# MPLAB Harmony Math Libraries Help

MPLAB Harmony Integrated Software Framework

# Math Libraries Help

This section provides descriptions of the Math libraries that are available in MPLAB Harmony.

## *CMSIS-DSP Library*

This topic describes the CMSIS-DSP Library.

## Introduction

The Cortex Microcontroller System Interface Standard (CMSIS)-DSP Library is the ARM® DSP Math Library (Version 1.5.1) integrated with MPLAB Harmony.

### Description

The CMSIS-DSP Library contains functions implementing 16-bit (Q15) and 32-bit (Q31) fixed-point math, as well as 32-bit floating point (F32) math. The functions.

Functions included in the CMSIS-DSP Library include complex math, vector math, matrix math, digital filters, adaptive filters, control and transforms. In many cases, these functions require specific data structures to operate, which are detailed in the header file.

## Using the Library

This topic describes the basic architecture of the CMSIS-DSP Library and provides information and examples on its use.

### Description

**Interface Header File**: `arm_math.h`

The interface to the DSP Fixed-Point library is defined in the `arm_math.h` header file. Any C language source (`.c`) file that uses the DSP Fixed-Point library must include `arm_math.h`.

**Library Source Files**

The CMSIS-DSP Library source files are provided in the `<install-dir>\packs\arm\cmsis\CMSIS\DSP\Source` directory.

**Library Files**

The CMSIS-DSP Library archive file is installed with MPLAB Harmony in the following location:

`<install-dir>\packs\arm\CMSIS\Lib\GCC` directory for ARM MCUs

Please refer to the Volume I: Getting Started With MPLAB Harmony for information on how the CMSIS-DSP Library interacts with the MPLAB Harmony Integrated Software Framework.

### *Library Overview*

The library interface routines are divided into various sub-sections, which address one of the blocks or the overall operation of the CMSIS-DSP Library.

| Library Interface Section | Description |
|---|---|
| Basic Math Functions | Basic vector math functions. |
| Fast Math Functions | This set of functions provides a fast approximation to sine, cosine, and square root. |
| Complex Math Functions | This set of functions operates on complex data vectors. The data in the complex arrays is stored in an interleaved fashion (real, imaginary, real, imaginary, ...). In the API functions, the number of samples in a complex array refers to the number of complex values; the array contains twice this number of real values. |
| Filters | Implementation of biquad cascade, IIR Direct Form I and II Transposed, convolution, correlation, FIR, IIR Lattice, LMS, and Normalized LMS filter functions |
| Matrix Functions | This set of functions provides basic matrix math operations. The functions operate on matrix data structures. |
| Transforms | FFT, DCT Type IV, and Real FFT functions. |
| Statistical Functions | Maximum, Minimum, Mean, Power, RMS, Standard Deviation and Variance calculations. |
| Support Functions | Vector Copy, Vector Fill, and conversion between F32, Q15, Q32 and Q7 values. |
| Interpolation Functions | Linear and Bilinear interpolation functions. |
| Motor Control Functions | PID Motor Control and Vector Clark, Vector Park, and Vector Inverse Park transforms. |

The CMSIS-DSP Library uses fixed-point fractional functions to optimize execution speed. These functions limit the accuracy of the calculations to the bits specified for the function. Due to parallelism in some operations, the 16-bit version of the functions are more efficient than their 32-bit counterparts. In many cases both 16-bit and 32-bit functions are available to give the user the choice of balance between speed and functional resolution.

Fractional representation of a real number is given by:

Q*n.m*

where:

- *n* is the number of data bits to the left of the radix point
- *m* is the number of data bits to the right of the radix point
- a signed bit is implied, and takes one bit of resolution
- Shorthand may eliminate the leading 0, such as in Q0.15, which may be shortened to Q15, and similarly Q0.31, which is shortened to Q31

*Qn.m* numerical values are used by the library processing data as integers. In this format the n represents the number of integer bits, and the m represents the number of fractional bits. All values assume a sign bit in the most significant bit. Therefore, the range of the numerical value is:

$$-2^{(n-1)} \text{ to } [2^{(n-1)} - 2^{(-m)}]; \text{ with a resolution of } 2^{(-m)}.$$

A Q16 format number (Q15.16) would range from -32768.0 (0x8000 0000) to 32767.99998474 with a precision of 0.000015259 (or $2^{-16}$).

For example, a numerical representation of the number 3.14159 in Q2.13 notation would be:

$$3.14159 * 2^{13} = 25735.9 => 0x6488$$

And converting from the Q7.8 format with the value 0x1D89 would be:

$$0x1D89 / 2^{8} = 7561 / 256 => 29.5316, \text{ accurate to } 0.00391$$

A majority of the CMSIS-DSP Library uses functions with variables in Q15 or Q31 format. This limits the equivalent numerical range to roughly -1.0 to 0.999999999. It is possible to represent other number ranges, but scaling before and after the function call are necessary. All library functions will saturate the output if the value exceeds the maximum or is lower than the minimum allowable value for that resolution. Some prescaling may be necessary to prevent unwanted saturation in functions that may otherwise create calculation errors.

Usually, a Q16, Q31 and a floating point version of each function is available.

## Library Functions and Interfaces

Provides information on the list of available functions and interfaces.

### Description

A list of the available CMSIS-DSP Library functions and interfaces and their descriptions can be found at:

https://arm-software.github.io/CMSIS_5/DSP/html/index.html

## Configuring the Library

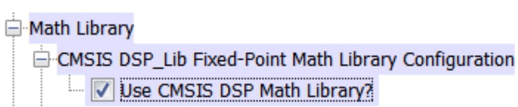
Provides information on configuring the CMSIS-DSP Library.

### *Configuring the Library Using MHC*

Provides information on using MHC to configure the library.

### Description

The application can be configured to use the CMSIS-DSP Library for the selected device configuration through the MPLAB Harmony Configurator (MHC) using the Math Library selection dialog, as shown in the following figure. This configuration will add the CMSIS-DSP Library to your project. Also, the `arm_math.h` header file will be added to the header files section and the header location is added to the include path.




**Note:** Only ARM® devices are supported at this time.

# *DSP Fixed-Point Math Library*

This topic describes the DSP Fixed-Point Math Library.

## Introduction

The DSP Fixed-Point Library is available for the PIC32MZ family of microcontrollers. This library was created from optimized assembly routines written specifically for devices with microAptiv™ core features that utilize DSP ASE.

### Description

The DSP Fixed-Point Library contains building block functions for developing digital signal processing algorithms. The library supports the Q15 and Q31 fractional data formats. The functions are implemented in efficient assembly specifically targeted at the DSP extensions in this core family. The library makes these functions available in a simple C-callable structure.

Functions included in the DSP Fixed-Point Library include complex math, vector math, matrix math, digital filters, and transforms. In many cases, these functions require specific data structures to operate, which are detailed in the header file and examples.

## Using the Library

This topic describes the basic architecture of the DSP Fixed-Point Library and provides information and examples on its use.

### Description

**Interface Header File**: `dsp.h`, `libq.h`

The interface to the DSP Fixed-Point library is defined in the `dsp.h` header file. Any C language source (`.c`) file that uses the DSP Fixed-Point library must include `dsp.h`. This file is automatically added to the project when 'use DSP library' is selected in MHC. In addition, this file name is added to the `#include` section of `system_definitions.h` after the configurations are completed through MHC.

Some functions make special use of the optimized fixed-point math library `libq.h`. For use of those functions, the `libq.h` file must also be included in a project. The `libq.h` file is also installed with MPLAB Harmony. Specific notes within each function will describe if the function is dependent on the LibQ Fixed-Point Math Library.

**Library Files**: `dsp_pic32mz.a`, `LIBQ_Library.X.a`, and `dsp_pic32mz_ef.a`

The DSP Fixed-Point library archive (`.a`) files are installed with MPLAB Harmony. Although there are two PIC32 DSP files, the linker will only utilize one of these depending on your device usage. If you have a device using a FPU, the `dsp_pic32mz_ef.a` file is used by the linker. Otherwise, the linker will utilize `dsp_pic32mz.a`. In a future release of the tools, the linker in the MPLAB XC32 C/C++ Compiler may be changed to do this automatically. Both of these files are added to a project when the 'use DSP library' option is selected in MHC.

This library is only available in binary form, with prototypes for each function described in the `dsp.h` file.

For functions that are supported by the LibQ Fixed-Point Math library, the `LIBQ_Library.X.a` library must also be installed. This library is also available in binary form and is installed with MPLAB Harmony. In some cases, the linker in the MPLAB XC32 C/C++ Compiler may not acknowledge the LibQ Fixed-Point Math Library file. If the library is included in the project, and the message *undefined reference* is encountered upon compilation, it may be necessary to add the specific assembly file function to your project. The source code for each function can be found in the `<install-dir>/framework/math/libq` folder of your MPLAB Harmony installation.

### *Library Overview*

The library interface routines are divided into various sub-sections, which address one of the blocks or the overall operation of the DSP Fixed-Point Math Library.

| Library Interface Section | Description |
|---|---|
| Complex Math Functions | General mathematical operations using a complex structure with the form (a + bi) |
| Vector Math Functions | Mathematical operations on a array of numbers or vector |
| Matrix Math Functions | Mathematical operations on a matrix |
| Digital Filter Functions | FIR and IIR filtering functions with various architectures |
| Transform Functions | FFT, Windows and related transform elements |
| Support Functions | Quick support functions for numerical transform |

The DSP Fixed-Point Library uses fixed-point fractional functions to optimize execution speed. These functions limit the accuracy of the calculations to the bits specified for the function. Due to parallelism in some operations, the 16-bit version of the functions are more efficient than their 32-bit counterparts. In many cases both 16-bit and 32-bit functions are available to give the user the choice of balance between speed and functional resolution.

Fractional representation of a real number is given by:

Q*n.m*

where:

- *n* is the number of data bits to the left of the radix point
- *m* is the number of data bits to the right of the radix point
- a signed bit is implied, and takes one bit of resolution
- Shorthand may eliminate the leading 0, such as in Q0.15, which may be shortened to Q15, and similarly Q0.31, which is shortened to Q31

*Qn.m* numerical values are used by the library processing data as integers. In this format the n represents the number of integer bits, and the m represents the number of fractional bits. All values assume a sign bit in the most significant bit. Therefore, the range of the numerical value is:

$$-2^{(n-1)} \text{ to } [2^{(n-1)} - 2^{(-m)}]; \text{ with a resolution of } 2^{(-m)}.$$

A Q16 format number (Q15.16) would range from -32768.0 (0x8000 0000) to 32767.99998474 with a precision of 0.000015259 (or $2^{-16}$).

For example, a numerical representation of the number 3.14159 in Q2.13 notation would be:

$$3.14159 * 2^{13} = 25735.9 => 0x6488$$

And converting from the Q7.8 format with the value 0x1D89 would be:

$$0x1D89 / 2^8 = 7561 / 256 => 29.5316, \text{ accurate to } 0.00391$$

A majority of the DSP Fixed-Point Library uses functions with variables in Q15 or Q31 format. Representations of these numbers are given in **Data Types and Constants** in the Library Interface section, and generally are int16_t (for Q15 fractional representation) and int32_t (for Q31 fractional representation). This limits the equivalent numerical range to roughly -1.0 to 0.999999999. It is possible to represent other number ranges, but scaling before and after the function call are necessary.

All library functions will saturate the output if the value exceeds the maximum or is lower than the minimum allowable value for that resolution. Some prescaling may be necessary to prevent unwanted saturation in functions that may otherwise create calculation errors.

## *Table of Library Functions*

| Family | Function | Definition |
|---|---|---|
| Complex Math | Addition | DSP_ComplexAdd32 |
| | Conjugate | DSP_ComplexConj32 |
| | Dot Product | DSP_ComplexDotProd32 |
| | Multiplication | DSP_ComplexMult32 |
| | Scalar Multiplication | DSP_ComplexScalarMult32 |
| | Subtraction | DSP_ComplexSub32 |
| Digital Filter | FIR | DSP_FilterFIR32 |
| | FIR Decimation | DSP_FilterFIRDecim32 |
| | FIR Interpolation | DSP_FilterFIRInterp32 |
| | FIR LMS | DSP_FilterLMS16 |
| | IIR | DSP_FilterIIR16; DSP_FilterIIRSetup16 |
| | IIR Biquad | DSP_FilterIIRBQ16; DSP_FilterIIRBQ16_fast; DSP_FilterIIRBQ32 |
| | IIR Biquad Cascade | DSP_FilterIIRBQ16_cascade8; DSP_FilterIIRBQ16_cascade8_fast |
| | IIR Biquad Parallel | DSP_FilterIIRBQ16_parallel8; DSP_FilterIIRBQ16_parallel8_fast |
| Matrix Math | Addition | DSP_MatrixAdd32 |
| | Equality | DSP_MatrixEqual32 |
| | Initialization | DSP_MatrixInit32 |
| | Multiplication | DSP_MatrixMul32 |
| | Scale | DSP_MatrixScale32 |
| | Subtraction | DSP_MatrixSub32 |
| | Transpose | DSP_MatrixTranspose32 |
| Transform | FFT | DSP_TransformFFT16; DSP_TransformFFT32 |
| | Setup factors | DSP_TransformFFT16_setup; DSP_TransformFFT32_setup |
| | inverse FFT | DSP_TransformIFFT16 |

| | | |
|---|---|---|
| | Windows | DSP_TransformWindow_Bart16; DSP_TransformWindow_Bart32; DSP_TransformWindow_Black16; DSP_TransformWindow_Black32; DSP_TransformWindow_Cosine16; DSP_TransformWindow_Cosine32; DSP_TransformWindow_Hamm16; DSP_TransformWindow_Hamm32; DSP_TransformWindow_Hann16; DSP_TransformWindow_Hann32; DSP_TransformWindow_Kaiser16; DSP_TransformWindow_Kaiser32; |
| | Window Initialization | DSP_TransformWinInit_Bart16; DSP_TransformWinInit_Bart32; DSP_TransformWinInit_Black16; DSP_TransformWinInit_Black32; DSP_TransformWinInit_Cosine16; DSP_TransformWinInit_Cosine32; DSP_TransformWinInit_Hamm16; DSP_TransformWinInit_Hamm32; DSP_TransformWinInit_Hann16; DSP_TransformWinInit_Hann32; DSP_TransformWinInit_Kaiser16; DSP_TransformWinInit_Kaiser32 |
| Vector Math | Absolute value | DSP_VectorAbs16; DSP_VectorAbs32 |
| | Addition | DSP_VectorAdd16;<br>DSP_VectorAdd32 |
| | Addition w/ constant | DSP_VectorAddc16; DSP_VectorAddc32 |
| | Binary exponent | DSP_VectorBexp16; DSP_VectorBexp32 |
| | Log, Exponent, Square root | DSP_VectorExp; DSP_VectorLog10; DSP_VectorLog2; DSP_VectorLn; DSP_VectorSqrt; |
| | Multiplication & Division | DSP_VectorMul16; DSP_VectorMul32; DSP_VectorDotp16;<br>DSP_VectorDotp32; DSP_VectorMulc16; DSP_VectorMulc32; DSP_VectorDivC; DSP_VectorRecip |
| | Subtraction | DSP_VectorSub16; DSP_VectorSub32 |
| | Power (sum of squares) | DSP_VectorSumSquares16; DSP_VectorSumSquares32 |
| | Equality check | DSP_VectorChkEqu32 |
| | Maximum | DSP_VectorMax32; DSP_VectorMaxIndex32 |
| | Minimum | DSP_VectorMin32; DSP_VectorMinIndex32 |
| | Copy & Fill | DSP_VectorCopy; DSP_VectorFill; DSP_VectorZeroPad |
| | Shift | DSP_VectorShift; DSP_VectorCopyReverse32 |
| | Negate | DSP_VectorNegate |
| | Statistics | DSP_VectorAutocorr16; DSP_VectorMean32; DSP_VectorRMS16; DSP_VectorStdDev16; DSP_VectorVari16; DSP_VectorVariance |

## Library Interface

### a) Complex Math Functions

| | Name | Description |
|---|---|---|
| | DSP_ComplexAdd32 | Calculates the sum of two complex numbers. |
| | DSP_ComplexConj16 | Calculates the complex conjugate of a complex number. |
| | DSP_ComplexConj32 | Calculates the complex conjugate of a complex number. |
| | DSP_ComplexDotProd32 | Calculates the dot product of two complex numbers. |
| | DSP_ComplexMult32 | Multiplies two complex numbers. |
| | DSP_ComplexScalarMult32 | Multiplies a complex number and a scalar number. |
| | DSP_ComplexSub32 | Calculates the difference of two complex numbers. |

### b) Digital Filter Functions

| | Name | Description |
|---|---|---|
| | DSP_FilterFIR32 | Performs a Finite Infinite Response (FIR) filter on a vector. |
| | DSP_FilterFIRDecim32 | Performs a decimating FIR filter on the input array. |
| | DSP_FilterFIRInterp32 | Performs an interpolating FIR filter on the input array. |
| | DSP_FilterIIR16 | Performs a single-sample cascaded biquad Infinite Impulse Response (IIR) filter. |
| | DSP_FilterIIRBQ16 | Performs a single-pass IIR Biquad Filter. |
| | DSP_FilterIIRBQ16_cascade8 | Performs a single-sample IIR Biquad Filter as a cascade of 8 series filters. |
| | DSP_FilterIIRBQ16_cascade8_fast | Performs a single-sample IIR Biquad Filter as a cascade of 8 series filters. |
| | DSP_FilterIIRBQ16_fast | Performs a single-pass IIR Biquad Filter. |
| | DSP_FilterIIRBQ16_parallel8 | Performs a 8 parallel single-pass IIR Biquad Filters, and sums the result. |

| | | |
|---|---|---|
| | DSP_FilterIIRBQ16_parallel8_fast | Performs a 8 parallel single-pass IIR Biquad Filters, and sums the result. |
| | DSP_FilterIIRBQ32 | Performs a high resolution single-pass IIR Biquad Filter. |
| | DSP_FilterIIRSetup16 | Converts biquad structure to coeffs array to set up IIR filter. |
| | DSP_FilterLMS16 | Performs a single sample Least Mean Squares FIR Filter. |

## c) Matrix Math Functions

| | Name | Description |
|---|---|---|
| | DSP_MatrixAdd32 | Addition of two matrices C = (A + B). |
| | DSP_MatrixEqual32 | Equality of two matrices C = (A). |
| | DSP_MatrixInit32 | Initializes the first N elements of a Matrix to the value num. |
| | DSP_MatrixMul32 | Multiplication of two matrices C = A x B. |
| | DSP_MatrixScale32 | Scales each element of an input buffer (matrix) by a fixed number. |
| | DSP_MatrixSub32 | Subtraction of two matrices C = (A - B). |
| | DSP_MatrixTranspose32 | Transpose of a Matrix C = A (T). |

## d) Transform Functions

| | Name | Description |
|---|---|---|
| | DSP_TransformFFT16 | Creates an Fast Fourier Transform (FFT) from a time domain input. |
| | DSP_TransformFFT16_setup | Creates FFT coefficients for use in the FFT16 function. |
| | DSP_TransformFFT32 | Creates an Fast Fourier Transform (FFT) from a time domain input. |
| | DSP_TransformFFT32_setup | Creates FFT coefficients for use in the FFT32 function. |
| | DSP_TransformIFFT16 | Creates an Inverse Fast Fourier Transform (FFT) from a frequency domain input. |
| | DSP_TransformWindow_Bart16 | Perform a Bartlett window on a vector. |
| | DSP_TransformWindow_Bart32 | Perform a Bartlett window on a vector. |
| | DSP_TransformWindow_Black16 | Perform a Blackman window on a vector. |
| | DSP_TransformWindow_Black32 | Perform a Blackman window on a vector. |
| | DSP_TransformWindow_Cosine16 | Perform a Cosine (Sine) window on a vector. |
| | DSP_TransformWindow_Cosine32 | Perform a Cosine (Sine) window on a vector. |
| | DSP_TransformWindow_Hamm16 | Perform a Hamming window on a vector. |
| | DSP_TransformWindow_Hamm32 | Perform a Hamming window on a vector. |
| | DSP_TransformWindow_Hann16 | Perform a Hanning window on a vector. |
| | DSP_TransformWindow_Hann32 | Perform a Hanning window on a vector. |
| | DSP_TransformWindow_Kaiser16 | Perform a Kaiser window on a vector. |
| | DSP_TransformWindow_Kaiser32 | Perform a Kaiser window on a vector. |
| | DSP_TransformWinInit_Bart16 | Create a Bartlett window. |
| | DSP_TransformWinInit_Bart32 | Create a Bartlett window. |
| | DSP_TransformWinInit_Black16 | Create a Blackman window. |
| | DSP_TransformWinInit_Black32 | Create a Blackman window. |
| | DSP_TransformWinInit_Cosine16 | Create a Cosine (Sine) window. |
| | DSP_TransformWinInit_Cosine32 | Create a Cosine (Sine) window. |
| | DSP_TransformWinInit_Hamm16 | Create a Hamming window. |
| | DSP_TransformWinInit_Hamm32 | Create a Hamming window. |
| | DSP_TransformWinInit_Hann16 | Create a Hanning window. |
| | DSP_TransformWinInit_Hann32 | Create a Hanning window. |
| | DSP_TransformWinInit_Kaiser16 | Create a Kaiser window. |
| | DSP_TransformWinInit_Kaiser32 | Create a Kaiser window. |

## e) Vector Math Functions

| | Name | Description |
|---|---|---|
| | DSP_VectorAbs16 | Calculate the absolute value of a vector. |
| | DSP_VectorAbs32 | Calculate the absolute value of a vector. |
| | DSP_VectorAdd16 | Calculate the sum of two vectors. |
| | DSP_VectorAdd32 | Calculate the sum of two vectors. |
| | DSP_VectorAddc16 | Calculate the sum of a vector and a constant. |
| | DSP_VectorAddc32 | Calculate the sum of a vector and a constant. |

| | | |
|---|---|---|
| | DSP_VectorAutocorr16 | Computes the Autocorrelation of a Vector. |
| | DSP_VectorBexp16 | Computes the maximum binary exponent of a vector. |
| | DSP_VectorBexp32 | Computes the maximum binary exponent of a vector. |
| | DSP_VectorChkEqu32 | Compares two input vectors, returns an integer '1' if equal, and '0' if not equal. |
| | DSP_VectorCopy | Copies the elements of one vector to another. |
| | DSP_VectorCopyReverse32 | Reverses the order of elements in one vector and copies them into another. |
| | DSP_VectorDivC | Divides the first N elements of inVector by a constant divisor, and stores the result in outVector. |
| | DSP_VectorDotp16 | Computes the dot product of two vectors, and scales the output by a binary factor. |
| | DSP_VectorDotp32 | Computes the dot product of two vectors, and scales the output by a binary factor |
| | DSP_VectorExp | Computes the EXP (e^x) of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorFill | Fills an input vector with scalar data. |
| | DSP_VectorLn | Computes the Natural Log, Ln(x), of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorLog10 | Computes the Log10(x), of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorLog2 | Computes the Log2(x) of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorMax32 | Returns the maximum value of a vector. |
| | DSP_VectorMaxIndex32 | Returns the index of the maximum value of a vector. |
| | DSP_VectorMean32 | Calculates the mean average of an input vector. |
| | DSP_VectorMin32 | Returns the minimum value of a vector. |
| | DSP_VectorMinIndex32 | Returns the index of the minimum value of a vector. |
| | DSP_VectorMul16 | Multiplication of a series of numbers in one vector to another vector. |
| | DSP_VectorMul32 | Multiplication of a series of numbers in one vector to another vector. |
| | DSP_VectorMulc16 | Multiplication of a series of numbers in one vector to a scalar value. |
| | DSP_VectorMulc32 | Multiplication of a series of numbers in one vector to a scalar value. |
| | DSP_VectorNegate | Inverses the sign (negates) the elements of a vector. |
| | DSP_VectorRecip | Computes the reciprocal (1/x) of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorRMS16 | Computes the root mean square (RMS) value of a vector. |
| | DSP_VectorShift | Shifts the data index of an input data vector. |
| | DSP_VectorSqrt | Computes the square root of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorStdDev16 | Computes the Standard Deviation of a Vector. |
| | DSP_VectorSub16 | Calculate the difference of two vectors. |
| | DSP_VectorSub32 | Calculate the difference of two vectors. |
| | DSP_VectorSumSquares16 | Computes the sum of squares of a vector, and scales the output by a binary factor. |
| | DSP_VectorSumSquares32 | Computes the sum of squares of a vector, and scales the output by a binary factor. |
| | DSP_VectorVari16 | Computes the variance of N elements of a Vector. |
| | DSP_VectorVariance | Computes the variance of N elements of inVector. |
| | DSP_VectorZeroPad | Fills an input vector with zeros. |

## f) Support Functions

| | Name | Description |
|---|---|---|
| | mul16 | multiply and shift integer |
| | mul16r | multiply and shift Q15 |
| | mul32 | multiply and shift Q31 |
| | SAT16 | saturate both positive and negative Q15 |
| | SAT16N | saturate negative Q15 |
| | SAT16P | saturate positive Q15 |

## g) Data Types and Constants

| | Name | Description |
|---|---|---|
| | biquad16 | Q15 biquad |
| | int16c | Q15 complex number (a + bi) |
| | int32c | Q31 complex number (a + bi) |
| | matrix32 | Q31 matrix |

| | | |
|---|---|---|
| | PARM_EQUAL_FILTER | IIR BQ filter structure Q15 data, Q31 storage |
| | PARM_EQUAL_FILTER_16 | IIR BQ filter structure Q15 |
| | PARM_EQUAL_FILTER_32 | IIR BQ filter structure Q31 |
| | PARM_FILTER_GAIN | filter gain structure |
| | _PARM_EQUAL_FILTER | IIR BQ filter structure Q15 data, Q31 storage |
| | _PARM_EQUAL_FILTER_16 | IIR BQ filter structure Q15 |
| | _PARM_EQUAL_FILTER_32 | IIR BQ filter structure Q31 |
| | MAX16 | maximum Q15 |
| | MAX32 | maximum Q31 |
| | MIN16 | minimum Q15 |
| | MIN32 | minimum Q31 |

## Description

This section describes the Application Programming Interface (API) functions of the DSP Fixed-Point Library.

Refer to each section for a detailed description.

## *a) Complex Math Functions*

## DSP_ComplexAdd32 Function

Calculates the sum of two complex numbers.

### File

dsp.h

### C

```
void DSP_ComplexAdd32(int32c * indata1, int32c * indata2, int32c * Output);
```

### Returns

pointer to result complex numbers (int32c)

None.

### Description

Function DSP_ComplexAdd32:

void DSP_ComplexAdd32(int32c *indata1, int32c *indata2, int32c *Output);

Calculates the sum of two complex numbers, indata1 and indata2, and stores the complex result in Output. Complex numbers must be in the structural form that includes real and imaginary components. The function saturates the output values if maximum or minimum are exceeded. All values are in Q31 fractional data format. (a + bi) + (c + di) => (a + c) + (b + d)i

### Remarks

None.

### Preconditions

Complex numbers must be in the int32c format.

### Example

```
int32c *res, result;
int32c *input1, *input2;
int32c test_complex_1 = {0x40000000,0x0CCCCCCC};
//                  (0.5 + 0.1i)
int32c test_complex_2 = {0x73333333,0xB3333334};
//                  (0.9 - 0.6i)
res=&result;
input1=&test_complex_1;
input2=&test_complex_2;

DSP_ComplexAdd32(input1, input2, res);

// result = {0x73333333, 0xC0000000} = (0.9 - 0.5i)
```

### Parameters

| Parameters | Description |
|---|---|
| indata1 | pointer to input complex number (int32c) |
| indata2 | pointer to input complex number (int32c) |

## DSP_ComplexConj16 Function

Calculates the complex conjugate of a complex number.

### File

dsp.h

### C

```
void DSP_ComplexConj16(int16c * indata, int16c * Output);
```

### Returns

pointer to result complex numbers (int16c)

None.

### Description

DSP_ComplexConj16:

void DSP_ComplexConj16(int16c *indata, int16c *Output);

CCalculates the complex conjugate of Indata, and stores the result in Outdata. Both numbers must be in the complex number data structure which includes real and imaginary components. Values are in Q15 fractional data format. The function will saturate the output if maximum or minimum values are exceeded. (a + bi) => (a - bi)

### Remarks

None.

### Preconditions

Complex numbers must be in the int32c format.

### Example

```
int16c *res, result;
int16c *input1;
int16c test_complex_1 = {0x4000,0x0CCC};
//                   (0.5 + 0.1i)

res=&result;
input1=&test_complex_1;

DSP_ComplexConj16(input1, res);

// result = {0x4000, 0xF334} = (0.5 - 0.1i)
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to input complex number (int16c) |

## DSP_ComplexConj32 Function

Calculates the complex conjugate of a complex number.

### File

dsp.h

### C

```
void DSP_ComplexConj32(int32c * indata, int32c * Output);
```

### Returns

pointer to result complex numbers (int32c)

None.

### Description

Function DSP_ComplexConj32:

void DSP_ComplexConj32(int32c *indata, int32c *Output);

Calculates the complex conjugate of indata, and stores the result in Output. Both numbers must be in the complex number data structure, which includes real and imaginary components. Values are in Q31 fractional data format. The function will saturate the output if maximum or minimum values are exceeded. (a + bi) => (a - bi)

### Remarks

None.

### Preconditions

Complex numbers must be in the int32c format.

### Example

```
int32c *res, result;
int32c *input1;
int32c test_complex_1 = {0x40000000,0x0CCCCCCC};
//                  (0.5 + 0.1i)

res=&result;
input1=&test_complex_1;

DSP_ComplexConj32(input1, res);

// result = {0x40000000, 0xF3333334} = (0.5 - 0.1i)
```

### Parameters

| Parameters | Description |
|---|---|
| indata1 | pointer to input complex number (int32c) |

## DSP_ComplexDotProd32 Function

Calculates the dot product of two complex numbers.

### File

dsp.h

### C

```
void DSP_ComplexDotProd32(int32c * indata1, int32c * indata2, int32c * Output);
```

### Returns

pointer to result complex numbers (int32c)

None.

### Description

Function DSP_ComplexDotProd32:

void DSP_ComplexDotProd32(int32c *indata1, int32c *indata2, int32c *Output);

Calculates the dot product of two complex numbers, indata1 and indata2, and stores the result in Output. All numbers must be in complex structural format that includes real and imaginary components, and the numbers are in fractional Q31 format. The function will saturate the output if it exceeds maximum or minimum ratings. The formula for the dot product is as follows: Output(real) = (Input1.re * Input2.re) + (Input1.im * Input2.im); Output(img) = [(Input1.re * Input2.im) - (Input1.im * Input2.re)]i (a + bi) dot (c + di) => (a * c + b * d) + (a * d - b * c)i

### Remarks

None.

### Preconditions

Complex numbers must be in the int32c format.

## Example

```
int32c *res, result;
int32c *input1, *input2;
int32c test_complex_1 = {0x40000000,0x0CCCCCCC};
//                  (0.5 + 0.1i)
int32c test_complex_2 = {0x73333333,0xB3333334};
//                  (0.9 - 0.6i)
res=&result;
input1=&test_complex_1;
input2=&test_complex_2;

DSP_ComplexDotProd32(input1, input2, res);

// result = {0x31EB851E, 0xCE147AE3} = (0.39 - 0.39i)
```

## Parameters

| Parameters | Description |
|---|---|
| indata1 | pointer to input complex number (int32c) |
| indata2 | pointer to input complex number (int32c) |

# DSP_ComplexMult32 Function

Multiplies two complex numbers.

## File

dsp.h

## C

```
void DSP_ComplexMult32(int32c * indata1, int32c * indata2, int32c * Output);
```

## Returns

pointer to result complex numbers (int32c)

None.

## Description

Function DSP_ComplexMult32:

void DSP_ComplexMult32(int32c *indata1, int32c *indata2, int32c *Output);

Multiplies two complex numbers, indata1 and indata2, and stores the complex result in Output. All numbers must be in the int32c complex data structure. All data is in Q31 fractional format. The function will saturate if maximum or minimum values are exceeded. Output(real) = (Input1.re * Input2.re) - (Input1.im * Input2.im); Output(img) = [(Input1.re * Input2.im) + (Input1.im * Input2.re)]i (a + bi) x (c + di) => (a * c - b * d) + (a * d + b * c)i

## Remarks

None.

## Preconditions

Complex numbers must be in the int32c format.

## Example

```
int32c *res, result;
int32c *input1, *input2;
int32c test_complex_1 = {0x40000000,0x0CCCCCCC};
//                  (0.5 + 0.1i)
int32c test_complex_2 = {0x73333333,0xB3333334};
//                  (0.9 - 0.6i)
res=&result;
input1=&test_complex_1;
input2=&test_complex_2;

DSP_ComplexMult32(input1, input2, res);

// result = {0x4147AE14, 0xE51EB8551} = (0.51 - 0.21i)
```

### Parameters

| Parameters | Description |
|---|---|
| indata1 | pointer to input complex number (int32c) |
| indata2 | pointer to input complex number (int32c) |

## DSP_ComplexScalarMult32 Function

Multiplies a complex number and a scalar number.

### File

dsp.h

### C

```
void DSP_ComplexScalarMult32(int32c * indata, int32_t Scalar, int32c * Output);
```

### Returns

pointer to result complex numbers (int32c)

None.

### Description

Function DSP_ComplexScalarMult32:

void DSP_ComplexScalarMult32(int32c *indata, int32_t Scalar, int32c *Output);

Multiplies a complex number, indata, by a scalar number, Scalar, and stores the result in Output. indata and Output must be in int32c structure with real and imaginary components. All data must be in the fractional Q31 format. The function will saturate if maximum or minimum values are exceeded. Output(real) = (Input1.re * Scalar); Output(img) = [(Input1.im * Scalar)]i (a + bi) * C => (a * C + b * Ci)

### Remarks

None.

### Preconditions

Complex numbers must be in the int32c format.

### Example

```
int32c *res, result;
int32c *input1;
int32_t  scalarInput = 0x20000000; // 0.25
int32c test_complex_1 = {0x40000000,0x0CCCCCCC};
//                  (0.5 + 0.1i)

res=&result;
input1=&test_complex_1;

DSP_ComplexScalarMult32(input1, scalarInput, res);

// result = {0x10000000, 0x03333333} = (0.125 + 0.025i)
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to input complex number (int32c) |
| Scalar | fractional scalar input value (int32_t) |

## DSP_ComplexSub32 Function

Calculates the difference of two complex numbers.

### File

dsp.h

### C

```
void DSP_ComplexSub32(int32c * indata1, int32c * indata2, int32c * Output);
```

### Returns

pointer to result complex numbers (int32c)

None.

### Description

Function DSP_ComplexSub32:

void DSP_ComplexSub32(int32c *indata1, int32c *indata2, int32c *Output);

Calculates the difference of two complex numbers, indata1 less indata2, and stores the complex result in Output. Both numbers must be in a complex data structure, which includes real and imaginary components. The function saturates the output values if maximum or minimum are exceeded. Real and imaginary components are in the Q31 fractional data format. (a + bi) - (c + di) => (a - c) + (b - d)i

### Remarks

None.

### Preconditions

Complex numbers must be in the int32c format.

### Example

```
int32c *res, result;
int32c *input1, *input2;
int32c test_complex_1 = {0x40000000,0x0CCCCCCC};
//                  (0.5 + 0.1i)
int32c test_complex_2 = {0x73333333,0xB3333334};
//                  (0.9 - 0.6i)
res=&result;
input1=&test_complex_1;
input2=&test_complex_2;

DSP_ComplexSub32(input1, input2, res);

// result = {0xCCCCCCCD, 0x59999998} = (-0.4 + 0.7i)
```

### Parameters

| Parameters | Description |
|---|---|
| indata1 | pointer to input complex number (int32c) |
| indata2 | pointer to input complex number (int32c) |

## *b) Digital Filter Functions*

## DSP_FilterFIR32 Function

Performs a Finite Infinite Response (FIR) filter on a vector.

### File

dsp.h

### C

```
void DSP_FilterFIR32(int32_t * outdata, int32_t * indata, int32_t * coeffs2x, int32_t * delayline, int N,
int K, int scale);
```

### Returns

None.

### Description

Function DSP_FilterFIR32:

void DSP_FilterFIR32(int32_t *outdata, int32_t *indata, int32_t *coeffs2x, int32_t *delayline, int N, int K, int scale);

Performs an FIR filter on the vector indata, and stores the output in the vector outdata. The number of samples processed in the array is given by N. The number of filter taps is given by K. The values are scaled upon input by the binary scaling factor (right shift), scale. The array of 2*K coefficients is contained in the array coeffs2x, where the values are in order b0, b1, b2... and repeated. Lastly the delayline is an array of K values that are initialized to zero and represent previous values. All values are in fractional Q31 data format. The function will saturate results if minimum or maximum values are exceeded.

## Remarks

Filter coefs must be repeated within the array. The array is twice as large as the number of taps, and the values are repeated in order b0, b1, b2,...bn, b0, b1, b2,... bn. The function updates the delayline array, which must be K elements long. The array should be initialized to zero prior to the first processing. It will contain values for processing cascaded filters within a loop.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four. K must be greater than 2 and a multiple of 2. delayline must have K elements, and be initialized to zero. coeffs2x must have 2*K elements.

## Example

```
#define TAPS 4
#define numPOINTS 256

int filterN = numPOINTS;
int filterK = TAPS;
int filterScale = 1;  // scale output by 1/2^1 => output * 0.5
int32_t FilterCoefs[TAPS*2] = {0x40000000, 0x20000000, 0x20000000, 0x20000000,
            0x40000000, 0x20000000, 0x20000000, 0x20000000};
// note repeated filter coefs, A B C D A B C D
//             0.5, 0.25, 0.25, 0.25, 0.5, 0.25, 0.25, 0.25

int32_t outFilterData[numPOINTS]={0};
int32_t inFilterData[numPOINTS];
int filterDelayLine[TAPS]={0};

while(true)
{

//   put some data into input array, inFilterData, here //

DSP_FilterFIR32(outFilterData, inFilterData, FilterCoefs, filterDelayLine,
            filterN, filterK, filterScale);
}
```

## Parameters

| Parameters | Description |
| --- | --- |
| outdata | pointer to destination array of elements (int32_t) |
| indata | pointer to source array of elements (int32_t) |
| coeffs2x | pointer to an array of coefficients (int32_t) |
| delayline | pointer to an array of delay variables (int32_t) |
| N | number of points in the array to process (int) number of samples (int) |
| K | number of filter taps |
| scale | binary scaler divisor (1 / 2^scale) (int) |

# DSP_FilterFIRDecim32 Function

Performs a decimating FIR filter on the input array.

## File

dsp.h

## C

```
void DSP_FilterFIRDecim32(int32_t * outdata, int32_t * indata, int32_t * coeffs, int32_t * delayline, int
N, int K, int scale, int rate);
```

## Returns

None.

## Description

Function DSP_FilterFIRDecim32:

void DSP_FilterFIRDecim32(int32_t *outdata, int32_t *indata, int32_t *coeffs, int32_t *delayline, int N, int K, int scale, int rate);

Compute a FIR decimation filter on the input vector indata, and store the results to the vector outdata. The total number of output elements is set by N, and therefore the outdata array must be at least N in length. The decimation ratio is given by rate. The input is sampled every integer value of rate, skipping every (rate-1) input samples. The input array must therefore be (rate*N) samples long. The amount of filter taps is specified by K. Coeffs specifies the coefficients array. The delayline array holds delay inputs for calculation, and must be initialized to zero prior to calling the filter. Both coeffs and delayline must be K in length. Scale divides the input by a scaling factor by right shifting the number of bits (1/2^scale). All values of input, output, and coeffs are given in Q31 fractional data format. The function will saturate if the output value exceeds the maximum or minimum value.

Y = b0 * X0 + (b1 * X(-1)) + (b2 * X(-2)

## Remarks

Coefs are loaded into the array with corresponding to the least delay first (C0, C(-1), C(-2)). K must be greater than rate. Even while decimating the input stream, every input passes through the delayline. So FIR filters of arbitrary length will give the same output as a non-decimating FIR, just with fewer responses.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. delayline must have K elements, and be initialized to zero. coeffs must have K elements. outdata must have N elements indata must have (N*rate) elements

## Example

```c
#define N 8         // number of output samples
#define TAPS 5
#define SKIP 3

int testFilterN = N;        // number of output elements
int testFilterK = TAPS;     // number of taps
int testFilterRate = SKIP;  // decimation rate R
int32_t outFiltDataDec[N]={0};
int32_t *inTestFilter[N*SKIP];
int filtScaleNum = 1;       // scale output (1 /2^n) => Y * 0.5

int32_t filtDelayTest[8]={0};  // always initialize to zero

// get pointer to input buffer here //
inTestFilter = &inputBuffer;

DSP_FilterFIRDecim32(outFiltDataDec, inTestFilter, inTestCoefs,
        filtDelayTest, testFilterN, testFilterK, filtScaleNum, testFilterRate);
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of elements (int32_t) |
| indata | pointer to input array of elements (int32_t) |
| coeffs | pointer to an array of coefficients (int32_t) |
| delayline | pointer to an array of delay variables (int32_t) |
| N | number of output elements to be processed (int) |
| K | number of filter taps and coeffs (int) |
| scale | binary scaler divisor (1 / 2^scale) (int) |
| rate | decimation ratio (int) |

# DSP_FilterFIRInterp32 Function

Performs an interpolating FIR filter on the input array.

## File

dsp.h

## C

```c
void DSP_FilterFIRInterp32(int32_t * outdata, int32_t * indata, int32_t * coeffs, int32_t * delayline, int
N, int K, int scale, int rate);
```

## Returns

None.

## Description

Function DSP_FilterFIRInterp32:

void DSP_FilterFIRInterp32(int32_t *outdata, int32_t *indata, int32_t *coeffs, int32_t *delayline, int N, int K, int scale, int rate);

Perform an interpolating FIR filter on the first N samples of indata, and stores the result in outdata. The number of output elements is N*rate. The number of filter taps, K, must be an even multiple of N. The coefficients array, Coeffs, must be K elements long. The delay line array, delayline, must be K/R elements long, and be initialized to zero. All data elements must be in Q31 fractional data format. Scaling is performed via binary shift on the input equivalent to (1/2^shift). The function will saturate the output if it exceeds maximum or minimum values. The function creates R output values for each input value processed. The delayline of previous values is processed with R elements of the coefficient array. Numerically:

Y(1,0) = X(0)*C(0) + X(-1)*C(rate) + X(-2)*C(2*rate) ... Y(1,1) = X(0)*C(1) + X(-1)*C(rate+1) + X(-2)*C(2*rate + 1) ... Y(1,rate) = X(0)*C(N) + X(-1)*C(rate+N) + X(-2)*C(2*rate + N) ...

where output Y corresponds to (input,rate) different outputs, input X has (M/rate) sample delays and C is the coefficient array.

## Remarks

The function processes each input (rate) times. With each pass, coefficients are offset so that (K/rate) multiply accumulate cycles occur.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. delayline must have (K/R) elements, and be initialized to zero. K (taps) must be an even multiple of R (rate). outdata must have R*N elements.

## Example

```
// interpret evenly 1/3 spaced values
#define N 4         // number of output samples
#define TAPS 6
#define INTERP 3

int ifiltN = N;
int ifiltK = TAPS;  // k must be an even multiple of R
int ifiltR = INTERP;

int32_t ifiltOut[N*INTERP]={0};
int32_t ifiltDelay[2]={0};  // must be initialized to zero
int ifiltScale = 0;         // no scaling

int32_t ifiltCoefsThirds[TAPS]={0x2AAAAAA9, 0x55555555,0x7FFFFFFE,
                                0x55555555,0x2AAAAAA9,0x00000000};
//                  0.333333, 0.6666667, 0.99999999, 0.6666667, 0.33333333, 0

int32_t ifiltInput[N]={0x0CCCCCCD, 0x19999999, 0x26666666, 0x33333333};
//                  0.1,  0.2,  0.3,  0.4

DSP_FilterFIRInterp32(ifiltOut, ifiltInput, ifiltCoefsThirds, ifiltDelay,
                                ifiltN, ifiltK, ifiltScale, ifiltR);

// ifiltOut = {0x04444444, 0x08888889, 0x0CCCCCCD, 0x11111111, 0x15555555, 0x19999999,
//          0x1DDDDDDD, 0x22222221, 0x26666665, 0x2AAAAAAA,0x2EEEEEEE, 0x33333332}
// = 0.0333, 0.0667, 0.1, 0.1333, 0.1667, 0.2, 0.2333, 0.2667, 0.3, 0.3333, 0.3667, 0.4
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of elements (int32_t) |
| indata | pointer to input array of elements (int32_t) |
| coeffs | pointer to an array of coefficients (int32_t) |
| delayline | pointer to an array of delay variables (int32_t) |
| N | number of output elements to be processed (int) |
| K | number of filter taps and coeffs (int) |
| scale | binary scaler divisor (1 / 2^scale) (int) |
| rate | decimation ratio (int) |

## DSP_FilterIIR16 Function

Performs a single-sample cascaded biquad Infinite Impulse Response (IIR) filter.

## File

dsp.h

## C

```
int16_t DSP_FilterIIR16(int16_t in, int16_t * coeffs, int16_t * delayline, int B, int scale);
```

## Returns

Sample output Y (int16_t)

## Description

Function DSP_FilterIIR16:

int16_t DSP_FilterIIR16(int16_t in, int16_t *coeffs, int16_t *delayline, int B, int scale);

Performs a single element cascaded biquad IIR filter on the input, in. The filter contains B number of biquad sections, and cascades the output of one to the input of the next. B must be greater than 2 and a multiple of 2. The int16_t output generated by the function is the computation from the final biquad stage. Delay pipeline array delayline must contain 2*B values and be initialized to zero prior to use. The coefficient array must contain 4*B elements, and must be set up in order of biquad a1, a2, b1, b2. A binary (right shift) factor, scale, will scale the output equivalent to (1/2^scale). All numerical values must be in Q15 fractional data format. The function will saturate values if maximum or minimum values are exceeded.

Y = X0 + (b1 * X(-1)) + (b2 * X(-2) + (a1 * Y(-1)) + (a2 * Y(-2))

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. B must be greater than 2 and a multiple of 2. delayline must have 2*B elements, and be initialized to zero. coeffs must have 4*B elements.

## Example

```
#define B 8         // use * biquad filters in cascade

int dataSamples = 256;
int i, j;
biquad16 bquad[B];
int16_t coefs[4*B]= {0};
int16_t delaylines[2*B]= {0};
int16_t Y, X;
int scaleBquad = 1;  // scale output (1 /2^n) => Y * 0.5

// do something to set up coefs, for instance this example //

for (j=0; jRemarks:Filter coefs must be stored within the array as a1, a2, b1, b2, a1, a2, b1, b2, in order
of biquads form input to output. A function to translate the coeffs from biquad structure to coeffs is
available in DSP_FilterIIRSetup16. The function updates the delayline array, which must be 2*B elements
long. The array should be initialized to zero prior to the first processing. It will contain values for
processing cascaded filters within a loop.
```

## Parameters

| Parameters | Description |
|---|---|
| in | input data element X (int16_t) |
| coeffs | pointer to an array of coefficients (int16_t) |
| delayline | pointer to an array of delay variables (int16_t) |
| B | number of cascaded biquad filter groups to process (int) |
| scale | binary scaler divisor (1 / 2^scale) (int) |

# DSP_FilterIIRBQ16 Function

Performs a single-pass IIR Biquad Filter.

## File

dsp.h

## C

```
int16_t DSP_FilterIIRBQ16(int16_t Xin, PARM_EQUAL_FILTER * pFilter);
```

## Returns

Sample output Y (int16_t)

## Description

Function DSP_FilterIIRBQ16:

int16_t DSP_FilterIIRBQ16(int16_t Xin, PARM_EQUAL_FILTER *pFilter);

Calculates a single pass IIR biquad filter on Xin, and delivers the result as a 16-bit output. All math is performed using 32 bit instructions, with results truncated to 16-bits for the output. The delay register is stored as a 32-bit value for subsequent functions. All values are fractional Q15 and Q31, see data structure for specifics.

Y = X(0)*b0 + (b1 * X(-1)) + (b2 * X(-2)) - (a1 * Y(-1)) - (a2 * Y(-2))

## Remarks

The delay register values should be initialized to zero prior to the first call to the function, they are updated each pass. A gain of 2 has been hard coded into the function. This implies that all coefs should be input at half value. This is purposeful, since many filter designs need a div2 to have each coef between the required -1

## Preconditions

Delay register values should be initialized to zero.

## Example

```
PARM_EQUAL_FILTER *ptrFilterEQ;
PARM_EQUAL_FILTER FilterEQ;
uint16_t DataIn, DataOut;
ptrFilterEQ = &FilterEQ;

// 48KHz sampling; 1 KHz bandpass filter; Q=0.9
//  divide by 2 and convert to Q15
//   b0 = 0.06761171785499065
//   b1 = 0
//   b2 = -0.06761171785499065
//   a1 = -1.848823142275648
//   a2 = 0.8647765642900187

// note all coefs are half value of original design, gain handled in algorithm
ptrFiltEQ32->b[0]=0x0453;       // feed forward b0 coef
ptrFiltEQ32->b[1]=0;            // feed forward b1 coef
ptrFiltEQ32->b[2]=0xFBAD;       // feed forward b2 coef

// note all coefs are half value of original design, gain handled in algorithm
// note subtract is handled in algorithm, so coefs go in at actual value
ptrFiltEQ32->a[0]=0x89AD;       // feedback a1 coef
ptrFiltEQ32->a[1]=0x3758;       // feedback a2 coef

for (i=0;i<256;i++)
    {
    // *** get some input data here
       DataIn32 = three_hundred_hz[i];

       DataOut = DSP_FilterIIRBQ16(DataIn, ptrFilterEQ);

     // *** do something with the DataOut here
     }
```

## Parameters

| Parameters | Description |
|---|---|
| Xin | input data element X (int16_t) |
| pFilter | pointer to filter coef and delay structure |

## DSP_FilterIIRBQ16_cascade8 Function

Performs a single-sample IIR Biquad Filter as a cascade of 8 series filters.

## File

dsp.h

## C

```
int16_t DSP_FilterIIRBQ16_cascade8(int16_t Xin, PARM_EQUAL_FILTER * pFilter_Array);
```

## Returns

Sample output Y (int16_t)

## Description

Function DSP_FilterIIRBQ16_cascade8:

int16_t DSP_FilterIIRBQ16_cascade8(int16_t Xin, PARM_EQUAL_FILTER *pFilter_Array);

Calculates a single pass IIR biquad cascade filter on Xin, and delivers the result as a 16-bit output. The cascade of filters is 8 unique biquad filters arranged in series such that the output of one is provided as the input to the next. A unique filter coefficient set is provided to each, and 32 bit delay lines are maintained for each. All math is performed using 32 bit instructions, which results truncated to 16-bits for the output. Global gain values are available on the output. Fracgain is a Q15 fractional gain value and expgain is a binary shift gain value. The combination of the two can be utilized to normalize the output as desired. All values are fractional Q15 and Q31, see data structure for specifics.

Y = Y7 <- Y6 <- Y5 <- Y4 <- Y3 <- Y2 <- Y1 <- Y0 where each Yn filter element represents a unique IIR biquad: Yn = Y(n-1)*b0 + (b1 * Y(n-2)) + (b2 * Y(n-3)) - (a1 * Yn(-1)) - (a2 * Yn(-2)) and: for Y0; Y(n-1) = Xin(0)

## Remarks

The delay register values should be initialized to zero prior to the first call to the function, they are updated each pass. A gain of 2 has been hard coded into the function. This implies that all coefs should be input at half value. This is purposeful, since many filter designs need a div2 to have each coef between the required -1

## Preconditions

Delay register values should be initialized to zero.

## Example

```
PARM_EQUAL_FILTER filtArray[8];
uint16_t dataY, dataX;

// example to use 2 filter blocks as notch filters
// fill entire Filter Array with coefs
for (i=0;i<8;i++)
{
    filtArray[i].Z[0]=0;
    filtArray[i].Z[1]=0;

    // note all coefs are half value of original design, gain handled in algorithm
    // all pass
    filtArray[i].b[0]=0x4000;
    filtArray[i].b[1]=0;        // feed forward b1 coef
    filtArray[i].b[2]=0;  // feed forward b2 coef

    filtArray[i].a[0]=0;  // feedback a1 coef
    filtArray[i].a[1]=0;  // feedback a2 coef
}
    // Unique filters for example
    // 10KHz notch filter -- divide coefs by 2
    b0 = 0.5883783602332997
    b1 = -0.17124071441396285
    b2 = 0.5883783602332997
    a1 = -0.17124071441396285
    a2 = 0.1767567204665992

    // note all coefs are half value of original design, gain handled in algorithm
    filtArray[3].b[0]=0x25a7;           // feed forward b0 coef
    filtArray[3].b[1]=0xf508;           // feed forward b1 coef
    filtArray[3].b[2]=0x25a7;           // feed forward b2 coef

    // note all coefs are half value of original design, gain handled in algorithm
    // note subtract is handled in algorithm, so coefs go in at actual value
    filtArray[3].a[0]=0xf508;           // feedback a1 coef
    filtArray[3].a[1]=0x0b4f;           // feedback a2 coef
```

```
    // 1 KHz notch filter -- divide coefs by 2
    b0 = 0.90875540649449O8
    b1 = -1.7990948352036205
    b2 = 0.9087554064944908
    a1 = -1.7990948352036205
    a2 = 0.8175108129889816

    // note all coefs are half value of original design, gain handled in algorithm
    filtArray[7].b[0]=0x3a29;           // feed forward b0 coef
    filtArray[7].b[1]=0x8cdc;           // feed forward b1 coef
    filtArray[7].b[2]=0x3a29;           // feed forward b2 coef

    // note all coefs are half value of original design, gain handled in algorithm
    // note subtract is handled in algorithm, so coefs go in at actual value
    filtArray[7].a[0]=0x8cdc;           // feedback a1 coef
    filtArray[7].a[1]=0x3452;           // feedback a2 coef

for (i=0;i<256;i++)
    {
     // *** get input data here
     dataX = compound_300_1K_hz16[i];

     dataY = DSP_FilterIIRBQ16_cascade8(dataX, filtArray);

     // *** do something with the DataY here
     }
```

## Parameters

| Parameters | Description |
|---|---|
| Xin | input data element X (int16_t) |
| pFilter | pointer to filter coef and delay structure |

# DSP_FilterIIRBQ16_cascade8_fast Function

Performs a single-sample IIR Biquad Filter as a cascade of 8 series filters.

## File

dsp.h

## C

```
int16_t DSP_FilterIIRBQ16_cascade8_fast(int16_t Xin, PARM_EQUAL_FILTER_16 * pFilter_Array);
```

## Returns

Sample output Y (int16_t)

## Description

Function DSP_FilterIIRBQ16_cascade8_fast:

int16_t DSP_FilterIIRBQ16_cascade8_fast(int16_t Xin, PARM_EQUAL_FILTER_16 *pFilter_Array);

Calculates a single pass IIR biquad cascade filter on Xin, and delivers the result as a 16-bit output. The cascade of filters is 8 unique biquad filters arranged in series such that the output of one is provided as the input to the next. A unique filter coefficient set is provided to each, and 16 bit delay lines are maintained for each. All math is performed using 16 bit instructions, which results rounded to 16-bits for the output. All values are fractional Q15, see data structure for specifics. The function will saturate the output should it exceed maximum or minimum values.

Y = Y7 <- Y6 <- Y5 <- Y4 <- Y3 <- Y2 <- Y1 <- Y0 where each Yn filter element represents a unique IIR biquad: Yn = Y(n-1)*b0 + (b1 * Y(n-2)) + (b2 * Y(n-3)) - (a1 * Yn(-1)) - (a2 * Yn(-2)) and: for Y0; Y(n-1) = Xin(0)

## Remarks

The delay register values should be initialized to zero prior to the first call to the function, they are updated each pass. A gain of 2 has been hard coded into the function. This implies that all coefs should be input at half value. This is purposeful, since many filter designs need a div2 to have each coef between the required -1

## Preconditions

Delay register values should be initialized to zero.

## Example

```
PARM_EQUAL_FILTER_16 filtArray[8];
uint16_t dataY, dataX;

// example to use 2 filter blocks as notch filters
// fill entire Filter Array with coefs
for (i=0;i<8;i++)
{
    filtArray[i].Z[0]=0;
    filtArray[i].Z[1]=0;

    // note all coefs are half value of original design, gain handled in algorithm
    // all pass
    filtArray[i].b[0]=0x4000;
    filtArray[i].b[1]=0;        // feed forward b1 coef
    filtArray[i].b[2]=0;  // feed forward b2 coef

    filtArray[i].a[0]=0;  // feedback a1 coef
    filtArray[i].a[1]=0;  // feedback a2 coef
}
    // Unique filters for example
    // 10KHz notch filter -- divide coefs by 2
    b0 = 0.5883783602332997
    b1 = -0.17124071441396285
    b2 = 0.5883783602332997
    a1 = -0.17124071441396285
    a2 = 0.1767567204665992

    // note all coefs are half value of original design, gain handled in algorithm
    filtArray[3].b[0]=0x25a7;           // feed forward b0 coef
    filtArray[3].b[1]=0xf508;           // feed forward b1 coef
    filtArray[3].b[2]=0x25a7;           // feed forward b2 coef

    // note all coefs are half value of original design, gain handled in algorithm
    // note subtract is handled in algorithm, so coefs go in at actual value
    filtArray[3].a[0]=0xf508;           // feedback a1 coef
    filtArray[3].a[1]=0x0b4f;           // feedback a2 coef

    // 1 KHz notch filter -- divide coefs by 2
    b0 = 0.9087554064944908
    b1 = -1.7990948352036205
    b2 = 0.9087554064944908
    a1 = -1.7990948352036205
    a2 = 0.8175108129889816

    // note all coefs are half value of original design, gain handled in algorithm
    filtArray[7].b[0]=0x3a29;           // feed forward b0 coef
    filtArray[7].b[1]=0x8cdc;           // feed forward b1 coef
    filtArray[7].b[2]=0x3a29;           // feed forward b2 coef

    // note all coefs are half value of original design, gain handled in algorithm
    // note subtract is handled in algorithm, so coefs go in at actual value
    filtArray[7].a[0]=0x8cdc;           // feedback a1 coef
    filtArray[7].a[1]=0x3452;           // feedback a2 coef

for (i=0;i<256;i++)
    {
     // *** get input data here
     dataX = compound_300_1K_hz16[i];

     dataY = DSP_FilterIIRBQ16_cascade8_fast(dataX, filtArray);

     // *** do something with the DataY here
     }
```

### Parameters

| Parameters | Description |
| --- | --- |
| Xin | input data element X (int16_t) |
| pFilter | pointer to filter coef and delay structure |

## DSP_FilterIIRBQ16_fast Function

Performs a single-pass IIR Biquad Filter.

### File

dsp.h

### C

```
int16_t DSP_FilterIIRBQ16_fast(int16_t Xin, PARM_EQUAL_FILTER_16 * pFilter);
```

### Returns

Sample output Y (int16_t)

### Description

Function DSP_FilterIIRBQ16_fast:

int16_t DSP_FilterIIRBQ16_fast(int16_t Xin, PARM_EQUAL_FILTER_16 *pFilter);

Calculates a single pass IIR biquad filter on Xin, and delivers the result as a 16-bit output. All math is performed using 16 bit instructions, with results rounded to 16-bits for the output. The delay register is stored as a 16-bit value for subsequent functions. The function will saturate the results if maximum or minimum fractional values are exceeded. All values are fractional Q15 format.

Y = X(0)*b0 + (b1 * X(-1)) + (b2 * X(-2)) - (a1 * Y(-1)) - (a2 * Y(-2))

### Remarks

The delay register values should be initialized to zero prior to the first call to the function, they are updated each pass. A gain of 2 has been hard coded into the function. This implies that all coefs should be input at half value. This is purposeful, since many filter designs need a div2 to have each coef between the required -1

### Preconditions

Delay register values should be initialized to zero.

### Example

```
PARM_EQUAL_FILTER_16 *ptrFilterEQ;
PARM_EQUAL_FILTER_16 FilterEQ;
uint16_t DataIn, DataOut;
ptrFilterEQ = &FilterEQ;

// 48KHz sampling; 1 KHz bandpass filter; Q=0.9
//  divide by 2 and convert to Q15
//   b0 = 0.06761171785499065
//   b1 = 0
//   b2 = -0.06761171785499065
//   a1 = -1.848823142275648
//   a2 = 0.8647765642900187

// note all coefs are half value of original design, gain handled in algorithm
ptrFiltEQ32->b[0]=0x0453;       // feed forward b0 coef
ptrFiltEQ32->b[1]=0;            // feed forward b1 coef
ptrFiltEQ32->b[2]=0xFBAD;       // feed forward b2 coef

// note all coefs are half value of original design, gain handled in algorithm
// note subtract is handled in algorithm, so coefs go in at actual value
ptrFiltEQ32->a[0]=0x89AD;       // feedback a1 coef
ptrFiltEQ32->a[1]=0x3758;       // feedback a2 coef

for (i=0;i<256;i++)
    {
    // *** get some input data here
       DataIn32 = three_hundred_hz[i];
```

```
        DataOut = DSP_FilterIIRBQ16_fast(DataIn, ptrFilterEQ);

      // *** do something with the DataOut here
      }
```

## Parameters

| Parameters | Description |
|---|---|
| Xin | input data element X (int16_t) |
| pFilter | pointer to filter coef and delay structure |

# DSP_FilterIIRBQ16_parallel8 Function

Performs a 8 parallel single-pass IIR Biquad Filters, and sums the result.

## File

dsp.h

## C

```
int16_t DSP_FilterIIRBQ16_parallel8(int16_t Xin, PARM_EQUAL_FILTER * pFilter);
```

## Returns

Sample output Y (int16_t)

## Description

Function DSP_FilterIIRBQ16_parallel8:

int16_t DSP_FilterIIRBQ16_parallel8(int16_t Xin, PARM_EQUAL_FILTER *pFilter);

Calculates a 8 parallel, single pass IIR biquad filters on Xin, sums the result and delivers the result as a 16-bit output. All math is performed using 32 bit instructions, which results truncated to 16-bits for the output. The delay register is stored as a 32-bit value for subsequent functions. Output is tuned by 2 multiplier factors. First each parallel section has a fractional gain (attenuation) that enables individual scaling of that section. Second, a global binary (log2N) gain is applied to the result. The combination of gain factors enable both gain and attenuation. All values are fractional Q15 and Q31, see data structure for specifics.

Y = Y7/8 + Y6/8 + Y5/8 + Y4/8 + Y3/8 + Y2/8 + Y1/8 + Y0/8 where each Yn filter element represents a unique IIR biquad: Yn = X(0)*b0 + (b1 * X(n-1)) + (b2 * X(n-2)) - (a1 * Yn(-1)) - (a2 * Yn(-2))

## Remarks

The delay register values should be initialized to zero prior to the first call to the function, they are updated each pass. A gain of 2 has been hard coded into the function. This implies that all coefs should be input at half value. This is purposeful, since many filter designs need a div2 to have each coef between the required -1

## Preconditions

Delay register values should be initialized to zero. The sum of all fracgain should be <= 1

## Example

```
PARM_EQUAL_FILTER filtArrayPara[8];
uint16_t dataY, dataX;

// fill entire Filter Array with coefs
for (i=0;i<8;i++)
{
    filtArrayPara[i].Z[0]=0;
    filtArrayPara[i].Z[1]=0;

    filtArrayPara[i].G.fracGain = 0x7FFF;       // gain = 1 default
    filtArrayPara[i].G.expGain = 1;             // == 2^N; gain of 2

    // note all coefs are half value of original design, gain handled in algorithm
    // none pass -- default
    filtArrayPara[i].b[0]=0;        // feed forward b0 coef
    filtArrayPara[i].b[1]=0;        // feed forward b1 coef
    filtArrayPara[i].b[2]=0;        // feed forward b2 coef

    // note all coefs are half value of original design, gain handled in algorithm
    // note subtract is handled in algorithm, so coefs go in at actual value
    filtArrayPara[i].a[0]=0;        // feedback a1 coef
```

```
        filtArrayPara[i].a[1]=0;        // feedback a2 coef
    }

        // 1K bandpass Q=0.9
        filtArrayPara[7].G.fracGain = 0x4000;   // gain = 0.5 because using 2 outputs
        // note all coefs are half value of original design, gain handled in algorithm
        filtArrayPara[7].b[0]=0x04ad;
        filtArrayPara[7].b[1]=0;                // feed forward b1 coef
        filtArrayPara[7].b[2]=0xfb53;           // feed forward b2 coef

        // note all coefs are half value of original design, gain handled in algorithm
        // note subtract is handled in algorithm, so coefs go in at actual value
        filtArrayPara[7].a[0]=0x8a90;           // feedback a1 coef
        filtArrayPara[7].a[1]=0x36a4;           // feedback a2 coef

        // 300 Hz bandpass    Q=0.9
        filtArrayPara[6].G.fracGain = 0x1000;   // gain = 0.125 as an example
        // note all coefs are half value of original design, gain handled in algorithm
        filtArrayPara[6].b[0]=0x017b;           // feed forward b0 coef
        filtArrayPara[6].b[1]=0;                // feed forward b1 coef
        filtArrayPara[6].b[2]=0xfe85;           // feed forward b2 coef

        // note all coefs are half value of original design, gain handled in algorithm
        // note subtract is handled in algorithm, so coefs go in at actual value
        filtArrayPara[6].a[0]=0x8316;           // feedback a1 coef
        filtArrayPara[6].a[1]=0x3d08;           // feedback a2 coef

    for (i=0;i<256;i++)
        {
         // *** get input data here
         dataX = compound_300_1K_hz16[i];

         dataY = DSP_FilterIIRBQ16_cascade8_fast(dataX, filtArray);

         // *** do something with the DataY here
         }
```

## Parameters

| Parameters | Description |
|---|---|
| Xin | input data element X (int16_t) |
| pFilter | pointer to filter coef and delay structure |

# DSP_FilterIIRBQ16_parallel8_fast Function

Performs a 8 parallel single-pass IIR Biquad Filters, and sums the result.

## File

dsp.h

## C

```
int16_t DSP_FilterIIRBQ16_parallel8_fast(int16_t Xin, PARM_EQUAL_FILTER_16 * pFilter);
```

## Returns

Sample output Y (int16_t)

## Description

Function DSP_FilterIIRBQ16_parallel8_fast:

int16_t DSP_FilterIIRBQ16_parallel8_fast(int16_t Xin, PARM_EQUAL_FILTER_16 *pFilter);

Calculates a 8 parallel, single pass IIR biquad filters on Xin, sums the result and delivers the result as a 16-bit output. All math is performed using 16 bit instructions, which results rounded to 16-bits for the output. The delay register is stored as a 16-bit value for subsequent functions. Output is tuned by 2 multiplier factors. First each parallel section has a fractional gain (attenuation) that enables individual scaling of that section. Second, a global binary (log2N) gain is applied to the result. The combination of gain factors enable both gain and attenuation. All values are fractional Q15. The function will round outputs and saturate if maximum or minimum values are exceeded.

Y = Y7/8 + Y6/8 + Y5/8 + Y4/8 + Y3/8 + Y2/8 + Y1/8 + Y0/8 where each Yn filter element represents a unique IIR biquad: Yn = X(0)*b0 + (b1 * X(n-1)) + (b2 * X(n-2)) - (a1 * Yn(-1)) - (a2 * Yn(-2))

## Remarks

The delay register values should be initialized to zero prior to the first call to the function, they are updated each pass. A gain of 2 has been hard coded into the function. This implies that all coefs should be input at half value. This is purposeful, since many filter designs need a div2 to have each coef between the required -1

## Preconditions

Delay register values should be initialized to zero. The sum of all fracgain should be <= 1

## Example

```
PARM_EQUAL_FILTER_16 filtArrayPara[8];      // note change in data structure
uint16_t dataY, dataX;

// fill entire Filter Array with coefs
for (i=0;i<8;i++)
{
    filtArrayPara[i].Z[0]=0;
    filtArrayPara[i].Z[1]=0;

    filtArrayPara[i].G.fracGain = 0x7FFF;       // gain = 1 default
    filtArrayPara[i].G.expGain = 1;             // log2N; gain of 2

    // note all coefs are half value of original design, gain handled in algorithm
    // none pass -- default
    filtArrayPara[i].b[0]=0;        // feed forward b0 coef
    filtArrayPara[i].b[1]=0;        // feed forward b1 coef
    filtArrayPara[i].b[2]=0;        // feed forward b2 coef

    // note all coefs are half value of original design, gain handled in algorithm
    // note subtract is handled in algorithm, so coefs go in at actual value
    filtArrayPara[i].a[0]=0;        // feedback a1 coef
    filtArrayPara[i].a[1]=0;        // feedback a2 coef
 }

    // 1K bandpass Q=0.9
    filtArrayPara[7].G.fracGain = 0x4000;   // gain = 0.5 because using 2 outputs
    // note all coefs are half value of original design, gain handled in algorithm
    filtArrayPara[7].b[0]=0x04ad;
    filtArrayPara[7].b[1]=0;                // feed forward b1 coef
    filtArrayPara[7].b[2]=0xfb53;           // feed forward b2 coef

    // note all coefs are half value of original design, gain handled in algorithm
    // note subtract is handled in algorithm, so coefs go in at actual value
    filtArrayPara[7].a[0]=0x8a90;           // feedback a1 coef
    filtArrayPara[7].a[1]=0x36a4;           // feedback a2 coef

    // 300 Hz bandpass    Q=0.9
    filtArrayPara[6].G.fracGain = 0x1000;   // gain = 0.125 as an example
    // note all coefs are half value of original design, gain handled in algorithm
    filtArrayPara[6].b[0]=0x017b;           // feed forward b0 coef
    filtArrayPara[6].b[1]=0;                // feed forward b1 coef
    filtArrayPara[6].b[2]=0xfe85;           // feed forward b2 coef

    // note all coefs are half value of original design, gain handled in algorithm
    // note subtract is handled in algorithm, so coefs go in at actual value
    filtArrayPara[6].a[0]=0x8316;           // feedback a1 coef
    filtArrayPara[6].a[1]=0x3d08;           // feedback a2 coef

for (i=0;i<256;i++)
    {
     // *** get input data here
     dataX = compound_300_1K_hz16[i];

     dataY = DSP_FilterIIRBQ16_cascade8_fast(dataX, filtArray);

     // *** do something with the DataY here
     }
```

### Parameters

| Parameters | Description |
|---|---|
| Xin | input data element X (int16_t) |
| pFilter | pointer to filter coef and delay structure |

## DSP_FilterIIRBQ32 Function

Performs a high resolution single-pass IIR Biquad Filter.

### File

dsp.h

### C

```
int32_t DSP_FilterIIRBQ32(int32_t Xin, PARM_EQUAL_FILTER_32 * pFilter);
```

### Returns

Sample output Y (int32_t)

### Description

Function DSP_FilterIIRBQ32:

int32_t DSP_FilterIIRBQ32(int32_t Xin, PARM_EQUAL_FILTER_32 *pFilter);

Calculates a single pass IIR biquad filter on Xin, and delivers the result as a 16-bit output. All math is performed using 32 bit instructions, with results truncated to 32-bits for the output. The delay register is stored as a 32-bit value for subsequent functions. All values are fractional Q31, see data structure for specifics.

Y = X(0)*b0 + (b1 * X(-1)) + (b2 * X(-2)) - (a1 * Y(-1)) - (a2 * Y(-2))

### Remarks

The delay register values should be initialized to zero prior to the first call to the function, they are updated each pass. A gain of 2 has been hard coded into the function. This implies that all coefs should be input at half value. This is purposeful, since many filter designs need a div2 to have each coef between the required -1

### Preconditions

Delay register values should be initialized to zero.

### Example

```
PARM_EQUAL_FILTER_32 *ptrFiltEQ32;
PARM_EQUAL_FILTER_32 FilterEQ32;
int32_t DataIn32, DataOut32;

ptrFiltEQ32 = &FilterEQ32;

ptrFiltEQ32->Z[0]=0;
ptrFiltEQ32->Z[1]=0;

//  1000 Hz Q= 0.9 BP filter design, 44.1K sampling
//
//    b0 = 0.07311778239751009  forward
//    b1 = 0
//    b2 = -0.07311778239751009
//    a1 = -1.8349811166056893  back
//    a2 = 0.8537644352049799

// note all coefs are half value of original design, gain handled in algorithm
ptrFiltEQ32->b[0]=0x04ADF635;   // feed forward b0 coef
ptrFiltEQ32->b[1]=0;            // feed forward b1 coef
ptrFiltEQ32->b[2]=0xFB5209CB;   // feed forward b2 coef

// note all coefs are half value of original design, gain handled in algorithm
// note subtract is handled in algorithm, so coefs go in at actual value
ptrFiltEQ32->a[0]=0x8A8FAB5D;  // feedback a1 coef
ptrFiltEQ32->a[1]=0x36A41395;  // feedback a2 coef

for (i=0;i<256;i++)
```

```
    {
     // *** get input data here
       DataIn32 = three_hundred_hz[i];

       DataOut32 = DSP_FilterIIRBQ32(DataIn32, ptrFiltEQ32);

     // *** do something with the DataOut32 here
     }
```

### Parameters

| Parameters | Description |
|---|---|
| Xin | input data element X (int32_t) |
| pFilter | pointer to high resolution filter coef and delay structure |

## DSP_FilterIIRSetup16 Function

Converts biquad structure to coeffs array to set up IIR filter.

### File

dsp.h

### C

```
void DSP_FilterIIRSetup16(int16_t * coeffs, biquad16 * bq, int B);
```

### Returns

None.

### Description

Function DSP_FilterIIRSetup16:

void DSP_FilterIIRSetup16(int16_t *coeffs, biquad16 *bq, int B);

Converts an array of biquad coefficients, bq, into an linear array of coefficients, coeffs. The output array must be 4*B elements long. The number of biquads in the resulting factor is given by B. All numerical values must be in Q15 fractional data format.

### Remarks

None.

### Preconditions

coeffs must have 4*B elements.

### Example

```
see DSP_FilterIIR16 for example.
```

### Parameters

| Parameters | Description |
|---|---|
| coeffs | pointer to an array of coefficients (int16_t) |
| bq | pointer to array of biquad structure filter coefs (biquad16) |
| B | number of cascaded biquad filter groups to process (int) |

## DSP_FilterLMS16 Function

Performs a single sample Least Mean Squares FIR Filter.

### File

dsp.h

### C

```
int16_t DSP_FilterLMS16(int16_t in, int16_t ref, int16_t * coeffs, int16_t * delayline, int16_t * error,
int K, int16_t mu);
```

### Returns

(int16_t) - FIR filter output

## Description

Function DSP_FilterLMS16:

int16_t DSP_FilterLMS16(int16_t in, int16_t ref, int16_t *coeffs, int16_t *delayline, int16_t *error, int K, int16_t mu);

Computes an LMS adaptive filter on the input in. Filter output of the FIR is given as a 16 bit value. The filter target is ref, and the calculation difference between the output and the target is error. The filter adapts its coefficients, coefs, on each pass. The number of coefficients (filter taps) is given by the value K. The delayline array should be initialized to zero prior to calling the filter for the first time, and have K elements. The value mu is the rate at which the filter adapts. All values are Q15 fractional numbers. The function will saturate the output if it exceeds maximum or minimum values. The LMS will adapt its coefs to attempt to drive the output value toward the ref value. The rate of adaption on each pass depends on mu and the error from the previous calculation.

## Remarks

Filter coefs may start at random or zero value, but convergence is dependent on the amount of update required.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. delayline must have (K) elements, and be initialized to zero. K (taps) must be a multiple of 4, and >= 8. mu must be positive.

## Example

```
#define lmsTAPS 8

int16_t lmsOut;
int lmsTaps = lmsTAPS;

int16_t lmsCoefs[lmsTAPS]={0x5000, 0x4000,0x3000, 0x2000,0x1000, 0x0000,0xF000, 0xE000};
int16_t lmsDelay[lmsTAPS]={0};
int16_t *ptrLMSError;
int16_t lmsError = 0x0200;
int16_t inVal=0;

int16_t refVal = 0x0CCC;  // some target value = 0.1
int16_t lmsAdapt = 0x3000;

ptrLMSError = &lmsError;

for (i=0;i<200;i++)
{
// get some input value here //
 if (i < 100)
 {
     inVal = 0x4233;
 }
 else
 {
     inVal = 0xCF10;
 }

 lmsOut =  DSP_FilterLMS16(inVal, refVal, lmsCoefs, lmsDelay,
       ptrLMSError, lmsTaps, lmsAdapt);
}
```

## Parameters

| Parameters | Description |
|---|---|
| in | input data value (int16_t) |
| ref | target output value (int16_t) |
| coeffs | pointer to an array of coefficients (int16_t) |
| delayline | pointer to an array of delay variables (int16_t) |
| error | output minus reference (int16_t) |
| K | number of filter taps and coeffs (int) |
| mu | adaption rate (int16_t) |

## *c) Matrix Math Functions*

## DSP_MatrixAdd32 Function

Addition of two matrices C = (A + B).

### File

dsp.h

### C

```
void DSP_MatrixAdd32(matrix32 * resMat, matrix32 * srcMat1, matrix32 * srcMat2);
```

### Returns

None.

### Description

Function DSP_MatrixAdd32:

void DSP_MatrixAdd32(matrix32 *resMat, matrix32 *srcMat1, matrix32 *srcMat2);

Vector summation of two matrices, where both have 32-bit integer elements. The resulting output will saturate if element addition exceeds MAX32 or MIN32.

### Remarks

Execution Time (cycles): 225 cycles + 23 / matrix_element. The function will saturate the output value if it exceeds maximum limits per element.

### Preconditions

Both matrices must be equivalent in rows and columns. Both Matrices must be set into structure (ROWS, COLUMNS, vector_pointer).

### Example

```
#define ROW 2
#define COL 2

matrix32 *resMat, *srcMat1, *srcMat2;
int32_t result[ROW*COL];

int32_t matA[ROW*COL] = {1,2,3,4};
int32_t matB[ROW*COL] = {2,4,6,8};

matrix32 mat, mat2, mat3;
resMat=&mat;
srcMat1=&mat2;
srcMat2=&mat3;

srcMat1->row=ROW;
srcMat1->col=COL;
srcMat1->pMatrix=matA;

srcMat2->col=COL;
srcMat2->row=ROW;
srcMat2->pMatrix=matB;

resMat->row=ROW;
resMat->col=COL;
resMat->pMatrix=result;

DSP_MatrixAdd32(resMat, srcMat1, srcMat2);

// result[i] = matA[i] + matB[i] = {3,6,9,0xA}
```

### Parameters

| Parameters | Description |
|---|---|
| resMat | pointer to new sum Matrix C (*int32_t) |
| srcMat1 | pointer to the Matrix A structure (*int32_t) |
| srcMat2 | pointer to the Matrix B structure (*int32_t) |

## DSP_MatrixEqual32 Function

Equality of two matrices C = (A).

### File

dsp.h

### C

```
void DSP_MatrixEqual32(matrix32 * resMat, matrix32 * srcMat);
```

### Returns

None.

### Description

Function DSP_MatrixEqual32:

void DSP_MatrixEqual32(matrix32 *resMat, matrix32 *srcMat);

Vector copy of all elements from one matrix to another. C is a duplicate of A.

### Remarks

Execution Time (cycles): 163 cycles + 12 / matrix_element.

### Preconditions

None.

### Example

```
#define ROW 2
#define COL 2

matrix32 *resMat, *srcMat1, *srcMat2;
int32_t result[ROW*COL];

int32_t matA[ROW*COL] = {5,2,-3,8};

matrix32 mat, mat2;
resMat=&mat;
srcMat1=&mat2;

srcMat1->row=ROW;
srcMat1->col=COL;
srcMat1->pMatrix=matA;

resMat->row=ROW;
resMat->col=COL;
resMat->pMatrix=result;

DSP_MatrixEqual32(resMat, srcMat1, srcMat2);

// result[i] = matA[i] = {5, 2, -3, 8}
```

### Parameters

| Parameters | Description |
|---|---|
| resMat | pointer to completed new Matrix C (*int32_t) |
| srcMat | pointer to the Matrix A structure (*int32_t) |

## DSP_MatrixInit32 Function

Initializes the first N elements of a Matrix to the value num.

### File

dsp.h

## C

```
void DSP_MatrixInit32(int32_t * data_buffer, int N, int32_t num);
```

## Returns

None.

## Description

Function DSP_MatrixInit32:

void DSP_MatrixInit32(int32_t *data_buffer, int N, int32_t num);

Copy the value num into the first N Matrix elements of data_buffer.

## Remarks

None.

## Preconditions

data_buffer must be predefined to be equal to or greater than N elements. N must be a factor of four, or it will truncate to the nearest factor of four.

## Example

```
#define ROW 3
#define COL 3

int32_t numElements = 4;  // multiple of 4
int valueElements = -1;

int32_t matA[ROW*COL] = {5,2,-3,8,4,2,-6,8,9};

DSP_MatrixInit32(matA, numElements, valueElements);

// matA[i] = {-1,-1,-1,-1,4,2,-6,8,9}
```

## Parameters

| Parameters | Description |
|---|---|
| data_buffer | pointer to the Matrix to be initialized (int32_t[M*N]) |
| N | number of elements to be initialized (int32_t) |
| num | value to be initialized into the matrix (int32_t) |

# DSP_MatrixMul32 Function

Multiplication of two matrices C = A x B.

## File

dsp.h

## C

```
void DSP_MatrixMul32(matrix32 * resMat, matrix32 * srcMat1, matrix32 * srcMat2);
```

## Returns

None.

## Description

Function DSP_MatrixMul32:

void DSP_MatrixMul32(matrix32 *resMat, matrix32 *srcMat1, matrix32 *srcMat2);

Multiplication of two matrices, with inputs and outputs being in fractional Q31 numerical format. The output elements will saturate if the dot product exceeds maximum or minimum fractional values.

## Remarks

Execution Time (cycles): 319 cycles + 38 / output matrix_element. The function will saturate the output value if it exceeds maximum limits per element.

## Preconditions

Matrices must be aligned such that columns of A = rows of B. resMat must have the format of rows of A, columns of B. All Matrices must be set into structure (ROWS, COLUMNS, vector_pointer).

## Example

```
#define ROW1 3
#define COL1 2
#define ROW2 2
#define COL2 2

matrix32 *resMat, *srcMat1, *srcMat2;
int32_t result[ROW1*COL2];

int32_t test_MatrixA[ROW1*COL1]=
{
    0x40000000,0x20000000,      // 0.5,  0.25
    0xD999999A,0x4CCCCCCC,      // -0.3, 0.6
    0xC0000000,0x0CCCCCCD       // -0.5  0.1
};

int32_t test_MatrixB[ROW2*COL2]=
{
    0x40000000,0x20000000,      // 0.5, 0.25
    0x0CCCCCCD,0xCCCCCCCD       // 0.1, -0.4
};

matrix32 mat, mat2, mat3;
resMat=&mat;
srcMat1=&mat2;
srcMat2=&mat3;

srcMat1->row=ROW1;
srcMat1->col=COL1;
srcMat1->pMatrix=test_MatrixA;

srcMat2->col=COL2;
srcMat2->row=ROW2;
srcMat2->pMatrix=test_MatrixB;

resMat->row=ROW1;  // note resulting matrix MUST have ROW1 & COL2 format
resMat->col=COL2;
resMat->pMatrix=result;

DSP_MatrixMul32(resMat, srcMat1, srcMat2);

// result[] = matA[] x matB[] =
//    { 0x23333333, 0x03333333   // 0.275, 0.025
//      0xF47AE147, 0xD7AE147B   // -0.9, -0.315
//      0xE147AE14, 0xEAE147AE } // -0.24, -0.165
```

## Parameters

| Parameters | Description |
|---|---|
| resMat | pointer to different Matrix C structure (*int32_t) |
| srcMat1 | pointer to the Matrix A structure (*int32_t) |
| srcMat2 | pointer to the Matrix B structure (*int32_t) |

### DSP_MatrixScale32 Function

Scales each element of an input buffer (matrix) by a fixed number.

## File

dsp.h

## C

```
void DSP_MatrixScale32(int32_t * data_buffer, int N, int32_t num);
```

## Returns

None.

## Description

Function DSP_MatrixScale32:

void DSP_MatrixScale32(int32_t *data_buffer, int N, int32_t num);

Multiply the first N elements of an input buffer by a fixed scalar num. The resulting value is stored back into the input buffer. N number total samples of the input buffer are processed. All values are in Q31 fractional integer format. The result of calculations is saturated to the MAX32 or MIN32 value if exceeded.

## Remarks

Execution time (cycles): 190 + 9 cycles / element, typical.

## Preconditions

data_buffer must be predefined to be equal to or greater than N elements. N must be a factor of four, or will truncate to the nearest factor of four.

## Example

```
int32_t numScale = 0x40000000;  // 0.5
int valN = 12;
int32_t inputBufScale[12] = {0x40000000, 0x40000000, 0x20000000, 0x20000000,
            0x19999999, 0xCCCCCCCD, 0xF3333333, 0x80000000,
            0x7FFFFFFF, 0x00000000, 0x40000000, 0x70000000 };
// 0.5, 0.5, 0.25, 0.25, 0.25, 0.2, -0.4, -0.1, -1, 1, 0, 0.5, 0.875

DSP_MatrixScale32(inputBufScale,valN,numScale);

// inputBufScale[i] = {0x20000000, 0x20000000, 0x10000000, 0x10000000,
//           0x0CCCCCCC, 0xE6666666, 0xF9999999, 0xC0000000,
//           0x3FFFFFFF, 0x00000000, 0x20000000, 0x38000000}
//  0.25, 0.25, 0.125, 0.125, 0.1, -0.2, -0.05, -0.5, 0.5, 0, 0.25, 0.4375
```

## Parameters

| Parameters | Description |
|---|---|
| data_buffer | pointer to the Matrix to be initialized (int32_t[M*N]) |
| N | number of elements to be initialized (int) |
| num | value to be initialized into the matrix (int32_t) |

# DSP_MatrixSub32 Function

Subtraction of two matrices C = (A - B).

## File

dsp.h

## C

```
void DSP_MatrixSub32(matrix32 * resMat, matrix32 * srcMat1, matrix32 * srcMat2);
```

## Returns

None.

## Description

Function DSP_MatrixSub32:

void DSP_MatrixSub32(matrix32 *resMat, matrix32 *srcMat1, matrix32 *srcMat2);

Vector subtraction of two matrices, where both have 32-bit integer elements. The resulting output will saturate if element addition exceeds MAX32 or MIN32.

## Remarks

Execution Time (cycles): 222 cycles + 21 / matrix_element. The function will saturate the output value if it exceeds maximum limits per element.

## Preconditions

Both matrices must be equivalent in rows and columns. All Matrices must be set into structure (ROWS, COLUMNS, vector_pointer)

## Example

```
#define ROW 2
```

```
#define COL 2

matrix32 *resMat, *srcMat1, *srcMat2;
int32_t result[ROW*COL];

int32_t matA[ROW*COL] = {5,2,-3,8};
int32_t matB[ROW*COL] = {2,2,2,2};

matrix32 mat, mat2, mat3;
resMat=&mat;
srcMat1=&mat2;
srcMat2=&mat3;

srcMat1->row=ROW;
srcMat1->col=COL;
srcMat1->pMatrix=matA;

srcMat2->col=COL;
srcMat2->row=ROW;
srcMat2->pMatrix=matB;

resMat->row=ROW;
resMat->col=COL;
resMat->pMatrix=result;

DSP_MatrixSub32(resMat, srcMat1, srcMat2);

// result[i] = matA[i] - matB[i] = {3,0,-5,6}
```

## Parameters

| Parameters | Description |
|---|---|
| resMat | pointer to different Matrix C structure (*int32_t) |
| srcMat1 | pointer to the Matrix A structure (*int32_t) |
| srcMat2 | pointer to the Matrix B structure (*int32_t) |

# DSP_MatrixTranspose32 Function

Transpose of a Matrix C = A (T).

## File

dsp.h

## C

```
void DSP_MatrixTranspose32(matrix32 * desMat, matrix32 * srcMat);
```

## Returns

None.

## Description

Function DSP_MatrixTranspose32:

void DSP_MatrixTranspose32(matrix32 *desMat, matrix32 *srcMat);

Transpose of rows and columns of a matrix.

## Remarks

Execution Time (cycles): 210 cycles + 10 / matrix_element.

## Preconditions

Matrix definitions for ROWS and COLS must be transposed prior to the function call.

## Example

```
#define ROW 3
#define COL 4

matrix32 *resMat, *srcMat1;
```

```
int32_t result[ROW*COL];

int32_t matA[ROW*COL] = { 1,  2,  3,  4,
                         5,  6,  7,  8,
                        -1, -3, -5, -7};

matrix32 mat, mat2;
resMat=&mat;
srcMat1=&mat2;

srcMat1->row=ROW;
srcMat1->col=COL;
srcMat1->pMatrix=matA;

resMat->row=COL;   // note the shift in columns and rows
resMat->col=ROW;
resMat->pMatrix=result;

DSP_MatrixTranspose32(resMat, srcMat1);

// result[] = matA(T)[] = {   1,  5, -1,
//                            2,  6, -3,
//                            3,  7, -5,
//                            4,  8, -7}
```

### Parameters

| Parameters | Description |
|---|---|
| desMat | pointer to transposed new Matrix C (*int32_t) |
| srcMat | pointer to the Matrix A structure (*int32_t) |

## *d) Transform Functions*

## DSP_TransformFFT16 Function

Creates an Fast Fourier Transform (FFT) from a time domain input.

### File

dsp.h

### C

```
void DSP_TransformFFT16(int16c * dout, int16c * din, int16c * twiddles, int16c * scratch, int log2N);
```

### Returns

None.

### Description

Function DSP_TransformFFT16:

void DSP_TransformFFT16(int16c *dout, int16c *din, int16c *twiddles, int16c *scratch, int log2N);

Performs an complex FFT on the input, din, and stores the complex result in dout. Performs 2^log2N point calculation, and the working buffer scratch as well as the input and output must be 2^log2N in length. Coefficient twiddle factors come from twiddles, and may be loaded with the use of DSP_TransformFFT16_setup. All values are 16 bit (Q15) fractional.

### Remarks

Scratch must be declared but need not be initialized. Din may be aided with a window function prior to calling the FFT, but is not required. Din is a complex number array, but may be loaded solely with real numbers if no phase information is available.

### Preconditions

din, dout, twiddles and scratch must have N elements N is calculated as 2^(log2N) log2N must be >= 3 FFT factors must be calculated in advance, use DSP_TransformFFT16_setup

### Example

```
int log2N = 8;  // log2(256) = 8
int fftSamples = 256;
```

```
int16c  *fftDin;
int16c  fftDout[fftSamples];
int16c  scratch[fftSamples];
int16c  fftCoefs[fftSamples];

int16c *fftc;
fftc = &fftCoefs;

DSP_TransformFFT16_setup(fftc, log2N);  // call setup function

while (1)
{
    fftDin = &fftin_8Khz_long_window16;  // get 256 point complex data

    DSP_TransformFFT16(fftDout, fftDin, fftc, scratch, log2N);

    // do something with the output, fftDout
};
```

## Parameters

| Parameters | Description |
|---|---|
| dout | pointer to complex output array (int16c) |
| din | pointer to complex input array (int16c) |
| twiddles | pointer to an complex array of factors (int16c) |
| scratch | pointer to a complex scratch pad buffer (int16c) |
| log2N | binary exponent of number of samples (int) |

# DSP_TransformFFT16_setup Function

Creates FFT coefficients for use in the FFT16 function.

## File

dsp.h

## C

```
void DSP_TransformFFT16_setup(int16c * twiddles, int log2N);
```

## Returns

None.

## Description

Function DSP_TransformFFT16_setup:

void DSP_TransformFFT16_setup(int16c *twiddles, int log2N);

Calculates the N twiddle factors required to operate the FFT16 function. These factors are done in serial fashion, and require considerable processing power. Ideally this function would be run only once prior to an ongoing FFT, and the results held in a buffer.

## Remarks

This function is of considerable length and executed in C. It is recommended it only be called once for any given FFT length in time sensitive applications.

## Preconditions

twiddles must be N in length N is calculated (2^log2N)

## Example

```
see DSP_TransformFFT16 for example.
```

## Parameters

| Parameters | Description |
|---|---|
| twiddles | pointer to a complex array of factors (int16c) |
| log2N | binary exponent of number of data points (int) |

## DSP_TransformFFT32 Function

Creates an Fast Fourier Transform (FFT) from a time domain input.

### File

dsp.h

### C

```
void DSP_TransformFFT32(int32c * dout, int32c * din, int32c * twiddles, int32c * scratch, int log2N);
```

### Returns

None.

### Description

Function DSP_TransformFFT32:

void DSP_TransformFFT32(int32c *dout, int32c *din, int32c *twiddles, int32c *scratch, int log2N);

Performs an complex FFT on the input, din, and stores the complex result in dout. Performs 2^log2N point calculation, and the working buffer scratch as well as the input and output must be 2^log2N in length. Coefficient twiddle factors come from twiddles, and may be loaded with the use of DSP_TransformFFT16_setup. All values are 16 bit (Q31) fractional.

### Remarks

Scratch must be declared but need not be initialized. Din may be aided with a window function prior to calling the FFT, but is not required. Din is a complex number array, but may be loaded solely with real numbers if no phase information is available.

### Preconditions

din, dout, twiddles and scratch must have N elements N is calculated as 2^(log2N) log2N must be >= 3 FFT factors must be calculated in advance, use DSP_TransformFFT32_setup

### Example

```
int log2N = 8;  // log2(256) = 8
int fftSamples = 256;

int32c  *fftDin;
int32c  fftDout[fftSamples];
int32c  scratch[fftSamples];
int32c  fftCoefs[fftSamples];

int32c *fftc;
fftc = &fftCoefs;

DSP_TransformFFT32_setup(fftc, log2N);  // call setup function

while (1)
{
    fftDin = &fftin_5Khz_long_window32;  // get 256 point complex data

    DSP_TransformFFT32(fftDout, fftDin, fftc, scratch, log2N);

    // do something with the output, fftDout
};
```

### Parameters

| Parameters | Description |
|---|---|
| dout | pointer to complex output array (int32c) |
| din | pointer to complex input array (int32c) |
| twiddles | pointer to an complex array of FFT factors (int32c) |
| scratch | pointer to a complex scratch pad buffer (int32c) |
| log2N | binary exponent of number of samples (int) |

## DSP_TransformFFT32_setup Function

Creates FFT coefficients for use in the FFT32 function.

### File

dsp.h

### C

```
void DSP_TransformFFT32_setup(int32c * twiddles, int log2N);
```

### Returns

None.

### Description

Function DSP_TransformFFT32_setup:

void DSP_TransformFFT32_setup(int32c *twiddles, int log2N);

Calculates the N FFT twiddle factors required to operate the FFT32 function. These factors are done in serial fashion, and require considerable processing power. Ideally this function would be run only once prior to an ongoing FFT, and the results held in a buffer.

### Remarks

This function is of considerable length and executed in C. It is recommended it only be called once for any given FFT length in time sensitive applications.

### Preconditions

twiddles must be N in length N is calculated (2^log2N)

### Example

```
see DSP_TransformFFT32 for example.
```

### Parameters

| Parameters | Description |
|---|---|
| twiddles | pointer to a complex array of coefficients (int32c) |
| log2N | binary exponent of number of data points (int) |

## DSP_TransformIFFT16 Function

Creates an Inverse Fast Fourier Transform (FFT) from a frequency domain input.

### File

dsp.h

### C

```
void DSP_TransformIFFT16(int16c * dout, int16c * din, int16c * twiddles, int16c * scratch, int log2N);
```

### Returns

None.

### Description

Function DSP_TransformIFFT16:

void DSP_TransformIFFT16(int16c *dout, int16c *din, int16c *twiddles, int16c *scratch, int log2N);

Performs an complex Inverse FFT on the input, din, and stores the complex result in dout. Performs 2^log2N point calculation, and the working buffer scratch as well as the input and output must be 2^log2N in length. Coefficient twiddle factors come from twiddles, and may be loaded with the use of DSP_TransformFFT16_setup. All values are 16 bit (Q15) fractional.

### Remarks

Scratch must be declared but need not be initialized. Din may be aided with a window function prior to calling the FFT, but is not required. A very similar function to the FFT is executed for the inverse FFT. This requires twiddle factors set in advance with the same method as used in the FFT. Complex conjugate and scaling are handled within the algorithm. The output is scaled using binary shifting based on log2N. Since the algorithm reduces the output by a scale factor of log2N, the resolution is reduced proportionally to the number of data points.

### Preconditions

din, dout, twiddles and scratch must have N elements N is calculated as 2^(log2N) log2N must be >= 3 FFT factors must be calculated in advance, use DSP_TransformFFT16_setup

## Example

```
int ilog2N = 10;  // log2(64) = 6; log2(256) = 8; log2(1024) = 10;
int ifftSamples = pow(2,ilog2N);

int16c  *ifftDin;
int16c ifftDout[ifftSamples];
int16c  iscratch[ifftSamples];
int16c  ifftCoefs[ifftSamples];
int16c  ifftTimeOut[ifftSamples];

// set up twiddle factors, these are used for both FFT and iFFT

int16c *ifftc;
ifftc = &ifftCoefs;
DSP_TransformFFT16_setup( ifftc, ilog2N);  // call to coef setup

// in this example, we take an FFT of an original time domain (sine wave)
// the output of the FFT is used as the input of the iFFT for comparison

ifftDin = &fftin_800hz_verylong16;
DSP_TransformFFT16(ifftDout, ifftDin, ifftc, iscratch, ilog2N);

// ifftDout = frequency domain output, complex number array

DSP_TransformIFFT16(ifftTimeOut, ifftDout, ifftc, iscratch, ilog2N);

// do something with the output, fftTimeOut, time domain
```

## Parameters

| Parameters | Description |
|---|---|
| dout | pointer to complex output array (int16c) |
| din | pointer to complex input array (int16c) |
| twiddles | pointer to an complex array of factors (int16c) |
| scratch | pointer to a complex scratch pad buffer (int16c) |
| log2N | binary exponent of number of samples (int) |

# DSP_TransformWindow_Bart16 Function

Perform a Bartlett window on a vector.

## File

dsp.h

## C

```
void DSP_TransformWindow_Bart16(int16_t * OutVector, int16_t * InVector, int N);
```

## Returns

None.

## Description

Function DSP_TransformWindow_Bart16:

void DSP_TransformWindow_Bart16(int16_t *OutVector, int16_t *InVector, int N);

Compute a Bartlett (Triangle) Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q15 fractional format. The Bartlett Window follows the equation:

Window(n) = 1 - (abs(2*n - N)/N) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

```
int16_t OutVector16[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector16[i]= 0x4000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Bart16(OutVector16, InVector16, WindowN);
// OutWindow = 0x0000, 0x1000, 0x2000, 0x3000, 0x4000, 0x3000, 0x2000, 0x1000
```

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

# DSP_TransformWindow_Bart32 Function

Perform a Bartlett window on a vector.

## File

dsp.h

## C

```
void DSP_TransformWindow_Bart32(int32_t * OutVector, int32_t * InVector, int N);
```

## Returns

None.

## Description

Function DSP_TransformWindow_Bart32:

void DSP_TransformWindow_Bart32(int32_t *OutVector, int32_t *InVector, int N);

Compute a Bartlett (Triangle) Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q31 fractional format. The Bartlett Window follows the equation:

Window(n) = 1 - (abs(2*n - N)/N) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

```
int32_t OutVector32[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector32[i]= 0x40000000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Bart32(OutVector32, InVector32, WindowN);
// OutWindow = 0x0, 0x10000000, 0x20000000, 0x30000000, 0x40000000,
//                       0x30000000, 0x20000000, 0x10000000
```

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

## DSP_TransformWindow_Black16 Function

Perform a Blackman window on a vector.

### File

dsp.h

### C

```
void DSP_TransformWindow_Black16(int16_t * OutVector, int16_t * InVector, int N);
```

### Returns

None.

### Description

Function DSP_TransformWindow_Black16:

void DSP_TransformWindow_Black16(int16_t *OutVector, int16_t *InVector, int N);

Compute a Blackman Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q15 fractional format. The Blackman Window follows the equation:

Window(n) = 0.42659 - 0.49656 * COS(2*Pi*n/(N-1)) + 0.076849 * COS(4*Pi*n/(N-1)) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

```
int16_t OutVector16[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector16[i]= 0x4000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Black16(OutVector16, InVector16, WindowN);
// OutWindow = 0x0071, 0x0665, 0x1DF1, 0x3B00, 0x3B00, 0x1DF1, 0x0665, 0x0071
```

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

## DSP_TransformWindow_Black32 Function

Perform a Blackman window on a vector.

### File

dsp.h

### C

```
void DSP_TransformWindow_Black32(int32_t * OutVector, int32_t * InVector, int N);
```

## Returns

None.

## Description

Function DSP_TransformWindow_Black32:

void DSP_TransformWindow_Black32(int32_t *OutVector, int32_t *InVector, int N);

Compute a Blackman Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q31 fractional format. The Blackman Window follows the equation:

Window(n) = 0.42659 - 0.49656 * COS(2*Pi*n/(N-1)) + 0.076849 * COS(4*Pi*n/(N-1)) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

```
int32_t OutVector32[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector32[i]= 0x40000000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Black32(OutVector32, InVector32, WindowN);
// OutWindow = 0x0070B490, 0x06649680, 0x1DF13240, 0x3B003D80, 0x3B003D80,
//                      0x1DF13240, 0x06649680, 0x0070B490
```

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

# DSP_TransformWindow_Cosine16 Function

Perform a Cosine (Sine) window on a vector.

## File

dsp.h

## C

```
void DSP_TransformWindow_Cosine16(int16_t * OutVector, int16_t * InVector, int N);
```

## Returns

None.

## Description

Function DSP_TransformWindow_Cosine16:

void DSP_TransformWindow_Cosine16(int16_t *OutVector, int16_t *InVector, int N);

Compute a Cosine Window on the first N samples of the input vector, InVector. The output is stored in OutWindow. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q15 fractional format. The Cosine Window follows the equation:

Window(n) = SIN(Pi*n/(N-1)) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

```
int16_t OutVector16[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector16[i]= 0x4000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Cosine16(OutVector16, InVector16, WindowN);
// OutWindow = 0x0000, 0x1BC5, 0x320A, 0x3E65, 0x3E65, 0x320A, 0x1BC5, 0x0071
```

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

# DSP_TransformWindow_Cosine32 Function

Perform a Cosine (Sine) window on a vector.

## File

dsp.h

## C

```
void DSP_TransformWindow_Cosine32(int32_t * OutVector, int32_t * InVector, int N);
```

## Returns

None.

## Description

Function DSP_TransformWindow_Cosine32:

void DSP_TransformWindow_Cosine32(int32_t *OutVector, int32_t *InVector, int N);

Compute a Cosine Window on the first N samples of the input vector, InVector. The output is stored in OutWindow. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q31 fractional format. The Cosine Window follows the equation:

Window(n) = SIN(Pi*n/(N-1)) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

```
int32_t OutVector32[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector32[i]= 0x40000000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Cosine32(OutVector32, InVector32, WindowN);
// OutWindow = 0x00000000, 0x1BC4C060, 0x32098700, 0x3E653800, 0x3E653800,
//                        0x32098700, 0x1BC4C060, 0x00000000
```

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

## DSP_TransformWindow_Hamm16 Function

Perform a Hamming window on a vector.

### File

dsp.h

### C

```
void DSP_TransformWindow_Hamm16(int16_t * OutVector, int16_t * InVector, int N);
```

### Returns

None.

### Description

Function DSP_TransformWindow_Hamm16:

void DSP_TransformWindow_Hamm16(int16_t *OutVector, int16_t *InVector, int N);

Compute a Hamming Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q15 fractional format. The Hamming Window follows the equation:

Window(n) = 0.54 - 0.46 * COS(2*Pi*n/N) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

```
int16_t OutVector16[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector16[i]= 0x4000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Hamm16(OutVector16, InVector16, WindowN);
// OutWindow = 0x051F, 0x0DBE, 0x228F, 0x3761, 0x4000, 0x3761, 0x228F, 0x0DBE
```

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

## DSP_TransformWindow_Hamm32 Function

Perform a Hamming window on a vector.

### File

dsp.h

### C

```
void DSP_TransformWindow_Hamm32(int32_t * OutVector, int32_t * InVector, int N);
```

## Returns

None.

## Description

Function DSP_TransformWindow_Hamm32:

void DSP_TransformWindow_Hamm32(int32_t *OutVector, int32_t *InVector, int N);

Compute a Hamming Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q31 fractional format. The Hamming Window follows the equation:

Window(n) = 0.54 - 0.46 * COS(2*Pi*n/N) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

```
int32_t OutVector32[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector32[i]= 0x40000000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Hamm32(OutVector32, InVector32, WindowN);
// OutWindow = 0x051EB860, 0x0DBE26C0, 0x228F5C40, 0x37609200, 0x40000000,
//                      0x37609200, 0x228F5C40, 0x0DBE26C0
```

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

# DSP_TransformWindow_Hann16 Function

Perform a Hanning window on a vector.

## File

dsp.h

## C

```
void DSP_TransformWindow_Hann16(int16_t * OutVector, int16_t * InVector, int N);
```

## Returns

None.

## Description

Function DSP_TransformWindow_Hann16:

void DSP_TransformWindow_Hann16(int16_t *OutVector, int16_t *InVector, int N);

Compute a Hanning Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q15 fractional format. The Hanning Window follows the equation:

Window(n) = 0.5 - 0.5 * COS(2*Pi*n/N) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

```
int16_t OutVector16[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector16[i]= 0x4000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Hann16(OutVector16, InVector16, WindowN);
// OutWindow = 0x0000, 0x095F, 0x2000, 0x36A1, 0x4000, 0x36A1, 0x2000, 0x095F
```

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

## DSP_TransformWindow_Hann32 Function

Perform a Hanning window on a vector.

### File

dsp.h

### C

```
void DSP_TransformWindow_Hann32(int32_t * OutVector, int32_t * InVector, int N);
```

### Returns

None.

### Description

Function DSP_TransformWindow_Hann32:

void DSP_TransformWindow_Hann32(int32_t *OutVector, int32_t *InVector, int N);

Compute a Hanning Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q31 fractional format. The Hanning Window follows the equation:

Window(n) = 0.5 - 0.5 * COS(2*Pi*n/N) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

```
int32_t OutVector32[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector32[i]= 0x40000000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Hann32(OutVector32, InVector32, WindowN);
// OutWindow = 0x00000000, 0x095F61C0, 0x20000000, 0x36A09E80, 0x40000000,
//                        0x36A09E80, 0x20000000, 0x095F61C0
```

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

## DSP_TransformWindow_Kaiser16 Function

Perform a Kaiser window on a vector.

### File

dsp.h

### C

```
void DSP_TransformWindow_Kaiser16(int16_t * OutVector, int16_t * InVector, int N);
```

### Returns

None.

### Description

Function DSP_TransformWindow_Kaiser16:

void DSP_TransformWindow_Kaiser16(int16_t *OutVector, int16_t *InVector, int N);

Compute a Kaiser Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q15 fractional format. The Kaiser Window follows the equation:

Window(n) = 0.402 - 0.498 * COS(2*Pi*n/N) + 0.098 * cos(4*Pi*n/N) + 0.001 * cos(6*Pi*n/N) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

```
int16_t OutVector16[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector16[i]= 0x4000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Kaiser16(OutVector16, InVector16, WindowN);
// OutWindow = 0x0031, 0x0325, 0x1375, 0x304F, 0x3FCF, 0x304F, 0x1375, 0x0325
```

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

## DSP_TransformWindow_Kaiser32 Function

Perform a Kaiser window on a vector.

### File

dsp.h

### C

```
void DSP_TransformWindow_Kaiser32(int32_t * OutVector, int32_t * InVector, int N);
```

### Returns

None.

### Description

Function DSP_TransformWindow_Kaiser32:

void DSP_TransformWindow_Kaiser32(int32_t *OutVector, int32_t *InVector, int N);

Compute a Kaiser Window on the first N samples of the input vector, InVector. The output is stored in OutVector. Operations are performed at higher resolution and rounded for the most accuracy possible. Input and output values are in Q31 fractional format. The Kaiser Window follows the equation:

Window(n) = 0.402 - 0.498 * COS(2*Pi*n/N) + 0.098 * cos(4*Pi*n/N) + 0.001 * cos(6*Pi*n/N) where n is the window sample number N is the total number of samples The functional output computes WinVector(n) = Window(n) * InVector(n)

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

```
int32_t OutVector32[8]={0};
int  WindowN = 8;

for (i=0;i<WindowN;i++)
{
   InVector32[i]= 0x40000000;  // constant 0.5 for functional testing
}

   DSP_TransformWindow_Kaiser32(OutVector32, InVector32, WindowN);
// OutWindow = 0x003126F6, 0x032555C8, 0x1374BCA0, 0x304F66C0, 0x3FCED900,
//                       0x304F66C0, 0x1374BCA0, 0x032555C8
```

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

## DSP_TransformWinInit_Bart16 Function

Create a Bartlett window.

### File

dsp.h

### C

```
void DSP_TransformWinInit_Bart16(int16_t * OutWindow, int N);
```

### Returns

None.

### Description

Function DSP_TransformWinInit_Bart16:

void DSP_TransformWinInit_Bart16(int16_t *OutWindow, int N);

Create a N-element Bartlett (Triangle) Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are in Q15 fractional format. The Bartlett Window follows the equation:

Window(n) = 1 - (abs(2*n - N)/N) where n is the window sample number N is the total number of samples

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

# DSP_TransformWinInit_Bart32 Function

Create a Bartlett window.

## File

dsp.h

## C

```
void DSP_TransformWinInit_Bart32(int32_t * OutWindow, int N);
```

## Returns

None.

## Description

Function DSP_TransformWinInit_Bart32:

void DSP_TransformWinInit_Bart32(int32_t *OutWindow, int N);

Create a N-element Bartlett (Triangle) Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values Q31 fractional format. The Bartlett Window follows the equation:

Window(n) = 1 - (abs(2*n - N)/N) where n is the window sample number N is the total number of samples

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

# DSP_TransformWinInit_Black16 Function

Create a Blackman window.

## File

dsp.h

## C

```
void DSP_TransformWinInit_Black16(int16_t * OutWindow, int N);
```

## Returns

None.

## Description

Function DSP_TransformWinInit_Black16:

void DSP_TransformWinInit_Black16(int16_t *OutWindow, int N);

Create a N-element Blackman Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are Q16 fractional format. The Blackman Window follows the equation:

Window(n) = 0.42659 - 0.49656 * COS(2*Pi*n/(N-1)) + 0.076849 * COS(4*Pi*n/(N-1)) where n is the window sample number N is the total number of samples

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

# DSP_TransformWinInit_Black32 Function

Create a Blackman window.

## File

dsp.h

## C

```
void DSP_TransformWinInit_Black32(int32_t * OutWindow, int N);
```

## Returns

None.

## Description

Function DSP_TransformWinInit_Black32:

void DSP_TransformWinInit_Black32(int32_t *OutWindow, int N);

Create a N-element Blackman Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are Q31 fractional format. The Blackman Window follows the equation:

Window(n) = 0.42659 - 0.49656 * COS(2*Pi*n/(N-1)) + 0.076849 * COS(4*Pi*n/(N-1)) where n is the window sample number N is the total number of samples

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

## DSP_TransformWinInit_Cosine16 Function

Create a Cosine (Sine) window.

### File

dsp.h

### C

```
void DSP_TransformWinInit_Cosine16(int16_t * OutWindow, int N);
```

### Returns

None.

### Description

Function DSP_TransformWinInit_Cosine16:

void DSP_TransformWinInit_Cosine16(int16_t *OutWindow, int N);

Create a N-element Cosine Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are in Q15 fractional format. The Cosine Window follows the equation:

Window(n) = SIN(Pi*n/(N-1)) where n is the window sample number N is the total number of samples

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

## DSP_TransformWinInit_Cosine32 Function

Create a Cosine (Sine) window.

### File

dsp.h

### C

```
void DSP_TransformWinInit_Cosine32(int32_t * OutWindow, int N);
```

### Returns

None.

### Description

Function DSP_TransformWinInit_Cosine32:

void DSP_TransformWinInit_Cosine32(int32_t *OutWindow, int N);

Create a N-element Cosine Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are in Q31 fractional format. The Cosine Window follows the equation:

Window(n) = SIN(Pi*n/(N-1)) where n is the window sample number N is the total number of samples

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

## DSP_TransformWinInit_Hamm16 Function

Create a Hamming window.

### File

dsp.h

### C

```
void DSP_TransformWinInit_Hamm16(int16_t * OutWindow, int N);
```

### Returns

None.

### Description

Function DSP_TransformWinInit_Hamm16:

void DSP_TransformWinInit_Hamm16(int16_t *OutWindow, int N);

Create a N-element Hamming Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are in Q15 fractional format. The Hamming Window follows the equation:

Window(n) = 0.54 - 0.46 * COS(2*Pi*n/N) where n is the window sample number N is the total number of samples

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

## DSP_TransformWinInit_Hamm32 Function

Create a Hamming window.

### File

dsp.h

### C

```
void DSP_TransformWinInit_Hamm32(int32_t * OutWindow, int N);
```

### Returns

None.

## Description

Function DSP_TransformWinInit_Hamm32:

void DSP_TransformWinInit_Hamm32(int32_t *OutWindow, int N);

Create a N-element Hamming Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are in Q31 fractional format. The Hamming Window follows the equation:

Window(n) = 0.54 - 0.46 * COS(2*Pi*n/N) where n is the window sample number N is the total number of samples

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

# DSP_TransformWinInit_Hann16 Function

Create a Hanning window.

## File

dsp.h

## C

```
void DSP_TransformWinInit_Hann16(int16_t * OutWindow, int N);
```

## Returns

None.

## Description

Function DSP_TransformWinInit_Hann16:

void DSP_TransformWinInit_Hann16(int16_t *OutWindow, int N);

Create a N-element Hanning Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are in Q15 fractional format. The Hanning Window follows the equation:

Window(n) = 0.5 - 0.5 * COS(2*Pi*n/N) where n is the window sample number N is the total number of samples

## Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

## Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

## Example

## Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

## DSP_TransformWinInit_Hann32 Function

Create a Hanning window.

### File

dsp.h

### C

```
void DSP_TransformWinInit_Hann32(int32_t * OutWindow, int N);
```

### Returns

None.

### Description

Function DSP_TransformWinInit_Hann32:

void DSP_TransformWinInit_Hann32(int32_t *OutWindow, int N);

Create a N-element Hanning Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are in Q31 fractional format. The Hanning Window follows the equation:

Window(n) = 0.5 - 0.5 * COS(2*Pi*n/N) where n is the window sample number N is the total number of samples

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

## DSP_TransformWinInit_Kaiser16 Function

Create a Kaiser window.

### File

dsp.h

### C

```
void DSP_TransformWinInit_Kaiser16(int16_t * OutWindow, int N);
```

### Returns

None.

### Description

Function DSP_TransformWinInit_Kaiser16:

void DSP_TransformWinInit_Kaiser16(int16_t *OutWindow, int N);

Create a N-element Kaiser Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are in Q15 fractional format. The Kaiser Window follows the equation:

Window(n) = 0.402 - 0.498 * COS(2*Pi*n/N) + 0.098 * cos(4*Pi*n/N) + 0.001 * cos(6*Pi*n/N) where n is the window sample number N is the total number of samples

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int16_t) |
| N | number of samples (int) |

## DSP_TransformWinInit_Kaiser32 Function

Create a Kaiser window.

### File

dsp.h

### C

```
void DSP_TransformWinInit_Kaiser32(int32_t * OutWindow, int N);
```

### Returns

None.

### Description

Function DSP_TransformWinInit_Kaiser32:

void DSP_TransformWinInit_Kaiser32(int32_t *OutWindow, int N);

Create a N-element Kaiser Window, and store the output to OutWindow. Operations are performed at higher resolution floating point, and rounded for the most accuracy possible. Output values are in Q31 fractional format. The Kaiser Window follows the equation:

Window(n) = 0.402 - 0.498 * COS(2*Pi*n/N) + 0.098 * cos(4*Pi*n/N) + 0.001 * cos(6*Pi*n/N) where n is the window sample number N is the total number of samples

### Remarks

This function is performed in C. The function may be optimized for the library. It is dependent on the floating point math library. The functional window is an intermediate result that needs to be multiplied by an input vector prior to FFT processing. Because of significant processing time the window need only be computed once and the multiply of the (window * input) vector done during recurring loop processing.

### Preconditions

N must be a positive number. OutWindow must be declared with N elements or larger.

### Example

### Parameters

| Parameters | Description |
|---|---|
| OutWindow | pointer to output array of elements (int32_t) |
| N | number of samples (int) |

# *e) Vector Math Functions*

## DSP_VectorAbs16 Function

Calculate the absolute value of a vector.

### File

dsp.h

### C

```
void DSP_VectorAbs16(int16_t * outdata, int16_t * indata, int N);
```

### Returns

None.

### Description

Function DSP_VectorAbs16:

void DSP_VectorAbs16(int16_t *outdata, int16_t *indata, int N);

Computes the absolute value of each element of indata and stores it to outdata. The number of samples to process is given by the parameter N. Data is in a Q15 fractional format. outdata[i] filled with the absolute value of elements of indata

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to eight and a multiple of eight.

### Example

```
int16_t *pOutdata;
int16_t outVal[8];
int16_t inBufTest[16] = {-5,2,-3,4,-1,0,-2,-8,-21,21,10,100,200,127,-127,-2};
int Num = 8;

pOutdata = &outVal;

DSP_VectorAbs16(pOutdata, inBufTest, Num);

// outVal[i] = {5,2,3,4,1,0,2,8}
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of 16-bit elements (int16_t) |
| indata | pointer to input array of 16-bit elements (int16_t) |
| N | number of samples (int) |

## DSP_VectorAbs32 Function

Calculate the absolute value of a vector.

### File

dsp.h

### C

```
void DSP_VectorAbs32(int32_t * outdata, int32_t * indata, int N);
```

### Returns

None.

### Description

Function DSP_VectorAbs32:

void DSP_VectorAbs32(int32_t *outdata, int32_t *indata, int N);

Computes the absolute value of each element of indata and stores it to outdata. The number of samples to process is given by the parameter N. Data is in a Q31 fractional format. outdata[i] filled with N elements of abs(indata[i])

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to eight and a multiple of eight.

## Example

```
int16_t *pOutdata;
int32_t outVal[8];
int32_t inBufTest[16] = {-5,2,-3,4,-1,0,-2,-8,-21,21,10,100,200,127,-127,-2};
int Num = 8;

pOutdata = &outVal;

DSP_VectorAbs32(pOutdata, inBufTest, Num);

// outVal[i] = {5,2,3,4,1,0,2,8}
```

## Parameters

| Parameters | Description |
| --- | --- |
| outdata | pointer to output array of 16-bit elements (int32_t) |
| indata | pointer to input array of 16-bit elements (int32_t) |
| N | number of samples (int) |

# DSP_VectorAdd16 Function

Calculate the sum of two vectors.

## File

dsp.h

## C

```
void DSP_VectorAdd16(int16_t * outdata, int16_t * indata1, int16_t * indata2, int N);
```

## Returns

None.

## Description

Function DSP_VectorAdd16:

void DSP_VectorAdd16(int16_t *outdata, int16_t *indata1, int16_t *indata2, int N);

Computes the sum value of each element of indata1 + indata2 and stores it to outdata. The number of samples to process is given by the parameter N. Data is in the Q15 fractional format. outdata[i] filled with N elements of indata1[i] + indata2[i]

## Remarks

This must be assembled with .set microMIPS.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to eight and a multiple of eight.

## Example

```
int16_t *pOutdata;
int16_t outVal[8];
int16_t inBufTest[16] = {-5,2,-3,4,-1,0,-2,-8,-21,21,10,100, 200, 127,-127,-2};
int16_t inBuf2[16]=     { 1,2, 3,4, 5,6, 7, 8, 9, 10,-1,-100,-127,127,-7,  0};
int Num = 8;

pOutdata = &outVal;

DSP_VectorAdd16(pOutdata, inBufTest, inBuf2, Num);

// outVal[i] = inBufTest[i] + inBuf2[i] = {-4,4,0,8,4,6,5,0}
```

## Parameters

| Parameters | Description |
| --- | --- |
| outdata | pointer to output array of 16-bit elements (int16_t) |
| indata1 | pointer to input array of 16-bit elements (int16_t) |
| indata2 | pointer to input array of 16-bit elements (int16_t) |

| | |
|---|---|
| N | number of samples (int) |

## DSP_VectorAdd32 Function

Calculate the sum of two vectors.

### File

dsp.h

### C

```
void DSP_VectorAdd32(int32_t * outdata, int32_t * indata1, int32_t * indata2, int N);
```

### Returns

None.

### Description

Function DSP_VectorAdd32:

void DSP_VectorAdd32(int32_t *outdata, int32_t *indata1, int32_t *indata2, int N);

Computes the sum value of each element of indata1 + indata2 and stores it to outdata. The number of samples to process is given by the parameter N. Data is in a Q31 fractional format. outdata[i] filled with N elements of indata1[i] + indata2[i]

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int16_t *pOutdata;
int32_t outVal[8];
int32_t inBufTest[16] = {-5,2,-3,4,-1,0,-2,-8,-21,21,10,100, 200, 127,-127,-2};
int32_t inBuf2[16]=     { 1,2, 3,4, 5,6, 7, 8, 9, 10,-1,-100,-127,127,-7,  0};
int Num = 8;

pOutdata = &outVal;

DSP_VectorAdd32(pOutdata, inBufTest, inBuf2, Num);

// outVal[i] = inBufTest[i] + inBuf2[i] = {-4,4,0,8,4,6,5,0}
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of 16-bit elements (int32_t) |
| indata1 | pointer to input array of 16-bit elements (int32_t) |
| indata2 | pointer to input array of 16-bit elements (int32_t) |
| N | number of samples |

## DSP_VectorAddc16 Function

Calculate the sum of a vector and a constant.

### File

dsp.h

### C

```
void DSP_VectorAddc16(int16_t * outdata, int16_t * indata, int16_t c, int N);
```

### Returns

None.

### Description

Function DSP_VectorAddc16:

void DSP_VectorAddc16(int16_t *outdata, int16_t *indata, int16_t c, int N);

Computes the sum value of each element of (indata + c) and stores it to outdata. The number of samples to process is given by the parameter N. Data is in a Q15 fractional format. outdata[i] filled with N elements of indata[i] + c

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to eight and a multiple of eight.

### Example

```
int16_t *pOutdata;
int16_t outVal[8];
int16_t inBufTest[16] = {-5,2,-3,4,-1,0,-2,-8,-21,21,10,100, 200, 127,-127,-2};
int16_t constValue =  3;
int Num = 8;

pOutdata = &outVal;

DSP_VectorAddc16(pOutdata, inBufTest, constValue, Num);

// outVal[i] = inBufTest[i] + constValue = {-2,5,0,7,2,3,1,-5}
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of 16-bit elements (int16_t) |
| indata | pointer to input array of 16-bit elements (int16_t) |
| c | constant value added to all indata1 elements (int16_t) |
| N | number of samples (int) |

## DSP_VectorAddc32 Function

Calculate the sum of a vector and a constant.

### File

dsp.h

### C

```
void DSP_VectorAddc32(int32_t * outdata, int32_t * indata, int32_t c, int N);
```

### Returns

None.

### Description

Function DSP_VectorAddc32:

void DSP_VectorAddc32(int32_t *outdata, int32_t *indata, int32_t c, int N);

Computes the sum value of each element of (indata + c) and stores it to outdata. The number of samples to process is given by the parameter N. Data is in a Q31 fractional format. outdata[i] filled with N elements of indata1[i] + c

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int16_t *pOutdata;
int32_t outVal[8];
int32_t inBufTest[16] = {-5,2,-3,4,-1,0,-2,-8,-21,21,10,100, 200, 127,-127,-2};
```

```
int32_t constValue =  3;
int Num = 8;

pOutdata = &outVal;

DSP_VectorAddc32(pOutdata, inBufTest, constValue, Num);

// outVal[i] = inBufTest[i] + constValue = {-2,5,0,7,2,3,1,-5}
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of 16-bit elements (int32_t) |
| indata | pointer to input array of 16-bit elements (int32_t) |
| c | constant value added to all indata1 elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorAutocorr16 Function

Computes the Autocorrelation of a Vector.

### File

dsp.h

### C

```
void DSP_VectorAutocorr16(int16_t * outCorr, int16_t * inVector, int N, int K);
```

### Returns

None.

### Description

Function DSP_VectorAutocorr16:

void DSP_VectorAutocorr16(int16_t *outCorr, int16_t *inVector, int N, int K);

Calculates the autocorrelation, with a lag of 1 to K, on the first N elements of inVector and returns the 16-bit scalar result in outCorr. The autocorrelation is calculated from other statistical equations including mean and variance. While in some cases these equations exist inside the DSP library, the functions are executed in a serial fashion within this code to provide enhanced performance. The unbiased function has the form -

mean (M) = sum[0..N-1](x(n) / N) variance (V) = sum[0..N-1]((x(n) - M)^2) / (N-1) autocovariance (ACV)[k] = sum[0..(N-k)]((x(n) - M) * (x(n+k) - M) / (N-k)) autocorrelation (AC)[k] = CV[k] / V where N is the number of vector elements, n is the index of those elements x(n) is a single element in the input vector M is the mean of the N elements of the vector k is the lag or series index

The output of the function will return K elements, and the outCorr array should be sized to accept those 16-bit results. The outputs correspond to k=1, k=2, .., k=K delay states. The function returns a 16-bit value in rounded, saturated Q15 format.

Input values of the vector and output scalar value is Q15 fractional format. This format has data that ranges from -1 to 1, and has internal saturation limits of those same values. Some care has been taken to reduce the impact of saturation by adding processing steps to effectively complete the processing in blocks. However, in some extreme cases of data variance it is still possible to reach the saturation limits.

### Remarks

This function is optimized with microMIPS and M14KCe ASE DSP instructions. This function is dependent on the LibQ library, and the _LIBQ_Q16Div specifically.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. outCorr must be an array with at least K values. N must be greater than or equal to four and a multiple of four.

### Example

```
int  autocvN = 16;                    // N value, number of samples in array
int  autocvLag = 4;                   // Lag value, output shifts to observe
int16_t outAC[16]={0};
int16_t CVIn16[16] = {0x1999, 0xD99A, 0x1000, 0x6000, 0x1999, 0x1999, 0x2666,
     0x3333, 0x1000, 0x6000, 0x1999, 0x1999, 0x2666, 0x3333, 0x1999, 0x0CCC};
//  = { .2, -.3, .125, .75, .2, .2, .3, .4, .125, .75, .2, .2, .3, .4, .2, .1};

DSP_VectorAutocorr16(outAC, CVIn16, autocvN, autocvLag);

// outAC = {0xF406, D46C, 0x098F, 0x191A}
```

```
//    = -0.093567, -0.34045, 0.07468, 0.19611
```

### Parameters

| Parameters | Description |
|---|---|
| outCorr | pointer to output array (int16_t) |
| inVector | pointer to source array of elements (int16_t) |
| N | number of samples (int) |
| K | lag value, number of output elements (int) |

## DSP_VectorBexp16 Function

Computes the maximum binary exponent of a vector.

### File

dsp.h

### C

```
int DSP_VectorBexp16(int16_t * DataIn, int N);
```

### Returns

Binary exponent [log2 multiplier] (int)

### Description

Function DSP_VectorBexp16:

int DSP_VectorBexp16(int16_t *DataIn, int N);

Calculates the maximum binary exponent on the first N elements of the input vector DataIn, and stores the integer result. The returned value represents the potential binary scaling of the vector, and may be used with other functions that auto scale their output without saturation. Inputs are given in Q15 fractional data format.

### Remarks

None.

### Preconditions

N must be a multiple of 2 and greater or equal to 2.

### Example

```
int valN = 4;
int16_t  dummy16[valN]={0x3004, 0x00CC, 0xFC04, 0xFFF0};
//                        0.375, 0.0062, -0.0311, -0.00049
int answer;

answer =   DSP_VectorBexp16(dummy16, valN);

// answer = 1, maximum binary gain is 2.
```

### Parameters

| Parameters | Description |
|---|---|
| DataIn | pointer to input array of 16-bit elements (int16_t) |
| N | number of samples (int) |

## DSP_VectorBexp32 Function

Computes the maximum binary exponent of a vector.

### File

dsp.h

### C

```
int DSP_VectorBexp32(int32_t * DataIn, int N);
```

## Returns

Binary exponent [log2 multiplier] (int)

## Description

Function DSP_VectorBexp32:

int DSP_VectorBexp32(int32_t *DataIn, int N);

Calculates the maximum binary exponent on the first N elements of the input vector DataIn, and stores the integer result. The returned value represents the potential binary scaling of the vector, and may be used with other functions that auto scale their output without saturation. Inputs are given in Q31 fractional data format.

## Remarks

None.

## Preconditions

None.

## Example

```
int valN=4;
int32_t  datInput32[4]={0xFF000000, 0x07000000,0x000CCCCC, 0x08000000};
//                        -0.007183, 0.054688, 0.0003906, 0.0625
int answer32;

answer32 =   DSP_VectorBexp32(datInput32, valN);

// answer = 3, maximum binary gain is 8.
```

## Parameters

| Parameters | Description |
|---|---|
| DataIn | pointer to input array of 16-bit elements (int32_t) |
| N | number of samples (int) |

# DSP_VectorChkEqu32 Function

Compares two input vectors, returns an integer '1' if equal, and '0' if not equal.

## File

dsp.h

## C

```
int DSP_VectorChkEqu32(int32_t * indata1, int32_t * indata2, int N);
```

## Returns

(int) - '1' if vectors are equal, '0' if vectors are not equal

## Description

Function DSP_VectorChkEqu32:

int DSP_VectorChkEqu32(int32_t *indata1, int32_t *indata2, int N);

Compares the first N values of indata1 to the same elements of indata2. The comparison requires that all numbers be in Q31 fractional data format. Returns the integer value '1' if all numbers are equal, and '0' if they are not equal. N must be greater than or equal to four and a multiple of four, or it will be truncated to the nearest multiple of four.

## Remarks

None.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

## Example

```
int      outCheck;
int      Num = 4;
int32_t inBufTestA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
```

```
                           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  1,      -1,      0.9,     0.8,     0.2,    0.5,     1,      -0.6
int32_t inBufTestB[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x80000000, 0x40000000, 0x7FFFFFFF, 0x20000000};
//                  1,      -1,      0.9,     0.8,     -1,    0.5,     1,      0.25

outCheck = DSP_VectorChkEqu32(inBufTestA, inBufTestB, Num);

// outCheck = 1  // true for first 4 numbers of series
```

### Parameters

| Parameters | Description |
|---|---|
| indata1 | pointer to input array 1 of elements (int32_t) |
| indata2 | pointer to input array 2 of elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorCopy Function

Copies the elements of one vector to another.

### File

dsp.h

### C

```
void DSP_VectorCopy(int32_t * outdata, int32_t * indata, int N);
```

### Returns

None.

### Description

Function DSP_VectorCopy:

void DSP_VectorCopy(int32_t *outdata, int32_t *indata, int N);

Fills the first N values of an input vector outdata with the elements from indata. N must be a multiple of four and greater than or equal to four or it will be truncated to the nearest multiple of four. The vector result and the scalar value to fill are both Q31 fractional format.

### Remarks

None.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int     Num = 4;
int32_t inBufTestA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  1,      -1,      0.9,     0.8,     0.2,    0.5,     1,      -0.6
int32_t inBufTestB[8]={0x00000000, 0x7FFFFFFF, 0x40000000, 0x0CCCCCCC,
                           0x40000000, 0x60000000, 0x80000000, 0x20000000};
//                  0,      1,      0.5,     0.1,     0.75,    0.5,     -1,      0.25

DSP_VectorCopy(inBufTestA, inBufTestB, Num);

// inBufTestA =  {0x00000000, 0x7FFFFFFF, 0x40000000, 0x0CCCCCCC,
//          0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334} // first 4 values copied
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of values (int32_t) |
| indata | pointer to source array of elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorCopyReverse32 Function

Reverses the order of elements in one vector and copies them into another.

### File

dsp.h

### C

```
void DSP_VectorCopyReverse32(int32_t * outdata, int32_t * indata, int N);
```

### Returns

None.

### Description

Function DSP_VectorCopyReverse32:

void DSP_VectorCopyReverse32(int32_t *outdata, int32_t *indata, int N);

Fills the first N values of an input vector Outdata with the reverse elements from INDATA. N must be a multiple of 4 and greater than 4 or will be truncated to the nearest multiple of 4. The vectors are both Q31 fractional format.

### Remarks

None.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int     Num = 4;
int32_t inBufTestA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  1,      -1,       0.9,     0.8,     0.2,    0.5,     1,      -0.6
int32_t inBufTestB[8]={0x00000000, 0x7FFFFFFF, 0x40000000, 0x0CCCCCCC,
                           0x40000000, 0x60000000, 0x80000000, 0x20000000};
//                  0,      1,       0.5,     0.1,     0.75,    0.5,    -1,      0.25

DSP_VectorCopyReverse32(inBufTestA, inBufTestB, Num);

// inBufTestA =  {0x0CCCCCCC, 0x40000000, 0x7FFFFFFF, 0x00000000,
//           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334}
//   first 4 values copied reverse order
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of values (int32_t) |
| indata | pointer to source array of elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorDivC Function

Divides the first N elements of inVector by a constant divisor, and stores the result in outVector.

### File

dsp.h

### C

```
void DSP_VectorDivC(_Q16 * outVector, _Q16 * inVector, _Q16 divisor, int N);
```

### Returns

None.

### Description

Function DSP_VectorDivC:

void DSP_VectorDivC(_Q16 *outVector, _Q16 *inVector, _Q16 divisor, int N);

Divides each element of the first N elements of inVector by a constant, divisor. The output is stored to outVector. Both vectors and the scalar are _Q16 format, which is 32-bit data with 15 bits for the integer and 16 bits for the fractional portion. If values exceed maximum or minimum they will saturate to the maximum or minimum respectively.

## Remarks

This function uses the Microchip PIC32MZ LibQ library to function. The user must include that library and header file into the design in order to operate this function. For more information on the Div function see the LibQ documentation for _LIBQ_Q16Div.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. This function uses the Div function from the LibQ library. That library must be compiled as part of the project.

## Example

```
int divNum = 4;
_Q16 divScalar = 0x00020000;  // 2.0
_Q16 inDivVec[8] = {0x08000000, 0xfffc0000,0x00024000,0x00100000,0x00038000,
       0x00400000,0xfffe0000,0x00058000};
//     2048, -4, 2.25, 16, 3.5, 64, -2, 5.5
_Q16 outDivVec[8] = {0};

DSP_VectorDivC(outDivVec, inDivVec,  divScalar, divNum);

// outDivVec =  0x04000000, 0xFFFE0000, 0x00012000, 0x00080000, 0, 0, 0, 0
//                 1024.0,        -2.0,      1.125,       16.0, 0, 0, 0, 0
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of elements (_Q16) |
| indata | pointer to source array of elements (_Q16) |
| divisor | scalar divisor for the input vector (_Q16) |
| N | number of samples (int) |

# DSP_VectorDotp16 Function

Computes the dot product of two vectors, and scales the output by a binary factor.

## File

dsp.h

## C

```
int16_t DSP_VectorDotp16(int16_t * indata1, int16_t * indata2, int N, int scale);
```

## Returns

int16_t - scaled output of calculation, Q15 format

## Description

Function DSP_VectorDotp16:

int16_t DSP_VectorDotp16(int16_t *indata1, int16_t *indata2, int N, int scale);

Calculates the dot product of two input vectors, and scales the output. Function will saturate if it exceeds maximum or minimum values. Scaling is done by binary shifting, after accumulation in a 32 bit register. All calculations are done in Q15 fractional format. return = 1/(2^scale) * sum(indata1[i] * indata2[i])

## Remarks

This must be assembled with .set microMIPS.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to eight and a multiple of eight.

## Example

```
int16_t inBufMultA[8]={0x7FFF, 0x8000, 0x7333, 0x6666, 0x1999, 0x4000, 0x7FFF, 0xB334};
//                       1,      -1,       0.9,     0.8,     0.2,    0.5,     1,      -0.6
int16_t inBufMultB[8]={0x0CCD, 0x0CCD, 0x4000, 0xC000, 0xE667, 0x4000, 0x0000, 0x0CCD};
```

```
//                         0.1,     0.1,     0.5,    -0.5,    -0.2,    0.5,     0,       0.1
int Num = 8;
int scaleVal = 2;
int16_t outScalar;

int Num = 8;

outScalar = DSP_VectorDotp16(inBufMultA, inBufMultB, Num, scaleVal);

// outScalar = 1/(2^scaleVal)*(inBufMultA[] dot inBufMultB[]) =
//   (1/4) * (0.1 + -0.1 + 0.45 + -0.4 + -0.04 + 0.25 + 0 + -0.06) = 0.25 * 0.20 = 0.05
//      = (int16_t)0x0666
```

### Parameters

| Parameters | Description |
|---|---|
| indata1 | pointer to input array of 16-bit elements (int16_t) |
| indata2 | pointer to input array of 16-bit elements (int16_t) |
| scale | number of bits to shift return right (int) |
| N | number of samples (int) |

## DSP_VectorDotp32 Function

Computes the dot product of two vectors, and scales the output by a binary factor

### File

dsp.h

### C

```
int32_t DSP_VectorDotp32(int32_t * indata1, int32_t * indata2, int N, int scale);
```

### Returns

int16_t - scaled output of calculation, Q31 format

### Description

Function DSP_VectorDotp32:

int32_t DSP_VectorDotp32(int32_t *indata1, int32_t *indata2, int N, int scale);

Calculates the dot product of two input vectors, and scales the output. Function will saturate if it exceeds maximum or minimum values. Scaling is done by binary shifting, after calculation of the result. All calculations are done in Q31 fractional format. return = 1/(2^scale) * sum(indata1[i] * indata2[i])

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int32_t inBufMultA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                          0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                 1,      -1,      0.9,     0.8,     0.2,    0.5,     1,      -0.6
int32_t inBufMultB[8]={0x0CCCCCCD, 0x0CCCCCCD, 0x40000000, 0xC0000000,
                          0xE6666667, 0x40000000, 0x00000000, 0x0CCCCCCD};
//                 0.1,     0.1,     0.5,    -0.5,    -0.2,    0.5,     0,       0.1
int Num = 8;
int scaleVal = 2;
int32_t outScalar;

int Num = 8;

outScalar = DSP_VectorDotp32(inBufMultA, inBufMultB, Num, scaleVal);

// outScalar = 1/(2^scaleVal)*(inBufMultA[] dot inBufMultB[]) =
//   (1/4) * (0.1 + -0.1 + 0.45 + -0.4 + -0.04 + 0.25 + 0 + -0.06) = 0.25 * 0.20 = 0.05
//      = (int32_t)0x06666666
```

### Parameters

| Parameters | Description |
| --- | --- |
| indata1 | pointer to input array of 16-bit elements (int32_t) |
| indata2 | pointer to input array of 16-bit elements (int32_t) |
| scale | number of bits to shift return right (int) |
| N | number of samples (int) |

## DSP_VectorExp Function

Computes the EXP (e^x) of the first N elements of inVector, and stores the result in outVector.

### File

dsp.h

### C

```
void DSP_VectorExp(_Q16 * outVector, _Q16 * inVector, int N);
```

### Returns

None.

### Description

Function DSP_VectorExp:

void DSP_VectorExp(_Q16 *outVector, _Q16 *inVector, int N);

Computes the Exp value, e to the power of X, on the first N elements of inVector. The output is stored to outVector. Both vectors are _Q16 format, which is 32-bit data with 15 bits for the integer and 16 bits for the fractional portion. If values exceed maximum or minimum they will saturate to the maximum or zero respectively.

### Remarks

Inclusion of the LibQ header file and library is mandatory to use this function.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. This function uses the Exp and Div functions from the LibQ library. That library must be compiled as part of the project.

### Example

```
int expNum = 4;
_Q16 inExpVec[8] = {0x00010000, 0xffff0000,0x00020000,0x00030000,0x00038000,
            0x00040000,0xfffe0000,0x00058000};
//          1.0,  -1.0,  2.0,  3.0,   3.5,   4.0,  -2.0,  5.5
_Q16 outExpVec[8] = {0};

DSP_VectorExp(outExpVec, inExpVec, expNum);

// outExpVec = 0x0002B7E1, 0x00005E2D, 0x00076399, 0x001415E6, 0, 0, 0, 0
//                2.71828,   0.26787,     7.3891,    20.0855, 0, 0, 0, 0
```

### Parameters

| Parameters | Description |
| --- | --- |
| outdata | pointer to destination array of elements (_Q16) |
| indata | pointer to source array of elements (_Q16) |
| N | number of samples (int) |

## DSP_VectorFill Function

Fills an input vector with scalar data.

### File

dsp.h

### C

```
void DSP_VectorFill(int32_t * indata, int32_t data, int N);
```

### Returns

None.

### Description

Function DSP_VectorFill:

void DSP_VectorFill(int32_t *indata, int32_t data, int N);

Fills the first N values of an input vector indata with the value data. N must be a multiple of four and greater than or equal to four or it will be truncated to the nearest multiple of four. The vector result and the scalar value to fill are both Q31 fractional format.

### Remarks

None.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int32_t fillValue = 0x3FFFFFFF;
int     Num = 4;
int32_t inBufTestA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  1,      -1,      0.9,     0.8,     0.2,    0.5,     1,      -0.6

DSP_VectorFill(inBufTestA, fillValue, Num);

// inBufTestA =  {0x3FFFFFFF, 0x3FFFFFFF, 0x3FFFFFFF, 0x3FFFFFFF,
//            0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334} // first 4 values filled
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to source array of elements (int32_t) |
| data | scalar value to fill the array (int32_t) |
| N | number of samples (int) |

## DSP_VectorLn Function

Computes the Natural Log, Ln(x), of the first N elements of inVector, and stores the result in outVector.

### File

dsp.h

### C

```
void DSP_VectorLn(_Q4_11 * outVector, _Q16 * inVector, int N);
```

### Returns

None.

### Description

Function DSP_VectorLn:

void DSP_VectorLn(_Q4_11 *outVector, _Q16 *inVector, int N);

Computes the Ln(x) value, on the first N elements of inVector. The output is stored to outVector. Input vector is _Q16 format, which is 32-bit data with 15 bits for the integer and 16 bits for the fractional portion. The output vector is reduced resolution Q4.11 format, which is a 16-bit integer format with 11 bits representing the fractional resolution. If values exceed maximum or minimum they will saturate to the maximum or zero respectively.

### Remarks

This function uses the Microchip PIC32MZ LibQ library to function. The user must include that library and header file into the design in order to operate this function. For more information on the Ln function see the LibQ documentation for _LIBQ_Q4_11_ln_Q16. A negative number input will return a saturated negative value (0x8000).

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. This function uses the Ln function from the LibQ library. That library must be compiled as part of the project.

## Example

```
int lnNum = 4;
_Q16 inLnVal[8] = {0x40000000, 0xffff0000,0x00020000,0x00100000,0x00038000,
       0x00400000,0xfffe0000,0x00058000};
//          16384.0,  -1.0,  2.0,  16.0,   3.5,   64.0,  -2.0,  5.5
_Q4_11 outLnVal[8] = {0};

DSP_VectorLn(outLnVal, inLnVal,  lnNum);

// outLnVal =     0x4DA2,        0x8000,   0x058C,   0x162E, 0, 0, 0, 0
//                 9.704,  sat negative,   0.6934,    2.772, 0, 0, 0, 0
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of elements (_Q16) |
| indata | pointer to source array of elements (_Q4_11) |
| N | number of samples (int) |

# DSP_VectorLog10 Function

Computes the Log10(x), of the first N elements of inVector, and stores the result in outVector.

## File

dsp.h

## C

```
void DSP_VectorLog10(_Q3_12 * outVector, _Q16 * inVector, int N);
```

## Returns

None.

## Description

Function DSP_VectorLog10:

void DSP_VectorLog10(_Q3_12 *outVector, _Q16 *inVector, int N);

Computes the Log10(x) value, on the first N elements of inVector. The output is stored to outVector. Input vector is _Q16 format, which is 32-bit data with 15 bits for the integer and 16 bits for the fractional portion. The output vector is reduced resolution Q3.12 format, which is a 16-bit integer format with 12 bits representing the fractional resolution. If values exceed maximum or minimum they will saturate to the maximum or zero respectively.

## Remarks

This function uses the Microchip PIC32MZ LibQ library to function. The user must include that library and header file into the design in order to operate this function. For more information on the Log10 function see the LibQ documentation for _LIBQ_Q3_12_log10_Q16. A negative number input will return a saturated negative value (0x8000).

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. This function uses the Log10 function from the LibQ library. That library must be compiled as part of the project.

## Example

```
int logNum = 4;
_Q16 inLogVal[8] = {0x40000000, 0xffff0000,0x00020000,0x00100000,0x00038000,
                    0x00400000,0xfffe0000,0x00058000};
//          16384.0,  -1.0,  2.0,  16.0,   3.5,   64.0,  -2.0,  5.5
_Q3_12 outLogVal[8] = {0};

DSP_VectorLog10(outLogVal, inLogVal,  logNum);

// outLogVal =    0x436E,        0x8000,    0x04D1,   0x1344, 0, 0, 0, 0
```

```
//                4.2144,  sat negative,   0.3010,   1.2041, 0, 0, 0, 0
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of elements (_Q16) |
| indata | pointer to source array of elements (_Q3_12) |
| N | number of samples (int) |

# DSP_VectorLog2 Function

Computes the Log2(x) of the first N elements of inVector, and stores the result in outVector.

## File

dsp.h

## C

```
void DSP_VectorLog2(_Q5_10 * outVector, _Q16 * inVector, int N);
```

## Returns

None.

## Description

Function DSP_VectorLog2:

void DSP_VectorLog2(_Q5_10 *outVector, _Q16 *inVector, int N);

Computes the Log2 value, where log2(x) = ln(x) * log2(e), on the first N elements of inVector. The output is stored to outVector. Input vector is _Q16 format, which is 32-bit data with 15 bits for the integer and 16 bits for the fractional portion. The output vector is reduced resolution Q5.10 format, which is a 16-bit integer format with 10 bits representing the fractional resolution. If values exceed maximum or minimum they will saturate to the maximum or zero respectively.

## Remarks

This function uses the Microchip PIC32MZ LibQ library to function. The user must include that library and header file into the design in order to operate this function. For more information on the Log2 function see the LibQ documentation for _LIBQ_Q5_10_log2_Q16. A negative number input will return a saturated negative value (0x8000).

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. This function uses the Log2 function from the LibQ library. That library must be compiled as part of the project.

## Example

```
int log2Num = 4;
_Q16 inLog2Val[8] = {0x40000000, 0xffff0000,0x00020000,0x00030000,0x00038000,
           0x00040000,0xfffe0000,0x00058000};
//         16384.0,  -1.0,  2.0,  3.0,   3.5,   4.0,  -2.0,   5.5
_Q5_10 outLog2Val[8] = {0};

DSP_VectorLog2(outLog2Val, inLog2Val,  log2Num);

// outLog2Val =    0x3800,        0x8000,   0x0400,   0x0657, 0, 0, 0, 0
//                  14.0,  sat negative,      1.0,    1.585, 0, 0, 0, 0
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of elements (_Q16) |
| indata | pointer to source array of elements (_Q5_10) |
| N | number of samples (int) |

# DSP_VectorMax32 Function

Returns the maximum value of a vector.

### File

dsp.h

### C

```
int32_t DSP_VectorMax32(int32_t * indata, int N);
```

### Returns

(int32_t) - maximum value within the vector, Q31 format

### Description

Function DSP_VectorMax32:

int32_t DSP_VectorMax32(int32_t *indata, int N);

Returns the highest value of the first N elements of the vector indata. The comparison requires that all numbers be in Q31 fractional data format. N must be greater than or equal to four and a multiple of four, or it will be truncated to the nearest multiple of four.

### Remarks

None.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and multiple of four.

### Example

```
int32_t   outCheck;
int     Num = 4;
int32_t inBufTestA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  1,      -1,       0.9,     0.8,     0.2,    0.5,     1,      -0.6

outCheck = DSP_VectorMax32(inBufTestA, Num);

// outCheck = 0x7FFFFFFF  // first 4 values
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to input array of elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorMaxIndex32 Function

Returns the index of the maximum value of a vector.

### File

dsp.h

### C

```
int DSP_VectorMaxIndex32(int32_t * indata, int N);
```

### Returns

int - index of the position of the maximum array element

### Description

Function DSP_VectorMaxIndex32:

int DSP_VectorMaxIndex32(int32_t *indata, int N);

Returns the index of the highest value of the first N elements of the vector indata. The comparison requires that all numbers be in Q31 fractional data format. N must be greater than or equal to four and a multiple of four, or it will be truncated to the nearest multiple of four.

### Remarks

Index values range from 0 .. (n-1).

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int     indexValue;
int     Num = 8;
int32_t inBufTestA[8]={0x3FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                       0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                 0.5,     -1,      0.9,    0.8,    0.2,   0.5,    1,     -0.6

indexValue = DSP_VectorMaxIndex32(inBufTestA, Num);

// returnValue =  6 (position corresponding to 0x7FFFFFFF)
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to source array of elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorMean32 Function

Calculates the mean average of an input vector.

### File

dsp.h

### C

```
int32_t DSP_VectorMean32(int32_t * indata1, int N);
```

### Returns

int32_t - mean average value of the vector

### Description

Function DSP_VectorMean32:

int32_t DSP_VectorMean32(int32_t *indata, int N);

Calculates the mean average of the first N elements of the vector indata. The values of indata1 are in Q31 fractional format. The value N must be greater than or equal to four and a multiple of four, or it will be truncated to the nearest multiple of four.

### Remarks

None.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int32_t   returnValue;
int     Num = 4;
int32_t inBufTestA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                       0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                 1,     -1,      0.9,    0.8,    0.2,   0.5,    1,     -0.6

returnValue = DSP_VectorMean32(inBufTestA, Num);

// returnValue =  0x36666666 = (1-1+0.9+0.8)/4 = 0.425
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to source array of elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorMin32 Function

Returns the minimum value of a vector.

### File

dsp.h

### C

```
int32_t DSP_VectorMin32(int32_t * input, int N);
```

### Returns

(int32_t) - minimum value within the vector, Q31 format

### Description

Function DSP_VectorMin32:

int32_t DSP_VectorMin32(int32_t *indata, int N);

Returns the lowest value of the first N elements of the vector indata. The comparison requires that all numbers be in Q31 fractional data format. N must be greater than or equal to four and a multiple of four, or it will be truncated to the nearest multiple of four.

### Remarks

None.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and multiple of four.

### Example

```
int32_t   outCheck;
int      Num = 4;
int32_t inBufTestA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  1,      -1,      0.9,     0.8,     0.2,    0.5,     1,      -0.6

outCheck = DSP_VectorMin32(inBufTestA, Num);

// outCheck = 0x80000000  // first 4 values
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to input array of elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorMinIndex32 Function

Returns the index of the minimum value of a vector.

### File

dsp.h

### C

```
int DSP_VectorMinIndex32(int32_t * indata, int N);
```

### Returns

int32_t - mean average value of the vector

### Description

Function DSP_VectorMinIndex32:

int DSP_VectorMinIndex32(int32_t *indata, int N);

Returns the relative position index of the lowest value of the first N elements of the vector indata. The comparison requires that all numbers be in Q31 fractional data format. N must be greater than or equal to four and a multiple of four, or it will be truncated to the nearest multiple of four.

### Remarks

Index values range from 0 .. (n-1).

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int     indexValue;
int     Num = 8;
int32_t inBufTestA[8]={0x3FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  0.5,     -1,       0.9,     0.8,     0.2,    0.5,     1,      -0.6

indexValue = DSP_VectorMinIndex32(inBufTestA, Num);

// returnValue =  1 (position corresponding to 0x80000000)
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to source array of elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorMul16 Function

Multiplication of a series of numbers in one vector to another vector.

### File

dsp.h

### C

```
void DSP_VectorMul16(int16_t * outdata, int16_t * indata1, int16_t * indata2, int N);
```

### Returns

None.

### Description

Function DSP_VectorMul16:

void DSP_VectorMul16(int16_t *outdata, int16_t *indata1, int16_t *indata2, int N);

Multiples the value of each element of indata1 * indata2 and stores it to outdata. The number of samples to process is given by the parameter N. Data is in the Q15 fractional format. outdata[i] filled with N elements of indata1[i] * indata2[i]

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to eight and a multiple of eight.

### Example

```
int16_t *pOutdata;
int16_t outVal[8];
int16_t inBufMultA[8]={0x7FFF, 0x8000, 0x7333, 0x6666, 0x1999, 0x4000, 0x7FFF, 0xB334};
//                        1,      -1,      0.9,     0.8,     0.2,    0.5,     1,      -0.6
int16_t inBufMultB[8]={0x0CCD, 0x0CCD, 0x4000, 0xC000, 0xE667, 0x4000, 0x0000, 0x0CCD};
//                        0.1,     0.1,     0.5,    -0.5,    -0.2,    0.5,     0,       0.1
int Num = 8;

pOutdata = &outVal;

DSP_VectorMul16(pOutdata, inBufMultA, inBufMultB, Num);

// outVal[i] = inBufTest[i] * inBuf2[i] =
//    {0x0CCD, 0xF333, 0x399A, 0xCCCD, 0xFAE2, 0x2000, 0x0000, 0xF852}
//      0.1,    -0.1,    0.45,   -0.4,    -0.04,    0.25,     0,      -0.06
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of 16-bit elements (int16_t) |
| indata1 | pointer to input array of 16-bit elements (int16_t) |

| | |
|---|---|
| indata2 | pointer to input array of 16-bit elements (int16_t) |
| N | number of samples (int) |

## DSP_VectorMul32 Function

Multiplication of a series of numbers in one vector to another vector.

### File

dsp.h

### C

```
void DSP_VectorMul32(int32_t * outdata, int32_t * indata1, int32_t * indata2, int N);
```

### Returns

None.

### Description

Function DSP_VectorMul32:

void DSP_VectorMul32(int32_t *outdata, int32_t *indata1, int32_t *indata2, int N);

Multiples the value of each element of indata1 * indata2 and stores it to outdata. The number of samples to process is given by the parameter N. Data is in the Q31 fractional format. outdata[i] filled with N elements of indata1[i] * indata2[i]

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int16_t *pOutdata;
int32_t outVal[8];
int32_t inBufMultA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  1,      -1,       0.9,     0.8,     0.2,    0.5,     1,      -0.6
int32_t inBufMultB[8]={0x0CCCCCCD, 0x0CCCCCCD, 0x40000000, 0xC0000000,
                           0xE6666667, 0x40000000, 0x00000000, 0x0CCCCCCD};
//                  0.1,     0.1,     0.5,    -0.5,    -0.2,    0.5,     0,       0.1
int Num = 8;

pOutdata = &outVal;

DSP_VectorMul32(pOutdata, inBufMultA, inBufMultB, Num);

// outVal[i] = inBufTest[i] * inBuf2[i] =
//    {0x0CCCCCCD, 0xF3333333, 0x3999999A, 0xCCCCCCCD, 0xFAE147AE,
//                                              0x20000000, 0x00000000, 0xF851EB86}
//      0.1,    -0.1,    0.45,   -0.4,    -0.04,    0.25,     0,      -0.06
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of 16-bit elements (int32_t) |
| indata1 | pointer to input array of 16-bit elements (int32_t) |
| indata2 | pointer to input array of 16-bit elements (int32_t) |
| N | number of samples (int) |

## DSP_VectorMulc16 Function

Multiplication of a series of numbers in one vector to a scalar value.

### File

dsp.h

### C

```
void DSP_VectorMulc16(int16_t * outdata, int16_t * indata, int16_t c, int N);
```

### Returns

None.

### Description

Function DSP_VectorMulc16:

void DSP_VectorMulc16(int16_t *outdata, int16_t *indata, int16_t c, int N);

Multiples the value of each element of indata1 * c and stores it to outdata. The number of samples to process is given by the parameter N. Data is in a Q15 fractional format. outdata[i] filled with N elements of indata[i] * c

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to eight and a multiple of eight.

### Example

```
int16_t *pOutdata;
int16_t outVal[8];
int16_t inBufMultA[8]={0x7FFF, 0x8000, 0x7333, 0x6666, 0x1999, 0x4000, 0x0000, 0xB334};
//                        1,      -1,       0.9,     0.8,     0.2,    0.5,    0,      -0.6
int16_t constValue = 0x4000;
int Num = 8;

pOutdata = &outVal;

DSP_VectorMulc16(pOutdata, inBufMultA, constValue, Num);

// outVal[i] = inBufTest[i] * constValue =
//    {0x4000, 0xC000, 0x399A, 0x3333, 0x1999, 0x2000, 0x0000, 0xD99A}
//      0.5,   -0.5,   0.45,    0.4,     0.1,    0.25,    0,      -0.3
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of 16-bit elements (int16_t) |
| indata | pointer to input array of 16-bit elements (int16_t) |
| c | scalar multiplicand (int16_t) |
| N | number of samples (int) |

## DSP_VectorMulc32 Function

Multiplication of a series of numbers in one vector to a scalar value.

### File

dsp.h

### C

```
void DSP_VectorMulc32(int32_t * outdata, int32_t * indata, int32_t c, int N);
```

### Returns

None.

### Description

Function DSP_VectorMulc32:

void DSP_VectorMulc32(int32_t *outdata, int32_t *indata, int32_t c, int N);

Multiples the value of each element of indata * c and stores it to outdata. The number of samples to process is given by the parameter N. Data is in a Q31 fractional format. outdata[i] filled with N elements of indata[i] * c

## Remarks

This must be assembled with .set microMIPS.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

## Example

```
int16_t *pOutdata;
int32_t outVal[8];
int32_t inBufMultA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                       0x19999999, 0x40000000, 0x00000000, 0xB3333334};
//                    1,     -1,     0.9,     0.8,     0.2,    0.5,     1,     -0.6
int32_t constValue = 0x4000;
int Num = 8;

pOutdata = &outVal;

DSP_VectorMulc32(pOutdata, inBufMultA, constValue, Num);

// outVal[i] = inBufTest[i] * constValue =
//    {0x40000000, 0xC0000000, 0x3999999A, 0x33333333, 0x19999999,
//                                              0x20000000, 0x00000000, 0xD999999A}
//      0.5,    -0.5,    0.45,     0.4,     0.1,    0.25,     0,      -0.3
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of 16-bit elements (int32_t) |
| indata | pointer to input array of 16-bit elements (int32_t) |
| c | scalar multiplicand (int32_t) |
| N | number of samples (int) |

# DSP_VectorNegate Function

Inverses the sign (negates) the elements of a vector.

## File

dsp.h

## C

```
void DSP_VectorNegate(int32_t * outdata, int32_t * indata, int N);
```

## Returns

None.

## Description

Function DSP_VectorNegate:

void DSP_VectorNegate(int32_t *outdata, int32_t *indata, int N);

Sign inversion of the first N values of an indata are assigned to outdata. N must be a multiple of four and greater than or equal to four or it will be truncated to the nearest multiple of four. The vector result and the scalar value to fill are both Q31 fractional format.

## Remarks

None.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

## Example

```
int     Num = 4;
int32_t inBufTestA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                       0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  1,      -1,      0.9,     0.8,     0.2,    0.5,     1,      -0.6
int32_t outBufTest[8]={0x0CCCCCCD, 0x0CCCCCCD, 0x40000000, 0xC0000000,
```

```
                              0xE6666667, 0x40000000, 0x00000000, 0x0CCCCCCD};
//                  0.1,     0.1,     0.5,    -0.5,    -0.2,    0.5,     0,       0.1;

DSP_VectorNegate(outBufTest, inBufTestA, Num);

// inBufTestA =  {0x80000000, 0x7FFFFFFF, 0x8CCCCCCD, 0x9999999A,
//             0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334} // first 4 values neg
//                -1,    1,    -0.9,    -0.8,    -0.2,    0.5,    0,    0.1
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of elements (int32_t) |
| indata | pointer to source array of elements (int32_t) |
| N | number of samples (int) |

# DSP_VectorRecip Function

Computes the reciprocal (1/x) of the first N elements of inVector, and stores the result in outVector.

## File

dsp.h

## C

```
void DSP_VectorRecip(_Q16 * outVector, _Q16 * inVector, int N);
```

## Returns

None.

## Description

Function DSP_VectorRecip:

void DSP_VectorRecip(_Q16 *outVector, _Q16 *inVector, int N);

Computes the reciprocal (1/x) on the first N elements of inVector. The output is stored to outVector. Both vectors are _Q16 format, which is 32-bit data with 15 bits for the integer and 16 bits for the fractional portion. If values exceed maximum or minimum they will saturate to the maximum or minimum respectively.

## Remarks

This function uses the Microchip PIC32MZ LibQ library to function. The user must include that library and header file into the design in order to operate this function. For more information on the Div function see the LibQ documentation for _LIBQ_Q16Div. A value of zero in the array will not cause an error, but will return 0.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. This function uses the Div function from the LibQ library. That library must be compiled as part of the project.

## Example

```
int recNum = 4;
_Q16 inRecVec[8] = {0x08000000, 0xfffc0000,0x00020000,0x00100000,0x00038000,
               0x00400000,0xfffe0000,0x00058000};
//             2048.0, -4.0, 2.0, 16.0, 3.5, 64.0, -2.0, 5.5
_Q16 outRecVec[8] = {0};

DSP_VectorRecip(outRecVec, inRecVec,  recNum);

// outRecVec =  0x00000020, 0xFFFFC0000, 0x00008000, 0x00001000, 0, 0, 0, 0
//                0.000488,       -0.25,        0.5,      0.0625, 0, 0, 0, 0
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of elements (_Q16) |
| indata | pointer to source array of elements (_Q16) |
| N | number of samples (int) |

## DSP_VectorRMS16 Function

Computes the root mean square (RMS) value of a vector.

### File

dsp.h

### C

```
int16_t DSP_VectorRMS16(int16_t * inVector, int N);
```

### Returns

int16_t - RMS function output, Q15 format

### Description

Function DSP_VectorRMS16:

int16_t DSP_VectorRMS16(int16_t *inVector, int N);

Computes the root mean square value of the first N values of inVector. Both input and output are Q15 fractional values. The function will saturate if maximum or minimum values are exceeded.

### Remarks

This function is optimized with microMIPS and M14KCe ASE DSP instructions. This function is dependent on the LibQ library, and uses the _LIBQ_Q16Sqrt external function call.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and multiple of four.

### Example

```
int16_t vecRMSIn[32]={0x1999, 0xD99A, 0x4000, 0x2666,0x1999,0x1999,0x2666, 0x3333};
// 0.2, -0.3, 0.5, 0.3, 0.2, 0.2, 0.3, 0.4
int16_t RMSOut=0;
int Nrms = 8;

RMSOut = DSP_VectorRMS16(vecRMSIn, Nrms);

// RMSOut = 0x287C (= 0.31628)
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to input array of 16-bit elements (int16_t) |
| N | number of samples (int) |

## DSP_VectorShift Function

Shifts the data index of an input data vector.

### File

dsp.h

### C

```
void DSP_VectorShift(int32_t * outdata, int32_t * indata, int N, int shift);
```

### Returns

None.

### Description

Function DSP_VectorShift:

void DSP_VectorShift(int32_t *outdata, int32_t *indata, int N, int shift);

Shifts N data elements of indata to outdata, with an index change of shift. The amount of data shifted includes zero padding for the first (shift) elements if shift is positive. The vector size of indata and outdata need not be the same, however, N must not exceed either array size.

## Remarks

Destination array values shift to left (relative to the input vector) when shift is positive (back filled with zeros) and shift to the right when shift is negative. The total amount of values copied to the destination array is the length of N less the shift amount.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must not exceed the amount of elements in the source array. shift must not exceed the number of elements in the destination array.

## Example

```
int shiftValue = 3;
int     Num = 8;
int32_t inBufTestA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  1,      -1,      0.9,     0.8,     0.2,    0.5,     1,      -0.6
int32_t inBufTestB[8]={0x80000000, 0x7FFFFFFF, 0x40000000, 0x0CCCCCCC,
                           0x40000000, 0x60000000, 0x80000000, 0x20000000};
//                 -1,      1,       0.5,     0.1,     0.75,    0.5,     -1,      0.25

DSP_VectorShift(inBufTestA, inBufTestB, Num, shiftValue);

// inBufTestA =  {0x00000000, 0x00000000, 0x00000000, 0x80000000,
//             0x7FFFFFFF, 0x40000000, 0x0CCCCCCC, 0x40000000} // shifted 3 positive
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of elements (int32_t) |
| indata | pointer to source array of elements (int32_t) |
| N | number of samples (int) |
| shift | number of indexes to shift (int) |

# DSP_VectorSqrt Function

Computes the square root of the first N elements of inVector, and stores the result in outVector.

## File

dsp.h

## C

```
void DSP_VectorSqrt(_Q16 * outVector, _Q16 * inVector, int N);
```

## Returns

None.

## Description

Function DSP_VectorSqrt:

void DSP_VectorSqrt(_Q16 *outVector, _Q16 *inVector, int N);

Computes the Sqrt(x) on the first N elements of inVector. The output is stored to outVector. Both vectors are _Q16 format, which is 32-bit data with 15 bits for the integer and 16 bits for the fractional portion. If values exceed maximum or minimum they will saturate to the maximum or zero respectively.

## Remarks

This function uses the Microchip PIC32MZ LibQ library to function. The user must include that library and header file into the design in order to operate this function. For more information on the Sqrt function see the LibQ documentation for _LIBQ_Q16Sqrt. A negative number input will return a saturated value (0x00FFFFxx).

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. This function uses the Sqrt function from the LibQ library. That library must be compiled as part of the project.

## Example

```
int sqrtNum = 4;
_Q16 inSqrtVec[8] = {0x40000000, 0xffff0000,0x00020000,0x00100000,0x00038000,
```

```
          0x00400000,0xfffe0000,0x00058000};
//          16384.0,  -1.0,  2.0,  16.0,   3.5,   64.0,  -2.0,  5.5
_Q16 outSqrtVec[8] = {0};

DSP_VectorSqrt(outSqrtVec, inSqrtVec,  sqrtNum);

// outSqrtVec =  0x00800000, 0x00FFFF80, 0x00016A0A, 0x00040000, 0, 0, 0, 0
//                 128.0,  sat negative,   1.41422,      4.0,    0, 0, 0, 0
```

### Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to destination array of elements (_Q16) |
| indata | pointer to source array of elements (_Q16) |
| N | number of samples (int) |

## DSP_VectorStdDev16 Function

Computes the Standard Deviation of a Vector.

### File

dsp.h

### C

```
int16_t DSP_VectorStdDev16(int16_t * inVector, int N);
```

### Returns

int16_t - Standard Deviation of N selected elements

### Description

Function DSP_VectorStdDev16:

int16_t DSP_VectorStdDev16(int16_t *inVector, int N);

Calculates the standard deviation on the first N elements of inVector and returns the 16-bit scalar result. The standard deviation is the square root of the variance, which is a measure of the delta from mean values. The mean value of the vector is computed in the process. The function has the form -

StdDev = SQRT(sum[0..N]((x(i) - M(N))^2) / (N-1)) where N is the number of vector elements x(i) is a single element in the vector M(N) is the mean of the N elements of the vector

Input values of the vector and output scalar value is Q15 fractional format. This format has data that ranges from -1 to 1, and has internal saturation limits of those same values. Some care has been taken to reduce the impact of saturation by adding processing steps to effectively complete the processing in blocks. However, in some extreme cases of data variance it is still possible to reach the saturation limits.

### Remarks

The input vector elements number, N, must be at least 4 and a multiple of 4. This function is optimized with microMIPS and M14KCe ASE DSP instructions. This function is dependent on the LibQ library, and the _LIBQ_Q16Sqrt specifically.

### Preconditions

The pointers inVector must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four. Dependent on use of the LibQ library.

### Example

```
int16_t vecStDevIn[32]={0x4000, 0xD99A, 0x1000, 0x6000,0x1999,0x1999,0x2666, 0x3333};
        // .2, -.3, .125, .75, .2, .2, .3, .4
int16_t StDevOut, Var16Out;
int Nstdev = 4;

StDevOut = DSP_VectorStdDev16(vecStDevIn, Nstdev);
        // StDevOut = 0x3A9E (= 0.45797)
```

### Parameters

| Parameters | Description |
|---|---|
| inVector | pointer to source array of elements (int16_t) |
| N | number of samples (int) |

## DSP_VectorSub16 Function

Calculate the difference of two vectors.

### File

dsp.h

### C

```
void DSP_VectorSub16(int16_t * outdata, int16_t * indata1, int16_t * indata2, int N);
```

### Returns

None.

### Description

Function DSP_VectorSub16:

void DSP_VectorSub16(int16_t *outdata, int16_t *indata1, int16_t *indata2, int N);

Computes the difference value of each element of indata1 - indata2 and stores it to outdata. The number of samples to process is given by the parameter N. Data is in a Q15 fractional format. outdata[i] filled with N elements of indata1[i] - indata2[i]

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to eight and a multiple of eight.

### Example

```
int16_t *pOutdata;
int16_t outVal[8];
int16_t inBufTest[16] = {-5,2,-3,4,-1,0,-2,-8,-21,21,10,100, 200, 127,-127,-2};
int16_t inBuf2[16]=     { 1,2, 3,4, 5,6, 7, 8, 9, 10,-1,-100,-127,127,-7,  0};
int Num = 8;

pOutdata = &outVal;

DSP_VectorSub16(pOutdata, inBufTest, inBuf2, Num);

// outVal[i] = inBufTest[i] - inBuf2[i] = {-6,0,-6,0,-6,-6,-9,-16}
```

### Parameters

| Parameters | Description |
| --- | --- |
| outdata | pointer to output array of 16-bit elements (int16_t) |
| indata1 | pointer to input array of 16-bit elements (int16_t) |
| indata2 | pointer to input array of 16-bit elements (int16_t) |
| N | number of samples (int) |

## DSP_VectorSub32 Function

Calculate the difference of two vectors.

### File

dsp.h

### C

```
void DSP_VectorSub32(int32_t * outdata, int32_t * indata1, int32_t * indata2, int N);
```

### Returns

None.

### Description

Function DSP_VectorSub32:

void DSP_VectorSub32(int32_t *outdata, int32_t *indata1, int32_t *indata2, int N);

Computes the difference value of each element of indata1 - indata2 and stores it to outdata. The number of samples to process is given by the parameter N. Data is in a Q31 fractional format. outdata[i] filled with N elements of indata1[i] - indata2[i]

## Remarks

This must be assembled with .set microMIPS.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

## Example

```
int16_t *pOutdata;
int32_t outVal[8];
int32_t inBufTest[16] = {-5,2,-3,4,-1,0,-2,-8,-21,21,10,100, 200, 127,-127,-2};
int32_t inBuf2[16]=     { 1,2, 3,4, 5,6, 7, 8, 9, 10,-1,-100,-127,127,-7,  0};
int Num = 8;

pOutdata = &outVal;

DSP_VectorSub32(pOutdata, inBufTest, inBuf2, Num);

// outVal[i] = inBufTest[i] - inBuf2[i] = {-6,0,-6,0,-6,-6,-9,-16}
```

## Parameters

| Parameters | Description |
|---|---|
| outdata | pointer to output array of 16-bit elements (int32_t) |
| indata1 | pointer to input array of 16-bit elements (int32_t) |
| indata2 | pointer to input array of 16-bit elements (int32_t) |
| N | number of samples (int) |

# DSP_VectorSumSquares16 Function

Computes the sum of squares of a vector, and scales the output by a binary factor.

## File

dsp.h

## C

```
int16_t DSP_VectorSumSquares16(int16_t * indata, int N, int scale);
```

## Returns

int16_t - scaled output of calculation, Q15 format

## Description

Function DSP_VectorSumSquares16:

int16_t DSP_VectorSumSquares16(int16_t *indata, int N, int scale);

Calculates the sum of the squares of each element of an input vector, and scales the output. Function will saturate if it exceeds maximum or minimum values. Scaling is done by binary shifting, after accumulation in a 32 bit register. All calculations are done in Q15 fractional format. return = 1/(2^scale) * sum(indata[i]^2)

## Remarks

This must be assembled with .set microMIPS.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to eight and a multiple of eight.

## Example

```
int16_t inBufMultA[8]={0x7FFF, 0x8000, 0x7333, 0x6666, 0x1999, 0x4000, 0x7FFF, 0xB334};
//                        1,      -1,       0.9,     0.8,     0.2,    0.5,     1,      -0.6
int Num = 8;
int scaleVal = 3;
int16_t outScalar;

outScalar = DSP_VectorSumSquares16(inBufMultA, Num, scaleVal);
```

```
// outScalar = 1/(2^scaleVal)* sum(inBufMultA[i]^2) =
//   (1/8) * (1 + 1 + 0.81 + 0.64 + 0.04 + 0.25 + 1 + 0.36) = 0.125 * 5.1 = 0.6375
//      = (int16_t)0x5199
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to input array of 16-bit elements (int16_t) |
| scale | number of bits to shift return right (int) |
| N | number of samples (int) |

## DSP_VectorSumSquares32 Function

Computes the sum of squares of a vector, and scales the output by a binary factor.

### File

dsp.h

### C

```
int32_t DSP_VectorSumSquares32(int32_t * indata, int N, int scale);
```

### Returns

int32_t - scaled output of calculation, Q15 format

### Description

Function DSP_VectorSumSquares32:

int32_t DSP_VectorSumSquares32(int32_t *indata, int N, int scale);

Calculates the sum of the squares of each element of an input vector, and scales the output. The function will saturate if it exceeds maximum or minimum values. Scaling is done by binary shifting, after calculation of the results. All calculations are done in Q31 fractional format. return = 1/(2^scale) * sum(indata[i]^2)

### Remarks

This must be assembled with .set microMIPS.

### Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and multiple of four.

### Example

```
int32_t inBufMultA[8]={0x7FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                           0x19999999, 0x40000000, 0x00000000, 0xB3333334};
//                     1,     -1,     0.9,     0.8,     0.2,    0.5,     1,    -0.6
int Num = 8;
int scaleVal = 3;
int32_t outScalar;

outScalar = DSP_VectorSumSquares32(inBufMultA, Num, scaleVal);

// outScalar = 1/(2^scaleVal)* sum(inBufMultA[i]^2) =
//   (1/8) * (1 + 1 + 0.81 + 0.64 + 0.04 + 0.25 + 1 + 0.36) = 0.125 * 5.1 = 0.6375
//      = (int32_t)0x51999999
```

### Parameters

| Parameters | Description |
|---|---|
| indata | pointer to input array of 16-bit elements (int32_t) |
| scale | number of bits to shift return right (int) |
| N | number of samples (int) |

## DSP_VectorVari16 Function

Computes the variance of N elements of a Vector.

### File

dsp.h

### C

```
int16_t DSP_VectorVari16(int16_t * inVector, int N);
```

### Returns

int16_t - Variance of N selected elements

### Description

Function DSP_VectorVari16:

int16_t DSP_VectorVari16(int16_t *inVector, int N);

Calculates the variance on the first N elements of inVector and returns the 16-bit scalar result. The variance is a measure of the delta from mean values, and the mean value of the vector is computed in the process. The function has the form -

var = sum[0..N]((x(i) - M(N))^2) / (N-1) where N is the number of vector elements x(i) is a single element in the vector M(N) is the mean of the N elements of the vector

Input values of the vector and output scalar value is Q15 fractional format. This format has data that ranges from -1 to 1, and has internal saturation limits of those same values. Some care has been taken to reduce the impact of saturation by adding processing steps to effectively complete the processing in blocks. However, in some extreme cases of data variance it is still possible to reach the saturation limits.

### Remarks

The input vector elements number, N, must be at least 4 and a multiple of 4. This function is optimized with microMIPS and M14KCe ASE DSP instructions.

### Preconditions

The pointers inVector must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

### Example

```
int16_t vecStDevIn[32]={0x4000, 0xD99A, 0x1000, 0x6000,0x1999,0x1999,0x2666, 0x3333};
        // .2, -.3, .125, .75, .2, .2, .3, .4
int16_t Var16Out;
int Nvar = 4;

Var16Out= DSP_VectorVari16(vecStDevIn, Nvar);  // 16-bit variance function
        // Var16Out = 0x1AD8 (= 0.20974)
```

### Parameters

| Parameters | Description |
|---|---|
| inVector | pointer to source array of elements (int16_t) |
| N | number of samples (int) |

## DSP_VectorVariance Function

Computes the variance of N elements of inVector.

### File

dsp.h

### C

```
int32_t DSP_VectorVariance(int32_t * inVector, int N);
```

### Returns

int32_t - Variance of N selected elements

### Description

Function DSP_VectorVariance:

int32_t DSP_VectorVariance(int32_t *inVector, int N);

Calculates the variance on the first N elements of inVector and returns the 32-bit scalar result. The variance is a measure of the delta from mean values, and the mean value of the vector is computed in the process. The function has the form -

var = sum[0..N]((x(i) - M(N))^2) / (N-1) where N is the number of vector elements x(i) is a single element in the vector M(N) is the mean of the N elements of the vector

Input values of the vector and output scalar value is Q31 fractional format. This format has data that ranges from -1 to 1, and has internal saturation limits of those same values. Some care has been taken to reduce the impact of saturation by adding processing steps to effectively complete the processing in blocks. However, in some extreme cases of data variance it is still possible to reach the saturation limits.

## Remarks

The input vector elements number, N, must be at least 4 and a multiple of 4. This function is optimized with microMIPS and M14KCe ASE DSP instructions.

## Preconditions

The pointers inVector must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

## Example

```
int varN = 8;

int32_t inVarVec[8] = {0xE6666667, 0x40000000,0x40000000,0x0CCCCCCC,
           0x00000000,0x59999999,0x20000000,0xC0000000};
//     -0.2, 0.5, 0.5, 0.1, 0, 0.7, 0.25, -0.5
int32_t outVar = 0;

outVar = DSP_VectorVariance(inVarVec, varN);

// outVar == 0x1490D2A6, = 0.1606696
```

## Parameters

| Parameters | Description |
|---|---|
| inVector | pointer to source array of elements (int32_t) |
| N | number of samples (int) |

# DSP_VectorZeroPad Function

Fills an input vector with zeros.

## File

dsp.h

## C

```
void DSP_VectorZeroPad(int32_t * indata, int N);
```

## Returns

None.

## Description

Function DSP_VectorZeroPad:

void DSP_VectorZeroPad(int32_t *indata, int N);

Fills the first N values of an input vector indata with the value zero. N must be a multiple of four and greater than or equal to four or it will be truncated to the nearest multiple of four. The vector result is in Q31 fractional format.

## Remarks

None.

## Preconditions

The pointers outdata and indata must be aligned on 4-byte boundaries. N must be greater than or equal to four and a multiple of four.

## Example

```
int     Num = 4;
int32_t inBufTestA[8]={0x3FFFFFFF, 0x80000000, 0x73333333, 0x66666666,
                       0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
//                  0.5,     -1,      0.9,     0.8,     0.2,    0.5,     1,     -0.6

DSP_VectorZeroPad(inBufTestA, Num);

// inBufTestA =  {0x00000000, 0x00000000, 0x00000000, 0x00000000,
//                            0x19999999, 0x40000000, 0x7FFFFFFF, 0xB3333334};
```

```
//                  0,      0,       0,     0,     0.2,    0.5,     1,      -0.6
```

## Parameters

| Parameters | Description |
|---|---|
| indata | pointer to source array of elements (int32_t) |
| N | number of samples (int) |

## *f) Support Functions*

## mul16 Function

### File

dsp.h

### C

```
static inline int16_t mul16(int16_t a, int16_t b);
```

### Description

multiply and shift integer

## mul16r Function

### File

dsp.h

### C

```
static inline int16_t mul16r(int16_t a, int16_t b);
```

### Description

multiply and shift Q15

## mul32 Function

### File

dsp.h

### C

```
static inline int32_t mul32(int32_t a, int32_t b);
```

### Description

multiply and shift Q31

## SAT16 Function

### File

dsp.h

### C

```
static inline int32_t SAT16(int32_t x);
```

### Description

saturate both positive and negative Q15

## SAT16N Function

### File

dsp.h

### C

```
static inline int32_t SAT16N(int32_t x);
```

### Description

saturate negative Q15

## SAT16P Function

### File

dsp.h

### C

```
static inline int32_t SAT16P(int32_t x);
```

### Description

saturate positive Q15

## *g) Data Types and Constants*

## biquad16 Structure

### File

dsp.h

### C

```
typedef struct {
  int16_t a1;
  int16_t a2;
  int16_t b1;
  int16_t b2;
} biquad16;
```

### Members

| Members | Description |
|---|---|
| int16_t a1; | feedback delay 1 coef |
| int16_t a2; | feedback delay 2 coef |
| int16_t b1; | feedforward delay 1 coef |
| int16_t b2; | feedforward delay 1 coef |

### Description

Q15 biquad

## int16c Structure

### File

dsp.h

### C

```
typedef struct {
  int16_t re;
  int16_t im;
} int16c;
```

### Members

| Members | Description |
|---|---|
| int16_t re; | real portion (a) |
| int16_t im; | imaginary portion (b) |

## Description

Q15 complex number (a + bi)

# int32c Structure

## File

dsp.h

## C

```
typedef struct {
  int32_t re;
  int32_t im;
} int32c;
```

## Members

| Members | Description |
|---|---|
| int32_t re; | real portion (a) |
| int32_t im; | imaginary portion (b) |

## Description

Q31 complex number (a + bi)

# matrix32 Structure

## File

dsp.h

## C

```
typedef struct {
  int32_t row;
  int32_t col;
  int32_t * pMatrix;
} matrix32;
```

## Members

| Members | Description |
|---|---|
| int32_t row; | matrix rows |
| int32_t col; | matrix columns |
| int32_t * pMatrix; | matrix pointer to data |

## Description

Q31 matrix

# PARM_EQUAL_FILTER Structure

## File

dsp.h

## C

```
typedef struct _PARM_EQUAL_FILTER {
  PARM_FILTER_GAIN G;
  int16_t log2Alpha;
  int16_t b[3];
  int16_t a[2];
  int32_t Z[2];
} PARM_EQUAL_FILTER;
```

## Members

| Members | Description |
|---|---|
| PARM_FILTER_GAIN G; | Filter max gain multiplier |

| | |
|---|---|
| int16_t log2Alpha; | coefficient scaling bit shift value |
| int16_t b[3]; | Feedforward Coefficients, Q15 format |
| int16_t a[2]; | Feedback Coefficients, Q15 format |
| int32_t Z[2]; | Filter memory, should be initialized to zero. |

### Description

IIR BQ filter structure Q15 data, Q31 storage

## PARM_EQUAL_FILTER_16 Structure

### File

dsp.h

### C

```
typedef struct _PARM_EQUAL_FILTER_16 {
  PARM_FILTER_GAIN G;
  int16_t log2Alpha;
  int16_t b[3];
  int16_t a[2];
  int16_t Z[2];
} PARM_EQUAL_FILTER_16;
```

### Members

| Members | Description |
|---|---|
| PARM_FILTER_GAIN G; | Filter max gain multiplier |
| int16_t log2Alpha; | coefficient scaling bit shift value |
| int16_t b[3]; | Feedforward Coefficients, Q15 format |
| int16_t a[2]; | Feedback Coefficients, Q15 format |
| int16_t Z[2]; | Filter memory, should be initialized to zero. |

### Description

IIR BQ filter structure Q15

## PARM_EQUAL_FILTER_32 Structure

### File

dsp.h

### C

```
typedef struct _PARM_EQUAL_FILTER_32 {
  PARM_FILTER_GAIN G;
  int log2Alpha;
  int32_t b[3];
  int32_t a[2];
  int32_t Z[2];
} PARM_EQUAL_FILTER_32;
```

### Members

| Members | Description |
|---|---|
| PARM_FILTER_GAIN G; | Filter max gain multiplier |
| int log2Alpha; | coefficient scaling bit shift value |
| int32_t b[3]; | Feedforward Coefficients, Q15 format |
| int32_t a[2]; | Feedback Coefficients, Q15 format |
| int32_t Z[2]; | Filter memory, should be initialized to zero. |

### Description

IIR BQ filter structure Q31

## PARM_FILTER_GAIN Structure

### File

dsp.h

### C

```
typedef struct {
  int16_t fracGain;
  int16_t expGain;
} PARM_FILTER_GAIN;
```

### Members

| Members | Description |
|---|---|
| int16_t fracGain; | Q15 fractional filter gain |
| int16_t expGain; | log2N (binary) filter gain |

### Description

filter gain structure

## MAX16 Macro

### File

dsp.h

### C

```
#define MAX16 ((int16_t) 0x7FFF)      // maximum Q15
```

### Description

maximum Q15

## MAX32 Macro

### File

dsp.h

### C

```
#define MAX32 ((int32_t) 0x7FFFFFFF)  // maximum Q31
```

### Description

maximum Q31

## MIN16 Macro

### File

dsp.h

### C

```
#define MIN16 ((int16_t) 0x8000)      // minimum Q15
```

### Description

minimum Q15

## MIN32 Macro

### File

dsp.h

### C

```
#define MIN32 ((int32_t) 0x80000000)  // minimum Q31
```

### Description

minimum Q31

# Files

## Files

| Name | Description |
|---|---|
| dsp.h | DSP functions for the PIC32MZ device family. |

### Description

This section lists the source and header files used by the DSP Fixed-Point Math Library.

## *dsp.h*

DSP functions for the PIC32MZ device family.

### Functions

| | Name | Description |
|---|---|---|
| | DSP_ComplexAdd32 | Calculates the sum of two complex numbers. |
| | DSP_ComplexConj16 | Calculates the complex conjugate of a complex number. |
| | DSP_ComplexConj32 | Calculates the complex conjugate of a complex number. |
| | DSP_ComplexDotProd32 | Calculates the dot product of two complex numbers. |
| | DSP_ComplexMult32 | Multiplies two complex numbers. |
| | DSP_ComplexScalarMult32 | Multiplies a complex number and a scalar number. |
| | DSP_ComplexSub32 | Calculates the difference of two complex numbers. |
| | DSP_FilterFIR32 | Performs a Finite Infinite Response (FIR) filter on a vector. |
| | DSP_FilterFIRDecim32 | Performs a decimating FIR filter on the input array. |
| | DSP_FilterFIRInterp32 | Performs an interpolating FIR filter on the input array. |
| | DSP_FilterIIR16 | Performs a single-sample cascaded biquad Infinite Impulse Response (IIR) filter. |
| | DSP_FilterIIRBQ16 | Performs a single-pass IIR Biquad Filter. |
| | DSP_FilterIIRBQ16_cascade8 | Performs a single-sample IIR Biquad Filter as a cascade of 8 series filters. |
| | DSP_FilterIIRBQ16_cascade8_fast | Performs a single-sample IIR Biquad Filter as a cascade of 8 series filters. |
| | DSP_FilterIIRBQ16_fast | Performs a single-pass IIR Biquad Filter. |
| | DSP_FilterIIRBQ16_parallel8 | Performs a 8 parallel single-pass IIR Biquad Filters, and sums the result. |
| | DSP_FilterIIRBQ16_parallel8_fast | Performs a 8 parallel single-pass IIR Biquad Filters, and sums the result. |
| | DSP_FilterIIRBQ32 | Performs a high resolution single-pass IIR Biquad Filter. |
| | DSP_FilterIIRSetup16 | Converts biquad structure to coeffs array to set up IIR filter. |
| | DSP_FilterLMS16 | Performs a single sample Least Mean Squares FIR Filter. |
| | DSP_MatrixAdd32 | Addition of two matrices C = (A + B). |
| | DSP_MatrixEqual32 | Equality of two matrices C = (A). |
| | DSP_MatrixInit32 | Initializes the first N elements of a Matrix to the value num. |
| | DSP_MatrixMul32 | Multiplication of two matrices C = A x B. |
| | DSP_MatrixScale32 | Scales each element of an input buffer (matrix) by a fixed number. |
| | DSP_MatrixSub32 | Subtraction of two matrices C = (A - B). |
| | DSP_MatrixTranspose32 | Transpose of a Matrix C = A (T). |
| | DSP_TransformFFT16 | Creates an Fast Fourier Transform (FFT) from a time domain input. |
| | DSP_TransformFFT16_setup | Creates FFT coefficients for use in the FFT16 function. |
| | DSP_TransformFFT32 | Creates an Fast Fourier Transform (FFT) from a time domain input. |
| | DSP_TransformFFT32_setup | Creates FFT coefficients for use in the FFT32 function. |
| | DSP_TransformIFFT16 | Creates an Inverse Fast Fourier Transform (FFT) from a frequency domain input. |
| | DSP_TransformWindow_Bart16 | Perform a Bartlett window on a vector. |
| | DSP_TransformWindow_Bart32 | Perform a Bartlett window on a vector. |

| | | |
|---|---|---|
| | DSP_TransformWindow_Black16 | Perform a Blackman window on a vector. |
| | DSP_TransformWindow_Black32 | Perform a Blackman window on a vector. |
| | DSP_TransformWindow_Cosine16 | Perform a Cosine (Sine) window on a vector. |
| | DSP_TransformWindow_Cosine32 | Perform a Cosine (Sine) window on a vector. |
| | DSP_TransformWindow_Hamm16 | Perform a Hamming window on a vector. |
| | DSP_TransformWindow_Hamm32 | Perform a Hamming window on a vector. |
| | DSP_TransformWindow_Hann16 | Perform a Hanning window on a vector. |
| | DSP_TransformWindow_Hann32 | Perform a Hanning window on a vector. |
| | DSP_TransformWindow_Kaiser16 | Perform a Kaiser window on a vector. |
| | DSP_TransformWindow_Kaiser32 | Perform a Kaiser window on a vector. |
| | DSP_TransformWinInit_Bart16 | Create a Bartlett window. |
| | DSP_TransformWinInit_Bart32 | Create a Bartlett window. |
| | DSP_TransformWinInit_Black16 | Create a Blackman window. |
| | DSP_TransformWinInit_Black32 | Create a Blackman window. |
| | DSP_TransformWinInit_Cosine16 | Create a Cosine (Sine) window. |
| | DSP_TransformWinInit_Cosine32 | Create a Cosine (Sine) window. |
| | DSP_TransformWinInit_Hamm16 | Create a Hamming window. |
| | DSP_TransformWinInit_Hamm32 | Create a Hamming window. |
| | DSP_TransformWinInit_Hann16 | Create a Hanning window. |
| | DSP_TransformWinInit_Hann32 | Create a Hanning window. |
| | DSP_TransformWinInit_Kaiser16 | Create a Kaiser window. |
| | DSP_TransformWinInit_Kaiser32 | Create a Kaiser window. |
| | DSP_VectorAbs16 | Calculate the absolute value of a vector. |
| | DSP_VectorAbs32 | Calculate the absolute value of a vector. |
| | DSP_VectorAdd16 | Calculate the sum of two vectors. |
| | DSP_VectorAdd32 | Calculate the sum of two vectors. |
| | DSP_VectorAddc16 | Calculate the sum of a vector and a constant. |
| | DSP_VectorAddc32 | Calculate the sum of a vector and a constant. |
| | DSP_VectorAutocorr16 | Computes the Autocorrelation of a Vector. |
| | DSP_VectorBexp16 | Computes the maximum binary exponent of a vector. |
| | DSP_VectorBexp32 | Computes the maximum binary exponent of a vector. |
| | DSP_VectorChkEqu32 | Compares two input vectors, returns an integer '1' if equal, and '0' if not equal. |
| | DSP_VectorCopy | Copies the elements of one vector to another. |
| | DSP_VectorCopyReverse32 | Reverses the order of elements in one vector and copies them into another. |
| | DSP_VectorDivC | Divides the first N elements of inVector by a constant divisor, and stores the result in outVector. |
| | DSP_VectorDotp16 | Computes the dot product of two vectors, and scales the output by a binary factor. |
| | DSP_VectorDotp32 | Computes the dot product of two vectors, and scales the output by a binary factor |
| | DSP_VectorExp | Computes the EXP (e^x) of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorFill | Fills an input vector with scalar data. |
| | DSP_VectorLn | Computes the Natural Log, Ln(x), of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorLog10 | Computes the Log10(x), of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorLog2 | Computes the Log2(x) of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorMax32 | Returns the maximum value of a vector. |
| | DSP_VectorMaxIndex32 | Returns the index of the maximum value of a vector. |
| | DSP_VectorMean32 | Calculates the mean average of an input vector. |
| | DSP_VectorMin32 | Returns the minimum value of a vector. |
| | DSP_VectorMinIndex32 | Returns the index of the minimum value of a vector. |
| | DSP_VectorMul16 | Multiplication of a series of numbers in one vector to another vector. |
| | DSP_VectorMul32 | Multiplication of a series of numbers in one vector to another vector. |
| | DSP_VectorMulc16 | Multiplication of a series of numbers in one vector to a scalar value. |
| | DSP_VectorMulc32 | Multiplication of a series of numbers in one vector to a scalar value. |
| | DSP_VectorNegate | Inverses the sign (negates) the elements of a vector. |
| | DSP_VectorRecip | Computes the reciprocal (1/x) of the first N elements of inVector, and stores the result in outVector. |

| | | |
|---|---|---|
| | DSP_VectorRMS16 | Computes the root mean square (RMS) value of a vector. |
| | DSP_VectorShift | Shifts the data index of an input data vector. |
| | DSP_VectorSqrt | Computes the square root of the first N elements of inVector, and stores the result in outVector. |
| | DSP_VectorStdDev16 | Computes the Standard Deviation of a Vector. |
| | DSP_VectorSub16 | Calculate the difference of two vectors. |
| | DSP_VectorSub32 | Calculate the difference of two vectors. |
| | DSP_VectorSumSquares16 | Computes the sum of squares of a vector, and scales the output by a binary factor. |
| | DSP_VectorSumSquares32 | Computes the sum of squares of a vector, and scales the output by a binary factor. |
| | DSP_VectorVari16 | Computes the variance of N elements of a Vector. |
| | DSP_VectorVariance | Computes the variance of N elements of inVector. |
| | DSP_VectorZeroPad | Fills an input vector with zeros. |
| | mul16 | multiply and shift integer |
| | mul16r | multiply and shift Q15 |
| | mul32 | multiply and shift Q31 |
| | SAT16 | saturate both positive and negative Q15 |
| | SAT16N | saturate negative Q15 |
| | SAT16P | saturate positive Q15 |

## Macros

| | Name | Description |
|---|---|---|
| | MAX16 | maximum Q15 |
| | MAX32 | maximum Q31 |
| | MIN16 | minimum Q15 |
| | MIN32 | minimum Q31 |

## Structures

| | Name | Description |
|---|---|---|
| | _PARM_EQUAL_FILTER | IIR BQ filter structure Q15 data, Q31 storage |
| | _PARM_EQUAL_FILTER_16 | IIR BQ filter structure Q15 |
| | _PARM_EQUAL_FILTER_32 | IIR BQ filter structure Q31 |
| | biquad16 | Q15 biquad |
| | int16c | Q15 complex number (a + bi) |
| | int32c | Q31 complex number (a + bi) |
| | matrix32 | Q31 matrix |
| | PARM_EQUAL_FILTER | IIR BQ filter structure Q15 data, Q31 storage |
| | PARM_EQUAL_FILTER_16 | IIR BQ filter structure Q15 |
| | PARM_EQUAL_FILTER_32 | IIR BQ filter structure Q31 |
| | PARM_FILTER_GAIN | filter gain structure |

## Description

Digital Signal Processing (DSP) Library

The DSP Library provides functions that are optimized for performance on the PIC32MZ families of devices that have microAptiv core features and utilize DSP ASE. The library provides advanced mathematical operations for complex numbers, vector and matrix mathematics, digital filtering and transforms.

All functions are implemented in efficient assembly with C-callable prototypes. In some cases both 16-bit and 32-bit functions are supplied to enable the user with a choice of resolution and performance.

For most functions, input and output data is represented by 16-bit fractional numbers in Q15 format, which is the most commonly used data format for signal processing. Some functions use other data formats internally for increased precision of intermediate results.

The Q15 data type used by the DSP functions is specified as int16_t in the C header file that is supplied with the library. Note that within C code, care must be taken to avoid confusing fixed-point values with integers. To the C compiler, objects declared with int16_t type are integers, not fixed-point, and all arithmetic operations performed on those objects in C will be done as integers. Fixed-point values have been declared as int16_t only because the standard C language does not include intrinsic support for fixed-point data types.

Some functions also have versions operating on 32-bit fractional data in Q31 format. These functions operate similarly to their 16-bit counterparts. However, it should be noted that the 32-bit functions do not benefit much from the SIMD capabilities offered by DSP ASE. Thus, the performance of the 32-bit functions is generally reduced compared to the performance of the corresponding 16-bit functions.

Signed fixed point types are defined as follows:

Qn.m where:

- n is the number of data bits to the left of the radix point
- m is the number of data bits to the right of the radix point
- a signed bit is implied

Unique variable types for fractional representation are also defined:

Exact Name # Bits Required Type Q0.15 (Q15) 16 int16_t Q0.31 (Q31) 32 int32_t

Table of DSP Library functions:

Complex Math:

void DSP_ComplexAdd32(int32c *indata1, int32c *indata2, int32c *Output);

void DSP_ComplexConj16(int16c *indata, int16c *Output);

void DSP_ComplexConj32(int32c *indata, int32c *Output);

void DSP_ComplexDotProd32(int32c *indata1, int32c *indata2, int32c *Output);

void DSP_ComplexMult32(int32c *indata1, int32c *indata2, int32c *Output);

void DSP_ComplexScalarMult32(int32c *indata, int32_t Scalar, int32c *Output);

void DSP_ComplexSub32(int32c *indata1, int32c *indata2, int32c *Output);

Filter Functions:

void DSP_FilterFIR32(int32_t *outdata, int32_t *indata, int32_t *coeffs2x, int32_t *delayline, int N, int K, int scale);

void DSP_FilterFIRDecim32(int32_t *outdata, int32_t *indata, int32_t *coeffs, int32_t *delayline, int N, int K, int scale, int rate);

int16_t DSP_FilterIIR16(int16_t in, int16_t *coeffs, int16_t *delayline, int B, int scale);

void DSP_FilterIIRSetup16(int16_t *coeffs, biquad16 *bq, int B);

void DSP_FilterFIRInterp32(int32_t *outdata, int32_t *indata, int32_t *coeffs, int32_t *delayline, int N, int K, int scale, int rate);

int16_t DSP_FilterLMS16(int16_t in, int16_t ref, int16_t *coeffs, int16_t *delayline, int16_t *error, int K, int16_t mu);

int16_t DSP_FilterIIRBQ16_fast(int16_t Xin, PARM_EQUAL_FILTER_16 *pFilter);

int16_t DSP_FilterIIRBQ16(int16_t Xin, PARM_EQUAL_FILTER *pFilter);

int32_t DSP_FilterIIRBQ32(int32_t Xin, PARM_EQUAL_FILTER_32 *pFilter);

int16_t DSP_FilterIIRBQ16_cascade8(int16_t Xin, PARM_EQUAL_FILTER *pFilter_Array);

int16_t DSP_FilterIIRBQ16_cascade8_fast(int16_t Xin, PARM_EQUAL_FILTER_16 *pFilter_Array);

int16_t DSP_FilterIIRBQ16_parallel8(int16_t Xin, PARM_EQUAL_FILTER *pFilter);

int16_t DSP_FilterIIRBQ16_parallel8_fast(int16_t Xin, PARM_EQUAL_FILTER_16 *pFilter);

Matrix Functions:

void DSP_MatrixAdd32(matrix32 *resMat, matrix32 *srcMat1, matrix32 *srcMat2);

void DSP_MatrixEqual32(matrix32 *resMat, matrix32 *srcMat);

void DSP_MatrixInit32(int32_t *data_buffer, int32_t N, int32_t num);

void DSP_MatrixMul32(matrix32 *resMat, matrix32 *srcMat1, matrix32 *srcMat2);

void DSP_MatrixScale32(int32_t *data_buffer, int32_t N, int32_t num);

void DSP_MatrixSub32(matrix32 *resMat, matrix32 *srcMat1, matrix32 *srcMat2);

void DSP_MatrixTranspose32(matrix32 *desMat, matrix32 *srcMat);

Transforms:

void DSP_TransformFFT16(int16c *dout, int16c *din, int16c *twiddles, int16c *scratch, int log2N);

void DSP_TransformIFFT16(int16c *dout, int16c *din, int16c *twiddles, int16c *scratch, int log2N);

void DSP_TransformFFT16_setup(int16c *twiddles, int log2N);

void DSP_TransformFFT32(int32c *dout, int32c *din, int32c *twiddles, int32c *scratch, int log2N);

void DSP_TransformFFT32_setup(int32c *twiddles, int log2N);

void DSP_TransformWindow_Bart16(int16_t *OutVector, int16_t *InVector, int N);

void DSP_TransformWindow_Bart32(int32_t *OutVector, int32_t *InVector, int N);

void DSP_TransformWindow_Black16(int16_t *OutVector, int16_t *InVector, int N);

void DSP_TransformWindow_Black32(int32_t *OutVector, int32_t *InVector, int N);

void DSP_TransformWindow_Cosine16(int16_t *OutVector, int16_t *InVector, int N);

void DSP_TransformWindow_Cosine32(int32_t *OutVector, int32_t *InVector, int N);

void DSP_TransformWindow_Hamm16(int16_t *OutVector, int16_t *InVector, int N);

void DSP_TransformWindow_Hamm32(int32_t *OutVector, int32_t *InVector, int N);

void DSP_TransformWindow_Hann16(int16_t *OutVector, int16_t *InVector, int N);

void DSP_TransformWindow_Hann32(int32_t *OutVector, int32_t *InVector, int N);

void DSP_TransformWindow_Kaiser16(int16_t *OutVector, int16_t *InVector, int N);

void DSP_TransformWindow_Kaiser32(int32_t *OutVector, int32_t *InVector, int N);
void DSP_TransformWinInit_Bart16(int16_t *OutWindow, int N);
void DSP_TransformWinInit_Bart32(int32_t *OutWindow, int N);
void DSP_TransformWinInit_Black16(int16_t *OutWindow, int N);
void DSP_TransformWinInit_Black32(int32_t *OutWindow, int N);
void DSP_TransformWinInit_Cosine16(int16_t *OutWindow, int N);
void DSP_TransformWinInit_Cosine32(int32_t *OutWindow, int N);
void DSP_TransformWinInit_Hamm16(int16_t *OutWindow, int N);
void DSP_TransformWinInit_Hamm32(int32_t *OutWindow, int N);
void DSP_TransformWinInit_Hann16(int16_t *OutWindow, int N);
void DSP_TransformWinInit_Hann32(int32_t *OutWindow, int N);
void DSP_TransformWinInit_Kaiser16(int16_t *OutWindow, int N);
void DSP_TransformWinInit_Kaiser32(int32_t *OutWindow, int N);
Vector Math:
void DSP_VectorAbs16(int16_t *outdata, int16_t *indata, int N);
void DSP_VectorAbs32(int32_t *outdata, int32_t *indata, int N);
void DSP_VectorAdd16(int16_t *outdata, int16_t *indata1, int16_t *indata2, int N);
void DSP_VectorAdd32(int32_t *outdata, int32_t *indata1, int32_t *indata2, int N);
void DSP_VectorAddc16(int16_t *outdata, int16_t *indata, int16_t c, int N);
void DSP_VectorAddc32(int32_t *outdata, int32_t *indata, int32_t c, int N);
void DSP_VectorAutocorr16(int16_t *outCorr, int16_t *inVector, int N, int K);
int DSP_VectorBexp16(int16_t *DataIn, int N);
int DSP_VectorBexp32(int32_t *DataIn, int N);
int DSP_VectorChkEqu32(int32_t* indata1, int32_t *indata2, int N);
void DSP_VectorCopy(int32_t *outdata, int32_t *indata, int N);
void DSP_VectorCopyReverse32(int32_t *outdata, int32_t *indata, int N);
void DSP_VectorDivC(_Q16 *outVector, _Q16 *inVector, _Q16 divisor, int N);
int16_t DSP_VectorDotp16(int16_t *indata1, int16_t *indata2, int N, int scale);
int32_t DSP_VectorDotp32(int32_t *indata1, int32_t *indata2, int N, int scale);
void DSP_VectorExp(_Q16 *outVector, _Q16 *inVector, int N);
void DSP_VectorFill(int32_t *indata, int32_t data, int N);
void DSP_VectorLog10(_Q3_12 *outVector, _Q16 *inVector, int N);
void DSP_VectorLog2(_Q5_10 *outVector, _Q16 *inVector, int N);
void DSP_VectorLn(_Q4_11 *outVector, _Q16 *inVector, int N);
int32_t DSP_VectorMax32(int32_t *indata, int N);
int DSP_VectorMaxIndex32(int32_t *indata, int N);
int32_t DSP_VectorMean32(int32_t *indata, int N);
int32_t DSP_VectorMin32(int32_t *input, int N);
int DSP_VectorMinIndex32(int32_t *indata, int N);
void DSP_VectorMul16(int16_t *outdata, int16_t *indata1, int16_t *indata2, int N);
void DSP_VectorMul32(int32_t *outdata, int32_t *indata1, int32_t *indata2, int N);
void DSP_VectorMulc16(int16_t *outdata, int16_t *indata, int16_t c, int N);
void DSP_VectorMulc32(int32_t *outdata, int32_t *indata, int32_t c, int N);
void DSP_VectorNegate(int32_t *outdata, int32_t *indata, int N);
void DSP_VectorRecip(_Q16 *outVector, _Q16 *inVector, int N);
int16_t DSP_VectorRMS16(int16_t *inVector, int N);
void DSP_VectorShift(int32_t *outdata, int32_t *indata, int N, int shift);
int16_t DSP_VectorStdDev16(int16_t *inVector, int N);
void DSP_VectorSqrt(_Q16 *outVector, _Q16 *inVector, int N);
void DSP_VectorSub16(int16_t *outdata, int16_t *indata1, int16_t *indata2, int N);
void DSP_VectorSub32(int32_t *outdata, int32_t *indata1, int32_t *indata2, int N);
int16_t DSP_VectorSumSquares16(int16_t *indata, int N, int scale);
int32_t DSP_VectorSumSquares32(int32_t *indata, int N, int scale);
int16_t DSP_VectorVari16(int16_t *inVector, int N);

int32_t DSP_VectorVariance(int32_t *inVector, int N);
void DSP_VectorZeroPad(int32_t *indata, int N);

## File Name

dsp.h

## Company

Microchip Technology Inc.

# LibQ Fixed-Point 'C' Math Library

This topic describes the LibQ Fixed-Point 'C' Math Library.

## Introduction

The LibQ Fixed-Point 'C' Math Library is available for the PIC32 family of microcontrollers.

### Description

The LibQ Fixed-Point 'C' Math Library provides fixed-point math functions written in C for portability between core processors.

The library utilizes signed fixed point types (fractional Q types specified by Qn.m) as follows:

Qndm where:

- n is the number of data bits to the left of the radix point
- m is the number of data bits to the right of the radix point
- a signed bit is implied (unless stated otherwise)

Whereas, the implied fractional scaling of the integer value is given by 2^(-m), i.e. arithmetic left-shift of m bit positions of the fractional part into the value. This necessarily reduces the maximum magnitude of that can be stored in the n+m bit value, since only n bit remain and 1 of those bits is usually the sign..

For convenience, short names are also defined for arbitrary scaled fractional types:

- q15 is signed fractional 16 bit value
- q31 is signed fractional 32 bit value

In addition, A pseudo floating point 32 bit format (FxQFloat32) is defined that consists of 16 bit mantissa and a 16 bit exponent (base 2).

Functions in the library are prefixed with the type of the return value and followed by the argument types, as follows:

libq_: libq_q15_sin_Q2d13

For example, libq_q1d15_Sin_q10d6 returns a Q1.15 value equal to the to the sine of an angle specified as a Q10.6 value (in degrees between 0 and 360). Argument types separated by an underscore.

For arbitrary scaled types (q15 and q31), the scaling of the result will depend on the function and the scaling of the arguments. For instance, libq_q15_Add_q15_q15(a,b) will return a scaled value type that is the same as the two input types (which also must have equivalent Q format).

The library supports the original ETSI family of basic operations as described in:

"ETSI G.729 recommendation Coding of speech at 8 kbit/s using conjugate-structure algebraic-code excited linear prediction (CS-ACELP)".

This includes:

- Saturated arithmetic operations, such as L_add, L_sub, sub, add.
- Multiplication operations, such as mult, mult_r and L_mult.
- Arithmetic shift operations, such as shl and shr.
- Data conversion operations, such as extract_l, extract_h, and round.
- Normalization to maximize resolution, such as norm_l
- Loading of 15 bit values into 32 bit values, such as L_deposit_h
- Signed negation, such as L_negate
- Multiply accumulate, such as L_mac, L_macNs, mac_r
- Multiply subtract, such as L_msu, L_msuNs msu_r
- Divide, such as div_s
- Saturate value, such as L_sat
- Rounding, such as round.
- Left Shift, such as L_shl and shl
- Right Shift, such as L_shr, L_shr_r and shr
- Extraction of 16 bit values, such as extract_l
- Absolute value, such as L_abs

The 'C' Code implementation provides portability of the library, yet the functions easily translate to specific processor assembly code (intrinsic operations) when needed.

**Note:** The LibQ Fixed-Point 'C' Math Library functions do not correspond to the LibQ Fixed-Point Math Library, which is optimized for the microAptiv core processor and is written in Assembly language.

## Using the Library

This topic describes the basic architecture of the LibQ Fixed-Point 'C' Math Library and provides information and examples on its use.

### Description

**Interface Header File**: `libq_C.h`

The interface to the LibQ Fixed-Point 'C' Math Library is defined in the `libq_C.h` header file. Any C language source (`.c`) file that uses the LibQ Fixed-Point Library should include `libq_C.h`.

**Library File**:

The LibQ Fixed-Point 'C' Math Library archive (`.a`) file is installed with MPLAB Harmony.

## Library Interface

### Functions

| | Name | Description |
|---|---|---|
| | libq_q15_Abs_q15 | Saturated Absolute value. |
| | libq_q15_Add_q15_q15 | Add two 16-bit 2s-complement fractional values. |
| | libq_q15_DivisionWithSaturation_q15_q15 | Fractional division with saturation. |
| | libq_q15_ExtractH_q31 | Extracts upper 16 bits of input 32-bit fractional value. |
| | libq_q15_ExtractL_q31 | Extracts lower 16-bits of input 32-bit fractional value.<br>Descriptionf Extracts lower 16-bits of input 32-bit fractional value and returns them as 16-bit fractional value. This is a bit-for-bit extraction of the bottom 16-bits of the 32-bit input. This function relates to the ETSI extract_l function. |
| | libq_q15_Negate_q15 | Negate 16-bit 2s-complement fractional value with saturation. |
| | libq_q15_MacR_q31_q15_q15 | Multiply accumulate with rounding. |
| | libq_q15_RoundL_q31 | Rounds the lower 16-bits of the 32-bit fractional input. |
| | libq_q15_MsuR_q31_q15_q15 | Multiply-Subtraction with rounding |
| | libq_q1d15_Sin_q10d6 | Approximates the sine of an angle. |
| | libq_q31_Abs_q31 | Saturated Absolute value. |
| | libq_q31_Add_q31_q31 | Add two 32-bit 2s-complement fractional values. |
| | libq_q31_DepositH_q15 | Place 16 bits in the upper half of 32 bit word. |
| | libq_q15_Sub_q15_q15 | Subtract two 16-bit 2s-complement fractional values |
| | libq_q31_DepositL_q15 | Place 16 bits in the lower half of 32 bit word. |
| | libq_q31_Multi_q15_q31 | Implement 16 bit by 32 bit multiply. |
| | libq_q31_Negate_q31 | Negate 32-bit 2s-complement fractional value with saturation. |
| | libq_q15_ExpAvg_q15_q15_q1d15 | Exponential averaging |
| | libq_q31_Mac_q31_q15_q15 | Multiply-Accumulate function WITH saturation |
| | libq_q31_Msu_q31_q15_q15 | L_msu(a,b,c) |
| | libq_q31_ShiftLeft_q31_i16 | 'Arithmetic' Shift of the 32-bit value. |
| | libq_q20d12_Sin_q20d12 | 3rd order Polynomial apprx. of a sine function |
| | Fx16Norm | Normalize the 16-bit fractional value. |
| | Fx32Norm | Normalize the 32-bit number. |
| | libq_q15_MultipyR2_q15_q15 | fractional multiplication of two 16-bit fractional values giving a 16 bit rounded result. |
| | libq_q15_ShiftLeft_q15_i16 | 'Arithmetic' Shift of the 16-bit input argument. |
| | libq_q15_ShiftRight_q15_i16 | 'Arithmetic' RIGHT Shift on a 16-bit value. |
| | libq_q15_ShiftRightRound_q15_i16 | Performs an 'Arithmetic' RIGHT Shift on a 16-bit input. |
| | libq_q31_Mult2_q15_q15 | fractional multiplication of two 16-bit fractional values. |
| | libq_q31_ShiftRight_q31_i16 | 'Arithmetic' RIGHT Shift on a 32-bit value. |
| | libq_q31_ShiftRightRound_q31_i16 | 'Arithmetic' RIGHT Shift on a 32-bit value |
| | libq_q31_Sub_q31_q31 | Subtract two 32-bit 2s-complement fractional values |

### Data Types and Constants

| | Name | Description |
|---|---|---|
| | q15 | q15 n.n (signed) |
| | q31 | q31 n.n (signed) |

| | | |
|---|---|---|
| | q63 | Q63 n.n (signed) |
| | _LIBQ_C_H_ | This is macro _LIBQ_C_H_. |
| | BITMASKFRACT16 | Bit Mask for 16 |
| | BITMASKFRACT32 | Bit Mask for 32 |
| | Fl2Fract16 | Converts floating point constant value to fractional 16-bit value |
| | Fl2Fract32 | Converts floating point constant value to fractional 32-bit value |
| | Fl2FxPnt | Converts floating point constant value to fixed/fractional value |
| | Fl2FxPnt16 | Converts floating point constant value to fixed point 16-bit value |
| | Fl2FxPnt32 | Converts floating point constant value to fixed point 32-bit value |
| | Fl2Int16 | Converts floating point constant expression to 16-bit integer value |
| | Fl2Int32 | Converts floating point constant expression to 32-bit integer value |
| | FrMax | find the maximum of two numbers |
| | FrMin | find the minimum of two numbers |
| | LOG102Q5D11 | log10(2) scaled to Q5.11 format |
| | MAXFRACT16 | 0.999969 |
| | MAXFRACT32 | 0.9999999995 |
| | MAXINT16 | Maximum and minimum values for 16-bit data types. |
| | MAXINT32 | This is macro MAXINT32. |
| | MAXPFLOAT32 | minimum and maximum definitions for FX floating point data types |
| | MINFRACT16 | 1.000000 |
| | MINFRACT32 | 1.0000000000 |
| | MININT16 | This is macro MININT16. |
| | MININT32 | This is macro MININT32. |
| | MINPFLOAT32 | This is macro MINPFLOAT32. |
| | MSBBITFRACT16 | 16-bit Sign Bit |
| | MSBBITFRACT32 | 32-bit Sign Bit |
| | NINETYQ10D22 | Ninety degrees scaled to Q10d22 |
| | NINETYQ10D6 | Ninety degrees scaled to Q10d6 |
| | NORMNEGFRACT16 | Max -val for 16 |
| | NORMNEGFRACT32 | Max -val for 32 |
| | NORMPOSFRACT16 | Min +val for 16 |
| | NORMPOSFRACT32 | Min +val for 32 |
| | NUMBITSFRACT16 | Num of bits 16 |
| | NUMBITSFRACT32 | Num of bits 32 |
| | ONEEIGHTYQ10D22 | 180 degrees scaled to Q10d22 |
| | ONEEIGHTYQ10D6 | 180 degrees scaled to Q10d6 |
| | ROUNDFRACT32 | Rounding value |
| | THREESIXTYQ10D22 | 360 degrees scaled to Q10d22 |
| | THREESIXTYQ10D6 | 360 degrees scaled to Q10d6 |
| | TWOSEVENTYQ10D22 | 270 degrees scaled to Q10d22 |
| | TWOSEVENTYQ10D6 | 270 degrees scaled to Q10d6 |
| | UNITYFLOAT | This is macro UNITYFLOAT. |
| | FxQFloat32 | FxQFloat32 pseudo floating point type (limited floating point) |
| | Exponent16ToQFloat32 | Converts a power of 2 16-bit integer to 32-bit floating point value. |
| | Fl2QFloat32 | Converts a decimal floating-point constant expression to pseudo float |
| | i16 | Q16d0 |

## Description

This section describes the Application Programming Interface (API) functions, macros, and types of the LibQ Fixed Point 'C' Math Library.

Refer to each section for a detailed description.

### *Functions*

## libq_q15_Abs_q15 Function

Saturated Absolute value.

### File

libq_C.h

### C

```
q15 libq_q15_Abs_q15(q15);
```

### Returns

q15 result - abs(input) <= MAXFRACT16

### Description

Function libq_q15_Abs_q15:

Creates a saturated Absolute value. It takes the absolute value of the 16-bit 2s-complement fractional input with saturation. The saturation is for handling the case where taking the absolute value of MINFRACT16 is greater than MAXFRACT16, or the allowable range of 16-bit values. This function relates to the ETSI abs function.

### Parameters

| Parameters | Description |
|---|---|
| q15 a | input argument |

## libq_q15_Add_q15_q15 Function

Add two 16-bit 2s-complement fractional values.

### File

libq_C.h

### C

```
q15 libq_q15_Add_q15_q15(q15, q15);
```

### Returns

q15 - a+b on Range: MINFRACT16 <= result <= MAXFRACT16

### Description

Function libq_q15_Add_q15_q15: f

Add two 16-bit 2s-complement fractional (op1 + op2) to produce a 16-bit 2s-complement fractional result with saturation. The saturation is for handling the overflow/underflow cases, where the result is set to MAX16 when an overflow occurs and the result is set to MIN16 when an underflow occurs. This function does not produce any status flag to indicate when an overflow or underflow has occured. It is assumed that the binary point is in exactly the same bit position for both 16-bit inputs and the resulting 16-bit output.

## libq_q15_DivisionWithSaturation_q15_q15 Function

Fractional division with saturation.

### File

libq_C.h

### C

```
q15 libq_q15_DivisionWithSaturation_q15_q15(q15, q15);
```

### Returns

q15 result - ratio a/b in 16-bit fractional format

### Description

Function libq_q15_DivisionWithSaturation_q15_q15():

Performs fractional division with saturation. There are three restrictions that the calling code must satisfy.

1. Both the numerator and denominator must be positive.

2. In order to obtain a non-saturated result, the numerator must be LESS than or equal to the denominator.
3. The denominator must not equal zero.

If 'num' equals 'den', then the result equals MAXINT16.

This function relates to the ETSI div_s function.

### Parameters

| Parameters | Description |
|---|---|
| q15 num | 16-bit fractional numerator |
| q15 den | 16-bit fractional denumerator |

## libq_q15_ExtractH_q31 Function

Extracts upper 16 bits of input 32-bit fractional value.

### File

libq_C.h

### C

```
q15 libq_q15_ExtractH_q31(q31);
```

### Returns

q15 result - Upper 16 bits of 32-bit argument a

### Description

Function libq_q15_ExtractH_q31:

Extracts upper 16 bits of input 32-bit fractional value and returns them as 16-bit fractional value. This is a bit-for-bit extraction of the top 16-bits of the 32-bit input. This function relates to the ETSI extract_h function.

## libq_q15_ExtractL_q31 Function

Extracts lower 16-bits of input 32-bit fractional value.

Descriptionf Extracts lower 16-bits of input 32-bit fractional value and returns them as 16-bit fractional value. This is a bit-for-bit extraction of the bottom 16-bits of the 32-bit input. This function relates to the ETSI extract_l function.

### File

libq_C.h

### C

```
q15 libq_q15_ExtractL_q31(q31);
```

### Returns

q15 - Lower 16 bits of 32-bit argument a

### Description

Function libq_q15_ExtractL_q31:

## libq_q15_Negate_q15 Function

Negate 16-bit 2s-complement fractional value with saturation.

### File

libq_C.h

### C

```
q15 libq_q15_Negate_q15(q15);
```

### Returns

q15 result on range: MINFRACT16 <= result <= MAXFRACT16

### Description

Function libq_q15_Negate_q15:

Negate 16-bit 2s-complement fractional value with saturation. The saturation is for handling the case where negating a MINFRACT16 is greater than MAXFRACT16, or the allowable range of values. This function relates to the ETSI negate function.

## libq_q15_MacR_q31_q15_q15 Function

Multiply accumulate with rounding.

### File

libq_C.h

### C

```
q15 libq_q15_MacR_q31_q15_q15(q31, q15, q15);
```

### Returns

q15 result - a+b*c rounded

### Description

Function libq_q15_MacR_q31_q15_q15:

This function is multiply-accumulate WITH Rounding applied to the accumulator result before it is saturated and the top 16-bits taken. This function first multiplies the two 16-bit input values 'b x c' which results in a 32-bit value. This result is left shifted by one to account for the extra sign bit inherent in the fractional-type multiply. So, the shifted number now has a '0' in the Lsb. The shifted multiplier output is then added to the 32-bit fractional input 'a'. Then the 32-bits of the accumulator output are rounded by adding '2^15'. This value is then saturated to be within the q15 range. It is assumed that the binary point of the 32-bit input value a is in the same bit position as the shifted multiplier output. This function is for fractional Qtype format data only and it therefore will not give the correct results for true integers.

This function relates to the ETSI L_mac_r function.

### Parameters

| Parameters | Description |
|---|---|
| q31 a | 32-bit accumulator operand |
| q15 b | 16-bit multiplication operand |
| q15 c | 16-bit multiplication operand |

## libq_q15_RoundL_q31 Function

Rounds the lower 16-bits of the 32-bit fractional input.

### File

libq_C.h

### C

```
q15 libq_q15_RoundL_q31(q31);
```

### Returns

q15 result

### Description

Function libq_q15_RoundL_q31:

Rounds the lower 16-bits of the 32-bit fractional input into a 16-bit fractional value with saturation. This converts the 32-bit fractional value to 16-bit fractional value with rounding. This function calls the 'Add' function to perform the 32-bit rounding of the input value and 'ExtractH' function to extract to top 16-bits. This has the effect of rounding positive fractional values up and more positive, and has the effect of rounding negative fractional values up and more positive. This function relates to the ETSI round function.

## libq_q15_MsuR_q31_q15_q15 Function

Multiply-Subtraction with rounding

### File

libq_C.h

### C

```
q15 libq_q15_MsuR_q31_q15_q15(q31, q15, q15);
```

### Returns

q15 result - a-b*c rounded to Q1.15

### Description

Function libq_q15_MsuR_q31_q15_q15:

This function is like Multiply-Subtract but WITH Rounding applied to the subtractor result before it is saturated and the top 16-bits taken. This function first multiplies the two 16-bit input values 'b x c' which results in a 32-bit value. This result is left shifted by one to account for the extra sign bit inherent in the fractional-type multiply. So, the shifted number now has a '0' in the Lsb. The shifted multiplier output is then SUBTRACTED From the 32-bit fractional input 'a'. Then the 32-bits output From this subtraction are rounded by adding '2^15'. This value is then saturated to be within the q15 range. It is assumed that the binary point of the 32-bit input value a is in the same bit position as the shifted multiplier output.

This function is for fractional Q-type format data only and it therefore will not give the correct results for true integers.

This function relates to the ETSI msu_r function.

### Parameters

| Parameters | Description |
|---|---|
| q31 a | Value which is subtracted from |
| q15 b | multiplication operand 1 |
| q15 c | multiplication operand 2 |

## libq_q1d15_Sin_q10d6 Function

Approximates the sine of an angle.

### File

libq_C.h

### C

```
q15 libq_q1d15_Sin_q10d6(q15 angleQ10d6);
```

### Returns

q15 sine(angle) value in Q1.15

### Description

Function libq_q1d15_Sin_q10d6:

This function approximates the sine of an angle using the following algorithm: sin(x) = 3.140625x + 0.02026367x^2 - 5.325196x^3 + 0.5446778x^4 + 1.800293x^5. The approximation is accurate for any value of x from 0 degrees to 90 degrees. Because sin(-x) = - sin(x) and sin(x) = sin(180 - x), the sine of any angle can be inferred from an angle in the first quadrant. Therefore, any angle > 90 is converted to an angle between 0 & 90. The coefficients of the algorithm have been scaled by 1/8 to fit a Q1d15 format. So the result is scaled up by 8 to obtain the proper magnitudes. The algorithm expects the angle to be in degrees and represented in Q10.6 format. The computed sine value is returned in Q1.15 format.

### Preconditions

none.

### Parameters

| Parameters | Description |
|---|---|
| q15 angle | The angle in degrees for which the sine is computed in Q10.6 |

## libq_q31_Abs_q31 Function

Saturated Absolute value.

### File

libq_C.h

### C

```
q31 libq_q31_Abs_q31(q31);
```

### Returns

q31 result - abs(a) <= MAXFRACT32

### Description

Function libq_q31_Abs_q31:

Creates a saturated Absolute value. It takes the absolute value of the 32-bit 2s-complement fractional input with saturation. The saturation is for handling the case where taking the absolute value of MINFRACT32 is greater than MAXFRACT32, or the allowable range of 32-bit values.

This function relates to the ETSI L_abs function.

## libq_q31_Add_q31_q31 Function

Add two 32-bit 2s-complement fractional values.

### File

libq_C.h

### C

```
q31 libq_q31_Add_q31_q31(q31, q31);
```

### Returns

q31 result a+b on range: MINFRACT32 <= result <= MAXFRACT32

### Description

Function libq_q31_Add_q31_q31:

Add two 32-bit 2s-complement fractional (op1 + op2) to produce a 32-bit 2s-complement fractional result with saturation. The saturation is for handling the overflow/underflow cases, where the result is set to MAX32 when an overflow occurs and the result is set to MIN32 when an underflow occurs. This function does not produce any status flag to indicate when an overflow or underflow has occured. It is assumed that the binary point is in exactly the same bit position for both 32-bit inputs and the resulting 32-bit output. This function relates to the ETSI L_add function.

## libq_q31_DepositH_q15 Function

Place 16 bits in the upper half of 32 bit word.

### File

libq_C.h

### C

```
q31 libq_q31_DepositH_q15(q15);
```

### Returns

q31 result 16-bits of a in upper MSB's and zeros in the lower LSB's

### Description

Function libq_q31_DepositH_q15:

Composes a 32-bit fractional value by placing the input 16-bit fractional value in the composite MSB's and zeros the composite 16-bit LSB's This is a bit-for-bit placement of input 16-bits into the upper part of 32-bit result.

This function relates to the ETSI L_deposit_H function.

## libq_q15_Sub_q15_q15 Function

Subtract two 16-bit 2s-complement fractional values

### File

libq_C.h

### C

```
q15 libq_q15_Sub_q15_q15(q15, q15);
```

### Returns

q15 result a+b on range: MINFRACT16 <= result <= MAXFRACT16

### Description

Function libq_q15_Sub_q15_q15:

Subtract two 16-bit 2s-complement fractional (op1 - op2) to produce a 16-bit 2s-complement fractional difference result with saturation. The saturation is for handling the overflow/underflow cases, where the result is set to MAX16 when an overflow occurs and the result is set to MIN16 when an underflow occurs. This function does not produce any status flag to indicate when an overflow or underflow has occured. It is assumed that the binary point is in exactly the same bit position for both 16-bit inputs and the resulting 16-bit output. This function relates to the ETSI sub function.

## libq_q31_DepositL_q15 Function

Place 16 bits in the lower half of 32 bit word.

### File

libq_C.h

### C

```
q31 libq_q31_DepositL_q15(q15);
```

### Returns

q31 result - SignExtended 16-bit MSB's and a Value in lower 16-bit LSB's

### Description

Function libq_q31_DepositL_q15:

Composes a 32-bit fractional value by placing the 16-bit Fraction input value into the lower 16-bits of the 32-bit composite value. The 16-bit MSB's of the composite output are sign extended. This is a bit-for-bit placement of input 16-bits into the bottom portion of the composite 32-bit result with sign extention. This function relates to the ETSI L_deposit_l function.

## libq_q31_Multi_q15_q31 Function

Implement 16 bit by 32 bit multiply.

### File

libq_C.h

### C

```
q31 libq_q31_Multi_q15_q31(q15 argAQ1d15, q31 argBQ1d31);
```

### Returns

q31 result - a*b rounded

### Description

Function libq_q31_Multi_q15_q31():

Implement 16 bit by 32 bit multiply as shown below The 's' and 'u' notation shows the processing of signed and unsigned numbers.

-B1- -B0- s u 2nd argument is 32 bits -A0- s 1st argument is 16 bits

### ------------

A0B0 A0B0 s=s*u 1st 32-bit product is A0*B0 A0B1 A0B1 s=s*s 2nd 32-bit product is A0*B1

### ------------

-S2- -S1- -S0- s=s+s 48-bit result is the sum of products -P1- -P0- 32-bit return is the most significant bits of sum

The algorithm is implemented entirely with the fractional arithmetic library. The unsigned by signed multiply is implemented by shifting bits 15:1 to bits 14:0 of a 16-bit positive fractional number, which throws away bit 0 of the 32-bit number. Since that affects result bits that are used for rounding, rounding processing is included. Saturation processing is handled implicitly in the fractional arithmetic library, except for the case of maximum negative numbers.

## libq_q31_Negate_q31 Function

Negate 32-bit 2s-complement fractional value with saturation.

### File

libq_C.h

### C

```
q31 libq_q31_Negate_q31(q31);
```

### Returns

q31 result on range: MINFRACT32 <= result <= MAXFRACT32

### Description

Function libq_q31_Negate_q31:

Negate 32-bit 2s-complement fractional value with saturation. The saturation is for handling the case where negating a MINFRACT32 is greater than MAXFRACT32, or the allowable range of values. This function relates to the ETSI L_negate function.

## libq_q15_ExpAvg_q15_q15_q1d15 Function

Exponential averaging

### File

libq_C.h

### C

```
q15 libq_q15_ExpAvg_q15_q15_q1d15(q15 prevAvgQ15, q15 newMeasQ15, q15 lamdaQ1d15);
```

### Returns

q15 result - S(k+1) = S(k)*L + X(k)*(1-L)

### Description

Function libq_q15_ExpAvg_q15_q15_q1d15()

Exponential averaging implements a smoothing function based on the form: avg[i+1] = avg[i] * lamda + new * (1-lamda) In this implementation, is has been optimized as follows. avg[i+1] = (avg[i] - new) * lamda + new

The optimization precludes accurate processing of new numbers that differ from the current average by more than unity. If the difference is greater than unity or less than negative unity, the difference is saturated.

The effect is akin to a smaller lambda, e.g., the new value will have a greater weight than expected. If the smoothing is of data that is entirely positive or entirely negative, then the saturation will not be an issue.

### Parameters

| Parameters | Description |
|---|---|
| q15 S(k) | Previous exponential average |
| q15 X(k) | New value to be averaged in |
| q15 L | exponential averaging constant in Q1.15 |

## libq_q31_Mac_q31_q15_q15 Function

Multiply-Accumulate function WITH saturation

### File

libq_C.h

### C

```
q31 libq_q31_Mac_q31_q15_q15(q31, q15, q15);
```

### Returns

q31 result, a+b*c saturated

### Description

Function libq_q31_Mac_q31_q15_q15():

Performs a Multiply-Accumulate function WITH saturation. This routine returns the fully fractional 32-bit result From the accumulator output 'SAT(addOut_Q1d31)=outQ1d15' where 'multOut_Q1d31 + a_Q1d31 = addOut_Q1d31', and 'b_Q1d15 x c_Q1d15 = multOut_Q1d31'. The multiply is performed on the two 16-bit fully fully fractional input values 'b x c' which results in a 32-bit value. This result is left shifted by one to account for the extra sign bit inherent in the fully fully fractional-type multiply. The shifted number represents a Q1d31 number with the lsb set to '0'. This Q1d31 number is added with the 32-bit fully fully fractional input argument 'a'. Saturation is applied on the output of the accumulator to keep the value within the 32-bit fully fractional range and then this value is returned. This function is for fully fractional Q-type format data only and it therefore will not give the correct results for true integers.

This function relates to the ETSI L_mac function.

### Parameters

| Parameters | Description |
| --- | --- |
| q31 a | 32-bit accumulator operand 1 in Q1d31 |
| q15 b | 16-bit multiplication operand 1 in Q1d15 |
| q15 c | 16-bit multiplication operand 2 in Q1d15 |

## libq_q31_Msu_q31_q15_q15 Function

### File

libq_C.h

### C

```
q31 libq_q31_Msu_q31_q15_q15(q31, q15, q15);
```

### Description

L_msu(a,b,c)

## libq_q31_ShiftLeft_q31_i16 Function

'Arithmetic' Shift of the 32-bit value.

### File

libq_C.h

### C

```
q31 libq_q31_ShiftLeft_q31_i16(q31, i16);
```

### Returns

q31 result - arithmetically shifted 32-bit signed integer output

### Description

Function libq_q31_ShiftLeft_q31_i16:

Performs an 'Arithmetic' Shift of the 32-bit input argument 'a' left by the input argument 'b' bit positions. If 'b' is a positive number, a 32-bit left shift is performed with 'zeros' inserted to the right of the shifted bits. If 'b' is a negative number, a 32-bit right shift by b bit positions with 'sign extention':

positive value: # of bits to left shift (zeros inserted at LSB's) negative value: # of bits to right shift (sign extend)

Saturation is applied if shifting causes an overflow or an underflow.

This function relates to the ETSI L_shl function.

### Parameters

| Parameters | Description |
| --- | --- |
| q31 a | 32-bit signed integer value to be shifted |
| i16 | 16-bit signed integer shift index |

## libq_q20d12_Sin_q20d12 Function

3rd order Polynomial apprx. of a sine function

### File

libq_C.h

### C

```
q31 libq_q20d12_Sin_q20d12(q31 angQ20d12);
```

### Returns

q31 Sine(angle) value in Q20.12

### Description

Function libq_q20d12_Sin_q20d12:

3rd order Polynomial apprx. of a sine function

## Preconditions

none.

## Parameters

| Parameters | Description |
|---|---|
| q31 angle | The angle in radians for which the sine is computed in Q20.12 |

# Fx16Norm Function

Normalize the 16-bit fractional value.

## File

libq_C.h

## C

```
int16_t Fx16Norm(q15);
```

## Returns

i16 result - The number of left shifts required to normalize

## Description

Function Fx16Norm:

Produces then number of left shifts needed to Normalize the 16-bit fully fractional input. If the input 'a' is a positive number, it will produce the number of left shifts required to normalized it to the range of a minimum of [(MAXFRACT16+1)/2] to a maximum of [MAXFRACT16]. If the input 'a' is a negative number, it will produce the number of left shifts required to normalized it to the range of a minimum of [MINFRACT16] to a maximum of [MINFRACT16/2]. This function does not actually normalize the input, it just produces the number of left shifts required. To actually normalize the value the left shift function should be used with the value returned From this function.

the 16-bit input on range: 0 => result < 16 (i.e. NUMBITSFRACT16) If a>0: 0x4000 > Normalized Value <= 0x7fff i.e. (MAXFRACT16+1)/2 > aNorm <= MAXFRACT16 If a<0: 0x8000 >= Normalilzed Value < 0xC000 i.e. MINFRACT16>= aNorm < MINFRACT16/2

This function relates to the ETSI norm_s function.

## Parameters

| Parameters | Description |
|---|---|
| q15 | a in Q1.15 |

# Fx32Norm Function

Normalize the 32-bit number.

## File

libq_C.h

## C

```
int16_t Fx32Norm(q31);
```

## Returns

int16_t result - The number of left shifts required to normalize the

## Description

Function Fx32Norm:

Produces then number of left shifts needed to Normalize the 32-bit fractional input. If the input 'a' is a positive number, it will produce the number of left shifts required to normalized it to the range of a minimum of [(MAXFRACT32+1)/2] to a maximum of [MAXFRACT32]. If the input 'a' is a negative number, it will produce the number of left shifts required to normalized it to the range of a minimum of [MINFRACT32] to a maximum of [MINFRACT32/2]. This function does not actually normalize the input, it just produces the number of left shifts required. To actually normalize the value the left-shift function should be used with the value returned From this function.

32-bit input on range: 0 => result < 32 (i.e. NUMBITSFRACT32) If a>0: 0x40000000 > Normalized Value <= 0x7fffffff i.e. (MAXFRACT32+1)/2 > aNorm <= MAXFRACT32 If a<0: 0x80000000 >= Normalized Value < 0xC0000000 i.e. MINFRACT32>= aNorm < MINFRACT32/2

This function relates to the ETSI norm_l function.

## Parameters

| Parameters | Description |
|---|---|
| q31 a | 32-bit Q1.d31 to be normalized |

## libq_q15_MultipyR2_q15_q15 Function

fractional multiplication of two 16-bit fractional values giving a 16 bit rounded result.

### File

libq_C.h

### C

```
q15 libq_q15_MultipyR2_q15_q15(q15, q15);
```

### Returns

q15 result - a*b rounded 16-bit signed integer (Q1.15) output value

### Description

Function libq_q15_MultipyR2_q15_q15:

Performs fractional multiplication of two 16-bit fractional values and returns a ROUNDED 16-bit fractional result. The function performs a Q15xQ15->Q30 bit multiply with a left shift by '1' to give a Q31 result. This automatic shift left is done to get rid of the extra sign bit that occurs in the interpretation of the fractional multiply result. Saturation is applied to any 32-bit result that overflows. Rounding is applied to the 32-bit SHIFTED result by adding in a weight factor of 2^15, again any overflows are saturated. The TOP 16-bits are extracted and returned. This function is for fractional 'Qtype' data only and it therefore will not give the correct results for true integers (because left shift by '1'). This function assumes that the binary point in the 32-bit shifted multiplier output is between bit_16 and bit_15 when the rounding factor is added. For the special case where both inputs equal the MINFACT16, the function returns a value equal to MAXFACT16, i.e. 0x7fff = 'libq_q15_Mult_q15_q15(0x8000,0x8000)'. This function internally calls the libq_q15_mult_q15_q31() routine to perform the actual multiplication and the rounding routine to perform the actual rounding.

This function relates to the ETSI mult_r function.

### Parameters

| Parameters | Description |
|---|---|
| q15 a | value in Q1.15 |
| q15 b | value in Q1.15 |

## libq_q15_ShiftLeft_q15_i16 Function

'Arithmetic' Shift of the 16-bit input argument.

### File

libq_C.h

### C

```
q15 libq_q15_ShiftLeft_q15_i16(q15, i16);
```

### Returns

q15 result - arithmetically shifted 16-bit signed integer output

### Description

Function libq_q15_ShiftLeft_q15_i16:

Performs an 'Arithmetic' Shift of the 16-bit input argument 'a' left by the input argument 'b' bit positions. If 'b' is a positive number, a 16-bit left shift is performed with 'zeros' inserted to the right of the shifted bits. If 'b' is a negative number, a right shift by abs(b) positions with 'sign extention' Saturation is applied if shifting causes an overflow or an underflow.

positive value: # of bits to left shift (zeros inserted at LSB's) {To not always saturate: if 'a=0', then max b=15, else max b=14} negative value: # of bits to right shift (sign extend)

This function relates to the ETSI shl function.

## Parameters

| Parameters | Description |
| --- | --- |
| q15 a | 16-bit signed integer value to be shifted. |
| i16 b | 16-bit signed integer shift value |

# libq_q15_ShiftRight_q15_i16 Function

'Arithmetic' RIGHT Shift on a 16-bit value.

## File

libq_C.h

## C

```
q15 libq_q15_ShiftRight_q15_i16(q15, i16);
```

## Returns

q15 result - 16-bit signed shifted output

## Description

Function libq_q15_ShiftRight_q15_q15:

Performs an 'Arithmetic' RIGHT Shift on a 16-bit input by 'b' bit positions. For positive shift directions (b>0), 'b' Lsb-bits are shifted out to the right and 'b' sign-extended Msb-bits fill in From the left. For negative shift directions (b<0), 'b' Lsb's are shifted to the LEFT with 0's filling in the empty lsb position. The left shifting causes 'b' Msb-bits to fall off to the left, saturation is applied to any shift left value that overflows. This function calls the left-shift function to perform any 16-bit left shifts. This function does not provide any status-type information to indicate when overflows occur.

positive value: # of bits to right shift (sign extend) { To get all sign bits, b>=15 } negative value: # of bits to left shift (zeros inserted at LSB's)

This function relates to the ETSI shr function.

## Parameters

| Parameters | Description |
| --- | --- |
| q15 a | 16-bit signed input value to shift |
| i16 b | 16-bit signed integer shift index |

# libq_q15_ShiftRightRound_q15_i16 Function

Performs an 'Arithmetic' RIGHT Shift on a 16-bit input.

## File

libq_C.h

## C

```
q15 libq_q15_ShiftRightRound_q15_i16(q15, i16);
```

## Returns

q15 result - Arithmetically shifted 16-bit signed integer output

## Description

Function libq_q15_ShiftRightRound_q15_q15:

Performs an 'Arithmetic' RIGHT Shift on a 16-bit input by 'b' bits with Rounding applied. The rounding occurs by adding a bit weight of "1/2 Lsb", where the "Lsb" is the Ending (shifted) Lsb. For example: The initial Bit#(b) is after the right shift Bit#(0), so the rounding bit weight is Bit#(b-1). Rounding does not occur on either left shifts or on no shift needed cases. For positive shift directions (b>0), 'b' Lsb-bits are shifted out to the right and 'b' sign-extended Msb-bits fill in From the left. For negative shift directions (b<0), 'b' Lsb's are shifted to the LEFT with 0's filling in the empty lsb position. The left shifting causes 'b' Msb-bits to fall off to the left, saturation is applied to any shift left value that overflows. This function calls the left-shift function to perform the actual 16-bit left shift. This function does not provide any status-type information to indicate when overflows occur.

positive value: # of bits to right shift (sign extend) {b > 15, results in all sign bits} negative value: # of bits to left shift (zeros inserted at LSB's)

This function relates to the ETSI shr_r function.

## Parameters

| Parameters | Description |
| --- | --- |
| q15 a | 16-bit signed integer value to be shifted |
| i16 b | 16-bit signed integer shift index |

# libq_q31_Mult2_q15_q15 Function

fractional multiplication of two 16-bit fractional values.

## File

libq_C.h

## C

```
q31 libq_q31_Mult2_q15_q15(q15, q15);
```

## Returns

q31, a*b

## Description

Function libq_q31_Mult2_q15_q15:

Performs fractional multiplication of two 16-bit fractional values and returns the 32-bit fractional scaled result. The function performs the Q15xQ15->Q30 fractional bit multiply. It then shifts the result left by '1', to give a Q31 type result, (the lsb is zero-filled). This automatic shift left is done to get rid of the extra sign bit that occurs in the interpretation of the fractional multiply result. Saturation is applied to any results that overflow, and then the function returns the 32-bit fractional q31 result. This function is for fractional 'Q' data only and it therefore will not give correct results for true integers (because left shift by '1'). For the special case where both inputs equal the MINFRACT16, the function returns a value equal to MAXFACT32, i.e. 0x7fffffff = libq_q15_mult_q15_q31(0x8000,0x8000).

This function relates to the ETSI L_mult function.

## Parameters

| Parameters | Description |
| --- | --- |
| q15 a | multiplicand a |
| q15 b | multiplicand b |

# libq_q31_ShiftRight_q31_i16 Function

'Arithmetic' RIGHT Shift on a 32-bit value.

## File

libq_C.h

## C

```
q31 libq_q31_ShiftRight_q31_i16(q31, i16);
```

## Returns

q31 result - Arithmetically shifted 32-bit signed integer output

## Description

Function libq_q31_ShiftRight_q31_q15:

Performs an 'Arithmetic' RIGHT Shift on a 32-bit input by 'b' bit positions. For positive shift directions (b>0), 'b' Lsb-bits are shifted out to the right and 'b' sign-extended Msb-bits fill in From the left. For negative shift directions (b<0), 'b' Lsb's are shifted to the LEFT with 0's filling in the empty lsb position. The left shifting causes 'b' Msb-bits to fall off to the left, saturation is applied to any shift left value that overflows. This function calls the left-shift function to perform any 32-bit left shifts. This function does not provide any status-type information to indicate when overflows occur.

positive value: # of bits to right shift (sign extend) negative value: # of bits to left shift (zeros inserted at LSB's)

This function relates to the ETSI L_shr function.

## Parameters

| Parameters | Description |
| --- | --- |
| q31 a | 32-bit signed integer value to be shifted |
| i16 b | 16-bit signed integer shift index |

## libq_q31_ShiftRightRound_q31_i16 Function

'Arithmetic' RIGHT Shift on a 32-bit value

### File

libq_C.h

### C

```
q31 libq_q31_ShiftRightRound_q31_i16(q31, i16);
```

### Returns

q31 result - Arithmetically shifted 32-bit signed integer output

### Description

Function libq_q31_ShiftRightRound_q31_q15:

Performs an 'Arithmetic' RIGHT Shift on a 32-bit input by 'b' bits with Rounding applied. The rounding occurs before any shift by adding a bit weight of "1/2 Lsb", where the "Lsb" is the Ending (shifted) Lsb. For example: The initial Bit#(i+b) is after the right shift Bit#(i), so the rounding bit weight is Bit#(i+b-1). Rounding does not occur on left shifts, when b is negative. After rounding, this function calls the right-shift function to perform the actual 32-bit right shift. For positive shift directions (b>0), 'b' Lsb-bits are shifted out to the right and 'b' sign-extended Msb-bits fill in From the left. For negative shift directions (b<0), 'b' Lsb's are shifted to the LEFT with 0's filling in the empty lsb position. The left shifting causes 'b' Msb-bits to fall off to the left, saturation is applied to any shift left value that overflows. This function calls the left-shift function to perform the actual 32-bit left shift. This function does not provide any status-type flag to indicate occurence of overflow.

positive value: # of bits to right shift (sign extend) negative value: # of bits to left shift (zeros inserted at LSB's)

This function relates to the ETSI L_shr_r function.

### Parameters

| Parameters | Description |
|---|---|
| q31 a | 32-bit signed integer value to be shifted |
| i16 b | 16-bit signed integer shift index |

## libq_q31_Sub_q31_q31 Function

Subtract two 32-bit 2s-complement fractional values

### File

libq_C.h

### C

```
q31 libq_q31_Sub_q31_q31(q31, q31);
```

### Returns

q31 result a+b on range: MINFRACT31 <= result <= MAXFRACT31

### Description

Function libq_q31_Sub_q31_q31:

Subtract two 32-bit 2s-complement fractional (op1 - op2) to produce a 16-bit 2s-complement fractional difference result with saturation. The saturation is for handling the overflow/underflow cases, where the result is set to MAX32 when an overflow occurs and the result is set to MIN32 when an underflow occurs. This function does not produce any status flag to indicate when an overflow or underflow has occured. It is assumed that the binary point is in exactly the same bit position for both 16-bit inputs and the resulting 16-bit output. This function relates to the ETSI sub function.

## *Data Types and Constants*

## q15 Type

### File

libq_C.h

### C

```
typedef int16_t q15;
```

### Description

q15 n.n (signed)

## q31 Type

### File

libq_C.h

### C

```
typedef int32_t q31;
```

### Description

q31 n.n (signed)

## q63 Type

### File

libq_C.h

### C

```
typedef int64_t q63;
```

### Description

Q63 n.n (signed)

## _LIBQ_C_H_ Macro

### File

libq_C.h

### C

```
#define _LIBQ_C_H_
```

### Description

This is macro _LIBQ_C_H_.

## BITMASKFRACT16 Macro

### File

libq_C.h

### C

```
#define BITMASKFRACT16 (~((uint16_t)0x0))      /* Bit Mask for 16 */
```

### Description

Bit Mask for 16

## BITMASKFRACT32 Macro

### File

libq_C.h

### C

```
#define BITMASKFRACT32 (~((uint32_t)0x0L))     /* Bit Mask for 32 */
```

### Description

Bit Mask for 32

## Fl2Fract16 Macro

Converts floating point constant value to fractional 16-bit value

### File

libq_C.h

### C

```
#define Fl2Fract16(value) \
( \
  (q15)Fl2FxPnt((value), 15) \
)
```

### Returns

q15 - Equivalent fractional value

### Description

Function Fl2Fract16:

Converts floating point constant value to fractional 16-bit value with rounding.

### Parameters

| Parameters | Description |
| --- | --- |
| value | Floating point value constant expression to convert. |

## Fl2Fract32 Macro

Converts floating point constant value to fractional 32-bit value

### File

libq_C.h

### C

```
#define Fl2Fract32(value) \
( \
  (q31)Fl2FxPnt((value), 31) \
)
```

### Returns

Equivalent fractional value as AtiFract32.

### Description

Function Fl2Fract32:

Converts floating point constant value to fractional 32-bit value with rounding.

### Parameters

| Parameters | Description |
| --- | --- |
| value | Floating point value constant expression to convert. |

## Fl2FxPnt Macro

Converts floating point constant value to fixed/fractional value

### File

libq_C.h

### C

```
#define Fl2FxPnt(value, bits) \
( \
```

```
    ((double)(value)*(double)(1UL<<(bits))) + \
      (((double)((double)(value) >= 0.0)) - ((double)0.5)) \
  )
```

## Returns

double - Equivalent floating point value

## Description

Function Fl2FxPnt:

Converts floating point constant value to fixed/fractional value of specified precision with rounding.

## Parameters

| Parameters | Description |
| --- | --- |
| value | Floating point value constant expression to convert. |
| int_t bits | Number of fractional bits. |

# Fl2FxPnt16 Macro

Converts floating point constant value to fixed point 16-bit value

## File

libq_C.h

## C

```
#define Fl2FxPnt16(value, bits) \
( \
  (q15)Fl2FxPnt((value), (bits)) \
)
```

## Returns

q15 - Equivalent fixed point value

## Description

Function Fl2FxPnt16:

Converts floating point constant value to fixed point 16-bit value with rounding.

## Parameters

| Parameters | Description |
| --- | --- |
| value | Floating point value constant expression to convert. int_t bits -- Number of fractional bits. |

# Fl2FxPnt32 Macro

Converts floating point constant value to fixed point 32-bit value

## File

libq_C.h

## C

```
#define Fl2FxPnt32(value, bits) \
( \
  (q31)Fl2FxPnt((value), (bits)) \
)
```

## Returns

q31 - Equivalent fixed point value

## Description

Function Fl2FxPnt32:

Converts floating point constant value to fixed point 32-bit value with rounding.

### Parameters

| Parameters | Description |
|---|---|
| value | Floating point value constant expression to convert. |
| int_t bits | Number of fractional bits. |

## Fl2Int16 Macro

Converts floating point constant expression to 16-bit integer value

### File

libq_C.h

### C

```
#define Fl2Int16(value) ((int16_t)((double)(value)))
```

### Returns

int_t - Calculated value.

### Description

Function Fl2Int16:

Converts floating point constant expression to 16-bit integer value Conversion is safe for compilers which assign fractional data type to constants with decimal point

### Parameters

| Parameters | Description |
|---|---|
| value | Floating point value constant expression to convert. |

## Fl2Int32 Macro

Converts floating point constant expression to 32-bit integer value

### File

libq_C.h

### C

```
#define Fl2Int32(value) ((int32_t)((double)(value)))
```

### Returns

int_t - Calculated integer value.

### Description

Function Fl2Int32:

Converts floating point constant expression to 32-bit integer value Conversion is safe for compilers which assign fractional data type to constants with decimal point

### Parameters

| Parameters | Description |
|---|---|
| value | Floating point value constant expression to convert. |

## FrMax Macro

### File

libq_C.h

### C

```
#define FrMax(a,b) ((a)>(b)?(a):(b))
```

### Description

find the maximum of two numbers

## FrMin Macro

### File

libq_C.h

### C

```
#define FrMin(a,b) ((a)<(b)?(a):(b))
```

### Description

find the minimum of two numbers

## LOG102Q5D11 Macro

### File

libq_C.h

### C

```
#define LOG102Q5D11 Fl2FxPnt16(0.301029996,11)
```

### Description

log10(2) scaled to Q5.11 format

## MAXFRACT16 Macro

### File

libq_C.h

### C

```
#define MAXFRACT16 MAXINT16       /* +0.999969 */
```

### Description

0.999969

## MAXFRACT32 Macro

### File

libq_C.h

### C

```
#define MAXFRACT32 MAXINT32       /* +0.9999999995 */
```

### Description

0.9999999995

## MAXINT16 Macro

### File

libq_C.h

### C

```
#define MAXINT16 ((int16_t) 0x7fff)
```

### Description

Maximum and minimum values for 16-bit data types.

## MAXINT32 Macro

### File

libq_C.h

### C

```
#define MAXINT32 ((int32_t)0x7fffffffL)
```

### Description

This is macro MAXINT32.

## MAXPFLOAT32 Macro

### File

libq_C.h

### C

```
#define MAXPFLOAT32 {MAXFRACT16, MAXINT16}
```

### Description

minimum and maximum definitions for FX floating point data types

## MINFRACT16 Macro

### File

libq_C.h

### C

```
#define MINFRACT16 MININT16       /* -1.000000 */
```

### Description

1.000000

## MINFRACT32 Macro

### File

libq_C.h

### C

```
#define MINFRACT32 MININT32       /* -1.0000000000 */
```

### Description

1.0000000000

## MININT16 Macro

### File

libq_C.h

### C

```
#define MININT16 ((int16_t) (-MAXINT16 - 1))
```

### Description

This is macro MININT16.

## MININT32 Macro

### File

libq_C.h

### C

```
#define MININT32 ((int32_t)(-MAXINT32 - 1))
```

### Description

This is macro MININT32.

## MINPFLOAT32 Macro

### File

libq_C.h

### C

```
#define MINPFLOAT32 {MINFRACT16, MAXINT16}
```

### Description

This is macro MINPFLOAT32.

## MSBBITFRACT16 Macro

### File

libq_C.h

### C

```
#define MSBBITFRACT16 MININT16                /* 16-bit Sign Bit */
```

### Description

16-bit Sign Bit

## MSBBITFRACT32 Macro

### File

libq_C.h

### C

```
#define MSBBITFRACT32 MININT32                /* 32-bit Sign Bit */
```

### Description

32-bit Sign Bit

## NINETYQ10D22 Macro

### File

libq_C.h

### C

```
#define NINETYQ10D22 Fl2FxPnt32(90,22)  /* Ninety degrees scaled to Q10d22*/
```

### Description

Ninety degrees scaled to Q10d22

## NINETYQ10D6 Macro

### File

libq_C.h

### C

```
#define NINETYQ10D6 Fl2FxPnt16(90,6)   /* Ninety degrees scaled to Q10d6 */
```

### Description

Ninety degrees scaled to Q10d6

## NORMNEGFRACT16 Macro

### File

libq_C.h

### C

```
#define NORMNEGFRACT16 ((q15)0xc000)          /* Max -val for 16 */
```

### Description

Max -val for 16

## NORMNEGFRACT32 Macro

### File

libq_C.h

### C

```
#define NORMNEGFRACT32 ((q31)0xc0000000L)     /* Max -val for 32 */
```

### Description

Max -val for 32

## NORMPOSFRACT16 Macro

### File

libq_C.h

### C

```
#define NORMPOSFRACT16 ((q15)0x4000)          /* Min +val for 16 */
```

### Description

Min +val for 16

## NORMPOSFRACT32 Macro

### File

libq_C.h

### C

```
#define NORMPOSFRACT32 ((q31)0x40000000L)     /* Min +val for 32 */
```

### Description

Min +val for 32

## NUMBITSFRACT16 Macro

### File

libq_C.h

### C

```
#define NUMBITSFRACT16 ((int16_t)0x010)        /* Num of bits 16  */
```

### Description

Num of bits 16

## NUMBITSFRACT32 Macro

### File

libq_C.h

### C

```
#define NUMBITSFRACT32 ((int16_t)0x020)        /* Num of bits 32  */
```

### Description

Num of bits 32

## ONEEIGHTYQ10D22 Macro

### File

libq_C.h

### C

```
#define ONEEIGHTYQ10D22 Fl2FxPnt32(180,22) /* 180 degrees scaled to Q10d22   */
```

### Description

180 degrees scaled to Q10d22

## ONEEIGHTYQ10D6 Macro

### File

libq_C.h

### C

```
#define ONEEIGHTYQ10D6 Fl2FxPnt16(180,6)  /* 180 degrees scaled to Q10d6    */
```

### Description

180 degrees scaled to Q10d6

## ROUNDFRACT32 Macro

### File

libq_C.h

### C

```
#define ROUNDFRACT32 ((q31)0x00008000L)      /* Rounding value  */
```

### Description

Rounding value

## THREESIXTYQ10D22 Macro

### File

libq_C.h

### C

```
#define THREESIXTYQ10D22 Fl2FxPnt32(360,22) /* 360 degrees scaled to Q10d22   */
```

### Description

360 degrees scaled to Q10d22

## THREESIXTYQ10D6 Macro

### File

libq_C.h

### C

```
#define THREESIXTYQ10D6 Fl2FxPnt16(360,6)  /* 360 degrees scaled to Q10d6    */
```

### Description

360 degrees scaled to Q10d6

## TWOSEVENTYQ10D22 Macro

### File

libq_C.h

### C

```
#define TWOSEVENTYQ10D22 Fl2FxPnt32(270,22) /* 270 degrees scaled to Q10d22   */
```

### Description

270 degrees scaled to Q10d22

## TWOSEVENTYQ10D6 Macro

### File

libq_C.h

### C

```
#define TWOSEVENTYQ10D6 Fl2FxPnt16(270,6)  /* 270 degrees scaled to Q10d6    */
```

### Description

270 degrees scaled to Q10d6

## UNITYFLOAT Macro

### File

libq_C.h

### C

```
#define UNITYFLOAT 1.0
```

### Description

This is macro UNITYFLOAT.

## FxQFloat32 Variable

### File

libq_C.h

### C

```
struct {
  q15 man;
  i16 exp;
} FxQFloat32;
```

### Description

FxQFloat32 pseudo floating point type (limited floating point)

### Remarks

Extended FxQflExt32 used with f2Qfloat32)

## Exponent16ToQFloat32 Macro

Converts a power of 2 16-bit integer to 32-bit floating point value.

### File

libq_C.h

### C

```
#define Exponent16ToQFloat32(value) \
( \
  (((value) < 0) ? ((float)1.0/(float)(1UL<<(-(value)))): \
   ((float)(1UL<<(value)))) \
)
```

### Returns

32-bit floating point value of 2^n.

### Description

Function Exponent16ToQFloat32

Converts a power of 2 16-bit integer to 32-bit floating point value.

### Parameters

| Parameters | Description |
|---|---|
| int16_t | 16-bit integer number for power (expected to be a variable). |

## Fl2QFloat32 Macro

Converts a decimal floating-point constant expression to pseudo float

### File

libq_C.h

### C

```
#define Fl2QFloat32(mantissa, exponent) \
  { \
    Fl2Fract16(mantissa), \
    Fl2Int16(exponent) \
  }
```

### Returns

Calculated integer value.

### Description

Function Fl2QFloat32:

Converts a decimal floating-point constant expression to pseudo float

### Parameters

| Parameters | Description |
|---|---|
| mantissa | Floating-point value constant expression to convert to the mantissa portion of the floating-point number. |
| exponent | Integer value constant expression to convert to the exponent portion of the floating-point number. |

## i16 Type

### File

libq_C.h

### C

```c
typedef int16_t i16;
```

### Description

Q16d0

## Files

### Files

| Name | Description |
|---|---|
| libq_C.h | C-code fixed point math functions. |

### Description

This section lists the source and header files used by the LibQ Fixed-Point 'C' Math Library.

## *libq_C.h*

C-code fixed point math functions.

### Functions

| | Name | Description |
|---|---|---|
| | Fx16Norm | Normalize the 16-bit fractional value. |
| | Fx32Norm | Normalize the 32-bit number. |
| | libq_q15_Abs_q15 | Saturated Absolute value. |
| | libq_q15_Add_q15_q15 | Add two 16-bit 2s-complement fractional values. |
| | libq_q15_DivisionWithSaturation_q15_q15 | Fractional division with saturation. |
| | libq_q15_ExpAvg_q15_q15_q1d15 | Exponential averaging |
| | libq_q15_ExtractH_q31 | Extracts upper 16 bits of input 32-bit fractional value. |
| | libq_q15_ExtractL_q31 | Extracts lower 16-bits of input 32-bit fractional value.<br>Descriptionf Extracts lower 16-bits of input 32-bit fractional value and returns them as 16-bit fractional value. This is a bit-for-bit extraction of the bottom 16-bits of the 32-bit input. This function relates to the ETSI extract_l function. |
| | libq_q15_MacR_q31_q15_q15 | Multiply accumulate with rounding. |
| | libq_q15_MsuR_q31_q15_q15 | Multiply-Subtraction with rounding |
| | libq_q15_MultipyR2_q15_q15 | fractional multiplication of two 16-bit fractional values giving a 16 bit rounded result. |
| | libq_q15_Negate_q15 | Negate 16-bit 2s-complement fractional value with saturation. |
| | libq_q15_RoundL_q31 | Rounds the lower 16-bits of the 32-bit fractional input. |
| | libq_q15_ShiftLeft_q15_i16 | 'Arithmetic' Shift of the 16-bit input argument. |
| | libq_q15_ShiftRight_q15_i16 | 'Arithmetic' RIGHT Shift on a 16-bit value. |
| | libq_q15_ShiftRightRound_q15_i16 | Performs an 'Arithmetic' RIGHT Shift on a 16-bit input. |
| | libq_q15_Sub_q15_q15 | Subtract two 16-bit 2s-complement fractional values |
| | libq_q1d15_Sin_q10d6 | Approximates the sine of an angle. |
| | libq_q20d12_Sin_q20d12 | 3rd order Polynomial apprx. of a sine function |

| | | |
|---|---|---|
| | libq_q31_Abs_q31 | Saturated Absolute value. |
| | libq_q31_Add_q31_q31 | Add two 32-bit 2s-complement fractional values. |
| | libq_q31_DepositH_q15 | Place 16 bits in the upper half of 32 bit word. |
| | libq_q31_DepositL_q15 | Place 16 bits in the lower half of 32 bit word. |
| | libq_q31_Mac_q31_q15_q15 | Multiply-Accumulate function WITH saturation |
| | libq_q31_Msu_q31_q15_q15 | L_msu(a,b,c) |
| | libq_q31_Mult2_q15_q15 | fractional multiplication of two 16-bit fractional values. |
| | libq_q31_Multi_q15_q31 | Implement 16 bit by 32 bit multiply. |
| | libq_q31_Negate_q31 | Negate 32-bit 2s-complement fractional value with saturation. |
| | libq_q31_ShiftLeft_q31_i16 | 'Arithmetic' Shift of the 32-bit value. |
| | libq_q31_ShiftRight_q31_i16 | 'Arithmetic' RIGHT Shift on a 32-bit value. |
| | libq_q31_ShiftRightRound_q31_i16 | 'Arithmetic' RIGHT Shift on a 32-bit value |
| | libq_q31_Sub_q31_q31 | Subtract two 32-bit 2s-complement fractional values |

## Macros

| | Name | Description |
|---|---|---|
| | _LIBQ_C_H_ | This is macro _LIBQ_C_H_. |
| | BITMASKFRACT16 | Bit Mask for 16 |
| | BITMASKFRACT32 | Bit Mask for 32 |
| | Exponent16ToQFloat32 | Converts a power of 2 16-bit integer to 32-bit floating point value. |
| | Fl2Fract16 | Converts floating point constant value to fractional 16-bit value |
| | Fl2Fract32 | Converts floating point constant value to fractional 32-bit value |
| | Fl2FxPnt | Converts floating point constant value to fixed/fractional value |
| | Fl2FxPnt16 | Converts floating point constant value to fixed point 16-bit value |
| | Fl2FxPnt32 | Converts floating point constant value to fixed point 32-bit value |
| | Fl2Int16 | Converts floating point constant expression to 16-bit integer value |
| | Fl2Int32 | Converts floating point constant expression to 32-bit integer value |
| | Fl2QFloat32 | Converts a decimal floating-point constant expression to pseudo float |
| | FrMax | find the maximum of two numbers |
| | FrMin | find the minimum of two numbers |
| | LOG102Q5D11 | log10(2) scaled to Q5.11 format |
| | MAXFRACT16 | 0.999969 |
| | MAXFRACT32 | 0.9999999995 |
| | MAXINT16 | Maximum and minimum values for 16-bit data types. |
| | MAXINT32 | This is macro MAXINT32. |
| | MAXPFLOAT32 | minimum and maximum definitions for FX floating point data types |
| | MINFRACT16 | 1.000000 |
| | MINFRACT32 | 1.0000000000 |
| | MININT16 | This is macro MININT16. |
| | MININT32 | This is macro MININT32. |
| | MINPFLOAT32 | This is macro MINPFLOAT32. |
| | MSBBITFRACT16 | 16-bit Sign Bit |
| | MSBBITFRACT32 | 32-bit Sign Bit |
| | NINETYQ10D22 | Ninety degrees scaled to Q10d22 |
| | NINETYQ10D6 | Ninety degrees scaled to Q10d6 |
| | NORMNEGFRACT16 | Max -val for 16 |
| | NORMNEGFRACT32 | Max -val for 32 |
| | NORMPOSFRACT16 | Min +val for 16 |
| | NORMPOSFRACT32 | Min +val for 32 |
| | NUMBITSFRACT16 | Num of bits 16 |
| | NUMBITSFRACT32 | Num of bits 32 |
| | ONEEIGHTYQ10D22 | 180 degrees scaled to Q10d22 |
| | ONEEIGHTYQ10D6 | 180 degrees scaled to Q10d6 |
| | ROUNDFRACT32 | Rounding value |
| | THREESIXTYQ10D22 | 360 degrees scaled to Q10d22 |

| | | |
|---|---|---|
| | THREESIXTYQ10D6 | 360 degrees scaled to Q10d6 |
| | TWOSEVENTYQ10D22 | 270 degrees scaled to Q10d22 |
| | TWOSEVENTYQ10D6 | 270 degrees scaled to Q10d6 |
| | UNITYFLOAT | This is macro UNITYFLOAT. |

## Types

| | Name | Description |
|---|---|---|
| | i16 | Q16d0 |
| | q15 | q15 n.n (signed) |
| | q31 | q31 n.n (signed) |
| | q63 | Q63 n.n (signed) |

## Variables

| | Name | Description |
|---|---|---|
| | FxQFloat32 | FxQFloat32 pseudo floating point type (limited floating point) |

## Description

The libq_c Fixed-Point Math Library provides fixed-point math functions written in C for portability between core processors.

Signed fixed point types (fractional Q types specified by Qn.m) are named as follows in the library names:

Qndm where:

- n is the number of data bits to the left of the radix point
- m is the number of data bits to the right of the radix point
- a signed bit is implied (unless stated otherwise)

For convenience, short names are also defined for arbitrary scaled fractional types:

q15 is signed fractional 16 bit value q31 is signed fractional 32 bit value i16 is signed integer, i.e. Q16d0

In addition, A pseudo floating point 32 bit format (FxQFloat32) is defined that consists of 16 mantissa and a 16 bit exponant (base 2).

Functions in the library are prefixed with the type of the return value and followed by argument types (in order):

libq___: libq_q15_sin_Q2d13

For example, libq_q1d15_Sin_q10d6 returns a Q1.15 value equal to the to the sine of an angle specified as a Q10.6 value (in degrees between 0 and 360)

Argument types do not always match the return type. Refer to the function prototype for a specification of its arguments.

In some cases, both the return type and the argument type are specified within the function name. For example,

For arbitrary scaled types (q15, q16, q31, and q32) the scaling of the result will depend on the function and the scaling of the arguments. For instance, libq_q15_Add_q15_q15(a,b) will return a scaled value type that is the two input types (which must have equivalent scaled value type).

## Remarks

The libq_c functions do not correspond to the libq fixed-point library optimized for the microaptive core processor and written in asm.

Table of LIBQ_C math functions:

Sine: libq_q1d15_Sin_q10d6 libq_q20d12_Sin_q20d12

Abs: libq_q15_Abs_q15 libq_q31_Abs_q31

Negate: libq_q15_Negate_q15 libq_q31_Negate_q31

Round: libq_q15_RoundL_q31

Deposit: libq_q31_DepositH_q15 libq_q31_DepositL_q15

Extract: libq_q15_ExtractH_q31 libq_q15_ExtractL_q31

Add: libq_q15_Add_q15_q15 libq_q31_Add_q31_q31

Subtract: libq_q15_Sub_q15_q15 libq_q31_Sub_q31_q31

Shift(Scale): libq_q15_ShiftLeft_q15_q15 libq_q31_ShiftLeft_q31_q15 libq_q15_ShiftRight_q15_q15 libq_q31_ShiftRight_q31_q15 libq_q15_ShiftRightRound_q15_q15 libq_q31_ShiftRightRound_q31_q15

Multiply: libq_q15_Mult_q15_q15 libq_q15_MultipyR2_q15_q15 libq_q31_Multi_q15_q31

Divide: libq_q15_DivisionWithSaturation_q15_q15

Multiply-Accumulate: libq_q31_Mac_q31_q15_q15 libq_q15_MacR_q31_q15_q15

Multiply-Subtract: libq_q31_Msu_q31_q15_q15 libq_q15_MsuR_q31_q15_q15

Exponential-Averaging: libq_q15_ExpAvg_q15_q15_q1d15

Table of LIBQ_C conversion functions:

Normalize Q value: Fx16Norm Fx32Norm

Float-to-Q value: Fl2Fract16 Fl2Fract32 Fl2FxPnt16 Fl2FxPnt32 Fl2FxPnt

Float-To-Integer: Fl2Int16 Fl2Int32

Float-To-FxQFloat32: Fl2QFloat32

Exponent-To-Float: Exponent16ToFloat32

## File Name

libq_c.h

## Company

Microchip Technology Inc.

# *LibQ Fixed-Point Math Library*

This topic describes the LibQ Fixed-Point Math Library.

## Introduction

The LibQ Fixed-Point Math Library is available for the PIC32MZ family of microcontrollers. This library was created from optimized assembly routines written specifically for devices with microAptiv™ core features.

### Description

The LibQ Fixed-Point Math Library simplifies writing fixed point algorithms, supporting Q15, Q31 and other 16-bit and 32-bit data formats. Using the simple, C callable functions contained in the library, fast fixed point mathematical operations can be easily executed. Fixed-point mathematical calculations may replace some functions implemented in the floating point library (`math.h`), depending on performance and resolution requirements.

Functions included in the LibQ library include capabilities for trigonometric, power and logarithms, and data conversion. In many cases the functions are identical other than the precision of their operands and the corresponding value that they return.

These functions are implemented in efficient assembly, and generally tuned to optimize performance over code size. In some cases the library breaks out functions that enable one to be optimized for accuracy, while another version is optimized for speed. These functions such as _LIBQ_Q2_29_acos_Q31 and _LIBQ_Q2_29_acos_Q31_Fast are otherwise identical and can be used interchangeably. Each of these functions are typically used in computationally intensive real-time applications where execution time is a critical parameter.

## Using the Library

This topic describes the basic architecture of the LibQ Fixed-Point Math Library and provides information and examples on its use.

### Description

**Interface Header File**: `libq.h`

The interface to the LibQ Fixed-Point Math Library is defined in the `libq.h` header file. Any C language source (`.c`) file that uses the LibQ Fixed-Point Library should include `libq.h`.

**Library File**:

The LibQ Fixed-Point Math Library archive (`.a`) file is installed with MPLAB Harmony.

## *Library Overview*

The LibQ Fixed-Point Math Library contains functions for manipulating Q15, Q31 and other intermediate integer representations of real numbers. The Library Interface section details the operation of the data formats and explains each function in detail.

The library interface routines are divided into various sub-sections, which address one of the blocks or the overall operation of the DSP Fixed-Point Math Library.

| Library Interface Section | Description |
|---|---|
| Divide Functions | _Q16 fixed point divide function. |
| Square Root Functions | Square root of a positive _Q16 fixed point value function. |
| Log Functions | Log calculation functions. |
| Power Functions | Power calculation functions. |
| Exponential Functions | Exponential calculation functions. |
| Sine Functions | Sine calculation functions. |
| Cosine Functions | Cosine calculation functions. |
| Target Functions | Target calculation functions. |
| Arcsin Functions | Arcsin calculation functions. |
| Arccos Functions | Arccos calculation functions. |
| Arctan2 Functions | Arctan2 calculation functions. |
| Random Number Functions | _Q15 and _Q31 pseudo-random value functions. |
| Float Functions | Float conversion functions. |
| String Functions | ASCII to _Q15 conversions. |

Signed fixed-point types are defined as follows:

Q*n*_*m* where:

- *n* is the number of data bits to the left of the radix point
- *m* is the number of data bits to the right of the radix point
- a signed bit is implied

For convenience, short names are also defined:

| Exact Name | Number of Bits Required | Short Name |
|---|---|---|
| _Q0_15 | 16 | _Q15 |
| _Q15_16 | 32 | _Q16 |
| _Q0_31 | 32 | _Q31 |

*Qn_m* numerical values are used by the library processing data as integers. In this format the n represents the number of integer bits, and the m represents the number of fractional bits. All values assume a sign bit in the most significant bit. The range of the numerical value therefore is:

$$-2^{(n-1)} \text{ to } [2^{(n-1)} - 2^{(-m)}]\text{; with a resolution of } 2^{(-m)}.$$

A _Q16 format number (_Q15_16) would range from -32768.0 (0x8000 0000) to 32767.99998474 with a precision of 0.000015259 (or $2^{-16}$).

For example, a numerical representation of the number 3.14159 in _Q2_13 notation would be:

$$3.14159 * 2^{13} = 25735.9 => 0x6488$$

And converting from the _Q7_8 format with the value 0x1D89 would be:

$$0x1D89 / 2^{8} = 7561 / 256 => 29.5316\text{, accurate to } 0.00391$$

Functions in the library are prefixed with the type of the return value. For example, _LIBQ_Q16Sqrt returns a _Q16 value equal to the square root of its argument. Argument types do not always match the return type. Refer to the function prototype for a specification of its arguments.

In cases where the return value is not a fixed-point type, the argument type is appended to the function name. For example, _LIBQ_ToFloatQ31 accepts a type _Q31 argument.

In some cases, both the return type and the argument type are specified within the function name. For example:

| Function Name | Return Type | Argument Type |
|---|---|---|
| _LIBQ_Q15_sin_Q2_13 | _Q15 | _Q2_13 |
| _LIBQ_Q31_sin_Q2_29 | _Q31 | _Q2_29 |

## *Table of Library Functions*

| Math Function | Function Definition |
|---|---|
| Divide | _Q16 _LIBQ_Q16Div (_Q16 dividend, _Q16 divisor); |
| Square Root | _Q16 _LIBQ_Q16Sqrt (_Q16 x); |
| Exponential | _Q16 _LIBQ_Q16Exp (_Q16 x); |
| Log | _Q4_11 _LIBQ_Q4_11_ln_Q16 (_Q16 x);<br>_Q3_12 _LIBQ_Q3_12_log10_Q16 (_Q16 x);<br>_Q5_10 _LIBQ_Q5_10_log2_Q16 (_Q16 x); |
| Power | _Q16 _LIBQ_Q16Power (_Q16 x, _Q16 y); |
| Sine | _Q15 _LIBQ_Q15_sin_Q2_13 (_Q2_13 x);<br>_Q31 _LIBQ_Q31_sin_Q2_29 (_Q2_29 x); |
| Cosine | _Q15 _LIBQ_Q15_cos_Q2_13 (_Q2_13 x);<br>_Q31 _LIBQ_Q31_cos_Q2_29 (_Q2_29 x); |
| Tangent | _Q7_8 _LIBQ_Q7_8_tan_Q2_13 (_Q2_13 x);<br>_Q16 _LIBQ_Q16_tan_Q2_29 (_Q2_29 x); |
| Arcsin | _Q2_13 _LIBQ_Q2_13_asin_Q15 (_Q15 x);<br>_Q2_29 _LIBQ_Q2_29_asin_Q31 (_Q31 x);<br>_Q2_29 _LIBQ_Q2_29_asin_Q31_Fast (_Q31 x); |
| Arccos | _Q2_13 _LIBQ_Q2_13_acos_Q15 (_Q15 x);<br>_Q2_29 _LIBQ_Q2_29_acos_Q31 (_Q31 x);<br>_Q2_29 _LIBQ_Q2_29_acos_Q31_Fast (_Q31 x); |

| | |
|---|---|
| Arctan | _Q2_13 _LIBQ_Q2_13_atan_Q7_8 (_Q7_8 x);<br>_Q2_29 _LIBQ_Q2_29_atan_Q16 (_Q16 x); |
| Arctan2 | _Q2_13 _LIBQ_Q2_13_atan2_Q7_8 (_Q7_8 y, _Q7_8 x);<br>_Q2_29 _LIBQ_Q2_29_atan2_Q16 (_Q16 y, _Q16 x); |
| Random Number | _Q15 _LIBQ_Q15Rand (int64_t *pSeed);<br>_Q31 _LIBQ_Q31Rand (int64_t *pSeed); |
| Float | float _LIBQ_ToFloatQ31 (_Q31 x);<br>float _LIBQ_ToFloatQ15 (_Q15 x);<br>_Q31 _LIBQ_Q31FromFloat (float x);<br>_Q15 _LIBQ_Q15FromFloat (float x); |
| String | void _LIBQ_ToStringQ15 (_Q15 x, char *s);<br>_Q15 _LIBQ_Q15FromString (char *s); |

## Library Interface

### a) Divide Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q16Div | _Q16 fixed point divide. |

### b) Square Root Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q16Sqrt | Square root of a positive _Q16 fixed point value. |

### c) Log Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q3_12_log10_Q16 | Calculates the value of Log10(x). |
| | _LIBQ_Q4_11_ln_Q16 | Calculates the natural logarithm ln(x). |
| | _LIBQ_Q5_10_log2_Q16 | Calculates the value of log2(x). |

### d) Power Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q16Power | Calculates the value of x raised to the y power (x^y). |

### e) Exponential Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q16Exp | Calculates the exponential function e^x. |

### f) Sine Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q15_sin_Q2_13 | Calculates the value of sine(x). |
| | _LIBQ_Q31_sin_Q2_29 | Calculates the value of sine(x). |

### g) Cosine Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q15_cos_Q2_13 | Calculates the value of cosine(x). |
| | _LIBQ_Q31_cos_Q2_29 | Calculates the value of cosine(x). |

### h) Target Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q16_tan_Q2_29 | Calculates the value of tan(x). |
| | _LIBQ_Q7_8_tan_Q2_13 | Calculates the value of tan(x). |

## i) Arcsin Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q2_13_asin_Q15 | Calculates the asin value of asin(x). |
| | _LIBQ_Q2_29_asin_Q31 | Calculates the value of asin(x). |
| | _LIBQ_Q2_29_asin_Q31_Fast | Calculates the value of asin(x). This function executes faster than the _LIBQ_Q2_29_asin_Q31 function, but is less precise. |

## j) Arccos Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q2_13_acos_Q15 | Calculates the value of acos(x). |
| | _LIBQ_Q2_29_acos_Q31 | Calculates the value of acos(x). |
| | _LIBQ_Q2_29_acos_Q31_Fast | Calculates the value of acos(x). This function executes faster than _LIBQ_Q2_29_acos_Q31 but is less precise. |

## k) Arctan Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q2_13_atan_Q7_8 | Calculates the value of atan(x). |
| | _LIBQ_Q2_29_atan_Q16 | Calculates the value of atan(x). |

## l) Arctan2 Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q2_13_atan2_Q7_8 | Calculates the value of atan2(y, x). |
| | _LIBQ_Q2_29_atan2_Q16 | Calculates the value of atan2(y, x). |

## m) Random Number Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q15Rand | Generate a _Q15 random number. |
| | _LIBQ_Q31Rand | Generate a _Q31 random number. |

## n) Float Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q15FromFloat | Converts a float to a _Q15 value. |
| | _LIBQ_Q31FromFloat | Converts a float to a _Q31 value. |
| | _LIBQ_ToFloatQ15 | Converts a _Q15 value to a float. |
| | _LIBQ_ToFloatQ31 | Converts a _Q31 value to a float. |

## o) String Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q15FromString | ASCII to _Q15 conversion. |
| | _LIBQ_ToStringQ15 | _Q15 to ASCII conversion. |

## p) Data Types and Constants

| | Name | Description |
|---|---|---|
| | _Q15_MAX | Maximum value of _Q15 (~1.0) |
| | _Q15_MIN | Minimum value of _Q15 (-1.0) |
| | _Q16_MAX | Maximum value of _Q16 (~32768.0) |
| | _Q16_MIN | Minimum value of _Q16 (-32768.0) |
| | _Q2_13_MAX | Maximum value of _Q2_13 (~4.0) |
| | _Q2_13_MIN | Minimum value of _Q2_13 (-4.0) |
| | _Q2_29_MAX | Maximum value of _Q2_29 (~4.0) |
| | _Q2_29_MIN | Minimum value of _Q2_29 (-4.0) |
| | _Q3_12_MAX | Maximum value of _Q3_12 (~8.0) |
| | _Q3_12_MIN | Minimum value of _Q3_12 (-8.0) |
| | _Q31_MAX | Maximum value of _Q31 (~1.0) |
| | _Q31_MIN | Minimum value of _Q31 (-1.0) |
| | _Q4_11_MAX | Maximum value of _Q4_11 (~16.0) |

| | | |
|---|---|---|
| | _Q4_11_MIN | Minimum value of _Q4_11 (-16.0) |
| | _Q5_10_MAX | Maximum value of _Q5_10 (~32.0) |
| | _Q5_10_MIN | Minimum value of _Q5_10 (-32.0) |
| | _Q7_8_MAX | Maximum value of _Q7_8 (~128.0) |
| | _Q7_8_MIN | Minimum value of _Q7_8 (-128.0) |
| | _Q0_15 | 1 sign bit, 15 bits right of radix |
| | _Q0_31 | 1 sign bit, 31 bits right of radix |
| | _Q15 | Short name for _Q0_15 |
| | _Q15_16 | 1 sign bit, 15 bits left of radix, 16 bits right of radix |
| | _Q16 | Short name for _Q15_16 |
| | _Q2_13 | 1 sign bit, 2 bits left of radix, 13 bits right of radix |
| | _Q2_29 | 1 sign bit, 2 bits left of radix, 29 bits right of radix |
| | _Q3_12 | 1 sign bit, 3 bits left of radix, 12 bits right of radix |
| | _Q31 | Short name for _Q_0_31 |
| | _Q4_11 | 1 sign bit, 4 bits left of radix, 11 bits right of radix |
| | _Q5_10 | 1 sign bit, 5 bits left of radix, 10 bits right of radix |
| | _Q7_8 | 1 sign bit, 7 bits left of radix, 8 bits right of radix |
| | _LIBQ_H | Guards against multiple inclusion |

## Description

This section describes the Application Programming Interface (API) functions, macros, and types of the LibQ Fixed Point Math Library.

Refer to each section for a detailed description.

## *a) Divide Functions*

## _LIBQ_Q16Div Function

_Q16 fixed point divide.

### File

libq.h

### C

```
_Q16 _LIBQ_Q16Div(_Q16 dividend, _Q16 divisor);
```

### Returns

_Q16 quotient of the divide operation

### Description

Function _LIBQ_Q16Div:

_Q16 _LIBQ_Q16Div (_Q16 dividend, _Q16 divisor);

Quotient (_Q16) = Dividend (_Q16) / Divisor (_Q16).

### Remarks

The _LIBQ_Q16Div operation saturates its result.

Execution Time (cycles): 143 typical (80 to 244) Program Memory 204 bytes

Error <= 0.000015258789 (accurate to least significant _Q16 bit within the non-saturated range)

### Preconditions

Divisor must not equal 0.

### Example

```
_Q16  quotient, dividend, divisor;

dividend = (_Q16)0x00010000;  // 1
divisor  = (_Q16)0x00008000;  // 0.5

quotient = _LIBQ_Q16Div (dividend, divisor);
```

```
// quotient now equals 2;  i.e.,  (_Q16)0x00020000;
```

### Parameters

| Parameters | Description |
|---|---|
| dividend | The divide operation dividend (_Q16) |
| divisor | The divide operation divisor (_Q16) |

## *b) Square Root Functions*

## _LIBQ_Q16Sqrt Function

Square root of a positive _Q16 fixed point value.

### File

libq.h

### C

```
_Q16 _LIBQ_Q16Sqrt(_Q16 x);
```

### Returns

_LIBQ_Q16Sqrt returns the _Q16 fixed point value which is the square root of the input parameter.

### Description

Function _LIBQ_Q16Sqrt:

_Q16 _LIBQ_Q16Sqrt(_Q16 x);

Calculate the square root of a positive _Q16 fixed point value, and return the _Q16 result.

### Remarks

Execution Time (cycles): 240 typical (104 to 258) Program Memory 152 bytes

Error <= 0.000015258789 (accurate to least significant _Q16 bit)

### Preconditions

The input value must be positive.

### Example

```
_Q16 squareRoot;

squareRoot = _LIBQ_Q16Sqrt((_Q16)0x01000000);  // The square root of 256.0 is 16.0 (0x00100000)

squareRoot = _LIBQ_Q16Sqrt((_Q16)0x00004000);  // The square root of 0.25 is 0.5 (0x00008000)

squareRoot = _LIBQ_Q16Sqrt((_Q16)0x5851f42d);  // The square root of 22609.953125 is 150.366074 (0x00965db7)
```

### Parameters

| Parameters | Description |
|---|---|
| x | The _Q16 fixed point value input from which to find the square root. |

## *c) Log Functions*

## _LIBQ_Q3_12_log10_Q16 Function

Calculates the value of Log10(x).

### File

libq.h

## C

```
_Q3_12 _LIBQ_Q3_12_log10_Q16(_Q16 x);
```

## Returns

_LIBQ_Q3_12_log10_Q16 returns the _Q3_12 fixed point result from the calculation log10(x).

## Description

Function _LIBQ_Q3_12_log10_Q16:

_Q3_12 _LIBQ_Q3_12_log10_Q16 (_Q16 x);

Calculates the log10(x), where log10(x) = ln(x) * log10(e). x is of type _Q16 and must be positive. The resulting value is of type _Q3_12.

## Remarks

Execution Time (cycles): 301 typical (14 to 346) Program Memory 176 bytes

Error <= 0.000244140625 (accurate to least significant _Q3_12 bit)

## Preconditions

The input x must be positive.

## Example

```
_Q3_12 resultLog10;

resultLog10 = _LIBQ_Q3_12_log10_Q16 ((_Q16)0x12ed7d91);  // _LIBQ_Q3_12_log10_Q16(4845.490494) = 3.685303
(0x3af7)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The input value from which to calculate log10(x). |

# _LIBQ_Q4_11_ln_Q16 Function

Calculates the natural logarithm ln(x).

## File

libq.h

## C

```
_Q4_11 _LIBQ_Q4_11_ln_Q16(_Q16 x);
```

## Returns

_LIBQ_Q4_11_ln_Q16 returns the _Q4_11 fixed point result from the calculation ln(x).

## Description

Function _LIBQ_Q4_11_ln_Q16:

_Q4_11 _LIBQ_Q4_11_ln_Q16 (_Q16 x);

Calculates the natural logarithm ln(x). x is of type _Q16 and must be positive. The resulting value is of type _Q4_11.

## Remarks

Execution Time (cycles): 301 typical (14 to 346) Program Memory 176 bytes

Error <= 0.00048828 (accurate to least significant _Q4_11 bit)

## Preconditions

The input x must be positive.

## Example

```
_Q4_11 resultLN;

resultLN = _LIBQ_Q4_11_ln_Q16 ((_Q16)0x00004000);  // _LIBQ_Q4_11_LN_Q16(0.250000) = -1.386230 (0xf4e9)
```

### Parameters

| Parameters | Description |
|---|---|
| x | The input value from which to calculate ln(x). |

## _LIBQ_Q5_10_log2_Q16 Function

Calculates the value of log2(x).

### File

libq.h

### C

```
_Q5_10 _LIBQ_Q5_10_log2_Q16(_Q16 x);
```

### Returns

_LIBQ_Q5_10_log2_Q16 returns the _Q5_10 fixed point result from the calculation log2(x).

### Description

Function _LIBQ_Q5_10_log2_Q16:

_Q5_10 _LIBQ_Q5_10_log2_Q16 (_Q16 x);

Calculates the log2(x), where log2(x) = ln(x) * log2(e). x is of type _Q16 and must be positive. The resulting value is of type _Q5_10.

### Remarks

Execution Time (cycles): 227 typical (14 to 268) Program Memory 164 bytes

Error <= 0.0009765625 (accurate to least significant _Q5_10 bit)

### Preconditions

The input x must be positive.

### Example

```
_Q5_10 resultLog2;

resultLog2 = _LIBQ_Q5_10_log2_Q16 ((_Q16)0x40000000);  // _LIBQ_Q5_10_log2_Q16(16384.000000) = 14.000000
(0x3800)
```

### Parameters

| Parameters | Description |
|---|---|
| x | The input value from which to calculate log2(x). |

## *d) Power Functions*

## _LIBQ_Q16Power Function

Calculates the value of x raised to the y power (x^y).

### File

libq.h

### C

```
_Q16 _LIBQ_Q16Power(_Q16 x, _Q16 y);
```

### Returns

_LIBQ_Q16Power returns the _Q16 fixed point result from the calculation x raised to the y.

### Description

Function _LIBQ_Q16Power:

_Q16 _LIBQ_Q16Power (_Q16 x, _Q16 y);

Calculates the x raised to the y power. Both x and y are of type _Q16. x must be positive. The calculation will saturate if the resulting value is outside the range of the _Q16 representation.

## Remarks

Execution Time (cycles): 882 typical (586 to 1042) Program Memory 1038 bytes

Error <= 0.000015258789 (accurate to least significant _Q16 bit within the non-saturated range)

## Preconditions

x must be positive.

## Example

```
_Q16 resultPower;

resultPower = _LIBQ_Q16Power ((_Q16)0x00020000, (_Q16)0xffff0000);  // _LIBQ_Q16Power(2.000000, -1.000000)
= 0.500000 (0x00008000)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The _Q16 input value x from which to calculate x raised to the y. |
| y | The _Q16 input value y from which to calculate x raised to the y. |

# e) Exponential Functions

## _LIBQ_Q16Exp Function

Calculates the exponential function e^x.

## File

libq.h

## C

```
_Q16 _LIBQ_Q16Exp(_Q16 x);
```

## Returns

_LIBQ_Q16Exp returns the _Q16 fixed point result from the calculation e^x.

## Description

Function _LIBQ_Q16Exp:

_Q16 _LIBQ_Q16Exp(_Q16 x);

Calculates the exponential function e^x. The calculation will saturate if the resulting value is outside the range of the _Q16 representation. For x > 10.3972015380859375, the resulting value will be saturated to 0x7fffffff. For x < -10.3972015380859375 the resulting value will be saturated to 0.

## Remarks

The function _LIBQ_Q16Div is called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 170 typical (18 to 292) Program Memory 446 bytes

Error <= 0.000015258789 (accurate to least significant _Q16 bit within the non-saturated range)

## Preconditions

None.

## Example

```
_Q16 expResult;

expResult = _LIBQ_Q16Exp((_Q16)0x00010000);   // _LIBQ_Q16Exp(1.000000) = 2.718277 (0x0002b7e1)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The exponent value |

# f) Sine Functions

## _LIBQ_Q15_sin_Q2_13 Function

Calculates the value of sine(x).

### File

libq.h

### C

```
_Q15 _LIBQ_Q15_sin_Q2_13(_Q2_13 x);
```

### Returns

_LIBQ_Q15_sin_Q2_13 returns the _Q15 fixed point result from the calculation sine(x).

### Description

Function _LIBQ_Q15_sin_Q2_13:

_Q15 _LIBQ_Q15_sin_Q2_13 (_Q2_13 x);

Calculates the sine(x), where x is of type _Q2_13 radians and the resulting value is of type _Q15.

### Remarks

Execution Time (cycles): 100 typical (100 to 102) Program Memory 220 bytes

Error <= 0.00003052 (accurate to least significant _Q15 bit)

### Preconditions

None.

### Example

```
_Q15 resultSin;

resultSin = _LIBQ_Q15_sin_Q2_13 ((_Q2_13)0x4093);  // _LIBQ_Q15_sin_Q2_13(2.017944) = 0.901672 (0x736a)
```

### Parameters

| Parameters | Description |
|---|---|
| x | The _Q2_13 input value from which to calculate sine(x). |

## _LIBQ_Q31_sin_Q2_29 Function

Calculates the value of sine(x).

### File

libq.h

### C

```
_Q31 _LIBQ_Q31_sin_Q2_29(_Q2_29 x);
```

### Returns

_LIBQ_Q31_sin_Q2_29 returns the _Q31 fixed point result from the calculation sine(x).

### Description

Function _LIBQ_Q31_sin_Q2_29:

_Q31 _LIBQ_Q31_sin_Q2_29 (_Q2_29 x);

Calculates the sine(x), where x is of type _Q2_29 radians and the resulting value is of type _Q31.

### Remarks

Execution Time (cycles): 246 typical (244 to 266) Program Memory 598 bytes

Error <= 0.00000000047 (accurate to least significant _Q31 bit)

### Preconditions

None.

## Example

```
_Q31 resultSin;

resultSin = _LIBQ_Q31_sin_Q2_29 ((_Q2_29)0x5a637cfe);  // _LIBQ_Q31_sin_Q2_29( 2.824644562) =  0.311668121
(0x27e4bdb1)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The _Q2_29 input value from which to calculate sine(x). |

# g) Cosine Functions

## _LIBQ_Q15_cos_Q2_13 Function

Calculates the value of cosine(x).

### File

libq.h

### C

```
_Q15 _LIBQ_Q15_cos_Q2_13(_Q2_13 x);
```

### Returns

_LIBQ_Q15_cos_Q2_13 returns the _Q15 fixed point result from the calculation cosine(x).

### Description

Function _LIBQ_Q15_cos_Q2_13:

_Q15 _LIBQ_Q15_cos_Q2_13 (_Q2_13 x);

Calculates the cosine(x), where x is of type _Q2_13 radians and the resulting value is of type _Q15.

### Remarks

Execution Time (cycles): 102 cycles Program Memory 224 bytes

Error <= 0.00003052 (accurate to least significant _Q15 bit)

### Preconditions

None

### Example

```
_Q15 resultCos;

resultCos = _LIBQ_Q15_cos_Q2_13 ((_Q2_13)0x2171);  // _LIBQ_Q15_cos_Q2_13(1.045044) = 0.501862 (0x403d)
```

### Parameters

| Parameters | Description |
|---|---|
| x | The _Q2_13 input value from which to calculate cosine(x). |

## _LIBQ_Q31_cos_Q2_29 Function

Calculates the value of cosine(x).

### File

libq.h

### C

```
_Q31 _LIBQ_Q31_cos_Q2_29(_Q2_29 x);
```

### Returns

_LIBQ_Q31_cos_Q2_29 returns the _Q31 fixed point result from the calculation sine(x).

## Description

Function _LIBQ_Q31_cos_Q2_29:

_Q31 _LIBQ_Q31_cos_Q2_29 (_Q2_29 x);

Calculates the cosine(x), where x is of type _Q2_29 radians and the resulting value is of type _Q31.

## Remarks

Execution Time (cycles): 265 typical (22 to 288) Program Memory 746 bytes

Error <= 0.00000000047 (accurate to least significant _Q31 bit)

## Preconditions

None.

## Example

```
_Q31 resultCos;

resultCos = _LIBQ_Q31_cos_Q2_29 ((_Q2_29)0x07e2e1c2);  // _LIBQ_Q31_cos_Q2_29( 0.246445540) =  0.969785686
(0x7c21eff7)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The _Q2_29 input value from which to calculate cosine(x). |

# *h) Target Functions*

## _LIBQ_Q16_tan_Q2_29 Function

Calculates the value of tan(x).

## File

libq.h

## C

```
_Q16 _LIBQ_Q16_tan_Q2_29(_Q2_29 x);
```

## Returns

_LIBQ_Q16_tan_Q2_29 returns the _Q16 fixed point result from the calculation tan(x). The resulting value is saturated.

## Description

Function _LIBQ_Q16_tan_Q2_29:

_Q16 _LIBQ_Q16_tan_Q2_29 (_Q2_29 x);

Calculates the tan(x), where x is of type _Q2_29 radians and the resulting value is of type _Q16.

## Remarks

The functions _LIBQ_Q31_sin_Q2_29, _LIBQ_Q31_cos_Q2_29, and _LIBQ_Q16Div are called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 703 typical (22 to 796) Program Memory 88 bytes

Error <= 0.000015259 (accurate to least significant _Q16 bit for the input range -1.568 .. 1.568) Error rises from 0.0 to 0.065 for the input range -1.568 .. -1.570765808 and 1.568 .. 1.570765808)

## Preconditions

None

## Example

```
_Q16 resultTan;

resultTan = _LIBQ_Q16_tan_Q2_29 ((_Q2_29)0x16720c36);  // _LIBQ_Q16_tan_Q2_29( 0.701421838) =  0.844726562
(0x0000d840)
```

### Parameters

| Parameters | Description |
|---|---|
| x | The _Q2_29 input value from which to calculate tan(x). |

## _LIBQ_Q7_8_tan_Q2_13 Function

Calculates the value of tan(x).

### File

libq.h

### C

```
_Q7_8 _LIBQ_Q7_8_tan_Q2_13(_Q2_13 x);
```

### Returns

_LIBQ_Q7_8_tan_Q2_13 returns the _Q7_8 fixed point result from the calculation tan(x).

### Description

Function _LIBQ_Q7_8_tan_Q2_13:

_Q7_8 _LIBQ_Q7_8_tan_Q2_13 (_Q2_13 x);

Calculates the tan(x), where x is of type _Q2_13 radians and the resulting value is of type _Q7_8.

### Remarks

Execution Time (cycles): 288 typical (18 to 346) Program Memory 980 bytes

Error <= 0.00390625 (accurate to least significant _Q7_8 bit)

### Preconditions

None

### Example

```
_Q7_8 resultTan;

resultTan = _LIBQ_Q7_8_tan_Q2_13 ((_Q2_13)0x2e20);  // _LIBQ_Q7_8_tan_Q2_13(1.441406) = 7.683594 (0x07af)
```

### Parameters

| Parameters | Description |
|---|---|
| x | The _Q2_13 input value from which to calculate tan(x). |

## *i) Arcsin Functions*

## _LIBQ_Q2_13_asin_Q15 Function

Calculates the asin value of asin(x).

### File

libq.h

### C

```
_Q2_13 _LIBQ_Q2_13_asin_Q15(_Q15 x);
```

### Returns

_LIBQ_Q2_13_asin_Q15 returns the _Q2_13 fixed point result from the calculation asin(x).

### Description

Function _LIBQ_Q2_13_asin_Q15:

_Q2_13 _LIBQ_Q2_13_asin_Q15 (_Q15 x);

Calculates asin(x), where x is of type _Q15 and the resulting value is of type _Q2_13. The output value will be radians in the range pi >= result >= -pi.

## Remarks

The functions _LIBQ_Q16Sqrt and _LIBQ_Q16Div are called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 578 typical (22 to 656) Program Memory 336 bytes

Error <= 0.00012207 (accurate to least significant _Q2_13 bit)

A higher resolution version of this function exists with equivalent performance, see _LIBQ_Q2_29_asin_Q31_Fast

## Preconditions

None.

## Example

```
_Q2_13 resultAsin;

resultAsin = _LIBQ_Q2_13_asin_Q15 ((_Q15)0x3231);  // _LIBQ_Q2_13_asin_Q15(0.392120) = 0.402954 (0x0ce5)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The _Q15 input value from which to calculate asin(x). |

# _LIBQ_Q2_29_asin_Q31 Function

Calculates the value of asin(x).

## File

libq.h

## C

```
_Q2_29 _LIBQ_Q2_29_asin_Q31(_Q31 x);
```

## Returns

_LIBQ_Q2_29_asin_Q31 returns the _Q2_29 fixed point result from the calculation asin(x).

## Description

Function _LIBQ_Q2_29_asin_Q31:

_Q2_29 _LIBQ_Q2_29_asin_Q31 (_Q31 x);

Calculates the asin(x), where x is of type _Q31 and the resulting value is of type _Q2_29. The output value will be in radians the range pi >= result >= -pi.

## Remarks

The functions _LIBQ_Q2_29_asin_Q31_Fast and_LIBQ_Q31_sin_Q2_29 are called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 2525 typical (286 to 4330) Program Memory 138 bytes

Error <= 0.0000000019 (accurate to least significant _Q2_29 bit for the range -0.9993..0.9993) Error <= 0.0000000346 (accurate to 5th least significant _Q2_29 bit for the range -1.0 .. -0.9993 and 0.9993 .. 1.0)

A faster version of this function exists with modestly reduced accuracy, see _LIBQ_Q2_29_asin_Q31_Fast

## Preconditions

None.

## Example

```
_Q2_29 resultAsin;

resultAsin = _LIBQ_Q2_29_asin_Q31 ((_Q31)0x7fe50658);  // _LIBQ_Q2_29_asin_Q31( 0.9991767816) =
1.5302172359 (0x30f78a23)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The _Q31 input value from which to calculate asin(x). |

## _LIBQ_Q2_29_asin_Q31_Fast Function

Calculates the value of asin(x). This function executes faster than the _LIBQ_Q2_29_asin_Q31 function, but is less precise.

### File

libq.h

### C

```
_Q2_29 _LIBQ_Q2_29_asin_Q31_Fast(_Q31 x);
```

### Returns

_LIBQ_Q2_29_asin_Q31_Fast returns the _Q2_29 fixed point result from the calculation asin(x).

### Description

Function _LIBQ_Q2_29_asin_Q31_Fast:

_Q2_29 _LIBQ_Q2_29_asin_Q31_Fast (_Q31 x);

Calculates the asin(x), where x is of type _Q31 and the resulting value is of type _Q2_29. The output value will be in radians the range pi >= result >= -pi.

### Remarks

Execution Time (cycles): 507 typical (22 to 1300) Program Memory 638 bytes

Error <= 0.000000911 (accurate to 9 least significant _Q2_29 bits)

A higher resolution version of this function exists with reduced performance, see _LIBQ_Q2_29_asin_Q31

### Preconditions

None.

### Example

```
_Q2_29 resultAsin;

resultAsin = _LIBQ_Q2_29_asin_Q31_Fast ((_Q31)0x7fe50658);  // _LIBQ_Q2_29_asin_Q31_Fast( 0.9991767816) =
1.5302172359 (0x30f78a23)
```

### Parameters

| Parameters | Description |
|---|---|
| x | The _Q31 input value from which to calculate asin(x). |

## *j) Arccos Functions*

## _LIBQ_Q2_13_acos_Q15 Function

Calculates the value of acos(x).

### File

libq.h

### C

```
_Q2_13 _LIBQ_Q2_13_acos_Q15(_Q15 x);
```

### Returns

_LIBQ_Q2_13_acos_Q15 returns the _Q2_13 fixed point result from the calculation acos(x).

### Description

Function _LIBQ_Q2_13_acos_Q15:

_Q2_13 _LIBQ_Q2_13_acos_Q15 (_Q15 x);

Calculates the acos(x), where x is of type _Q15 and the resulting value is of type _Q2_13. The output value will be radians in the range pi >= result >= -pi.

## Remarks

The function _LIBQ_Q2_13_asin_Q15 is called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 588 typical (32 to 666) Program Memory 24 bytes

Error <= 0.00012207 (accurate to least significant _Q2_13 bit)

A higher precision function with equivalent performance exists, see _LIBQ_Q2_29_acos_Q31_Fast

## Preconditions

None.

## Example

```
_Q2_13 resultAcos;

resultAcos = _LIBQ_Q2_13_acos_Q15((_Q15)0x2993); // _LIBQ_Q2_13_acos_Q15(0.324799) = 1.239990 (0x27ae)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The _Q15 input value from which to calculate acos(x). |

# _LIBQ_Q2_29_acos_Q31 Function

Calculates the value of acos(x).

## File

libq.h

## C

```
_Q2_29 _LIBQ_Q2_29_acos_Q31(_Q31 x);
```

## Returns

_LIBQ_Q2_29_acos_Q31 returns the _Q2_29 fixed point result from the calculation acos(x).

## Description

Function _LIBQ_Q2_29_acos_Q31:

_Q2_29 _LIBQ_Q2_29_acos_Q31 (_Q31 x);

Calculates the acos(x), where x is of type _Q31 and the resulting value is of type _Q2_29. The output value will be radians in the range pi >= result >= -pi.

## Remarks

The functions _LIBQ_Q2_29_asin_Q31_Fast and _LIBQ_Q31_cos_Q2_29 are called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 3370 typical (70 to 4824) Program Memory 142 bytes

Error <= 0.0000000019 (accurate to least significant _Q2_29 bit for the range -0.9993..0.9993) Error <= 0.0000000355 (accurate to 5th least significant _Q2_29 bit for the range -1.0 .. -0.9993 and 0.9993 .. 1.0)

A similar function with higher performance and reduced precision exists, see _LIBQ_Q2_29_acos_Q31_Fast

## Preconditions

None.

## Example

```
_Q2_29 resultAcos;

resultAcos = _LIBQ_Q2_29_acos_Q31 ((_Q31)0xee63708c);  // _LIBQ_Q2_29_acos_Q31(-0.1375903431) =
1.7088244837 (0x36aeb0af)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The _Q31 input value from which to calculate acos(x). |

## _LIBQ_Q2_29_acos_Q31_Fast Function

Calculates the value of acos(x). This function executes faster than _LIBQ_Q2_29_acos_Q31 but is less precise.

### File

libq.h

### C

```
_Q2_29 _LIBQ_Q2_29_acos_Q31_Fast(_Q31 x);
```

### Returns

_LIBQ_Q2_29_acos_Q31_Fast returns the _Q2_29 fixed point result from the calculation acos(x).

### Description

Function _LIBQ_Q2_29_acos_Q31_Fast:

_Q2_29 _LIBQ_Q2_29_acos_Q31_Fast (_Q31 x);

Calculates the acos(x), where x is of type _Q31 and the resulting value is of type _Q2_29. The output value will be radians in the range pi >= result >= -pi.

### Remarks

The function _LIBQ_Q2_29_asin_Q31_Fast is called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 517 typical (32 to 1310) Program Memory 28 bytes

Error <= 0.000000911 (accurate to 9 least significant _Q2_29 bits)

A higher precision function with reduced performance exists, see _LIBQ_Q2_29_acos_Q31

### Preconditions

None.

### Example

```
_Q2_29 resultAcos;

resultAcos = _LIBQ_Q2_29_acos_Q31_Fast ((_Q31)0xee63708c);  // _LIBQ_Q2_29_acos_Q31_Fast(-0.1375903431) =
1.7088244837 (0x36aeb0af)
```

### Parameters

| Parameters | Description |
|---|---|
| x | The _Q31 input value from which to calculate acos(x). |

## *k) Arctan Functions*

## _LIBQ_Q2_13_atan_Q7_8 Function

Calculates the value of atan(x).

### File

libq.h

### C

```
_Q2_13 _LIBQ_Q2_13_atan_Q7_8(_Q7_8 x);
```

### Returns

_LIBQ_Q2_13_atan_Q7_8 returns the _Q2_13 fixed point result from the calculation atan(x).

### Description

Function _LIBQ_Q2_13_atan_Q7_8:

_Q2_13 _LIBQ_Q2_13_atan_Q7_8 (_Q7_8 x);

Calculates the atan(x), where x is of type _Q7_8 and the resulting value is of type _Q2_13. The output value will be radians in the range pi >= result >= -pi.

## Remarks

The function _LIBQ_Q2_13_atan2_Q7_8 is called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 240 typical (202 to 256) Program Memory 16 bytes

Error <= 0.00012207 (accurate to least significant _Q2_13 bit)

## Preconditions

None.

## Example

```
_Q2_13 resultAtan;

resultAtan = _LIBQ_Q2_13_atan_Q7_8 ((_Q7_8)0x0097);  // _LIBQ_Q2_13_atan_Q7_8(0.589844) = 0.532959 (0x110e)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The _Q7_8 input value from which to calculate atan(x). |

# _LIBQ_Q2_29_atan_Q16 Function

Calculates the value of atan(x).

## File

libq.h

## C

```
_Q2_29 _LIBQ_Q2_29_atan_Q16(_Q16 x);
```

## Returns

_LIBQ_Q2_29_atan_Q16 returns the _Q2_29 fixed point result from the calculation atan(x).

## Description

Function _LIBQ_Q2_29_atan_Q16:

_Q2_29 _LIBQ_Q2_29_atan_Q16 (_Q16 x);

Calculates the atan(x), where x is of type _Q16 and the resulting value is of type _Q2_29. The output value will be radians in the range pi >= result >= -pi.

## Remarks

The function _LIBQ_Q2_29_atan2_Q16 is called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 354 typical (178 to 360) Program Memory 16 bytes

Error <= 0.000000003 (accurate within one least significant _Q2_29 bit)

## Preconditions

None.

## Example

```
_Q2_29 resultAtan;

resultAtan = _LIBQ_Q2_29_atan_Q16 ((_Q16)0x00098b31);  // _LIBQ_Q2_29_atan_Q16(9.543716) = 1.466396 (0x2eecb7ee)
```

## Parameters

| Parameters | Description |
|---|---|
| x | The _Q16 input value from which to calculate atan(x). |

# *l) Arctan2 Functions*

## _LIBQ_Q2_13_atan2_Q7_8 Function

Calculates the value of atan2(y, x).

### File

libq.h

### C

```
_Q2_13 _LIBQ_Q2_13_atan2_Q7_8(_Q7_8 y, _Q7_8 x);
```

### Returns

_LIBQ_Q2_13_atan2_Q7_8 returns the _Q2_13 fixed point result from the calculation atan2(y, x).

### Description

Function _LIBQ_Q2_13_atan2_Q7_8:

_Q2_13 _LIBQ_Q2_13_atan2_Q7_8 (_Q7_8 y, _Q7_8 x);

Calculates the atan2(y, x), where y and x are of type _Q7_8 and the resulting value is of type _Q2_13. The output value will be radians in the range pi >= result >= -pi.

### Remarks

The function _LIBQ_Q16Div is called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 220 typical (22 to 250) Program Memory 288 bytes

Error <= 0.00012207 (accurate to least significant _Q2_13 bit)

### Preconditions

None.

### Example

```
_Q2_13 resultAtan2;

resultAtan2 = _LIBQ_Q2_13_atan2_Q7_8 ((_Q7_8)0x589d, (_Q7_8)0xf878); // _LIBQ_Q2_13_atan2_Q7_8(88.613281,
-7.531250) = 1.655518 (0x34fa)
```

### Parameters

| Parameters | Description |
|---|---|
| y | The _Q7_8 input value from which to calculate atan2(y, x). |
| x | The _Q7_8 input value from which to calculate atan2(y, x). |

## _LIBQ_Q2_29_atan2_Q16 Function

Calculates the value of atan2(y, x).

### File

libq.h

### C

```
_Q2_29 _LIBQ_Q2_29_atan2_Q16(_Q16 y, _Q16 x);
```

### Returns

_LIBQ_Q2_29_atan2_Q16 returns the _Q2_29 fixed point result from the calculation atan2(y, x).

### Description

Function _LIBQ_Q2_29_atan2_Q16:

_Q2_29 _LIBQ_Q2_29_atan2_Q16 (_Q16 y, _Q16 x);

Calculates the atan(y, x), where y and x are of type _Q16 and the resulting value is of type _Q2_29. The output value will be radians in the range pi >= result >= -pi.

### Remarks

The C function __divdi3 is called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 348 typical (20 to 376) Program Memory 464 bytes

Error <= 0.000000003 (accurate within one least significant _Q2_29 bit)

## Preconditions

None.

## Example

```
_Q2_29 resultAtan2;

resultAtan2 = _LIBQ_Q2_29_atan2_Q16 ((_Q16)0xf6276270, x(_Q16)0x34b4b4c0);  //
_LIBQ_Q2_29_atan2_Q16(-2520.615479, 13492.706055) = -0.184684 (0xfa1710c7)
```

## Parameters

| Parameters | Description |
|---|---|
| y | The _Q16 input value from which to calculate atan2(y, x). |
| x | The _Q16 input value from which to calculate atan2(y, x). |

### *m) Random Number Functions*

### _LIBQ_Q15Rand Function

Generate a _Q15 random number.

## File

libq.h

## C

```
_Q15 _LIBQ_Q15Rand(int64_t * pSeed);
```

## Returns

_LIBQ_Q15Rand returns a random _Q15 value. _LIBQ_Q15Rand also updates the int64_t *pSeed value.

## Description

Function _LIBQ_Q15Rand:

_Q15 _LIBQ_Q15Rand (int64_t *pSeed);

Generates a _Q15 pseudo-random value based on the seed supplied as a parameter. The first time this function is called, the seed value must be supplied by the user; this initial seed value can either be constant or random, depending on whether the user wants to generate a repeatable or a non-repeatable pseudo-random sequence.

The function updates the *pSeed value each time it is called. The updated *pSeed value must be passed back to the function with each subsequent call.

Warning: The pseudo-random sequence generated by this function may be insufficient for cryptographic use.

## Remarks

Execution Time (cycles): 32 Program Memory 92 bytes

## Preconditions

None.

## Example

```
// Initialize seed to a constant or random value
static int64_t  randomSeed = 0xA71078BE72D4C1F1;

_Q15           randomValue;

randomValue = _LIBQ_Q15Rand(&randomSeed);
...
randomValue = _LIBQ_Q15Rand(&randomSeed);
```

## Parameters

| Parameters | Description |
|---|---|
| pSeed | A pointer to the seed value used by the function to generate a pseudo-random sequence. |

## _LIBQ_Q31Rand Function

Generate a _Q31 random number.

### File

libq.h

### C

```
_Q31 _LIBQ_Q31Rand(int64_t * pSeed);
```

### Returns

_LIBQ_Q31Rand returns a pseudo-random _Q31 value. _LIBQ_Q31Rand also updates the int64_t *pSeed value.

### Description

Function _LIBQ_Q31Rand:

_Q31 _LIBQ_Q31Rand (int64_t *pSeed);

Generates a _Q31 pseudo-random value based on the seed supplied as a parameter. The first time this function is called, the seed value must be supplied by the user; this initial seed value can either be constant or random, depending on whether the user wants to generate a repeatable or a non-repeatable pseudo-random sequence.

The function updates the *pSeed value each time it is called. The updated *pSeed value must be passed back to the function with each subsequent call.

Warning: The pseudo-random sequence generated by this function may be insufficient for cryptographic use.

### Remarks

Execution Time (cycles): 32 Program Memory 88 bytes

### Preconditions

None.

### Example

```
// Initialize seed to a constant or random value
static int64_t  randomSeed = 0x7F18BA710E72D4C1;

_Q31  randomValue;

randomValue = _LIBQ_Q31Rand(&randomSeed);
...
randomValue = _LIBQ_Q31Rand(&randomSeed);
```

### Parameters

| Parameters | Description |
|---|---|
| pSeed | A pointer to the seed value used by the function to generate a pseudo-random sequence. |

## *n) Float Functions*

## _LIBQ_Q15FromFloat Function

Converts a float to a _Q15 value.

### File

libq.h

### C

```
_Q15 _LIBQ_Q15FromFloat(float x);
```

### Returns

_LIBQ_Q15FromFloat returns the _Q15 fixed point value corresponding to the floating point (float) input value.

## Description

Function _LIBQ_Q15FromFloat:

_Q15 _LIBQ_Q15FromFloat(float x);

Converts a floating point value to a _Q15 fixed point representation. The _Q15 fixed point value is returned by the function. The conversion will saturate if the value is outside the range of the _Q15 representation.

## Remarks

The C library functions __gesf2, __lesf2, __addsf3, __mulsf3, and __fixsfsi are called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 213 typical (158 to 224) Program Memory 96 bytes

## Preconditions

None.

## Example

```
_Q15 q15;

q15 = _LIBQ_Q15FromFloat((float)0.5);  // q15 now equals (_Q15)0x4000

q15 = _LIBQ_Q15FromFloat((float)-1.0);  // q15 now equals (_Q15)0x8000

q15 = _LIBQ_Q15FromFloat((float)-0.233828);  // q15 now equals (_Q15)0xe212
```

## Parameters

| Parameters | Description |
|---|---|
| x | The float point value to convert to _Q15 fixed point |

# _LIBQ_Q31FromFloat Function

Converts a float to a _Q31 value.

## File

libq.h

## C

```
_Q31 _LIBQ_Q31FromFloat(float x);
```

## Returns

_LIBQ_Q31FromFloat returns the _Q31 fixed point value corresponding to the floating point (float) input value.

## Description

Function _LIBQ_Q31FromFloat:

_Q31 _LIBQ_Q31FromFloat(float x);

Converts a floating point value to a _Q31 fixed point representation. The _Q31 fixed point value is returned by the function. The conversion will saturate if the value is outside the range of the _Q31 representation.

## Remarks

The C library functions __gesf2, __lesf2, __addsf3, __mulsf3, and __fixsfsi are called by this routine and thus must be linked into the executable image.

Execution Time (cycles): 210 typical (158 to 214) Program Memory 100 bytes

## Preconditions

None.

## Example

```
_Q31 q31;

q31 = _LIBQ_Q31FromFloat((float)0.000008);  // q31 now equals (_Q31)0x00004000

q31 = _LIBQ_Q31FromFloat((float)-1.0);  // q31 now equals (_Q31)0x80000000
```

```
q31 = _LIBQ_Q31FromFloat((float)0.690001);  // q31 now equals (_Q31)0x5851f400
```

### Parameters

| Parameters | Description |
| --- | --- |
| x | The floating point value to convert to _Q31 fixed point. |

## _LIBQ_ToFloatQ15 Function

Converts a _Q15 value to a float.

### File

libq.h

### C

```
float _LIBQ_ToFloatQ15(_Q15 x);
```

### Returns

_LIBQ_ToFloatQ15 returns the floating point (float) value corresponding to the _Q15 input value.

### Description

Function _LIBQ_ToFloatQ15:

float _LIBQ_ToFloatQ15(_Q15 x);

Converts a _Q15 fixed point value to a floating point representation. The floating point value is returned by the function.

### Remarks

The C library functions __floatsisf and __divsf3 are called by this routine and thus must be linked in to the executable image.

Execution Time (cycles): 158 typical (54 to 176) Program Memory 28 bytes

### Preconditions

None.

### Example

```
float f;

f = _LIBQ_ToFloatQ15((_Q15)0x4000);  // f now equals 0.5

f = _LIBQ_ToFloatQ15((_Q15)0x8000);  // f now equals -1.0

f = _LIBQ_ToFloatQ15((_Q15)0xb7ff);  // f now equals -0.562531
```

### Parameters

| Parameters | Description |
| --- | --- |
| x | The _Q15 fixed point value to convert to float |

## _LIBQ_ToFloatQ31 Function

Converts a _Q31 value to a float.

### File

libq.h

### C

```
float _LIBQ_ToFloatQ31(_Q31 x);
```

### Returns

_LIBQ_ToFloatQ31 returns the floating point (float) value corresponding to the _Q31 input value.

### Description

Function _LIBQ_ToFloatQ31:

float _LIBQ_ToFloatQ31(_Q31 x);

Converts a _Q31 fixed point value to a floating point representation. The floating point value is returned by the function.

### Remarks

The C library functions __floatsisf and __divsf3 are called by this routine and thus must be linked in to the executable image.

Execution Time (cycles): 163 typical (54 to 176) Program Memory 28 bytes

### Preconditions

None.

### Example

```
float f;

f = _LIBQ_ToFloatQ31((_Q31)0x00004000);  // f now equals 0.000008

f = _LIBQ_ToFloatQ31((_Q31)0x80000000);  // f now equals -1.0

f = _LIBQ_ToFloatQ31((_Q31)0x5851f42d);  // f now equals 0.690001
```

### Parameters

| Parameters | Description |
| --- | --- |
| x | The _Q31 fixed point value to convert to float |

## *o) String Functions*

## _LIBQ_Q15FromString Function

ASCII to _Q15 conversion.

### File

libq.h

### C

```
_Q15 _LIBQ_Q15FromString(char * s);
```

### Returns

_LIBQ_Q15FromString returns the _Q15 fixed point value represented by the input string.

### Description

Function _LIBQ_Q15FromString:

_Q15 _LIBQ_Q15FromString(char *s);

Convert an ASCII string into a _Q15 fixed point value. The ASCII string must be in an -N.NNNNNN format. Leading spaces are ignored. The conversion stops at either the first non-conforming character in the string or the Null string terminator. There must be no spaces within the string value itself.

### Remarks

Execution Time (cycles): 296 typical (28 to 346) Program Memory 172 bytes

### Preconditions

None.

### Example

```
_Q15  x;

x = _LIBQ_Q15FromString("0.125");      // x will equal 0.125 using
                            // an internal value of 0x1000

x = _LIBQ_Q15FromString("-1.0");       // x will equal -1.0 using
                            // an internal value of 0x8000

x = _LIBQ_Q15FromString("0.999969");   // x will equal 0.999969 using
                            // an internal value of 0x7FFF
```

## Parameters

| Parameters | Description |
|---|---|
| s | A pointer to the ASCII input string representing the _Q15 fixed point value. |

## _LIBQ_ToStringQ15 Function

_Q15 to ASCII conversion.

### File

libq.h

### C

```
void _LIBQ_ToStringQ15(_Q15 x, char * s);
```

### Returns

An ASCII string that represents the _Q15 fixed point value in -N.NNNNNN format. The output string will be terminated by a Null (0x00) character.

### Description

Function _LIBQ_ToStringQ15:

void _LIBQ_ToStringQ15(_Q15 x, char *s);

Convert a _Q15 fixed point value to an ASCII string representation in a -N.NNNNNN format.

### Remarks

Execution Time (cycles): 118 typical (28 to 132) Program Memory 200 bytes

### Preconditions

The character string "s" must be at least 10 characters long, including the Null string terminator.

### Example

```
char  s[10];

_LIBQ_ToStringQ15((_Q15)0x1000, s);      // s will equal "0.125000"

_LIBQ_ToStringQ15((_Q15)0x8000, s);      // s will equal "-1.000000"

_LIBQ_ToStringQ15((_Q15)0x7FFF, s);      // s will equal "0.999969"
```

### Parameters

| Parameters | Description |
|---|---|
| x | The fixed point value to be converted into an ASCII string (_Q15) |
| s | A pointer to the output string of at least 10 characters |

## *p) Data Types and Constants*

## _Q15_MAX Macro

### File

libq.h

### C

```
#define _Q15_MAX ((_Q15)0x7FFF)        // Maximum value of _Q15 (~1.0)
```

### Description

Maximum value of _Q15 (~1.0)

## _Q15_MIN Macro

### File

libq.h

### C

```
#define _Q15_MIN ((_Q15)0x8000)        // Minimum value of _Q15 (-1.0)
```

### Description

Minimum value of _Q15 (-1.0)

## _Q16_MAX Macro

### File

libq.h

### C

```
#define _Q16_MAX ((_Q16)0x7FFFFFFF)    // Maximum value of _Q16 (~32768.0)
```

### Description

Maximum value of _Q16 (~32768.0)

## _Q16_MIN Macro

### File

libq.h

### C

```
#define _Q16_MIN ((_Q16)0x80000000)    // Minimum value of _Q16 (-32768.0)
```

### Description

Minimum value of _Q16 (-32768.0)

## _Q2_13_MAX Macro

### File

libq.h

### C

```
#define _Q2_13_MAX ((_Q2_13)0x7FFF)      // Maximum value of _Q2_13 (~4.0)
```

### Description

Maximum value of _Q2_13 (~4.0)

## _Q2_13_MIN Macro

### File

libq.h

### C

```
#define _Q2_13_MIN ((_Q2_13)0x8000)      // Minimum value of _Q2_13 (-4.0)
```

### Description

Minimum value of _Q2_13 (-4.0)

## _Q2_29_MAX Macro

### File

libq.h

### C

```
#define _Q2_29_MAX ((_Q2_29)0x7FFFFFFF)  // Maximum value of _Q2_29 (~4.0)
```

### Description

Maximum value of _Q2_29 (~4.0)

## _Q2_29_MIN Macro

### File

libq.h

### C

```
#define _Q2_29_MIN ((_Q2_29)0x80000000)  // Minimum value of _Q2_29 (-4.0)
```

### Description

Minimum value of _Q2_29 (-4.0)

## _Q3_12_MAX Macro

### File

libq.h

### C

```
#define _Q3_12_MAX ((_Q3_12)0x7FFF)      // Maximum value of _Q3_12 (~8.0)
```

### Description

Maximum value of _Q3_12 (~8.0)

## _Q3_12_MIN Macro

### File

libq.h

### C

```
#define _Q3_12_MIN ((_Q3_12)0x8000)      // Minimum value of _Q3_12 (-8.0)
```

### Description

Minimum value of _Q3_12 (-8.0)

## _Q31_MAX Macro

### File

libq.h

### C

```
#define _Q31_MAX ((_Q31)0x7FFFFFFF)    // Maximum value of _Q31 (~1.0)
```

### Description

Maximum value of _Q31 (~1.0)

## _Q31_MIN Macro

### File

libq.h

### C

```
#define _Q31_MIN ((_Q31)0x80000000)    // Minimum value of _Q31 (-1.0)
```

### Description

Minimum value of _Q31 (-1.0)

## _Q4_11_MAX Macro

### File

libq.h

### C

```
#define _Q4_11_MAX ((_Q4_11)0x7FFF)      // Maximum value of _Q4_11 (~16.0)
```

### Description

Maximum value of _Q4_11 (~16.0)

## _Q4_11_MIN Macro

### File

libq.h

### C

```
#define _Q4_11_MIN ((_Q4_11)0x8000)      // Minimum value of _Q4_11 (-16.0)
```

### Description

Minimum value of _Q4_11 (-16.0)

## _Q5_10_MAX Macro

### File

libq.h

### C

```
#define _Q5_10_MAX ((_Q5_10)0x7FFF)      // Maximum value of _Q5_10 (~32.0)
```

### Description

Maximum value of _Q5_10 (~32.0)

## _Q5_10_MIN Macro

### File

libq.h

### C

```
#define _Q5_10_MIN ((_Q5_10)0x8000)      // Minimum value of _Q5_10 (-32.0)
```

### Description

Minimum value of _Q5_10 (-32.0)

## _Q7_8_MAX Macro

### File

libq.h

### C

```
#define _Q7_8_MAX ((_Q7_8)0x7FFF)        // Maximum value of _Q7_8 (~128.0)
```

### Description

Maximum value of _Q7_8 (~128.0)

## _Q7_8_MIN Macro

### File

libq.h

### C

```
#define _Q7_8_MIN ((_Q7_8)0x8000)        // Minimum value of _Q7_8 (-128.0)
```

### Description

Minimum value of _Q7_8 (-128.0)

## _Q0_15 Type

### File

libq.h

### C

```
typedef int16_t _Q0_15;
```

### Description

1 sign bit, 15 bits right of radix

## _Q0_31 Type

### File

libq.h

### C

```
typedef int32_t _Q0_31;
```

### Description

1 sign bit, 31 bits right of radix

## _Q15 Type

### File

libq.h

### C

```
typedef _Q0_15 _Q15;
```

### Description

Short name for _Q0_15

## _Q15_16 Type

### File

libq.h

### C

```
typedef int32_t _Q15_16;
```

### Description

1 sign bit, 15 bits left of radix, 16 bits right of radix

## _Q16 Type

### File

libq.h

### C

```
typedef _Q15_16 _Q16;
```

### Description

Short name for _Q15_16

## _Q2_13 Type

### File

libq.h

### C

```
typedef int16_t _Q2_13;
```

### Description

1 sign bit, 2 bits left of radix, 13 bits right of radix

## _Q2_29 Type

### File

libq.h

### C

```
typedef int32_t _Q2_29;
```

### Description

1 sign bit, 2 bits left of radix, 29 bits right of radix

## _Q3_12 Type

### File

libq.h

### C

```
typedef int16_t _Q3_12;
```

### Description

1 sign bit, 3 bits left of radix, 12 bits right of radix

## _Q31 Type

### File

libq.h

### C

```
typedef _Q0_31 _Q31;
```

### Description

Short name for _Q_0_31

## _Q4_11 Type

### File

libq.h

### C

```
typedef int16_t _Q4_11;
```

### Description

1 sign bit, 4 bits left of radix, 11 bits right of radix

## _Q5_10 Type

### File

libq.h

### C

```
typedef int16_t _Q5_10;
```

### Description

1 sign bit, 5 bits left of radix, 10 bits right of radix

## _Q7_8 Type

### File

libq.h

### C

```
typedef int16_t _Q7_8;
```

### Description

1 sign bit, 7 bits left of radix, 8 bits right of radix

## _LIBQ_H Macro

### File

libq.h

### C

```
#define _LIBQ_H
```

### Description

Guards against multiple inclusion

# Files

## Files

| Name | Description |
|---|---|
| libq.h | Optimized fixed point math functions for the PIC32MZ families of devices with microAptiv core features. |

## Description

This section lists the source and header files used by the LibQ Fixed-Point Math Library.

# *libq.h*

Optimized fixed point math functions for the PIC32MZ families of devices with microAptiv core features.

## Functions

| | Name | Description |
|---|---|---|
| | _LIBQ_Q15_cos_Q2_13 | Calculates the value of cosine(x). |
| | _LIBQ_Q15_sin_Q2_13 | Calculates the value of sine(x). |
| | _LIBQ_Q15FromFloat | Converts a float to a _Q15 value. |
| | _LIBQ_Q15FromString | ASCII to _Q15 conversion. |
| | _LIBQ_Q15Rand | Generate a _Q15 random number. |
| | _LIBQ_Q16_tan_Q2_29 | Calculates the value of tan(x). |
| | _LIBQ_Q16Div | _Q16 fixed point divide. |
| | _LIBQ_Q16Exp | Calculates the exponential function e^x. |
| | _LIBQ_Q16Power | Calculates the value of x raised to the y power (x^y). |
| | _LIBQ_Q16Sqrt | Square root of a positive _Q16 fixed point value. |
| | _LIBQ_Q2_13_acos_Q15 | Calculates the value of acos(x). |
| | _LIBQ_Q2_13_asin_Q15 | Calculates the asin value of asin(x). |
| | _LIBQ_Q2_13_atan_Q7_8 | Calculates the value of atan(x). |
| | _LIBQ_Q2_13_atan2_Q7_8 | Calculates the value of atan2(y, x). |
| | _LIBQ_Q2_29_acos_Q31 | Calculates the value of acos(x). |
| | _LIBQ_Q2_29_acos_Q31_Fast | Calculates the value of acos(x). This function executes faster than _LIBQ_Q2_29_acos_Q31 but is less precise. |
| | _LIBQ_Q2_29_asin_Q31 | Calculates the value of asin(x). |
| | _LIBQ_Q2_29_asin_Q31_Fast | Calculates the value of asin(x). This function executes faster than the _LIBQ_Q2_29_asin_Q31 function, but is less precise. |
| | _LIBQ_Q2_29_atan_Q16 | Calculates the value of atan(x). |
| | _LIBQ_Q2_29_atan2_Q16 | Calculates the value of atan2(y, x). |
| | _LIBQ_Q3_12_log10_Q16 | Calculates the value of Log10(x). |
| | _LIBQ_Q31_cos_Q2_29 | Calculates the value of cosine(x). |
| | _LIBQ_Q31_sin_Q2_29 | Calculates the value of sine(x). |
| | _LIBQ_Q31FromFloat | Converts a float to a _Q31 value. |
| | _LIBQ_Q31Rand | Generate a _Q31 random number. |
| | _LIBQ_Q4_11_ln_Q16 | Calculates the natural logarithm ln(x). |
| | _LIBQ_Q5_10_log2_Q16 | Calculates the value of log2(x). |
| | _LIBQ_Q7_8_tan_Q2_13 | Calculates the value of tan(x). |
| | _LIBQ_ToFloatQ15 | Converts a _Q15 value to a float. |
| | _LIBQ_ToFloatQ31 | Converts a _Q31 value to a float. |
| | _LIBQ_ToStringQ15 | _Q15 to ASCII conversion. |

## Macros

| | Name | Description |
|---|---|---|
| | _LIBQ_H | Guards against multiple inclusion |
| | _Q15_MAX | Maximum value of _Q15 (~1.0) |
| | _Q15_MIN | Minimum value of _Q15 (-1.0) |

| | | |
|---|---|---|
| | _Q16_MAX | Maximum value of _Q16 (~32768.0) |
| | _Q16_MIN | Minimum value of _Q16 (-32768.0) |
| | _Q2_13_MAX | Maximum value of _Q2_13 (~4.0) |
| | _Q2_13_MIN | Minimum value of _Q2_13 (-4.0) |
| | _Q2_29_MAX | Maximum value of _Q2_29 (~4.0) |
| | _Q2_29_MIN | Minimum value of _Q2_29 (-4.0) |
| | _Q3_12_MAX | Maximum value of _Q3_12 (~8.0) |
| | _Q3_12_MIN | Minimum value of _Q3_12 (-8.0) |
| | _Q31_MAX | Maximum value of _Q31 (~1.0) |
| | _Q31_MIN | Minimum value of _Q31 (-1.0) |
| | _Q4_11_MAX | Maximum value of _Q4_11 (~16.0) |
| | _Q4_11_MIN | Minimum value of _Q4_11 (-16.0) |
| | _Q5_10_MAX | Maximum value of _Q5_10 (~32.0) |
| | _Q5_10_MIN | Minimum value of _Q5_10 (-32.0) |
| | _Q7_8_MAX | Maximum value of _Q7_8 (~128.0) |
| | _Q7_8_MIN | Minimum value of _Q7_8 (-128.0) |

## Types

| | Name | Description |
|---|---|---|
| | _Q0_15 | 1 sign bit, 15 bits right of radix |
| | _Q0_31 | 1 sign bit, 31 bits right of radix |
| | _Q15 | Short name for _Q0_15 |
| | _Q15_16 | 1 sign bit, 15 bits left of radix, 16 bits right of radix |
| | _Q16 | Short name for _Q15_16 |
| | _Q2_13 | 1 sign bit, 2 bits left of radix, 13 bits right of radix |
| | _Q2_29 | 1 sign bit, 2 bits left of radix, 29 bits right of radix |
| | _Q3_12 | 1 sign bit, 3 bits left of radix, 12 bits right of radix |
| | _Q31 | Short name for _Q_0_31 |
| | _Q4_11 | 1 sign bit, 4 bits left of radix, 11 bits right of radix |
| | _Q5_10 | 1 sign bit, 5 bits left of radix, 10 bits right of radix |
| | _Q7_8 | 1 sign bit, 7 bits left of radix, 8 bits right of radix |

## Description

The LibQ Fixed-Point Math Library provides fixed-point math functions that are optimized for performance on the PIC32MZ families of devices that have microAptiv core features. All functions are optimized for speed. This header file specifies characteristics of each function, including execution time, memory size, and resolution.

Signed fixed point types are defined as follows:

Qn_m where:

- n is the number of data bits to the left of the radix point
- m is the number of data bits to the right of the radix point
- a signed bit is implied

For convenience, short names are also defined:

Exact Name (& Bits) Required Short Name _Q0_15 (16) _Q15; _Q15_16 (32) _Q16; _Q0_31 (32) _Q31

Functions in the library are prefixed with the type of the return value. For example, _LIBQ_Q16Sqrt returns a Q16 value equal to the square root of its argument.

Argument types do not always match the return type. Refer to the function prototype for a specification of its arguments.

In cases where the return value is not a fixed point type, the argument type is appended to the function name. For example, _LIBQ_ToFloatQ31 accepts a type _Q31 argument.

In some cases, both the return type and the argument type are specified within the function name. For example,

Function Name (Return Type) [Argument Type]: _LIBQ_Q15_sin_Q2_13 (_Q15) [_Q2_13]; _LIBQ_Q31_sin_Q2_29 (_Q31) [_Q2_29]

Table of LIBQ functions:

Divide: _Q16 _LIBQ_Q16Div (_Q16 dividend, _Q16 divisor);

Square root: _Q16 _LIBQ_Q16Sqrt (_Q16 x);

Exponential: _Q16 _LIBQ_Q16Exp (_Q16 x);

Log: _Q4_11 _LIBQ_Q4_11_ln_Q16 (_Q16 x); _Q3_12 _LIBQ_Q3_12_log10_Q16 (_Q16 x); _Q5_10 _LIBQ_Q5_10_log2_Q16 (_Q16 x);

Power: _Q16 _LIBQ_Q16Power (_Q16 x, _Q16 y);

Sine: _Q15 _LIBQ_Q15_sin_Q2_13 (_Q2_13 x); _Q31 _LIBQ_Q31_sin_Q2_29 (_Q2_29 x);

Cosine: _Q15 _LIBQ_Q15_cos_Q2_13 (_Q2_13 x); _Q31 _LIBQ_Q31_cos_Q2_29 (_Q2_29 x);

Tangent: _Q7_8 _LIBQ_Q7_8_tan_Q2_13 (_Q2_13 x); _Q16z _LIBQ_Q16_tan_Q2_29 (_Q2_29 x);

Arcsin: _Q2_13 _LIBQ_Q2_13_asin_Q15 (_Q15 x); _Q2_29 _LIBQ_Q2_29_asin_Q31 (_Q31 x); _Q2_29 _LIBQ_Q2_29_asin_Q31_Fast (_Q31 x);

Arccos: _Q2_13 _LIBQ_Q2_13_acos_Q15 (_Q15 x); _Q2_29 _LIBQ_Q2_29_acos_Q31 (_Q31 x); _Q2_29 _LIBQ_Q2_29_acos_Q31_Fast (_Q31 x);

Arctan: _Q2_13 _LIBQ_Q2_13_atan_Q7_8 (_Q7_8 x); _Q2_29 _LIBQ_Q2_29_atan_Q16 (_Q16 x);

Arctan2: _Q2_13 _LIBQ_Q2_13_atan2_Q7_8 (_Q7_8 y, _Q7_8 x); _Q2_29 _LIBQ_Q2_29_atan2_Q16 (_Q16 y, _Q16 x);

Random number: _Q15 _LIBQ_Q15Rand (int64_t &pSeed); _Q31 _LIBQ_Q31Rand (int64_t &pSeed);

Float: float _LIBQ_ToFloatQ31 (_Q31 x); float _LIBQ_ToFloatQ15 (_Q15 x); _Q31 _LIBQ_Q31FromFloat (float x); _Q15 _LIBQ_Q15FromFloat (float x);

String: void _LIBQ_ToStringQ15 (_Q15 x, char &s); _Q15 _LIBQ_Q15FromString (char &s);

## File Name

libq.h

## Company

Microchip Technology Inc.

# Index

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