Appendix E.1: Students' guide

Project: Waves, Fourier series and music

You must produce a report using word processing software (maximum length: 10 pages of single-spaced text in Times New Roman 12) containing the following elements:

1. State and briefly explain the Fourier theorem of periodic waves. (3%)

2. Explain the concept of harmonics. Explain what a Fourier analysis is. (10%)

3. Explain how to calculate harmonic coefficients and give an example. (15%)

4. Illustrate a Fourier synthesis. Do a demonstration using *Maple*. Establish links with music. Explain why the same note produced by two different instruments has different sounds. What do these notes have in common? (27%)

5. Explain why it is preferable to digitize sound. What is recorded on a compact disk or computer? (14%)

Don't forget the introduction and conclusion. (4 %)

Appendix 1: Hand in your lab report on the low-pass RC filter. Compare the values obtained in the lab with the simulation in *Maple*. Are there any differences? (15%)

Appendix 2: After having made a high-pass RC filter in the lab, analyze its main characteristics (maximum length: two pages). (12%)

A few rules and comments:

- Three-person teams (one from each group [A, B and C]). Record the teams during the first week.
- Each team is responsible for its internal organization and the fair distribution of tasks.
- Each team must make an appointment and meet with the teacher at least once before February 20 to present a progress report.
- The second examination during the week of March 19 will focus on the content of this report.
- Don't forget to fill out your logbook.
- Your list of references must include at least one Web site not on the list provided and one textbook.
- You will be evaluated on the quality, conciseness and clarity of your presentation. Use appropriate language.

Deadline: March 16

Physics lab: Low-pass RC filter

For the next two hours, you will be working with the following circuit:

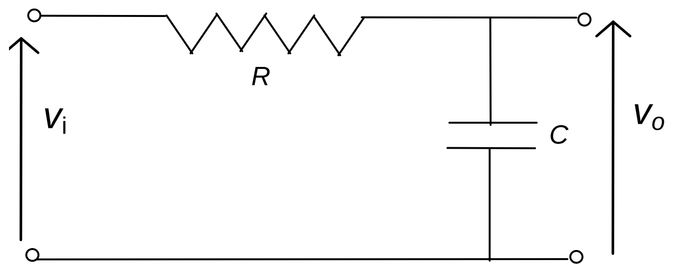


Figure 1

V_i Input voltage
V_o: Output voltage

Transmittance, *T*, is the ratio between V_o and V_i (see Benson, *Physique 2*, ERPI, ch. 12, p.13).

Theoretical analysis of filter

1. Express *T* of this filter as a function of *R, C,* and ω (ω being the angular frequency of the sinusoidal voltage applied to the input of the filter), and as a function of *R*, *C* and *f* (*f* being the frequency of the voltage applied to the input). Demonstrate how this value can be obtained by using a bleeder resistor.

2. The following graph illustrates the gain $G = 20 \cdot \log T$ as a function of f for $R = 10\ \text{k}\Omega$ and $C = 0.1\ \mu\text{F}$. Check a few values.

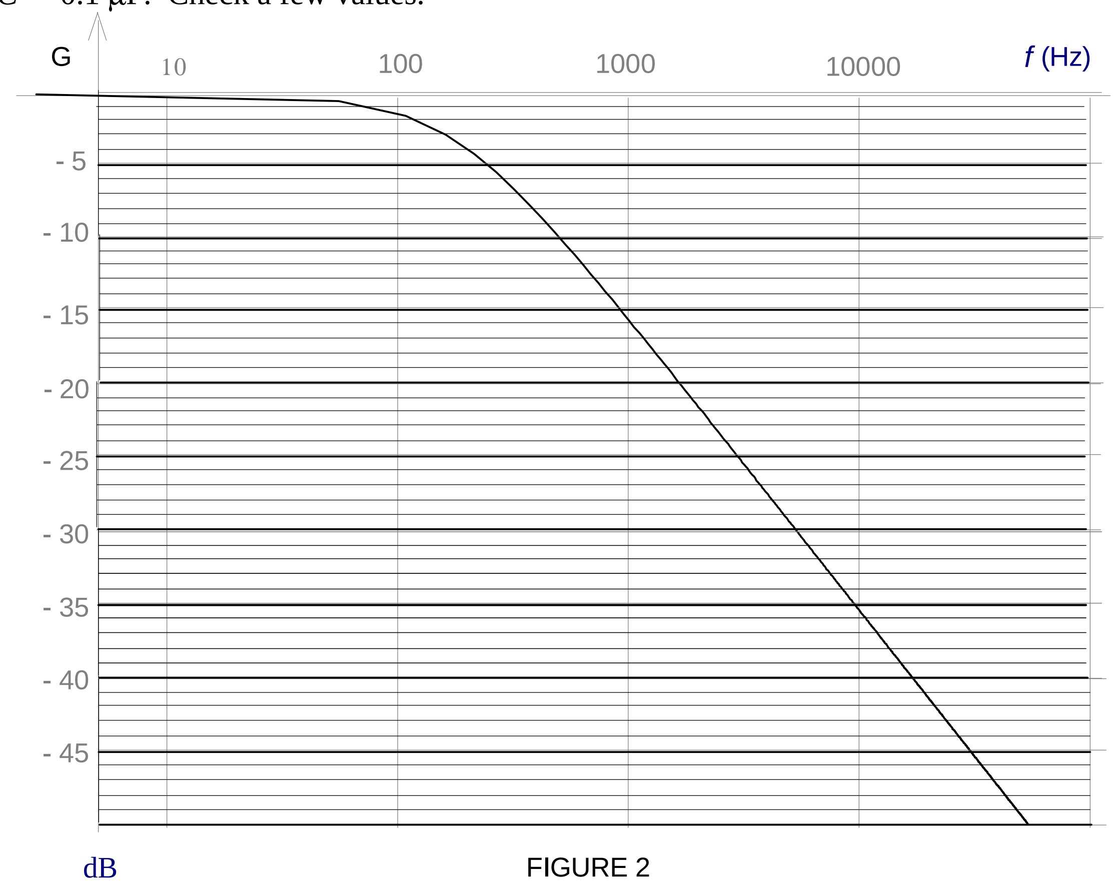


FIGURE 2

3. Cut-off frequency, f_o, is the frequency at which a gain (in fact, a loss) of –3 dB is obtained. Find the cut-off frequency of this filter on the graph, showing how you arrived at your reading. Compare the theoretical value obtained using the following formula:

$$f_0 = \frac{1}{2\pi RC}$$

Reminder (Fourier): All periodic signals of frequency f can be expressed as follows:

$v = v_0 + v_1 + v_2 + v_3 + v_4 + \ldots$

where:

- v_0 is a constant giving the average of the function
- v_1 is a sinusoidal function of frequency f (called the fundamental frequency)
- v_2 is a sinusoidal function of frequency $2f$ (called the second harmonic)

Experimental analysis of filter

1. The squarewave signal v of frequency f, represented below, is applied to the input of the filter. Adjust the oscillator accordingly. Harmonics v_1, v_3, v_5, v_7, such as $v = v_0 + v_1 + v_2 + v_3 + v_4 + \ldots$, are also represented (even-numbered harmonics are nil in this case).

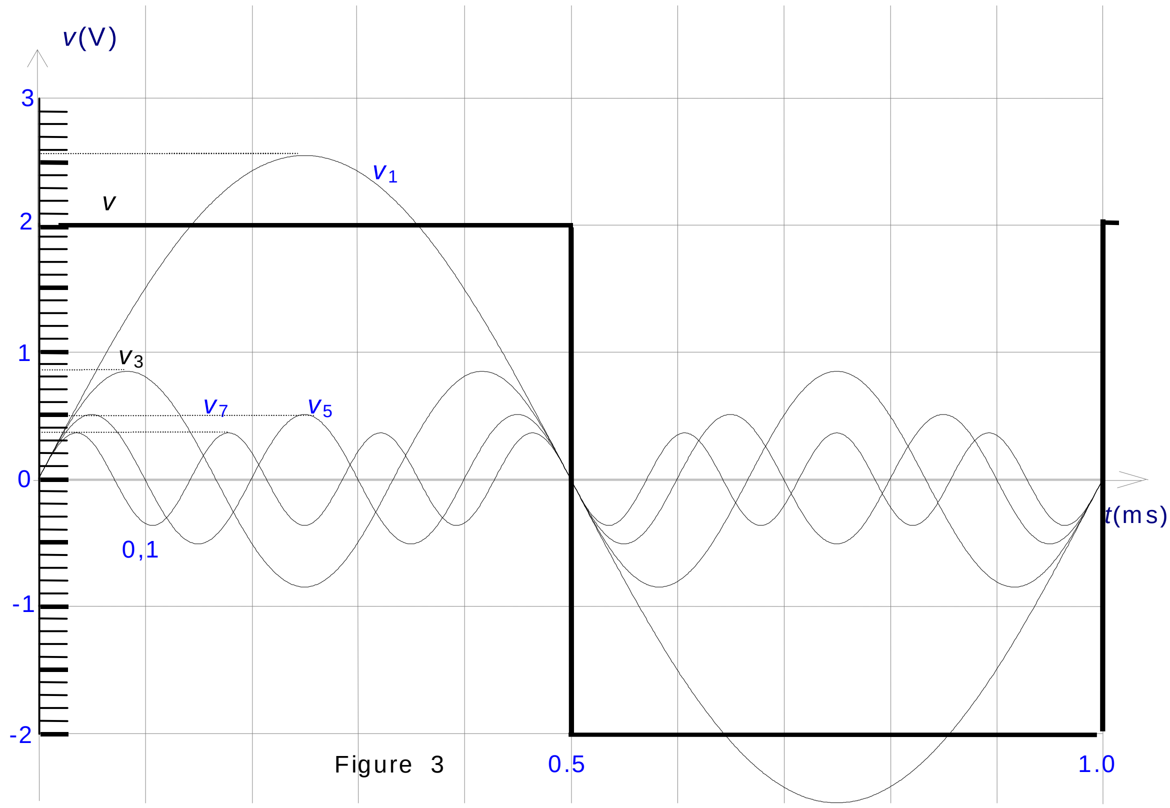


Figure 3

- Determine the value of f, frequency of voltage v.
- What is v_0 called? Determine its value.
- Determine the frequencies of harmonics 3, 5 and 7.
- Express each voltage v_1, v_3 and v_5 as follows: $v = V_{\text{max}}.\sin(2\pi f\, t + \varphi)$.
- Draw the frequency spectrum of voltage v on Figure 4 below.

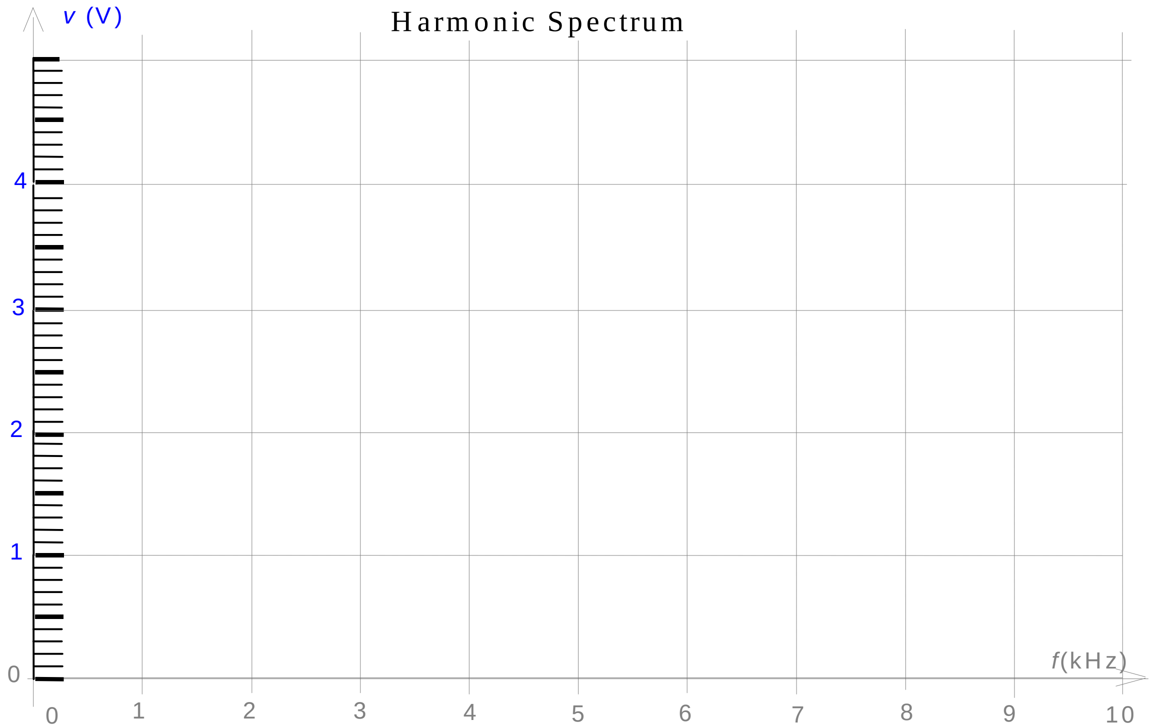


FIGURE 4

- Using the graph in Figure 2, determine the gain corresponding to a frequency of 10 kHz.

- Find the following using a voltmeter and an oscilloscope:

  a) the corresponding value of T

  b) the amplitude A_{1s} of voltage v_{1s} obtained at the output of the filter if voltage v_1 is applied to the input of the filter (first harmonic of voltage v)

  c) Demonstrate that A_{1s} is weak compared with A_1 (A_1: amplitude of v_1). You might want to calculate the ratio between A_{1s} and A_1.

- On Figure 5 below, illustrate the speed of the output voltage of the filter when the squarewave voltage v in Figure 3 is applied to the input.

Question: What is the function of this filter for high-frequency voltages?

10% bonus on report: Use an appropriate applet to find the above-mentioned voltage. Don't forget the phase!

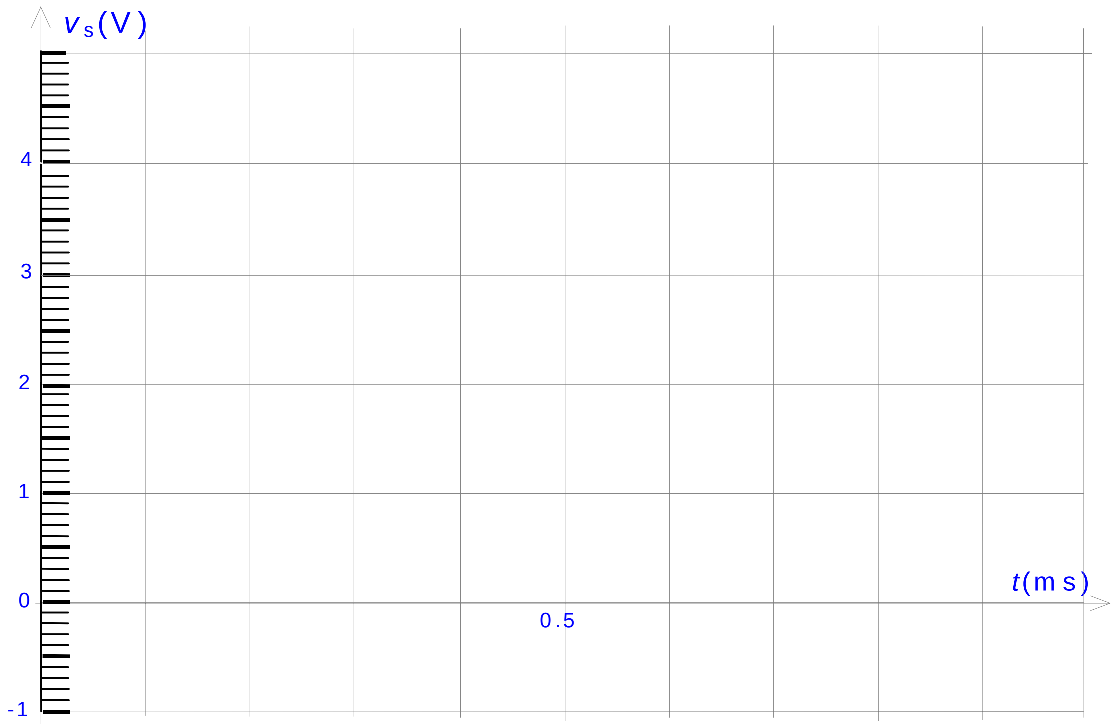


FIGURE 5

Write a complete report on this experiment (goal, theoretical framework, devices, results, analysis and conclusion).

Logbook

The following are the three principal elements that must be included in your logbook. Be clear, brief and precise.

1. What did you contribute to the team during this project?

2. What did the team do for you?

3. What links between disciplines did you discover during the project?

   Be precise; clearly state the themes or topics dealt with in your previous or current courses.

The logbook will be evaluated separately (2% of term mark).

Interesting Web sites

Fourier series:

http://www.univ-lemans.fr/enseignements/physique/02/divers/fourier.html
http://walet.phy.umist.ac.uk/2C2/Notes/node16.html
http://perso.club-internet.fr/fgrevat/fourier/fourier.html
http://lumimath.univ-mrs.fr/~jlm/cours/fourier

Fourier synthesis:

http://www.ac-nice.fr/index1.htm
http://forum.swarthmore.edu/key/nucalc/detail.html
http://www.maplesoft.com/cybermath/html/fourier.html
http://www.maplesoft.com/apps/categories/education/appliedmath/html/K10.4-Fourier.html
http://www.univ-lemans.fr/enseignements/physique/02/divers/syntfour.html

Advanced text:

http://perso.aricia.fr/alluin/spectre/PRSpectr.htm
http://www.saliege.com/dynamique/projet/Fourier/FFT1.html (with other applets)

Filters:

http://www.saliege.com/dynamique/faust98/coursinfo/MAPLE/David/filtre1.html

Appendix P.1: Second examination

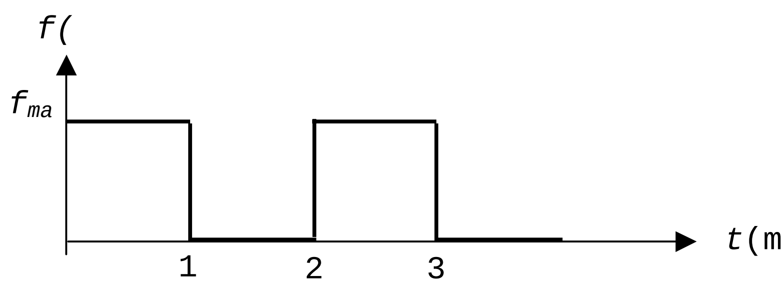
Instructions:

- Duration of examination: 75 minutes
- Weighting: 10 marks
- Maximum of six lines for each of the answers to questions 1, 2 and 5; two marks per question
- No documentation allowed
- Nonprogrammable calculator permitted

1. a) Define a periodic wave in mathematical terms.
   b) State and briefly explain the Fourier theorem of periodic waves.

2. Explain the concept of harmonics. Explain what a Fourier analysis is.

3. Calculate the coefficients of the first, second and third harmonics for the following periodic wave:



4. Using harmonics, illustrate the Fourier synthesis for a square wave.

5. Explain the process of digitizing a wave. Give two advantages of working with digitized waves.

Reminder:

$$a_0 = \frac{1}{T}\int_0^T f(t)dt; \quad a_n = \frac{2}{T}\int_0^T f(t)\cos\left(\frac{2\pi nt}{T}\right)dt; \quad b_n = \frac{2}{T}\int_0^T f(t)\sin\left(\frac{2\pi nt}{T}\right)dt$$

Appendix P.2: Summary of results of a mini survey of students

At the end of the semester, we distributed a questionnaire on the different sections of the course. The students expressed great satisfaction with the course and with this activity in particular.

Some reactions of students to the integration course

- "Of course we were faced with things that were harder to understand, but working in teams helped us stay cool and focus on the topic."
- "This project helped me establish links between physics and math. Transforming periodic waves into a Fourier series is a mathematical task and everything related to frequencies and the digitization of sound is physics."
- ". . . more extensive mathematization of physics by transforming a wave into an infinite series of other waves. I realized that math is really a way of representing the world, which I hadn't really understood until now."
- "I learned that teamwork is much more motivating and productive than individual work."
- "My teammates brought my laziness to my attention and made me work."
- "This integration project is a perfect blend of physics and mathematics."