RL78/F14 BLDC Starter Kit
User's Manual: Hardware

RENESAS MCU
RL78/F14 Series

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1. Introduction

The Renesas Motor Control starter kit called Y-BLDC-SK-RL78F14, is based on the RL78/F14 device from the powerful 16-bit RL78 microcontroller family with a maximum operating frequency of 32MHz and delivering up to 52DMIPs.

The kit enables engineers to easily test and evaluate the performance of the RL78/F14 in a laboratory environment when driving any 3-phase Permanent Magnet Synchronous Motor (e.g. Brushless Motor) using an advanced sensor less Field Oriented Control algorithm. Typical applications for this type of solution are compressors, air conditioning, fans, air extractors, pumps, home appliances inverters and industrial drives.

The phase current measurement is done via three shunts which offers a low cost solution, avoiding the need for an expensive current sensor or hall sensor. A single shunt current reading method is also available to ensure an even more compacter bill of material.

The powerful user-friendly PC Graphical User Interface (GUI) gives real time access to key motor performance parameters and provides a unique motor auto-tuning facility.

The hardware is designed for easy access to key system test points and for the ability to hook up to an RL78/F14 debugger known as E1.

The Y-BLDC-SK-RL78F14 Starter Kit is an ideal tool to check out all the key performance parameters of your selected motor, before embarking on a final end application system design.

*Figure 1. RL78/F14 BLDC Starter Kit Top View in Three Shunt Configuration*
Figure 2. Overview of PC Graphical User Interface
1. Do not connect Power Source with more than 3A before loading your Software to the device!!!

   Otherwise there may be a short circuit trough the FETs.

   The board can measure up to 17A trough each phase shunt but however as heat dissipation is untested for more than 36W power supply it is not recommended to use a bigger power supply. This is not covered by any warranty.

2. When power supply of E1 On-Chip debugger is used please note that the maximum current provided by the debugger is limited to 200mA. Thus an external power supply is required in case all functions on the Starter Kit are used to full extend.
2. Specifications & Hardware overview

<table>
<thead>
<tr>
<th>ITEM</th>
<th>SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TYPE OF MOTORS SUPPORTED</strong></td>
<td>3-phase Permanent Magnet Synchronous (PMSM, PMAC, BLAC)</td>
</tr>
<tr>
<td></td>
<td>3-phase Brushless DC (BLDC)</td>
</tr>
<tr>
<td><strong>KIT MOTOR PARTNAME</strong></td>
<td>Fulling Motor</td>
</tr>
<tr>
<td><strong>KIT MAX INPUT RANGE</strong></td>
<td>External power supply: 5.3V to 18V&lt;sub&gt;DC&lt;/sub&gt;, 3A&lt;sub&gt;nom&lt;/sub&gt;, 17A&lt;sub&gt;peak&lt;/sub&gt;, 24V&lt;sub&gt;DC&lt;/sub&gt;&amp; 40V&lt;sub&gt;peak&lt;/sub&gt; &lt;500ms</td>
</tr>
<tr>
<td><strong>TRANSISTOR USED</strong></td>
<td>Renesas MOSFETs: NP75N04YUG, 40V, 75A</td>
</tr>
<tr>
<td><strong>TRANSISTOR DRIVER</strong></td>
<td>Renesas MOSFET driver Intelligent Power Device: R2A25108KFP, 40V, 75A</td>
</tr>
<tr>
<td><strong>POWER SUPPLY OPTION</strong></td>
<td>External supply: up to 18V&lt;sub&gt;DC&lt;/sub&gt;</td>
</tr>
<tr>
<td><strong>CURRENT DETECTION</strong></td>
<td>One or three shunt configuration (10mΩ)</td>
</tr>
<tr>
<td><strong>USB IC USED ON THE BOARD</strong></td>
<td>FT2232D – Dual USB UART IC from FTDI, 9.6Kbd communication speed</td>
</tr>
<tr>
<td><strong>MICROCONTROLLER</strong></td>
<td>RL78/F14 (R5F10PMJ), 80-pin QFP, 32MHz, 256KB Flash, 20KB RAM</td>
</tr>
<tr>
<td><strong>MCU PERFORMANCE</strong></td>
<td>32MHz, 52DMiPs, 32 CoreMark</td>
</tr>
<tr>
<td><strong>KIT CLOCK SOURCE OPTION</strong></td>
<td>32MHz or 24MHz (fIH)</td>
</tr>
<tr>
<td><strong>KEY FEATURES (MCU SECTION)</strong></td>
<td>3-phase inverter Timer RD, Event Link controller (ELC),</td>
</tr>
<tr>
<td></td>
<td>10-bit A/D Converter, Data transfer controller (DTC),</td>
</tr>
<tr>
<td></td>
<td>LIN/UART module, CAN interface</td>
</tr>
<tr>
<td><strong>MCU EMBEDDED Firmware</strong></td>
<td>Sensor less vector control algorithm (Field Oriented Control)</td>
</tr>
<tr>
<td><strong>SWITCHING FREQUENCY</strong></td>
<td>16KHz to 24KHz, 24KHz@32MHz by default (PWM frequency)</td>
</tr>
<tr>
<td><strong>CONTROL LOOP FREQUENCY (SAMPLING FREQUENCY)</strong></td>
<td>4KHz to 8KHz, 8KHz@24KHz PWM by default</td>
</tr>
<tr>
<td><strong>CONTROL LOOP TIMING</strong></td>
<td>87.5µs under IAR and 78.33µs under CS+ including the FOC</td>
</tr>
<tr>
<td></td>
<td>loop and current and speed PI controllers</td>
</tr>
<tr>
<td><strong>CODE SIZE IN FLASH / RAM</strong></td>
<td>25.87KB / 2.23KB under IAR and 24.79KB / 2.02KB under CS+, including auto/manual PI tuning and Motor identification</td>
</tr>
<tr>
<td><strong>TOOL USED, VERSION</strong></td>
<td>IAR Embedded Workbench for Renesas RL78 1.40.X</td>
</tr>
<tr>
<td></td>
<td>CS+ for CC V4.0.0</td>
</tr>
<tr>
<td><strong>COMPILER OPTIMIZATION LEVEL</strong></td>
<td>Maximum optimization for speed</td>
</tr>
<tr>
<td><strong>ENVIRONMENT STANDARDS</strong></td>
<td>RoHS compliant including China regulations</td>
</tr>
<tr>
<td></td>
<td>WEEE, RoHS</td>
</tr>
</tbody>
</table>

Table 1. Specification and Hardware Overview

The RL78/F14 starter kit consists of three pieces of separated boards, which are congregated by two pairs of connectors, including the system control microcontroller and communications.
management board (Y-BLDC-SK-RL78F14 MCU board), the gate pre-driver and current measurement amplifier board (Y-BLDC-SK-RL78F14 pre-driver board) and the integrated low voltage power inverter board (Y-BLDC-SK-MOSFET board).

The PCB is a two layers board and ensures the management of BLDC up to 18V\textsubscript{DC} (24V<60s & 40V < 500ms) and up to 17A\textsubscript{max}.

Please find below the Y-BLDC-SK-RL78F14 kit:

![Y-BLDC-SK-RL78F14 kit](image)

*Figure 3. Overview of RL78/F14 BLDC Starter Kit with Motor*

To obtain the maximum flexibility, the YBLDCSKRL78F14 kit includes:

- A complete on-board 3-phase inverter with a low voltage motor (15V), so it becomes easy to test the powerful sensor less algorithm running on the Renesas 16-bit RL\textsubscript{78/F14} microcontroller
- DC bus voltage provided via 15V external power supply
- Renesas low voltage MOSFET power devices. Power rating up to 3000W
- One- /Three- shunt current measurement resistors
- Renesas intelligent power device R2A25108KFP to pre-drive the power MOSFET inverter bridge, sense and amplifier the shunt current
  - Wide range operating: 5.3V to 18V(VBAT), 24V<60s
o On-chip three phase pre-driver circuit
  ▪ PWM control
  ▪ Totem pole type MOSFET gate drive circuit, high drive capability:
    Ciss = 10000pF
  ▪ Dead time control (adjustable)

o On-chip current sense amplifier with reference bias buffer

• USB communication using FT2232D USB to Serial UART/FIFO IC. The interface can be configured for
  o PC GUI control
    ▪ Motor operation, modify motor and control parameters
    ▪ Motor tuning
  o Offering 9.6Kbd communication speed with the PC GUI

In the Y-BLDC-SK-RL78F14 Starter Kit, the RL78/F14 in an 80-pin package was selected to ensure the management of inverter, external communications, three or single shunts, the E1 debugger, three voltages phases, the over-current detection, the Bus voltage monitoring, etc.

In Appendix A: Schematic shows the detailed I/O pins assignment of the RL78/F14 to manage the complete kit.
3. Connectors description

As shown in the following figure, you can find the positions and the descriptions of the connectors present on the board. Please refer to the board schematics for the full description of the connectors in Appendix A: Schematic.

The E1 connector is used for the programming and the debugging of the software running on the RL78/F14. It can be connected to the IAR integrated development environments or CS+ for CC.

![Connectors of RL78/F14 MCU Board](image)

*Figure 4. Connectors of RL78/F14 MCU Board*
Figure 5. Connectors of RL78/F14 Pre-Driver Board

Figure 6. Connectors of RL78/F14 MOSFET Board
4. LED function description

The LED available on the board is directly connected to the three phase bus voltage (15V) and allow the user to understand the status of the board, which indicates the presence of the switches drive supply.

![LED in RL78/F14 MOSFET Board](image1)

*Figure 7. LED in RL78/F14 MOSFET Board*

![LED of RL78/F14 MOSFET Board](image2)

*Figure 8. LED of RL78/F14 MOSFET Board*
5. Test points for debugging

Several specific test points, which connect to some microcontroller pins, are available on the board to visualize with the oscilloscope the behavior of some internal analog signals. For more details about the test points please refer to Appendix A: Schematic.

The figure below is showing the connector TP1 to be used for the tuning of the current PI gains. In this way an oscilloscope is needed to see the response of the system to the stimulation. It is not available in software but another particular procedure to help the calibration — Cur. PI tuning is offered, in detail see Chapter 20 Motor Auto-calibration using the PC GUI. Tuning can be obtained in the PC GUI, there is no need of an oscilloscope.

![Test Points Diagram](image)

*Figure 9. Test Points of RL78/F14 MCU Board*
Figure 10. Test Points of RL78/F14 Pre Driver Board
6. Internal power board description

The power board is a complete 3-phase bridge composed with discrete low voltage and high current MOSFETs. The MOSFETs are the Renesas NP75N04YUG n-channel power MOSFETs. Please refer to the data-sheet available on the Renesas website: www.renesas.eu for the switches characteristics and to the board schematics for the details on the driving circuit. The maximum current is 75A, and the maximum voltage is 40VDC.

![Diagram of RL78/F14 MOSFET Board]

**Figure 11. Three Shunts Current Reading Configuration of RL78/F14 MOSFET Board**

The inverter has the classical schema as showing in the following figure with the three shunts on the lower arms, with the possibility to use a single shunt by removing two of them.
Furthermore, the intelligent power device R2A25108KFP is adopted to pre-drive the six low voltage MOSFETS NP75N04YUG.

Please find in Appendix A: Schematic the drawing in more details.
7. Single shunt current reading

While the normal configuration of the board and the standard software are based on three shunts current reading, we also offer the possibility to configure the board for single shunt current reading.

Some hardware modifications are required and a different software version has to be programmed into the RL78/F14 flash memory.

The required hardware modifications are the following (please refer to the board schematics):

- Set the J3 and J4 closed, then R41 and R23 are shorted. Only R32 is adopted to measure current.
- Resistors R41 and R23 have to be removed.

The components involved in the modifications are indicated in the figure below.

![Single Shunt Current Reading Configuration of RL78/F14 MOSFET Board](image)

*Figure 14. Single Shunt Current Reading Configuration of RL78/F14 MOSFET Board*
8. Current reading timing in three shunts and single shunt configurations

The figures below show the different situations related to the two configurations. The first figure is related to three shunts current reading, the other are related to the single shunt current reading.

![Three Shunt and Single Shunt Current Reading](image)

**Figure 15. Three Shunt and Single Shunt Current Reading**

Three shunts configuration (J3 and J4 are open)

In the three shunts configuration the current in one shunt is equal to the corresponding phase current when the corresponding lower switch is ON.

The most suitable moment to read the current in this configuration is at the trough of the PWM.

By default the Y-BLDC-SK-RL78F14 Starter Kit is delivered in the three shunts configuration.

Single shunt configuration (J3 and J4 are closed)

In the single shunt configuration, only when one or two of the lower switches are ON the current through the shunt is related with the phase current.

When only one of the lower switches is ON, the current in the shunt is equal to the current of the corresponding inverter phase.

When two of the lower switches are ON, the current in the shunt is equal to the sum of the currents of the corresponding phases that is it is minus the current of the third phase.

**Important Note:**


The intelligent device R2A25108KFP is used to measure in real-time the motor currents flowing through the shunts resistors, where the shunts are called R23, R32, R41.
The default value: Shunt $R_{23} = R_{32} = R_{41} = 10m\Omega$; $R_{FB} = 15K\Omega$; $R_S = 1K\Omega$.

For further information please refer to Appendix A: Schematic.

The amplifier circuit shown below is made to manage current up to 14.7A (17A) flowing through the shunts and the output of the amplifier is connected directly to the Microcontroller RL78/F14.

![Amplifier Circuit](image)

**Figure 16. R2A25108KFP for Current Measurement**

Please find below the equations related to the amplifier circuit that are useful to change the range of currents to be measured through the three shunts.

If $R_{FB} = R_{22} = R_{25}$ and $R_S = R_{21} = R_{24}$, then the amplification of the circuit is $R_{25}/R_{24} = 15$.

So the output voltage ($V_{out}$ to MCU) is:

$$V_{out} = 2.5V - V_{shunt} \times R_{25}/R_{24}, \text{ and } V_{shunt} = R_{shunt} \times I_{shunt}$$

So

$$V_{out} = 2.5V - (R_{shunt} \times I_{shunt}) \times R_{25}/R_{24}$$

And the term

$$\Delta V = (R_{shunt} \times I_{shunt}) \times R_{25}/R_{24}$$
It is mandatory to keep between -2.5V and 2.5V with some margin (margin of 0.3V could be enough) so:

\[-2.2V < \text{Delta}_V < 2.2V\]

So the maximum current will be:

\[I_{\text{shunt max dc}} = \frac{2.2V}{(R_{\text{shunt}} \times (R_{25}/R_{24}))}\]

The default values are the following:

\[R_{\text{shunt}} = 0.01\,\Omega, \quad R_{25} = 15\,K, \quad R_{24} = 1\,K, \quad \text{so} \quad I_{\text{shunt max dc}} = 14.7\,\text{Adc}\]

If there exists no margin then \(I_{\text{shunt max dc}} = \frac{2.5V}{(R_{\text{shunt}} \times (R_{25}/R_{24}))} = 17\,\text{Adc}\)

To manage different values it is enough to change \(R_{\text{shunt}}, R_{25}\) and \(R_{24}\) but it is important to keep the following conditions:

\[R_{22} = R_{25}\] and \[R_{21} = R_{24}\]

The shunt resistor value needs to be updated in the software itself in the file called: “const_def.h” as shown below:

```c
/* hardware settings */
#ifndef RSHUNT_OHM
    #define RSHUNT_OHM     ( 0.01 )     // shunt resistors [Ohm]
#endif // ifndef RSHUNT_OHM

#ifndef RSGAIN
    #define RSGAIN     ( 15 )         // circuit gain
#endif // ifndef RSGAIN
```

*Figure 17. Shunt Resistor Value in Embedded Source Code*
9. Microcontroller RL78/F14 short overview

The RL78/F14 is a high-performance 16-bit microcontroller with a maximum operating frequency of 32MHz and delivers up to 52DMIPS. The RL78/F14 includes hardware support for math calculations, multifunction timers for three phase PWM generation, encoder decoding and general support functions (Timers RD, RG and RJ), event link controller (ELC) for reducing software overhead, a data transfer controller (DTC) for automatic data transfer, 10-bit A/D converter and 8-bit D/A converter, LIN/UART module and CAN interface for network communication.

The main specifications of the F14 are as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>RL78 Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU core</td>
<td>RL78 CPU running at 32MHz, delivering 52DMIPS, peripherals running up to 64MHz</td>
</tr>
<tr>
<td></td>
<td>General registers: 8-bit x 32</td>
</tr>
<tr>
<td></td>
<td>Multiply/divide and multiply - accumulate:</td>
</tr>
<tr>
<td></td>
<td>16 bits \times 16 bits = 32 bits (Unsigned or signed)</td>
</tr>
<tr>
<td></td>
<td>32 bits ÷ 32bits = 32 bits (Unsigned)</td>
</tr>
<tr>
<td></td>
<td>16 bits \times 16 bits + 32 bits = 32 bits (Unsigned or signed)</td>
</tr>
<tr>
<td>Power supply voltage</td>
<td>2.7 to 5.5V</td>
</tr>
<tr>
<td>Flash / RAM memory</td>
<td>Max.128 KB / 8KB</td>
</tr>
<tr>
<td>On-chip peripheral functions</td>
<td>Data transfer controller (DTC): max. 52 sources</td>
</tr>
<tr>
<td>Timers</td>
<td>16-bit timer array unit: 8 to 16 channels</td>
</tr>
<tr>
<td></td>
<td>16-bit timer RD: 2 channels</td>
</tr>
<tr>
<td></td>
<td>16-bit timer RJ: 1 channel</td>
</tr>
<tr>
<td></td>
<td>Watchdog timer: 1 channel</td>
</tr>
<tr>
<td></td>
<td>Real-time clock: 1 channel</td>
</tr>
<tr>
<td>Communications</td>
<td>CSI, UART/UART(LIN-bus supported)/SPI</td>
</tr>
<tr>
<td></td>
<td>LIN module (master/slave supported)</td>
</tr>
<tr>
<td></td>
<td>I2C/simplified I2C, CAN interface(RS-CAN lite)</td>
</tr>
<tr>
<td>Analog</td>
<td>8/10-bit resolution A/D converter: 4 to 31 channels</td>
</tr>
<tr>
<td></td>
<td>8-bit D/A converter: 1 channel</td>
</tr>
<tr>
<td></td>
<td>On-chip comparator: 1 channel (input pin: 4 channels)</td>
</tr>
<tr>
<td>Safety</td>
<td>WWDT,</td>
</tr>
<tr>
<td></td>
<td>Illegal instruction execution detection function</td>
</tr>
<tr>
<td></td>
<td>Flash memory CRC operation function,</td>
</tr>
<tr>
<td></td>
<td>RAM1 bit error correction function,</td>
</tr>
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<td></td>
<td>RAM2 bit error detection function,</td>
</tr>
<tr>
<td></td>
<td>Invalid memory access detection function,</td>
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<tr>
<td></td>
<td>Frequency detection function,</td>
</tr>
<tr>
<td></td>
<td>Clock monitor function,</td>
</tr>
<tr>
<td></td>
<td>Stack pointer monitor function,</td>
</tr>
<tr>
<td></td>
<td>I/O port output signal level detection function,</td>
</tr>
<tr>
<td></td>
<td>A/D test function</td>
</tr>
<tr>
<td>Clock generation circuit</td>
<td>Main system clock oscillator: 1 to 20 MHz</td>
</tr>
<tr>
<td></td>
<td>High-speed on-chip oscillator (HOCO): 32 MHZ (typ.)</td>
</tr>
</tbody>
</table>
Low-speed on-chip oscillator (LOCO): 15KHz (typ.)
Subsystem clock oscillator
PLL
Other
Event link controller (ELC)
Option byte

Table 2. Main Specifications Overview of Microcontroller RL78/F14

Please find below the RL78/F14 package block diagram.

Figure 18. RL78/F14 Package Block Diagram

Please find below the memory line-up including the part-names.

RL78/F14xx - Basic Material Codes

Figure 19. RL78/F14 memory line-up and temperature range
Note:

To receive a copy of the *Hardware Users’ Manual*, please contact your local Renesas sales representative.
10. Renesas intelligent power device R2A25108KFP short overview

The R2A25108KFP device is an Intelligent Power Device to drive the power MOSFET inverter of the three phase brushless motor.

**Figure 20. Top View of R2A25108KFP**

This device contains three set of MOSFET-drivers, charge pump circuit for the gate drive of high side and low side external power MOSFET, zero-crossing detector for detection of motor position, three channels of current sense amplifier and safety functions as over voltage detection circuit (OVD), low voltage detection circuit (UVD), thermal shut down circuit (TSD), short circuit protection circuit etc.

The main features of the R2A25108KFP are as follows:

- Wide range operating voltage: 5.3V to 18V (VBAT)
- On-chip three phase pre-driver circuit
  - PWM control
- Totem pole type MOSFET gate drive circuit, high drive capability: $C_{iss} = 10000\, pF$
- Dead time control (adjustable)

- On-chip charge pump circuit (for power supply of gate drive)
- On-chip zero-crossing detection circuit
- On-chip current sense amplifier with reference bias buffer
- On-chip safety functions
  - Low voltage detection circuit (LVD)
  - Over voltage detection circuit (OVD)
  - Thermal shutdown circuit (TSD)
  - Short circuit protection; adjustable detection level
    - Function for the short to battery protection
    - Function for the short to GND protection
- Internal oscillation circuit; 175 KHz typ.
- 48 pin LQFP package
- Comply with AEC-Q100

For further details please refer to the data-sheet available on the Renesas website:
www.renesas.eu.
An application example is shown below.

Figure 21. R2A25108KFP Application Example
11. **Permanent Magnets Brushless Motor model**

The synchronous permanent magnets motor (sinusoidal brushless motor) is widely used in the industry. More and more home appliance makers are now using such brushless motor, mainly because of the intrinsic motor efficiency.

The permanent magnet motor is made with few components:

- A **stator** formed by stacking sheared metal plates where internally the copper wiring is wound, constructing the stator winding
- A **rotor** in which permanent magnets are fixed
- Two covers with ball bearings that keep together the stator and the rotor; the rotor is free to rotate inside the stator

![Diagram of Stator Windings of BLDC Model](image)

**Figure 22. Stator Windings of BLDC Model**

The working principle is quite simple: if we supply the motor with a three-phase system of sinusoidal voltages at constant frequency, in the stator windings flow sinusoidal currents, which create a rotating magnetic field.

The permanent magnets in the rotor tend to stay aligned with the rotating magnetic field, so the rotor rotates at synchronous speed.

The main challenge in driving this type of motor is to know the rotor position in real-time, so mainly implementation are using a position sensor or a speed sensor.

In our implementation, the system is using either **one or three shunts** to detect the rotor position in real-time.
Let’s analyze the motor from a mathematic point of view.

If we apply three voltages \(v_a(t), v_b(t), v_c(t)\) to the stator windings, the relations between phase voltages and currents are:

\[
\begin{align*}
    v_a &= R_s i_a + \frac{d\lambda_a}{dt} \\
    v_b &= R_s i_b + \frac{d\lambda_b}{dt} \\
    v_c &= R_s i_c + \frac{d\lambda_c}{dt}
\end{align*}
\]

- \(\lambda_i\) is the magnetic flux linkage with the i-th stator winding
- \(R_s\) is the stator phase resistance (the resistance of one of the stator windings)

The magnetic flux linkages \(\lambda_i\) are composed by two items, one due to the stator currents, one to the permanent magnets.

**Figure 23. Reference System Transformation from abc to dq axis**

The permanent magnet creates a magnetic field that is constant in amplitude and fixed in position in respect to the rotor. This magnetic field can be represented by vector \(\Lambda_m\) whose position in respect to the stator is determined by the angle \(\vartheta\) between the vector direction and the stator reference frame.
The contribution of the permanent magnets in the flux linkages depends on the relative position of the rotor and the stator, represented by the mechanical-electric angle $\vartheta$.

It is, in every axis, the projection of the constant flux vector $\Lambda_m$ in the direction of the axis:

$$\lambda_a = L_i_a + \Lambda_m \cos(\vartheta)$$
$$\lambda_b = L_i_b + \Lambda_m \cos(\vartheta - \frac{2\pi}{3})$$
$$\lambda_c = L_i_c + \Lambda_m \cos(\vartheta - \frac{4\pi}{3})$$

Supposing that the rotor is rotating at constant speed $\omega$ (that is: $\vartheta(t) = \omega t$) the flux linkages derivatives can be calculated, and we obtain:

$$v_a = R_S i_a + L \frac{di_a}{dt} - \omega \Lambda_m \sin(\vartheta)$$
$$v_b = R_S i_b + L \frac{di_b}{dt} - \omega \Lambda_m \sin(\vartheta - \frac{2\pi}{3})$$
$$v_c = R_S i_c + L \frac{di_c}{dt} - \omega \Lambda_m \sin(\vartheta - \frac{4\pi}{3})$$

A “three phase system” may be represented by an equivalent “two phase system”. So by using specific transformations, our three equations system is equivalent to a two equations system. It is basically a mathematical representation in a new reference coordinates system.

In the two phases ($\alpha, \beta$) fixed system the above equations become:

$$v_\alpha = R_S i_\alpha + \frac{d\lambda_\alpha}{dt}$$
$$v_\beta = R_S i_\beta + \frac{d\lambda_\beta}{dt}$$

For the magnetic field equations, we got:

$$\lambda_\alpha = L_i_\alpha + \lambda_{am} = L_i_\alpha + \Lambda_m \cos(\vartheta)$$
$$\lambda_\beta = L_i_\beta + \lambda_{bm} = L_i_\beta + \Lambda_m \sin(\vartheta)$$

After performing the derivation:

$$\frac{d\lambda_\alpha}{dt} = L \frac{di_\alpha}{dt} - \omega \Lambda_m \sin(\vartheta) = L \frac{di_\alpha}{dt} - \omega \lambda_{bm}$$
$$\frac{d\lambda_\beta}{dt} = L \frac{di_\beta}{dt} + \omega \Lambda_m \cos(\vartheta) = L \frac{di_\beta}{dt} + \omega \lambda_{am}$$
Finally, we obtain for the voltages in \((\alpha, \beta)\) system:

\[
v_\alpha = R_S i_\alpha + L \frac{di_\alpha}{dt} - \omega \lambda_{f\beta m}
\]

\[
v_\beta = R_S i_\beta + L \frac{di_\beta}{dt} + \omega \lambda_{am}
\]

A second reference frame is used to represent the equations as the frame is turning at the rotor speed. So the “d” axis is chosen in the direction of the magnetic vector \(\Lambda_m\), and with the “q” axis orthogonal to the “d” axis. The new reference system is \((d, q)\).

The reference frame transformations from the \((\alpha, \beta)\) system to the \((d, q)\) system depends on the instantaneous position angle \(\vartheta\).

We can see

\[
v_d = R_S i_d + L \frac{di_d}{dt} - \omega \lambda_{qm}
\]

\[
v_q = R_S i_q + L \frac{di_q}{dt} + \omega \lambda_{dm}
\]

and

\[
\lambda_{dm} = Li_d + \Lambda_m
\]

\[
\lambda_{qm} = Li_q
\]

So we obtain two inter-dependent equations in the \((d, q)\) system:

\[
v_d = R_S i_d + L \frac{di_d}{dt} - \omega Li_q
\]

\[
v_q = R_S i_q + L \frac{di_q}{dt} + \omega Li_d + \omega \Lambda_m
\]

These two equations represent the mathematical motor model as shown in the following figure.
A control algorithm which wants to produce determined currents in the (d, q) system must impose voltages given from the formulas above.

This is ensured by closed loop PI control on both axis “d” & “q” (Proportional Integral).

Since there is a mutual influence between the two axes, decoupling terms can be used.

In the block scheme the mechanic part is included, where “p” is the number of pole pairs, while “B” represents friction, “J” the inertia, “τ_{load}” the load torque and “τ” the motor torque, “Λ” is “Λ_m”:

\[
\tau = \frac{3}{2} p \Lambda i_q
\]

Thus, the torque can be controlled directly by the current \( i_q \) only. This approach is similar to the DC motor equation in which the torque is proportional to the winding current.

The angular speed \( \omega \) is represented in the scheme as \( \omega_e \) to distinguish the electrical speed from the mechanical one \( \omega_{mec} \).

Let’s now consider the equations we have seen in (α,β) system:

\[
v_\alpha = R_s i_\alpha + \frac{d\lambda_\alpha}{dt}
\]

\[
v_\beta = R_s i_\beta + \frac{d\lambda_\beta}{dt}
\]
These equations show that magnetic flux can be obtained from applied voltages and measured currents simply by integration:

\[
\lambda_\alpha = \lambda_{\alpha 0} + \int_0^t (v_\alpha - R_S i_\alpha) dt \\
\lambda_\beta = \lambda_{\beta 0} + \int_0^t (v_\beta - R_S i_\beta) dt
\]

Furthermore:

\[
\Lambda_m \cos(\vartheta) = \lambda_\alpha - Li_\alpha \\
\Lambda_m \sin(\vartheta) = \lambda_\beta - Li_\beta
\]

If the synchronous inductance L is small, the current terms can be neglected, if not they have to be considered. In general:

\[
x = \Lambda_m \cos(\vartheta) = \lambda_\alpha - Li_\alpha = \lambda_{\alpha 0} + \int_0^t (v_\alpha - R_S i_\alpha) dt - Li_\alpha \\
y = \Lambda_m \sin(\vartheta) = \lambda_\beta - Li_\beta = \lambda_{\beta 0} + \int_0^t (v_\beta - R_S i_\beta) dt - Li_\beta
\]

So in the (\(\alpha, \beta\)) system phase we obtain from the flux components:

\[
\vartheta = \arctan\left(\frac{y}{x}\right)
\]

The system speed \(\omega\) can be obtained as the derivative of the angle \(\vartheta\).

\[
\omega = \frac{d}{dt} \vartheta(t)
\]

Based on this, a sensor less control algorithm was developed to give the imposed phase voltages, to measure phase currents, to estimate the angular position \(\vartheta\) and finally the system speed.
12. Sensor less Field Oriented Control algorithm

Please, find below the sensor less vector control algorithm block diagram.

![FOC Algorithm Block Diagram](image)

**Figure 25. FOC Algorithm Block Diagram**

The main difference between the three shunts configuration and the single shunt one is in the “Current Reading” block, the rest of the algorithm remains the same in principle, even if the blocks order has been adjusted.
13. **Software Tools used**

The embedded software delivered in the Y-BLDC-SK-RL78F14 Starter Kit is developed under IAR integrated development tool and CS+ for CC IDE. Please find below the details of the IDE used.

13.1 IAR Embedded Workbench IDE

13.1.1 IAR Embedded Workbench Usage

The software was designed under IAR Embedded Workbench for Renesas RL78 Version: **1.40.6**.

![Figure 26. Product Version of IAR Embedded Workspace for Renesas RL78](image)

The device selected in the program is: RL78/F14-R5F10PMJ, it means the RL78/F14 with 256KB flash, 20KB RAM in an 80-pin package.

![Figure 27. Product Version of IAR Embedded Workspace for Renesas RL78](image)
13.1.2 Project importation into IAR Embedded Workbench

The IAR Embedded Workbench will have been installed in the default or user location.

The default location is as follows:

Start Menu =>

All programs =>

IAR Systems =>

IAR Embedded Workbench for Renesas RL78 1.40 =>

IAR Embedded Workbench.exe

Click on the “IAR Embedded Workbench.exe” to open, (Note that Windows Vista and 7 users may have to use “Run as administrator”) and the opening screen should open as below.

![Opening Screen of IAR Embedded Workspace for RL78](image)

Figure 28. Opening Screen of IAR Embedded Workspace for RL78

To open the YBLDCSKRL78F14 IAR motor control workspace and project follow the sequence shown below (see also figure above):

File =>

Open =>

Workspace =>

Sample Application destination folder\YBLDCSKRL78F14\IAR\Three Shunt =>

Select the “YBLDCSKRL78F14.eww” IAR Workspace file => Press Open
The project should then open in the IAR IDE and should look something like the window above. Here you can see two projects, YBLDCSKRL78F14_32MHz and YBLDCSKRL78F14_24MHz, which means clock source running at 24MHz and 32MHz are both offered. **We take the 32MHz one as a sample to introduce.**

Please note that depending on settings used previously then the IAR workspace and project windows can look slightly different. All the settings have been pre-set so that the workspace appearance is as constant as possible. For full details of IAR Embedded Workbench, please refer to the documentation included as part of the IAR installation.

To open any of the source files listed in the project (on the Left Hand Side of the project window), just double click on the relevant file.

Next the debugging interface E1 should be selected following the 5 steps as shown in the figure below.

Right click on the project name “YBLDCSKRL78F14_32MHz” and select “Options”, click “Debugger” and select “E1” option in the driver drop down menu, then press “OK” button.
The next step is to build the project.

The necessary settings have been set in the IDE so that it is not necessary to configure or make changes to any of the build options. These can obviously be viewed for reference, just select the “Option” menu as described above and click on any of the relevant button.

Note:

It is recommended that no changes are made to any of the build settings as the resulting build results could not be guaranteed.

The project can be built from the build ICON in the workspace or from the “Rebuild All” option in the “Project” drop down menu.

The project should be built without errors as shown in the following figure.
Launch the IAR debugger by clicking on the green button on the embedded workbench IDE window.

**Figure 32. Project Download and Debug Button**

If the debugger is being used for the first time the emulator needs to be configured before connecting and downloading the code to the board and RL78/F14. This applies to any hardware emulation setting and (i.e. E1, TK and IECUBE).

The user will be prompted by the following pop up window.

**Figure 33. Hardware Emulator Setting Popup Window**
The configuration window will open as shown below. Please check that the settings are as shown in the window below, changing any setting as necessary and then press the “OK” button.

![Hardware Emulator Setup Window](image)

**Figure 34. Hardware Emulator Setup Window**

After connection the E1 debugger to the target board powered by USB or external power supply, please click on “Download and Debug” to start the debugging and load the program into the microcontroller flash memory.

The IAR debugger will open a progress window which will initially connect to the board and then program the RL78/F14. Once this stage is complete the debugger window will open as shown below.
Figure 35. Debugging Window of Project

Other debugging windows can be opened to “watch variables, monitor registers, view the stack, memory etc.” These can be selected by using the “View” menu tab at the top of the workbench and then selecting the required debugging function. Please note that there are some other debugging function such as “Events” that are located under “Emulator” tab.

Data is held for all debugging options whether displayed or not, so that windows can be opened or closed as required to make the management of the workspace and the data viewed clearer.

Software breakpoints can be set in the C source or assembler window by simply double clicking on the source code line or the line in the appropriate window. Or by right clicking the mouse button are also available. Click the “Emulator” tab then select “Breakpoint Toggle during Run”, this can help setting breakpoint during debugging running, see figure below.

Figure 36. Enable Breakpoints Toggle during Run

The main debugging control functions are shown below.
For a full explanation of all debugging options, please use the full documentation included in the IAR installation. These can be accessed via the “Help” tab in the embedded workbench IDE.

The program is loaded after clicking the “Run” button. The E1 debugger can be removed to run the software on its own. Necessary Parameters can be tuned in the GUI.

13.2 CS+ for CC

An additional software project version for the Y-BLDC-SK-RL78F14 Starter Kit is available under CS+ for CC IDE. Please find below the details of the IDE used.

13.2.1 CS+ for CC Usage

The software was designed under CS+ for CC Version: **V4.00.00**.
The device selected in the program is R5F10PMJ. The compiler used is “Renesas CC-RL”.

The debug tool adopted is RL78 E1.

![Device, Compiler and Debugger selected](image)

### 13.2.2 Project importation into CS+ for CC

The CS+ for CC will have been installed in the default or user location.

The default location is as follows:

- Start Menu =>
- All programs =>
- Renesas Electronics CS+=>

```
CS+ for CC (RL78, RX, RH850).exe
```

Click on the file “CS+ for CC (RL78, RX, RH850).exe” to open. (Note that Windows Vista and 7 users may have to use “Run as administrator”) and the opening screen should open as below.

![Opening Screen of CS+ for CC](image)
To open the YBLDCSKRL78F14 CS+ for CC motor control project follow the sequence shown below:

File =>
  Open =>
  Sample Application destination folder\YBLDCSKRL78F14\CS+\Three Shunt =>
  Select the file “YBLDCSKRL78F14.mtpj” =>
  Press Open

![Opening Screen of YBLDCSKRL78F14 under CS+ for CC]

The project should then open in the CS+ for CC IDE and should look something like the window above. Here you can see project YBLDCSKRL78F14 and two subprojects YBLDCSKRL78F14_32MHz and YBLDCSKRL78F14_24MHz, which means clock source running at 32MHz and 24MHz are both offered. **We take the 32MHz one as a sample to introduce by right click on the project name “YBLDCSKRL78F14_32MHz” and click on the file “Set**
YBLDCSKRL78F14_32MHz as Active Project” if necessary as shown in the following figure.

![Figure 42. Set YBLDCSKRL78F14_32MHz as Active Project](image)

Please note that depending on settings used previously then the CS+ for CC project windows can look slightly different. All the settings have been pre-set so that the IDE appearance is as constant as possible. For full details of CS+ for CC, please refer to the documentation included as part of the CS+ for CC installation or click on the file “Help” in the CS+ for CC IDE as shown in the figure above.

To open any of the source files listed in the project (on the left hand side of the project window), just double click on the relevant file.

The next step is to build the project.

The necessary settings have been set in the IDE so that it is not necessary to configure or make changes to any of the build options. These can obviously be viewed for reference, just right click on the “CC-RL” menu and select the “Property” option then click on any of the relevant button as shown in the following 3 steps in the figure below.

Note:

It is recommended that no changes are made to any of the build settings as the resulting build results could not be guaranteed.
Build Settings in CS+ for CC

The project can be built from the build ICON or the rebuild ICON.

The project should be built without errors as shown in the following figure.
Launch the CS+ for CC debugger by clicking on the white button.

The CS+ for CC debugger will open a progress window which will initially connect to the board and then program the RL78/F14. Once this stage is complete the debugger window will open as shown below.
Other debugging windows can be opened to “watch variables, CPU registers, trace, memory etc.” These can be selected by using the “View” menu tab at the top of the IDE and then selecting the required debugging function.

Data is held for all debugging options whether displayed or not, so that windows can be opened or closed as required to make the management of the IDE and the data viewed clearer.

The main debugging control functions are shown below.

For a full explanation of all debugging options, please use the full documentation included in the CS+ for CC installation. These can be accessed via the “Help” tab in the CS+ for CC IDE.

The program is loaded after clicking the Run button. The E1 debugger can be removed to run the software on its own. Necessary Parameters can be tuned in the GUI.
14. **Software description and Resources used**

The software delivered in the Y-BLDC-SK-RL78F14 Starter Kit, previously described, is working on the RL78/F14 microcontroller clocked at 32MHz and its operating voltage is 5V which guarantee a high noise immunity.

**Note:** Clock source running at 24MHz and 32MHz are both offered.

Using the interrupt skipping function it is possible to regulate separately the PWM frequency (Pulse Width Modulation) and the sampling frequency also called control loop frequency. For instance, if the PWM frequency is set to 24 KHz and the control loop is set to 8 KHz, so the ratio is 3 which means that the full vector control algorithm is processed every three PWM cycles.

Please find below detailed information related to the software blocks of the motor control embedded software:

![Diagram of Software Blocks](image)

**Figure 47. Software Blocks of FOC Motor Control Embedded Software**

The complete software uses the resources below in the three shunts configuration. It includes the serial communication interface, the board management, the LED management, the EEPROM management, the auto-tuning algorithm and self-identification and of course the complete sensor less vector control algorithm.

- **FLASH memory usage:** 25.87KB and **RAM memory usage:** 2.23KB under IAR
- **FLASH memory usage:** 24.79KB and **RAM memory usage:** 2.02KB under CS+ for CC

The embedded software package is called “YBLDCSKRL78F14_iar.zip” and “YBLDCSKRL78F14_cs+.zip” including three shunt and single shunt current measurement configurations with clock source at 32MHz and 24 MHz, respectively, running under IAR environment and CS+ for CC.

The control loop of the field oriented control algorithm (e.g. sampling frequency, “SAM_FRE_CUSTOM_HZ”) is set to 8 KHz by default. The Pulse Width Modulation (PWM,
“PWM_FREQ_CUSTOM_HZ”) frequency is set by default to 24 KHz. The parameters are visible in the module name “customize.h”.

As the sampling period is 125µs (8KHz), and the control loop for the inverter control takes maximum of 87.5µs under IAR and 78.33µs under CS+, the CPU load of the motor control algorithm with all the option enable is: 87.5/125 = 70% under IAR and 78.33/125 = 62.66% under CS+, where the CPU clock is running at 32MHz. It leaves 30% under IAR and 37.34% under CS+ of the CPU to perform additional tasks, like board management, system control, display, etc.

The following flowcharts show the software implementation of the motor control part of the software.

Please find below the flowchart for the main loop, the interrupt service routines and the Automatic Tuning.

![Flow Chart for the Main Loop](image-url)
Flow Chart for the Main Loop in detail

Main Program

- EEPROM parameters upload
- A/D channels offset reading
- Peripherals initialization
- Variables initialization
- Interrupt enabling

Main loop synchronization

- cnt_int == 0 ?
  - NO
  - YES
    - cnt_int = NUM_INT

Main loop body

- Speed ramp management
- Communication management
- General board management
- Parameters modification management

Figure 49. Flow Chart for the Main Loop in detail
**Control Interrupt in Three Shunt Current Reading Model**

1. **Phase currents** ($i_{u\text{mea}}, i_{v\text{mea}}$) reading

2. **Transformations (using the phase angle $\vartheta$):**
   
   ($i_{u\text{mea}}, i_{v\text{mea}}$) → ($i_{a\text{mea}}, i_{b\text{mea}}$) → ($i_{d\text{mea}}, i_{q\text{mea}}$)

3. **Read DC Link voltage** $v_{bus}$

4. **Phase angle update:** $\vartheta = \vartheta_{\text{new}}$

5. **Current PI controls use** ($i_{d\text{ref}}, i_{q\text{ref}}$), ($i_{d\text{mea}}, i_{q\text{mea}}$) to produce ($v_{d\text{out}}, v_{q\text{out}}$)

6. **Transformations (using the phase angle $\vartheta$):**
   
   ($v_{d\text{out}}, v_{q\text{out}}$) → ($v_{a\text{out}}, v_{b\text{out}}$) → ($v_{u\text{out}}, v_{v\text{out}}$)

7. **PWM output commands generation** (using $v_{u\text{out}}, v_{v\text{out}}$)

8. **$v_{bus}$ is used to calculate maximum phase voltage** (used in current PI controls)

9. **Phase estimation based on** $\text{old}_v_{a\text{out}}, \text{old}_v_{b\text{out}}, i_{a\text{mea}}, i_{b\text{mea}}$, produces new estimated phase angle $\vartheta_{\text{est}}$

10. **Voltage memories update:** $\text{old}_v_{a\text{out}} = v_{a\text{out}}, \text{old}_v_{b\text{out}} = v_{b\text{out}}$

11. **Speed estimation produces** $\omega_{\text{est}}$

12. **Estimation errors detection** (if errors: alarm is set)

**Start-up in progress?**

- **YES**
  - Start-up procedure produces $i_{d\text{ref}}, i_{q\text{ref}}, \vartheta_{\text{stup}}$
  - $\vartheta_{\text{new}} = \vartheta_{\text{stup}}$
- **NO**
  - $i_{d\text{ref}} = 0$
  - Speed PI control uses ($\omega_{\text{ref}}, \omega_{\text{est}}$) to get $i_{q\text{ref}}$
  - $\vartheta_{\text{new}} = \vartheta_{\text{est}}$

13. **Main loop synchronization**

   - **cnt_int > 0?**
     - **NO**
     - **YES** $\rightarrow \text{cnt_int}$

---

**Figure 50. Control Interrupt in Three Shunt Current Reading Model**
The auto-tuning process and the self-identification mechanisms are fully independent from the main sensor less vector control software and can be used in the 1st phases of starter and configuration of the software.

---

**Figure 51. Features of Auto-Tuning and Motor Self-Identification**

The three blocks mentioned above and the completed FOC algorithm are located in the library called: “BLDC-SK-Lib_threeShunt” or “BLDC-SK-Lib_singleShunt” located in the folder called: “MC_Library” as shown below:

<table>
<thead>
<tr>
<th>MC_Library</th>
<th>Function Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>mcrplib.h</td>
<td>Header file for the Math Library block</td>
</tr>
<tr>
<td>mod_ident.h</td>
<td>Header file for the Motor Self-identification</td>
</tr>
<tr>
<td>PI_tun.h</td>
<td>Header file for the PI Coefficients auto-tuning</td>
</tr>
<tr>
<td>motorcontrol.h</td>
<td>Header file for complete FOC algorithm in interrupt service routines</td>
</tr>
<tr>
<td>BLDC-SK-Lib_threeShunt</td>
<td>Library file containing the four blocks above</td>
</tr>
</tbody>
</table>

*Table 3. Contents of MC_Library*

The complete project source code under IAR embedded environment and CS+ for CC is described below. For each C module, a specific header file is associated.

<table>
<thead>
<tr>
<th>Source Files</th>
<th>Functions Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLDC-SK-Lib_threeShunt</td>
<td>Contains PI auto-tuning, Motor identification and estimators routines</td>
</tr>
<tr>
<td>hwsetup.c</td>
<td>Basic hardware initialization</td>
</tr>
<tr>
<td>stl_support.c</td>
<td>Support routines for the self-test functions</td>
</tr>
<tr>
<td>main.c</td>
<td>The main program loop</td>
</tr>
<tr>
<td>userif.c</td>
<td>Communication routines (i.e. GUI)</td>
</tr>
<tr>
<td>par_tab.c</td>
<td>The Parameter management definitions and tables</td>
</tr>
<tr>
<td>globalvar.c</td>
<td>Global variable definitions</td>
</tr>
</tbody>
</table>

*Table 4. C Modules of Project Source Code*
Please find below the important Header files included into the project folder.

<table>
<thead>
<tr>
<th>Header Files</th>
<th>Functions Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>customise.h</td>
<td>Basic motor parameters (Not modifiable through the GUI)</td>
</tr>
<tr>
<td>const_def.h</td>
<td>Definition of the basic numerical constants</td>
</tr>
<tr>
<td>par_tab.h</td>
<td>Parameter definitions, function prototypes and references</td>
</tr>
<tr>
<td>hwsetup.h</td>
<td>Hardware definitions, references and function prototypes</td>
</tr>
<tr>
<td>globalvars.h</td>
<td>Global variable definitions and references</td>
</tr>
<tr>
<td>multiply.h</td>
<td>Assembler Basic math function references</td>
</tr>
<tr>
<td>mask.h</td>
<td>General support definitions and references</td>
</tr>
<tr>
<td>userif.h</td>
<td>General support definitions, references and function prototypes</td>
</tr>
</tbody>
</table>

Table 5. Head Files of Project Source Code

The following table shows the assembler modules in the project.

<table>
<thead>
<tr>
<th>Assembler Modules</th>
<th>Functions Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Test</td>
<td>IEC assembler Self-test routines (RAM, FLASH, Registers and Clock)</td>
</tr>
<tr>
<td>multiply</td>
<td>Combined math’s functions</td>
</tr>
<tr>
<td>cstartup</td>
<td>Customized start up file (Includes March C RAM test)</td>
</tr>
<tr>
<td>delay</td>
<td>1us and 100us delay</td>
</tr>
</tbody>
</table>

Table 6. Assembler Modules of Project Source Code

The following table shows the data flash library modules in the project.

<table>
<thead>
<tr>
<th>Data Flash Library</th>
<th>Functions Descriptions</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>fdl*</td>
<td>RL78 FDL T01 (flash data library files)</td>
<td>IAR V1.xx</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RENESAS and IAR V2.xx</td>
</tr>
</tbody>
</table>

Table 7. Data Flash Library Files of Project Source Code

Note:

For updates of the data flash library (FDL) please check on the following site:

15. Start-up procedure – Embedded software

When the motor is in stand-still, the phase of the permanent magnet flux vector cannot be detected with the used algorithm. So an appropriate start-up procedure has to be applied.

The idea is to move the motor in feed-forward (with higher current than that required to win the load), till a speed at which the estimation algorithm can work. Then the system can be aligned to the estimated phase, and the current can be reduced to the strictly necessary quantity.

The following graph illustrates the strategy used (the suffix “ref” stands for reference, the suffix “mea” stands for measured).

![Diagram of Start-up Procedure in Embedded Software](image)

**Figure 52. Startup Procedure in Embedded Software**

Referring to the graph above, the start-up procedure (in case of three shunts current reading) is described below.

a) At the beginning $t_0$, the system phase is unknown. No current is imposed to the motor; the system phase is arbitrarily decided to be $\vartheta_a=0$. All the references: $i_{dref}$, $i_{qref}$ and $speed_{ref}$ are set to zero.

b) From the moment $t_0$, while the $i_{qref}$ and the $speed_{ref}$ are maintained to zero, $i_{dref}$ is increased with a ramp till the value $i_{start}$ is reached at the moment $t_1$.

The references are referred to an arbitrary $(d_a, q_a)$ system based on the arbitrary phase $\vartheta_a$. From this moment, the phase estimation algorithm begins to be performed, and the estimated phase $\vartheta_{est}$ is used to calculate the components of the measured current, referred to the $(d, q)$ system based on the estimated phase, $i_{dmea}$ and $i_{qmea}$. The components of the current referred
to the arbitrary \((d_a, q_a)\) system are controlled to follow the references by the current PI controllers. On the other hand, since the phase \(\theta_{est}\) is still not correctly estimated, \(i_{d_{mea}}\) and \(i_{q_{mea}}\) have no physical meaning. Even if they are not shown in the graph, the applied voltages are subjected to the same treatment (\(v_{d_{mea}}\) and \(v_{q_{mea}}\) are calculated in the algorithm).

c) At \(t = t_1\), while \(i_{q_{ref}}\) is maintained to zero and \(i_{d_{ref}}\) is maintained to its value \(i_{start}\), speed\_ref is increased with a ramp till the value \(s_{start}\) is reached at the \(t = t_2\). The system phase \(\theta_a(t)\) is obtained simply by integration of speed\_ref; in the meanwhile, the phase estimation algorithm begins to align with the real system phase. Furthermore \(i_{d_{mea}}\) and \(i_{q_{mea}}\) begin to be similar to the real flux and torque components of the current. The real components are supposed to be \(i_{d0}\) and \(i_{q0}\) (those values are obtained applying a low-pass filter to \(i_{d_{mea}}\) and \(i_{q_{mea}}\)).

The interval \((t_2-t_1)\) is the start-up time, and it is supposed to be large enough to allow the estimation algorithm to reach the complete alignment with the real phase of the system.

d) At \(t = t_2\), the phase estimation process is supposed to be aligned. At this point a reference system change is performed: from the arbitrary \((d_a, q_a)\) reference to the \((d, q)\) reference based on the estimated phase \(\theta_{est}\).

The current references are changed to the values \(i_{d0}\) and \(i_{q0}\), and all the PI controllers are initialized with these new values. The speed PI integral memory is initialized with the value \(i_{q0}\), while the current PI integral memories are initialized with the analogous voltage values \(v_{d0}\) and \(v_{q0}\), obtained from \(v_{d_{mea}}\) and \(v_{q_{mea}}\).

e) After \(t > t_2\), the normal control is performed, based on the estimated phase \(\theta_{est}\); the speed reference is increased with the classical ramp; the \(i_d\) current reference is decreased with a ramp, till it reaches the value zero at the moment \(t_3\); then it is maintained to zero; the \(i_q\) current reference is obtained as output of the speed PI controller.
16. Reference system transformations in details

Find below the detailed equations used for the coordinates transformations in the embedded software for the RL78/F14 microcontroller.

\[
g_\alpha = \frac{2}{3} \left( g_u - \frac{1}{2} g_v - \frac{1}{2} g_w \right) = g_a
\]

\[
g_\beta = \frac{2}{3} \left( \sqrt{3} \frac{1}{2} g_v - \sqrt{3} \frac{1}{2} g_w \right) = \frac{1}{\sqrt{3}} \left( g_v - g_w \right) = \frac{1}{\sqrt{3}} \left( g_u + 2 g_v \right)
\]

\[\text{(u, v, w)} \rightarrow (\alpha, \beta)\]

\[
g_u = g_\alpha
\]

\[
g_v = -\frac{1}{2} g_\alpha + \frac{\sqrt{3}}{2} g_\beta = (-g_\alpha + \sqrt{3} g_\beta) / 2
\]

\[
g_w = -\frac{1}{2} g_\alpha - \frac{\sqrt{3}}{2} g_\beta = (-g_\alpha - \sqrt{3} g_\beta) / 2
\]

\[\text{(\alpha, \beta)} \rightarrow (u, v, w)\]

\[
g_d = g_\alpha \cos(\vartheta) + g_\beta \sin(\vartheta)
\]

\[
g_q = -g_\alpha \sin(\vartheta) + g_\beta \cos(\vartheta)
\]

\[\text{(\alpha, \beta)} \rightarrow (d, q)\]

\[
g_\alpha = g_d \cos(\vartheta) - g_q \sin(\vartheta)
\]

\[
g_\beta = g_d \sin(\vartheta) + g_q \cos(\vartheta)
\]

\[\text{(d, q)} \rightarrow (\alpha, \beta)\]

\[
\begin{align*}
v_u &= V \cos(\omega t + \varphi_0) \\
v_v &= V \cos(\omega t + \varphi_0 - 2\pi / 3) \\
v_w &= V \cos(\omega t + \varphi_0 - 4\pi / 3)
\end{align*}
\]

\[
\leftrightarrow \begin{align*}
v_\alpha &= V \cos(\omega t + \varphi_0) \\
v_\beta &= V \sin(\omega t + \varphi_0)
\end{align*}
\]

\[
\leftrightarrow \begin{align*}
v_d &= V \cos(\varphi_0) \\
v_q &= V \sin(\varphi_0)
\end{align*}
\]
17. Rotor position estimation

The rotor position estimation method which has been chosen is the direct integration of the back EMF. Such method is enabled by default in the RL78/F14 inverter kit.

Please find below the fundamental equations:

\[
\begin{align*}
    x &= \Lambda_m \cos(\vartheta) = \lambda_\alpha - L_i \alpha = \lambda_{\alpha 0} + \int_0^t (v_\alpha - R_s i_\alpha) \, dt - L_i \alpha \\
    y &= \Lambda_m \sin(\vartheta) = \lambda_\beta - L_i \beta = \lambda_{\beta 0} + \int_0^t (v_\beta - R_s i_\beta) \, dt - L_i \beta \\
    \vartheta &= \arctan\left(\frac{x}{y}\right) \\
    \omega &= \frac{d}{dt} \vartheta(t)
\end{align*}
\]

The challenges in this approach are the calculation of the integrals which is well known as a problematic issue in a numeric context, and the choice of the initial conditions, which are not known in general. There are two possibilities to overcome these difficulties:

1. To use a so-called "approximated integration", which means that instead of using an integral \((1/s)\), a special transfer function is chosen, which is very similar to the integral in certain conditions.

2. To correct the result of the integration with a sort of feedback signal, obtained combining the estimated phase with the real flux amplitude, known as a parameter of the system.

In the 1st case, we choose an integral approximation function which has a limited memory of the errors and with a zero DC gain. The goal is to reject any low frequency component, preventing the result to diverge, and automatically forgetting the errors (noise, etc.). This is obtained by combining a low-pass filter with a second low-pass filter, as in the following schemes in Figure 53 and Figure 54:

![Filter Diagram of approximated Integration in Rotor Position Estimation](image)

*Figure 53. Filter Diagram of approximated Integration in Rotor Position Estimation*
\[ Y(s) = \frac{S}{(s + \omega_0)^2} \]

**Figure 54. Corresponding S-domain Functions for Filters in Figure 53**

It is evident the relationship between \( Y(s) \) and the integral \( I(s) = \frac{1}{s} \) for \( s = j\omega \), when \( \omega >> \omega_0 \).

In the 2nd case, to prevent the integral to diverge, and the errors related to wrong initial conditions are rejected, by the correcting action of the feedback.

The block scheme of the exact BEMF integration method for flux position estimation is the following:

**Figure 55. Block Scheme of the Exact BEMF Integration Method for Flux Position Estimation**
The inputs of the system are the imposed voltage vector $V$ and the measured current vector $I$. The motor phase resistance $R_s$, the synchronous inductance $L_s$ and the permanent magnet flux amplitude $\lambda_m$ are known as parameters and motor dependent.

The integral operation is corrected with a signal obtained modulating accordingly with the estimated phase the error between the estimated flux amplitude and the amplitude of the permanent magnets flux.

The gain of this correction is indicated with $G$. It is this feedback which avoids the integral divergence due to the errors or offsets. The higher $G$ is, the higher is the relationship between the estimated amplitude and the theoretical one, but the larger can be the induced phase error.

The choice of $G$ is a trade-off, in order to guarantee that the integral remains close to its theoretical value, but free enough to estimate the correct system phase.

In the **default embedded software** delivered on the Y-BLDC-SK-RL78F14 Starter Kit, this first strategy is selected. The choice to test the second one is left to the user thanks to the setting of the macros in the source code. Such modifications required a compilation of the embedded software.
18. PC Graphical User Interface in details

Please install the Motor Control PC GUI on your machine by following the instructions of the Quick Start Guide delivered in the Y-BLDC-SK-RL78F14 Starter Kit. After connecting the Fulling Motor (FL28BL26-15V-8006AF, 15VDC, 8000RPM), please connect the board RL78/F14 and select the COM port or use the Auto-detection mechanism. See in Chapter 20 Figure 65.

The PC Graphical User interface supports such Operating Environment:

- Windows® 10  (32-bit, 64-bit)
- Windows® 8.1  (32-bit, 64-bit)
- Windows® 8  (32-bit, 64-bit)
- Windows® 7  (32-bit, 64-bit)

Please find below the detailed descriptions of the PC GUI tabs and windows.

![Motor Control Reference Platform User Interface - Y-BLDC-SK-RL78F14](image)

**Figure 56. Detail Descriptions of PC GUI**

- Set motor speed, stop it, and reverse
- Display internal quantities (Motor speed, torque and direct current, frequency, etc.)
By clicking on the button “Save data to file”, it becomes possible to record regularly all the values display in real-time in a file, as described in figure below:

![Image of Property Monitor displaying Motor speed, Imposed Freq., Direct Current, Torque Current, Direct Voltage, Quadrature Voltage, DC Bus Voltage, and Alarm Code.]

Click to record in real-time All the values and store them In a “.CSV” format file.

Monitor the recording of the values to be stored in the “.CSV” file.

Figure 57. Save Data to File in Real-Time

Furthermore, the Speed control window displays the Alarm codes status of the board itself:

![Image of Property Monitor displaying Motor speed, Imposed Freq., Direct Current, Torque Current, Direct Voltage, Quadrature Voltage, DC Bus Voltage, and Alarm Code.]

Alarm 0: Normal operation
Alarm 1: EEPROM fault
Alarm 3: Loss of Phase

Figure 58. Alarm Codes Status of the Board
Alarm code 1:

The alarm 1 is called “EEPROM alarm” and described in the software by “EQP_ALL”. This alarm is set when one or more EEPROM parameters are higher than the maximum allowed value or lower than the minimum allowed value.

The maximum and minimum values are specified in the two constants tables called: "par_max[]" "par_min[]" in the "pac_tab.c" file. Another root cause for the alarm 1 is the EEPROM hardware failure when the error is accessed in read or write mode.

When this alarm is active, the access to the EEPROM is restricted. To reset the alarm the default parameters set should be reloaded in the EEPROM. By using the PC GUI and the parameters setting window, it becomes possible to clean the EEPROM content. **The first step is to write the magic number “33” in the first parameter n°00. The second step is to reset the board by pressing the “reset” button on the PCB, then click the “Reload” button in the parameters setting window.**

At this point a coherent set of parameters is loaded and the alarm should disappear.

Finally, if the alarm is produced by a hardware failure of the EEPROM itself, then the board needs to be repaired.

Alarm code 3:

The alarm 3 is called “loss of phase” and described in the software by “TRIP_ALL”. This alarm is produced when the sensor less position detection algorithm is producing inconsistent results. It means that the rotor position is unknown due to a lack of accuracy, so the motor is stopped.

This alarm can be reset by setting the speed reference to zero on the PC GUI.

Please find below an extract of the header file “const_def.h”.

```c
/* alarms */
#define EQP_ALL (1)       // eeprom alarm code
#define FAULT_ALL (2)     // ipm hardware alarm code
#define TRIP_ALL (3)      // loss of phase alarm code
```

**Figure 59. Function Descriptions of Alarm Code Statuses in Source Code in Embedded Software**

Then by clicking on the “Parameters Setting” button, the important window can be displayed showing all the parameters of the system that can be changed in real-time without having to recompile the embedded software.
The detailed description of each parameter is displayed when pointing the mouse on the question mark, see figure above. Each parameters unit is displayed.

Note: To change one value in real-time, simply enter the new value and click on “Write” to program the new value into the EEPROM.

Figure 61. Buttons Function-Descriptions in Parameters Window
All the parameters can be changed on the fly and after pushing the “Write” button, it’s automatically set.

**Speed range limitations**

The Y-BLDC-SK-RL78F14 Starter Kit is driving any BLDC using a sensor less vector control algorithm. So it means that there is a **minimum** speed to reach in order to run the motor properly using the three shunts current measurement methods. In the case of the Fulling Motor FL28BL26-15V-8006AF delivered with the kit, the minimum speed is **700RPM**. Below this speed, the current flowing through the three shunts are too low to be detected.

The FL28BL26-15V-8006AF brushless motor is able to reach its maximum speed of **8000RPM** (without load) when the power supply is 15V.
19. EEPROM parameters: detailed description

Please find below the software parameters list including their full description. Each parameters located in the “customize.h” header file can be tuned by the user directly by the Graphic User Interface, without re-compiling the program.

<table>
<thead>
<tr>
<th>Parameter number</th>
<th>Short name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>SEL_OP</td>
<td>default parameters setting, Used to perform special operations, like default parameter set re-loading</td>
</tr>
<tr>
<td>1</td>
<td>RPM_MIN</td>
<td>Set the Minimum Speed in RPM</td>
</tr>
<tr>
<td>2</td>
<td>RPM_MAX</td>
<td>Set the Maximum Speed in RPM</td>
</tr>
<tr>
<td>3</td>
<td>R_ACC</td>
<td>Set the acceleration [RPM/s]</td>
</tr>
<tr>
<td>4</td>
<td>R_DEC</td>
<td>Set the deceleration [RPM/s]</td>
</tr>
<tr>
<td>5</td>
<td>C_POLI</td>
<td>Set the number of polar couples</td>
</tr>
<tr>
<td>6</td>
<td>I_START</td>
<td>Set the start-up current (peak) [Ampere/AMP_DIV]. Used to specify the peak phase current value to be used during the start-up</td>
</tr>
<tr>
<td>7</td>
<td>I_MAX</td>
<td>Set the maximum phase current (peak) [Ampere/AMP_DIV]</td>
</tr>
<tr>
<td>8</td>
<td>R_STA</td>
<td>Set the stator resistance [Ohm/OHM_DIV]</td>
</tr>
<tr>
<td>9</td>
<td>L_SYN</td>
<td>Set the synchronous inductance [Henry/HEN_DIV]</td>
</tr>
<tr>
<td>10</td>
<td>PM_FLX</td>
<td>Set the permanent magnets flux [Weber/WEB_RES]. This value is only used when the exact integration flux estimation algorithm is selected. By default, it’s not needed as the approximated integration is selected.</td>
</tr>
<tr>
<td>11</td>
<td>KP_CUR</td>
<td>Set the Current loop Proportional coefficient: KP</td>
</tr>
<tr>
<td>12</td>
<td>KI_CUR</td>
<td>Set the Current loop Integral coefficient: KI</td>
</tr>
<tr>
<td>13</td>
<td>KP_VEL</td>
<td>Set the Speed loop Proportional coefficient: KP</td>
</tr>
<tr>
<td>14</td>
<td>KI_VEL</td>
<td>Set the Speed loop Integral coefficient: KI</td>
</tr>
<tr>
<td>15</td>
<td>STP_TIM</td>
<td>Set the Start-up acceleration time [ms]</td>
</tr>
</tbody>
</table>

Table 8. Full Descriptions of Software Parameters in EEPROM
20. **Motor Auto-calibration using the PC GUI**

The full calibration of any 3-phase Brushless DC motor can be performed automatically using the PC Graphical User Interface. Three specific buttons are now available for and shown below:

![Image of the PC GUI with buttons for Current PI-tuning, Auto PI-tuning, and Motor Identification]

In a few clicks, the software is tuned to the custom motor and ready to run.

*Figure 62. Buttons of Current PI-tuning, Auto PI-tuning and Motor Identification*

In terms of DC Brushless motor driven in sinusoidal mode and FOC algorithm, the most important parameters to tune are:

1. Current PI parameters: **Proportional** $K_p$ and **Integral** $K_i$
2. Motor parameters: **Stator resistance** $R_s$, **the synchronous inductance** $L_s$, and **Permanent Magnet flux** $\Lambda_m$.

Please find below the auto-tuning process step by step of the Fulling Motor FL28BL26-15V-8006AF delivered with the Y-BLDC-SK-RL78F14 Starter Kit. The FL28BL26-15V-8006AF motor is a low voltage Permanent Magnet Synchronous Motor. The auto-tuning procedure will be performed using the kit running the sensor less vector control algorithm.

a) Please find below the specifications of the Motor delivered by the motor maker:

- **Motor Manufacturer:** FULLING  [www.motor-fulling.com](http://www.motor-fulling.com)
- **Motor type:** 3-phase DC Brushless **FL28BL26-15V-8006AF**
  - Maximum current: **0.3A**
  - Bus Voltage: **15V**
  - Speed rated: **8000 RPM**
  - Number of pole pairs: **2**
Specifications of three-phase Brushless DC FL28BL26-15V-8006AF

b) Let’s connect the 15VDC Power supply to the YBLDCSKRL78F14 kit.

c) Now, connect the USB cable to the PC and the Kit and connect the motor to the kit:

Figure 64. Top Overview of RL78/F14 BLDC Starter Kit with Motor
Connect PC GUI to the RL78/F14 BLDC Starter Kit

d) Launch the PC GUI by clicking on the “Motor Control Demonstration for RL78 F14" ICON on the desktop, or follow these instructions “Start Menu => All programs => Renesas Electronics Europe GmbH => Motor Control Demonstrator for RL78F14 => Motor Control Demonstrator for RL78 F14.exe”.

e) Firstly click on the “setup” button and select “RL78F14_Kit” and select appropriate serial port “COM X” (in my case it is COM 11) and click on “Connect” to ensure the PC GUI is connected to the RL78/F14 kit.

On the left hand side, the new buttons appear: “Cur. PI tuning”, “Cu. PI tuning (AUTO)” and “Motor Identification”, which are needed for the self-calibration of the motor. See in Figure 62.

f) Clean the EEPROM content and start with the default parameters in the EEPROM.

The first thing to do is to ensure that the inverter board is the default state and the default parameters are written inside. The procedure below ensures it:

1) Click on the “Parameters Setting” button and enter the magic number “33” in the first line called: “00. Default Parameters setting”

2) Click the “Write” button in the parameter setting window

3) Then push the “RESET” button on the board as shown in figure below

4) Click the “Reload” button in the parameter setting window to get the default parameters defined in the “customize.h” header file in the IDE workspace.
5) Set the maximum current (parameter n°07) as it will influence all the next steps: Click on “Parameters Setting”, Enter the value: 300 (the unit is in mA) and click on “Write” to save the parameter into the EEPROM and close the parameters setting window. The maximum current parameter is fundamental for the auto-calibration. The maximum value allowed by the motor must be used to guarantee the highest resolution.

![Board Reset Button in RL78/F14 BLDC Starter Kit](image)

**Figure 66. Board Reset Button in RL78/F14 BLDC Starter Kit**

![Maximum Current for Auto-tuning](image)

**Figure 67. Maximum Current for Auto-tuning**

g) Click now on “Cu. PI tuning (AUTO)” button and press “Start” to perform an automatic Current PI tuning. The two coefficients of the PI current block will be extracted thanks to
the embedded software able to generate a step voltage and measuring the motor response.

![Image of the user interface showing the current auto PI-tuning settings]

**Figure 68. Start Current Auto PI-tuning**

And click on "Yes" to accept the results to be programmed into the EEPROM as shown below.

![Image of the user interface showing the acceptance of results]

**Figure 69. Accept Results of Current Auto PI-tuning**

Important note: The proportional and integral coefficients are just **starter values** for the next step “Cu. PI tuning”.

![Image of the user interface with a note on the coefficients]
h) Now click on the button “Cu. PI tuning” to open the manual current PI tuning window and check the step answer by clicking on “Apply current step” button.

![Image of manual current PI tuning window]

**Figure 70. Start Step Response Checking the Results of Current Auto PI-tuning**

![Image of step response graph]

**Figure 71. Results of Step Response**

Note: You can manually adjust the value of Kp and Ki, or just slide the slider point to obtain an even better step response and also increase the step current level by increasing the percentage of “Cur. [%] to 90%. The default value is 50%.

Depending on the motor, the parameters found by the automatic procedure can be too fast or too slow. Please use the “Zoom” function to check the beginning of the step.
Once it’s done, the window can be closed as the proportional and integral coefficients of the PI current are tuned.

i) Perform an auto-identification of the motor parameters by clicking on “Motor Identification” and click “Start”:

![Figure 72. Start Motor Identification](image)

During this process the rotor should start rotating, please leave the rotor free and no loaded.

And finally accept the results to store them into the EEPROM by clicking on “Yes”, as shown in the following figure.

![Figure 73. Accept the Result of Motor Identification](image)
The stator resistance, the synchronous inductance and the Permanent Magnet flux have been measured and tuned.

Important note:

- The value above are just **starter values**, alternately the phase resistance can be found to be sure by measuring the phase-to-phase resistance.

- The measurement unit is Ohm/100. The measured value should firstly be divided by 2 then multiplied by 100, please enter this value in the parameter 08, "Stator Resistance".

j) Now please click on “Parameters Setting” and enter the number of pole pairs: 2 (parameter n°5) and enter a minimum speed or 1000 RPM

k) Set a start-up current equal to less than the maximum current. Please enter an average value that will not damage the motor. Here enter 200 in the parameter 06, “Startup Current”, which means 0.2 Amperes, as shown in the figure below.

![Parameter Setting](image)

**Figure 74. Set Startup Current**

Then let’s close the window.

l) Now, let’s try to run the motor. Please click on the button: “Speed Control”:
To start the motor, let’s enter a speed which is 1.5 times the minimum speed, in this case **1500 RPM**

m) When the motor is running, you can adjust the two speed PI parameters: the proportional and integral terms: #13 and #14

Please follow the procedure: while running at a medium speed range: 2 times the minimum speed. In our example, the speed is set to 2000 RPM
Speed PI proportional gain should be tuned in the real application and under load conditions. As starting values, low values should be chosen, they can be increased at medium working speed until instability arises. High frequency instability is related to the proportional value too high, low frequency instability is related to integral value too high. When instability arises, the value should be halved. Some kind of tuning of speed parameters can be performed using high value of acceleration ramp, and imposing speed reference variations, as done with the current PIs.

The PI calibration procedure should be iterated till the desired system response is reached. The speed reference could be changed depending on the motor/application. You can find below two graphs indicating an example of tuning procedure. This procedure should be made using the real working environment.

Speed parameters can influence the success of the start-up phase: if the algorithm fails in this phase, giving alarm n°3, try modifying the speed proportional gain first, and then the integral gain.
Start Speed I calibration

Set speed to 1000 rpm

Set speed to 1500 rpm

Speed Oscillation

Increase I Parameter

Set speed to 1000 rpm

Reduce I Parameter by 1/4

Go to set P

Figure 77. The Integral Term Tuning Procedure
The Proportional Term Tuning Procedure

- Start Speed P calibration
- Set PI parameter to standard value
- Set speed to 1000 rpm
- Set Acceleration Ramp to 10kr/s
- Set speed to 1000 rpm
- Reduce acceleration ramp
- Set speed to 1500 rpm
- Phase current > Limit? (Yes: Increase P parameter. No: Speed Oscillation?)
- Speed Oscillation? (Yes: Reduce P parameter by 1/4. No: Go to set P)

Figure 78. The Proportional Term Tuning Procedure
n) Test the parameters found in all the speed ranges and different rotations.

o) Finally the parameters list can be saved in a file in .CSV (“Save” button) or .h file (“Create.h” button) format for further use and can also be uploaded later on:

![Parameter Table]

Figure 79. Save PC GUI Parameters

**Troubleshooting:**

At the stage l) if the motor doesn’t start or generate an alarm n°3, please set the speed to “0” to clear the alarm which indicates that the software lost the phase. One first test is to increase or decrease the start-up current and the minimum speed or the speed PI gains. The value of the stator resistor can affect the startup and rotating procedures.

When the motor is running, you can verify the number of pole pairs taking measurement of the effective speed, and comparing it with the imposed frequency: the number of pole pairs n is:

\[ n = \frac{\text{freq} \times 60}{\text{speed}} \]

if you change the number of pole pairs, remember to adjust also the minimum (and maximum) speed values.

For some motors, the no-load start-up is easier if the inductance parameter is set to 0 (parameter #9)

All the procedure is tuned to manage motors which maximum current is close to the inverter capability (shunt value is 0.01 Ohm).

If you try to use it for very small motors, the results will be influenced by the losses in current reading resolution.
21. Updating the RL78/F14 Flash memory using the Renesas Programming Flash Tool

The procedure below explains in details how to re-program the RL78/F14 flash memory using the Renesas Flash Programing tool, called the RFP. It could be used to update the RL78/F14 kit with the latest Firmware version downloaded from the website: http://www.renesas.eu/update?oc=Y-BLDC-SK-RL78F14

The RFP must be used with the E1 debugger and there’s no need to install the full version of the development environment IAR.

Please have a look at the specific Flash Programming Tool website to us the latest software version for RFP V30100:

http://www.renesas.eu/updates?oc=RFP-EE

Please follow the steps below to update the flash memory of your RL78/F14 MCU using the RFP tool.
Step 1: Open RFP software v3.01.00 select and click on "Create new Project", select "RL78" in Microcontroller drop down menu, write the project name and browse your project folder.

Step 2: Select the E1 in Tool drop down menu in the communication box and make sure in tool details pop window select power supply "None"

*Figure 80. Update the Flash Memory using RFP*
Step 3: Browse the file with the ".hex" of your project in the program and then click the large "Start" button

Figure 81. Start Updating the Flash Memory using RFP
The RFP will open a progress bar and connect to the board and device. The results of reading from the device should be as shown below.

Figure 82. Successful Update the Flash Memory using RFP

Congratulations! The new firmware is now programmed into the RL78/F14 flash memory.
22. Communication Protocol between the MCU and the PC GUI

After the introduction of the auto-tuning, a new set of information is exchanged between the GUI and the board. To distinguish between the software versions the answer to the check request is used. In the previous software version the answer to a check com request ("c"), was the uppercase ("C"). In the versions with auto-tuning the answer code is ("d").

The serial communication speed tested is 9.6 Kbd.

*************************************************************************************************************
*** MULTIPOINT MASTER-SLAVE SERIAL COMMUNICATION SIMPLIFIED PROTOCOL ***
*************************************************************************************************************

ASCII: '!'=0x21, '#'=0x23, '?'=0x3F, 'C'=0x43, 'W'=0x57, 'c'=0x63, 'w'=0x77

Master String:

\[ l \ i \ s \ o \ a \ n \ D_1 \ldots D_m \ k \]

\( l \) = frame total length (1 byte)
\( i \) = master string identification ("?" = question)
\( s \) = station address (1 byte)
\( o \) = operation code (1 byte)
\( a \) = data address (1 byte)
\( n \) = data number (1 byte)
\( D_x \) = x-th data byte (1 byte)
\( k \) = checksum (1 byte)

Master operation codes:

\( 'c' \) = check request
\( 'w' \) = word reading (1 word = 2 bytes)
\( 'W' \) = word writing (1 word = 2 bytes)

Possible master frames (questions):

check: \[ l \ ? \ s \ c \ k \] \( (l=5) \)
word read.: \[ l \ ? \ s \ w \ a \ n \ k \] \( (l=7) \)
word writ.: \[ l \ ? \ s \ W \ a \ n \ D_{11} \ldots D_n \ D_{n1} \ D_{n0} \ k \] \( (l=7+2*n) \)
Slave string:
\[ l \ i \ s \ o \ a \ n \ D_1 \ .. \ D_m \ k \]
\[ l = \text{frame total length (1 byte)} \]
\[ i = \text{slave string identification ('!' = OK answer, '#' = NOK answer)} \]
\[ s = \text{station address (1 byte)} \]
\[ o = \text{operation code (1 byte)} \]
\[ a = \text{data address (1 byte)} \]
\[ n = \text{data number (1 byte)} \]
\[ D_x = x\text{-th data byte (1 byte)} \]
\[ k = \text{checksum (1 byte)} \]

Slave operation codes:
'\text{C}' = check answer
'\text{w}' = word reading answer (word = 2 byte)
'\text{W}' = word writing answer (word = 2 byte)

Possible slave frames (answers):
\begin{align*}
\text{nok:} & \quad l \ # \ s \ o \ k \quad (l=5) \\
\text{check:} & \quad l \ ! \ s \ C \ k \quad (l=5) \\
\text{word read.:} & \quad l \ ! \ s \ w \ a \ n \ D_{11} \ D_{10} \ .. \ D_{n1} \ D_{n0} \ k \quad (l=7+2*n) \\
\text{word writ.:} & \quad l \ ! \ s \ W \ k \quad (l=5)
\end{align*}

Addresses:
If the address "a" specified in the question is a \(< \text{NUM\_PAR} \) (number of EEPROM parameters), then an EEPROM parameter (GUI table) is read or written. Otherwise if a \(\geq\) \text{NUM\_PAR\_EQP}, then a parameter in the RAM table (Cf. module “userif.h") is read or written. Its address in the RAM table is a-\text{NUM\_PAR}.

Operation example:

Example 1
PC request of reading 16 words from the structure UIF\_R, starting from the second one (UIF\_R.ram\_tab[1], .., IF\_R.ram\_tab[16]):
0 07 Number of bytes in the frame
1 3F Master string indicator "?"
2 00 Station address (it is always 0 in our boards)
3 77 word reading operation "w"
4 41 data start address
   (1(address in UIF_R.ram_tab) + 40h (offset to add for ram reading/writing))
5 10 number of data (10h=16dec)
6 39 checksum

Board answer:
0 27 Number of bytes in the frame (27h=39dec)
1 21 Slave string indicator "!"
2 00 Station address (it is always 0 in our boards)
3 77 word reading operation "w"
4 41 data start address (1(address in UIF_R.ram_tab)+40h(offset to add for ram reading))
5 10 number of data (10h=16dec)
6 00 MSB of the 1st word of data (UIF_R.ram_tab[1]=UIF_R.var.rpm, speed)
7 00 LSB of the 1st word of data
8 00 MSB of the 2nd word of data (UIF_R.ram_tab[2]=UIF_R.var.fre, imposed frequency)
9 00 LSB of the 2nd word of data
10 00 MSB of the 3rd word of data (UIF_R.ram_tab[3]=UIF_R.var.id, d axis current)
11 00 LSB of the 3rd word of data
12 00 MSB of the 4th word of data (UIF_R.ram_tab[4]=UIF_R.var.iq, q axis current)
13 00 LSB of the 4th word of data
14 00 MSB of the 5th word of data (UIF_R.ram_tab[5])
15 00 LSB of the 5th word of data
16 00 MSB of the 6th word of data (UIF_R.ram_tab[6])
17 00 LSB of the 6th word of data
18  00 MSB of the 7th word of data (UIF_R.ram_tab[7]=UIF_R.var.vb, bus voltage)
19  18 LSB of the 7th word of data
20  00 MSB of the 8th word of data (UIF_R.ram_tab[8])
21  00 LSB of the 8th word of data
22  00 MSB of the 9th word of data (UIF_R.ram_tab[9]=UIF_R.var.all, alarm)
23  01 LSB of the 9th word of data
24  00 MSB of the 10th word of data (UIF_R.ram_tab[10])
25  00 LSB of the 10th word of data
26  00 MSB of the 11th word of data (UIF_R.ram_tab[11])
27  00 LSB of the 11th word of data
28  00 MSB of the 12th word of data (UIF_R.ram_tab[12])
29  00 LSB of the 12th word of data
30  00 MSB of the 13th word of data (UIF_R.ram_tab[13])
31  00 LSB of the 13th word of data
32  00 MSB of the 14th word of data (UIF_R.ram_tab[14])
33  00 LSB of the 14th word of data
34  00 MSB of the 15th word of data (UIF_R.ram_tab[15])
35  00 LSB of the 15th word of data
36  00 MSB of the 16th word of data (UIF_R.ram_tab[16])
37  00 LSB of the 16th word of data
38  69 checksum

Example 2

PC request of writing 4 words in the structure UIF_W, starting from the third one (UIF_W.ram_tab[2], .., UIF_W.ram_tab[5]):

0  0F Number of bytes in the frame (0Fh=15dec)
1  3F Master string indicator "?"
2  00 Station address (it is always 0 in our boards)
3  57  word writing operation "W"
4  42  data start address (2(-address in UIF_W.ram_tab)+40h(offset to add for ram
  reading/writing))
5  04  number of data
6  03  MSB of the 1st word of data (value (03E8h=1000dec) to be written in
  UIF_W.ram_tab[2] = UIF_W.var.rif, speed ref)
7  E8  LSB of the first word of data
8  00  MSB of the second word of data (value to be written in UIF_W.ram_tab[3], not
  used)
9  00  LSB of the second word of data
10  00  MSB of the third word of data (value to be written in UIF_W.ram_tab[4], not used)
11  00  LSB of the third word of data
12  00  MSB of the fourth word of data (value to be written in UIF_W.ram_tab[5], not used)
13  00  LSB of the fourth word of data
14  E7  checksum

Board answer (indicates that the request is received and processed):

0  05  Number of bytes in the frame
1  21  Slave string indicator "!"
2  00  Station address (it is always 0 in our boards)
3  57  word writing operation "W"
4  E6  checksum

Note: Four new operation codes have been added:
'y'(=0x79): word reading (EEPROM minimum value)
'z'(=0x7A): word reading (EEPROM maximum value)
'k'(=0x6B): word reading (measurement samples vector)
'j'(=0x6A): word reading (EEPROM default value)
In these cases the address is a < NUM_PAR.

To understand in more details the software implementation, please find below the extract of the “userif.h” module, part of the embedded software.

```c
typedef union
{
    struct
    {
        signed short rrf; // 0 internal speed reference
        signed short rpm; // 1 measured/estimated speed
        signed short fre; // 2 applied frequency
        signed short id;  // 3 direct current
        signed short iq;  // 4 quadrature current
        signed short vd;  // 5 direct voltage
        signed short vq;  // 6 quadrature voltage
        signed short vb;  // 7 bus voltage
        signed short ali; // 8 alarm
        signed short flg; // 9 status flags
        signed short tor; // 10 current vector amplitude
        signed short torv; // 11 voltage vector amplitude
        signed short du0; // 12
        signed short du1; // 13
        signed short du2; // 14
        signed short du3; // 15
        signed short mod; // 16 mode
        signed short rs;  // 17 stator resistance
        signed short ls;  // 18 synchronous inductance
        signed short fl;  // 19 permanent magnet flux
        signed short kpi; // 20 current loop kp
        signed short kii; // 21 current loop ki
        signed short pwnf; // 22 pwm frequency [Hz]
        signed short sf;  // 23 sampling frequency [Hz]
        signed short ena; // 24 extra features enable flags
        signed short du4; // 25
        signed short du5; // 26
        signed short du6; // 27
        signed short du7; // 28
        signed short du8; // 29
        signed short du9; // 30
        signed short du10; // 31
    } ram_tab[N_RAM_READ];
} UIF_R_U;

typedef union
{
    struct
    {
        signed short trg; // 0 trigger
        signed short mod; // 1 mode
        signed short rrf; // 2 speed reference
        signed short crs; // 3 current ratio
        signed short sel; // 4 variable and time scale selection
        signed short du0; // 5
        signed short du1; // 6
        signed short du2; // 7
    } ram_tab[N_RAM_WRITE];
} UIF_W_U;
```

*Figure 83. Variables in RAM*
```c
#include _USERIF_C

#define USERIF_C

EXTERN UIF_R_t UIF_R;
EXTERN UIF_W_t UIF_W;
EXTERN OUTB_t *wbuf;
EXTERN uint16_t *rbuf;
EXTERN uint16_t *pbuf;

#else  // _USERIF_C
EXTERN UIF_R_t UIF_R;
EXTERN UIF_W_t UIF_W;
EXTERN OUTB_t *wbuf, *outbuf1;
EXTERN uint16_t *rbuf;
EXTERN uint16_t *pbuf;
#endif  

Figure 84. Variable Externs

/*
--- Special Working Modes ---

Special working modes are controlled through UIF_R.var.mod:
if it is 0 then normal mode is used, other values stay for special modes. A feedback of the working mode is given in UIF_R.var.mod, which is equal to the working mode.
If the working mode requires a trigger from the GUI to execute some operations, UIF_W.var.trg bit 0 is used (it is automatically cleared after being detected); the feedback regarding the requested operation status is given by some bits in UIF_R.var.flg: bit 0 = 1 means BUSY, while if it is 0 means READY, bit A = 1 means last operation was ENDED_OK, while if it is 0 means ENDED_FAIL. Trigger requests are not accepted if UIF_R.var.sta is not ready. It means that the GUI has to stay in polling for this flag after a trigger.
Other important flags are bit 7 (alarm), and bit 9 which indicates that the motor is driven.
Working status can be changed only when the motor is not driven (UIF_R.var.flg has bit 5 equal to 0).
*/

#define ENA_CURFI_TUN UIF_R.var.enaa |= WSET0;
#define ENA_CURFI_AUT UIF_R.var.enaa |= WSET1;
#define ENA_AUTO_IDEM UIF_R.var.enaa |= WSET2;
//Define ENA_OSCI_MIND UIF_R.var.enaa |= WSET3;
#define NORM_MODE_CODE ( 0 ) // normal inverter behavior
#define CURFI_TUN_CODE ( 1 ) // current PI gains manual tuning mode
#define CURFI_AUT_CODE ( 2 ) // current PI gains automatic detection mode
#define AUTO_IDEM_CODE ( 3 ) // motor parameters auto-identification mode
#define NORM_MODE_REQ ( NORM_MODE_CODE == UIF_R.var.mod )
#define CURFI_TUN_REQ ( CURFI_TUN_CODE == UIF_R.var.mod )
#define CURFI_AUT_REQ ( CURFI_AUT_CODE == UIF_R.var.mod )
#define AUTO_IDEM_REQ ( AUTO_IDEM_CODE == UIF_R.var.mod )

Figure 85. Special Working Modes (1)
#define NORM_Mode ( NORM_MODE_CODE == UIF_R.var.mod )
#define CURPI_TUN ( CURPI_TUN_CODE == UIF_R.var.mod )
#define CURPI_AUT ( CURPI_AUT_CODE == UIF_R.var.mod )
#define AUTO_IDEN ( AUTO_IDEN_CODE == UIF_R.var.mod )

#define NOT_NORM_Mode ( NORM_MODE_CODE != UIF_R.var.mod )
#define NOT_CURPI_TUN ( CURPI_TUN_CODE != UIF_R.var.mod )
#define NOT_CURPI_AUT ( CURPI_AUT_CODE != UIF_R.var.mod )
#define NOT_AUTO_IDEN ( AUTO_IDEN_CODE != UIF_R.var.mod )

#define SET_NORM_MODE UIF_R.var.mod = NORM_MODE_CODE;
#define SET_CURPI_TUN UIF_R.var.mod = CURPI_TUN_CODE;
#define SET_CURPI_AUT UIF_R.var.mod = CURPI_AUT_CODE;
#define SET_AUTO_IDEN UIF_R.var.mod = AUTO_IDEN_CODE;

#define ALRM_ON (UIF_R.var.flg & WSET7)
#define ALRM_OFF (! ALRM_ON)
#define COM_ON (UIF_R.var.flg & WSET8)
#define COM_OFF (! COM_ON)
#define STA_BSY (UIF_R.var.flg & WSET9)
#define STA_RDY (! STA_BSY)
#define END_NOK (UIF_R.var.flg & WSETA)
#define END_OK (! END_NOK)
#define ICOM_ON (UIF_R.var.flg & WSETB)
#define ICOM_OFF (! ICOM_ON)

#define SET_ALRM_ON UIF_R.var.flg | WSET7;
#define RES_ALRM_ON UIF_R.var.flg & WCLR7;
#define SET_COM_ON UIF_R.var.flg | WSET8;
#define RES_COM_ON UIF_R.var.flg & WCLR8;
#define SET_STA_BSY UIF_R.var.flg | WSET9;
#define RES_STA_BSY UIF_R.var.flg & WCLR9;
#define SET_END_NOK UIF_R.var.flg | WSETA;
#define RES_END_NOK UIF_R.var.flg & WCLRA;
#define SET_ICOM_ON UIF_R.var.flg | WSETB;
#define RES_ICOM_ON UIF_R.var.flg & WCLRB;

#define GUI_TRI (UIF_W.var.trg & WSET0)
#define RES_GUI_TRI UIF_W.var.trg & WCLR0;
#define GUI_STP (UIF_W.var.trg & WSET1)
#define RES_GUI_STP UIF_W.var.trg & WCLR1;

Figure 86. Special Working Modes(2)
23. Revision History

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<td>June 17, 2016</td>
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<td>1.1</td>
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<td>1.2</td>
<td>June 20, 2017</td>
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24. Appendix A: Schematic
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http://www.renesas.com

Refer to "http://www.renesas.com" for the latest and detailed information.

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Colophon 1.0
RL78/F14 BLDC Starter Kit