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STUDY ON HIGH CURRENT PWM UNIPOLAR FOUR PHASES DRIVER FOR STEPPER MOTOR CONTROL

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Abstract

This paper presents the study on high – current PWM, unipolar stepper motor controller/driver, are remarkable for simplicity, high – reliability, multifunctional facilities for four phases hybrid stepper motor.

Keywords: stepper motor, PWM control, unipolar stepper driver, dedicated IC.

1. Introduction

The progress of incremental motion control system has been enforced by the multiplicity of their utilization in numerically controlled :X –Y plotters, CNC machines, sewing machines, ATMs, ticket machines, postal sorters, laboratory systems ,medical equipment, peripheral computer equipments, communication through laser and satellites, nuclear techniques, industrial robots, aeronautical and military equipments.

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.
[1][2].

Stepper motor advantages:

- the rotation angle of the motor is proportional to the input pulse;
- the motor has full torque at standard – still (if the windings are energized);
- precise positioning and repeat – ability of movement since good stepper motors have an accuracy of 3 -5 % of a step and this error is non cumulative from one step to the next;
- excellent response to starting / stopping / reversing;
- memorize the position;
- they are compatible with digital technique, the motor response to digital input pulses provides open – loop control, making the motor simpler and less costly to control;
- it is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft;
- a wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses;

To achieve a high speed operating the stepper motor requires complex drive circuits adapted with the motor type. Without performances as: amortization, the maxim run frequency, the maxim dynamic torque, etc., as well as efficiency and power dissipation of the motor depends on the control and supply circuits.

2. The basics of 4 – phase high – resolution hybrid stepping motors

The figure 1 show the motor structure diagram, cross –section parallel to shaft (4 – phase standard – 1.8^{o} per step – hybrid stepping motor). Hybrid stepper 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 rotor 2 polarized south. The stator contains 8 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 is becomes magnetized to the same pole when current is run through. (running a current through a given coil magnetizes the facing poles to the same magnetism, either north pole or south pole). The two facing pole form a single phase. Since there are 4 – phases, A through D, the motor is called a 4 – phase hybrid stepping motor. There ate 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 [14] [15].

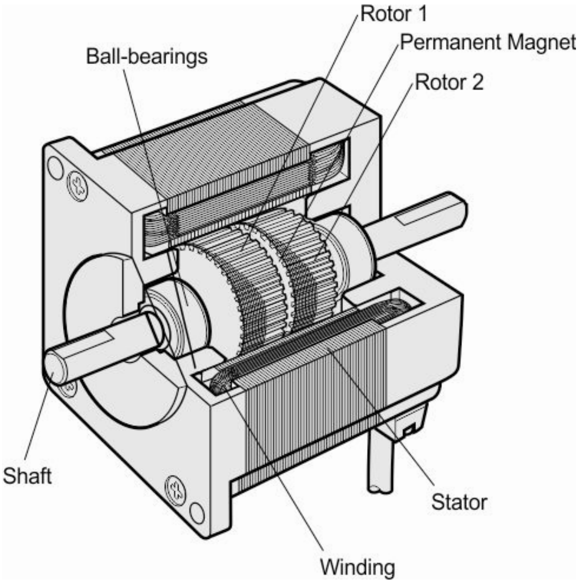

Fig. 1: Motor structure diagram: cross –section parallel to shaft (4 – phase standard – 1.8^o per step – hybrid stepping motor)

The figure 2 show cross – section perpendicular to shaft 94 – phase high – resolution hybrid stepping motor (0.9^o per step). The 4 – phase high – resolution (0.9^o per step) stepping motor has half the step angle of the standard (1.8^o per step) stepping motor. The high – resolution type increases motor resolution from 200 pulses (360^o/ 1.8^o) to 400 pulses (360^o/ 0.9^o). If an even smaller step – angle is needed half – step driving and micro – step driving are other option. Even with the same fundamental structure as the standard stepping motor, doubling the number of rotor teeth (100 rotor teeth) produces high – resolution with 0.9^o per step (400 pulses per revolution).

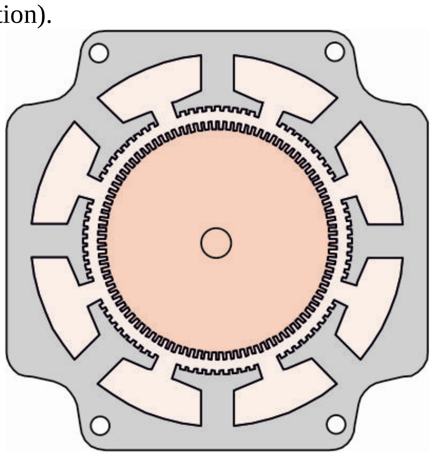

Fig. 2: Motor structure diagram: cross –section perpendicular shaft (4 – phase high-resolution – 0.9^o per step – hybrid stepping motor)

Positioning accuracy (show in figure 3) is important, especially in bi – directional positioning. The high – resolution stepper motor (0.9^o per step) has higher positioning accuracy than the standard stepping motor 1.8^o per step).

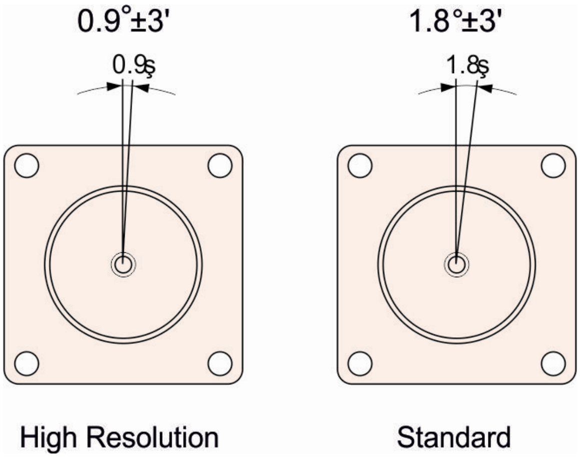

Fig. 3: Improved positional accuracy

3. Pulse distributors

Pulse distributors are circuits which provide at the outputs pulse trains to control the motors corresponding with the input pulse frequency, direction and the chosen operating mode. To energize the motor phases this output pulses are passed through a driver circuit. The pulse distributor, shown in figure 4 is based on a PROM (MH74188) controlled by a reversible binary counter MMC4029[2][12] [13] The motor-step control is achieved by the appropriate memory programming corresponding to the three operating mode (see Table1).

4. The 4 – phase driver

The schematic diagram of driver for 4 phase stepping motor control is shown in figure 5.
The SLA 7024 M[17][19] driver, drive the 4 phase stepper motor in output current ratings max. 1.5 A. The SLA 7024 M are designed for high – efficiency and high – performance operation of 4 phase unipolar stepper motor. An automated, innovative packaging technology combined with power FETs and monolithic logic/control circuitry advances power multi-chip modules. PWM current is regulated by appropriately choosing current – sensing resistors, a voltage reference, a voltage divider, and RC timing networks. The RC components limit the OFF interval and control current decay . Inputs are compatible with 5 V logic and microprocessors.
The output current (and motor coil current) waveform is illustrated in figure 6. Setting the PWM current trip point requires various external components:
V_b = Reference supply (typically 5V)
R_1, R_2 = Voltage – divider resistors in the reference supply circuit
R_S = Current sensing resistor (s)

Table 1: memory programming

	E	D	C	B	A	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	
4S	0	0	0	0	0	1	0	0	0	1	0	0	0	F1
	0	0	0	0	1	0	1	0	0	0	1	0	0	F2
	0	0	0	1	0	0	0	1	0	0	0	1	0	F3
	0	0	0	1	1	0	0	0	1	0	0	0	1	F4
	0	0	1	0	0	1	0	0	0	1	0	0	0	F1
	0	0	1	0	1	0	1	0	0	0	1	0	0	F2
	0	0	1	1	0	0	0	1	0	0	0	1	0	F3
	0	0	1	1	1	0	0	0	1	0	0	0	1	F4
4D	0	1	0	0	0	1	1	0	0	1	1	0	0	F1F2
	0	1	0	0	1	0	1	1	0	0	1	1	0	F2F2
	0	1	0	1	0	0	0	1	1	0	0	1	1	F3F4
	0	1	0	1	1	1	0	0	1	1	0	0	1	F4F2
	0	1	1	0	0	1	1	0	0	1	1	0	0	F1F2
	0	1	1	0	1	0	1	1	0	0	1	1	0	F2F3
	0	1	1	1	0	0	0	1	1	0	0	1	1	F3F4
	0	1	1	1	1	1	0	0	1	1	0	0	1	F4F2
8M	1	0	0	0	0	1	0	0	0	1	0	0	0	F1
	1	0	0	0	1	1	1	0	0	1	1	0	0	F1F2
	1	0	0	1	0	0	1	0	0	0	1	0	0	F2
	1	0	0	1	1	0	1	1	0	0	1	1	0	F2F3
	1	0	1	0	0	0	0	1	0	0	0	1	0	F3
	1	0	1	0	1	0	0	1	1	0	0	1	1	F3F4
	1	0	1	1	0	0	0	0	1	0	0	0	1	F4
	1	0	1	1	1	1	0	0	1	1	0	0	1	F4F2

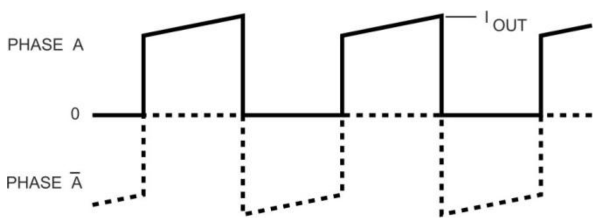

Fig.6: Phase a coil current waveform

I_{OUT} is set to meet the specified running current for the motor (Figure 7) and is determined by:

$$I_{OUT} = \frac{V_{REF}}{R_S} \tag{1}$$

or, if V_{REF} is not known

$$I_{OUT} = \frac{R_2}{R_1 + R_2} \bullet \frac{V_b}{R_S} \tag{2}$$

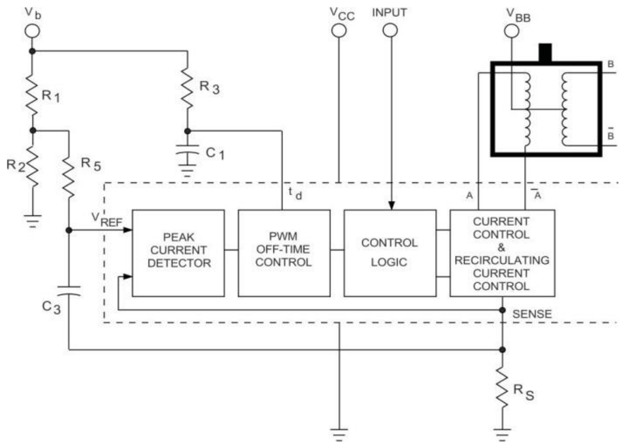

Fig.7: PWM control (run mode)

Reduced/ Hold current Mode: additional circuitry (Figure 8) enables reducing motor current. The external transistor changes the voltage – divider ratio, V_{REF} , and reduces the output current. I_{HOLD} is determined by resistors R_2 and R_X in parallel:

$$I_{HOLD} = \frac{R_2 R_X}{R_1 R_2 + R_1 R_X + R_2 R_X} \bullet \frac{V_b}{R_S} \qquad (3)$$

$$I_{HOLD} = \frac{R_2^{'}}{R_1 + R_2^{'}} \bullet \frac{V_b}{R_S} \qquad (4)$$

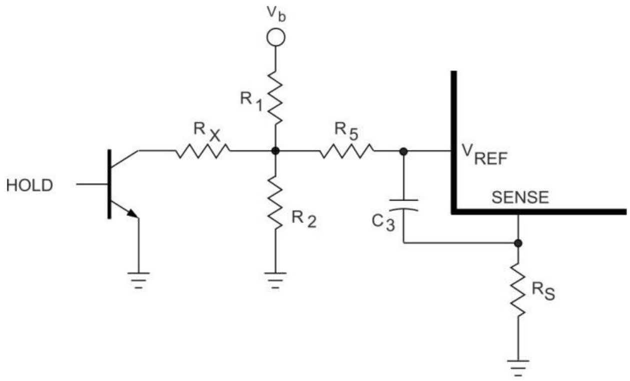

Fig. 8: Holde curent mode

General view of the hardware implementation is shown in Figure 9.

5. Results

The dimension of the driver is approximate 1000x15000x35 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 4 – phase hybrid stepping motor Model HY 1001613050 A6, SK 1642, made in Italy , with a rated current of 1.2 A, 1.1Ω, 0.9^0 was used to connect with this proposed driver. Experimental results demonstrate that the responses can reach 30 kilo pulses per second as driving a five-phase stepping motor with a phase current of 124 A. A 30 kilo pulses pulse rate means that the motor can rotate at speed of around 40 revolutions per second when operated in half step mode.

6. Conclusion

This paper presents a design of a compact and intelligence 4 - 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 1.2 amperes and 0kpps, respectively. Self – test function also imbedded inside the PCL-838 (80C31-CPU)[20] 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.

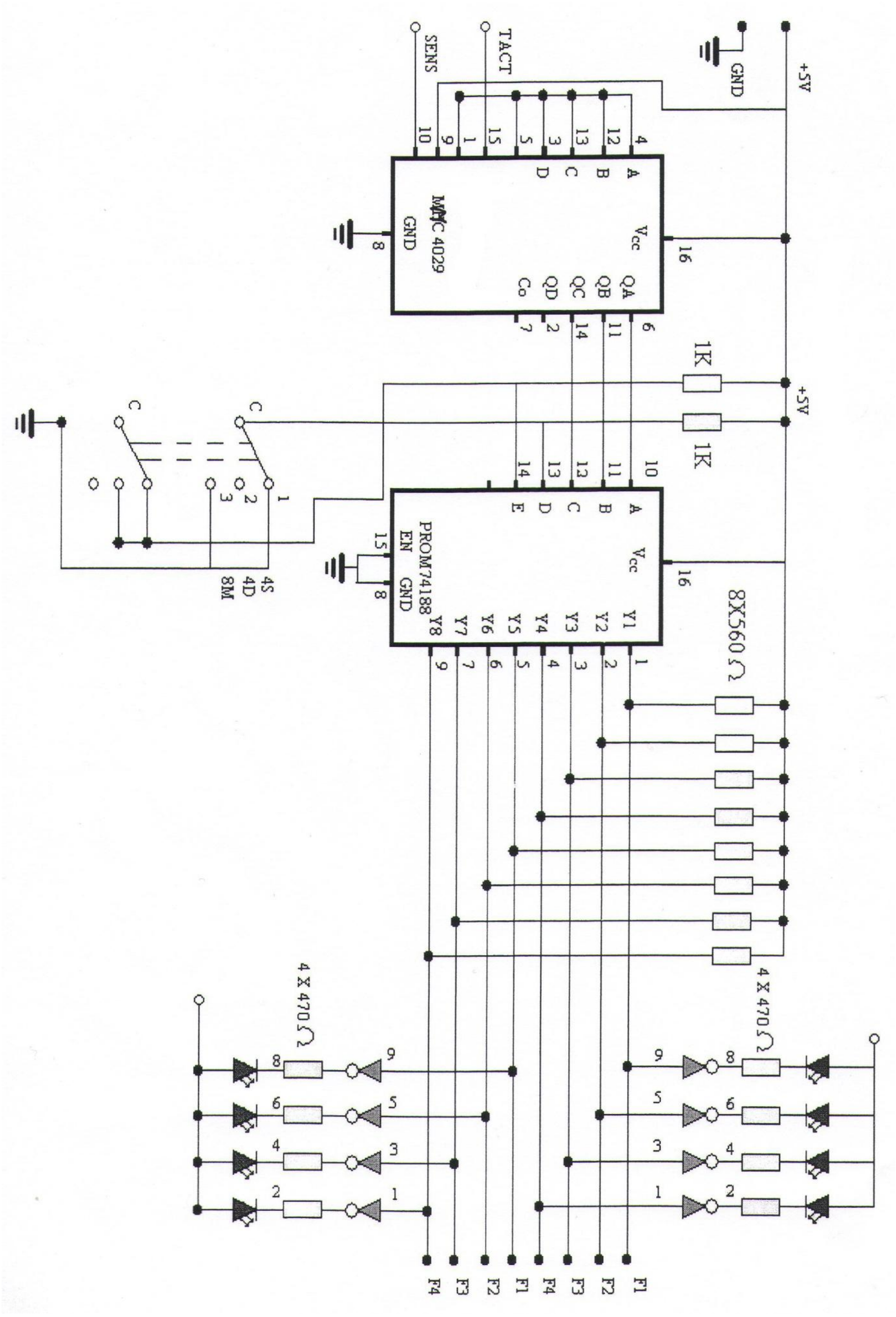

Fig. 4: Pulse generator based on a PROM MH 74188 memory

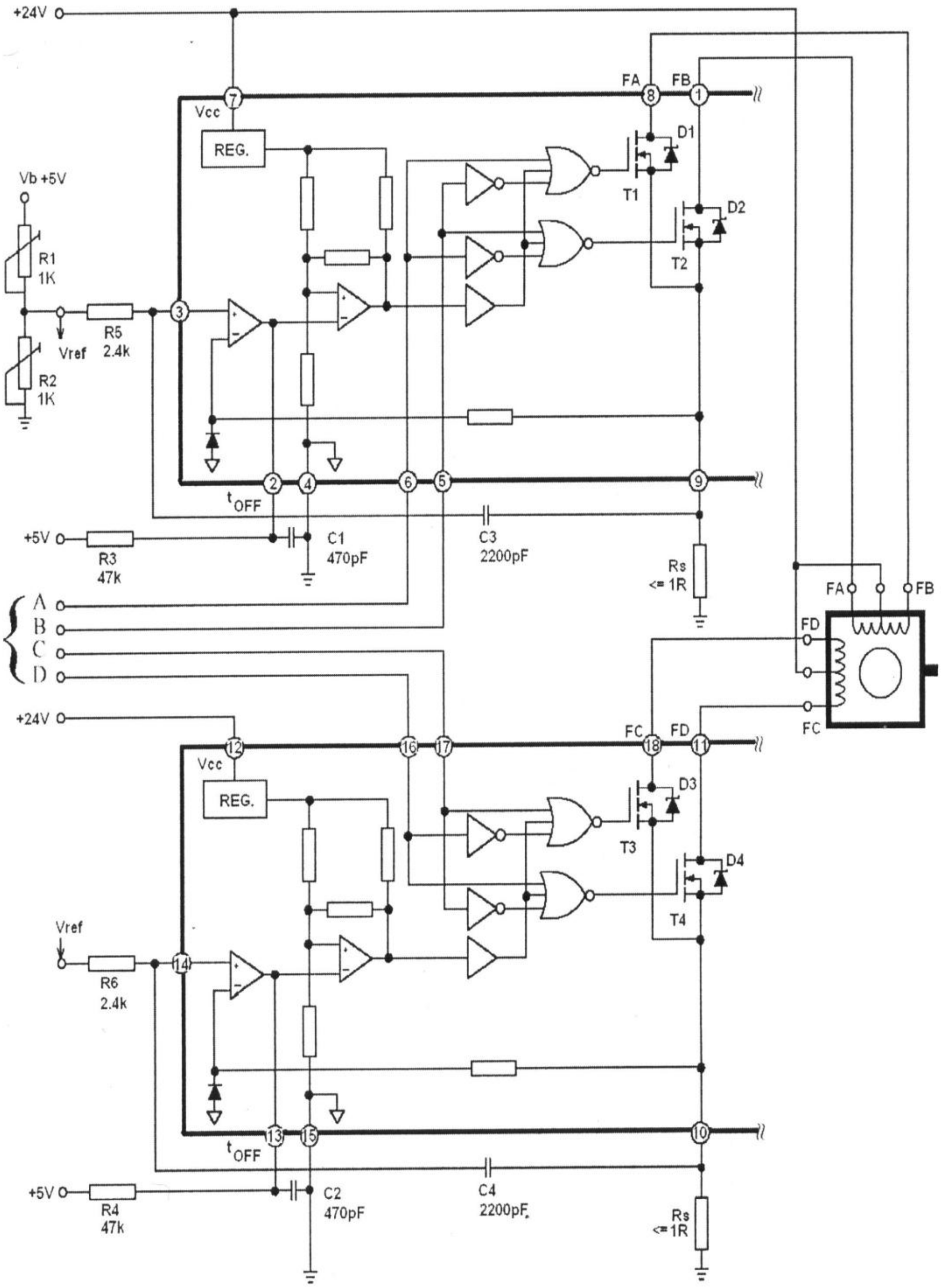

Fig. 5 : Schematic diagram of driver

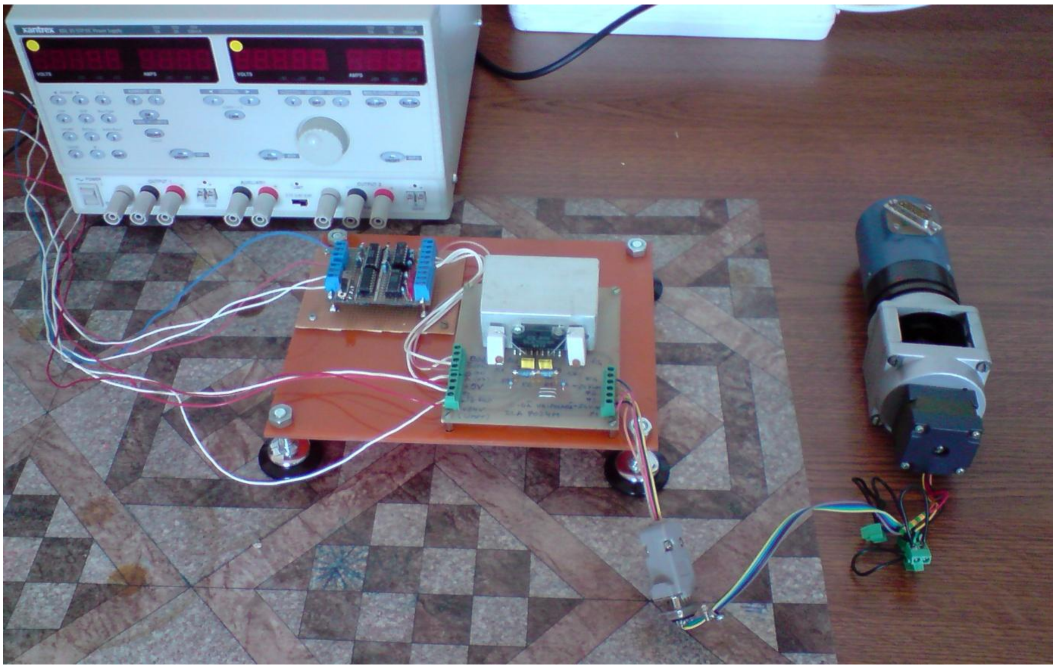

Fig. 9:General view of the hardware implementation

References

[1] T. Kenjo and A. Sugawara, S*tepping Motors and Microprocessor Control*, London, Oxford Clarendon Press, 2003.

[2] Acarnley, P.P., *Stepping Motors: a Guide to Modern Theory and Practice*. Peter Peregrinus Ltd.,ISBN: 0 86 341027 8, London, 1992.

[3] Takasaki, K., Sugawara, A., Stepping *Motors and Their Microprocessor Controls*. Clarendon Prsss, ISBN: 019859386 4 hbk, Oxford, 1994.

[4] Morar, A., *Sisteme electronice de comandă şi alimentare a motoarelor pas cu pas implementate pe calculatoare pesonale (Electronic systems for stepping motor control implemented on personal computer)* Teză de doctorat, Universitatea Tehnică din Cluj-Napoca, 2001.

[5] Morar, A., *Comanda inteligenta a actionarilor electrice cu motoare pas cu pas*, Editura MEDIAMIRA, Cluj-Napoca, 2007.

[6] Marc Botson, Jeffrey S. Sat and Stephen R. Silver, *Spontaneous Speed Reversals in Stepper Motor*,IEEE Trans. Control Systems Technology, vol. 14, No. 2, pp. 369-373, Mar. 2006.

[7] J. McGuiness and Berger Lahr, *Advantages of Five Phase Motors in Microstepping Drive*, in Proc. 1994 IEE Colloquium on Stepper Motors and Their Control.

[8] A. Bellini, C. Concari, G. Franceschini, and A. Toscani, *Mixed-Mode PWM for High-performance Stepping Motors,* IEE Trans. Industrial Electronics, vol. 54, No. 6, pp. 3167-3177, Dec. 2007.

[9] T. S. Weerakoon and L. Samaranayake, *Development of a Novel Drive Topology for a Five Phase Stepper Motor,* In Proc. 2008 IEEE Industrial and Information Systems Conf., pp.1-6.

[10] Puran Adhikari and Michael Okaro, *Five-level Five-phase PWM Signal Generation using FPGA,* IEE Trans. Industrial Electronics, vol. 55, No. 5, pp. 1-5, May, 2008.

[11] Berrezzek Farid, Omeiri Amar, *A Study of New Techniques of Controlled PWM Inverters,* European Journal of Scientific Research, Vol. 32 No. 1, 2009, pp.77-87.

[12] Shyh-Ming Jong, Shun-Te Siao, Yuan Kang, *An Implementation of FPGA Based Driver For approaching High Resolution of Five-phase Hibrid Stepper Motor*,Machine Learning and Cybernetics (ICMLC), 2010 International Conference, vol. 5, July 2010, pp.2543-2548.

[13] Baluta, Gh., *Actionari electrice de mica putere-Aplicatii*, Editura POLITEHNIUM, Iasi, 2004.

[14] *** *The Basics of Stepping Motors*, Oriental Motor Co.Ltd, Japan, 2010.

[15] *** *Application Guides of Step Motor,* Oriental Motor Co.Ltd, Japan, 2010.

[16] *** Oriental *Motor-Stepping Motors-General Catalog-2012/2013.*

[17] *** *STMicroelectronics, Motion Control Application Manual*, 2010.

[18] *** *LEM Module,* Data Book, Geneve, Switzerland, 2010

[19] *** Portescap: “*Motion Systems*”, 2011.

[20] *** PCL – 838 Stepping Motor Control Card,, PC – Lab Card Series Laboratory Manual, 2008.