AN2009
APPLICATION NOTE

PWM MANAGEMENT FOR 3-PHASE BLDC MOTOR DRIVES USING THE ST7MC

INTRODUCTION

The ST7MC microcontroller family is the second generation of the 8-bit microcontroller family dedicated to the driving of 3-phase brushless motors. Permanent Magnet Brushless DC motors are replacing DC brush motors more and more in many applications due to advantages such as higher efficiency, quieter operation and better reliability. These motors require the control of an inverter stage. In most cases the switching devices are MOSFET transistors or IGBTs and are organized in a three-phase bridge with free-wheeling diodes as shown in Figure 1. There are two methods of controlling the motor and reading information back from the rotor. These are called the sensor and the sensorless methods. The sensor method uses Hall sensors whereas the sensorless method reads the Back Electromotive Force (BEMF) signal back to determine the position of the rotor and so is less expensive.

The ST7MC microcontroller features a dedicated peripheral to drive this type of motor with the best efficiency in order to maintain the advantages of these types of motor. Besides the high flexibility of this dedicated peripheral, its high hardware integration allows cost savings for the application by reducing external components. It is suitable for both sensor and sensorless methods of PM BLDC motor control.

Although using the sensorless mode has big advantages in terms of cost and size, it makes the motor drive a little more complicated. The purpose of this application note is to explain in which cases the ST7MC motor control unit can directly read the BEMF voltage and how to quickly set up its control registers in order to use all the advanced features of this product. We will detail and explain the PWM management inside the ST7MC in order to help the developer use all the advantages of this flexibility to optimize the design and the efficiency of the application.

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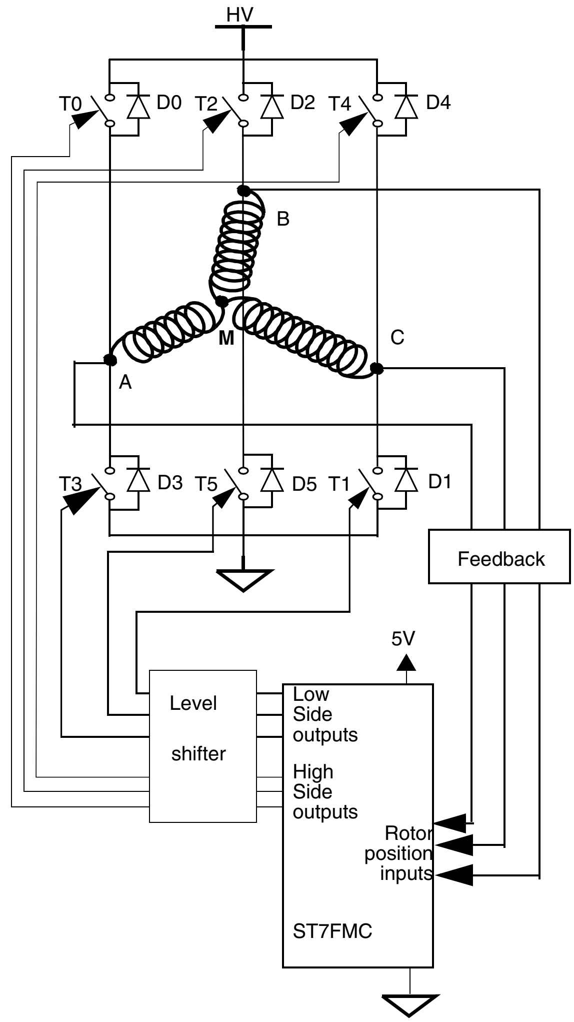
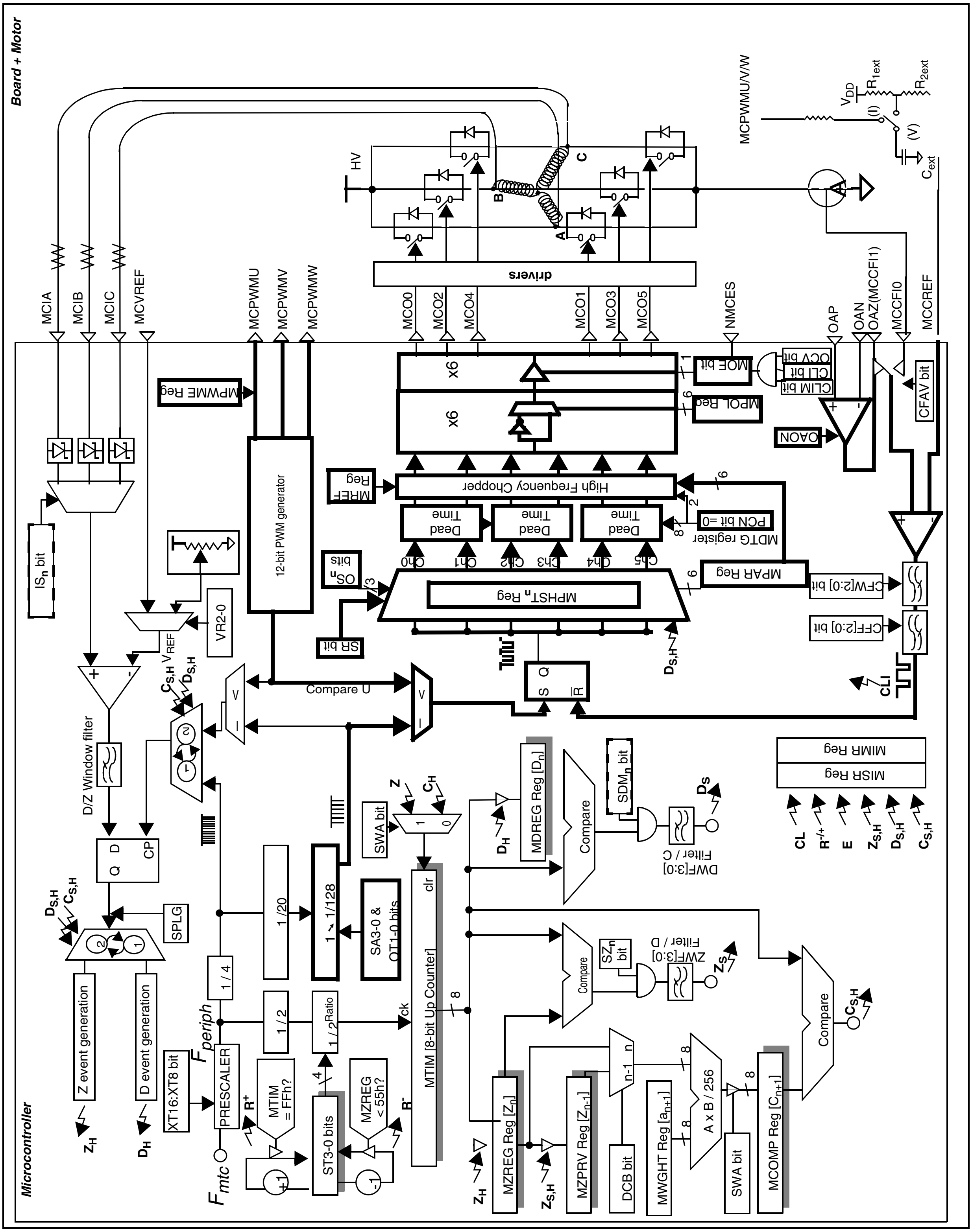
Figure 1. ST7FMC Microcontroller with a three-phase bridge



1 MOTOR CONTROL MACROCELL INTRODUCTION

Figure 2 below gives a detailed view of the motor control macrocell included in the ST7MC microcontroller. In bold are the parts of the macrocell that are going to be described in this application note and that have a role in the PWM management. The purpose of this document is to ease the understanding of the PWM management with the ST7MC to control a brushless 3-phase DC motor and to make this explanation easier, the schematic on the figure below can be taken as a reference of a global view of the mechanism. Besides the drawings of the functionalities, the names of the registers involved and often even the bits are written in this schematic. Anyhow, each time a register is discussed in this document, either a reference or an exact description will be made for that register.

Figure 2. **Detailed view of the MTC for PM BLDC motor control**



2 SIX-STEP, 120° DRIVE AND PWM POWER CONTROL

To control a BLDC motor with the best efficiency, we have to know the rotor position at all times. To achieve this there are two modes. One is called the sensor mode, where the information read back from the motor is the one coming from Hall Effect sensors (1 per phase). The other one is the sensorless mode, where the Back Electromotive Force (BEMF) signal information is the one read back from the motor. The strength of the ST7FMC is that it is compatible with all the modes to control a BLDC motor, whether it is sensorless or not and it is even suitable with different variations within the sensorless or sensor modes which will be detailed later on in this application note.

In sensorless mode, in order to be able to read the BEMF information, the phase switching has to include a dead time during which no current flows in one of the motor windings.

As shown in Figure 4, in six-step, 120° drive, power is removed from each winding every three steps. During this dead-time phase, it is possible to detect the BEMF zero-crossing event on this non powered winding (see Figure 3 for an example).

In order to control the speed, the torque or the power applied to the motor, a PWM signal is usually logically ANDed with the switch control signals. This control is implemented by modifying the duty cycle of this logically ANDed PWM signal.

With this method, the BEMF voltage is referred to point M of the motor and not to ground. Because this point is at high voltage, the microcontroller cannot read its value directly.

Note: In sensor mode the six-step drive or the sinusoidal drive can be implemented as the feedback signal comes independently from the Hall Effect sensor in the dedicated input of the microcontroller. However, in six-step drive, the method will be exactly the same as the one detailed for the sensorless mode. For the sensor sinusoidal mode, the PWM management is the same as for the AC induction motor drive.

Figure 3. Reading the BEMF (Step Σ_4)

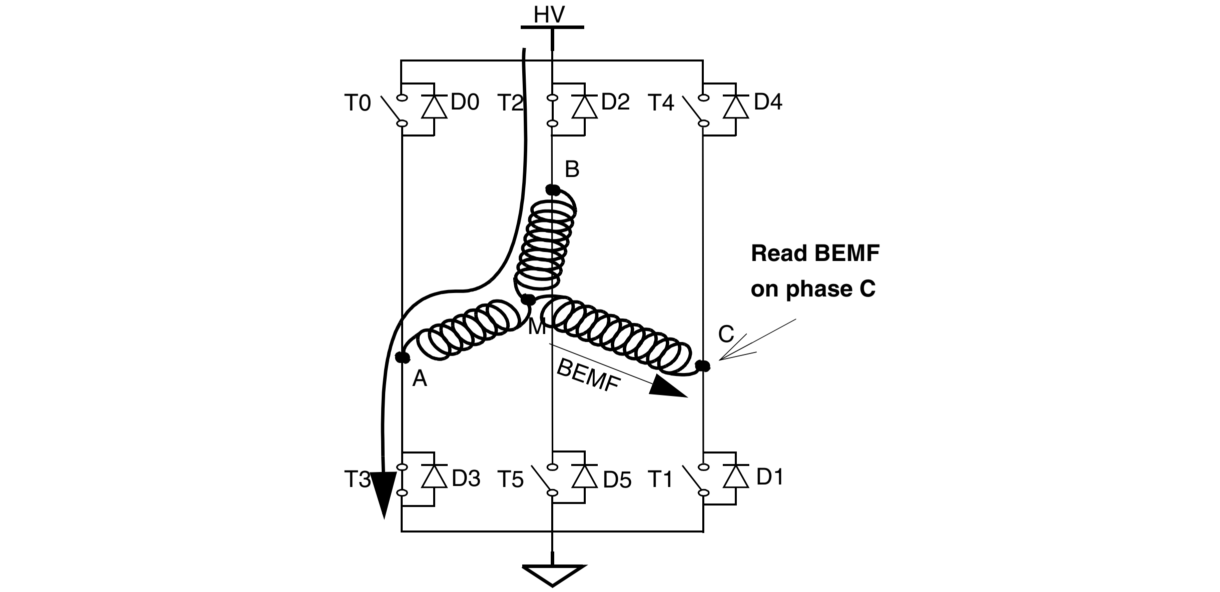
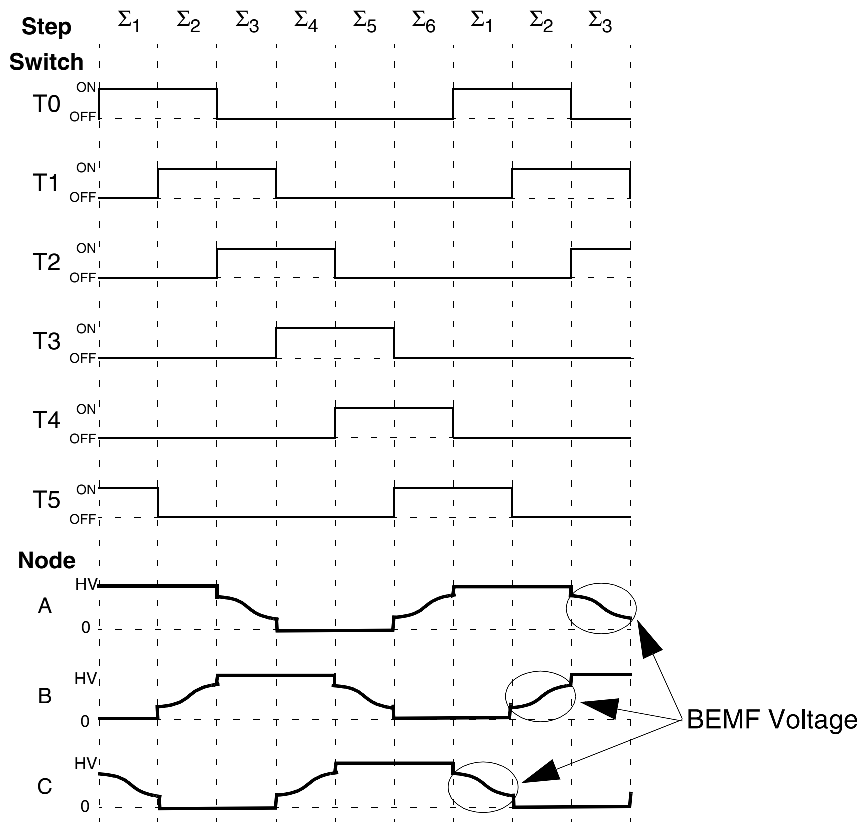


Figure 4. Six-step, 120° drive: control signal on the transistor gate



Note: voltages are represented without any PWM or demagnetization effect.

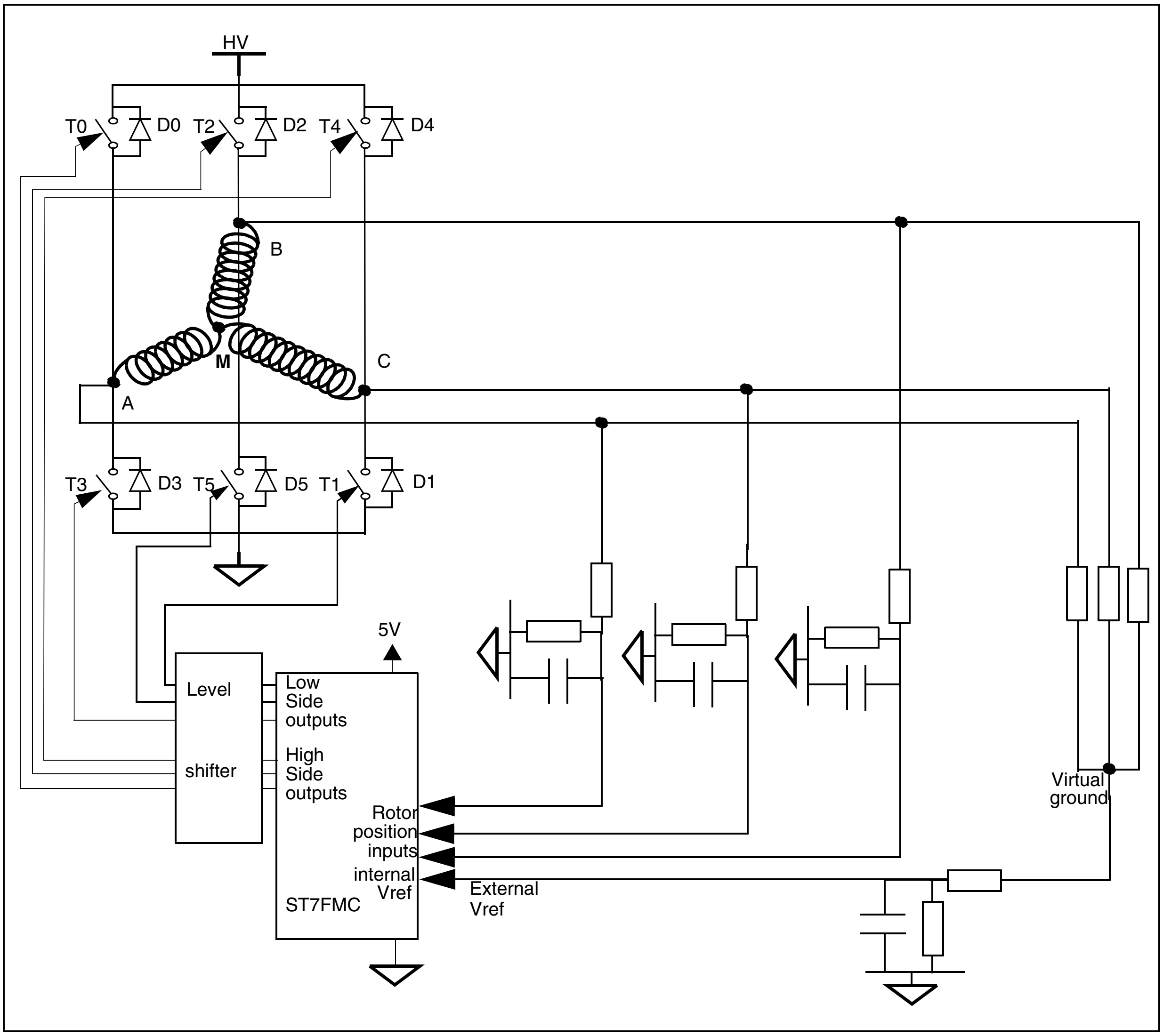
3 SENSORLESS CONTROL METHODS

In order to make the BEMF signal readable by the microcontroller and to detect the zero-crossing voltage of this signal, there are two main methods which we will call the *classic method* for the first one and the *ST method* for the second. The ST7FMC microcontroller is suitable for both methods. Each method is declinable in sub-method and the ST7MC allows complete flexibility on which sub-method to use. Please refer to the Application Note AN1946 for a complete view and details on all the methods as this document briefly covers only the 2 main methods.

3.1 CLASSIC METHOD

The classic method involves dividing and filtering the signal coming from the non-powered phase to make it readable by the 5V microcontroller as shown in Figure 5. A virtual ground is built and is used as the voltage reference to detect the zero-crossing event of the BEMF signal. With this method, the PWM signal which is logically ANDed with the switch control signal can be applied either on the high or on the low side switches as explained in the next section. The ST7MC is able to detect the BEMF zero-crossing signal during either the PWM signal ON time or OFF time.

Figure 5. Classic sensorless control method

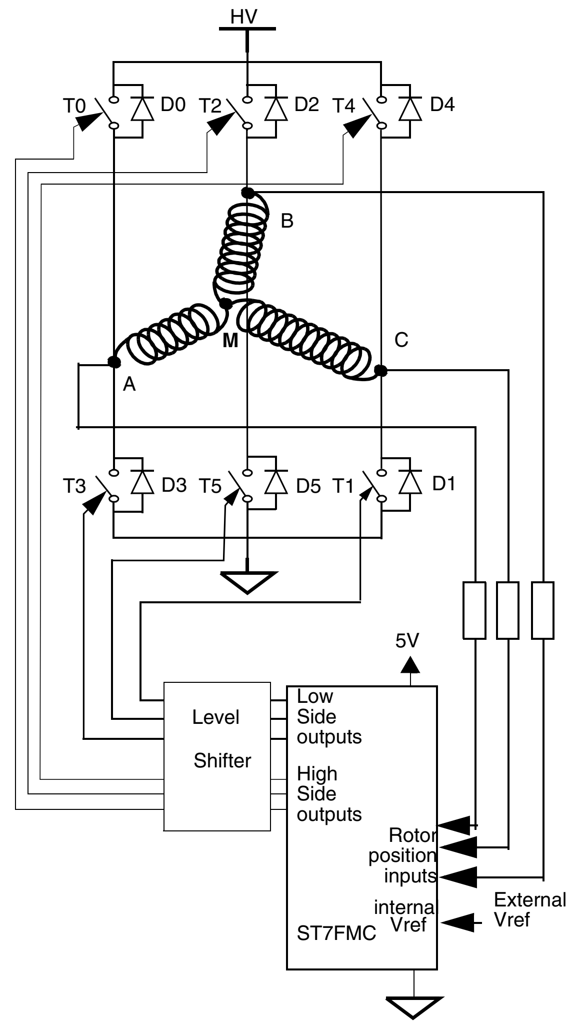


Note: The digital filter of ST7MC allows use of the classical method wiring without an analog filter. In that case we can remove the virtual neutral network and replace this by just a voltage divider on the High VOLTAGE BUS. In this situation, sampling at PWM "OFF" is possible only for PWM applied on the high side switch. Please refer to Application Note AN1946 for more details on this method.

3.2 ST METHOD

With the ST Method, by using the free-wheeling diodes during the OFF time of the PWM signal, the M potential is put to ground and the ST7MC microcontroller samples the BEMF signal voltage during the OFF time of the PWM signal. This involves the fact that the PWM has to be applied on the high side and that an OFF time is needed as explained in the next section of this application note. However, fewer external components are required as it is no longer necessary to divide and filter the signal coming from the non-powered winding. As shown in Figure 6, only 3 external resistors are needed to limit the current input in the microcontroller pins.

Figure 6. ST sensorless control Method



4 PWM MANAGER IN VOLTAGE MODE AND CURRENT MODE

The PWM signal logically ANDed with the switch control signal is used to control the power applied to the motor. It can either control the voltage on the motor with a fixed PWM duty cycle or the current by means of an integrated current control circuitry.

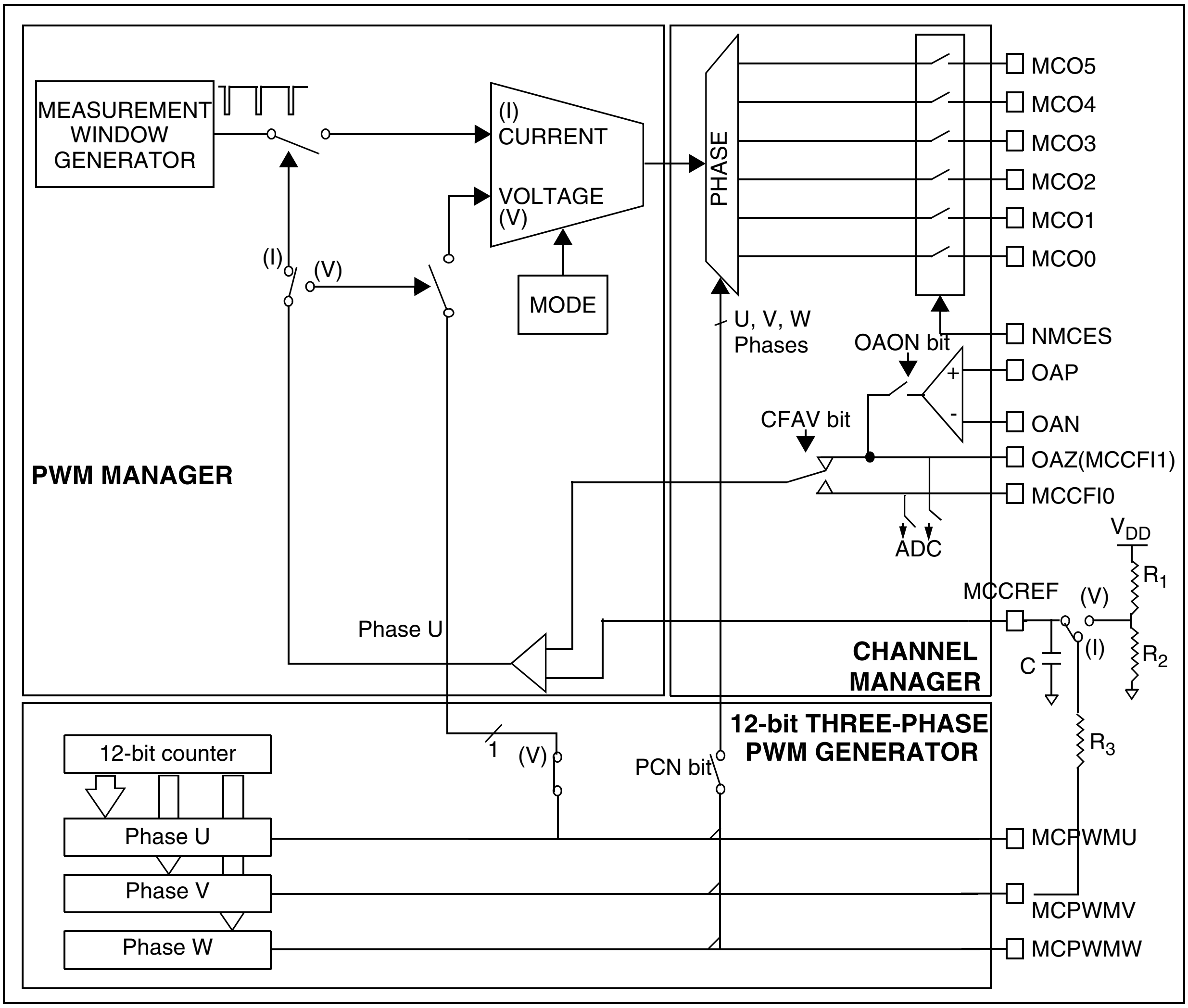
When the PWM signal controls the voltage, the motor is driven in voltage mode. When it is controlling the current, the motor is driven in current mode.

Voltage mode allows you to control the speed easily by changing the motor reference voltage. It does not give you fine control of the current but you can limit the current and consequently the torque to a maximum value. The voltage control is done by the PWM duty cycle.

Current mode allows you to permanently control the torque by changing the motor reference current, because torque is proportional to current. The current in the windings is regulated in real time and there is a true DC current flowing through the DC Bus. Current mode also allows the current for each of the 6 steps to be finely controlled as the current control is done during the PWM cycle.

Depending on whether the motor is driven in current or voltage mode, the PWM signal does not have the same origin as shown in Figure 7.

Figure 7. The PWM manager



The PWM manager manages two different integral parts of the way the ST7MC drives the motor:

– Current regulation or limitation

– Generation of the PWM signal applied on the switches

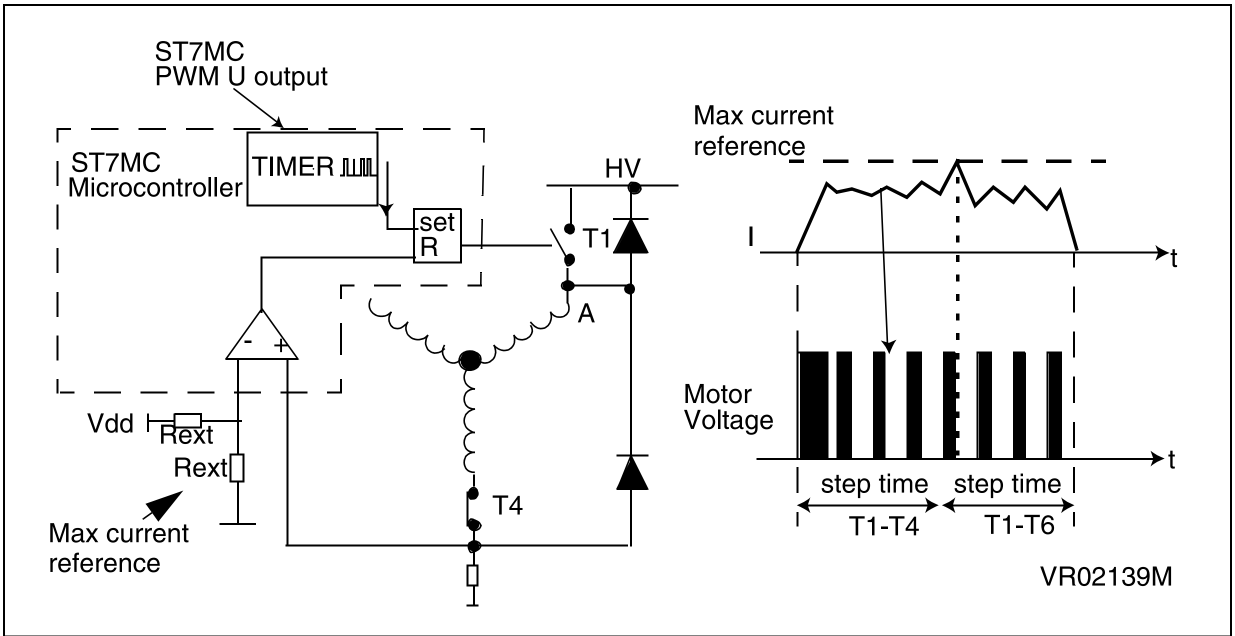
The PWM manager has two distinct motor driving modes: voltage mode and current mode. In both cases, the motor control 12-bit timer peripheral has an essential role.

In Figure 7, the PWM manager uses the paths indicated by the (I) symbol for current mode and by the (V) symbol for voltage mode.

4.1 PWM MANAGER IN VOLTAGE MODE

4.1.1 Description

Figure 8. Current limitation in voltage mode control



In voltage mode, the PWM of the 12-bit timer (through the compare U register) gives the voltage which is supplied to the motor, it is the voltage control of the motor. This PWM signal is the one logically ANDed with the control switches signal in order to be able to detect the zero-crossing and demagnetization events.

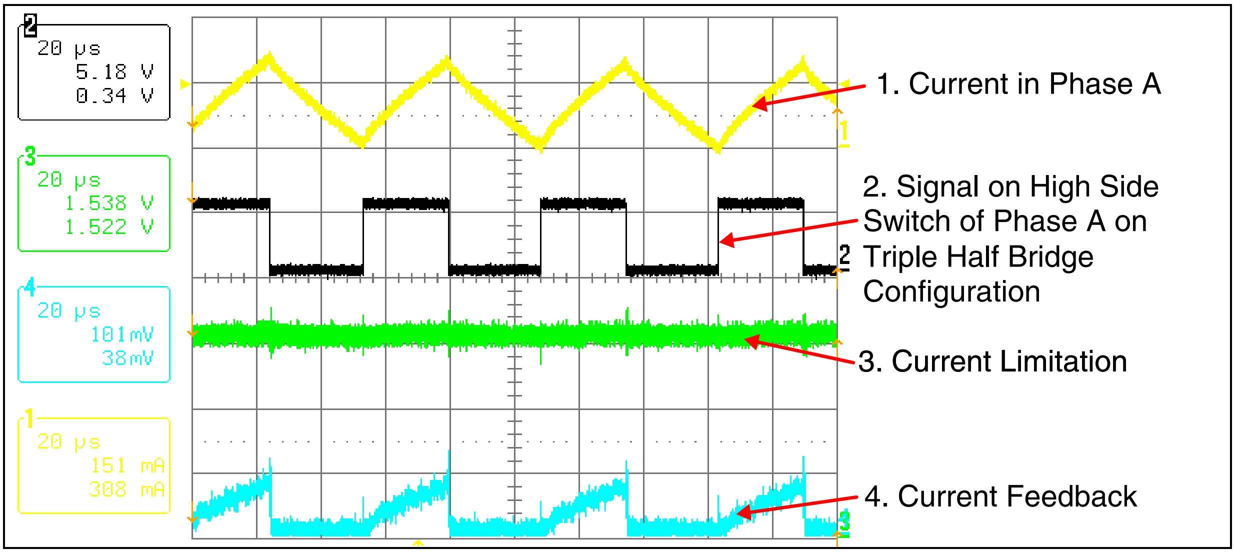
In voltage control mode, we can set a limitation to the current. The current limitation can be set by the user with an external resistor divider as shown in Figure 7 (R1 and R2) and Figure 8 (Rext). Usually this current limitation is the one given by the motor manufacturer. When the current feedback reaches the maximum reference current at the comparator input, the transistor to which the PWM is applied is put in off state until the current feedback becomes less than the maximum current limit. So, one of the inputs of the internal comparator is the maximum current limitation, the other input is the current feedback from the motor (MCCFI0 pin or the output of the internal operational amplifier if used as shown in Figure 7).

This current limitation is for protection and should normally never be reached when running the motor correctly.

Figure 9 is a capture made with an oscilloscope of the different signals in Voltage mode:

We can see that the current feedback from the motor never reaches the current limitation and the increase and decrease of the current in the motor corresponds to the PWM signal on the waveform 2.

Figure 9. Oscilloscope waveforms: Voltage Mode



Note: In speed regulation, the PWM duty cycle value only needs to be correct when starting the motor. Once the target speed is reached, the PWM duty cycle will be adjusted automatically by the ST7MC.

4.1.2 PWM signal register setting in Voltage mode

In voltage mode, the 12-bit timer is used to set the PWM signal.

Compare 0 registers:

The compare 0 high and low registers are for setting the frequency of the PWM.

COMPARE 0 PRELOAD REGISTER HIGH (MCP0H)

Read/Write (except bits 7:4)

Reset Value: 0000 1111 (0Fh)

7							0
-	-	-	-	CP0H3	CP0H2	CP0H1	CP0H0

Bits 7:4 = Reserved.

Bits 3:0 = **CP0H[3:0]** *Most Significant Bits of Compare 0 preload value.*

COMPARE 0 PRELOAD REGISTER LOW (MCP0L)

Read/Write

Reset Value: 1111 1111 (FFh)

7							0
CP0L7	CP0L6	CP0L5	CP0L4	CP0L3	CP0L2	CP0L1	CP0L0

Bits 7:0 = **CP0L[7:0]** *Low byte of Compare 0 preload value.*

Compare U registers:

The compare U high and low registers are for setting the duty cycle of the PWM signal in voltage mode.

COMPARE PHASE U PRELOAD REGISTER HIGH (MCPUH)

Read/Write

Reset Value: 0000 0000 (00h)

7							0
CPUH7	CPUH6	CPUH5	CPUH4	CPUH3	CPUH2	CPUH1	CPUH0

Bits 7:0 = **CPUH[7:0]** *Most Significant Byte of phase U preload value*

COMPARE PHASE U PRELOAD REGISTER LOW (MCPUL)

Read/Write Read/Write (except bits 2:0)

Reset Value: 0000 0000 (00h)

7							0
CPUL7	CPUL6	CPUL5	CPUL4	CPUL3	-	-	-

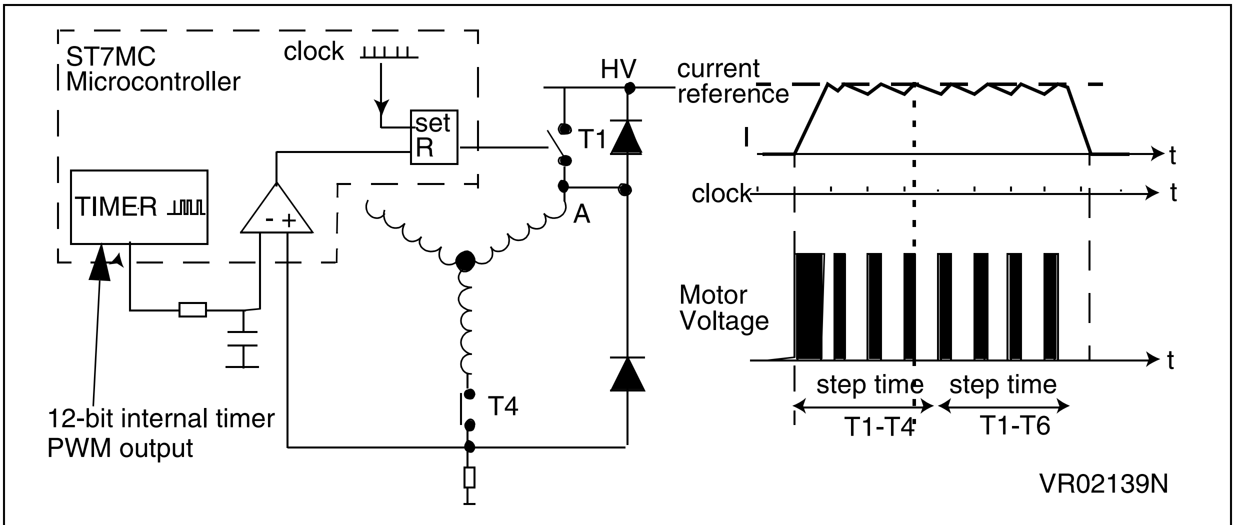
Bits 7:5 = **CPUL[7:3]** *Low bits of phase U preload value*.

Bits 2:0 = Reserved.

4.2 PWM MANAGER IN CURRENT MODE CONTROL

4.2.1 Description

Figure 10. Current regulation in current mode control



In current mode, the PWM output by the 12-bit timer (either MCPWMU, V or W) represents the reference current to be applied to the motor. The PWM duty cycle is the current level at which we want to polarise the motor. At 100% duty cycle, the signal output is at 5V, this corresponds to the maximum current to be applied to the motor for maximum torque. The PWM duty cycle is obtained by dividing the reference current we want in the motor (depending on the torque needed) by the maximum current. For example, if the maximum current is 1A and if the reference current has to be 0.2A, the PWM duty cycle will be 20%.

An external resistor and capacitor are added as shown in Figure 7 (R3) and Figure 10 in order to generate the reference current based on a digital to analog converter (DAC) of the PWM signal.

So, for the internal comparator, one of the inputs is the current feedback of the motor (MCCFI0 pin or the output of the internal operational amplifier if used), the other input is the reference current given by the filtered PWM signal from the 12-bit timer.

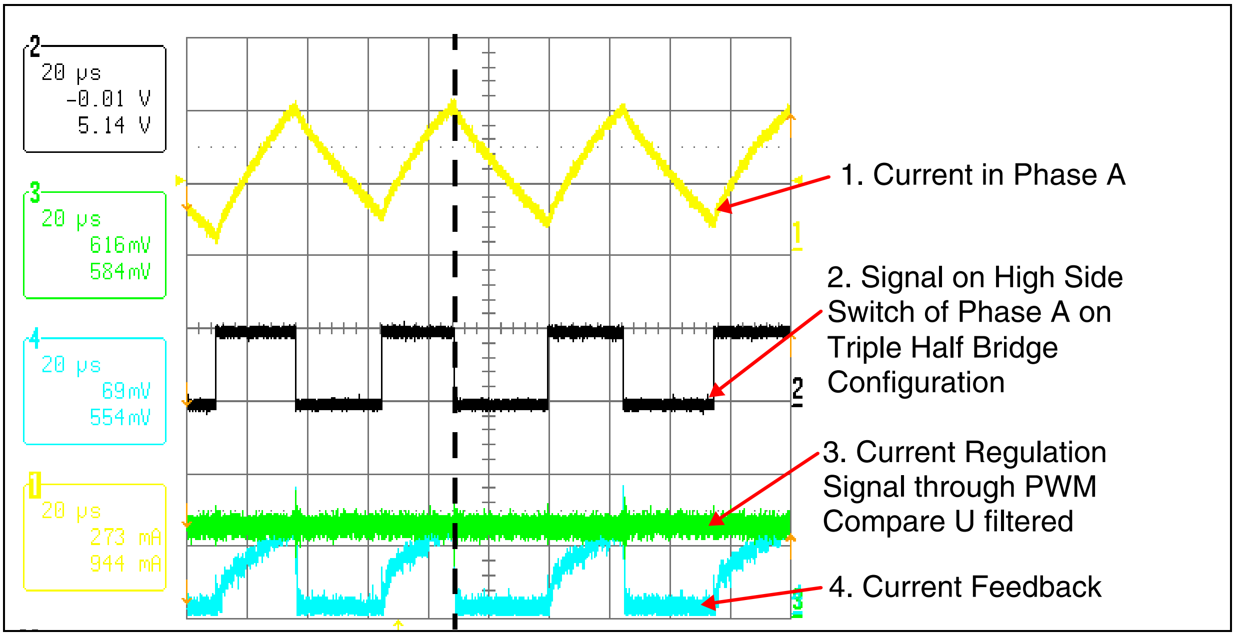
We see in Figure 7 and Figure 10 that the internal clock is used in current mode control. The internal clock outputs a PWM signal as well. The frequency of this signal is user-selectable from several values from 390Hz to 50KHz through 4 bits and the off-time of this signal is also user-selectable (from 2.5µs to 40µs) with a minimum value of 2.5µs needed to allow the stabilization of the system if the ST method is used to allow the sampling of the back-EMF signal during off-time. The PWM signal frequency output by the clock represents the current frequency used to supply the motor. The off-time of this PWM signal is variable, with a lower limit of 2.5µs in the sensorless mode ST method. The PWM signal output by the internal clock is applied to the designated switch. This mechanism has the following procedure as shown in Figure 10:

When the current feedback from the motor reaches the reference current given by the 12-bit timer PWM signal at the comparator input, the internal clock signal is reset. The switch where the PWM is applied is put in an OFF state until the current feedback is lower than the reference current as shown in Figure 10. That’s why the duty cycle of the internal clock is variable. A minimum off-time has to be defined by the software programmer in sensorless ST method but the duty cycle is modified depending on the motor behaviour.

Figure 11 is a capture done with an oscilloscope of the different signals in Current mode.

We can see that as soon as the current back from the motor reaches the level of the current limitation, the PWM signal on waveform 2, meaning the PWM signal on the high side switch of the corresponding phase is put off.

Figure 11. Oscilloscope waveforms: Current Mode



Note: In speed regulation, the 12-bit timer PWM duty cycle only has to have the right value to start the motor. Once the target speed is reached, the PWM duty cycle will be adjusted automatically by the ST7MC.

4.2.2 PWM signal register setting in Current mode

In current mode, a combination of an internal clock and the output of the current comparator is used to set the PWM signal, the registers described below are the ones used to set the frequency and the minimum OFF time if needed from the PWM signal for the internal clock.

PRESCALER & SAMPLING REGISTER (MPRSR)

Read/Write

Reset Value: 0000 0000 (00h)

7	6	5	4	3	2	1	0
SA3	SA2	SA1	SA0	X	X	X	X

Bits 7:4 = **SA[3:0]**: *Sampling Ratio.*

These bits contain the sampling ratio value for current mode. This sets the frequency of the PWM according to the following table

Table 1. Frequency selection

SA3	SA2	SA1	SA0	Sampling Frequency
0	0	0	0	50.0 KHz
0	0	0	1	40.0 KHz
0	0	1	0	33.33 KHz
0	0	1	1	25.0 KHz
0	1	0	0	20.0 KHz
0	1	0	1	18.1 KHz
0	1	1	0	15.4 KHz
0	1	1	1	12.5 KHz
1	0	0	0	10 KHz
1	0	0	1	6.25 KHz
1	0	1	0	3.13 KHz
1	0	1	1	1.56 KHz
1	1	0	0	1.25 KHz
1	1	0	1	961 Hz
1	1	1	0	625 Hz
1	1	1	1	390 Hz

PWM REGISTER (MPWME)

Read/Write

Reset Value: 0000 0000 (00h)

7	6	5	4	3	2	1	0
X	PWMW	PWMV	PWMU	OT3	OT2	OT1	OT0

The current reference is provided to the comparator by Phase U, V or W of the PWM Generator (up to 12-bit accuracy) and the signal from the three compare registers U, V or W can be output by setting the PWMU, PWMV or PWMW bits.

Bits 3:0 = **OT[3:0]**: *Off Time selection*

These bits are used to select the OFF time in sensorless current mode as shown in the following table

Table 2. off time table

OT3	OT2	OT1	OT0	Off Time sensorless mode (SR=0) (DS[3:0]=0)	Sensor Mode (SR=1) or sampling during ON time in sensorless (SPLG =1 and/or DS[3:0] bits)
0	0	0	0	2.5 µs	No minimum off time
0	0	0	1	5 µs	
0	0	1	0	7.5 µs	
0	0	1	1	10 µs	
0	1	0	0	12.5 µs	
0	1	0	1	15 µs	
0	1	1	0	17.5 µs	
0	1	1	1	20 µs	
1	0	0	0	22.5 µs	
1	0	0	1	25 µs	
1	0	1	0	27.5 µs	
1	0	1	1	30 µs	
1	1	0	0	32.5 µs	
1	1	0	1	35 µs	
1	1	1	0	37.5 µs	
1	1	1	1	40 µs	

4.3 SUMMARY VOLTAGE/CURRENT MODE

In voltage mode, the 12-bit timer PWM signal (compare U register) gives the voltage to be applied to the motor. This PWM signal is applied to the switches. The internal clock is not used in this mode.

A current limitation is implemented in voltage mode. The current limitation can be set by an external divider resistor or by an other PWM signal filtered.

In current mode, the 12-bit timer PWM signal gives the reference current to be applied to the motor. This signal has to be filtered by an external RC. The internal clock is used and the PWM signal from the internal clock is applied to the switches.

In current mode, the current is regulated by comparing the reference current and the feedback current from the motor.

5 MANAGEMENT OF PWM AND READING OF BEMF

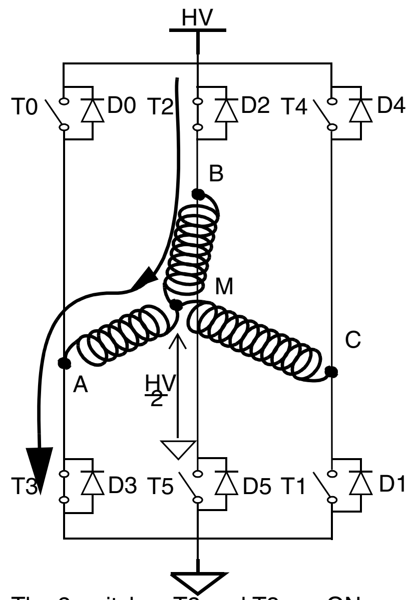
Depending on the control method used to drive the motor, the PWM signal to detect the BEMF zero voltage crossing signal can be applied in 2 ways:

– On the high side: During the step, the PWM is applied only on the high side switch, the low side is ON during the complete step.

– On the low side: During the step, the PWM is applied only on the low side switch, the high side is ON during the complete step.

In the ST7MC device, OE [5:0] bits in the MPAR register are used to define whether the corresponding outputs are in high or low side switch position. Then OO [5:0] bits in MPHST register define if the channel is active or not and finally OS [2:0] bits in MCRB register distribute the PWM on the active channels high or low side. Please refer to the product datasheet for the motor control device in the channel manager section for more details or to Section 6 to see a complete configuration.

Figure 12. Current during PWM ON time



5.1 PWM ON THE HIGH SIDE

When the related switches are ON, the current passes through the two switches and two motor windings (these are switches T2 and T3 in the example in Figure 12).

The potential at point M is HV/2. If nothing is done, the BEMF can not be read by the ST7MC because the voltage is too high to be read by the microcontroller.

Using the classic method, the BEMF is divided and filtered as is the rebuilt virtual ground and so the BEMF zero-crossing event can be read when the PWM is ON on the high side switch.

When the PWM signal is ON when using the Classic method, the voltage at the virtual ground will be HV/2 divided and filtered and the voltage at point C will be (HV/2 + BEMF) divided and filtered so the comparison can be done by the comparator in the microcontroller as it will stay within the microcontroller supply voltage range (0 - Vdd) after division and filtering.

When the high side switch PWM is OFF, the current inside the motor continues to flow in the same direction (Figure 13). While the switch is off, the current can only use the diode (D5 in our example).

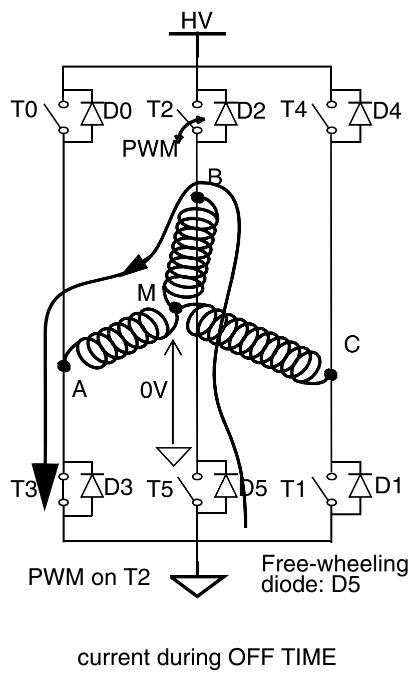
In this case the potential in A is the Von of the T3 switch, the potential in B is -Vf of D5 and the potential at M is (Von-Vf)/2. It is close to zero because in most cases Von = Vf.

In this case the microcontroller can read the complete BEMF voltage referred to the ground terminal on the phase C.

This is the configuration used for the ST method where the sampling of the BEMF signal is only done during the Off time of the PWM signal. No dividers nor filters are needed externally as we are looking at a signal that is close to the MCU ground level.

Note: This sampling method of the BEMF signal is also appropriate for the classic method. In fact the sampling of the BEMF can be done either during ON or OFF time of the PWM for the classic method.

Figure 13. PWM on high side: Current during OFF time



5.2 PWM ON THE LOW SIDE

When the related switches are ON (example of Figure 12) the current passes through the two switches and two motor windings.

When the low side is switched OFF, the current inside the motor continues to flow in the same direction (Figure 14). While the switch is OFF, the current can only use the diode (D0 in our example).

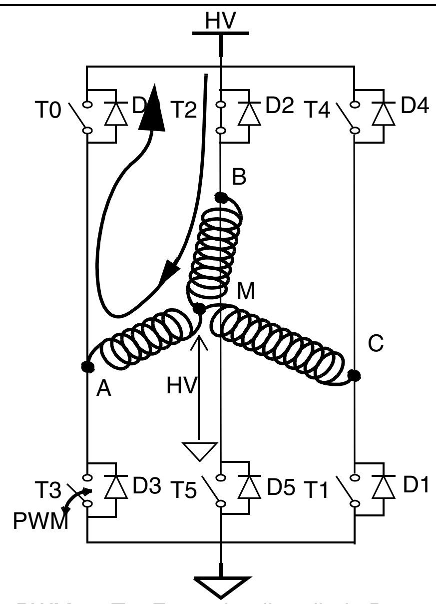
In this case the potential at A is (HV+Vf), the potential at B is (HV-Von) and the potential at M is (2xHV+Von-Vf)/2. We can consider it to be HV (because in most cases Von = Vf).

In this case the microcontroller can read the BEMF voltage only if the Classic method is used during ON time of the PWM signal because the signal in C is divided and filtered before the microcontroller input pin. Considering the ST method, the sampling of the BEMF is done only during the OFF time of the PWM and as with the ST method, the signal is not divided and filtered in C before the microcontroller pin, this method can not be used as the voltage in C is close to HV during the PWM off time.

– Von is the voltage of the switch when it is turned ON

– Vf is the forward voltage of a diode

Figure 14. PWM on low side: Current during OFF time



PWM on T3; Free-wheeling diode D0

5.3 EXAMPLE OF CONFIGURATION OF THE ST7MC REGISTERS

As explained in section 2 “Sensorless control methods”, we have described 2 main sensorless control methods which the ST7MC is compatible with. Please refer to AN1946 for more details. The steps to correctly configure the ST7MC registers depending on the sensorless control method used are as follows:

– Generate a Pulse Width Modulation signal. If the ST sensorless control method is used, then a 2.5µs minimum off time is needed to read the BEMF voltage during the off time (useless in Classic method detection).

In Voltage mode (the VOC1 bit is reset in the MCRA register), when driving a PM BLDC motor (the PCN bit is reset in the MDTG register) in six-step drive, a single PWM signal is used to supply the input stage. This PWM signal which is applied to the switches is generated using the 12-bit PWM counter for frequency and the 13 bit compare U register for duty cycle (MCPUL:MCPUH registers).

In Current mode (VOC1 bit is set in the MCRA register), the PWM output signal is generated by a combination of the output of the measurement window generator and the output of the current comparator and is directed to the output channel manager as well. This can be done by setting the PWM frequency through SA[3:0] bits in the MPRSR register and the minimum off time using the OT[3:0] bits in the MPWME register. The off time is also dependent on the output of the current comparator as explained in Section 4 of this document.

– Apply this PWM on the high side or low side switches depending on the sensorless control method used. To do so, you have to configure the microcontroller with the right configuration. In order to configure correctly the registers, this sequence has to be followed.

– Split the switches in two parts by means of the high side/low side configuration. This is done using the OE [5:0] bits in the MPAR register.

PARITY REGISTER (MPAR)

Read/Write

Reset Value: 0000 0000 (00h)

7	6	5	4	3	2	1	0
X	X	OE5	OE4	OE3	OE2	OE1	OE0

Bits 5:0 = **OE[5:0]**: *Output Parity Mode.*

0: Output channel is High

1: Output channel Low

For example: T1, T3, T5 low side and T0, T2, T4 high side.

– Select the group you want to read the BEMF from by programming the REO bit in the MPOL register. The group the BEMF is read from depends on the sensorless control method used. If the ST method is used, the high side group has to be selected because the PWM has to be applied on the high side as seen in the previous chapter, therefore, the BEMF can be read only from the high side group, REO bit is reset. If the classic method is used, the BEMF can be read either from the high side group or from the low side group, it depends on where the PWM signal will be applied as described below. So in this configuration, the REO bit can be set or reset. Select also the polarity of the output channel through the MPOL register.

POLARITY REGISTER (MPOL)
Read/Write (some bits write-once)
Reset Value: 0011 1111 (3Fh)

7	6	5	4	3	2	1	0
ZVD	REO	OP5	OP4	OP3	OP2	OP1	OP0

Bit 7 = **ZVD**: *Z vs D edge polarity.*

0: Zero-crossing and End of Demagnetization have opposite edges

1: Zero-crossing and End of Demagnetization have same edge

Bit 6 = **REO**: *Read on High or Low channel bit*

0: Read the BEMF signal on High channels

1: Read on Low channels

Note: This bit always has to be configured whatever the sampling method.

Bits 5:0 = **OP[5:0]**: *Output channel polarity.*
These bits are used together with the OO[5:0] bits in the MPHST register to control the output channels.

0: Output channel is Active Low

1: Output channel is Active High.

– Select the PWM direction after Demagnetization (D) event just before the Zero-crossing (Z) event. The demagnetization event and the corresponding PWM configuration will be explained in Section 5. So the PWM direction can be selected using the OS1 bit in MCRB register. The same is true for the group to read the BEMF from, the PWM can be applied differently depending on the sensorless control method used. If the ST method is used, then the PWM signal has to be applied on the high side, which means that the OS1 bit is reset in MCRB register. If the classic sensorless control method is used, then the PWM signal can be applied either on the high side or on the low side. In both cases, the microcontroller is able to detect the BEMF. So, in that case OS1 bit can be set or reset. It depends mainly on the application and on the user.

MPHST register bits OO[5:0] are used to put the corresponding output channel active or not. This has to be configured each step over the repetition of the six steps.

PHASE STATE REGISTER (MPHST)

Read/Write

Reset Value: 0000 0000 (00h)

7	6	5	4	3	2	1	0
X	X	OO5*	OO4*	OO3*	OO2*	OO1*	OO0*

Bits 5:0 =**OO[5:0]***: *Channel On/Off bits*

These bits are used to switch channels on/off at the next commutation

0: Channel Off, the relevant switch is OFF, no PWM possible

1: Channel On the relevant switch is ON, PWM is possible

OO[5:0] Bit Meaning

OO[5:0]	Output Channel State
0	Inactive
1	Active

***** = Preload bits, new value taken into account at next C event

In addition to the PWM configuration flexibility, the ST7MC microcontroller features a dead time generator embedded in the motor control peripheral. This is used mainly for the generation of the 3 sinewave 120° shifts for the drive of an AC induction 3-phase motor but it can be used to perform “synchronous rectification” as explained in the next chapter when driving a PM BLDC motor.

6 SYNCHRONOUS RECTIFICATION

6.1 SYNCHRONOUS RECTIFICATION PRINCIPLE

Whatever method is used, the classic method or the ST method, as soon as a PWM signal is logically ANDed with the switch control signal, the free wheeling diodes of the triple half bridge configuration are used during the off time off the PWM signal and the current continues to flow in the same direction in the motor. The ST7MC features a dead time generator that allows application of complementary PWM on the switch adjacent to the one where PWM is applied. With this feature, the conduction losses can be reduced. This is called the “synchronous rectification”.

Precautions must be taken to avoid short circuits in half bridges. This is ensured by driving high and low side switches with complementary signals and by managing the time between the switching-off and the switching-on instants of the adjacent switches. This time is the dead-time and has to be adjusted depending on the devices connected to the PWM outputs and their characteristics (intrinsic delays of level-shifters, delays due to power switches,...).

In the ST7MC, the dead time is set on six dedicated bits in a register allowing a range of dead times from 125ns to 16µs. When Fmtc is 16MHz. Dead time can be set with steps of 125, 250 or 500ns.

As an example on Figure 14, if the dead time generator is activated, then during the off time of the PWM on T3, T0 will be switched-on so the current will flow through the switch and not through the free-wheeling diode D0.

Figure 15 shows the relationship between the output signals of the deadtime register on the adjacent switches and its inputs.

Once activated, the dead time generator generates two output signals on the adjacent switches: A and B.

The A output signal is the same as the input phase signal except for the rising edge, which is delayed relative to the input signal rising edge.

The B output signal is the opposite of the input phase signal except the rising edge which is delayed relative to the input signal falling edge.

Figure 15. Dead times waveform

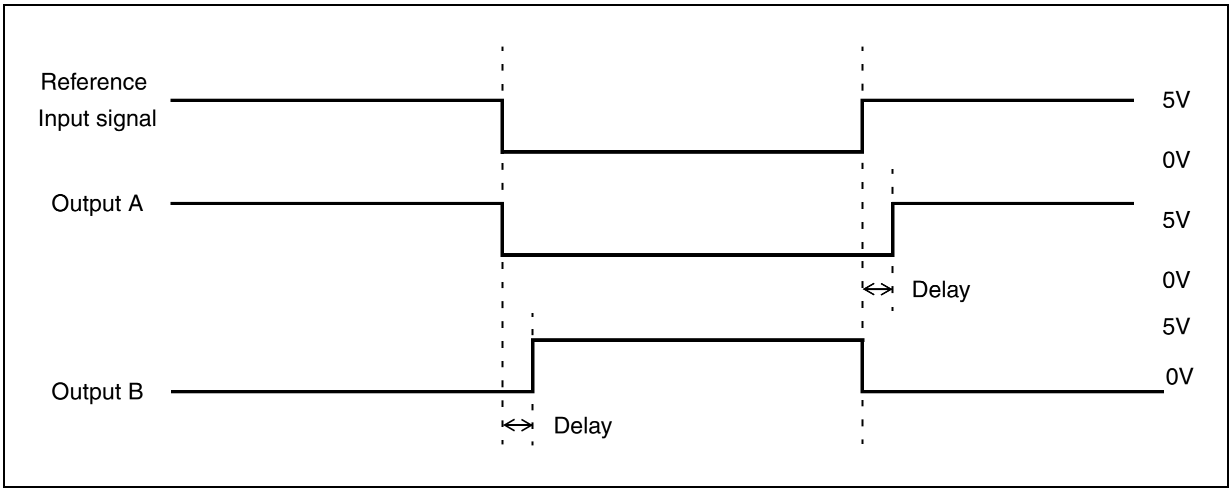


Figure 16 and Figure 17 show waveforms of the signal on 2 adjacent switches during synchronous rectification. Figure 17 is a zoom of Figure 16

The dead time has been set in this example to 0.75µs.

Figure 16. Oscilloscope waveform: synchronous rectification 1

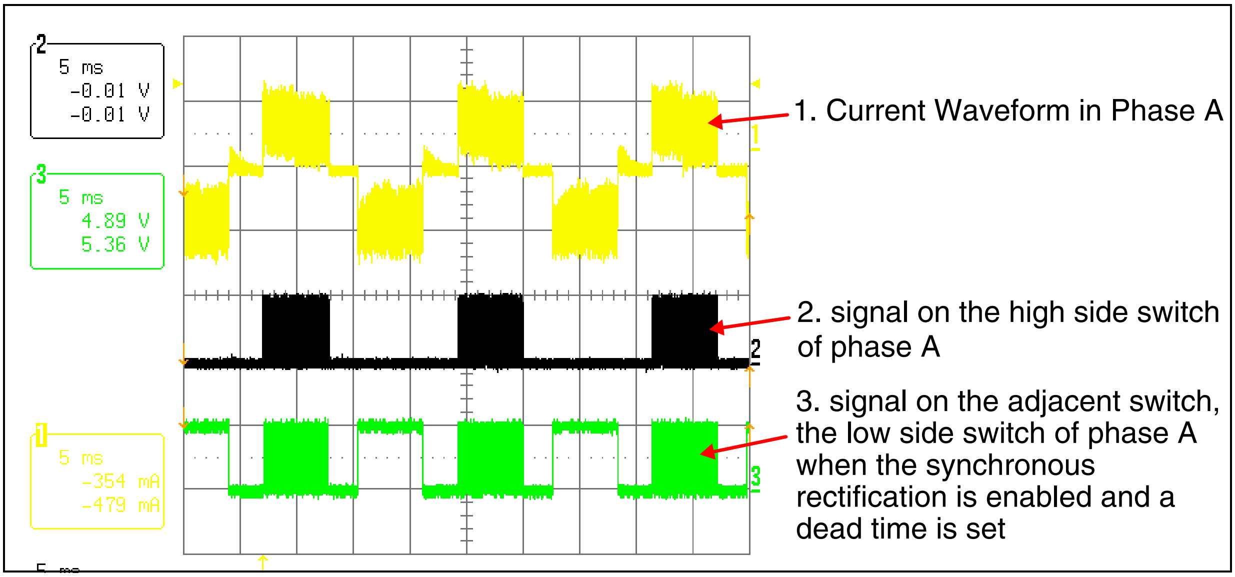
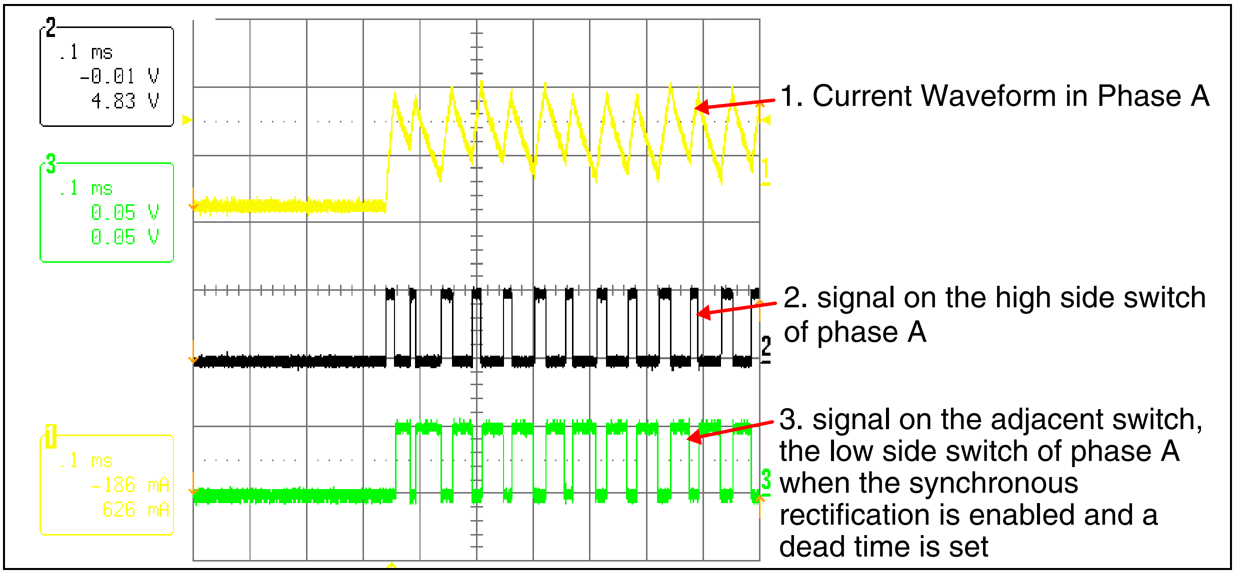


Figure 17. Oscilloscope waveform: synchronous rectification 2



6.2 SYNCHRONOUS RECTIFICATION CONFIGURATION

When driving a PM BLDC motor (PCN bit is reset in MDTG register), the PWM applied to the output channel depends if the motor is driven in voltage or current mode but the dead times are applied in the same way regardless of the source of the PWM signal.

As soon as the dead time generator is activated (DTE bit is set in MDTG register), a complementary PWM is applied to the adjacent switch. The dead time value is set-up through the bits DTG [5:0] in MDTG register. The range can go from 125ns to 16µs with steps of 125ns, 250ns and 500ns when Fmtc is 16MHz.

Note: It is also possible to add a chopper on the PWM signal output using bits HFE[1:0] and HFRQ[2:0] in the MREF register.

DEAD TIME GENERATOR REGISTER (MDTG)

Read/Write (except bits 5:0 write once-only)

Reset Value: 1111 1111 (FFh)

7							0
PCN	DTE	DTG5	DTG4	DTG3	DTG2	DTG1	DTG0

Bit 7 = **PCN:** *Number* of *PWM Channels*.

0: Only PWM U signal is output to the PWM manager for six-step mode motor control (e.g. PM BLDC motors)

1: The three PWM signals U, V and W are output to the channel manager (e.g. for three-phase sinewave generation)

Bit 6 = **DTE***: Dead Time Generator Enable

0: Disable the Dead Time generator

1: Enable the Dead Time generator and apply complementary PWM signal to the adjacent switch

Bits 5:0 = **DTG[5:0]*:** *Dead time generator set-up*.

These bits set-up the deadtime duration and resolution

***** = write once-only bit if PCN bit is set, read/write if PCN bit is reset. To clear the DTE bit if PCN=1, it is mandatory to clear the PCN bit first.

7 WINDING DEMAGNETIZATION

When the microcontroller switches from one step to the next, the non-powered winding needs a certain demagnetization time. During this time, the current in the winding continues in the same direction but decreases to zero. It is not possible to see the BEMF voltage as long as this current is still present, because during this time the voltage on the winding is tied to 0V or HV by the free-wheeling diode.

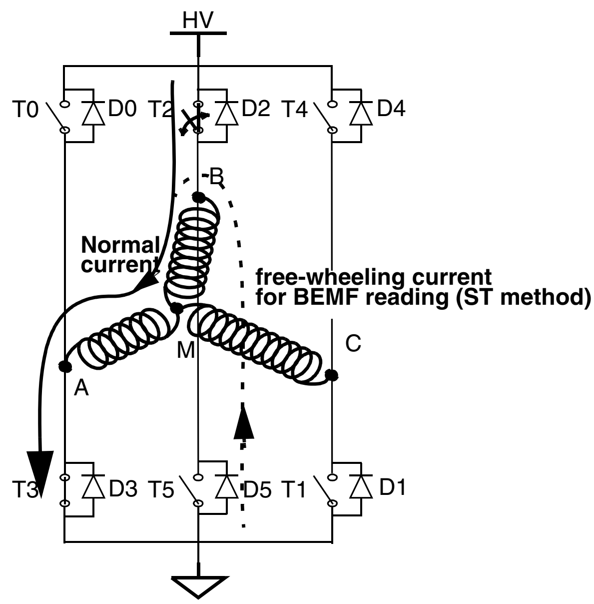
Due to the winding self-induction, the demagnetization time decreases if the reverse voltage on the winding increases. We want to decrease the demagnetization time of the winding so that the window to detect the BEMF zero voltage crossing event is wider. So the goal to decrease this time and to accelerate the end of demagnetization event is to apply the maximum reverse voltage on the winding that needs to be demagnetized. To do so, depending on the previous step configuration as we are going to describe in this section, we can apply either the PWM on the low side switch or on the high side switch to accelerate the demagnetization.

Let's look at two examples to illustrate the two possible cases:

7.1 ACCELERATION OF DEMAGNETIZATION WHEN PWM IS APPLIED ON THE LOW SIDE SWITCH

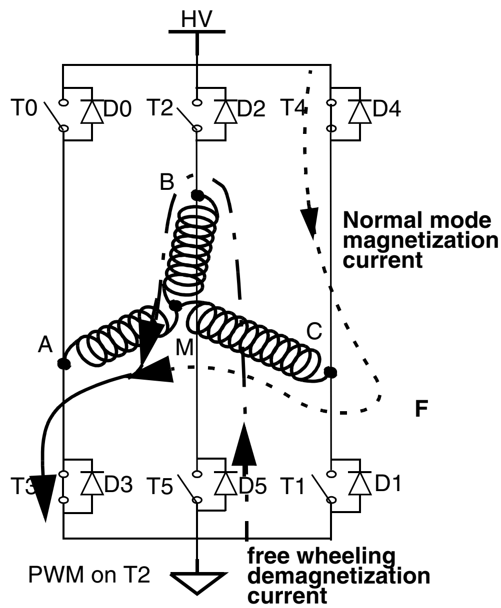
Figure 18 shows step Σ4 (switches T2-T3 are ON) with the normal current and the free-wheeling current (dotted line) during the PWM OFF time of the high side switch T2.

Figure 18. Step Σ4 (switches T2-T3 are ON)



When switching from step Σ4 (switches T2-T3 are ON) to step Σ5 (switches T4-T3 are ON), a free-wheeling, decreasing demagnetization current is still present through the B terminal (dashed line) and an increasing magnetization current appears through the C terminal (dotted line). Figure 19 shows these two currents during the PWM ON time.

Figure 19. Step Σ5 (switches T4-T3 are ON) during the demagnetization PWM ON time



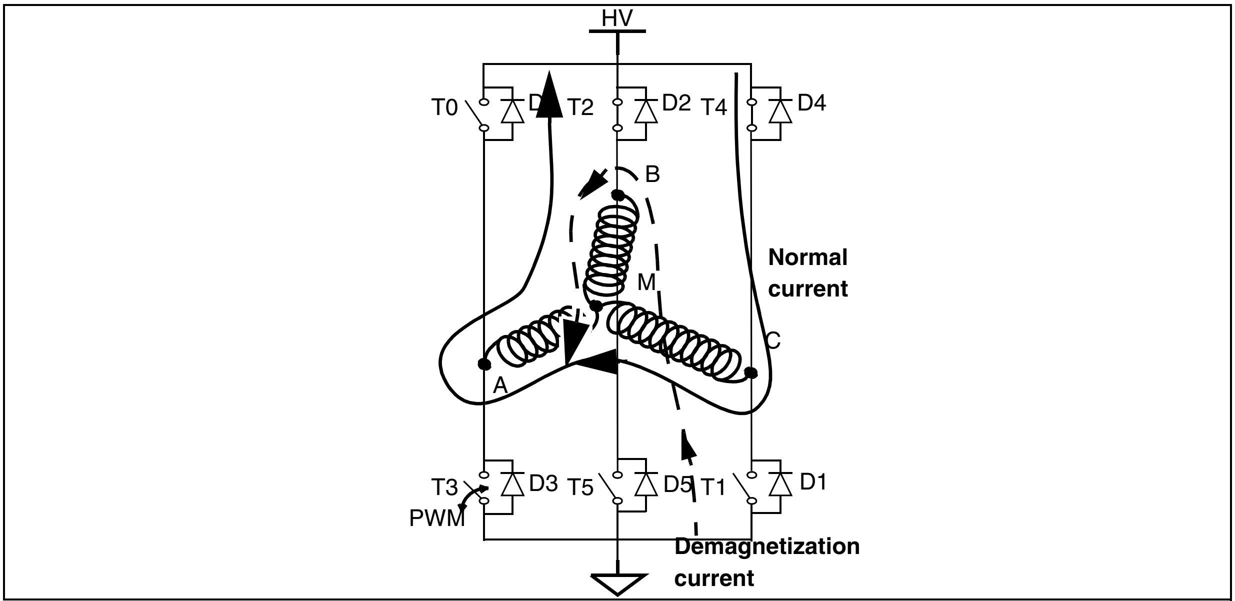
This means, during the PWM ON time:

– The potential of B is zero

– The potential of M is close to HV/3

Now depending on the switch we are going to apply the PWM signal, the demagnetization time of winding B will be decreased and the end of demagnetization event will be accelerated during this PWM signal OFF time. The numerous dedicated registers in the ST7MC peripheral allow the flexibility to choose where to apply the PWM signal between the different events. The maximum reverse voltage to decrease the demagnetization time is achieved during the OFF time of the PWM signal.

Figure 20. Acceleration of demagnetization during low side switch PWM OFF time



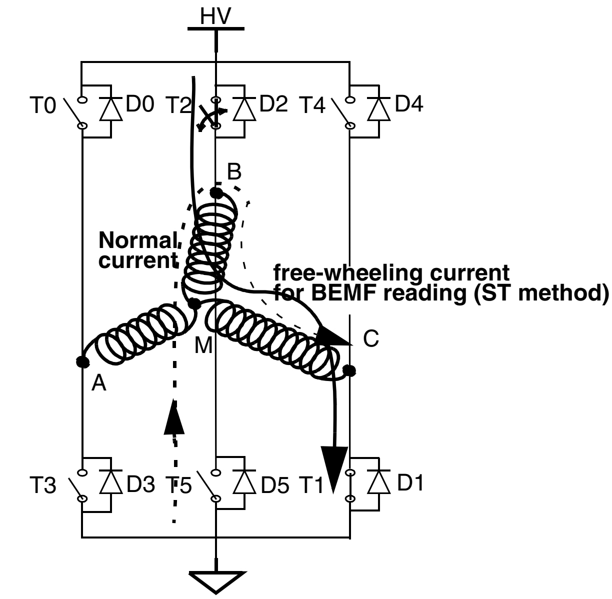
In our example, during step Σ4 (switches T2-T3 are ON), the V_{MB} voltage on the MB winding was positive. At the beginning of step Σ5 (switches T4-T3 are ON), the voltage on terminal B will be tied to 0V and the shortest demagnetization configuration is the one that provides the highest voltage at point M to apply the maximum reverse voltage and decrease the demagnetization time.

It is easy to verify that the highest voltage (2HV/3) is obtained when the PWM is applied only on the low side switch T3. During the OFF time of this PWM signal (configuration shown in Figure 20), the voltage at point M is 2HV/3. Otherwise if the PWM signal is applied on the high side switch T4, then during the OFF time of the PWM signal, the voltage at point M is 0V. So, in this configuration, the PWM signal has to be applied on the low side switch T3 after the commutation event in order to accelerate the demagnetization time during the OFF time of this PWM signal.

7.2 ACCELERATION OF DEMAGNETIZATION WHEN PWM IS APPLIED ON THE HIGH SIDE SWITCH

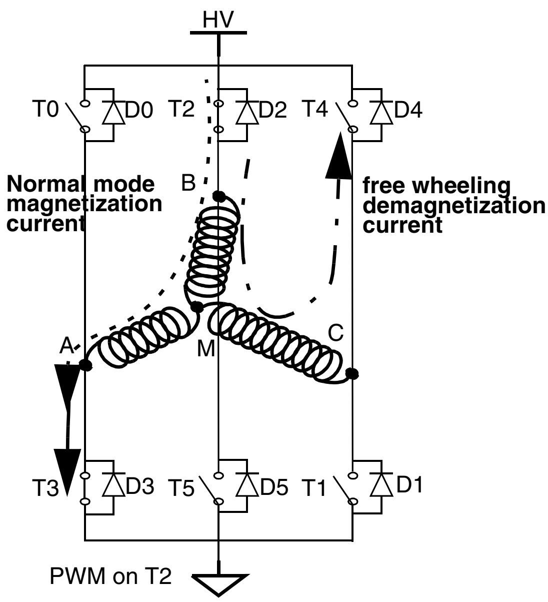
Figure 21 shows step Σ3 (switches T2-T1 are ON) with the normal current and the free-wheeling current (dotted line) during the PWM OFF time of the high side switch T2.

Figure 21. Step Σ3 (switches T2-T1 are ON)



When switching from step Σ3 (switches T2-T1 are ON) to step Σ4 (switches T2-T3 are ON), a free-wheeling, decreasing demagnetization current is still present through the C terminal (dashed line in Figure 22) and an increasing magnetization current appears through the B terminal (dotted line). Figure 22 shows these two currents during the PWM ON time.

Figure 22. Step Σ4 (switches T2-T3 are ON) during the demagnetization PWM ON time



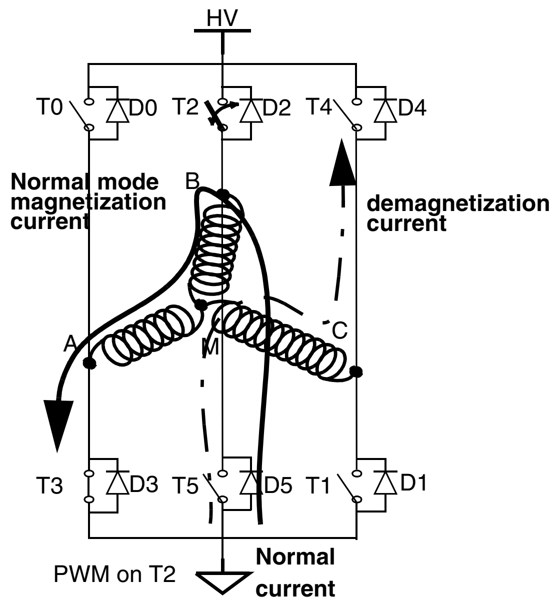
This means, during the PWM ON time:

– The potential of B is HV

– The potential of M is close to 2HV/3

Now depending on the switch we are going to apply the PWM signal ON, the demagnetization time of winding C will be decreased and the end of demagnetization event will be accelerated during this PWM signal OFF time. The goal is to apply the maximum reverse voltage on winding C.

Figure 23. Acceleration of demagnetization during high side switch PWM off time



In our example, during step Σ3 (switches T2-T1 are ON), the V_{MC} voltage on the MC winding was negative. At the beginning of step Σ4 (switches T2-T3 are ON), the voltage on terminal C will be tied to HV and the shortest demagnetization configuration is the one that provides the lowest voltage at point M to apply the maximum reverse voltage and decrease the demagnetization time.

It is easy to verify that the lowest voltage HV/3 is obtained when the PWM is applied only on the high side switch T2. During the OFF time of this PWM signal, the voltage at point M is HV/3 (configuration shown in Figure 23). Otherwise if the PWM signal is applied on the low side switch T3, then during the OFF time of the PWM, the voltage at point M is HV. So, in this configuration, the PWM signal has to be applied on the high side switch T2 after the commutation event in order to accelerate the demagnetization time.

7.3 REGISTERS CONFIGURATION TO ACCELERATE THE DEMAGNETIZATION.

The ST7MC allows you to program different PWM configurations in sensorless mode. In sensor mode, the demagnetization event is useless as the feedback information is not read from the windings.

In order to minimize the demagnetization time in sensorless mode, the ST7MC allows you to modify the PWM direction between the step commutation and the end of demagnetization.

In sensorless mode the OS2 bit in register MCRB enables the PWM on the high side or low side channels between the commutation and the demagnetization event.

Table 3. OS bits in MCRB register

OS2 bit	PWM after C and before D	OS1 bit	PWM after D and before Z	OS0	PWM after Z and before next C
0	On High Channels	0	On High Channels	0	On high channels
				1	On low channels
		1	On Low Channels	0	On high channels
				1	On low channels
1	On Low Channels	0	On High Channels	0	On high channels
				1	On low channels
		1	On Low Channels	0	On high channels
				1	On low channels

D event: Demagnetization

C event: Commutation

Z event: BEMF zero voltage crossing event

8 CONFIGURATION EXAMPLE

This section gives a configuration example for a six-step 120° motor drive for a PM BLDC motor in sensorless, current and autoswitched mode. The sensorless control method used would be the ST method.

The configuration registers can be divided in two parts: Table 4 lists the configuration bits that only need to be written once, Table 5 gives the step-dependent configuration bits. The registers in Table 2 must be updated within each commutation interrupt routine in order to select the configuration for the next step.

Table 4. General Configuration Registers

Register	Value								Comments
	7	**6**	**5**	**4**	**3**	**2**	**1**	**0**	
MPAR	TES1	TES0	OE5	OE4	OE3	OE2	OE1	OE0	Outputs 0, 2, 4 are HIGH channels Outputs 1, 3, 5 are LOW channels
	0	0	1	0	1	0	1	0	
MCRA	MOE	CKE	SR	DAC	V0C1	SWA	PZ	DCB	The motor runs in autoswitched mode, current mode, sensorless mode.
	1	1	0	0	1	1	X	X	
MCRB	Res	CPB	HDM	SDM	OCV	OS2	OS1	OS0	PWM after end of demagnetization: on HIGH channels.
	0	S	S	S	S	S	0	1	
MCRC	OI	HZ	SZ	SC	SPLG	VR2	VR1	VR0	Hardware Z event Sampling at the end of PWM off time
	0	1	0	0	0	X	X	X	
MDTG	PCN	DTE	DTG5	DTG4	DTG3	DTG2	DTG1	DTG0	Only PWM U is output to the PWM manager No Dead time generator
	0	0	0	0	0	0	0	0	
MPHST	IS1	IS0	OO5	OO4	OO3	OO2	OO1	OO0	Input selection and output data change at each step.
	S	S	S	S	S	S	S	S	

Notes:
- Bits marked with X depend on the motor and / or the application:
  PZ depends on the noise present in the application,
  DCB depends on the motor symmetry;
  VR[2:0] bits depend on the noise level on the BEMF input pins.
- Bits marked with S have to be modified after each commutation (step dependent configuration). These bits are summarized in Table 4. Those bits are taken in account only at the next commutation event.

Table 5. Step Configuration Registers

Step	Σ_1	Σ_2	Σ_3	Σ_4	Σ_5	Σ_6
Current direction	A to B	A to C	B to C	B to A	C to A	C to B
High side	T0	T0	T2	T2	T4	T4
Low side	T5	T1	T1	T3	T3	T5
OO<5-0> output bits	100001	000011	000110	001100	011000	110000
Measure done on terminal:	C	B	A	C	B	A
Connected to pin	MCIC	MCIB	MCIA	MCIC	MCIB	MCIA
IS<1:0> selection bits value	10	01	00	10	01	00
MPHST	10100001	01000011	00000110	10001100	01011000	00110000
Back EMF shape	Falling	Rising	Falling	Rising	Falling	Rising
CPB value for BEMF detection (ZVD=0)	0	1	0	1	0	1
Voltage on measured point at the start of demagnetization	0V	HV	0V	HV	0V	HV
Transition at end of demagnetization	0V->BEMF (rising)	HV->BEMF (falling)	0V->BEMF (rising)	HV->BEMF (falling)	0V->BEMF (rising)	HV->BEMF (falling)
Hardware demagnetization	always possible	not always possible	always possible	not always possible	always possible	not always possible
HDM-HDM bit value (Hard - Soft Demagnetization Mask bits)	10	11	10	11	10	11
PWM side selection for accelerating demagnetization	Low Side	High Side	Low Side	High Side	Low Side	High Side
Driver selection for accelerating demagnetization	T5	T0	T1	T2	T3	T4
OS2 bit	0	1	0	1	0	1
MCRB	xx010001	xx111101	xx010001	xx111101	xx010001	xx111101

9 CONCLUSION

As seen in this document, the ST7MC with the features of its dedicated peripheral offers a lot of combinations for the PWM management when driving a BLDC motor. Thanks to a high hardware integration (both digital and analog) and a high flexibility of configuration through dedicated registers, the PWM management can be fine-tuned and optimized to reach and maintain the best efficiency of the motor whatever the control method.

This flexibility combined with the fact that the ST7MC family comes with the 8-bit ST7 core, a very well known and stable core, and is offered in a wide range of packages (8Kbytes to 60Kbytes memory size Flash/ROM and from 32 pins to 80 pins) allow this part to be suitable for all the motor control applications requiring a scalar motor control.

The associated development kit, ST7MC-KIT/BLDC, that is provided with full C libraries software and reference hardware design allows you to get his application up and running in a minimum amount of time for a better “time to market”.

In conclusion, a good time to market, high performances and cost savings are the keys of a successful design done with the ST7MC.

10 REVISION HISTORY

Table 6. Document revision history

Date	Revision	Changes
06-Jan-2005	1	Initial release
12-Jul-2007	2	Removed references to obsolete products

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