

## FIVE PHASE STEPPING MOTOR DRIVE WITH DEDICATED IC

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### ABSTRACT

*Stepping motors are digitally controlled motors used for precise positioning. They enable simple, accurate control of rotation angle and rotation speed, so they are suitable for wide variety of applications. Five- phase stepping motors in comparison with 2 phase stepping motors have improved performance characteristics because of its multiple number of phases. Two examples of improved performance characteristics are low oscillation and high response. A dedicated new lower cost 5 phase step motor controller IC was developed to create a small but powerful package for use in high volume applications. This IC has all the drive functions of an indexer (sequencer) and can control motor phase currents accurately and efficiently. The power circuitry is packaged in a cost effective separate module using a bipolar drive format with N channel MOSFETs. The step motor driver circuitry consists of four parts as follows: sequencer, pre-driver and current control, P channel MOS array, N channel MOS array.*

**Keywords:** hybrid stepper motor, five- phase, Pulse Width Modulation (PWM), sequencer, dedicated IC, MOS array

### 1. Introduction

Stepper Motors are used to obtain the motion profiles in the field of Robotics and Automation Engineering. Stepper motors are preferred in applications where high precision controls in position and velocity, is important such as in aerospace, printers, scanners, copiers, faxes, word processors, optical and magnetic disk devices, medical equipment, X-Y plotters, CNC machines, semiconductor fabrication equipment, agricultural automation applications, textile equipment's, and telescope. Moreover reliability, lack of contact, aging, mechanical ruggedness and availability of torque at zero speed are the attractive features of Stepper Motors. Among the various types of stepping motors, the hybrid stepping motor has a permanent magnet rotor and a toothed magnetic structure on both the stator and rotor, so that a permanent-magnet torque as well as reluctance torque can be generated [1]. Two – phase stepper motors are commonly used, but five-phase stepper motors have the superior characteristics of resolution, vibration and performance compared with two phases motors. When both stepping motors are operated in half step mode, two phase motor provides a resolution of 400 steps per revolution while a five phase motor has a resolution of 1000

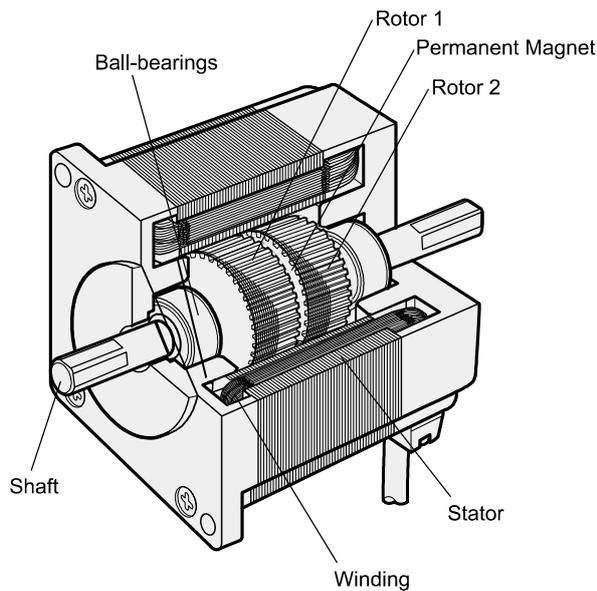
steps. This resolution is 2.5 times higher when compared with two phase stepper motor. The applications where high precision, low vibration and low noise is required, five-phase hybrid stepper motor can be employed compared to two-phase hybrid stepper motor. Five-phase stepper motors are superior in dynamic performance [2]. A high precise position control using five-phase hybrid stepper motor is achieved in open loop control achieves. The higher the number of phases, smaller will be positioning deviations. Microstepping is a technology that achieves low resonance, low noise operation, at extremely low speeds by controlling the flow of electric current fed to the motor coil and thereby dividing the motor's basic step angle into smaller steps. Pulse Width Modulation (PWM) technique is usually used to excite the driver to operate the motors.

### 2. Structure of Five – Phase Stepper Motor

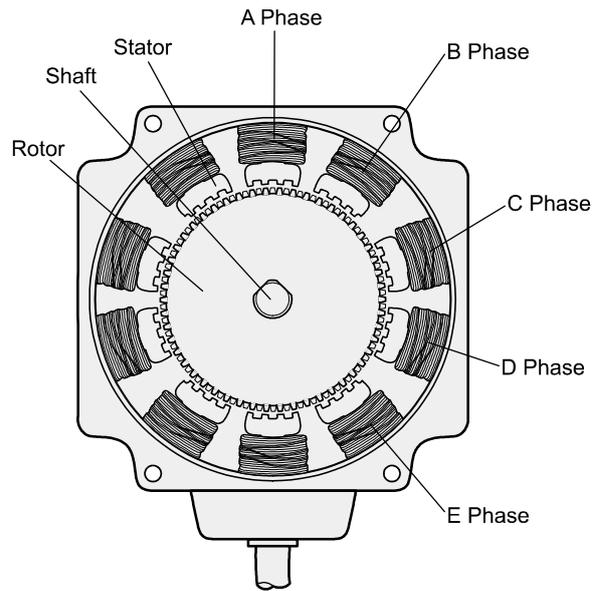
The five-phase hybrid stepper motor is developed with high resolution with no low speed resonance problems. The five-phase stepper can also be classified under permanent magnet hybrid stepper motor. The stator windings are energized in the proper sequencer to produce a rotating magnetic field

which turns the rotor. The significant advantage of the five-phase stepper motor is its excellent torque retention capability at high operating speed. The motor used for implementation is a five-phase hybrid stepper motor and it is shown in figure 1 and figure 2[15]. The figures above show two cross-sections of a 5-phase hybrid stepping motor. Hybrid stepping motors are composed primarily of two parts, the stator and the rotor. The rotor in turn is comprised of three components: rotor 1, rotor 2 and the permanent magnet. The rotors are magnetized in the axial direction, with rotor 1 polarized north and the rotor 2 polarized south. The stator contains 10 magnet poles

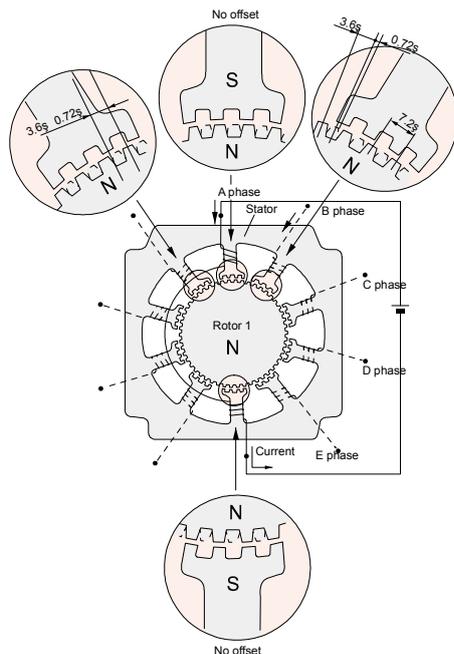
with small teeth, each of which is wrapped in wire to form a coil. The coil is connected to the facing magnet pole and is wound so it becomes magnetized to the small pole when current is run through it. (Running a current through a given coil magnetizes the facing poles to the same magnetism, either North Pole or South Pole.) The two facing poles form a single phase. Since there are five phases, A trough E, the motor is called a 5- phase stepping motor. There are 50 teeth on the outside of the rotor, with the teeth of rotor 1 and rotor 2 mechanically offset from each other by half a tooth pitch.



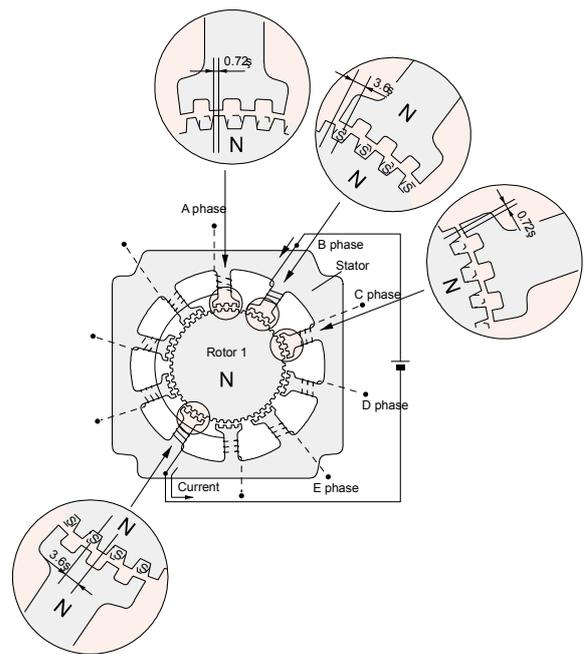
**Fig. 1 - 5 Phase Stepping Motor Cross-Section Parallel to Shaft**



**Fig. 2 - 5 Phase Stepping Motor Cross-Section Perpendicular to Shaft**



**Fig. 3 - When Phase A Is Excited**



**Fig. 4 - When Phase B Is Excited**

Figure 3 and figure 4 help to describe the relationship on the positions of the stator and rotor teeth when magnetized. When phase A is excited, its poles are polarized south. This attracts the teeth of rotor cup 1, which are polarized north, while repelling the teeth of rotor cup 2, which are polarized south. Therefore, the forces on the entire unit in equilibrium hold the rotor stationary. At this time, the teeth of the phase B poles, which are not excited, are misaligned with the south-polarized teeth of rotor 2 so that they are offset at  $0.72^\circ$ . When excitation switches from phase A to B shown in figure 4, the phase B poles are polarized north, attracting the south polarity of rotor 2 and repelling the north polarity of rotor cup 1. In other words, when excitation switches from phase A to B, the rotor rotates by  $0.72^\circ$ . As excitation shifts from phase A to phases B, C, D and E, then back around to phase A, the stepping motor rotates precisely in  $0.72^\circ$  steps. To rotate in reverse, the excitation sequence is reversed as phase A, E, D, C, B, then back to phase A. High resolution of  $0.72^\circ$  is inherent in the mechanical offset between the stator and rotor, accounting for the achievement of precise positioning without the use of an encoder or other sensors [16].

### 3. Constant Current Driving Technology

The driving technology with constant current is shown in figure 5. The constant current drive, on the other hand, is now the most commonly used drive method, since it offers excellent torque performance at high speeds. The stepping motor rotates through the sequential switching of current, flowing through the windings. When the speed increases, the switching rate also becomes faster and the current rise falls, resulting in lost in torque. The chopping of a DC voltage that is far higher than the motor's rated voltage will ensure that the rated current reaches the motor, even at higher speeds. The current flowing to the motor windings, detected as a voltage, through a current detecting resistor, is compared to the reference voltage. Current control is accomplished by holding the switching transistor 2, ON when the voltage across the detecting resistor is lower than the reference voltage. That is when it hasn't reached the rated current or turning transistor 2, OFF. When the value is higher than the reference voltage that is when it exceeds the rated current, thereby providing a constant flow of rated current. [16] Voltage – Current relationship in constant current chopper drive is shown in figure 6.

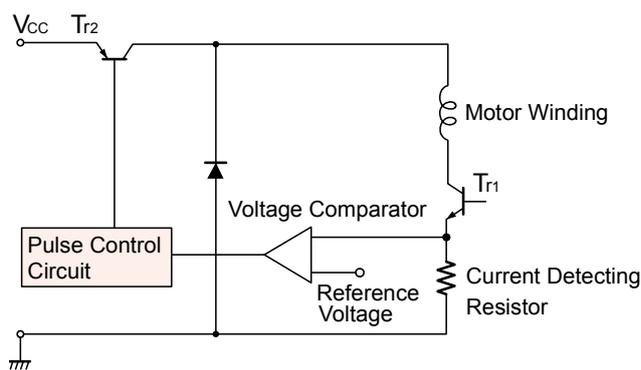


Fig. 5 - Constant current control

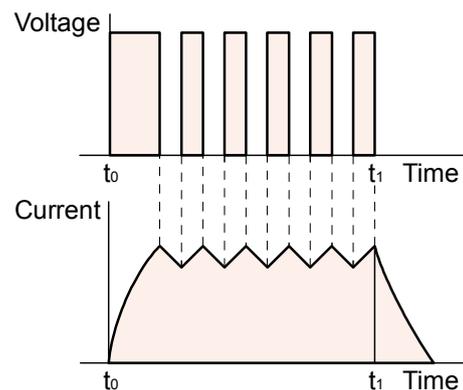


Fig. 6 - Voltage – Current relationship in constant current chopper drive

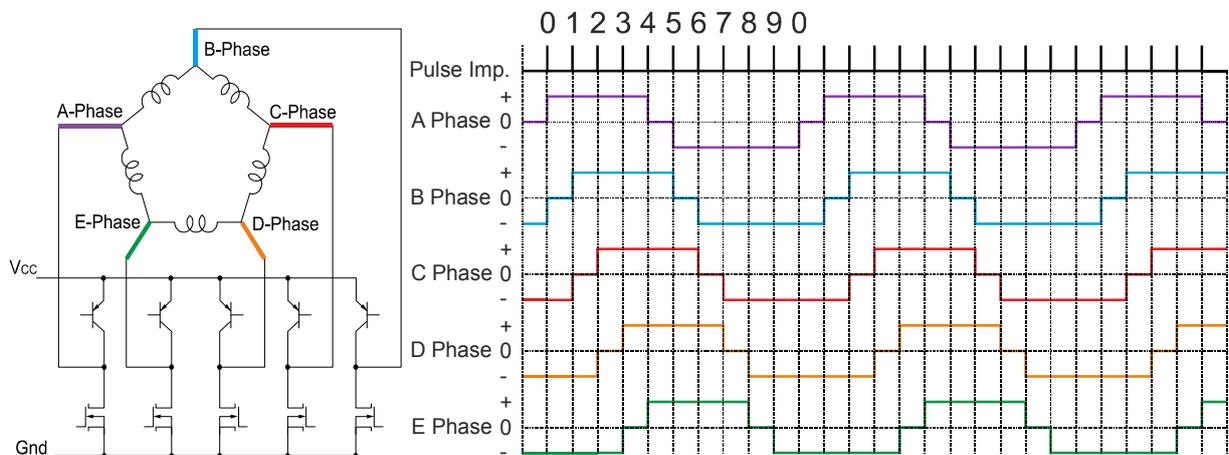


Fig. 7 - Pentagon 4-phase excitation sequence

#### 4. Driving and Controlling Five Phase Stepping Motor

The 5 phase stepper motor control use a simple 4 of 5 phase excitation (pentagon configuration) which employs a simpler and well balanced current control scheme. Pentagon 4-phase excitation sequence (full step – 0.72°/step) is shown in figure 7. This is system to the 0.72° stepper motor, in which four phases are

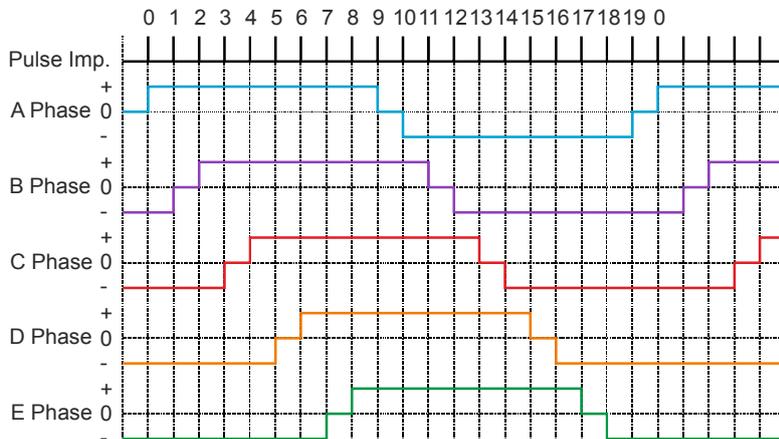


Fig. 8- Pentagon 4-5-phase excitation sequence

The 5 phase stepper motor control use a simple 4 of 5 phase excitation (pentagon configuration) which employs a simpler and well balanced current control scheme. Pentagon 4-phase excitation sequence (full step – 0.72°/step) is shown in figure 7. This is system to the 0.72° stepper motor, in which four phases are excited. The step angle is 0.72°. It offers a great damping effect, and therefore stable operation. Pentagon 4- 5 -phase excitation sequence (half step – 0.36°/step) is shown in figure 8. A step sequence of alternating the 4-phase and 5-phase excitation produces rotation at 0.36° per step. One rotation may be divided into 1000 steps. In a general pentagon driving system, the current flows as shown in figure 9. The relation between  $I_0$  and  $I_{0M}$  is as follows:  $I_0 = 4 \times I_{0M}$ . With some driving system, the relation can also be as follows:  $I_0 = 2 \times I_{0M}$ .

#### 5. Full/Half Stepping Drive System

The typical IC uses P channel MOSFETs to the high side and N channel to the low side of the power bridge circuit used to drive a motor. This configuration allows the pre-drive circuit to employ an equivalent circuit structure represented by figure 10. A typical drive IC composed of a monolithic IC circuit (for current control) and a hybrid IC circuit consists of discrete signal transistors and resistors. The monolithic IC, which controls phase current, uses a bipolar process. It was not reasonable to include a separate middle scale logic circuit to be used for sequencing functions due to its negative characteristics, higher cost and more importantly, its larger size (real estate). Because of this situation, an

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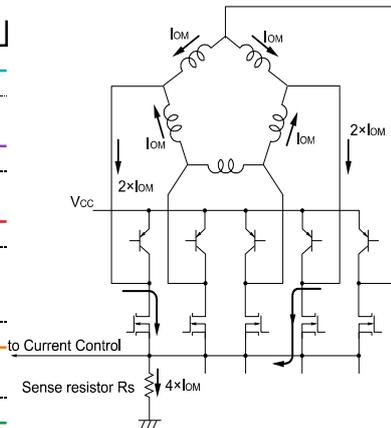


Fig. 9- Coil current flow at pentagon driving

exclusive C-MOS gate array was used for the sequencing control circuitry. The stepper motor driver circuitry consists of four parts as follows:

1. Sequencer (ex. EIC 2033)
2. Pre-driver and current control (ex. EIC 4031)
3. P channel MOS array (ex. EIC 4011)
4. N channel MOS array (ex. EIC 4011)

This drive configuration is the most current 5 phase stepper motor drive currently in use today.

The design procedure of this driver is described detailed as follows. For compact design consideration, a five phase stepping motor driver chips EIC 2033, EIC 4031, EIC 4021, EIC 4011 is adopted. EIC 2033 is a special designed IC that imbedded a function sequence (half/full) circuit to control the pre – driver. (EIC 4031). When this chip receives an input clock, the sequence circuit generates proper phase sequence to drive the output stages. The chip EIC 4031 (pre-driver and current control) operated with current feedback to achieve a constant current driver. A constant current driver can drive a motor according to the winding current of the motor.

EIC 4031 is also equipped with a dedicated circuit to drive gates of P-channel MOSFET's and N- channel MOSFET's so as to simplify the design of driving stages. The configuration of the proposed driver is illustrated in figure 11. EIC 2033 can operate in two different modes, four-phase excitation mode or four-five-phase excitation mode. Four-phase excitation mode or four-five-phase excitation mode are also termed as full step and half step mode respectively. A five phase stepping motor in full/half step mode, can reach the resolution of 500/1000 steps per revolution,

or 0.72/0.36 degrees per step. The resolution can be selected simply with a DIP switch. In a normal condition, the drivers were controlled by two signals termed as clock (CK) and direction (DIR) pulses. In this design, PCL-838 ISA Stepping Motor Control Card PC –LabCard[20] was used to provide a self-test function. The PCL-838 has been specifically designed as user-friendly solution for your stepping motor control application. It's on-board 80C31-CPU, along

with a 16MHz clock crystal, and two 8254 programmable timers, controls up to three driver axis (one motor/channel) independently and simultaneously. Digital pulse and directional output signals control each motor by step rate and clockwise/counter-clockwise (CW/CCW) direction. The hardware implementation of half/full stepping control of five – phase hybrid stepper motor is shown in figure 12.

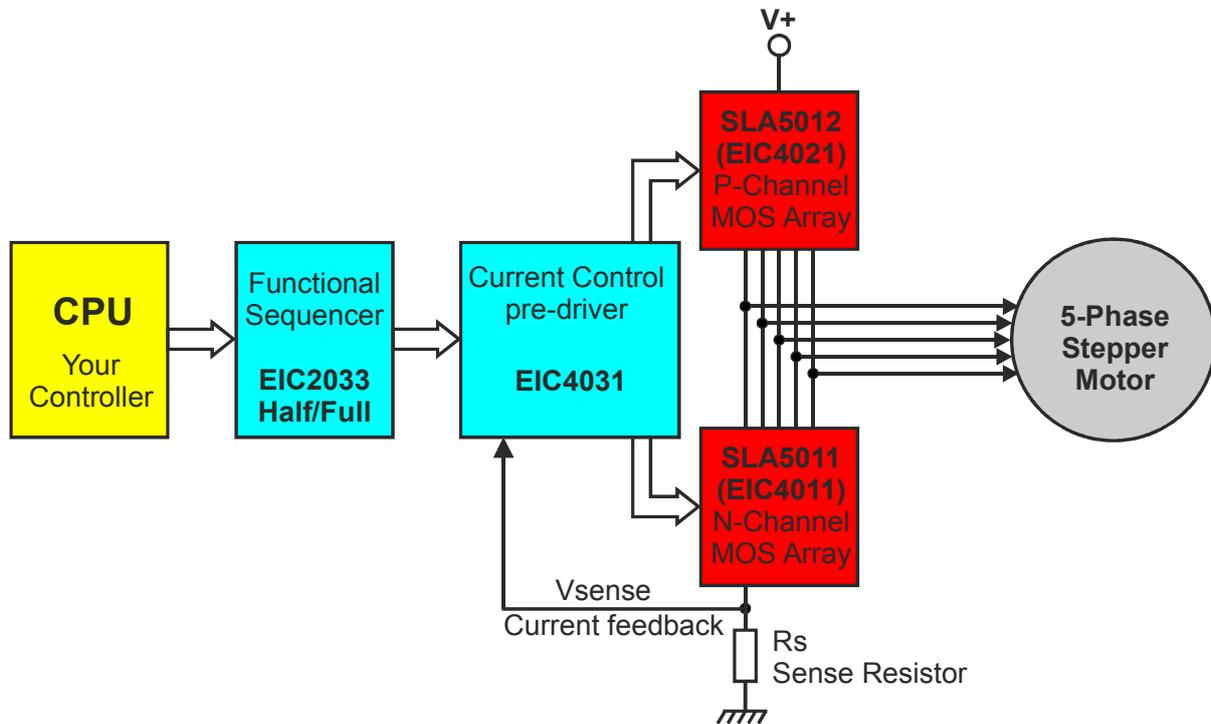


Fig. 10- The block diagram of five-phase stepping motor control

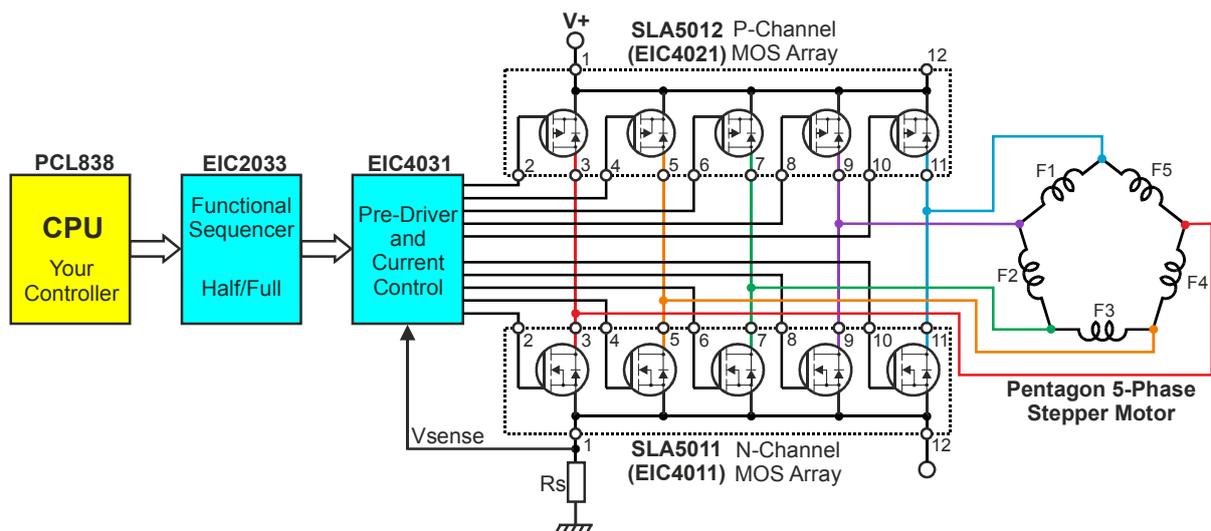
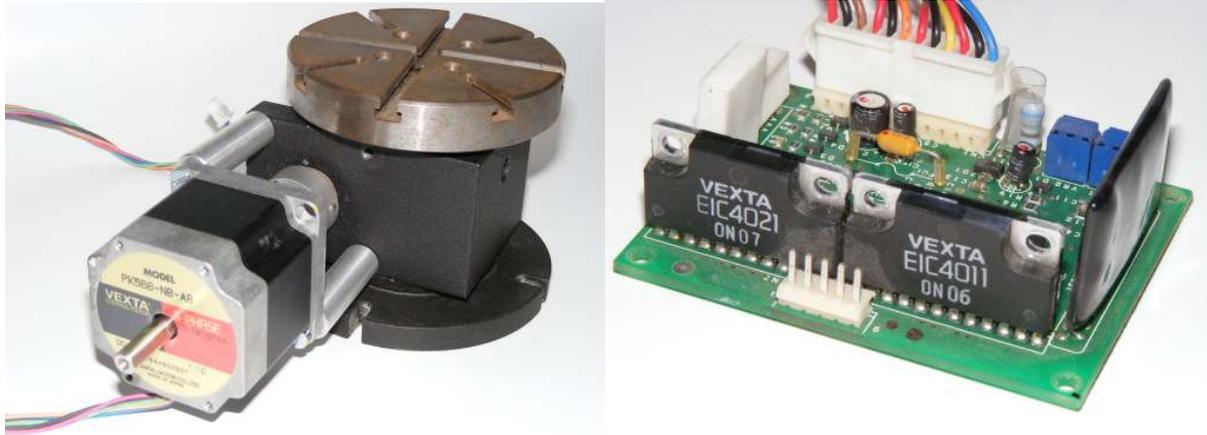


Fig. 11- The configuration of the proposed driver



**Fig. 12- Hardware Implementation**

## 6. Results

The dimension of the driver is approximate 70x65x35 millimeters, which is smaller than a business card in length and width. A positioning card (PCL-838) plugged inside an IBM PC is utilized to test the accuracy and the speed of the driver. For easy implementation, this positioning card was implemented with ISA bus interface. This card output clock and direction signals as inputs to the tested driver. A software package including several functions was designed with C language so as to be feasible to test this driver. The most used function of this package was linear acceleration and deceleration so that the motor may start and stop more smoothly and allow the motor to reach a higher speed that in the case of without acceleration and deceleration. A five – phase stepping motor Model PK566-NB-A8, with a rated current of 1.4A, 1.1 $\Omega$ , from VEXTA ORIENTAL MOTOR, Japan ,was used to connect with this proposed driver. Experimental results demonstrate that the responses can reach 60 kilo pulses per second as driving a five-phase stepping motor with a phase current of 1.4 A. A 60 kilo pulses pulse rate means that the motor can rotate at speed of around 50 revolutions per second when operated in half step mode.

## 7. Conclusion

This paper presents a design of a compact and intelligence five-phase stepping motor drive. With special designed IC, the driver is smaller than a business card. Although it is a compact driver, it can provide a winding current and pulse rate up to 1.4 amperes and 60kpps, respectively. Self – test function also imbedded inside the PCL-838 (80C31-CPU) of the driver so that engineers can check whether the driver is normal or not without a external equipment. Considering the positioning ability and precise speed control, this proposed driver can provide valuable Robotics and Automation Engineering applications involving either position control or speed control.

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