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A time interval generator with the STM32 microcontroller

Abstract

The paper presents a concept of utilization of counter-timer circuits built in popular microcontrollers for generating precise time intervals. The main aim was to generate pulses START and STOP wholly in hardware without using a core of the microcontroller. This enables minimizing the value of time jitter of the generated time intervals and allows the use of remaining resources of the microcontroller freely. The introduced method of generation exploits the possibility of simultaneous synchronization of TIM2 and TIM3 timers from an overloaded TIM1 timer. Dependent timers work in *One Pulse Mode*. START and STOP signals are generated by PWM channels of individual timers. PWM channels can be configured independently which gives the possibility to generate START and STOP pulses of different polarity and width. Generation of a time interval can be triggered automatically (TIM1) or through one of the inputs of the microcontroller. The implemented generator is characterized by the generated range of time interval from 0 to 100 s and the resolution of 40 ns. The jitter of 100 ps was obtained. The concept is suitable to apply in any microcontroller of the STM32 family. It allows the generation of precise and adjustable delays in the application without the need to significantly expand a hardware part of the device.

Keywords: microcontroller, time delay, time-to-digital-converter.

1. Introduction

Systems for precise measurement and generation of a time interval are mainly used in physical laboratories as well as for inspection and manufacturing of different kinds of patterns. The vast majority of common implementations is done on ASIC circuits (Application Specific Integrated Circuit) and FPGA (Field-Programmable Gate Array) structures. The best implementations enable generating time intervals with a resolution and time jitter at a level of single picosecond. The simplest method of generation of the delay involves deducting an appropriate number of intervals of the reference signal and allows for the resolution equal to its period. Hereby, resolutions equal to single nanosecond are obtained. Increase in the resolution of the generated time intervals can be obtained by precise changes of reference signal frequencies [1] or by dynamic change of the phase of a reference clock signal [2]. Other methods that enable an increase in the resolution use multi-phase switched clock signals or comparison of the capacitor charging curve from a current source [3]. However, a high resolution of generated time intervals is not always a key parameter of a given application. A resolution arising from the period of the reference clock – with a low value of the time jitter – is often enough. The presented time interval generator uses existing, built-in hardware resources of a microcontroller. The benchmark of the frequency is a quartz resonator with an oscillator circuit of the microcontroller or an attached source with a frequency ranging from 4 MHz to 32 MHz.

2. Concept of the microcontroller time interval generator

The project of the precise time intervals generator can be divided into three main parts. They are: a triggering controller, a START pulse generation module and a STOP pulse generation module. Each of these parts is a properly configured timer circuit. Modern microcontrollers have from a few to several hardware counter-timer circuits that can be adapted to work as elements of a delay generator. The modules generating START and STOP pulses additionally use circuits of direct control of the microcontroller outputs.

A typical task of a timer steering the output of the microcontroller is a square wave generation with variable filling (PWM). This task involves control of the flip-flop output at the time of reloading the timer and reset it when the counted value is equal to the value from the compare register. Cyclic operation of such a circuit enables generation of pulses with the time depending on the value put into the comparator register and the repetition period equal to the time of reloading the timer. Timing systems of STM32 microcontrollers can operate in a single pulse mode. A hardware or software triggered timer is stopped after counting to zero. This mode is ideally suited to generate START and STOP pulses that define the beginning and the end of the generated time interval. In addition, the ability of PWM channels to work with different polarization allows adjusting logic levels to application requirements of the generator.

The START pulse generation module includes the timer whose initial value is equal to the duration of the pulse. The value of the digital comparator is equal to the duration of the START pulse. At the time of triggering the timer, its value is equal to the value of the digital comparator and the output activation occurs. After counting to zero the output becomes idle (Figure 1).

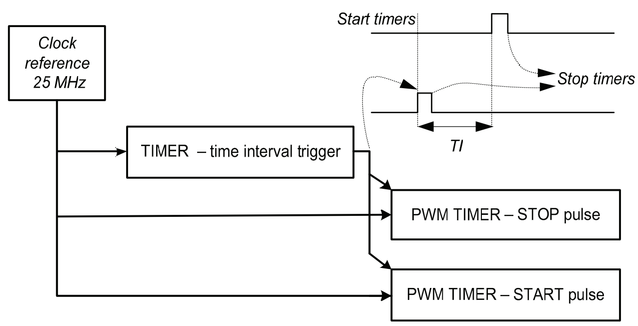

Fig. 1. Functional diagram of the time interval generator

Simultaneously with the release of the timer generating a sequence START, the timer of circuit generation of the STOP pulse is launched. The initial value of this timer is higher than the compare value, which causes that in the beginning of counting the output remains idle. When the timer state is equal to the value from the digital comparator, the generated time interval is over. That causes the generation of the STOP pulse. The reset of this timer ends a cycle of the generator work. The initial value of the timer in the STOP circuit is the sum of the generated time delay and the duration of a pulse signaling the end of the cycle.

The start of generation of the sequences indicating the beginning and the end of the generated delay is performed by a trigger module. It is the next timer clocked by the same signal (25 MHz) whose counting cycle defines the frequency of repetition of the generated time intervals. This timer should have the option of hardware synchronization of the systems operating on the modules of START and STOP pulses generation. In the presented time interval generator, software triggering of timers is useless in the operating function of interruption from the trigger module. Such a method does not provide a simultaneous start of counting by both timers. Furthermore, the time of interruption operation – even at its maximum priority – is not constant, which results in a significant increase in the time jitter of the generated time interval. The repetition time of a sequence should be longer than the generated time interval plus the STOP pulse width.

3. STM32 family device implementation

The basic element of most time interval generators is a reference source of a clock signal, whose parameters to a large extent affect the parameters of the whole generator. Microcontrollers, including the STM32 family, are generally clocked from a built-in generator whose work is stabilized by the attached quartz resonator. The parameters of such a frequency standard are generally sufficient in typical applications of microcontrollers. The frequency of the signal generated by the internal oscillator is in a range from 4 MHz to 36 MHz. A higher operating frequency of the microcontroller can be achieved by using a built-in PLL loop. However, its inclusion and the use for generating the reference clock results in increasing the time jitter. It is also possible to supply the microcontroller with an external reference signal, for example from an OCXO quartz generator, characterized by significantly improved parameters regarding the stability of the generated frequency. The range of frequencies of the added external reference signal is the same as in the case of the quartz resonator (Figure 2).

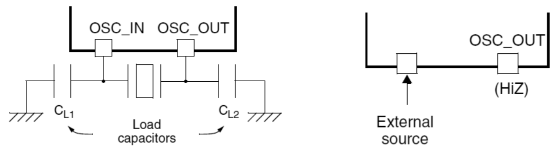

Fig. 2. Possible clock sources of the STM32 microcontroller

Fully hardware operation of time interval generation by counter-timer circuits of the microcontroller is only possible when ensuring their work in a master – slave configuration. Additionally, in order to accomplish the presented concept, the microcontroller must enable synchronization of two timers from one signal generated by the main timer. In the STM32 family of microcontrollers, there exists the possibility to synchronize the TIM2 and TIM3 circuits from the internal ITR0 signal. This signal is generated by the TIM1 timer circuit, e.g. as a result of its overloading (Figure 3).

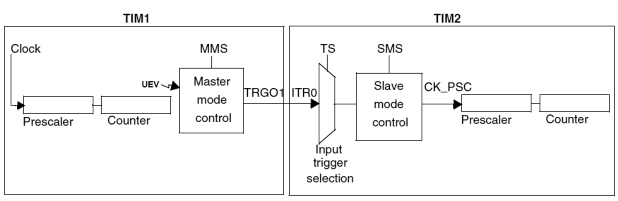

Fig. 3. Configuration of master - slave STM32 timers

The TIM1 is the main circuit which triggers TIM2 and TIM3 operations. Its time of overloading is responsible for the frequency of repetition of the generated START – STOP sequences. For a 16-bit timer and a clock frequency of 25 MHz, it is possible to achieve the repetition periods up to 2.5 seconds. When this value is insufficient, it is possible to use a 16-bit prescaler of frequencies, available for each of the counter-timer circuits of the microcontroller. The timer generating the START pulse is the TIM3 circuit, together with one of the four compare channels. The selected channel controls the directly associated output of the microcontroller. The timer works in configuration One Pulse Mode in the downcounter mode. The reload register and compare values (ARR and CCR) are equal. The generated pulse begins at the moment of timer triggering and ends when the timer counts to zero. The ARR and CCR values determine the duration of the generated START pulse. At the same time both TIM2 and TIM3 start working. The TIM2 also works in One Pulse Mode configuration and the downcounter mode. The value entered in the CCR register is the duration of the STOP pulse expressed in cycles of the reference clock. In turn, the ARR register contains the value that is the sum of the generated time interval and the CCR registry value. The possible connection of the timer internal trigger in STM32 microcontrollers is shown in Table 1.

Tab. 1. Timer internal trigger connection in STM32 microcontrollers

Slave TIM	ITR0 (TS = 000)	ITR1 (TS = 001)	ITR2 (TS = 010)	ITR3 (TS = 011)
TIM1	TIM5	TIM2	TIM3	TIM4
TIM8	TIM1	TIM2	TIM4	TIM5

4. Test results

One of the basic parameters of the examined time interval generator is the value of the time jitter of the generated time intervals that equals the length of the repeated START – STOP sequences. Measurements were made in the measurement system shown in Figure 4 with an oscilloscope Le Croy wavepro 950 with the sampling of 4 GS/s.

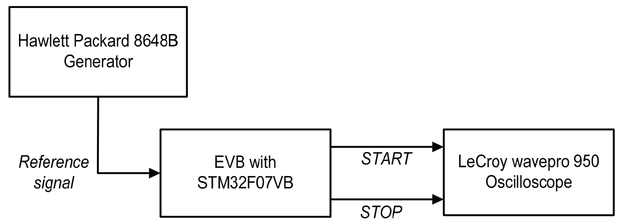

Fig. 4. The test setup

The implementation of the generator realized on the processor STM32F07VB (EVB DISCOVERY series) was examined. The source of the reference signal was a resonator attached originally to the processor, with a frequency of 25 MHz (stability 2×10^{-5}). The received deviation was at the level of 100 ps for the time interval equal to 4 us. Inclusion of the PLL loop integrated in the processor in the path of the pulse causes an increase in the standard deviation of the generated time interval to the value of 110 ps. During the other experiment, a Hewlett Packard 8648B generator was used as a reference clock signal, giving the stability of about 3×10^{-6} [4]. In such a configuration the standard deviation was reduced to 85 ps. Using the same external clock signal generator with the frequency multiplied to 50 MHz by the internal PLL loop increased the time jitter to 100 ps.

5. Conclusions

In the paper, the concept of a time interval generator created by using peripheral microcontrollers blocks of the STM32 family has been presented and discussed in detail. The presented solution can be implemented on all STM32 microcontrollers. The created circuit allows the generation of a time interval in a range of 40 ns to 2.6 ms with a step of 40 ns. In the case of using microcontrollers from the STM32F2 series, containing a 32-bit TIM2 timer, a generation range expands to more than 100 seconds. The time jitter of the generated time intervals is dependent on the stability of the source of the reference clock signals. For a standard quartz resonator with stability of 20 ppm, the value of the time jitter is approx. 100 ps. The use of a more stable external source of a reference signal can slightly reduce the value of the time jitter of the generated time intervals. The parameters of the pulse paths of the microcontroller have a big impact on the value of the time jitter. The proposed solution can be modified by the inclusion of a built-in PLL loop in the pulse path. This allows the reduction of the resolution of the generator to 10 ns (for systems of F4 series). On the other hand, it causes an increase in the value of the time jitter, resulting from too low stability of the reference clock signals generated in such a way. The experimental studies were performed by using the subfamily of microcontrollers, characterized by a relatively low clock frequency (48 MHz). In systems with a higher maximum clock frequency, whose pulse paths should have a lower time jitter, it is possible to implement the time interval generator with parameters comparable or even better than the presented above.

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6. References

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