University of British Columbia
Electrical and Computer Engineering
ELEC 302
Electronic Circuits for Electromechanical Design
Instructor: Dr. Kenichi Takahata

Laboratory 4 – Motor Control using Semiconductor Sensor, BJTs Circuits, and Diode Rectifier

Introduction

In this laboratory, we will experimentally test the sensor-controlled motor operation and its control circuit discussed in class. The system uses electronic components and circuits that you have learned in this course such as BJT amplifier, inverter, and diode peak rectifier. In this system, the distance between a magnet-embedded wheel driven by a DC motor and a Hall-effect magnetic sensor is detected by measuring the sensor signal to control the wheel's rotation.

The set-up is shown in Fig. 4.1 that conceptually explains this experiment (illustrated with blades instead of the wheel). The magnetic fields established by rotating magnets are detected by the sensor, producing small AC-like signals (with a voltage level of 10-100 mV for the sensor to be used) depending on the intensity of the field, or distance between the sensor and the wheel/magnets.

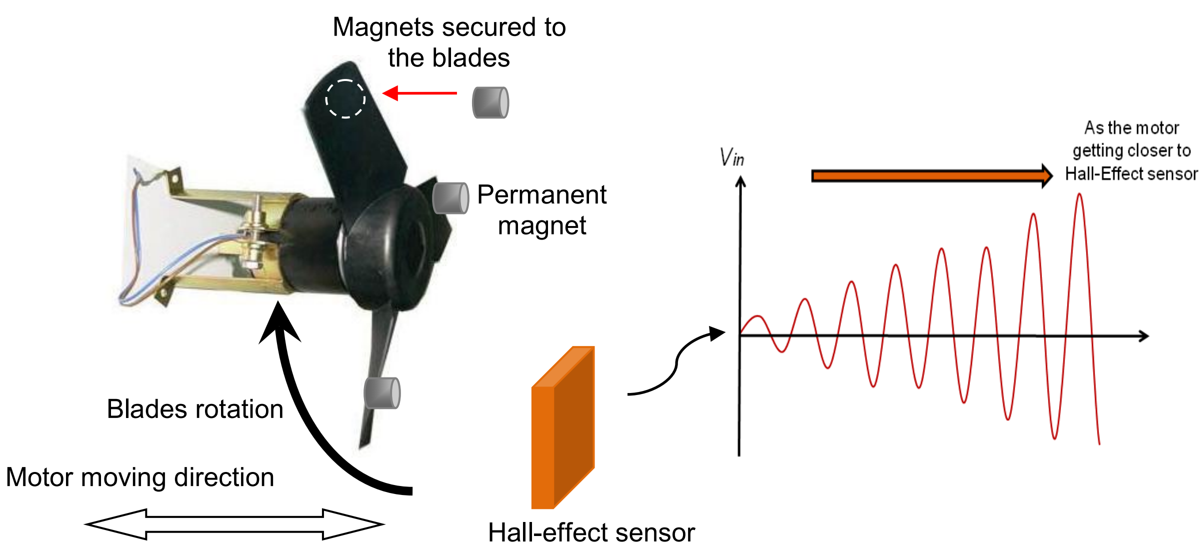

Fig. 4.1: Small signals generated by magnetic sensor due to rotating magnets

The sensor signal itself is not suitable to drive the motor directly. To control the motor, the signal is first amplified, and then rectified and filtered to produce a DC voltage that corresponds to the amplitude of the sensor signal, i.e., distance between the wheel and the sensor. This DC voltage signal is fed to an inverter/switching circuit for the motor control. The system configuration is shown in Fig. 4.2. In this lab, you will build a circuit to achieve this system and verify the sensor-controlled motor operation.

Before you start, make sure to read **Lab Instructions.pdf** posted on the course website. This lab also assumes that you have read **Oscilloscope operation & Part identification.pdf**.

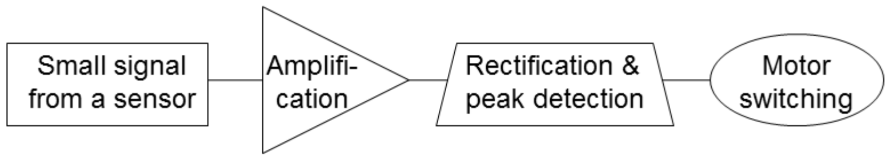

Fig. 4.2: System configuration

Components Required for the Laboratory

- One Hall-effect sensor (FW Bell GH-600, note this is not the same model discussed in class. This model provides a better sensitivity.)
- One DC motor with a rotor wheel (in which six permanent magnets are embedded)
- One power transistor TIP122 with a heat sink plate (TIP122 is called Darlington transistor that consists of two BJTs and is designed for power switching applications.)
- Two transistors 2N3904
- One diodes 1N4148
- Capacitors & resistors
- Small breadboard

Pre-Laboratory Assignments

1) Collect the data sheets for the Hall-effect sensor, transistors, and diode listed above.
2) Review through "BJT reading assignment.ppt".
3) Read the description of Tasks in these sheets. Note that the circuit topology here is the same as the one discussed in the reading assignment above, but the values of some of the parts are modified due to the availability. The circuit to be used (see Fig. 4.5) and the separate sensor-motor module to be connected with the circuit are provided in the lab.

FYI: The terminals of the module are arranged in separate connectors as shown in Fig. 4.3. For the sensor connector, $V_H(-)$ and $I_C(-)$ go to the ground. (These connector pins are arranged so that they fit the holes of the breadboard without any hole between the pins.)

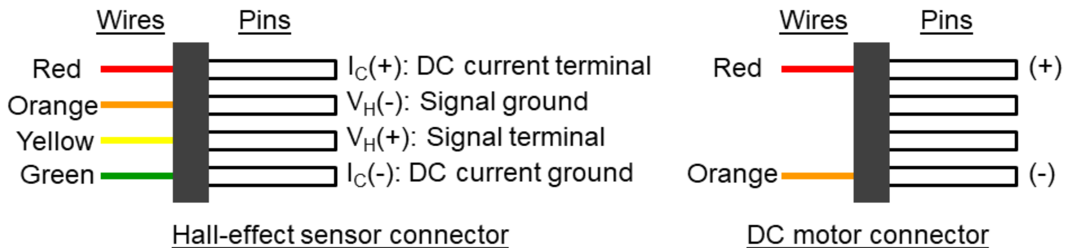

Fig. 4.3: Connectors and pins for the sensor and the motor used in the set-up

References

ELEC 302 lecture notes for BJT and diode, and reading assignment "Design of Sensor-Controlled Motor System", K. Takahata, UBC, 2024

SAFETY NOTES:

- **YOU MUST WEAR SAFETY GLASSES DURING THE ENTIRE EXPERIMENTS.**
- **PLACE THE MOTOR SET-UP SO THAT THE PLASTIC COVER FACES YOU.**

Task 1: Motor Switching

1) The motor switching circuit is shown in Fig. 4.4 (note the voltage source has been changed from 5 V used in class to 2.5 V to limit the motor speed). First, decouple the inverter circuit (of Q1) from the diode/capacitor peak rectifier AND from the motor drive circuit (of Q2). This means that the points "**a**" and "**b**" in Fig. 4.5 are disconnected. Measure and record V_O in Fig. 4.4 when you provide 0 V (low state) and 0.7 V (high state) as V_I to Q1 – check the inverter function and the operation mode of Q1, and describe your observation.

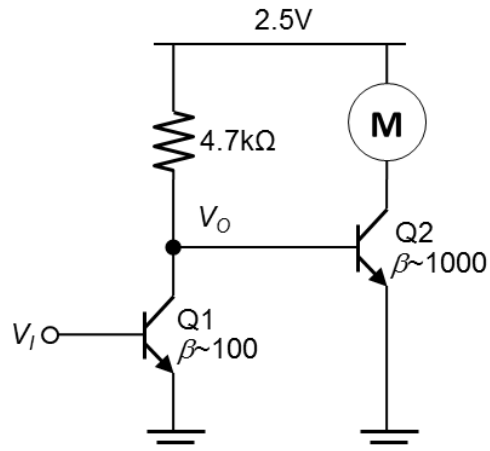

Fig. 4.4: Motor switching circuit

2) Keep V_I to be 0.7 V. Set the distance between the rotor wheel and the plastic plate (that the senor is mounted) to be ~5 mm. Re-connect V_O to the Base of Q2 (i.e., reconnect the point "**b**" in Fig. 4.5). Connect a 2.5-V power supply to the motor circuit. Vary V_I between 0.7 V and 0 V and check if powering to the motor is controlled as you expect. **When you reduce V_I towards 0 V, do it with caution because the motor/wheel will start to rotate rapidly.** Describe your observation. After the measurement, turn off the 2.5-V supply.

Task 2: Sensor Signal Amplification and Peak Rectification for Motor Control

1) The Hall-effect sensor needs a constant, bias DC current for its operation. For the particular sensor used, establish a 10-mA current (using a 1-kΩ resistor) flowing from the terminal I_C(+) to the ground (I_C(-)) – make sure the polarities are correct (Fig. 4.3).

2) A sensor signal produced by rotating magnets appears as a series of pulses. First, decouple the sensor output V_H(+) from the 100-nF DC blocking capacitor (i.e., disconnect the point "**c**" in Fig. 4.5). Apply 0 V to V_I of Q1 and turn on the 2.5-V supply (the wheel starts to rotate). Using an oscilloscope, measure and record the signal generated at the sensor output when the sensor is placed ~2 mm away from the rotating wheel. Sketch the waveform on the time axis while showing the approximate peak voltage level observed. The signal may not be very stable, but you can take an approximate average of the peak voltage. Repeat it when the sensor is set apart, ~5 mm away from the rotating wheel.

3) As noted earlier, the sensor signal needs to be amplified, rectified and filtered before being fed to the motor switching circuit. For the amplification, we use a 4-R's *CE* amplifier with Q3 as shown in Fig. 4.5. Re-connect the sensor output V_H(+) to the input of the amplifier (i.e., reconnect the point "**c**"). Decouple the output of the amplifier from the peak rectifier (i.e., disconnect the point "**d**"), and measure an approximate peak level of the amplified signal at the output (at R_L) using the oscilloscope, for the sensor-to-wheel distance of both ~5 mm and

~2 mm cases. Based on this result and the result from #2 for the 5-mm distance case, calculate the voltage gain A_v of the amplifier. Also measure and record I_C of Q3 (by probing a voltage across its R_C).

In your report, compare the above measured A_v with a theoretical A_v – for this calculation, consider the sensor's output resistance (you can take an average of the resistance range shown in the sensor's datasheet) that is coupled at the input node (point "**c**") of the amplifier. Sketch a small-signal equivalent circuit of this amplifier with the sensor (which is essentially a signal source with the output resistance) for this work. You may use the β value measured in the Lab 3 to calculate the theoretical gain because we used the same BJT model in the Lab 3. Discuss the results in the measurements and comparison with the theoretical value.

4) Now reconnect the peak rectifier back to the amplifier (i.e., reconnect the point "**d**"). Note the rectifier is still decoupled from Q1 (i.e., the point "**a**" is still disconnected) at this moment. Observe and record the rectified DC voltage level and the rippled level at the output of the rectifier. Find a voltage drop at the diode (by comparing the rectified voltage with the approximate peak level of the amplified signal measured in #3). Vary the sensor-to-wheel distance between ~2 mm and ~5 mm, and observe if the DC voltage level changes as you expect. Discuss your observation.

5) Finally, re-connect the output of the peak rectifier to Q1 of the motor switching circuit (i.e., reconnect the point "**a**"). Now the system is complete. Re-measure the DC voltage level at the output of the rectifier (or the Base of Q1) while varying the sensor-to-wheel distance between ~2 mm and ~5 mm. Observe and describe the dependence of the motor operation on the distance. Discuss the mechanism of the motor control.

6) Before you leave, ensure that the circuit on the breadboard is complete and all properly connected so that it will instantly work, because another team will use it in the next session.

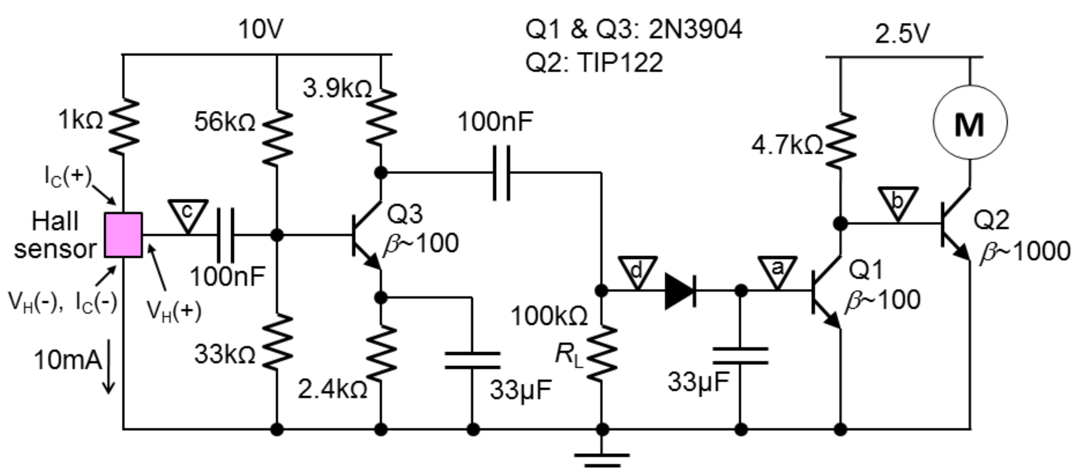

Fig. 4.5: Overall circuit design

Report (due date & time – see "Laboratory" page on the course website)

An individual report is required for this experiment. Refer to "Lab instructions.pdf" and follow the report format and other instructions described. Please ensure to present all your data clearly (using diagrams, tables, and graphs as required) and include the following:

- Explanation of the tests that were undertaken and diagrams of their set-ups.
- Descriptions of the measurements you performed in the laboratory.
- Table(s) of measurements obtained where applicable.