AN2281
Application note

Low cost self-synchronizing PMAC motor drive using ST7FLITE35

Introduction

Due to their high efficiency, power by size ratio and silent operation, Permanent Magnet AC (PMAC) motors are increasingly used in many applications. They are becoming the predominant type of motor used in applications where the above advantages are required, especially fans, compressors and pumps.

Since PMAC motors are synchronous machines, to get the best efficiency from them, the excitation must be switched from one motor phase to another in exact synchronism with the rotor motion. This concept, commonly known as self-synchronization, uses direct feedback of the rotor angular position to ensure that the PMAC machine never loses synchronization.

This application note describes a low-voltage single-sensor three-phase AC permanent magnet motor, also known as PMAC or BLAC (brushless AC) control system.

It includes a depiction of:

- Reference schematics, which can be used for up to 12V-50W PMAC motors and based on ST7LITE35 microcontroller and on STS8C5H30L complementary P-channel and N-channel MOSFETs,
- Firmware library, developed with the Cosmic C compiler and STVD7 release 3.x.x. It is composed of several C modules containing a set of convenient functions for sinusoidal waveform generation, synchronization mechanism and closed loop control of PMAC motors.

Contents

1 Theory of operation

Standard induction motors, normally designed to run at base speeds between 850 to 3500 rpm, are not particularly well suited to low-speed operation, as their efficiency drops with the reduction in speed. They may also be unable to deliver sufficient smooth torque at low speeds.

The use of a gearbox is the traditional mechanical solution to this problem. However, the gearbox is a complicated piece of machinery that takes up space, reduces efficiency, and needs both maintenance and significant quantities of oil. Replacing the gearbox with permanent magnet motors/drive configurations saves space and installation costs, energy and maintenance, and provides more flexibility in production and facility design. These motors use magnets to produce the magnetic rotor field rather than the magnetizing component of the stator current like in the induction motor.

Figure 1 shows a cross section of a typical permanent magnet (PM) motor. The rotor has an iron core on the surface of which is mounted a thin permanent magnet. An alternating magnet of opposing magnetization produces radial directed flux density across the air gap. This flux then reacts with currents in the stator windings to produce torque.

The two most common types of brushless PM motors are classified as:

- Synchronous, with a uniformly rotating stator field as an induction motor. This type is also referred to as PMAC (BLAC)
- Switched or trapezoidal, with stator fields that are switched in discrete steps. This type is also referred to as PMDC (BLDC)

Figure 1. Cross-section of PM motors

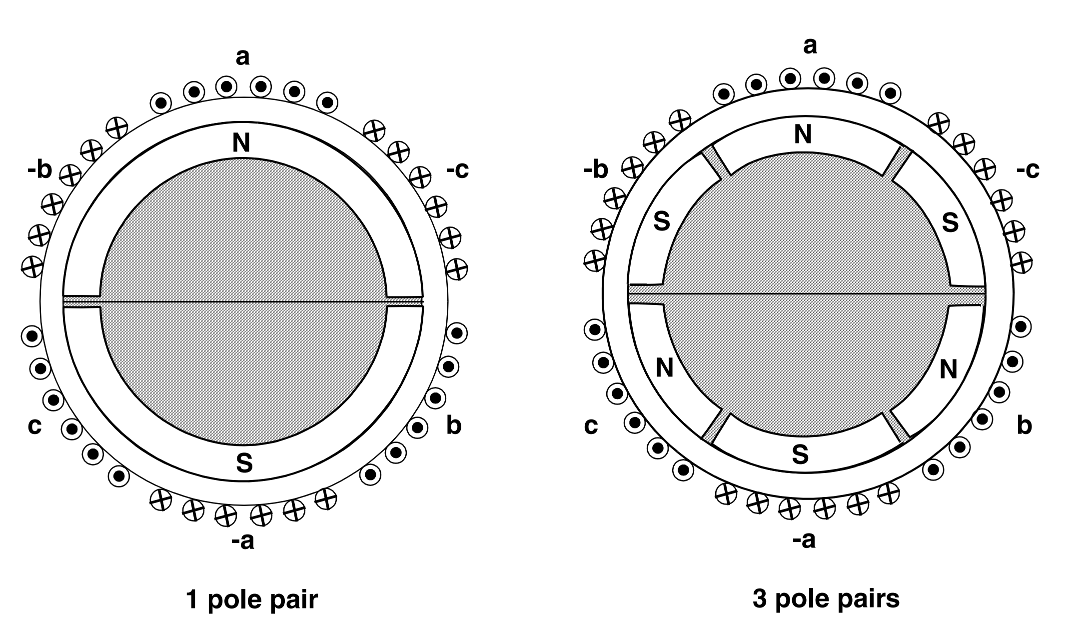
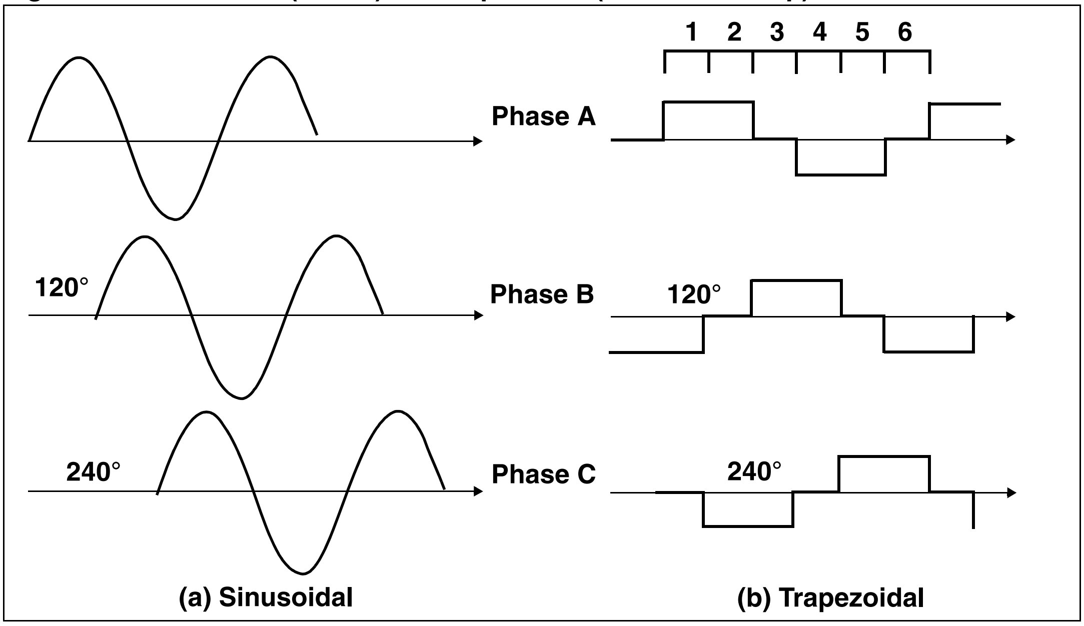


Figure 2 provides a direct comparison of ideal current excitation waveforms for typical three-phase sinusoidal and trapezoidal PM motors.

Figure 2. Sinusoidal (PMAC) and trapezoidal (PMDC or 6-step) current excitation



PMDC motors are specifically designed to develop nearly constant output torque when excited with a six-step switched current waveform. Their stator windings are concentrated into narrow phase belts. The resulting back-EMF voltage, induced in each stator phase winding during rotation, can be modeled quite accurately as a trapezoidal waveform.

PMAC motors are, on the contrary, specifically designed to be excited with a sinusoidal current waveform. Their stator windings are typically distributed over multiple slots in order to approximate a sinusoidal distribution so that the resulting back-EMF waveforms generated are sinusoidal shaped.

Except for the intrinsic characteristics of stator windings, a PM machine can be excited with both drive methods without any great loss of efficiency. The main difference between the two types of excitation consists of the acoustic noise generated. The abrupt variation of the trapezoidal phase current, in fact, generally introduces a great amount of acoustic and electronic noise in comparison to the sinusoidal phase current.

In the 6-step PMDC method, one of the three phases is always unexcited, making it possible to access back-EMF zero-crossing (i.e. rotor position) information, while in a PMAC motor drive the three phases are always excited during the electrical period, making it necessary to use at least one rotor position sensor.

Nevertheless, the relatively reduced amount of noise when a PM motor is excited with sinusoidal current in comparison to 6-step excitation makes it the preferred choice for all applications in which audible noise is a critical issue.

Actually, some complex algorithms for driving PMAC sensorless motors have been developed, but they require more computational power than would be available from an 8-bit microcontroller.

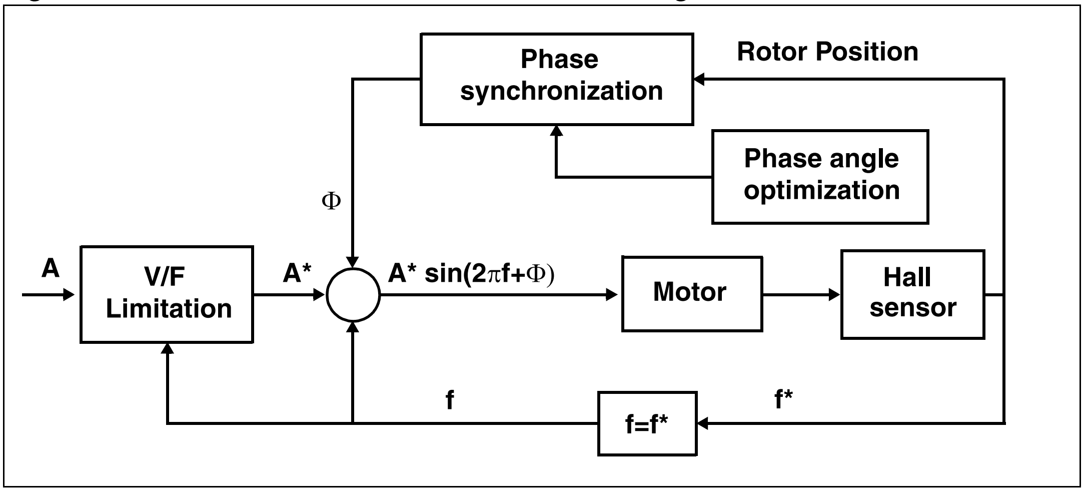
2 PMAC motor control basics

PMAC machines are synchronous so the average torque can be produced only when the excitation is synchronized with the rotor frequency and instantaneous position. By continuously detecting the rotor angular position and rotational speed, the excitation can be properly switched among the PMAC motor phases in exact synchronism with the rotor motion.

This concept, commonly known as self-synchronization, uses direct feedback of the rotor angular position to ensure that the PMAC machine never loses synchronization. Generally, Hall sensors are used to get information about the angular position of rotor, detecting the magnetic field direction generated by the rotor. In particular, the usage of only one sensor is supported with the system presented in this document.

Figure 3 shows the block diagram of the PMAC self-synchronization algorithm implemented in the software library.

Figure 3. PMAC motor control basics: the block diagram



Each of the three phases of the motor is supplied by a sinusoidal waveform whose frequency, amplitude and phase have been respectively indicated with f, A* and Φ.

Every time an Hall sensor signal transition occurs, the algorithm estimates the rotor frequency f* and utilizes this value as statorical frequency (f) for the successive electrical semi-period. Meanwhile, the phase of the sine wave is also updated and set equal to phase angle Φ or $\Phi+\pi$ depending on the Hall sensor edge transition (rising or falling). Generally, for a large operating speed range, the proper value of Φ is strongly dependent on the motor speed affecting the driving efficiency. The provided library allows you to set the optimum Φ as a linear function of the speed (in rpm).

Since there are no direct information on current and torque, a V/F limitation has also been implemented in order to allow you to limit the maximum flowing current for a given speed.

3 Implementation on the ST7LITE35 microcontroller

The algorithm presented in the previous paragraph has been implemented on the ST7FLITE35 microcontroller. Although they belong a family of low-cost ST microcontrollers, ST7FLITE3x devices nevertheless have all the necessary features to be able to drive a PMAC motor using one Hall sensor.

- The **Lite Timer** has been used to measure the period (or better the semi-period) of the Hall sensor signal and the **12-bit autoreload Timer** with its 4 PWM outputs has been used to generate the three voltage phases.
- The **internal RC oscillator** with 1% tolerance allows you to further reduce the cost and the size of the overall system and avoid PCB layout optimization issues related to the presence of external oscillators.

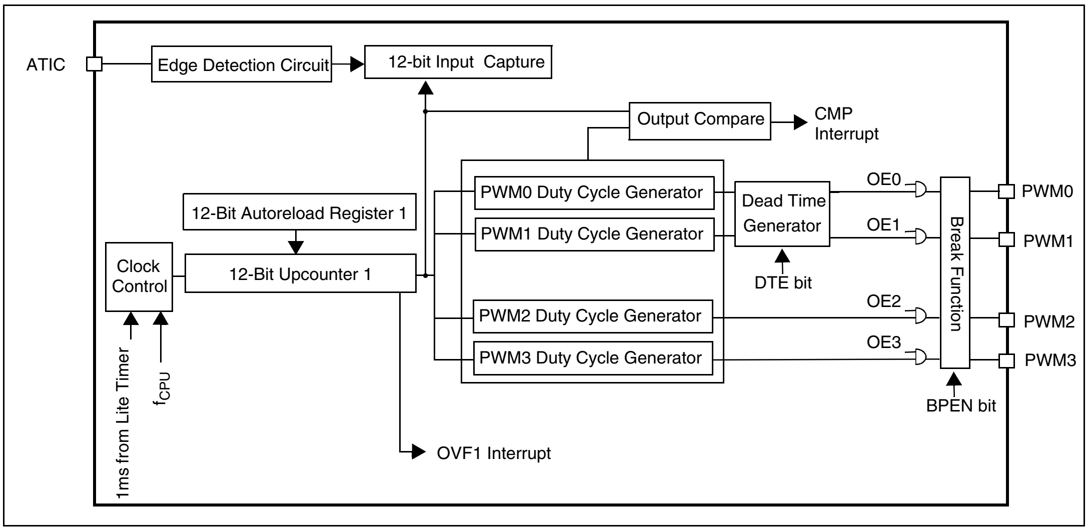
3.1 ST7LITE3x 12-bit autoreload timer (ART) in PWM mode

3.1.1 Block diagram and functional description

The 12-bit ART is based on one or two free-running 12-bit upcounters with an input capture register and four PWM output channels.

The PWM mode of the dual 12-bit autoreload timer allows up to four Pulse Width Modulated signals to be generated on the PWMx output pins. The four PWM signals can have the same frequency (f_{PWM}) or two different frequencies depending on the ENCNTR2 bit which enables single timer or dual timer mode (see *Figure 4* and *Figure 5*).

Figure 4. The dual 12-bit autoreload timer: single timer mode (ENCNTR2=0)



The PWM frequency is controlled by the counter period and the ATR register value following formula

$$f_{PWM} = f_{COUNTER} / (4096 - ATR) \qquad (3.1)$$

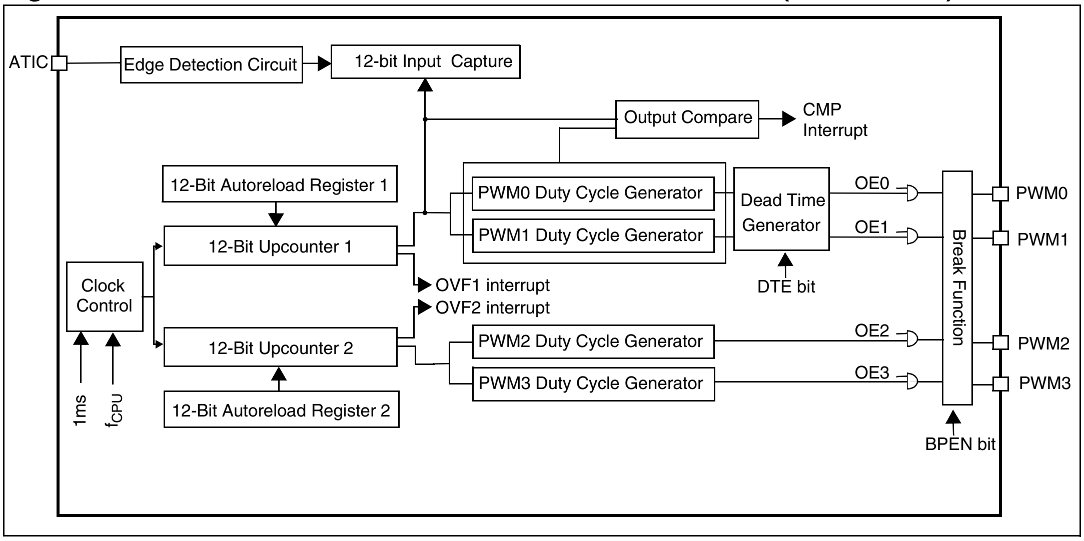
In dual timer mode, PWM2 and PWM3 can be generated with a different frequency controlled by CNTR2 and ATR2.

The duty cycle is selected by programming the DCRx registers. These are preload registers. The DCRx values are transferred in active duty cycle registers after an overflow event if the corresponding transfer bit (TRANx bit) is set.

The TRAN1 bit controls the PWMx outputs driven by counter 1 and the TRAN2 bit controls the PWMx outputs driven by counter 2.

PWM generation and output compare are done by comparing these active DCRx values with the counter.

Figure 5. The dual 12-bit autoreload timer: dual timer mode (ENCNTR2=1)



At reset, the counter starts counting from 0. When an upcounter overflow occurs (OVF event), the preloaded Duty cycle values are transferred to the active Duty Cycle registers and the PWMx signals are set to a high level. When the upcounter matches the active DCRx value the PWMx signals are set to a low level. To obtain a signal on a PWMx pin, the contents of the corresponding active DCRx register must be greater than the contents of the ATR register.

The polarity bits can be used to invert any of the four output signals. The inversion is synchronized with the counter overflow if the corresponding transfer bit in the ATCSR2 register is set.

The PWMx output signals can be enabled or disabled using the OEx bits in the PWMCR register.

3.1.2 Three-phase sinusoidal waveform generation

In order to produce the three-phase sinusoidal voltages, three of the four available PWM outputs have been enabled. Since these three PWM signals must have the same frequency, single timer mode has been selected (ENTNCR2=0).

To allow the necessary duty cycle updating, the OVFIE bit of the ATCSR register has been set. This way an interrupt is generated every $1/f_{PWM}$ seconds.

Furthermore, to reduce the acoustical noise introduced by the switching of the three-phase inverter, a PWM frequency out of the audible range has been chosen. In particular, to achieve the selected 15.625 KHz switching frequency, $f_{COUNTER}$ has been fixed equal to f_{CPU} (8 MHz) and, consequently, using formula (3.1), the ATR1 registers have been written with value 3584.

To reduce the contribution of the OVF interrupt service routine to the overall CPU load, the calculations necessary for computing the three sinusoidal varying duty cycles are carried out once per two PWM periods (that is once every two interrupts). This way, the number of traced points per sine wave period (NP) is given by:

$$N_P = \frac{f_{PWM}}{2 * f_{SINE}} \qquad (3.2)$$

Since at least 18 samples per sine wave cycle must be traced to generate a sine wave with a Total Harmonic Distortion minor than 5%, (3.2) limits the maximum sine wave frequency to 434 Hz that is equivalent to about 26,000 rpm for an one poles pair motor.

3.1.3 Third harmonic modulation

Basically, to provide the voltage needed for the PMAC motor, the reference PWM signal could be a pure sine wave, but this kind of modulation has the drawback that it makes poor usage of the DC bus voltage.

Adding a third harmonic modulation to the reference sine wave, allows the phase-to-phase voltage amplitude to be increased without deteriorating current and phase-to-phase voltage THD (a 120-degree phase-shift on the fundamental corresponds to a 360-degree shift for the third harmonic). On this subject, the literature demonstrates that, if the third harmonic amplitude is equal to one sixth of the fundamental one, it is possible to increase the phase-to-phase voltage amplitude by 15% with respect to the pure sine wave approach.

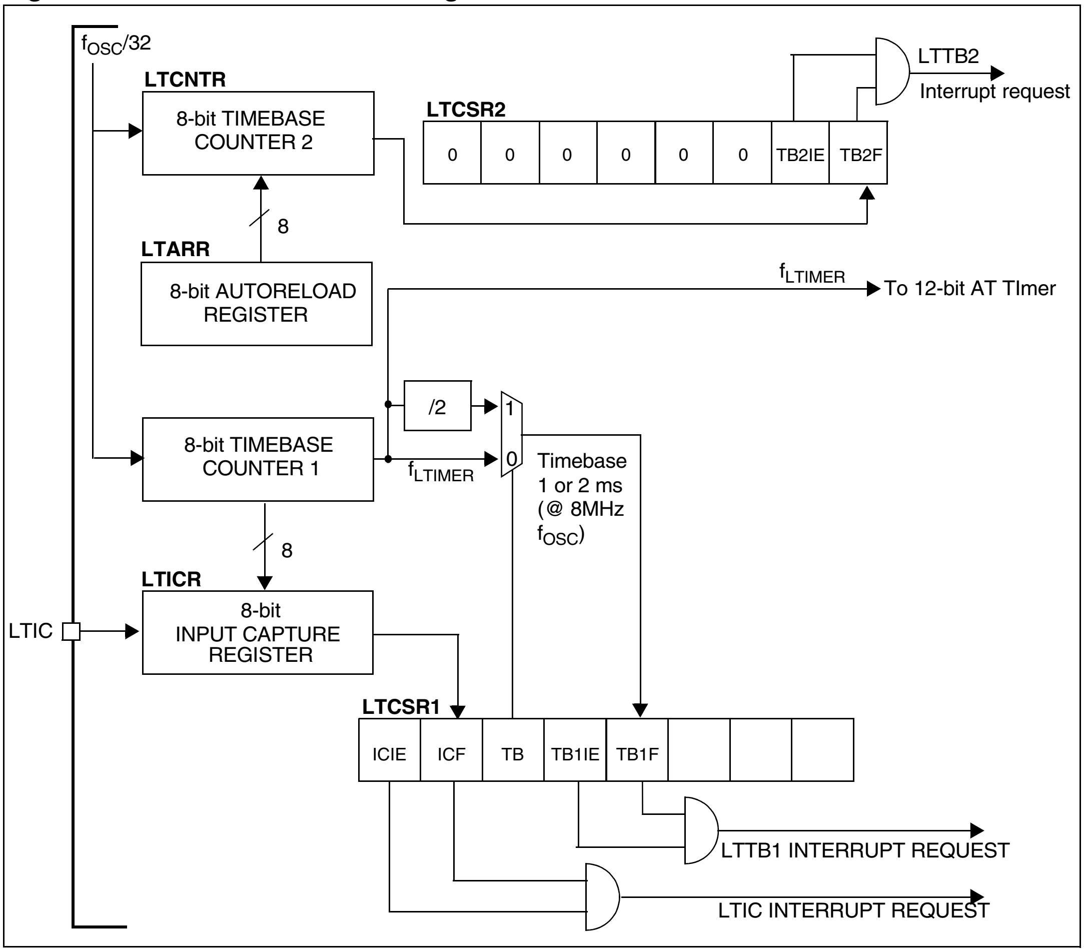
3.2 Lite timer for measuring the rotor speed

3.2.1 Block diagram and functional description

The Lite timer (LT) can be used for general-purpose timing functions. It is based on two free-running 8-bit upcounters and one 8-bit input capture register.

Figure 6 shows the Lite timer block diagram.

Figure 6. The Lite timer block diagram



After an MCU reset, counter 1 starts incrementing from 0 at a frequency of $f_{OSC/32}$. An overflow event occurs when the counter rolls over from F9h to 00h. If f_{OSC}=8 MHz, then the time period between two counter overflow events is 1 ms. This period can be optionally doubled by setting the TB bit in the LTCSR1 register.

When Counter 1 overflows, the TB1F bit is set by hardware and an interrupt request is generated if the TB1IE bit is set.

The Counter 2 functions in a similar way to Counter 1 but, after an MCU reset, it increments starting from the value stored in the LTARR register instead of starting from 0.

As you can see in *Figure 6*, Counter 1 is associated with an 8-bit input capture register, used to latch the free-running upcounter after a rising or falling edge is detected on the LTIC pin.

When an input capture occurs, the ICF bit is set and the LTICR register contains the MSB of Counter 1. An interrupt is generated if the ICIE bit is set.

3.3 Lite timer configuration for measuring the Hall sensor period

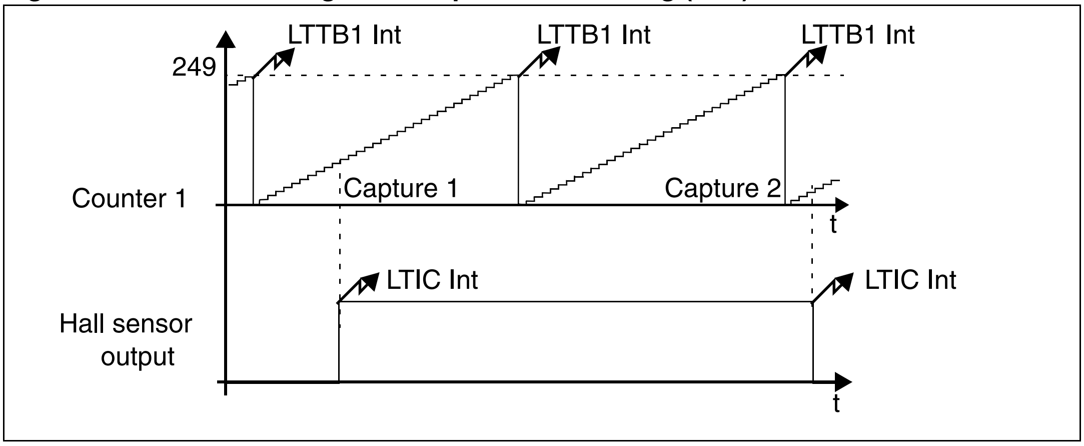
As mentioned in the previous paragraph, the LTICR register can be used to latch Counter 1 every time an edge is detected on the LTIC pin. This characteristic of the Lite Timer, together with the possibility of generating an interrupt when the upcounter overflows (LTTB1 Interrupt), allows you to precisely measure the semi-period of the Hall sensor signal.

Based on *Figure 7*, it is possible to draw the following mathematical relationship:

$$\frac{t_H}{2} = ((250\text{-Capture }1)+\text{Capture }2+250*(N-1))*\frac{32}{f_{OSC}} \quad N>0 \qquad (3.3)$$

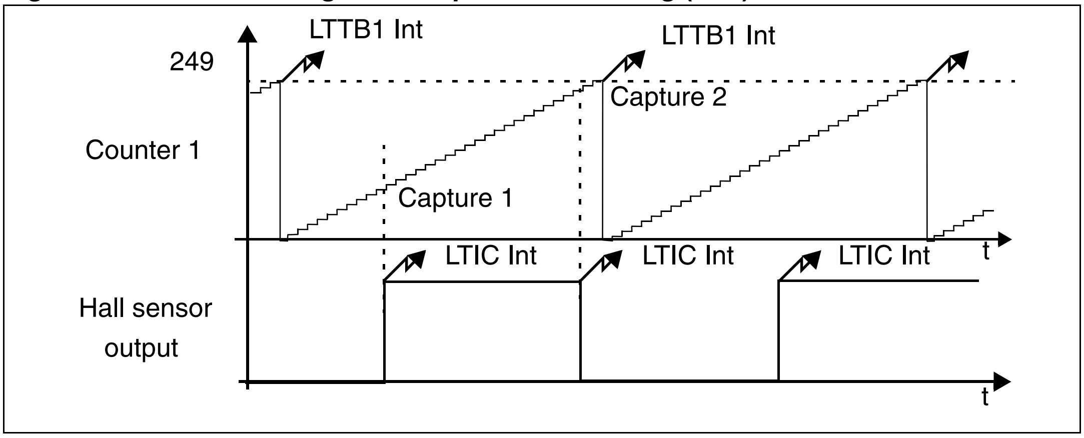
where t_H represents the Hall sensor signal period, Capture 1 and Capture 2 indicate the values of Counter 1 at the edges of the Hall sensor signal and N is the number of LTTB1 interrupt events between the two Hall sensor output transitions taken into account.

Figure 7. Hall sensor signal semi-period measuring (N>0)



The relationship (3.3) is valid only under the condition N>0 and, then it can not be used to measure frequencies higher than 500Hz. In this case the formula to be used, as can be deduced from *Figure 8*, is the (3.4):

Figure 8. Hall sensor signal semi-period measuring (N=0)



$$\frac{t_H}{2} = (\text{Capture 2} - \text{Capture 1}) * \frac{32}{f_{OSC}} \qquad (3.4)$$

Please note that in both (3.3) and (3.4) $t_H/2$ is computed with a resolution equal to:

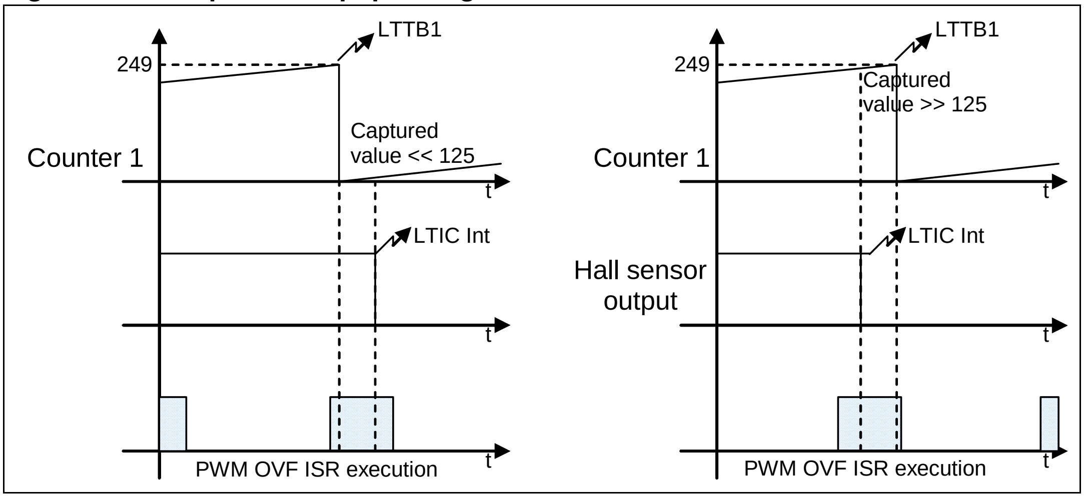
$$\frac{32}{f_{OSC}}$$

that is 4µsec at 8 MHz f_{OSC}.

You can observe that, in order to measure the Hall sensor semi-period correctly, the LTIC and LTTB1 ISRs must be executed by the microcontroller core in the same order in which the related interrupts events occurred. This would normally happen if no other interrupts service routines are executing. However in our software, a third interrupt source is enabled (PWM update event), so a potentially erroneous situation could arise due to the interrupt priority mechanism.

Figure 9 describes two possible situations:

Figure 9. Multiple interrupt pending situation



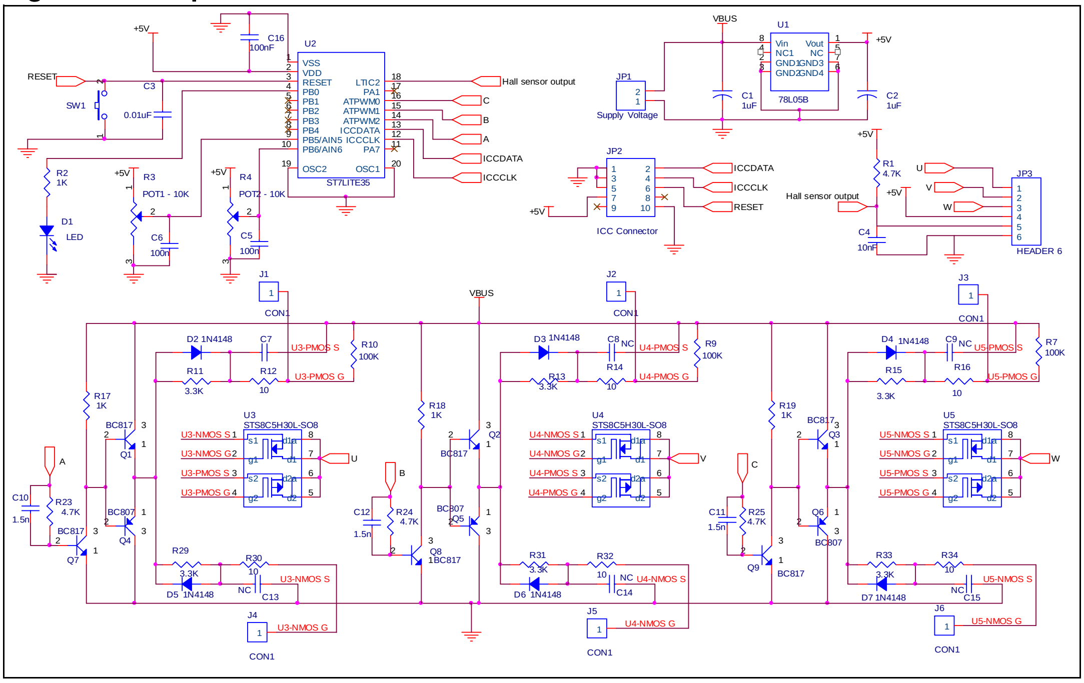
Due to the higher interrupt priority of LTIC with respect to LTTB1, in both cases the LTIC ISR is executed before LTTB1 ISR.

In this case, the value stored in the LTICR is used to reconstruct the correct sequence: if the content of the LTICR is lower than 125, it is assumed that the LTTB1 event occurred just before a LTIC event so that the Lite Timer overflow counter must be incremented before the semi-period computation. On the contrary, if the LTICR contains a value higher than 125, it is assumed that the LTIC occurred just before a Lite timer overflow (LTTB1 event). In this case, the overflow counter must not be incremented before the semi-period computation but it will be taken into account at the next LTIC event.

4 Application schematics

Figure 10 shows the application schematic:

Figure 10. Proposed reference schematic



As you can see in *Figure 10*, the proposed schematic has a logic section basically consisting of the ST7FLITE35 microcontroller, and a power section including the three-phase inverter.

The power supply is consists only of an L7805 voltage regulator. The simplicity of this type of solution limits the minimum operating voltage to almost 7V but you could obtain a lower value by using a low drop voltage regulator (i.e. L4979D).

4.1 Gate driving and dead time insertion circuit

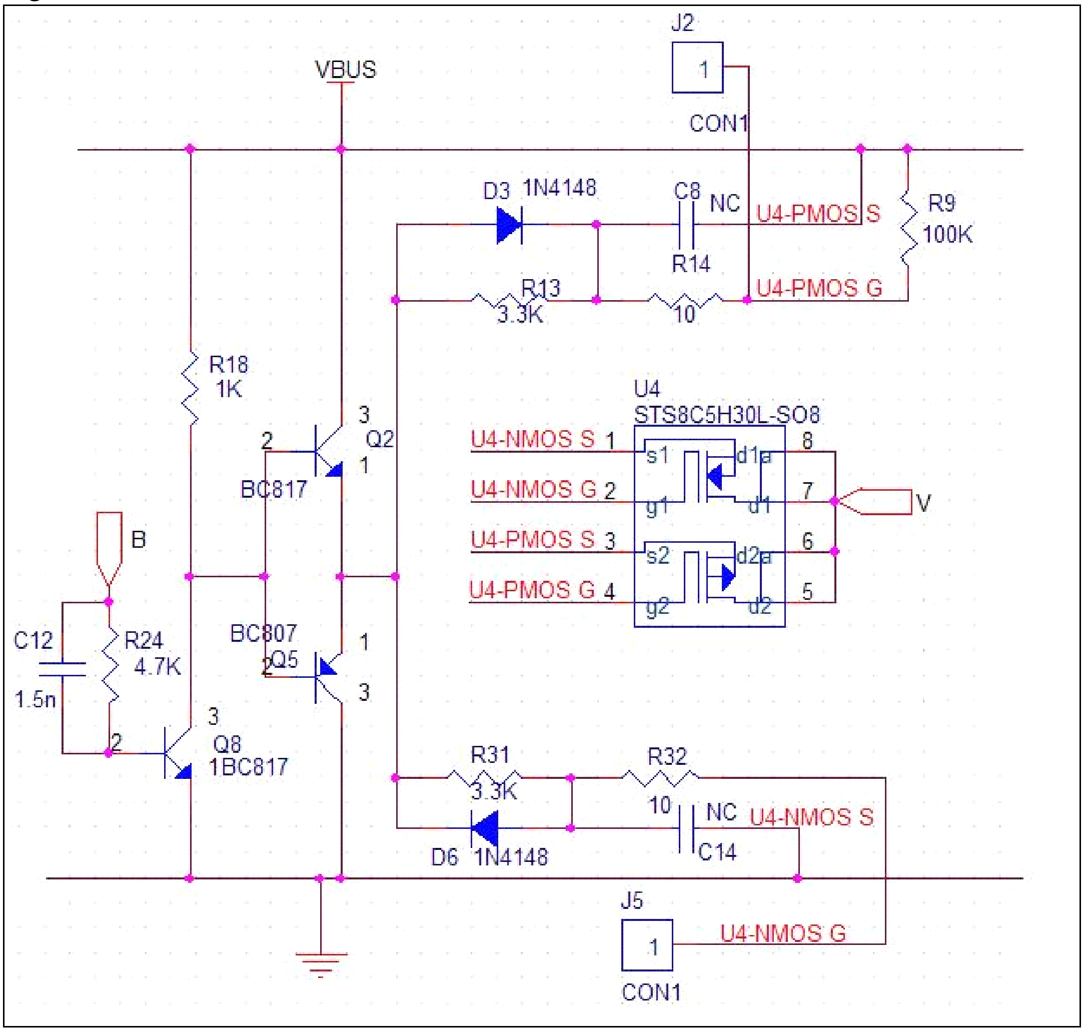
Figure 11 shows in detail one of the three legs of the DC-AC inverter used in the reference schematic, with the corresponding gate driving circuit. The description of this leg is valid for the whole inverter.

In order to drive the U4 MOSFETs correctly and to avoid their contemporary conduction, the signal coming from the microcontroller and applied at the base of bipolar transistor Q8 is, first of all, level shifted by the emitter follower stage (Q8) and, then, a dead time is inserted delaying the turn-on of the NMOS and PMOS devices and by making their turn-off instantaneous.

Referring to the control signal (applied on point B in *Figure 11*) low-to-high transition and assuming the P-channel MOSFET fully turned on when $|V_{GS}|=V_{TH}$, you can compute the dead time value by solving the following equation:

$$\left(1-e^{-\frac{t}{R_{13}*C_{PMOSin}}}\right)V_{BUS}=V_{THp} \qquad (4.1)$$

Figure 11. The dead time insertion circuit



That leads to:

$$t_{DTf} = R_{13} * C_{PMOSin} * \ln\left(\frac{V_{BUS}}{V_{BUS} - V_{THp}}\right) \quad (4.2)$$

Likewise, for the high-to-low transition, it is possible to obtain:

$$t_{DTf} = R_{31} * C_{PMOSin} * \ln\left(\frac{V_{BUS}}{V_{BUS} - V_{THn}}\right) \quad (4.3)$$

where C_{PMOSin} and C_{NMOSin} are, respectively, the equivalent input capacitance of PMOS and NMOS and can be computed, with reference to the STS8C5H30L datasheet, as $C_{iss}+2C_{rss}$.

The values of resistors R_{13} and R_{31} in the schematic in *Figure 11* have been sized in order to guarantee a minimum dead time in the worst condition (i.e. 7V supply voltage, high-to-low control signal transition), of about 0.5 µsec.

5 Library parameters

This paragraph describes the parameters used in the PMAC motor control library supplied with this application note. All the command lines mentioned in this paragraph are included in the *PMAC_Param.h* header file.

5.1 Phase synchronization and phase angle optimization

As discussed in *Figure 2*, every time an Hall sensor edge occurs, the phase of the sine wave is refreshed, depending on the transition (high-to-low or low-to-high), with the phase angle Φ or with $\Phi+\Pi$. Moreover, the Hall sensor signal semi-period is stored so that the sine wave frequency can be computed by averaging the last 4 semi-period measurements.

The tuning of the phase angle Φ is extremely important and it can enormously effect the efficiency of the system. Two different solutions for phase angle optimization are possible using the library supplied with this application note:

5.1.1 Phase angle tuned by Pot2

If the command line:

```
#define PHASE_READING_FROM_POT2
```

is not commented, the phase angle is read by the potentiometer Pot2. The minimum and maximum available phase angles are configurable by definition statements:

```
#define MIN_PHASE (u16)  xxx //in 360°/65535 unit  (180° <=> 32768)
#define MAX_PHASE  (u16)  xxx //in 360°/65535 unit   (180° <=> 32768)
```

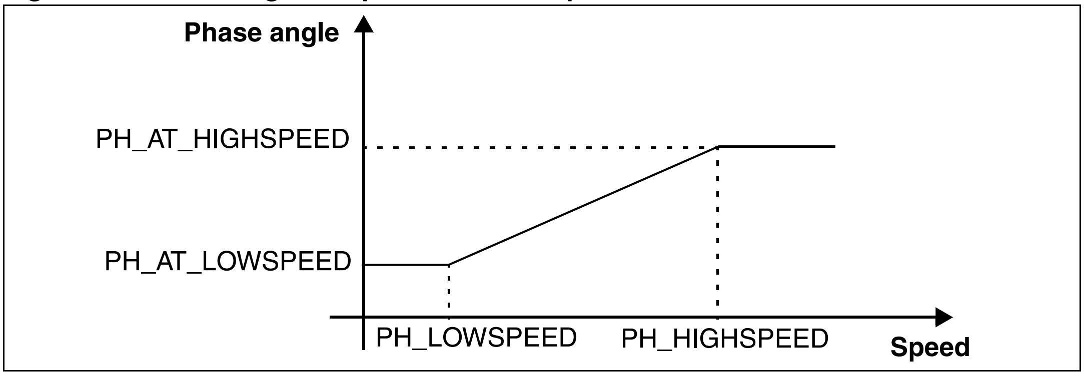
5.1.2 Phase angle as a function of frequency

If the command line:

```
#define PHASE_READING_FROM_POT2
```

is commented out, the phase angle is computed as a linear function of the rotor speed following the relationship illustrated in *Figure 12*:

Figure 12. Phase angle vs speed relationship



PH_AT_HIGHSPEED, PH_AT_LOWSPEED (in 360°/65535 unit), PH_LOWSPEED and PH_HIGHSPEED (in rpm) are configurable in the *PMAC_Param.h* header file.

5.2 Start-up phase parameters

The motor start-up procedure implemented in the library presented in this application note basically consists of two different phases:

- Rotor alignment phase
- Sinusoidal three-phase voltage ramp-up

5.2.1 Rotor alignment phase

This phase pre-positions the rotor in order to put it in a known position. This allows the proper alignment of the statorical flux during motor start-up, avoiding any unwanted rotor vibrations. Moreover, putting the rotor in a known position causes the current waveform during the motor start-up to be repetitive and deterministic, and thus easily adjustable. In spite of all this, in some applications, it can be useful not perform the alignment phase. This usually produces a higher and more uncontrolled current but it can lead to a faster ramp-up of the motor.

In the library supplied with this application note, you can disable or enable the rotor alignment by commenting the command line in or out.

```
#define ROTOR_ALIGNMENT
```

The rotor pre-positioning is achieved by applying a linearly increasing voltage (starting from zero volts) to one of the three phases of the motor while the other two are grounded.

The two command lines:

```
#define ALIGNMENT_DURATION  xxx   //Alignment duration in msec

#define FINAL_DUTY     xxx //Final duty cycle in 1/255 units

                            //(85 <=> 33%)
```

set the alignment phase duration and the final duty cycle (normally it should not exceed 33%).

5.2.2 Sinusoidal three-phase voltage ramp-up

This procedure initializes the sinusoidal three-phase voltage generation and, in order to reduce the start-up motor current, carries out a linear increase of the sine amplitude. The command lines:

```
#define START_VOLT  xxx         // in 1/255 unit. 255 <=> maximum

                              // modulation index

#define START_SPEED  xxx        // in rpm
```

allow to you initialize the three-phase sinusoidal voltage amplitude and frequency. Note that statorical frequency initialization is necessary because the self-synchronization algorithm discussed in *Section 2* can work properly only if the rotor frequency f* can be measured. The initialized value of statorical frequency will be, therefore, applied to the motor until a valid f* measurement has been performed.

If the alignment phase has been performed,

```
#define START_PHASE   xxx        //expressed in 360°/65535
```

also initializes the phase of the sine wave so that the stator and rotor magnetic fields can be synchronous starting from the first electrical period.

Moreover, the command lines

```
#define START_UP_DURATION  xxx     // in msec
#define FIN_VOLT   xxx          //  in 1/255 units
```

set the sine wave amplitude at the end of the ramp-up and the ramp-up duration.

5.2.3 Open loop driving mode

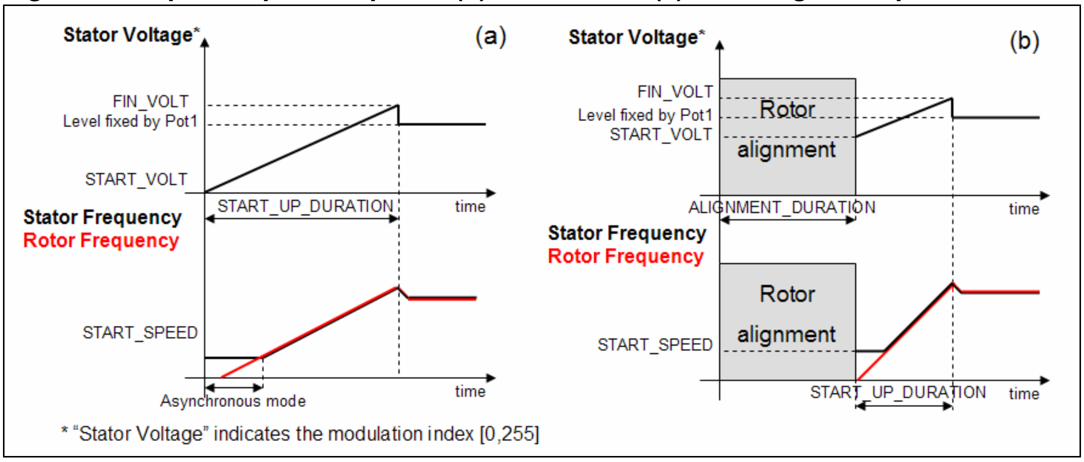
Once the voltage ramp-up is over, open loop driving mode allows you adjust the amplitude of the sinusoidal three-phase voltage applied to the motor using potentiometer Pot1.

The minimum and maximum amplitudes are definable and the related command lines are:

```
#define MAX_VOLTAGE   xxx    // Expressed in 1/255 units
#define MIN_VOLTAGE    xxx     //Expressed in 1/255 units
```

Figure 13 summarizes the basics of open loop driving mode:

Figure 13. Open loop start-up with (b) and without (a) rotor alignment phase



5.2.4 Closed loop driving mode for speed regulation

Closed loop driving mode includes a PI regulator acting on the amplitude of the three-phase voltage for speed regulation. You set the target speed using potentiometer Pot. The minimum and maximum target speeds are definable by command lines:

```
#define MIN_SPEED  xxx   //in rpm
#define MAX_SPEED   xxx   // in rpm
```

You can optimize the dynamic response of the system by acting on the sampling time and the proportional and integral constants of the PI regulator in following command lines:

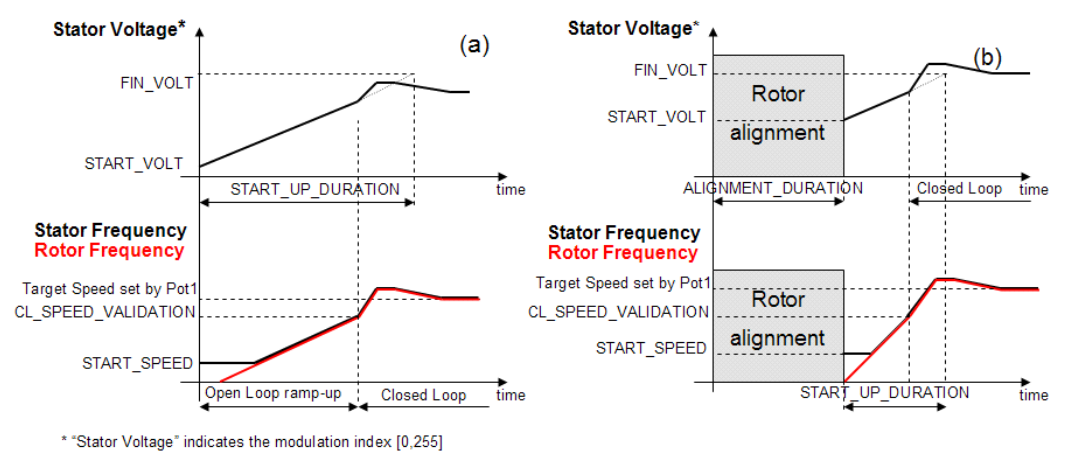
```
#define SAMPLING_TIME  xxx  //in msec
#define  kp  xxx
#define  ki   xxx
```

With the purpose of avoiding too strong a response by the PI regulator at the end of the motor start-up, when the error between target speed and measured speed could be high, PI regulation is enabled (and ramp-up ended) if, during the voltage ramp-up the actual speed of the rotor is higher than an established threshold speed defined by:

```
#define CL_SPEED_VALIDATION    xxx    // in rpm
```

The control system, therefore, starts the motor as already described for open loop and it enables the PI regulator either at the end of the start-up or when rotor reaches the speed CL_SPEED_VALIDATION. *Figure 14* summarizes the closed loop start-up strategy.

Figure 14. Closed loop start-up with (b) and without (a) rotor alignment phase



6 Getting started with the ST7FLITE35-based PMAC motor control system

Follow this procedure to perform a system evaluation and be able to get started quickly running your own motor.

6.1 Hardware connections

To start a 12V PMAC motor with the system presented in this application note, please connect, with reference to *Figure 9*:

- the three phases of the motor to connector JP3-1,2,3
- the Hall sensor supply voltage, output and ground, respectively, to connector JP3-4,5,6
- the 12V supply voltage to connector JP1 (the negative pole to JP1-1)

6.2 Development tools

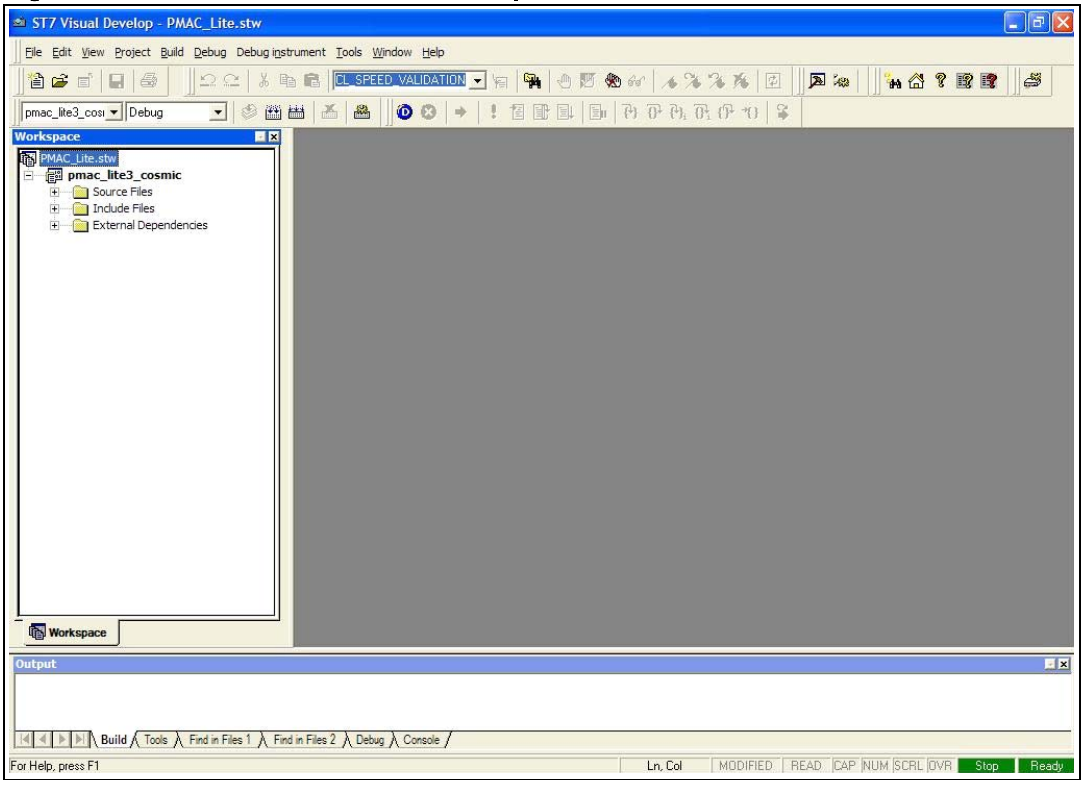
This section presents the available material that is needed to start working with the ST7FLITE35 and the PMAC software library discussed in this document.

6.2.1 Integrated development environments (IDE)

Different IDE interfaces are available for free: ST proprietary's STVD7 (free download available on internet: www.st.com), or third party IDE (e.g. Softec Microsystems' STVD7 for InDART-STX).

The software library presented in this document has been compiled using Cosmic C compiler (ver. 4.5c) launched with Softec STVD7 version 3.10. Please note that the 16K limited free version of Cosmic compiler is able to compile the software library.

Figure 15. Softec STVD7 ver3.10 development tool



6.2.2 Real time emulators

Two types of real-time development tools are available for debugging applications using ST7FLITE35:

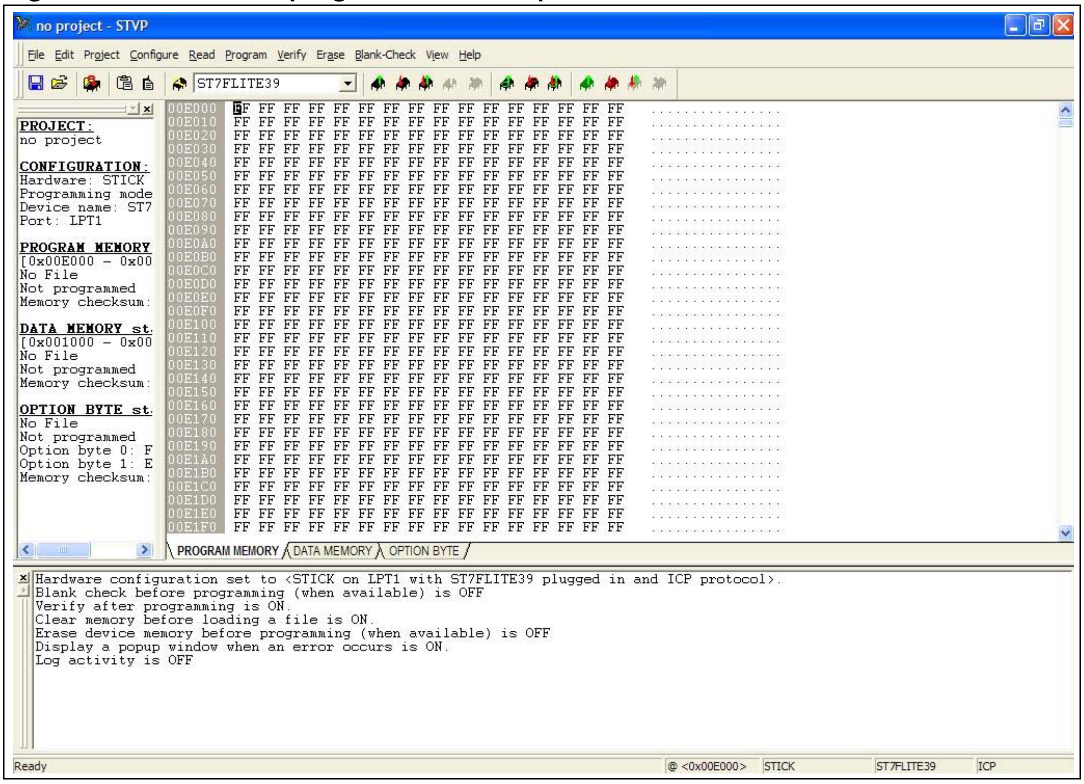
- In-circuit debugger from Softec (sales type: STXF-INDART/USB).The inDART-STX from Softec Microsystems is both an emulator and a programming tool. This is achieved using the In-circuit debug module embedded on the MCU. The real-time features of the Indart include access to working registers and 2 breakpoint settings. However trace is not available.
- ST7MDT10-EMU3. Full-featured emulator: real-time with trace capability, performance analysis, advanced breakpoints, some logic analyzer capabilities,... You can also use it as a programming tool with the ICC ADDON module, which is included with the emulator. This ICC-ADDON module allows you to do In-Circuit-Debugging with STVD7.

6.2.3 Programmers

In order to program an MCU with the generated S19 file, output of the compilation, you should also install the ST Visual Programmer software (available on ST website www.st.com) and use a dedicated hardware programming interface (STICK programmer for In-Circuit-Programming, for instance). The Visual Programming tool provides an easy way to erase, program and verify the MCU contents.

Please note that the inDART-STX from Softec Microsystems is also a programming tool (installation of DataBlaze Programmer software is required).

Figure 16. ST7 Visual programmer development tool



6.3 Library source code

6.3.1 Software downloads

The complete source files are available for free on the ST website as a zip file in the Technical Literature section.

Note: Important: It is highly recommended to check for the latest releases of the library before starting a new development, and to verify the release notes on ST's website from time to time in order to keep up-to-date about new features that might be useful for your project.

6.3.2 File structure

Once the files are unzipped, the following library structure is created.

Figure 17. The library structure

```
\sources
\Debug
\Release
```

To produce the target *.S19* file, you should open the ST7VD workspace "*PMAC_Lite.stw*" and compile the project by pressing the "Rebuild All" button of the ST7VD development tool.

Two different sets of compiler and linker options (Debug and Release) can be handled by the tool depending on the development stage.

6.4 How to set the library parameters to run a PMAC motor for the first time

To run a 12V PMAC motor with the motor control system described in this document, you first need do some configuration to the software library. In the *PMAC_Param.h* header file, set the number of motor pole pairs in the command line

```
#define POLES_PAIRS_NUMBER   x
```

Then, you need to find out the optimum phase angle   (an oscilloscope with a current probe is necessary). To do this, you should:

- Enable the tuning of phase angle via the Pot2 potentiometer and set the minimum and maximum angle respectively at 0 and 360°:

```
#define MIN_PHASE  (u16)  0              //in 1/65535 unit  180° <=> 32768
#define MAX_PHASE  (u16)  65535    //in 1/65535 unit  180° <=> 32768
```

- Select open loop driving mode using this define:

```
#define DRIVING_MODE   OPEN_LOOP
```

and setting the minimum and maximum voltages between 0% and 100%:

```
#define MAX_VOLTAGE 255
#define MIN_VOLTAGE  0
```

- Disable V/F curve limitation
- Disable the rotor alignment phase
- Configure the start-up phase parameters, initially disabling the alignment phase and fixing the ramp-up parameters as follows:

```
#define START_SPEED    400        //in rpm
#define START_UP_DURATION   500  // in msec
#define START_VOLT   25          // in 1/255 unit
#define FIN_VOLT         130     //  in 1/255 unit
```

- Adjust potentiometer Pot1 to about 50%

After you have made these settings, you should compile the software library and program the microcontroller.

6.4.1 Determining the phase angle and optimizing the start-up parameters

After device programming, once the ICC cable has been removed, microcontroller begins to execute the firmware and motor should start moving. As earlier discussed, the value of phase angle Φ can greatly influence the efficiency of the system so that a wrong value of could even prevent the motor from starting. For this reason, Pot2 should be slowly turned (starting from 0% position) until motor start running and, then, the phase angle should be finely tuned in order to increase the motor efficiency (that is reducing the current at fixed speed). This can be easily achieved by changing the MIN_PHASE and MAX_PHASE parameters with the purpose of progressively incrementing the resolution of potentiometer Pot2.

It could happen that, even if you slowly turn the Pot2 potentiometer from the 0% position to the 100% position, the motor does not start spinning. In this case, the voltage fed to the motor may not be sufficient and you should increase it slightly by turning the Pot1 potentiometer towards the 100% position. While doing this, you should monitor one of the three phase currents to be sure it does not exceed the absolute maximum ratings of the motor. Then repeat the procedure for optimum phase identification.

Once the motor has started running, you should then try to determine the optimum phase angle versus frequency characteristic in order to find out the best PH_AT_HIGHSPEED, PH_AT_LOWSPEED, PH_LOWSPEED and PH_HIGHSPEED parameters.

You should then disable “phase angle read by Pot2”.

7 Conclusion and results

A low-voltage three-phase AC permanent magnet motor (PMAC or BLAC) control system has been developed using ST7FLITE35. Some concluding remarks concerning the CPU load and the code memory size are given below. This is followed by a series of oscilloscope captures illustrating the proper behavior of the system.

7.1 Motor control related CPU load

The CPU load computation has been performed when using closed loop driving mode, with Ph/f linear relationship enabled and V/f limitation disabled. The system was driving a 4 pole-pair motor, running at 10,000 rpm.

The most important contributors to the CPU load were these motor control tasks:

- **Sine wave generation**. As discussed in *Section 3.1*, the sine wave update is performed in the 12-bit autoreload timer overflow interrupt service routine (LART_OVF1_IT_Routine). When the three PWM duty cycles are not computed, the execution time of this interrupt service routine is about 4 µsec. while, when the three duty cycles are updated, the execution time is around 27.5 µsec. Considering then, that a interrupt is generated every 64 µsec., the contribution of this task to the CPU load is equivalent to:

$$\frac{4+27.5}{2*64} *100=24.6\%$$

- **Hall sensor signal semi-period measurement**. As earlier discussed, this task is performed in the Lite Timer Input Capture interrupt service routine. Considering a 4 pole-pair motor running at 10,000 rpm, the incoming Hall sensor signal frequency is 666.7Hz. One LTIC interrupt is therefore generated every 750µsec. Since the execution time of this routine, is around 26.5 µsec., the contribution of this task to the CPU load, under the described conditions, is equivalent to 3.5%.
- **PI regulation**. Assuming a sampling time of 25msecs and considering that the execution time of this routine is, in worst case conditions, around 150µsec, the contribution of PI regulation to the CPU load is less than 1% and therefore negligible.
- **Period to frequency conversion**. In order to guarantee a high level of synchronization, sine wave frequency should be computed, starting from the measured semi-periods, at least once per Hall sensor period.

Considering that, for a motor with 4 pole pairs running at 10,000 rpm, the incoming Hall sensor signal frequency is 666.7Hz and that the average time required for executing the time to frequency conversion is around 222µsec, the contribution of this task to the CPU load is given by

$$222*10^{-4}*666.7=14.8\%$$

Under the described conditions, the overall CPU load is then

$$\text{CPU load} = 24.6 + 3.5 + 14.8 = 42.9\% \qquad (7.1)$$

7.2 Code memory size

Table 1 summarizes the size of the compiled code, in terms of program and RAM memory, in different settings situations and with "Release" compiler options:

Table 1. RAM and program memory code size

Settings	Program memory size	RAM size
Open loop, rotor alignment phase disabled, phase angle read by potentiometer, V/f limitation disabled	1470 b	55 b
Open loop, rotor alignment phase enabled, Phase angle computed from Ph/f relationship, V/f limitation enabled	2027 b	63 b
Closed loop, rotor alignment phase disabled, phase angle read by potentiometer, V/f limitation disabled	1859 b	66 b
Closed loop, rotor alignment phase enabled, Phase angle computed from Ph/f relationship, V/f limitation enabled	2438 b	76 b

7.3 Example oscilloscope captures

Figure 17 and *Figure 18.* show a typical start-up in open loop. The capture shows the signal on pin ATPWM0 (filtered so that only the modulating signal is visible), the Hall sensor output and the current flowing through phase W of the motor (see *Figure 9*). The rotor alignment is enabled in *Figure 17* and it is possible to observe its final phase (before the sine wave starts to be generated) while it has been disabled in the start-up shown in *Figure 18.*.

Figure 19. illustrates a typical start-up in closed loop. Please observe that sinus amplitude is modulated every SAMPLING_TIME (75) milliseconds in order to make the speed constant.

Finally, *Figure 20.* shows typical steady-state behavior.

Figure 18. Open loop start-up with rotor alignment enabled

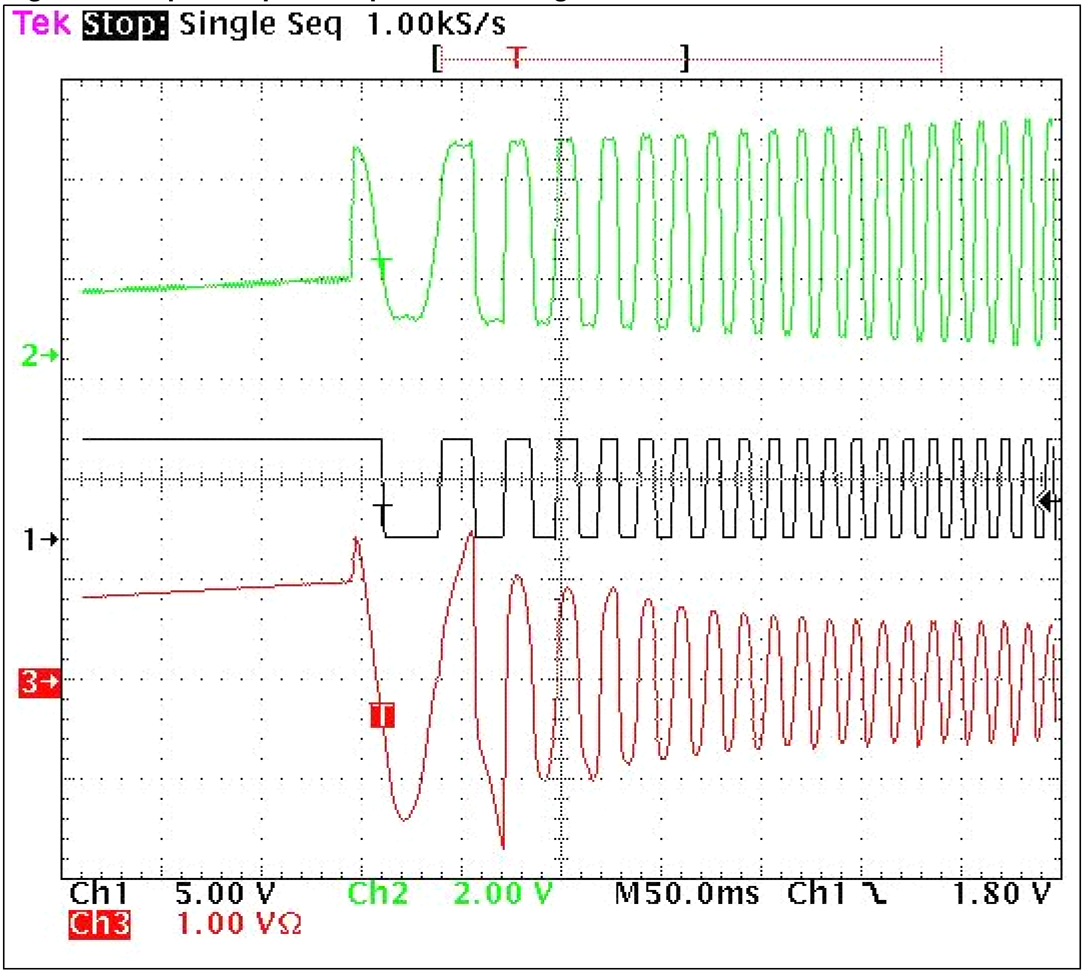


Figure 19. Open loop start-up without rotor alignment

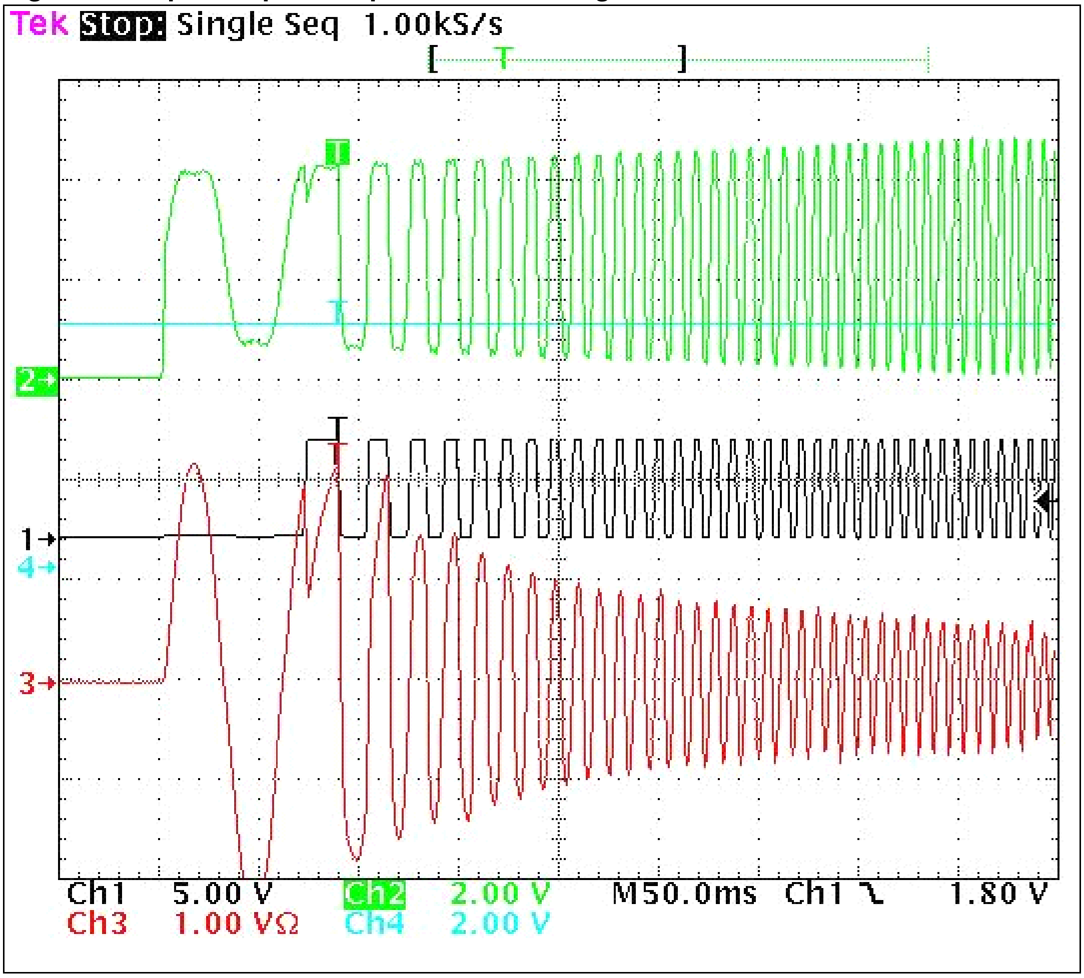


Figure 20. Closed loop start-up

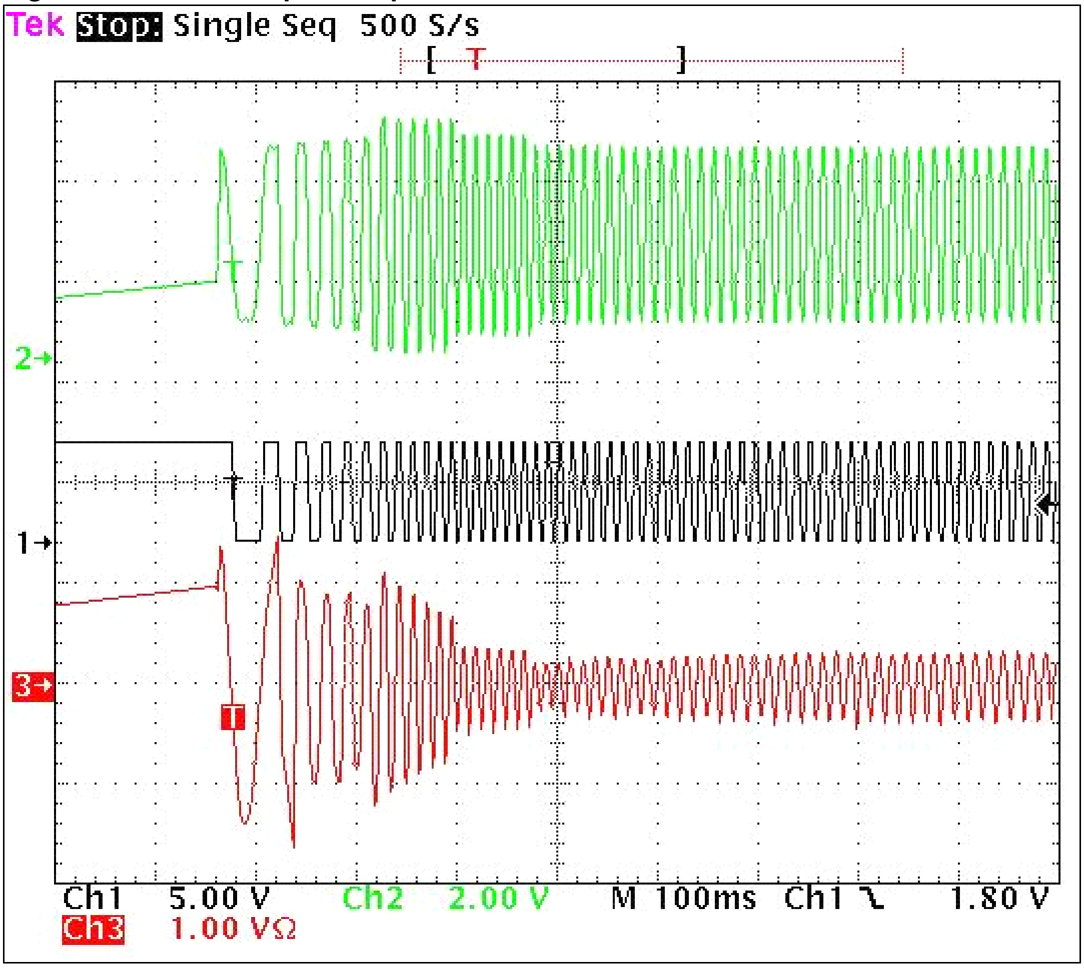
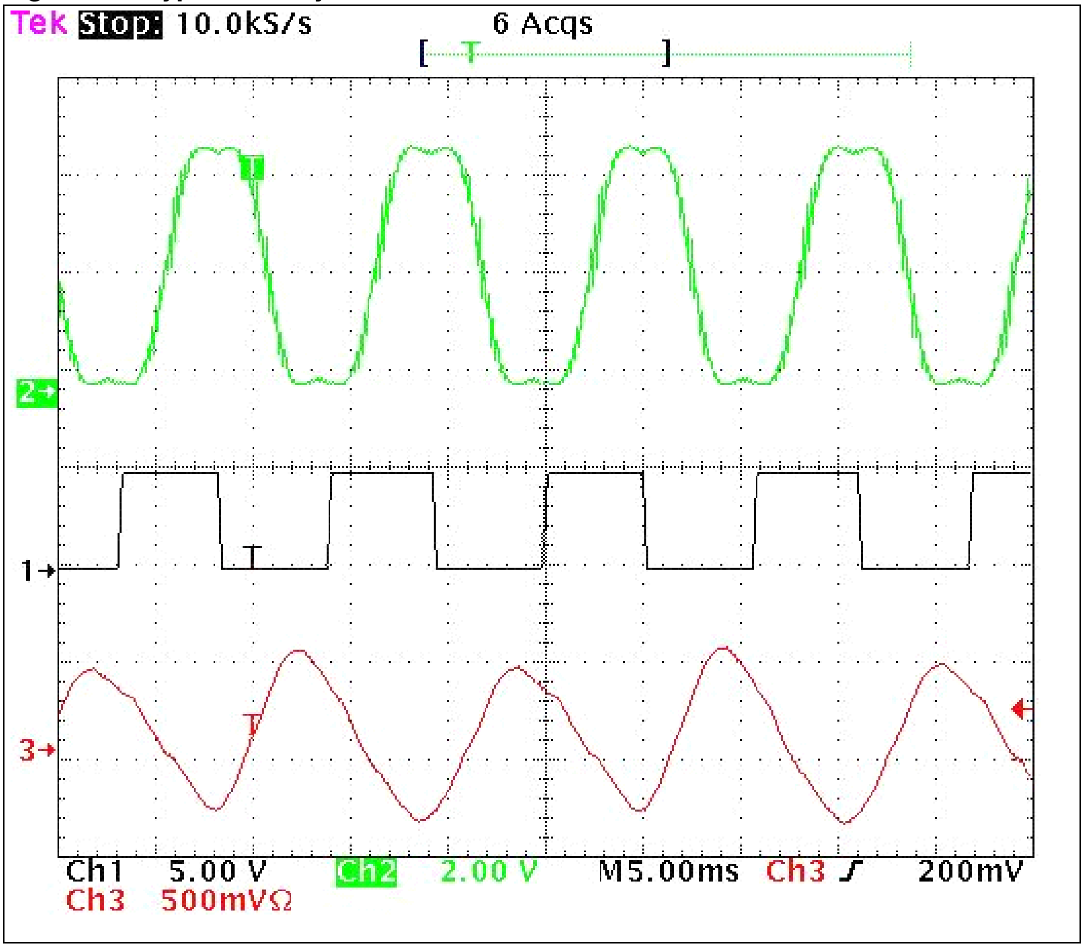


Figure 21. Typical steady-state conditions



Appendix A List of software functions and interrupt service routines

My_functions.c Module

Set_Spinning_Direction

Description: This function allows you to set the rotation direction of the motor before the start-up procedure

Input: Value CW or CCW ("direction" type has been defined in *My_functions.h* header file)

Returns: None

Caution: This function must be called when the motor is stopped, before the start-up procedure. Calling the function while the motor is running could cause damage to the motor.

Soft_Start

Description: This function carries out a soft motor start up by performing a linear increase of the three-phase sinusoidal voltage.

Input: None

Returns: None

See also:: Start-up procedure description in *Section 5.2*

Note: start_up_on_going variable is equal to 1 if soft start is on-going, 0 if it is over.

DoRotorAlignment

Description: This function performs the rotor alignment by exciting the motor phase W (see *Figure 9*) and keeping the other two at ground

Input: None

Returns: None

Caution: The function is compiled only if rotor alignment phase is enabled

Duration: ~ ALIGNMENT_DURATION.

See also:: Start-up procedure description in *Section 5.2*

DoMotorControl

Description: This function performs a closed loop speed control. It utilizes a PI (proportional and integral) regulation algorithm to determine the most appropriate voltage value to get the expected rotor speed.

Input: Target speed in u16 format. Data returned by Get_Target_Speed function can be directly used as input data

Returns: None

Caution: The function is compiled only if closed loop driving mode is defined.

Duration: The PI routine average execution time is strongly dependent on the error between actual and target speed. In worst-case conditions (high error), the routine duration is equal to 157 µsec.

See also:: *Section 5.2.4*

Get_Rotor_Freq

Description: This function computes the stator frequency to be applied to the motor. At start-up, the function returns the stator frequency initialization value. As soon as the first valid Hall sensor semi-period measurement has been performed and until the fourth semi-period measurement has been completed, the function returns the last measured rotor frequency. After the fourth semi-period measurement has been carried out, the average rotor frequency (based on last 4 measurements) is returned.

Input: None

Returns: Stator frequency with 0.1192Hz resolution.

Duration: 222 µsec in steady state

Freq_computing

Description: This function is called by Get_Rotor_Freq function, it performs the division for converting the Hall sensor signal semi-period measurements into a frequency (0x3FFFF/period).

Input: Hall sensor semi-period (u16 format with 16µsec resolution).

Returns: Electrical frequency, defined by the formula:

Electrical frequency = Rotor speed (in rpm)* Number of Pole pairs/60

with 0.1192Hz resolution.

Duration: 204 µsec.

lt.c Module

LT_TB1_IT_Routine

Description: Lite Timer counter 1 overflow interrupt service routine.

The Lite Timer is configured so that this interrupt occurs every 1 msec., two variables are incremented in this interrupt service routine. Then "counter" variable is used for Hall sensor signal semi-period measurement and the "timebase_1ms" variable is used as 1 msec time base.

Input: None

Returns: None

Duration: 4.35µsec

LT_ICAP_IT_Routine

Description: Lite Timer input capture interrupt service routine.

Hall sensor signal semi-period measurement is performed in this routine. Moreover, depending on the logical value of the Hall sensor signal, the phase of the PWM modulated sinusoidal voltage output on pin ATPWM0 (phase C) is forced with phase angle value Φ or with $\Phi+\pi$. Finally, the watchdog timer is enabled/refreshed so that, if no Hall sensor edges occur in 127msec (corresponding to an electrical frequency of less than 4 Hz), a hardware reset is generated.

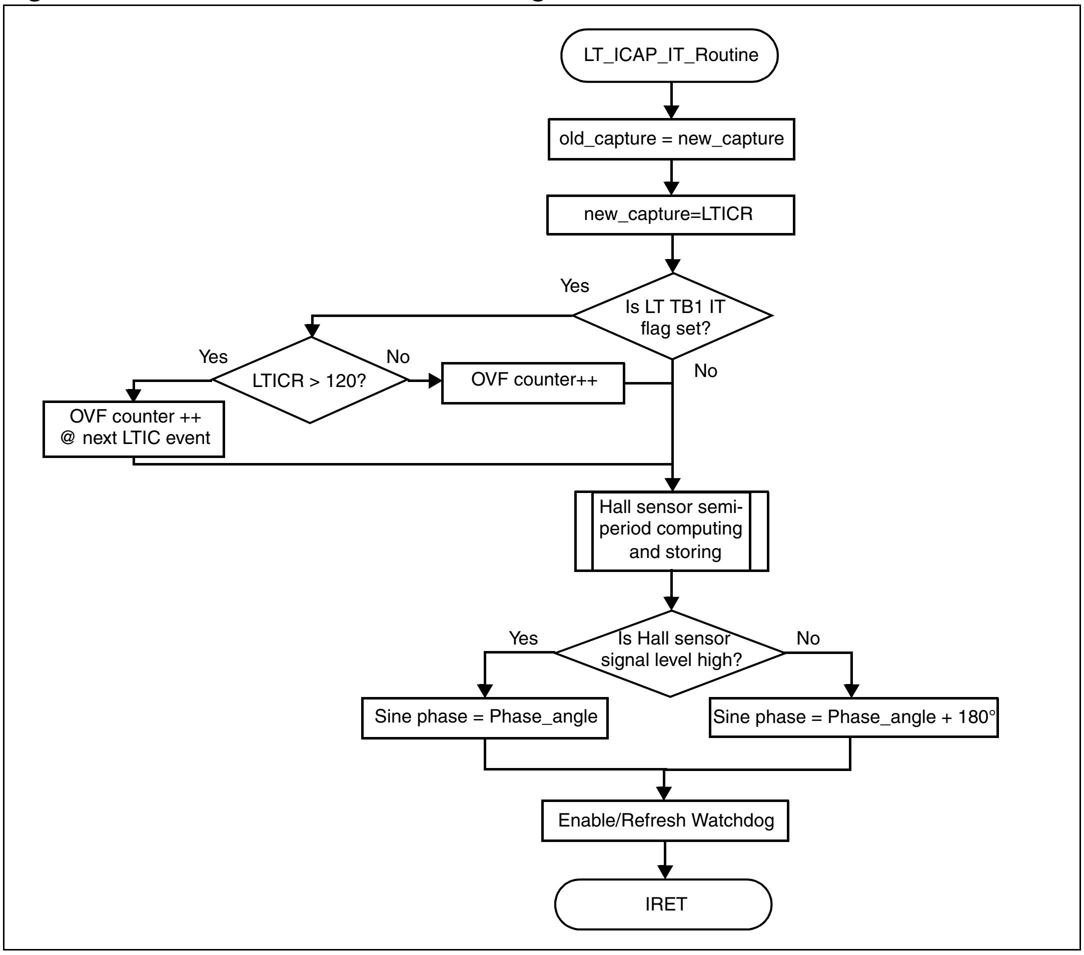
Figure 22 shows the flowchart of this interrupt service routine.

Input: None

Returns: None

Duration: The average duration is 26.15 µsec.

Figure 22. LT_ICAP_IT_Routine block diagram



lart.c Module

LART_OVF1_IT_Routine

Description: 12-bit autoreload timer overflow interrupt service routine.

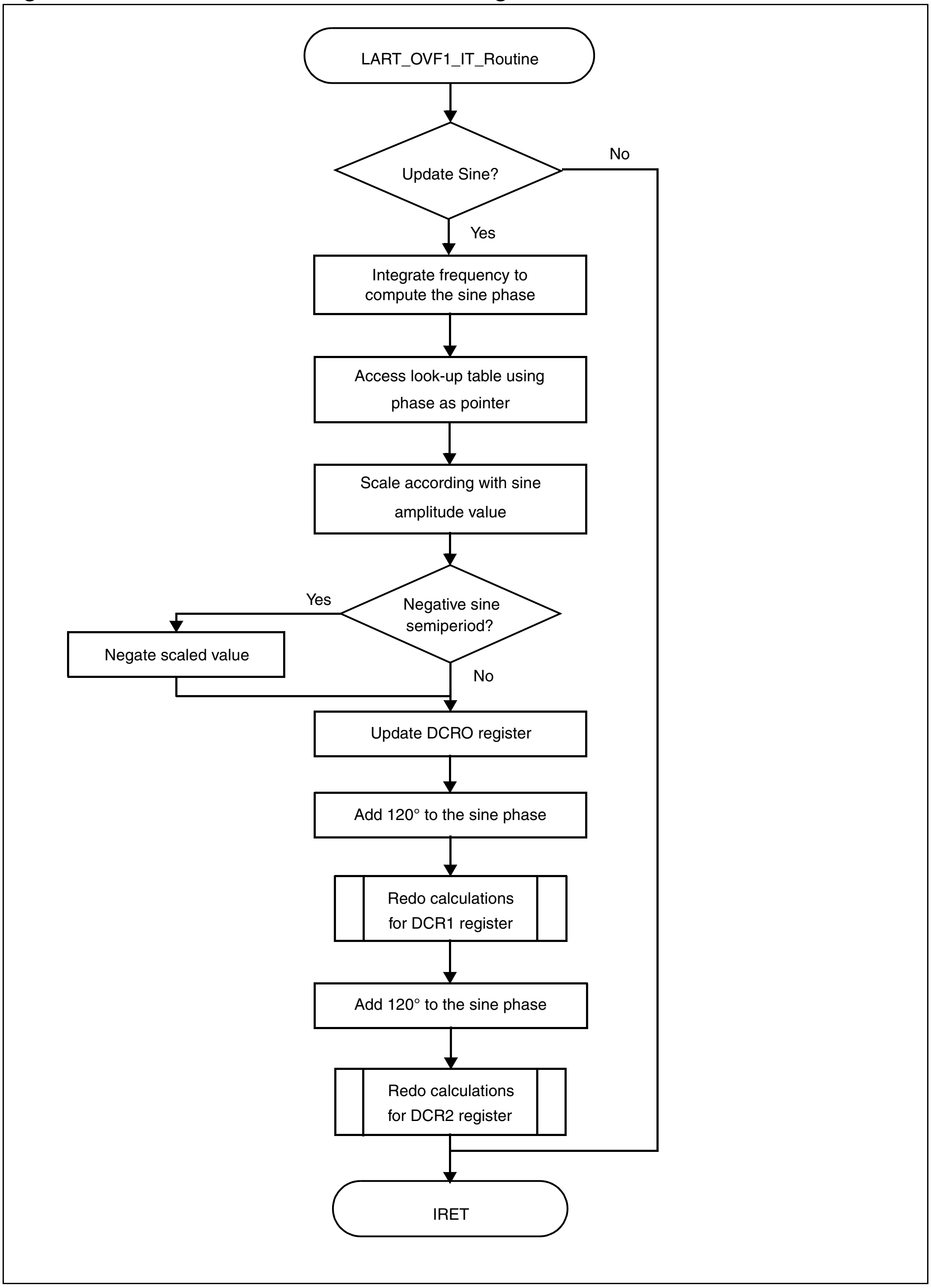
Sine waveform updating is performed in this routine once every two PWM periods. A look-up table with 256 8-bit entries for storing sine values has been used. *Figure 23* shows the flowchart of this interrupt service routine.

Input: None

Returns: None

Duration: The average duration is 15.75 µsec.

Figure 23. LART_OVF1_IT_Routine block diagram



8 Revision history

Table 2. Document revision history

Date	Revision	Changes
28-Mar-2006	1	Initial release.