M16C/28 Group

Solutions of Three-Phase Motor Control Programming

1.0 Abstract

This application note discusses how to use 3-phase motor control timer function.

2.0 Introduction

The explanation of this issue is applicable to M16C/28 Group (M30280M4A-XXXFP).

3.0 Inverter Control

3.1 What Is Inverter Control?

Inverter control voluntarily changes the frequency to drive a motor. For example, 3-phase motors can be drived with waveform that is out of phase by 120 degrees, however, when the motor is powerd with 3-phases of commercial power supply, its motor frequency depends on the frequency of commercial power supply .

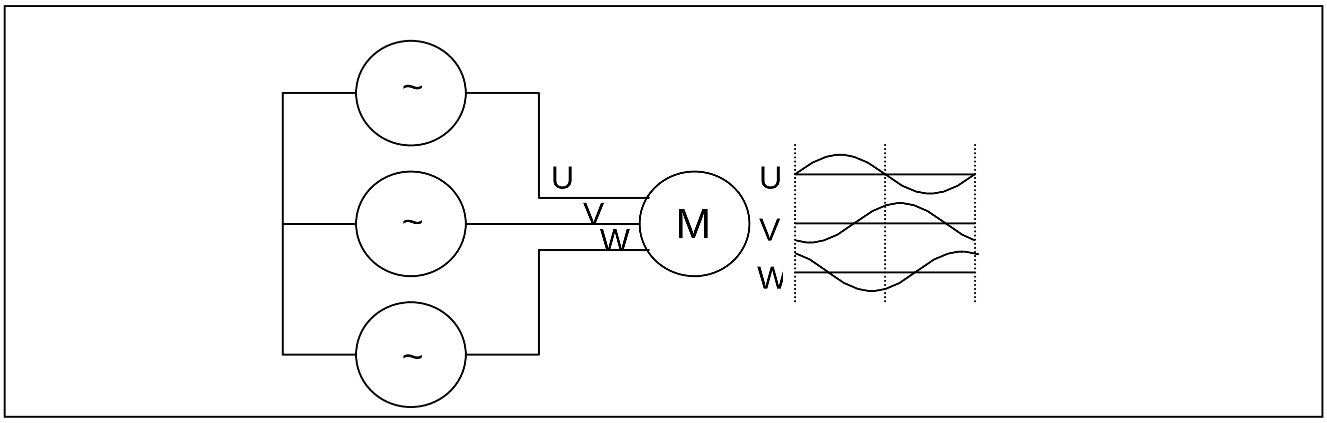


Figure 3.1 3-phase motor drive

Inverter control converts commercial AC poser supply to DC powersupply first, and then, generates motor drive frequency by swithing transistors. This switching is controlled by MCU. Therefore, changing switching interval can generate voluntary motor drive frequency

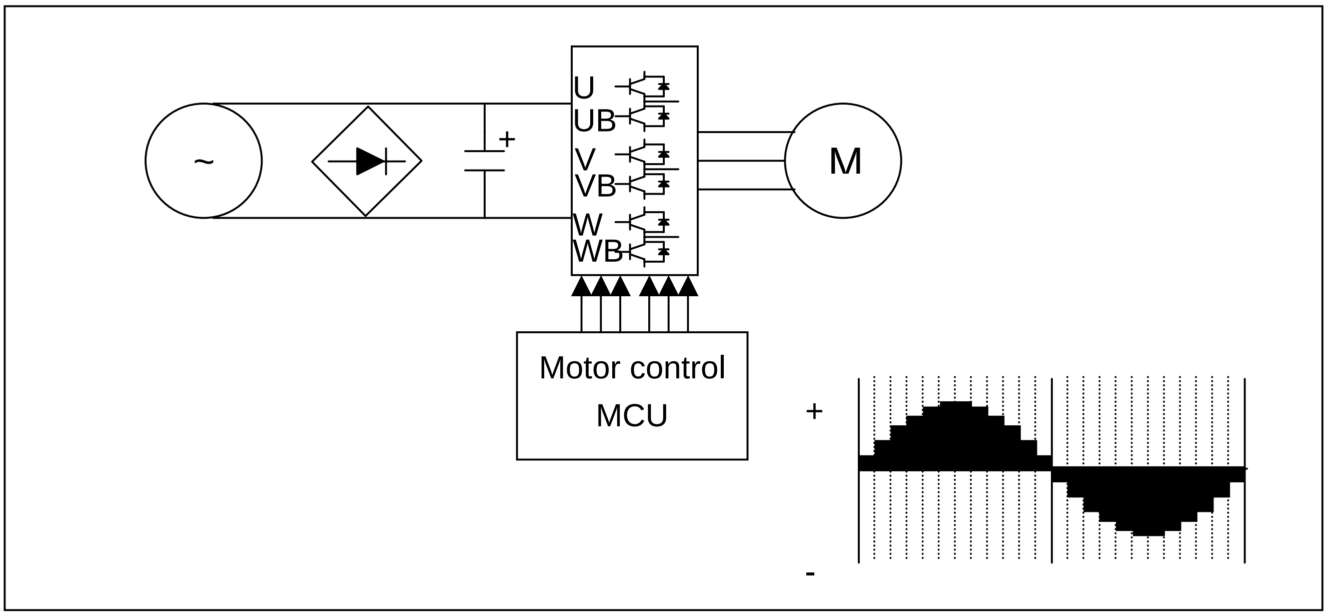


Figure 3.2 Example of inverter control using MCU

3.2 Output Waveforms

MCUs can not directly output a sinusoidal wave or high voltage for driving a motor. An interface circuit is therefore necessary between the MCU and the motor, as shown in Figure 3.3. The port output of the MCU is connected to U, V, W, B, VB, and WB terminals, as shown in the figure.

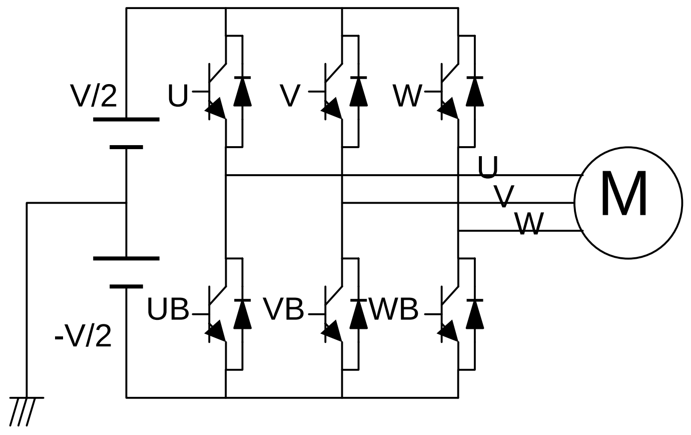


Figure 3.3 Power transistors such as IPM and IGBT

When alternating ON and OFF signals are input to U and UB terminals of the transistors in Fig. 3.4, the output voltages of the transistors are also altered, and the alternating current wave (square wave) is respectively generated in the U phase.

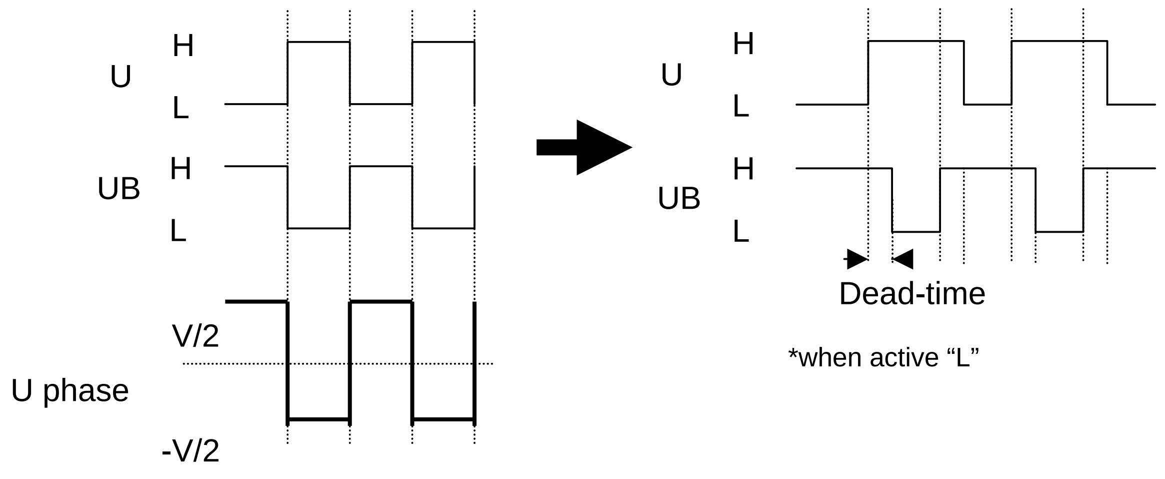


Figure 3.4 MCU output and generated waveforms

If both U and UB are turned on at the same time, the short circuit current goes through the transistors and causes a direct short-circuit, destroying the transistors. This is called an arm short-circuit.
To avoid an arm short-circuit, the 3-phase motor control timer makes a switching time delay, preventing both transistors from being switched ON at the same time. This time delay will be referred to as "dead-time" in this document. If you program the dead-time interval generation in the initial setup procedure of the motor drive control process, the MCU will automatically generate the corresponding dead-time.
Quantizing the sinusoidal wave by time domain and converting each unit of charging energy to the H (or L) length of the charging voltage will generate the equivalent sinusoidal waveform.

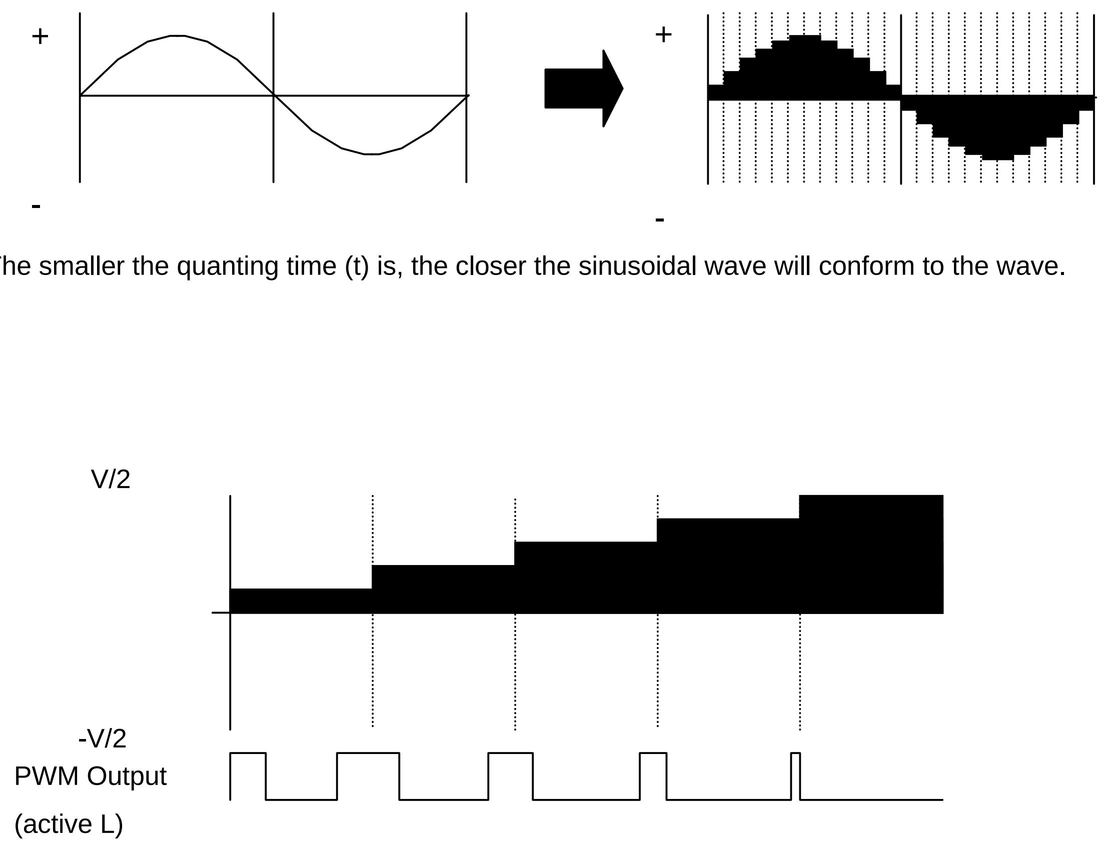

+
-
+
-
*The smaller the quanting time (t) is, the closer the sinusoidal wave will conform to the wave.
V/2
-V/2
PWM Output
(active L)

Figure 3.5 Quantized squrae waveform (by time unit)

4.0 How To Use Timer Function For Three-phase Motor Control

4.1 Three-Phase Waveform Output Methods

This chapter explains basic methods of 3-phase waveform output.

4.2 Carrier Frequency

The carrier frequency is the reference of PWM pulse width of the output voltage.

Assuming that the sinusoidal wave overlaps the carrier, the distance between the both waves becomes the output phase pulse width.

There are two methods of carrier frequencies; sawtooth wave modulation method and triangular (back-to-back sawtooth) wave modulation method.

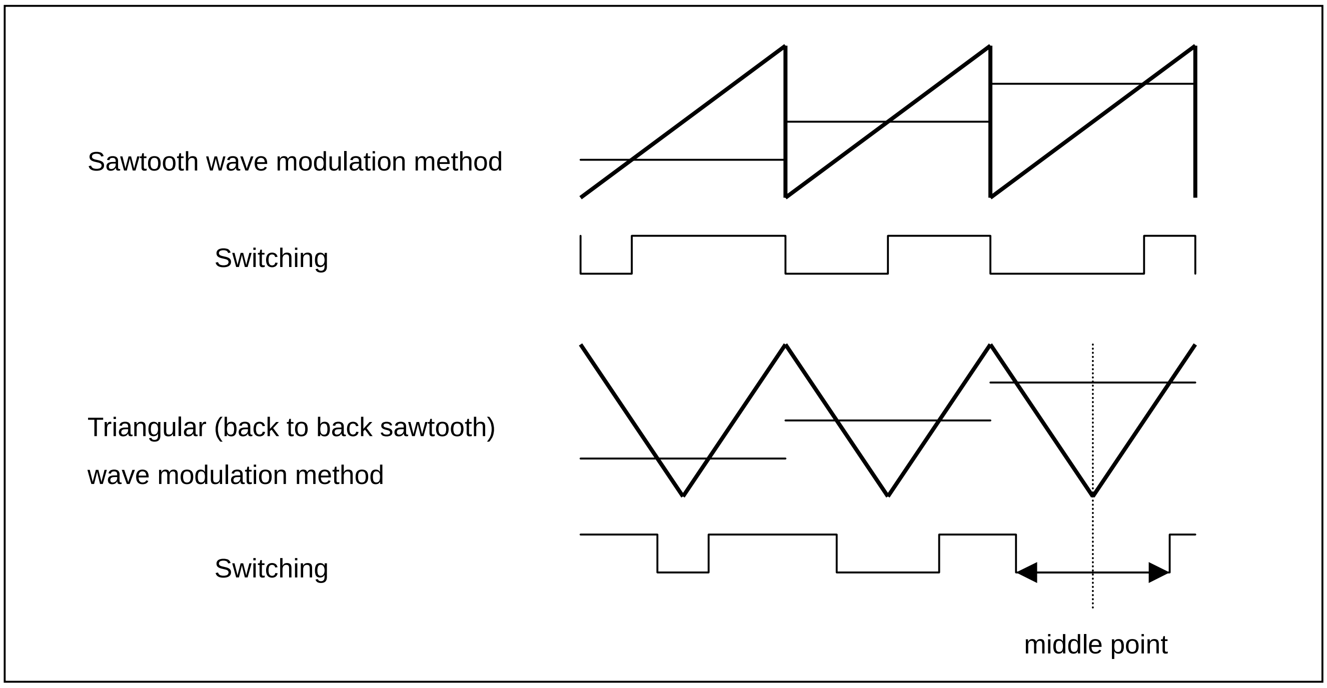

Sawtooth wave modulation method
Switching
Triangular (back to back sawtooth)
wave modulation method
Switching
middle point

Figure 4.1 Methods of carrier frequency

Sawtooth wave modulation method changes duty with starting point of carrier period as a reference.
On the other hand, triangular wave modulation changes duty with the middle point as a reference.

4.3 PWM Emulation Methods

3-phase motor control timer basicaly generates one full carrier if sawtootn wave modulation and a half carrier if triangular. The peak timing of the carrier period is generated by TB2. The TB2 underflow trigger starts TAi (i =4,1,2) one shot. This TAi determines PWM duty.
In case of using sawtooth wave modulation, set the trigger of dead-time timer at rising and falling edge of TAi.
In case of using triangular wave modulation, set the trigger at only rising edge of Tai.

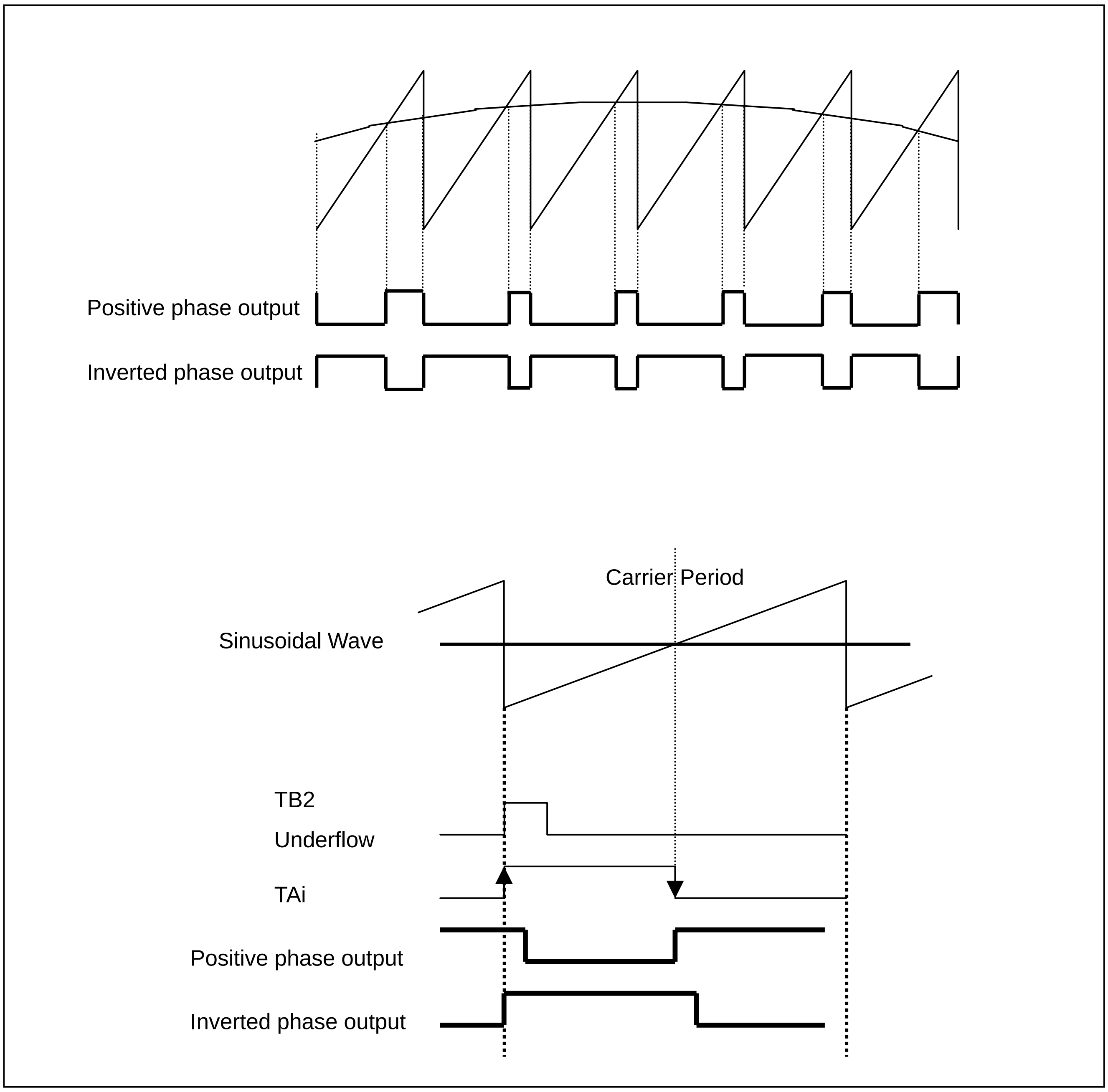
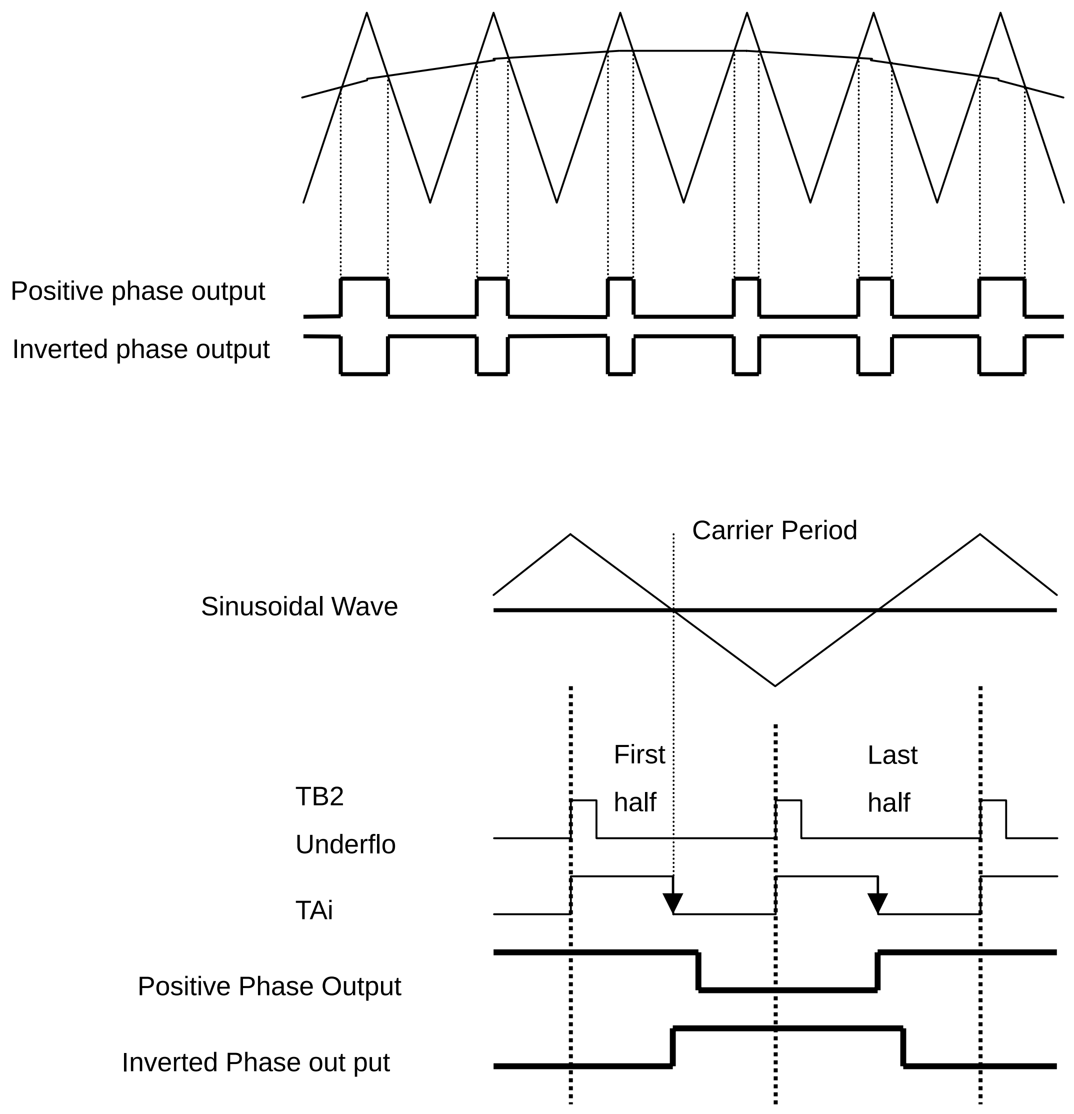


Figure 4.2 PWM in sawtooth wave modulation



We difine the output PWM waveform to be a mirror image at the peack of the carrier.

(Inreal practive, when the sinusoidal wave becomes an arch this mirror image does not happen.)

Figure 4.3 PWM in triangular sawtooth modulation

If you use privously described triangular modulation method to output waveform, you have to set timing by generating interrupt every half-period of the carrier and set TAi again.
To reduce this load, there is a function that sets TAi values for both first half and last half, in one full-carrier.
This function is called 3-phase mode 1.
3-phase mode 1 enables to set value to TAi alternatively from two registers.

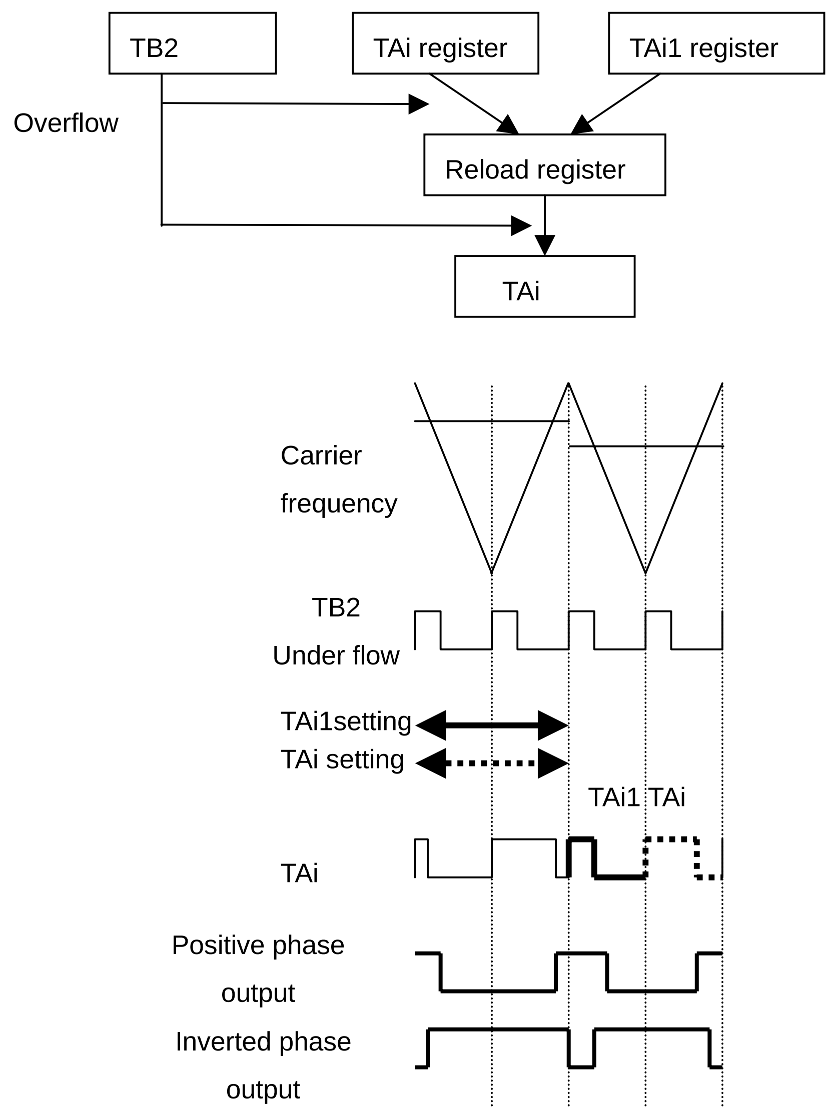


Figure 4.4 Relationship between TB2 and TAi/TAi1 registers in 3-phase mode 1

*TAi1 register cannot be updated near the TB2 underflow. Please refer to technical news for the detail.

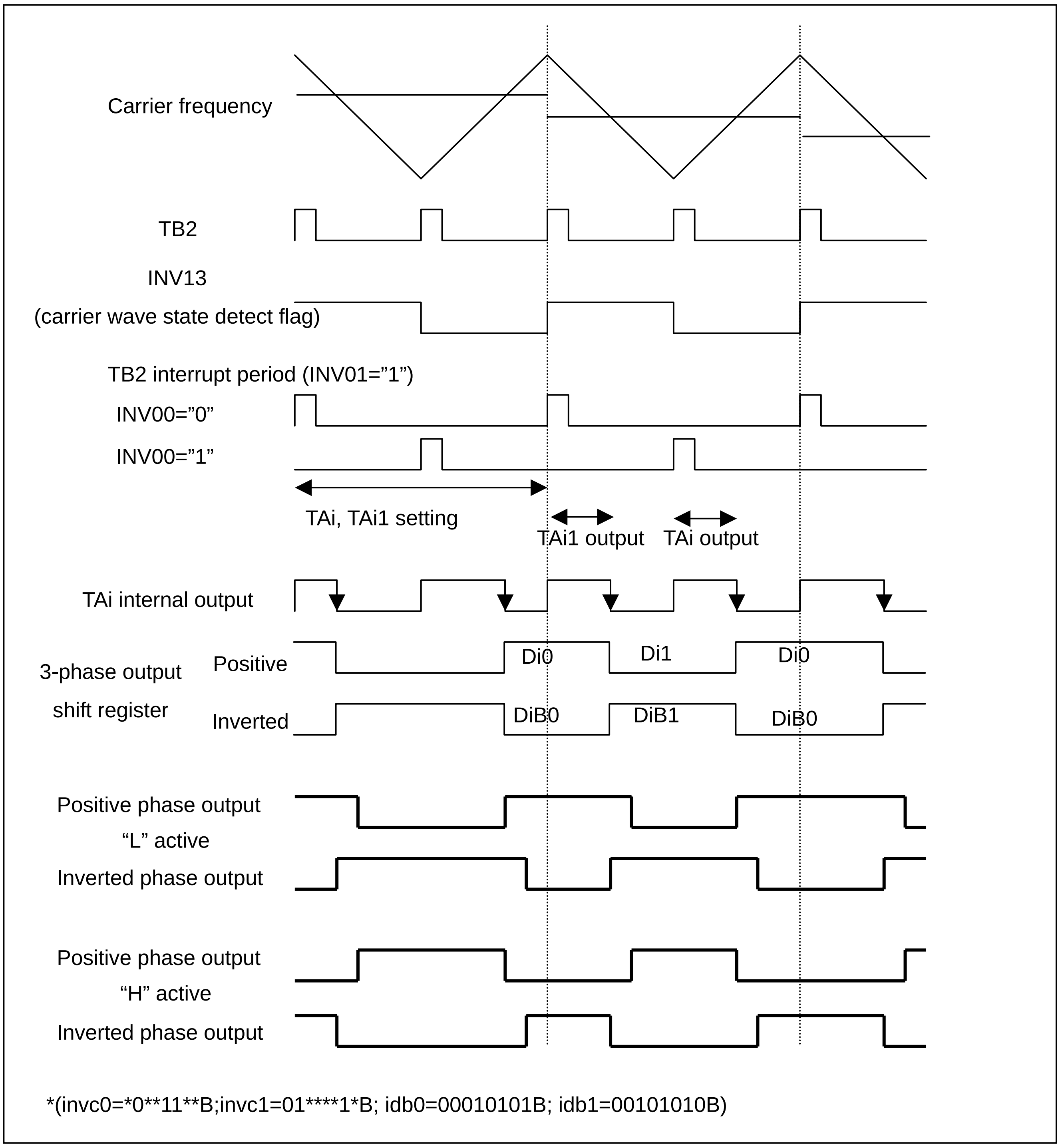


Figure 4.5 3-phase mode1 setting and output

If an initial value (INV01="0") is set to interrupt valid output specification and interrupt cycle setting counter(ICTB2) is set to "2", TB2 interrupt is generated at the same timing with INV00="1" as indicated in the figure 4.5, at the initial state. If the same timing with INV00="0" is required, please set odd number to interrupt cycle setting counter (ICTB2), for the first cycle only.

4.4 Carrier Frequency

To change carrier frequency, the TB2 interrupt period must be changed. However, when triangular wave modulation is used, two TB2 underflows become one carrier period. Therefore, special caution should be paid to carrier period modification.

When you use triangular wave modulation to control by every full-period of the carrier, (invc0=*0******B and invc0=0*****1*B), set TB2 reload timing to Timer A output after odd numbered times (TB2sc=*******1B) , and when you use rectangular wave modulation to control by every half period of carrier (invc0=*0******B and invc0=1*****1*B or invc0=********B and invc0=******0*B), set TB2 reload timing to TB2 underflow (TB2sc=00000000B) , so that variation of carrier period becomes in line with the TAi set timing.

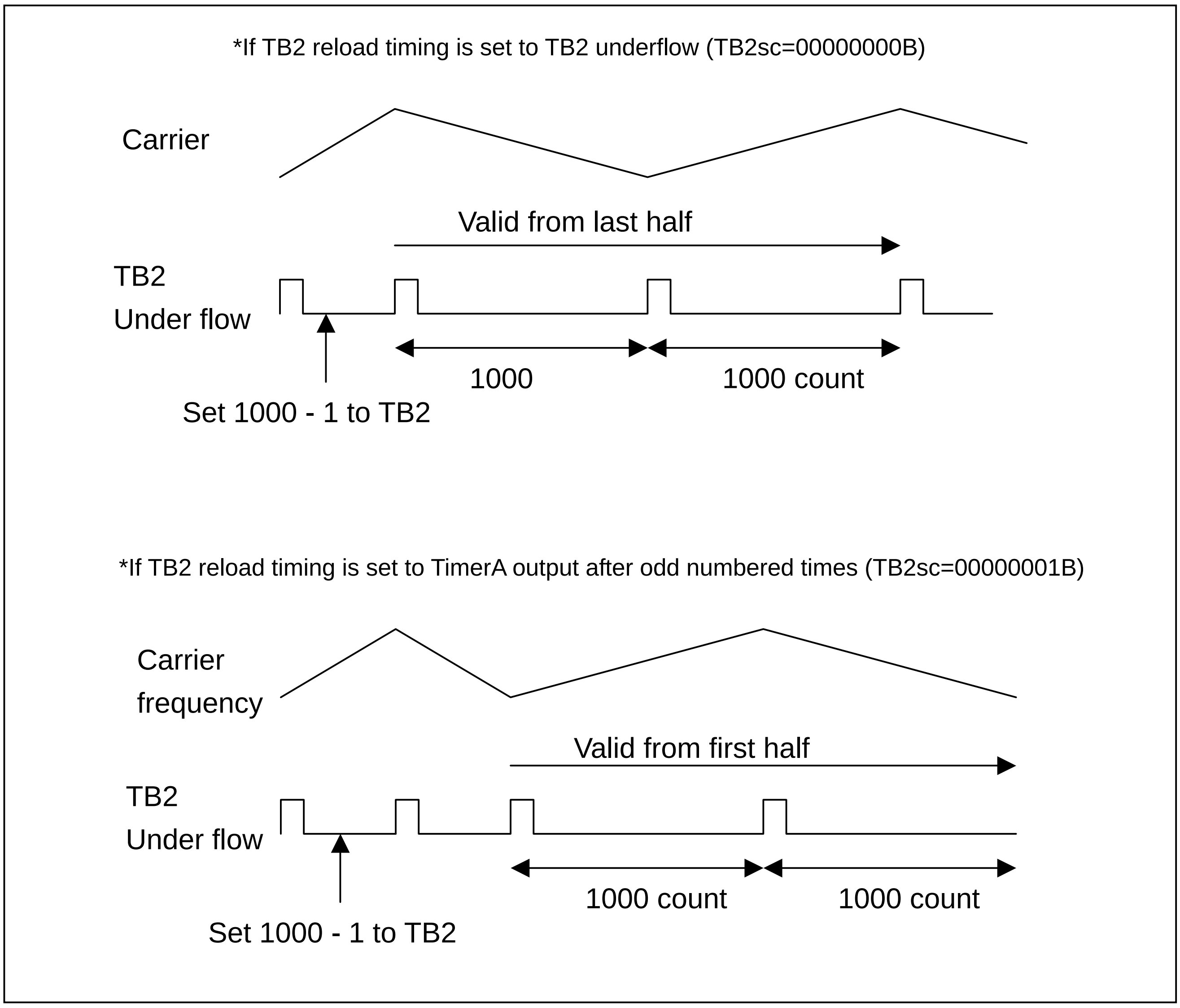


Figure 4.6 Carrier period setting and output

4.5 How To Use Three-phase Output Buffer Register

By updating 3-phase output buffer register value, output level can be fixed (continuous on, continuous off) for a certain period, or same leveled waveform can be output for both positive and inverted phase.
This function enables to realize 2-phase modulation output (See Chapter 5) and trapezoidal waveform output (See Chapter 6).

*The 3-phase output buffer register contents are transferred to the shift register at the first TB2 underflow after updating.

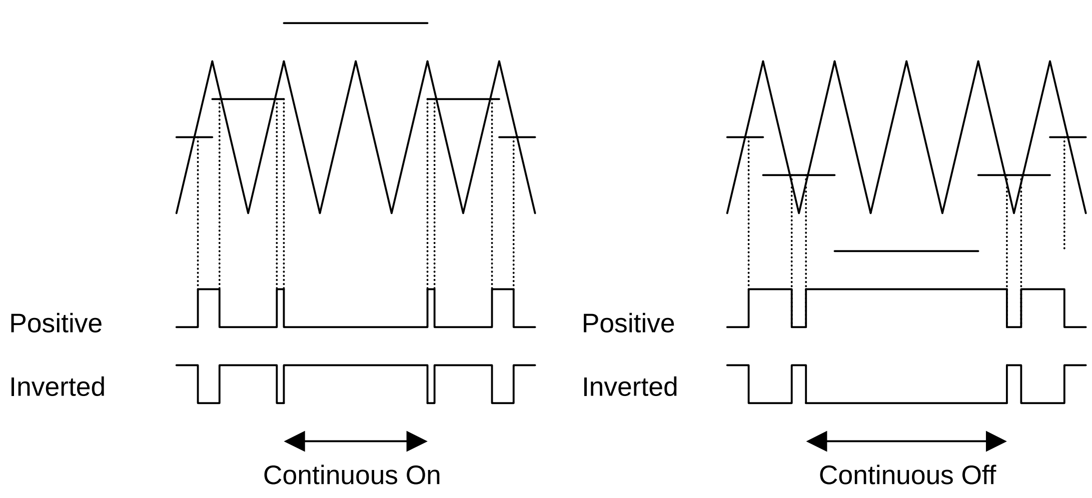


Figure 4.7 Waveform generated by 2-phase modulation output (See chapter 5)

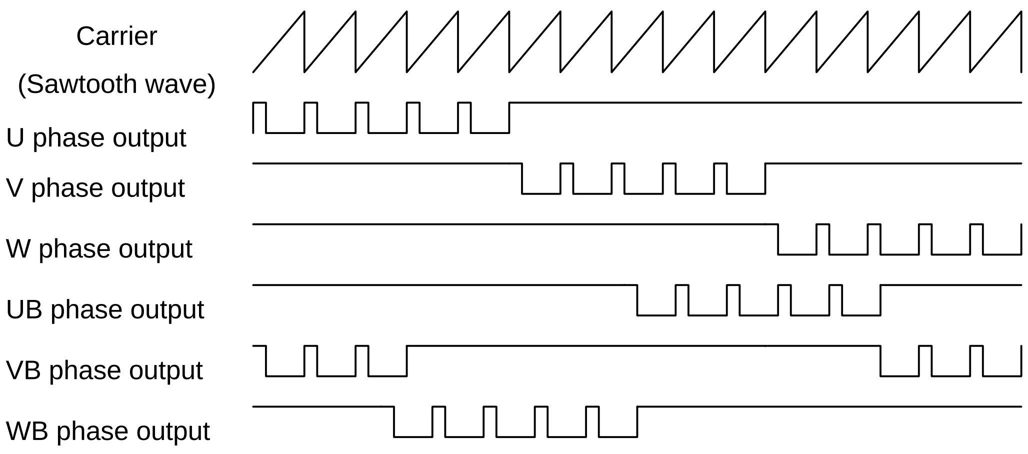


Figure 4.8 Waveform generated by trapezoidal waveform output (See Chapter 6)

4.6 Notes Concerning PWM Data Setup

The following are notes concerning the TAi setting and the 3-phase motor control timer.

1. Lower limit of TAi Value

If registers TAi is set to “0” (in case of dead-timer f2, ”0”, “1”), the internal TAi timer will not start counting and the falling edge will not be generated, and as a result, the output wave keeps its current state. Setting TAi0 or TAi 1 to “0” and “1” should be avoided except in special cases.

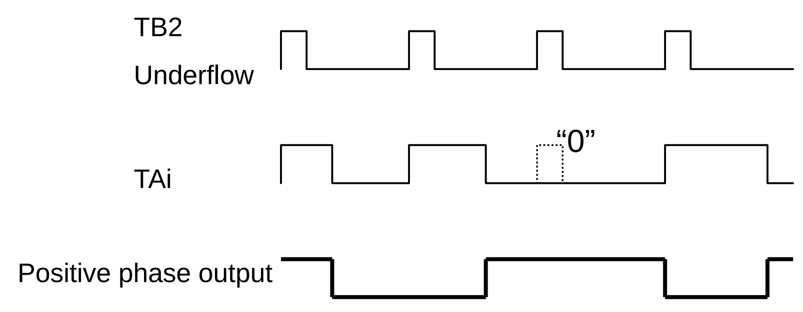


Figure 4.9 Positive phase output when TAi =0

2. Upper Limit of Tai Value

If the value larger than the TB2 value (in case of dead-timer f2, TB2 value-1) is set to registers TAi, the internal TAi timer continues counting even when it enters the TB2 periods. This inhibits the generation of the falling edge, and the output wave keeps its current state. The result, as shown in Fig.4.10, is a reversed wave. Please avoid setting larger values except in special cases.

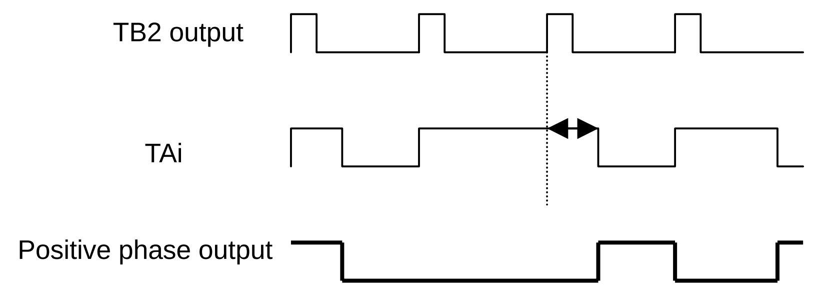


Figure 4.10 Output waveform when TAi>TB2

3. Re-starting Dead-time Timer

By setting the PWM data, the dead-time timer is re-started while it is counting, resulting in a dead-time overlap.

Triangular (back-to-back sawtooth) wave modulation method: dead-time f1

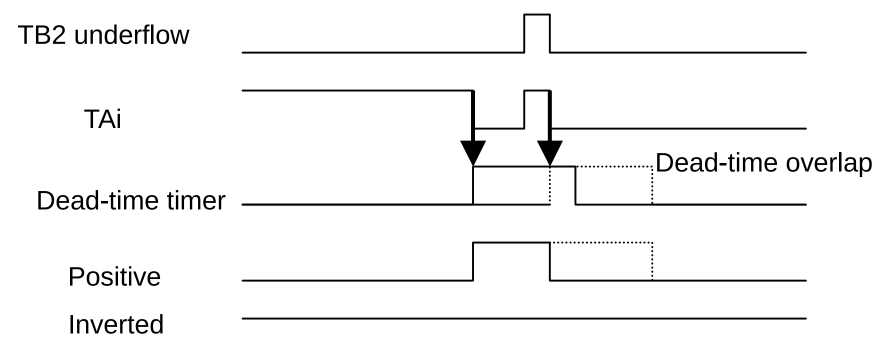
((TB2 value +1) - TAi1 value) + TAi value < dead-time value

TAi1 value + ((TB2 value + 1) - TAi value) < dead-time value

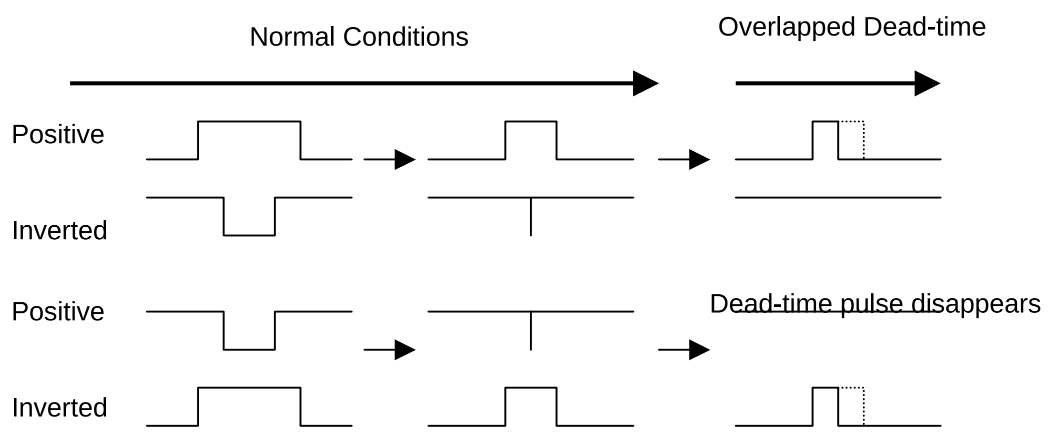
Sawtooth wave modulation method: dead-time f1

((TB2 value + 1) - TAi value) – 1 < dead-time value

TAi value -1 <dead-time value



Re-start of dead-time timer



PWM conditions and dead-time

Figure 4.11

4. Output waveform after updating 3-phase output buffer register

When dead-time timer setting trigger select bit is “0” (invc1=000*****B) , and waveform output is changed from fixed to from output to PWM output by 3-phase output buffer register.

When positive phase is changed from “L fixed” to PWM output and TAi, TAi1>TB2 – dead-time, the output dead-time can be shortened.

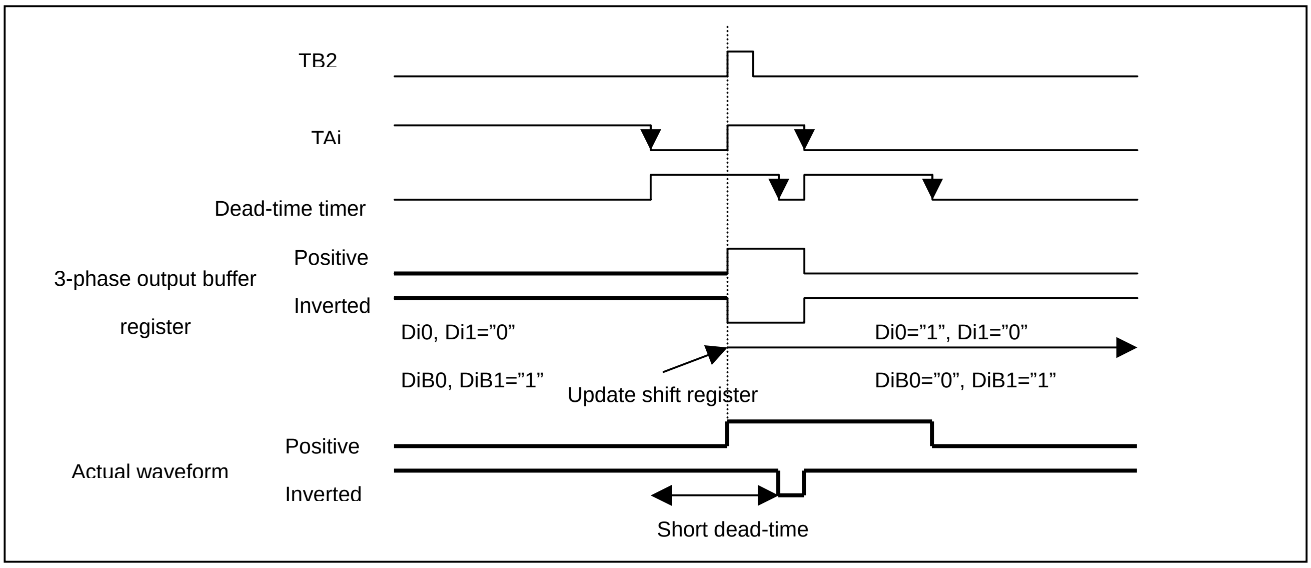


Figure 4.12 Waveform with short dead-time

When you change from fixed-wave output to PWM output by updating 3-phase output buffer register, max value should be set to TAi and TAi1 data (if dead-timer f1=TB2 value, if f2=TB2 value-1)

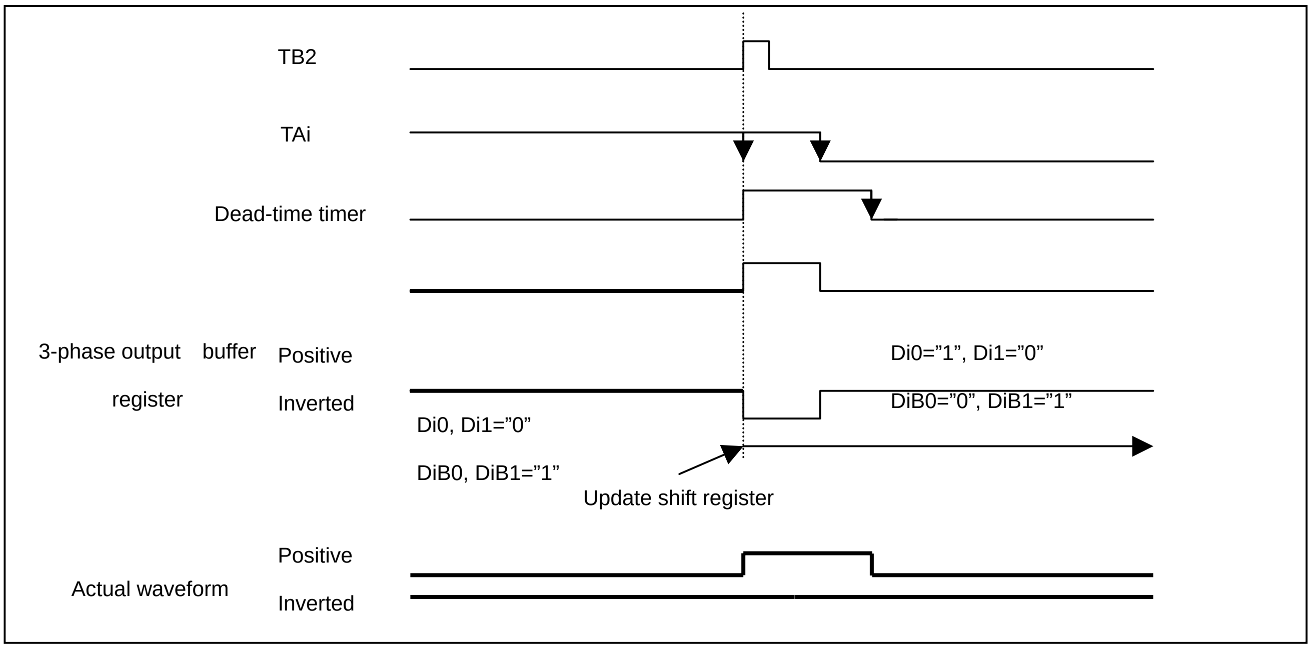


Figure 4.13 Waveform when setting max value to TAi and TAi1

5.0 Three-phase sinusoidal wave output

5.1 How to output Three-phase waveform

This chapter explains the methods of 3-phase sinusoidal waveform output by using 3-phase motor control timer.

5.2 Output methods by using Three-phase motor control timer

Select triangular modulation and 3-phase mode1 of 3-phase motor control timer function.

5.3 PWM Data Calculations

The following explains an example of how to calculate the TAi setting value.

The reference of output waveform should be Sine 0°=duty 50%, and TAi setting value will be a plus or minus of this reference.

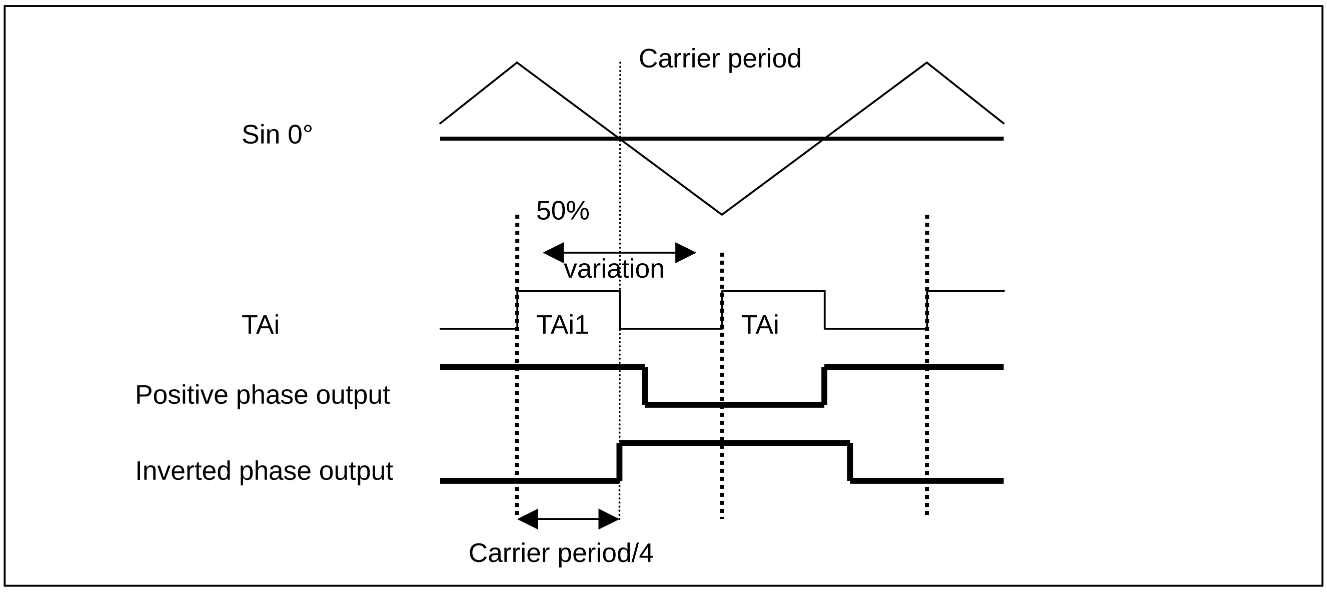


Figure 5.1 Relationship of TAi and PWM data

Duty 50%=carrier period/4

TAi1 data = carrier period/4 - variation value

Since sinusoidal wave is –1~0~1, the waveform becomes as indicated in the below figure.

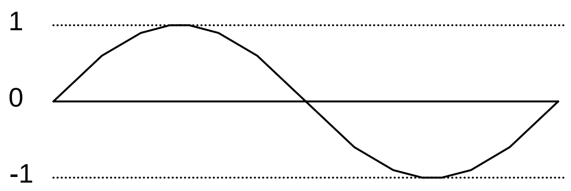


Figure 5.2 Sinusoidal wave

The value X that makes a duty of –50~0~50% is calculated as:

X = 50%   x   sinN°

X = carrier period / 4   x sinN°

Therefore, the setting value of the width can be calculated as:

TAi1data = carrier period/4 - carrier period/4 x sinN°

TAi data = carrier period/2 - TAi1 data

When current control is performed by physics operation such as a vector operation, TAi data should be calculated as:

TAi1data = carrier period /4 - the calculated current control value x the constant

TAi data = carrier period/2 - TAi data

5.4 Variation of Load Output Wave

The PWM load value is obtained by multiplying the pre-calculated PWM wave in each phase by the modulation rate.

$$\text{PWMi data} = \frac{\text{carrir frequency}}{4} \pm \frac{\text{carrir frequency} \times \sin N°}{4} \times \text{modulation rate}$$

For example, if V/F control is used, the modulation value is varied in combination with the variation of the output frequency, and the relationship of the PWM wave length (V) and the output wave is controlled.

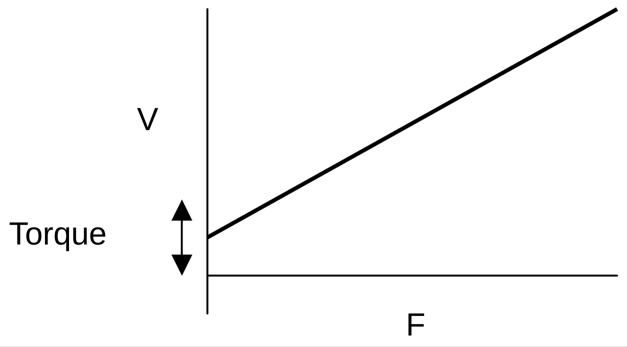


Figure 5.3 V/F control

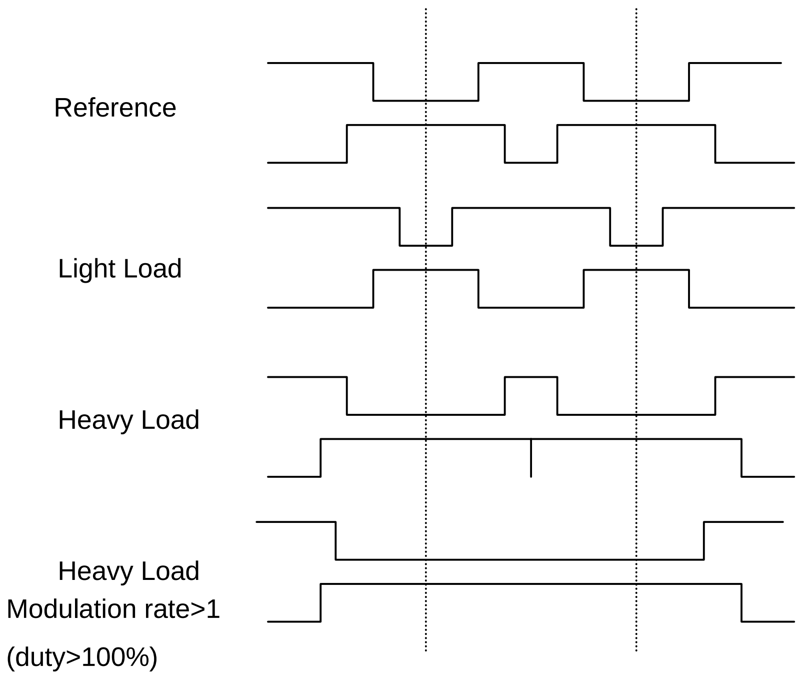


Figure 5.4 Relationship of modulation rate and output wave

5.5 Two-Phase Modulation Output (continuous on, continuous off)

When PWM duty is wider or narrower than the regular duty width, on/off control that is longer than the carrier period is carried out to reduce the dead-time loss.

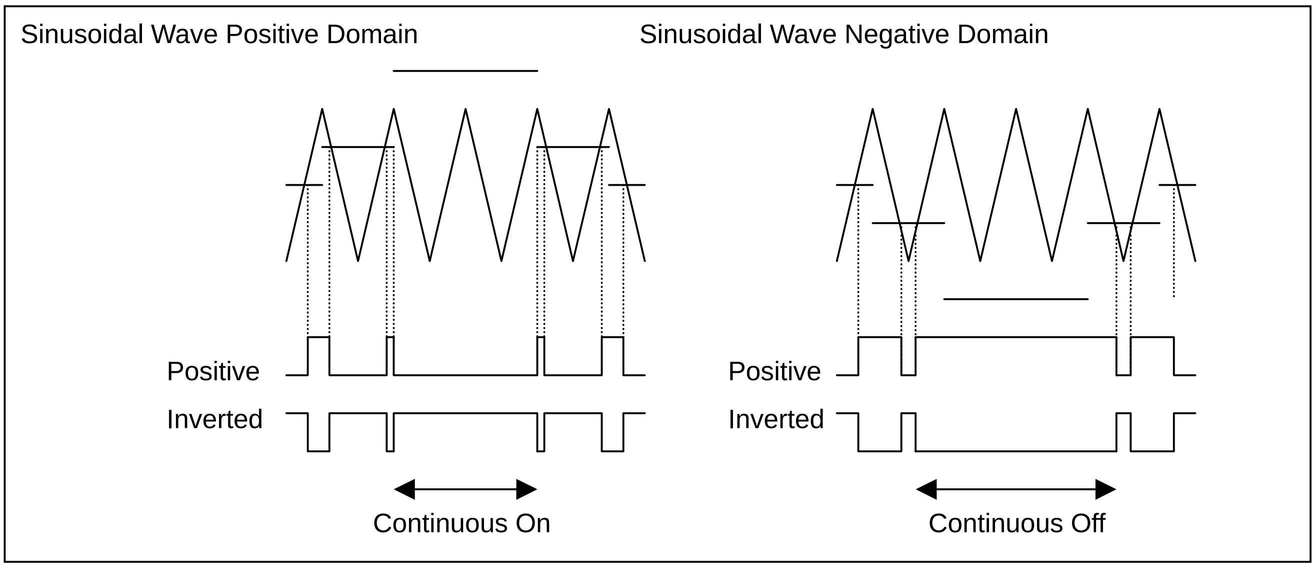

Sinusoidal Wave Positive Domain
Sinusoidal Wave Negative Domain
Positive
Inverted
Continuous On
Positive
Inverted
Continuous Off

Figure 5.5 Waveform of 2-phase modulation output

5.5.1 Continuous on/off waveform output realized by updating Three-phase output buffer register

As shown in the figure below, continuous ON/OFF waveform output can be realized by updating the content of 3-phase output buffer register at right timing.
In this method, you are directly updating the contents of the 3-phase output buffer register, and updating the wrong bit can cause a short-circuit wave. Therefore, make sure you always set the simultaneous positive/inverted phase low output function (invc0 bit 4) to “1” in order to prevent a short circuit.

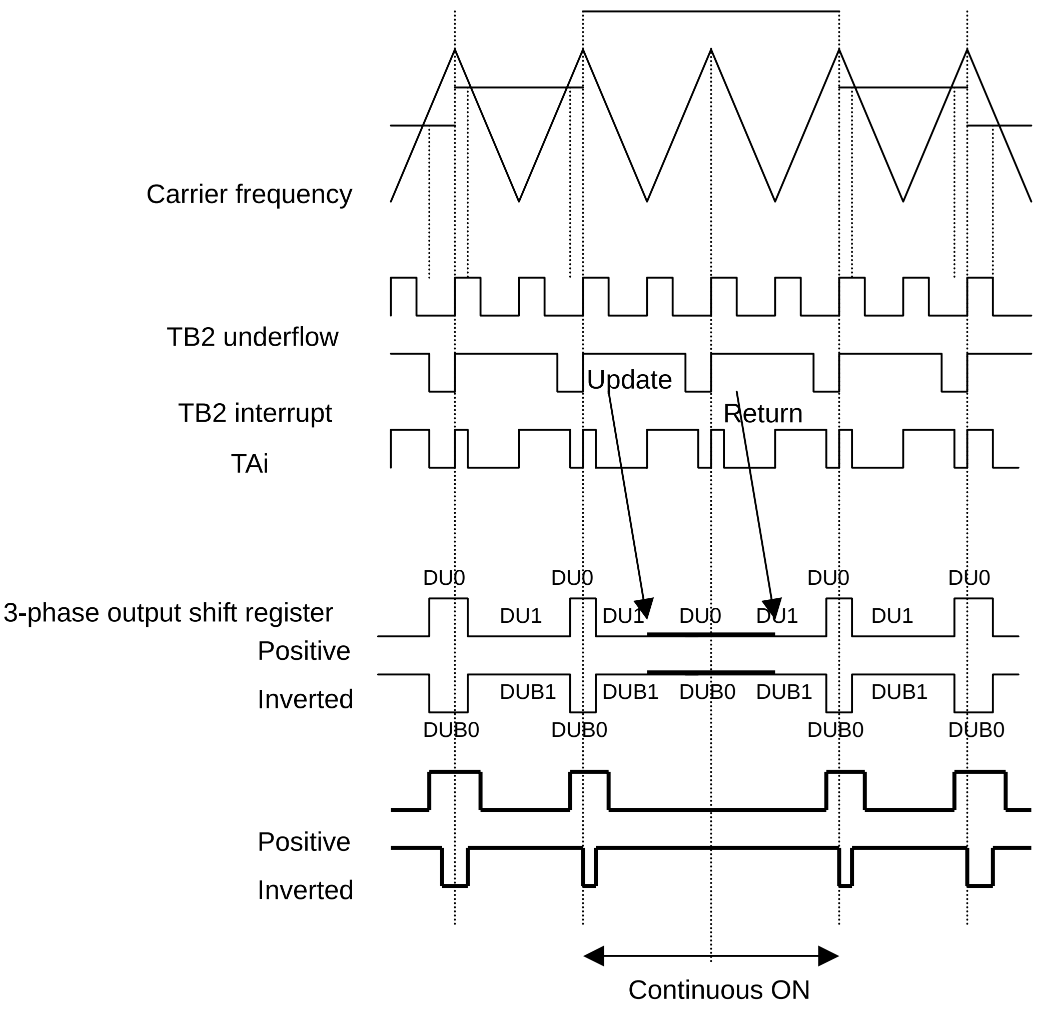


Figure 5.6.1 Timing of writing the 3-phase output buffer register

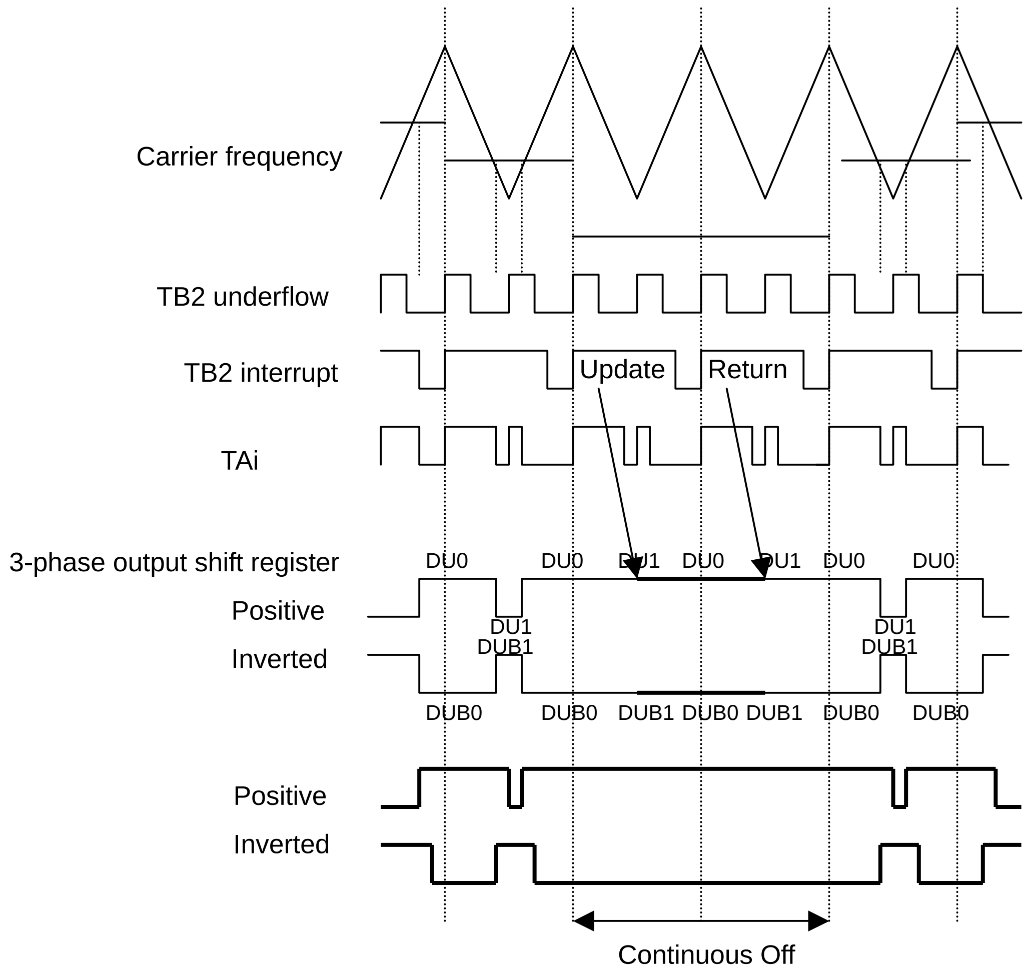
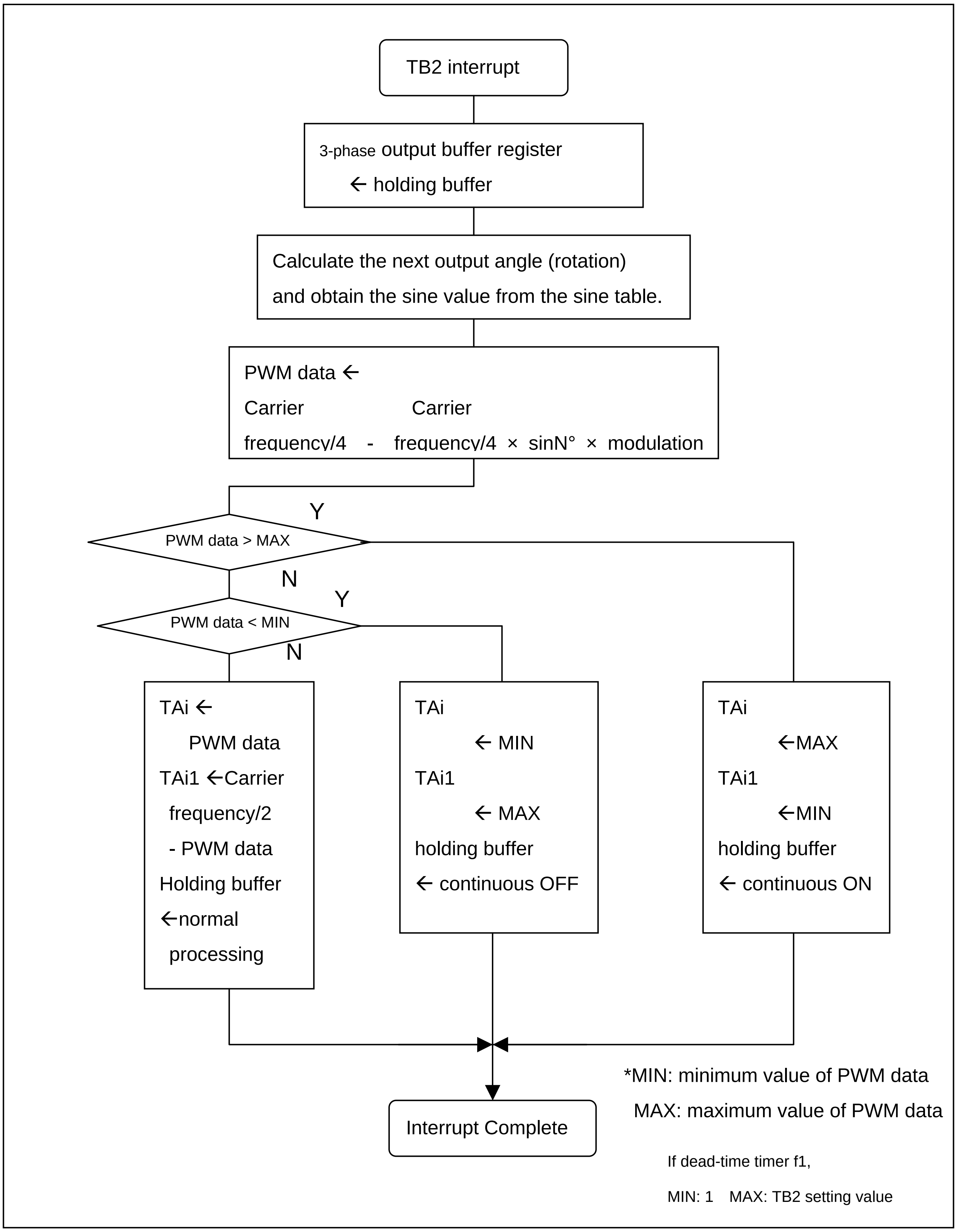


Figure 5.6.2 Timing of writing the 3-phase output buffer register

*3-phase output buffer register contents are transferred to the shift register at the first TB2 underflow after updating.


TB2 interrupt
3-phase output buffer register ← holding buffer
Calculate the next output angle (rotation) and obtain the sine value from the sine table.
PWM data ← Carrier frequency/4 - Carrier frequency/4 × sinN° × modulation
PWM data > MAX
Y
N
PWM data < MIN
Y
N
TAi ← PWM data
TAi1 ←Carrier frequency/2 - PWM data
Holding buffer ←normal processing
TAi ← MIN
TAi1 ← MAX
holding buffer ← continuous OFF
TAi ←MAX
TAi1 ←MIN
holding buffer ← continuous ON
Interrupt Complete
*MIN: minimum value of PWM data
MAX: maximum value of PWM data
If dead-time timer f1,
MIN: 1 MAX: TB2 setting value
Figure 5.7 TB2 interrupt process flowchart (Method 1)

5.5.2 Continuous On/Off Waveform Output Realized by Timer Set Value

Continuous on/off waveform output can be generated by setting the TAi, TAi1 register to “0” and making the shift register contents go to the “no shift condition” as shown in Figure 5.8.

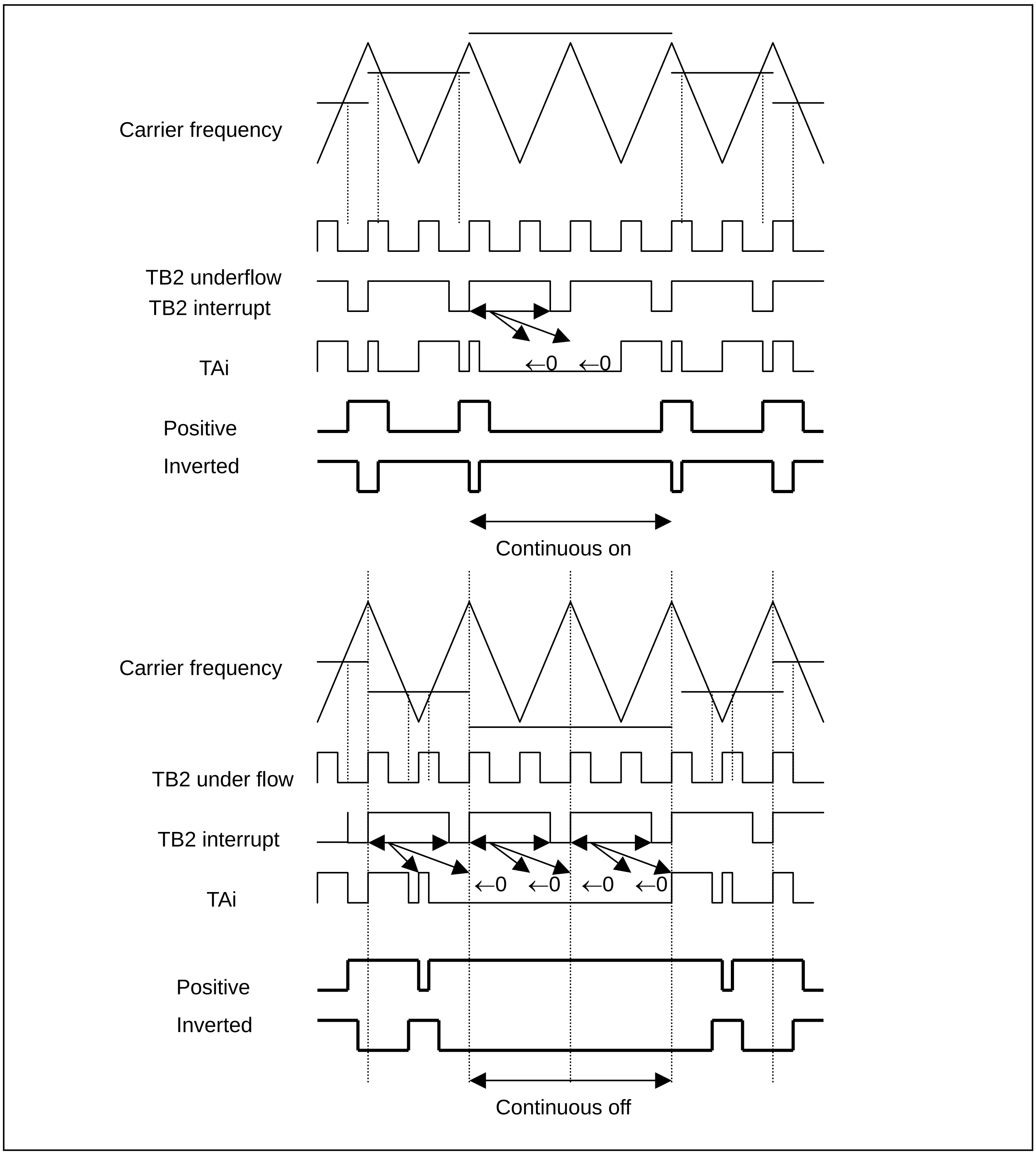


Figure 5.8 Timing and flow of setting register TAi

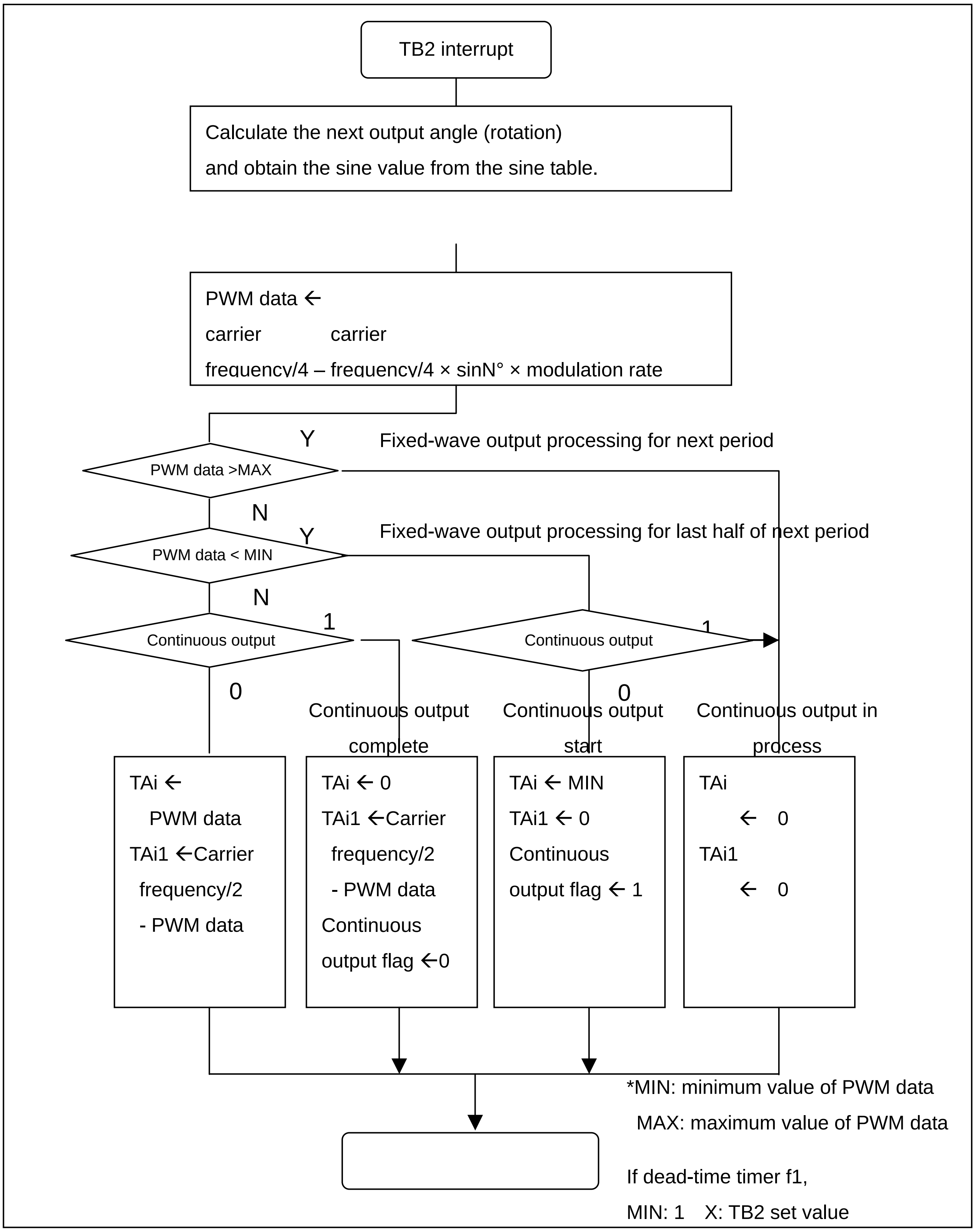

TB2 interrupt
Calculate the next output angle (rotation)
and obtain the sine value from the sine table.
PWM data ←
carrier
frequency/4 – carrier
frequency/4 × sinN° × modulation rate
PWM data >MAX
Y
Fixed-wave output processing for next period
N
PWM data < MIN
Y
Fixed-wave output processing for last half of next period
N
Continuous output
1
0
Continuous output
1
0
Continuous output complete
Continuous output start
Continuous output in process
TAi ← PWM data
TAi1 ←Carrier frequency/2 - PWM data
TAi ← 0
TAi1 ←Carrier frequency/2 - PWM data
Continuous output flag ←0
TAi ← MIN
TAi1 ← 0
Continuous output flag ← 1
TAi ← 0
TAi1 ← 0
*MIN: minimum value of PWM data
MAX: maximum value of PWM data
If dead-time timer f1,
MIN: 1 X: TB2 set value

Figure 5.9 TB2 interrupt process flowchart (Method 2.)

5.6 Output Frequency Variation

The output frequency variation can be done by manipulating the sinusoidal wave output angle, which, for example, can be obtained by skip-reading the sine table. The following explains the manipulation method of the output angle for an induction motor.

For example, there are 360 units of data available. The sampling speed of the carrier frequency is 3.6kHz and each data is plotted as one-degree angle. If the output frequency is 10Hz, the data table is sampled every carrier period. But, if the output frequency is changed to 5Hz, the sinusoidal wave period is doubled, therefore, each data is sampled twice.

	Standard	
angle	sinN° at 10Hz	sinN° at 5Hz
0	0	0
1	0.0175	0
2	0.0349	0.0175
3	0.0523	0.0175
4	0.0698	0.0349
5	0.0872	0.0349
6	0.1045	0.0523
7	0.1219	0.0523
8	0.1392	0.0698
9	0.1564	0.0698
10	0.1736	0.0872

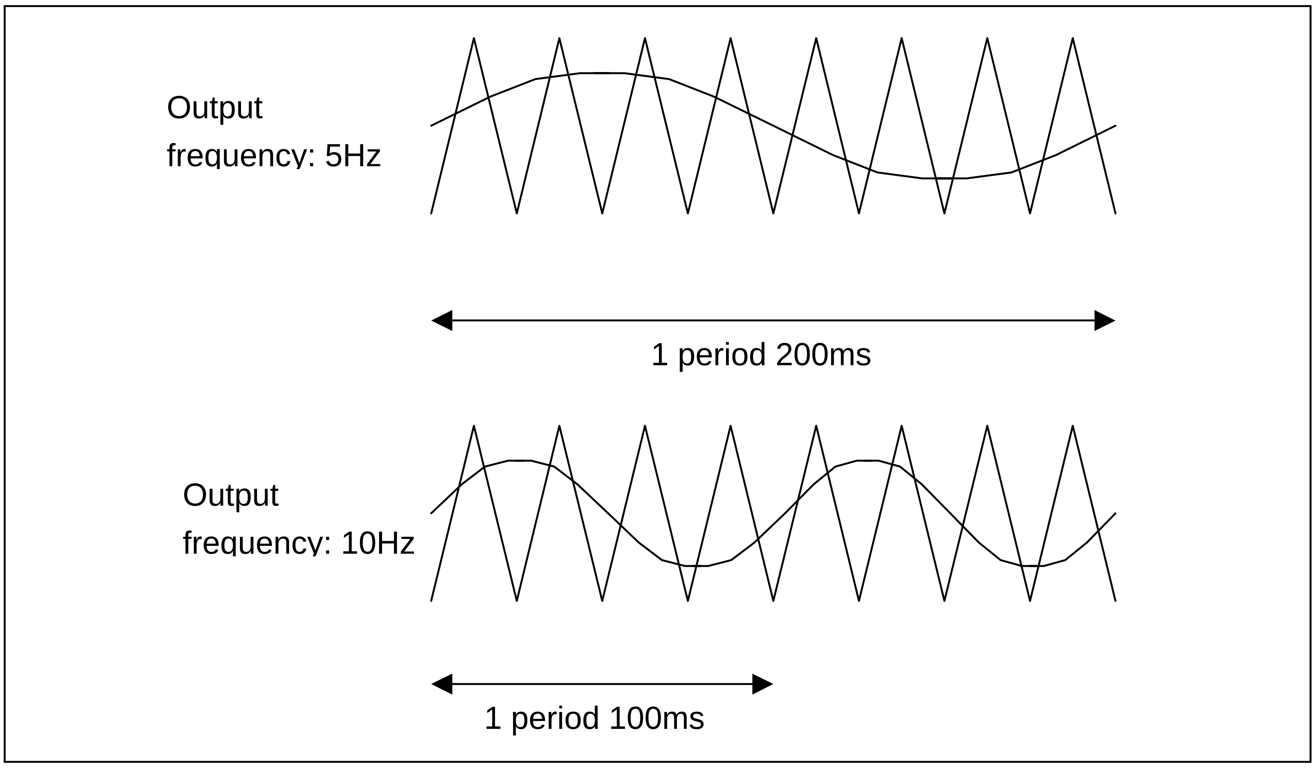


Figure 5.10 Output frequency variation

6.0 How to realize trapezoidal wave control

6.1 How to output trapezoidal waveform

This chapter explains an example of trapezoidal waveform output using 3-phase motor control timer function.

6.2 How to output trapezoidal waveform by using three-phase motor control timer function.

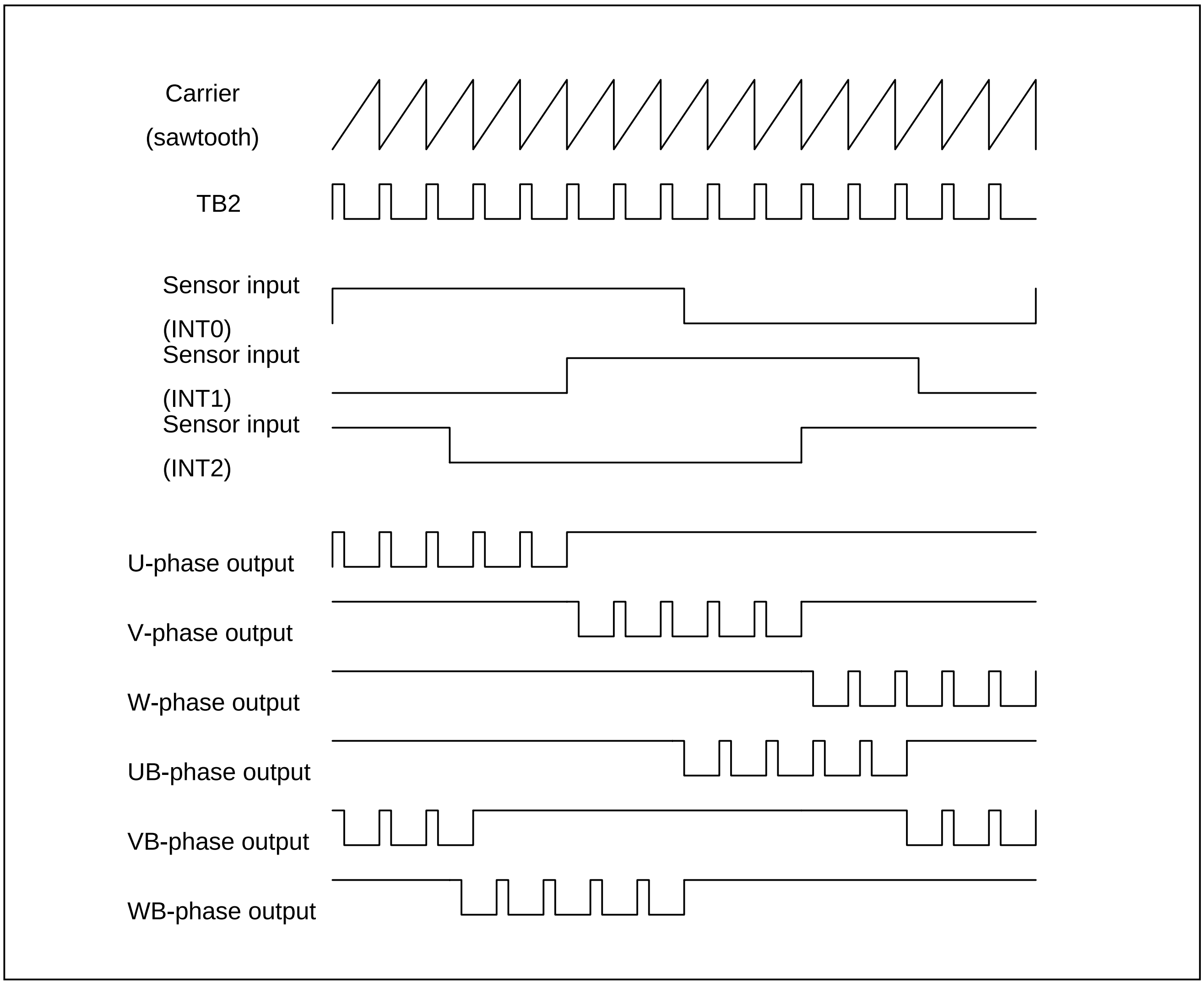


Figure 6.1 Relationship of sensor input of trapezoidal wave control and wave output

Select the sawtooth wave as the modulation mode, and use 3-phase mode 0. Switch each phase to active during the INT interrupt with the 3-phase output buffer register.
(invc0=*1**1100; invc1=0000010*; idb0=00******; idb1=00******;)

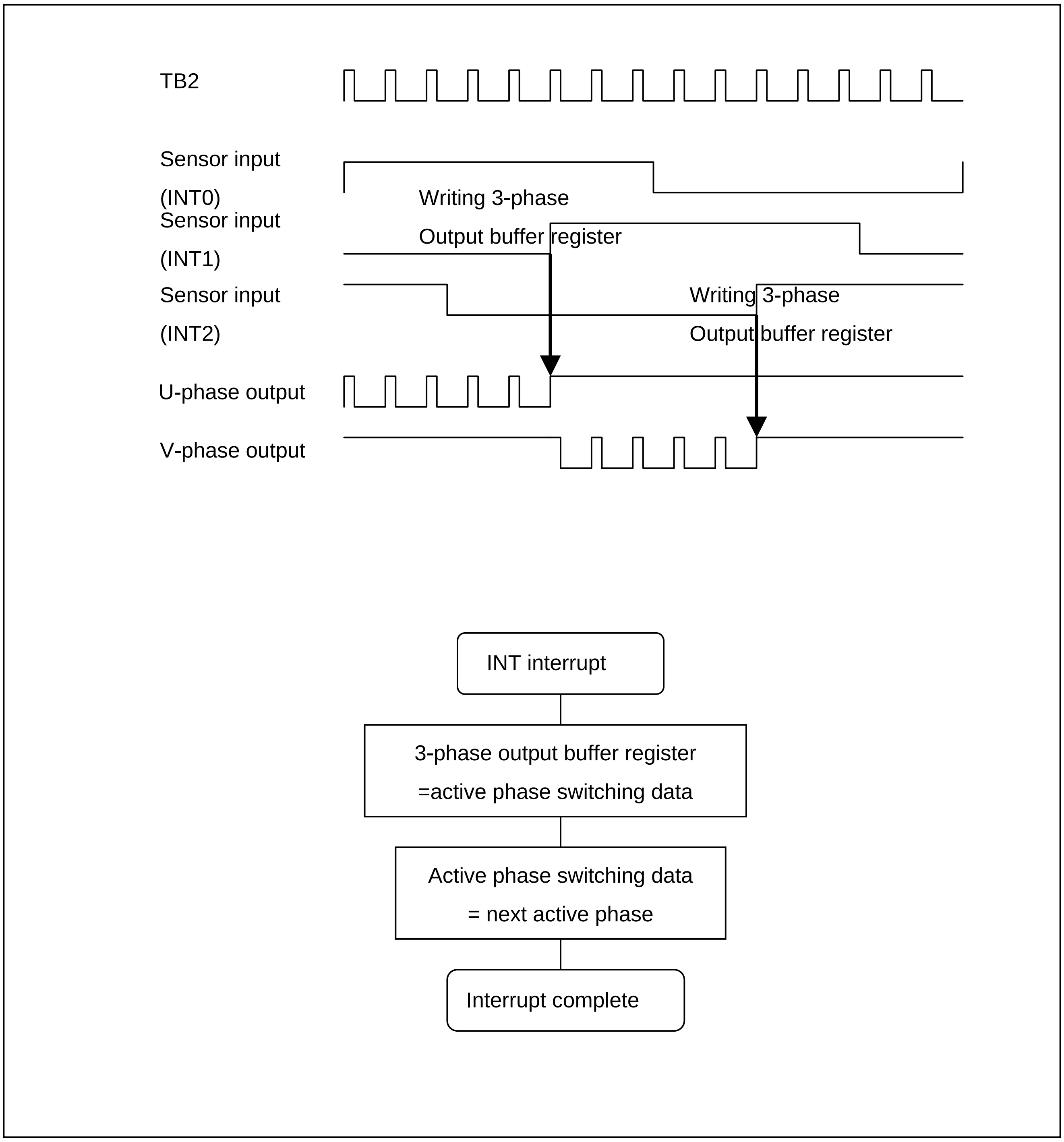

TB2
Sensor input (INT0)
Sensor input (INT1)
Sensor input (INT2)
Writing 3-phase Output buffer register
Writing 3-phase Output buffer register
U-phase output
V-phase output
INT interrupt
3-phase output buffer register =active phase switching data
Active phase switching data = next active phase
Interrupt complete

Figure 6.2 Sensor interrupt and output phase

6.3 High speed control

Trapezoidal wave control is based on the torque-to-speed ratio. Specifically, the user can control the speed by updating the values of TA4, TA1, and TA2 each time the torque command value changes.

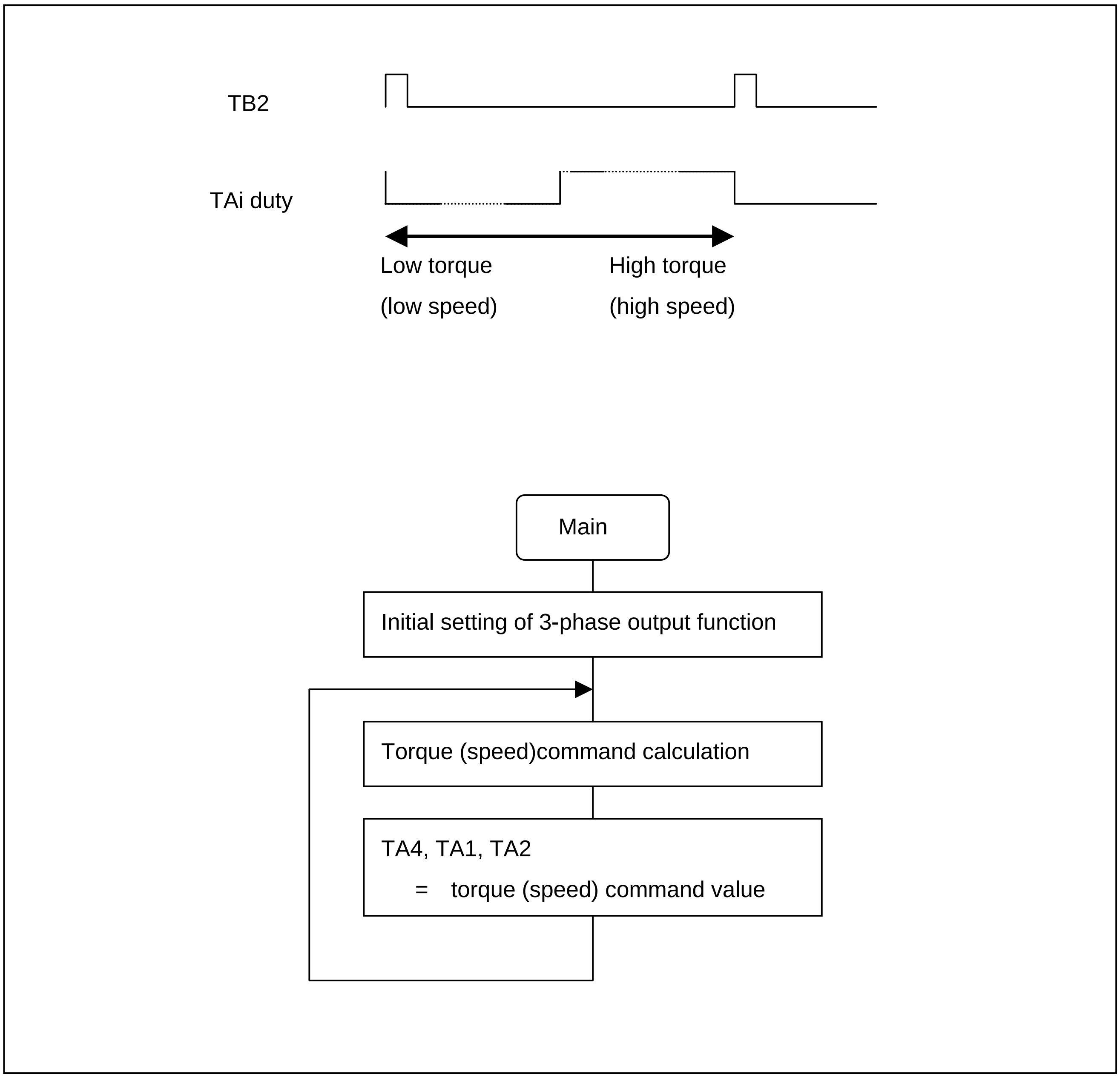

TB2
TAi duty
Low torque
(low speed)
High torque
(high speed)
Main
Initial setting of 3-phase output function
Torque (speed)command calculation
TA4, TA1, TA2
= torque (speed) command value

Figure 6.3 Relationship of torque command value and TAi

7.0 Sample Program

The following is a sample program to be used as a reference for realizing 3-phase motor drive waveform. This sample program may require modification and adjustment comforming to each user aplication.

7.1 Sample Program For Sinusoidal Waveform Output

The following is a sample program for realizing 3-phase sinusoidal waveform output.

```
/*******************************************************************************
*      Sample program for sinusoidal waveform output
*
*******************************************************************************/

/*******************************************************************************/
/*                                                                             */
/*      SFR Setting                                                            */
/*                                                                             */
/*******************************************************************************/
volatile char invc0;
#pragma ADDRESS  invc00348h                  /* 3-phase PWM control register 0 */
volatile char invc1;
#pragma ADDRESS  invc10349h                  /* 3-phase PWM control register 1 */
volatile char icTB2;
#pragma ADDRESS  icTB2      034dh                 /* Interrupt cycle set counter */
volatile char idb0;
#pragma ADDRESS  idb0  034ah                 /* 3-phase output buffer register 0 */
volatile char idb1;
#pragma ADDRESS  idb1  034bh                 /* 3-phase output buffer register1 */
volatile char   ta1mr;
#pragma ADDRESS  ta1mr      0397h                 /* Timer A1 mode register */
volatile char ta2mr;
#pragma ADDRESS  ta2mr      0398h                 /* Timer A2 mode register */
volatile char ta4mr;
#pragma ADDRESS  ta4mr      039ah                 /* Timer A mode register */
volatile char TB2mr;
#pragma ADDRESS  TB2mr      039dh                 /* Timer B2 mode register */
volatile char TB2sc;
#pragma ADDRESS  TB2sc      039eh                 /* Timer B2 specific mode register*/
volatile char trgsr;
#pragma ADDRESS  trgsr 0383h                 /* Trigger select register */
volatile short TB2;
#pragma ADDRESS  TB2  0394h                  /* Timer B 2 */
volatile char      dtt;
#pragma ADDRESS  dtt    034ch                /* Dead-time timer */
volatile short ta4;
#pragma ADDRESS  ta4    038eh                /* Timer A 4 */
volatile short ta1;
```

```
#pragma ADDRESS  ta1    0388h                   /* Timer A 1 */
volatile short ta2;
#pragma ADDRESS  ta2    038ah                   /* Timer A2 */
volatile short ta41;
#pragma ADDRESS  ta41  0346h                    /* Timer A4-1 */
volatile short ta11;
#pragma ADDRESS  ta11  0342h                    /* Timer A1-1 */
volatile short ta21;
#pragma ADDRESS  ta21  0344h                    /* Timer A2-1 */
volatile char       TB2ic;
#pragma ADDRESS  TB2ic       005ch                    /* Timer B2 interrupt control register */
volatile char       tabsr;
#pragma ADDRESS  tabsr 0380h                    /* Count start flag */
volatile char       prcr;
#pragma ADDRESS  prcr   000ah                   /* Protect register */

/*******************************************************************************/
/*                                                                             */
/*       Initialize                                                            */
/*                                                                             */
/*******************************************************************************/
void main_ini(void);


#define CLK 20000000            /*MCU Frequency Hz*/
#define CARR 20000              /*Carrier Frequency Hz*/
#define DTT_TM 40               /*Dead-time x 0.1 us */

#define carr_set_2 ((CLK/CARR)/2)               /*Carrier period 1/2    */
#define carr_set_4 ((CLK/CARR)/4)               /*Carrier period 1/4    */
#define dtt_set ((CLK*DTT_TM)/10000000)         /* Dead-time timer value     */

void main_ini()
{
        icTB2=1;                /*   One TB2 interrupt at every other TB2 underflow*/

        prcr=0x02;              /* Protect cancel*/
        invc0=0x16;             /* Select 3-phase motor control timer function    output in halting state                 */
        invc1=0x42;             /*   3-phase mode 1                                      */
        TB2sc=0x01;             /*   Synchronize reload timing every full-period of the carrier*/
        prcr=0x00;              /*   Protect*/

        idb0=0x15;              /*Set idb0 */
        idb1=0x2a;              /*Set idb1 */
        ta1mr=0x12;             /*One-shot pulse mode      */
        ta2mr=0x12;             /*One-shot pulse mode      */
        ta4mr=0x12;             /*One-shot pulse mode      */
        TB2mr=0x00;             /*Timer mode               */
        trgsr=0x45;             /*Triger select register TB2 trigger*/

        TB2=carr_set_2-1;                       /*One-half carrier period        */
        dtt=dtt_set;                            /*Dead-time timer value          */
        ta4=ta1=ta2=carr_set_4;                 /*Duty 50%*/
        ta41=ta11=ta21=carr_set_4;              /*Duty 50%*/

        TB2ic=0x07;                         /* Interrupt level 7 */

        asm("       FSET        I");    /* Enable interrupt */

        tabsr=0x96;                         /*Count start flag, timer start*/

        prcr=0x02;
        invc0=0x1e;             /*   Enable output*/
        prcr=0x00;          /*Protect*/

}
```

```
/*******************************************************************************/
/*                                                                             */
/*      Sine table                                                             */
/*                                                                             */
/*      To improve the precision of your calculations, prepare a sine table by a factor of FFFF/2 */
/*                                                                             */
/*******************************************************************************/

const short sin_tbl[610]=
{
          572,   1144,   1715,   2286,   2856,        3425,   3993,   4560,   5126,   5690,
         6252,   6813,   7371,   7927,   8481,        9032,   9580, 10126, 10668, 11207,
        11743, 12275, 12803, 13328, 13848,        14364, 14876, 15383, 15886, 16384,
        16876, 17364, 17846, 18323, 18795,        19260, 19720, 20174, 20621, 21063,
        21497, 21926, 22347, 22762, 23170,        23571, 23965, 24351, 24730, 25101,
        25465, 25821, 26169, 26509, 26842,        27165, 27481, 27788, 28087, 28377,
        28659, 28932, 29196, 29451, 29697,        29935, 30163, 30381, 30591, 30791,
        30982, 31164, 31336, 31498, 31651,        31794, 31928, 32051, 32165, 32270,
        32364, 32449, 32523, 32588, 32643,        32688, 32723, 32748, 32763, 32767,
        32763, 32748, 32723, 32688, 32643,        32588, 32523, 32449, 32364, 32270,
        32165, 32051, 31928, 31794, 31651,        31498, 31336, 31164, 30982, 30791,
        30591, 30382, 30163, 29935, 29697,        29451, 29196, 28932, 28659, 28378,
        28087, 27788, 27481, 27166, 26842,        26510, 26169, 25821, 25465, 25101,
        24730, 24351, 23965, 23571, 23170,        22762, 22347, 21926, 21497, 21063,
        20621,20174, 19720, 19260, 18795,        18323, 17847, 17364, 16877, 16384,
        15886, 15383, 14876, 14364, 13848,        13328, 12803, 12275, 11743, 11207,
        10668, 10126,   9580,   9032,   8481,        7927,   7371,   6813,   6252,   5690,
         5126,   4560,   3993,   3425,   2856,        2286,   1715,   1144,    572,      0,
         -572, -1143, -1715, -2286, -2856,        -3425, -3993, -4560, -5126, -5690,
        -6252, -6813, -7371, -7927, -8481,        -9032, -9580,-10126,-10668,-11207,
     -11743,-12275,-12803,-13328,-13848,        -14364,-14876,-15383,-15886,-16384,
     -16876,-17364,-17846,-18323,-18795,        -19260,-19720,-20174,-20621,-21062,
     -21497,-21926,-22347,-22762,-23170,        -23571,-23965,-24351,-24730,-25101,
     -25465,-25821,-26169,-26509,-26841,        -27165,-27481,-27788,-28087,-28377,
     -28659,-28932,-29196,-29451,-29697,        -29935,-30163,-30381,-30591,-30791,
     -30982,-31164,-31336,-31498,-31651,        -31794,-31928,-32051,-32165,-32270,
     -32364,-32449,-32523,-32588,-32643,        -32688,-32723,-32748,-32763,-32767,
     -32763,-32748,-32723,-32688,-32643,        -32588,-32523,-32449,-32364,-32270,
     -32165,-32051,-31928,-31794,-31651,        -31498,-31336,-31164,-30982,-30791,
     -30591,-30382,-30163,-29935,-29698,        -29451,-29196,-28932,-28659,-28378,
     -28087,-27788,-27481,-27166,-26842,        -26510,-26169,-25821,-25465,-25101,
     -24730,-24351,-23965,-23571,-23170,        -22762,-22347,-21926,-21498,-21063,
     -20621,-20174,-19720,-19260,-18795,        -18323,-17847,-17364,-16877,-16384,
     -15886,-15384,-14876,-14364,-13848,        -13328,-12803,-12275,-11743,-11207,
     -10668,-10126, -9580, -9032, -8481,      -7927, -7371, -6813, -6252, -5690,
        -5126, -4561, -3994, -3425, -2856,      -2286, -1715, -1144,   -572,      0,
        572,   1144,   1715,   2286,   2856,        3425,   3993,   4560,   5126,   5690,
       6252,   6813,   7371,   7927,   8481,        9032,   9580, 10126, 10668, 11207,
      11743, 12275, 12803, 13328, 13848,         14364, 14876, 15383, 15886, 16384,
      16876, 17364, 17846, 18323, 18795,         19260, 19720, 20174, 20621, 21063,
      21497, 21926, 22347, 22762, 23170,         23571, 23965, 24351, 24730, 25101,
      25465, 25821, 26169, 26509, 26842,         27165, 27481, 27788, 28087, 28377,
      28659, 28932, 29196, 29451, 29697,         29935, 30163, 30381, 30591, 30791,
      30982, 31164, 31336, 31498, 31651,         31794, 31928, 32051, 32165, 32270,
      32364, 32449, 32523, 32588, 32643,         32688, 32723, 32748, 32763, 32767,
      32763, 32748, 32723, 32688, 32643,         32588, 32523, 32449, 32364, 32270,
      32165, 32051, 31928, 31794, 31651,         31498, 31336, 31164, 30982, 30791,
      30591, 30382, 30163, 29935, 29697,         29451, 29196, 28932, 28659, 28378,
      28087, 27788, 27481, 27166, 26842,         26510, 26169, 25821, 25465, 25101,
      24730, 24351, 23965, 23571, 23170,         22762, 22347, 21926, 21497, 21063,
      2062120174, 19720, 19260, 18795,          18323, 17847, 17364, 16877, 16384,
      15886, 15383, 14876, 14364, 13848,         13328, 12803, 12275, 11743, 11207,
      10668, 10126,   9580,   9032,   8481,          7927,   7371,   6813,   6252,   5690,
       5126,   4560,   3993,   3425,   2856,        2286,   1715,   1144,    572,      0,
       -572, -1143, -1715, -2286, -2856,           -3425, -3993, -4560, -5126, -5690,
      -6252, -6813, -7371, -7927, -8481,           -9032, -9580,-10126,-10668,-11207,
    -11743,-12275,-12803,-13328,-13848,          -14364,-14876,-15383,-15886,-16384,
    -16876,-17364,-17846,-18323,-18795,          -19260,-19720,-20174,-20621,-21062,
    -21497,-21926,-22347,-22762,-23170,          -23571,-23965,-24351,-24730,-25101,
    -25465,-25821,-26169,-26509,-26841,          -27165,-27481,-27788,-28087,-28377,
    -28659,-28932,-29196,-29451,-29697,          -29935,-30163,-30381,-30591,-30791
};
```

```
/******************************************************************************/
/*                                                                            */
/*      Calculations performed in main routine (ex. Induction motor)          */
/*          1.Skip-read value of sine table                                   */
/*          2.Torque command value for output frreqency                       */
/*                                                                            */
/******************************************************************************/
void main_pro(void);

signed short out_bin=100;       /*Output freqency value (temporary value)*/
signed short torq=1500;         /*Torque data (temporary value)*/
signed short tq_dat;            /*Torque command value x carrier/4*/
signed short sin_cut;           /*Skip-read value for sine pinter */


void main_pro()
{

/*Skip-read value=23040 x output frequency / carrier frequency   23040=360°x 64       */
        sin_cut=(signed short)(((signed long)out_bin*23040)/CARR);

        tq_dat=(signed short)(((signed long)torq*carr_set_4)/1000); /*Torque comand value   x   carrier/4*/

}
```

```
/*******************************************************************************/
/*                                                                             */
/*      TB2 interrupt process                                                  */
/*                                                                             */
/*******************************************************************************/

void TB2_int(void);

void PWM_uvw_set(void);
void PWM_uvwa_set(void);
void PWM_uvwb_set(void);
void PWM_buf(void);
void i_con(void);
void angle(void);

unsigned char idb0_b=0x15;      /*idb0 operation-use*/
unsigned char idb1_b=0x2a;          /*idb1 operation-use*/
signed short tq_dat;            /*Torque command value   x   carrier/4*/
signed short sinpt_sum;             /*Counter for sine pointer sum*/
signed short sin_pt;            /*Sine table pointer*/
signed short PWM_u_w;               /*U-phase PWM command value*/
signed short PWM_v_w;               /*V-phase PWM command value*/
signed short PWM_w_w;               /*W-phase PWM command value*/
#define PWM_max    (carr_set_2-1)   /*Max. PWM setting*/
#define PWM_min 1                   /*Min. PWM setting*/


/*        TB2 interrupt (no 2-phase modulation)          */

#pragma   INTERRUPT/B   TB2_int
void TB2_int(void)
{

        angle();                        /*Calculate sine table pointer   */
        i_con();                        /*Calculate PWM command value                    */
        PWM_uvw_set();                      /*PWM command value upper limit revision, set timer*/

}
```

```
/*        TB2 interrupt (with 2-phase modulation by updating timer value)              */

#pragma   INTERRUPT/B   TB2_int
void TB2_int(void)
{

        angle();                          /*Calculate sine table pointer    */
        i_con();                          /*Calculate PWM command value     */

        PWM_uvwa_set();                   /*PWM command value upper limit revision, set timer*/

}


/*        TB2 interrupt (with 2-phase modulation by updating 3-phase output buffer)              */

#pragma   INTERRUPT/B   TB2_int
void TB2_int(void)
{

        PWM_buf();                        /*Set 3-phase output buffer*/
        angle();                          /*Calculate sine table pointer    */
        i_con();                          /*Calculate PWM command value                    */

        PWM_uvwb_set();                   /*PWM command value upper limit revision, set timer*/

}
```

```
/********************************************************************************/
/*                                                                              */
/*      Module for TB2 interrupt (in case of induction motor)                  */
/*      Calculation of sine angle                                               */
/*       Calculation of PWM Duty                                                */
/*                                                                              */
/********************************************************************************/



void angle()
{
        sinpt_sum=sin_cut+sinpt_sum;            /*sine pointer sum←skip-read value + sine pointer sume*/
        if(sinpt_sum>23040)                  /*Sine pointer sum max. value?   23040=360° x   64*/
        {
                sinpt_sum=sinpt_sum-23040;      /*Sine pointer sum max. value revision*/
        }
        else
        {
        }
        sin_pt=sinpt_sum>>6;                    /*Sine pointer←Sine pointer sum / 64*/
}


void i_con()
{
/*    U-phase PWM command value = carrier/4-(sinN° x (toruqe command value x carrier/4))          */
        PWM_u_w=carr_set_4-(signed short)(((signed long)sin_tbl[sin_pt]*(signed long)(tq_dat*2))>>16);

/*    V-phase PWM command value = carrier/4-(sin(N+120) ° x (toruque command value x carrier/4))            */
        PWM_v_w=carr_set_4-
                        (signed short)(((signed long)sin_tbl[sin_pt+120]*(signed long)(tq_dat*2))>>16);

/*    W-phase PWM command value = carrier/4-(sin(N+240) ° x (toruqe command value x carrier/4))             */
        PWM_w_w=carr_set_4-
                        (signed short)(((signed long)sin_tbl[sin_pt+240]*(signed long)(tq_dat*2))>>16);


}
```

```
/*********************************************************************************/
/*                                                                              */
/*      Module for TB2 interrupt                                                */
/*                      PWM data setting                                        */
/*                                                                              */
/*********************************************************************************/

/*                          no 2-phase modulation                               */

void PWM_uvw_set()
{

/*U-phase PWM revision*/
        if(PWM_max<PWM_u_w)                     /*Duty at MAX?*/
        {
                ta41=PWM_max;                   /*First half←MAX value      */
                ta41=PWM_max;                   /*First half←MAX value      */
                ta4=PWM_min;                    /*Last half←MIN value       */
        }
        else
        {
                if(PWM_min>PWM_u_w)             /*Duty at MIN?*/
                {
                        ta41=PWM_min;           /*First half←MIN value      */
                        ta41=PWM_min;           /*First half←MIN value      */
                        ta4=PWM_max;            /*Last half←MAX value       */
                }
                else                    /*MIN<Duty<MAX*/
                {
                        ta41=PWM_u_w;           /*First half←PWM command value     */
                        ta41=PWM_u_w;           /*First half←PWM command value     */
                        ta4=carr_set_2-PWM_u_w; /*Last half←carrier period/2 - U-phase PWM
                                                  command value*/
                }
        }

/*V-phase PWM revision*/
        if(PWM_max<PWM_v_w)                     /*Duty at MAX?*/
        {
                ta11=PWM_max;                   /*First half←MAX value      */
                ta11=PWM_max;                   /*First half←MAX value      */
                ta1=PWM_min;                    /*Last half←MIN value       */
        }
        else
        {
                if(PWM_min>PWM_v_w)             /*Duty at MIN?*/

                {
```

```
                ta11=PWM_min;                   /*First half←MIN value      */
                ta11=PWM_min;                   /*First half←MIN value      */
                ta1=PWM_max;                    /*Last half←MAX value*/
            }
            else                                /*MIN<Duty<MAX*/


            {
                ta11=PWM_v_w;                   /*First half←PWM command value    */
                ta11=PWM_v_w;                   /*First half←PWM command value    */
                ta1=carr_set_2-PWM_v_w;         /*Last half←carrier period/2- V-phase PWM
                                                command value*/
            }
        }


/*W-phase PWM revision*/
        if(PWM_max<PWM_w_w)                     /*Duty at MAX?*/
        {
            ta21=PWM_max;                       /*First half←MAX value      */
            ta21=PWM_max;                       /*First half←MAX value*/
            ta2=PWM_min;                        /*Last half←MIN value       */
        }
        else
        {
            if(PWM_min>PWM_w_w)                 /*Duty at MIN?*/
            {
                ta21=PWM_min;                   /*First half←MIN value      */
                ta21=PWM_min;                   /*First half←MIN value */
                ta2=PWM_max;                    /*Last half←MAX value */
            }
            else                                /*MIN<Duty<MAX */
            {
                ta21=PWM_w_w;                   /*First half←PWM command value    */
                ta21=PWM_w_w;                   /*First half←PWM command value    */
                ta2=carr_set_2-PWM_w_w;         /*Last half←carrier period/2- W-phasePWM
                                                command value*/
            }
        }
}
```

```
/*   with 2-phase modulation by setting timer value to “0”    */

struct tag{
            char  bit0:1;
            char  bit1:1;
            char  bit2:1;
      }flag_buf;
#define arm_u_flg flag_buf.bit0  /*U-phase continuous arm output judgment flag*/
#define arm_v_flg flag_buf.bit1  /*V-phase continuous arm output judgment flag*/
#define arm_w_flg flag_buf.bit2  /*W-phase continuous arm output judgment flag*/

void PWM_uvwa_set()
{
/*U-phase PWM revision*/
      if(PWM_max<PWM_u_w)                   /*Duty at MAX? */
      {
            ta41=0;                         /*Continuous output start/ in process*/
            ta41=0;                         /*Continuous output start/ in process*/
            ta4=0;                          /*    ←0        */
      }
      else
      {
            if(PWM_min>PWM_u_w)             /*Duty at MIN?*/
            {
                  if(arm_u_flg==1)          /*Continuous output in process   */
                  {
                        ta41=0;             /*First half←0          */
                        ta41=0;             /*First half←0          */
                        ta4=0;              /*Last half←0           */
                  }
                  else                /*Continuous output start   */
                  {
                        ta41=PWM_min;       /*First half←MIN value*/
                        ta41=PWM_min;       /*First half←MIN value*/
                        ta4=0;              /*Last half←0           */
                        arm_u_flg=1;        /*Continuous output flag set             */
                  }
            }
            else                      /*MIN<Duty<MAX*/
            {
                  if(arm_u_flg==1)          /*Continuous output complete*/
                  {
                        ta41=0;                   /*First half←0          */
                        ta41=0;                   /*First half←0          */
                        ta4=carr_set_2-PWM_u_w;   /*Last half←carrier period/2- U-phase PWM
                                                    command value*/
```

```
                    arm_u_flg=0;                  /*Continuous output flag clear     */
                }
                else                    /*Normal processing*/
                {
                    ta41=PWM_u_w;                 /*First half←PWM command value      */
                    ta41=PWM_u_w;                 /*First half←PWM command value      */
                    ta4=carr_set_2-PWM_u_w;       /*Last half←carrier period/2 – U-phase PWM
                                                    command value*/
                }
            }
        }

/*V-phase PWM revision*/
        if(PWM_max<PWM_v_w)             /*Duty at MAX?*/
        {
            ta11=0;                     /*Continuous output start/ in process*/
            ta11=0;                     /*Continuous output start/ in process*/
            ta1=0;                      /*   ←0                 */
        }
        else
        {
            if(PWM_min>PWM_v_w)                 /*Duty at MIN? */
            {
                if(arm_v_flg==1)        /*Continuous output in process   */
                {
                    ta11=0;             /*First half←0          */
                    ta11=0;             /*First half←0          */
                    ta1=0;              /*Last half←0           */
                }
                else                    /*Continuou-arm start*/
                {
                    ta11=PWM_min;               /*First half←MIN value       */
                    ta11=PWM_min;               /*First half←MIN value       */
                    ta1=0;                      /*Last half←0           */
                    arm_v_flg=1;        /*Continuous output flag set             */
                }
            }
            else                        /*MIN<Duty<MAX*/
            {
                if(arm_v_flg==1)                /*Continuous output complete*/
                {
                    ta11=0;                             /*First half←0          */
                    ta11=0;                             /*First half←0          */
                    ta1=carr_set_2-PWM_v_w;             /*Last half←carrier period/2 – V-phase PWM
                                                          command value*/
                    arm_v_flg=0;                /*Continuous output flag clear    */
                }
                else                    /*Normal processing*/
                {
                    ta11=PWM_v_w;                       /*First half←PWM command value     */
                    ta11=PWM_v_w;                       /*First half←PWM command value     */
                    ta1=carr_set_2-PWM_v_w;             /*Last half←carrier period/2 - V-phase PWM
                                                          command value*/
                }
            }
        }

/*W-phase PWM revision*/
        if(PWM_max<PWM_w_w)                     /*Duty at MAX?*/
        {
            ta21=0;                     /*Continuous output start / in process*/
            ta21=0;                     /*Continuous output start / in process*/
            ta2=0;                      /*   ←0        */
        }
        else
        {
            if(PWM_min>PWM_w_w)                 /*Duty at MIN? */
            {
                if(arm_w_flg==1)        /*Continuous output in process          */
                {
                    ta21=0;             /*First half←0          */
                    ta21=0;             /*First half←0          */
                    ta2=0;              /*Last half←0           */
                }
                else                    /*Continuous output start   */
                {
                    ta21=PWM_min;                       /*First half←MIN value       */
                    ta21=PWM_min;                       /*First half←MIN value*/
                    ta2=0;                      /*Last half←0           */
                    arm_w_flg=1;                /*Continuous arm flag set           */
                }
            }
            else                        /*MIN<Duty<MAX*/
            {
                  if(arm_w_flg==1)                  /*Continuous-arm complete*/
                  {
                        ta21=0;                           /*First half←0           */
                        ta21=0;                           /*First half←0           */
                        ta2=carr_set_2-PWM_w_w;           /*Last half←carrier period/2 – W-phase PWM
                                                            command value*/
                        arm_w_flg=0;                      /*Continuous-arm flag clear       */
                  }
                  else                        /*Normal processing */
                  {
                        ta21=PWM_w_w;                     /*First half←PWM command value     */
                        ta21=PWM_w_w;                     /*First half←PWM command value     */
                        ta2=carr_set_2-PWM_w_w;           /*Last half←carrier period/2 – W-phase PWM
                                                            command value*/
                  }
            }
      }
}

/*2-phase modulation realized by setting 3-phase output buffer register        */


void PWM_buf()
{
      idb0=idb0_b;            /*Set 3-phase output buffer register to "0" */
      idb1=idb1_b;            /*Set 3-phase output buffer register to "1" */
}


void PWM_uvwb_set()
{

/*U-phase PWM revision*/
      if(PWM_max<PWM_u_w)                     /*Duty at MAX ? */
      {
            idb0_b=idb0_b&0xfc;
            idb0_b=idb0_b|0x02;

            ta41=PWM_max;                 /*First half←MAX value      */
            ta41=PWM_max;                 /*First half←MAX value      */
            ta4=PWM_min;                  /*Last half←MIN value       */
      }
      else
```

```
        {
                if(PWM_min>PWM_u_w)                 /*Duty at MIN? */
                {
                        idb1_b=idb1_b&0xfc;
                        idb1_b=idb1_b|0x01;
                        ta41=PWM_min;                       /*First half←MIN value       */
                        ta41=PWM_min;                       /*First half←MINE value      */
                        ta4=PWM_max;                        /*Last half←MAX value        */
                }
                else                            /*MIN<Duty<MAX */
                {
                        idb0_b=idb0_b&0xfc;
                        idb0_b=idb0_b|0x01;
                        idb1_b=idb1_b&0xfc;
                        idb1_b=idb1_b|0x02;

                        ta41=PWM_u_w;                       /*First half←PWM command value      */
                        ta41=PWM_u_w;                       /*First half←PWM command value      */
                        ta4=carr_set_2-PWM_u_w;             /*Last half←carrier period/1 – U-phase PWM
                                                              command value*/
                }
        }

/*V-phase PWM revision*/
        if(PWM_max<PWM_v_w)                         /*Duty at MAX ?*/
        {
                idb0_b=idb0_b&0xf3;
                idb0_b=idb0_b|0x08;

                ta11=PWM_max;                       /*First half←MAX value       */
                ta11=PWM_max;                       /*First half←MAX value       */
                ta1=PWM_min;                        /*Last half←MIN value        */
        }
        else
        {
                if(PWM_min>PWM_v_w)                 /*Duty at MIN? */
                {
                        idb1_b=idb1_b&0xf3;
                        idb1_b=idb1_b|0x04;

                        ta11=PWM_min;                       /*First half←MIN value       */
                        ta11=PWM_min;                       /*First half←MIN value */
                        ta1=PWM_max;                        /*Last half←MAX value        */
                }
                else                            /*MIN<Duty<MAX*/
                {
                        idb0_b=idb0_b&0xf3;
                        idb0_b=idb0_b|0x04;
                        idb1_b=idb1_b&0xf3;
                        idb1_b=idb1_b|0x08;

                        ta11=PWM_v_w;                   /*First half←PWM command value     */
                        ta11=PWM_v_w;                   /*First half←PWM command value     */
                        ta1=carr_set_2-PWM_v_w;         /*Last half←carrier period/2 - V-phase PWM
                                                          command value*/
                }
        }

/*W-phase PWM revision */
        if(PWM_max<PWM_w_w)                     /*Duty at MAX?*/
        {
                idb0_b=idb0_b&0xcf;
                idb0_b=idb0_b|0x20;

                ta21=PWM_max;                           /*First half←MAX value      */
                ta21=PWM_max;                           /*First half←MAX value*/
                ta2=PWM_min;                    /*Last half←MIN value*/
        }
        else
        {
                if(PWM_min>PWM_w_w)             /*Duty at MIN? */
                {
                        idb1_b=idb1_b&0xcf;
                        idb1_b=idb1_b|0x10;
                        ta21=PWM_min;                           /*First half←MIN value       */
                        ta21=PWM_min;                           /*First half←MIN value*/
                        ta2=PWM_max;                    /*Last half←MAX value*/
                }
                else                            /*MIN<Duty<MAX */
                {
                        idb0_b=idb0_b&0xcf;
                        idb0_b=idb0_b|0x10;
                        idb1_b=idb1_b&0xcf;
                        idb1_b=idb1_b|0x20;

                        ta21=PWM_w_w;                   /*First half←PWM command value     */
                        ta21=PWM_w_w;                   /*First half←PWM command value     */
                        ta2=carr_set_2-PWM_w_w;         /*Last half←carrier period/2 – W-phase PWM
                                                          command value*/
                }
        }
}
```

7.2 Trapezoidal waveform sample program

The following is a sample program to be used as a reference for trapezoidal waveform output.

```
/********************************************************************************
*       Trapezoidal waveform sample programming
*
********************************************************************************/
/*******************************************************************************/
/*                                                              */
/*      SFR setting                                                         */
/*                                                              */
/*******************************************************************************/
volatile char invc0;
#pragma ADDRESS         invc0           0348h                   /* 3-phase PWM control register0 */
volatile char invc1;
#pragma ADDRESS         invc1           0349h                   /* 3-phase PWM control register 1 */
volatile char icTB2;
#pragma ADDRESS         icTB2           034dh                   /* Interrupt cycles setting counter */
volatile char idb0;
#pragma ADDRESS         idb0            034ah                   /* 3-phase output buffer register 0 */
volatile char idb1;
#pragma ADDRESS         idb1            034bh                   /* 3-phase output buffer register 1 */
volatile char   ta1mr;
#pragma ADDRESS         ta1mr           0397h                   /* Timer A1 mode register */
volatile char ta2mr;
#pragma ADDRESS         ta2mr           0398h                   /* Timer A2 mode register */
volatile char ta4mr;
#pragma ADDRESS         ta4mr           039ah                   /* Timer A4 mode register */
volatile char TB2mr;
#pragma ADDRESS         TB2mr           039dh                   /* Timer B2 mode register */
volatile char TB2sc;
#pragma ADDRESS         TB2sc           039eh                   /* Timer B2 special mode register*/
volatile char trgsr;
#pragma ADDRESS         trgsr           0383h                   /* Trigger select register */
volatile short TB2;
#pragma ADDRESS         TB2             0394h                   /* Timer B2 */
volatile char     dtt;
#pragma ADDRESS         dtt             034ch                   /* Dead-time timer */
volatile short ta4;
#pragma ADDRESS         ta4             038eh                   /* TimerA4 */
volatile short ta1;
#pragma ADDRESS         ta1             0388h                   /* TimerA1 */
volatile short ta2;
#pragma ADDRESS         ta2             038ah                   /* TimerA2 */
volatile short ta41;
#pragma ADDRESS         ta41            0346h                   /* TimerA4-1 */
volatile short ta11;

#pragma ADDRESS         ta11            0342h                   /* TimerA1-1 */
```

```
volatile short ta21;
#pragma ADDRESS       ta21          0344h              /* TimerA2-1 */
volatile char     TB2ic;
#pragma ADDRESS       TB2ic         005ch              /* Timer B2 interrupt control register */
volatile char     tabsr;
#pragma ADDRESS       tabsr         0380h              /* Count start flag */
volatile char     prcr;
#pragma ADDRESS       prcr          000ah              /* Protect register */
volatile char     ifsr;
#pragma ADDRESS       ifsr          035fh              /* External interrupt trigger select register */
volatile char     int0ic;
#pragma ADDRESS       int0ic        005dh              /* INT0 interrupt control register */
volatile char     int1ic;
#pragma ADDRESS       int1ic        005eh              /* INT1 interrupt control register */
volatile char     int2ic;
#pragma ADDRESS       int2ic        005fh              /* INT2 interrupt control register */
volatile char     p7;
#pragma ADDRESS       p7            03edh              /* Port 7 register */
volatile char     p8;
#pragma ADDRESS       p8            03f0h              /* Port 8 register */
volatile char     pd7;
#pragma ADDRESS       pd7           03efh              /* Port 7 direction register */
volatile char     pd8;
#pragma ADDRESS       pd8           03f2h              /* Port 8 direction register */
volatile char     tprc;
#pragma ADDRESS       tprc          025ah              /* 3-phase protet control register */
volatile char     pfcr;
#pragma ADDRESS       pfcr          0358h              /* Port function control register */


/**********************************************************************************/
/*                                                                               */
/*      Initialize                                                               */
/*                                                                               */
/**********************************************************************************/
void main_ini(void);

#define CLK 20000000                /* MCU frequency      Hz */
#define CARR 20000              /* Carrier frequency   Hz */

#define carr_set (CLK/CARR)         /* Carrier frequency    */

void main_ini()
{
      icTB2=1;              /*    One TB2 interrupt at every other TB2 underflow*/

      prcr=0x02;       /* Protect*/
      invc0=0x44;           /*Select 3-phase motor control timer functionm, output in halting state*/
```

```
        invc1=0x60;          /*3-phase mode 0 dead-time timer invalid*/
        prcr=0x00;      /*Protect*/

        TB2sc=0x00;          /*   Synchronize reload timing with TB2             */

        idb0=0x0ff;          /*Set 3-phase output buffer register to " 0" */
        idb1=0x0ff;          /*Set 3-phase output buffer register to "1" */

        ta1mr=0x12;          /*One-shot pulse mode      */
        ta2mr=0x12;          /*One-shot pulse mode      */
        ta4mr=0x12;          /*One-shot pulse mode      */
        TB2mr=0x00;          /*Timer mode               */
        trgsr=0x45;          /*Trigger select register TB2 trigger */

        TB2=carr_set;        /*Carrier period  */
        dtt=1;               /*Dead-timer timer MIN. value setting*/

        ta4=1;               /*Torque 0%*/
        ta1=1;               /*Torque 0%*/
        ta2=1;               /*Torque 0%*/

        /*Use INT for position input*/
        ifsr=0x07;      /*INT 0,1,2   both edges*/
        int0ic=7;            /*INT 0,1,2 interrupt level setting*/
        int1ic=7;
        int2ic=7;

        asm("      FSET      I");    /* Enable interrupt */

        tabsr=0x96;          /*Count start flag, Timer start*/

        prcr=0x02;           /*   protect cancel*/
        invc0=0x4c;          /*   Enable output*/
        prcr=0x00;           /*   Protect    */
}
```

```
/******************************************************************************/
/*                                                                            */
/*      Calculation performed in main routine                                 */
/*      1.   Setting PWM Duty                                                 */
/*                                                                            */
/******************************************************************************/
void dc_PWM_set(void);

unsigned short  tk_dat_w;                   /*Torque command value*/


void dc_PWM_set(void)
{
        ta4=ta1=ta2=tk_dat_w;
}


/******************************************************************************/
/*                                                                            */
/*     Angle detect ( when using INT)interrupt                                */
/*     Switching by 3-phase output buffer register of active phase in each phase*/
/*                                                                            */
/******************************************************************************/

#pragma   INTERRUPT/B   int0_int
void int0_int(void);
#pragma   INTERRUPT/B   int1_int
void int1_int(void);
#pragma   INTERRUPT/B   int2_int
void int2_int(void);
void rad_to_PWM(void);

unsigned char   idb0_bufb=0x0ff;            /*Next output phase*/
signed      short       rad_datw=0;                 /*Input angle*/
struct tag{
                char  bit0:1;
                char  bit1:1;
                char  bit2:1;


                char  bit3:1;

        }dc_buf;
#define edge0_flg dc_buf.bit1
#define edge1_flg dc_buf.bit2
#define edge2_flg dc_buf.bit3
```

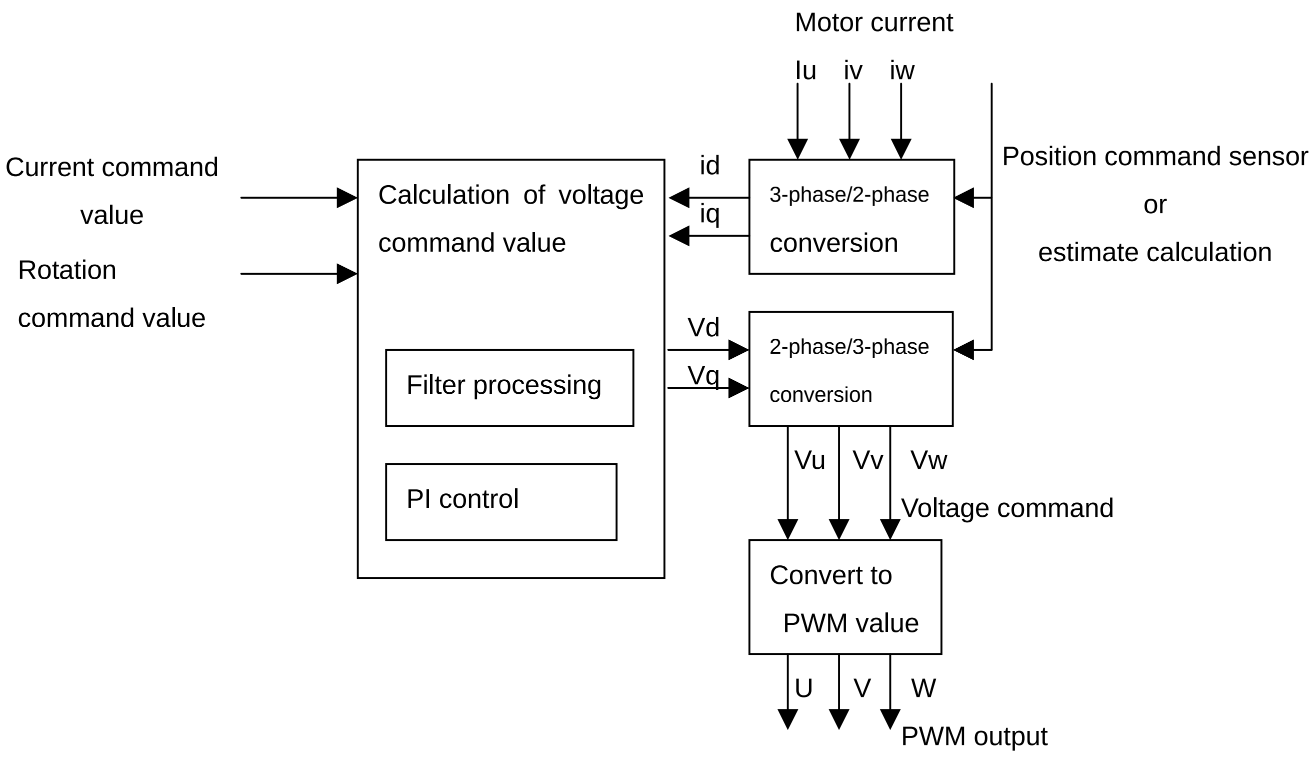
```
void int0_int(void)
{
        idb0=idb0_bufb;                 /*Change output phase */
        if(edge0_flg==0)
        {
                edge0_flg=1;
                rad_datw=60;            /*Set next angle*/
        }
        else
        {
                edge0_flg=0;
                rad_datw=240;           /*Set next angle*/
        }


        rad_to_PWM();                   /*Set next output phase*/
}

void int1_int(void)
{
        idb0=idb0_bufb;         /*Change output phase*/
        if(edge1_flg==0)
        {
                edge1_flg=1;
                rad_datw=180;           /*Set next angle*/
        }
        else
        {
                edge1_flg=0;
                rad_datw=0;             /*Set next angle */
}
        rad_to_PWM();                   /*Set next output phase*/
}

void int2_int(void)
{
        idb0=idb0_bufb;         /*Change output phase*/
        if(edge2_flg==0)
        {
                edge2_flg=1;
                rad_datw=300;           /*Set next angle*/
                rad_to_PWM();
        }
        else
        {
                edge2_flg=0;

                rad_datw=120;           /*Set next anlge*/
        }
        rad_to_PWM();                /*Set next output phase*/
}


void rad_to_PWM(void)
{
        switch(rad_datw)
        {
                case 0:
                        idb0_bufb=0x0de;     /* Set next output phase    U     WB          */
                        break;
                case 60:
                        idb0_bufb=0x0db;     /*Set next output phase     V     WB          */
                        break;
                case 120:
                        idb0_bufb=0x0f9;     /*Set next output phase     V     UB          */
                        break;
                case 180:
                        idb0_bufb=0x0ed;     /*Set next output phase     W     UB          */
                        break;
                case 240:
                        idb0_bufb=0x0e7;     /*Set next output phase     W     VB          */
                        break;
                case 300:
                        idb0_bufb=0x0f6;     /*Set next output phase     U     VB          */
                        break;
                default:
                        idb0_bufb=0x0ff;     /*Set next output phase     off         */
                        break;
        }
}
```

7.3 Feedback control sample program

The followings are the control modules used for program development of vector control.

- 3-phase/2-phase conversion
- 2-phase/3-phase conversion
- PI control
- Filter processing

*Please refert to previous sample program for PWM output



7.3.1 Three-phase / two-phase conversion module

Following is the an example of 3-phase/2-phase conversion.

$$\begin{pmatrix} id \\ iq \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \cos\theta & \cos(\theta+240) & \cos(\theta+120) \\ -\sin\theta & -\sin(\theta+240) & -\sin(\theta+120) \end{pmatrix} \begin{pmatrix} iu \\ iv \\ iw \end{pmatrix}$$

To improve precision of calculation, the rest of the sample program is caclculated as follows.

iu: U-phase current value	$\times 2^{6}$
iv: V-phase current value	$\times 2^{6}$
iw: W-phase current value	$\times 2^{6}$
id: d shaft current value	$\times 2^{6}$
iq: q shaft current value	$\times 2^{6}$
Sine table	$\times 2^{15}$

```
/*********************************************************************************
*         3-phase/2-phase conversion sample program
*
*********************************************************************************/
void dq_samp(void);

signed short iu_6w;          /* U-phase current[2^6]              */
signed short iv_6w;          /* V-phase current value[2^6]              */
signed short iw_6w;          /* W-phase current value[2^6]              */
signed short work_6w;               /* work[2^6]              */
signed short id_6w;          /* d shaft current[2^6]              */
signed short iq_6w;          /* q shaft current[2^6]              */
signed short sin_pt;         /* sine table pointer              */

void dq_samp()
{
      iw_6w=-(iu_6w+iv_6w);            /*  W-phase  current  value[2^6]=-(U-phase  current  value[2^6]+V-phase
current value[2^6]) */ work_6w=(signed short)((
              (sin_tbl[sin_pt+90]*(long)iu_6w)
              +(sin_tbl[sin_pt+90+240]*(long)iv_6w)
               +(sin_tbl[sin_pt+90+120]*(long)iw_6w)
               )>>15);
                   /* work[2^6]=(                                   */
                   /*            cosθ × U-phase current value[2^6]                  */
                   /*            +cos(θ+240) × V-phase current value[2^6]                  */
                         /*            +cos(θ+120) × W current value[2^6]   )              */
                   /*      *sine table is [2^15]                                   */

      id_6w=(short)(((long)work_6w*26755)>>15);      /* d shaft current [2^6]=work[2^6] × √ 2/3          */

      work_6w=(signed short)((
              -(sin_tbl[sin_pt]*(long)iu_6w)
              -(sin_tbl[sin_pt+240]*(long)iv_6w)
               -(sin_tbl[sin_pt+120]*(long)iw_6w)
               )>>15);

                   /* work[2^6]=(                                   */
                   /*            -sinθ × U-phase current value[2^6]                  */
                   /*            -sin(θ+240) × V-phase current value[2^6]                  */
                   /*            -sin(θ+120) × W current value[2^6]     )              */
                   /*      *sine table is [2^15]                                   */
      iq_6w=(short)(((long)work_6w*26755)>>15);      /* q shaft current [2^6]=work[2^6] ×√ 2/3          */
}
```

7.3.2 Two phase/three-phase conversion module

The following is an example of 2-phase/3-phase conversion.

$$\begin{pmatrix} Vu \\ Vv \\ Vw \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \cos\theta & -\sin(\theta) \\ \cos(\theta+240) & -\sin(\theta+240) \\ \cos(\theta+120) & -\sin(\theta+120) \end{pmatrix} \begin{pmatrix} Vd \\ Vq \end{pmatrix}$$

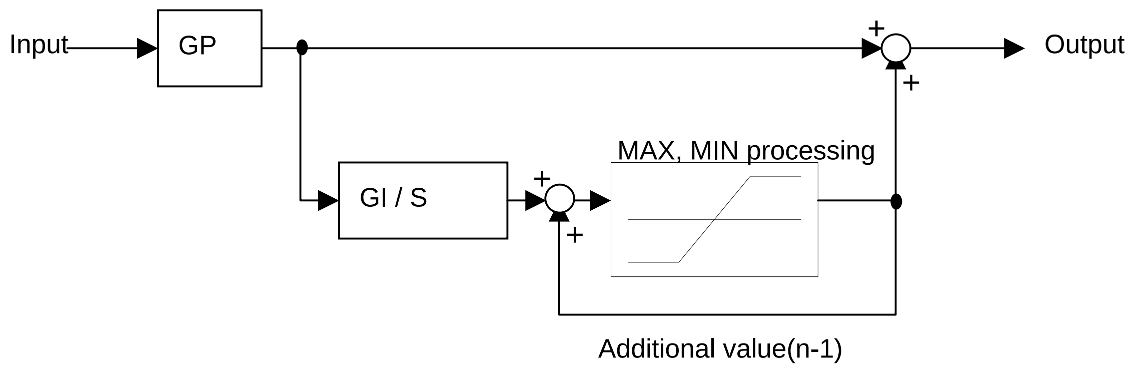
To improve precision of calculation, the rest of the sample program is calculated as follows.

Vd: d shaft voltage value	$\times 2^{6}$
Vq: q shaft voltage value	$\times 2^{6}$
Vu: U-phase voltage command value	$\times 2^{6}$
Vv: V-phase voltage command value	$\times 2^{6}$
Vw: W-phase voltage command value	$\times 2^{6}$
Sine table	$\times 2^{15}$

```
/*******************************************************************************
*         2-phase/3-phase conversion sample program
*
*******************************************************************************/
void uvw_samp(void);

signed short vd_6w;          /* d shaft voltage[2^6]                */
signed short vq_6w;          /* q shaft voltage[2^6]                */
signed short vu_6w;          /* U-phase voltage command [2^6]    */
signed short vv_6w;          /* V-phase voltage command [2^6]    */
signed short vw_6w;          /* W-phawe voltage command [2^6]   */
signed short work_6w;             /* work[2^6]               */
signed short sin_pt;         /* sine table pointer           */


void uvw_samp()
{
        work_6w=(signed short)((
                  (sin_tbl[sin_pt+90]*(long)vd_6w)
                  -(sin_tbl[sin_pt]*(long)vq_6w)
                   )>>15);
                           /* work[2^6]=(                              */
                                /*            cosθ× d shaft voltage[2^6]         */
                                /*            -sinθ× q shaft voltage[2^6])       */
                           /*      *Sine table is [2^15]                  */

        vu_6w=(short)(((long)work_6w*26752)>>15);      /* U-phase voltage command [2^6]=work[2^6] ×√ 2/3*/

        work_6w=(signed short)((
                  (sin_tbl[sin_pt+90+240]*(long)vd_6w)
                  -(sin_tbl[sin_pt+240]*(long)vq_6w)
                   )>>15);
                           /* work[2^6]=(                                    */
                                /*            cos(θ+240) x d shaft voltage[2^6]                      */
                                /*            -sin(θ+240) x q shaft voltage [2^6])                   */
                                /*      *Sine table is [2^15]                  */

        vv_6w=(short)(((long)work_6w*26752)>>15);      /* V-phase voltage command[2^6]=work[2^6] ×√ 2/3  */

        vw_6w=-(vu_6w+vv_6w);
                           /* W-phase voltage command [2^6]=                          */
                           /*      -(U-phase voltage command [2^6]+V-phae voltage command[2^6])             */
}
```

7.3.3 PI Control Module

The following is an exmaple of PI control



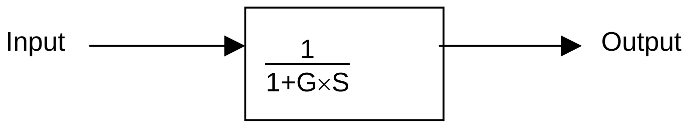
To improve precision of calculation, the rest of sample program is calculated as follows.

Input data	$\times 2^{6}$
Output data	$\times 2^{6}$
Gain P	$\times 2^{10}$
Gain I / control period	$\times 2^{18}$

```
/*******************************************************************************
*          PI control sample program
*
*******************************************************************************/
void  PI_samp(void);

signed short data_in_6w;                /* Input data[2^6]                  */
signed short data_out_6w;               /* Output data[2^6]                 */
signed short GP_10w;                    /* Gain P[2^10]              */
signed short GI_t_18w;                  /* (Gain I/ control period t)[2^18]        */
signed long sum_16l;                    /* Additional    value[2^16]                 */
signed long work1_16l;                  /* work1[2^16]               */
signed long work2_16l;                  /* work2[2^16]               */
#define work2_limit 500                 /* work2 limit value    500 is temprorary data        */

void  PI_samp()
{

        work1_16l =(long)data_in_6w * GP_10w;    /*work1[2^16] = input data[2^6] x gain P [2^10]*/

        sum_16l = sum_16l + ((work1_16l >> 11) * GI_t_18w) >> 7;
                        /*  Additional    value[2^16]=additional    value[2^16]+((work1[2^16]÷ 2^11)  x  (gain  I  /  t)
                        [2^18]) × 2^7 */

        work2_16l = work1_16l + sum_16l;            /* work2[2^16]=work2[2^16] + additional value[2^16] */

        if(work2_16l > work2_limit)
        {
                work2_16l = work2_limit;
        }else
        {
                if(work2_16l < -work2_limit)
                {
                        work2_16l = -work2_limit;
                }
        }

        data_out_6w = (short)(work2_16l >> 10);    /* output data[2^6]=work2[2^16] ÷ 2^10 */

}
```

7.3.4 Filter control module

The following is an example of filter control.



To improve precision of calculation, the rest of sample program is calculated as follows.

Input data	$\times2^{6}$
Output data	$\times2^{6}$
Gain P	$\times2^{10}$
Gain I / control period	$\times2^{18}$

```
/***********************************************************************************
*      Filter control sample program
*
***********************************************************************************/
void  fill_samp(void);

signed short data_in_6w;               /* Input data[2^6]                  */
signed short fill_out_6w;              /* Output data[2^6]                 */
signed short G_t21;               /* 1/(gain x control period) [2^21]      */
signed long fill_22l;             /* Additional value[2^22]                */

void  fill_samp()
{
      fill_22l=fill_22l
            +(long)((G_t21*(long)(data_in_6w-fill_out_6w))>>5);
                        /* Additional value[2^16] = additional value[2^22]
                             +(1/(gain x control period)[2^21]
                             x (input data[2^6] – output data[2^6])) / 2^5                  */
      fill_out_6w=(short)(fill_22l>>16);      /* output data[2^6] = additional value[2^22]>>16 */
}
```

8.0 Reference Document

Data sheet

Please refer to M16C/28 Group data sheet

9.0 Website URL and Customer Support Center

Renesas Technology Corp. Website
http://www.renesas.com/

Inquiries for Renesas products
Customer Support Center: csc@renesas.com

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