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GENERATING PWM BY USING MICROCONTROLLER STM32F4DISOVERY

Abstract. *The generating pulse-width modulated signal algorithm in the desired form and frequency on special microcontroller STM32F4Discovery pins was developed. The adjustment in-out port features microcontroller for PWM signal generating on their pins is considered. The timer adjustment features by means where signal generating has been modulated has been given.*

Keywords: *microcontroller STM32F4Discovery, timer prescaler, in-out port, algorithm, PWM modulation, output signal, average voltage.*

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РЕАЛИЗАЦИЯ ШИМ НА МИКРОКОНТРОЛЛЕРЕ STM32F4DISCOVERY

Аннотация *Для реализации модулированного сигнала требуемой частоты и формы проведена разработка алгоритма его получения на специализированных выходах микроконтроллера STM32F4Discovery. Рассмотрены особенности настройки портов микроконтроллера для формирования широтно-импульсно модулированного сигнала на их выходах. Также рассмотрены особенности настройки таймера, посредством которого осуществляется формирование модулированного сигнала.*

Ключевые слова*: микроконтроллер STM32F4DISCOVERY, пред делитель таймера, порт ввода-вывода, алгоритм, ШИМ модуляция, выходной сигнал, усредненное значение.*

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РЕАЛІЗАЦІЯ ШІМ НА МІКРОКОНТРОЛЕРІ STM32F4DISOVERY

Анотація. *Для формування модульованого сигналу бажаної частоти та форми виконана розробка алгоритма його отримання на спеціалізованих виходах мікроконтролера STM32F4Discovery. Розглянуто особливості налаштування портів мікроконтролера для формування широтно-імпульсного модульованого сигналу на їх виходах. Також розглянуто особливості налаштування таймера, за рахунок якого можливе формування модульованого сигналу.*

Ключові слова: *мікроконтролер STM32F4Discovery, перед дільник таймера, порт вводу-виводу, алгоритм, ШІМ модуляція, вихідний сигнал, середнє значення.*

Introduction

Voltage inverters, power factor correctors and active rectifiers are widely used to power the electrical drive systems and different alternate current consumers' power systems. To ensure a high quality in the electrical energy at the inlet and (or) at the output in such converters in different kinds pulse width modulation (PWM) are used[1-3].

Pulse width modulation is pulse constant frequency signal and variable duty cycle, i.e. the ratio pulse repetition period for its duration [4].

Due to the task in the duty cycle (pulse width) the average PWM output voltage can be changed.

With high-speed appearance, powerful microprocessor technology, the PWM principle is widely used in modern frequency converters to form three-phase sinusoidal variable frequency and amplitude voltage, to control a DC motor speed, in a variable inverters, where getting from the rectified DC alternate desired frequency, amplitude and shape signal are needed [5].

Using the PWM allows you to modify amplitudes in the rectified voltage by adjusting the duty cycle [6].

As a switch for rectified voltage switching bipolar, field, high-speed IGBT transistors are used. It allows the high switching at a high frequency. Thus, due to certain law switching from the original rectified voltage signal the output signal in desired shape and frequency can be obtained.

By using the PWM almost any form modulated signal can be generated by means of modern microcontrollers.

There are analog and digital PWM. Analog is used in analog electronic systems and is considered as a classical PWM. However, nowadays digital PWM is widely used for generating signals in different shape and frequency by means of microcontrollers.

PWM is divided into unipolar and bi-polar [7]. There is no negative signal in unipolar PWM. Unipolar power supply has only a positive potential (+ V) and ground signal (GND).

Most modern MCUs have unipolar power supply and their output signals are unipolar.

The principle in forming a digital PWM illustrated in Figure 1.

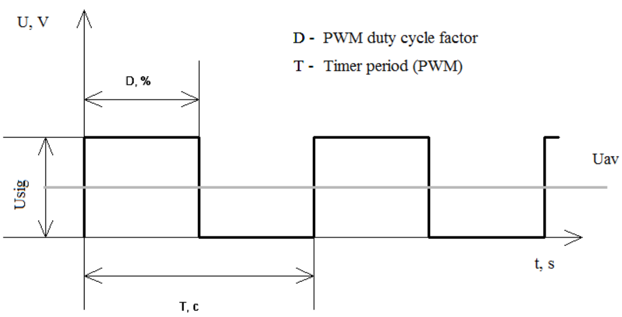

Fig.1 – The principle of the digital PWM generating

Figure 1 shows the signal frequency which depends on the microcontroller's timer period. Duty cycle D can change its value from 0 to 100%. In this case, the duty ratio signal is 50%. Thus, by using the pulse ratio changing duty cycle can be changed the average PWM value output can be changed. This principle is widely used to control the direct current motor speed, because the angular velocity in the motor is linearly depends on the armature voltage.

Research materials

For the different modulated signals generation and microcontrollers' capabilities in carrying out this task demonstration, the PWM description obtained features 32-bit microcontroller STMicroelectronics STM32F4DISCOVERY was taken (Fig.2).

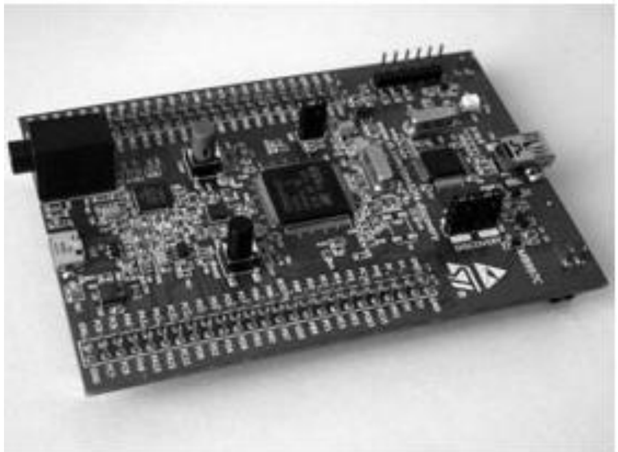

Fig.2 – STMicroelectronics STM32F4DISCOVERY microcontroller

Main technical micro-controller characteristics STM32F4Discovery are shown in Table. 1.

Table 1. – STM32F4Discovery microcontroller technical characteristics

Architecture	ARM Cortex M4
Clock speed, MHz	168
Flash memory (Flash), Mb	1
Memory (RAM), Kb	192

There is also a built - in programmer - debugger ST-Link / V2, the 3-axis accelerometer, digital microphone, USB-OTG (On-The-Go), 24-bit audio DAC (digital to analog converter) with Class A amplifier the D Class, 4 user light emission diodes (LEDs), 2 buttons (User Button, and Reset).

There are 14 timers. TIM1 and TIM8 and have main PWM and complementary channels.

The delay between turning on the main and complementary channel are called "dead time". It prevents through currents in circuits with transistors, which form a three-phase voltage by using PWM, which can be used to construct various frequency converters electrical drive systems.

To generate PWM by using microcontroller STM32F4Discovery embedded timers, which can generate a PWM signal on specific microcontroller's port in-out pins.

In this case the PWM signal generating by using TIM4 and TIM1 timers will be considered. Information about the timers in-out ports, which used to generate the PWM signal can be found in the owner's manual in the microcontroller STM32F4Discovery [8].

The general algorithm in-out port settings, timers' settings to generate the PWM signal is shown in Fig. 3.

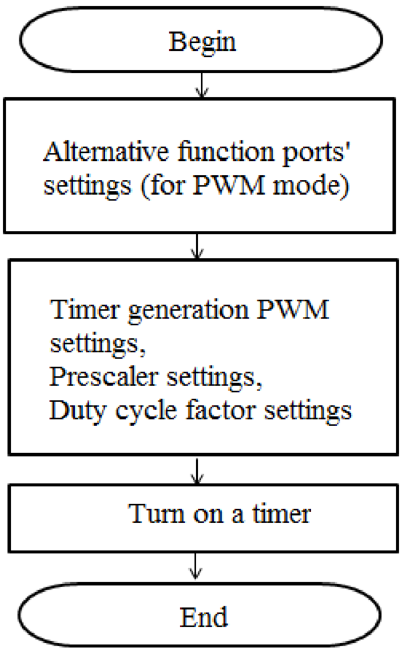

Fig.3 – Peripheral devices' setup algorithm for PWM generation (in-out ports, timers)

Thus, alternate function-defined signal use in-out port should be enabled. This means the timer can use the port pin to generate PWM signal. In other words, the in-out port pin passes under timer control.

To obtain the desired PWM frequency and duty ratio the prescaler (PSC), the timer period (auto reload register ARR) must be configured, as well as to load a value into a capture-compare register (CCR) to adjust the desired the signal duty cycle.

After the above settings implementation, the timer activation is need. In STM32F4Discovery microcontroller to reduce power consumption on all peripheral devices such as in-out ports, timers, etc. are turned off on default.

In order to use them, programmatically bus clock adjustment must be made to ports channels are connected to.

To generate a PWM signal by using TIM4 used in-out port D, pins PD12-PD15. These outputs are connected to the user LEDs. The timer has four channels (Figure 4).

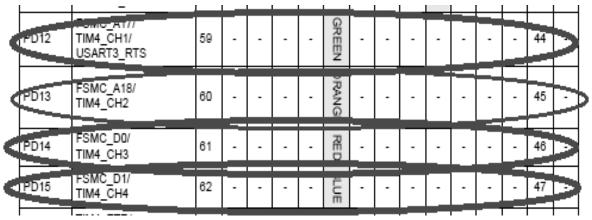

Fig.4 – Port D pins, used as a timer TIM4 PWM channels

In order to obtain the desired frequency and duty cycle PWM signal, this determines the average value in the output voltage need to configure special timer registers. This is the timer period register ARR (i.e. its overflow time) and capture compare register CCR. The first register is responsible for the switching frequency; the second is responsible for the duty cycle. There is own capture-compare register for each PWM channel. CCR1, CCR2, CCR3, CCR4 respectively for each channel.

Each timer is clocked by the bus-defined frequency. It can be determined by running Excel STM32F4xx_Clock_Configuration file developed by STMicroelectronics company. Microcontroller clock speed is 168 MHz TIM4 timer clock frequency is 84 MHz (Figure 5).

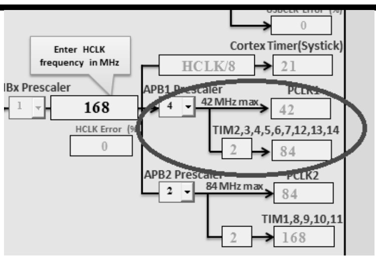

Fig.5 –Timer TIM4 clock frequency

Prescaler (TIM_PSC Register) of any timer is used to set the number of cycles of the timer. By default, the TIM4 has 84 MHz frequency. I.e. the default timer will produce 84 million cycles in 1 second. Prescaler allows configuring the timer clock frequency divider (i.e. it divides the fundamental frequency, in this case 84 MHz).

Prescaler is calculated as follows:

$$PSC = \frac{TIMxCLK}{TIMxCNT} - 1 = \\ = 84000000/1000000 - 1 = 84 - 1. \quad (1)$$

where PSC – prescaler value, TIMxCLK – timer clock input frequency, TIMxCNT – counter clock [9].

To receive necessary output PWM signal frequency a value to ARR register should be recorded which is calculated by using the following ratio calculation:

$$ARR\_VAL = \frac{TIMxCNT}{TIMx\_out\_freq} - 1 = \\ 1000000/100 - 1 = 10000 - 1 \quad (2)$$

where ARR_VAL – ARR register value, TIMxCNT – counter frequency=1000000, TIMx_ out_ freq – necessary PWM output frequency (in this case 100 Hz).

The last step is to set the desired duty cycle, which will provide necessary value in the output voltage. This setting is performed by the capture-compare register (CCRx), based on the following ratios:

$$D = \frac{CCRx\_VAL}{ARR\_VAL} \cdot 100\% <=> \\ CCRx\_VAL = D \cdot ARR\_VAL / 100\% = \\ = 100 \cdot 10000 / 100 = 10000. \quad (3)$$

where D – duty cycle ratio (in this case 100%, i. e. the number at which the whole period will be over-full by signal), CCRx_ VAL –CCRx register value (x – register's number for the specific line), ARR_VAL – a value to record to register ARR.

Thus the CCRx_VAL register value is the in the range 0..10000.

Accordingly, the intensity of the user LEDs brightness depending on the value of CCRx_VAL register. Thus it is possible to change the duty cycle of each PWM channel, writing to the CCR1, CCR2, CCR3, CCR4 different values.

To write a program for STM32F4Discovery microcontroller in C programming language integrated development environment Atollic True Studio is used.

Setting in-out port code snippets, the timer settings for generating PWM are shown in Fig. 6,7 respectively [10].

```
*main.c

void GPIOinit() {
GPIO_InitTypeDef gpio_init;

// Инициализация портов ввода-вывода (светодиоды)
// Включаем порт D
RCC_AHB1PeriphClockCmd(RCC_AHB1Periph_GPIOD, ENABLE);
// Выбираем выводы 12-15
gpio_init.GPIO_Pin = GPIO_Pin_12 | GPIO_Pin_13 | GPIO_Pin_14 | GPIO_Pin_15;
// Режим альтернативной функции
gpio_init.GPIO_Mode = GPIO_Mode_AF;
// Частота переключения вывода
gpio_init.GPIO_Speed = GPIO_Speed_100MHz;
// Режим подтяжки канала резисторами
gpio_init.GPIO_OType = GPIO_OType_PP;
// Подтяжка к питанию
gpio_init.GPIO_PuPd = GPIO_PuPd_UP;
// Применяем все настройки
GPIO_Init(GPIOD, &gpio_init);

// Связываем выводы порта D с таймером TIM4
GPIO_PinAFConfig(GPIOD, GPIO_PinSource12, GPIO_AF_TIM4);
GPIO_PinAFConfig(GPIOD, GPIO_PinSource13, GPIO_AF_TIM4);
GPIO_PinAFConfig(GPIOD, GPIO_PinSource14, GPIO_AF_TIM4);
GPIO_PinAFConfig(GPIOD, GPIO_PinSource15, GPIO_AF_TIM4);

}
```

Fig.6 – In-out port D settings

```

void TimerInit() {

TIM_TimeBaseInitTypeDef time_init;
TIM_OCInitTypeDef oc_init;

// Настройки таймера
// Включаем таймер
RCC_APB1PeriphClockCmd(RCC_APB1Periph_TIM4, ENABLE);
// Переменная преддлителя таймера
uint16_t PrescalerValue = 84-1;
// Период таймера
time_init.TIM_Period = 10000-1;
// Устанавливаем пределитель
time_init.TIM_Prescaler = PrescalerValue;
// Режим счета таймера (счет вверх)
time_init.TIM_CounterMode = TIM_CounterMode_Up;
// Применение настроек
TIM_TimeBaseInit(TIM4, &time_init);
```

Fig.7 – Timer settings

PWM output signal voltage waveforms dependencies at a frequency of 100 Hz depending on time, when the duty cycle factor is 50%, and 100% are given in Fig.8,9 respectively.

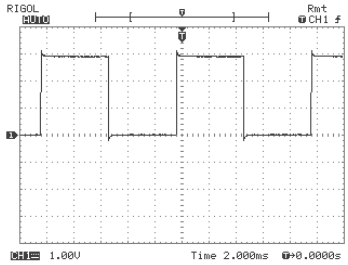

Fig.8 – PWM output signal waveform (D = 50 %)

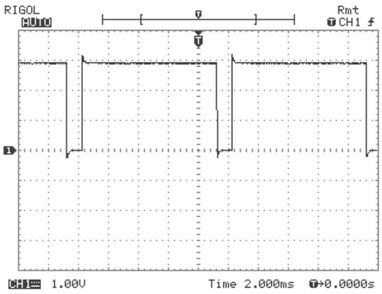

Fig.9 – PWM output signal waveform (D = 90 %)

By varying the duty cycle ratio in the timer capture-compare register CCRx value with a constant timer period, the modulated any form signal can be obtained. The sine wave generation signal at a frequency of 50 Hz will be considered. It will be implemented by half waves, i.e. one half-wave will be taken out to one channel, the other half-wave to another PWM timer channel. Generation takes place at every timer overflow interrupt. The next sinusoidal signal array value will be loaded to CCRx on every interrupt. The array consists of 40 sinusoidal signal points on half wave. The values of the array are calculated in advance. Generation of PWM sinusoid is performed by using the timer TIM1. Settings are similar to TIM4. The calculation of the timer period is as follows: since the frequency sine wave 50 Hz, respectively, with a period of 0.02. Because signal is formed by half-periods, the half-period value equal to 0.01. The half wave contains 40 points to generate a sinusoidal signal, so half-cycle value is divided by 40. The value of the timer period is 0.00025. Further the TIM1 timer period adjusting. The maximum value in the CCR to generate a sine wave will be 250. By loading to CCRx sinusoid array values on timer overflow interrupt from TIM1 (when the value of the timer period ARR is reached) sine wave modulated signal on the two channels is obtained. On one channel - is positively half-wave, on the other - negative (channels TIM1 CH3 and CH4, respectively port A pins PA8, PA10). Interrupt handler will be called every 0.00025 seconds. The results of the generation of a sinusoidal signal by means of PWM (PWM signal and averaging values [11] of the signal voltage) at different duty cycle factors are shown in Figure 10 (a,b) as a plot of the output voltage depending on time.

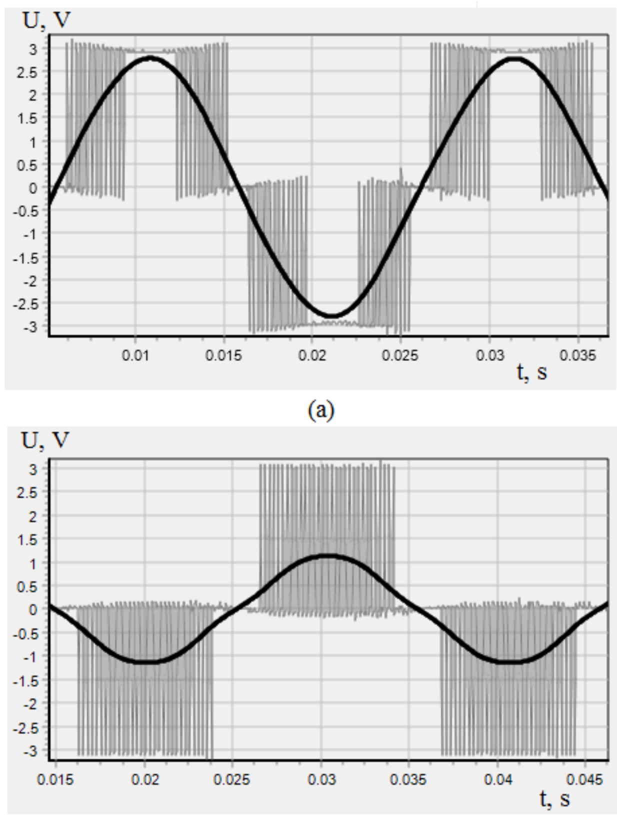

Fig.10 – The dependences of the output voltage PWM signal and their average values on time (a,b)

The code snippets in the interrupt handler, where entering values from the sine array to the capture-compare registers CCR1 and the CCR3 takes place, and thus the generation in the sinusoidal signal by pulse duty cycle changing on each interrupt call (Figure 11).

```
// Обработчик прерыванеия по переполнению таймера TIM1
void TIM1_UP_TIM10_IRQHandler(void) {
if (TIM_GetITStatus(TIM1, TIM_IT_Update) != RESET) {
TIM_ClearITPendingBit(TIM1, TIM_IT_Update);


TIM1->CCR1 = k*sinarr[i];
TIM1->CCR3 = k*sinarrinv[i];


i++;

if(i==82) {i=0;}
}
}
```

Fig.11 – Timer TIM1 overflow interrupt Handler

The data array for generation sinusoidal PWM signal on microcontroller pins is given in Figure 12

```
const uint32_t sinarr[82] = {

        0,20,39,58,77,96,113,131,147,162,177,190,202,213,223,231,238,243,247,249,250,249,247,
        243,238,231,223,213,202,190,177,162,147,131,113,96,77,58,39,20,0,0,0,0,0,0,0,0,0,0,0,0,
        0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
};

const uint32_t sinarrinv[82] = {

        0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0, 0,
        0,20,39,58,77,96,113,131,147,162,177,190,202,213,223,231,238,243,247,249,250,249,
        247,243,238,231,223,213,202,190,177,162,147,131,113,96,77,58,39,20,0

};
```

Fig.12 – The array of data for generation PWM sinusoidal signal

Conclusion

As a research result, the algorithm of in-out port settings, and timer settings for PWM generation was developed by using STM32F4Discovery microcontroller. Also, the determination features in the specific parameters have been considered, such as the frequency in the timer bus, timer prescaler, timer period, the pulse duty cycle (CCRx- capture-compare register for each channel). As the example, various signals by means of PWM were formed. Rectangular 100 Hz signal varying the duty ratio (duty ratio 50 %, and 100 %) and also it was formed more complex sinusoidal signal at frequency of 50 Hz with varying duty cycle on the two outputs in port A (PA8-PA10). The amplitude in the sine wave: in the first case (Figure 10 a) is 3 V. By changing the duty cycle factor the next signal of 1 V amplitude was made (Figure 10 b). Code snippets for port settings implementing and timer to generate PWM in C programming language in integrated development environment Atollic True Studio was given.

Thus the duty ratio in the PWM pulse affects on the output voltage average value. Output PWM frequency depends on the timer period.

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