} \qquad \textbf{Eqn. 3-79}$$

$$f16CC2 = CC2 \cdot \frac{Emax}{Umax} \qquad \textbf{Eqn. 3-80}$$

The input for the recurrent PI controller is f16Error which is adapted as

$$\text{f16Error} = \text{f16Desired} - \text{f16Actual} \qquad \textbf{Eqn. 3-81}$$

$$\text{f16Error} = \frac{\text{Error}}{\text{EMax}} \qquad \textbf{Eqn. 3-82}$$

where f16Error is a fractional number which must be within the fractional range <-1, 0.9999>. The f16Error value is processed within the PI controller algorithm and the delayed value is stored in f16Error_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 f16Error is assumed to be already in the correct 16-bit fixed point number format. Other controller variables as f32Acc, f16Error16K_1 are internally handled by the algorithm of the recurrent PI controller. The controller coefficients f16CC1, f16CC2 must be prepared in the correct 16-bit fixed point number format by user. A scaling shift ui16NShift 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

$$f16Uk = f16Acc + f16CC1Sc \cdot f16Error + f16CC2Sc \cdot f16ErrorK1 \qquad \textbf{Eqn. 3-83}$$

where

$$\text{f16CC1Sc} = \text{f16CC1} \cdot 2^{-\text{uiNShift16}} \qquad \textbf{Eqn. 3-84}$$

$$\text{f16CC2Sc} = \text{f16CC2} \cdot 2^{-\text{uiNShift16}} \qquad \textbf{Eqn. 3-85}$$

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.

$$\text{ui16NShift} = \max\left(\text{ceil}\left(\frac{\log(\text{f16CC1})}{\log(2)}\right), \text{ceil}\left(\frac{\log(\text{f16CC2})}{\log(2)}\right)\right) \quad \textit{Eqn. 3-86}$$

Example:

After the controller coefficients Kp and 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 3-88.

Table 3-88. Controller Coefficients: K_p=125[V/A]; K_i=24000[V/A]; T_s=125e-6[sec]; ErrorMAX=IMAX=8[A]; UMAX=240[V]

Controller Coefficients	Bilinear Transformation	Backward Rectangular	Forward Rectangular
CC1	126.5	128	125
CC2	-123.5	-125	-122
f16CC1	4.216666667	4.266666667	4.166666667
f16CC2	-4.116666667	-4.166666667	-4.066666667
ui16NShuft	3	3	3
f16CC1Sc	0.527083333	0.533333333	0.520833333
f16CC2Sc	-0.514583333	-0.520833333	-0.508333333

3.34.7 Returns

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

3.34.8 Range Issues

The PI controller parameters are in the following range

$$-1 \le \text{f16ErrorK\_1} \le 0.9999 \quad \textit{Eqn. 3-87}$$

$$-1 \le \text{f16CC1Sc} \le 0.9999 \quad \textit{Eqn. 3-88}$$

$$-1 \le \text{f16CC2Sc} \le 0.9999 \quad \textit{Eqn. 3-89}$$

$$0 \le ui16NShift < 16 \quad \textit{Eqn. 3-90}$$

3.34.9 Special Issues

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

3.34.10 Implementation

Example 3-34. Implementation Code

```
#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);
}
```

3.34.11 See Also

See **GFLIB_ControllerPIp**, **GFLIB_ControllerPIrLim**, **GFLIB_ControllerPIDp** and **GFLIB_ControllerPIDr** for more information.

3.34.12 Performance

Table 3-89. Performance of GFLIB_ControllerPIr function

Code Size (words)	19	
Data Size (words)	0	
Execution Clock	Min	38 cycles
	Max	38 cycles

3.35 GFLIB_ControllerPIrLim

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

3.35.1 Synopsis

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

3.35.2 Prototype

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

3.35.3 Arguments

Table 3-90. Function Arguments

Name	In/Out	Format	Range	Description
f16Error	In	SF16	0x8000... 0x7FFF	error as input argument; the Frac16 data type is defined in header file GFLIB_types.h
*pudtCtrl	In/Out	struct	N/A	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

Table 3-91. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_CONTROLLER_PI_RECURRENT_LIM_T	f32Acc	In/Out	SF32	0x80000000... 0x7FFFFFFF	Internal controller accumulator
	f16ErrorK_1	In/out	SF16	0x8000 ... 0x7FFF	Input error at step k-1; delayed value of error at step k
	f16CC1Sc	In	SF16	0x8000 ... 0x7FFF	First controller coefficient scaled to fractional format
	f16CC2Sc	In	SF16	0x8000 ... 0x7FFF	Second controller coefficient scaled to fractional format
	ui16NShift	In	UI16	0...15	Scaling shift
	f16UpperLim	In	SF16	—	Upper limit of the controller; f16UpperLimit > f16LowerLimit
	f16LowerLim	In	SF16	—	Lower limit of the controller; f16UpperLimit > f16LowerLimit
	ui16SatFlag	Out	UI16	—	Saturation flag; if set to 1, the controller output reached f16UpperLimit or f16LowerLimit

3.35.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.35.5 Dependencies

List of all dependent files:

1. GFLIB_ControllerPIRecurrentLimAsm.h
2. GFLIB_types.h

3.35.6 Description

The time continuos function of the PI controller is defined as

$$u(t) = K_P \cdot e(t) + K_I \cdot \int_0^t e(t)dt \qquad \textit{Eqn. 3-91}$$

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

$$u(k) = u(k-1) + CC1 \cdot e(k) + CC2 \cdot e(k-1) \qquad \textit{Eqn. 3-92}$$

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

Table 3-92. Controller Coefficients

Controller Coefficients	Bilinear Transformation	Backward Rectangular	Forward Rectangular
CC1	$K_P + K_I \cdot T_S/2$	$K_P + K_I \cdot T_S$	K_P
CC2	$-K_P + K_I \cdot T_S/2$	$-K_P$	$-K_P + K_I \cdot T_S$

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

$$u(k) = \begin{cases} \text{UpperLimit} & \rightarrow u(k) > \text{UpperLimit} \\ u(k) & \rightarrow \text{LowerLimit} \le u(k) \le \text{UpperLimit} \\ Lower\text{Limit} & \rightarrow u(k) < \text{LowerLimit} \end{cases} \qquad \textit{Eqn. 3-93}$$

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

$$f16Uk = f32Acc + f16CC1 \cdot f16Error + f16CC2 \cdot \text{f16ErrorK\_1} \quad \textbf{Eqn. 3-94}$$

where f32Acc is the accumulated controller portion over time and is used as an internal variable of this algorithm. f16CC1 and f16CC2 are the recurrent controller coefficients which are adapted as

$$f16CC1 = CC1 \cdot \frac{Emax}{Umax} \quad \textbf{Eqn. 3-95}$$

$$f16CC2 = CC2 \cdot \frac{Emax}{Umax} \quad \textbf{Eqn. 3-96}$$

The input for the recurrent PI controller is considered f16Error which is adapted as

$$\text{f16Error} = \text{f16Desired} - \text{f16Actual} \quad \textbf{Eqn. 3-97}$$

$$\text{f16Error} = \frac{\text{Error}}{\text{Emax}} \quad \textbf{Eqn. 3-98}$$

where f16Error is a fractional number which must be within the fractional range <-1, 0.9999>. The f16Error value is processed within the PI controller algorithm and the delayed value is stored in f16Error_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 f16Error is assumed to be already in the correct 16-bit fixed point number format. Other controller variables as f32Acc, f16Error16K_1 are internally handled by the algorithm of the recurrent PI controller. The controller coefficients f16CC1, f16CC2 must be prepared in the correct 16-bit fixed point number format by 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 PI controller is calculated by the following formula as

$$f16Uk = f16Acc + f16CC1Sc \cdot f16Error + f16CC2Sc \cdot f16ErrorK1 \quad \textbf{Eqn. 3-99}$$

where

$$\text{f16CC1Sc} = \text{f16CC1} \cdot 2^{-\text{uiNShift16}} \quad \textbf{Eqn. 3-100}$$

$$\text{f16CC2Sc} = \text{f16CC2} \cdot 2^{-\text{uiNShift16}} \quad \textbf{Eqn. 3-101}$$

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.

$$ui16NShift = \max\left(\text{ceil}\left(\frac{\log(f16CC1)}{\log(2)}\right), \text{ceil}\left(\frac{\log(f16CC2)}{\log(2)}\right)\right) \quad \textit{Eqn. 3-102}$$

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 3-93.

Table 3-93. Controller Coefficients: Kp=125[V/A]; Ki=24000[V/A]; Ts=125e-6[sec]; ErrorMAX=IMAX=8[A]; UMAX=240[V]

Controller Coefficients	Bilinear Transformation	Backward Rectangular	Forward Rectangular
CC1	126.5	128	125
CC2	-123.5	-125	-122
f16CC1	4.216666667	4.266666667	4.166666667
f16CC2	-4.116666667	-4.166666667	-4.066666667
ui16NShuft	3	3	3
f16CC1Sc	0.527083333	0.533333333	0.520833333
f16CC2Sc	-0.514583333	-0.520833333	-0.508333333

3.35.7 Returns

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

3.35.8 Range Issues

The PI controller parameters are in the following range

$$-1 \le f16ErrorK\_1 \le 0.9999 \quad \textit{Eqn. 3-103}$$

$$-1 \le f16CC1Sc \le 0.9999 \quad \textit{Eqn. 3-104}$$

$$-1 \le f16CC2Sc \le 0.9999 \quad \textit{Eqn. 3-105}$$

$$0 \le ui16NShift < 16 \quad \textit{Eqn. 3-106}$$

3.35.9 Special Issues

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

3.35.10 Implementation

Example 3-35. Implementation Code

```
#include "gflib.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);
}
```

3.35.11 See Also

See **GFLIB_ControllerPIp**, **GFLIB_ControllerPIr**, **GFLIB_ControllerPIDp** and **GFLIB_ControllerPIDr** for more information.

3.35.12 Performance

Table 3-94. Performance of GFLIB_ControllerPIrLim Function

Code Size (words)	29	
Data Size (words)	0	
Execution Clock	Min	51 cycles
	Max	51 cycles

3.36 GFLIB_ControllerPIDpInitVal

The function initializes the integral portion of the parallel form of the **GFLIB_ControllerPIDp** algorithm.

3.36.1 Synopsis

```
#include ”gflib.h”
void GFLIB_ControllerPIDpInitVal(Frac16 f16InitVal,
GFLIB_CONTROLLER_PID_P_PARAMS_T *pudtPidParams)
```

3.36.2 Prototype

```
asm void GFLIB_ControllerPIDpInitValFAsm(Frac16 f16InitVal,
GFLIB_CONTROLLER_PID_P_PARAMS_T *pudtPidParams)
```

3.36.3 Arguments

Table 3-95. Function Arguments

Name	Type	Format	Range	Description
f16InitVal	In	SF16	0x8000 ... 0x7FFF	Initial integral portion of the PID controller
*pudtPidParams	In/Out	N/A	N/A	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

Table 3-96. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_CONTROLLER_PID_P_PARAMS_T	f16PropGain	In	SF16	0x0... 0x7FFF	Proportional gain
	f16IntegGain	In	SF16	0x0... 0x7FFF	Integral gain
	f16DerGain	In	SF16	0x0... 0x7FFF	Derivative gain
	i16PropGainShift	In	SI16	0...13	Proportional gain shift
	i16IntegGainShift	In	SI16	0...13	Integral gain shift
	i16DerGainShift	In	SI16	0...13	Derivative gain shift
	f32IntegPartK_1	In/Out	SF32	0x80000000... 0x7FFFFFFF	State variable; integral part at step k-1; can be modified outside of the function.
	f16UpperLimit	In	SF16	0x8000 ... 0x7FFF	Upper limit of the controller; f16UpperLimit > f16LowerLimit
	f16LowerLimit	In	SF16	0x8000 ... 0x7FFF	Lower limit of the controller; f16UpperLimit > f16LowerLimit
	i16LimitFlag	Out	SI16	0 or 1	Limitation flag; if set to 1, the controller output reached f16UpperLimit or f16LowerLimit

3.36.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.36.5 Dependencies

List of all dependent files:

1. GFLIB_ControllerPIDpAsm.h
2. GFLIB_types.h

3.36.6 Description

The **GFLIB_ControllerPIDpInitVal** function initializes the integral potion of the PID controller so as the output is the value in the first step.

3.36.7 Returns

None.

3.36.8 Range Issues

The input data value is in the range of <-1,1)

3.36.9 Special Issues

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

3.36.10 Implementation

Example 3-36. Implementation Code

```
#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;

        /* Integral portion initialization to zero*/
        GFLIB_ControllerPIDpInitVal(0, &mudtControllerParam);

        /* 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);
}
```

3.36.11 See Also

See **GFLIB_ControllerPIp**, **GFLIB_ControllerPIr**, **GFLIB_ControllerPIrLim** and **GFLIB_ControllerPIDr** for more information.

3.36.12 Performance

Table 3-97. Performance of GFLIB_ControllerPIDpInitVal Function

Code Size (words)	4	
Data Size (words)	0	
Execution Clock	Min	25 cycles
	Max	25 cycles

3.37 GFLIB_ControllerPIDp

The function calculates the parallel form of the Proportional-Integral-Derivative (PID) regulator.

3.37.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_ControllerPIDp(Frac16 f16InputErrorK, Frac16
f16InputDErrorK, GFLIB_CONTROLLER_PID_P_PARAMS_T *pudtPidParams, const
Int16 *pi16SatFlag, Frac16 *pf16InputDErrorK_1)
```

3.37.2 Prototype

```
asm Frac16 GFLIB_ControllerPIDpFAsm(Frac16 f16InputErrorK, Frac16
f16InputDErrorK, GFLIB_CONTROLLER_PID_P_PARAMS_T *pudtPidParams, const
Int16 *pi16SatFlag, Frac16 *pf16InputDErrorK_1)
```

3.37.3 Arguments

Table 3-98. Function Arguments

Name	Type	Format	Range	Description
f16InputErrorK	In	SF16	0x8000 ... 0x7FFF	Input error at step K processed by P and I terms of the PID algorithm
f16InputDErrorK	In	SF16	0x8000 ... 0x7FFF	Input error at step K processed by the D term of the PID algorithm
*pudtPidParams	In/Out	N/A	N/A	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
*pi16SatFlag	In	N/A	N/A	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
*pf16InputDErrorK_1	In/Out	N/A	N/A	Pointer to a 16-bit fractional variable; input error at step K-1processed 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

Table 3-99. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_CONTROLLER_PID_P_PARAMS_T	f16PropGain	In	SF16	0x0... 0x7FFF	Proportional gain
	f16IntegGain	In	SF16	0x0... 0x7FFF	Integral gain
	f16DerGain	In	SF16	0x0... 0x7FFF	Derivative gain
	i16PropGainShift	In	SI16	0...13	Proportional gain shift
	i16IntegGainShift	In	SI16	0...13	Integral gain shift
	i16DerGainShift	In	SI16	0...13	Derivative gain shift
	f32IntegPartK_1	In/Out	SF32	0x80000000... 0x7FFFFFFF	State variable; integral part at step k-1; can be modified outside of the function.
	f16UpperLimit	In	SF16	0x8000 ... 0x7FFF	Upper limit of the controller; f16UpperLimit > f16LowerLimit
	f16LowerLimit	In	SF16	0x8000 ... 0x7FFF	Lower limit of the controller; f16UpperLimit > f16LowerLimit
	i16LimitFlag	Out	SI16	0 or 1	Limitation flag; if set to 1, the controller output reached f16UpperLimit or f16LowerLimit

3.37.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.37.5 Dependencies

List of all dependent files:

1. GFLIB_ControllerPIDpAsm.h
2. GFLIB_types.h

3.37.6 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

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:

$$u(t) = K\left[e(t) + \frac{1}{T_I}\int_0^{\tau} e(\tau)d(\tau) + T_D \cdot \frac{d}{dt}e_D(t)\right] \qquad \textbf{Eqn. 3-107}$$

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.

$$u_I(k) = u_I(k-1) + T \cdot e(k) \qquad \textbf{Eqn. 3-108}$$

The derivative term is approximated in the same way as the integral term (backward difference).

$$\frac{d}{dt}e_D(t) = \frac{e_D(k) - e_D(k-1)}{T} \qquad \textbf{Eqn. 3-109}$$

The discrete time domain representation of the PID algorithm

$$u(k) = K \cdot e(k) + u_I(k-1) + K_I \cdot e(k) + K_D \cdot (e_D(k) - e_D(k-1)) \quad \textbf{Eqn. 3-110}$$

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]

$$K_I = K \cdot \frac{T}{T_I} \quad \textbf{Eqn. 3-111}$$

$$K_D = K \cdot \frac{T_D}{T} \quad \textbf{Eqn. 3-112}$$

The discrete time domain representation of the PID algorithm scaled into the fractional range.

$$u_f(k) = K_{sc} \cdot e_f(k) + u_{If}(k-1) + K_{Isc} \cdot e_f(k) + K_{Dsc} \cdot (e_{Df}(k) - e_{Df}(k-1)) \quad \textbf{Eqn. 3-113}$$

where

$$u_f(k) = u(k) / u_{max} \quad \textbf{Eqn. 3-114}$$

$$e_f(k) = e(k) / e_{max} \quad \textbf{Eqn. 3-115}$$

$$e_{Df}(k) = e_D(k) / e_{max} \quad \textbf{Eqn. 3-116}$$

$$K_{sc} = K \cdot \frac{e_{max}}{u_{max}} \quad \textbf{Eqn. 3-117}$$

$$K_{Isc} = K \cdot \frac{T}{T_I} \cdot \frac{e_{max}}{u_{max}} = K_I \cdot \frac{e_{max}}{u_{max}} \quad \textbf{Eqn. 3-118}$$

$$K_{Dsc} = K \cdot \frac{T_D}{T} \cdot \frac{e_{max}}{u_{max}} = K_D \cdot \frac{e_{max}}{u_{max}} \quad \textbf{Eqn. 3-119}$$

where

e_{max} - input max range
u_{max} - output max range

Each parameter (e.g. K_{sc}) of the PID algorithm is represented by two parameters in the processor implementation (e.g. f16PropGain and i16PropGainShift).

$$f16PropGain = K_{sc} \cdot 2^{-i16PropGainShift} \quad \textbf{Eqn. 3-120}$$

$$f16IntegGain = K_{Isc} \cdot 2^{-i16IntegGainShift} \quad \textbf{Eqn. 3-121}$$

$$f16DerGain = K_{Dsc} \cdot 2^{-i16DerGainShift} \quad \textbf{Eqn. 3-122}$$

where

$$0 \le f16PropGain < 1 \quad \textbf{Eqn. 3-123}$$

$$0 \le f16IntegGain < 1 \quad \textbf{Eqn. 3-124}$$

$$0 \le f16DerGain < 1 \quad \textbf{Eqn. 3-125}$$

$$0 \le i16PropGainShift < 14 \quad \textbf{Eqn. 3-126}$$

$$0 \le i16IntegGainShift < 14 \quad \textbf{Eqn. 3-127}$$

$$0 \le i16DerGainShift < 14 \quad \textbf{Eqn. 3-128}$$

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 f16PropGain is <0,1). It is necessary to scale the K_{sc} parameter using i16PropGainShift to fit the parameter f16PropGain into the range <0,1)

Solution:

The most precise scaling approach is to scale down the parameter K_{sc} to have the f16PropGain in the following range

0.5 <= f16PropGain < 1

and to calculate the corresponding i16PropGainShift parameter.

$$\frac{\log(K_{sc}) - \log(0.5)}{\log 2} \ge i16PropGainShift \quad \textbf{Eqn. 3-129}$$

$$\frac{\log(1.8) - \log(0.5)}{\log 2} \ge i16PropGainShift \quad \textbf{Eqn. 3-130}$$

$$1.8 \ge i16PropGainShift \quad \textbf{Eqn. 3-131}$$

$$\frac{\log(K_{sc}) - \log(1)}{\log 2} < i16PropGainShift \quad \textbf{Eqn. 3-132}$$

$$\frac{\log(K_{sc})}{\log 2} < i16PropGainShift \quad \textbf{Eqn. 3-133}$$

$$0.8 < i16PropGainShift \quad \textbf{Eqn. 3-134}$$

The parameter i16PropGainShift is in the following range:

$$0.8 < i16PropGainShift \leq 1.8 \quad \textbf{Eqn. 3-135}$$

Because this parameter is an integer value, the result is

$$i16PropGainShift = 1 \quad \textbf{Eqn. 3-136}$$

Then

$$f16PropGain = K_{sc} \cdot 2^{-i16PropGainShift} \quad \textbf{Eqn. 3-137}$$

$$f16PropGain = 1.8 \cdot 2^{(-1)} = 0.9 \quad \textbf{Eqn. 3-138}$$

Result:

f16PropGain = 0.9

i16PropGainShift = 1

Note:

Ti > 4*Td

3.37.7 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:

$$f16LowerLimit \leq PIDresult \leq f16UpperLimit$$

3.37.8 Range Issues

The PID controller parameters are in the following range

$$0 \leq f16PropGain < 1$$

$$0 \leq f16IntegGain < 1$$

$$0 \leq f16DerGain < 1$$

$$0 \leq i16PropGainShift < 14$$

$$0 \leq i16IntegGainShift < 14$$

$$0 \leq i16DerGainShift < 14$$

3.37.9 Special Issues

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

3.37.10 Implementation

Example 3-37. Implementation Code

```
#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;

         /* Integral portion initialization to zero*/
         GFLIB_ControllerPIDpInitVal(0, &mudtControllerParam);

         /* 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);
}
```

3.37.11 See Also

See **GFLIB_ControllerPIp**, **GFLIB_ControllerPIr**, **GFLIB_ControllerPIrLim** and **GFLIB_ControllerPIDr** for more information.

3.37.12 Performance

Table 3-100. Performance of GFLIB_ControllerPIDp Function

Code Size (words)	71	
Data Size (words)	0	
Execution Clock	Min	103 cycles
	Max	103 cycles

3.38 GFLIB_ControllerPIDr

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

3.38.1 Synopsis

```
#include ”gflib.h”
Frac16 GFLIB_ControllerPIDr(Frac16 f16Error,
GFLIB_CONTROLLER_PID_RECURRENT_T * const pudtCtrl)
```

3.38.2 Prototype

```
asm Frac16 GFLIB_ControllerPIDRecurrentFAsm(Frac16 f16Err,
GFLIB_CONTROLLER_PID_RECURRENT_T * const pudtCtrl)
```

3.38.3 Arguments

Table 3-101. Function Arguments

Name	In/Out	Format	Range	Description
f16Error	In	SF16	0x8000 ... 0x7FFF	Error as input argument; the Frac16 data type is defined in header file GFLIB_types.h
*pudtCtrl	In/Out	struct	N/A	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

Table 3-102. User Type Definitions

Typedef	Name	In/Out	Format	Range	Description
GFLIB_CONTROLLER_PID_RECURRENT_T	f32Acc	In/Out	SF32	0x80000000... 0x7FFFFFFF	Internal controller accumulator
	f16ErrorK_1	In/Out	SF16	0x8000 ... 0x7FFF	Input error at step k-1; delayed value of error at step k
	f16CC1Sc	In	SF16	0x8000 ... 0x7FFF	First controller coefficient scaled to fractional format
	f16CC2Sc	In	SF16	0x8000 ... 0x7FFF	Second controller coefficient scaled to fractional format
	f16CC3Sc	In	SF16	0x8000 ... 0x7FFF	Third controller coefficient scaled to fractional format
	ui16NShift	In	UI16	0...15	Scaling shift

3.38.4 Availability

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

This library module is targeted for the 56800E and 56800Ex platforms.

3.38.5 Dependencies

List of all dependent files:

- GFLIB_ControllerPIDRecurrentAsm.h
- GFLIB_types.h

3.38.6 Description

The time continuos function of the PID controller is defined as

$$u(t) = K_P \cdot e(t) + K_I \cdot \int_0^t e(t)dt + K_D \cdot \frac{de(t)}{t} \qquad \textit{Eqn. 3-139}$$

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

$$u(k) = u(k-1) + CC1 \cdot e(k) + CC2 \cdot e(k-1) + \mathrm{CC3} \cdot e(k-2) \qquad \textit{Eqn. 3-140}$$

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

Table 3-103. Controller Coefficients

Controller Coefficients	Integration with Bilinear Transformation Derivation with Backward Rectangular	Integration with Backward Rectangular Derivation with Backward Rectangular
CC1	$K_P + K_I \cdot T_S/2 + K_D/T_S$	$K_P + K_I \cdot T_S + K_D/T_S$
CC2	$-K_P + K_I \cdot T_S/2 - 2K_D/T_S$	$-K_P - 2K_D/T_S$
CC3	K_D/T_S	K_D/T_S

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

$$f16Uk = f32Acc + f16CC1 \cdot f16Error + f16CC2 \cdot \text{f16ErrorK\_1} + \text{f16CC3} \cdot \text{f16ErrorK\_2}$$

Eqn. 3-141

where f32Acc is the accumulated controller portion over time and is used as an internal variable of this algorithm. f16CC1, f16CC2 and f16CC3 are the recurrent controller coefficients which are adapted as

$$f16CC1 = CC1 \cdot \frac{Emax}{Umax} \qquad \textbf{Eqn. 3-142}$$

$$f16CC2 = CC2 \cdot \frac{Emax}{Umax} \qquad \textbf{Eqn. 3-143}$$

$$f16CC3 = CC3 \cdot \frac{Emax}{Umax} \qquad \textbf{Eqn. 3-144}$$

The input for the recurrent PI controller is considered f16Error which is adapted as

$$\text{f16Error} = \text{f16Desired} - \text{f16Actual} \qquad \textbf{Eqn. 3-145}$$

$$\text{f16Error} = \frac{\text{Error}}{\text{EMax}} \qquad \textbf{Eqn. 3-146}$$

where f16Error is a fractional number which must be within the fractional range <-1, 0.9999>. The f16Error value is processed within the PID controller algorithm and the delayed values are stored in f16Error_1, f16Error_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 f16Error is assumed to be already in the correct 16-bit fixed point number format. Other controller variables as f32Acc, f16Error16K_1, f16Error16K_2 are internally handled by the algorithm of the recurrent PID controller. The controller coefficients f16CC1, f16CC2, and f16CC3 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

Eqn. 3-147

$$f16Uk = f16Acc + f16CC1Sc \cdot f16Error + f16CC2Sc \cdot f16ErrorK1 + f16CC3Sc \cdot f16ErrorK2$$

where

$$f16CC1Sc = f16CC1 \cdot 2^{-ui16NShift} \quad \textit{Eqn. 3-148}$$

$$f16CC2Sc = f16CC2 \cdot 2^{-ui16NShift} \quad \textit{Eqn. 3-149}$$

$$f16CC3Sc = f16CC3 \cdot 2^{-ui16NShift} \quad \textit{Eqn. 3-150}$$

ui16NShift is chosen that the coefficients reside within the common range <-1, 0.9999>.

$$ui16NShift = \max\left(ceil\left(\frac{\log(f16CC1)}{\log(2)}\right), ceil\left(\frac{\log(f16CC2)}{\log(2)}\right), ceil\left(\frac{\log(f16CC3)}{\log(2)}\right)\right) \quad \textit{Eqn. 3-151}$$

In addition, ui16NShift is chosen as a power of 2, then the final de-scaling is a simple shift operation.

3.38.7 Returns

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

3.38.8 Range Issues

The PID controller parameters are in the following range

$$-1 \le f16ErrorK\_1 \le 0.9999 \quad \textit{Eqn. 3-152}$$

$$-1 \le f16ErrorK\_2 \le 0.9999 \quad \textit{Eqn. 3-153}$$

$$-1 \le f16CC1Sc \le 0.9999 \quad \textit{Eqn. 3-154}$$

$$-1 \le f16CC2Sc \le 0.9999 \quad \textit{Eqn. 3-155}$$

$$-1 \le f16CC3Sc \le 0.9999 \quad \textit{Eqn. 3-156}$$

$$0 \le ui16NShift < 16 \quad \textit{Eqn. 3-157}$$

3.38.9 Special Issues

The function **GFLIB_ControllerPIDr** is saturation mode independent.

3.38.10 Implementation

Example 3-38. Implementation Code

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

```
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);
}
```

3.38.11 See Also

See **GFLIB_ControllerPIp**, **GFLIB_ControllerPIr**, **GFLIB_ControllerPIrLim** and **GFLIB_ControllerPIDp** for more information.

3.38.12 Performance

Table 3-104. Performance of GFLIB_ControllerPIDr function

Code Size (words)	22	
Data Size (words)	0	
Execution Clock	Min	45 cycles
	Max	45 cycles

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