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An Improved Driving Circuit with TIP41C and TIP42C Transistors to Speed Up Operation of PCB Machine

Abstract: *This paper presents design of a new driving circuit for the PCB machine in use at our Control and Instrumentation Lab. The new driving circuit is constructed with TIP41C and TIP42C transistors in order to overcome speed limitation of the previously developed relay based driving circuit. The improved driving circuit successfully operated the PCB machine and speeded up its operation by almost 4 times. Along with an image processing algorithm we have also developed during this study, the PCB machine is now able to get schematic file of a circuit as an input and perform complete trace line drawing and hole drilling of the schematic onto a PCB card with almost no human intervention in between. An example PCB card processed by the machine is demonstrated at the end of the paper.*

Streszczenie. *W artykule opisano projekt nowego układu sterowania dla maszyny PCB. Nowy obwód, oparty na tranzystorach TIP41C oraz TIP42C, eliminuje ograniczenia szybkości, występujące w poprzednio zaprojektowanych systemie. Zbudowany system zapewnia wysoki stopień automatyzacji, w większości eliminując działania człowieka.* ***(Ulepszony układ sterowania maszyny PCB dla zwiększenia szybkości pracy, oparty na tranzystorach TIP41C i TIP42C).***

Key Words: PCB Machine, Driving Circuit, Trace Line Drawing, Hole Drilling.
Słowa kluczowe: maszyna PCB, układ sterowania, rysowanie po śladach, wiercenie otworów.

Introduction

In our previous work, we had demonstrated development of a PCB machine that was able to draw trace lines and drill holes on a PCB card [1]. The driving circuit that ran mechanical parts of the PCB machine was constructed with relays. We had mentioned that due to constructional limitations of relays, we could not operate the machine above a certain speed. The speed of the machine was determined by pulses sent from the driving circuit to two bipolar step motors placed on the PCB machine. In our previous work, the optimal operating speed of the PCB machine was obtained by sending pulses of length 14 msec to the bipolar step motors. This value was determined experimentally. When pulse length of less than 14 msec was used, the step motor did not work properly, i.e. either too much sound, vibrations or other disturbances were observed while the machine was working. These disturbances were raised due to switching mechanism of relays. As it is well known, the mechanical part that causes to relay to switch on and off is made of a coil. When sufficient amount of current is passed through the coil, the electromagnetic force created by the current causes the relay's normally open contact to move to a closed position or a normally closed contact to move to an open position. When the current is cut off, the electromagnetic force vanishes and the relay's contact comes back to it's initial position. In our previous work, we had shown that the time that it takes for the relay's contact to switch back and forth when it is stimulated is large for operation of the PCB machine and causes it to work slowly. For example, the relay based driving circuit was not able to respond pulse lengths of less 4 msec due to the limitation mentioned above.

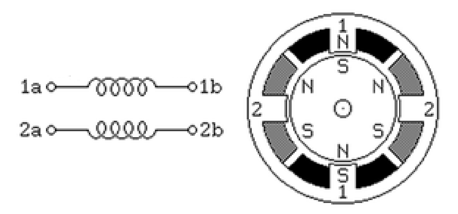
Goals of this study

This study involves improving operation of a PCB drawing and drilling system at our lab. The study involves two parts. In the first part, we'll develop a faster and more robust driving circuit than the one we had developed in our earlier work. In the second part of this study, we'll develop an image processing program which processes schematic file of a circuit to extract edge coordinates of trace lines and center point of pads and puts them into a Microsoft Excel file. After these two additions, the PCB machine will be able to automatically draw a schematic file onto a PCB card along with drilling a hole at center of pads with almost no human intervention.

Method

The PCB machine at our lab has 2 bipolar step motors, and 2 DC motors. Step motors are responsible to move the machine in X and Y coordinates. The first DC motor runs the drill and the second one actuates —the electromagnet. The electromagnet moves the drill in up or down directions. The job of the driving circuit is to control/run these four electrical motors in order to draw trace lines and drill holes on a PCB card as well as to communicate with host computer to perform data exchange.

An ideal bipolar step motor is modeled with two coil windings. In practice, the internal resistance of each coil windings is also taken into consideration. One pass over two windings involves 4 steps. These steps are obtained by stimulating 4 terminals of the motor in an exact order. The Figure 1 demonstrates a bipolar step motor model and 4 steps needed to run the motor.



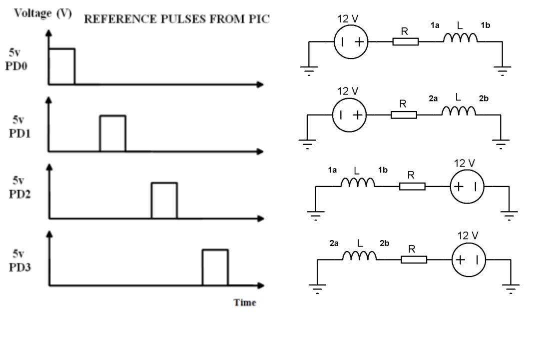
(a)

	1a	2a	1b	2b
STEP 1	1	0	0	0
STEP 2	0	1	0	0
STEP 3	0	0	1	0
STEP 4	0	0	0	1

(b)

Fig 1(a). An ideal bipolar step motor model. (b) The order of 4 steps needed to run the motor.

The steps given in the Figure 1b are merely reference pulses that specify the order and the direction of the voltage requirements that has to be supplied to terminals of the motor. It is the job of the driving circuit to receive these reference pulses and translate them into adequate voltage signals with correct polarities. The Figure 2 shows actual voltage requirements that need to be formed at terminals of the bipolar step motor based on reference signals sent from PDO, PD1, PD2 and PD3 pins of a PIC 18F452.



(a) (b)

Fig 2(a). Reference signals sent from microcontroller. (b) Voltage requirements that need to be generated at windings of the bipolar step motor corresponding to reference signals in (a).

In order to provide voltage requirements specified in the Figure 2b to the terminals of the motor, we have developed a circuit consist of one TIP41C, two TIP42C transistors and a resistor [3,4]. The circuit can be considered as current amplification circuit where the small amount of current supplied from a pin of a microcontroller is to provide high amount of current to a motor winding (connected to between 1a and 1b terminals). In addition to that, the amplifier circuit is put into on or off state by the transistor labeled as T2. The Figure 3 shows the schematic of the current amplifier circuit.

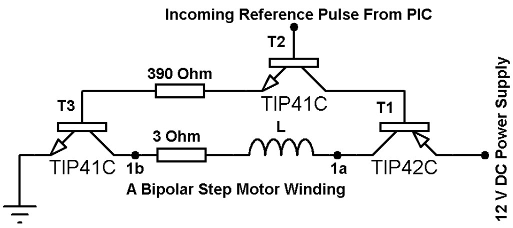


Fig 3. The schematic file of the current amplifier circuit.

The step motors we used have around 3 ohm internal resistances on their each winding. To run the motor, 12 V voltages are applied to the amplifier's input with 10 ohm high power resistances. RD0 pin of a PIC 18F452 is connected to the base of T2 transistor. A reference pulse on this pin causes both T1 and T3 transistors to operate in the saturation region while the T1 transistor is operating in the active region. Hence on the lower path, VT1EC (voltage drop in between emitter and collector terminals of T1 transistor) and VT3CE (voltage drop in between collector and emitter terminals of T3 transistor) voltages are almost zero. This result in all the voltages applied from 12V power supply to appear on terminals of the motor winding which are denoted as 1a and 1b in the Figure 3. The torque generated at the motor shaft in this case will be at highest peak.

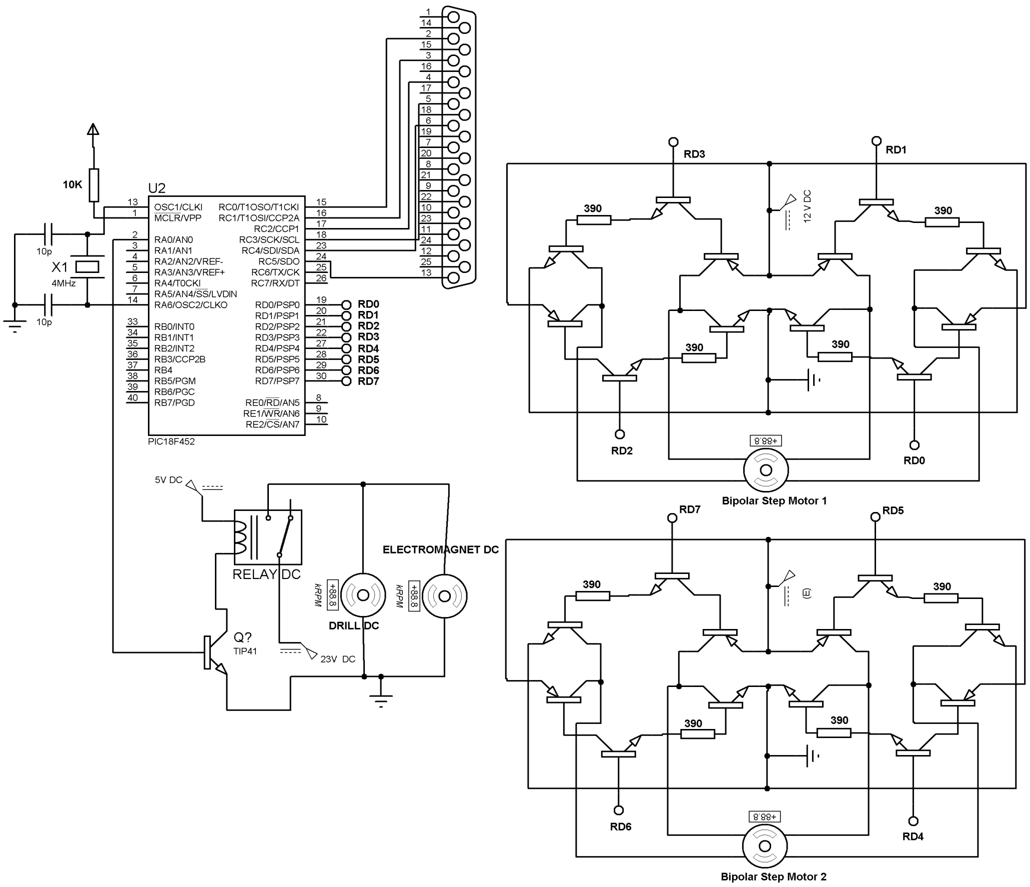
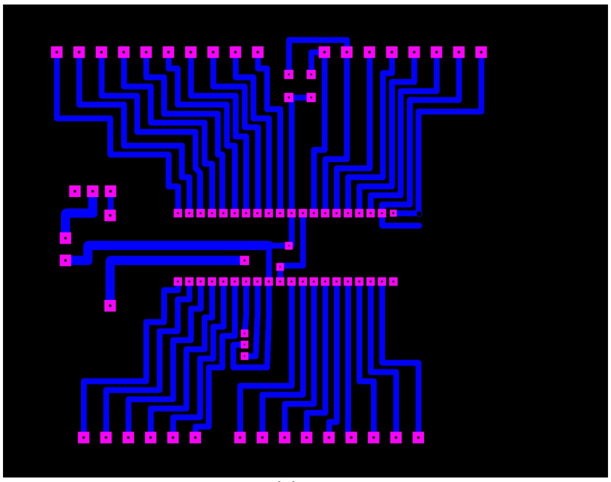


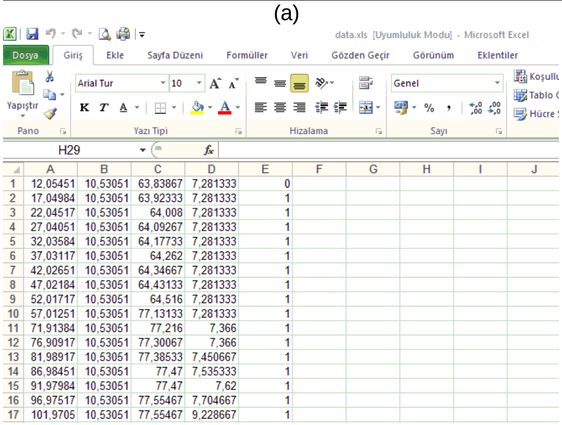
Fig 4. The schematic file of the new driving circuit.

An image processing algorithm

We have also developed an image processing algorithm for our PCB machine using Matlab [2,3]. The algorithm takes a schematic file of a circuit, processes it to extract coordinates of edges of trace lines and center point of pads and puts them in an Excel file. An example schematic file and corresponding Excel file generated by our image processing algorithm is given in the Figure 5.



(a)



	A	B	C	D	E
1	12,05451	10,53051	63,83867	7,281333	0
2	17,04984	10,53051	63,92333	7,281333	1
3	22,04517	10,53051	64,008	7,281333	1
4	27,04051	10,53051	64,09267	7,281333	1
5	32,03584	10,53051	64,17733	7,281333	1
6	37,03117	10,53051	64,262	7,281333	1
7	42,02651	10,53051	64,34667	7,281333	1
8	47,02184	10,53051	64,43133	7,281333	1
9	52,01717	10,53051	64,516	7,281333	1
10	57,01251	10,53051	77,13133	7,281333	1
11	71,91384	10,53051	77,216	7,366	1
12	76,90917	10,53051	77,30067	7,366	1
13	81,98917	10,53051	77,38533	7,450667	1
14	86,98451	10,53051	77,47	7,535333	1
15	91,97984	10,53051	77,47	7,62	1
16	96,97517	10,53051	77,55467	7,704667	1
17	101,9705	10,53051	77,55467	9,228667	1

(b)

Fig 5(a). A bitmap image of a schematic file. (b) it's corresponding Microsoft Excel file generated by the Matlab.

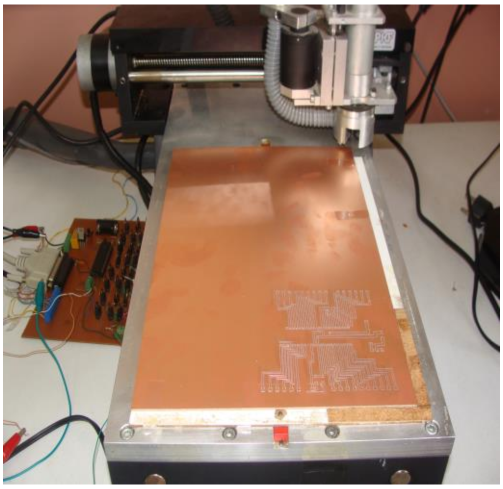
Channels: Volt / Div = 5V ; Time / Div = 5 msec

Fig 6. Pulses sent from PDO pin of the PIC and terminal voltages of corresponding motor winding.

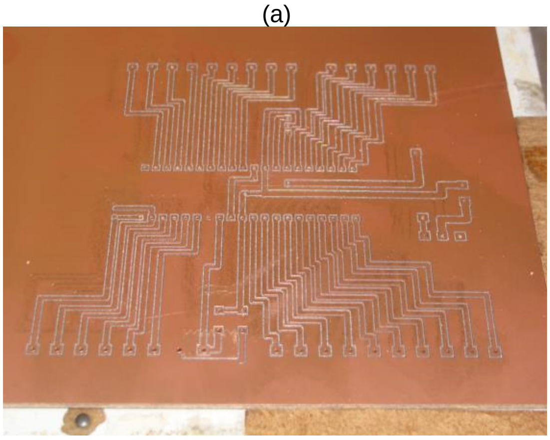
Results

The new driving circuit successfully ran our PCB machine. The overall speed of the PCB machine is improved up almost 4 times. In our previous work, we had demonstrated that, the relay based driving circuit responds to the reference pulses sent from microcontroller with almost 4 msec delay. To show that the new driving circuit successfully generates 12V voltages on motor windings based on reference signals with almost no delay, we give oscilloscope measurements from actual PCB card for the signal from PDO pin of the PIC and the voltage on the corresponding step motor winding in the Figure 6. The signal for step motor winding is measured from its terminal to ground.

As it is seen from the Figure 6, the new driving circuit successfully generates 12 V signal at terminals of a step motor winding when 5V reference pulse is supplied from the micro controller. The response of the driving circuit to the reference pulse is seen to be very fast. There is almost no delay in between starting point of 5V pulse from PD0 pin and 12 V voltages on the motor winding. Similarly, as soon as the 5V pulse ends, driving circuit immediately removes 12 V signal form terminals of the motor winding.



(a)



(b)

Fig 7. Two pictures of a PCB card processed by the PCB machine.

Another point, we experimented on the new driving circuit was that how fast we could run our PCB machine with it. This is directly related to the pulse lengths sent from PORTD<0-3> pins of the PIC. We have experimented on 3 different values of pulse lengths. These were 1 msec, 2 msec and 3.25 msec. When we supplied pulse length of 1msec, step motors were not able to move the head on which the drill and electromagnet connected on top of it. When 2 msec pulse length was used a, step motors moved the head very fast, but the torque obtained was not very strong, i.e. we were able to stop the head with a small force with our hand while it is moving along X-Y directions. When 3.25 msec pulse length was applied, step motors moved the head almost 4 times faster than the speed obtained by the previous driving circuit as well as provided adequately strong torch for operation of the drill.

The PCB machine we have developed is currently in use at our Control and Instrumentation lab. After embedding the new driving circuit, it's speed is now adequately fast to be used in real time applications. The Figure 7 shows an example of such a processed PCB card. For this card it took 35 minutes for the PCB machine to finish up all tracing and drilling of the card.

The width of a trace line that can be drawn on a PCB by our machine is determined by the bit of the drill. To process the above card, we have used a bit with 1 mm in diameter. Using thicker bits avoids drawing thin trace lines. On the other hand, using thinner bits has drawback of being broken during operation.

Conclusion

We have designed and implemented a new driving circuit for the PCB machine in use at our Control and Instrumentation lab. The new driving circuit is constructed with TIP41C and TIP42C transistors and accelerated the operation of the PCB machine by almost 4 times as compared to its previous speed. We have also developed an image processing algorithm that is able to find coordinates of edges of trace lines and mid-point of pads in a schematic file. The PCB machine at our lab is now able to get a schematic file as an input and generate complete drawing and drilling of a PCB card with almost no human intervention in between. The only human intervention to the process is an adjustment of the height of the drill which is easily done in seconds. The adjustment is needed because the height of the drill bit has to be at a pre-specified higher position for drawing and at a pre-specified lower position for the drilling. In our future studies, we'll continue to work on improving the PCB machine's operation in both hardware and software aspects.

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