PHY3802L: INTERMEDIATE LAB

Iel.1 Summing (inverting) amplifier

1. Purpose: Learn about operational amplifiers.

2. Apparatus: power supply (+/- 15V)
function generator
oscilloscope
breadboard
electronic components (resistors, op.amp. chip, ..)
DMM

3. Background information:

3.1 About operational amplifiers:

An operational amplifier is a differential amplifier with very high gain ("open-loop gain" A_0), very high input impedance (Z_{in}), and very low output impedance (Z_{out}).

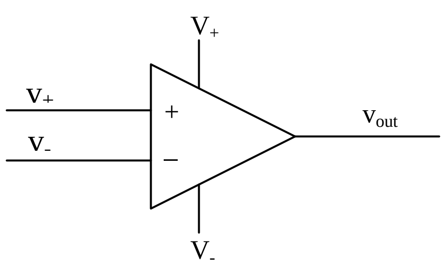

Fig. 1

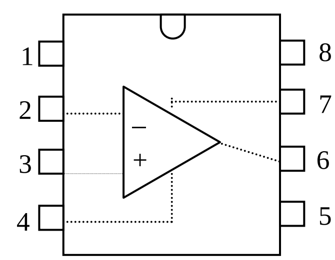

Fig.2

In normal operation, it needs to be supplied by symmetric voltages V_+ and V_- ($V_- = -V_+$). Its behavior is described by $v_{out} = A_0 (v_+ - v_-)$. In amplifier applications it is usually used with "negative feedback", i.e. part of the output signal is fed back to the negative input (i.e. effectively subtracted from the input signal). The behavior of such circuits can be calculated using the "opamp rules":

1. the input currents are 0: $i_+ = i_- = 0$
2. the input voltage difference is 0: $v_+ - v_- = 0$

(These rules are strictly speaking only valid for an ideal opamp, but are a reasonable approximation for real opamps).

The opamp chip that we are using in this lab is the 741A opamp. It comes in an 8-pin dual-inline package (DIP) (see fig. 2). The connections for the pins are as follows: pins 2 and 3 are for v_- and v_+, pin 4 is for negative supply voltage, pin 7 for positive supply voltage, and pin 6 is for the output.

3.2 Negative feedback

In amplifiers, opamps are used in circuits with "negative feedback", i.e. a circuit in which a fraction of the output voltage is subtracted from the input.
The effective input voltage v' is therefore

$$v' = v_{in} - B \cdot v_{out} \quad ,$$

where B = "feedback factor" (feedback fraction) is determined by details of the feedback circuit.
The amplification with feedback, A_f (called "closed-loop gain"), is defined as

$$A_f = \frac{v_{out}}{v_{in}}$$

From the property of the opamp, it follows that $v_{out} = A_0 v' = A_0 (v_{in} - B v_{out})$, and therefore

$$A_f = \frac{A_0}{1 + A_0 B}$$

Note:

- The *"closed loop gain"* $A_f < A_0$
- If $A_0 B >> 1$, then $A_f \approx 1/B$, i.e. the gain of the amplifier depends only on the feedback fraction B, not on the open-loop gain A_0 of the opamp; so, variation of A_0 does not matter!

4. Procedure:

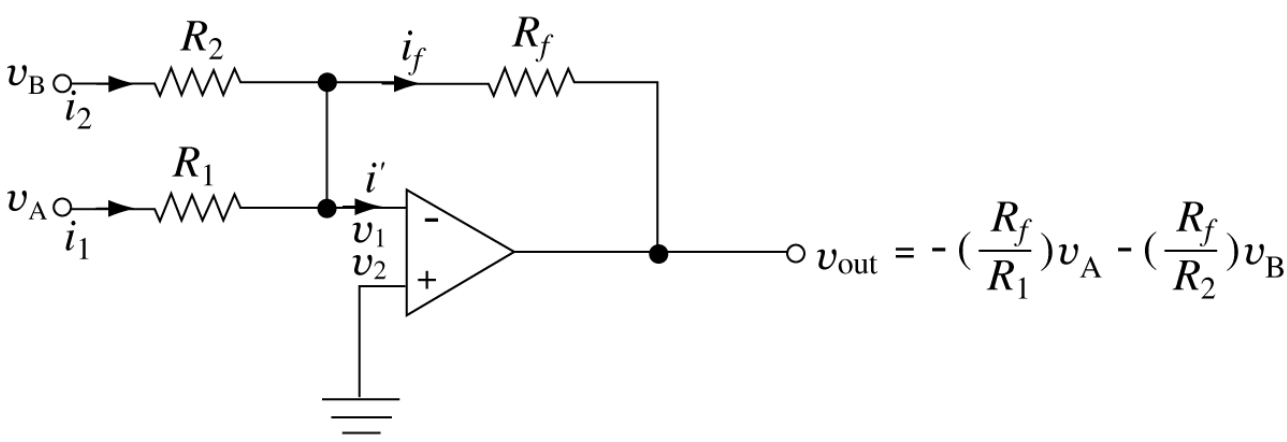

Fig. 3: Summing amplifier

(1) Construct the summing amplifier shown in fig. 3, using resistor values $R_f \approx 8k\Omega$, $R_1 \approx 2k\Omega$ and $R_2 \approx 1k\Omega$. Use 12 V as supply voltage, unless instructed otherwise.

(2) Apply a sinusoidal signal of about 200mV amplitude (from the function generator) to each input separately with the other grounded and measure the sign and magnitude of the amplification factor.

(3) Then connect the same signal to both inputs and measure the output magnitude. Compare with predicted values (do they agree *within errors*? Estimate how precisely you measure the gain, and how precisely you can predict the gain).

(4) Apply a sinusoidal signal to both inputs; vary the amplitude of the input signal from 100mV to 1.3V (in 100mV steps) and measure the gain (i.e. ratio of amplitude of the output signal and amplitude of input signal). Plot the output amplitude as a function of the nominal output signal amplitude (i.e. the output signal amplitude expected from the formula given in fig.3). Estimate uncertainties on measured and expected signal size and gain. Describe your observations, and try to explain what you observe.

(5) Change the supply voltage to 10V (both positive and negative), and repeat the measurements of (4)
for 100mV, 300mV, 500mV, 800 to 1300mV input signal amplitude.

(6) Restore the supply voltage to 12V. For a fixed input amplitude (abut 0.5V), measure the *gain* (v_{out}/ v_{in}) as a function of frequency of the sinusoidal, from about 500Hz to the maximum frequency available on the function generator. Take data for 3 frequency values per decade. Discuss the frequency dependence of the gain, and establish a relation between it and the observations of items (7) and (8).

(7) Instead of a sinusoidal signal, use a triangular wave and a square wave as input, and observe the output waveforms for three frequencies (lowest, highest, and a value in the middle of your range). Draw the waveforms and comment on your observations.

(8) Set the frequency of the function generator to about 1kHz. Measure the rise time of the square wave signal (both input to and output from the amplifier). Relate your measurements to the slew rate of the opamp (see the data sheet) and the frequency dependence of the gain.

5. Bibliography:

There are many books on modern electronics; examples of more useful ones are:

(1) Robert E. Simpson: Introductory Electronics for Scientists and Engineers, Allyn and Bacon, Newton, Mass. 1987

(2) William L. Faissler: An Introduction to Modern Electronics John Wiley & Sons, New York 1991

(3) Paul Horowitz and Winfield Hill: The Art of Electronics,
Cambridge University Press, Cambridge 1989
(4) D.V. Bugg: Electronics Circuits, Amplifiers and Gates, Institute of Physics Publishing,
Bristol 1991
(5) Mark N. Horenstein: Microelectronic Circuits and Devices, 2nd ed., Prentice Hall, 1995
(6) A. de Sa: Electronics for Scientists, Prentice Hall, 1997