(For Counsellor's use only)

Grade . . . . Name . . . .

Evaluated by . . . . Enrolment Number . . . .

EXPERIMENT 6

DETECTION AND MEASUREMENT OF CHARGE USING AN OPAMP

Structure

6.1 INTRODUCTION

A transducer converts a physical variable into a suitable output. For example, a piezo-electric transducer converts mechanical pressure into an electrical signal, which can further be used to drive another circuit. On the other hand **an optoelectrical** transducer such as a **photodiode** gives an electrical signal when visible light shines on its cathode.
Varied examples **of such** transducers **can be** found **in our** day to-day life, right from a door buzzer to a gas lighter. Transducers are used to **measure** a physical parameter or to control it. Signals obtained from the transducers usually need amplification before measurement.

In this experiment, you will see how an electrical charge can be measured. Such a charge is generated by an electromechanical transducer.

You have already studied about **an operational amplifier (OPAMP) and** the various mathematical operations it can perform. You have also seen earlier the various opamp configurations.

Objective

- In the following experiment, we will use a circuit for an electronic system composed of three opamps to detect and measure the electrical charge such as that on a charged capacitor, or a charge generated by an electromechanical transducer.

6.2 APPARATUS

- 1 no. strong magnet
- 1 no. search coil of 300 turns, dia. 3 mm.
- 3 no. OPAMP 741
- 1 no. circuit board with resistors, capacitors and switches
- 1 no, transistor power supply, plus and minus 12 volts

6.3 STUDY MATERIAL:

6.3.1 Coil of Wire as a Transducer

The basic principle of an **electromechanical** transducer is that of electromagnetic induction, namely **generation** of an induced **emf in** a conductor (coil) caused by a change of **magnetic** flux linking the coil.

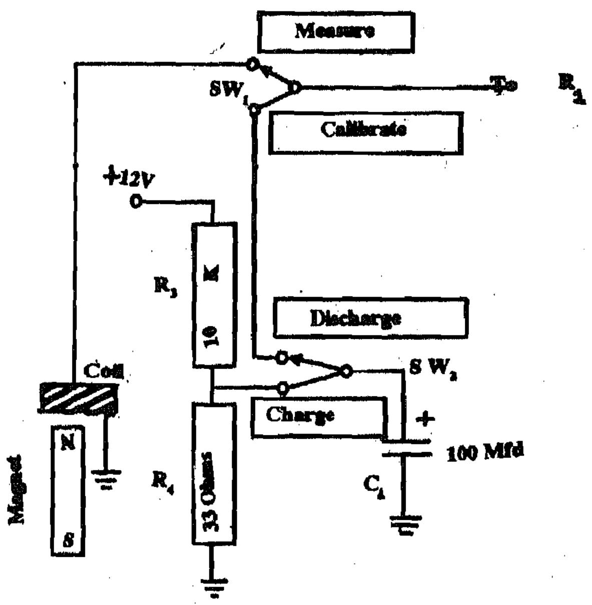

Fig.6.1

The magnet shown in Fig.6.1 is a magnet which can lift an iron nail from a distance of about 5 **mm**, and **hold** it vertically. When the magnet is moved **very** fast near the **search** wil an emf is induced in **the** coil. The emf in the coil, has an equivalent of charge Q, as explained **below. Faraday's** Law of Induction gives this **emf as the** following.

$$e_i = -N\frac{d\phi}{dt}$$

Where

$$\frac{d\phi}{dt}$$

is the rate of change of flux linked with the coil. N is the number of turns in the searchcoil. The negative sign indicates that the direction of the emf from this coil is such as to oppose the motion of the coil in the field. The charge amplifier measures the transferred charge Q in terms of the output voltage e_o.

6.3.2 Principle of the charge-measuringsystem.

The output from the transducer is in the formofvoltageinsomecases, and in the form of current in other cases. The output varies with time, and the total charge transferred during the process is the quantity of interest. The charge transferred (as indicated by the transducer) is easily found by integrating using an integrating circuit, which you have built and tested in a previous experiment.

If the transducer output is a voltage, it is simply amplified with a voltage amplifier and then sent to the input of a voltage integrator. If the transducer output is a current then it is first sent to a current-to-voltage circuit, whose output in turn is sent to the integrator.

Because of some inherent defects in the 741 opamps you will use, it is not possible to integrate over a very long time (more thana few seconds). So a separate sampling circuit is used to take the output from the integrator and keep it in storage for anextended time so that you can note the value conveniently.

6.3.3 Current amplifier, and current-to-voltageconversion.

The voltage signal that may come out of a typical charge-outputtransducer like a search coil will be of the order of a few ten of millivolts only. The voltage will usually last for only a few milliseconds, and is in the shape of a "triangular pulse" in many applications. This pulse has to be amplified by a voltage amplifier of gain about 1000. The circuit of a useful amplifier is shown in Fig.6.2.

Note tbat this is aninvertingamplifier, whose gain is determined by the resistors R_1 and R,. The value of R_1 is small when compared to the feedback resistor R_2.This combination is selected so thatthe input transduceris nearly short-circuited to ground through the 39-ohm resistor. This insures that the circuit will work as a current amplifier as well as a voltage-to-current converter.

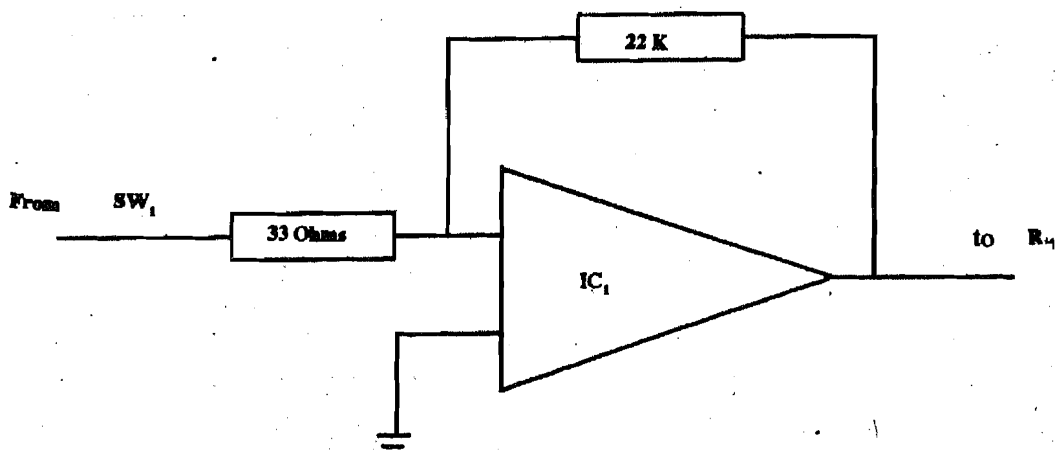

Fig.6.2

6.3.4 Voltage Integrator

The voltage integrator is designed using741 (IC2) Operational amplifier. The circuit is shown in Fig.6.3.

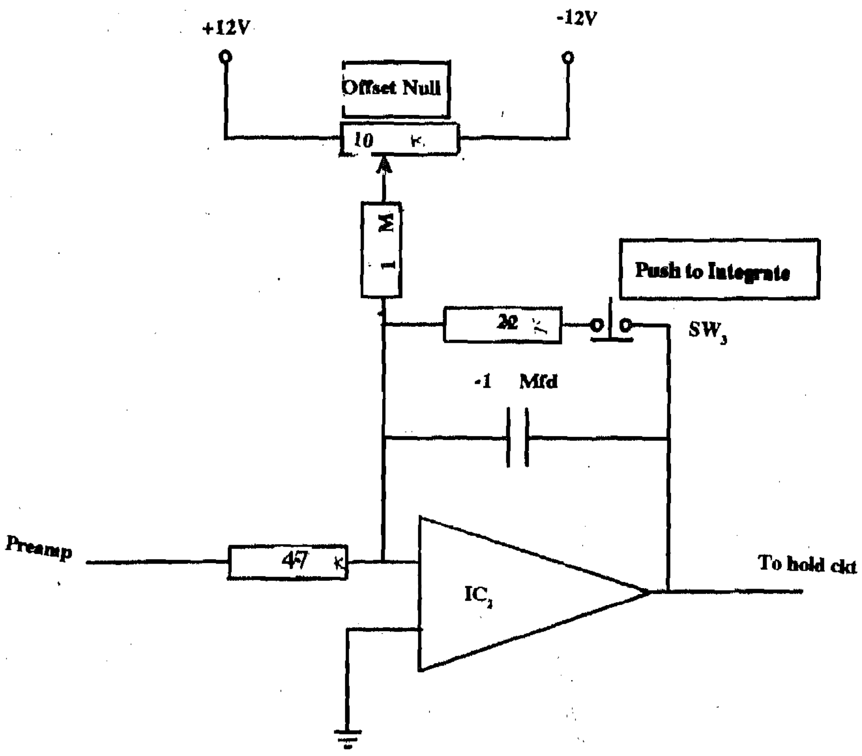

Fig.6.3

The amplifier has offset voltage of the order few millivolts. When used for a long time integration the offset is also integrated, sometimes completely masking the input. High quality Amplifiers like FET input Operational amplifier 740 will not pose this problem but are expensive. By doing the integration for a short interval of time and using an offset null circuit the following circuit is designed with operational amplifier 741 which is suitable for the experiments in this section.

The output of the integrator is given by

$$V_0 = \frac{R_2}{R_1 R_7 C_2} \int V_i \, dt$$

6.3.5. Holding circuit

The output of the integrator is used to charge the capacitor C_3 through a diode. The circuit is shown in Fig.6.4.

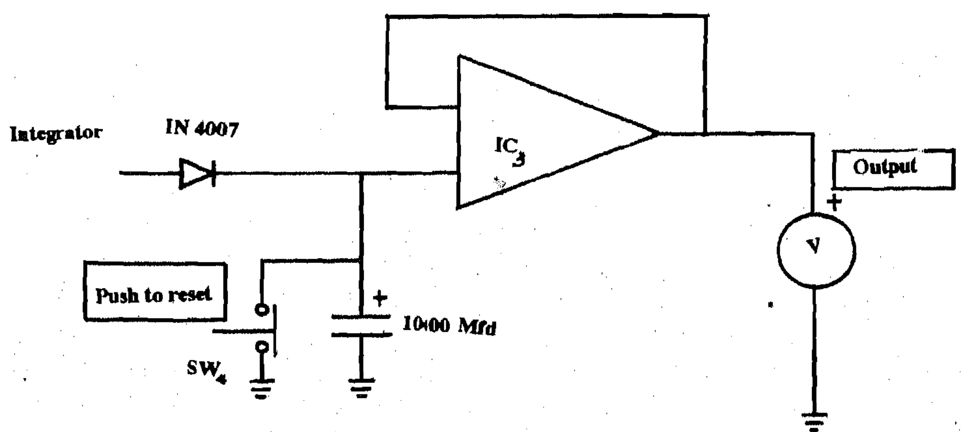

Fig.6.4

Thus the output of the integrator is copied on the capacitor. The integrator is then switched to the scalar mode as soon as the integration is over by releasing the switch SW,. The capacitor C_3 is prevented fmm discharging by the diode connected between output of the amplifier and capacitor C,. The voltage across capacitor C_3 is fed to a voltage follower made of IC3. The voltage follower output can be connected to any voltmeter.

SAQ.

What will happen if the voltmeter is connected directly to the capacitor C, ?.

....

....

....

....

6.3.6 Measuring the charge stored in a .capacitor.

The complete circuit diagram of the set up is given in Fig.6.5

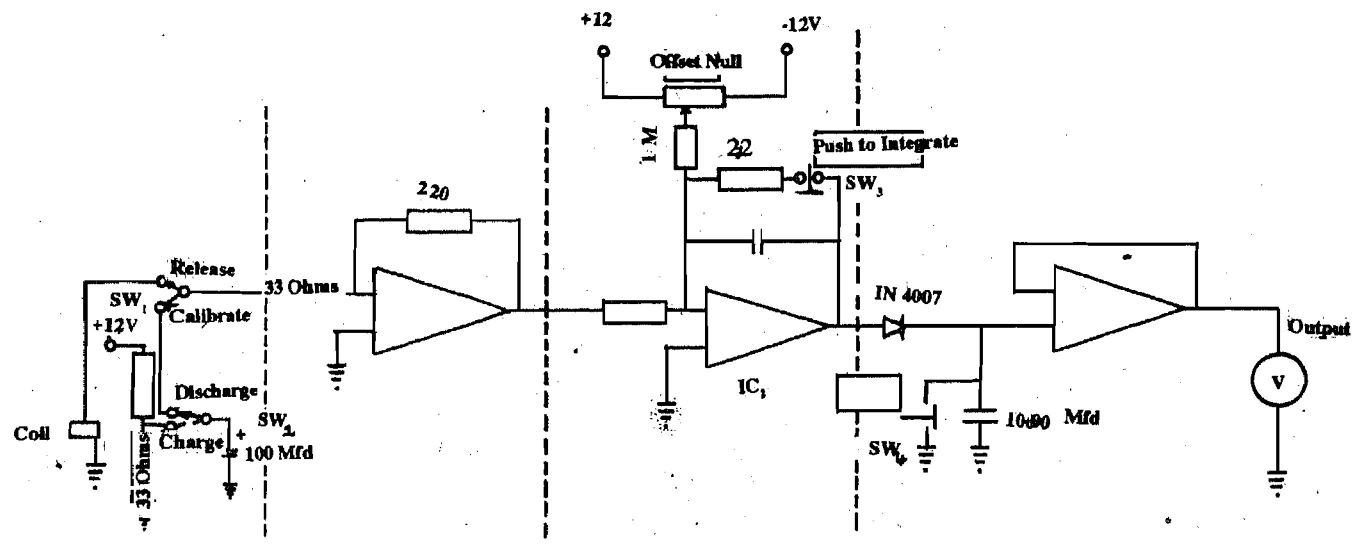

Fig.6.5

Note the potential divider circuit made of R_3 and R_4 which can be used to get few tens of millivolts. The capacitor is charged to 50 millivolts V_1 and discharged through the amplifier-integrator-sample circuit by pressingswitch. The output that shows up corresponds to a charge of Q given by

$$Q = C_1 * V_1 \text{ Coulombs}$$

where C_1 is the capacitance of the capacitor and V_1 the voltage (50 millivolts) to which the capacitor C_1 is charged. The charge sensitivity S of the circuit is calculated using the following expression.

$$S = (C_1 * V_1)/V_o \text{ Coulomb/volt}$$

To find the total amount of unknown charge transferred, the output due to the charge V_x is measured. Q_x the unknown charge is given by the following expression.

$$Q_x = V_x * S \text{ Coulomb}$$

The capacitance of an unknown capacitor is determined by charging the capacitor C_x to a voltage V_1 and discharging through the same circuit. If the output voltage in this case is V_x then the capacitance of the unknown capacitance is calculated using the expression which follows.

$$C_x = S*(V_x/V_1) \quad \text{Coulombs/volt}$$

6.3.7 Measurement of magnetic field strength.

When used with a search coil, the output corresponds to the time integral of induced voltage. The output in this case corresponds to the total magnetic flux that has linked the search coil.

$$Q = \int i\,dt = \int \frac{E}{R_1}\,dt = \frac{N}{R_1}\int \frac{d\phi}{dt}\,dt$$

Since

$$N\frac{d\phi}{dt} = -E; \quad Q = \frac{N\Delta\phi}{R_1}$$

Also $Q = V_xS ; \Delta\phi = AB$

Where A is the area of the coil and B is the magnetic flux density.

Comparing the expressions for Q we write the following.

$$V_xS = \frac{NAB}{R_1}$$

B the magnetic flux density is calculated from

$$B = V_x S \frac{R_1}{NA}$$

in Tesla.

6.4. PRECAUTIONS:

It is very important to choose an Operational Amplifier with very small bias current. Take care to discharge the capacitor before beginning the measurement.

6.5 PROCEDURE

6.5.1 Nulling the offset of the integrator

The offset of the integrator is nullified by the following procedure.

a. Put the calibrate switch **SW1** in CAL position

b. Hold down tbe inlegrate push switch SW3.

c. Watch the output. Adjust the offset potentiometer so that the output shows a steady but slow increase. Discharge the capacitor by pressing the rest switch SW4. Adjust the offset so that the variationat the output is still slower. Repeat steps band c until the outputstays at zero when you hold the integrate switch down. This offset adjustment need not be carried out every time you use the circuit, because the settings will stay fixed for a long time.

6.5.2 Calibration of the circuit.

The amplifier is calibrated by discharging a known quantity of charge. By this means the charge sensitivity is measured.

a. Discharge the capacitor by pressing **SW2** while holding the integrate key down. Then release the integrate switch. Note down the out put and enter in the TABLE 1.

TABLE 1.

Capacitance in microfarads	Input V_1 in volts	Output V_0 in volts	Charge Sensit. in Coul./volt

Repeat the measurement with an unknown capacitor of capacitance C_x by replacing the capacitor C_1 with C_x. The capacitor C_x is charged and then discharged. The output V_x is noted down and entered in the TABLE 2. given below.

TABLE 2.

Input V_1 in volts	Output V_x in volts	Capacitance C_x in microfarads

Repeat the measurements with series and parallel combinations of capacitors and verify the law of capacitor combinations. Enter your findings in TABLE 3.

TABLE 3.

Input V_1 in volts	Output V_x in volts	Capacitance C_x in microfarads

6.5.3 Magnetic Flux Density Measurement

a. Put the CAL switch in MEASURE position.
b. Move a magnet into the search coil while holding the integrate switch down.
c. Note down the output in volts and enter the value in the TABLE 4.

TABLE 4.

Coil and Magnet movement	Output V_x in volts	Flux density B in Tesla (calc.)

SAQ

When you move the magnet very very slowly you do not get any output even though the same amount of flux has been linked. Explain how the circuit is not able to follow very very slow change in the magnetic fields.

....

....

....

....

6.6 CONCLUSIONS

You have noticed the properties of integrating a charge pulse signal in this experiment. The integral of the pulse is proportional to the total amount of charge that has flowed through the coil. Hence you can measure the charge flowed through a circuit. You have also measured the magnetic field density that existed near the search coil.

SAQ

1) Compare Fig.6.3 with the integration circuit provided in the experiment on OPAMP **INTEGRATION** and note down the similarities and differences.

....

....

....

....

2) Replace the 741 Opamp with **FET** (740) **Opamp** and note down the performance, **compared** to the 741.

....

....

....

....

3) Leave the circuit for a longtime, **say** about 10 minutes, and watch the dutput. Give a reason for the behavior you observe.

....

....

....

4) If you feed 50mV AC through the input, what do you expect at the output? Could you estimate the AC voltage?

. . . .

. . . .

. . . .