Electronics 1 Lab (CME 2410)

School of Informatics & Computing
German Jordanian University

Laboratory Experiment (9)

Operational Amplifiers Characteristics

1. Objective:

To be familiar with Operational Amplifiers there configurations and the parameters CMRR and Slew-Rate.

2. Theory:

The Operational Amplifier (O.A. or OpAmp) is the most important and the most used among the linear integrated components.
It is an amplifier characterized by:

- high gain
- high input impedance
- low output impedance
- DC amplification

The word "Operational Amplifier" originates from the fact that at the beginning of integration technology this circuit was used in the analogical computers to carry out mathematical operations on electrical signals.
The O.A. is available in different kinds of containers among which the 8 pins-mini-DIP is very common (mini dual in line package) -see data sheets.
The symbol generally used to represent the O.A. is the one shown in Fig. 6.1. In most displayed circuits the supply voltages are omitted to get a clear schematic.

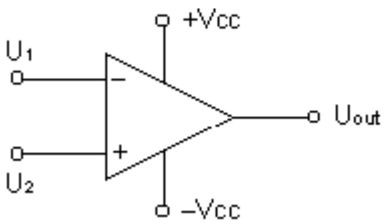


Figure 6.1

where:

U_1, U_2 represent the input voltages to ground

U_{out} represents the output voltage to ground

± V_{CC} represent the supply voltages of the integrated circuits.

The most important O.A. parameters are:

1) CMRR: **C**ommon **M**ode **R**ejection **R**atio
2) Vos : Input Offset Voltage
3) SLEW-RATE

In particular we will consider the integrated **µA741**

1) CMRR

The O.A. quality is specified by the Common Mode Rejection Ratio:

$$G = \frac{A_d}{A_{cm}}$$

where
A_d = differential amplification,
A_{cm} = common mode amplification.

The ratio is generally expressed in decibels (dB):

$$\text{CMMR} = 20\ \text{dB} \cdot \log \frac{A_d}{A_{cm}}$$

As theoretically we have $A_{cm} = 0$ (ideal case) we should get a ratio of $G = \infty$.
Really, because of building asymmetries, A_{cm} is slightly different from 0, and as a consequence the ratio will not be infinite but it will have in any case to result very high.

The typical value for the µA741 is of CMMR = 95 dB (80 – 100 dB).

2) V_{os} (input offset voltage)

In a structure of differential kind the output should be zero if the inputs are the same:

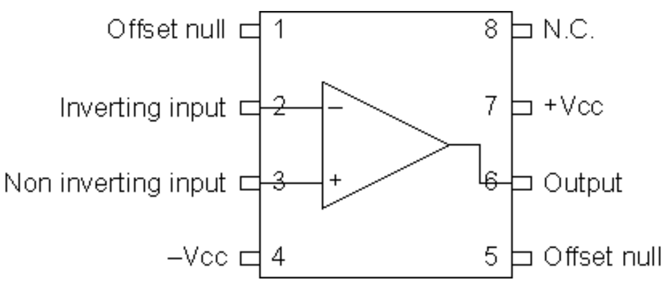
$$U_2 = U_1 \Rightarrow U_2 - U_1 = 0 \Rightarrow U_{out} = A_d \cdot (U_2 - U_1) = 0$$

however, because of technical problems, a small output voltage is always present.

The data sheets report as value V_{OS} the voltage that has to be applied to the input terminals to get the output voltage null.

For the µA741 we have $V_{os} \approx 2$ mV.

The µA741 (and most of the integrated operationals) has two pins (1 and 5) "offset null" to which it is possible to connect a potentiometer whose regulation allows getting the O.A. output to zero (Fig. 6.2 and Fig. 6.3).



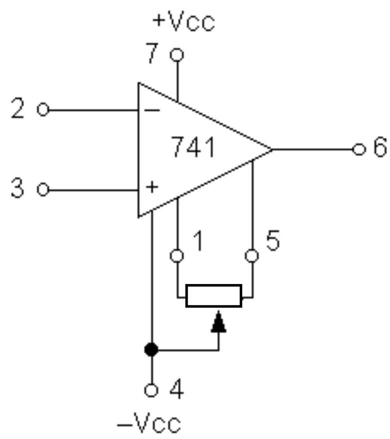


Fig. 6.2: Connections of the µA741 Fig. 6.3: V_{OS} compensation

3) SLEW-RATE

It represents the quickness with which the O.A. answers to a step pulse. We define:

$$SR = \frac{\Delta U_{out}}{\Delta t}$$

(the typical value of the µA741: SR = 0.5 V/ µs).

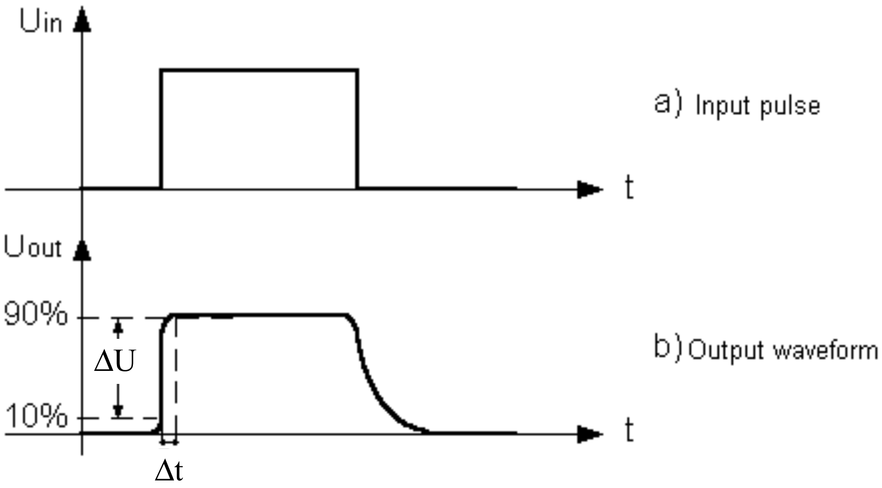


Fig. 6.4

ΔU is measured (for convention) between the 10% and the 90% of the amplitude of the output signal (see Fig. 6.4-b).
In a U-t diagram the SR represents therefore, as we can see, the straight line slope.
Generally, the features of the output signal that can determine some problems bound to the SR are:

- a too high amplitude
- a too high frequency

Let's consider for example the two signals 1 and 2 with the same frequency but with different amplitude (Fig. 6.5)

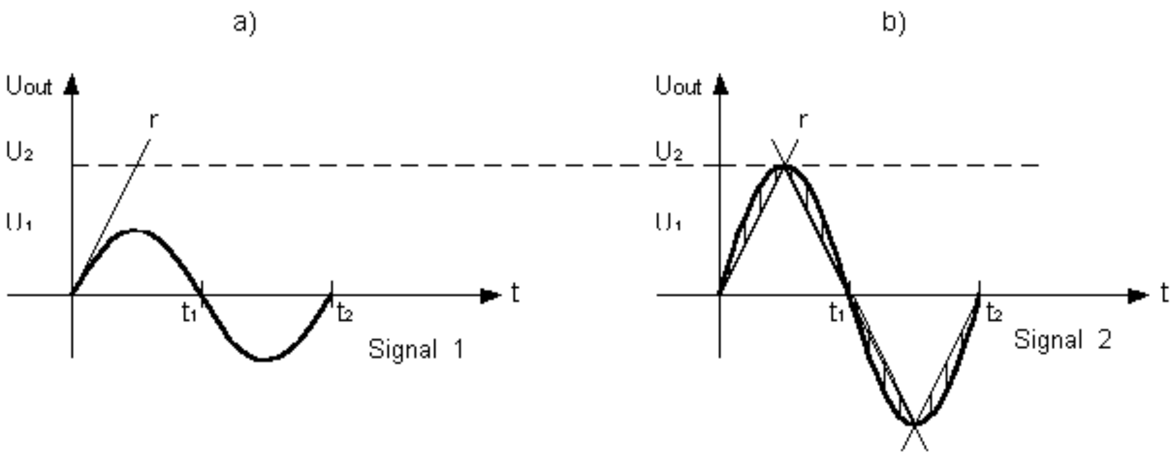


Fig. 6.5

The straight line r with the slope determined from the SR = ΔU / Δt :

- if r doesn't intersect the waveform (Fig. 6.5-a) we have no output distortions;
- if instead the straight lines intersect the waveform (Fig. 6.5-b) then the output signal will be

delta, i.e. bound to the straight line r trend.

Let's consider now two signals of the same amplitude but with a different frequency.

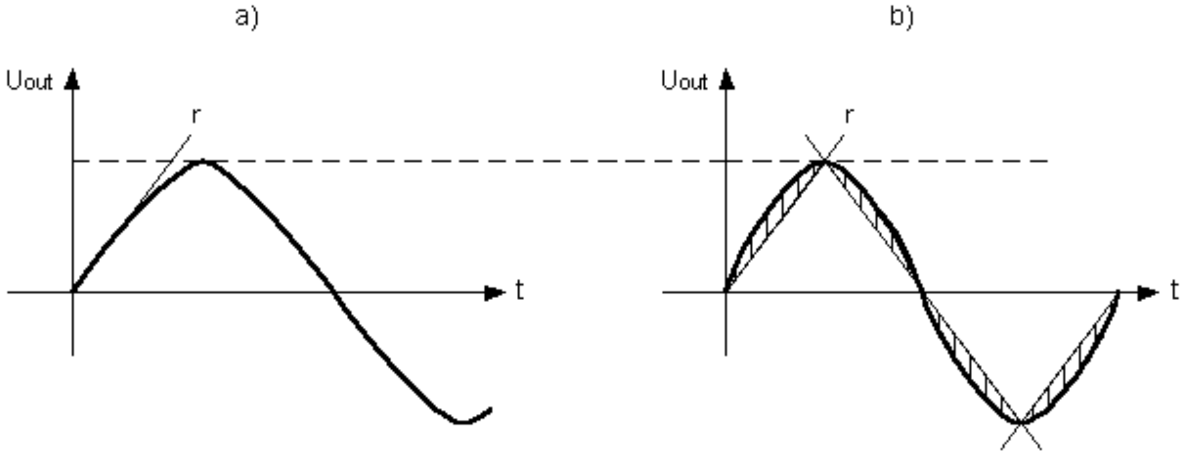


Fig. 6.6

In the case of Fig. 6.6-a we have not any distortion bound to the SR, while in the case of Fig. 6.6-b the distortion is present since the signal frequency is too high.

The SR determines the maximum O.A. operation frequency $f_{\max}$. Appling the definition of SR to the sinusoidal function $u(t) = \mathrm{U}_{\max} \cdot \sin(2\pi f \cdot t)$ we get:

$$\mathrm{SR} := \frac{\Delta U}{\Delta t} = \left.\frac{du(t)}{dt}\right|_{\max} = \mathrm{U}_{\max} \cdot 2\pi \cdot f_{\max}$$

$$\underline{f_{\max} = \frac{\mathrm{SR}}{2\pi \cdot \mathrm{U}_{\max}}}$$

3. *Equipment & Instruments*

- Module No. : DL 3155M16
- Function Generator
- Oscilloscope

4. *Components List:*

See values in the units you are using.

5. *Calculation data:*

- Inverting O.A. (
  Gain or voltage amplification: $A = - R_f / R_i$
- Non-inverting O.A. (
  Gain or voltage amplification: $A = 1 + R_f / R_i$

6. Procedure (PART 1):

1. Use Module 16 unit (1) and set the main switch to ON;

<u>INVERTING O.A.</u>

2. connect the signal generator and the oscilloscope as shown in Fig. 6.7-a;

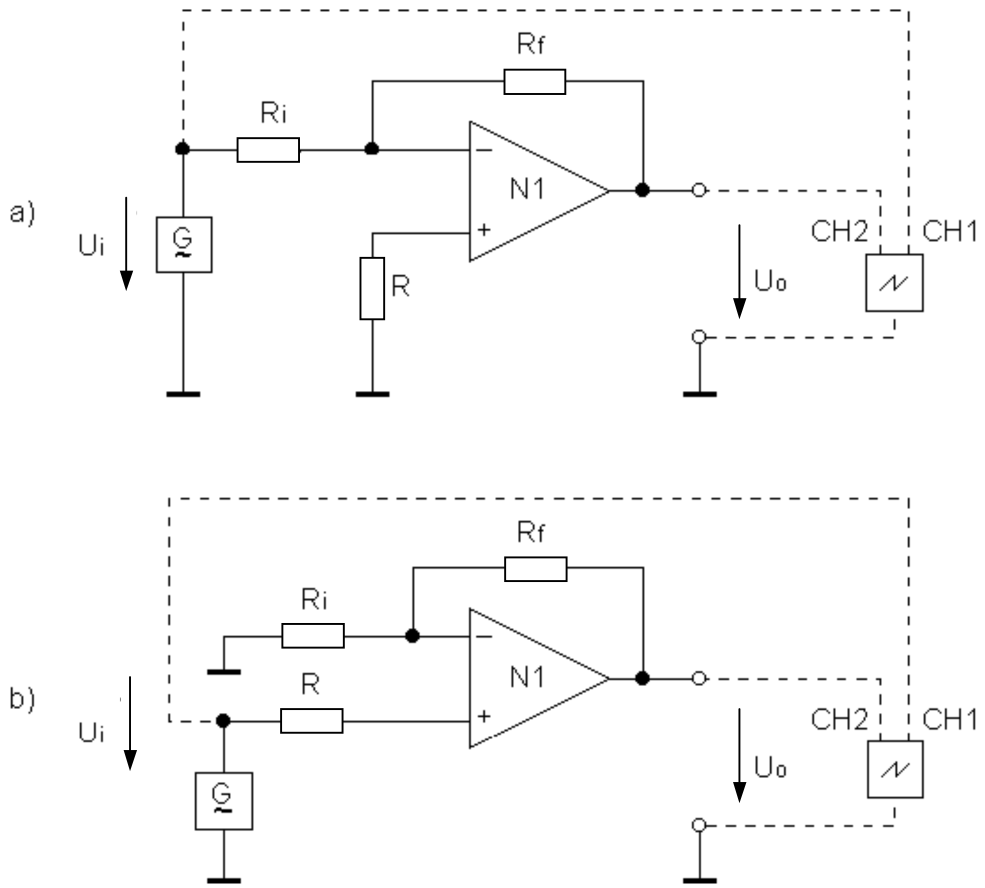


Fig. 6.7 a) Inverting O.A. b) Non-inverting O.A.

3. set the switches S1 and S2 to OFF;

4. adjust the oscilloscope in the following way:
   CH1 and CH2 = 0.5 VOLT/DIV,
   SWEEP = 250 µs/DIV,
   Coupling = DC;

5. without supplying the signal generator display the lines of channel 1 and of channel 2;

6. supply the signal generator and adjust the output to a sinusoidal voltage of U_{pp} = 1V and f = 1 kHz;

7. Observe the displayed output signal of the inverting O.A.: this signal is inverted, i.e. the output has a phase shift of $\varphi_o = 180°$ against the input signal;

8. Draw in Fig. 6.8-a the signals displayed on the oscilloscope;

9. measure the value of the peak-to-peak output voltage and the gain, by writing the results in Tab. 6.1.;

10. calculate the gain, write the result in Table 6.1 and compare the calculated value with the measured one;

11. set the switch S2 to ON: ($R_f = R_3$ and $R_i = R_2$);

12. adjust the image amplitude CH2 = 2 VOLT/DIV

13. repeat the procedure of points 9 and 10 ;

14. set the switches S1 = ON and S2 = OFF: ($R_f = R_4$ and $R_i = R_1$);

15. adjust the image amplitude CH2 = 0.1 VOLT/DIV

16. repeat the procedure of points 9 and 10 ;

17. set the switch S1 = ON and S2 = ON: ($R_f = R_3$ and $R_i = R_1$);

18. adjust the image amplitude CH2 = 1 VOLT/DIV

19. repeat the procedure of points 9 and 10 and observe what happens: the inverting O.A. gain can be made lower, equal or higher than one;

NON-INVERTING O.A.

20. connect the signal generator and the oscilloscope as shown in Fig. 6.7-b;

21. set the switches S1 and S2 to OFF;

22. adjust the oscilloscope in the following way:
    CH1 and CH2 = 0.5 VOLT/DIV
    SWEEP = 250 µs/DIV,
    Coupling = DC;

23. supply the signal generator and adjust the output to a sinusoidal voltage of U_{pp} = 1V and f = 1 kHz;

24. Observe the displayed output signal of the non-inverting O.A.: this signal is in phase and, besides, it is wider than the input signal;

25. Draw in Fig. 6.8-b the signals displayed on the oscilloscope;

26. repeat the procedure from point 9 to point 19 and observe what happens: the gain of the non-inverting O.A. cannot be made lower or equal to one but only higher;

7. Results (PART 1):

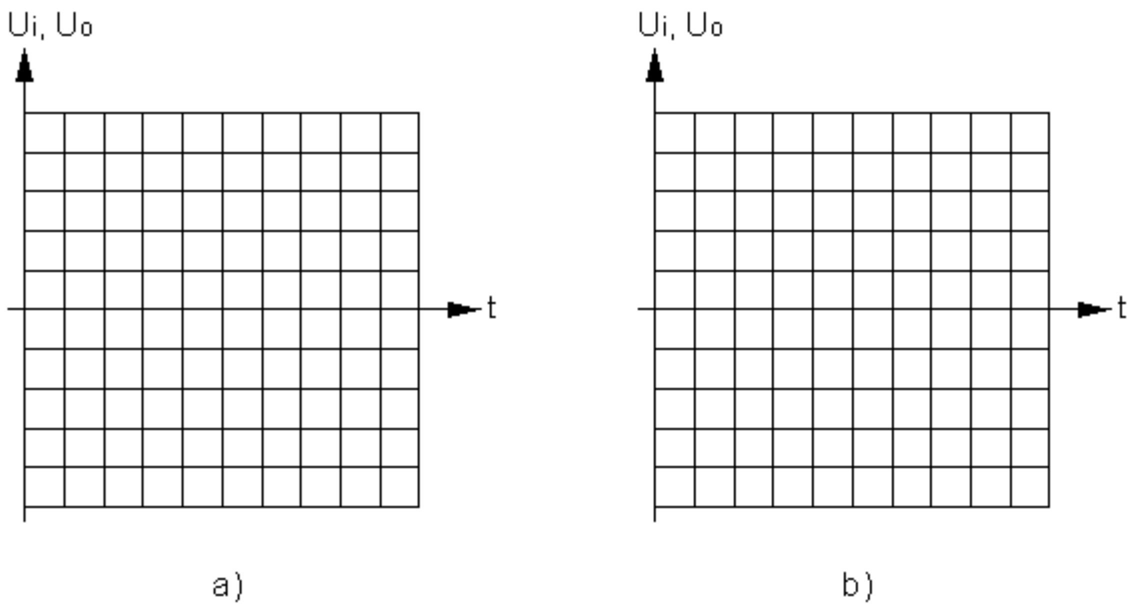


Fig. 6.8

INVERTING O.A.				
R_i / Ω	**R_f / Ω**	**U_0 / V**	**A measured**	**A calculated**
R_2 =	**R_4 =**			
R_2 =	**R_3 =**			
R_1 =	**R_4 =**			
R_1 =	**R_3 =**			

NON-INVERTING O.A.				
R_i / Ω	**R_f / Ω**	**U_0 / V**	**A measured**	**A calculated**
R_2 =	**R_4 =**			
R_2 =	**R_3 =**			
R_1 =	**R_4 =**			
R_1 =	**R_3 =**			

Tab. 6.1

8. *Procedure (PART 2):*

C.M.R.R.

1. Use Module 16 unit (2) and set the main switch to ON;

2. set the switches S1, S2 and S3 to OFF;

3. connect the signal generator, the oscilloscope and the circuit jacks as it is shown in Fig. 6.9-a (differential mode)

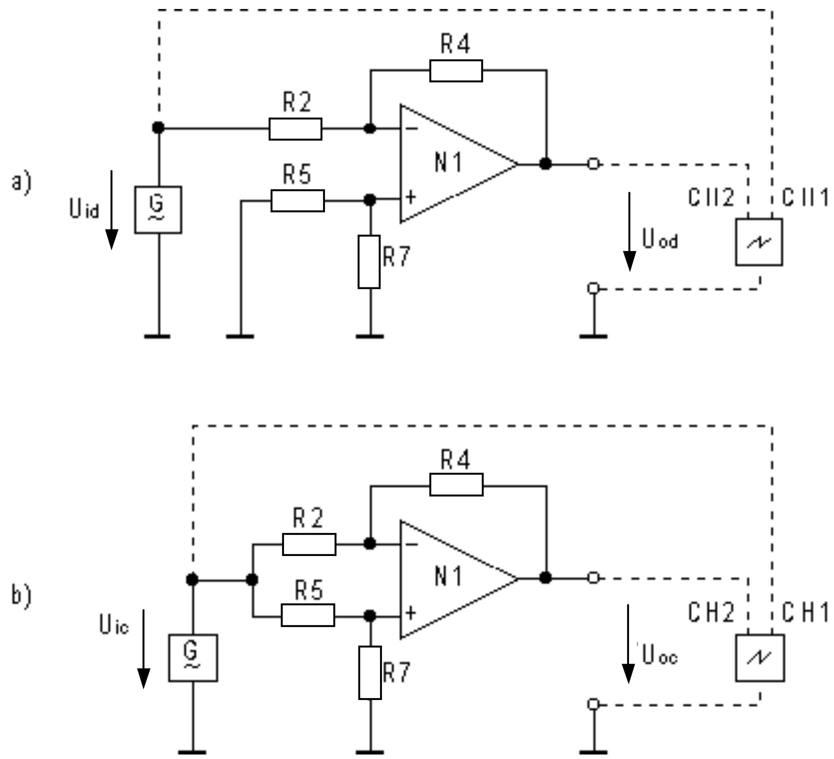


Fig. 6.9: a) CMRR (differential mode)
b) CMRR (common mode)

4. adjust the oscilloscope in the following way:
CH1 = 0.1 VOLT/DIV,
CH2 = 5 VOLT/DIV,
SWEEP = 250 µs/DIV,
Coupling = DC;

5. without supplying the signal generator display the lines of channel 1 and channel 2;

6. supply the signal generator and adjust the output to a sinusoidal voltage of Upp = 0.28 V (or to a lower value) and f = 1 kHz;

7. measure the value of the peak-to-peak output voltage (Uod) and write the value in Table 6.2.;

8. calculate the differential gain (Ad) and write the result in Table 6.2.;

9. connect the signal generator, the oscilloscope and the circuit jacks as it is shown in Fig. 6.9 b (common mode)

10. adjust the oscilloscope in the following way:
    CH1 = 5 VOLT/DIV,
    CH2 = 50 mV/DIV,
    SWEEP = 500 μs/DIV,
    Coupling = AC;

11. supply the signal generator and adjust the output to a sinusoidal voltage of Upp = 10 V (or to a lower value) and f = 1 kHz;

12. measure the value of the peak-to-peak output voltage (Uoc) and write the value in Tab. 6.2;

13. calculate the common mode gain (Ac) and write the result in Tab. 6.2;

14. determine the CMRR and write the result in Tab. 6.2;

15. verify that the result is higher than the minimum value indicated from the manufacturer.

SLEW-RATE

1. connect the signal generator, the oscilloscope and the circuit jacks as it is shown in Fig. 6.9-a (note: the grounding of the resistance R5 is not necessary but it is advisable);

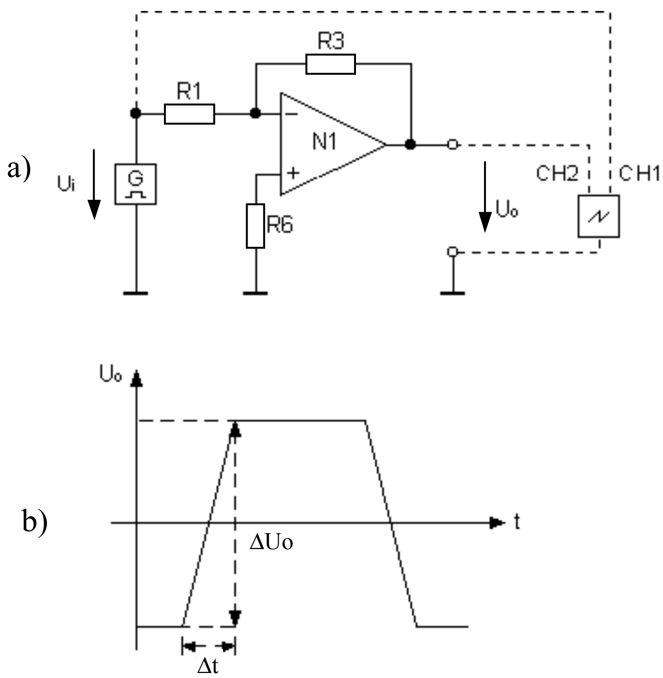


Fig. 6.10 a) Inverting O.A b) Slew-rate

2. adjust the oscilloscope in the following way:
   CH1 = 1 VOLT/DIV,
   CH2 = 5 VOLT/DIV,
   SWEEP = 10 μs/DIV,
   Coupling = AC;

3. without supplying the signal generator display the lines of channel 1 and 2;

4. supply the signal generator and adjust the output to a square wave voltage of $U_{pp} = 5$ V (or to a lower value) and f = 10 kHz;

5. observe the output signal of the O.A. on the oscilloscope display;

6. measure the value of the peak-to-peak output voltage (ΔU_0) and write the value in Tab. 6.3;

7. measure the time (Δt) that is used from the output voltage to pass from its minimum value to the maximum one and write the value in Tab. 6.3;

8. determine the SLEW-RATE value and write the result in Tab. 6.3;

9. verify that the result is higher than the minimum value indicated from the manufacturer.

9. Results (PART 2):

Differential Mode			**Common Mode**			**CMRR/dB**
U_{id} / V	U_{od} /V	A_d	U_{ic} /V	U_{oc} /V	A_c	

Tab. 6.2

ΔU_o V	**Δt** µs	**Slew-Rate** V/µs

Tab.6.3