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ENSC387: Introduction to Electromechanical Sensors and Actuators

LAB 4: STEPPER MOTORS

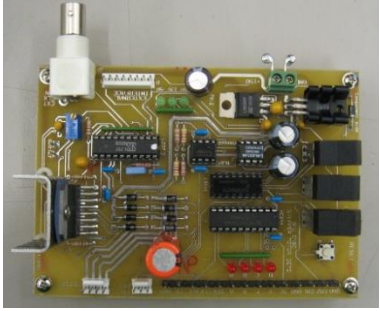





DATE DUE: REFER TO COURSE WEBPAGE OR CANVAS AS DIRECTED BY YOUR INSTRUCTOR

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1 Objective

Through this lab you will become familiar with the functionality of stepper motors. You will observe full stepping and half stepping in both static and dynamic conditions of various motors.

2 Required Materials

Description	Photo	Description	Photo
Stepper Motor Demo CKT board		Inertial Load (for KP4M4 motor)	
Stepper Motor (marked KP4M4)		Test Cables BNC to BNC and BNC-Seizer	
Thompson-Airpax LB82763 Stepper Motor with feedback pot (c/w hex key)		Wavetek Model 19 or Model 182A (Push-button Range Select) Function Generator	 Power switch is located at rear

- It is assumed that the assigned workstation for this experiment is equipped with the standard complement of test equipment. You will need the power supply and oscilloscope.

3 Introduction

Stepper motors are an attractive solution for precise position control. Thanks to modern microcontrollers, good accuracy, complicated patterns, and quick operation are possible and inexpensive to implement. High torque can be obtained at low speeds. Usually, all these merits surpass several limitations including problems with oscillations and decreased torque at higher rotational speeds. This lab introduces stepper motors and some characteristics inherent to their control, namely resonance frequency and reduced torque with increased speed, both of which make open-loop control difficult when high performance is required.

Controlling stepper motors is performed by simply energizing, in a proper sequence, the various stator pole windings (phases). Sometimes the polarity of the energizing current must be specified as well. Some stepper motors use bifilar windings on the stator poles to simplify the hardware drive circuitry required to alter the polarity of the energizing current. Bifilar motors use a center-tapped winding on each pole so that if the centre-tap is tied to +V, grounding (through a pull-down transistor) opposite ends of the winding, the polarity of the energizing current can be controlled. Therefore, a bifilar stator pole has 3 wires per winding. Unifilar motors have a single winding per pole which should be excited by a bipolar supply – normally achieved via an "H-Bridge" circuit with the motor winding appearing as the cross-bar in the "H". Thus, a unifilar stator pole has 2 wires per winding only.

To simplify the sequencing of the motor windings (and eliminate the possibility of damaging the driver circuitry from mis-sequencing), this experiment uses an L297 stepper motor controller chip and an L298 H-Bridge driver, mounted on a demo board (Figure 1). The controller chip converts direction and step pulses into the four control signals required by the driver. Please note that the L297 will drive either bifilar or unifilar motors, but the L298 is compatible with unifilar windings only.

The datasheets of both the STMicroelectronics L297 and L298 ICs as well as other related lab support documents can be found in the 387 course support folder on the Lab1 Computers:

Lab1 Computers > Windows Desktop > Reference Materials > Course Specific

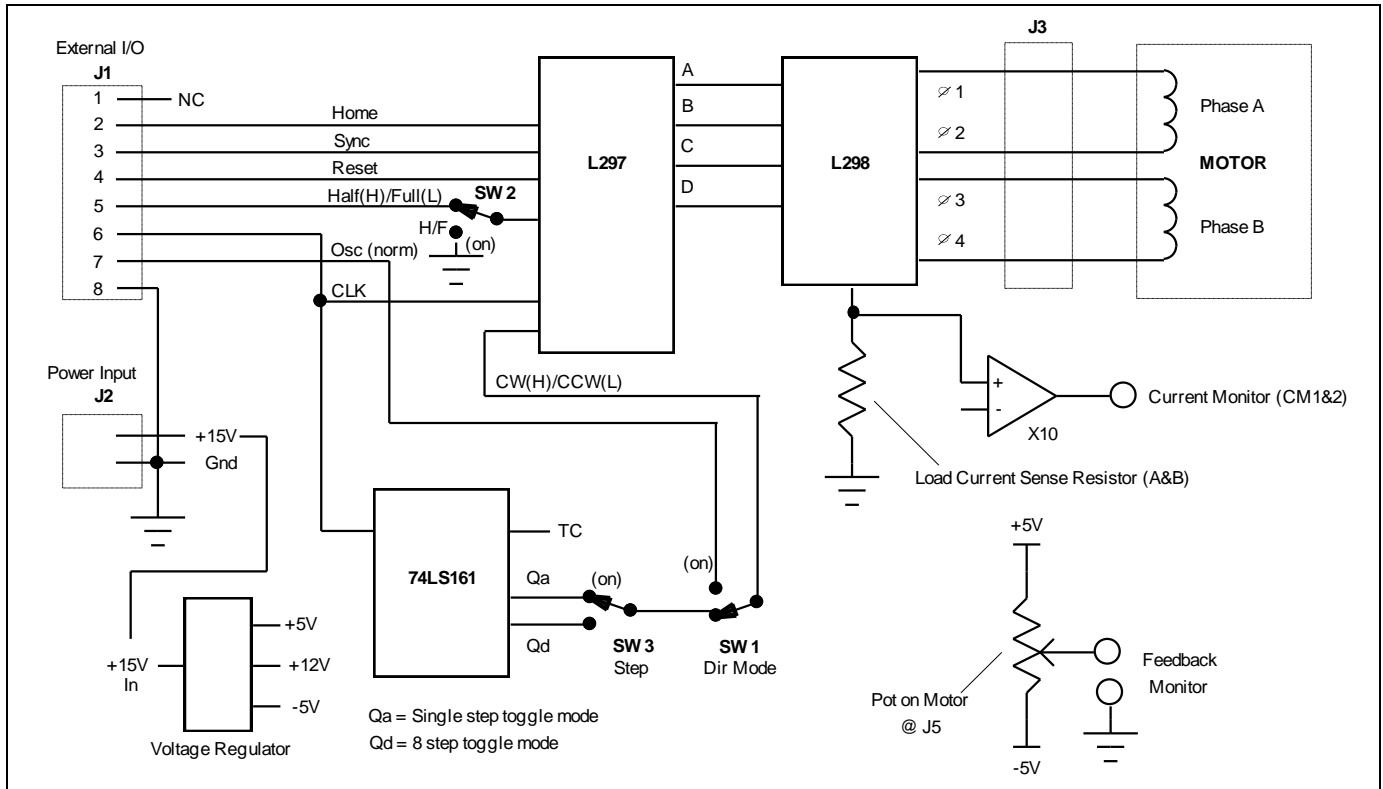


Figure 1: Simplified functional block diagram of the stepper motor demo board.

4 Stepper Motor Modes (L297 Controller)

The specification sheets on the STMicroelectronics L297 stepper motor controller describe the 3 main operating modes for stepping motors (not including reverse direction); wave drive, half-step and normal drive. The L297 controller has 8 unique output signal states. The 3 modes of operation select which of the 8 states are used and their sequence. For the reverse direction, the selected states are cycled in the reverse order. These three different operating modes are described below.

4.1 Full Step mode (sometimes called “Wave Drive”)

In Full step mode, only 1 field winding is energized at a time and the rotor takes full steps. There are 4 stator windings and the normal sequence would be ABCDA... Only 4 of the 8 controller states are used. Unfortunately, to make things confusing, the L297 controller labels the sequence ACBDA. The LED's on the controller board are labeled ABCD and you will notice that they illuminate in the sequence ACBDA. If we wished to make the motor rotate in the reverse direction, we would reverse the sequence (ADCBA)¹.

Full step mode is entered when the **Half/Full switch** is forced low (Full position) when the current state is even (2, 4, 6, or 8 or when only 1 LED is on). See the L297 datasheet for details.

¹This is further described in the Half-Step Mode sub-section.

4.2 Half-Step Mode

In half-step mode the field windings turn on in an overlapping sequence that allows the current to flow in 2 adjacent field windings at the same time. When these 2 windings are "ON" at the same time, the rotor locks into position mid-way between poles (thus the name 1/2 step mode). When one of these 2 winding currents is turned off, the rotor proceeds to the next pole. Thus, the stepper motor appears to have twice the angular resolution. The stator winding sequence is A, AB, B, BC, C, CD, D, DA, A. Note the state labeling confusion mentioned above in the Full Step mode. To reverse the motor rotation, the sequence A, DA, D, DC, C, CB, B, BA, A would be used. All 8 states of the controller are used in this mode of operation.

Half-step mode is entered by forcing the **Half/Full switch** high (Half position). See the datasheets for the L297 controller for details.

4.3 Two Phase "on" mode (sometimes called Normal Mode)

The Two Phase "on" mode is the "complement" to Full step mode (Wave drive mode) because the motor takes full steps, but at the half-step intervals. In this mode, two windings are energized at a time, and only 4 of the 8 states are used. Since 2 windings are energized at a time, the rotor will align itself halfway between the stator poles (like we discussed in half step mode). You can get more torque from the stepper motor since you are activating two stator coils at any one time (and thus you have to supply more operating current). The sequence for this mode is AB, BC, CD, DA, AB. If we wanted to reverse the motor, we would reverse the sequence.

Two Phase "on" mode is entered when the **Half/Full switch** is forced low (Full position) when the current state is odd (1, 3, 5, 7). State 5 (state BD on the L297 specification sheet) corresponds to the reset state so **pressing the FULL switch and then the RESET button should initiate Two-Phase-On mode**.

5 The L298 Stepper Driver

The L298 driver is simply an "H" bridge power driver chip designed to drive a pair of field windings in both polarities by the proper sequencing of transistor switches. The proper sequencing is provided by the L297 controller. A schematic diagram of an H-bridge circuit is shown in Figure 2.

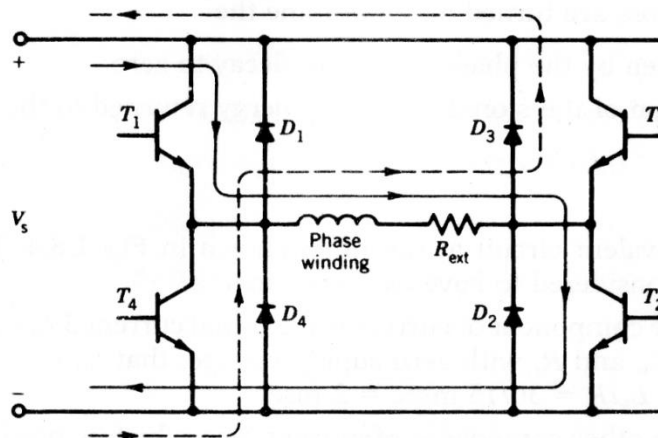


Figure 2: H-bridge driver circuit.

6 Lab Procedure

Set up the function generator to output a TTL level (0-5V) 5 Hz square wave², and connect it to the *EXT CLK IN* (BNC connector) on the board. Set up the power supply for +15V, limited to 500mA; apply power at terminal block *J2* and note the polarity. The 3 green LEDs near the lower edge of the board should light up.

All I/O control lines (with the exception of *HOME* on External Interface connector pin 2) are passively pulled up to a logic high level using 2k7 resistors, and can be pulled low by grounding them. All Test-points are buffered to help prevent accidental circuitry damage.

To maximize access to the range of features available from the L297 and L298 motor controllers, our stepper motor demo board provides a Reset pushbutton switch for the L297 plus three motor mode controls, rocker switches *SW1* (*MODE DIR* Direction Mode), *SW2* (*H/F* Half/Full), *SW3* (*STEP* Interval – single or 8 step). Refer to circuit board layout diagram shown in Figure 3.

The **RESET** pushbutton switch forces the controller into the home position or state 5 of the L297 operation.

6.1 Switch Functions

Note: Switch default positions are defined as depressed toward circuit board outer edge.

SW1 (*MODE DIR* Direction Mode) controls whether the motor runs continuously in one direction or automatically switches directions (Continuous or Auto Reverse). **Default = Continuous.**

SW2 sets Half or Full step mode. As noted above, setting this switch to Half step mode will initiate Half step mode regardless of the current state of the controller. The state entered when set to Full step mode depends on the current state of the controller. Sometimes it goes into the standard full step mode and at other times the Two Phase On mode. Both these modes have a full step size. **Default = Full Step mode.**

SW3 controls the duration of the direction reversals set by *SW1*, either after every clock pulse or after 8 clock pulses. **Default = Single Step-Toggle mode.**

² A function generator with an array of range multiplier pushbutton switches is preferred, e.g., Wavetek 182A.

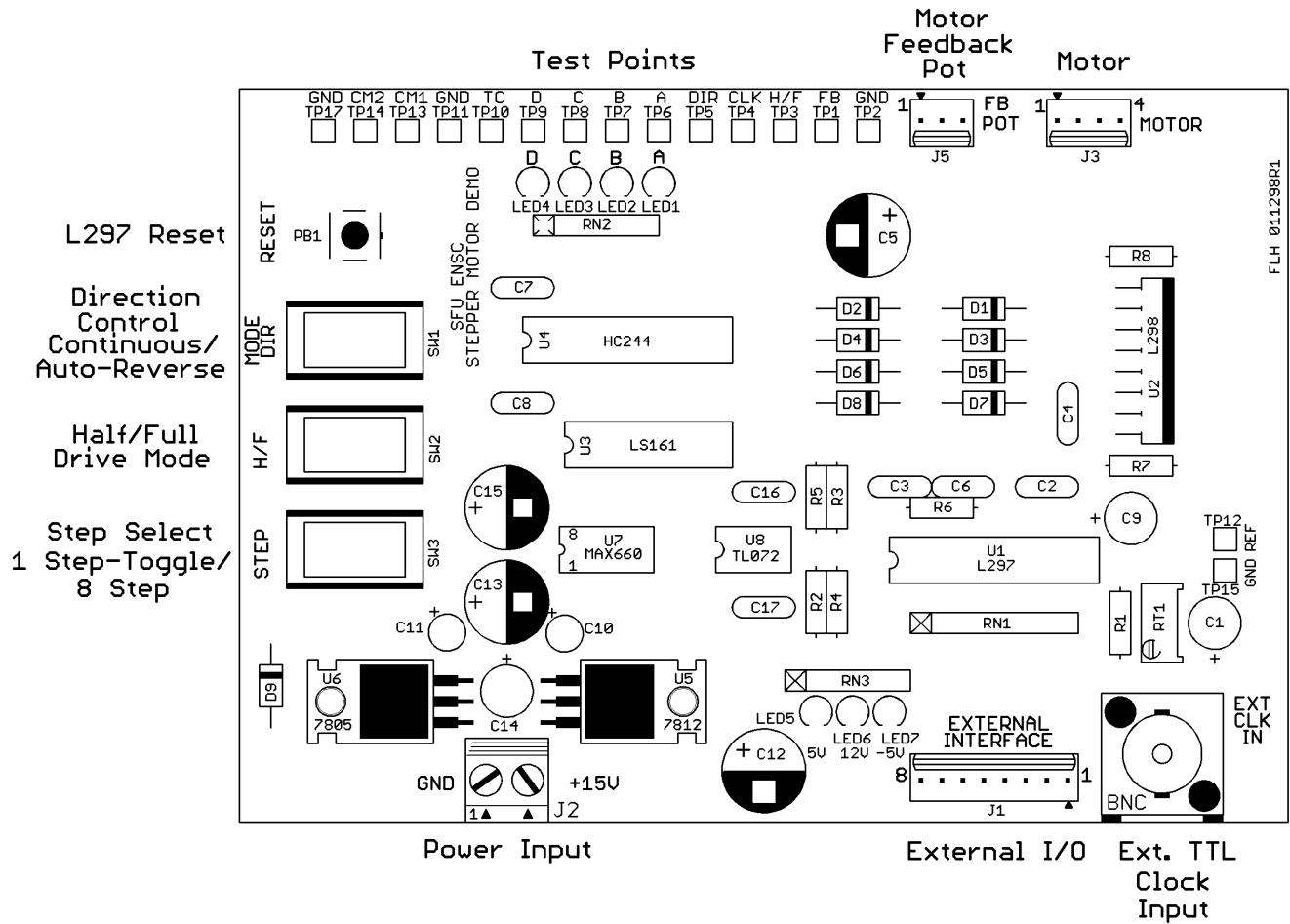


Figure 3: Component layout of the stepper motor demo board.

With the power *OFF*, connect the *small black motor* (marked as KP4M4, see Figure 4) to the 4 pin-header labelled *Motor*.



(a)



(b)

Figure 4: Small black stepper motor (KP4M4) with inertial load unmounted and mounted.

In the following procedure, repeat Steps 1 through 4 with the motor in all 3 modes of operation (Full step, Half-Step, and Two Phase “on” modes).

- To set Full step mode, first adjust the clock rate (function generator) to something quite slow (say 1 or 2 Hz), set the Half/Full switch to "Half" position and observe the 4 red sequence LED's. You will notice that at times there will be 2 LED's on and at other times there will be only 1 LED on. When there is only 1 LED on, throw the Half/Full switch to "Full" and thus enter Full step mode.
- To enter half-step mode, simply push the Half/Full switch to the "Half" position.
- To set up for the two phase “on” mode, press the Half/Full switch to "Full" and hit the **reset** button (forcing the controller into state 5, the home position) on the controller card.

You should be able to identify any of the modes by observing the 4 sequence LED's and comparing them to the timing diagrams in the L297 datasheet.

6.2 Procedure Steps

1. Determine the maximum step rate that the motor is capable of responding to by gradually increasing the CLK frequency (from the signal generator) until the motor stalls (F_{stall}). Why do you think it stalls?
2. Gradually reduce the CLK frequency until the motor resumes rotating ($F_{reacquire}$). How does this compare with the stall frequency? Explain your findings.
3. Determine the maximum frequency at which the motor turns from a standing start (F_{pull_in}). (For this step, use the frequency multiplier buttons on the function generator to rapidly switch between the lowest CLK frequency scale and the scale that simulates the jump).
4. Repeat steps 1-3 with an additional inertial load.
5. Count the number of steps in a revolution. Knowing that the number of phases is 4, can you calculate the number of teeth on the rotor?

6.3 Transient Response

Stepper motors have a transient response that is often compared to a simple second order system. However, the transient response is much more complex when we get into details. To measure the transient response we are going to use the larger chromed motor with an integral potentiometer to enable you to get a voltage out proportional to position (**Error! Reference source not found.**). Note that the potentiometer is a servo type that has no mechanical limits to its rotation (continuously rotatable), but it does have a zero-index “dead zone” where the output at the wiper is

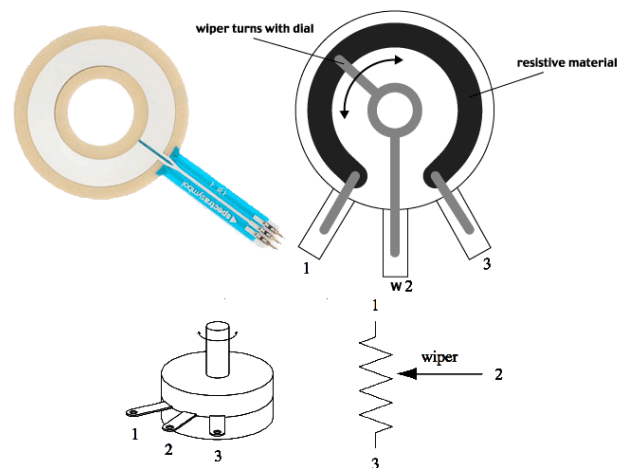


Figure 5: Servo potentiometer

undefined. Figure 5 helps to explain this.

With the power *OFF*, connect the stepper cable to the board header J3 labelled *MOTOR* and the potentiometer cable to J5, *FB POT*. The controller board can be set to step continuously 1 step forward and 1 step back so that you can observe the transient response easily. To do this, set the Step Select switch to Single Step/Toggle, and the direction control switch to Auto Reverse. The function generator supplying the *CLK* should be set for approximately 10 Hz.

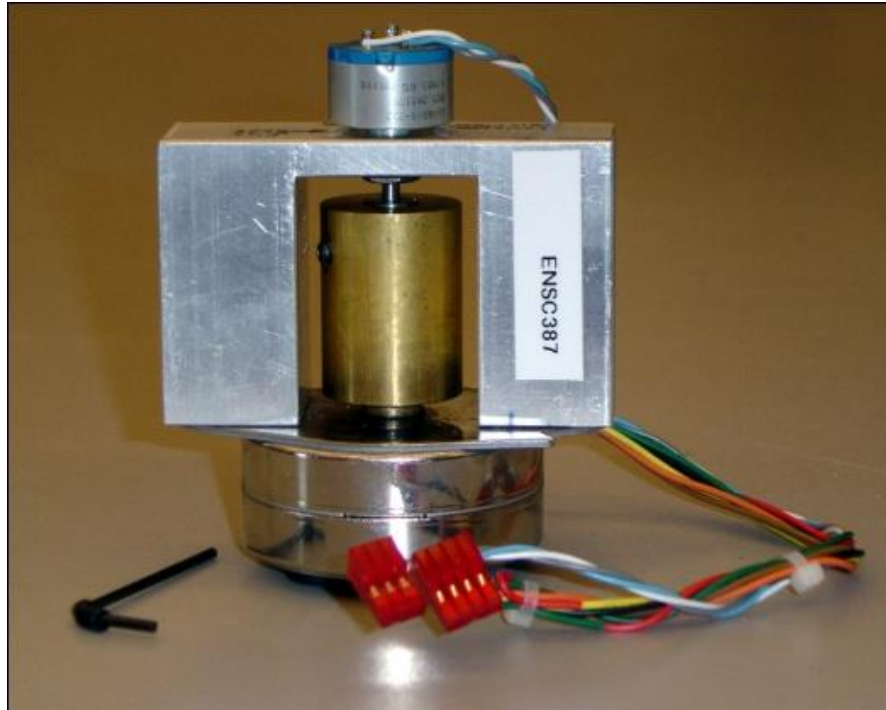


Figure 6: Fuji stepper motor with feedback potentiometer.

To enhance the transient overshoot, an inertial load in the form of a large brass collar has been provided. This inertial load can be “attached” to the motor shaft by simply tightening the single set-screw (using the supplied hex key), or it can be “disengaged” by loosening the set-screw and allowing the motor shaft to turn freely inside the collar. Unfortunately, there is a slight misalignment between the pot and the motor shaft, so that at some positions of the shaft, the motor shaft binds slightly producing a damping effect on the transient output. For this transient response measurement, use the part of the shaft movement that allows the minimum friction movement.

Observe and measure the transient response in both full step and half step mode³ with and without the extra inertial load. You may have to adjust the clock frequency for an optimal display on the scope. Note your observations with measurements and sketches and try to explain your results.

The test pin labelled *TC*⁴ can be used to trigger the scope at one of the points where the motor reverses direction (i.e., 1 step CCW, 1 step CW, TC, CCW, CW, TC...). Set the scope trigger channel for DC input

³ For Half-Step operation, it may be necessary to increase the power supply current limit slightly <750mA. Ensure that the ICs on the controller board do not get uncomfortably warm to the touch. If too warm, remove power and permit proper cool-down.

coupling mode. Connect the other scope trace, also in DC input mode, to the test-point labelled FB. Keep the scope's input channel sensitivity fairly high up to see the position response. You should readily see the typical overshoot response to the step input. Notice that the amplitude of the ringing can be quite high, as much as 80% of the step size. A DSO (digital storage oscilloscope) may also prove useful to better observe the ringing. What implications does the ringing have on the maximum step rate? Could you suggest a better method of determining the extent of ringing in this lab set up?

6.4 Stepper current measurements

If we keep the same trigger point, (you may use the BNC-Seizer probe connected to the scope EXTERNAL TRIGGER input⁵) and look at both the stator windings current waveforms and at the same time look at the position output, we should be able to see the current build-up (should look like an exponential) before the rotor starts to move. For this purpose, Current Monitor test-points CM1 and CM2 are provided on the board. The current level should not change appreciably as the toggling frequency is increased and of course, the delay time should also be relatively constant as well. If we try to force the stepper to step too quickly, the next step command will come before the rotor position has settled giving an even more complex current waveform. After the rotor starts to move, the induced current from the moving rotor will create a much more complex current waveform. A snapshot of stator current switching transient is shown in Figure 7. Try to explain the current waveform shape. Make the same current measurements in the other stepper modes and try to explain any differences.

⁴ On the Presettable BCD decade counter U3-74LS161, TC refers to the Terminal Count output. TC goes high on maximum count state for only 1 count state.

⁵ Set the scope for trigger on EXT via the Trigger Menu button > Source = Ext.

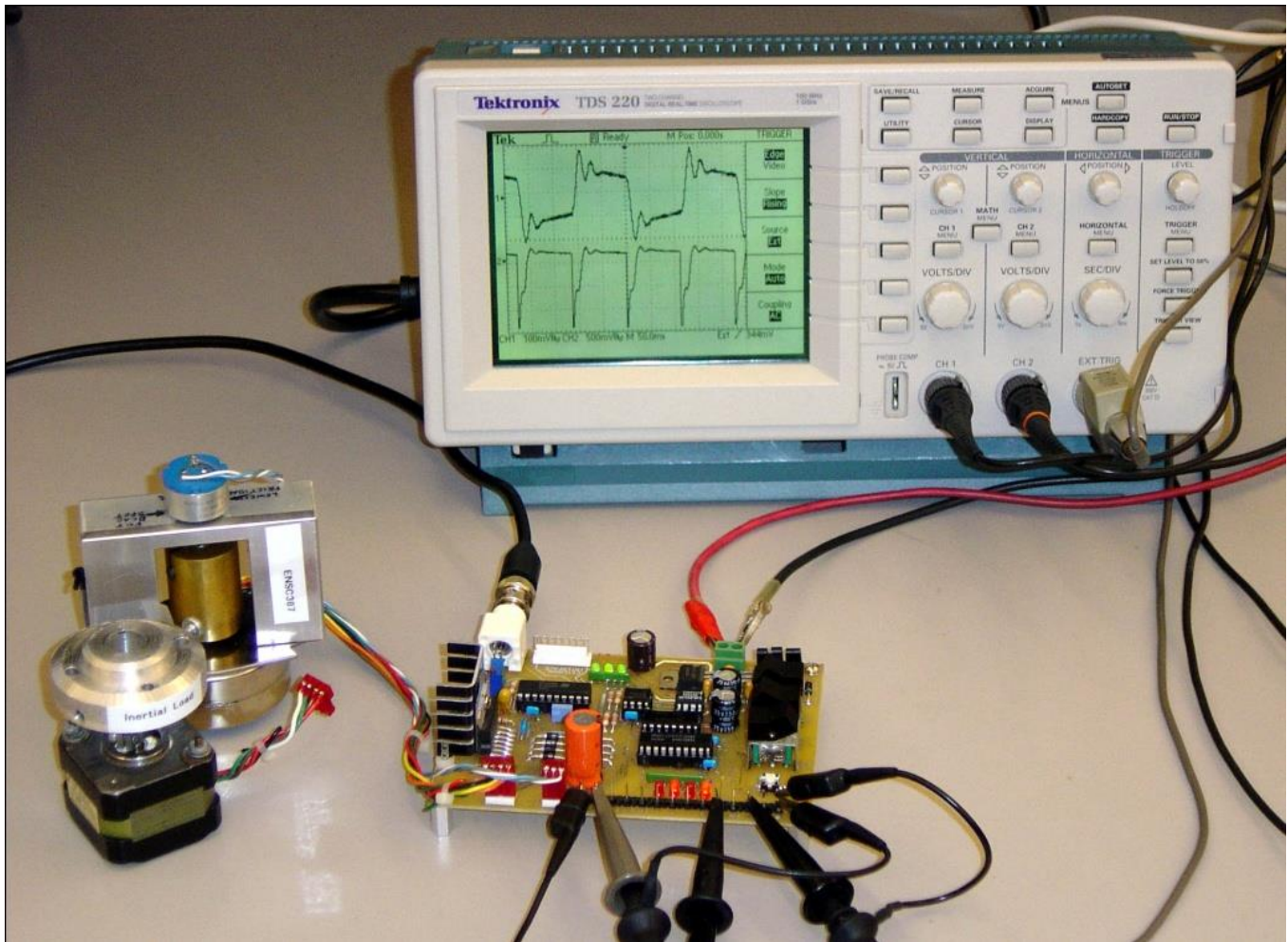


Figure 7: Set up for measuring the stepper motor stator current switching transient.