- PWM Mode (Pulse Width Modulation)
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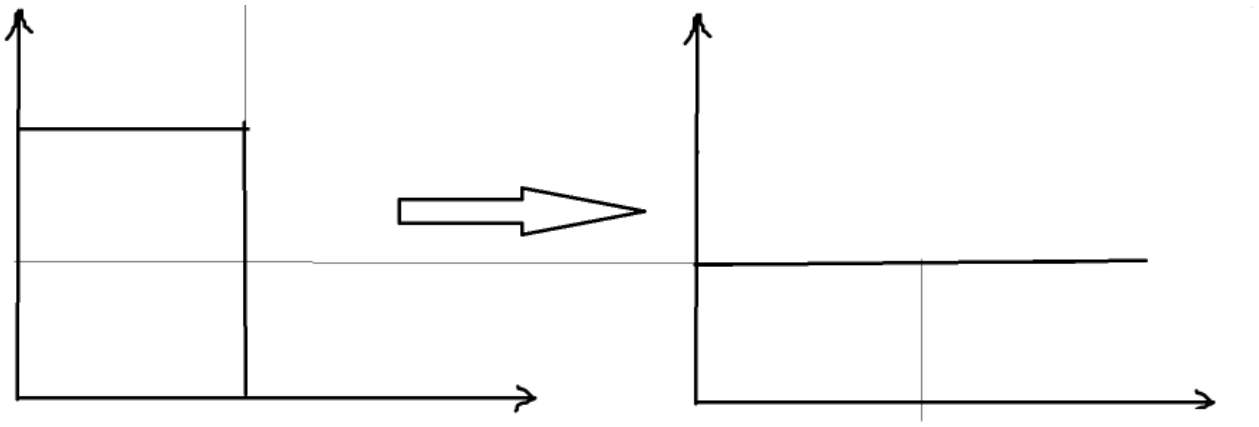
    - 2- Inverted Mode Behavior in Phase Correct PWM:
- Let's Code :)

PWM Mode (Pulse Width Modulation)

- PWM is a method to control the power delivered to electronic devices by switching a digital signal ON and OFF rapidly.

```
![1752934377067](image/README/1752934377067.png)
```



Characteristics:

- **Amplitude** : The voltage level of the signal (e.g., 3.3V or 5V).
- **Period (T)** : Total time for one full ON + OFF cycle.

  T = 1 / Frequency
- **Frequency (f)** : Number of cycles per second (Hz).

  f = 1 / T
- **On-time (Ton)** : Duration of the HIGH (ON) signal.
- **Off-time (Toff)** : Duration of the LOW (OFF) signal.

  Toff = T - Ton
- **Duty Cycle (D)** : Percentage of time the signal is ON in one period.

  D = (Ton / T) × 100%

Example Duty Cycles:

- 0% → Always OFF
- 25% → ON for 25%, OFF for 75%
- 50% → ON and OFF are equal
- 75% → ON for 75%, OFF for 25%
- 100% → Always ON

Why do we use PWM (Pulse Width Modulation)?

1. **Load Control (Power Control)**
   - **PWM controls the average power** delivered to a load without wasting energy.
   - It's used to:
     - Control **LED brightness**
     - Adjust **motor speed**
     - Manage **heater power**
     - Drive **buzzers/speakers**

    - Efficient because power is switched ON/OFF (not dissipated as heat like analog control).
2. **A Way of Communication (Signal Modulation)**
    - **PWM is used to encode information** in the width of the pulses.
    - Used in:
        - **Servo motors** : Position is controlled by PWM pulse width (e.g., 1–2 ms in a 20 ms frame).
        - **DC-DC Converters** : PWM regulates output voltage by controlling switching elements.
        - **IR remote controls** : Encode binary data using PWM-like pulses.

How to generate PWM?

Software Methods

1. Using DIO + Delay (Software PWM)

- Toggle the pin HIGH and LOW manually .
- Use `delay_us()` or `delay_ms()` to control **on-time** and **off-time** .
- ```
  while (1) {
    DIO_HIGH;
    delay_us(on_time);
    DIO_LOW;
    delay_us(off_time);
  }
  ```

❌ CPU blocking, not accurate

2. Using Timer in CTC Mode (Clear Timer on Compare Match)

- Set a compare value (OCRn) to create a fixed period.
- Toggle pin using **interrupt or toggle mode** .
- Change the ON time by adjusting OCRn dynamically.

```
TCCR0 |= (1 << WGM01); // CTC mode
TCCR0 |= (1 << COM0A0); // Toggle OC0A on match
```
```

```
OCR0A = value; // Control frequency/duty
```

More accurate But only 50% duty cycle , to control duty cycle we need more control

```
#define DUTY_TICKS 75  // 30% of 250 (for 1ms period)
#define PERIOD_TICKS 250

volatile uint8_t counter = 0;

void PWM_CTC_init() {
    DDRB |= (1 << PB0);               // PB0 = Output (PWM pin)

    TCCR0 |= (1 << WGM01);            // CTC mode
    TCCR0 |= (1 << CS01) | (1 << CS00); // Prescaler = 64
    OCR0 = 1;                         // Interrupt every 2 ticks (fine control)

    TIMSK |= (1 << OCIE0);            // Enable CTC interrupt
    sei();                            // Enable global interrupts
}

ISR(TIMER0_COMP_vect) {
    counter++;

    if (counter == 1) {
        PORTB |= (1 << PB0); // Start of cycle: turn ON
    }

    if (counter == DUTY_TICKS) {
        PORTB &= ~(1 << PB0); // After ON time: turn OFF
    }

    if (counter >= PERIOD_TICKS) {
        counter = 0; // Reset after full PWM period
    }
}
```

3. **Using Timer in Normal Mode (Same As Clear Timer on Compare Match)**

Hardware Methods

1. PWM Timers
2. PWM mode in normal timers

What is Fast PWM Mode?

1 - Set on TOP, Clear on Compare Match (Direct or Not Inverted)

Fast PWM is a timer mode where:

- The timer counts **from 0 up to a TOP value** (e.g., 255 or OCRx).
- At each tick (timer increase), the timer compares its value with `OCRx`.
- Based on the compare result, it controls the output pin (OCx):
  - At **Compare Match** : the pin is **cleared** (set LOW)
  - At **TOP** : the pin is **set** (set HIGH again)

This results in a pulse with variable ON time = PWM.

It's the one used in arduino ide (analogWrite(value))

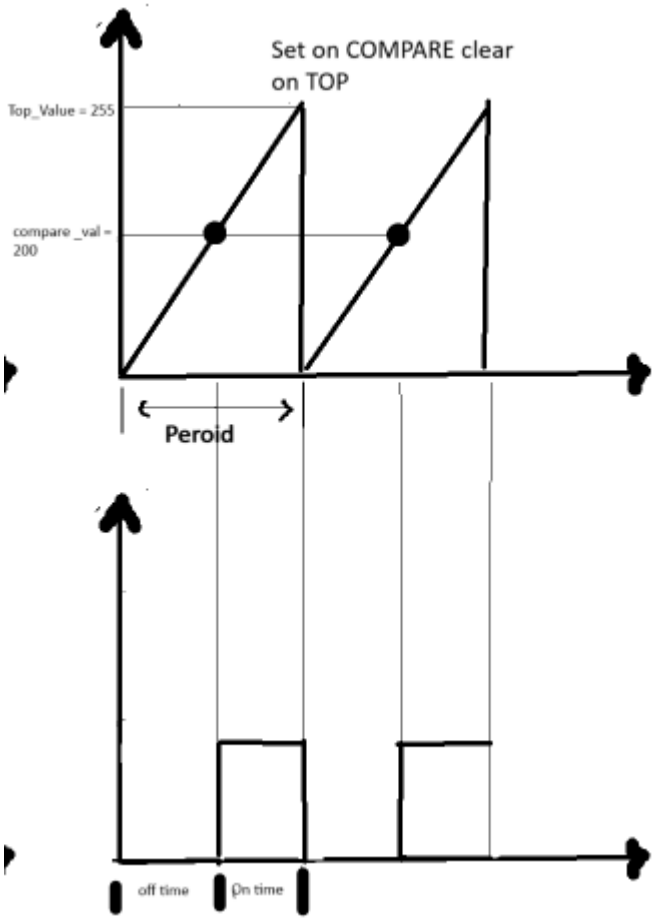
```
![1752916328301](image/README/1752916328301.png)
```

2 - Clear on TOP, Set on Compare Match (Inverted)

This configuration gives you an **inverted PWM signal** — where the **pin is LOW during the ON time** , and **HIGH during the OFF time** .

This is called **inverting PWM mode** , because the pulse logic is flipped:

- Duty cycle is still controlled by `OCRx`
- But the pulse is **LOW for the ON time** , **HIGH for the OFF time**



What is Phase Correct PWM Mode?

Phase Correct PWM is a timer mode where the counter **counts up** to a maximum value (TOP), then **counts down** back to zero.

This creates a **symmetric PWM waveform** , with no phase shift — that's why it's called **"phase correct."**

How it works (in AVR 8-bit Timer0)

- Timer counts: `0 → 1 → 2 → ... → 255 → 254 → ... → 0`
- **Compare Match** occurs twice:
  - Once while **counting up**
  - Once while **counting down**

1- Direct (Non-Inverting Mode) , (Set on Downcounting , Clear on upcounting)

Counting Direction	Action on Match	
Up-counting	**Clear**	Goes LOW
Down-counting	**Set**	Goes HIGH

```
![1752920685431](image/README/1752920685431.png)
```

2- Inverted Mode Behavior in Phase Correct PWM:

Counting Direction	Compare Match Action	
Up-counting	**Set**(goes HIGH)	ON (inverted)
Down-counting	**Clear**(goes LOW)	OFF (inverted)

🔁 The **pulse is HIGH during off-time** and LOW during on-time.

```
![1752920990561](image/README/1752920990561.png)
```

Let's Code :)

Timer_inteface.h

```
#ifndef TIMER_INTERFACE_H
#define TIMER_INTERFACE_H


enum{

        TIMER0_OV_INT,  /* overflow source */
        TIMER0_OC_INT,   /* Output Compare Match */
        TIMER1_OV_INT,
        TIMER1_OC1A_INT,
        TIMER1_OC1B_INT,
        TIMER1_ICU_INT,
        TIMER2_OV_INT,
        TIMER2_OC_INT,

}typedef TIMER_IntSource_t;

enum{
        TIMER_NO_CLOCK,
```

```
        TIMER_NO_PRESCALER,
        TIMER_PRESCALER_DIVISION_8,
        TIMER_PRESCALER_DIVISION_64,
        TIMER_PRESCALER_DIVISION_256,
        TIMER_PRESCALER_DIVISION_1024,
        TIMER_EXTERNAL_CLOCK_FALLING_EDGE,
        TIMER_EXTERNAL_CLOCK_RISING_EDGE,

}typedef TIMER_Prescaler_t;


/*TIMER0*/


enum{
        T0_NORMAL,
        T0_COMPARE_MATCH,
        T0_FAST_PWM,
        T0_PHASE_CORRECT_PWM,

}typedef TIMER0_WFG_Mode_t;

enum{
        T0_INT_OVERFLOW,
        T0_INT_COMPARE,
        T0_INT_DISABLED
}typedef TIMER0_INT_State;

enum{
        T0_OC0_DISCONNECT,
        T0_OC0_NON_PWM_TOGGEL,
        T0_OC0_NON_PWM_CLEAR,
        T0_OC0_NON_PWM_SET,
        T0_OC0_FAST_PWM_CLRON_COM_SETON_TOP,
        T0_OC0_FAST_PWM_SETON_COM_CLRON_TOP,
        T0_OC0_PHASE_CORRECT_PWM_CLRON_UPCOUNTCOM_SETON_DOWNCOUNTCOM,
        T0_OC0_PHASE_CORRECT_PWM_SETON_UPCOUNTCOM_CLRON_DOWNCOUNTCOM
}typedef TIMER0_OUT_HW_Option;

struct{

        TIMER0_WFG_Mode_t  WFG_Mode;
        TIMER_Prescaler_t  Prescaler;
        TIMER0_OUT_HW_Option   Out_HW_Opt;
        TIMER0_INT_State    INT_State;

}typedef TIMER0_cfg_t;

#endif
```

timer prog.c

```
#include "STD_TYPES.h"
#include "BIT_MATH.h"
```

```c
#include "ErrType.h"
#include "TIMER_interface.h"
#include "TIMER_reg.h"
#include "TIMER_cfg.h"
#include "TIMER_private.h"

/*  Timer0 ISR  -> 2
 *  Timer1 ISR  -> 4
 *  Timer2 ISR  -> 2
 */

static void(*GlobalCallBackFucn[8])(void) = {NULL};

uint8 TIMER0_u8Init(const TIMER0_cfg_t  *Copy_suCfg){

        uint8 Local_u8ErrState = OK;

        if(Copy_suCfg != NULL){

                /* Select Mode */
                switch(Copy_suCfg->WFG_Mode){
                case T0_NORMAL:CLR_BIT(TCCR0, TCCR0_WGM00);CLR_BIT(TCCR0,
TCCR0_WGM01);break;
                case T0_COMPARE_MATCH:CLR_BIT(TCCR0, TCCR0_WGM00);SET_BIT(TCCR0,
TCCR0_WGM01); break;
                case T0_FAST_PWM:SET_BIT(TCCR0, TCCR0_WGM00);SET_BIT(TCCR0,
TCCR0_WGM01); break;
                case T0_PHASE_CORRECT_PWM:SET_BIT(TCCR0,
TCCR0_WGM00);CLR_BIT(TCCR0, TCCR0_WGM01); break;
                default: Local_u8ErrState = NOK;
                }

                /* Enable Interrupt Mode*/
                switch(Copy_suCfg->INT_State){
                case T0_INT_OVERFLOW:SET_BIT(TIMSK, TIMSK_TOIE0); break;
                case T0_INT_COMPARE: SET_BIT(TIMSK, TIMSK_OCIE0); break;
                case T0_INT_DISABLED:CLR_BIT(TIMSK, TIMSK_TOIE0); CLR_BIT(TIMSK,
TIMSK_OCIE0);break;
                default:Local_u8ErrState = NOK;
                }

                /* Select Hardware action on Pin OC0*/

                switch(Copy_suCfg->Out_HW_Opt){
                case T0_OC0_DISCONNECT: CLR_BIT(TCCR0, TCCR0_COM00);CLR_BIT(TCCR0,
TCCR0_COM01);break;
                case T0_OC0_NON_PWM_TOGGEL:     SET_BIT(TCCR0,
TCCR0_COM00);CLR_BIT(TCCR0, TCCR0_COM01);break;
                case T0_OC0_NON_PWM_CLEAR:CLR_BIT(TCCR0,
TCCR0_COM00);SET_BIT(TCCR0, TCCR0_COM01);break;
                case T0_OC0_NON_PWM_SET:SET_BIT(TCCR0, TCCR0_COM00);SET_BIT(TCCR0,
TCCR0_COM01);break;
                case T0_OC0_FAST_PWM_CLRON_COM_SETON_TOP:CLR_BIT(TCCR0,
TCCR0_COM00);SET_BIT(TCCR0, TCCR0_COM01);break;
                case T0_OC0_FAST_PWM_SETON_COM_CLRON_TOP:SET_BIT(TCCR0,
TCCR0_COM00);SET_BIT(TCCR0, TCCR0_COM01);break;
                case
```

```
T0_OC0_PHASE_CORRECT_PWM_CLRON_UPCOUNTCOM_SETON_DOWNCOUNTCOM:CLR_BIT(TCCR0,
TCCR0_COM00);SET_BIT(TCCR0, TCCR0_COM01);break;
                case
T0_OC0_PHASE_CORRECT_PWM_SETON_UPCOUNTCOM_CLRON_DOWNCOUNTCOM:SET_BIT(TCCR0,
TCCR0_COM00);SET_BIT(TCCR0, TCCR0_COM01);break;
                default: Local_u8ErrState= NOK;
                }

                /*Set Prescaler */
                TCCR0 &= MASK_LEAST_3_BIT;
                TCCR0 |= (Copy_suCfg->Prescaler);

        }else{
                Local_u8ErrState = NULL_PTR_ERR;
        }



        return Local_u8ErrState;

}


uint8 TIMER_u8SetCallBackFunc(uint8 Copy_u8IntSource,void(*Copy_pvCallBackFucn)
(void)){

        uint8 Local_u8ErrState = OK;
        if(Copy_pvCallBackFucn != NULL){
                GlobalCallBackFucn[Copy_u8IntSource] =Copy_pvCallBackFucn;

        }else{
                Local_u8ErrState = NULL_PTR_ERR;
        }

        return Local_u8ErrState;
}

void TIMER0_voidSetPreloadValue(uint8 Copy_u8PreloadVal){

        TCNT0 = Copy_u8PreloadVal;

}

void TIMER0_voidSetCompareValue(uint8 Copy_u8CompareVal){

        OCR0 = Copy_u8CompareVal;

}


void TIMER0_voidSetPrescaler(TIMER_Prescaler_t  Copy_PrescalerVal){

        /* Set Prescaler */
        TCCR0 &= MASK_LEAST_3_BIT;
        TCCR0 |= Copy_PrescalerVal;

}
```

```
uint8 TIMER0_u8SetCompareOutputMode(TIMER0_OUT_HW_Option Copy_u8OutputMode){
        uint8 Local_u8ErrState = OK;
        switch(Copy_u8OutputMode){
        case T0_OC0_DISCONNECT: CLR_BIT(TCCR0, TCCR0_COM00);CLR_BIT(TCCR0,
TCCR0_COM01);break;
        case T0_OC0_NON_PWM_TOGGEL:     SET_BIT(TCCR0, TCCR0_COM00);CLR_BIT(TCCR0,
TCCR0_COM01);break;
        case T0_OC0_NON_PWM_CLEAR:CLR_BIT(TCCR0, TCCR0_COM00);SET_BIT(TCCR0,
TCCR0_COM01);break;
        case T0_OC0_NON_PWM_SET:SET_BIT(TCCR0, TCCR0_COM00);SET_BIT(TCCR0,
TCCR0_COM01);break;
        case T0_OC0_FAST_PWM_CLRON_COM_SETON_TOP:CLR_BIT(TCCR0,
TCCR0_COM00);SET_BIT(TCCR0, TCCR0_COM01);break;
        case T0_OC0_FAST_PWM_SETON_COM_CLRON_TOP:SET_BIT(TCCR0,
TCCR0_COM00);SET_BIT(TCCR0, TCCR0_COM01);break;
        case
T0_OC0_PHASE_CORRECT_PWM_CLRON_UPCOUNTCOM_SETON_DOWNCOUNTCOM:CLR_BIT(TCCR0,
TCCR0_COM00);SET_BIT(TCCR0, TCCR0_COM01);break;
        case
T0_OC0_PHASE_CORRECT_PWM_SETON_UPCOUNTCOM_CLRON_DOWNCOUNTCOM:SET_BIT(TCCR0,
TCCR0_COM00);SET_BIT(TCCR0, TCCR0_COM01);break;
        default: Local_u8ErrState= NOK;
        }

        return Local_u8ErrState;
}

void TIMER0_voidPWMDisable(void)
{

    CLR_BIT(TCCR0,TCCR0_COM00);
    CLR_BIT(TCCR0,TCCR0_COM01);
}

uint8  TIMER0_u8EnableInt(TIMER0_INT_State Copy_sIntOpt){
        uint8 Local_u8ErrState = OK;

        switch(Copy_sIntOpt){
        case T0_INT_OVERFLOW:SET_BIT(TIMSK, TIMSK_TOIE0); break;
        case T0_INT_COMPARE: SET_BIT(TIMSK, TIMSK_OCIE0); break;
        default:Local_u8ErrState = NOK;
        }

        return Local_u8ErrState;

}
uint8  TIMER0_u8DisableInt(TIMER0_INT_State Copy_sIntOpt){
        uint8 Local_u8ErrState = OK;
        switch(Copy_sIntOpt){
        case T0_INT_OVERFLOW:CLR_BIT(TIMSK, TIMSK_TOIE0); break;
        case T0_INT_COMPARE: CLR_BIT(TIMSK, TIMSK_OCIE0); break;
        case T0_INT_DISABLED:CLR_BIT(TIMSK, TIMSK_TOIE0); CLR_BIT(TIMSK,
TIMSK_OCIE0);break;
        default:Local_u8ErrState = NOK;
        }
```

```
        return Local_u8ErrState;

}

void  TIMER0_vStopTimer(){
        TCCR0 &= MASK_LEAST_3_BIT;
        TCCR0 |= TIMER_NO_PRESCALER;
        /*Disable All interrupts */
        CLR_BIT(TIMSK, TIMSK_TOIE0); CLR_BIT(TIMSK, TIMSK_OCIE0);
}




/* Timer 0  Overflow ISR */

__attribute__((signal))  void __vector_11(void);

void __vector_11(void){

    if(GlobalCallBackFucn[TIMER0_OV_INT] != NULL){
                GlobalCallBackFucn[TIMER0_OV_INT]();
        }else{

    }

}

/* Timer 0  Out Compare match ISR */

__attribute__((signal))  void __vector_10(void);

void __vector_10(void){

    if(GlobalCallBackFucn[TIMER0_OC_INT] != NULL){
                GlobalCallBackFucn[TIMER0_OC_INT]();
        }else{

    }

}
```

PWM_interface.h

```
/*
 * PWM_interface.h
 *
 *  Created on: Jul 19, 2025
 *      Author: Computec
 */

#ifndef PWM_INTERFACE_H_
#define PWM_INTERFACE_H_
```

```
#define PWM_FAST_NON_INVERTED     0u
#define PWM_FAST_INVERTED         1u
#define PWM_PHASE_NON_INVERTED    2u
#define PWM_PHASE_INVERTED        3u

void PWM0_voidInit(uint8 Copy_u8Mode);
void PWM0_voidSetDutyCycle(uint8 Copy_u8Duty); // 0-100%
void PWM0_voidStop(void);


#endif /* PWM_INTERFACE_H_ */
```

PWM_prog.c

```
#include "STD_TYPES.h"
#include "BIT_MATH.h"
#include "ErrType.h"
#include "DIO_interface.h"
#include "PWM_interface.h"
#include "PWM_prv.h"
#include "Timers_interface.h"

static uint8 Global_PWM0_Mode  = 0;
uint8 PWM0_voidInit(uint8 Copy_u8Mode)
{
    /* Set OCR0 (PB3) as output */
        SET_BIT( DIO_u8PORTB , DIO_u8PIN3);
        TIMER0_cfg_t Local_Timer0_PWM;
        uint8 Local_u8ErrorState = OK ;
    switch (Copy_u8Mode)
    {
        case PWM_FAST_NON_INVERTED:
                Global_PWM0_Mode = PWM_FAST_NON_INVERTED ;
            Local_Timer0_PWM.WFG_Mode = T0_FAST_PWM  ;
            Local_Timer0_PWM.Out_HW_Opt = T0_OC0_FAST_PWM_CLRON_COM_SETON_TOP ;
            break;

        case PWM_FAST_INVERTED:
                Global_PWM0_Mode = PWM_FAST_INVERTED;
            Local_Timer0_PWM.WFG_Mode = T0_FAST_PWM  ;
            Local_Timer0_PWM.Out_HW_Opt = T0_OC0_FAST_PWM_SETON_COM_CLRON_TOP ;
            break;

        case PWM_PHASE_NON_INVERTED:
                Global_PWM0_Mode = PWM_PHASE_NON_INVERTED;
            Local_Timer0_PWM.WFG_Mode = T0_PHASE_CORRECT_PWM  ;
            Local_Timer0_PWM.Out_HW_Opt =
T0_OC0_PHASE_CORRECT_PWM_CLRON_UPCOUNTCOM_SETON_DOWNCOUNTCOM ;
            break;

        case PWM_PHASE_INVERTED:
                Global_PWM0_Mode = PWM_PHASE_INVERTED;
            Local_Timer0_PWM.WFG_Mode = T0_PHASE_CORRECT_PWM  ;
```

```
            Local_Timer0_PWM.Out_HW_Opt =
T0_OC0_PHASE_CORRECT_PWM_SETON_UPCOUNTCOM_CLRON_DOWNCOUNTCOM;
            break;
        default : Local_u8ErrorState = NOK;
    }
    Local_Timer0_PWM.INT_State = T0_INT_DISABLED ;
    Local_Timer0_PWM.Prescaler = TIMER_PRESCALER_DIVISION_64 ;

    TIMER0_u8Init(&Local_Timer0_PWM);

    return Local_u8ErrorState ;
}

void PWM0_voidSetDutyCycle(uint8 Copy_u8Duty){
    if (Copy_u8Duty > 100) {
        Copy_u8Duty = 100;
    }

    uint8 Local_u8Cv;

    switch (Global_PWM0_Mode) {
        case PWM_FAST_NON_INVERTED:
        case PWM_PHASE_NON_INVERTED:
            Local_u8Cv = ((Copy_u8Duty * 255UL) / 100);
            break;

        case PWM_FAST_INVERTED:
        case PWM_PHASE_INVERTED:
            Local_u8Cv = 255 - ((Copy_u8Duty * 255UL) / 100);
            break;

        default:
            Local_u8Cv = 0;  // Safe default
    }

    TIMER0_voidSetCompareValue(Local_u8Cv);
}


void PWM0_voidStop(void){
        TIMER0_vStopTimer();
}
```