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AN N-CHANNEL MOSFET-BASED ELECTRONIC ELECTROSCOPE

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Abstract. *A new design method for a simple electronic electroscope is implemented around an n-channel metal-oxide-semiconductor field-effect transistor (MOSFET). Two important techniques have been used in this study. The first technique is to use an npn-bipolar junction transistor to keep the MOSFET's drain voltage (V_d) to be constant. The second technique is to use a voltage divider circuit for adding initial charges to the MOSFET's gate. In the designing part, we have found that the appropriate approximate voltage V_d and current I_d are 100 mV and 1 mA, respectively. Hence, the proposed electroscope can detect both positive and negative charges without p-channel MOSFET requirement. This newly invented instrument together with a metal leaf electroscope and a physical pendulum can be applied to physics laboratories, and they would make the experiments more interesting.*

Keywords: Electronics electroscope, Polarity of charge, n-channel MOSFET

1. **Introduction.** In general, a metal leaf electroscope is used for electrostatic experiments. In this way, the metal leaves at the inner-end of the conductor are unfolded when a charged material is brought close to the antenna (sensing electrode) at the outer-end of the conductor. The disadvantage of this electroscope is that the metal leaves always expand, regardless of whether the tested material is positive or negative charge. This makes the experimenters not aware of the types of charges unless there are the known reference charges in the experiment. Due to this problem and the need to make the experiment more innovative and interesting, over the years, a wide range of devices has been successively invented in order to indicate the types of electric charges [1-10]. Many of the recently developed charge detection devices are based on electronic devices or electronic circuits which are referred to "electronic electroscope". The developed electroscopies could be divided into two main groups: a group of the electroscopies using various simple electronic devices and a group of electroscopies based on special designing electronic circuits. For the first group, interesting examples include the use of a digital voltmeter, a light-emitting diode, a neon bulb, an ultraviolet lamp with a basic electroscope, and a piezoelectric lighter [1]. Interesting examples of the second group are based on a nonpolar capacitor connected to a digital voltmeter [2], MOSFET logic gates [3-5], MOSFET operational amplifiers (Op-amps) [6,7], bipolar junction transistor (BJT) [8,9], and MOSFET [10], etc. After considering the capabilities of each method, it is found that most of them can indicate only types of charges which are tested. However, there are few methods [2,5-7,10] attemping to design a circuit which is able to measure the amount of electric charges.

MOSFETs have been found useful in many applications [10-16]. Interestingly, after reconsidering the electronic electroscope designed by using MOSFET proposed by Yavaş and Karadag [10], we found that it is necessary to use two sensing electrodes which are

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connected to an n-channel MOSFET and a p-channel MOSFET to enable the device to detect both positive and negative charges. In this paper, an n-channel MOSFET is used for positive charge detection and a p-channel MOSFET is used for negative charge detection. While performing the experiment by using an n-channel MOSFET alone, we surprisingly discovered that if the gate terminal of the MOSFET is charged by rubbing it gently on the sensing electrode by hands and the drain's voltage is set to be a low suitable voltage, the drain's current will have occurred and it will remain in a small value (approximately a few mA). When an object with positive charges is placed near the sensing electrode, the drain's current will be increased. Conversely, for a negatively charged object, the drain's current will be decreased. In order to stabilize the electroscope in this work, we designed an additional circuit for adding the initial charges into the MOSFET's gate terminal and a particular circuit for controlling the voltage at the MOSFET's drain terminal to be constant. The advantage of our alternative proposed electroscope is that using a single sensing electrode leads to high precision of the detecting position and reliable results. In what follows, the additional designed circuits and working principle are explained in Section 2. In Section 3, the results from a traditional electronic electroscope and our designed electroscope are compared. Types of charges can be identified by our device. Moreover, it is applied to the experiment of physical pendulum. The results from our electroscope are in good agreement with those from a Hall-effect sensor. Finally, the conclusion is provided in the last section.

2. Proposed Electronic Electroscope.

2.1. Circuit description. In this section, the circuit diagram will be explained. Figure 1 illustrates the circuit diagram of the proposed electronic electroscope. In this work, an n-channel MOSFET number IRF530N is used to connect with a BJT BD139. The voltage source V_{dd} is set to be 5 V. V_g, V_d and I_d denote the voltage of gate terminal, the voltage of the drain terminal, and the drain-current of the MOSFET, respectively. The copper wire is used to act as the sensing electrode of the electroscope. The resistor R_3 is used to convert the current I_d to the voltage value V_{r3}. The 0.01 μF capacitor C_1 is connected in parallel to the gate terminal of the MOSFET. As a result, this will increase the electrical capacitance at the gate terminal to enhance its ability for maintaining charges. The 100 μF capacitor C_2 is connected in parallel to the resistor R_3 to reduce the noise from the power line when an oscilloscope is connected to measure the voltage V_{r3}. The variable resistors R_1 and R_2 function as the voltage divider circuits to provide the voltages V_{r1} and V_{r2} respectively. An npn-BJT acts as a circuit controlling the voltage at MOSFET's drain (V_d) to be constant. This will result in voltage V_d having an approximate value of $V_d = V_{r2} - 0.6$ V. The npn-BJT is also used to transfer the current I_d to the resistor R_3.

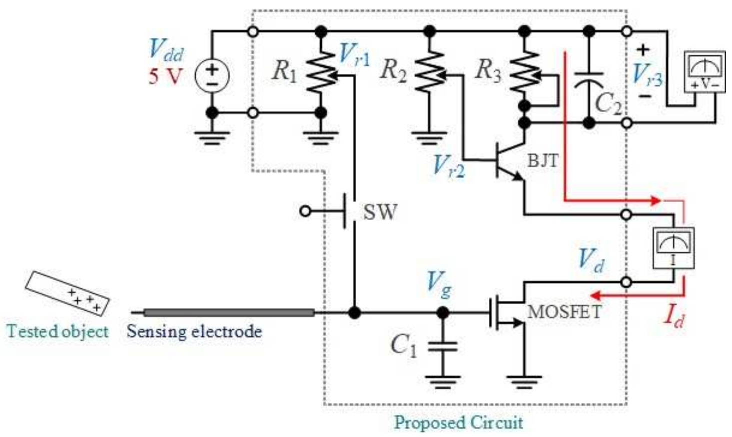


FIGURE 1. Circuit diagram of the proposed electronic electroscope

2.2. **Circuit setting.** According to the IRF530N datasheet, the MOSFET's threshold voltage ranges from 2 V to 4 V. In this study, we found that the optimum V_d is approximately 100 mV and I_d is approximately 1 mA. The MOSFET can maintain its conductivity after applying initial charges to the MOSFET's gate. R_3 is determined to have the value of 2.25 kΩ; as a result, a voltage V_{r3} is approximately equal to 2.25 V when the I_d current is 1 mA. The switch (SW) in normal state is open, but when it is pressed, a voltage V_{r1} is sent to the gate terminal of the MOSFET, resulting in $V_g = V_{r1}$. To find the suitable value of the initial voltage V_{r1}, we performed an experiment by pressing the switch and varying the voltage V_{r1} from 1.5 V to 4.5 V to obtain the relation between I_d and V_g as shown in Figure 2. Here, MOSFET operation is in weak-inversion region [15,16]. It is found that if I_d of 1 mA is chosen, V_{r1} of 3.1 V is required. In practice, after the switch is open, V_g and I_d have a small drop. However, they can still be maintained without returning to zero. When the tested object is positively charged and placed near the end of the sensing electrode, the positive charges are induced more at the gate of the MOSFET. This causes an increase in the current I_d of the MOSFET. Experimenters can classify types of charges and detect a quantity of charges by using an ampere meter to measure the drain current I_d or by using a voltmeter to measure the voltage V_{r3}. On the other hand, if the tested object is negatively charged, I_d and V_{r3} will decrease from their initial values. Note that without the tested object, I_d and V_{r3} will return to 1 mA and 2.25 V, respectively.

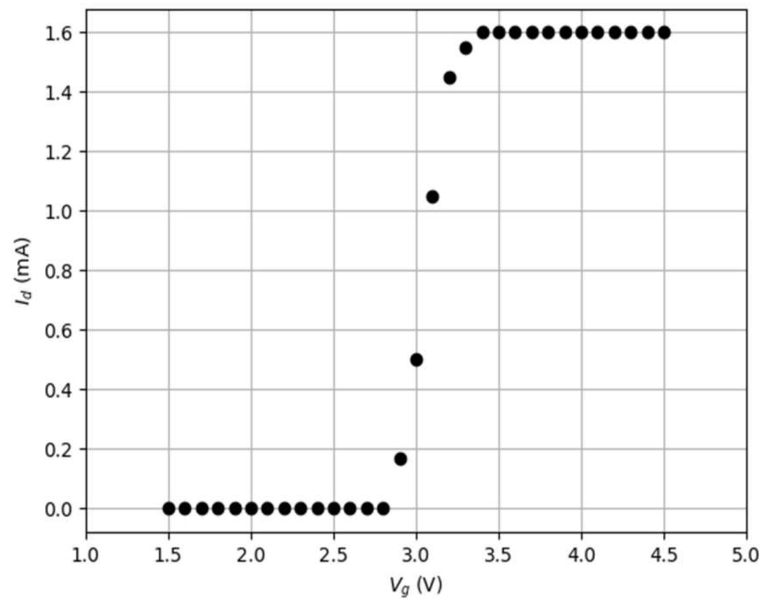
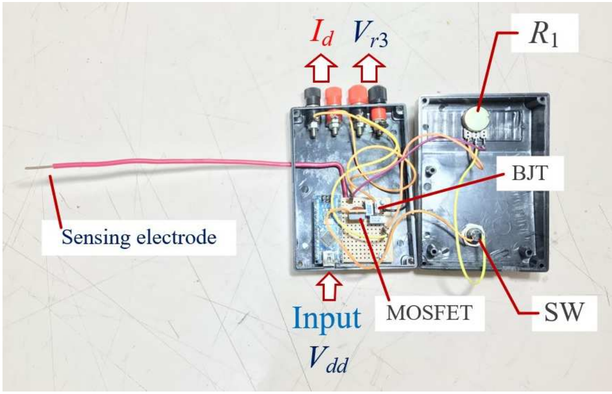


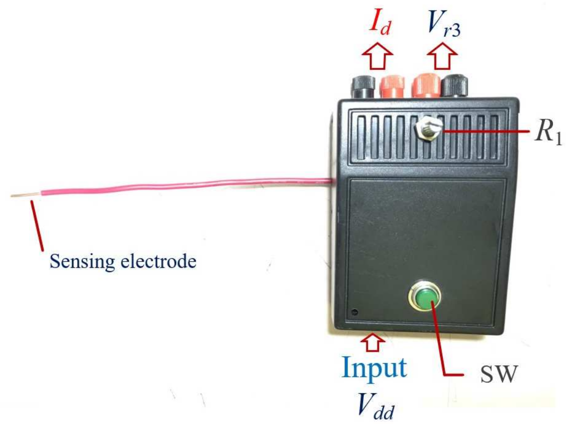
FIGURE 2. The relation between I_d and V_g

3. **Experiment.** We set up the circuit on a perfboard, packed in a plastic case as shown in Figure 3. A sensing electrode is protruded outside the case while the rotating knob varying the resistor R_1 and the push-button switch SW are located on the top of the case. In addition, two points for measuring the voltage V_{r3} and the other two points for measuring the current I_d were placed on one side of the case. In this section, three experiments are demonstrated to be examples of using our proposed electronic electroscope.

3.1. **Comparison between a traditional metal leaf electroscope and the proposed electroscope.** To demonstrate the capabilities of the created electronic electroscope, we performed a comparative experiment with a metal leaf electroscope as done in the previous experiment [9]. In the first demonstration, we used an analog ampere meter to show the measurement results.



(a)



(b)

FIGURE 3. Proposed electronic electroscope: (a) Inside case; (b) outside case

Figures 4(a) and 4(b) show a metal leaf electroscope and the electronic electroscope with analog ampere meter. Initially, it was seen that two metal leaves did not open and the needle of the meter was at 1 mA. After rubbing a plastic ruler with flannel, electric charges will be exchanged between them, resulting in opening of the leaves when the ruler is placed near a metal leaf electroscope as seen in Figures 4(c) and 4(d). When this charged ruler is close to the sensing electrode, it causes I_d to be greater than 1 mA. That means the ruler is positively charged. The difference of material types is shown in Figures 4(e) and 4(f). In this trial, the ruler is rubbed with hair. The metal leaf is opened as the previous trial while I_d measured by ampere meter is less than 1 mA, which indicates that the ruler is negatively charged. It should be noticed that our electroscope can classify types of charges by the needle of the meter that sweeps to the right or left. Moreover, our device can quantitatively detect charges accumulated in the tested object. The more the needle sweeps, the more the charges accumulate.

3.2. **Detecting charge types of discharged metal leaf electroscope.** In the second experiment, a positively charged ruler due to rubbing with flannel is placed close to the sensing electrode of metal leaf electroscope. Then the charges are discharged by touching the sensing electrode with a finger. Consequently, negative charges will remain in the metal leaf electroscope. This can be confirmed by putting the sensing electrode of our electroscope near that of metal leaf electroscope. The results are illustrated in Figures 5(a) and 5(b) where the needle of ampere meter is swept to the left. The trial in Figures 5(c) and 5(d) is similar to that in Figures 5(a) and 5(b), but the tested ruler is negative. As expected, the remaining charges are positive. This is verified by the needle swept to

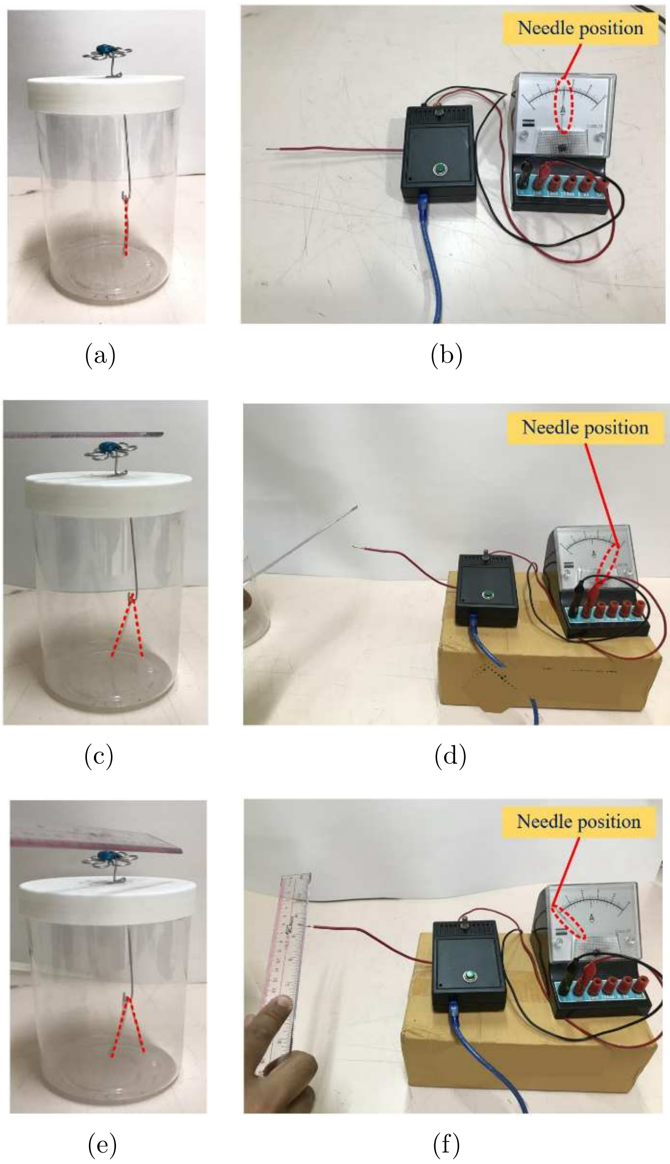


Figure 4. Comparison between a traditional metal leaf electroscope (left) and the proposed electroscope (right): The electroscopes without a tested object (a) and (b), with a positively charged object (c) and (d), and with a negatively charged object (e) and (f)

the right. It should be noticed that the remaining charges in the metal leaf are opposite to the charges of the tested ruler.

3.3. **The experiment of pendulum oscillation based on charge detection.** In this section, an oscillation of a pendulum will be detected by our electroscope, compared with that detected by a Hall-effect sensor. A considered pendulum system consists of a metal rod, an insulating coupling, and a metal pendulum as seen in Figure 6. A small magnet is attached at the upper end of the pendulum, which is closed to a Hall-effect sensor magnetically detecting a period of an oscillation. Another way we use to detect the oscillation is charging the pendulum by bringing a positively charged ruler near the rod and then touching the metal pendulum with a finger to obtain a negatively charged pendulum as illustrated in Figure 7. The electric charge will not leak from the rod according to an insulating coupling. After that, the sensing electrode of the proposed electroscope is put below the pendulum to detect a period. Here, we use oscilloscope to monitor the resulting signals from a Hall-effect sensor and voltage V_{r3} as shown in Figure 8. The blue and pink

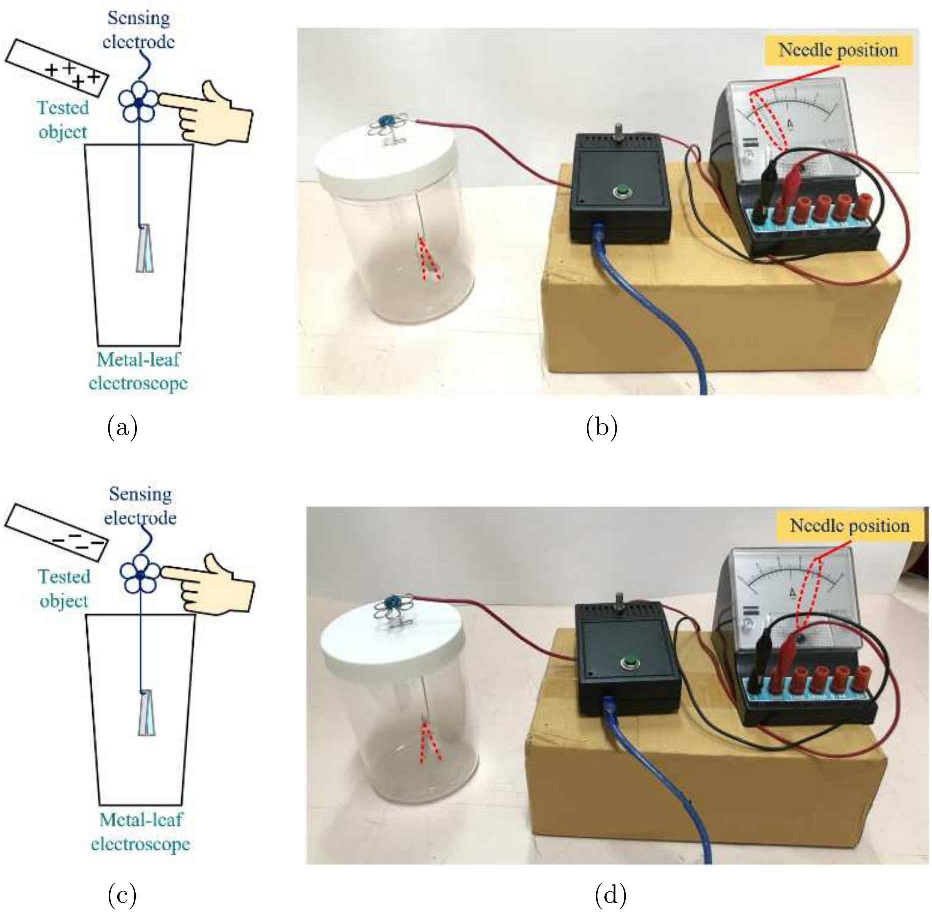


FIGURE 5. Detecting charge types of discharged metal leaf electroscope by our proposed electroscope when the tested object is positive (a) and (b), and negative (c) and (d)

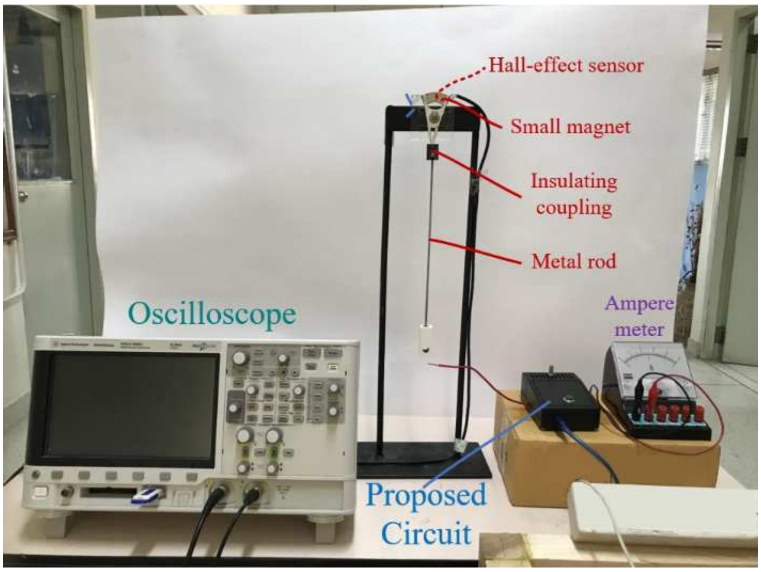


FIGURE 6. A pendulum system for oscillation

lines represent the signals from the Hall-effect sensor and the proposed electroscope (V_{r3}), respectively. The signals from both devices behave like sine waves. In Figure 8(a), the average of V_{r3} is lower than 2.25 V because of negative charges accumulated in the rod. Crests of V_{r3} correspond to the largest distance between a pendulum and the sensing

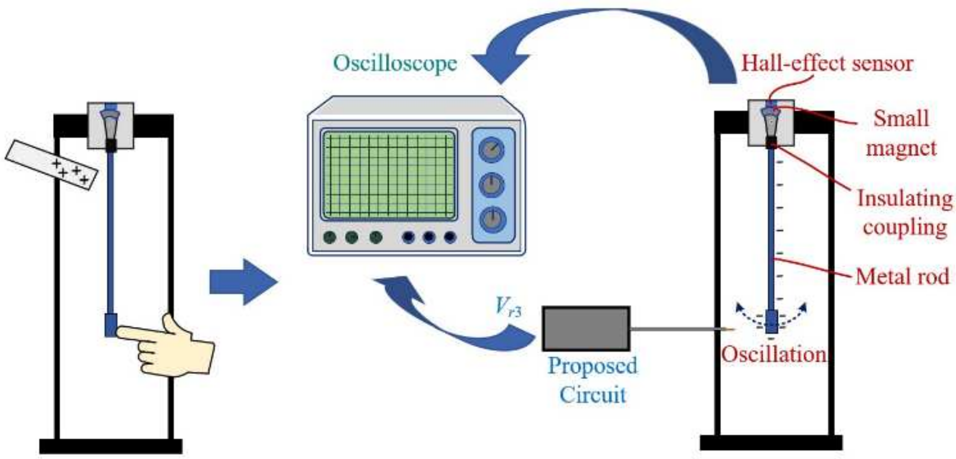
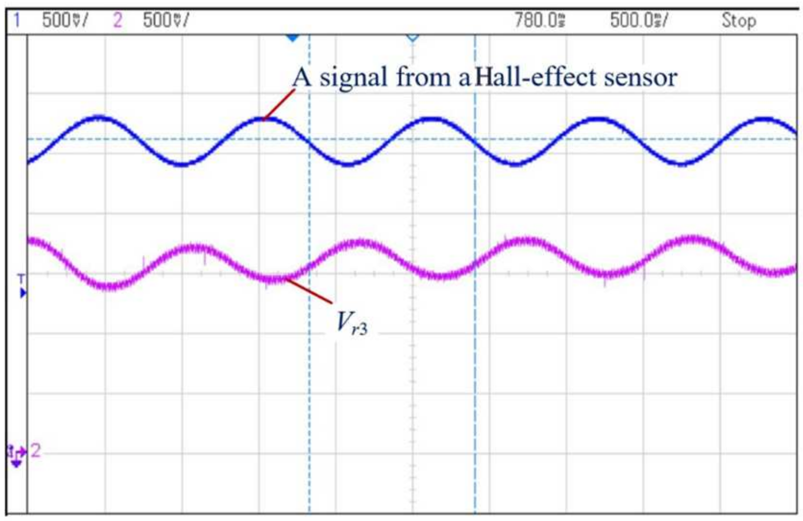
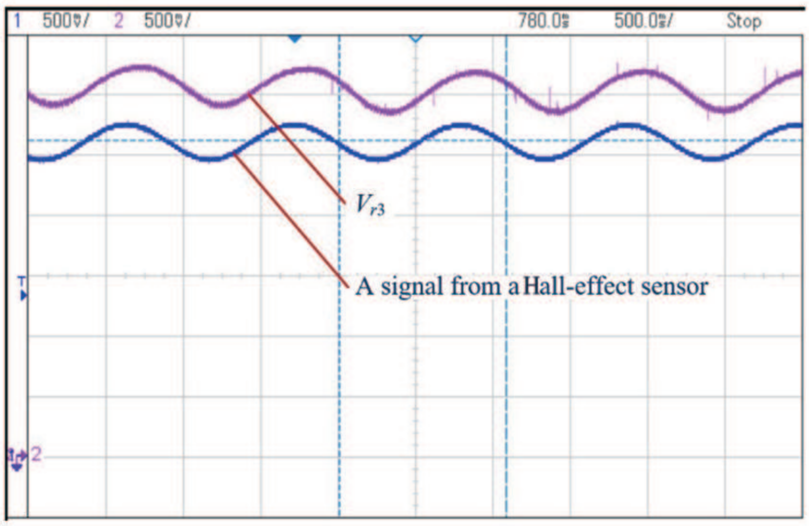


FIGURE 7. A diagram for measuring the oscillation



(a)



(b)

FIGURE 8. Oscillation detecting charge types of discharged metal leaf electroscope by our proposed electroscope when the tested object is positive (a) and negative (b)

electrode while the troughs of V_{r3} correspond to the shortest distance between them. Conversely, the average of V_{r3} is higher than 2.25 V due to the positive accumulated charges as seen in Figure 8(b). Crests and troughs of V_{r3} correspond to the shortest and largest distance between a pendulum and the sensing electrode, respectively. It is found that the periods of V_{r3} in both Figures 8(a) and 8(b) are equal to that obtained from the Hall-effect sensor. The results confirm that our designed device can be used to measure the period of a pendulum.

4. **Conclusion.** An electronic electroscope is designed, based on a single n-channel MOSFET together with the simple circuits for adding charges at the gate terminal and controlling voltage at the drain terminal. The results from the first two experiments show that the electroscope can identify types and quantities of charges on the tested objects. It can be also applied to the experiment of a physical pendulum. Although phases of V_{r3} due to a positive pendulum are opposite to that due to a negative pendulum, the periods achieved from them and the signal from the Hall-effect sensor are equal. This insists that our electroscope is able to measure a period of oscillation effectively. We hope that our proposed device will be applied to other physics experiment such as a simple pendulum and spring oscillation. Future research approaches include improving the circuit and calibrating the measurement results to be able to show the amount of charge in coulombs.

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