Application Note

32

Intelligent Stepper Motor (ISM) Function

V850E2/Dx4

32-bit Microcontroller

Renesas Electronics
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1. Handling of unused Pins

   Handle unused pins in accord with the directions given under Handling of Unused Pins in the manual.

   – The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.

2. Processing at power-on

   The state of the product is undefined at the moment when power is supplied.

   – The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.

     In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.

     In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.

3. Prohibition of access to reserved addresses

   Access to reserved addresses is prohibited.

   – The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.

4. Clock signals

   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.

   – When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.

5. Differences between products

   Before changing from one product to another, i.e. to one with a different part number, confirm that the change will not lead to problems.

   – The characteristics of MPU/MCU in the same group but having different part numbers may differ because of the differences in internal memory capacity and layout pattern. When changing to products of different part numbers, implement a system-evaluation test for each of the products.

Table of Contents

Chapter 1 Overview of ISM in the Dx4-H Series

Within the Dx4-H series, the Intelligent Stepper Motor (ISM) function supports 6 channels; this means, that 6 stepper motors can be attached and driven, with two coils (horizontal and vertical) for each motor.

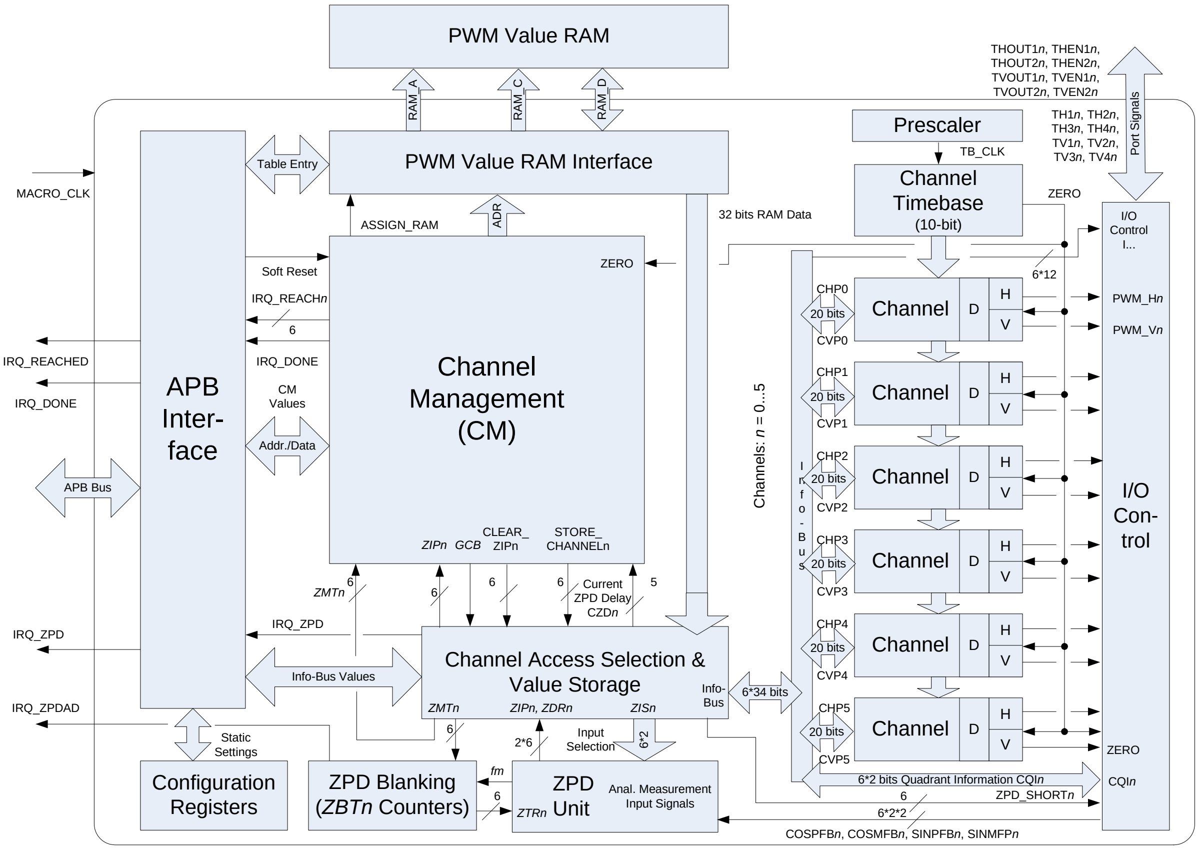


Figure 1-1 Overview of ISM within Dx4-H Series

When looking at the overview, it is obvious that the ISM contains a “standard” stepper motor function with 6 channels (seen on the right hand side), and in addition a “*Channel Management*” function, which will allow automated operation by feeding in values into the channels.

In fact, the *Channel Management* function can be disabled, so that pure PWM output control is possible by software.

In addition, functionality is included within the *Channel Management*, which allows automated *Zero Point Detection (ZPD)*, too. From the view of the *Channel Management*, the regular *PWM Mode* and the *ZPD Mode* are simply two different operation modes, how to serve a channel with values for the output (PWM or direct port settings), and when to read and analyze values from the ports (coil inductions).

Chapter 2 General Notices

2.1 Abbreviations in this Application Note

Typically, all variables and register settings are written by 3- or 4-letter-abbreviations. These abbreviations can be identified within the User's Manual by looking at the register and bit names of ISM, and skipping some common letters like "ISM*x*G" (for global settings), "ISM*x*C" (for channel related settings), "ISM*x*S/I/F" (for sign, integer and fraction of parameters and variables).

Note The letter "*n*" is used to distinguish between channels, i.e., it is a channel index.

2.2 The Initial State

After the *Hardware RESET*, the ISM function is set to a passive default state.

- *Channel Management* is disabled (*GCE* is cleared).
- All PWM output channels have a 0% duty cycle (PWM off) setting.
- The Quadrant of all channels is set to 0.
- The central *Time Base* counter is running at its slowest speed.
- The *Channel Management* update speed is set to its slowest speed.
- All Interrupts are disabled.
- The linkage of ISM and the analogue *ZPD* hardware is disabled.

2.2.1 Functionality of *GCE* (Channel Management Enable)

By clearing *GCE,* the *Channel Management (CM)* is stopped. Stopping is performed synchronously, i.e., when *GCE* is cleared, the current processing of all channels is completed. After *GCB* is cleared, the *CM* is effectively stopped. PWM and all other output settings remain active as set on the last *CM* pass. In this state, all parameters and variables can be redefined arbitrarily.

2.2.2 Analogue Part Linkage (*GZL*)

Whenever *Zero Point Detection (ZPD)* is used within your application, always set the *GZL* flag. This activates the linkage between the digital and analogue components of port and ISM.

Note If *GZL* is not activated, all settings of *GCS, GZF, GRV, GFD, GFL, GZO, GZP* and *GZE* are blocked, so that *ZPD* operations cannot be performed.

2.2.3 Functionality of *GEN* (Soft Reset)

GEN is always set on *Hardware RESET*.

By clearing the *GEN* flag by software, the ISM macro is forcibly reset by software. On this synchronous soft-reset, **all** internal state machines, processing (*GCE* is automatically cleared) and also PWM is stopped and forced to reset conditions. RAM contents, variables and parameters remain untouched, however. These can still be modified by software. Registers are keeping their values, except the following: *GCE*, *GCB, CZCn, CZDn, ZIPn and ZAFn* are cleared on soft-reset.

Cautions

1. As the soft-reset functionality is allowed in any state of the ISM macro, inconsistencies of status flags with the internal state machines of ISM may occur. For example, an interrupt pending flag may indicate an interrupt, but the interrupt could no more be generated due to the soft-reset. For this reason, after a soft-reset, it is the responsibility of the application software, to clear status flags accordingly.
2. When Soft Reset is activated and deactivated, distortion on the PWM outputs will occur, because the Soft Reset happens asynchronously. While the distortion on activation of Soft Reset is unavoidable (PWM immediately goes to recirculation via power), the distortion on restart after Soft Reset can be avoided by software (disabling of port output while synchronously re-activating the ISM).
3. As PWM value settings are not touched by the Soft Reset, PWM output will continue immediately after Soft Reset is released, unless the corresponding registers are cleared by software in advance.

2.3 How to generate a first PWM Output

ISM is almost ready-to-use after a *Hardware RESET*. Therefore, only few steps are required to see an appropriate PWM output.

- Enable the associated ports of the device for the corresponding peripheral mode and *input* mode.
- Set the *Central Time Base* speed by *GTB.*
- Set the PWM duty cycle values by *CHPn* and *CVPn.*
- Set the PWM quadrant by *CQIn.*
- If there is no resistive load on the outputs, enable the *Recirculation* to *VSS* by *IHRn* and *IVRn*, so that push-pull operation is activated on the ports.

Notes

1. The usage of *input* mode must be combined with the associated port setting to enable port control by the peripheral, i.e., the ISM.
   In this way, ISM will select input or output direction depending on its internal processing.
2. The *Quadrant* selects which of the 4 signals per channel will be applied the PWM.
3. If *Recirculation* is not enabled, each port will only drive or not drive one voltage level; i.e., the PWM toggles from and to high-impedance.

Chapter 3 About Stepper Motor Movement

3.1 The Physics of a Stepper Motor

The Stepper Motor consists of a permanent magnet, which rotates within the magnetic fields of two coils.

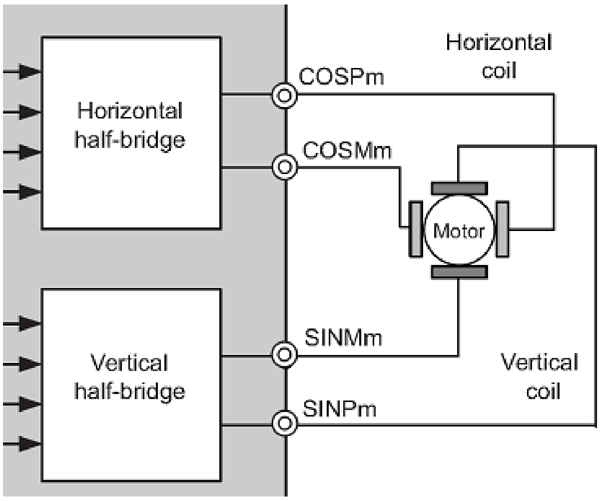


Figure 3-1 Stepper Motor Coil Connection

By using two driver bridges (one for the horizontal coil, one for the vertical coil), both coils can be driven currents in both directions. Depending on the device hardware (port structures), either half-bridges or full-bridges are used.

Half-bridges are two push-pull drivers with high-impedance function, while full-bridges are 4 discrete power transistors, which are forming a H-bridge, with the motor coil in its middle.

Like this, when adding the forces of the magnetic fields of both coils, the motor anchor can be rotated by changing the amplitude and direction of the fields.

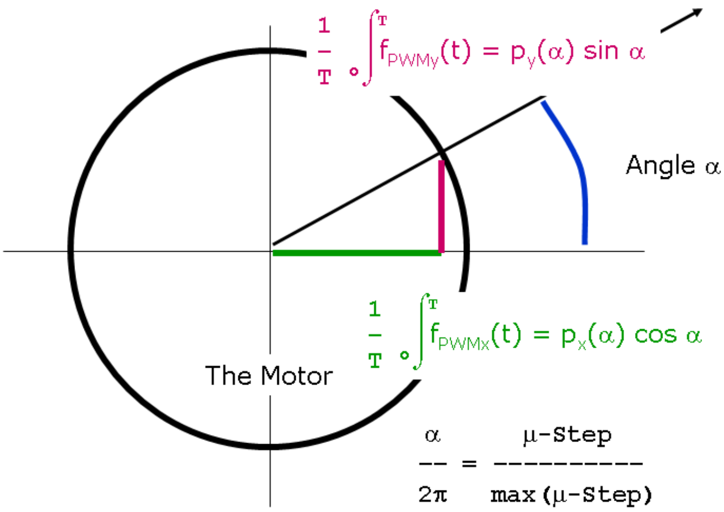


Figure 3-2 Forces and Angle of the Stepper Motor

The average amplitude of the magnetic field is determined by the PWM duty cycle, which is represented by the integration of the PWM along its period. Doing this for both coils, their forces are adding up (red and green components) to an angle α.

Now, the four *Quadrants* are defined in the mathematical way, where quadrant 0 is where both vertical and horizontal currents are positive (angles 0 to $\pi/2$), and quadrant 3 is where vertical current is negative and horizontal current is positive (angles $3\pi/2$ to 2π).

3.1.1 *Microsteps*: Moving the Motor

When moving the motor anchor, a certain amount of *Microsteps* can be applied. In hardware, this is related to the resolution of the PWM, which is applied to the coils. ISM supports a resolution of $4*[2^{10}-1]$ microsteps in PWM granularity (if directly applied by software), or a subset of 512 or 128 microsteps from those, which can be chosen by the *Channel Management*.

Each microstep corresponds to one combination of PWM for the horizontal and vertical coil, where the vectorized addition of the vertical and horizontal PWM duty cycles must be a constant, so that the resulting magnetic force is a constant, too. This is valid for an *ideal* motor. For realistic motors, the combinations of PWM duty cycles may cause variable magnetic forces, in order to compensate mechanical issues like misalignments etc.

When numbering the microsteps, starting off at angle zero in the positive mathematical way (“left” turning), the resulting angle of the anchor is proportional to the microstep number.

Rotation of the motor anchor now is achieved by applying the microsteps in an incremental sequence. The delay between the microsteps appliance will then determine the velocity (rotation speed) of the anchor.

An alternative way to rotate the motor is to apply microsteps in constant time intervals, but to change the velocity (rotation speed), some microsteps are missed out from the sequence, causing a “jump” of the anchor. ***This is the way how the Channel Management of ISM is performing the motor rotation*.**

The direction of rotation is determined by reversing the microstep order.

3.1.2 *Macrosteps*: Performing several Turns

One *Macrostep* is defined to be one full turn of the motor’s anchor.

The *Channel Management* of ISM defines either 128 or 512 *Microsteps* for one *Macrostep*. This means, that for one turn, it will apply either 128 or 512 PWM combinations at maximum to the motor coils. It will miss out microsteps, the faster the turning shall be.

The *Motor Position* now is a number of *Macrosteps plus Microsteps*, because typically, a stepper motor contains a *gear*.

In this way, the motor position is formed to a binary number, with the upper binary part being the macrosteps, and the lower binary part being the microsteps.

While the microstep number is determining the PWM combination to be applied to the motor coils, the macrosteps and microsteps are used for the motor movement in general (acceleration, velocity etc).

3.2 The PWM Generation of ISM

Following a *Prescaler (GTB)*, the central *Time Base* determines the PWM output of ISM; this means that all PWM outputs of ISM are having the same frequency and are all synchronous.

In order to avoid that too many edges are occurring at the same time on several ports, each PWM output can be assigned to a delay, which is set in clocks of the central time base (*CDVn* and *CDHn*).

The level of the PWM is in the range 0 ... 2^{10}- 1, where 0 means no PWM output (0%), and 2^{10}-1 sets the output level to full 100%. The zero level (0%) output is important to allow to switch off the output completely. 100% level is achieved, because the PWM compare value can be set one count more than the range of counting of the timebase.

The duty cycle of the PWM is set by defining the values *CHPn* and *CVPn*, for each channel, for the horizontal and vertical PWM, respectively. As the maximum count c of the Channel Timebase is 2^{10}- 2, and the duty cycle is given by a/(c+1), the following formula is given for the duty cycle P:

$$P\% = \frac{CHP}{2^{10} - 1} \qquad P\% = \frac{CVP}{2^{10} - 1}$$

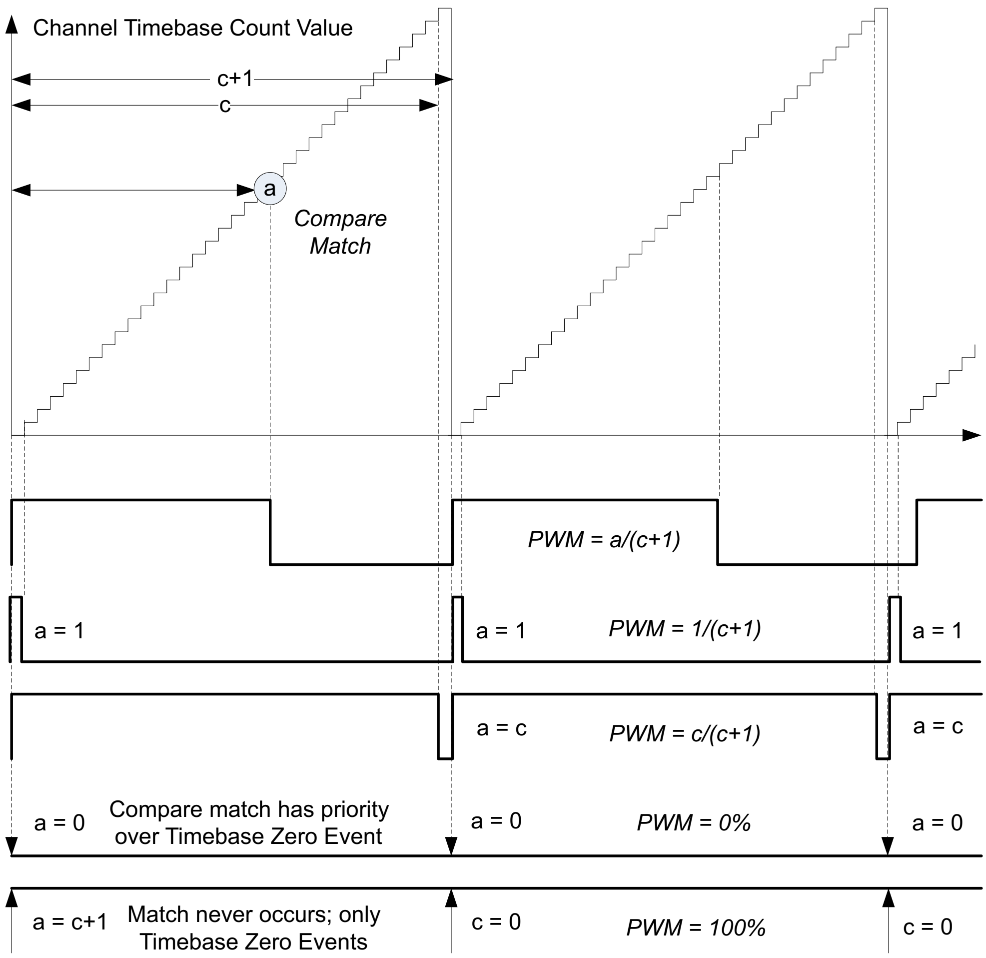


Figure 3-3 PWM Generation of ISM

3.2.1 ISM Clocking

The clock of the central time base is selected by the prescaler, and it depends on the ISM *Macro Clock (System Clock)*, which is set in the *Clock Controller* of the device.

$$f_{PWM} = \frac{f_{macro}}{(GTB\ Factor) \times (2^{10} - 1)}$$

3.2.2 PWM Output Generation

Every *Channel* of ISM consists of two PWM output pairs; one pair for the horizontal (cosine, COS) and another pair for the vertical (sine, SIN) coil of the attached stepper motor. PWM duty cycle settings are double-buffered in registers, so that a change of the PWM duty cycle is not causing distortion on the PWM signals.

Depending on the *Quadrant*, the vertical and horizontal PWM output is directed to the output ports of ISM. Horizontal PWM is output to the *COSx* ports, while vertical PWM is output to the *SINx* ports.

Table 3-1 Quadrant Assignments

Quadrant Selection			Output Generation			
Quadrant	**Angle**	**CQI*n***	**COSP**	**COSM**	**SINP**	**SINM**
0	0° - 90°	00B	PWM_H	0	PWM_V	0
1	90° - 180°	01B	0	PWM_H	PWM_V	0
2	180° - 270°	10B	0	PWM_H	0	PWM_V
3	270° - 360°	11B	PWM_H	0	0	PWM_V

Notes

1. In this table, *PWM_H* refers to the horizontal PWM, and *PWM_V* refers to the vertical PWM.
2. The port assignments for channel *n* of the Dx4 devices are as follows:
   - SINP ⇔ SM*n*1
   - SINM ⇔ SM*n*2
   - COSP ⇔ SM*n*3
   - COSM ⇔ SM*n*4

3.3 Recirculation of Inductance

Recirculation means performing a short-circuit on a stepper motor coil, during the low-phase of the attached PWM. During the high-phase of the PWM the output voltage drives a current through the coil, and during the low-phase, this current of the coil, which represents an amount of energy, can be discharged through the short-cut.

If recirculation is enabled, the PWM output of ISM performs a driving of the output FET stages, which looks like this for a certain quadrant:

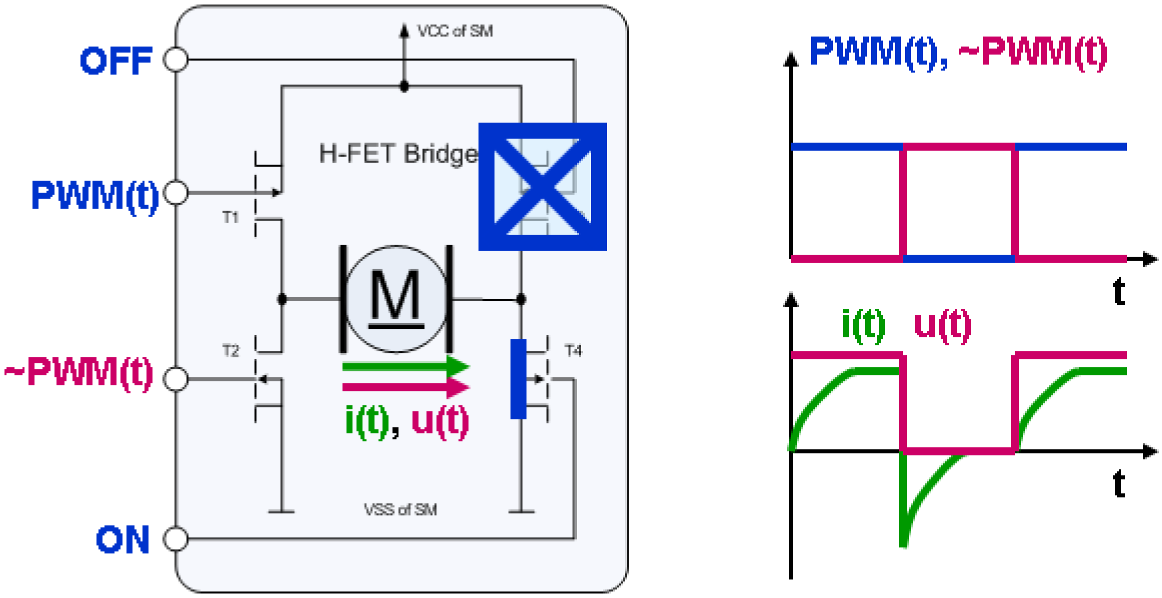


Figure 3-4 Inductive Output driving with Recirculation enabled

Obviously, the generated short-circuit by “~PWM(t)” avoids voltage peaks, because the current i(t) can continuously discharge. If recirculation is switched off, the disadvantage of the inductive voltage peak becomes obvious:

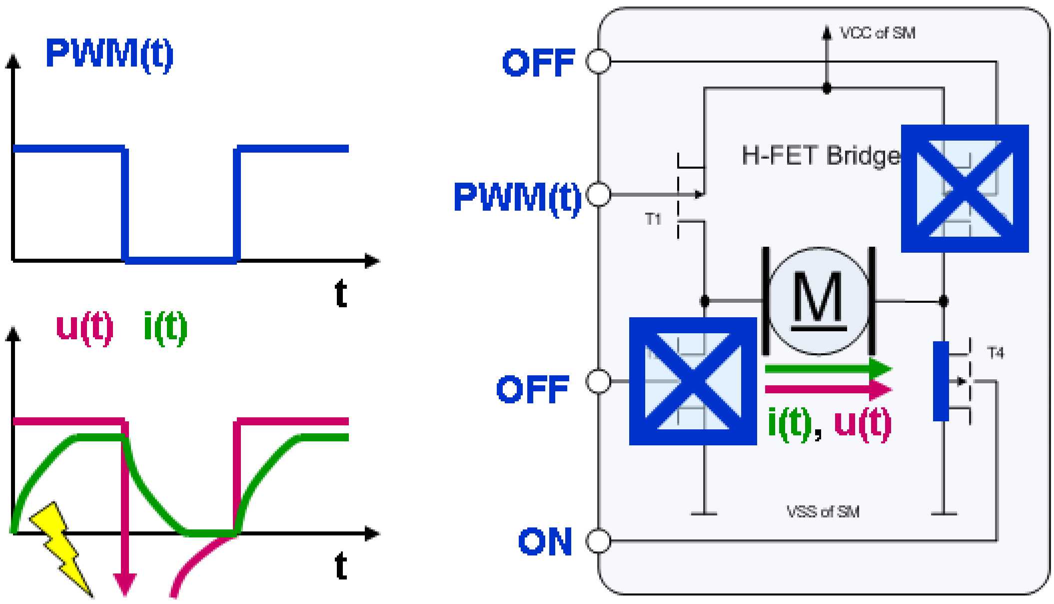


Figure 3-5 Inductive Output driving with Recirculation disabled

3.4 The ISM Channel Circuitry

As a summary of the previous chapters, a full detailed drawing of the circuitry of one stepper motor channel is shown below.

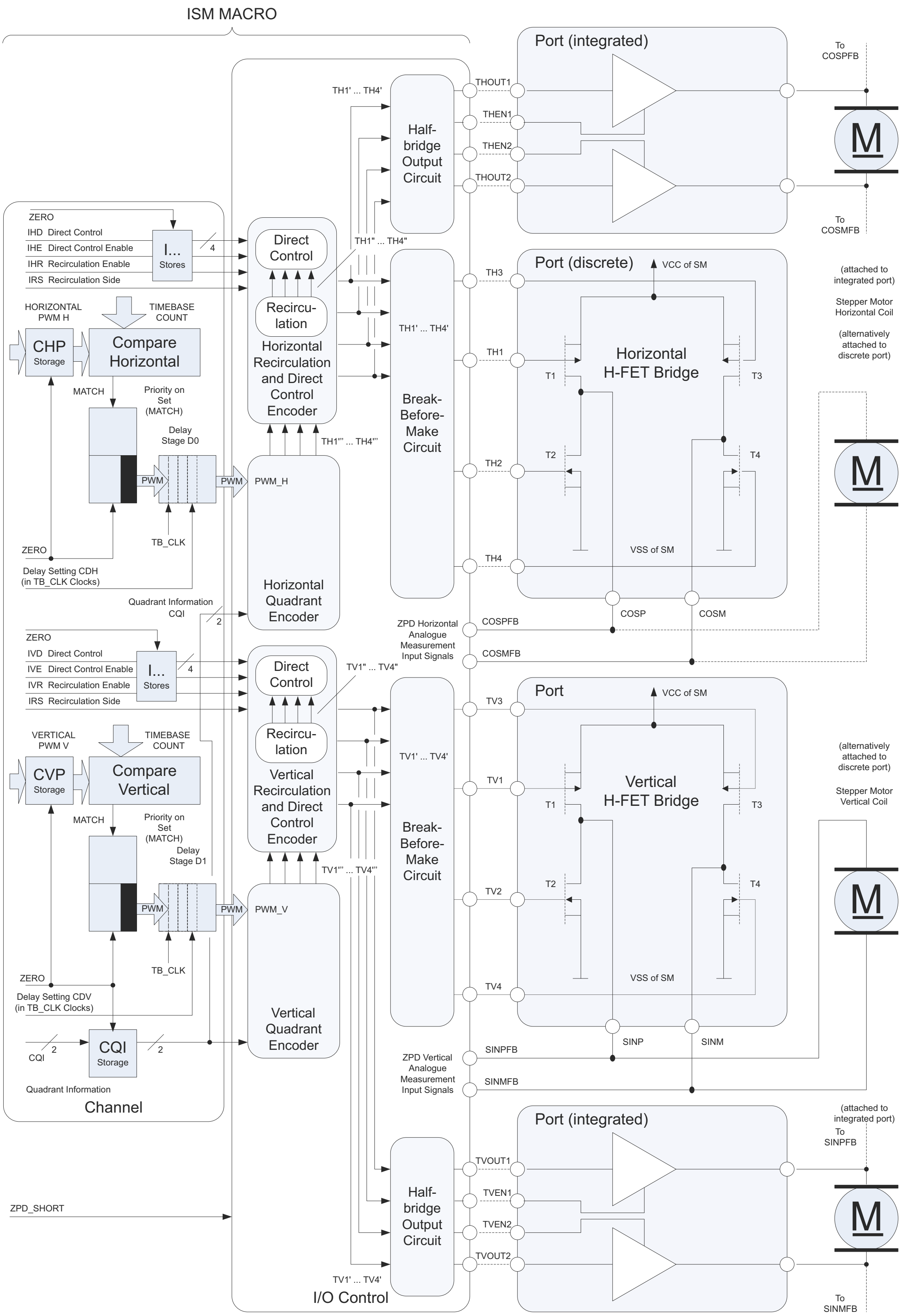


Figure 3-6 Circuitry of one ISM Channel

Chapter 4 Automated Motor Movement

Within this chapter, more deep functional description about the processing of the *Channel Management (CM)* is given. In an overview, the functional blocks of the *CM* are looking like this:

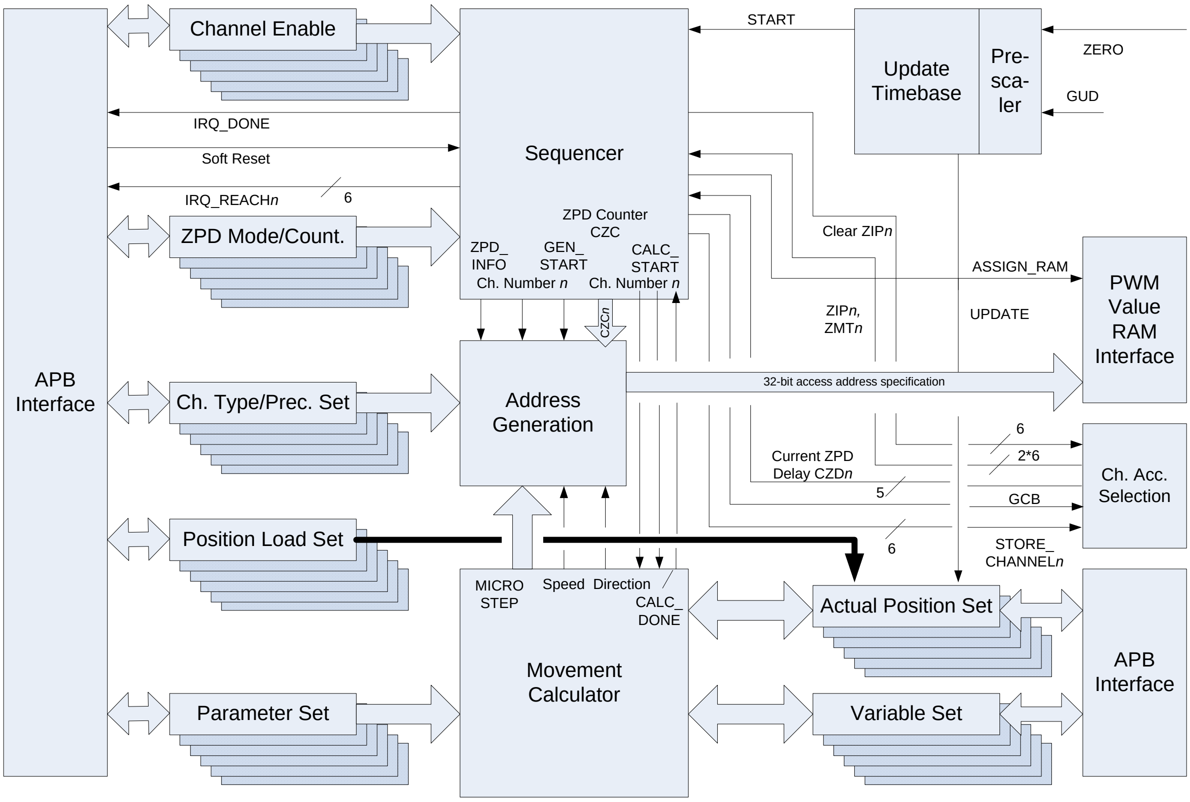


Figure 4-1 Channel Management Details

When globally enabled by *GCE*, the *Sequencer* is triggered by its implicit Update Timebase (Speed defined by *GUD*, triggers START). This starts the processing of all enabled channels (*CENn*). If a channel is not enabled (which can be individually set), its processing is skipped, thus leaving all its parameters, calculations etc. untouched.

4.1 Processing of PWM (non-ZPD) Channels

This is performed for all channels, which are enabled, and *CZPn* is cleared.

On processing of a channel, first the *Movement Calculator* is started (CALC_START). This block calculates a new microstep value for horizontal and vertical PWM, and evaluates the current speed level and motor direction. Further, the macrostep value is calculated. This is done by using an implicit algorithm, which considers external parameters, the current absolute position of the motor and static variables (digital processing results of previous and current calls per channel). The *Movement Calculator* indicates to the *Sequencer*, when the calculation is finished. If the *Movement Calculator* detects that the given target end position is reached by comparing the actual position set with the internal position variable, and the actual movement speed *VAS* is zero, it generates the per-channel signal IRQ_REACHn.

The *Movement Calculator* delivers its result, which are the current microstep values for the PWMs per channel, the associated speed levels and the motor directions.

Using these microstep values, the *Address Generation* block creates an access address to the *PWM Value RAM*. Like this, the microstep values are translated into PWM duty cycle and quadrant settings. The *Sequencer* fetches the values *CVPn*, *CHPn*, *CQIn*, *IHRn* and *IVRn* from the RAM and writes them into the appropriate register settings of the ISM channels, where the result becomes visible as changed PWM settings.

In summary, for each time-event of the *Update Timebase (GUD)*, new motor positions are calculated for each activated channel, and by a look-up table in the *PWM Value RAM*, they are translated into PWM values for the channels.

With the next ZERO event, the new values for the PWM settings (*CVPn, CHPn, CQI*n) and I/O control (*IHRn, IVRn*) will become active at the outputs. The ZERO event is the synchronous start of a new PWM cycle. The *Sequencer* is designed such, that it is capable to complete all processing of all channels within one PWM cycle.

After completion, the *Sequencer* stops in an idle state and waits on the next START event.

4.2 Processing of ZPD Channels (ZPD Mode)

This is performed for all channels, which are enabled, and *CZPn* is set, and the zero point is not yet detected.

In ZPD Mode, the *Movement Calculator* is neither used, nor started. Instead of the microstep result of the Movement Calculator, the value of CZC is used for the addressing of the PWM Value RAM.

When entering the ZPD mode for a channel n (*CZPn* was not set in the previous pass), *ZIPn, ZAFn, CZCn* and *CZDn* are initialized to zero, as the ZPD mode for this channel now begins.

A local copy of the ZPD table index delay *CZDn* for this channel is decremented, if it is above zero.

If the current *CZDn* delay has passed (*CZDn* has reached zero during this START event cycle), the next ZPD table index has to be applied by incrementing ZPD table index counter *CZCn* of this channel. If the count of

CZCn has reached the end of the table marked by ZPD table index limit *CTLn*, the counter *CZCn* is reset to zero again.

Like this, each entry of the *PWM Value RAM* ZPD table may have an execution time of *CZDn*, which is a 5-bit value in counts of the frequency of START (the *Update Timebase*). Subsequent equal entries can be put into the table, in order to get longer delay times.

On *ZMTn* is set, the *ZPD Blanking* activates *ZTRn* after its delay of *ZBTn* cycles of the ZPD measurement frequency f_m. Then, on *ZTRn*, the ZPD measurement is activated, using *ZISn* as parameter.

The ZPD Unit now will perform ZPD measurements for this channel (concurrently with other channels), until *ZTRn* is cancelled again, caused by the *Sequencer*, which cancels *ZMTn* according to a ZPD table entry. On cancelling, *ZTRn* immediately follows *ZMTn*. In case that the ZPD does not detect the zero position (level was at least once above the threshold), it activates the corresponding flag *ZIPn* for this channel.

If the ZPD measurement process is stopped, because *ZMTn* of the current channel is cleared (*ZMTn* of the corresponding ZPD table entry is cleared), but zero position was not detected meanwhile (*ZIPn* is set), the ZPD mode continues by processing the ZPD table from the PWM Value RAM.

If the signal *ZIPn* is not set for a channel, at the time point when *ZMTn* is cancelled, the ZPD mode for this channel is left automatically by clearing *CZPn*, and disabling the channel by clearing *CENn*. This will cause, that the channel is not processed any more, unless it is reactivated.

The value of *CZCn* is forwarded to the Address Generation Block.

Using *CZCn*, the *Address Generation* block creates an access address to the *PWM Value RAM*. Like this, the ZPD table index values are translated into PWM and output control settings. The *Sequencer* fetches the values *CVPn*, *CHPn*, *CQIn*, *IHRn*, *IVRn, IHEn, IVEn, IHDn, IVDn, IHRn, IVRn, ZMTn* and *CZDn* from the RAM and writes them into the appropriate register settings of the ISM channels, where the result becomes visible as changed PWM and/or output settings.

In summary, for each time-event of the *Update Timebase (GUD)*, a new ZPD table index is calculated for each activated channel, and by a look-up table in the *PWM Value RAM*, this is translated into PWM and output control values for the channels.

With the next ZERO event, the new values for the PWM settings (*CVPn, CHPn, CQI*n) and I/O control (*IHRn, IVRn, IHEn, IVEn, IHDn, IVDn*) will become active at the outputs. The ZERO event is the synchronous start of a new PWM cycle. The *Sequencer* is designed such, that it is capable to complete all processing of all channels within one PWM cycle.

After completion, the *Sequencer* stops in an idle state and waits on the next START event.

The ZPD mode operation is shown graphically in the following flowchart.

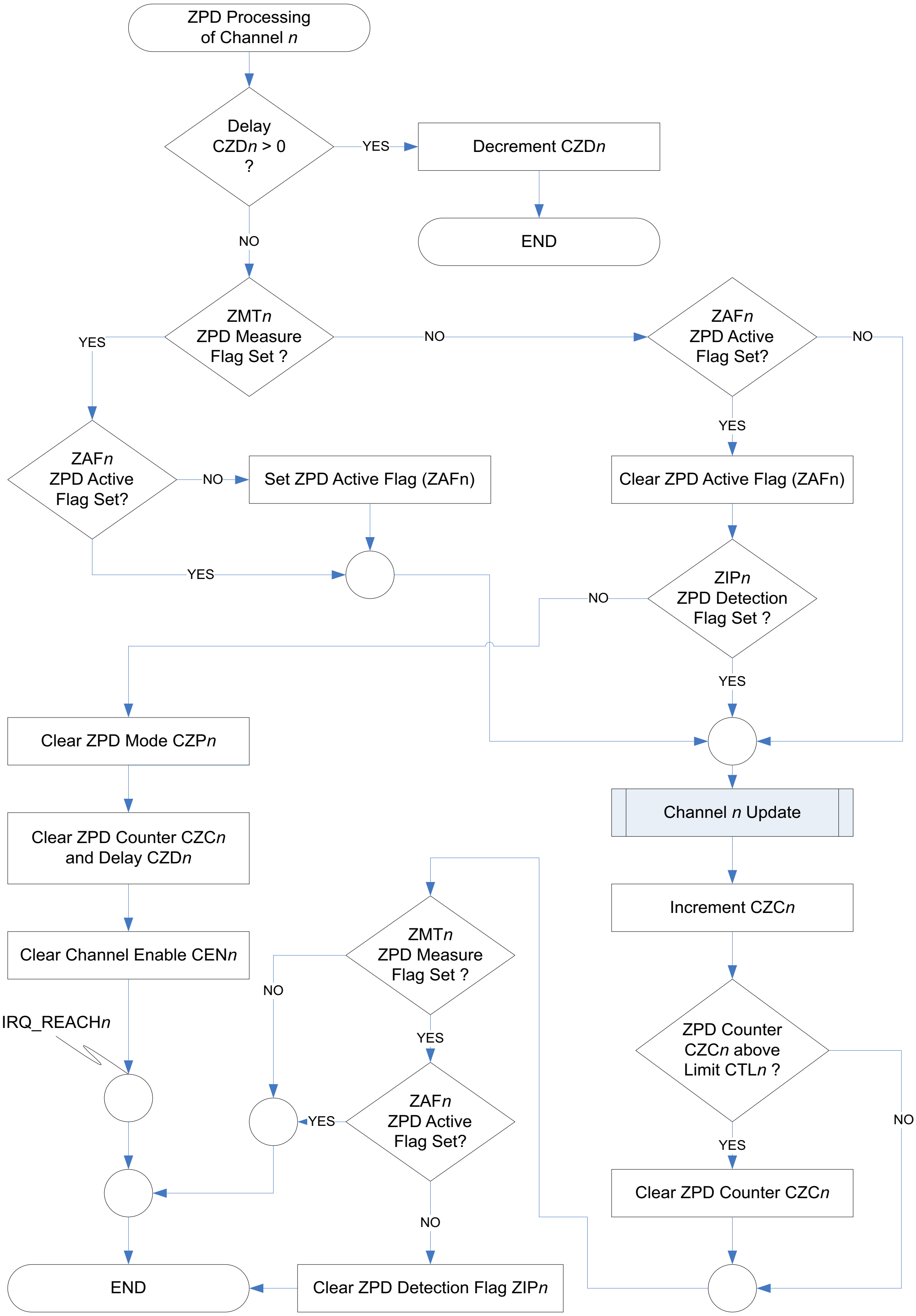


Figure 4-2 ZPD Processing Flow of ISM

4.3 Channel Management Processing Overview

Summarized from the chapters above, the processing of the *Channel Management* looks like this:

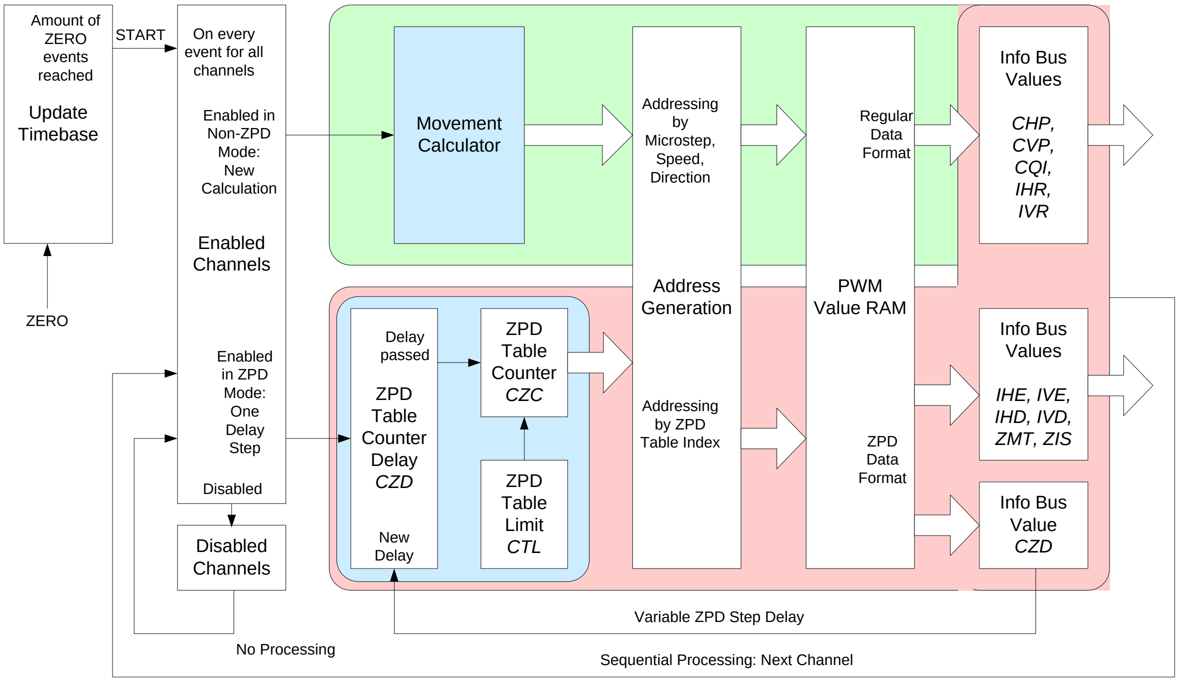


Figure 4-3 Channel Management Processing Overview

The *Info Bus* represents all registers, which are accessed by the *Channel Managment* during its processing.

Chapter 5 Looking into the PWM and ZPD Tables

5.1 Virtual Channels

As the *PWM Value RAM* is a lookup-table, it can also perform an abstraction of a physical channel (where the motor is attached to a port) into a logical or "virtual" channel.

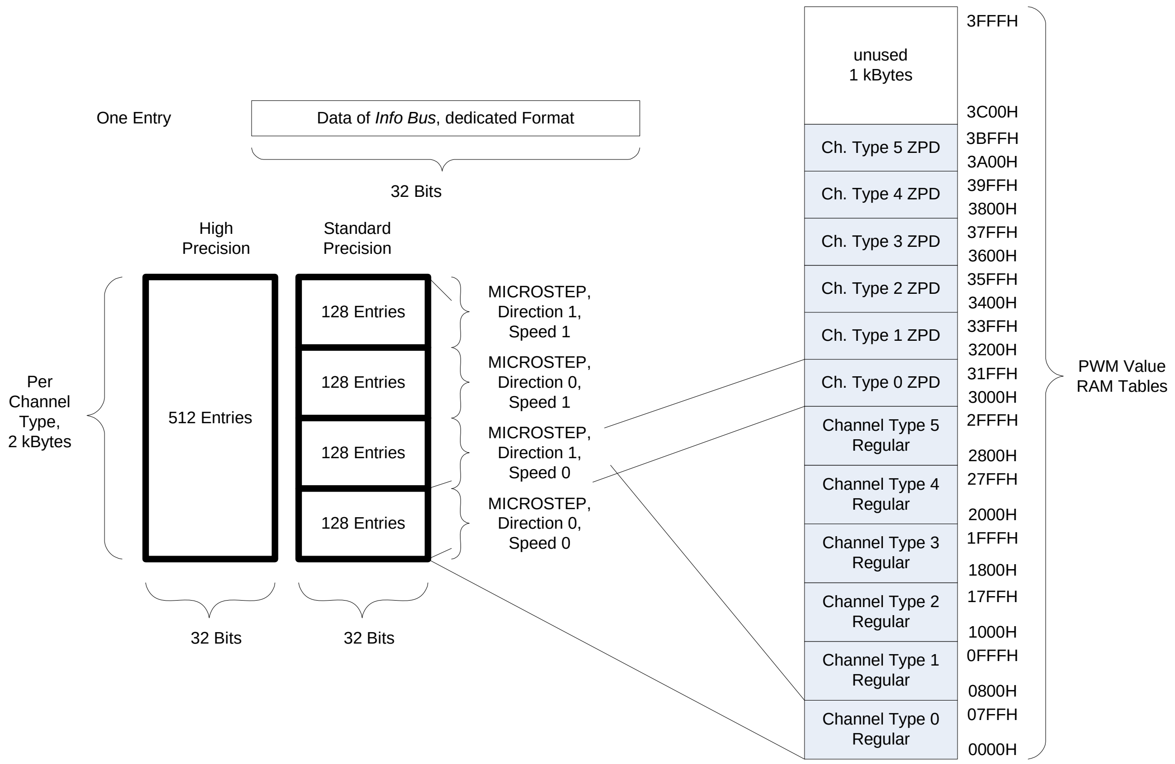


Figure 5-1 PWM Value RAM Layout

The application can define a virtual channel number *CCTn* for each physical channel *n.* This means, when addressing the content of channel *n*, not *n*, but *CCTn* instead is used for the addressing of the RAM. Like this, it is possible to have the same table for several channels, so that only a part of the RAM needs to be defined.

This virtual channel definition is valid for either "regular" PWM operation or ZPD mode of a channel.

Note If several motors are having the same characteristics, it is recommendable to use the same virtual channel number for them. Like this, the uploading of data phase into the RAM during startup can be drastically reduced.

5.2 Values for PWM Operation

5.2.1 Channels and Precision

As can be seen from the RAM layout, for each virtual channel there are two tables: The “regular” PWM operation table and the ZPD table.

Regarding the “regular” PWM operation table, there are two formats available, which can be selected by the *CCPn* flag.

(1) High Precision Mode

In high precision mode (*CCPn* set), for one turn of the motor the whole table section is used with 512 entries. Thus, the RAM is addressed in the following way, which also defines the layout of data to be copied there by the application:

CCT*n* (000B ... 101B)	Bits 10 ... 2	A1	A0
Channel Settings	MICROSTEP[8:0] from *Movement Calculator*	Always zero	

Figure 5-2 PWM Table Addressing Layout for High Precision Channels

In high precision mode, 512 angle positions can be stored, but there will be no distinguishing of the characteristic for current speed and direction of the motor.

(2) Low Precision Mode

In low precision mode (*CCPn* cleared), the table section is divided into 4 equally sized parts, with 128 entries each. Thus, the RAM is addressed in the following way, which also defines the layout of data to be copied there by the application:

CCT*n* (000B ... 101B)	VSP*n*	VDR*n*	Bits 8 ... 2	A1	A0
Channel Settings	Speed, Direction		MICROSTEP[6:0] from *Movement Calculator*	Always zero	

Figure 5-3 PWM Table Addressing Layout for Low Precision Channels

In low precision mode, 128 angle positions can be stored, but there are 4 tables to distinguish for speed and direction of the motor. Speed and direction flags are corresponding to the variables *VSPn* and *VDRn* of the *Movement Calculator*. These variables are automatically calculated, and they are depending on some parameters (speed limits, current position, target position).

Like this, optimized table sets can be stored, which are depending on the motor characteristics, and which are dynamically switched during operation and motor movement.

5.2.2 PWM Values

In the ideal case, one would expect that the values of the PWM duty cycles are sine and cosine waveforms, if they are related to the microstep or the angle of the motor anchor.

This assumes, that the force relations inside of the motor are ideal, that the forces can be added and that the forces of the horizontal and vertical coils are rectangular to each other. This is what is explained in the theory, as shown in *3.1 "The Physics of a Stepper Motor" on page 11* .

However, the mechanical physics of a stepper motor are not ideal, typically. Therefore, the values of the PWM duty cycles along with the motor anchor angle or microstep may showing waveforms like this:

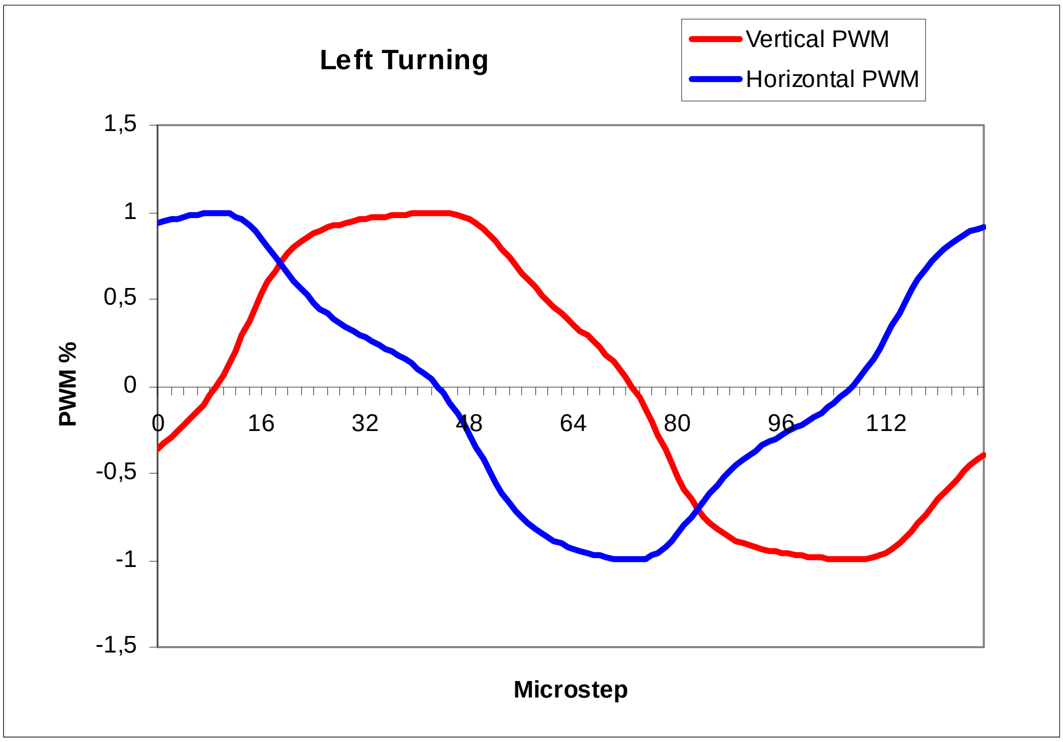


Figure 5-4 Non-ideal PWM Settings of a typical Stepper Motor

In this figure, the value "1" of the PWM refers to a duty cycle of 100%, meaning a value of "0x3FF" for the registers *CVPn* or *CHPn.*

Even more, when changing the rotation direction or when running faster or slower, the characteristics of a motor may vary. To support this, the ISM PWM tables in low precision mode are supporting the rotation direction and one level of speed hysteresis, which are changing the tables dynamically.

Note It is up to the user, to find out the best fitting PWM table sets of the used motors. If no background data is available, it is recommended to start off with ideal sine and cosine sequences for the PWM tables.

(1) Example of a Sine - Cosine Sequence PWM Table

When writing PWM tables into the *PWM Value RAM*, a standard table for a quick start could look like the following table. For different speed levels and directions, the same table can be used.

This table is “right turning”, because the sequence of quadrants is 4, 3, 2, 1.

The used access type is shown in advance of the table.

```
/*.............. ISM PWM RAM access structures .................*/

#define EE_ISM_SPEEDS        ( 2 )
#define EE_ISM_DIRECTIONS    ( 2 )
#define EE_ISM_TABLESIZE_STD ( 128 )


typedef struct eeism_pwmcell_t {

    volatile u32_t         cvp    : 10;
    volatile u32_t         chp    : 10;
    volatile u32_t         cqi    : 2;
    volatile u32_t         ivr    : 1;
    volatile u32_t         ihr    : 1;
    volatile u32_t         UNUSED : 8;

  } eeism_pwmcell_t;

typedef struct eeism_pwmstd_t {

    struct eeism_pwmcell_t std[ EE_ISM_SPEEDS ]
                              [ EE_ISM_DIRECTIONS ]
                              [ EE_ISM_TABLESIZE_STD ];
  } eeism_pwmstd_t;


/* Default PWM Table: SINE on CVP, COSINE on CHP */

const struct eeism_pwmstd_t EE_ISM_A_STDPWMTABLE1 = {

  /*  CVP     CHP    CQI   IVR IHR */
{
{{{ 0x000L, 0x3FFL, 0x3L, 1L, 1L, 0L }, /* 4th quadrant */
  { 0x032L, 0x3FDL, 0x3L, 1L, 1L, 0L },
  { 0x064L, 0x3FAL, 0x3L, 1L, 1L, 0L },
  { 0x096L, 0x3F3L, 0x3L, 1L, 1L, 0L },
  { 0x0C7L, 0x3EBL, 0x3L, 1L, 1L, 0L },
  { 0x0F8L, 0x3E0L, 0x3L, 1L, 1L, 0L },
  { 0x128L, 0x3D2L, 0x3L, 1L, 1L, 0L },
  { 0x158L, 0x3C3L, 0x3L, 1L, 1L, 0L },
  { 0x187L, 0x3B1L, 0x3L, 1L, 1L, 0L },
  { 0x1B5L, 0x39CL, 0x3L, 1L, 1L, 0L },
  { 0x1E2L, 0x386L, 0x3L, 1L, 1L, 0L },
  { 0x20DL, 0x36DL, 0x3L, 1L, 1L, 0L },
  { 0x238L, 0x352L, 0x3L, 1L, 1L, 0L },
  { 0x261L, 0x335L, 0x3L, 1L, 1L, 0L },
  { 0x288L, 0x316L, 0x3L, 1L, 1L, 0L },
  { 0x2AFL, 0x2F5L, 0x3L, 1L, 1L, 0L },
  { 0x2D3L, 0x2D3L, 0x3L, 1L, 1L, 0L },
  { 0x2F5L, 0x2AFL, 0x3L, 1L, 1L, 0L },
  { 0x316L, 0x288L, 0x3L, 1L, 1L, 0L },
  { 0x335L, 0x261L, 0x3L, 1L, 1L, 0L },
  { 0x352L, 0x238L, 0x3L, 1L, 1L, 0L },
  { 0x36DL, 0x20DL, 0x3L, 1L, 1L, 0L },
  { 0x386L, 0x1E2L, 0x3L, 1L, 1L, 0L },
  { 0x39CL, 0x1B5L, 0x3L, 1L, 1L, 0L },
  { 0x3B1L, 0x187L, 0x3L, 1L, 1L, 0L },
  { 0x3C3L, 0x158L, 0x3L, 1L, 1L, 0L },
  { 0x3D2L, 0x128L, 0x3L, 1L, 1L, 0L },
```

```
{ 0x3E0L, 0x0F8L, 0x3L, 1L, 1L, 0L },
{ 0x3EBL, 0x0C7L, 0x3L, 1L, 1L, 0L },
{ 0x3F3L, 0x096L, 0x3L, 1L, 1L, 0L },
{ 0x3FAL, 0x064L, 0x3L, 1L, 1L, 0L },
{ 0x3FDL, 0x032L, 0x3L, 1L, 1L, 0L },

{ 0x3FFL, 0x000L, 0x2L, 1L, 1L, 0L },    /* 3rd quadrant */
{ 0x3FDL, 0x032L, 0x2L, 1L, 1L, 0L },
{ 0x3FAL, 0x064L, 0x2L, 1L, 1L, 0L },
{ 0x3F3L, 0x096L, 0x2L, 1L, 1L, 0L },
{ 0x3EBL, 0x0C7L, 0x2L, 1L, 1L, 0L },
{ 0x3E0L, 0x0F8L, 0x2L, 1L, 1L, 0L },
{ 0x3D2L, 0x128L, 0x2L, 1L, 1L, 0L },
{ 0x3C3L, 0x158L, 0x2L, 1L, 1L, 0L },
{ 0x3B1L, 0x187L, 0x2L, 1L, 1L, 0L },
{ 0x39CL, 0x1B5L, 0x2L, 1L, 1L, 0L },
{ 0x386L, 0x1E2L, 0x2L, 1L, 1L, 0L },
{ 0x36DL, 0x20DL, 0x2L, 1L, 1L, 0L },
{ 0x352L, 0x238L, 0x2L, 1L, 1L, 0L },
{ 0x335L, 0x261L, 0x2L, 1L, 1L, 0L },
{ 0x316L, 0x288L, 0x2L, 1L, 1L, 0L },
{ 0x2F5L, 0x2AFL, 0x2L, 1L, 1L, 0L },
{ 0x2D3L, 0x2D3L, 0x2L, 1L, 1L, 0L },
{ 0x2AFL, 0x2F5L, 0x2L, 1L, 1L, 0L },
{ 0x288L, 0x316L, 0x2L, 1L, 1L, 0L },
{ 0x261L, 0x335L, 0x2L, 1L, 1L, 0L },
{ 0x238L, 0x352L, 0x2L, 1L, 1L, 0L },
{ 0x20DL, 0x36DL, 0x2L, 1L, 1L, 0L },
{ 0x1E2L, 0x386L, 0x2L, 1L, 1L, 0L },
{ 0x1B5L, 0x39CL, 0x2L, 1L, 1L, 0L },
{ 0x187L, 0x3B1L, 0x2L, 1L, 1L, 0L },
{ 0x158L, 0x3C3L, 0x2L, 1L, 1L, 0L },
{ 0x128L, 0x3D2L, 0x2L, 1L, 1L, 0L },
{ 0x0F8L, 0x3E0L, 0x2L, 1L, 1L, 0L },
{ 0x0C7L, 0x3EBL, 0x2L, 1L, 1L, 0L },
{ 0x096L, 0x3F3L, 0x2L, 1L, 1L, 0L },
{ 0x064L, 0x3FAL, 0x2L, 1L, 1L, 0L },
{ 0x032L, 0x3FDL, 0x2L, 1L, 1L, 0L },

{ 0x000L, 0x3FFL, 0x1L, 1L, 1L, 0L },    /* 2nd quadrant */
{ 0x032L, 0x3FDL, 0x1L, 1L, 1L, 0L },
{ 0x064L, 0x3FAL, 0x1L, 1L, 1L, 0L },
{ 0x096L, 0x3F3L, 0x1L, 1L, 1L, 0L },
{ 0x0C7L, 0x3EBL, 0x1L, 1L, 1L, 0L },
{ 0x0F8L, 0x3E0L, 0x1L, 1L, 1L, 0L },
{ 0x128L, 0x3D2L, 0x1L, 1L, 1L, 0L },
{ 0x158L, 0x3C3L, 0x1L, 1L, 1L, 0L },
{ 0x187L, 0x3B1L, 0x1L, 1L, 1L, 0L },
{ 0x1B5L, 0x39CL, 0x1L, 1L, 1L, 0L },
{ 0x1E2L, 0x386L, 0x1L, 1L, 1L, 0L },
{ 0x20DL, 0x36DL, 0x1L, 1L, 1L, 0L },
{ 0x238L, 0x352L, 0x1L, 1L, 1L, 0L },
{ 0x261L, 0x335L, 0x1L, 1L, 1L, 0L },
{ 0x288L, 0x316L, 0x1L, 1L, 1L, 0L },
{ 0x2AFL, 0x2F5L, 0x1L, 1L, 1L, 0L },
{ 0x2D3L, 0x2D3L, 0x1L, 1L, 1L, 0L },
{ 0x2F5L, 0x2AFL, 0x1L, 1L, 1L, 0L },
{ 0x316L, 0x288L, 0x1L, 1L, 1L, 0L },
{ 0x335L, 0x261L, 0x1L, 1L, 1L, 0L },
{ 0x352L, 0x238L, 0x1L, 1L, 1L, 0L },
{ 0x36DL, 0x20DL, 0x1L, 1L, 1L, 0L },
{ 0x386L, 0x1E2L, 0x1L, 1L, 1L, 0L },
{ 0x39CL, 0x1B5L, 0x1L, 1L, 1L, 0L },
{ 0x3B1L, 0x187L, 0x1L, 1L, 1L, 0L },
{ 0x3C3L, 0x158L, 0x1L, 1L, 1L, 0L },
{ 0x3D2L, 0x128L, 0x1L, 1L, 1L, 0L },
{ 0x3E0L, 0x0F8L, 0x1L, 1L, 1L, 0L },
{ 0x3EBL, 0x0C7L, 0x1L, 1L, 1L, 0L },
{ 0x3F3L, 0x096L, 0x1L, 1L, 1L, 0L },
{ 0x3FAL, 0x064L, 0x1L, 1L, 1L, 0L },
```

```
    { 0x3FDL, 0x032L, 0x1L, 1L, 1L, 0L },

    { 0x3FFL, 0x000L, 0x0L, 1L, 1L, 0L },    /* 1st quadrant */
    { 0x3FDL, 0x032L, 0x0L, 1L, 1L, 0L },
    { 0x3FAL, 0x064L, 0x0L, 1L, 1L, 0L },
    { 0x3F3L, 0x096L, 0x0L, 1L, 1L, 0L },
    { 0x3EBL, 0x0C7L, 0x0L, 1L, 1L, 0L },
    { 0x3E0L, 0x0F8L, 0x0L, 1L, 1L, 0L },
    { 0x3D2L, 0x128L, 0x0L, 1L, 1L, 0L },
    { 0x3C3L, 0x158L, 0x0L, 1L, 1L, 0L },
    { 0x3B1L, 0x187L, 0x0L, 1L, 1L, 0L },
    { 0x39CL, 0x1B5L, 0x0L, 1L, 1L, 0L },
    { 0x386L, 0x1E2L, 0x0L, 1L, 1L, 0L },
    { 0x36DL, 0x20DL, 0x0L, 1L, 1L, 0L },
    { 0x352L, 0x238L, 0x0L, 1L, 1L, 0L },
    { 0x335L, 0x261L, 0x0L, 1L, 1L, 0L },
    { 0x316L, 0x288L, 0x0L, 1L, 1L, 0L },
    { 0x2F5L, 0x2AFL, 0x0L, 1L, 1L, 0L },
    { 0x2D3L, 0x2D3L, 0x0L, 1L, 1L, 0L },
    { 0x2AFL, 0x2F5L, 0x0L, 1L, 1L, 0L },
    { 0x288L, 0x316L, 0x0L, 1L, 1L, 0L },
    { 0x261L, 0x335L, 0x0L, 1L, 1L, 0L },
    { 0x238L, 0x352L, 0x0L, 1L, 1L, 0L },
    { 0x20DL, 0x36DL, 0x0L, 1L, 1L, 0L },
    { 0x1E2L, 0x386L, 0x0L, 1L, 1L, 0L },
    { 0x1B5L, 0x39CL, 0x0L, 1L, 1L, 0L },
    { 0x187L, 0x3B1L, 0x0L, 1L, 1L, 0L },
    { 0x158L, 0x3C3L, 0x0L, 1L, 1L, 0L },
    { 0x128L, 0x3D2L, 0x0L, 1L, 1L, 0L },
    { 0x0F8L, 0x3E0L, 0x0L, 1L, 1L, 0L },
    { 0x0C7L, 0x3EBL, 0x0L, 1L, 1L, 0L },
    { 0x096L, 0x3F3L, 0x0L, 1L, 1L, 0L },
    { 0x064L, 0x3FAL, 0x0L, 1L, 1L, 0L },
    { 0x032L, 0x3FDL, 0x0L, 1L, 1L, 0L } },
...
      } };
```

5.3 Values for ZPD Operation

5.3.1 Addressing in ZPD Mode

When in ZPD mode for a channel, the addressing range for this channel is changed to the ZPD table sections of the *PWM Value RAM*.

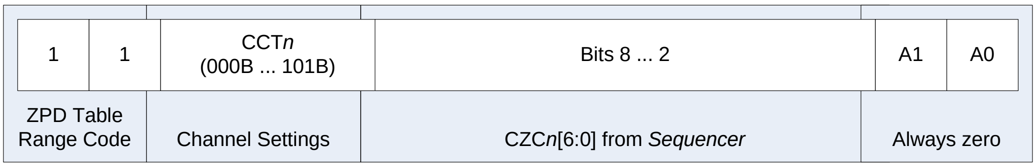


Figure 5-5 ZPD Table Addressing Layout

Again, the virtual channel number is used to select a ZPD table in general. Like this, the same ZPD table can be used to serve for several physical channels.

In contrary to the “regular” PWM operation mode, now simply the current ZPD table index *CZCn* is used for the addressing. Here, the RAM is no longer used as a “translator”, but used as an instruction table.

The instructions are derived from the data contents of the RAM, which are triggering measurements, causing delays, setting outputs and selecting inputs. In detail, the data format looks like this:

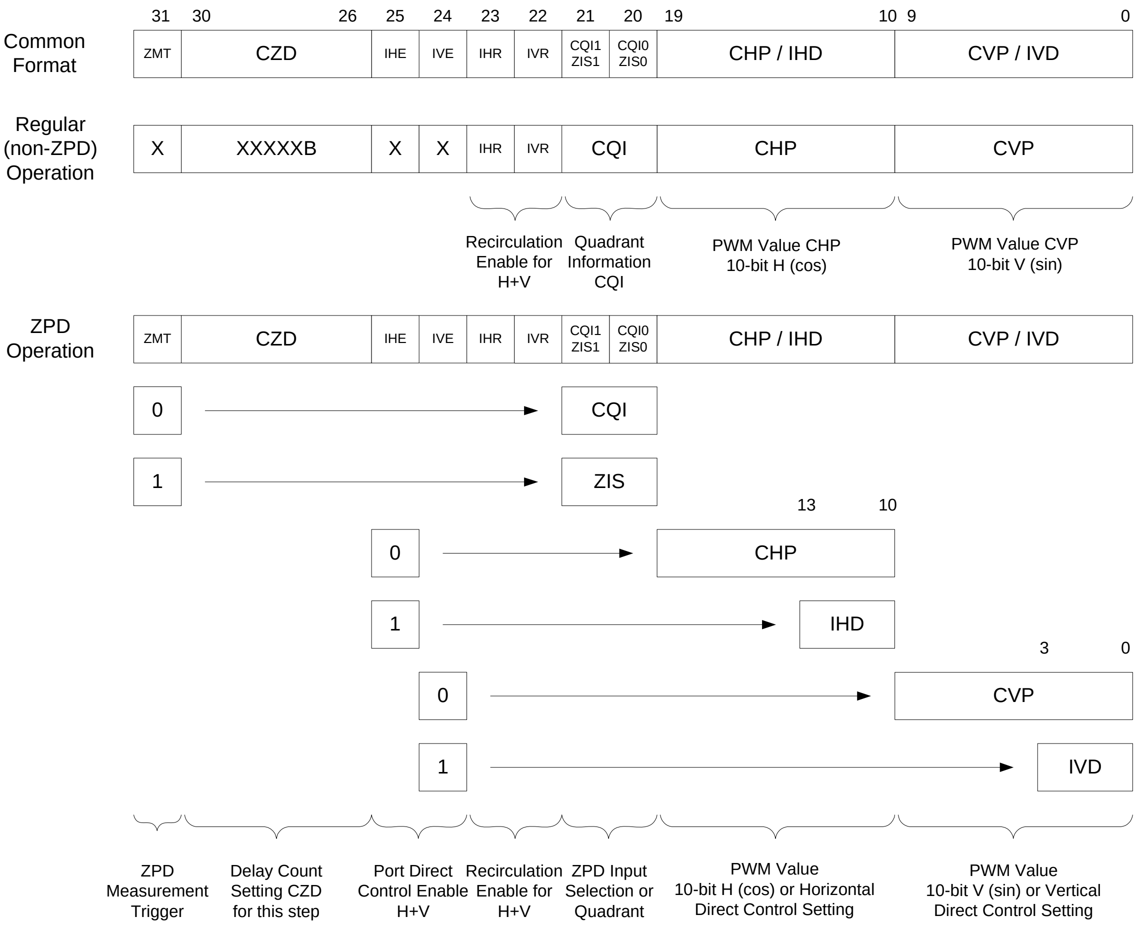


Figure 5-6 Common PWM Value RAM Data Format

Chapter 6 Performing Movements

Within this section, the movement of stepper motors using the *Channel Management* and the *Movement Calculator* is discussed. Operation with *Zero Point Detection* can be found in Chapter *7 "Performing Zero Point Detection" on page 37* .

6.1 Parameters and Variables

In order to understand the automated movement of a stepper motor by ISM, the knowledge about its parameters and variables is essential.

The *Movement Calculator* is using the parameters as constants for its algorithm, and it stores temporary values and results in variables.

Notes

1. The most important variable is *VAPn*, which shows the actual position in macro- and microsteps of a (physical) channel *n*. If *VAPn* matches *PMPn* (which is the target motor position to move to), the motor movement is stopped and the interrupt *IRQ_REACHED* is generated.
2. Be careful when thinking about the term "channel". For the PWM tables, there are ***"virtual"*** channels *CCTn*. This means, that for each physical channel *n*, a set of PWM values can be chosen. However, all other parts of ISM, including the *Movement Calculator* and its parameters and variables, are always referring to ***physical*** channels.

For parameters and variables there is no software reset (only by hardware), so that parameters and variables shall be initialized by software before starting or re-starting the *Channel Management*. Parameters and variables must not be changed during operation of the *Channel Management*, except *PMPn.*

As an overview, the following parameters and variables are existing for each physical channel *n*, and they are all accessible by software via registers. Most of them have a common format using 25 bits.

Table 6-1 Parameters of the Movement Calculator

Parameter	Abbreviation / Bit Name	Width / Bits	Register Name
Target Motor Position[a]	PMP	25	ISM*x*PAR0CFG*n*
Damping Factor	PDF	3	ISM*x*PAR1CFG*n*
Acceleration Limit	PAL	25	ISM*x*PAR2CFG*n*
Deceleration Limit	PDL	25	ISM*x*PAR3CFG*n*
Maximum Speed	PMS	25	ISM*x*PAR4CFG*n*
Hysteresis Correction	PHC	25	ISM*x*PAR5CFG*n*
Speed Threshold 1	PS1	25	ISM*x*PAR6CFG*n*
Speed Threshold 2	PS2	25	ISM*x*PAR7CFG*n*
Speed Threshold 3	PS3	25	ISM*x*PAR8CFG*n*
Speed Threshold 4	PS4	25	ISM*x*PAR9CFG*n*

a) This parameter is double-buffered. Change by software is possible at any time without disturbances. On each *START* event, the buffered value is updated.

Table 6-2 Variables of the Movement Calculator

Variable	Abbreviation / Bit Name	Width / Bits	Register Name
Actual Acceleration / Deceleration	VAX	25	ISM*x*VAR0CFG*n*
Actual Speed	VAS	25	ISM*x*VAR1CFG*n*
Previous Iteration Speed	VPS	25	ISM*x*VAR2CFG*n*
Temporary Calculator Register PT1	VPT	25	ISM*x*VAR3CFG*n*
Actual Position, Current Result	VAP	25	ISM*x*VAR4CFG*n*
Virtually Displayed Position	VVP	25	ISM*x*VAR5CFG*n*
Direction Flag	VDR	1	ISM*x*VAR6CFG*n*
Speed Flag	VSP	1	ISM*x*VAR7CFG*n*

6.1.1 Common 25-bit Number Format

For all parameters and variables which are 25 bits wide, a common number format is given.

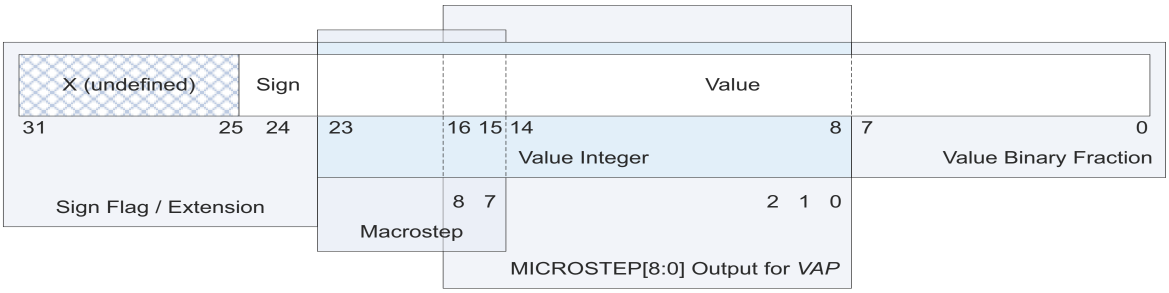


Figure 6-1 Common 25-bit Number Format

The number format consists of a sign flag, the macrosteps and the microsteps values. The storage format is a binary fixed-point format, with bits [23:8] being the integer and [7:0] the fraction part. Bit 24 is the sign (positive/negative), which can be extended by software to 32 bits by copying bit 24. Negative values are stored in 2’s complement.

(1) Sign Flag

All numbers within the *Movement Calculator* are signed numbers. This means, that the position of ***zero*** is a relative one. In fact, movements are always calculated by relative distances. If by software the variable *VAP* is set to a certain value *p*, before the *Channel Management* is started, this position now is assumed to be the actual position. To move towards zero by more steps than *p*, a negative value for the target position *PMP* would be entered.

Negative numbers have the sign flag set (1).

Note It makes sense to clear *PMPn* and *VAPn* after having reached the mechanical zero point of an instrument (i.e., by *Zero Point Detection*). Like this, all position values would be positive, and other values would have a positive sign, if their direction would point away from the mechanical stop, or have a negative sign, if their direction would point towards the mechanical stop.

(2) Value Integer

For position values, the value integer consists of the macrosteps and the microsteps. Depending on the precision setting of a channel (*CCPn*), either 9 or 7 bits are reserved for the microsteps, and the remaining bits up to bit 23 are used for the macrosteps.

(3) Value Binary Fraction

This part represents the fractional part of the value. Its binary step is $^{1}/_{256}$ of the value integer.

The binary fraction is used for internal calculations only. For user software, the following rules are important:

1. When setting the parameter *PMPn*,
   all bits of the binary fraction have to be ***set***.
2. When setting all other parameters or variables by software,
   all bits of the binary fraction have to be ***cleared***.

Caution If rule (1) is not followed, it may happen that because of permanent deviation of the algorithm, a target position can never be reached.

- The deviation of the algorithm of the *Movement Calculator* is less than 1 microstep.
- When moving “upwards”, the algorithm may stop less than 1 microstep below the target position, which however results in one count too less for the microstep, but an added fractional value. Like this, the position reached interrupt (*IRQ_REACHEDn*) can never be generated, because this interrupt is based on a comparison on *Value Integer* level.
- When moving “downwards”, the algorithm has no deviation. Therefore the target position can be reached in any case, independently of any settings of the binary fraction.

6.1.2 Parameter Description

(1) Target Position *PMPn*

Represents the requested target position of the motor, given in macrosteps (full turns) and microsteps (angle). The target position can be a negative number.

• Unit:	Absolute Position
• Example Setting: (for low precision setting, sine/cosine table)	0x001234FF +36 turns, 146°

(2) Damping Factor *PDFn*

Represents the inertia of the algorithm. The value given here is not a 25-bit number, but only a 3-bit number. It is the exponent 2^{PDF}, which divides the theoretical maximum speed required to reach the target position within only one algorithm pass.

• Unit:	Factor
• Example Setting: (chosen speed on every algorithm pass)	0x6 $^{1}/_{64}$ of maximum speed

(3) Acceleration Limit, Deceleration Limit *PALn, PDLn*

If acceleration or deceleration of the motor would become larger than these limits, acceleration or deceleration is set to these values. After a new speed has been calculated, the algorithm determines the corresponding acceleration/ decelerations and by case, it limits the speed, so that the acceleration and deceleration limits cannot be crossed.

• Unit: (from the physics: distance / time^2)	Acceleration: Microsteps * (CM Update Frequency)^2
• Example settings:	0x00000020
(using an update period *GUD* of 10 ms)	1250 microsteps / second^2
(for low precision setting)	9.77 turns / s^2

(4) Maximum Speed *PMSn*

If the speed of a motor would becomer larger than this limit, either positive or negative, the speed is limited to this value. The speed limit works independently of the acceleration limit.

• Unit: (from the physics: distance / time)	Speed: Microsteps * (CM Update Frequency)
• Example setting:	0x000009C0
(using an update period *GUD* of 10 ms)	975 microsteps / second
(for low precision setting)	7.62 turns / second

(5) Hysteresis Correction *PHCn*

Position values of *VAPn*, which are less than the given hysteresis by *PHCn* will be indicated to software as “zero” position, when software reads the current position via the *VVPn* variable. Also, *VVPn* always indicates a position which is by *PHCn* less than *VAPn*. Like this, the variable *VVPn* can be used by software as a dynamically compressed readout of the actual position.

• Unit:	Distance
• Example setting:	0x00000700
(indicated as still at zero)	+/- 7 turns of the motor

(6) Speed Thresholds *PS1n, PS2n, PS3n, PS4n*

Speed marks for switching of the *VSPn* flag, which dynamically switches the PWM tables for low-speed and high-speed operation of the motor. While *PS3n* and *PS4n* are marking a speed range for the high-speed operation, the values of *PS1n* and *PS2n* are marking the outside ranges for the low-speed operation. See *6.1.4 “Algorithm Code”* for details on these thresholds.

• Unit: (from the physics: distance / time)	Speed: Microsteps * (CM Update Frequency)
• Example settings:	*PS1* = 0x0000010E
	PS2 = 0x00000620
	PS3 = 0x000001C3
	PS4 = 0x0000056B

(calculate speed in the same way as for *4 “Maximum Speed PMSn”*).

6.1.3 Variable Description

(1) Actual Algorithm Values *VAXn, VASn, VAPn*

These values are representing the current *Movement Calculator* results for the physical channel *n*. Acceleration, speed and position values have to be interpreted like their associated parameter values.

Checking the values is possible anytime to monitor the movements by software.

(2) Temporary Storages *VPSn, VPTn*

These are internal values of the *Movement Calculator*, to resume the calculation after the next processing start. Previously calculated values and intermediate results are stored there.

Software access to these values is not senseful, but nevertheless possible.

(3) Virtual Position *VVPn*

A position value, which was submitted a hysteresis can be derived from the *VVPn* variable. Its generation is explained in *5 "Hysteresis Correction PHCn".*

(4) Flags of PWM Table Selection on Low-Precision Operation *VDRn, VSPn*

These flags are representing the PWM sub-table selection within a physical channel 's assigned virtual table set, if low-precision operation is chosen (*CCPn* is cleared).

In case of high-precision operation, these flags have no meaning, and the associated parameters *PS1n, PS2n, PS3n* and *PS4n* are not considered.

6.1.4 Algorithm Code

```
/* Calculation of new acceleration and speed */

VPT      =    VPT + ( ( PMP - VPT) >> PDF )
VAS      =    ( VPT - VAP ) >> PDF
VAX      =    VAS - VPS

/* Limitation of the acceleration and speed */

if ( VPS > 0 )
{
     if ( VAX > PAL )
     {
          VAS = VPS + PAL
     }

     if ( VAX < ( - PDL ) )
     {
          VAS = VPS - PDL
     }
}
else
{
     if ( VAX < ( - PAL ) )
     {
          VAS = VPS - PAL
     }

     if ( VAX > PDL )
     {
          VAS = VPS + PDL
```

```
        }
}

if ( VAS >= 0 )
{
        if ( VAS > PMS )
        {
                VAS = PMS
        }
}
else
{
        if ( ( -VAS ) > PMS )
        {
                VAS = ( - PMS )
        }
}

/* Result output for Microstep & store old speed */

VAP     =    VAP + VAS
VPS     =    VAS

/* Calculate SW displayed position */

if ( ( VAP - VVP ) > PHC )
{
        VVP = VAP - PHC
}

if ( ( VAP - VVP ) < ( - PHC ) )
{
        VVP = VAP + PHC
}

/* Select Table according to speed and direction */

if ( VAS > 0 )
{
        VDR = 0

        if ( ( VAS <= PS1 ) or ( VAS >= PS2 ) )
        {
                VSP = 0
        }

        else
        {
                VSP = VSP
        }

        if( ( VAS >= PS3 ) and( VAS <= PS4 ) )
        {
                VSP = 1
        }

        else
        {
                VSP = VSP
        }
}
else
{
        if ( VAS < 0 )
        {

                VDR = 1

                if ( ( ( -VAS ) <= PS1 ) or ( ( -VAS ) >= PS2 ) )
                {
```

```
                    VSP = 0
                }

                else
                {
                    VSP = VSP
                }

                if ( ( ( -VAS ) >= PS3 ) and( ( -VAS ) <= PS4 ) )
                {
                    VSP = 1
                }

                else
                {
                    VSP = VSP
                }
            }
        }

        if ( VAS == 0 )
        {
            VSP = 0
        }

        /* Negative Position suppression */

        if ( VAP < 0 )
        {
            VAP = 0
        }
```

6.2 Moving the Motors

Having all parameters set, the timebases defined and the RAM PWM tables set up, the motor movement can be started by activating the *Channel Management* for the selected channels.

Caution When using stepper motor hardware, always enable *Recirculation*. Otherwise, caused by the inductive load, damage to the output drivers may happen.

The following diagram shows a movement graphically, by reading out the variables by software.

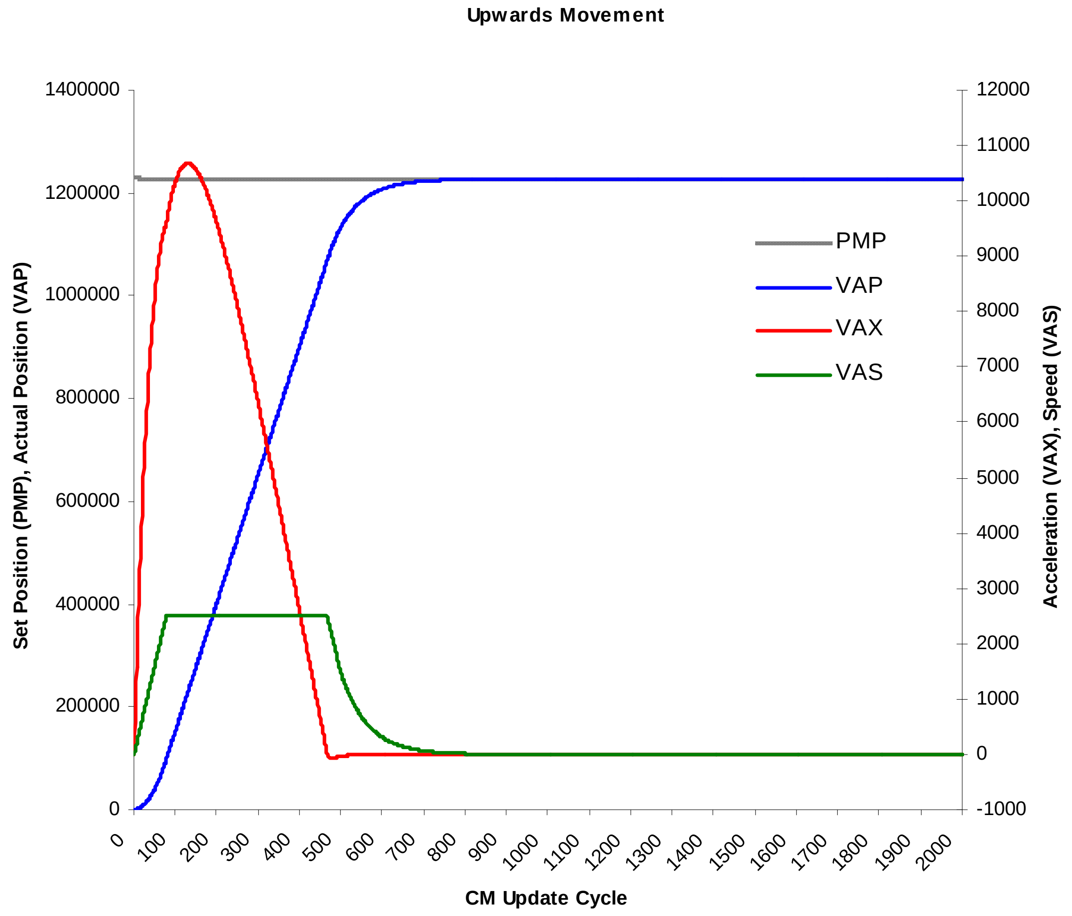


Figure 6-2 Graphical Movement Illustration

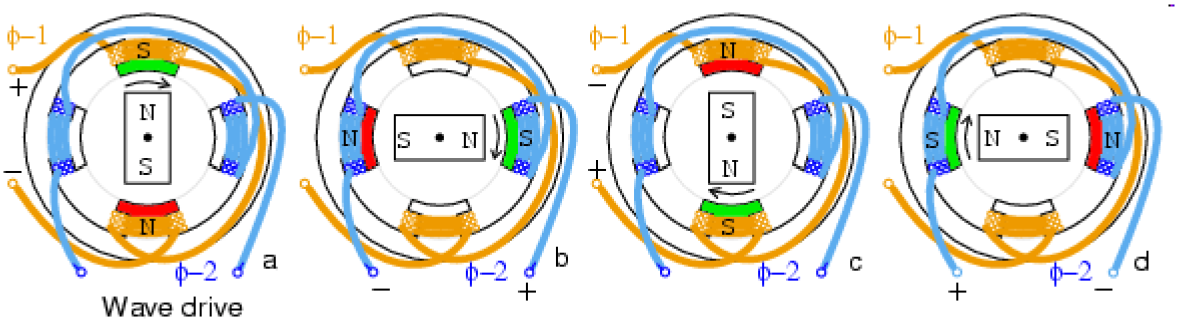
Chapter 7 Performing Zero Point Detection

7.1 Zero Point Detection (ZPD) Theory

In order to define the ZPD table entries, base knowledge about zero point detection is required. Let's have a look into a simplified stepper motor. In the following figure, four steps of movement are shown, one for each quadrant of the motor's anchor.

Within each quadrant, it is possible to detect, whether the motor could move, or whether it had hit its mechanical stop, and therefore, it could not move.

The detection of the mechanical stop is performed by measuring inductive pulses one one coil set, while the other coil set is powered for a movement of the anchor.



Φ1 Powered, Φ2 for Measure	Φ2 Powered, Φ1 for Measure	Φ1 Powered, Φ2 for Measure	Φ2 Powered, Φ1 for Measure

Figure 7-1 Four Quadrant Zero Point Detection[1]

Surely, it is not required to perform the measurement for all four quadrants. Alternatively, it's also possible to move the motor a full turn, and perform a measurement only in one of the four steps above.

Regarding the ZPD algorithms, there is some trade-off between quality (smoothness of movement, noise on hitting the stop) and the capabilities of the motor and the stepper motor driver hardware. From 1 to 4, the quality of ZPD increases:

1. Single-Quadrant ZPD
   One full turn of the motor in 90° steps, one measurement at 0°.
2. Single-Quadrant ZPD with PWM movement
   One full turn of the motor in fine PWM microsteps, accelerating sequence, one measurement at 0°.
3. Four-Quadrant ZPD
   Quarter-turn of the motor, measurement after each quarter-turn.
4. Four-Quadrant ZPD with PWM movement
   Quarter-turn of the motor by fine PWM microsteps, accelerating sequence, measurement after each quarter-turn.

ISM supports all four approaches.

1) Figure by "Lessons In Electric Circuits copyright (C) 2000-2012 Tony R. Kuphaldt"

7.1.1 The ZPD Measurement Principle

For all 4 cases, the same measurement principle is applied:

An analogue measurement of induced voltage is performed, while the other coil moves the anchor. If the anchor is still able to move, it will cause a small voltage induction in the measurement coil. If the motor has hit the mechanical stop, the anchor will almost not move any longer, and the induced voltage will decrease or disappear.

(1) Finding the Measurement Time Window

Typically, the measurement waveforms could look like this:

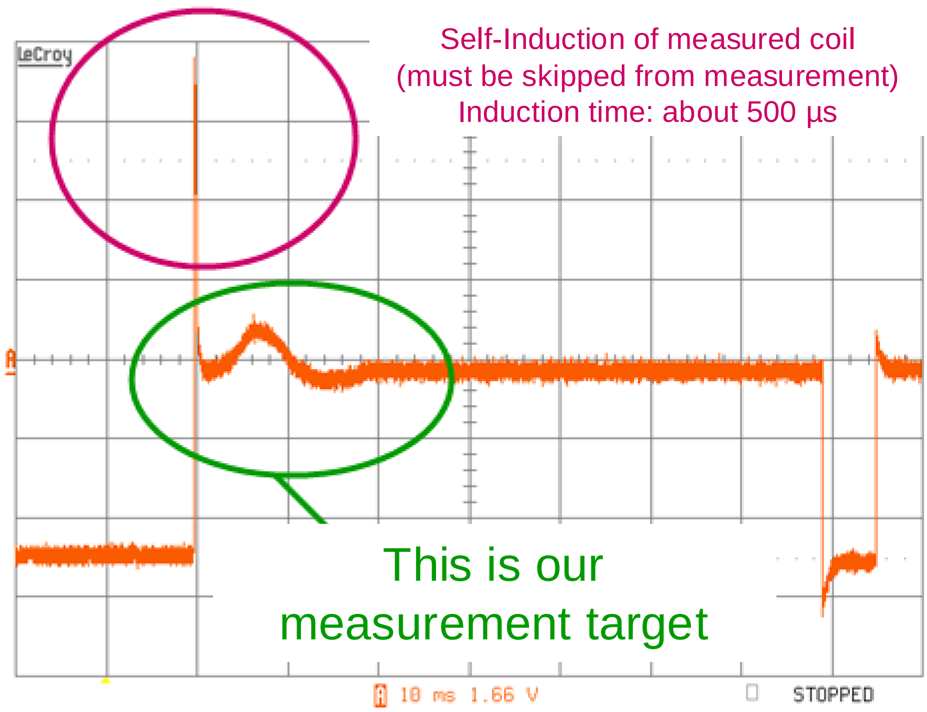


Figure 7-2 ZPD Measurement Waveform

Caused by the previous movement, the coil also creates a self-induction, when its current is switched off and it is attached to the measurement input. This self-induction is not relevant for the ZPD status, and therefore it must be reduced (also to protect our measurement circuitry) and blanked out from the measurement window.

Reduction of the self-induction can be performed by creating a short-circuit on the coil for a limited amount of time.

The measurement window has to be chosen by delaying the measurement start and limitation of the measurement time.

(2) Determining the Measurement Voltage Level

As a target, a voltage detector (comparator) has to be set up such, that it shows an indication above its level, if the zero point (ZP) has not yet been reached (induction was found), and that it shows an indication below its level, if the ZP has been reached (no induction was found). Like this, the ZP status is digitized into a single binary state flag.

As shown in the following figure, the difference in the voltage level between a reached ZP and a still turning motor is quite small.

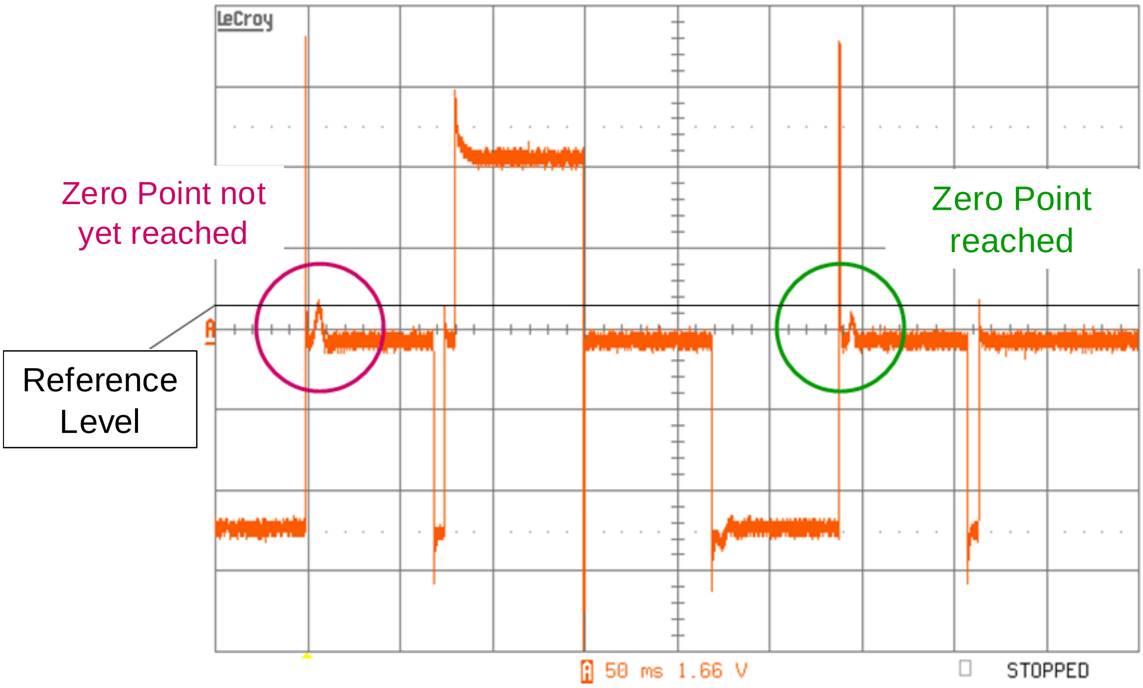


Figure 7-3 Reaching the Zero Point

In the best case, the induced voltage is slightly below the selected analogue reference level, when the ZP is reached.

If this is not the case, the reference level should be selected such, that it is by one selection step lower than the induced voltage, even if the ZP is reached. The remaining detection of the level in detail then has to be perfomed by using the digital filtering features of ISM.

(3) Definition of the Measurement Window using the Blanking Time

In general, ISM provides two options (which can also be combined), to set the timing of the measurement window: The *Blanking Time* and the ZPD table itself.

The *Blanking Time* is an additional delay, which can be applied optionally after a measurement start trigger (*ZMTn* set in the ZPD table).

Using the *Blanking Time* allows a delayed measurement start in a certain range, so that the self-induction phase of the coil and other undesired noisy phases can be skipped (blanked out).

The *Blanking Time* can be defined by the setting *ZBTn* for each physical channel individually. The value of *ZBTn* represents the number of *Measurement Cycles*[1] to wait, until the measurement phase is started.

The measurement phase then is shortened in its beginning by the *Blanking Time*.

The following figure shows the waveform of the induced voltage, while the ZP is not yet reached, and how the electrical parameters and delays can be set to define the measurement window.

1) See *7.2.2 "ZPD Measurement Cycles"* for details.

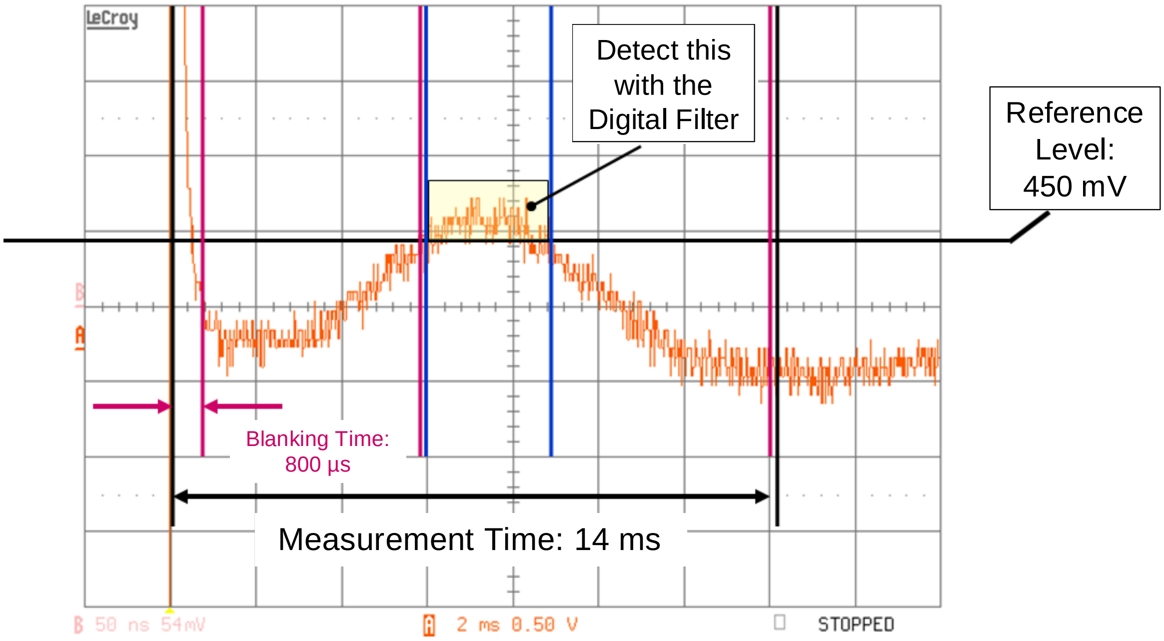


Figure 7-4 Using the Blanking Time

(4) Definition of the Measurement Window using the ZPD Table

As the ZPD table itself is a timed execution list, all timing can be derived from it, as long as the timing requirement is within the precision of the ZPD table execution (this depends on the *GUD* setting).

As an example, the measurement window also can be defined like this (we are assuming a cycle frequency of the *Channel Management* (*GUD*) of 500 Hz):

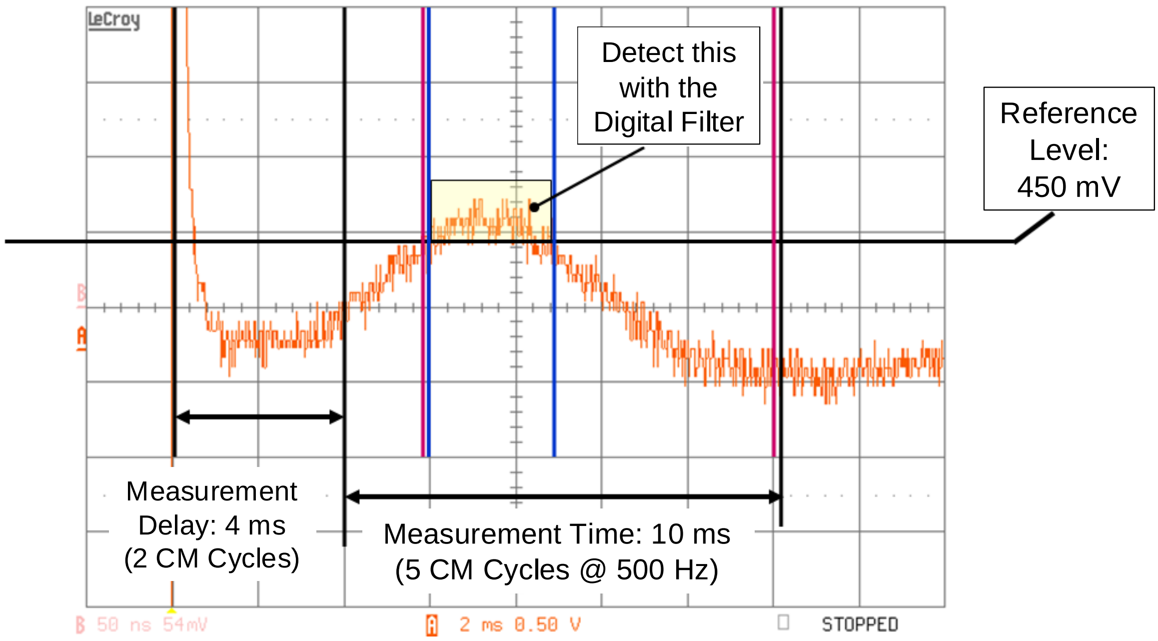


Figure 7-5 Using the Timing of the ZPD Table

(5) Setting up the Digital Filter of ZPD

The digital filter of the ZPD function of ISM has a maximum *depth* of 16 measurements. After each measurement phase, the digital filter compares the amount of measurement results, which have been above the reference level, against its filter *level*. If the level is less than this amount, the digital filter indicates a “one”, which is equal to a filtered signal above the reference level. Like this, the digital filter works like an adjustable *integration function.*

To achieve the best effectiveness of the filter with maximum adjustability, it is recommendable to have at least so many sampling points of the filter during the measurement window, that it is enough to use the full depth of the filter, if at least one *Measurement Cycle* is performed. Then, the variable integration can be adjusted in the full range of the filter depth.

Thus, in our example, we are using a *Measurement Cycle,* that allows us to repeat 15 times within the measurement window. Like this, it is a remaining option for us, either to use one *Measurement Cycle* with 15 sampling points, or to use more *Measurement Cycles* with less sampling points of the filter.

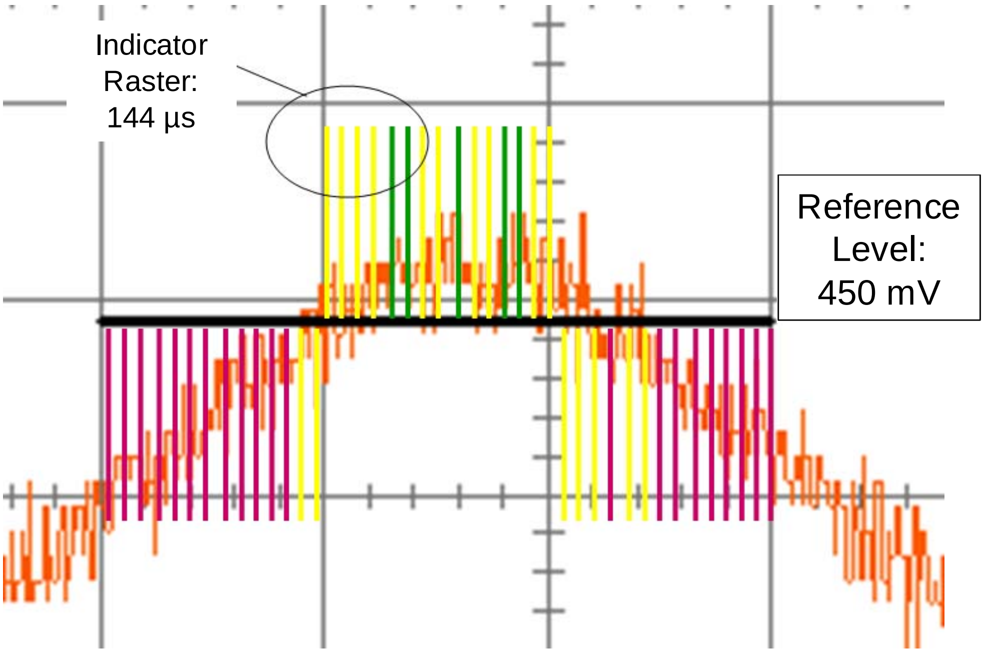


Figure 7-6 Setting up the Digital Filter of ZPD

Every green bar is representing a measurement, where the voltage of the signal was clearly above the reference level. Red bars are indicating measurements, where the voltage of the signal was clearly below the reference level. And the yellow bars are indicating measurements, where some uncertainty exists.

If we now set the digital filter *depth* to 15, *level* to a value between 1 and 3, the result of this single *Measurement Cycle* would be “one”, thus indicating that the ZP is not yet reached. A digital filter level of 6 or higher would cause a result of “zero” of the filter, because the amount of measurements above the level is not enough. In this case, the filter would indicate that the ZP was reached.

Now, depending on the condition when this measurement was taken (ZP or not ZP), the digital filter level can be set accordingly.

Note In most cases, the reference level on its own is enough to detect the ZP clearly. Then, the digital filter can be generally disabled by setting depth and level to 1. The digital filter is an additonal aid for detection in difficult cases.

7.2 The ZPD Function Settings

7.2.1 Analogue Hardware of ZPD

Attached to ISM, there is a quite sophisticated set of analogue hardware beside it. This hardware is activated by the flag *GZE*, powered by the flag *GZP*, and linked to ISM by the flag *GZL*.

Note ISM is capable to switch the direction of its ports dynamically during its operation. This feature is essential for the ZPD measurements. Therefore, take care that the appropriate port setting is activated, to let ISM have control on the port direction.

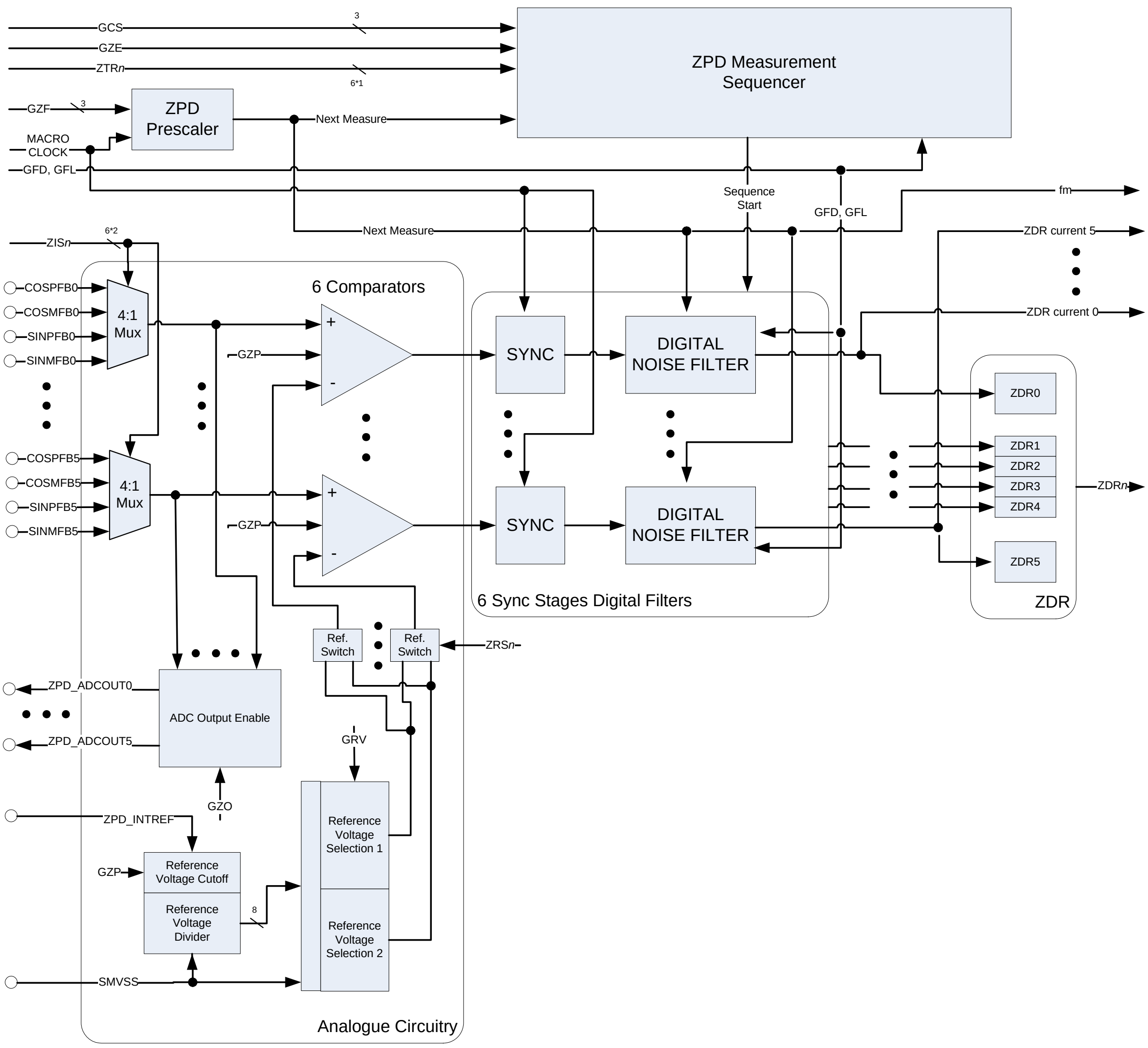


Figure 7-7 ZPD Analogue Circuitry

For each channel, one of its four ports can be assigned by *ZISn* for the measurement input of its individual analogue comparator. Common to all comparators are two selectable and adjustable reference sources *GRV*, which are defining the two different reference levels that can be assigned by *ZRSn*.

Behind this analogue stuff, the digital filters are attached, one for each channel with common settings *GFL*n and *GFDn*.

7.2.2 ZPD Measurement Cycles

The ZPD units within ISM have their own clocking scheme. Therefore, the clocking of ZPD is set independently from other ISM functionality by using the settings of *GZF, GCS* and *GFD.*

With these parameters, the *Measurement Cycle* of ZPD is defined as a frequency f_m.

$$fm = \frac{f(MACRO\_CLK)}{(GZF\ Factor) \times (GCS + GFD)}$$

In detail, the *Measurement Cycle* of ZPD looks like this:

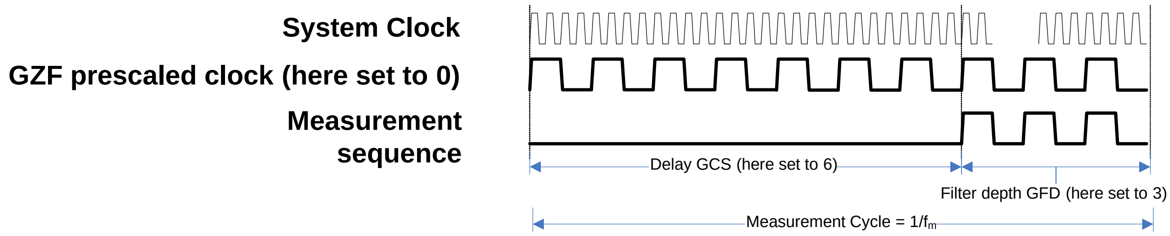


Figure 7-8 The ZPD Measurement Cycle

Whenever the ZPD measurement is active (*ZMTn* is set for a channel), the *Measurement Cycles* are continuously repeated. If at least one cycle detects that the ZP is not reached, this flag is kept stored and will cause that after stopping the measurement, the status of ZPD is “ZP not yet reached”.

During the time of *GCS*, no measurements are taken, because this is the analogue hardware settling time, where voltage jumps by possible port switchings before the measurement start are skipped.

(1) Example how to set up the Measurement Cycle

In the previous examples of ZPD measurement, certain settings have been assumed. Within this paragraph, the way to define these settings is described.

The example is defining a *Measurement Cycle* of 144 µs with 16 measurements.

1. Having one *Measurement Cycle* in the measurement window
   – We select to use a *GCS* delay of 1, and a filter depth *GFD* of 15. This yields an amount of 16 prescaled clocks of ZPD.
   – To fit the 16 clocks into 144 µs, a ZPD prescaled clock of 111 kHz is required.
   – If we assume a system clock of 80 MHz, a divider of 720 would be

required. So, we choose *GZF* to be 14 (factor $^1/_{512}$), and we are running a little bit faster.

2. Having four *Measurement Cycles* in the measurement window
   – We select to use a *GCS* delay of 1, and a filter depth *GFD* of 3. This yields an amount of 4 prescaled clocks of ZPD for each *Measurement Cycle*.
   – For *GZF,* the settings will be the same as above.

(2) Further Strategy Recommendations for the ZPD Measurements

1. The more depth *(GFD)* the digital filter has, the more flexibility in its adjustment is given.
2. Several *Measurement Cycles* are accumulating during the measurement phase, where *ZMTn* is set. This means, if at least one *Measurement Cycle* is indicating that ZP was ***not*** reached, this becomes valid for the whole measurement phase.
3. When adjusting the digital filter, it is recommendable to start off with a filter setting of *GFL=0* (level of 1).
   – Use this setting when the ZP is reached (motor hits the mechanical stop).
   – Adjust the reference level such, that it is one step below of the level, where the ZP would be recognized.
   – Now the ZP is no longer recognized. Increase the filter level, until it is recognized again.
   – This approach can be performed for several settings for the amount of *Measurement Cycles*. Then, choose the most reliable setting.
4. When setting up the ZPD table, be sure that the table always contains ***one or more full rotations*** of the motor. The table restarts continously from the beginning, if a ZPD measurement does not yield the ZP detection, or if no measurement is contained at all.
5. If the ZPD motor movement is creating too much jitter, it is possible to activate the *ZPD Vibration Damping* feature of ISM (*ZSSn*). If activated, the open end of the measured coil (measure input) will be short-cut with the other end of the coil, if this is connected to a power or ground side via *Direct I/O Control*, after the first setting of *ZIPn* during a measurement phase (*ZMTn* set).
   This short-cut works like an additional breaking or damping, because now, after the measurement can be aborted (ZP not found), the measured coil induces and kills the remaining movement energy of the anchor.

7.3 ZPD Operation

The ZPD operation for a channel can be individually started, if the following prerequisites are fulfilled:

1. *Channel Management* is activated for this physical channel (*GEN, CENn*).
2. The virtual channel for the physical channel *n* is selected (*CCTn*).
3. The ZPD table is defined for the used virtual channel (*CTLn*).
4. The analogue hardware is initialized and linked to ISM (*GZE, GZP, GZL*).
5. The ZPD operation mode is selected for the physical channel (*CZPn*).

The ZPD operation for a channel can be stopped by software, either bei clearing *CZPn*, or by disabling the channel (*CENn, GEN*).

The ZPD operation for a channel ends automatically, if during a measurement cycle (*ZMTn* set), no ZPD interrupt *IRQZPD* was generated (if enabled at all), and if the flag *ZIPn* is not set.

After the ZPD operation has ended automatically, the channel remains disabled (*CENn* cleared), until reactivated by software.

7.3.1 Using Direct I/O Control

When performing ZPD, it is often mandatory to perform special settings on the port outputs to the stepper motors, like creating short-cuts, keeping the measured end of a coil open, or driving current through the motor permanently.

To allow to do these kind of things, the *Direct I/O Control* function is available.

It is activated by the flags *IHEn* and *IVEn*.

If these are set, any PWM output to the motor *n* is disabled for these coils, and instead, the motor ports are driven by the codes of *IHDn* and *IVDn* directly. Also, *recirculation* is disabled, if *Direct I/O Control* is active.

Note However, even if *Direct I/O Control* is active, the break-before-make safety system of ISM still remains active. Therefore, it is not possible to destroy outputs by wrong codes, i.e., by trying to create power shortcuts.

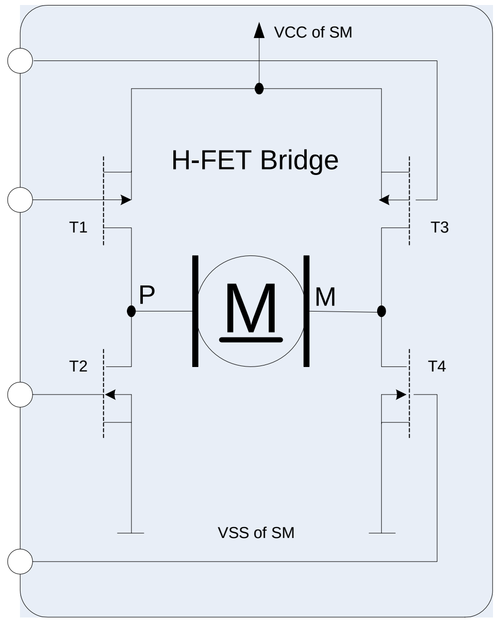


Figure 7-9 Virtual Transistors for Direct I/O Control

The control codes for *Direct I/O Control* are referring to “virtual transistors”, which are forming a H-FET bridge, where the motor coil is connected to.

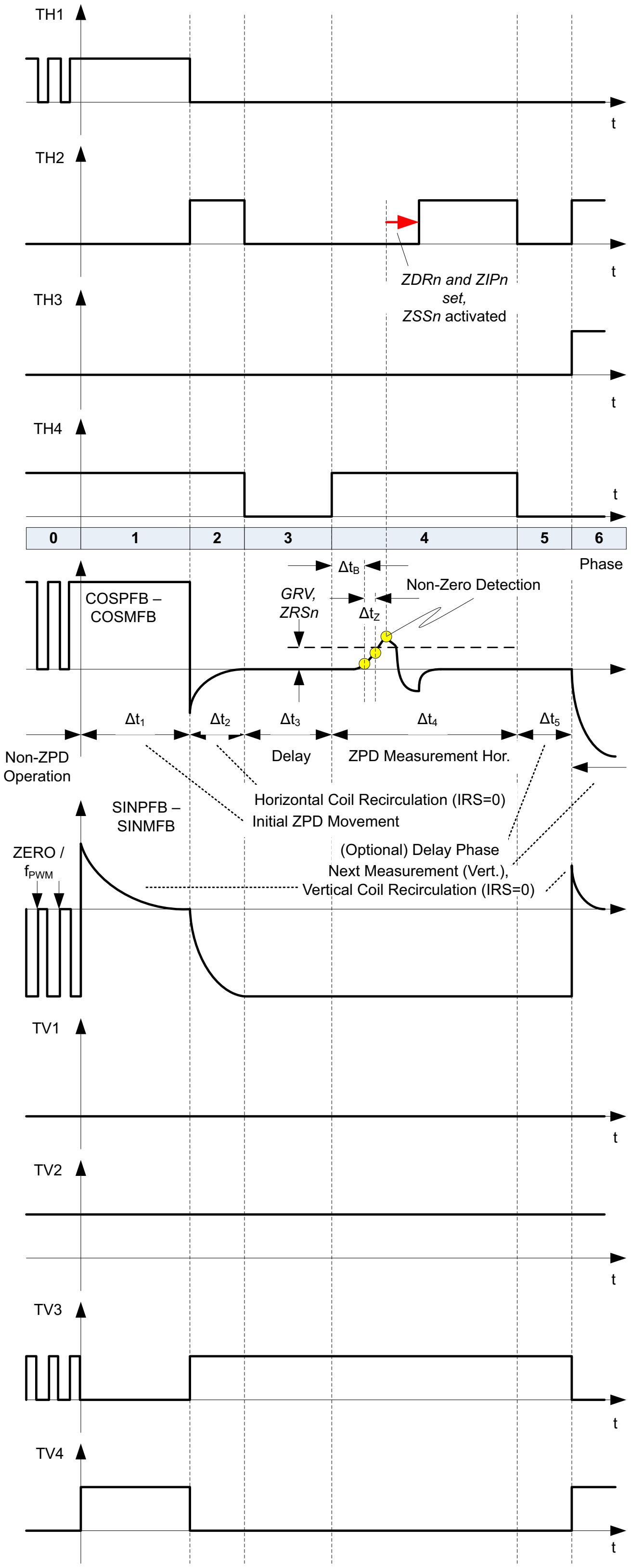
Every code of *IHDn* and *IVDn* is a bit-field of the activation of the transistors T1 to T4, where “1” means an activated transistor.

Examples:

- *IHD* = 0110B: Full powered coil from M to P (reverse current), (SM*n*2 to SM*n*1, or SM*n*4 to SM*n*3).
- *IHD* = 0101B: Coil is short-cut via ground level.
- *IHD* = 0011B: This is an illegal code. The safety system of ISM will refuse to activate neither T3, nor T4.

7.3.2 Executing a ZPD Table

The following illustration shows, how a ZPD table is executed and how this propagates to the virtual transistors and motor outputs.



ZPD RAM Table Entries
(First Steps)

Moving Backwards Quadrants 0 → 3 → 2 → 1 ...

	ZMT	CZD	IHE	IVE	IHR	IVR	CQI ZIS 1	CQI ZIS 0	CHP / IHD [T1T2T3T4]	CVP / IVD [T1T2T3T4]
1	0	Δt_1	0	0	1	1	0	0	100% (CHP)	0% (CVP)
2	0	Δt_2	0	0	1	1	1	1	0% (CHP)	100% (CVP)
3	0	Δt_3	1	1	0	0	1	1	0000_B (IHD)	0110_B (IVD)
	...									
3a*	0	Δt_{3a}	...				Optional steps, if Δt_3 is not sufficient			
	...									
4	1	Δt_4	1	1	0	0	1	1	0001_B (IHD)	0110_B (IVD)
	...									
4a*	1	Δt_{4a}	...				Optional steps, if Δt_4 is not sufficient			
	...									
5	0	Δt_5	1	1	0	0	0	0	0000_B (IHD)	0110_B (IVD)
6	0	Δt_6	0	0	1	1	1	0	100% (CHP)	0% (CVP)
	...	(to be continued ...)								

$\Delta t_{1\text{-}n}$ = *CZD*(phase) * *GUD* * *GTB* * $(2^{10} – 1) / f_{macro}$
[time values are given in CZD steps of START events].

Δt_Z : Period of ZPD Unit Sampling depending on *GZF*, while enabled during Phase 4

$\Delta t_Z = 1 / f_m$

Δt_B : ZPD Unit measurement Blanking Time, depending on *GZF*, started with ZMT trigger of Phase 4

$\Delta t_B = ZBT / f_m$

Δt_Z, Δt_B: Timing depends on settings of the ZPD Unit (*GZF, GCS, GFD*)

$f_m = f_{macro} / (GZF * (GCS + GFD))$

GRV, ZRSn : ZPD Detection Level of Channel *n*

ZERO events are assumed to be at a high frequency, related to the drawn signals.

Figure 7-10 Executing a ZPD Table

The following chapters are referring to the steps indicated within *Figure 7-10 “Executing a ZPD Table” on page 47* .

(1) Rotating the Anchor to 0°

Assuming that we are in *Quadrant* 0, the anchor is set to a horizontal direction by applying 100% PWM for horizontal and 0% PWM for vertical.

(2) Rotating the Anchor to 270° (approaching the Measurement Position)

A right turn of -90° is performed by applying 100% vertical PWM and 0% horizontal PWM in *Quadrant* 3. By applying 0% PWM, the energy of the horizontal coil is recirculated, so that its self-induction pulse is reduced.

(3) Preparing the ZPD Measurement

Using *Direct I/O Control*, the vertical coil is kept full powered, while the horizontal coil is disconnected. This phase is used as a delay, to approach the time-window of the ZPD induction within the horizontal coil. During this phase, the anchor is still moving towards the 270° position.

(a) Optional additional Delay

Depending on the clocking of ISM and the setting of *GUD*, additional delay steps can be required to wait on the correct time-window position. This can be realized by simply repeating the phase *3 “Preparing the ZPD Measurement”.*

(4) ZPD Measurement Phase

By activating *ZMT*, the ZPD measurement is started. At the same time, the horizontal coil is pulled to ground on one side, while its other side is attached to the analogue measurement input, which is selected by the *ZIS* setting. The vertical coil remains powered, in order to complete the anchor rotation.

Blanking Delay can be used to add further delay with higher precision to the time-window.

The ZPD measurement is performed using the defined *Measurement Cycles*. In our example, the level is reached that indicates that the zero point was not yet reached.

As a consequence, as *ZSS* is set, the horizontal coil is recirculated, as soon as the detection of non-zero-point has happened.

(a) Optional additional Delay within Measurement

By adding identical steps of phase *4 “ZPD Measurement Phase”,* the measurement phase can be extended. If the measurement phase ends by a step with *ZMT* cleared, the decision of stopping the execution is taken.

(5) Delay of ZPD Measurement Completion

This optional delay phase shall achieve that the anchor has finally reached the 270° position.

(6) Rotating the Anchor to 180°

By using PWM, the anchor is now rotated to the 180° position, which is in *Quadrant* 2. At this point, alternatively, a new measurement can already be prepared by continuing with an adjusted phase *3 “Preparing the ZPD Measurement”.*

Note Following further steps must achieve, that the anchor completes at least one full turn within one pass of the ZPD table. Like this, the motor keeps on turning, until the ZPD table execution is aborted in case the ZP is reached.

Revision History

The table below gives an overview about the revision history of this document.

Rev.	Date	Summary
01.00	Aug 30, 2010	first edition.
01.01	Feb 13, 2012	updated figure external references.

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