# Laboratory Guide of
# Signals and Mechatronic Systems

Degree in Naval Architecture and Marine Engineering
Integrated Master in Mechanical Engineering

September 11, 2019

# Contents

# Introduction

Who would be satisfied with a navigator or engineer, who had no practice or experience whereby to carry on his scientific conclusions out of their native abstract into the concrete and the real?

John Henry Newman (1801 — †1890)
*An essay in aid of a grammar of assent*, VIII 1, 2

There are four laboratory classes, as follows:

| Class | Shifts | Week | Class duration | Mark |
|-------|--------|------|----------------|------|
| 1 | All shifts | 2019 / 10 / 14 — 2019 / 10 / 18 | 1 hour | 0 to 4 |
| 2 | All shifts | 2019 / 10 / 21 — 2019 / 10 / 25 | 1 hour 30 minutes | 0 to 4 |
| 3 | All shifts | 2019 / 11 / 11 — 2019 / 11 / 15 | 1 hour 30 minutes | 0 to 4 |
| 4 | Shifts that in previous weeks began at 9h00 or 12h00 | 2019 / 11 / 18 — 2019 / 11 / 22 | 3 hours | 0 to 8 |
| 4 | Shifts that in previous weeks began at 10h30 | 2019 / 11 / 25 — 2019 / 11 / 29 | 3 hours | 0 to 8 |
| | | | Total | 0 to 20 |

Classes take place in the Control, Automation and Robotics Laboratory, Mechanical Engineering III building, basement floor 1.

The work will be developed in groups of 3 students. (Groups with 2 students will be allowed only if strictly necessary.) Each group must enrol in one of the 11 shifts available (numbered from 3 to 13). Enrolment takes place from 2019 / 09 / 23 to 2019 / 10 / 4, using Fenix.

Classes must be prepared in advance, according to what is found in each chapter, in sections entitled "Homework before class". Groups that show up in class without preparing this homework will not be allowed to carry out the experiments, and will receive a 0 mark in that class.

At the end of each class, each group delivers a report, filled in with the results obtained and relevant comments thereon. These reports can be found in this guide and must be printed out to be filled in during class. The last class also requires uploading some files with results using Fenix. Reports will *not* be accepted once the class is over.

Marks will consider the homework prepared, performance during classes, and results obtained. This applies to each group member *separately*; all are expected to participate actively in experiments. Punctuality is required when attending classes. The penalty for arriving late (i.e. more than 10 minutes after the beginning of the class) is a deduction of 0.5 to the mark of that class. A final laboratory mark of 9.5 or higher is required for approval in the course, and accounts for 30% of each student's final mark in the course.

It is possible to attend a different shift occasionally, but only subject to the instructor's authorisation.

Notice that this laboratory guide includes several links to websites where you can further explore the subjects addressed. (Use a PDF viewer that highlights links to see them.)

# Chapter 1

# Generating and measuring electrical signals

## 1.1 Introduction

This class has two objectives. The first is to provide a first contact with material used in electronics. The second is to acquaint you with measurement errors, their sources, and their acceptable (and unacceptable) values.

### 1.1.1 AD laboratory

The AD laboratory (figure 1.1) has:

- a breadbord, for the prototyping of electrical circuits;

- a voltmeter, to measure electrical potential in a circuit;

- an ammeter, to measure the current in a circuit;

- a DC power supply;

- a function generator;

- and other elements which we will not need.



Figure 1.1: AD laboratory.

The breadboard has hundreds of perforations, where components can be inserted. Below the perforations, metallic strips (figure 1.2) will connect the inserted components. Avoid using perforations where the plastic is burned.

Some perforations are connected vertically (terminal strips) and some are connected horizontally (bus strips). Figure 1.3 shows both strips and the manner of inserting integrated circuits. Notice that some breadboards

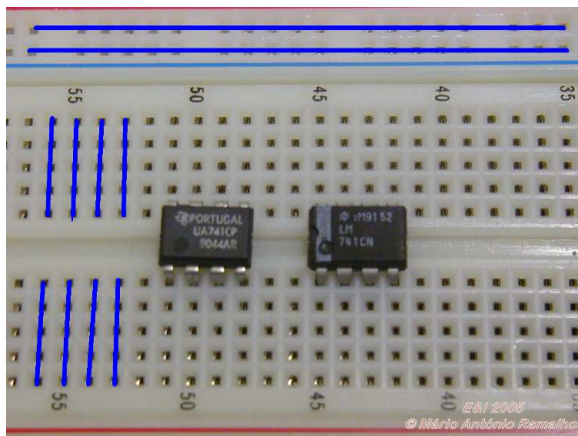Figure 1.2: How breadboard perforations are connected.



Figure 1.3: Terminal strips (vertical), bus strips (horizontal), and how to insert an integrated circuit.

have bus strips from side to side; others have separate bus strips for the left and right sides of the breadboard. This is the case of figure 1.2, indicated by the red and blue lines.

As you should know,

- the voltmeter is connected in parallel with the circuit where you measure the electrical potential;

- the ammeter is connected in series with the circuit where you measure the current.

Instead of the AD laboratory's voltmeter and ammeter, it is more expedient to use the multimeter, described in section 1.1.2. Instead of the AD laboratory's signal generator, which provides signals with a poor quality, it is more expedient to use an external signal generator, described in section 1.1.4.

### 1.1.2 Multimeter

The multimeter (figure 1.4) can work as

- voltmeter,

- ammeter,

- ohmmeter,

- frequency meter,

- capacitance meter.

Notice that cables must be connected differently for different functions. If you hear the multimeter beep, this is because your cables are wrongly connected. Correct your mistake *at once* or you may damage the multimeter.

### 1.1.3 Oscilloscope

The oscilloscope is used to show a plot:

- of one or two electrical potentials ($y$-axis, i.e. vertical axis) as a function of time ($x$-axis, i.e. horizontal axis): see figure 1.5, left;

Figure 1.4: Multimeter.

- of one electrical potential ($y$-axis) as a function of another electrical potential ($x$-axis): see figure 1.5, right.
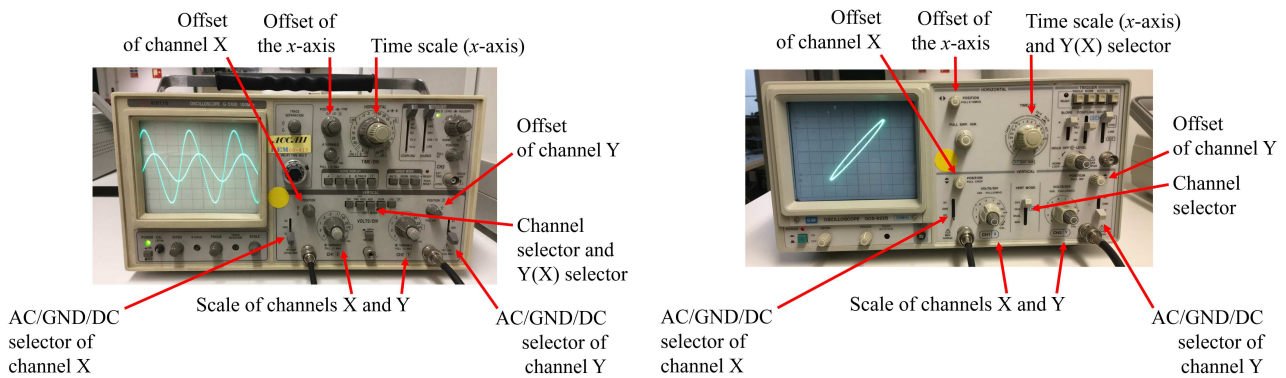


Figure 1.5: Some of the oscilloscopes in the laboratory; right: two sinusoidal signals as functions of time; left: two sinusoidal signals, one as function of the other.

Oscilloscopes use BNC (Bayonet Neill-Concelman) connectors; figure 1.6 shows a BNC tee connector, to connect the same signal to two connectors.



Figure 1.6: BNC tee connector.

Practical advice:

- Before you use a channel of the oscilloscope, set its selector to GND (ground) and make sure that the channel's offset is set to zero.

- There are buttons for fine tuning the amplitude. If used, you cannot know which scale you are using. So, always make sure they are *not* in use.

### 1.1.4   Function generator

The function generator (figure 1.7) can provide periodic variations of the electric potential. The frequency, amplitude and mean value of the resulting signal can be adjusted. The shape of the wave can be sinusoidal, square, or triangular.
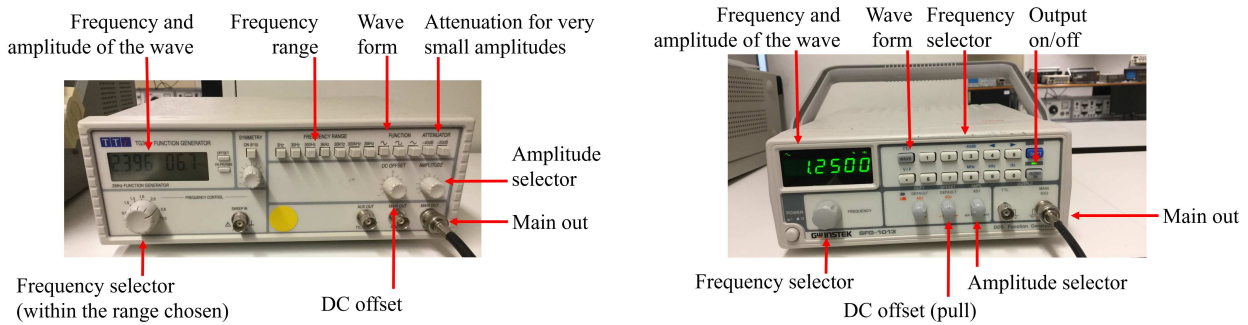


Figure 1.7: Some of the signal generators in the laboratory.

### 1.1.5   Colour code for resistors and capacitors

See figure 1.8 for the colour code of resistors. Capacitors in the laboratory are not marked with this colour code, but they could be. You can find a more complete version of the colour code here.
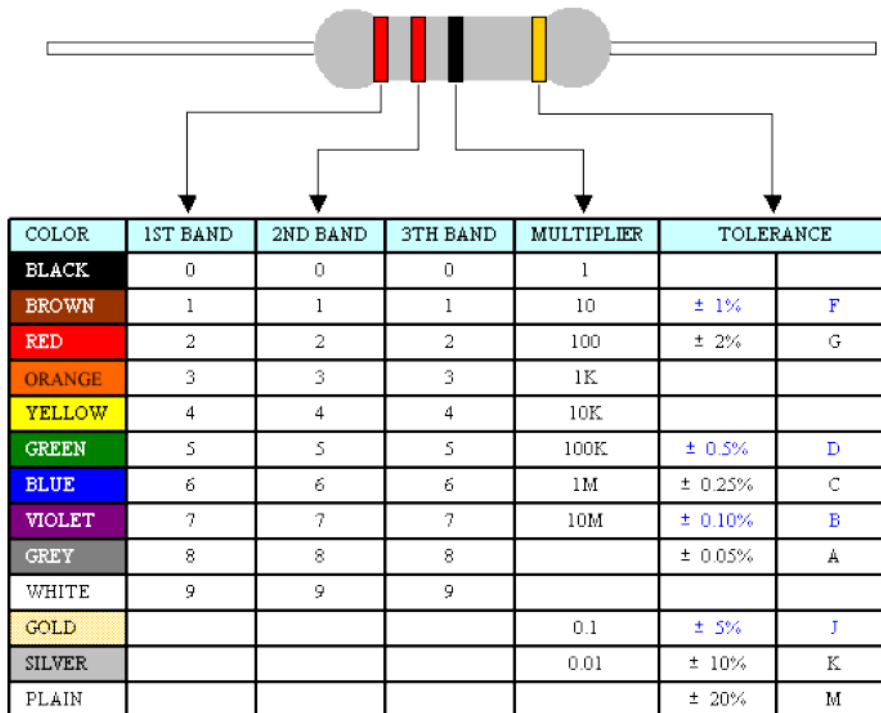


| COLOR | 1ST BAND | 2ND BAND | 3TH BAND | MULTIPLIER | TOLERANCE | |
|---|---|---|---|---|---|---|
| BLACK | 0 | 0 | 0 | 1 | | |
| BROWN | 1 | 1 | 1 | 10 | ± 1% | F |
| RED | 2 | 2 | 2 | 100 | ± 2% | G |
| ORANGE | 3 | 3 | 3 | 1K | | |
| YELLOW | 4 | 4 | 4 | 10K | | |
| GREEN | 5 | 5 | 5 | 100K | ± 0.5% | D |
| BLUE | 6 | 6 | 6 | 1M | ± 0.25% | C |
| VIOLET | 7 | 7 | 7 | 10M | ± 0.10% | B |
| GREY | 8 | 8 | 8 | | ± 0.05% | A |
| WHITE | 9 | 9 | 9 | | | |
| GOLD | | | | 0.1 | ± 5% | J |
| SILVER | | | | 0.01 | ± 10% | K |
| PLAIN | | | | | ± 20% | M |

Figure 1.8: Colour code.

### 1.1.6   Cables and jump wires

See figure 1.9. Practical advice:

- You can replace a BNC–jump wire cable with a BNC–bananas cable and two banana–jump wire cables.
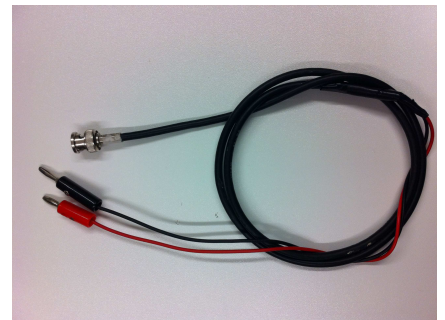
- Jump wires or jumpers, used for connections in the breadboard, should have a short stripped wire at the end; otherwise, two metallic parts may touch and spoil your circuits. Use the wire stripper and the pliers to solve this.
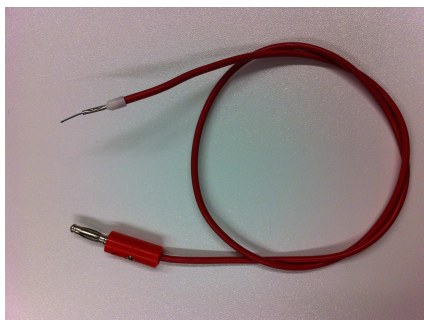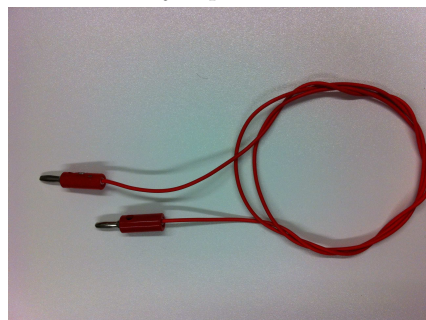

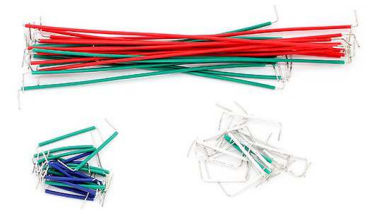BNC–BNC cable
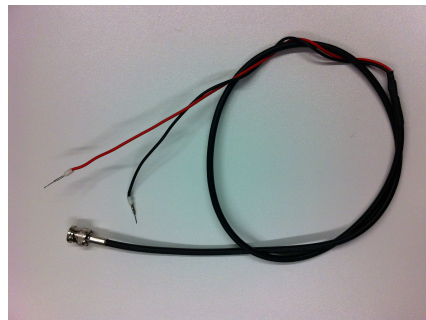

BNC–jump wire cable


BNC–bananas cable


Banana–jump wire cable


Banana–banana cable


Jump wires or jumpers

Figure 1.9: Cables and jump wires.

### 1.1.7 Box

There is one box (figure 1.10) per workbench with jump wires, pliers and a wire stripper.



Figure 1.10: Box with jump wires, pliers, and a wire stripper.

## 1.2 Homework before class

- Study the experimental procedure.

- Fill in, in your report:

  - the first table on equipment,
  - your answer to the question below that table,
  - the upper part of the table for items 1 and 2, with the resistor colours you will use (see figure 1.8);
  - the upper part of the said table, with the currents you expect in ideal circumstances.

## 1.3 Experiments in class

### 1.3.1 List of materials

- AD laboratory.
- Multimeter.
- Function generator.
- Oscilloscope.
- 470 Ω, 1 kΩ and 4,7 kΩ resistors.
- Cables, jumper wires, BNC tee.

### 1.3.2 Experimental procedure

1. Insert the three resistors in the breadboard. Use the multimeter to measure the resistance of each resistor. Fill in the table in your report.

2. Build the circuit in figure 1.11. Measure the electrical potential and the current for each of the three resistors. Fill in the table in your report.
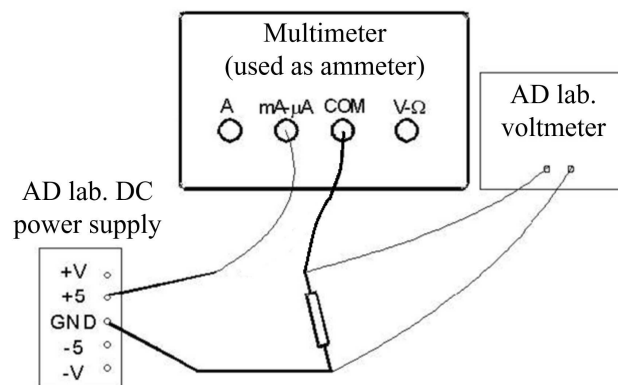


Figure 1.11: Circuit for item 2.

3. Connect a BNC–jump wire cable to channel X of the oscilloscope. Set the channel's selector to GND and adjust the offset to zero (i.e. make sure you see a horizontal line on the $x$-axis). Set the channel's selector to DC and hold the red jump wire with your hand. Adjust the vertical and time scales until you see a roughly sinusoidal signal. Measure its frequency. Explain where this signal comes from.

4. Put a BNC tee at the function generator's output. Connect it to channel X of the oscilloscope with a BNC–BNC cable. Turn the function generator on and generate a sinusoid with 10 V pp (i.e. with a peak-to-peak amplitude of 10 V, i.e. with a peak amplitude of 5 V), zero average, and 100 Hz. Adjust the vertical and time scales until you see two periods in the screen. Use the multimeter as an AC voltmeter, and connect it to the BNC tee with a BNC–bananas cable. Measure the electrical potential. Press the multimeter's "Hz" button to use it as a frequency meter. Fill the table and compare the values measured with the signal generator, the oscilloscope, and the multimeter.

5. Keep the BNC tee in the function generator's output. Connect it to both the X and Y channels of the oscilloscope. Set the selector of channel X to DC and the selector of channel Y to AC. Set the function generator for a 2 V pp, 2 kHz sinusoid. Change the function generator's DC offset and notice the settling time. Sketch what you see, and explain what is happening.

# Report of class 1

Number: _____ Name: _____

Number: _____ Name: _____

Number: _____ Name: _____

Date: 2019 / _____ / _____ Weekday: _____ Hour: _____ Workbench number: _____

## Homework before class

For each device, check the appropriate boxes as ☒.

| Device | Generates a signal | Measures a signal |
|---|---|---|
| Voltmeter | ☐ | ☐ |
| Ammeter | ☐ | ☐ |
| DC power supply | ☐ | ☐ |
| Function generator | ☐ | ☐ |
| Frequency meter | ☐ | ☐ |
| Capacitance meter | ☐ | ☐ |
| Oscilloscope | ☐ | ☐ |

Does it make any sense to connect a device that generates a signal to another device that generates a signal? Why?

_____

_____

_____

Also fill in the upper part of the table below.

## Items 1 and 2

| Values under ideal conditions | | | |
|---|---|---|---|
| $R_{\text{nominal}}$ | 470 Ω | 1 kΩ | 4, 7 kΩ |
| colours | | | |
| $U$ (V) | 5 | 5 | 5 |
| $I$ (mA) | | | |
| Values measured in the laboratory | | | |
| $R_{\text{measured}}$ | | | |
| $I$ (mA) | | | |
| $U$ (V) | | | |
| $U/I$ (Ω) | | | |
| resistor's tolerance | | | |

Comments:

_____

_____

# Item 3

Period: _____ Frequency: _____

Comments:

_____

_____

# Item 4

Oscilloscope's scales: _____
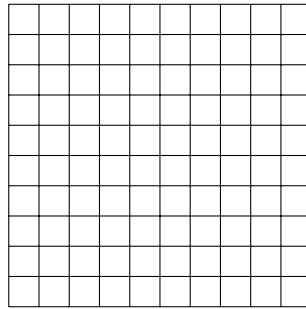


|  | Function generator | Oscilloscope | Multimeter |
|---|---|---|---|
| Amplitude |  |  |  |
| Frequency |  |  |  |

Comments:

_____

_____

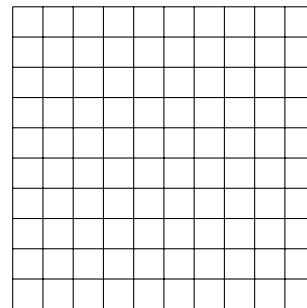_____

_____

# Item 5

Channel X, set to DC
Oscilloscope's scales: _____
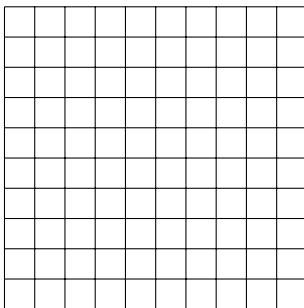
Channel Y, set to AC
Oscilloscope's scales: _____



Comments:

_____

_____

_____

# Chapter 2

# Operational amplifiers (op-amps)

## 2.1   Introduction

The objective of this class is to give you a first contact with an operational amplifier, and with some of the simplest and most useful circuits you can build with an op-amp.

We will use LM741 op-amps. See the integrated circuit's pinout in figure 2.1 and check figure 1.3 again. This is a very common op-amp, but there are other integrated circuits with different specifications (and pinouts) available in the market.
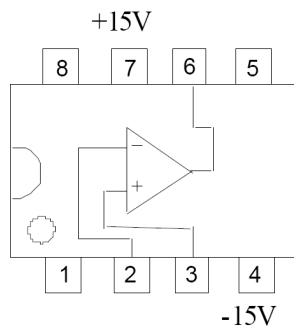
Figure 2.1: LM741 op-amp pinout (notice the indentation on the left side).

## 2.2   Homework before class

- Study the experimental procedure.

- Attach to your report a hand-written demonstration of the input-output relation of each of the four circuits you will build in class, shown in figure 2.2.

## 2.3   Experimental procedure

### 2.3.1   List of materials

- AD laboratory.

- Multimeter.

- Function generator.

- Oscilloscope.

- LM741 op-amp.

- Four 4.7 kΩ resistors.

- Cables, jumper wires, BNC tee.

### 2.3.2 Experimental procedure

1. Use the multimeter to set the AD laboratory's DC variable power supply to $+15$ V and $-15$ V. These values are needed to supply the op-amp.

2. Use the function generator to generate a 1 kHz, 15 V pp sinusoid, with a $+5$ V offset (mean value).

3. Build the inverting op-amp circuit. Use $R_{in} = 4.7$ kΩ and $R_F = 9.4$ kΩ. (To obtain 9.4 kΩ, should you use two 4.7 kΩ resistors in series or in parallel?) Connect the signal generator to the circuit's input, the circuit's input to channel X in the oscilloscope, and the circuit's output to channel Y. Adjust the vertical and time scales so that you can see two periods on screen, sketch what you see, and provide passing comments.



Inverting op-amp

Non-inverting op-amp

Subtractor, or differential, op-amp

Comparator op-amp

Figure 2.2: Op-amp circuits.

4. Build the non-inverting op-amp circuit. Use $R_2 = 4.7$ kΩ and $R_F = 9.4$ kΩ. Connect the signal generator to the circuit's input, the circuit's input to channel X in the oscilloscope, and the circuit's output to channel Y. Adjust the vertical and time scales so that you can see two periods on screen, sketch what you see, and provide passing comments.
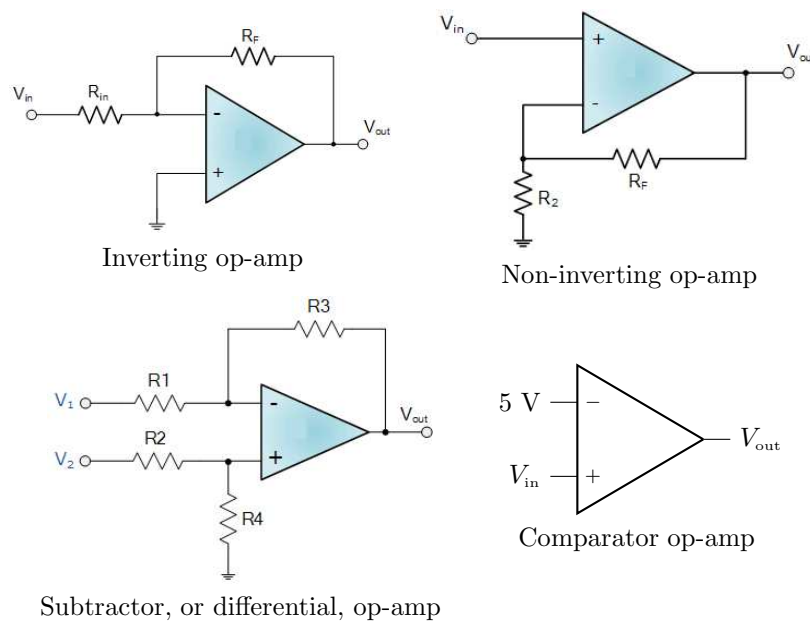
5. Build the subtractor op-amp circuit. Use $R_1 = R_2 = R_3 = R_4 = 4.7$ kΩ. Connect $V_1$ to the AD laboratory's $+5$ V DC power supply, $V_2$ to the the signal generator and to channel X in the oscilloscope, and the circuit's output to channel Y. Adjust the vertical and time scales so that you can see two periods on screen, sketch what you see, and provide passing comments.

6. Set the signal generator's offset to 0 V. Keep the frequency and amplitude of the sinusoid.

7. Build the comparator op-amp circuit. Connect the signal generator to $V_{in}$, the AD laboratory's $+5$ V DC power supply to the op-amp as shown in figure 2.2, $V_{in}$ to channel X in the oscilloscope, and the circuit's output to channel Y. Adjust the vertical and time scales so that you can see two periods on screen, sketch what you see, and provide passing comments.
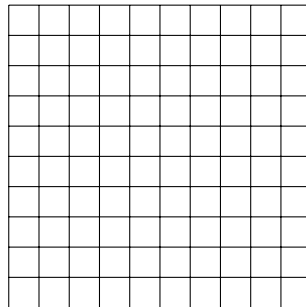
# Report of class 2

Number: _____ Name: _____

Number: _____ Name: _____

Number: _____ Name: _____

Date: 2019 / _____ / _____ Weekday: _____ Hour: _____ Workbench number: _____

## Homework before class

Attach a hand-written demonstration of the input-output relation of each of the four circuits you will build in class.
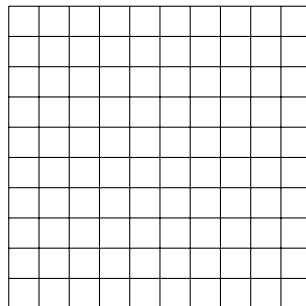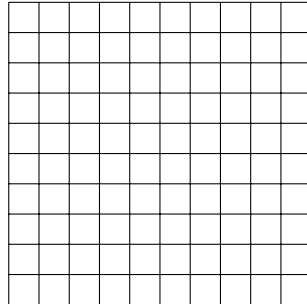
## Item 3

Oscilloscope's scales: _____

Comments:

_____

_____

## Item 4
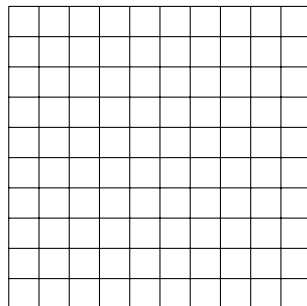
Oscilloscope's scales: _____

Comments:

# Item 5

Oscilloscope's scales: _____

# Item 7

Oscilloscope's scales: _____

Comments:

# Chapter 3

# Signal filtering

## 3.1 Introduction

This class has two objectives. The first is to make you understand what a filter does and what it can be used for. The second is to give you further acquaintance with simple op-amp circuits, which you will need further on.

### 3.1.1 Filters

Figures 3.1 and 3.2 show how first-order low-pass and high-pass filters can be implemented. In each case, there is a passive implementation (i.e. using only passive components, viz. a resistor and a capacitor), and an active implementation (i.e. with an active component, viz. an op-amp). We will use the passive implementations to separate the components of a signal. Separating a signal's components is important in practice to eliminate noise from experimental measurements.
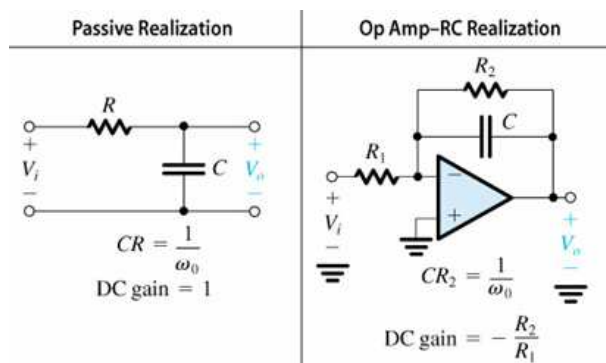


Figure 3.1: First-order low pass filters.

### 3.1.2 Material

Figure 3.3 shows a capacitor and a potentiometer (or variable resistor, or rheostat). The potentiometer has a slider on a resistor. The left and right terminals are connected to the terminals of the resistor; the middle terminal is connected to the slider. The slider changes the length of the resistance between the middle terminal and each of the other two. Remember that a conductor's resistance is proportional to its length.

## 3.2 Homework before class
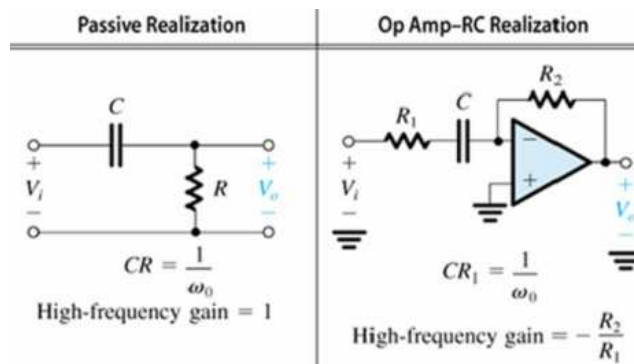
- Study the experimental procedure.
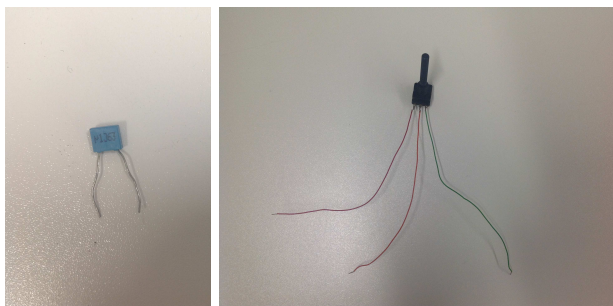
Figure 3.2: First-order high pass filters.



Figure 3.3: Left: capacitor; right: variable resistor, or potentiometer, or rheostat.

- Use SIMULINK file `simul_lab3.mdl` (figure 3.4) to train the filtering process. To run this simulation, click the $\triangleright$ icon. Try changing the amplitude and frequency of the sinusoids, and the cut-off frequency of the filter.

- Fill in, in your report, the demonstrations of the input-output relations of:

  - the active filters in figures 3.1 and 3.2 (which you could use in class instead of the passive filters),
  - the summing op-amp circuit in figure 3.5 which you will build.

## 3.3 Experimental procedure

### 3.3.1 List of materials

- AD laboratory.
- Multimeter.
- Function generator.
- Oscilloscope.
- LM741 op-amp.
- One 10 kΩ potentiometer.
- One 100 nF capacitor.
- Three resistors with the same resistance.
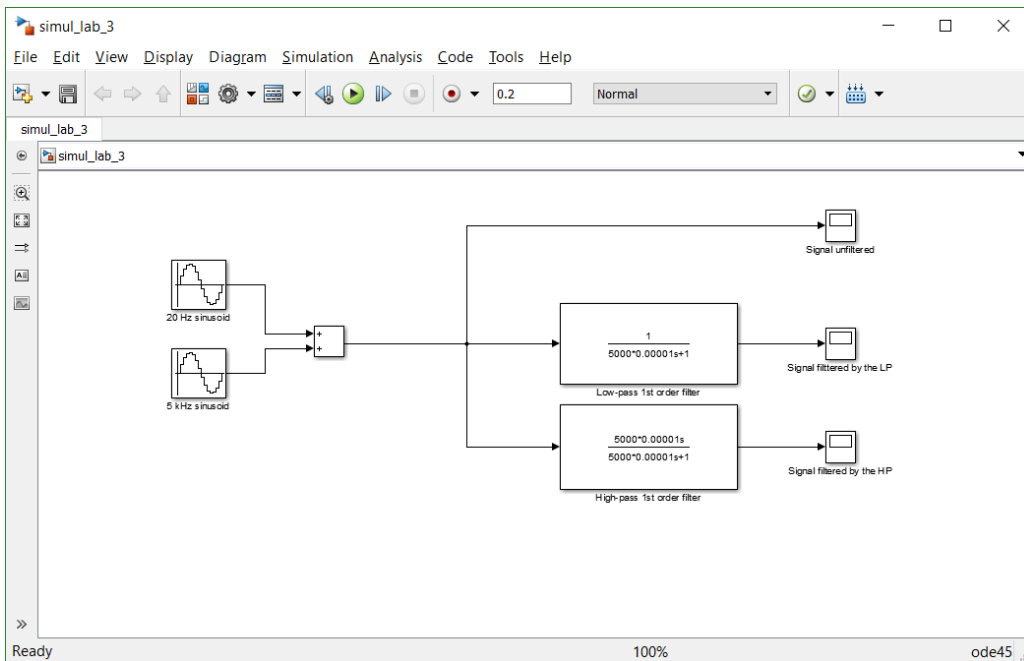- Cables, jumper wires.

Figure 3.4: File `simul_lab3.mdl`.

### 3.3.2 Experimental procedure

1. Use the function generator to generate a 5 kHz, 1 V pp sinusoid.

2. Use the AD laboratory's function generator to generate a 20 Hz, 5 V pp sinusoid. Use the multimeter as frequency meter to check the frequency.

3. Build the summing op-amp circuit in figure 3.5, using the three resistors, and use it to sum the two sinusoids of the two function generators. Do not forget to supply the op-amp with $-15$ V and $+15$ V from the AD laboratory's DC power supply.
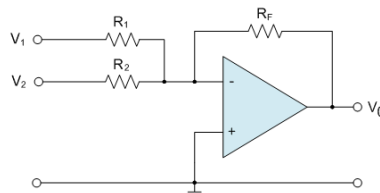


Figure 3.5: Summing op-amp circuit.

4. Connect the summing op-amp circuit's output to channel X of the oscilloscope. Adjust the scales so you can see one period of the lower frequency sinusoid.

5. Build the passive low-pass filter in figure 3.1 using the capacitor and the potentiometer. Connect the summing op-amp circuit's output to its input, and its output to channel Y of the oscilloscope. Vary the resistance of the potentiometer to eliminate the high frequency oscillation, without altering the low frequency oscillation. Sketch what you see.

6. Measure the resistance of the potentiometer, calculate the filter cut-off frequency, and offer passing comments.

7. Switch the potentiometer with the capacitor, thus obtaining the passive high-pass filter from figure 3.2. Vary the resistance of the potentiometer to eliminate the low frequency oscillation, without altering the high frequency oscillation. Sketch what you see.

17

8. Repeat for the high-pass filter what you did in item 6 above.

# Report of class 3

Number: _____ Name: _____

Number: _____ Name: _____

Number: _____ Name: _____

Date: 2019 / _____ / _____ Weekday: _____ Hour: _____ Workbench number: _____

## Transfer functions of the active high-pass and low-pass filters

## Input-output relation of the summing op-amp circuit

## Item 5

Oscilloscope's scales: _____
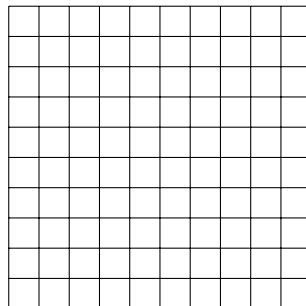
# Item 6

R = _____ Filter cut-off frequency: _____
Comments:

_____

_____

_____

# Item 7

Oscilloscope's scales: _____

# Item 8

R = _____ Filter cut-off frequency: _____
Comments:

_____

_____

_____

# Chapter 4

# Sensors and actuators in a control loop

## 4.1 Introduction

The objective of this class is to show you how measurement, actuation and signal processing components are used in practice. In this way you are expected to realise what the things you have been studying in classes and doing in the laboratory can be used for in real life.
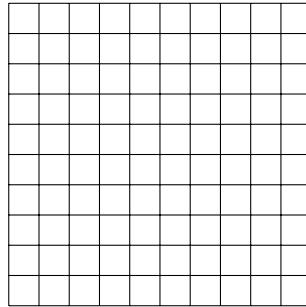
We will build a closed-loop control system for a DC motor as follows:

- Controlled variable: angular position of a shaft

- Sensor: potentiometer to measure the angular position of the shaft, providing a signal in the $-5$ V to $+5$ V range

- Analog-digital converter: National Instruments USB-6008 AD/DA converter, reading signals in the $-10$ V to $+10$ V range

- Controller: Computer running Matlab and Simulink, implementing a proportional controller (control action directly proportional to the closed-loop control error)

- Digital-analog converter: National Instruments USB-6008 AD/DA converter (again), outputting signals in the 0 V to $+5$ V range

- Actuator: DC motor, receiving a signal in the $-10$ V to $+10$ V range

It is clear from this description that you will have to build a signal conditioning system, converting the AD/DA converter's 0 V to $+5$ V output into a signal in the $-10$ V to $+10$ V range. If not, the shaft would rotate in one direction, but not on the other, and it would not reach its maximum rotation speed. (We will connect the sensor directly to one of the AD/DA converter's analog inputs. We will loose resolution, but our signal conditioning will be easier.) You may find a block diagram of this control loop in figure 4.1.
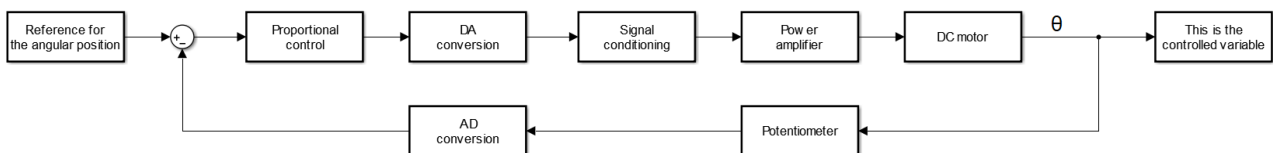


Figure 4.1: Block diagram of the control loop.

A simple model of the DC motor relates its angular position $\theta(t)$ (output) with the electrical potential supplied $v(t)$ (input):

$$G(s) = \frac{\Theta(s)}{V(s)} = \frac{K_m}{s(K_t s + 1)} \tag{4.1}$$

Notice that, in closed loop, with a proportional controller, we will have a second order system.

The motor is part of transducer and instrumentation trainer DigiAC 1750 (see figure 4.2).
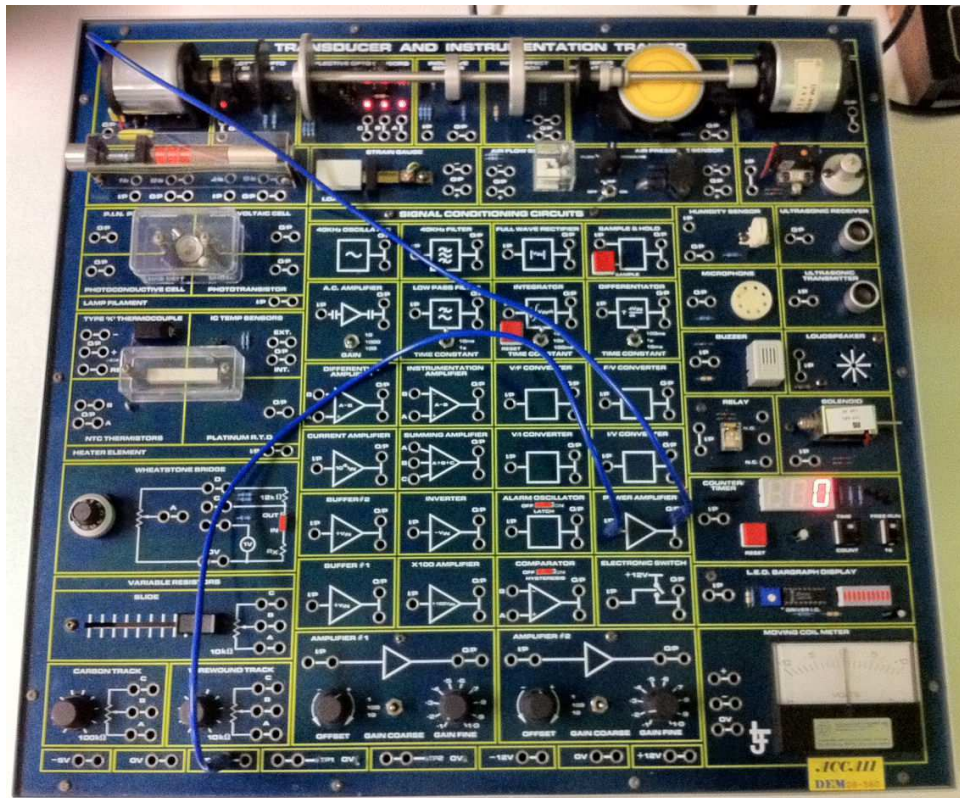
Figure 4.2: The DigiAC 1750.

## 4.2 Homework before class

- Study the experimental procedure.

- Use SIMULINK file `simul_lab4.mdl` (figure 4.3) to see what happens to the control loop when the proportional controller varies. Try different values. The motor parameters do not necessarily correspond to those of the motor in the laboratory.

- Project the signal conditioning system you will implement for the actuation. Notice that:
  - you will need the AD laboratory's variable DC power supply to supply the op-amps with $\pm 15$ V;
  - the op-amps will, consequently, saturate at those values of electrical potential;
  - you also have available $\pm 5$ V at the DC power supply.

- Knowing that the AD/DA converter uses 12 bits for the output, find the resolution of the actuation, including your signal conditioning.

- Suppose that, instead of connecting the potentiometer directly to one of the AD/DA converter's analog inputs, we would bother to pass it through a non-inverting op-amp circuit with two equal resistors. Find how much would the resolution of the reading improve.

- Find in the Experimental procedure below the signal that we will use as a reference for the control loop. Knowing that the $-5$ V to $+5$ V signal of the potentiometer corresponds to an entire rotation of the shaft, find the amplitude of the rotation that the reference will correspond to.

## 4.3 Experimental procedure

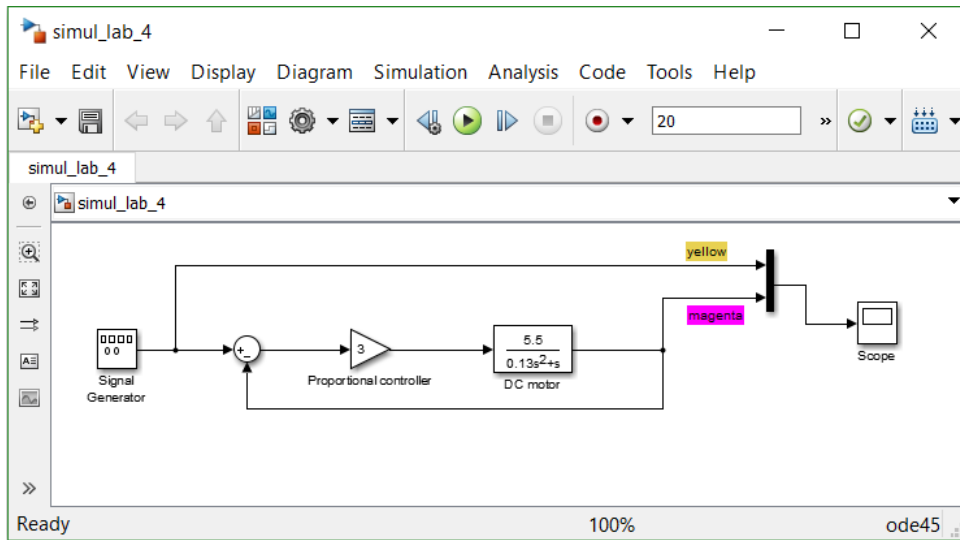### 4.3.1 List of materials

- AD laboratory.

Figure 4.3: File `simul_lab4.mdl`.

- DigiAC 1750.

- Multimeter.

- Function generator.

- Oscilloscope.

- Cables, jumper wires, BNC tee.

- Components for your signal conditioning system.

### 4.3.2  Experimental procedure

1. Implement your signal conditioning system. Test it using the function generator and the oscilloscope. Show the result to the instructor before proceeding.

2. Connect the AD/DA converter's analog output AO0 to the signal conditioning system.

3. Connect the signal conditioning system's output to the DigiAC's power amplifier (the AD/DA converter's current is too feeble to move the DC motor). Also connect its ground to the DigiAC's ground.

4. Connect the potentiometer to the AD/DA converter's analog input AI0.

5. Open Matlab R2015b (32-bit). Make sure you are using this version, since the AD/DA converter's driver will *not* work with any other version of Matlab.

6. Download folder `Files for lab 4` from Fenix. Change its name to `lab4_11111_22222_33333`, replacing the last three number with the student numbers of the members of your group.

7. Use SIMULINK file `control.mdl` (figure 4.4) to control the plant. That file uses a 50 ms sampling time, and provides a 2 V pp, 0.2 Hz square wave as reference for the control loop. Give different values to variable `K`, which is the loop's proportional controller, and see the different behaviour of the response.

8. For two different values of the controller, one corresponding to an underdamped response, and another to an overdamped response, save variable `output` in a file. Call the files `K123_underdamped.mat` and `K456_overdamped.mat`, replacing 123 and 456 with the values of the controller gain you are using. Zip the two files and submit them using Fenix *before the class is over*.
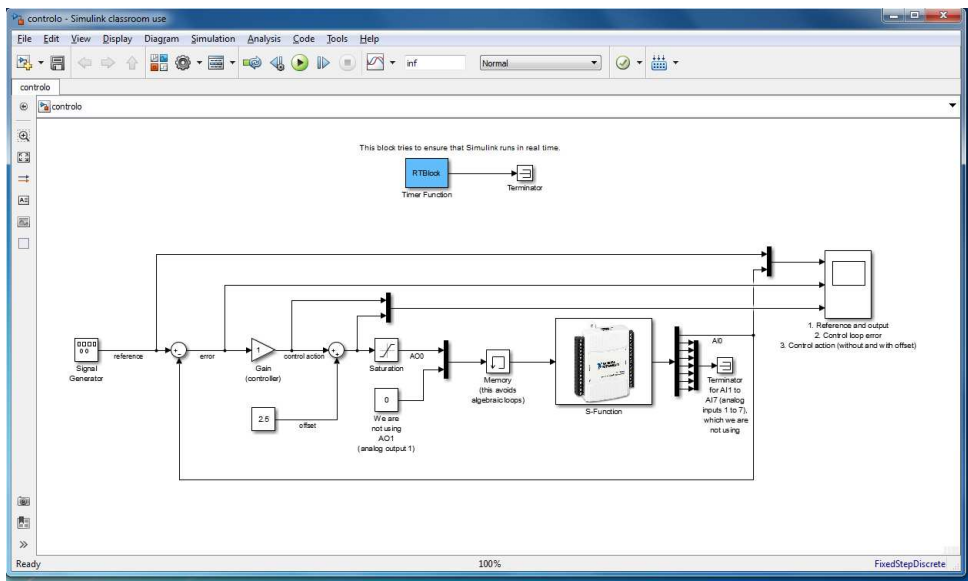
Figure 4.4: File `control.mdl`.

# Report of class 4

Number: _____ Name: _____
Number: _____ Name: _____
Number: _____ Name: _____
Date: 2019 / _____ / _____ Weekday: _____ Hour: _____ Workbench number: _____

## Project of the signal conditioning system

**Resolution of the actuation**

**Resolution improvement that would be obtained with signal conditioning of the potentiometer reading**

**Desired amplitude of the rotation of the shaft**

## Item 8

Submit your two files, zipped, using Fenix.

# Glossary

"You just come along with me and have a good time. The Galaxy's a fun place. You'll need to have this fish in your ear."

"I beg your pardon?" asked Arthur, rather politely he thought.

Ford was holding up a small glass jar which quite clearly had a small yellow fish wriggling around in it. (. . . )

"Listen!"

"But I can't speak Vogon!"

"You don't need to. Just put that fish in your ear."

Ford, with a lightning movement, clapped his hand to Arthur's ear, and he had the sudden sickening sensation of the fish slithering deep into his aural tract. Gasping with horror he scrabbled at his ear for a second or so, but then slowly turned goggle-eyed with wonder. He was experiencing the aural equivalent of looking at a picture of two black silhouetted faces and suddenly seeing it as a picture of a white candlestick. Or of looking at a lot of coloured dots on a piece of paper which suddenly resolve themselves into the figure six and mean that your optician is going to charge you a lot of money for a new pair of glasses.

He was still listening to the howling gargles, he knew that, only now it had taken on the semblance of perfectly straightforward English.

Douglas ADAMS (1952 — †2001), *The Hitchhiker's Guide to the Galaxy*, 5

**actuator** atuador
**ammeter** amperímetro
**amplitude** amplitude
**analog-digital converter** conversor analógico-digital
**banana** banana
**BNC tee** T BNC
**breadboard** placa de ensaio, *breadboard*
**cable** cabo
**capacitance meter** capacímetro
**capacitor** condensador
**closed-loop** anel fechado, malha fechada
**comparator op-amp circuit** circuito comparador
**controlled variable** variável controlada
**controller** controlador
**current** corrente
**DC motor** motor de corrente contínua
**DC power supply** fonte de tensão contínua
**differential op-amp circuit** circuito subtrator
**digital-analog converter** conversor digital-analógico
**electrical potential** potencial elétrico, tensão
**filter** filtro
**fine tuning** ajuste fino
**first order** primeira ordem
**frequency** frequência

**frequency meter** frequencímetro
**function generator** gerador de sinais
**ground** terra
**high-pass** passa-alto
**inverting op-amp circuit** circuito inversor
**jump wire, jumper** fio
**low-pass** passa-baixo
**mean value** valor médio
**multimeter** multímetro
**non-inverting op-amp circuit** circuito não-inversor
**operational amplifier (op-amp)** amplificador operacional (ampop)
**oscilloscope** osciloscópio
**overdamped** sobreamortecido
**peak amplitude** amplitude
**peak-to-peak amplitude** amplitude pico a pico
**pliers** alicate
**potentiometer** resistência variável, potenciómetro, reóstato
**power amplifier** amplificador de potência
**resistor** resistência
**rheostat** resistência variável, potenciómetro, reóstato
**sampling time** tempo de amostragem
**second order** segunda ordem

27

**sensor** sensor
**sinusoidal wave** onda sinusoidal
**square wave** onda quadrada
**subtractor op-amp circuit** circuito subtrator
**tuning** ajuste
**triangular wave** onda triangular

**underdamped** subamortecido

**variable resistor** resistência variável, potenciómetro, reóstato

**voltmeter** voltímetro

**wire stripper** descarnador