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# Digital Control System for Stepping Motor Driver Chip

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# Digital Control System for Stepping Motor Driver Chip

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**Abstract—**Stepper motor is a common execution unit in electromechanical control system. In order to realize the high precision and effective control of the stepper motor, a digital control scheme integrated in the stepping motor driver chip is proposed. On the ADMS platform, the digital control system is designed by Verilog HDL language, and the digital control system is connected with the H-bridge circuit. The control of the two-phase micro-stepping motor is realized by Eldo and Modelsim simulation. It can support SPI bus to set working mode, attenuation time, micro-stepping work mode and other parameters. The intelligent harmonic scheme can effectively reduce the ripple current, and the ripple current can be controlled. The control scheme adopts modular design, the coding is simple and easy, and has high application value.

## 1. INTRODUCTION

The device for converting the pulse signal of the stepping motor into the corresponding angular displacement is one of the actuators of the electromechanical control system[1][2]. It has the characteristics of low price, easy control, stable performance and no error accumulation[3~4]. The case of non overload motor speed and stop position just depends on the pulse signal frequency and pulse numbers, not affected by load change[5].At the same time, in the control process, the stepping motor does not need position sensor as feedback, which greatly reduces the difficulty of control system design, so it is widely used in a variety of automatic control situations[6]. However, because the stepping angle is large, the stepping motor is difficult to be used in situations with high precision. In order to further improve the accuracy, it is necessary to subdivide the motion process of the stepping motor[7~8]. In the control system of traditional stepping motor, the controller with MCU and H-bridge drive is mostly adopted, which increases the operation time greatly. Therefore, the digital control part will be integrated in the driver chip.

## 2. THE CONTROL PRINCIPLE OF H BRIDGE

A single H-bridge consists of four high voltage NMOSFET, which controls and stabilizes the current flowing through the motor by controlling the state of the four NMOSFET[9~10].

### *2.1. Four states of H Bridge*

The driving state of the H-bridge is the charging of the motor winding, which increases the current flowing through the motor winding. Therefore, the state is the conduction of the high and low bridge arms on different sides in accordance with the direction of the current. Taking the current flowing through the winding from left to right as an example, the driving state of the H-bridge can be shown in Fig 1.

The attenuation state of H-bridge is the discharge of motor winding, which can be divided into two kinds: slow attenuation state and fast attenuation state. The low bridge arm is turned on at the same time so that the current in the motor winding is slowly lost, so this attenuation mode is also known as slow attenuation, as shown in Fig 1.

The fast attenuation mode of the H bridge is that the arms on different sides of the bridge, which are opposite to the direction of the current flowing through the winding, are turned on at the same time, as shown in Fig 1.

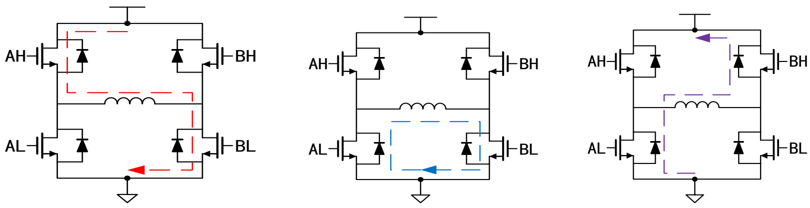


Figure 1. Three states of H bridge

### *2.2. Intelligent Harmonic Mode*

This mode requires a lower limit under the target current value. When the target current value does not change, the current is in a slow attenuation, and decreases slowly. When the target current value is lower than the current value, the current is in a rapid attenuation, in order to rapidly reduce the current to the vicinity of the target current value. Compared with other traditional continuous current modes, the harmonic mode has more than a pair of comparators, but the steady-state current variation amplitude is greatly reduced and the dynamic change speed is greatly improved, and the current accuracy is also relatively higher. The specific work processor is as follows: the current increases to $I_{tar}$ in the rising phase, the slow attenuation mode is used in the continuous phase, the current decreases to $I_{edg}$, the ripple current is small, and the fast attenuation mode is used in the descending stage, and the current drops rapidly to $I_{edg}$. The schematic diagram of intelligent harmonic continuous flow is shown in Fig 2:

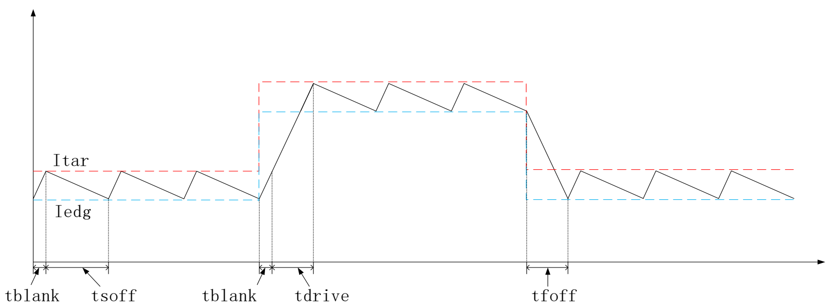


Figure 2. Intelligent harmonic example

## 3. Micro-stepping of Two-phase Stepping Motor

The micro-stepping motor divides a sinusoidal period equally, and each bisection point becomes a step [11~12]. The phase difference of the two-phase current is 90°.The current in the H bridge as follow:

$$I_a = I_{max} \sin(step * 360°/n) \quad (1)$$

$$I_b = I_{max} \cos(step * 360°/n) \tag{2}$$

Where $I_a$ is A phase current, $I_b$ is B phase current, $I_{max}$ is the full range current, step is the current number of steps, and n is the micro-step mode

## 4. DIGITAL CONTROLLER

The digital controller consists of a system controller, two H-bridge controllers, an input buffer and a data interface SPI. The overall architecture is shown in Fig 3.

### *4.1. System controller*

The system controller module is responsible for the transition of the working state of the system, and schedules the work of other modules according to the working state. The main flow chart is shown in Fig 4.

The system controller module has four states: 'IDLE', 'ADJS', 'WORK' and 'STOP'. When the system is reset, the system controller enters the 'IDLE'. The signal to be reset jumps up, and the system controller changes to the 'ADJS'. When the system is in 'ADJS', the system controller outputs 'switch_adjs'; the system controller outputs short pulses at a fixed frequency, which makes the internal current of the B-phase H-bridge controller rise to the maximum. When the internal current of the B-phase H-bridge controller reaches the current maximum, the ready signal will be given to make the system controller switch to the 'WORK'. When the system is in 'WORK', the system controller outputs 'switch_en'; and the system controller will output the corresponding switch_step according to the input step short pulse. When the system is in the working stage, that is, when the system is in 'ADJS' and 'WORK', and the error signal fault is logical '1', the system controller will enter the 'STOP'. When the system is in 'STOP', 'switch_step', 'swtich_en', and 'switch_adjs' are set to logical '0'. At this point, all the digital control parts are locked and no other actions can be performed. When the user eliminates the error after troubleshooting and sets the fault signal to logic '0', the system controller switches to 'IDLE'. Alternatively, the user makes a global reset of the overall system, and the system controller then switches to a 'IDLE'.

### *4.2. H-bridge controller*

The H-bridge controller module is mainly responsible for controlling the H-bridge and controlling the breaking of the H-bridge according to the working state. H-bridge controller mainly consists of three parts: counter, state controller and switch control module. The counter converts the pulse into steps under the clock pulse, that is, the counter counts once when the pulse rises. In order to place the effect of the burr, the rising edge of the pulse needs to maintain at least four clock cycles. The steps are added by one when turning forward and minus one when reversed, and the steps are transmitted to the outside world through the decoder as the digital input of current rudder DAC.

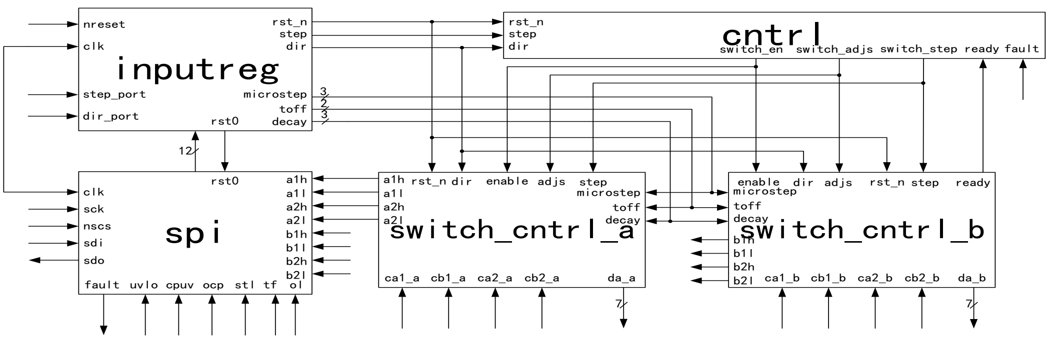


Figure 3. Digital controller

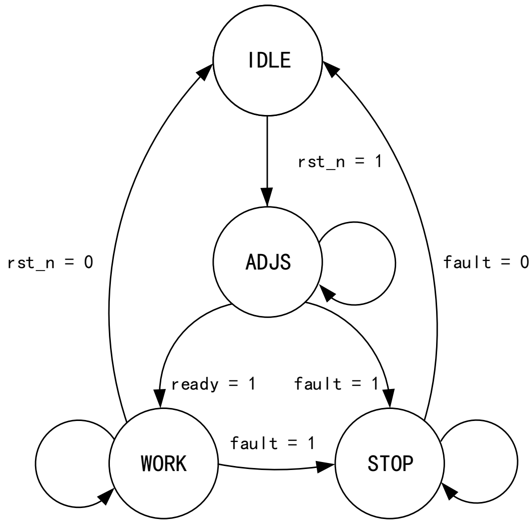


Figure 4. system controller flow chart

The state controller mainly controls the breaking of H-bridge, and its flow chart is shown in Fig 5.

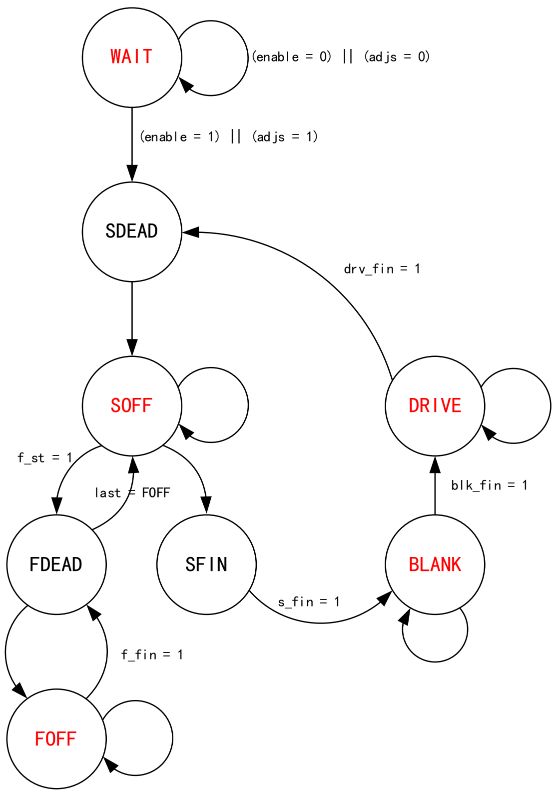


Figure 5. State controller in H-bridge controller

Among the various step modes and attenuation modes, there are three basic working states of H-bridge: driving stage, slow attenuation and fast attenuation. Therefore, in this design, the basic state is subdivided into eight types: ‘WAIT’(Wait for the system to start), ‘BLANK’(Blank detection H-bridge time), ‘DRIVE’(Drive state of H-bridge), ‘SDEAD’(Dead time of state transition), ‘SOFF’(Slow attenuation state of H bridge), ‘SFIN’(Dead time of state transition), ‘FDEAD’(Dead time of state transition) and

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‘FOFF’(Fast attenuation state of H bridge). Because the high back EMF of the motor winding will lead to the misjudgment of the system, it is necessary to avoid ‘BLANK’ state for this period of time.

In this design, due to the large inductance of the motor winding, the reaction electromotive force is too large, it is possible to break down the chip, the ‘dead zone’ state is inserted between the working states, and the short circuit caused by opening the same side bridge arm at the same time is avoided. At the same time, because the reaction EMF generated by the motor winding will interfere with the comparator in the process of state transition, in order to prevent the impact on the normal work flow, the ‘BLANK’ is inserted before the ‘DRIVE’. Take the harmonic attenuation mode as an example, the work flow is as follows: when the system is reset, the state converter is in ‘WAIT’. When the system starts to work, the state converter changes from ‘WAIT’ to ‘SDEAD’, and then to ‘SOFF’. The slow attenuation mode can be maintained at the current voltage with smaller ripples. When the voltage attenuates to the lower limit, the state transition logic sends out a s_fin signal. The state converter changes from ‘SOFF’ to ‘SFIN’, and then to ‘BLANK’ and ‘DRIVE’. In this design, in order to eliminate the interference of the comparator, the ‘BLANK’ will maintain the 7ns. When the state converter is in ‘DRIVE’, the state transition logic will send out a ‘drv_fin’ signal when the H-bridge current reaches the sinusoidal current value. The turntable converter changes from ‘DRIVE’ to ‘SDEAD’, and then to ‘SOFF’. Repeat the previous steps. When the step signal is provided from the outside and is in the rising phase, the state converter will be in the ‘DRIVE’ for a long time until the H-bridge current reaches the corresponding sinusoidal current value, and the driving state time is recorded. When the state converter is in the descending phase, the state converter passes from ‘SOFF’, ‘FDEAD’ to ‘FOFF’, and the attenuation counter starts to work. When the attenuation counter coincides with the recorded time, the state transition logic sends out a f_fin signal, and the state converter transitions to a ‘SOFF’ via a ‘FDEAD’. Repeat the state transition of the previous phase.

The function of the switch control module is to control the breaking of the high voltage nmos tube on the four arms of the H bridge according to the ‘dir’ signal of the rotation direction of the motor and the state of the state converter.

## 5. OVERALL SIMULATION RESULTS

In order to verify the performance, the Hspice Netlist of the peripheral drive circuit is translated into a Verilog file which can be read by the digital simulation period in the ADMS environment, and the digital part and the peripheral model are called in the testbench file for simulation.

The simulation results in 32 step mode are shown in Fig 6.

When using the device, the rotation direction of the motor can be changed.

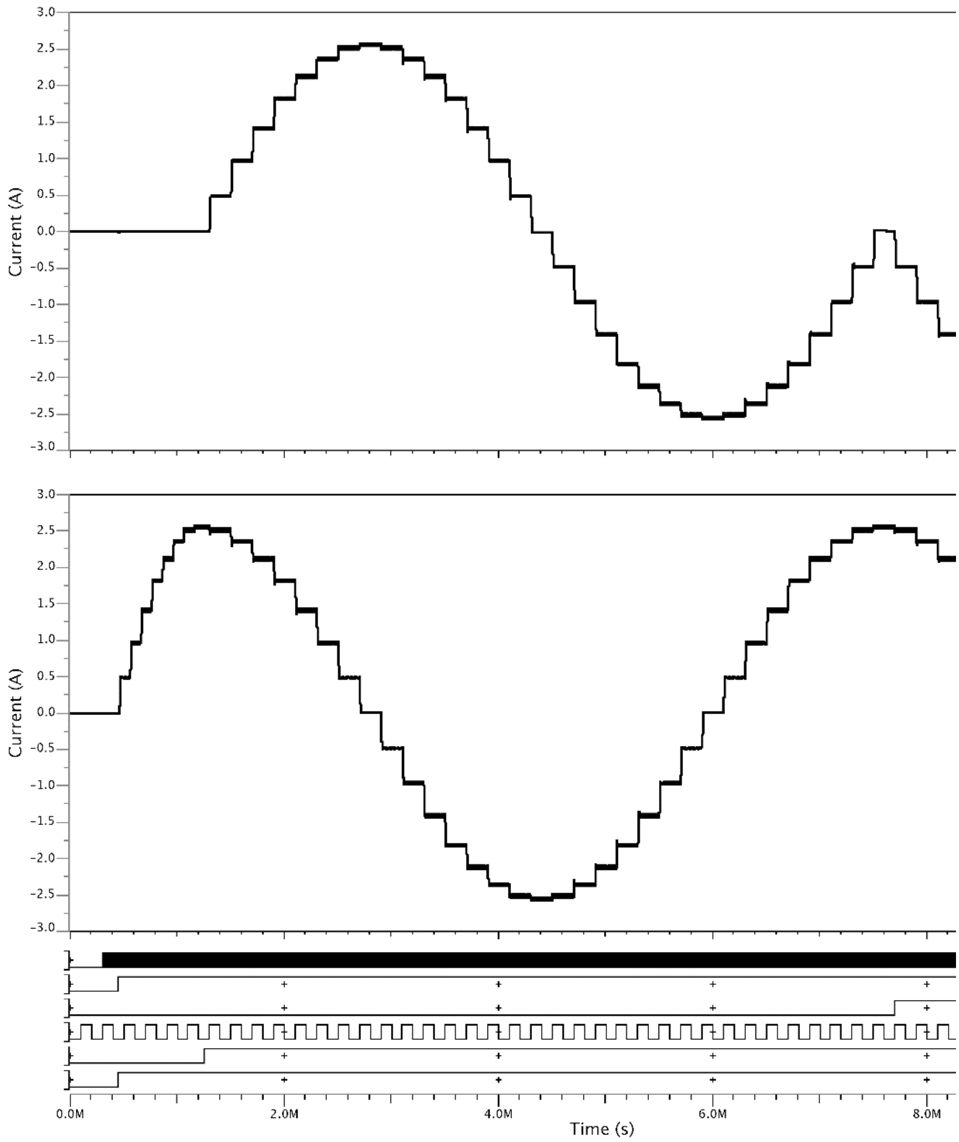


Figure 6. current waveform of 32 step mode

As can be seen from the above figure, the current ripple is relatively small during the rotation of the stepper motor, and there is no loss of steps during the rotation, and the rotation direction can be changed arbitrarily during use.

## 6. Conclusions

The principle of stepper motor subdivision drive is analyzed, and a highly reliable two-phase stepper motor subdivision drive digital control system is designed, which can be integrated in the driver chip. By using the intelligent harmonic mode, the current ripple can be effectively reduced, up to 32 subdivision control, and the user can configure the corresponding subdivision mode, rotation direction, attenuation time, attenuation mode and other parameters through the spi interface.

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