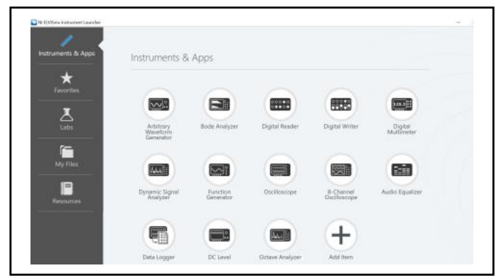
Lab 2: Operational amplifiers

Eng. Maths used here: functions
Basic calculus, percentages

Objective: to explore properties of real operational amplifiers through the design of two common circuits using a 741 OpAmp as a comparator:

- Design pulse train generator with asymmetric duty cycle using a comparator
- Design and build an alarm circuit

Equipment:

(a) Electronics Lab session	**(b) Home-based session (myDAQ)**
➢ Breadboard ➢ Operational Amplifier 741 (UA741CP is stocked in the lab) ➢ Light Dependent Photoresistor (LDR) (GL5528) ➢ Digital multimeter (DMM) – this includes voltmeter, ammeter, ohmmeter[1] ➢ Oscilloscope (2 channel GW Instek) ➢ Power supply and function generator (parts of the Hameg modular rack system) ➢ A range of resistors ➢ Wires for connections, wire cutting tool ➢ 4mm leads for power supply, “crocodile” clips, BNC cables, BNC T-connector	➢ Digilent development board ➢ Operational Amplifier 741: check your pack of components ➢ Light Dependent Photoresistor (LDR) (GL5528); in your pack of components ➢ myDAQ with two probes, and NI ELVISmx virtual instrument software: DMM, Oscilloscope, DC level  ➢ myDAQ probes ➢ A range of resistors, wires for connections

Background

Many electronic components are electrically and mathematically modelled as two-port networks (see Figures 1 and 2, below). This assumes <u>no</u> knowledge of the internal design of the component. The component presents a load to the network at its input, and is a source (voltage or current source) to the next circuit in the chain. Therefore, the electrically equivalent circuit comprises input impedance between input terminals, and a non-ideal voltage or current source between the output terminals. The source is functionally dependent in some way on the input voltage or current, and that is described mathematically by gain (or more generically, by transfer function).

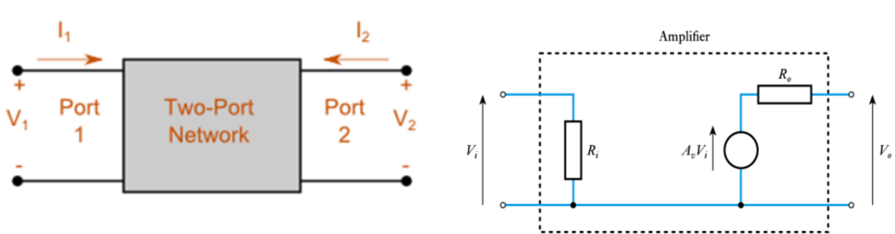


Figure 1. Two-port network model and op-amp equivalent circuit.

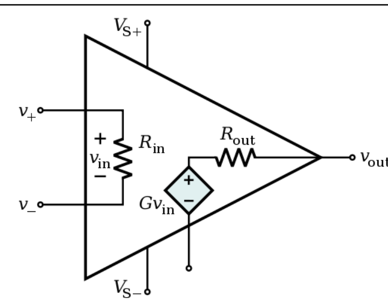


Figure 2. Equivalent circuit of a real voltage amplifier.

[1] In the Electronics Lab, use REAL DMMs. Elvis DMMs can cause problems due to their earthing when connected to the Elvis protoboard. If you want to use the Elvis protoboard, remove it from the Elvis kit, as that earths them.

In this lab you will use a common 741 OpAmp as a comparator to design two circuits. Through the analysis of their performance you will learn about the characteristics of the real OpAmps.

Exercise 1. Design pulse-train waveform generator with asymmetric duty cycle.

Task: Use 741 op-amp as a comparator to design a pulse-train generator with duty cycle of 0.25.

Steps:

- **Sketch the generic comparator circuit diagram**, naming all the components.
- **Sketch, on a graph**, the input and output waveforms for the 25% positive duty cycle, naming all signals and the relevant values or points.
- **Connect** the 741 power supply pins $+V_C$ and $-V_C$ to the **(a)** bench-top HAMEG dual power-supply OR **(b)** reference voltages ±15V on the Digilent board, connected to the myDAQ.

  Connecting HAMEG supply:
  - Use the channels 1 and 2 in series. (Select the "series" configuration by pressing the button on the front panel.)
  - Channel 2 needs to be with reverse polarity in series with channel 1.
  - Connect the HAMEG power supply ground to the circuit. (Why is this important?)
  - Set the power supply to around ±5V. (The second channel should automatically replicate the value of the first, if the power supply is set up properly.)

  Connecting Digilent Vref power supply:
  - Use a voltage divider to produce supply voltages of ±5V (R1:R2 = 1:2).
  - Alternatively, use +5V supply for the positive power supply, and DC level set to -5V, connected to the circuit power supply line via the Analogue output channel AO0.

- Reference (i.e. **connect) the inverting terminal** (V-) of the op-amp to the **ground**.
- **Connect non-inverting terminal** (V+) to the input, the **sinusoidal AC voltage, 2V peak**. The input is provided by the function generator. Function generator is set to a sinusoid of 2V amplitude. Frequency not relevant (set to some low value – adjust the time division on the scope accordingly).

  (a) In-lab bench-top oscilloscope:
  - Use the wave generator 50Ω output, no attenuation, no DC offset to start with.
  - Make sure that the grounds of the wave generator and the circuit are connected.
  - Adjust amplitude to 2V peak.

  (b) myDAQ function generator output:
  - connected to the Digilent board via the available Analogue Output channel, e.g. AO1.
  - Adjust amplitude to 2V peak.
  - Remember to press "RUN"

- **Connect the scope to the output** of the OpAmp, to observe the output voltage:

  (a) In-lab bench-top 'scope:
  - Ch1 to function generator (via BNC T-connector), Ch2 to output pin (via a breadboard 4mm connector)

  (b) myDAQ:
  - use Oscilloscope virtual instrument, connect via one of the Analogue Input channels, AI0 or AI1.

- **Observe** the output.
  - With no DC off-set in the input signal, the Vo should be a symmetric pulse-train.

  - Change the DC offset on the function generator. The Ch1 signal of the scope will move up and down. What happens to the Vo?
  - Find the DC offset for which you get a 25% duty cycle. Use that value (you can read it from the scope) to design the voltage divider reference in the next step.
- **Use a potentiometer (a pre-set variable resistor in kΩ range) or a voltage divider** for the voltage reference. Connect the inverting terminal (V-) to the voltage reference (= the output of the potentiometer or voltage divider).
  - For a positive Vref, you can use a voltage divider between +Vs and ground.
- **Connect** the non-inverting terminal to the AC signal of the function generator <u>without DC offset</u>.
- **Build and test**, first without load (open circuit), then on a load of 100Ω.
- **Make notes** of your design and tests in your lab diary. Make sure the notes are tidy and readable.
- **After the lab: try to derive the equation** for duty cycle, using component names as variables. Do you get the same voltage reference as you obtained empirically?

Questions:

1. Is your circuit an inverting or a non-inverting comparator? I.e. is the pulse train in phase with the sinusoidal input?

2. How would you change the design to change the phase difference between the input and output? (e.g. inverting → non-inverting, and vice versa).

3. How close is the maximum value of the OpAmp to the value of the power supply?

Exercise 2. Design an alarm circuit using 741 as a comparator.

Task: Design and test the alarm circuit which lights up a LED when a sensor for light, the LDR, detects light, and turns LED off in case of no light.

You can read about this project here:
http://www.learningaboutelectronics.com/Articles/LM741-op-amp-voltage-comparator.php

<u>Steps</u>:
- **Sketch the circuit diagram**, naming all components. A variation of an alarm circuit is given in the picture below (you may need different resistor values, and different arrangement of components!).
- **Check** the maximum current that the LED can take. (Use a data sheet from e.g. RS Components, by searching for the component by its name.)
- **Calculate** the value or estimate the range of the resistor needed to limit the current in the LED at the output (remember Lab 1!).
- Use a **Light Dependent Photoresistor (LDR)** as a sensor (resistance range: kΩ-MΩ). LDR needs to be in voltage divider configuration to provide input to the non-inverting terminal of the op-amp.

- Use a potentiometer (pre-set in the kΩ range) to set a voltage reference at the inverting terminal of the op-amp. Vary the potentiometer, and see what happens with the output.
- **If you wish, you can simulate** the circuit. Review and redesign, if necessary.
- **Build and test** the circuit.
- **If the circuit does not work as expected,** first of all check all the connections. Draw the circuit based on what you actually built on the board.
- **Document your design** in the log book, including all equations and assumptions. Make sure it flows logically, is tidy and readable.

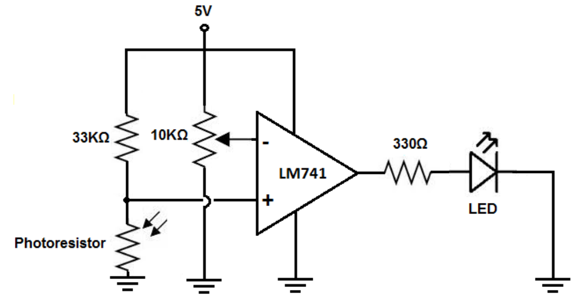


Figure 4. Alarm circuit example. Copied from: http://www.learningaboutelectronics.com/images/Night-light-circuit-using-LM741-op-amp.png

Questions:

1. How would the operation of the circuit change if you changed the voltage reference?

2. How would the operation of the circuit change if you swap the LDR and the resistor in its branch?

3. What was the most challenging part of this project, and why? What was the main thing you learnt from it?