Practical 2P12
Semiconductor Devices

What you should learn from this practical

Science
This practical illustrates some points from the lecture courses on Semiconductor Materials and Semiconductor Devices concerning the operation of bipolar transistors and integrated circuits.

Practical Skills
You will gain experience in constructing very simple electronic circuits using breadboard, voltage power supplies, using LabView to generate and read signals, and characterising circuits using digital multimeters (DMM’s).

Overview of the practical
This practical has two elements:
(1) to investigate the electrical characteristics of a bipolar transistor,
(2) to study some of the basic electrical characteristics of a standard type 741 integrated circuit operational amplifier, using a LabVIEW assisted DAQ (Data acquisition) card and oscilloscope, to generate and measure the medium frequency signals.

Experimental
(1) Investigation of the electrical characteristics of a bipolar transistor
You are provided with a BU406 power transistor, a prototype board, a power supply, a 1 kΩ resistor, three DMM’s and some lengths of wire. The
BU406 is an npn transistor and its circuit symbol is shown in fig. 1. It can be considered to be composed of a “sandwich” of three adjacent layers of differently doped semiconductor, in this case silicon. For an npn transistor, the first layer, called the emitter, is heavily doped n-type, next to this is a very thin layer of p-type material known as the base, and the final layer, again n doped, is the collector. In this way the device can be thought of as two back-to-back pn junctions. Under normal operating conditions the emitter base junction is forward biased which in this case entails making the emitter more negative than the base, whilst the base collector junction is reverse biased which is achieved by making the base more negative than the collector.

Figure 1:

The prototype board is used to construct simple electronic circuits quickly without the need for making soldered joints. Electrical connections are made by pushing wires into the holes in the surface of the board. The holes in the board are arranged in rows with all the holes in any given row electrically connected to each other whilst being electrically isolated from all other holes on the board. There are 94 rows each with 5 interconnected contacts on the board you are provided with. Electrical contact between wires is achieved simply by pushing them into holes which lie anywhere in
the same row on the board. The next set of electrical contacts can then be made by using holes in another row of the board and so on until the circuit is completed. An scheme of a typical prototyping (bread) board is given in Fig 2, together with a colour code chart to select resistor correctly.

Figure 2:

![Prototyping board with color code chart]

Eg: 2000 ohms.

**Experimental Procedure**

a) Measure the I-V characteristics of the emitter base junction of the transistor by constructing the circuit as shown in Figure 3. DO NOT apply more than 10V reverse bias otherwise the transistor will be destroyed.

Figure 3:

![Experiment circuit diagram]

**Note:** the input resistance of the DMM when configured to measure voltage is 10MΩ.
Use your data to compare the characteristics of the junction with those predicted by the ideal diode equation:

\[ I = I_0 \left[ \exp \left( \frac{qV}{kT} \right) - 1 \right] \]

Try to give reasons for any differences that you find.

b) Verify that the I-V characteristics of the collector base junction are similar to those you have just measured for the emitter base junction. (No more than 30 data points are required). Figure 4:

c) Investigate the behaviour of the transistor by constructing the circuit shown in Fig 5. In this case use the BU406 transistor with the large heat sink attached. Verify the relationship \( I_e = I_b + I_c \) for the currents flowing respectively in the emitter, base and collector. Note that a relatively small current in the base of the transistor can be used to control a much larger current through the collector. For a power transistor such as the BU406 this allows relatively large power dissipation loads to be driven.
CAUTION: The transistor, resistor and load will get HOT during these measurements! Do not leave on for periods of more than approximately one minute.

(2) Investigation of the electrical characteristics of an op amp

The industry standard 741 integrated circuit operational amplifier chip is available from many manufacturers in the usual plastic encapsulation, which we use in the bench test box. The actual silicon chip contains 20 transistors, 11 resistors and a few capacitors.

The standard circuit symbol for an op amp is the triangle, with the various connections shown in Fig.6. In the usual top view of the plastic encapsulated version there are 8 pins numbered in an anticlockwise sequence starting from the top left corner, which can be identified by the notch in the ‘top’ of the package and the indent spot against pin 1. In the 741 frequency compensation is internal and pins 1 and 5 for offset null are rarely required, making this circuit very easy to use at medium frequencies, such as audio applications. The power connections are usually plus and
minus 15 volts from a stabilised power supply, and the input and output signals can then be up to ± 12 volts, at low (mA) current.

Figure 6:

The three basic applications - there are hundreds of others - use negative feedback for stable and predictable performance; see figures 9 and 13. A proportion of the output signal determined by the choice of feedback resistor $R_f$ is feedback to produce, as far as possible, a zero voltage difference between the two input terminals of the amplifier. The gain of the amplifier depends on the mode of connection (whether inverting etc.) and the value of the input ($R_1$) and feedback ($R_f$) resistors.

You are given with:

(i) A few 741 operational amplifiers, wires and assorted resistors.
(ii) A stabilised power supply (CAUTION: BOX CONTAINS MAINS VOLTAGES) for the internal circuitry with external connections.
(iii) A standard breadboard to construct the circuit, which will consist: Op-Amp configurations, voltage divider, connection to the power supply, and DAQ (Data acquisition card).

**Experimentation**

1. Your first task is to use LabView software (you should already be familiar with the basics of using LabView) and DAQ (Data acquisition) card to generate digital square waveforms. Open Labview and build the circuit illustrated in Figure 7 to generate a square 5 volts wave signal.

Figure 7:

![Figure 7: DAQ Assistant and LabView software](image)

**Hint:** The DAQ Assistant path is illustrated here. The small block before Data input in the DAQ assistant is called ‘Build Array Function’. Once you place
2. We would like to convert 5 V square wave to 0.5 V. Next construct the voltage divider shown in Fig 8 using the bread board, where the input voltage (Vin) is the Digital Output, Port 0, Line 0 from your acquisition card. Use R1=10 kOhm, R2=1 kOhm. Once finished call the TA and ask for the waveform to be tested using the oscilloscope.

Figure 8:

![Voltage Divider Diagram]

3. The first typical configuration of an operational amplifier that will be investigated is the voltage follower. Using the breadboard, some small wires, and the voltage power supply construct the circuit in Figure 9. To help you familiarise yourself with the way this circuit can be built in a breadboard please refer to Figure 10.
4. You will now add to your LabView program a data acquisition (DAQ) box used to visualise the signals you are generating. Additionally you can add a ‘Wait’ box to modulate the frequency of your square wave. This is shown in Figure 12. Once you have done this, use a cable to connect the Vout from your voltage follower in (3) –i.e. Figure 10, to the Analog Input 0 (AI0) of the acquisition card. Remember to connect the GND or reference wire to the (-) or GND input in the DAQ card.
Figure 12:

Hint: This time when you add the DAQ assistant box select Acquire signal, Analog Input, Voltage, AI0.

5. If successful in acquiring 0.5 V pulses, and isolating the signal using a voltage follower, you will now be connecting the output from the voltage follower (Vout in Fig 10) to the input of the two configuration of OPAMP in Figure 13. First the non-inverting one, and then with the inverting. Use Figure 13 as guidance of how to build your circuits in the breadboard. Use R1(Rin) = 2 kΩ. For these, you will select at least six resistor values in the range 2.2kΩ to 50kΩ as the feedback resistor Rf(R2). For accurate results measure the exact value of each medium tolerance resistor used for Rf - and remember that your hands have finite resistance! For each value of Rf use your LabView script that acquires the waveforms on the Analog Input 0 (AI0) to measure the output voltage (V_o) and thereby to determine the gain (G = V_o/V_i), in each mode of operation. Hint: The data acquired by your Labview software can be exported to excel by right clicking on the chart.
Plot the gain (G) against the resistance ratio ($R_f/R_1$; $R_f > R_1$) and establish the (medium frequency) gain relationship(s) for the inverting and non-inverting configurations. Estimate the accuracy of your measurements and include a diagram of the interconnections used to obtain the data. For example Figure 9. What happens if you change the ‘milliseconds to wait’ box to 1000ms?

**Visualising electrical signals:**
An oscilloscope can acquire signals in real time. We have asked you to use LabView instead, in order to give you a taste of LabView’s application. Since there is only one oscilloscope available, when you get to points 3, 4 and 5 in this guide you can ask the assistant to please bring the oscilloscope and probe your signals. We will demonstrate how and oscilloscope can be used after you have the above tasks completed.

For your convenience, it would be useful to repeat point (4) in the procedure to add another Analog Input, for example in the AI2 channel. This way you will be able to acquire both the input and the output signals such that you can compare them and obtain the gain.
Rough timetable

Day 1: Electrical characterisation of the bipolar transistor and write up
Day 2 & 3: Characterisation of the op amp and write up.

The report

Aims: State clearly what the experiments aim to find out.
Methods: Explain in bare detail what you did.
Results: Describe what you observed at an appropriate level of detail.
Discussion: Explain your results. Make sure you have answered the questions posed in the text.

Sum up.

A good length would be about 1000 words. Do not write more than 1500 words.

References