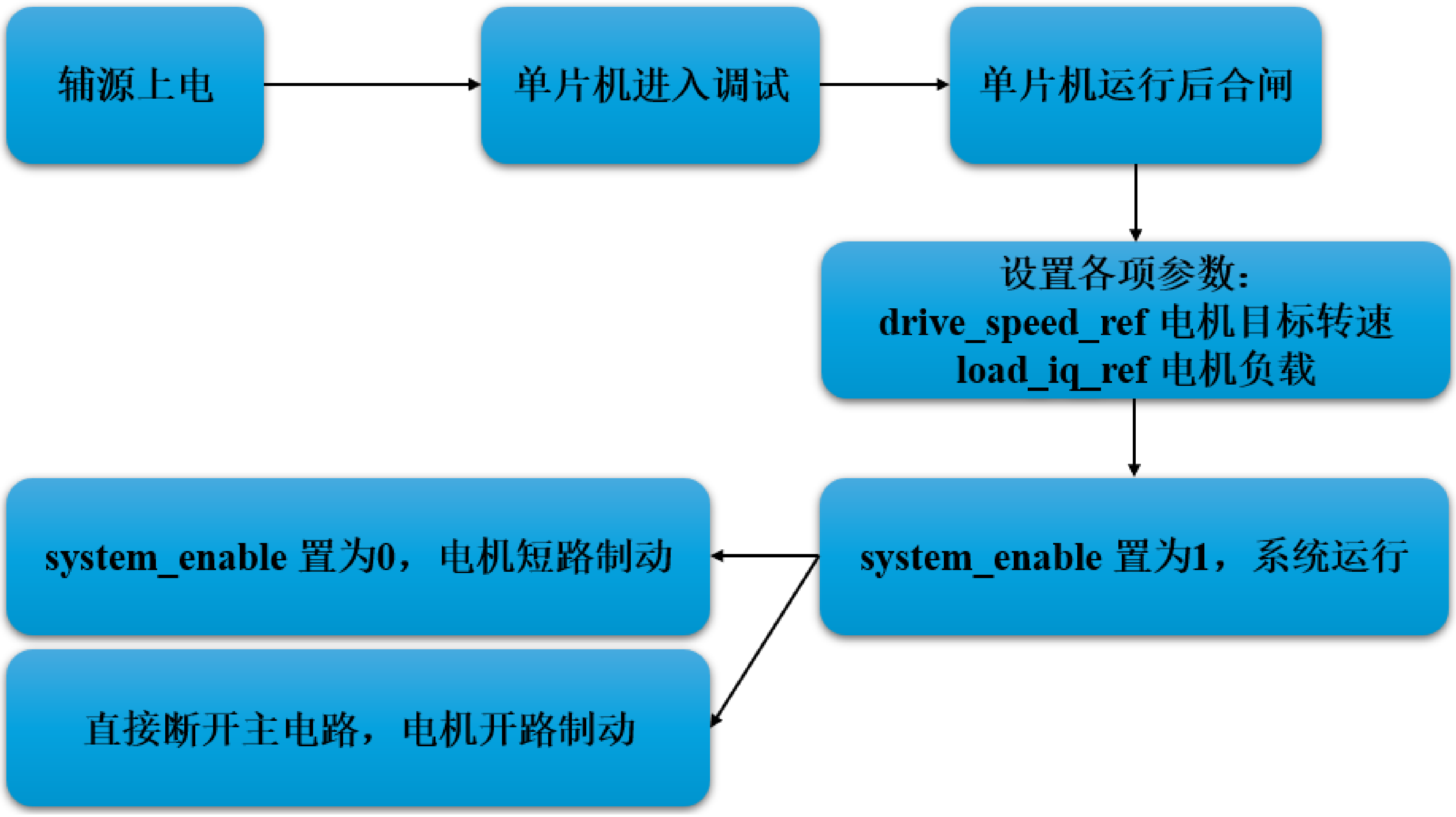
Chapter1 快速上手

1. 运行流程



Chapter2 CubeMX 配置指南

1. 旋转变压器(AD2S1210)配置

GPIO 配置

GPIO 参考配置如下:

- 驱动电机旋转变压器:

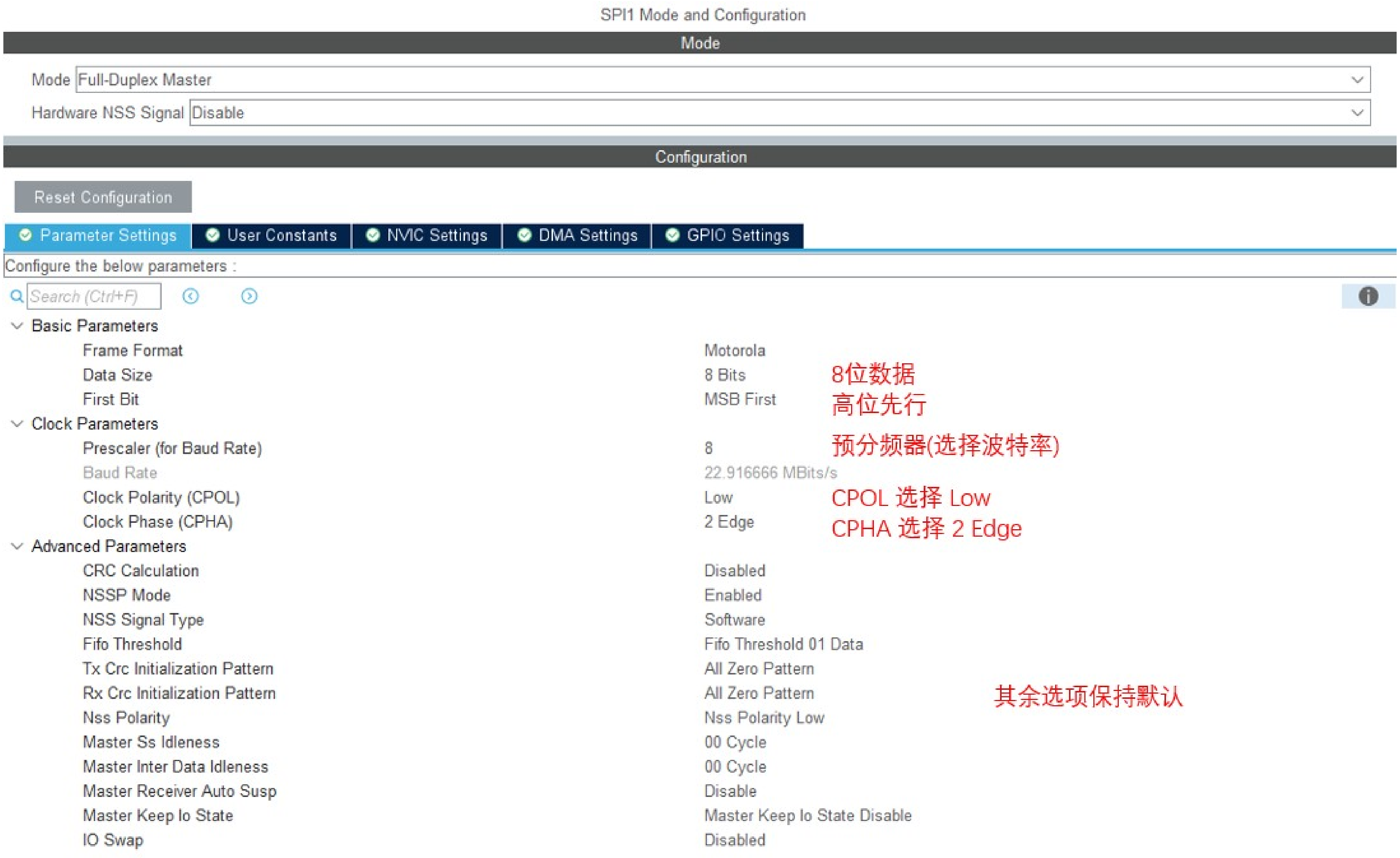
引脚	默认输出电平(GPIO output level)	GPIO模式(GPIO mode)	上拉/下拉(GPIO Pull-up/Pull down)	输出速率(Maxumum output speed)	旋变引脚
PA11	High	Output Push Pull	Pull-up	High	AD2S1_PCS
PA15(JTDI)	Low	Output Push Pull	Pull-up	Low	AD2S1_A0
PB2	High	Output Push Pull	Pull-up	Low	AD2S1_RD
PB6	Low	Output Push Pull	Pull-up	Low	AD2S1_DIR
PB7	High	Output Push Pull	Pull-up	High	SPI1_CS
PB9	Low	Output Push Pull	Pull-up	Low	AD2S1_A1
PF0	Low	Output Push Pull	Pull-up	High	AD2S1_SAM
PF1	High	Output Push Pull	Pull-up	Low	AD2S1_RESET

- 负载电机旋转变压器：

引脚	默认输出电平(GPIO output level)	GPIO模式(GPIO mode)	上拉/下拉(GPIO Pull-up/Pull down)	输出速率(Maxumum output speed)	旋变引脚
PB10	High	Output Push Pull	Pull-up	Low	AD2S2_PCS
PB12	Low	Output Push Pull	Pull-up	Low	AD2S2_A0
PC2_C	Low	Output Push Pull	Pull-up	Low	AD2S2_SAM
PC3_C	High	Output Push Pull	Pull-up	Low	AD2S2_RESET
PC13	High	Output Push Pull	Pull-up	Low	AD2S2_RD
PE0	Low	Output Push Pull	Pull-up	Low	AD2S2_DIR
PE1	High	Output Push Pull	Pull-up	Low	SPI2_CS
PE4	Low	Output Push Pull	Pull-up	Low	AD2S2_A1

SPI 配置

SPI 参考配置如下，一般配置 SPI 波特率在 25 MBits/s 以下：



SPI 的引脚：

引脚	SPI引脚
PB3(JTDO/TRACESWO)	SPI1_SCK
PB4(NJTRST)	SPI1_MISO
PB5	SPI1_MOSI
PB13	SPI2_SCK
PB14	SPI2_MISO
PB15	SPI2_MOSI

2. 逆变器配置

TIM 配置

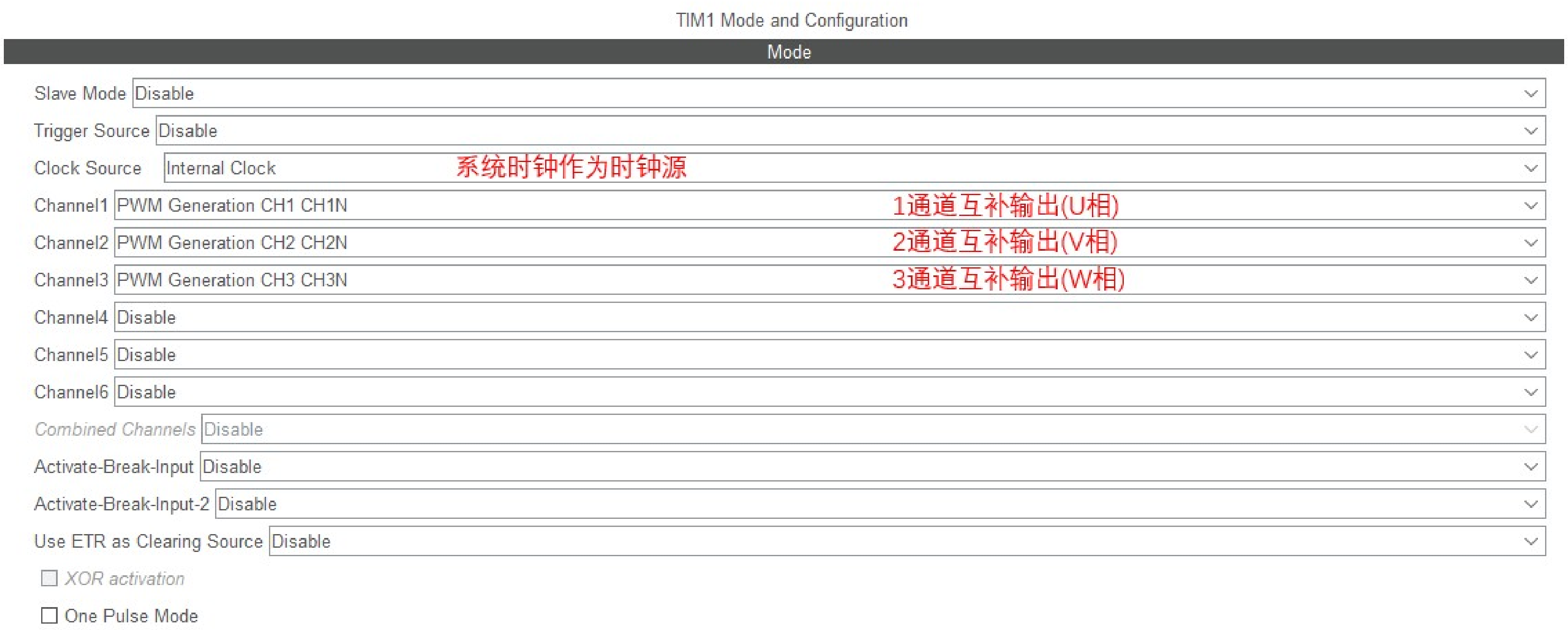
引脚分配

TIM1 负责负载电机的逆变器控制，TIM8 负责驱动电机的逆变器控制。TIM 的引脚分配如下：

引脚	TIM引脚
PA7	TIM8_CH1N
PB0	TIM8_CH2N
PB1	TIM8_CH3N
PC6	TIM8_CH1
PC7	TIM8_CH2
PC8	TIM8_CH3
PE8	TIM1_CH1N
PE9	TIM1_CH1
PE10	TIM1_CH2N
PE11	TIM1_CH2
PE12	TIM1_CH3N
PE13	TIM1_CH3

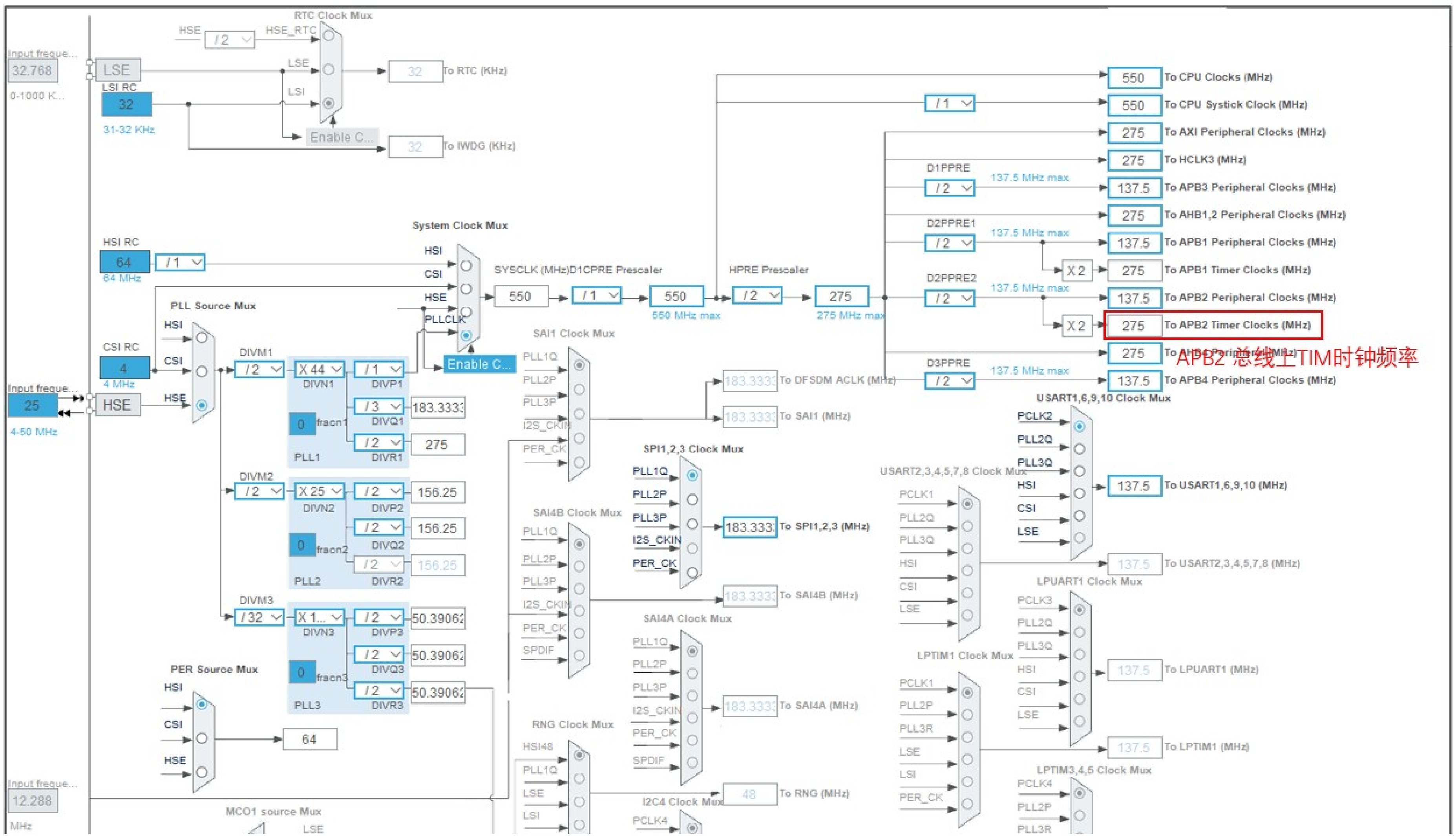
CHx 对应逆变器上桥臂，CHxN 对应逆变器下桥臂。

对应的 TIM 配置如下：

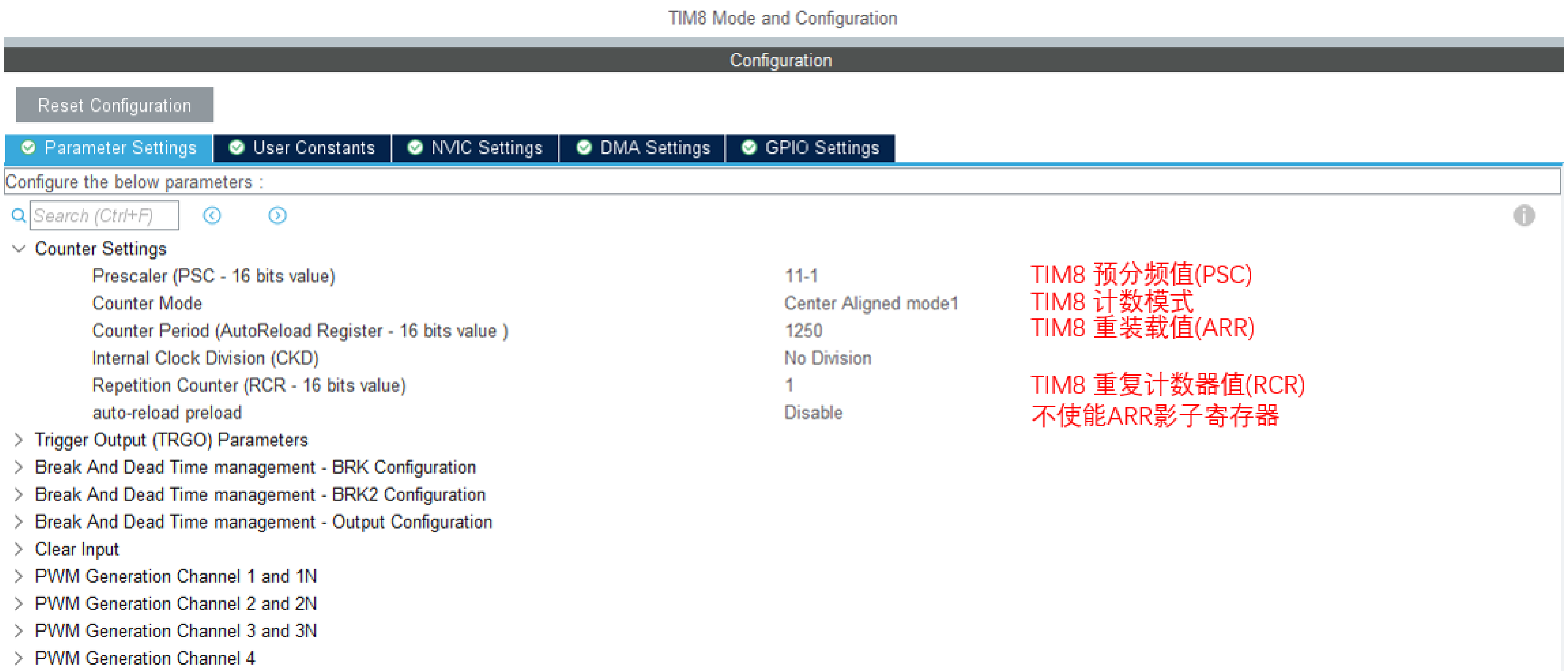


时基单元配置

在时钟树中可以看到 TIM1 和 TIM8 的输入频率均为 275MHz(TIM1 和 TIM8 在 APB2 总线上)：



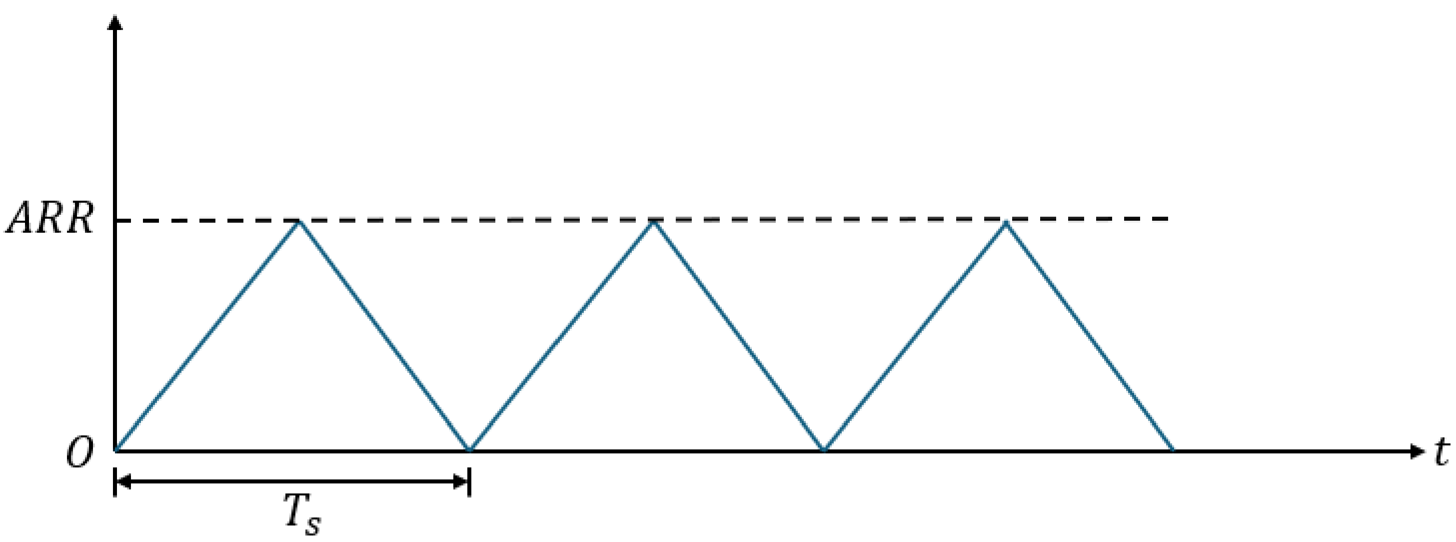
时基单元配置如下：



1. 定时器单次计数频率：

$$f_{TIM}=\frac{f_{APB}}{PSC+1}=\frac{275MHz}{11}=25MHz$$

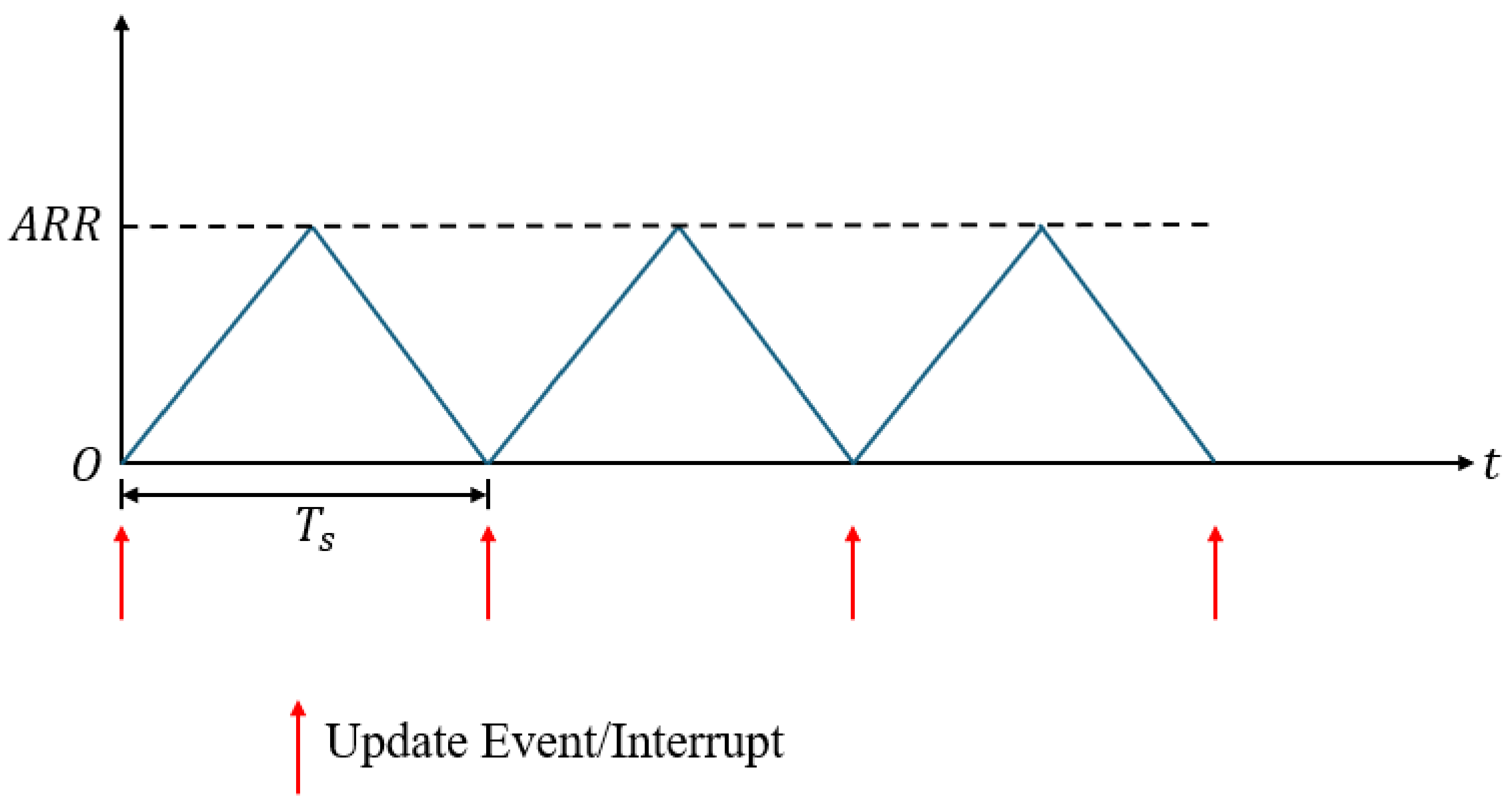
2. 由于使用中心对齐模式，PWM 载波波形如下：



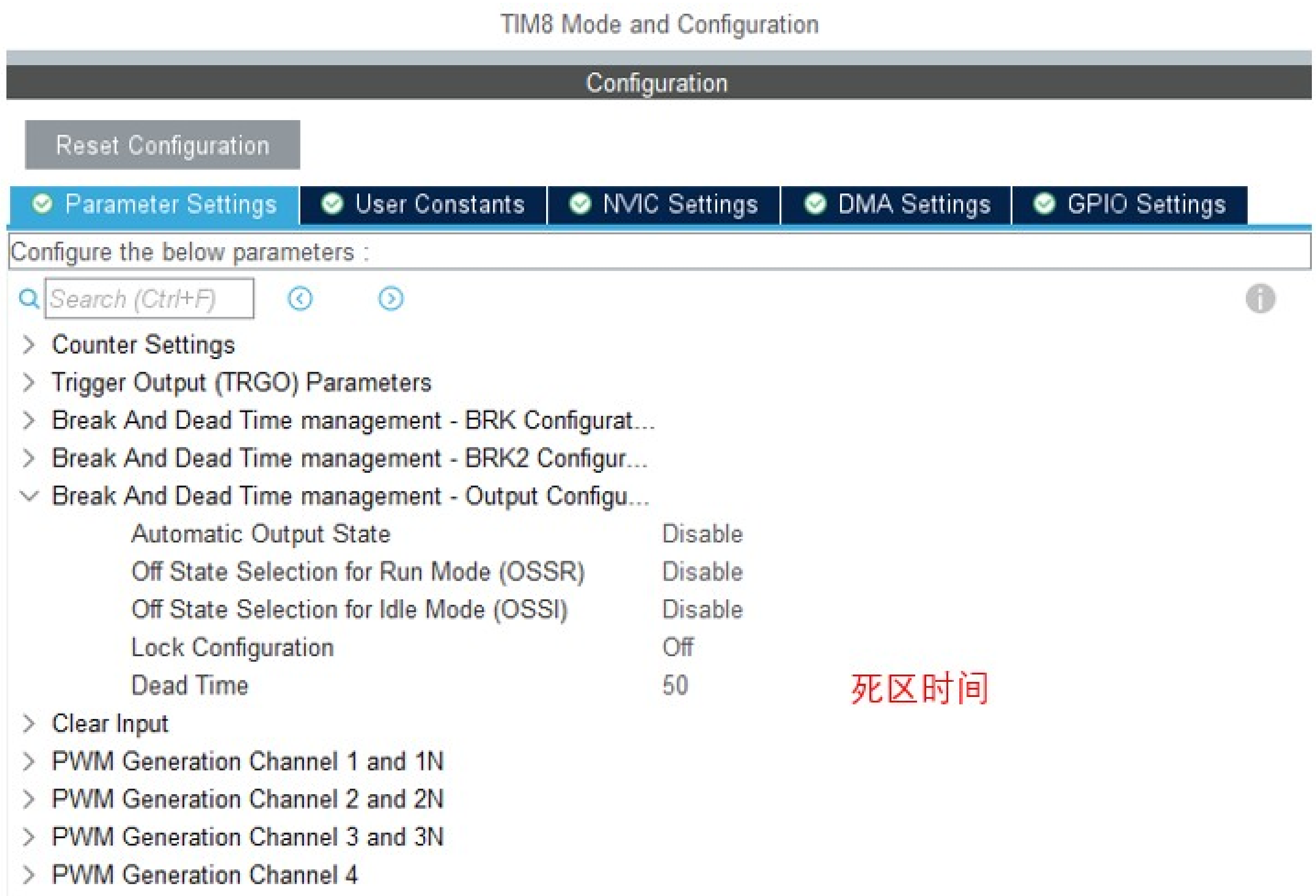
载波频率(逆变器开关频率)：

$$f_s = \frac{f_{TIM}}{2 \times ARR} = \frac{25MHz}{2 \times 1250} = 10kHz$$

3. 配置重复计数器 RCR 为 1，此时 TIM 定时器更新事件/更新中断在下图所示的地方产生：



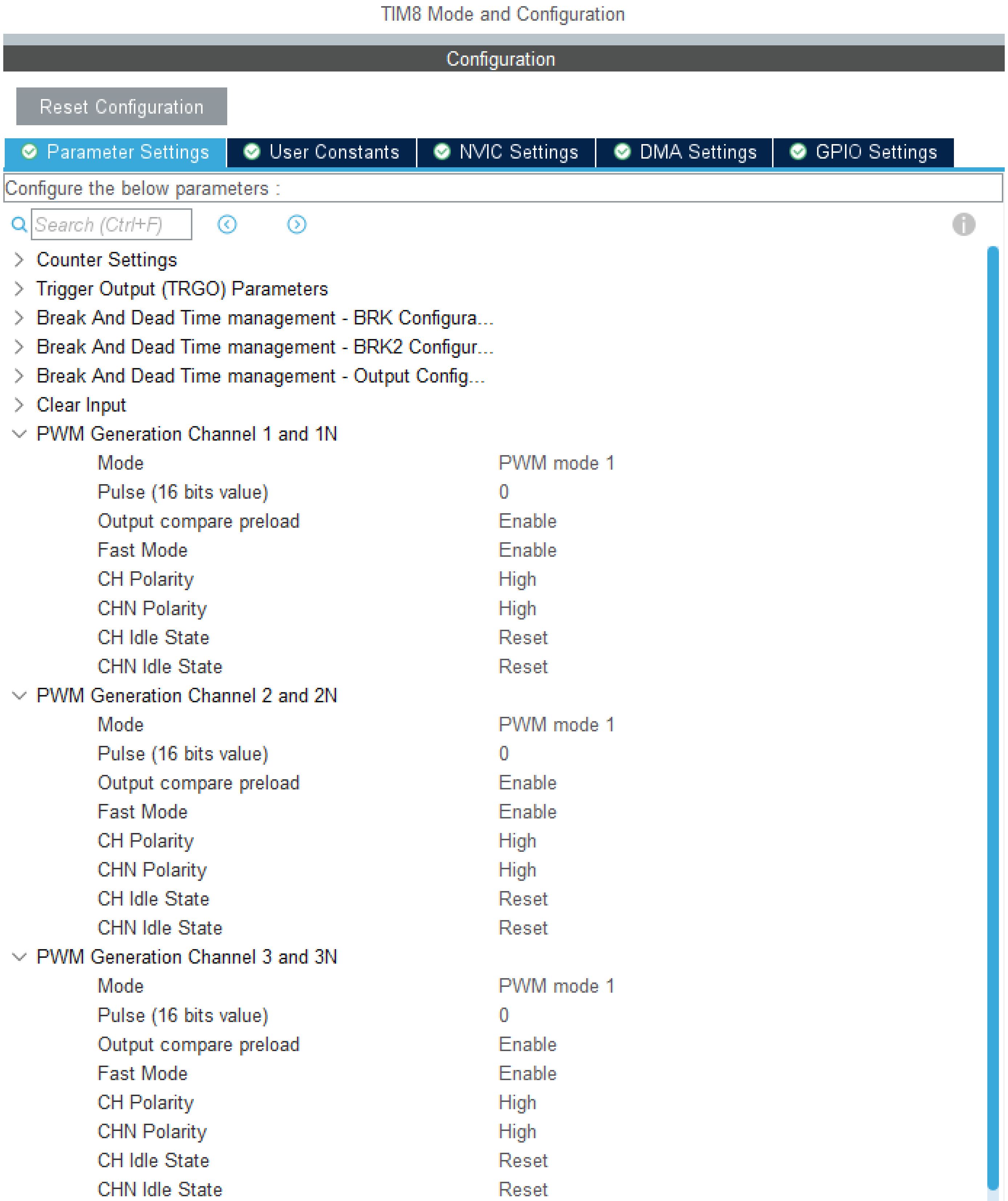
死区配置



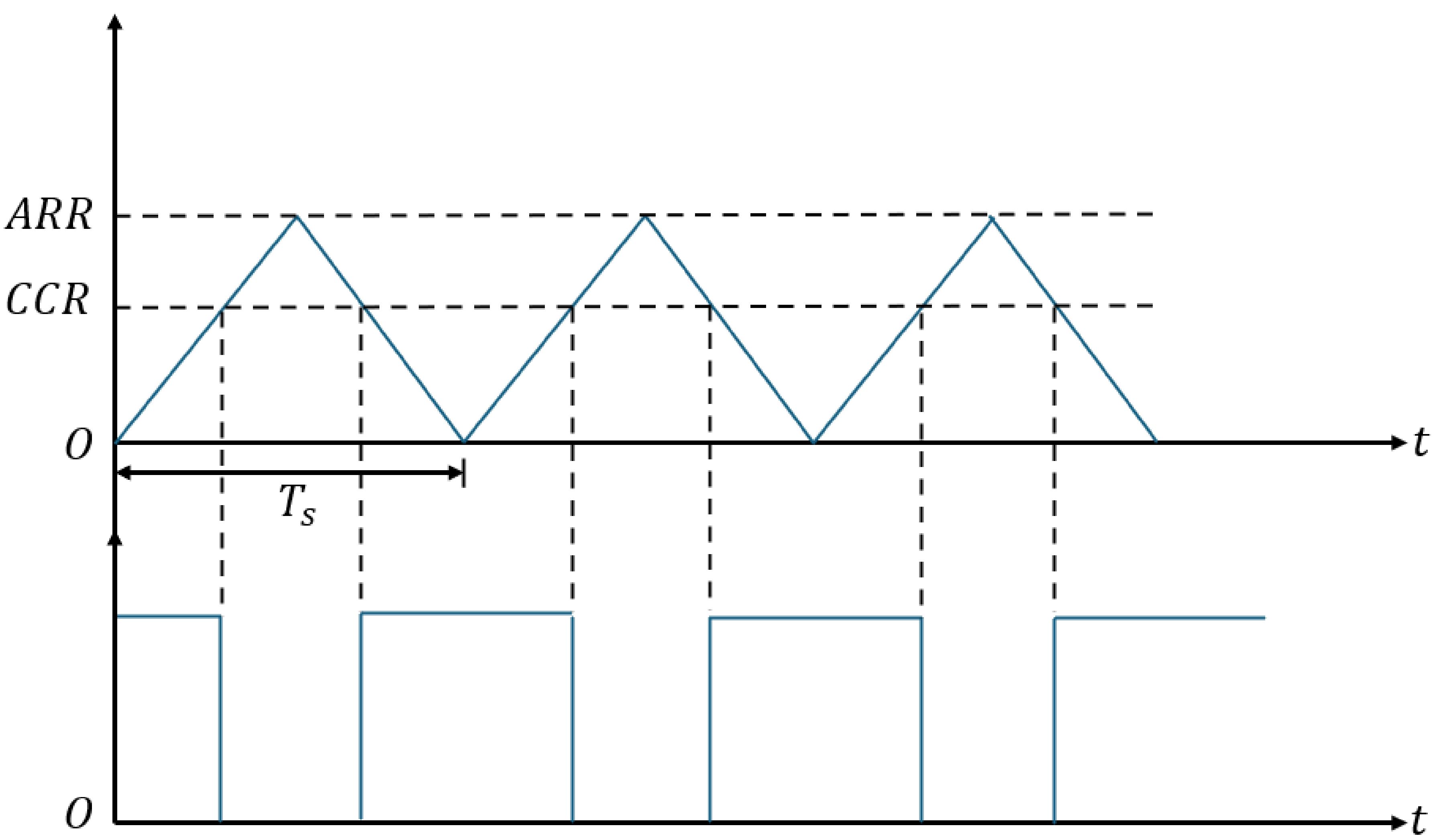
死区时间：

$$T_s = Dead\_Time \times \frac{1}{f_{TIM}} = 50 \times \frac{1}{275MHz} = 181ns$$

PWM 输出配置



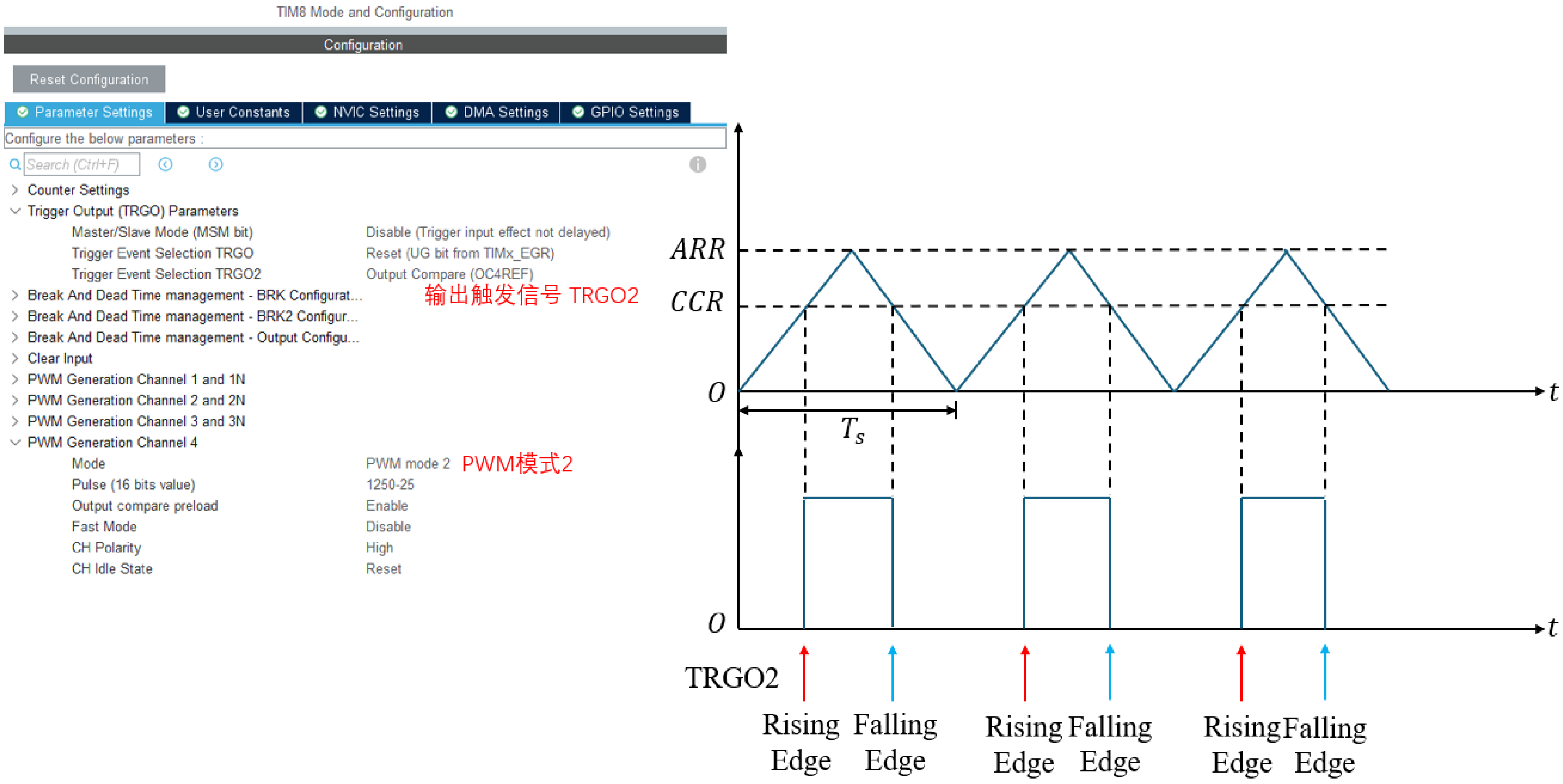
此时的 PWM 波形(逆变器上桥臂开关信号)如下:



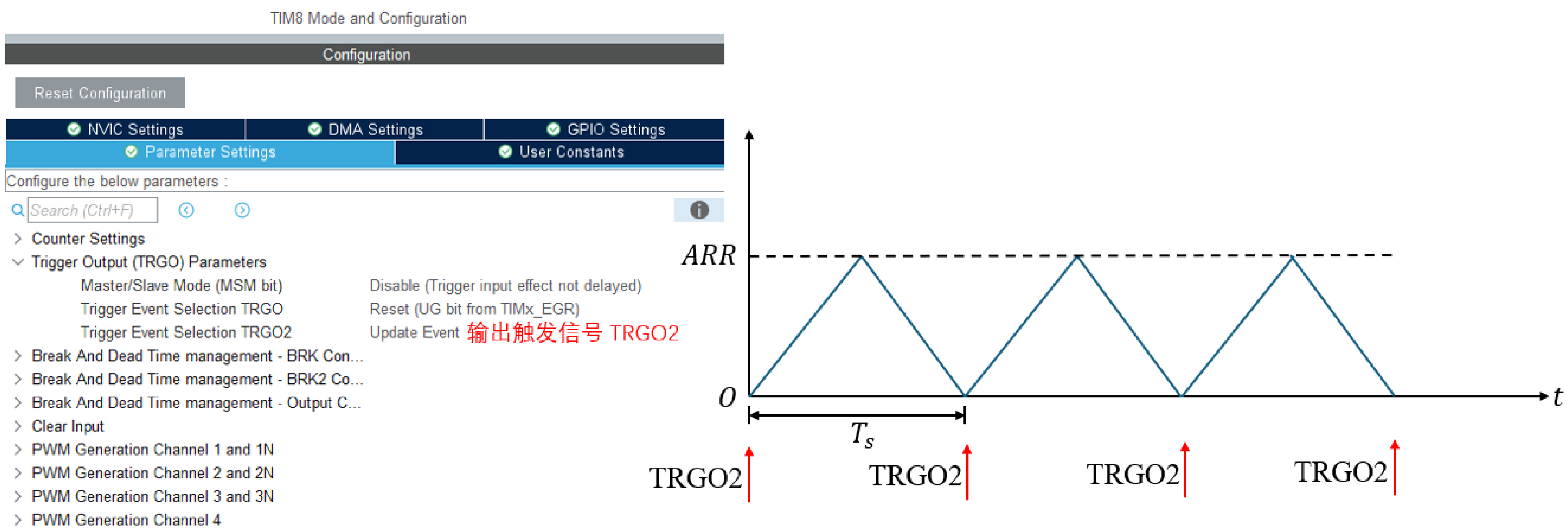
ADC 触发信号配置

配置模式1

使用 PWM 通道 4 形成 TRGO2 触发信号。



配置模式2

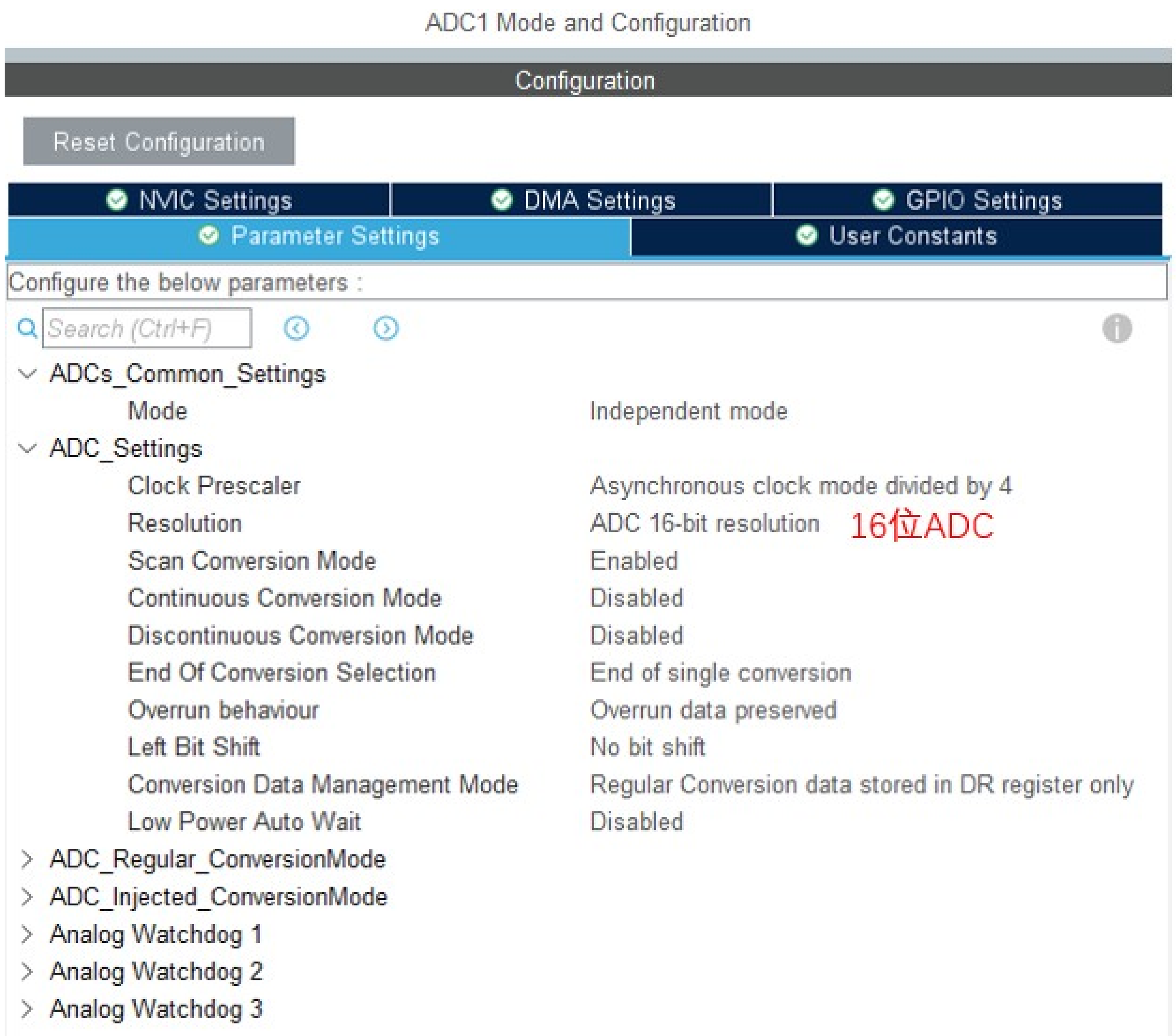


3. 采样配置

引脚分配

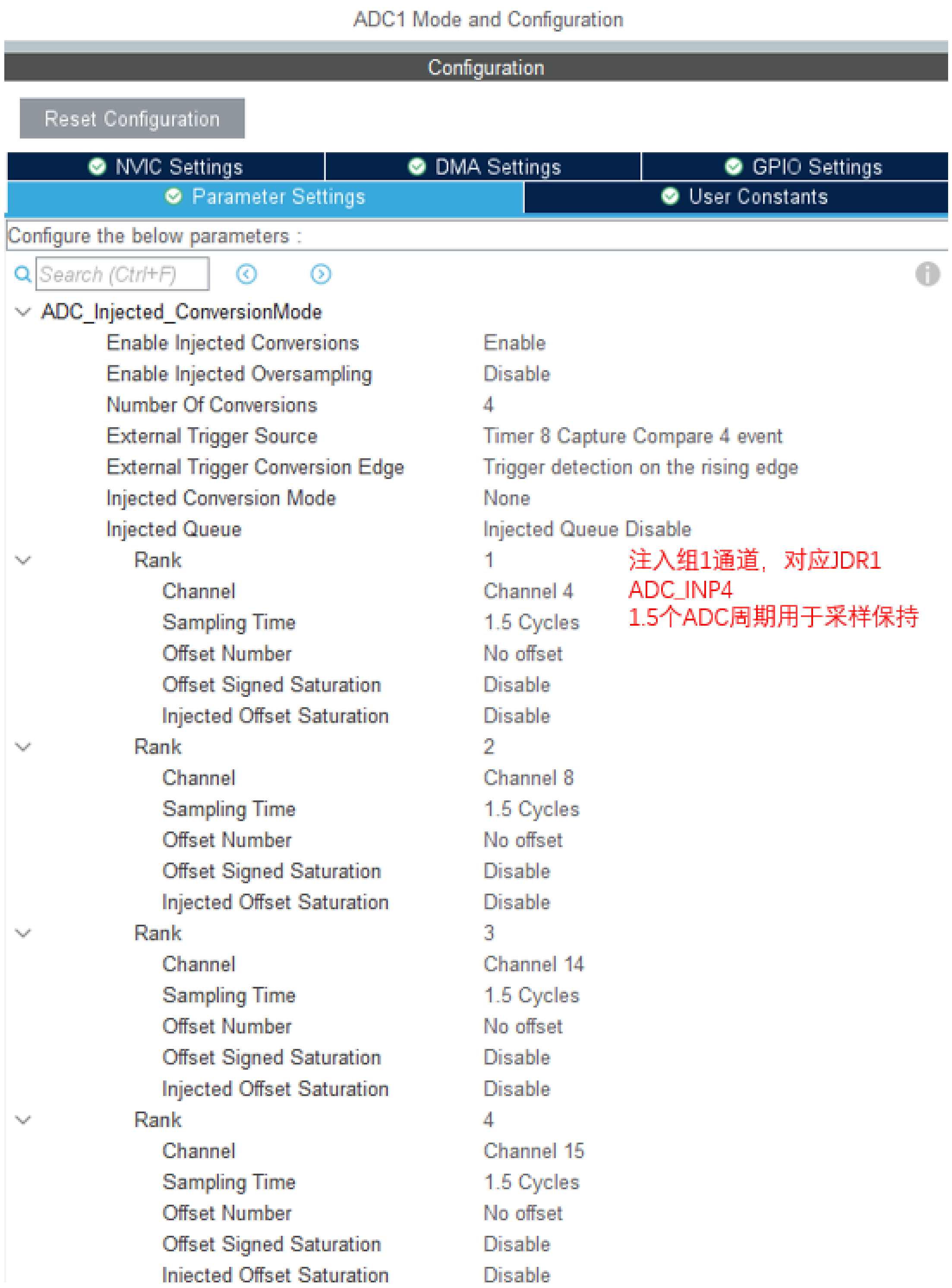
引脚	ADC引脚	用途
PA2	ADC1_INP14	负载电机U相
PA3	ADC1_INP15	负载电机V相
PC4	ADC1_INP4	驱动电机V相
PC5	ADC1_INP8	驱动电机U相

ADC基础配置



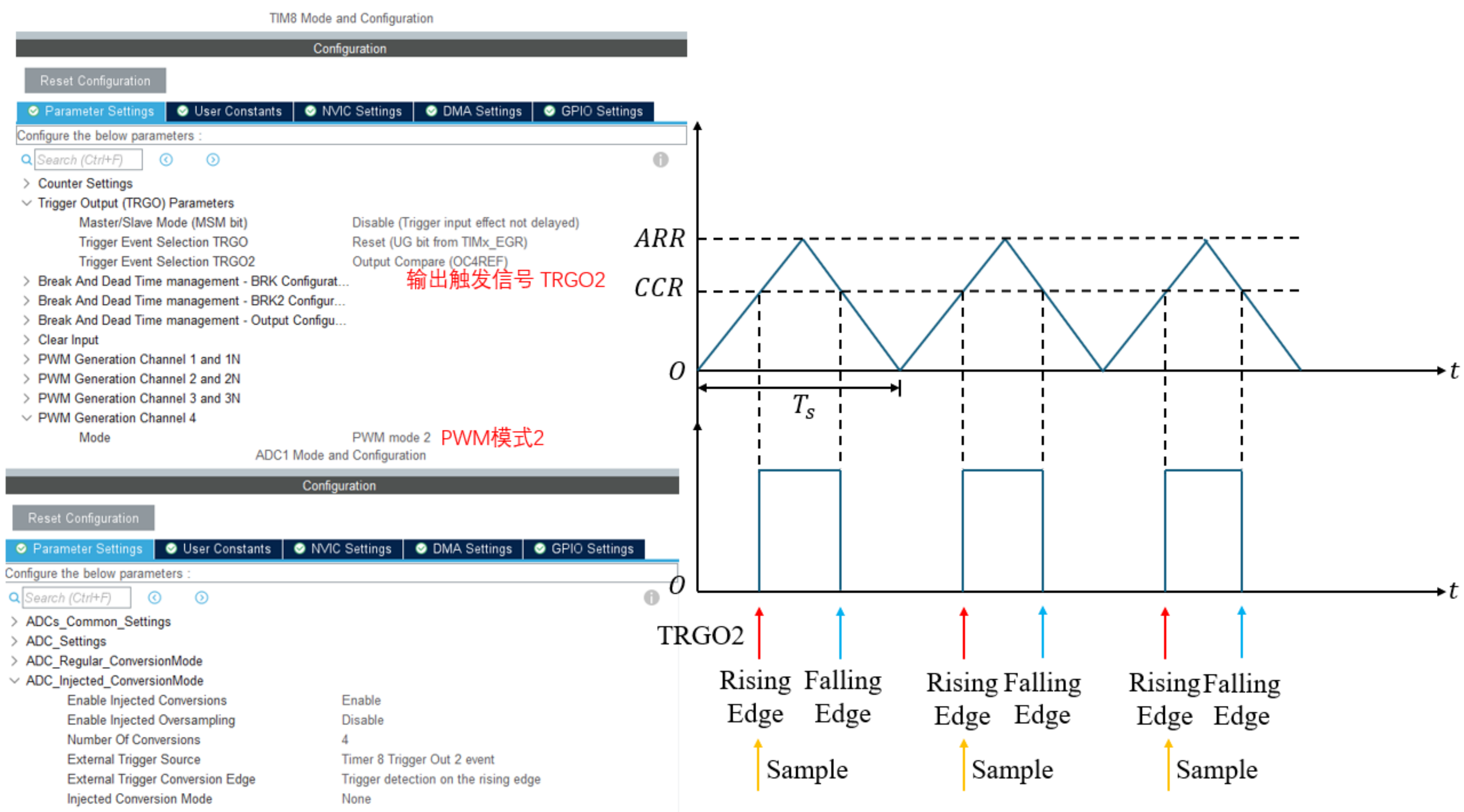
注入组配置

ADC 的注入组可以使用采用事件触发机制，且优先级最高，适合进行电流采样。

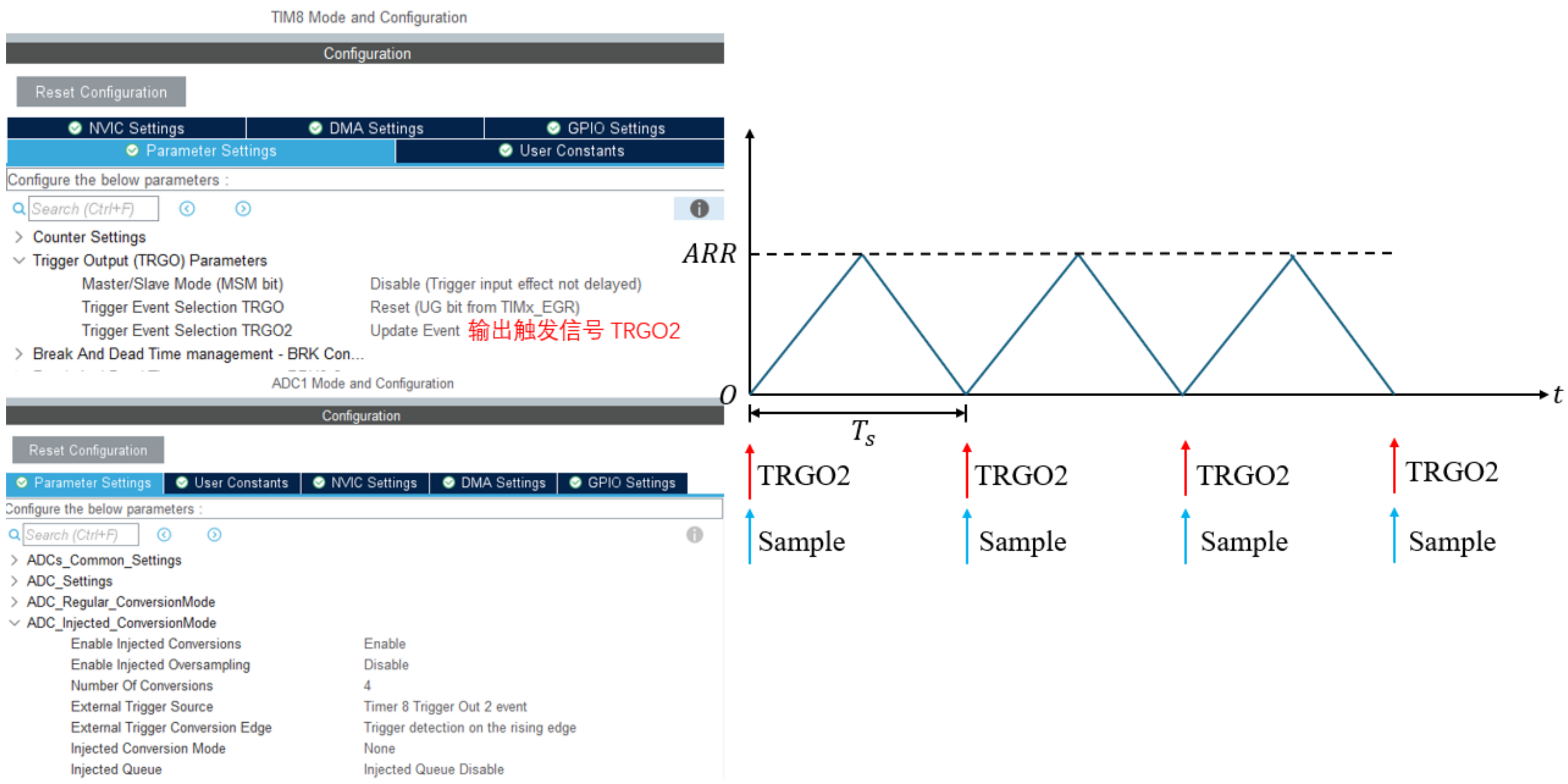


- 配置模式1

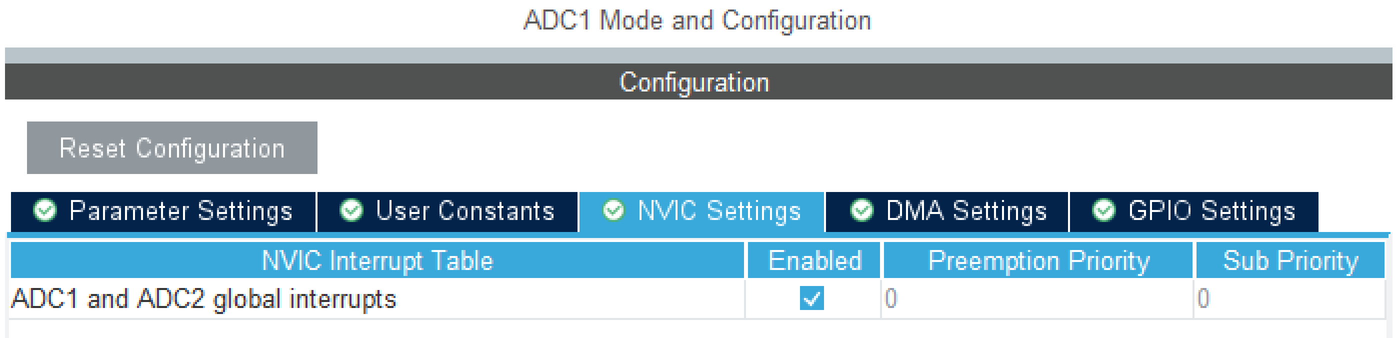
ADC 的触发事件可以为 `Capture Compare 4 event`：



- 配置模式2

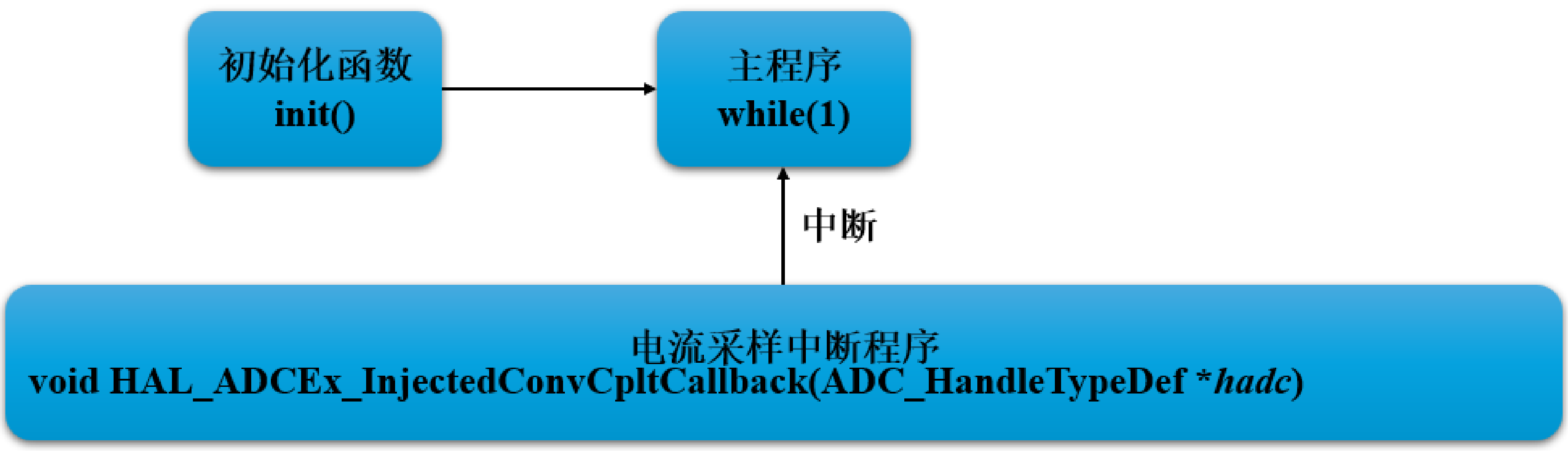


采样完成后会触发注入组采样中断，在 CubeMX 里面使能中断：



Chapter3 用户代码编写指南

1. 代码结构

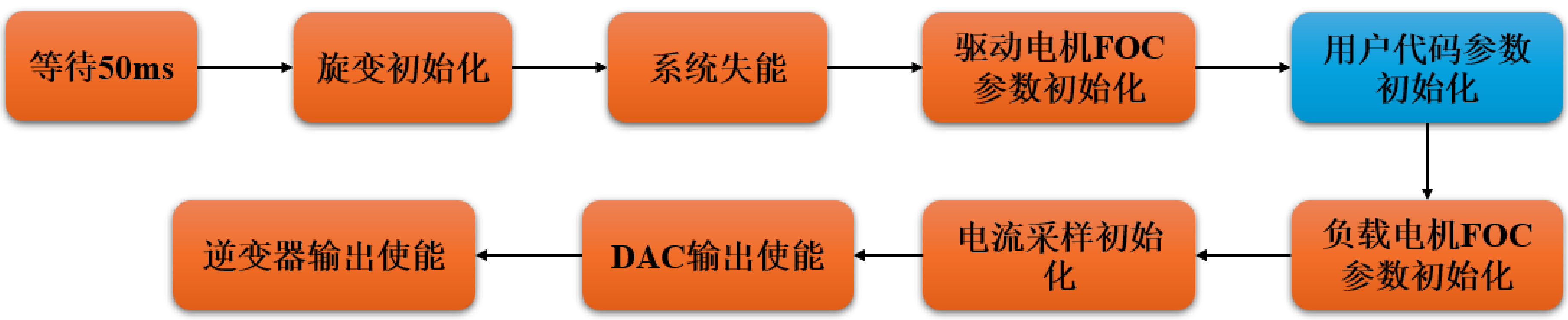


初始化程序

```c
/**
 * @brief   Init Program
 */
static void init(void)
{
    // Wait
    HAL_Delay(50);
    // Init AD2S1210
    AD2S1210_Init();
    // system init
```

```
    system_enable = 0;
    // Init FOC parameters
    // Drive Motor
    drive_speed_ref              = 0;
    Drive_curr.adc_val_u_offset = 0;
    Drive_curr.adc_val_v_offset = 0;
    Drive_curr.sample_flag      = CURR_SAMPLE_GET_OFFSET; // Read ADC Offset
    PID_init(&Drive_id_pi, 0.005, 12.5, 0, 80);           // Current PI Init
    PID_init(&Drive_iq_pi, 0.005, 12.5, 0, 80);
    PID_init(&Drive_speed_pi, 0.1, 0.1, 0, 1); // Speed PI Init
    // 用户在此处定义另外的初始化代码

    // Load Motor
    load_iq_ref                = 0;
    Load_curr.sample_flag      = CURR_SAMPLE_GET_OFFSET; // Read ADC Offset
    Load_curr.adc_val_u_offset = 0;
    Load_curr.adc_val_v_offset = 0;
    PID_init(&Load_id_pi, 0.005, 12.5, 0, 80); // Current PI Init
    PID_init(&Load_iq_pi, 0.005, 12.5, 0, 80);
    // Current Sample
    HAL_ADCEx_Calibration_Start(&hadc1, ADC_CALIB_OFFSET, ADC_SINGLE_ENDED);
    __HAL_ADC_CLEAR_FLAG(&hadc1, ADC_FLAG_JEOC);
    __HAL_ADC_CLEAR_FLAG(&hadc1, ADC_FLAG_EOC);
    HAL_TIM_PWM_Start(&htim8, TIM_CHANNEL_4);
    HAL_ADCEx_InjectedStart_IT(&hadc1);
    // Wait for Read ADC Offset
    while (Drive_curr.sample_flag == CURR_SAMPLE_GET_OFFSET || Load_curr.sample_flag == CURR_SAMPLE_GET_OFFSET) {
        ;
    }
    // DAC Init
    HAL_DAC_Start(&hdac1, DAC1_CHANNEL_1);
    // Open Inverter
    HAL_TIM_Base_Start_IT(&htim8);
    HAL_TIM_PWM_Start(&htim8, TIM_CHANNEL_1);
    HAL_TIM_PWM_Start(&htim8, TIM_CHANNEL_2);
    HAL_TIM_PWM_Start(&htim8, TIM_CHANNEL_3);
    HAL_TIMEx_PWMN_Start(&htim8, TIM_CHANNEL_1);
    HAL_TIMEx_PWMN_Start(&htim8, TIM_CHANNEL_2);
    HAL_TIMEx_PWMN_Start(&htim8, TIM_CHANNEL_3);
    HAL_TIM_PWM_Start(&htim1, TIM_CHANNEL_1);
    HAL_TIM_PWM_Start(&htim1, TIM_CHANNEL_2);
    HAL_TIM_PWM_Start(&htim1, TIM_CHANNEL_3);
    HAL_TIMEx_PWMN_Start(&htim1, TIM_CHANNEL_1);
    HAL_TIMEx_PWMN_Start(&htim1, TIM_CHANNEL_2);
    HAL_TIMEx_PWMN_Start(&htim1, TIM_CHANNEL_3);
}
```



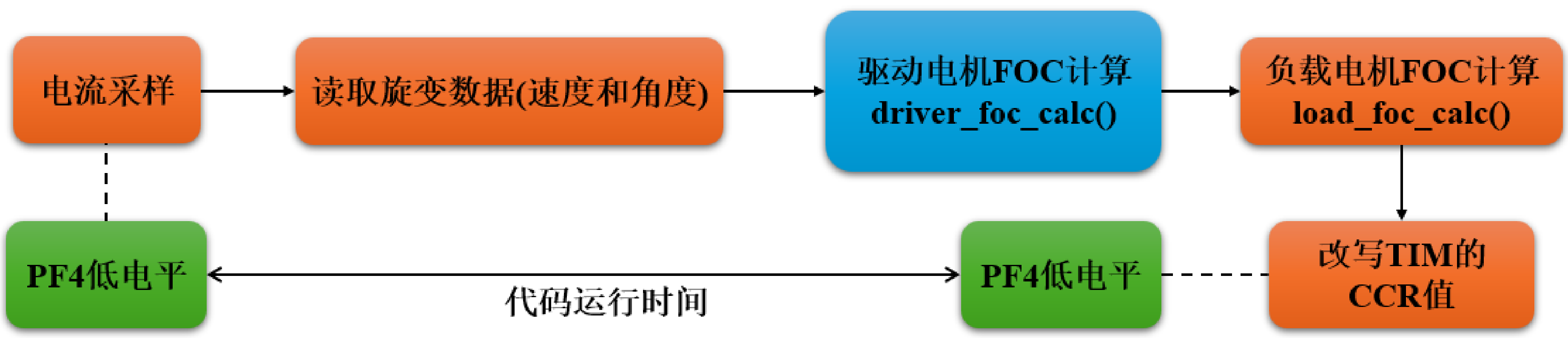
电流采样中断程序

```c
/**
 * @brief   ADC Injected Channel interrupt Callback function
 */
void HAL_ADCEx_InjectedConvCpltCallback(ADC_HandleTypeDef *hadc)
{
    static int adc_cnt                = 0;
    static uint32_t adc_u1_offset_sum = 0;
    static uint32_t adc_v1_offset_sum = 0;
    static uint32_t adc_u2_offset_sum = 0;
    static uint32_t adc_v2_offset_sum = 0;
    HAL_GPIO_WritePin(GPIOF, GPIO_PIN_4, 0); // Caculate running time
    UNUSED(hadc);
    /**********************************
     * @brief   Sample
     */
    if (hadc == &hadc1) {
        // Read Offset
        if (Drive_curr.sample_flag == CURR_SAMPLE_GET_OFFSET) {
            adc_u1_offset_sum += hadc1.Instance->JDR1;
            adc_v1_offset_sum += hadc1.Instance->JDR2;
            adc_u2_offset_sum += hadc1.Instance->JDR3;
            adc_v2_offset_sum += hadc1.Instance->JDR4;
            adc_cnt++;
            if (adc_cnt == 20) {
                adc_cnt                     = 0;
                Drive_curr.adc_val_u_offset = adc_u1_offset_sum / 20.0f;
                Drive_curr.adc_val_v_offset = adc_v1_offset_sum / 20.0f;
                Drive_curr.sample_flag      = CURR_SAMPLE_RUNNING;
                adc_u1_offset_sum           = 0;
                adc_v1_offset_sum           = 0;
                Load_curr.adc_val_u_offset  = adc_u2_offset_sum / 20.0f;
                Load_curr.adc_val_v_offset  = adc_v2_offset_sum / 20.0f;
                Load_curr.sample_flag       = CURR_SAMPLE_RUNNING;
                adc_u2_offset_sum           = 0;
                adc_v2_offset_sum           = 0;
            }
        }
        // Read Current
        else {
            Drive_curr.adc_val_u = hadc1.Instance->JDR1;
            Drive_curr.adc_val_v = hadc1.Instance->JDR2;
            Load_curr.adc_val_u  = hadc1.Instance->JDR3;
            Load_curr.adc_val_v  = hadc1.Instance->JDR4;
            adc_2_curr(&Drive_curr);
            adc_2_curr(&Load_curr);
            Drive_iabc.a = Drive_curr.curr_u;
            Drive_iabc.b = Drive_curr.curr_v;
            Drive_iabc.c = Drive_curr.curr_w;
            Load_iabc.a  = Load_curr.curr_u;
            Load_iabc.b  = Load_curr.curr_v;
            Load_iabc.c  = Load_curr.curr_w;
            // software protection
            if ((Drive_iabc.a * Drive_iabc.a > MAX_CURRENT * MAX_CURRENT) || (Drive_iabc.b * Drive_iabc.b > MAX_CURRENT * MAX_CURRENT) || (Drive_iabc.c * Drive_iabc.c > MAX_CURRENT * MAX_CURRENT) || (Load_iabc.a * Load_iabc.a > MAX_CURRENT * MAX_CURRENT) || (Load_iabc.b * Load_iabc.b > MAX_CURRENT * MAX_CURRENT) || (Load_iabc.c * Load_iabc.c > MAX_CURRENT * MAX_CURRENT)) {
                system_enable = 0;
            }
        }
    }
    // Angle and Speed Sample
    AD2S1210_Angle_Get();                   // Angle Sample
    AD2S1210_Speed_Get(system_sample_time); // Speed Sample
```

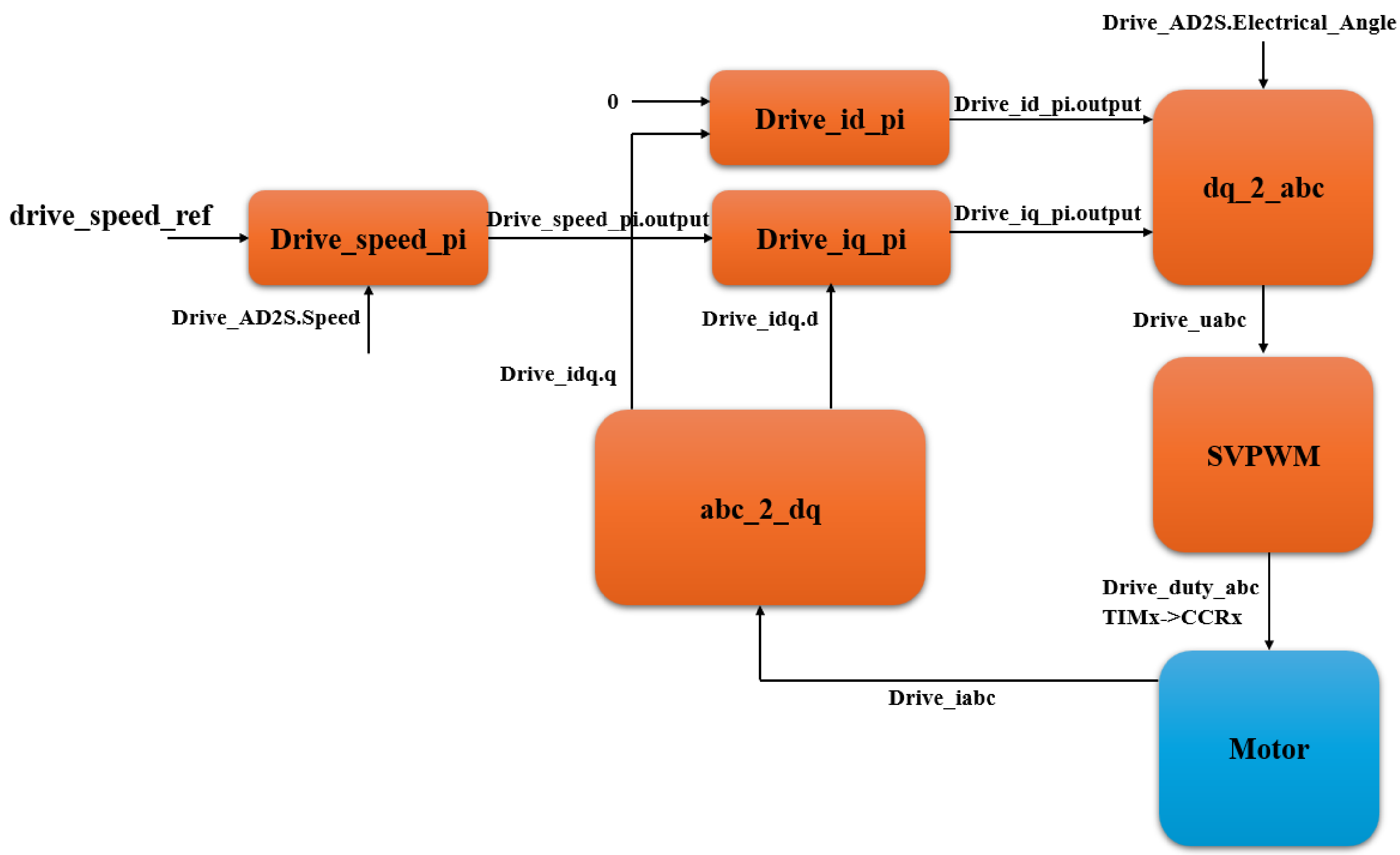
```c
    /***********************************
     * @brief   FOC Calculate
     */
    drive_foc_calc();
    load_foc_calc();

    /***********************************
     * @brief   Voltage-Source Inverter Control
     */
    if (system_enable == 0) {
        TIM8->CCR1 = 0;
        TIM8->CCR2 = 0;
        TIM8->CCR3 = 0;
        TIM1->CCR1 = 0;
        TIM1->CCR2 = 0;
        TIM1->CCR3 = 0;
    } else {
        TIM8->CCR1 = Drive_duty_abc.dutya * TIM8->ARR;
        TIM8->CCR2 = Drive_duty_abc.dutyb * TIM8->ARR;
        TIM8->CCR3 = Drive_duty_abc.dutyc * TIM8->ARR;
        TIM1->CCR1 = Load_duty_abc.dutya * TIM1->ARR;
        TIM1->CCR2 = Load_duty_abc.dutyb * TIM1->ARR;
        TIM1->CCR3 = Load_duty_abc.dutyc * TIM1->ARR;
    }

    HAL_GPIO_WritePin(GPIOF, GPIO_PIN_4, 1); // Caculate running time
}
```

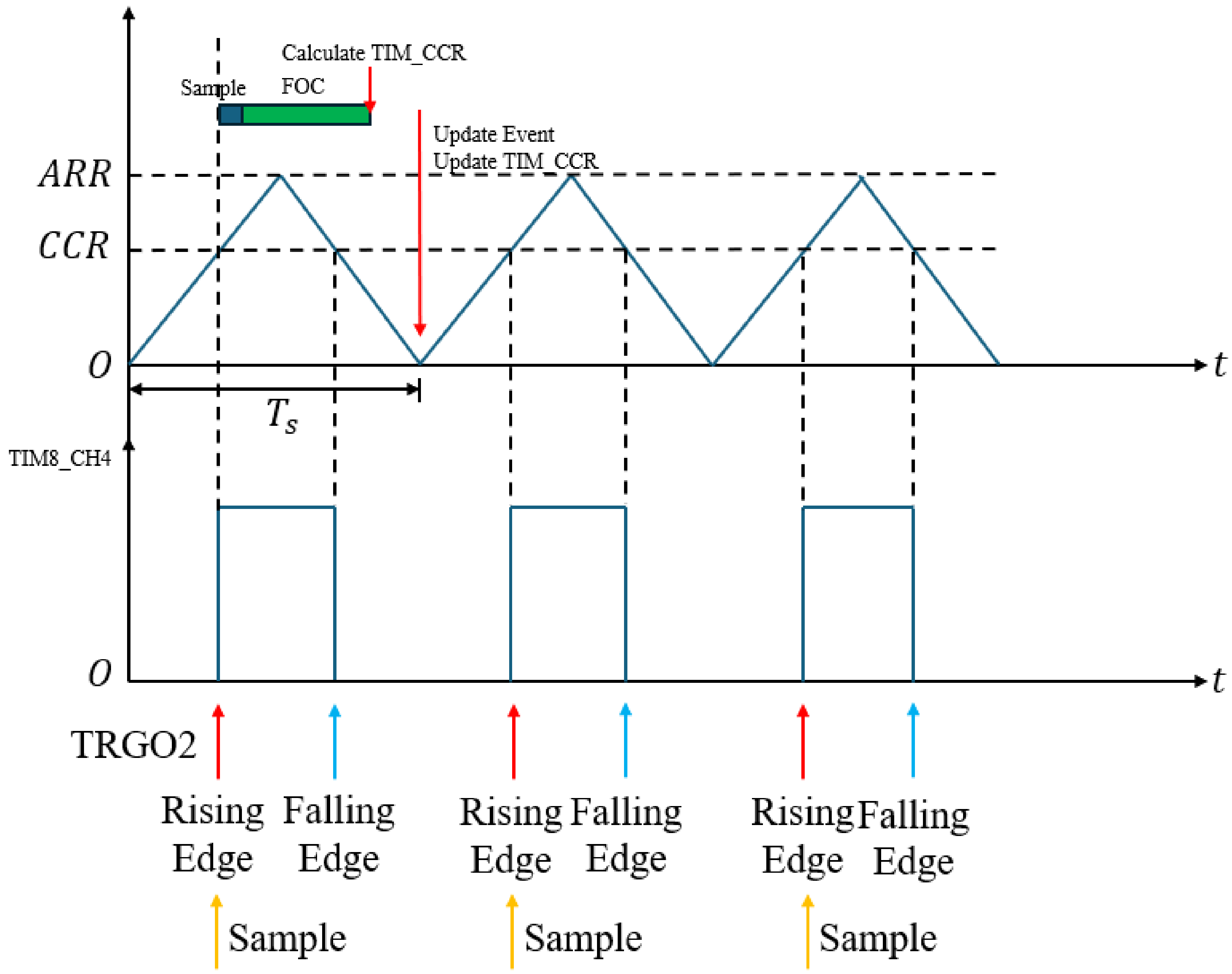


用户可以改写驱动电机的 FOC 代码(增加无感算法)。 `drive_foc_calc()` 函数运行逻辑如下：

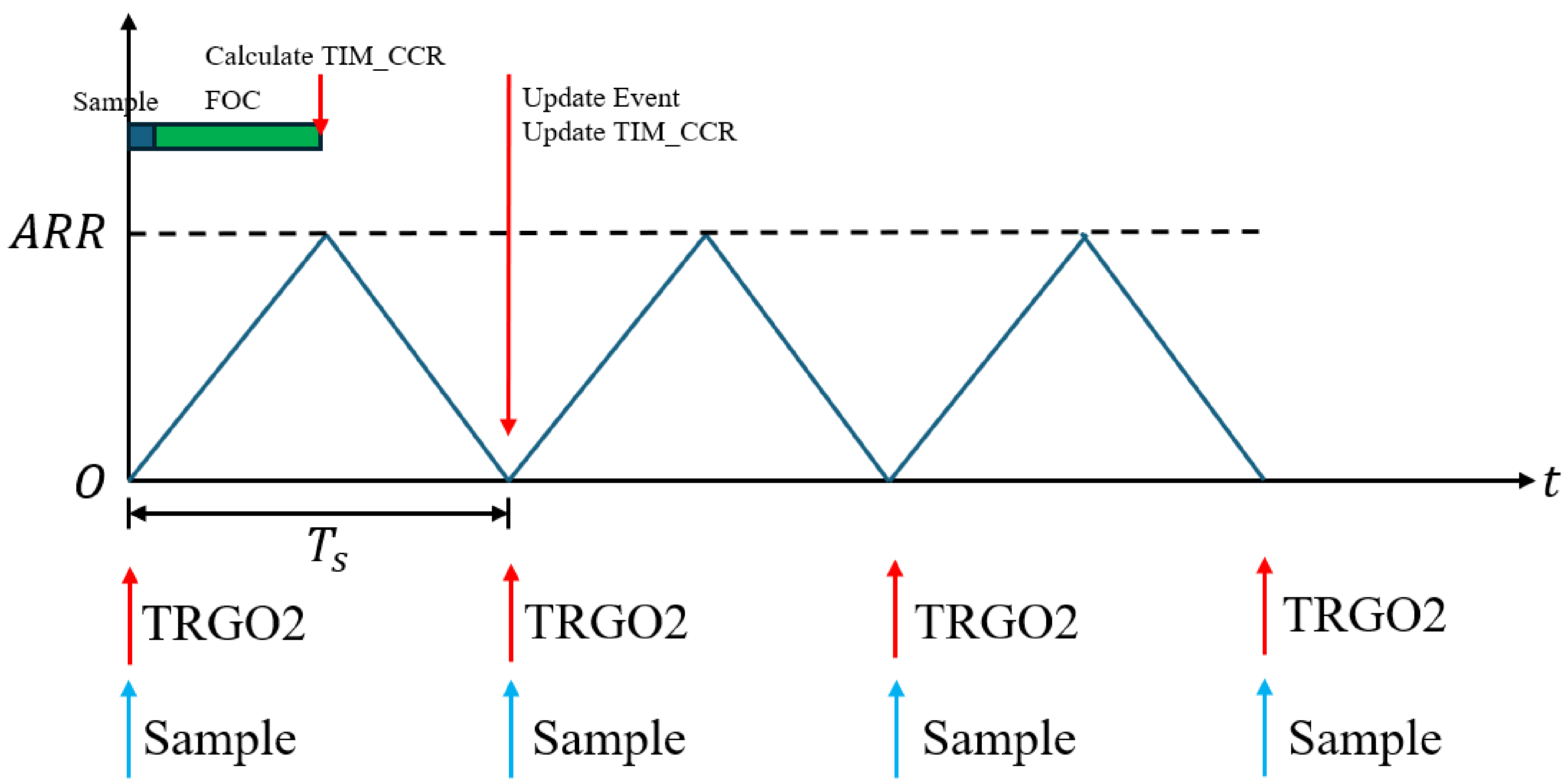


> 不同配置下的采样-更新时序：

- 配置模式1



- 配置模式2



2. 用户编写代码

用户应当在 `userpara.c` / `userpara.h` ， `drivefoc.c` / `drivefoc.h` ， `userinit.c` / `userinit.h` 三组文件中编写用户自定义代码。

`userpara.c/h` 文件

该文件进行全局变量定义，将全局变量单独列出一个文件以便于调试时观察变量。

`userinit.c/h` 文件

该文件内是用户代码参数初始化函数 `user_init()`。

用户在该函数内编写代码以便进行算法参数初始化。

`drivefoc.c/h` 文件

该文件内是用于进行驱动电机 FOC 算法的函数 `drive_foc_calc()`。

用户在该函数内编写**针对驱动电机的无感算法**。