A. Opamps

The objective of this work is to remind you the methods of calculation of circuits with operational amplifiers, and to continue to train you in LTSpice. When you encounter an opamp circuit, before starting any calculation, you should ask yourself 2 questions:

- Is it a known assembly: inverting amp, non-inverting amp?

- If not, can I reduce it to one of these two circuits? This is often possible by applying the principle of superposition, i.e. by calculating separately the contribution of each source present in the circuit.

It consists of 2 parts:

- A first part with 5 exercises.

- A second part dealing with simulations with LTSpice.

PART 1 : theory

NB1: except for the second point of exercise 5, the opamp is supposed to be ideal to realize the calculations.

NB2 : the opamps are supplied between +15V and -15V.

NB3 : when requested, the theoretical calculation must be verified with LTSpice. The simulations will be performed using the "UniversalOpamp2" model in the [Opamps] directory, with the simulation mode "transient" or continuous (DC op pn = DC operationnal point).

Exercise 1

In the circuits of figure 1, calculate the value of the voltage V. Use LTSpice to check your results.

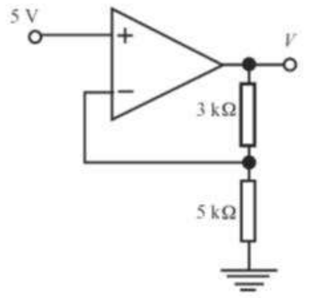
Exercise 2

In the circuit in Figure 2, calculate the values of V1 and V2. Use LTSpice to check your results.

Exercise 3

The circuit in Figure 3 measures light intensity using a photodiode. The latter, polarized in reverse, produces a current of 0.5μA per μW of incident power. Determine the value of R for which the sensitivity of the conditioner is 0.4mV/μW. Verify your result with LTSpice by replacing the {photodiode, voltage source} assembly with a suitable element.

a.



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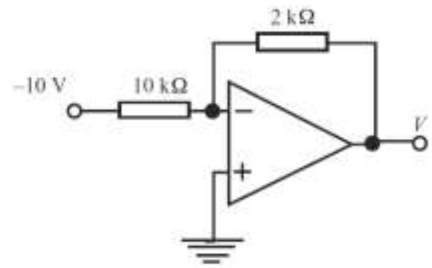

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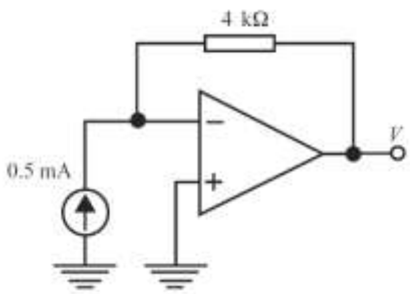

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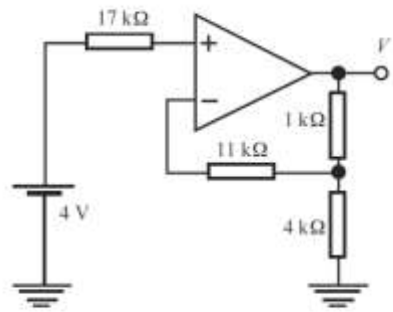

e.

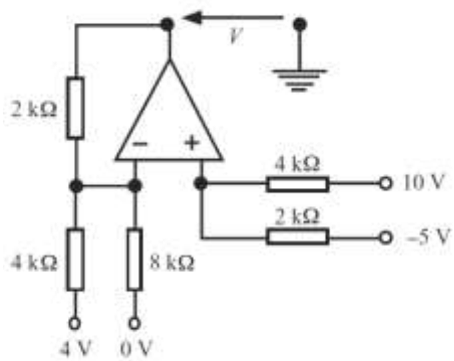

Figure1

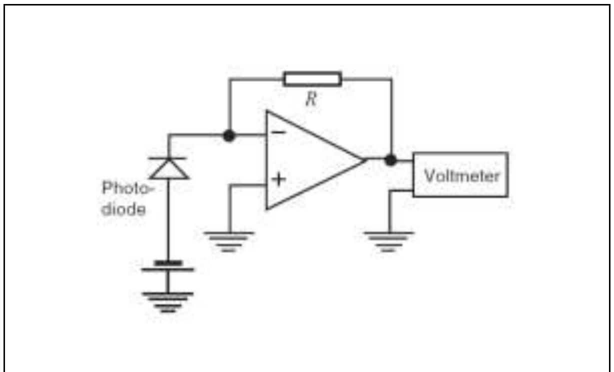	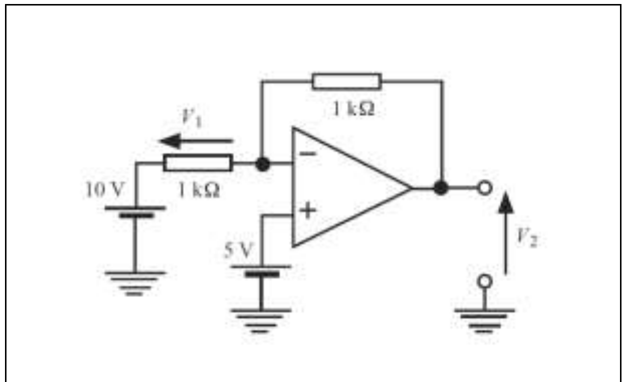
Figure 3	*Figure 2*

Exercise 4

In the circuit of figure 4, give the expression of Vo as a function of V1 and V2. Under what condition on resistors R1 to R4 is there a differential amplifier?

Exercise 5

For the circuit in Figure 5, express the relationship between Vs and Ve :

a. In the case of an ideal opamp.
b. Taking into account the input currents i+ and i-, as well as the offset voltage, denoted ed.

Assuming that the input currents are identical, for what value of R3 can the error due to these currents be cancelled?

NB: in the non-ideal case, we can reason by superposition to easily identify the contribution of each voltage/current.

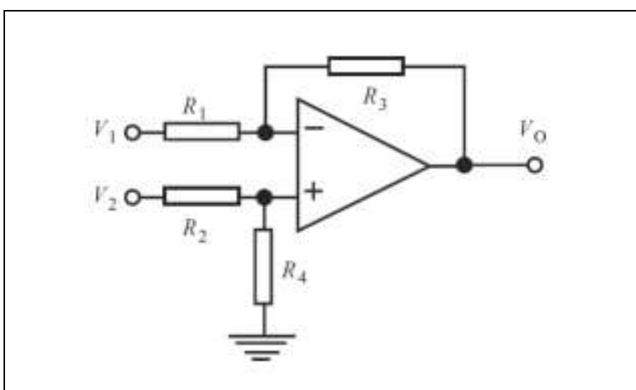	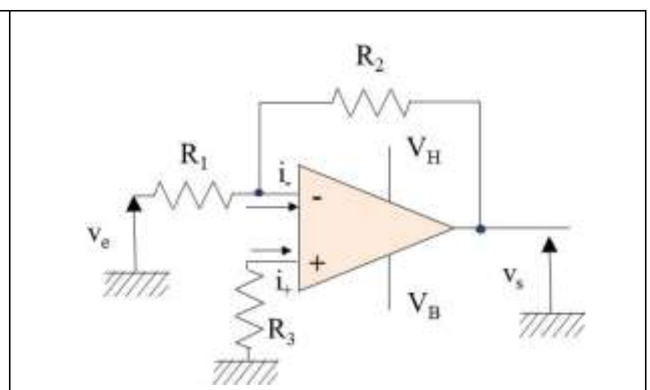
Figure 4	*Figure 5*

PART 2 : simulations

In these simulations, we will work with the UA741 opamp model. This model is not installed in the LTSpice library, so the following procedure must be followed to use it:

- Download the "UA741.301" file available on Moodle.
- In LTSpice, add the Spice directive to include this model : .op button on the right of the toolbar, then type: .include file directory.
- In the [Opamps] directory, search for opamp2. This is a blank template to which you can assign the parameters of other opamps.
- Right click on the opamp, write UA741 in the Value line, then click OK.

The UA741 template is now ready for use.

1. Bandwidth

The objective is to verify the invariance of the GBP gain-bandwidth product. To do this we will use the AC simulation mode

a. Simulate the opamp as buffer. Determine its cutoff frequency and its GBP product.
b. Compare with the A741 data sheet.
c. Do the same with an inverting amplifier of gain 10, then of gain 100.
d. Repeat the previous question with a non-inverting amplifier.
e. Conclude.

2. Summing, subtracting

Simulate the response as a function of time of 2 assemblies:

- A summing amplifier of gain -10.
- A differential amplifier of gain 10.

Smartly choose the 2 input signals to show easily the good operation of the circuit.

B. Instrumentation amplifier

PART 1: theory

Exercise 1

We wish to amplify a DC differential voltage (e1-e2) across the resistor r (see figure 1). For this purpose, we propose to use a differential amplifier with a differential gain Ad=10 and a common mode rejection ratio 20log(MCRR)=80[dB].

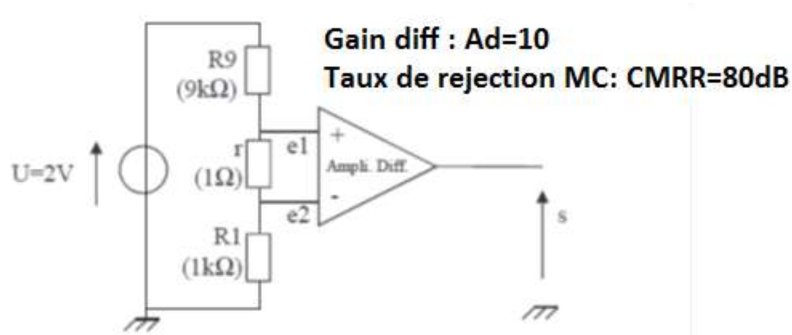

Figure 1

a. Recall the expression for the output s of the differential amplifier as a function of Ad and the common mode rejection ratio CMRR. What are the common mode rejection ratio CMRR and the common mode gain Amc of the differential amplifier?

b. Express and calculate the differential voltage Ud and the common-mode voltage Umc at the input of the amplifier as a function of U, R1, R9 and r.

c. What is the value of the voltage measured at the output of the amplifier? What is the measurement error?

d. Swap the two resistors R1 and R9; repeat questions b and c. Only one of the values is changed; which one?

Exercise 2

We wish to establish the expressions of the differential gain Ad and of the common mode rejection rate CMRR of the assembly below (Figure 2). We consider at first that the op-amp is ideal.

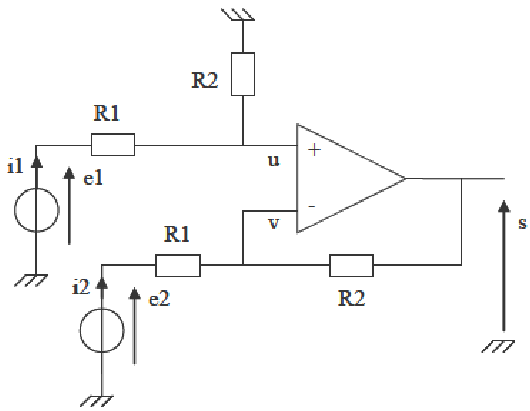

Figure 2

a. Write the equations of the circuit which will allow to determine s as a function of e1 and e2. Deduce the expression of s as a function of e1 and e2 and resistors. What is the expression of the differential gain, noted Ad, of the circuit ?

b. We now consider that the gain G of the op-amp is not infinite.
   a. Express s in the form s = Ad'.(e1-e2) by identifying Ad'=f(Ad,G).

We consider now that : $= \frac{G_0}{1+j\frac{\omega}{\omega_c}}$ with G0 >>1+Ad

c. Express Ad' in the form:

$$Ad' = \frac{Ad'_0}{1+j\frac{\omega}{\omega'_c}}$$

d. By identifying Ad'0=f(Ad) and 'c=f(Ad,G0,c), calculate the bandwidth of the assembly knowing that the figure of merit of the op-amp is F1=1[MHz] and Ad=9.

Exercise 3 : instrumentation amplifier INA128

We want to design an electronic system for the detection of heart activity signals (ECG electrocardiogram). The ECG signals are collected by several electrodes. They are placed on the skin at different places of the body. The complete diagram of the system is shown below (Figure 3):

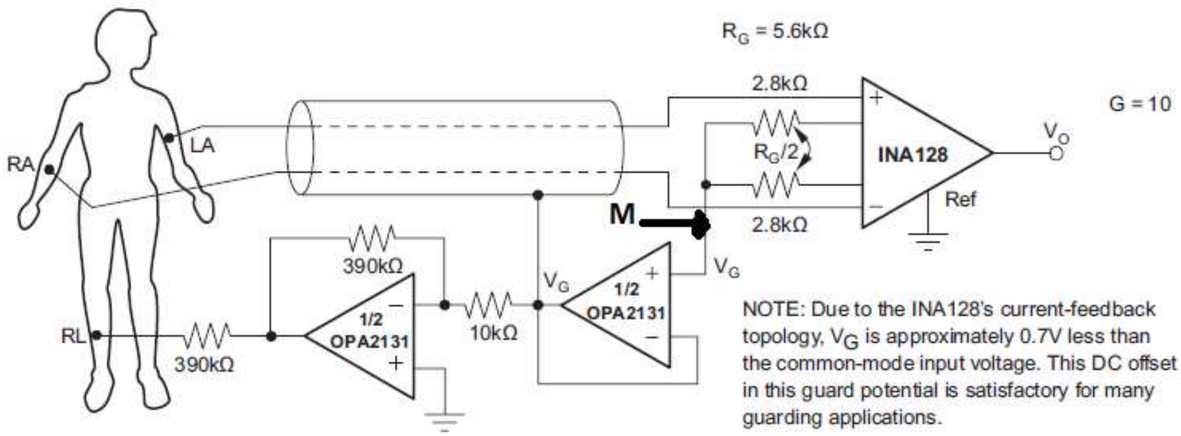

Figure 3

We use 3 electrodes: two electrodes, P1 (LA) and P2 (RA), are placed on the subject's arms and a reference electrode P3 (RL) placed on the right foot which will serve as a ground electrode (the patient will be connected to the circuit's ground). The voltages provided by the electrodes are p1 = 301 mV and p2 = 300 mV. The signals of interest are differential. In other words, the clinical information is contained in the difference in potential (p1-p2). The level of the differential signals is about 1 mV. These signals must be amplified. We set a total gain of about 1000. In our application, the bandwidth of interest of the ECG signals is between 0.2 Hz and 20-30 Hz approximately. We will study here the instrumentation amplifier setup.

This setup is based on the INA128 integrated instrumentation amplifier (see data sheet). Figure 4 shows a simplified diagram for this assembly (the power supply pins are not shown and the M point is disconnected):

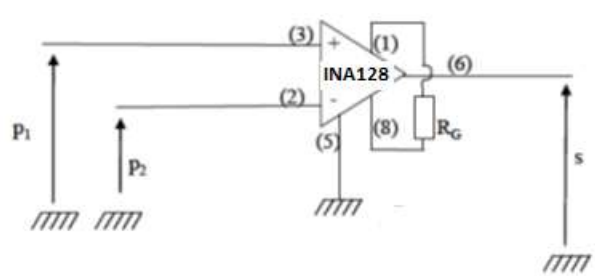

Figure 4

a. Write the equation of the amplifier output: s= fct(Ved=p1-p2, Vec=p1+p2, Ad, CMRR)

b. Based on the data sheet of the INA128 component (see appendix) or on your course, give the equation that allows to set the differential gain Ad. Calculate the value of RG that allows to have a differential gain Ad of about 50.

c. For the previously calculated gain Ad, give, based on the data sheet, the typical range of values in which the value of the common mode rejection ratio CMRR of the amplifier lies.

d. Choose the minimum value of the range determined previously. Deduce the value of the corresponding CMRR which is used in the output equation of the amplifier.

e. Calculate the measurement error due to the common mode (for the value of Ad and CMRR calculated previously).

f. The source impedance of electrodes P1 and P2 (placed on the skin) is typically some 100 k. What essential characteristic must the amplifier have and why? Give the value of this characteristic from the data sheet.

g. In what range of values is the value of the cut-off frequency?

PART 2 : simulations

a. Simulate in LTSpice the AI circuit corresponding to the internal schematic of the INA 128, using the "UniversalOpamp2" AO.

b. Set the external resistor RG so as to obtain differential gains of 10, 100 and 1000.

c. Display the differential and common mode gain as a function of frequency, choosing a frequency band wide enough to observe the differential gain cutoff frequency. What do you observe for each of these gains?

d. Compare the values of differential gain, CMRT, and cutoff frequency with the data sheet and comment on the differences.

e. Concerning the TRMC, propose a solution so that the simulated values are close to those in the datasheet.