Advanced Control Library

User Reference Manual

MCF51xx_ACLIB
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The following revision history table summarizes changes contained in this document.

Table 0-1. Revision History

Date	Revision Label	Description
	0	Initial release

Chapter 1 License Agreement

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Chapter 2 INTRODUCTION

2.1 Overview

This reference manual describes Advanced Control Library for MCF51xx family of microcontrollers. This library contains optimized functions for ColdFire V1 core. The library is supplied in a binary form, which is unique by its simplicity to integrate with the user application. For correct functionality of this library, Motor Control Library (MCLIB) and General Functions Library (GFLIB) must be installed and included in the application project.

2.2 Supported Compilers

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

- CodeWarrior™ Development Studio V6.1 ColdFireV1 AC256 ALPHA Service Pack

The library is delivered in the *ACLIB_MCF51.lib* library module. The interfaces to the algorithms included in this library have been combined into a single public interface include file, the *aclib.h*. This was done to reduce the number of files required for inclusion by the application programs. Refer to the specific algorithm sections of this document for details on the software application programming interface (API), defined and functionality provided for the individual algorithms.

2.3 Installation

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

Each Advanced Control Library release is installed in its own new folder, named *ACLIB_MCF51_rX.X*, where *X.X* denotes the actual release number. This way of library installation allows the users to maintain older releases and projects and gives them a free choice to select the active library release.

To start the installation process, follow the following steps:

1. Execute the *ACLIB_MCF51_rXX.exe* file.
2. Follow the Advanced Control Library software installation instructions on your screen.

2.4 Library Integration

The Advanced Control Library is added into a new CodeWarrior project by taking the following steps:

1. Create a new empty project.
2. Create *ACLIB* group in your new open project. Note that this step is not mandatory, it is mentioned here just for the purpose of maintaining file consistency in the CodeWarrior project window. In the CodeWarrior menu, choose Project > Create Group..., type ACLIB into the dialog window that pops up, and click <OK>.
3. Refer the *ACLIB_MCF51.lib* file in the project window. This can be achieved by dragging the library file from the proper library subfolder and dropping it into the *ACLIB* group in the CodeWarrior project window. This step will automatically add the *ACLIB* path into the project access paths, such as the user can take advantage of the library functions to achieve flawless project compilation and linking.
4. It is similar with the reference file *aclib.h*. This file can be dragged from the proper library subfolder and dropped into the ACLIB group in the CodeWarrior project window.
5. The following program line must be added into the user-application source code in order to use the library functions.

```
#include "aclib.h"
```

6. Since the Advanced Control Library is not stand-alone, General Functions Library (GFLIB) and Motor Control Library (MCLIB) must be installed and included in the application project prior to ACLIB.
7. Create *GFLIB* group in your new open project. Note that this step is not mandatory, it is mentioned here just for the purpose of maintaining file consistency in the CodeWarrior project window. In the CodeWarrior menu, choose Project > Create Group..., type GFLIB into the dialog window that pops up, and click <OK>.
8. Refer the *GFLIB_MCF51.lib* file in the project window. This can be done by dragging the library file from the proper library subfolder and dropping it into the *GFLIB* group in the CodeWarrior project window. This step will automatically add the *GFLIB* path into the project access paths, such as the user can take advantage of the library functions to achieve flawless project compilation and linking.

9. It is similar with the reference file *gflib.h* in the project window. This can be achieved by dragging the file from the proper library subfolder and dropping it into the *GFLIB* group in the CodeWarrior project window.
10. Create *MCLIB* group in your new open project. Note that this step is not mandatory, it is mentioned here just for the purpose of maintaining file consistency in the CodeWarrior project window. In the CodeWarrior menu, choose Project > Create Group..., type MCLIB into the dialog window that pops up, and click <OK>.
11. Refer the *MCLIB_MCF51.lib* file in the project window. This can be done by dragging the library file from the proper library subfolder and dropping it into the *MCLIB* group in the CodeWarrior project window. This step will automatically add the *MCLIB* path into the project access paths, such as the user can take the advantage of the library functions to achieve flawless project compilation and linking.
12. It is similar with the reference file *mclib.h* in the project window. This can be achieved by dragging the file from proper library subfolder and dropping it into the *MCLIB* group in the CodeWarrior project window.
13. The following program lines must be added into the user application source code in order to use the library functions.

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

2.5 API Definition

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

Synopsis

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

Arguments

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

Description

This subsection is a description of the function or macro. It explains algorithms being used by functions or macros.

Return

This optional subsection describes the return value (if any) of the function or macro.

Range Issues

This optional subsection specifies the ranges of input variables.

Special Issues

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

Implementation

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

See Also

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

Performance

This section specifies the actual requirements of the function or macro in terms of required code memory, data memory, and number of clock cycles to execute.

2.6 Data Types

The 32-bit core supports two types of two-complement data formats:

- Signed integer
- Unsigned integer

The signed and unsigned integer data types are useful for general-purpose computation; they are familiar with the microprocessor and microcontroller programmers.

Nevertheless, two other types of two-complement data formats are used in the library algorithms with a little software support:

- Signed fractional
- Unsigned fractional

Fractional data types allow powerful numeric and digital-signal-processing algorithms to be implemented.

2.6.1 Signed Integer (SI)

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

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

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

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

2.6.2 Unsigned Integer (UI)

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

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

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

2.6.3 Signed Fractional (SF)

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

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

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

2.6.4 Unsigned Fractional (UF)

The unsigned fractional numbers can be positive only, and they have nearly twice the magnitude of a signed number with the same number of bits. The unsigned fractional numbers lie in the following range:

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

The binary word is interpreted as having a binary point after the MSB. This data format is available for words and longs. The most positive, 16-bit, unsigned number is $FFFF, or $\{1.0 + (1.0 - 2^{-[N-1]})\} = 1.99997$. The smallest unsigned fractional number is zero ($0000).

2.7 User Common Types

Table 2-1. User-Defined Typedefs in *MCF51_types.h*

Mnemonics	Size — bits	Description
Word8	8	To represent 8-bit signed variable/value.
UWord8	8	To represent 16-bit unsigned variable/value.
Word16	16	To represent 16-bit signed variable/value.
UWord16	16	To represent 16-bit unsigned variable/value.
Word32	32	To represent 32-bit signed variable/value.
UWord32	32	To represent 16-bit unsigned variable/value.
Int8	8	To represent 8-bit signed variable/value.
UInt8	8	To represent 16-bit unsigned variable/value.
Int16	16	To represent 16-bit signed variable/value.
UInt16	16	To represent 16-bit unsigned variable/value.
Int32	32	To represent 32-bit signed variable/value.
UInt32	32	To represent 16-bit unsigned variable/value.
Frac16	16	To represent 16-bit signed variable/value.
Frac32	32	To represent 32-bit signed variable/value.
NULL	constant	Represents NULL pointer.
bool	16	Boolean variable.
false	constant	Represents false value.
true	constant	Represents true value.
FRAC16()	macro	Transforms float value from <–1, 1) range into fractional representation <–32768, 32767>.
FRAC32()	macro	Transforms float value from <–1, 1) range into fractional representation <–2147483648, 2147483648>.

Table 2-2. User-Defined Typedefs in *mclib_types.h*

Name	Structure Members	Description
MCLIB_3_COOR_SYST_T	Frac16 f16A Frac16 f16B Frac16 f16C	three phase system
MCLIB_2_COOR_SYST_T	Frac16 f16A Frac16 f16B	two phase system
MCLIB_2_COOR_SYST_ALPHA_BETA_T	Frac16 f16Alpha Frac16 f16Beta	two phase system — alpha/beta
MCLIB_2_COOR_SYST_D_Q_T	Frac16 f16D Frac16 f16Q	two phase system — generic DQ
MCLIB_ANGLE_T	Frac16 f16Sin Frac16 f16Cos	two phase system — sine and cosine components

2.8 Special Issues

All functions in the Advanced Control Library are implemented without storing any of the volatile registers (D0, D1, D2, A0, A1) used by the respective routine. Only non-volatile registers (D3, D4, D5, D6, D7, A2, A3, A4, A5) are saved by pushing the registers on the stack. Therefore, if the particular registers initialized before the library function call are to be used after the function call, it is necessary to save them manually.

Chapter 3 FUNCTION API

3.1 API Summary

Table 3-1. API Functions Summary

Name	Arguments	Output	Description
ACLIB_AngleTrackObsrv	*MCLIB_ANGLE_T *pudtSinCos* *ACLIB_ANGLE_TRACK_OBSRV_T *pudtCtrl*	void	This function calculates the algorithm of velocity and position-tracking observer.
ACLIB_PMSMBemfObsrvAB	*MCLIB_2_COOR_SYST_ALPHA_BETA_T *pudtCurrentAlphaBeta* *MCLIB_2_COOR_SYST_ALPHA_BETA_T *pudtVoltageAlphaBeta* *Frac16 f16Speed* *ACLIB_BEMF_OBSRV_AB_T * const pudtCtrl*	void	This function calculates the algorithms of finding permanent-magnet axis.

3.2 ACLIB_AngleTrackObsrv

The function calculates angle-tracking observer for determination of angular speed and position of input functional signal.

3.2.1 Synopsis

```
#include"aclib.h"
Frac16 ACLIB_AngleTrackObsrv(MCLIB_ANGLE_T *pudt16SinCos,
ACLIB_ANGLE_TRACK_OBSRV_T * pudtCtrl)
```

3.2.2 Arguments

Table 3-2. Function Arguments

Name	In/ Out	Format	Valid Range	Description
*pudtSinCos	in	MCLIB_ ANGLE_ T	N/A	Input signal of sine, cosine components to be filtered.
*pudtCtrl	in/out	ACLIB_A NGLE_T RACK_O BSRV_T	N/A	Pointer to an angle-tracking observer structure ACLIB_ANGLE_TRACK_OBSRV_T, which contains algorithm coefficients.

Table 3-3. User-Type Definitions

Typedef	Name	In/ Out	Format	Valid Range	Description
MCLIB_ANGLE_T	f16Sin	In	SF16	$8000... $7FFF	Sine component to be estimated.
	f16Cos	In	SF16	$8000... $7FFF	Cosine component to be estimated.
ACLIB_ANGLE_TRACK_OBSRV_T	f32Speed	in/out	SF32	0x80000000... 0x7FFFFFFF	Estimated speed as output of the first numerical integrator.
	f32A2	in/out	SF32	0x80000000... 0x7FFFFFFF	Output of the second numerical integrator.
	f16Theta	in/out	SF16	$8000... $7FFF	Estimated position.
	f16SinEstim	in	SF16	$8000... $7FFF	Sine signal to be estimated.
	f16CosEstim	in	SF16	$8000... $7FFF	Cosine signal to be estimated.
	f16K1Scaled	in	SF16	$8000... $7FFF	K1 coefficient scaled to fractional range.
	i16K1Shift	in	SI16	–F...F	Scaling shift.
	f16K2Scaled	in	SF16	$8000... $7FFF	K2 coefficient scaled to fractional range.
	i16K2Shift	in	SI16	–F...F	Scaling shift.
	f16A2Scaled	in	SF16	$8000... $7FFF	Scaling coefficient due to numerical integration.
	i16A2Shift	in	SI16	–F...F	Scaling shift.

3.2.3 Availability

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

This library module is targeted at MCF51xx platform.

3.2.4 Dependencies

List of all dependent files:

- MCLIB library
- GFLIB library
- ACLIB_AngleTrackObsrv.h
- MCF51_types.h

3.2.5 Description

This function calculates the angle-tracking observer algorithm. It is recommended to call this function at every sampling period. It requires two input arguments as sine and cosine samples. The practical implementation of the angle-tracking observer algorithm is described below.

The angle-tracking observer compares values of the input signals sin (θ), cos (θ) with their corresponding estimations sin (θ), cos (θ). As in any common closed-loop systems, the intention is to minimize observer error towards zero value. The observer error is given here by subtraction of the estimated resolver rotor angle θ from the actual rotor angle θ (see Figure 3-1).

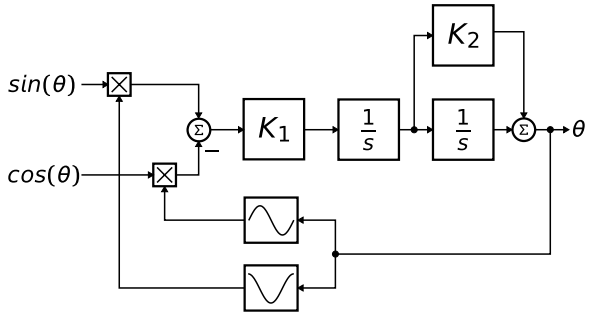

Figure 3-1. Block Scheme of the Angle-Tracking Observer

Note that mathematical expression of observer error is known as the formula of the difference of two angles:

$$\sin(\theta - \hat{\theta}) = \sin(\theta) \times \cos(\hat{\theta}) - \cos(\theta) \times \sin(\hat{\theta}) \qquad \textit{Eqn. 3-1}$$

In the case of minimal deviations of the estimated rotor angle compared to the actual rotor angle, the observer error may be expressed in the following form:

$$\sin(\theta - \hat{\theta}) \approx \theta - \hat{\theta} \qquad \textbf{Eqn. 3-2}$$

The primary benefit of the angle-tracking observer utilization, in comparison with the trigonometric method, is its smoothing capability. This filtering is achieved by the integrator and proportional and integral controller that are connected in series and closed by a unit-feedback loop. This block diagram nicely tracks actual rotor angle and speed and continuously updates their estimations. The angle-tracking observer transfer function is expressed as follows:

$$\frac{\hat{\theta}(s)}{\theta(s)} = \frac{K_1(1 + K_2 s)}{s^2 + K_1 K_2 s + K_1} \qquad \textbf{Eqn. 3-3}$$

The characteristic polynomial of the angle-tracking observer corresponds to the denominator of the transfer function:

$$s^2 + K_1 K_2 s + K_1 \qquad \textbf{Eqn. 3-4}$$

An appropriate dynamic behavior of the angle-tracking observer is achieved by placement of the poles of the characteristic polynomial. This general method is based on matching the coefficients of the characteristic polynomial with the coefficients of the general second-order system.

The analog integrators in Figure 3-1, marked as 1/*s*, are replaced by an equivalent of the discrete-time integrator using the backward Euler integration method. The discrete-time block diagram of the angle-tracking observer is shown in Figure 3-2.

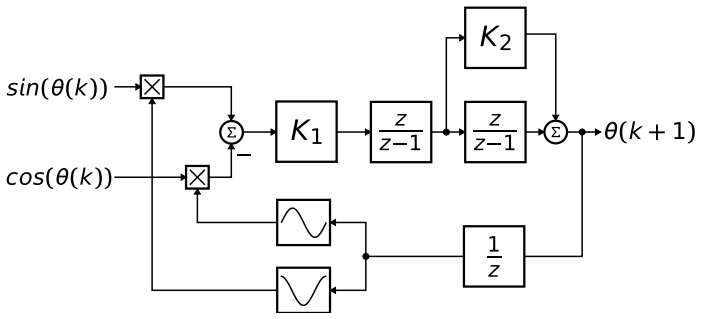

Figure 3-2. Block Scheme of Discrete-Time Tracking Observer

The essential equations for implementation of the angle-tracking observer, according to block scheme in Figure 3-2, are as follows:

$$e(k) = \sin(\mathrm{k}) \times \cos(\hat{\theta}(k)) - \cos(\mathrm{k}) \times \sin(\hat{\theta}(k)) \qquad \textbf{Eqn. 3-5}$$

$$\omega(k) = \omega(k-1) + K_1 \times \Delta T_S \times e(k) \qquad \textbf{Eqn. 3-6}$$

$$a_2(k) = a_2(k-1) + \Delta T_S \times \omega(k) \quad \textbf{Eqn. 3-7}$$

$$\theta(k) = K_2 \times \omega(k) + a_2(k) \quad \textbf{Eqn. 3-8}$$

In equations Equation 3-5 to Equation 3-8, there are coefficients and quantities that might be greater than one (for example, the actual rotor speed $\omega(k)$), or that are too small to be precisely represented within a 16-bit fractional value. Due to this fact a special transformation of equations Equation 3-5 to Equation 3-8 has to be carried out in order to be successfully implemented using fractional arithmetic.

$$K_{1FRAC} = \Delta T_S \times \frac{K_1}{\Omega_{MAX}} \quad \textbf{Eqn. 3-9}$$

$$K_{2FRAC} = K_2 \times \frac{\Omega_{MAX}}{\Theta_{MAX}} \quad \textbf{Eqn. 3-10}$$

$$A_{2FRAC} = \Delta T_S \times \frac{\Omega_{MAX}}{\Theta_{MAX}} \quad \textbf{Eqn. 3-11}$$

where the variables of the angle-tracking observer are:

- $e(k)$ — observer error in step k,
- ΔT_S — the sampling period [s],
- $\omega(k)$ — the actual rotor speed [rad/s] in step k,
- $\theta(k)$ — the actual rotor angle [rad] in step k,
- $a_2(k)$ — the actual rotor angle [rad] without scaled addition of speed in step k.

The scaled coefficients that are suitable for implementation on the core are as follows:

$$\text{f16K1Scaled} = K_{1FRAC} \times 2^{-\text{i16K1Shift}} \quad \textbf{Eqn. 3-12}$$

$$\text{f16K2Scaled} = K_{2FRAC} \times 2^{-\text{i16K2Shift}} \quad \textbf{Eqn. 3-13}$$

$$\text{f16A2Scaled} = A_{2FRAC} \times 2^{-\text{i16A2Shift}} \quad \textbf{Eqn. 3-14}$$

3.2.6 Return

The function returns an estimation of the actual rotor angle as a 16-bit fractional value.

3.2.7 Range Issues

The function works with the signed fractional values in the range <–1, 1).

3.2.8 Special Issues

N/A

3.2.9 Implementation

Example 3-1.

```
#include <hidef.h> /* for EnableInterrupts macro */
#include "derivative.h" /* include peripheral declarations */

#include "aclib.h"

#define ANGLETRACKOBSRV_K1_SCALED   (20589)
#define ANGLETRACKOBSRV_K1_SHIFT    (-3)
#define ANGLETRACKOBSRV_K2_SCALED   (17732)
#define ANGLETRACKOBSRV_K2_SHIFT    (0)
#define ANGLETRACKOBSRV_A2_SCALED   (26214)
#define ANGLETRACKOBSRV_A2_SHIFT    (-5)

MCLIB_ANGLE_T   mudtAngle;
ACLIB_ANGLE_TRACK_OBSRV_T   mudtAngleTrackObsrv;
Frac16  f16PositionOut;

void Isr(void);

void main (void)
{
        mudtAngleTrackObsrv.f32Speed= FRAC32(0);
        mudtAngleTrackObsrv.f32A2= FRAC32(0);
        mudtAngleTrackObsrv.f16Theta= FRAC16(0);
        mudtAngleTrackObsrv.f16SinEstim= FRAC16(0);
        mudtAngleTrackObsrv.f16CosEstim= FRAC16(0);
        mudtAngleTrackObsrv.f16K1Scaled =
ANGLETRACKOBSRV_K1_SCALED;
        mudtAngleTrackObsrv.i16K1Shift=
ANGLETRACKOBSRV_K1_SHIFT;
        mudtAngleTrackObsrv.f16K2Scaled=
ANGLETRACKOBSRV_K2_SCALED;
        mudtAngleTrackObsrv.i16K2Shift=
ANGLETRACKOBSRV_K2_SHIFT;
        mudtAngleTrackObsrv.f16A2Scaled=
ANGLETRACKOBSRV_A2_SCALED;
        mudtAngleTrackObsrv.i16A2Shift=
ANGLETRACKOBSRV_A2_SHIFT;
}

/* Periodical function or interrupt */
```

```
void ISR(void)
{
        /* Angle tracking observer calculation */
        f16PositionOut = ACLIB_AngleTrackObsrv(&mudtAngle,
&mudtAngleTrackObsrv);
}
```

3.2.10 Performance

Table 3-4. Performance of the ACLIB_AngleTrackObsrv Function

Code Size (bytes)	296 + 90 (GFLIB_SinLut) + 96 (GFLIB_CosLut)	
Data Size (bytes)	516 (GFLIB_SinLut)	
Execution Clock	Min	203 cycles
	Max	226 cycles

3.3 ACLIB_PMSMBemfObsrvAB

The function calculates the algorithm of back electro-motive force observer in a stationary reference frame.

3.3.1 Synopsis

```
#include"aclib.h"
void ACLIB_PMSMBemfObsrvAB
(
        MCLIB_2_COOR_SYST_ALPHA_BETA_T *pudtCurrentAlphaBeta,
        MCLIB_2_COOR_SYST_ALPHA_BETA_T *pudtVoltageAlphaBeta,
        Frac16 f16Speed,
        ACLIB_BEMF_OBSRV_AB_T *const pudtCtrl
)
```

3.3.2 Arguments

Table 3-5. Function Arguments

Name	In/ Out	Format	Valid Range	Description
*pudtCurrent AlphaBeta	in	*MCLIB_2_COOR_SYST_ALPHA_BETA_T*	N/A	Input signal of alpha/beta current components.
*pudtVoltage AlphaBeta	in	*MCLIB_2_COOR_SYST_ALPHA_BETA_T*	N/A	Input signal of alpha/beta voltage components.
f16Speed	in	*SF16*	$8000... $7FFF	Fraction value of electrical speed.
*pudtCtrl	in/out	*ACLIB_BEMF_OBSRV_AB_T*	N/A	Pointer to an observer structure, which contains coefficients.

Table 3-6. User Types

Typedef	Name	Format	Valid Range	Description
ACLIB_BEMF_OBSRV_AB_T	udtIObsrv.f32Alpha	SF32	0x80000000... 0x7FFFFFFF	Estimated current in alpha axis.
	udtIObsrv.f32Beta	SF32	0x80000000... 0x7FFFFFFF	Estimated current in beta axis.
	udtCtrl.f32IAlpha_1	SF32	0x80000000... 0x7FFFFFFF	State variable in alpha part of the observer; integral part at step k-1.
	udtCtrl.f32IBeta_1	SF32	0x80000000... 0x7FFFFFFF	State variable in beta part of the observer; integral part at step k-1.
	udtCtrl.f16PropScaled	SF16	$8000... $7FFF	Observer proportional gain.
	udtCtrl.i16PropShift	SI16	-F...F	Observer proportional gain shift.
	udtCtrl.f16IntegScaled	SF16	$8000... $7FFF	Observer integral gain.
	udtCtrl.i16IntegShift	SI16	-F...F	Observer integral gain shift.
	udtUnityVctr.f16Sin	MCLIB_ANGLE_T	$8000... $7FFF	Sine component of estimated unity vector.
	udtUnityVctr.f16Cos	MCLIB_ANGLE_T	$8000... $7FFF	Cosine component of estimated unity vector.
	f16IScaled	SF16	$8000... $7FFF	Scaling coefficient for current I_{FRAC}.
	f16UScaled	SF16	$8000... $7FFF	Scaling coefficient for voltage U_{FRAC}.
	f16WIScaled	SF16	$8000... $7FFF	Scaling coefficient for angular speed WI_{FRAC}.
	f16EScaled	SF16	$8000... $7FFF	Scaling coefficient for back-EMF E_{FRAC}.

3.3.3 Availability

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

This library module is targeted at MCF51xx platform.

3.3.4 Dependencies

List of all dependent files:

- MCLIB library
- GFLIB library
- ACLIB_PMSMBemfObsrvABAsm.h
- MCF51_types.h

3.3.5 Description

This back-emf observer is realized within stationary α,β reference frame.

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = R_S \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + \begin{bmatrix} sL_D & \Delta L\omega_r \\ -\Delta L_D\omega_r & sL_D \end{bmatrix} \times \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + (\Delta L \times (\omega_e i_D - i_Q') + k_e\omega_r) \times \begin{bmatrix} -\sin(\theta_r) \\ \cos(\theta_r) \end{bmatrix} \quad \textit{Eqn. 3-15}$$

where

- R_S — stator resistance
- L_d, L_q— D-axis and Q-axis inductance
- k_e — back-emf constant
- ω_e — rotor angular speed
- u_α, u_β — components of stator voltage vector
- i_α, i_β — components of stator current vector
- s — operator of derivative
- i_Q' — first derivative of i_q current
- $\Delta L = (L_D - L_Q)$ — motor saliency

This extended back-emf model includes both position information from the conventionally defined back-emf and the stator inductance as well. This allows to extract the rotor position and velocity information by estimating the extended back-emf only.

Both alpha and beta-axis consist of the stator-current observer based on RL motor circuit, which requires motor parameters.

The current observer is fed by the sum of the actual applied motor voltage, cross-coupled rotational term, which corresponds to the motor saliency $(L_D - L_Q)$

and compensator corrective output. The observer provides back-EMF signals as disturbance because back-EMF is not included in observer model.

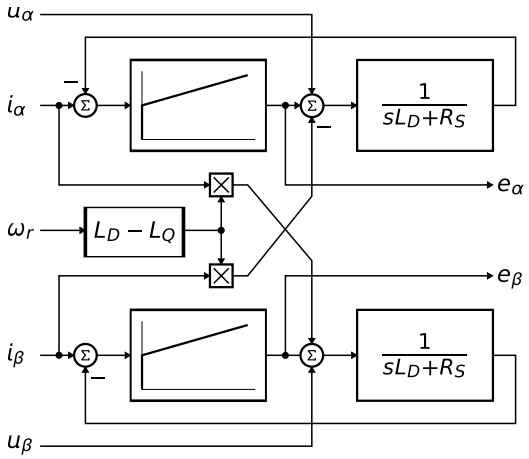

Figure 3-3. Block Diagram of Back-emf Observer

It is obvious that the accuracy of the back-emf estimates is determined by the correctness of used motor parameters (R, L), by fidelity of the reference stator voltage, and by quality of compensator such as bandwidth, phase lag, and so on.

Appropriate dynamic behavior of the back-emf observer is achieved by placement of the poles of the stator-current observer characteristic polynomial. This general method is based on matching the coefficients of the characteristic polynomial with the coefficients of the general second-order system.

$$\hat{E}_{\alpha\beta}(s) = -E_{\alpha\beta}(s) \times \left[\frac{F_c(s)}{sL_D + R_S + F_C(s)}\right] \qquad \textit{Eqn. 3-16}$$

Back-emf observer is a Luenberger-type observer with motor model, which is realized in fixed-point arithmetic transformed using backward Euler transformation.

$$\boldsymbol{i}_{FRFAC}(k) = U_{FRAC} \times \boldsymbol{u}_{FRAC}(k) + E_{FRAC} \times \boldsymbol{e}_{FRAC}(k) - WI_{FRAC} \times \omega_{eFRAC}(k)\boldsymbol{i}'_{FRAC}(k) \; I_{FRAC} \times \boldsymbol{i}_{FRAC}(k-1) \qquad \textit{Eqn. 3-17}$$

where

- $\boldsymbol{i}_{FRFAC}(k) = [i_\alpha, i_\beta]$ is a fractional representation of stator-current vector,
- $\boldsymbol{u}_{FRAC}(k) = [u_\alpha, u_\beta]$ is a fractional representation of stator-voltage vector,
- $\boldsymbol{e}_{FRAC}(k) = [e_\alpha, e_\beta]$ is a fractional representation of stator back-emf voltage vector,
- $\boldsymbol{i}'_{FRFAC}(k) = [i_\beta, -i_\alpha]$ is a fractional representation of complementary stator-current vector,
- $\omega_{FRFAC}(k)$ is a fractional representation of angular speed.

Scaling coefficients relating to maximal values are expressed as:

$$U_{FRAC} = \frac{\Delta T_S}{L_d + \Delta T_S R_S} \times \frac{U_{MAX}}{I_{MAX}} \quad \textit{Eqn. 3-18}$$

$$E_{FRAC} = \frac{\Delta T_S}{L_d + \Delta T_S R_S} \times \frac{E_{MAX}}{I_{MAX}} \quad \textit{Eqn. 3-19}$$

$$WI_{FRAC} = \frac{\Delta L \times \Delta T_S}{L_d + \Delta T_S R_S} \times \Omega_{MAX} \quad \textit{Eqn. 3-20}$$

$$I_{FRAC} = \frac{L_d}{L_d + \Delta T_S R_S} \quad \textit{Eqn. 3-21}$$

where:

- ΔT_S — sampling time in [sec]
- I_{MAX} — maximal peak current in [A]
- E_{MAX} — maximal peak back-emf voltage in [V]
- U_{MAX} — maximal peak stator voltage in [V]
- Ω_{MAX} — maximal angular speed in [rad/sec]

If a Luenberger-type stator-current observer is properly designed in the stationary reference frame, the back-emf can be estimated as a disturbance, produced by the observer controller. This is only valid if the back-emf term is not included in the observer model. The observer is actually a closed-loop current observer, so it acts as a state filter for the back-emf term.

The estimate of extended-emf term can be derived from Equation 3-16 as follows:

$$\frac{\hat{E}_{\alpha\beta}(s)}{E_{\alpha\beta}(s)} = \frac{sK_P + K_I}{s^2 L_D + sR_S + sK_P + K_I} \quad \textit{Eqn. 3-22}$$

The observer controller can be designed by comparing the closed-loop characteristic polynomial with that of a standard second-order system as:

$$s^2 + \left(\frac{K_P + R_S}{L_D}\right)s + \frac{K_I}{L_D} = s^2 + 2\xi\omega_0 s + \omega_0^2 \quad \textit{Eqn. 3-23}$$

where

- ω_0 is the natural frequency of the closed-loop system (loop bandwidth),
- ξ is the loop attenuation.

3.3.6 Return

The function returns a unity vector representing the estimated value of sine and cosine values of back-emf.

3.3.7 Range Issues

The function works with the signed fractional values in the range <–1, 1).

3.3.8 Special Issues

N/A

3.3.9 Implementation

Example 3-2.

```
#include <hidef.h> /* for EnableInterrupts macro */
#include "derivative.h" /* include peripheral declarations */

#include "aclib.h"

#define BEMFOBSRV_AB_PROP_GAIN_SCALED    (16719)
#define BEMFOBSRV_AB_PROP_GAIN_SHIFT     (-2)
#define BEMFOBSRV_AB_INTEG_GAIN_SCALED   (31737)
#define BEMFOBSRV_AB_INTEG_GAIN_SHIFT    (-5)
#define BEMFOBSRV_AB_I_SCALED            (28174)
#define BEMFOBSRV_AB_U_SCALED            (31964)
#define BEMFOBSRV_AB_E_SCALED            (22968)
#define BEMFOBSRV_AB_WI_SCALED           (0)
#define BEMFOBSRV_AB_MAX_CURRENT         (8.0)

MCLIB_2_COOR_SYST_ALPHA_BETA_T mudtI, mudtU;
ACLIB_BEMF_OBSRV_AB_T mudtBemfObsrv;
Frac16 f16Speed;

void Isr(void);

void main(void)
{
 mudtBemfObsrv.udtIObsrv.f32Alpha = FRAC32(0.0);
 mudtBemfObsrv.udtIObsrv.f32Beta = FRAC32(0.0);
 mudtBemfObsrv.udtCtrl.f32IAlpha_1 = FRAC32(0.0);
 mudtBemfObsrv.udtCtrl.f32IBeta_1 = FRAC32(0.0);
 mudtBemfObsrv.udtCtrl.f16PropScaled =
BEMFOBSRV_AB_PROP_GAIN_SCALED;
 mudtBemfObsrv.udtCtrl.i16PropShift =
BEMFOBSRV_AB_PROP_GAIN_SHIFT;
 mudtBemfObsrv.udtCtrl.f16IntegScaled =
BEMFOBSRV_AB_INTEG_GAIN_SCALED;
 mudtBemfObsrv.udtCtrl.i16IntegShift =
BEMFOBSRV_AB_INTEG_GAIN_SHIFT;
 mudtBemfObsrv.f16IScaled = BEMFOBSRV_AB_I_SCALED;
 mudtBemfObsrv.f16UScaled = BEMFOBSRV_AB_U_SCALED;
 mudtBemfObsrv.f16EScaled = BEMFOBSRV_AB_E_SCALED;
 mudtBemfObsrv.f16WIScaled = BEMFOBSRV_AB_WI_SCALED;
```

```
}

/* Periodical function or interrupt */
void Isr(void)
{
 /* Observer calculation */
 ACLIB_PMSMBemfObsrvAB(&mudtI, &mudtU, f16Speed,
&mudtBemfObsrv);
}
```

3.3.10 Performance

Table 3-7. Performance of the ACLIB_PMSMBemfObsrvAB Function

Code Size (bytes)	540 + 156 (GFLIB_DivsLSS) + 172 (GFLIB_SqrtPoly)	
Data Size (bytes)	72 (GFLIB_SqrtPoly)	
Execution Clock	Min	489 cycles
	Max	628 cycles